CAE Oxford Aviation Academy

MASS AND BALANCE • PERFORMANCE

ATPL GROUND TRAINING SERIES

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Chapter

1

EU-OPS 1 - Extract

SUBPART J

MASS AND BALANCE

OPS 1.605

General

(See Appendix 1 to OPS 1.605)

(a) An operator shall ensure that during any phase of operation, the loading, mass and centre of gravity of the aeroplane complies with the limitations specified in the approved Aeroplane Flight Manual, or the Operations Manual if more restrictive.

(b) An operator must establish the mass and the centre of gravity of any aeroplane by actual weighing prior to initial entry into service and thereafter at intervals of four years if individual aeroplane masses are used and nine years if fleet masses are used. The accumulated effects of modifications and repairs on the mass and balance must be accounted for and properly documented. Furthermore, aeroplanes must be reweighed if the effect of modifications on the mass and balance is not accurately known.

(c) An operator must determine the mass of all operating items and crew members included in the aeroplane dry operating mass by weighing or by using standard masses. The influence of their position on the aeroplane centre of gravity must be determined.

(d) An operator must establish the mass of the traffic load, including any ballast, by actual weighing or determine the mass of the traffic load in accordance with standard passenger and baggage masses as specified in OPS 1.620.

(e) An operator must determine the mass of the fuel load by using the actual density or, if not known, the density calculated in accordance with a method specified in the Operations Manual.

OPS 1.607

Terminology

(a) Dry operating mass. The total mass of the aeroplane ready for a specific type of operation excluding all usable fuel and traffic load. This mass includes items such as:

1. crew and crew baggage;

2. catering and removable passenger service equipment; and

3. potable water and lavatory chemicals.

(b) Maximum zero fuel mass. The maximum permissible mass of an aeroplane with no usable fuel. The mass of the fuel contained in particular tanks must be included in the zero fuel mass when it is explicitly mentioned in the Aeroplane Flight Manual limitations.

(c) Maximum structural landing mass. The maximum permissible total aeroplane mass upon landing under normal circumstances.

(d) Maximum structural take off mass. The maximum permissible total aeroplane mass at the start of the take-off run.

(e) Passenger classification.

1. Adults, male and female, are defined as persons of an age of 12 years and above.

2. Children are defined as persons who are of an age of two years and above but who are less than 12 years of age.

3. Infants are defined as persons who are less than two years of age.

(f) Traffic load. The total mass of passengers, baggage and cargo, including any non-revenue load.

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OPS 1.610

Loading, mass and balance

An operator shall specify, in the Operations Manual, the principles and methods involved in the loading and in the mass and balance system that meet the requirements of OPS 1.605. This system must cover all types of intended operations.

OPS 1.615

Mass values for crew

(a) An operator shall use the following mass values to determine the dry operating mass:

1. actual masses including any crew baggage; or

2. standard masses, including hand baggage, of 85 kg for flight crew members and 75 kg for cabin crew members; or

3. other standard masses acceptable to the Authority.

(b) An operator must correct the dry operating mass to account for any additional baggage. The position of this additional baggage must be accounted for when establishing the centre of gravity of the aeroplane.

OPS 1.620

Mass values for passengers and baggage

(a) An operator shall compute the mass of passengers and checked baggage using either the actual weighed mass of each person and the actual weighed mass of baggage or the standard mass values specified in Tables 1 to 3 below except where the number of passenger seats available is less than 10. In such cases passenger mass may be established by use of a verbal statement by, or on behalf of, each passenger and adding to it a predetermined constant to account for hand baggage and clothing. The procedure specifying when to select actual or standard masses and the procedure to be followed when using verbal statements must be included in the Operations Manual.

(b) If determining the actual mass by weighing, an operator must ensure that passengers' personal belongings and hand baggage are included. Such weighing must be conducted immediately prior to boarding and at an adjacent location.

(c) If determining the mass of passengers using standard mass values, the standard mass values in Tables 1 and 2 below must be used. The standard masses include hand baggage and the mass of any infant below two years of age carried by an adult on one passenger seat. Infants occupying separate passenger seats must be considered as children for the purpose of this subparagraph.

(d) Mass values for passengers — 20 seats or more

1. Where the total number of passenger seats available on an aeroplane is 20 or more, the standard masses of male and female in Table 1 are applicable. As an alternative, in cases where the total number of passenger seats available is 30 or more, the "all adult" mass values in Table 1 are applicable.

2. For the purpose of Table 1, holiday charter means a charter flight solely intended as an element of a holiday travel package. The holiday charter mass values apply provided that not more than 5 % of passenger seats installed in the aeroplane are used for the non-revenue carriage of certain categories of passengers.

Table 1

Passenger seats:	20 and more		30 and more
	Male	Female	all adult
All flights except holiday charters	88 kg	70 kg	84 kg
Holiday charters	83 kg	69 kg	76 kg
Children	35 kg	35 kg	35 kg

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(e) Mass values for passengers — 19 seats or less.

1. Where the total number of passenger seats available on an aeroplane is 19 or less, the standard masses in Table 2 are applicable.

Table 2

Passenger seats	1-5	6-9	10-19
Male	104 kg	96 kg	92 kg
Female	86 kg	78 kg	74 kg
Children	35 kg	35 kg	35 kg

2. On flights where no hand baggage is carried in the cabin or where hand baggage is accounted for separately, 6 kg may be deducted from the below male and female masses. Articles such as an overcoat, an umbrella, a small hand-bag or purse, reading material or a small camera are not considered as hand baggage for the purpose of this subparagraph.

(f) Mass values for baggage

1. Where the total number of passenger seats available on the aeroplane is 20 or more the standard mass values given in Table 3 are applicable for each piece of checked baggage. For aeroplanes with 19 passenger seats or less, the actual mass of checked baggage, determined by weighing, must be used.

2. For the purpose of Table 3:

(i) Domestic flight means a flight with origin and destination within the borders of one State;

(ii) Flights within the European region means flights, other than Domestic flights, whose origin and destination are within the area specified in Appendix 1 to OPS 1.620(f); and

(iii) Intercontinental flight, other than flights within the European region, means a flight with origin and destination in different continents.

Table 3

20 or more seats

Type of flight	Baggage standard mass
Domestic	11 kg
Within the European region	13 kg
Intercontinental	15 kg
All other	13 kg

(g) If an operator wishes to use standard mass values other than those contained in Tables 1 to 3 above, he must advise the Authority of his reasons and gain its approval in advance. He must also submit for approval a detailed weighing survey plan and apply the statistical analysis method given in Appendix 1 to OPS 1.620 (g). After verification and approval by the Authority of the results of the weighing survey, the revised standard mass values are only applicable to that operator. The revised standard mass values can only be used in circumstances consistent with those under which the survey was conducted. Where revised standard masses exceed those in Tables 1 to 3, then such higher values must be used.

(h) On any flight identified as carrying a significant number of passengers whose masses, including hand baggage, are expected to exceed the standard passenger mass, an operator must determine the actual mass of such passengers by weighing or by adding an adequate mass increment.

(i) If standard mass values for checked baggage are used and a significant number of passengers check in baggage that is expected to exceed the standard baggage mass, an operator must determine the actual mass of such baggage by weighing or by adding an adequate mass increment.

(j) An operator shall ensure that a commander is advised when a non-standard method has been used for determining the mass of the load and that this method is stated in the mass and balance documentation.

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OPS 1.625

Mass and balance documentation

(See Appendix 1 to OPS 1.625)

(a) An operator shall establish mass and balance documentation prior to each flight specifying the load and its distribution. The mass and balance documentation must enable the commander to determine that the load and its distribution is such that the mass and balance limits of the aeroplane are not exceeded. The person preparing the mass and balance documentation must be named on the document. The person supervising the loading of the aeroplane must confirm by signature that the load and its distribution are in accordance with the mass and balance documentation. This document must be acceptable to the commander, his/her acceptance being indicated by countersignature or equivalent. (See also OPS 1.1055 (a)12).

(b) An operator must specify procedures for last minute changes to the load.

(c) Subject to the approval of the Authority, an operator may use an alternative to the procedures required by paragraphs (a) and (b) above.

Appendix 1 to OPS 1.605

Mass and Balance — General

(See OPS 1.605)

(a) Determination of the dry operating mass of an aeroplane

1. Weighing of an aeroplane

(i) New aeroplanes are normally weighed at the factory and are eligible to be placed into operation without reweighing if the mass and balance records have been adjusted for alterations or modifications to the aeroplane. Aeroplanes transferred from one operator with an approved mass control programme to another operator with an approved programme need not be weighed prior to use by the receiving operator unless more than four years have elapsed since the last weighing.

(ii) The individual mass and centre of gravity (CG) position of each aeroplane shall be re-established periodically. The maximum interval between two weighings must be defined by the operator and must meet the requirements of OPS 1.605 (b). In addition, the mass and the CG of each aeroplane shall be re-established either by:

(A) Weighing; or

(B) Calculation, if the operator is able to provide the necessary justification to prove the validity of the method of calculation chosen, whenever the cumulative changes to the dry operating mass exceed ± 0,5 % of the maximum landing mass or the cumulative change in CG position exceeds 0,5 % of the mean aerodynamic chord.

2. Fleet mass and CG position

(i) For a fleet or group of aeroplanes of the same model and configuration, an average dry operating mass and CG position may be used as the fleet mass and CG position, provided that the dry operating masses and CG positions of the individual aeroplanes meet the tolerances specified in subparagraph (ii) below. Furthermore, the criteria specified in subparagraphs (iii), (iv) and (a)3 below are applicable.

(ii) Tolerances

(A) If the dry operating mass of any aeroplane weighed, or the calculated dry operating mass of any aeroplane of a fleet, varies by more than ± 0,5 % of the maximum structural landing mass from the established dry operating fleet mass or the CG position varies by more than ± 0,5 % of the mean aerodynamic chord from the fleet CG, that aeroplane shall be omitted from that fleet. Separate fleets may be established, each with differing fleet mean masses.

(B) In cases where the aeroplane mass is within the dry operating fleet mass tolerance but its CG position falls outsides the permitted fleet tolerance, the aeroplane may still be operated under the applicable dry operating fleet mass but with an individual CG position.

(C) If an individual aeroplane has, when compared with other aeroplanes of the fleet, a physical, accurately accountable difference (e.g. galley or seat configuration), that causes exceedance of the fleet tolerances, this aeroplane may be maintained in the fleet provided that appropriate corrections are applied to the mass and/or CG position for that aeroplane.

(D) Aeroplanes for which no mean aerodynamic chord has been published must be operated with their individual mass and CG position values or must be subjected to a special study and approval.

(iii) Use of fleet values

(A) After the weighing of an aeroplane, or if any change occurs in the aeroplane equipment or configuration, the operator must verify that this aeroplane falls within the tolerances specified in subparagraph 2.(ii) above.

(B) Aeroplanes which have not been weighed since the last fleet mass evaluation can still be kept in a fleet operated with fleet values, provided that the individual values are revised by computation and stay within the tolerances defined in subparagraph 2(ii) above. If these individual values no longer fall within the permitted tolerances, the operator must either determine new fleet values fulfilling the conditions of subparagraphs 2(i) and 2(ii) above, or operate the aeroplanes not falling within the limits with their individual values.

(C) To add an aeroplane to a fleet operated with fleet values, the operator must verify by weighing or computation that its actual values fall within the tolerances specified in subparagraph 2(ii) above.

(iv) To comply with subparagraph 2(i) above, the fleet values must be updated at least at the end of each fleet mass evaluation.

3. Number of aeroplanes to be weighed to obtain fleet values

(i) If "n" is the number of aeroplanes in the fleet using fleet values, the operator must at least weigh, in the period between two fleet mass evaluations, a certain number of aeroplanes defined in the Table below:

Number of aeroplanes in the fleet	Minimum number of weighings
2 or 3	N
4 to 9	(n + 3)/2
10 or more	(n + 51)/10

(ii) In choosing the aeroplanes to be weighed, aeroplanes in the fleet which have not been weighed for the longest time should be selected.

(iii) The interval between two fleet mass evaluations must not exceed 48 months.

4. Weighing procedure

(i) The weighing must be accomplished either by the manufacturer or by an approved maintenance organisation.

(ii) Normal precautions must be taken consistent with good practices such as:

(A) checking for completeness of the aeroplane and equipment;

(B) determining that fluids are properly accounted for;

(C) ensuring that the aeroplane is clean; and

(D) ensuring that weighing is accomplished in an enclosed building.

(iii) Any equipment used for weighing must be properly calibrated, zeroed, and used in accordance with the manufacturer's instructions. Each scale must be calibrated either by the manufacturer, by a civil department of weights and measures or by an appropriately authorised organisation within two years or within a time period defined by the manufacturer of the weighing equipment, whichever is less. The equipment must enable the mass of the aeroplane to be established accurately.

(b) Special standard masses for the traffic load. In addition to standard masses for passengers and checked baggage, an operator can submit for approval to the Authority standard masses for other load items.

(c) Aeroplane loading

1. An operator must ensure that the loading of its aeroplanes is performed under the supervision of qualified personnel.

2. An operator must ensure that the loading of the freight is consistent with the data used for the calculation of the aeroplane mass and balance.

3. An operator must comply with additional structural limits such as the floor strength limitations, the maximum load per running metre, the maximum mass per cargo compartment, and/or the maximum seating limits.

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(d) Centre of gravity limits

1. Operational CG envelope. Unless seat allocation is applied and the effects of the number of passengers per seat row, of cargo in individual cargo compartments and of fuel in individual tanks is accounted for accurately in the balance calculation, operational margins must be applied to the certificated centre of gravity envelope. In determining the CG margins, possible deviations from the assumed load distribution must be considered. If free seating is applied, the operator must introduce procedures to ensure corrective action by flight or cabin crew if extreme longitudinal seat selection occurs. The CG margins and associated operational procedures, including assumptions with regard to passenger seating, must be acceptable to the Authority.

2. In-flight centre of gravity. Further to subparagraph (d)1 above, the operator must show that the procedures fully account for the extreme variation in CG travel during flight caused by passenger/crew movement and fuel consumption/transfer.

Appendix 1 to OPS 1.620 (f)

Definition of the area for flights within the European region

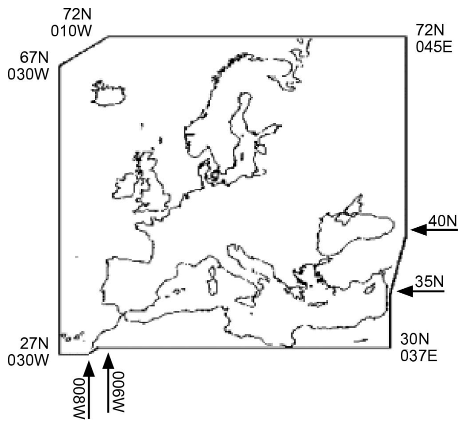
For the purposes of OPS 1.620 (f), flights within the European region, other than domestic flights, are flights conducted within the area bounded by rhumb lines between the following points:

— N7200	E04500
— N4000	E04500
— N3500	E03700
— N3000	E03700
— N3000	W00600
— N2700	W00900
— N2700	W03000
— N6700	W03000
— N7200	W01000
— N7200	E04500

as depicted in Figure 1 below:

Figure 1

European region



Appendix 1 to OPS 1.620 (g)

Procedure for establishing revised standard mass values for passengers and baggage

(a) Passengers

1. Weight sampling method. The average mass of passengers and their hand baggage must be determined by weighing, taking random samples. The selection of random samples must by nature and extent be representative of the passenger volume, considering the type of operation, the frequency of flights on various routes, in/outbound flights, applicable season and seat capacity of the aeroplane.

2. Sample size. The survey plan must cover the weighing of at least the greatest of:

(i) A number of passengers calculated from a pilot sample, using normal statistical procedures and based on a relative confidence range (accuracy) of 1 % for all adult and 2 % for separate male and female average masses; and

(ii) For aeroplanes:

(A) with a passenger seating capacity of 40 or more, a total of 2 000 passengers; or

(B) with a passenger seating capacity of less than 40, a total number of 50 x (the passenger seating capacity).

3. Passenger masses. Passenger masses must include the mass of the passengers' belongings which are carried when entering the aeroplane. When taking random samples of passenger masses, infants shall be weighted together with the accompanying adult (See also OPS 1.620 (c) (d) and (e)).

4. Weighing location. The location for the weighing of passengers shall be selected as close as possible to the aeroplane, at a point where a change in the passenger mass by disposing of or by acquiring more personal belongings is unlikely to occur before the passengers board the aeroplane.

5. Weighing machine. The weighing machine to be used for passenger weighing shall have a capacity of at least 150 kg. The mass shall be displayed at minimum graduations of 500 g. The weighing machine must be accurate to within 0,5 % or 200 g whichever is the greater.

6. Recording of mass values. For each flight included in the survey the mass of the passengers, the corresponding passenger category (i.e. male/female/children) and the flight number must be recorded.

(b) Checked baggage. The statistical procedure for determining revised standard baggage mass values based on average baggage masses of the minimum required sample size is basically the same as for passengers and as specified in subparagraph (a)1.. For baggage, the relative confidence range (accuracy) amounts to 1 %. A minimum of 2 000 pieces of checked baggage must be weighed.

(c) Determination of revised standard mass values for passengers and checked baggage

1. To ensure that, in preference to the use of actual masses determined by weighing, the use of revised standard mass values for passengers and checked baggage does not adversely affect operational safety, a statistical analysis must be carried out. Such an analysis will generate average mass values for passengers and baggage as well as other data.

2. On aeroplanes with 20 or more passenger seats, these averages apply as revised standard male and female mass values.

3. On smaller aeroplanes, the following increments must be added to the average passenger mass to obtain the revised standard mass values:

Number of passenger seats	Required mass increment
1-5 inclusive	16 kg
6-9 inclusive	8 kg
10-19 inclusive	4 kg

Alternatively, all adult revised standard (average) mass values may be applied on aeroplanes with 30 or more passenger seats. Revised standard (average) checked baggage mass values are applicable to aeroplanes with 20 or more passenger seats.

4. Operators have the option to submit a detailed survey plan to the Authority for approval and subsequently a deviation from the revised standard mass value provided this deviating value is determined by use of the procedure explained in this Appendix. Such deviations must be reviewed at intervals not exceeding five years.

5. All adult revised standard mass values must be based on a male/female ratio of 80/20 in respect of all flights except holiday charters which are 50/50. If an operator wishes to obtain approval for use of a different ratio on specific routes or flights then data must be submitted to the Authority showing that the alternative male/female ratio is conservative and covers at least 84 % of the actual male/female ratios on a sample of at least 100 representative flights.

6. The average mass values found are rounded to the nearest whole number in kg. Checked baggage mass values are rounded to the nearest 0,5 kg figure, as appropriate.

Appendix 1 to OPS 1.625

Mass and Balance Documentation

(a) Mass and balance documentation

1. Contents

(i) The mass and balance documentation must contain the following information:

(A) the aeroplane registration and type;

(B) the flight identification number and date;

(C) the identity of the commander;

(D) the identity of the person who prepared the document;

(E) the dry operating mass and the corresponding CG of the aeroplane;

(F) the mass of the fuel at take-off and the mass of trip fuel;

(G) the mass of consumables other than fuel;

(H) the components of the load including passengers, baggage, freight and ballast;

(I) the take-off mass, landing mass and zero fuel mass;

(J) the load distribution;

(K) the applicable aeroplane CG positions; and

(L) the limiting mass and CG values.

(ii) Subject to the approval of the Authority, an operator may omit some of this Data from the mass and balance documentation.

2. Last minute change. If any last minute change occurs after the completion of the mass and balance documentation, this must be brought to the attention of the commander and the last minute change must be entered on the mass and balance documentation. The maximum allowed change in the number of passengers or hold load acceptable as a last minute change must be specified in the Operations Manual. If this number is exceeded, new mass and balance documentation must be prepared.

(b) Computerised systems. Where mass and balance documentation is generated by a computerised mass and balance system, the operator must verify the integrity of the output data. He must establish a system to check that amendments of his input data are incorporated properly in the system and that the system is operating correctly on a continuous basis by verifying the output data at intervals not exceeding 6 months.

(c) Onboard mass and balance systems. An operator must obtain the approval of the Authority if he wishes to use an onboard mass and balance computer system as a primary source for despatch.

(d) Datalink. When mass and balance documentation is sent to aeroplanes via datalink, a copy of the final mass and balance documentation as accepted by the commander must be available on the ground.

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Appendix 1 to OPS 1.270

Stowage of baggage and cargo

Procedures established by an operator to ensure that hand baggage and cargo is adequately and securely stowed must take account of the following:

1. each item carried in a cabin must be stowed only in a location that is capable of restraining it;
2. mass limitations placarded on or adjacent to stowages must not be exceeded;
3. underseat stowages must not be used unless the seat is equipped with a restraint bar and the baggage is of such size that it may adequately be restrained by this equipment;
4. items must not be stowed in toilets or against bulkheads that are incapable of restraining articles against movement forwards, sideways or upwards and unless the bulkheads carry a placard specifying the greatest mass that may be placed there;
5. baggage and cargo placed in lockers must not be of such size that they prevent latched doors from being closed securely;
6. baggage and cargo must not be placed where it can impede access to emergency equipment; and
7. checks must be made before take-off, before landing, and whenever the fasten seat belts signs are illuminated or it is otherwise so ordered to ensure that baggage is stowed where it cannot impede evacuation from the aircraft or cause injury by falling (or other movement) as may be appropriate to the phase of flight.

Questions

1. **EASA Mass and Balance legislation can be found in:**

a. EU-OPS 1 subpart A
b. EU-OPS 1 subpart D
c. EU-OPS 1 subpart K
d. EU-OPS 1 subpart J

2. **The mass and centre of gravity of an aircraft must be established by actual weighing:**

a. by the pilot on entry of aircraft into service
b. by the engineers before commencing service
c. by the manufacturer prior to initial entry of aircraft into service
d. by the owner operator before the first flight of the day

3. **The operator must establish the mass of the traffic load:**

a. prior to initial entry into service
b. by actual weighing or determine the mass of the traffic load in accordance with standard masses as specified in EU-OPS subpart J
c. prior to embarking on the aircraft
d. by using an appropriate method of calculation as specified in the EU-OPS 1 subpart J

4. **The mass of the fuel load must be determined:**

a. by the operator using actual density or by density calculation specified in the Operations Manual
b. by the owner using actual density or by density calculation specified in EU-OPS 1 subpart J
c. by the pilot using actual density or by density calculation specified in the Operations Manual
d. by the fuel bowser operator using actual density or by density calculation specified in the Fuelling Manual

5. **The dry operating mass is the total mass of the aeroplane ready for a specific type of operation and includes:**

a. Crew and passenger baggage, special equipment, water and chemicals
b Crew and their hold baggage, special equipment, water and contingency fuel
c. Crew baggage, catering and other special equipment, potable water and lavatory chemicals
d. Crew and their baggage, catering and passenger service equipment, potable water and lavatory chemicals

6. **The maximum zero fuel mass is the maximum permissible mass of the aeroplane:**

a. with no usable fuel
b. with no usable fuel unless the Aeroplane Flight Manual Limitations explicitly include it
c. including the fuel taken up for take-off
d. including all usable fuel unless the Aeroplane Flight Operations Manual explicitly excludes it

7. **The maximum structural take-off mass is:**

   a. the maximum permissible total aeroplane mass on completion of the refuelling operation
   b. the maximum permissible total aeroplane mass for take-off subject to the limiting conditions at the departure airfield
   c. the maximum permissible total aeroplane mass for take-off but excluding fuel
   d. the maximum permissible total aeroplane mass at the start of the take-off run

8. **The regulated take-off mass:**

   a. is the lower of maximum structural take-off mass and the performance limited take-off mass
   b. is the higher of the maximum structural zero fuel mass and the performance limited take-off mass
   c. is the maximum structural take-off mass subject to any last minute mass changes
   d. is the maximum performance limited take-off mass subject to any last minute mass changes

9. **The take-off mass is:**

   a. the maximum permissible total aeroplane mass on completion of the refuelling operation
   b. the mass of the aeroplane including everyone and everything contained within it at the start of the take-off run
   c. the maximum permissible total aeroplane mass for take-off but excluding fuel
   d. the maximum permissible total aeroplane mass at the start of the take-off run

10. **The operating mass:**

   a. is the lower of the structural mass and the performance limited mass
   b. is the higher of the structural mass and the performance limited mass
   c. is the actual mass of the aircraft on take-off
   d. is the dry operating mass and the fuel load

11. **The basic empty mass is the mass of the aeroplane:**

   a. plus non-standard items such as lubricating oil, fire extinguishers, emergency oxygen equipment etc.
   b. minus non-standard items such as lubricating oil, fire extinguishers, emergency oxygen equipment etc.
   c. plus standard items such as unusable fluids, fire extinguishers, emergency oxygen equipment, supplementary electronics etc.
   d. minus non-standard items such as unusable fluids, fire extinguishers, emergency oxygen and supplementary electronic equipment etc.

12. **The traffic load:**

    a. includes passenger masses and baggage masses but excludes any non-revenue load
    b. includes passenger masses, baggage masses and cargo masses but excludes any non-revenue load
    c. includes passenger masses, baggage masses, cargo masses and any non-revenue load
    d. includes passenger masses, baggage masses and any non-revenue load but excludes cargo

13. **The operating mass:**

    a. is the take-off mass minus the traffic load
    b. is the landing mass minus the traffic load
    c. is the maximum zero fuel mass less the traffic load
    d. is the take-off mass minus the basic empty mass and crew mass

14. **The traffic load is:**

    a. the zero fuel mass minus the dry operating mass
    b. the take-off mass minus the sum of the dry operating mass and the total fuel load
    c. the landing mass minus the sum of the dry operating mass and the mass of the remaining fuel
    d. all the above

15. **The basic empty mass is the:**

    a. MZFM minus both traffic load and the fuel load
    b. take-off mass minus the traffic load and the fuel load
    c. operating mass minus the crew, special equipment and fuel load
    d. landing mass less traffic load

16. **Is it possible to fly a certified aircraft at a regulated take-off mass with both a full traffic load and a full fuel load?**

    a. It might be possible on some aircraft providing the mass and CG remain within limits
    b. Yes, all aircraft are able to do this
    c. No, it is not possible on any aeroplane
    d. Only if the performance limited take-off mass is less than the structural limited take-off mass

17. **It is intended to fly a certified aircraft loaded to the MZFM and MSTOM:**

    a. the CG must be within limits during take-off and landing
    b. the CG limits must be in limits throughout the flight, including loading/unloading
    c. the CG does not have to be within limits during the whole of the flight
    d. the CG does not have to be within limits during loading and unloading the aeroplane

18. The term 'baggage' means:

a. excess freight
b. any non-human, non-animal cargo
c. any freight or cargo not carried on the person
d. personal belongings

19. Certified transport category aircraft with less than 10 seats:

a. may simply accept a verbal mass from or on behalf of each passenger
b. may estimate the total mass of the passengers and add a pre-determined constant to account for hand baggage and clothing
c. may compute the actual mass of passengers and checked baggage
d. all the above

20. When computing the mass of passengers and baggage:

1. personal belongings and hand baggage must be included
2. infants must be classed as children if they occupy a seat
3. standard masses include infants being carried by an adult
4. table 1, table 2 and table 3 must be used as appropriate if using standard masses for passengers and freight
5. weighing must be carried out immediately prior to boarding and at an adjacent location

a. 1, 2 and 5 only
b. 2 and 4 only
c. 1, 2, 3 and 5 only
d. all the above

21. When computing the mass of passengers and baggage for an aircraft with 20 seats or more:

1. standard masses of male and female in table 1 are applicable
2. if there are thirty seats or more, the 'all adult' mass values in table 1 may be used as an alternative
3. holiday charter masses apply to table 1 and table 3 if the charter is solely intended as an element of a holiday travel package
4. holiday flights and holiday charters attract the same mass values

a. 1, 3 and 4 only
b. 1 and 2 only
c. 3 and 4 only
d. all the above

22. When computing the mass of passengers and baggage for an aircraft with 19 seats or less:

1. the standard masses in table 2 apply
2. if hand baggage is accounted for separately, 6 kg may be deducted from the mass of each passenger
3. table 2 masses vary with both the gender (male or female) of the seat occupant and the number of seats on the aircraft
4. standard masses are not available for baggage
5. standard masses are not available for freight

a. 1 only
b. 1, 2 and 4 only
c. 3 and 5 only
d. all the above

23. When computing the mass of checked baggage for an aircraft with twenty seats or more:

1. table 1 applies
2. table 2 applies
3. table 3 applies
4. baggage mass is categorized by destination
5. baggage mass is categorized by gender

a. 1, 3 and 4 only
b. 2, 3 and 5 only
c. 3 and 4 only
d. all the above

24. On any flight identified as carrying a significant number of passengers whose masses, including hand baggage, are expected to exceed the standard passenger mass the operator:

a. must determine the actual mass of such passengers
b. must add an adequate mass increment to each of such passengers
c. must determine the actual masses of such passengers or add a standard increment to the Standard Mass Table value for each of these passengers
d. need only determine the actual masses or apply an increment if the take-off mass is likely to be exceeded

25. If standard mass tables are being used for checked baggage and a number of passengers check in baggage that is expected to exceed the standard baggage mass, the operator:

a. must determine the actual masses of such baggage
b. must determine the actual mass of such baggage by weighing or by deducting an adequate mass increment
c. need make no alterations if the take-off mass is not likely to be exceeded
d. must determine the actual mass of such baggage by weighing or adding an adequate mass increment to the Standard Mass Table value for each item of such baggage

26. M & B documentation:

1. must be established prior to each flight
2. must enable the commander to determine that the load and its distribution is such that the limits of the aircraft are not exceeded
3. must include the name of the person preparing the document
4. must be signed by the person supervising the loading to the effect that the load and its distribution is in accordance with the data on the document
5. must include the aircraft commander's signature to signify acceptance of the document

a. all the above
b. 2, 4 and 5 only
c. 1, 4 and 5 only
d. 1 and 3 only

27. Once the M & B documentation has been signed prior to flight:

a. no load alterations are allowed
b. documented last minute changes to the load may be incorporated
c. the documentation is not signed prior to flight
d. acceptable last minute changes to the load must be documented

28. Individual aircraft (not part of a fleet) must be weighed:

1. on initial entry into service
2. annually if the records have not been adjusted for alterations or modifications
3. every four years after initial weigh
4. whenever major modifications have been embodied
5. whenever minor repairs have been carried out

a. 1 and 3 only
b. 1, 2 and 4 only
c. 1, 2 and 3 only
d. 1, 3 and 5 only

29. Aeroplane loading:

1. must be performed under the supervision of qualified personnel
2. must be consistent with the data used for calculating the aircraft weight and CG
3. must comply with compartment dimension limitations
4. must comply with the maximum load per running metre
5. must comply with the maximum mass per cargo compartment

a. 1 and 2 only
b. 1, 2, 4 and 5 only
c. 1, 2, 3, 4 and 5
d. 3, 4 and 5 only

30. Aircraft are usually weighed only when they enter the hangar for deep maintenance. This is because:

a. they have to be stripped down to the basic mass condition which is labour intensive and time consuming
b. they have to be stripped down to the DOM condition which is labour intensive and time costly
c. it is the only time the hangar doors are fully closed
d. there would not be sufficient aircraft for the program otherwise

Answers

1	2	3	4	5	6	7	8	9	10	11	12
d	c	b	a	d	b	d	a	b	d	c	c

13	14	15	16	17	18	19	20	21	22	23	24
a	d	c	a	b	d	d	c	b	d	c	c

25	26	27	28	29	30
d	a	d	a	c	a

Chapter

2

Definitions and Calculations

Continued Overleaf

2 Definitions and Calculations

Introduction

EU-OPS 1 Subpart J requires that during any phase of operation the loading, mass and centre of gravity of the aeroplane complies with the limitations specified in the approved Aeroplane Flight Manual, or the Operations Manual if more restrictive.

It is the responsibility of the commander of the aircraft to satisfy himself that this requirement is met.

Limitations

Limitations on mass are set to ensure adequate margins of strength and performance, and limitations on CG position are set to ensure adequate stability and control of the aircraft in flight.

Effects of Overloading

The four forces of lift, weight, thrust and drag acting on an aircraft all induce stress into the airframe structural members in the form of tension, compression, torsion, bending etc. The structure may, at the same time of absorbing these stresses, be subject to extremes of temperature ranging from minus 56°C to plus 40°C.

The stress and temperature factors gradually fatigue the structure as time progresses. Fatigue, in this sense of the word, is a permanent loss of the physical properties (strength, durability, hardness etc) of the materials comprising the structure. Fatigue will, if left undetected or unattended, eventually cause the structure to fail altogether – possibly with catastrophic and/or fatal consequences.

Fatigue is cumulative and non-reversible and the higher the fatigue level the greater the risk of premature structural failure. Structure that is inadvertently subject to additional fatigue may fail earlier than predicted or expected.

The aircraft designer must, for each individual part of the structure, determine the frequency of application of the stress producing loads and, together with the temperature factors, determine the types of stress involved. Based on this data, a Design Limit Load (DLL) is calculated for each member and for the complete structure. The DLL is the maximum load that can be applied to the structure repeatedly during normal operations without inducing excessive fatigue and the pilot must never deliberately exceed this value.

As a safeguard, the aviation authorities impose a factor of safety of 50% to the DLL to produce a Design Ultimate Load (DUL). The DUL is the minimum load the structure must be able to absorb in an emergency (heavier than normal landing or flight in exceptional gusty wind conditions) without collapsing. In order to keep weight to a minimum the aircraft's structure is manufactured from materials that are just capable of absorbing the DUL.

Structure subject to loads in excess of the DUL is likely to suffer some permanent damage and may even collapse altogether.

An aeroplane's principal function is to lift mass into the air, transport that mass through the air and then land it back on the ground without damage. Clearly, the greater the mass that has to be lifted the greater will be the loading on each member of the aircraft structure. Overloading the aeroplane will induce additional fatigue. For the purposes of cost efficiency it is important to maximize the mass transported by the aeroplane but without overloading it.

The manufacturer of the structural parts of the aircraft is responsible for determining the stresses the aeroplane will be subject to both on the ground and in the air, and to impose suitable mass limits so that the integrity of the structure is guaranteed throughout the aircraft's working life. The limits include: the maximum taxi mass (MTM); the maximum zero fuel mass (MZFM); the maximum structural take-off mass (MSTOM) and the maximum structural landing mass (MSLM). These values must never be exceeded in normal operation.

It is necessary at this point to note that, in Mass & Balance terms, mass and weight are synonymous (used to express the same thing).

Increasing age, inappropriate use, hostile environmental and climatic conditions are all factors that induce stress and fatigue into the aircraft's structure. However, weight is the principal stress factor for inducing fatigue into aircraft structure.

Weight also has pronounced effects on the aircraft's performance, handling and aerodynamic properties. With an increase in weight:

- Performance is reduced:
    - Take-off and landing distances will increase. V_1 decision speed, V_R rotation speed, V_2 take-off safety speed, and the stopping distance will all increase. The climb gradient, rate of climb and ceiling height will all reduce.
    - The rate of descent will increase.
    - The stalling speed will increase and maximum speed will reduce.
    - The safety margins and the effective speed range between low and high speed buffet will reduce.
    - Drag and fuel consumption will increase.
    - Range and endurance will reduce.
- Wing root stresses will increase.
- Manoeuvrability will reduce. The aircraft will become less responsive to control inputs and more difficult to fly.
- Wing root stresses and undercarriage loads will increase as will tyre and brake wear.

Effects of Out of Limit CG Position

The centre of gravity (CG) is:

- the point that the total weight of the aircraft is said to act through
- the point of balance
- that part of the aircraft that follows the flight path
- the point that the aircraft manoeuvres about in the air
- the point that the three axes of the aircraft pass through.

The position of the CG determines how stable or how manoeuvrable the aircraft will be. Starting at the mid position of the fuselage, a CG moving towards the nose of the aircraft will progressively increase the stability and, at the same time, progressively reduce the manoeuvrability. Similarly, a CG moving aft towards the tail of the aircraft will increase the manoeuvrability and decrease the stability. Too much stability increases the flying control stick forces and the work load on the pilot trying to overcome them. Too much manoeuvrability makes the aircraft unstable and difficult to control.

With regard to aeroplanes, the CG is not fixed. It moves in flight as a result of fuel burn, flap positions, and crew and passenger movements. It is the aircraft operator's responsibility to ensure that the CG movement is retained within the limits imposed by the manufacturer.

The manufacturer sets down CG range of movement limits to ensure that the average pilot is able to control the aircraft through all stages of flight safely, with normal piloting effort, free of fatigue.

The following paragraphs indicate the effects that might occur if the CG is caused to exceed the limits. Students are advised to learn them well – they are frequently asked in the exams.

A CG outside the forward limit:

- Drag increases, consequently fuel consumption, range and endurance decrease. In order to keep the nose of the aircraft from pitching downwards the tailplane must produce a balancing down load – a bit like a see-saw. The resulting elevator deflection increases drag, which in turn increases fuel consumption and reduces range and endurance.

- The longitudinal stability is increased, resulting in higher control column forces during manoeuvres with a corresponding increase in physical effort required to overcome them, leading to increased pilot fatigue.

- The increase in tail down force is equivalent to an increase in weight; consequently the stall speed will increase. An increase in stall speed has a significant effect on other performance aspects of the aircraft: take-off and landing speeds will increase, the available speed range will reduce and the safety margin between low and high speed buffet will narrow.

- The ability to pitch the aircraft's nose up or down will decrease because of the increased stability.

- Take-off speeds V_1, V_R, V_{MU} will increase. On the ground the aeroplane rotates about the main wheels and uses the elevators to raise the nose for take-off. The CG, being ahead of the main wheels, produces a down force that the elevators, together with the speed of the airflow passing over them, must overcome. The more forward the CG the greater the down force and, for a particular elevator deflection, the greater the speed of the airflow required. The aircraft must accelerate for longer to produce the airspeed required.

A CG outside the aft limit:

- Longitudinal stability is reduced and, if the CG is too far aft, the aircraft will become very unstable (like a bucking bronco). Stick forces in pitch will be light, leading to the possibility of over stressing the aircraft by applying excessive ‘g’.

- Recovering from a spin may be more difficult as a flat spin is more likely to develop.

- Range and endurance will probably decrease due to the extra drag caused by the extreme manoeuvres.

- Glide angle may be more difficult to sustain because of the tendency for the aircraft to pitch up.

Movement of CG in Flight

Figure 2.1 and the table below compare in a simplistic arrow format, the effects on aircraft performance of having the CG on the forward CG limit to the performance that would be achieved with the CG on the aft limit. The table goes on to show how an increase in mass affects performance. Be advised that the M&B examinations contain a number of performance related ‘theory type’ questions (they seldom include performance type calculations).

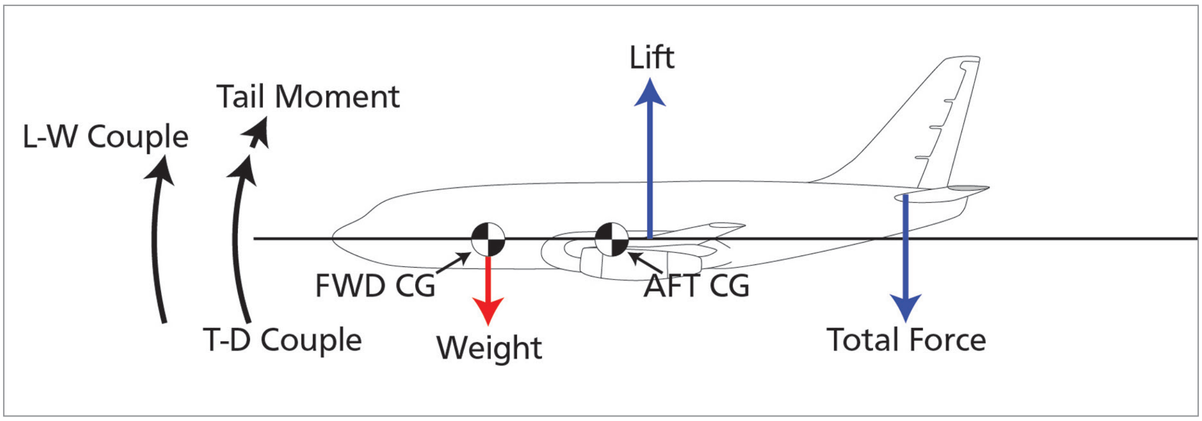


Figure 2.1

A ‘couple’ is two forces acting together to produce a turning motion.

CG ON FWD LIMIT		CG ON AFT LIMIT	
STABILITY	↑	STABILITY	↓
STICK FORCES	↑	STICK FORCES	↓
MANOEUVRABILITY	↓	MANOEUVRABILITY	↑
DRAG	↑	DRAG	↓
V_S (STALLING SPEED)	↑	V_S	↓
V_R (ROTATION SPEED)	↑	V_R	↓
RANGE	↓	RANGE	↑
FUEL CONSUMPTION	↑	FUEL CONSUMPTION	↓
ABILITY TO ACHIEVE		**ABILITY TO ACHIEVE**	
1. CLIMB GRADIENT	↓	CLIMB GRADIENT	↑
2. GLIDE SLOPE	↓	GLIDE SLOPE	↑

Some Effects of Increasing Aeroplane Mass

V_1	(DECISION SPEED)	↑
V_R	(ROTATION SPEED)	↑
V_{MU}	(MIN UNSTICK SPEED)	↑
V_S	(STALLING SPEED)	↑
TAKE-OFF AND LANDING RUN		↑
RANGE AND ENDURANCE		↓
RATE OF DESCENT		↑
MAX HORIZONTAL SPEED		↓
RATE OF CLIMB		↓
MAX ALTITUDE		↓
FUEL CONSUMPTION		↑
BRAKING ENERGY		↑
TYRE WEAR		↑
STRUCTURAL FATIGUE		↑

↑ = increase

↓ = decrease

EU-OPS 1 states that the CG position must remain within the range limits at all times, whether in the air, taking off, landing or loading and unloading on the ground. Changes to the load distribution that may occur during any stage of the intended flight i.e. fuel burn, passenger or crew movements, will affect the CG position and must be properly accounted for prior to take-off.

Definitions

The following definitions are to clarify and enhance the definitions that are found in CAP 696, pages 3 and 4.

Centre of Gravity

The point through which the force of gravity is said to act on a mass (in aircraft terms, the point on the aircraft through which the total mass is said to act in a vertically downward manner). The centre of gravity is also the point of balance and as such it affects the stability of the aircraft both on the ground and in the air.

Centre of Gravity Limits

The CG is not a fixed point; it has a range of movement between a maximum forward position and a maximum rearward position which is set by the aircraft manufacturer and cannot be exceeded. The CG must be on or within the limit range at all times. The limits are given in the flight manual and are defined relative to the datum. They may also be given as a percentage of the mean chord of the wing. (The wing mean chord was called the Standard Mean Chord but is now known as the Mean Aerodynamic Chord or more simply, the MAC.)

Datum

A point along the longitudinal axis (centre line) of the aeroplane (or its extension) designated by the manufacturer as the zero or reference point from which all balance arms (distances) begin. By taking moments about the datum the CG position of the aircraft can be determined. For the purposes of this phase of study the lateral displacement of the CG from the longitudinal axis is assumed to be zero.

Balance Arm

The distance from the aircraft's datum to the CG position or centroid of a body or mass. For example, the centroid of a square or rectangle is the exact centre of the square or rectangle and, in such cases, the balance arm is the distance from the datum to the exact centre of the square or rectangle. Unfortunately, cargo bays are seldom exact squares or rectangles and so the centroid (the point the total weight acts through) is given by the manufacturer.

For the purposes of calculations, all balance arms ahead of (in front of) the datum are given a negative (-) prefix and those behind (aft of) the datum are given a positive (+) prefix.

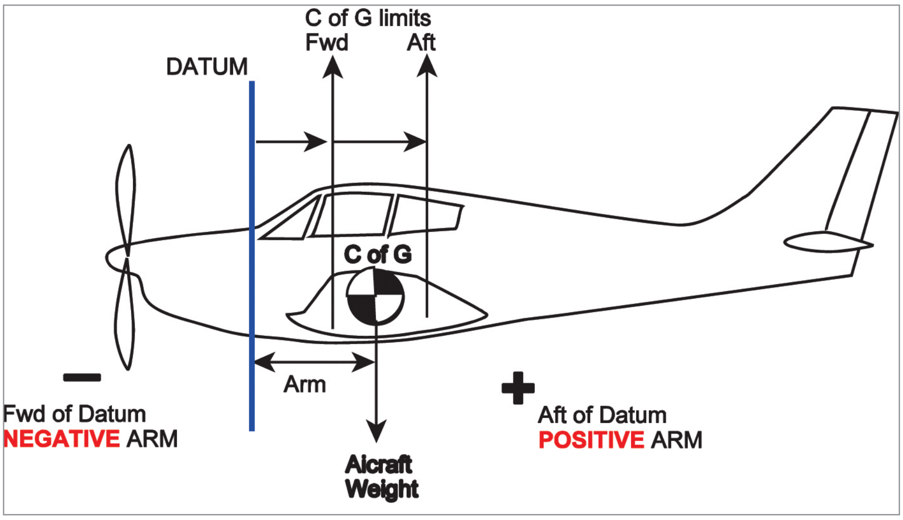


Figure 2.2 Positive and negative balance arms

Inexperienced students tend to get their positive and negative signs mixed up and thus fail to arrive at the correct answer. In arithmetical calculations, a positive value multiplied by a negative value results in a negative answer but two positive or two negative values multiplied together always produce a positive answer.

Loading Index

The result of multiplying a force by a mass often produces an answer of such magnitude that it is too bulky and time consuming to utilize. A Loading Index is simply a moment divided by a constant and has the effect of reducing the magnitude of the moment to one that is much easier to use.

ITEM	MASS (kg)	ARM (in)	MOMENT(kg in)	CONSTANT	INDEX
BEM	31 994	691	22 107 854	/1 000 000	22
FLT CREW	180	183	32 940	/1 000 000	0
CABIN CREW	540	1107	597 780	/1 000 000	0.6
SPECIAL EQUIPMENT	12 000	701	8 412 000	/1 000 000	8.4
DOM =	44 714		31 150 574	/1 000 000	31

Figure 2.3 Example of an index

In the example shown, the moment for the DOM is 31 150 574 but the Dry Operating Index (DOI) is only 31. Later, as you progress through the course, you will be using a DOI and another index called the Fuel Index to complete a Load and Trim Sheet.

Basic Empty Mass

See *CAP 696* for the definition of the BEM. All light aircraft use the BEM and its CG position as the foundation from which to calculate all relevant masses and CG positions. See *Figure 2.8* as an example.

Dry Operating Mass

See *CAP 696* for the definition of the DOM. All large aircraft use the DOM as the foundation from which to calculate all relevant masses and CG positions. The Load and Trim Sheet cannot be completed until the DOM and its CG position are known.

Operating Mass

See *CAP 696* for the definition of the OM. The OM is also used when completing the Load and Trim Sheet.

Traffic Load

See *CAP 696* for the definition of the traffic load. Originally known as the 'payload', the traffic load is the revenue generating load that pays the salaries and hopefully produces a profit for the operator. The definitions of and calculations of the traffic load constitute a sizeable part of the exam. There are six ways to define the traffic load and students need to be familiar with all of them.

Useful Load

The useful load is the sum of the traffic load and the take-off fuel load.

The Maximum Zero Fuel Mass

See *CAP 696* for the definition of the MZFM. The maximum stress in the wing roots occurs when the wing fuel tanks are empty. To ensure that the wings do not fold up permanently above the aircraft as the fuel is consumed a maximum zero fuel mass is imposed on the structure by the manufacturer.

Maximum Structural Taxi Mass

Every litre of fuel on board is essential for safe operations and aircraft are allowed to carry additional fuel for engine starting and ground taxiing purposes. This additional fuel, which is limited to a maximum value, is allowed to take the weight of the aircraft above the MSTOM during ground operations only. The additional fuel should be consumed by the time the aircraft is ready to commence the take-off run. The MSTM may also be referred to as the Ramp Mass or the Block Mass.

See CAP 696 for definitions of MSTOM, PLTOM, MSLM and PLLM

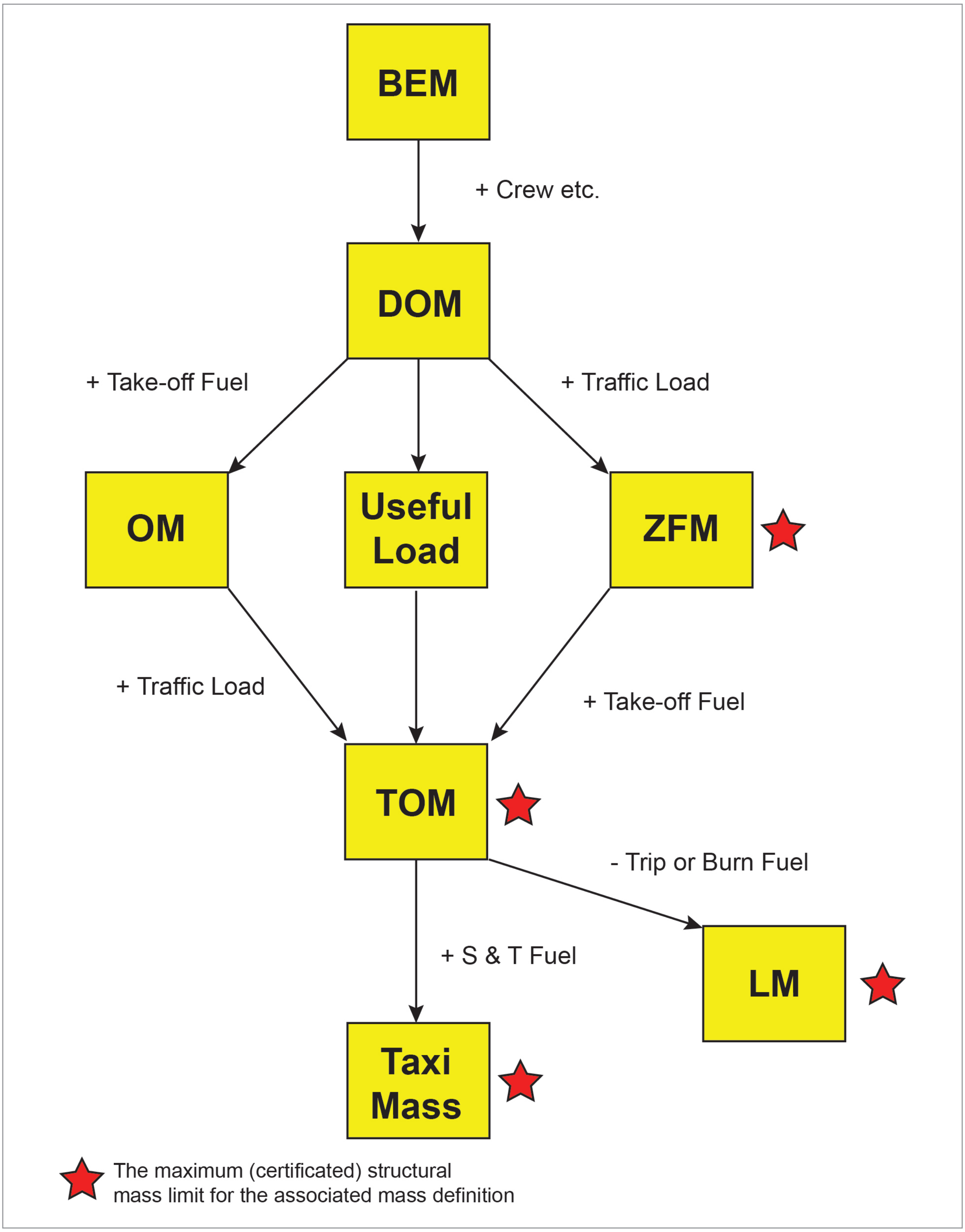


Figure 2.4 Definitions and flow diagram

Examples of 'definition' questions:

1. **The operating mass of an aircraft is:**

   a. the dry operating mass plus the take-off fuel mass.
   b. the empty mass plus the take-off fuel mass.
   c. the empty mass plus crew, crew baggage and catering.
   d. the empty mass plus the trip fuel mass.

2. **What effect has a centre of gravity close to the forward limit?**

   a. a better rate of climb capability.
   b. a reduction in the specific fuel consumption.
   c. a reduced rate of climb for a particular flight path.
   d. a decreased induced drag.

3. **The DOM of an aeroplane is:**

   a. TOM minus operating mass.
   b. LM plus trip fuel.
   c. useful load minus operating mass.
   d. TOM minus useful load.

4. **The traffic load of an aeroplane is:**

   a. TOM minus operating mass.
   b. LM plus trip fuel.
   c. useful load minus operating mass.
   d. TOM minus useful load.

Answers are shown on page 92.

Weighing of Aircraft

Aircraft are weighed on specialized weighing equipment in a draught free hangar at periods specified in EU-OPS 1, Subpart J. On each and every occasion of weighing a WEIGHING SCHEDULE is compiled by the person in charge of the weighing procedure. The schedule lists the BASIC EQUIPMENT installed on the aeroplane and records the mass values displayed on the weighing apparatus, together with the calculated moments. It culminates in a statement defining the Basic Empty Mass and Centre of Gravity position of the aeroplane and is signed by the person in charge of the weighing procedure. The schedule is then retained in the aircraft's TECHNICAL LOG until the next weigh. At each subsequent weigh the list of basic equipment on the previous weighing schedule is used to define the condition the aircraft must be prepared to in order that an accurate comparison of weights can be determined. The weighing procedure is a time and manpower consuming process as all non-basic items of equipment such as passenger seats and passenger service equipment (food and duty free trolleys etc) do not form part of the basic equipment. They must be removed prior to the weigh and be refitted afterwards.

Weighing Schedule

A/C Type ______ Mark _____ Registration Number ______

Registered owner _________ Date _____

List of Basic Equipment

	ITEM	MASS	ARM	MOMENT
1.	Pilot's seat	100	1	100
2.	C/pilot's seat	100	1	100
3.	Compass	25	2	50
4.	S/B compass	25	2	50
5.	Radio	20	2	40

ITEM	MASS (kg)	ARM	MOMENT (kg in)
Nose Wheel	134	-2	-268
Left Main	550	90	49 500
Right Main	550	90	49 500
BEM	**1234**	**80**	**98 732**

Signed ____________________ Date ______________

Figure 2.5 A weighing schedule (simplified for training purposes)

Any changes to the basic equipment that occur in the period between each weigh are recorded in the aeroplane's technical log and, as they vary from the equipment listed on the previous weighing schedule, they have to be accounted for separately at the next weigh.

Weighing Equipment. There are a number of ways of weighing aircraft accurately but, depending on the overall size and weight of the aeroplane, weigh-bridge scales, hydrostatic units or electronic equipment are the principal methods in use.

- **Weigh-bridge scales.** This equipment is generally used for light aeroplanes and consists of a separate electronic weighing platform for the nose or tail wheel and each main wheel assembly of the aircraft. The mass at each platform is recorded directly on the balance arm or electronic display and the masses are added together to give the BEM.

- **Hydrostatic units.** This equipment is used for larger, heavier aircraft and utilizes the principle embodied in Pascal's Law i.e. that the pressure of a liquid in a closed container is proportional to the load applied. The units are fitted at each jacking point and are interposed between the lifting jack and the jacking points on the aircraft. Again, the mass values on each unit are added together to give the BEM

- **Electronic equipment.** This equipment is also used on the larger, heavier aircraft and consists of strain gauges fitted at each jacking point and utilizes the principle that electrical resistance varies with the load applied. The readings are added together to give the BEM.

The other masses and CG positions applicable to the aircraft e.g. DOM, OM, TOM etc, can be determined by simple addition and multiplication once the Basic Empty Mass and CG position of the aeroplane have been established.

The mass of the fuel load can be calculated arithmetically providing the quantity and specific gravity of the fuel are known.

Actual mass of passengers and baggage can be used or the standard masses given in the tables in EU-OPS 1 Subpart J, can be used as an expedient alternative.

It is not normally possible to apply standard mass tables to freight because it varies so much from flight to flight. Therefore, in general, all freight has to be weighed. It is possible, in certain circumstances, for an operator to apply to the CAA for permission to produce and use standard mass tables for freight, but this exception is not part of the EU examinations syllabus.

Light aircraft use the BEM and CG position as the foundation from which the other mass and CG requirements are determined. Larger aircraft have additional mass and CG limits to comply with and they utilize a Load and Trim Sheet, incorporating the DOM as a basis, to simplify and standardize the process.

The operator of fleet aeroplanes of the same model and configuration may use an average DOM and CG position for the whole fleet providing the requirements of EU-OPS 1, Subpart J are met.

Minimum Equipment List

An aeroplane manufacturer must produce a Minimum Equipment List (MEL) for each of their aircraft type. The MEL defines, amongst other things, the minimum level of serviceable usable equipment the aircraft must have prior to flight. As an example, an aeroplane with three engines would be permitted to fly, in some circumstances, with only two engines operable.

The MEL serviceable equipment requirements vary according to the climatic and environmental conditions that exist in various theatres of the world. An aircraft operator will extract from the MEL those limitations applicable to his/her aircraft and will enter them into the Aircraft Operating Schedule.

In addition, the MEL lists the basic equipment requirements for each aircraft and also lists the optional specialist equipment that can be fitted for a particular role. It is therefore very useful when determining the BEM and DOM of an aeroplane.

Calculation of Fuel Mass

It is the commander of the aeroplane's responsibility to ensure that there is sufficient fuel on board the aeroplane to safely complete the intended flight and to land with not less than a specified level of fuel remaining in the tanks – irrespective of delays and diversions.

The safe operating fuel requirements defined above are satisfied by filling the tanks as shown in *Figure 2.6.* The Fuel Tank Contents:

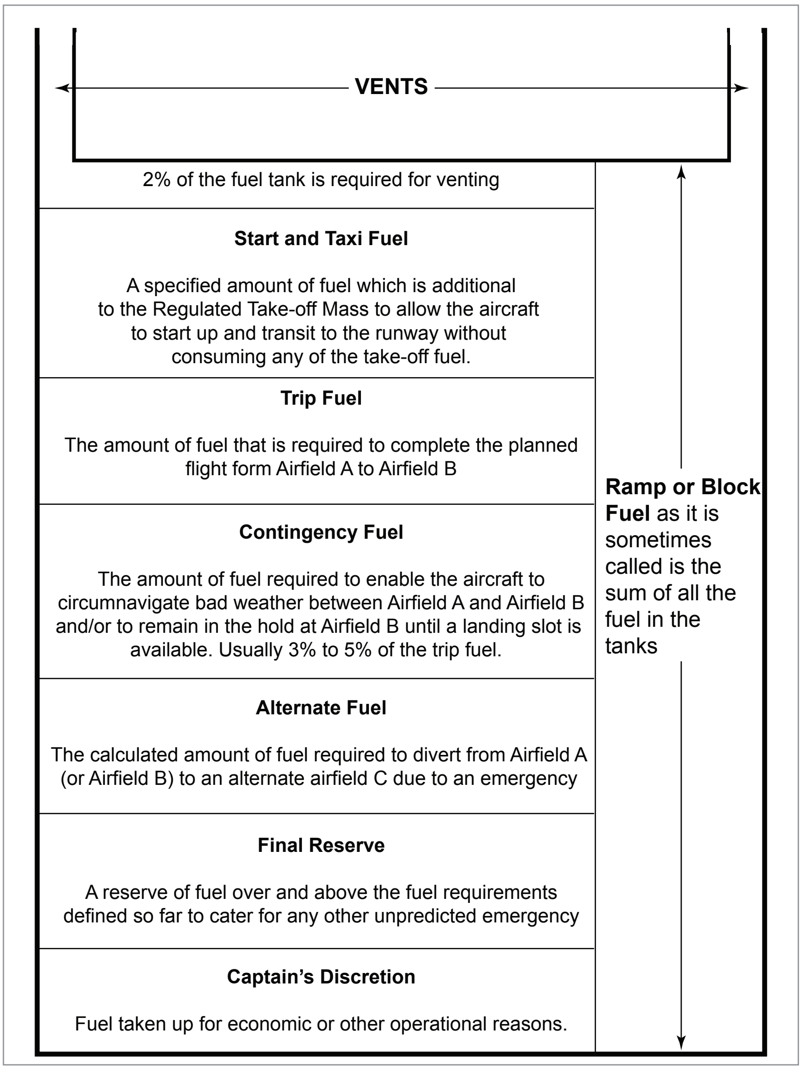


Figure 2.6 Fuel requirement regulations

Taking off at airfield 'A' and landing at airfield 'B' is classed as a trip or sector.

Having determined the mass of the trip fuel, the commander of the aeroplane may need to convert this mass value into a quantity value for the benefit of the refuel operator. Fuel is sometimes dispensed in gallons or litres.

In order to convert quantity (gallons or litres) into mass (pounds or kilograms) and vice versa, the density or the specific gravity (SG) of the fuel must be known. Normally, the delivery note provided by the refuel operator provides the SG of the fuel taken up. However, if, for some unforeseen reason, the actual fuel density is not known a standard fuel density, as specified by the operator in the Operations Manual, must be used. Density is defined as mass per unit volume and relative density or specific gravity (SG), is simply a comparison between the mass of a certain volume of a substance and the mass of an equal volume of pure water.

The following chart is a handy method of converting volume to mass. Students are advised to remember the chart and how to use it as it will not be provided in the exams.

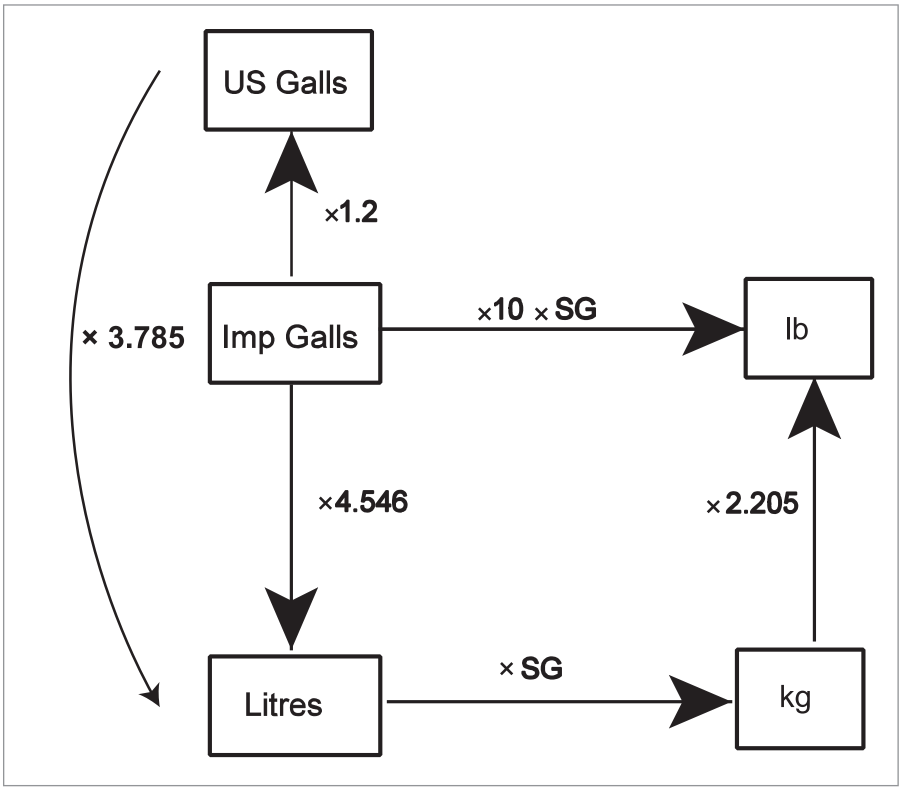


Figure 2.7 Quantity mass conversion chart

When moving in the direction of the arrows multiply by the numbers above the line. When moving against the direction of the arrows divide by the numbers above the line.

Note: *Conversion factors have been rounded for simplicity hence small errors might occur.*

Worked Example 1

a) Find the mass of 50 imperial gallons of AVGAS with a specific gravity of 0.72.

Mass = 50 × 10 × 0.72 = 360 lb

b) For 50 US gallons this would be:

Mass = 50 × 3.785 × 0.72 = 136.26 lb

Worked Example 2

Find the mass of 2250 litres of fuel with a density of 0.82.

Mass = 2250 × 0.82 = 1845 kg.

Try these on your own

1. You require 63 000 kg of fuel for your flight, the aircraft currently has 12 000 kg indicated on the gauges. How many US gallons of fuel do you request if the density is 0.81?

2. The refueller has metered 4596 imperial gallons; your fuel gauges indicated 5600 lb before refuelling. What should it indicate now? The fuel density is 0.79.

3. If the mass of 6000 US gallons of fuel is 16 780 kg, what is its SG?

4. The refuel bowser delivers 10 000 litres of fuel which is incorrectly entered on the aircraft load sheet as 10 000 kg of fuel. Is the aircraft heavier or lighter than the take-off mass recorded on the load sheet and how would this affect the range? (Take the SG of the fuel as 0.75).

   a. Heavier and would decrease the range.
   b. Heavier and would increase the range.
   c. Lighter and would decrease the range.
   d. Lighter and would increase the range.

Answers shown on page 92.

Calculation of the Basic Empty Mass and CG Position

In order to determine the Basic Empty Mass and CG position of an aeroplane the aircraft must first be prepared to the basic empty mass standard which entails removing all special equipment and usable fuel and oils.

The aircraft is placed such that its main wheels and the nose (or tail) wheels rest on the individual weighing scales which have been calibrated and zeroed. The readings on the scales are recorded as shown:

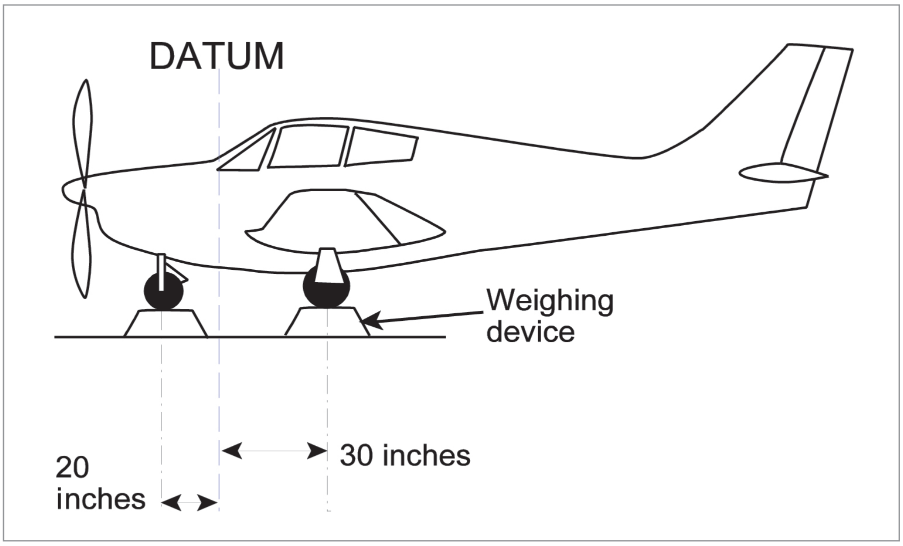


Figure 2.8 Basic empty mass and CG calculation

ITEM	MASS (lb)	ARM (in)	MOMENT
Nose wheel	500	-20	-10 000
L. Main wheel	2000	30	+60 000
R. Main wheel	2000	30	+60 000
BEM =	**4500 lb**	**Total Moment =**	**+110 000 lb in**

$$\textbf{CG} = \frac{\textbf{Total Moment}}{\textbf{Total Mass}} = \frac{\textbf{+110 000 lb in}}{\textbf{4500 lb}} = \textbf{+24.4 inches}$$

The Basic Empty Mass of the aeroplane is 4500 lb and the CG is 24.4 inches behind the datum (as shown by the positive sign).

The Basic Empty Mass is found by adding together the readings on the scales.

To find the CG position we need to take moments about the datum. In Mass & Balance terms a moment is a mass multiplied by a balance arm. Remember that arms (distances) forward of the datum are negative and a negative multiplied by a positive gives a negative value (see the nose wheel line above).

Notice in the example that each of the three entries above the line consist of a mass multiplied by an arm to give a moment. The entry below the line consists of a mass and a moment but no balance arm. The missing arm is the CG position.

To find the CG position the total moment is divided by the total mass. If the CG value is negative then the CG is in front of the datum otherwise it is behind the datum.

It is important to distinguish between mass and weight. Mass is the amount of matter in a body in kilograms and weight is the force that the matter exerts on the earth's surface, in Newtons.

If the readings on the weighing scales are given in Newtons but the question asks for the BEM and CG position then it is necessary to convert the weight into mass to arrive at the right answer.

ITEM	WEIGHT (N)	ARM (in)	MOMENT
Nose wheel	500	-20	-10 000
L. Main wheel	2000	30	+60 000
R. Main wheel	2000	30	+60 000
BEM =	**4500 N**	**Total Moment =**	**+110 000 N in**

$$\textbf{CG} = \frac{\text{Total Moment}}{\text{Total Mass}} = \frac{+\,110\,000\text{ N in}}{4\,500\text{ N}} = +\,24.4\text{ inches}$$

The weight of the aeroplane is 4500 N but to find the Basic Empty Mass we must divide the weight by 9.81 m/s^2

4500 N/ 9.81 m/s^2 = 458.7 kg

The BEM = 458.7 kg and the CG is 24.4 inches behind the datum

Try these examples yourself;

1. An aeroplane with a two wheel nose gear and four main wheels rests on the ground with a single nose wheel load of 725 kg and a single main wheel load of 6000 kg. The distance between nose wheels and the main wheels is 10 metres. What is the BEM and how far is the centre of gravity in front of the main wheels?

2. A tail wheel aeroplane has readings of 2000 lb and 2010 lb for the main wheels and 510 lb for the tail wheel. The tail wheel is 16 feet from the main wheels. What is the BEM and CG position? (1 foot = 12 inches).

3. A light aircraft has the datum 20 inches behind the nose wheel and 70 inches forward of the main wheels. The readings on the weighing scales are 255 N nose wheel and 1010 N on each main wheel. What is the BEM and CG position?

   (Answers shown on page 92)

Calculation of the Loaded Mass and CG Position for Light Aircraft

The loaded mass and CG is determined by tabulating the mass, arm and moment of the passengers, baggage, cargo, fuel and oil, adding the masses to the BEM to find the TOM and adding the moments to find the Total Moment. The CG is found by dividing the Total Moment by the Total Mass: CG = Total Moment/Total Mass.

The LM is found by subtracting the fuel and oil consumed during the flight from the TOM. The CG position of the LM is found by taking moments and dividing the LM Moment by the LM.

For simplicity and standardization the mass, arms and moment data is tabulated on a Load Manifest or Load Sheet. (See *Figure 2.9* for a complete example).

In the following pages we will concentrate on calculating the take-off mass and CG position for the single-engine piston aircraft SEP1 using these values.

Basic empty mass	2415 lb
Front seat occupants	340 lb
3rd and 4th seat passengers	340 lb
Baggage zone B	200 lb
Fuel at engine start	60 US.gal
Trip fuel (calculated fuel burn)	40 US.gal

When completed the load sheet can be used to check that limiting values such as MZFM, RAMP MASS, MSTOM and MSLM have not been exceeded. The mass and CG limits are presented in graphical form *(CAP 696, section 2, SEP1 page 4, Figure 2.5)* against which the calculated values can be checked.

Note: *Fuel for start, taxi and run up is normally 13 lb at an average entry of 10 in the column headed moment / 100*

ITEM	MASS (lb)	ARM (in)	MOMENT/100
Basic Empty Mass	**2415**	77.7	**1876.46**
Front seat occupants	**340**	79	**268.6**
3rd and 4th seat pax	**340**	117	**397.8**
Baggage zone A	**nil**	108	
5th and 6th seat pax	**nil**	152	
Baggage zone B	**200**	150	**300**
Baggage zone C	**nil**	180	
SUB TOTAL = ZERO FUEL MASS	**3295**		**2842.86**
Fuel loading 60 US. gal	**360**	75	**270**
SUB TOTAL = RAMP MASS	**3655**		**3112.86**
Subtract fuel for start, taxi and run up. (see note)	**-13**		**-10**
SUB TOTAL = TAKE-OFF MASS	**3642**		**3102.9**
Trip fuel	**-240**	75	**-180**
SUB TOTAL = LANDING MASS	**3402**		**2922.9**

Figure 2.9 Completed load sheet solution

Note: *Fuel for start, taxi and run up is normally 13 lb at an average entry of 10 in the column headed moment / 100*

The arm data is entered on the load sheet in the appropriate columns as shown above. The individual moments are calculated by multiplying the mass of an item by its balance arm from the datum and entering the figure in the moment column.

Moments are often large numbers containing more than six digits and this can be an extra source of difficulty. In the SEP example shown, the moments have been divided by one hundred to reduce the number of digits and make them more manageable. Take care if you use this procedure because you must remember at the end of any calculations to multiply the final answers by one hundred to arrive at the correct total moment.

The fuel load may be given as a quantity (Imperial or American gallons) rather than a mass and you must convert it to mass before you can complete the load sheet (see *Figure 2.7*). Fuel mass and distribution may also be given in tabular form as shown in the example above, where the fuel mass and moment have been taken from the *SEP1 fuel chart, Figure 2.3, of the CAP 696 Mass and Balance Manual.*

The take-off and landing CG positions can now be determined by using the following procedure:

Take-off CG

- Sum (add up) the vertical 'MASS' column to determine in turn, the ZFM, the Ramp Mass and the TOM.

  (ZFM = 3295 lb; Ramp Mass = 3655 lb and TOM = Ramp Mass – Start/Taxi fuel = 3655–13 = 3642 lb)

- Check the Operating Manual to ensure that limiting masses of MZFM, MSTM and Regulated TOM have not been exceeded.

- Sum the vertical 'MOMENTS' column to determine the total moment for ZFM, Ramp Mass moment and TOM.

  (ZFM moment = 284 286 lb in; Ramp Mass moment = 284 286 + 27 000 = 311 286 lb in; TOM moment 311 286 – 1000 = 310 286 lb in).

Note, the figures in the table are shown in the abbreviated form e.g. 310 286/100 = 3102.9 which is less accurate but easier to cope with.

- Divide the moment of the TOM by the TOM to determine the CG position at take-off. (TOM CG position = 310 290 ÷ 3642 = 85.2 inches aft of the datum).

- Check the Operating Manual to ensure that the CG is within limits at both the ZFM and TOM situations. If this is the case then the CG will remain within the limits throughout the flight and should not go out of limits during the journey provided the fuel is used in the correct sequence.

Landing CG

- Determine the moment of the fuel used in flight (the trip fuel) by multiplying its mass by the fuel arm. In light aircraft the fuel arm will usually be the same as the one used previously to calculate the take-off CG position. However, caution is required because in some large aircraft the balance arm of the fuel may change with the quantity of fuel consumed.

  THE FUEL CONSUMED WILL GIVE A NEGATIVE MASS IN THE MASS COLUMN AND THIS WILL CHANGE THE MOMENT SIGN E.G. IF THE FUEL ARM IS POSITIVE THE FUEL MOMENT WILL BECOME NEGATIVE.

- In the 'MASS' column, subtract the fuel used during the flight from the TOM to determine the Landing Mass.

  (Landing Mass = 3642 – 240 = 3402 lb).

- Check the Operating Manual to ensure that the Regulated Landing Mass has not been exceeded.

- In the 'MOMENTS' column, determine the sign of the fuel moment and add or subtract it as appropriate, to the TOM moment to determine the landing moment.

  (Landing Moment = 310 286 – [240 × 75] = 310 286 – 18 000 = 292 286 lb in [or 2922.9 lb in in the abbreviated form]).

- If the CG is within limits at the ZFM then, for large aircraft, it is not normally necessary to calculate the landing CG position because, as stated previously, the CG will be within limits throughout the flight. However, for light aircraft it is usual to determine the landing CG position and this is simply achieved by dividing the landing moment by the landing mass.

  (Landing CG position = 292 286 ÷ 3402 = 85.92 inches aft of the datum because it has a positive sign).

The CG can also be found by using the Centre of Gravity Envelope for the SEP1 shown below. This is a graphical representation of the mass and centre of gravity limits. The vertical axis is the mass in pounds, the horizontal axis is the CG position in inches aft of the datum and the slanted lines represent the moment/100.

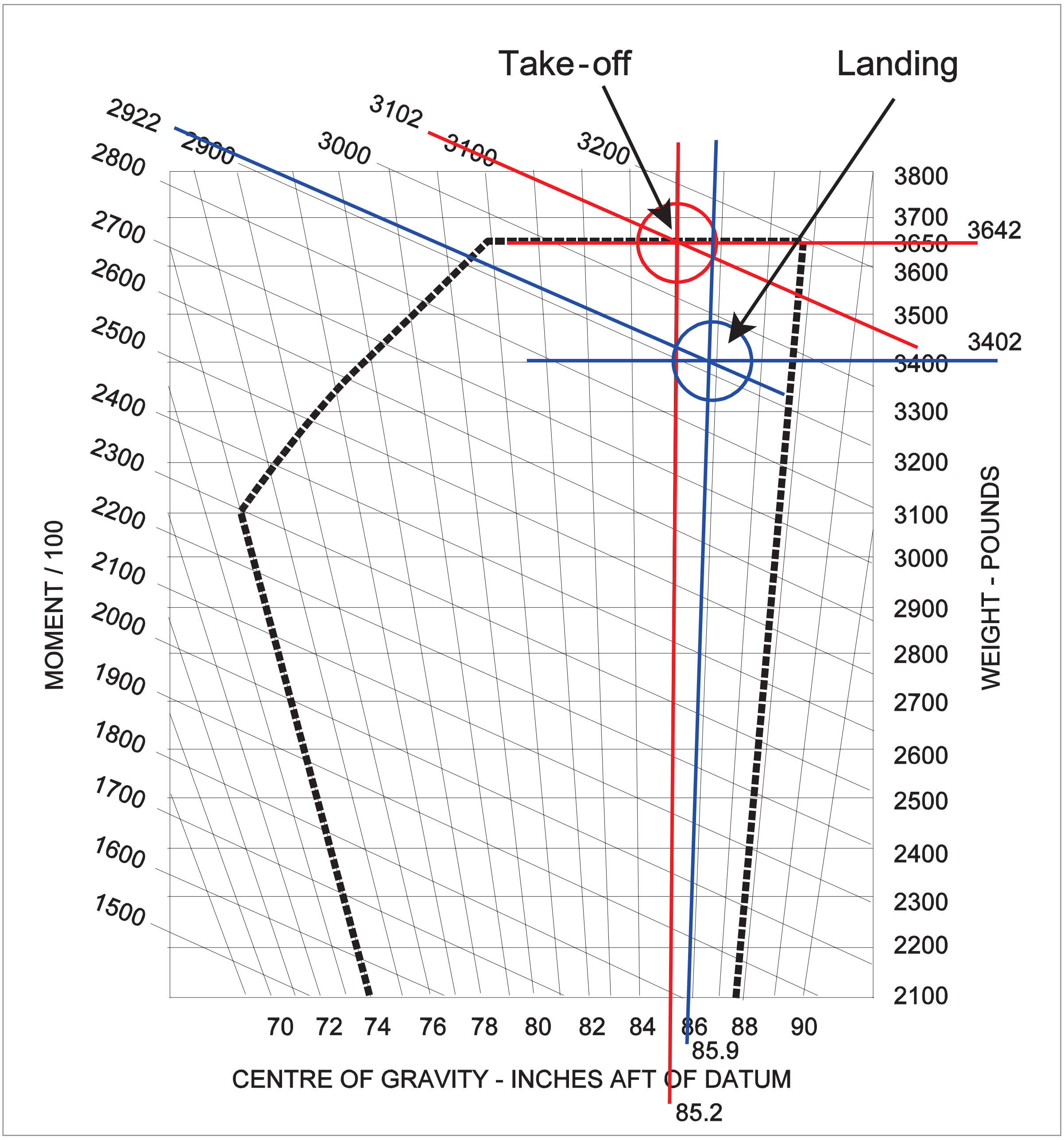


Figure 2.10 SEP1 CG Envelope

Example 3

Try this example of calculating the take-off and landing mass and CG position for a fictitious aircraft without using a formal load sheet.

For the data given below:

- Find the CG for take-off as loaded.
- Find the CG for landing after a flight lasting for 1 hour 30 minutes.

Maximum Take-off Mass	2245 lb
Maximum Landing Mass	2100 lb
Centre of Gravity limits	2 in forward to 6 in aft of datum
Fuel Consumption	7.0 US Gallons per hour
Oil Consumption	1.0 US quart per hour

ITEM	MASS (lb)	ARM (in)
Basic Mass	1275	-5
Seats 1 and 2	340	-2
Seats 3 and 4	170	30
Fuel 35 US Gallons (SG 0.72)		2
Oil 8 US quarts (SG 0.9)		-48
Baggage	45	70

Solution:

Lay out your solution in the same fashion as the load sheet:

Calculate fuel and oil mass using the density specified.

Fuel: 35 ÷ 1.2 × 0.72 × 10 = 210 lb (US.gal to pounds)

Oil : 8 ÷ 4 ÷ 1.2 × 0.9 × 10 = 15 lb (US.qt to pounds)

ITEM	MASS (lb)	ARM (in)	MOMENT
DOM	1275	-5	-6375
Seats 1 and 2	340	-2	-680
Seats 3 and 4	170	30	5100
Fuel 35 US.gal	210	2	420
Oil 8 US quarts	15	-48	-720
Baggage	45	70	3150
Take-off Mass	**2055 lb**	**Take-off Moment**	**895**

Take-off CG = **0.435 inches aft of datum** (within limits)

To calculate landing CG

Fuel used in one and a half hours = 1.5 × 7 ÷ 1.2 × 0.72 × 10 = 63 lb

Oil used = 1.5 × 0.25 ÷ 1.2 × 0.9 × 10 = 2.8 lb

Landing mass = 2055 - 63 - 2.8 = **1989.2 lb**

Landing moment = Take-off moment - Fuel used moment - Oil used moment

Landing moment = +895 - (63 × +2) - (2.8 × -48)

Landing moment = +895 - (126) - (-134) (minus and minus give plus)

Landing moment = +895 - 126 + 134

Landing moment = **+903**

Landing CG = $\dfrac{\mathbf{+\ 903}}{\mathbf{1989.2}}$

= **+ 0.454 inches aft of datum** (within limits)

Note: *Remember to check that the take-off mass and CG position and the landing mass and CG position are within the acceptable limits for the trip.*

CG Position as a Percentage of Mean Aerodynamic Chord (MAC)

In the previous examples the CG position and CG limits are given as distances from a datum. An alternative method is to state the CG position and its limits as a percentage of the Mean Aerodynamic Chord (MAC). This is common practice with many swept wing airliners and it is so with the twin jet we shall be studying next.

The mean aerodynamic chord is one particular chord on the wing calculated from the aerodynamic characteristics of that particular wing. Because the CG affects many aerodynamic considerations, particularly stability, it is useful to know the CG position in relation to the aerodynamic forces.

The length of the MAC is constant and it is at a fixed distance from the datum. The CG is located at some point along the MAC and the distance of the CG from the leading edge of the MAC is given in percentage forms - CG position of 25% MAC would mean that the CG was positioned at one quarter of the length of the MAC measured from the leading edge.

The method of calculating the percentage of MAC is shown below.

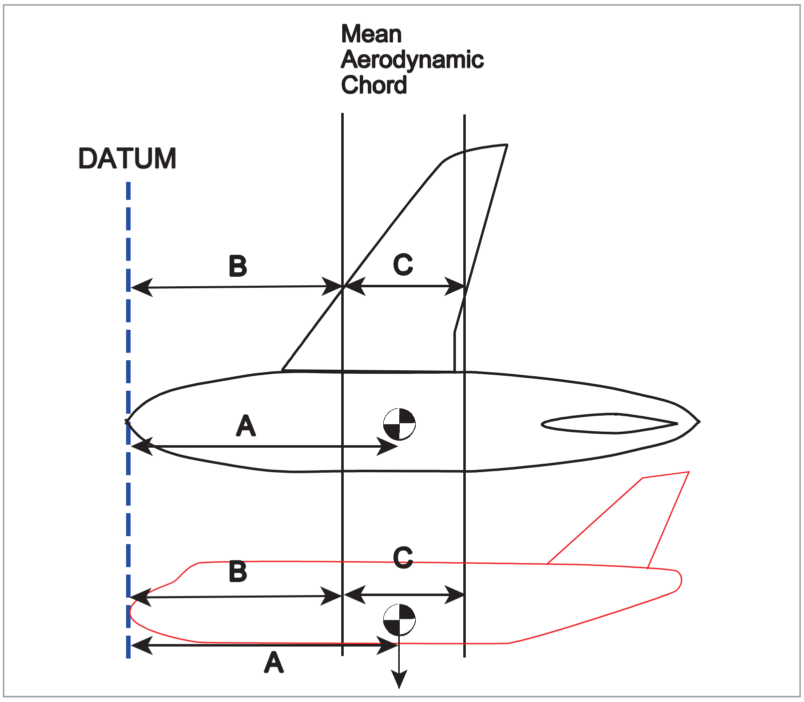


Figure 2.11

A = distance of CG from datum.

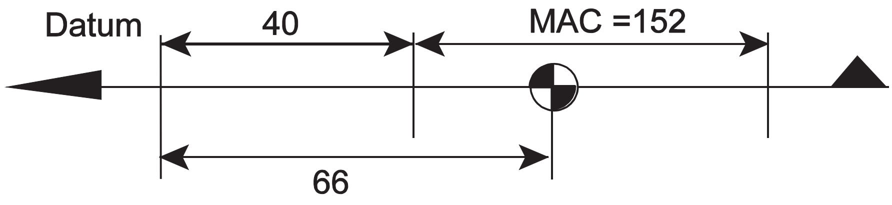
B = distance of MAC leading edge from datum.

C = length of MAC.

The CG as a percentage of MAC $= \dfrac{A - B}{C} \times 100$

Example 4

If the MAC is 152 in and its leading edge is 40 in aft of the datum, and the CG is 66 in aft of the datum, what is the CG position as a percentage of MAC?



$$\frac{66 - 40}{152} \times 100 = \mathbf{17.1\%}$$

Now try these:

1. An aircraft has a MAC of 82 inches. The leading edge of the MAC is 103 inches aft of the datum. If the CG position is 14.7% MAC, what is the CG distance from the datum?

2. If the CG position is 21% MAC, the MAC is 73 inches, and the CG datum is 26 inches aft of the leading edge of the MAC, what is the CG position relative to the datum?

3. The CG limits are from 5 inches forward to 7 inches aft of the datum. If the MAC is 41 inches and its leading edge is 15 inches forward of the datum, what are the CG limits as % MAC?

4. The MAC is 58 inches. The CG limits are from 26% to 43% MAC. If the CG is found to be at 45.5% MAC, how many inches is it out of limits?

5. An aircraft of mass 62 500 kg has the leading and trailing edges of the MAC at body stations +16 and +19.5 respectively (stations are measured in metres). What is the arm of the CG if the CG is at 30% MAC?

Answers can be found on page 92.

Repositioning of the Centre of Gravity

If the centre of gravity is found to be out of limits for any part of the flight, the aircraft must not take off until the load has been adjusted so as to bring the centre of gravity into limits.

This may be achieved in one of two ways:

- By repositioning mass which is already on board the aircraft. This will usually be baggage or passengers.

- By adding or removing mass. Mass put on to the aircraft purely for the purpose of positioning or correcting the CG position is known as ballast.

The minimum mass to be moved, or the minimum amount of mass to be loaded or off-loaded, will be that which just brings the centre of gravity on to the nearest limit. It may be preferable of course to bring the CG further inside the limits. When the amount of mass adjustment has been calculated, it must be ascertained that this makes the aircraft safe for both take-off and landing.

Repositioning of the Centre of Gravity by Repositioning Mass

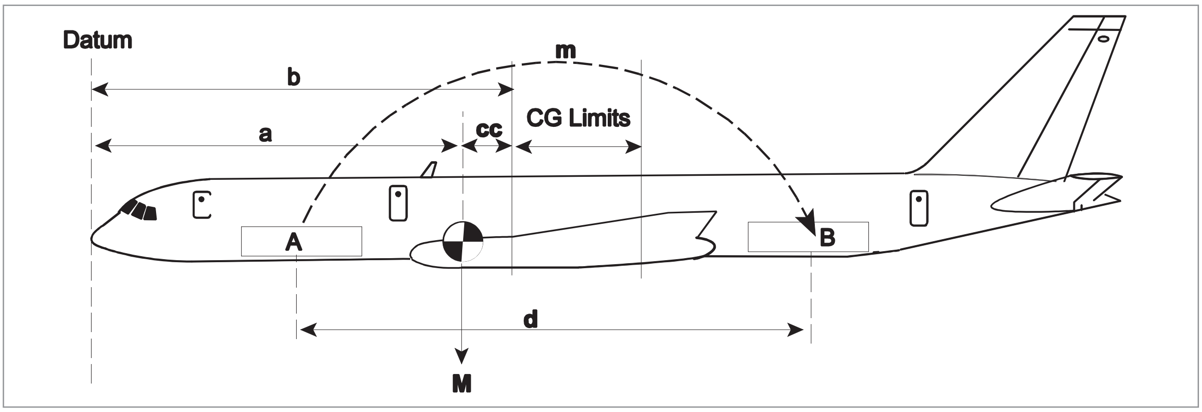


Figure 2.12 Repositioning mass

In *Figure 2.12* the centre of gravity has been found to be out of limits at a distance 'a' inches aft of the datum. The forward CG limit is 'b' inches aft of the datum. To bring the CG into limits, some baggage (m) will be moved from compartment A to compartment B.

If a mass of m lb is moved from A to B the change of moment will be

$$\mathbf{m \times d}$$

That is, the change of moment is equal to the mass moved (m) multiplied by the distance through which it moves (d).

If the total mass of the aircraft is **M**, with the CG at 'a' inches aft of the datum, the total moment around the datum is **M × a.**

It is required to move the CG to **'b'** inches aft of the datum. The new total moment will then be M × b.

The change in moment required is therefore M × b - M × a = M(b - a).

And M (b - a) = m × d

b - a is equal to the change to the CG position 'cc'.

And so **m × d = M × cc**

That is, the mass to move multiplied by the distance it moves is equal to the total aircraft mass multiplied by the distance the CG moves through.

Example 5

The CG limits of an aircraft are from -4 to +3 inches from the datum. It is loaded as shown below:

ITEM	MASS (lb)	ARM (in)	MOMENT (lb in)
Basic Empty Mass	2800	2	5600
Crew	340	-20	-6800
Fuel	600	10	6000
Forward Hold	0	-70	0
Aft Hold	150	80	12 000
Total Mass =	**3890**	**Total Moment =**	**16 800**

Therefore CG $= \dfrac{16\,800}{3890} =$ 4.32 in

The Aft Limit is +3 and so the CG is 1.32 in out of limits (too far aft).

It can be corrected by moving some freight or baggage from the rear hold to the forward hold, a distance of 150 in. (80 in aft to 70 in forward).

How much freight/baggage can be calculated by using our formula

$$\mathbf{m \times d = M \times cc}$$

$$m \times 150 = 3890 \times 1.32$$

$$m = \frac{3890 \times 1.32}{150}$$

Mass of freight and/or baggage to move = 34.232 lb

To check that the aircraft is safe for all fuel states after take-off, we will calculate the CG at the Zero Fuel Mass with 35 lb of baggage moved to the forward hold.

ITEM	MASS (lb)	ARM (in)	MOMENT (lb in)
Basic Mass	2800	2	5600
Crew	340	-20	-6800
Fuel (Zero)	0		
Fwd. Hold	35	-70	-2450
Aft Hold	115	80	9200
ZFM =	**3290**	**ZFM moment =**	**5550**

$$\textbf{ZFM CG} = \frac{\mathbf{5550}}{\mathbf{3290}}$$

$$= 1.69 \text{ in (in limits)}$$

Now try these:

1. The CG limits of an aircraft are from 83 in to 93 in aft of the datum. The CG as loaded is found to be at 81 in aft of the datum. The loaded mass is 3240 lb. How much mass must be moved from the forward hold, 25 in aft of the datum, to the aft hold, 142 in aft of the datum, to bring the CG onto the forward limit?

2. An aircraft has a loaded mass of 5500 lb. The CG is 22 in aft of the datum. A passenger, mass 150 lb, moves aft from row 1 to row 3 a distance of 70 in. What will be the new position of the CG? (All dimensions aft of the datum).

3. The loaded mass of an aircraft is 12 400 kg. The aft CG limit is 102 in aft of the datum. If the CG as loaded is 104.5 in aft of the datum, how many rows forward must two passengers move from the rear seat row (224 in aft) to bring the CG on to the aft limit, if the seat pitch is 33 in. Assume a passenger mass of 75 kg each.

4. An aircraft of mass 17 400 kg, has its CG at station 122.2. The CG limits are 118 to 122. How much cargo must be moved from the rear hold at station 162 to the forward hold at station -100 (forward of the datum) to bring the CG to the mid position of its range?

5. With reference to *Figure 2.13* how much load should be transferred from No. 2 hold to No. 1 hold in order to move the CG from the out-of-limits value of 5.5 m to the forward limit value of 4.8 m? The total mass of the aircraft is 13 600 kg.

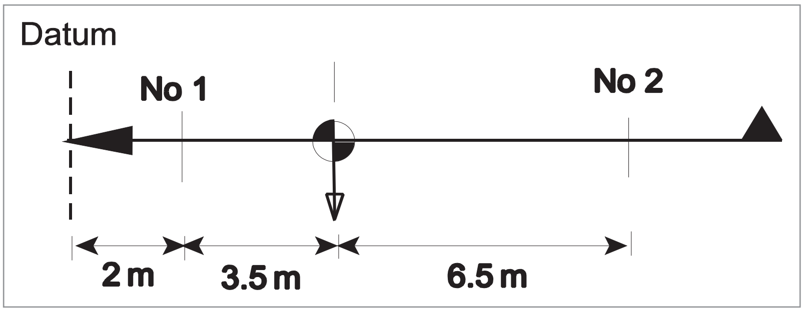


Figure 2.13 Moving Mass 1

6. With reference to *Figure 2.14* the loaded mass of the aircraft is found to be 1850 lb and the CG moment 154 000 lb in. How much mass must be moved from the forward hold 40 in aft of the datum, to the rear hold, 158 in aft of the datum, to bring the CG on to the forward limit?

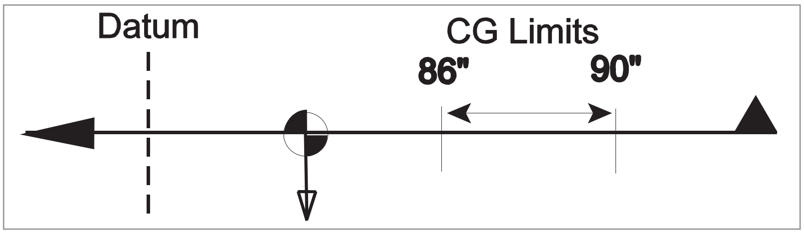


Figure 2.14 Moving Mass 2

Answers can be found on *page 92*.

Repositioning of the Centre of Gravity by Adding or Subtracting Mass

The position of the CG can also be adjusted by adding or subtracting mass. Mass added simply to reposition the CG is called **ballast.**

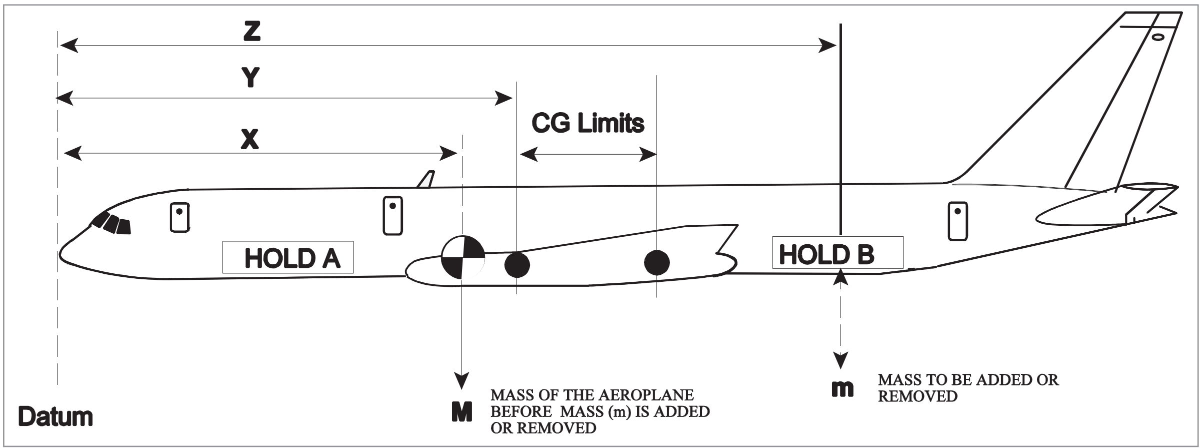


Figure 2.15 Adding or Removing Mass

To calculate the minimum amount of ballast required:

In *Figure 2.15* the CG has been found to be out of limits at a distance 'X' in aft of the datum. The forward CG limit is at a distance 'Y' in aft of the datum. To bring the CG into limits, ballast will be put in compartment B, a distance 'Z' in aft of the datum.

If the total mass of the aircraft is M lb, the total moment will be M × X lb in.

If ballast of m lb is placed in compartment B in order to move the CG to its fwd limit, the total mass will increase to M + m and the new total moment will be (M + m) × Y. Assuming equilibrium to be maintained, the original total moment plus the moment of the added mass must equal the new total moment.

Algebraically using the above notation then:

$$(M + m) \times Y \quad = \quad (M \times X) + (m \times Z)$$

New Total Moment = Old Total Moment + Cargo Moment

The same formula can be used for removing mass by changing the plus sign to a minus. So, for any calculation involving adding or subtracting mass remember the formula:

New Total Moment = Old total moment plus or minus the Cargo Moment

Note that when calculating a change in CG position using the New Moment = Old Moment ± Change in Moment the distances (X, Y and Z) are always measured from the datum itself.

We will do an example calculation together.

Example 6

The CG limits of an aircraft are from 84 in to 96 in aft of datum at all masses. It is loaded as shown below:

ITEM	MASS (lb)	ARM (in)	MOMENT (lb in)
Basic Mass	1250	80	100 000
Crew	340	82	27 880
Fuel	300	72	21 600
Baggage	0	140	0
	1890		**149 480**

$$CG = \frac{149\,480}{1890} = 79.1 \text{ in aft of datum}$$

The CG is out of limits by 4.9 in too far forward. It will be brought into limits by putting ballast in the baggage compartment. The minimum ballast would be that required to bring the CG to 84 in.

Using our formula:

$$\textbf{NTM} = \textbf{OTM} + \textbf{CM}$$

$$(1890 + m) \times 84 = (1890 \times 79.1) + (m \times 140)$$

$$158\,760 + 84m = 149\,499 + 140m$$

$$158\,760 - 149\,499 = 140m - 84m$$

$$9261 = 56m$$

$$\frac{9261}{56} = m$$

$$m = 165.4$$

Therefore mass of ballast required = 165.4 lb

It would be necessary to check that loading the ballast did not cause the total mass to exceed the Maximum Take-off Mass and as before, that the aircraft was in limits for landing.

Although this may appear to be a long winded method it will always provide the correct answer, remember you may be asked to calculate a mass to add or remove, a change to the CG or the position to put ballast.

Now try these adding or removing mass problems:

1. An aircraft has three holds situated 10 in, 100 in and 250 in aft of the datum, identified as holds A, B and C respectively. The total aircraft mass is 3500 kg and the CG is 70 in aft of the datum. The CG limits are from 40 in to 70 in aft of the datum. How much load must be removed from hold C to ensure that the CG is positioned on the forward limit?

2. An aircraft has a mass of 5000 lb and the CG is located at 80 in aft of the datum. The aft CG limit is at 80.5 in aft of the datum. What is the maximum mass that can be loaded into a hold situated 150 in aft of the datum without exceeding the limit?

3. The loaded mass of an aircraft is 108 560 lb and the CG position is 86.3 ft aft of the datum. The aft CG limit is 85.6 ft. How much ballast must be placed in a hold which is located at 42 ft aft of the datum to bring the CG onto the aft limit?

4. The aft CG limit of an aircraft is 80 in aft of the datum. The loaded CG is found to be at 80.5 in aft of the datum. The mass is 6400 lb. How much mass must be removed from a hold situated 150 in aft of the datum to bring the CG onto the aft limit?

5. An aircraft has a mass of 7900 kg and the CG is located at 81.2 in aft of the datum. If a package of mass 250 kg was loaded in a hold situated 32 in aft of the datum, what would the new CG position be?

6. The CG limits of an aircraft are from 72 in to 77 in aft of the datum. If the mass is 3700 kg and the CG position is 76.5 in aft of the datum, what will the change to the CG position be if 60 kg is removed from the fwd hold located at 147 in fwd of the datum?

7. An aeroplane has a zero fuel mass of 47 800 kg and a performance limited take-off mass of 62 600 kg. The distances of the leading edge and trailing edge of the MAC from the datum are 16 m and 19.5 m respectively. What quantity of fuel, in imperial gallons, must be taken up to move the CG from 30% MAC to 23% MAC if the tank arm is 16 m aft of the datum and the fuel SG is 0.72?

Answers shown on page 92.

Graphical Presentation

The aircraft mass and CG position are frequently calculated using one of a number of graphical methods. These notes give several examples of the graphs that may be used: see *CAP 696 and this book page 45 and page 75*. There are two things in common on any of the graphs used:

- The CG must be within the envelope or on the line of the envelope.
- The mass of the aeroplane is always shown on the vertical scale.

The example of a mass and CG envelope for the SEP1, shown in *CAP 696 Sect 2, SEP1 page 4*, is unusual in that it uses both mass and moments on the vertical scale.

The horizontal scale may use the CG position (inches, metres or centimetres), the moment of the CG (kg inches, kg metres or kg centimetres) or the percentage of the CG along the mean aerodynamic chord. The MEP1 envelope, shown in *CAP 696, Section 3 - MEP1 page 3,* is an example of using CG position and the MRJT envelope shown in *CAP 696, Section 4 - MRJT, page 9*, is an example of the use of the MAC percentage.

Cargo Handling

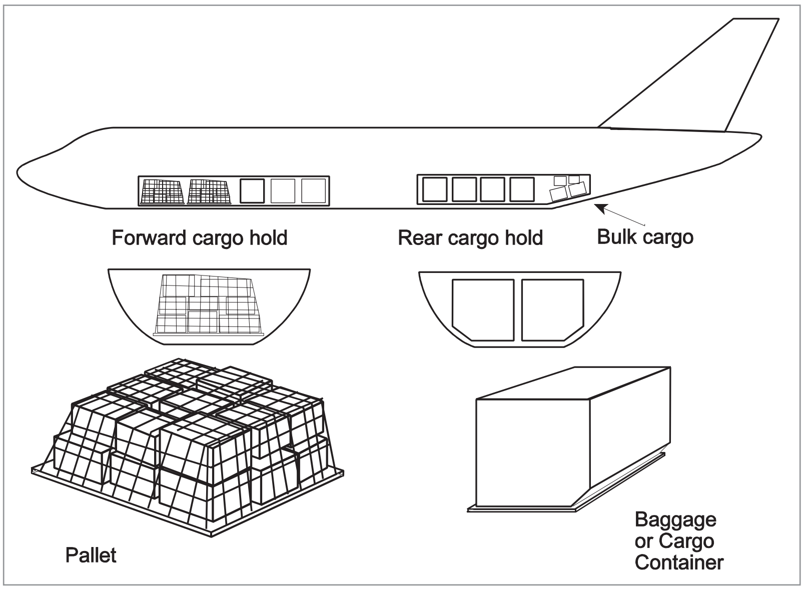


Figure 2.16 Cargo handling

Cargo Compartments

Compartments in the lower deck accommodate baggage and cargo. The compartments feature fire resistant sidewalls, ceilings and walkways. Cargo compartments are usually pressurized and heated and typically have fire detection and protection equipment. Cargo compartments usually have a maximum floor loading (kg/m^2) and maximum running load value (kg/m).

Containerized Cargo

Baggage and cargo can be loaded into standard size containers designed to fit and lock into the cargo compartment. The containers have an individual maximum mass limit and an individual floor loading limit (mass per unit area).

Palletized Cargo

Cargo can also be loaded onto standard size pallets and restrained with cargo nets or strops. Typically the forward area of the forward cargo compartment is configured to take palletized freight.

Bulk Cargo

Bulk cargo can be loosely loaded in the area at the aft of the rear cargo compartment and separated from the containers by a restraining net attached to the floor, ceiling and sidewalls.

Cargo Handling Systems

The forward and aft cargo compartments typically have separate cargo power drive systems to move containers and cargo pallets.

The power drive system is operated by a control panel at the door area of each cargo compartment and is capable of loading and unloading fully loaded containers or pallets in wet or dry conditions. A typical panel is shown in *Figure 2.17*.

Power drive units (PDU) are mounted in the floor and are controlled by the control joystick to move containers laterally and longitudinally in the doorway area and longitudinally in the compartment forward and aft of the doorway.

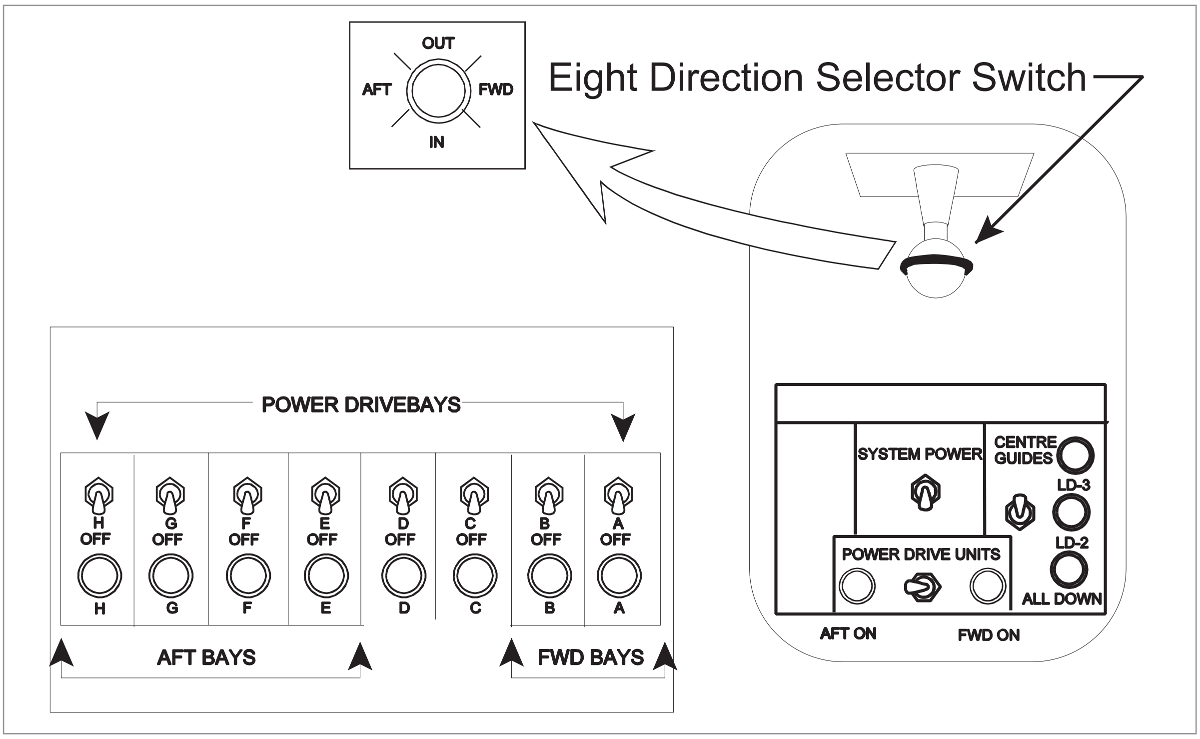


Figure 2.17 Cargo bay control panel.

Guides, rollers, stops, locks and tie down fittings are included in the appropriate places to provide adequate 'G' restraint for the containers in flight.

Floor Loading

The floors of the passenger cabin and the freight areas of the aircraft are limited in the load that they can carry. Placing excessive loads on the structure may not only cause visible panel creasing and local indentations but is likely to significantly accelerate structural fatigue. Fatigue is cumulative and can lead to major structural collapse of the structure with little or no warning.

The floor loading is defined both by linear loading and by area loading intensity.

Linear / Running Loads

The linear (or running) loading limitation (lb per linear foot or kg per linear inch) protects the aircraft underfloor frames from excessive loads. Depending on the units used, it is the total load permitted in any one inch or one foot length of the aircraft (irrespective of load width).

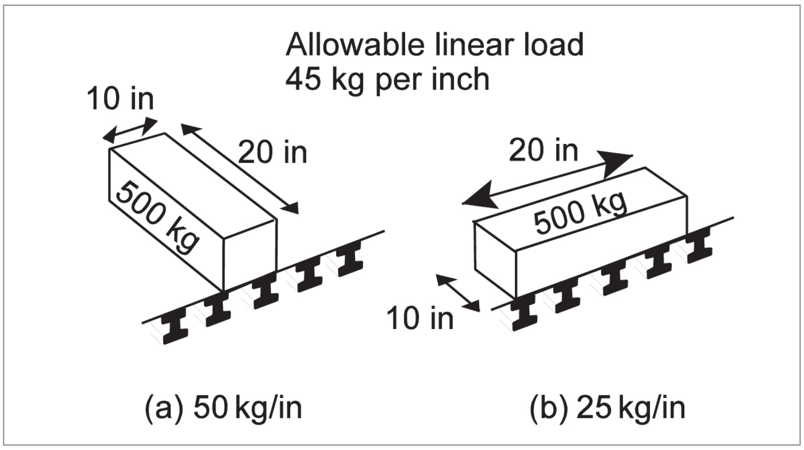


Figure 2.18 Linear Loading

Calculating the linear load distribution

As can be seen at *Figure 2.18*, example (a), the linear load on the floor members is 500 kg divided by the 10 inch length i.e. 50 kg/inch; which is greater than the 45 kg/in allowed. However, the way in which an item of load is located in an aircraft can create an acceptable situation out of an unacceptable one.

In example (b), by simply rotating the load through 90° the linear load on the floor members becomes 500 kg/20 inches i.e. 25 kg/in; which is well within the limit. It can be seen that the least linear loading occurs when the longest length is placed at right angles to the floor beams.

Area Load Limitations

Area load limitations (kg/sq metre or lb/sq ft) protect the aircraft floor panels. The two permissible intensities of pressure are "Uniformly Distributed" (UD) and "Concentrated" loads.

UD Loads

The general floor loading limitations for cargo are referred to as UD loads and are given as allowable lb/sq ft. Providing that a load (or series of loads) is within the allowable UD limitations for the floor area on which it rests, the loading is subject only to :

- not exceeding the linear load limitations.
- the individual and accumulated compartment load limitations.

Concentrated Loads

Load intensities which exceed the UD load intensities, "concentrated loads", can be carried providing approved load spreaders are used to distribute the load over sufficient area to ensure that loading limits are not exceeded.

Load Spreaders

When concentrated loads or items of load with hard or sharp areas are carried on an aircraft, some form of floor protection is essential. The normal practice is to employ standard load spreaders of 2 inch thick timber.

An Example of Load Intensity and Running Load for You to Do

An item of cargo has dimensions 3 ft × 4 ft × 12 ft and weighs 900 kg. Given that the maximum running load for the compartment is 20 kg/in and the maximum load intensity for the compartment is 70 kg/ft^2 what are the running load values and the floor intensity values for the cargo and are there any limitations in the way in which it may be carried?

(1 ft = 12 inches)

Considering the RUNNING LOAD (underfloor protection) first:

Max running load = Load / shortest length

Mid running load = Load / mid length

Min running load = Load / longest length

Max running load $= \dfrac{900 \text{ kg}}{(3 \text{ ft} \times 12 \text{ inches/ft})} = 25$ kg/in) Max = 20 kg/in) Exceeds limit

Mid running load $= \dfrac{900 \text{ kg}}{(4 \text{ ft} \times 12 \text{ inches/ft})} = 18.75$ kg/in) OK) Below limit

Min running load $= \dfrac{900 \text{ kg}}{(12 \text{ ft} \times 12 \text{ inches/ft})} = 6.25$ kg/in) OK) Below limit

Now considering the DISTRIBUTION LOAD INTENSITY (Floor protection)

Max distribution load on the floor = Load / smallest area

Mid distribution load on the floor = Load / medium area

Min distribution load on the floor = Load / largest area

Max dl $= \dfrac{900 \text{ kg}}{3 \text{ ft} \times 4 \text{ ft}} = \dfrac{900 \text{ kg}}{12 \text{ ft}^2} = 75 \text{ kg/ft}^2$) Max = 70 kg/ft^2) Exceeds limit

Mid dl $= \dfrac{900 \text{ kg}}{3 \text{ ft} \times 12 \text{ ft}} = \dfrac{900 \text{ kg}}{36 \text{ ft}^2} = 25 \text{ kg/ft}^2$) OK) Below limit

Min dl $= \dfrac{900 \text{ kg}}{4 \text{ ft} \times 12 \text{ ft}} = \dfrac{900 \text{ kg}}{48 \text{ ft}^2} = 18.75 \text{ kg/ft}^2$) OK) Below limit

The cargo can be carried providing it is placed on the cargo bay floor on either its medium area or largest area to prevent floor damage and that either the 4 feet length or the 12 feet length is placed parallel to the longitudinal axis of the aeroplane to prevent underfloor damage (spreading the load across the underfloor frames).

Single-engine Piston / Propeller Aircraft (SEP1)

The procedure for compiling the documentation for the single-engine piston/propeller aircraft (SEP1) given in CAP 696 is similar to the calculations previously specified in these notes, but notice that the load manifest and CG envelope are specific to that type of aircraft.

A number of examples are included in the question section, starting at page 77.

Light Twin Piston / Propeller Aircraft (MEP1)

The procedure for compiling the documentation for the twin engine aircraft (MEP1) given in CAP 696 is also similar to the procedures defined in these notes, but notice that the load manifest and CG envelope are specific to that type of aircraft.

A sample calculation based on compiling the load sheet for that aircraft is shown in *CAP 696, MEP1, page 2. CAP 696, MEP1 page 1*, contains specific information based on the Mass & Balance requirements for that particular aircraft.

These pages should be studied by the student after which some self-assessment questions should be attempted.

A number of examples are included in the question section, starting on page 81.

Medium Range Twin Jet (MRJT1)

The MRJT 1 (Medium Range Twin Jet) has a more complex loading and trim sheet which we shall deal with shortly.

CAP 696, MRJT1, pages 2 - 5, contain information specific to the MRJT 1 and should be studied in detail. Notes on particular items follow.

MRJT 1 Figure 4.1 and 4.2 Body Station

Though it would be possible to locate components and parts of the airframe structure by actually measuring their distance from the CG datum, it would be difficult and impractical on anything other than a very small aircraft. Instead, aircraft are divided about their three axes by a system of station numbers, water lines and buttock lines. The system of structural identification is not part of this subject except to say that in the past, station numbers were used as balance arms about the datum for first-of-kind aircraft. However, new variants of original series aircraft are often made by inserting additional lengths of fuselage and consequently, the distances of components and structure from the original datum undergo a change. The station numbers could all be re-numbered to enable them to retain their use as balance arms but it is often more beneficial to retain the original station numbers as they are. This means that on some variant aircraft they can no longer be used as balance arms for CG purposes and in order to find out how far a particular station is from the datum a conversion chart is required.

An example of such a chart is given in *CAP 696, Section 4, MRJT1, Page 1.*

Figure 4.1 of the CAP 696 Mass and Balance Manual shows a fuselage side view which includes the balance arms about the datum. The table at *Figure 4.2* shows how the station numbers for the aircraft can be converted into balance arms and vice versa. An examination of the table will show that this aircraft is a variant of a previous series aircraft in that two fuselage sections 500A to 500G and 727A to 727G have been inserted. This is the reason the balance arms and the station numbers are not coincidental and why the conversion chart is required. Notice from the chart that the centre section of the airframe (stations 540 to 727) which is the same as the original aircraft, has retained its original station numbers and they are coincidental with the balance arms.

Here are two examples of how to use the chart:

- Convert body station 500E into a balance arm.
  Body station 500E = 348 + 110 = Balance arm 458 inches.

- Convert balance arm 809 inches into a station number.
  Balance arm 809 – 82 = Station number 727

Further examination of the chart shows that balance arm 809 is actually station number 727D.

Now try these:

1. What is the station number at the nose of the aircraft?
2. What is the station number 1365 inches from the datum?
3. What is the distance of station 500 from the datum?
4. What is the distance of station 727C from the datum?

Answers can be found on page 92.

MRJT 1 Figure 4.3 and 4.4 Flap Position

The movement of the flaps on a large aircraft may have a considerable effect on the CG position. *Table 4.3* shows the moment change to the aircraft when the flaps are extended or retracted, for example retracting the flaps from 30° to 0° would cause a total moment change of minus 15 000 kg in. Conversely extension of the flaps from 0° to 40° would cause a total moment change of plus 16 000 kg in.

The stabilizer setting for take-off is extracted from the graph at *Figure 4.4.* The purpose of this is to allow the stabilizer trim to be set to allow the elevator sufficient authority to enable the aircraft to be rotated during the take-off run and controlled during the first stages of flight. The position of the CG will determine the stabilizer setting for take-off.

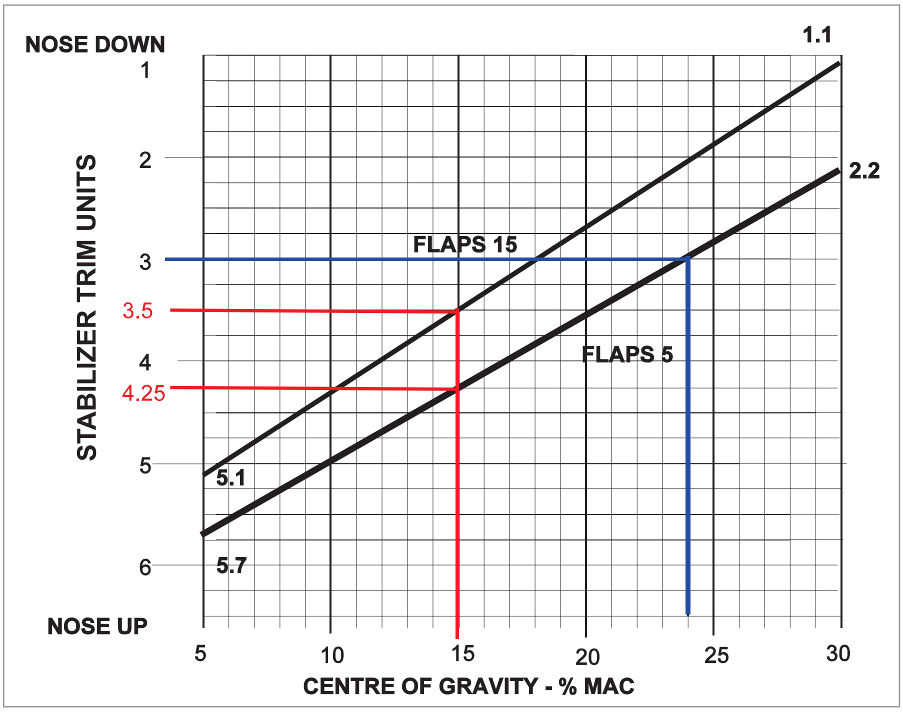


Figure 2.19 Stabilizer trim setting

Example 1

What is the stabilizer trim setting if the CG is 15% MAC and the flaps are moved from the 5° to the 15° position?

From the graph, if the CG is 15% MAC and the flap setting is 5° then the stabilizer trim setting will be 4.25 units nose up.

If the CG was the same 15% MAC with a flap setting of 15° then the stabilizer trim setting would be 3.5 units nose-up.

Example 2

If, as a result of the traffic and fuel load, the CG moved from 15% MAC to 24% MAC, what would be the change in stabilizer trim?

From the graph, the stabilizer trim for 5 degrees take-off flap would change from 4.25 trim units at 15% MAC to 3 trim units at 24% MAC.

Note: To enable the pilot to correctly set the stabilizer trim for take-off there will be a trim indicator on the instrument panel or as an integrated part of an electronic display unit.

MRJT1 Figure 4.9 Cargo Compartment Limitation (CAP 696, MRJT1, Page 5)

These tables detail the cargo compartment limitations which must be considered when items of cargo are loaded to ensure that the limitations are not exceeded.

Running Load

The running load is the fore/aft linear load. For example a box having dimensions of 3 feet by 3 feet by 3 feet and weighing 100 kg would have a running load of 100 ÷ 3 = 33.3 kg per **foot** which would be equal to 33.3 ÷ 12 = **2.78 kg per inch**. Be very careful to use the correct units

(Do not forget that there is a conversion chart on page 4 of the data sheets)

However, if a box having the same weight was 3 ft × 2 ft × 3 ft then it could be positioned so that the 2 ft side was running fore/aft in which case the running load would be:

100 ÷ 2 ÷ 12 = 4.16 kg per inch

The cargo may have to be orientated correctly to prevent exceeding the running load limitations.

Area Load

The first box would have a load intensity (mass per unit area) of 100 ÷ 9 = 11.1 kg per square foot as the area it would be standing on would be 3 × 3 = 9 square feet.

The second box, however, could be place on its side measuring 2 ft × 3 ft = 6 square feet area, it would therefore have a load intensity of 100 ÷ 6 = 16.66 kg per sq ft.

The cargo may have to be orientated correctly to prevent exceeding the distribution load limitations.

Calculation of the Loaded Mass and CG Position for Large Aircraft

The TOM and ZFM and their respective CG positions are determined by the method used for light aircraft except the DOM is used as the starting point as opposed to the BEM.

The fuel reserves and the traffic load compilation are more complex for a large aeroplane than for a light one, and so a Load and Trim Sheet is used to coordinate the data and simplify the procedure.

Many large aircraft operators do not bother to calculate the landing mass and CG position on the Trim Sheet but calculate the ZFM and CG position instead. The reason being that should a large aircraft need to divert to another airfield its actual landing mass could be many tonnes more, or less, than estimated value and its CG position could vary considerably from the projected value. Assuming that both TOM and the ZFM and their respective CG positions are within limits prior to take-off they will remain in limits throughout the flight (see *Figure 2.23* and *Figure 2.25* for examples of a completed Load Sheet and Trim Sheet respectively).

Compiling a Document (Load Sheet)

A load sheet in its simplest form is a list showing the BEM/DOM and CG position. Added in tabular form are the elements of the traffic load and fuel by their individual masses, arms and moments. From this list the take-off mass and CG position can be calculated.

A load sheet is individual to each type of aircraft and must be compiled before each flight.

A load sheet is required by EU-OPS 1 Subpart J to contain some mandatory information:

- The aeroplane registration and type
- The flight number
- The identity of the commander
- The identity of the person who prepared the document.
- The dry operating mass and CG position.
- The mass of take-off fuel and trip fuel.

- The mass of consumables other than fuel.
- The items of traffic load, passengers, baggage, freight.
- The take-off mass, landing mass and zero fuel mass.
- The load distribution.
- The aeroplane CG positions.
- The limiting mass and CG values.

Calculations (MRJT1)

Calculating the Underload Using the Formulae

The captain of the aircraft needs to know if he is able to accommodate any additional last minute changes to the load e.g. VIPs, emergency evacuation etc. Before the captain can allow any last minute additions to the load he must know if he has any spare load capacity or **underload** as it is referred to. Unfortunately, the underload is not simply the difference between the regulated take-off mass and the actual take-off mass; the MZFM and the Traffic Load have to be considered.

Clearly, if the aircraft is already at its MZFM it has no underload. Even if it is below the MZFM, any underload may have already been consumed by extra fuel uptake.

Any last minute load additions that are allowed will increase the size of the traffic load. The traffic load that can be carried is the lowest value of the Structural Traffic Load, the Take-off Traffic Load and the Landing Traffic Load.

The allowed traffic load is the lowest of the following (you are required to know these formulae):

- **Structural Limited Traffic Load** = MZFM – DOM
- **Take-off Limited Traffic Load** = RTOM – DOM – Take-off fuel
- **Landing Limited Traffic Load** = RLM – DOM – Fuel remaining

In the case of the MRJT1 aircraft, if the DOM = 34 300 kg, the take-off fuel = 12 000 kg and the fuel remaining at landing = 4000 kg:

Structural Limited Traffic Load	=	51 300 – 34 300 = 17 000 kg
Take-off Limited Traffic Load	=	62 800 – 34 300 – 12 000 = 16 500 kg
Landing Limited Traffic Load	=	54 900 – 34 300 – 4000 = 16 600 kg

The allowed traffic load is thus 16 500 kg. But if the actual traffic load was only 16 000 kg there would be a 500 kg underload.

You are required to know how to determine the allowable traffic load using the formulae above.

Fuel Load Definitions

Students need to have a basic knowledge of the fuel load definitions before they attempt traffic load calculations.

- **Start and Taxi Fuel:**
  The mass of fuel used in starting and operating the APU and the main engines and in taxiing to the runway threshold for take-off. It is assumed that at the point of releasing the brakes for take-off the aircraft is at or below the regulated take-off mass for the conditions prevailing. In operations where fuel is critical the start and taxi fuel must not be less than the amount expected to be consumed during the start and taxi procedures.

- **Trip Fuel:**
  This is the mass of fuel required to complete the take-off run, the climb, the cruise, the descent, the expected arrival procedures, and the approach and landing at the designated airport.

- **Contingency Fuel:**
  Fuel carried in addition to the trip fuel for unforeseen eventualities such as avoiding bad weather or having an extended hold duration at the destination airport. The contingency fuel in calculations is usually given as a percentage of the trip fuel e.g. if the trip fuel is 1000 kg mass the contingency fuel at 5% of the trip fuel would be 50 kg. Do not forget that the contingency fuel is part of the landing mass if it is not actually used during the trip.

- **Alternate (Diversion) Fuel:**
  That mass of fuel required to carry out a missed approach at the destination airfield, and the subsequent climb out, transit to, expected arrival procedures, approach, descent and landing at an alternate airfield.

- **Final Reserve Fuel:**
  The minimum fuel that should be in the tanks on landing. Essentially it is a final reserve for unplanned eventualities and should allow a piston engine aircraft to fly for a further 45 minutes or a jet engine aeroplane to fly for a further 30 minutes at a given height and holding speed.

- **Additional Fuel:**
  Only required if the sum of the trip, contingency, alternate and final reserve fuels are insufficient to cover the requirements of AMC OPS 1.255 (Instrument landings and power unit failures which are not required for calculations).

The take-off fuel for calculations is simply the sum of the above, excluding the start and taxi fuel.

Note that the fuel state requirements vary with the intended flight plan and they are not always required.

The landing fuel mass is the actual amount of fuel remaining in the tanks at touchdown. In a trip where no eventualities have occurred it will include the contingency, alternate, final reserve and additional fuel masses if they were included in the flight plan.

Calculating the underload using the Load and Trim Sheet

The Load and Trim Sheet used for the MRJT1 automatically calculates the underload but does it using a slightly different method than that shown above. Instead of determining the lowest traffic load the Load and Trim Sheet first determines the allowable Take-off Mass. It then calculates the allowable Traffic Load by deducting the Operating Mass from the allowable Take-off Mass. Finally, it calculates the underload by deducting the actual Traffic Load from the allowable Traffic Load.

The allowable Take-off Mass is the lowest of:

- **MZFM + Take-off Fuel**
- **Regulated Take-off Mass**
- **Regulated Landing Mass + Fuel used in flight**

For example, in the case of the MRJT1, the MZFM is given as 51 300 kg, the MSTOM is 62 800 kg and the MSLM is 54 900 kg. Let us assume that there are no performance limits so that the Regulated Take-off and Landing masses are equal to the Structural Limited Take-off Mass and the Structural Limited Landing Mass respectively. Let us also assume that the DOM is 34 000 kg, that the actual traffic load is 12 400 kg, the take-off fuel load is 16 000 kg and 8000 kg of fuel was used in flight.

Allowable Take-off Mass is the lowest of:

- **MZFM + Take-off Fuel**
  51 300 kg + 16 000 kg = 67 300 kg

- **Regulated Take-off Mass**
  62 800 kg = 62 800 kg

- **Regulated Landing Mass + Estimated fuel consumption**
  54 900 kg + 8000 kg = 62 900 kg

The maximum allowable Traffic Load for the conditions prevailing can now be determined by subtracting the Operating Mass from the Regulated Take-off Mass i.e.:

Maximum Traffic Load = Regulated Take-off Mass – Operating Mass

= 62 800 kg – (34 000 kg + 16 000 kg)

= 12 800 kg

The underload can now be determined by subtracting the actual traffic load from the maximum allowable traffic load.

Underload	=	**maximum traffic load – actual traffic load**
	=	12 800 kg – 12 400 kg
	=	400 kg

Fortunately, the MRJT1 Load and Trim Sheet makes easy work of the above calculations and you are advised to practise using the Load and Trim Sheet.

Example Calculations

Calculations may be carried out using the Loading Manifest (data sheet *Figure 4.10*) and CG limits envelope (*Figure 4.11*) or the Load and Trim Sheet (*Figure 4.12*) in *CAP 696, Chapter 4, MRJT1.*

We will do a sample calculation using both methods.

Using the following values complete the Loading Manifest *Figure 2.20* and check the limiting values with the CG envelope.

DOM	34 300 kg
	15% MAC
PAX	Total 116, standard weight 84 kg each
	10 each in zone A and G
	12 each in zone B and F
	24 each in zone C, D and E
CARGO	600 kg hold 1
	1500 kg hold 4 (includes checked baggage)
FUEL	15 000 kg at take-off
	260 kg start and taxi
	10 000 kg trip fuel

Use CAP 696, MRJT1, data sheets where required to find the balance arm for the MAC and vice versa. The moment/1000 is calculated from the arm/1000. The balance arm is calculated by dividing the total moment by the total weight. The fuel balance arm and quantity in each tank are also found from the data sheets.

Note: *the centre fuel tank content is used before the wing tank fuel content and the centre tank includes 24 kg of unusable fuel.*

As a start, if the DOM CG position is 15% MAC, then that is 15% of 134.5 inches *(CAP 696, MRJT1, Chapter 4, Page 2)* or 20.175 inches. That makes the CG balance arm 20.175 + 625.6 = 645.8 inches aft of the datum The fuel load balance arm can be extracted from *Figure 4.5* and *Figure 4.6* of the loading manual, for example the maximum contents of tanks one and two is 9084 kg with a balance arm of 650.7. Fill in the following blank sheet using the above information then check the aircraft has not exceeded any of the limits in the CG envelope.

See if your answer agrees with mine. (I have estimated changes to the fuel tank CG position and accounted for the unusable fuel in the centre tank. However, the fuel CG position will be fixed and there will be no unusable fuel to account for in the EASA exams)

If you wish to check the mass values and CG positions using the Load and Trim Sheet for the MRJT1 use a DOI of 40.5.

Maximum Permissible Aeroplane Mass Values

TAXI MASS ZERO FUEL MASS

TAKE-OFF MASS LANDING MASS

ITEM	MASS (kg)	B.A. in	MOMENT kg-in/1000	CG % MAC
1. DOM	34 300	645.8	22 150.9	15%
2. PAX Zone A		284		-
3. PAX Zone B		386		-
4. PAX Zone C		505		-
5. PAX Zone D		641		-
6. PAX Zone E		777		-
7. PAX Zone F		896		-
8. PAX Zone G		998		-
9. CARGO HOLD 1		367.9		-
10. CARGO HOLD 4		884.5		-
11. ADDITIONAL ITEMS				-
ZERO FUEL MASS				
12. FUEL TANKS 1&2				
13. CENTRE TANK				
TAXI MASS				
LESS TAXI FUEL				
TAKE-OFF MASS				
LESS FLIGHT FUEL				
EST. LANDING MASS				

Figure 2.20 Loading manifest - MRJT1

Maximum Permissible Aeroplane Mass Values

TAXI MASS	**63 060 kg**	ZERO FUEL MASS	**51 300 kg**
TAKE-OFF MASS	**62 800 kg**	LANDING MASS	**54 900 kg**

ITEM	MASS (kg)	B.A. in	MOMENT kg-in/1000	CG % MAC
1. DOM	**34 300**	645.8	22 150.9	15%
2. PAX Zone A	840	284	238.6	-
3. PAX Zone B	1008	386	389	-
4. PAX Zone C	2016	505	1018	-
5. PAX Zone D	2016	641	1292	-
6. PAX Zone E	2016	777	1566	-
7. PAX Zone F	1008	896	903	-
8. PAX Zone G	840	998	838	-
9. CARGO HOLD 1	600	367.9	221	-
10. CARGO HOLD 4	1500	884.5	1327	-
11. ADDITIONAL ITEMS				-
ZERO FUEL MASS	**46 144**	**649**	29 943.5	**17.4%**
12. FUEL TANKS 1&2	**9084**	650.7	5911	-
13. CENTRE TANK	**6176**	600.4	3708	-
TAXI MASS	61 404	644.3	39 562.5	-
LESS TAXI FUEL (C/TANK)	**-260**	600.5	-156	-
TAKE-OFF MASS	**61 144**	644.5	39 406.5	14%
LESS CENTRE TANK FUEL	**-5916**	600.4	-3552	-
LESS MAIN TANK FUEL	**-4084**	650.7	-2657.5	
EST. LANDING MASS	**51 144**	649.1	33 197	17.5%

Figure 2.21 Loading manifest - MRJT1 (Table 3)

Note: the fuel CG positions have been estimated for simplicity. However, it is most unlikely that you will be required to adjust for fuel tank CG changes.

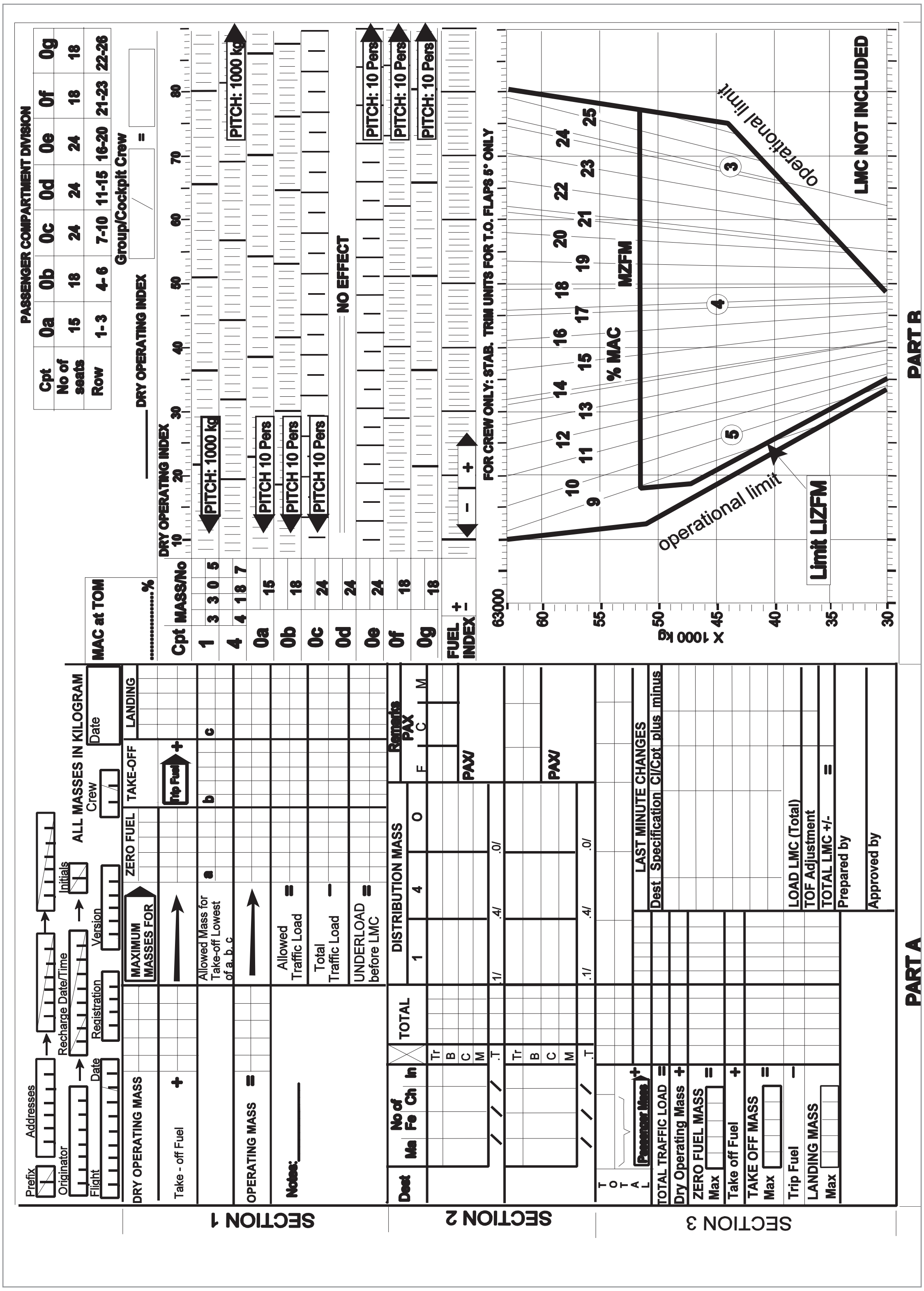


Figure 2.22 MRJT1 Load and Trim Sheet

Load and Trim Sheet (MRJT1)

Figure 2.22 shows a combined Load and Trim Sheet for a modern twin jet airliner designated EASA - Medium Range Twin Jet (MRJT1). See *CAP 696, MRJT1, Page 9, of the Loading Manual.* (Students may be required to complete a part of the Load and Trim Sheet during the EASA exams).

The left hand side of the page (part A) is the loading document which itemizes the mass and mass distribution within the aeroplane i.e. dry operating mass, traffic load and fuel load. The right hand side (part B) indicates how each mass in turn subsequently affects the position of the CG in relation to the mean aerodynamic chord. The ZFM and the TOM must be within the relevant area of the graph envelope on completion of the mass calculations otherwise the aircraft is unsafe to fly.

Part A (loading summary) should be completed as follows:

Section 1 is used to establish the limiting take-off mass, maximum allowable traffic load and underload before last minute changes (LMC)

Section 2 shows the distribution of the traffic load using the following abbreviations.

TR	Transit
B	Baggage
C	Cargo
M	Mail
Pax	Passengers
Pax F	First Class
Pax C	Club/Business
Pax Y	Economy

Section 3 summarizes the loading and is used to cross-check that limiting values have not been exceeded.

Part B is the distribution and trim portion. The lower part is the CG envelope graph, the vertical scale of which is given in terms of mass and the horizontal axis scale in terms of **MAC**.

1. Using data from the loading summary enter the Dry Operating Index (DOI) for the DOM.

2. Move the index vertically downwards into the centre of the first row of horizontal boxes. Note that each box within the row has a pitch which represents either a defined mass or a number of persons. There is also an arrow indicating the direction in which the pitch is to be read.

3. Move the index horizontally in the direction of the arrow to a pitch value corresponding to the value in the Mass/No box immediately to the left of the row.

4. Repeat operations 1 to 3 above for each subsequent row of boxes down to and including row 0g. After completing the index calculation for row 0g, drop a line vertically down until it bisects a mass on the vertical scale of the envelope corresponding to the Zero Fuel Mass. The point of bisection must occur within the MZFM envelope.

5. Go to the horizontal row of boxes marked 'Fuel index' and add the take-off fuel index.

6. After completing the fuel index calculation drop a line vertically down from it until it bisects a mass on the vertical scale of the envelope corresponding to the Take-off Mass. The point of bisection must occur within the TOM envelope.

7. Providing the ZFM and the TOM are within the envelope as described above, the aircraft is safe for the intended flight - including any permitted diversions.

Example:

The following example deals with part A and part B of the load sheet separately using the data shown.

DOM	=	34 300 kg	
DOI	=	45.0	
RTOM	=	62 800 kg	
MZFM	=	51 300 kg	
RLM	=	54 900 kg	
Passengers		130	(Average mass 84 kg)
Baggage		130	(@14 kg per piece)
Cargo		630 kg	
Take-off fuel		14 500 kg	
Trip Fuel		8500 kg	

Limitations for EASA - Medium Range Twin Jet

Maximum Structural Taxi Mass	63 060 kg
Maximum Structural Take-off Mass	62 800 kg
Maximum Structural Landing Mass	54 900 kg
Maximum Structural Zero Fuel Mass	51 300 kg
Maximum Number of Passengers	141

Cargo

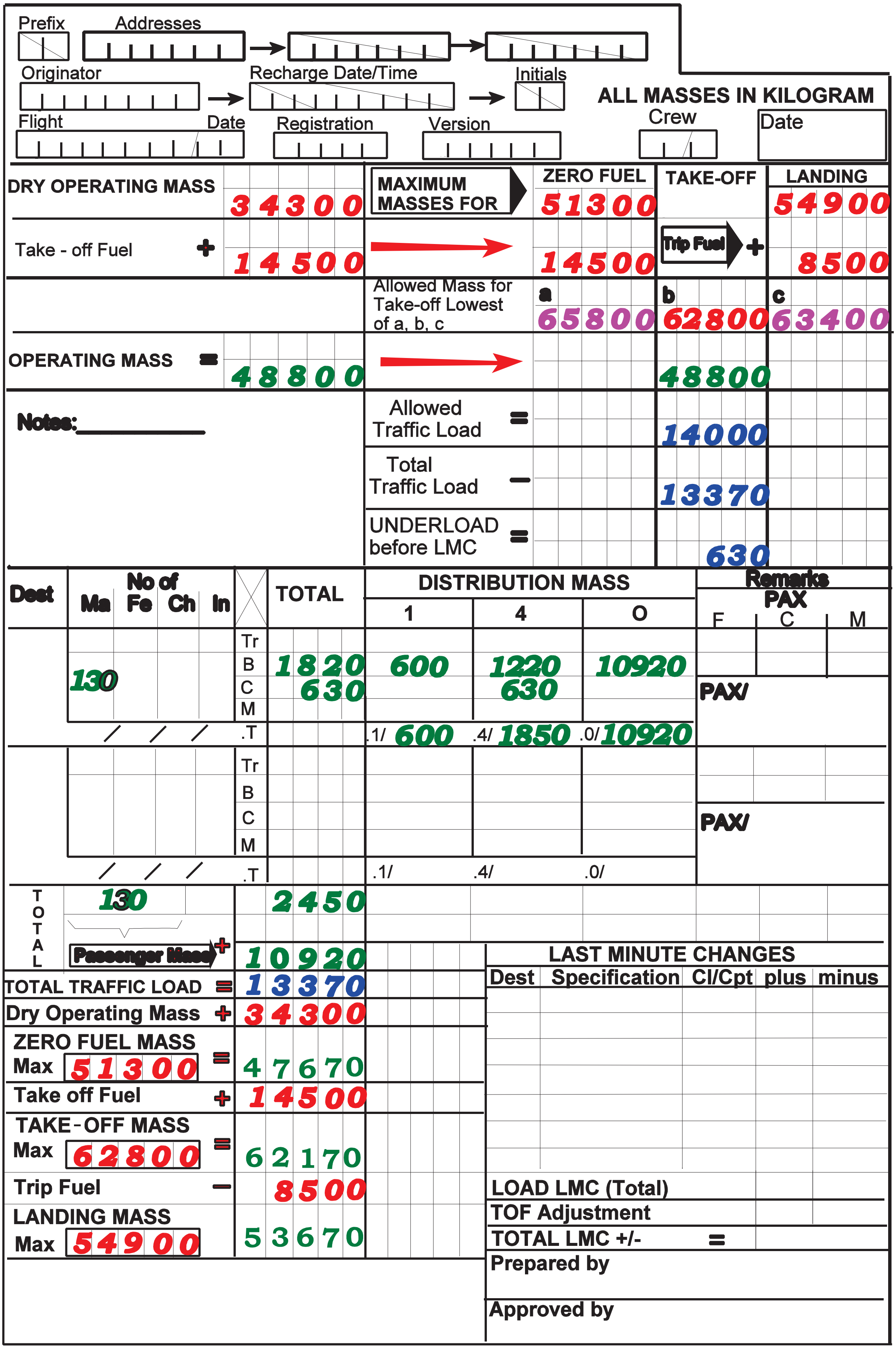
Hold 1 Max Volume	607 cu ft
Max Load	3305 kg
Hold 2 Max Volume	766 cu ft
Max Load	4187 kg

Standard Crew (Allowed for in DOM)

Flight Deck		2
Cabin Crew	forward	2
	aft	1

Section 1 of the load sheet is completed first in order to find the three potential take-off masses (a, b and c). The value at (a) is the take-off mass you would achieve if you loaded the aeroplane to the MZFM and then added your intended fuel load. The value at (b) is the regulated take-off mass for the take-off airfield conditions as existing and the value at (c) is the take-off mass you would achieve if you were to land at the regulated landing mass and then added back the mass of the trip fuel. The lowest of (a), (b) and (c) is the limiting take-off mass for traffic load calculations.

The maximum allowable traffic load for the trip can be determined by subtracting the operating mass from the limiting take-off mass. Subsequently, any underload can be calculated by subtracting the actual traffic load from the allowable traffic load (14 000 - 13 370 = 630). The underload sets the limiting mass for any last minute changes (LMC). Sections 2 and 3 of the load sheet detail the mass and distribution of the traffic load and give actual values of take-off and landing masses.



Prefix | Addresses
Originator | Recharge Date/Time | Initials
ALL MASSES IN KILOGRAM
Flight | Date | Registration | Version | Crew | Date

			MAXIMUM MASSES FOR	ZERO FUEL	TAKE-OFF	LANDING
DRY OPERATING MASS		34300		51300		54900
Take - off Fuel	+	14500	→	14500	Trip Fuel +	8500
			Allowed Mass for Take-off Lowest of a, b, c	a 65800	b 62800	c 63400
OPERATING MASS	=	48800	→		48800	
Notes:			Allowed Traffic Load =		14000	
			Total Traffic Load −		13370	
			UNDERLOAD before LMC =		630	

Dest	No of Ma	Fe	Ch	In		TOTAL	DISTRIBUTION MASS 1	4	O	Remarks PAX F	C	M
	130				Tr							
					B	1820	600	1220	10920			
					C	630		630		PAX/		
					M							
	/	/	/		.T		.1/ 600	.4/ 1850	.0/ 10920			
					Tr							
					B							
					C					PAX/		
					M							
	/	/	/		.T		.1/	.4/	.0/			
TOTAL	130					2450						
	Passenger Mass				+	10920						

TOTAL TRAFFIC LOAD	=	13370
Dry Operating Mass	+	34300
ZERO FUEL MASS Max 51300	=	47670
Take off Fuel	+	14500
TAKE-OFF MASS Max 62800	=	62170
Trip Fuel	−	8500
LANDING MASS Max 54900		53670

LAST MINUTE CHANGES

Dest	Specification	Cl/Cpt	plus	minus

LOAD LMC (Total)
TOF Adjustment
TOTAL LMC +/- =
Prepared by
Approved by

Figure 2.23 Completed load sheet

In part B the graph is entered at the top by drawing a vertical line from the DOM index of 45 into the row for cargo compartment 1. This row is split into sections by heavy lines representing 1000 kg, each section is split again into 10, each line representing 100 kg. The arrow in the box represents the direction to move to adjust for that mass.

Follow the same procedure for each cargo compartment or seating compartment until you have adjusted for all of the traffic load. Before adjusting for the fuel load draw the line down to intersect with the zero fuel mass to identify the ZFM CG position. Then adjust for the fuel index taken from the data sheets, page 30, and draw the line vertically down to identify the take-off CG position.

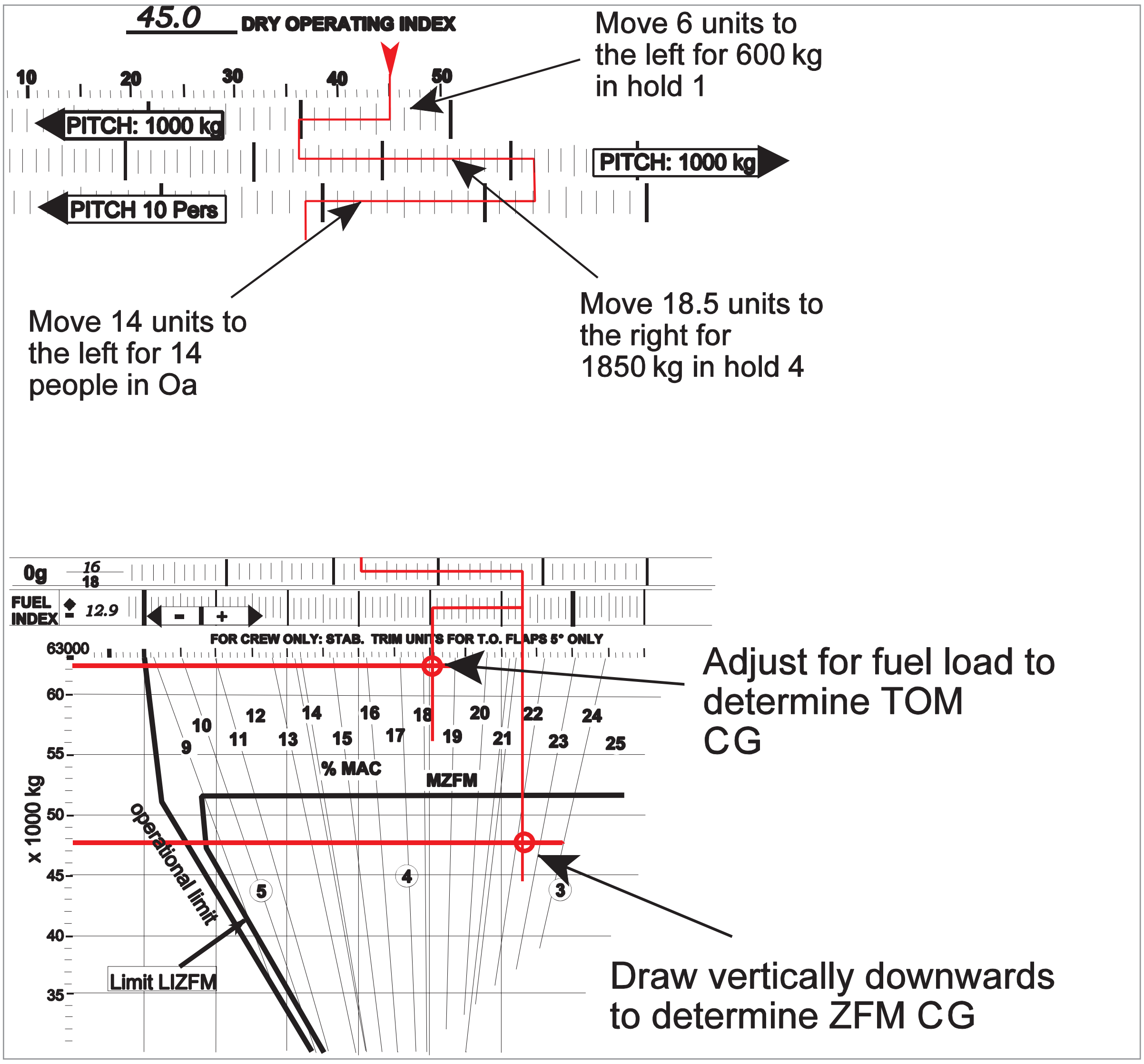


Figure 2.24 Load and trim calculation diagrams

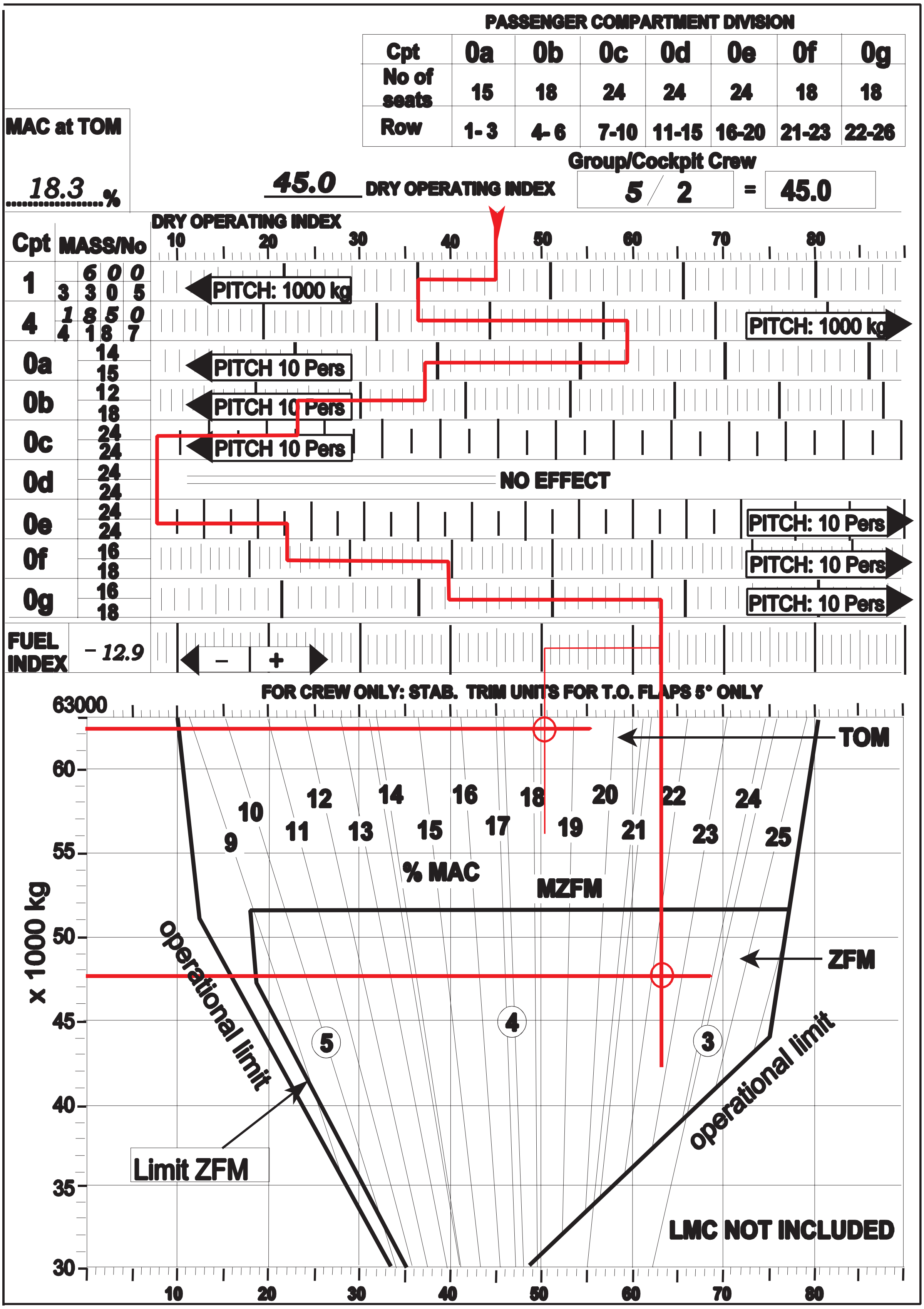


Figure 2.25 A completed trim sheet

Example

With regard to Part 'A' above (Calculating the traffic/underload), a typical question is given below. For practice work out the answer by using both the load sheet method described on *page 71* and the calculation method described on *page 64*.

A scheduled flight of three hours estimated time, within Europe, is to be conducted. Using the data given and the information in the *CAP 696 MRJT1*, calculate the maximum mass of freight that may be loaded in the following circumstances:

Performance limited take-off mass	67 900 kg
Performance limited landing mass	56 200 kg
MZFM	51 300 kg
DOM	34 960 kg
Fuel on board at ramp	15 800 kg
Taxi fuel	450 kg
Trip fuel	10 200 kg
Passengers (adults/each 84 kg)	115
(Children/each 35 kg)	6
Flight crew (each 85 kg)	2
Cabin crew (each 75 kg)	5

Allow standard baggage for each passenger (13 kg)

a. 1047 kg
b. 857 kg
c. 3347 kg
d. 4897 kg

Questions for SEP1, MEP1 and MRJT1

SELF-ASSESSMENT QUESTIONS FOR SINGLE-ENGINE PISTON/PROPELLER (SEP1) Unless told otherwise, assume that the maximum fuel capacity is 74 gallons.

For all questions refer to CAP 696 (Loading Manual).

1. Where is the reference datum?

a. 74 inches aft of the fwd CG position
b. 80.4 inches aft of the rear CG position
c. 87.7 inches aft of the rear CG position
d. 39 inches forward of the firewall

2. What are the CG limits?

a. fwd limit = 74 inches to 80.4 inches
b. fwd limit = 74 inches, aft limit = 80.4 inches
c. fwd limit = 74 inches, aft limit = 87.7 inches
d. fwd limit = 74 inches to 80.4 inches and aft limit = 87.7 inches

3. What is the CG at the BEM?

a. 77 inches
b. 87 inches
c. 77.7 metres
d. 77.7 inches

4. What is the structural load limit for the floor at baggage zone 'C'?

a. 50 lb per square foot
b. 100 lb per cubic foot
c. 100 lb per square foot
d. 100 kg per square inch

5. What is the distance of the main undercarriage from the firewall?

a. 97 inches
b. 58 inches
c. 87.7 inches
d. 39 inches

6. The aircraft has six seats. Assuming no other cargo or baggage, what is the maximum fuel that can be carried if all six seats are occupied and the mass of each occupant is 180 lb?

a. 50 lb but the CG would be dangerously out of limits
b. 155 lb but the CG would be dangerously out of limits
c. 50 lb and the CG would be in limits
d. 155 lb and the CG would be in limits

7. **Where is the centroid of baggage zone B?**

   a. 108 inches from the datum
   b. 120 inches from the datum
   c. 150 inches from the datum
   d. 180 inches from the datum

8. **Assuming the weight and access is not a problem, where can a box of mass 500 lb be positioned if the dimensions are 0.75 ft × 1.5 ft × 5 ft?**

   a. In any of the baggage zones if placed on its smallest area
   b. In zones ‘B’ or ‘C’ if placed on its largest area
   c. In zone ‘C’ only if placed on its middle area
   d. In zone ‘A’ only if placed on its largest area

9. **Assuming the weight and access is not a problem, where can a cubic box of mass 500 lb be positioned if the dimensions are 3.15 ft?**

   a. In any of the baggage zones
   b. In zone ‘B’ or ‘C’ only
   c. In zone ‘A’ only
   d. In zone ‘C’ only

10. **If the landing mass is 3155 lb and the trip fuel was 40 gallons, what was the ZFM if the fuel tanks held 60 gallons of fuel prior to take-off?**

   a. 3001 lb
   b. 3035 lb
   c. 3098 lb
   d. 3111 lb

11. **What is the maximum ramp mass?**

   a. 3650 lb
   b. 3663 lb
   c. 3780 lb
   d. 3870 lb

12. **How far is the main wheel from the aft CG limit?**

   a. 0.7 inches behind the rear datum
   b. 0.7 inches forward of the rear datum
   c. 6.6 inches forward of the rear datum
   d. 9.3 inches aft of the rear datum

13. **How far is the firewall from the fuel tank centroid?**

   a. 36 inches
   b. 37 inches
   c. 38 inches
   d. 39 inches

14. If the total moment is less than the minimum moment allowed:

a. useful load items must be shifted aft
b. useful load items must be shifted forward
c. forward load items must be increased
d. aft load items must be reduced

15. The CG is on the lower of the fwd CG limits:

a. at a mass of 2500 lb and moment of 185 000 lb in
b. at a moment of 175 000 lb in and a mass of 2365 lb
c. at a moment of 192 000 lb in and a mass of 2594 lb
d. all the above

Self-assessment Questions for MEP1

1. **What performance class does the aircraft belong to?**

    a. Performance Class 'A'
    b. Performance Class 'B'
    c. Performance Class 'C'
    d. Performance Class 'D'

2. **Where is the reference datum?**

    a. 78.4 inches forward of the wing leading edge at the inboard edge of the inboard fuel tank
    b. 25.3 inches forward of the nose wheel
    c. 109.8 inches forward of the main wheel
    d. All the above

3. **The main wheel is:**

    a. 19 inches forward of the fwd CG limit at the maximum take-off mass
    b. 27.8 inches behind the fwd CG limit at a take-off mass of 3400 lb
    c. 15.2 inches forward of the rear CG limit at the maximum take-off mass
    d. all the above

4. **The nose wheel is:**

    a. 56.7 inches forward of the fwd CG limit at maximum take-off mass
    b. 65.5 inches forward of the fwd CG limit at maximum take-off mass
    c. 69.3 inches aft of the rear CG limit at maximum take-off mass
    d. all the above

5. **What is the minimum fuel mass that must be consumed if the aircraft, having become airborne at maximum weight, decides to abort the flight?**

    a. 1260 lb
    b. 280 lb
    c. 237 lb
    d. 202 lb

6. **If the pilot has a mass of 200 lb, what is the maximum traffic load?**

    a. 1060 lb
    b. 1600 lb
    c. 1006 lb
    d. 6001 lb

7. **Assuming the maximum zero fuel mass and maximum take-off mass, what fuel load can be carried?**

    a. 38.9 imperial gallons
    b. 46.6 US gallons
    c. 176.8 litres
    d. Any one of the above

8. **A box of mass 100 lb is to be transported. The box dimensions are 9 × 9 × 12 inches. Which zones can it be carried in?**

   a. All zones, both the mass and structural loading are within limits
   b. Zones 2 and 3 only
   c. No zones, both the mass and structural loading would be exceeded
   d. No zones, the structural loading would be exceeded

9. **A box of mass 360 lb is to be transported. The dimensions of the box are 1.7 ft × 1.7 ft × 1.8 ft. Which zones can it be carried in?**

   a. Zones 2 and 3 only but placed on the 1.7 × 1.7 face
   b. Zones 2 and 3 only but placed on the 1.7 × 1.8 face
   c. No zones, both the mass and structural loading would be exceeded
   d. No zones, the structural loading would be exceeded

10. **Assuming floor loading limits are acceptable, how much freight and fuel load can be carried for MSTOM if the pilot's mass was 200 lb?**

    a. A full load in each zone plus 380 lb of fuel
    b. 50 lb in zones 1 or 4 but full loads in each of the other zones, plus 280 lb of fuel
    c. 350 lb load in zone 4 but full loads in all the other zones, plus 280 lb of fuel
    d A full freight load in each zone plus 280 lb of fuel

11. **What is the maximum fuel tank capacity?**

    a. Not given
    b. 123 US gallons
    c. 46.6 US gallons
    d. TOM minus ZFM

12. **If the aircraft is at MSTOM with full fuel tanks and a pilot of mass 200 lb, what traffic load can be carried?**

    a. Nil
    b. 579 lb providing at least 20.5 gallons of fuel are consumed in start, taxi and flight
    c. 625 lb providing at least 43.3 gallons of fuel are consumed in start, taxi and flight
    d. 759 lb providing at least 59.5 gallons of fuel are consumed in start, taxi and flight

13. **The CG when the TOM is 4300 lb and the corresponding moment is 408 500 lb in is:**

    a. 95 inches
    b. 59 inches
    c. 0.4 inches tail heavy
    d. 0.6 inches rear of the aft limit

14. **If the CG is 86 inches and the TOM is 4100 lb the aircraft is:**

    a. just on the forward CG limit
    b. just outside the forward CG limit
    c. just inside the aft CG limit
    d. within the two forward limits

Self-assessment Questions for MRJT1

1. **What is the total length of the fuselage?**

    a. 1365 inches
    b. 1375 inches
    c. 1387 inches
    d. 1395 inches

2. **How far is the front spar from the datum?**

    a. 562 inches
    b. 540 inches
    c. 500 inches
    d. 458 inches

3. **What is the distance between the two main access doors?**

    a. 940 inches
    b. 947 inches
    c. 974 inches
    d. 984 inches

4. **How far is the leading edge of the mean aerodynamic chord from the datum?**

    a. 540 inches forward of the datum
    b. 589.5 inches forward of the datum
    c. 625.6 inches aft of the datum
    d. 627.5 inches aft of the datum

5. **What is the length of the mean aerodynamic chord?**

    a. 104.5 inches
    b. 114.5 inches
    c. 124.5 inches
    d. 134.5 inches

6. **What moment change occurs when the flaps are fully retracted from the 15 degree position?**

    a. A reduction of 14 kg.in
    b. An increase of 14 kg.in
    c. A reduction of 14 000 kg.in
    d. An increase of 14 000 kg.in

7. **What change in moment occurs when the flaps are retracted from 40 degrees to 5 degrees?**

    a. A negative moment of 5 kg.in
    b. A negative moment of 11 kg.in
    c. A negative moment of 16 kg.in
    d. A negative moment of 5000 kg.in

8. What stabilizer trim setting is required for take-off when the CG is 19% MAC for 5 degrees of take-off flap?

a. 2.75
b. 3.75
c. 4.75
d. 5.75

9. What is the maximum structural take-off mass?

a. 63 060 kg
b. 62 800 kg
c. 54 900 kg
d. 51 300 kg

10. What is the CG range for maximum zero fuel mass?

a. 8% MAC to 27% MAC
b. 12%MAC to 20% MAC
c. 7.5% MAC to 27.5% MAC
d. 8.5% MAC to 26% MAC

11. Assuming the MZFM, what is the maximum allowable fuel mass for take-off?

a. 10 015 kg
b. 10 150 kg
c. 11 500 kg
d. 15 000 kg

12. Assuming the standard masses have been used for both passengers and baggage, what is the mass of a full passenger and baggage load?

a. 13 027 kg
b. 13 677 kg
c. 14 127 kg
d. 15 127 kg

13. What is the allowable hold baggage load for an aircraft with a full passenger complement?

a. 1533 kg
b. 1633 kg
c. 1733 kg
d. 1833 kg

14. What is the underload if only maximum passenger hold baggage is carried?

a. 3305 kg - 1833 kg = 1472 kg
b. 4187 kg - 1833 kg = 2354 kg
c. 7492 kg - 1833 kg = 5659 kg
d. 9247 kg - 1833 kg = 7414 kg

15. **If the crew mass is 450 kg and the Zero Fuel Mass is 51 300 kg, what is the Basic Empty Mass if a full traffic load is carried?**

a. 31 514 kg
b. 31 773 kg
c. 37 713 kg
d. 33 177 kg

16. **Using the values for the data given in the Loading Manual, would the aircraft be able to carry both a full fuel load and a full traffic load at take-off?**

a. No.
b. Yes, providing the BEM was not more than 31 145 kg.
c. Yes, providing the BEM was not less than 31 451 kg.
d. Yes, providing the BEM was not more than 31 514 kg.

17. **If the DOM is given as 34 300 kg and the aircraft has a full load of passengers and baggage, what additional cargo mass could it carry i.e. what is the underload?**

a. None.
b. 3123 kg.
c. 3223 kg.
d. 3323 kg.

18. **What is the maximum usable fuel quantity?**

a. 5311 US gallons.
b. 5294 US gallons.
c. 5123 US gallons.
d. 5032 US gallons.

19. **What is the maximum usable fuel mass?**

a. 16 092 kg.
b. 16 078 kg.
c. 16 064 kg.
d. 16 040 kg.

20. **What is the allowable start and taxi fuel?**

a. 160 kg.
b. 260 kg.
c. 360 kg.
d. 460 kg.

21. **What are the preferred zones for passenger loads if the pax load is low?**

a. Zones E, F and G.
b. Zones C, D and E.
c. Zones B, C and D.
d. A, B and C.

22. How many seats are there in zone B?

a. 15
b. 18
c. 21
d. 24

23. The leading edge of the MAC is given as 625.6 inches aft of the datum. What is the distance of the CG from the datum if it is found to be 16% of the MAC?

a. 547 inches.
b. 647 inches.
c. 747 inches.
d. 674 inches.

24. The CG is found to be 652.5 inches aft of the datum. What percentage is the CG of the MAC?

a. 10%.
b. 15%.
c. 20%.
d. 25%.

25. If a passenger moves from a seat position corresponding to the balance arm at zone D to a position corresponding to the balance arm at zone F, what distance will the passenger have travelled and how many seat rows will he have passed?

a. 255 inches and 8 seat rows.
b. 260 inches and 7 seat rows.
c. 265 inches and 6 seat rows.
d. 270 inches and 5 seat rows.

26. The balance arm for each of the seat zones is measured from the datum to:

a. the front border line of the zone.
b. the centre line of the zone.
c. the rear border line of the zone.
d. the front border line of the next zone in sequence.

27. What is the maximum and minimum running load of a box of mass 500 kg and dimensions of 1 m × 1.2 m × 1.2 m?

a. 12.7 kg/in and 10.6 kg/in.
b. 10 kg/in and 12.4 kg/in.
c. 11 kg/in and 9.5 kg/in.
d. 15 kg/in and 13.1 kg/in.

28. What is the maximum and minimum distribution load intensity for a box of mass 500 kg and dimensions of 1 m × 1.2 m × 1.2 m?

a. 50.5 kg/sq ft and 40.6 kg/sq ft.
b. 47.3 kg/sq ft and 37.7 kg/sq ft.
c. 45.1 kg/sq ft and 35.8 kg/sq ft.
d. 38.7 kg/sq ft and 32.3 kg/sq ft.

29. All other parameters being acceptable, a box with a maximum and minimum running load of 12 kg/in and 7 kg/in and a mass of 800 kg can be fitted into:

a. any compartment of either the forward or aft cargo compartment.
b. the front section of the aft cargo compartment or the rear section of the forward cargo compartment.
c. the rear section of the forward cargo compartment or the rear section of the aft cargo compartment.
d. the centre section of the forward cargo compartment only.

30. A box with a mass of 500 kg and dimensions 0.8 m and 0.9 m × 1.3 m has a maximum and minimum distribution load intensity of:

a. 64.6 kg/sq ft max and 39.7 kg/sq ft min.
b. 39.7 kg/sq ft max and 64.6 kg/sq ft min.
c. 44.7 kg/sq ft max and 39.7 kg/sq ft min.
d. 64.6 kg/sq ft max and 44.7 kg/sq ft min.

31. The maximum freight mass allowed is:

a. 17 017 lb.
b. 16 520 lb.
c. 16 017 lb.
d. 15 517 lb.

32. Assuming all other parameters are acceptable, a box with a mass of 500 kg and with equal sides of 8.5 ft would fit into:

a. either the front or rear cargo compartment.
b. the forward cargo compartment only.
c. neither cargo compartment.
d. the aft cargo compartment only.

33. The front compartment of the front cargo hold is situated below:

a. passenger zone A.
b. passenger zone B.
c. passenger zone C.
d. passenger zone D.

34. The balance arm of the centroid of the forward hold compartment is:

a. 228 inches.
b. midway between 228 inches and 286 inches.
c. midway between 286 inches and 343 inches.
d. 367.9 inches.

35. The maximum distribution load intensity for the cargo compartments is:

a. 68 lb per sq ft.
b. 68 kg per sq metre.
c. 68 kg per sq in.
d. 68 kg per sq ft.

36. Between 44 000 kg and 63 000 kg the rear CG limit as a percentage of the MAC:

a. is constant at 28%.
b. increases from 28% to 29.5%.
c. decreases from 28% to 26%.
d. decreases from 28% to 9%.

Referring to CAP 696, Section 4 (MRJT1), in particular Figure 4.13, answe questions 37 to 49 inclusive:

37. The traffic load is:

a. 39 800 kg obtained from ZFM, 51 300 kg less fuel mass 11 500 kg.
b. obtained from the sum of pax mass plus baggage mass plus total cargo compartment mass.
c. 13 370 kg obtained from 10 920 kg pax mass plus 2450 kg baggage mass plus 630 kg cargo mass.
d. 13 370 kg obtained from 10 920 kg pax mass, 1820 kg baggage mass and 630 kg cargo mass.

38. The cargo distribution in section 4 is:

a. 1220 kg.
b. 630 kg.
c. 1850 kg.
d. 1820 kg plus 630 kg.

39. The actual take-off mass is:

a. 51 300 kg ZFM plus 14 500 kg take-off fuel.
b. 62 800 kg less 8500 kg trip fuel.
c. 53 670 kg less 14 500 kg take-off fuel.
d. 47 670 kg ZFM plus 14 500 kg take-off fuel mass.

40. The landing mass is:

a. 62 800 kg take-off mass less 8500 kg trip fuel.
b. 62 170 kg take-off mass less 8500 kg trip fuel.
c. 62 170 kg take-off mass plus 8500 kg trip fuel.
d. 62 800 kg take-off mass plus 8500 kg trip fuel.

41. In order to determine the underload the pilot starts by selecting the lowest mass from the three key masses given. The key masses are:

a. dry operating mass, maximum zero fuel mass and take-off mass.
b. maximum zero fuel mass, take-off mass and landing mass.
c. dry operating mass, maximum zero fuel mass and landing mass.
d. traffic load, take-off mass and landing mass.

42. From the figures given, if the actual take-off fuel mass (14 500 kg) was added to the Maximum Zero Fuel Mass the aircraft would be:

a. below the maximum take-off mass by 350 kg.
b. over the maximum take-off mass by 530 kg.
c. over the maximum take-off mass by 3000 kg.
d. below the maximum take-off mass by 630 kg.

43. **The actual underload for the aircraft after the traffic load and fuel load have been accounted for is:**

a. zero.
b. 720 kg.
c. 630 kg.
d. 960 kg.

44. **What is the Dry Operating Index?**

a. 45
b. 12
c. 54
d. 10

45. **What are the seat row numbers in pax zone 'Oc'?**

a. 4 – 6
b. 6 – 8
c. 7 – 10
d. 8 -13

46. **What is the Take-off Mass as a percentage of the MAC?**

a. 18.3%.
b. 19.3%.
c. 20.3%.
d. 21.3%.

47. **Prior to take-off there is a change in destination and so the pilot decides to take 2000 kg of fuel less. Using the Load and Trim Sheet, calculate the new Take-off Mass and CG position:**

a. can not be calculated because the landing mass will be too high.
b. 60 800 kg take-off mass and CG 17.5% MAC.
c. 60 170 kg take-off mass and CG 18.8% MAC.
d. 60 170 kg take-off mass and 19.3% MAC.

48. **When adjusting the CG index for the fuel load, why is the line moved to the left as a minus index?**

a. Because the fuel will be consumed in flight.
b. Because the fuel is given a minus index in the fuel index correction table.
c. Because the centroid of the tanks is behind the CG position.
d. Because the graph would run out of range.

49. **For a fuel mass of 11 800 kg the index is:**

a. minus 4.5.
b. minus 5.7.
c. minus 6.3.
d. none of the above.

50. A scheduled flight of three hours estimated flight time, within Europe, is being planned. Calculate the maximum mass of freight that may be loaded in the following circumstances:

Structural limited take-off mass	**62 800 kg**
Structural limited landing mass	**54 900 kg**
MZFM	**51 300 kg**
Dry Operating Mass	**34 960 kg**
Fuel on board at ramp	**5 800 kg**
Taxi fuel	**450 kg**
Trip fuel	**10 200 kg**
Passengers (adults each 84 kg)	**115**
Passengers (children each 35 kg)	**6**
Flight crew (each 85 kg)	**2**
Cabin crew (each 75 kg)	**3**
Standard baggage for each passenger	**13 kg**

a. 4647 kg.
b. 4102 kg.
c. 1047 kg.
d. 5545 kg.

Answers

Answers to 'definition' example questions

1. a
2. c
3. d
4. a

Answers to Fuel Mass Conversions

1. 16 660 US.gal
2. 41 908 lb
3. 0.74
4. Answer d lighter by 2500 kg and range will increase.

Answer to Basic empty mass and CG position.

1. BEM of 25 450 kg and the CG is 57 cm in front of the main wheels.
2. 4520 lb and 21.7 inches aft of the main wheels
3. 232 kg and 60 inches aft of the datum

Answers to Percentage Mean Aerodynamic Chord Problems

1. 115.054 inches
2. 10.67 inches fwd of datum
3. Fwd limit 24.3%, Aft limit 53.6%
4. 1.45 inches out of limits
5. 17.05 m

Answers to Moving Mass Problems

1. 55.3846 lb
2. 23.9 inches
3. 7 rows
4. 146.1 kg
5. 952 kg
6. 43.2 lb

Answers to Adding or Removing Mass Problems

1. 500 kg
2. 35.97 lb
3. 1742.911 lb
4. 45.7 lb
5. 79.7 inches
6. 3.68 inches
7. 4444.38 imperial gallons

Answers to Station Numbers

1. Station 130
2. Station 1217
3. 348 inches
4. 787 inches

Answer to example Traffic Load Calculation

Maximum allowable freight mass = 1047 kg

Answers to SEP 1 Self-assessment Questions

1	2	3	4	5	6	7	8	9	10	11	12
d	d	d	c	b	b	c	b	b	b	b	d

13	14	15
a	a	d

Answers to MEP1 Self-assessment Questions

1	2	3	4	5	6	7	8	9	10	11	12
b	d	b	b	c	a	d	d	b	a	b	c

13	14
a	a

Answers to MRJT1 Self-assessment Questions

1	2	3	4	5	6	7	8	9	10	11	12
c	b	b	c	d	c	d	b	b	a	c	b

13	14	15	16	17	18	19	20	21	22	23	24
d	c	a	a	d	b	d	b	c	b	b	c

25	26	27	28	29	30	31	32	33	34	35	36
a	b	a	d	b	a	b	d	a	d	d	c

37	38	39	40	41	42	43	44	45	46	47	48
d	b	d	b	b	c	c	a	c	a	d	b

49	50
c	c

Chapter

3

Revision Questions

Questions

1. **Define the useful load:**

a. traffic load plus dry operating mass
b. traffic load plus usable fuel mass
c. dry operating mass plus usable fuel load
d. that part of the traffic load which generates revenue

2. **Determine the position of the CG as a percentage of the MAC given that the balance arm of the CG is 724 and the MAC balance arms are 517 to 1706.**

a. 14.2%
b. 15.3%
c. 16.3%
d. 17.4%

3. **The distance from the datum to the CG is:**

a. the index
b. the moment
c. the balance arm
d. the station

4. **Use CAP 696, MRJT1, fig 4.9. What is the balance arm, the maximum compartment load and the running load for the most aft compartment of the fwd cargo hold?**

a.	421.5 cm	3305 kg	13.12 kg per inch
b.	1046.5 inches	711 kg	7.18 kg per kg
c.	421.5 inches	2059 kg	13.12 kg per inch
d.	1046.5 m	711 kg	7.18 kg per in

5. **If the maximum structural landing mass is exceeded:**

a. the aircraft will be unable to get airborne
b. the undercarriage could collapse on landing
c. no damage will occur providing the aircraft is within the regulated landing mass
d. no damage will occur providing the aircraft is within the performance limited landing mass

6. **Use CAP 696, MRJT1 as appropriate. Prior to departure an MRJT is loaded with maximum fuel of 20 100 L at an SG of 0.78. Calculate the maximum allowable traffic load that can be carried given the following data:**

PLTOM	**62 800 kg**
PLLM	**54 200 kg**
DOM	**34 930 kg**
Taxi fuel	**250 kg**
Trip fuel	**9 250 kg**
Contingency and holding fuel	**850 kg**
Alternate fuel	**700 kg**

a. 13 092 kg
b. 12 442 kg
c. 16 370 kg
d. 16 842 kg

7. **Use CAP 696, fig 4.13. Assuming the fuel index moves minus 5.7 from the ZFM index, what is the take-off CG as a percentage of the MAC?**

 a. 20.1%
 b. 19.1%
 c. 23.0%
 d. 18.2%

8. **For a conventional light aeroplane with a tricycle undercarriage configuration, the higher the take-off mass:**

 1. stick forces at rotation will increase
 2. range will decrease but endurance will increase
 3. gliding range will reduce
 4. stalling speed will increase

 a. all statements are correct
 b. statement 3 only is correct
 c. statements 1 and 4 only are correct
 d. statement 4 only is correct

9. **Due to a mistake in the load sheet the aeroplane is 1000 kg heavier than you believe it to be. As a consequence:**

 a. V_1 will be later
 b. V_{MU} will be later
 c. V_R will be later
 d. V_1, V_{MU}, V_R will all occur earlier

10. **If the aeroplane was neutrally stable this would suggest that:**

 a. the CG is forward
 b. the CG is in mid range
 c. the CG is on the rear limit
 d. the CG is behind the rear limit

11. **The CG position is:**

 a. set by the pilot
 b. set by the manufacturer
 c. able to exist within a range
 d. fixed

12. **Which of the following has the least effect on the CG?**

 a. Cabin crew members performing their normal duties
 b. Fuel usage
 c. Stabilator trim setting
 d. Mass added or removed at the neutral point

13. **Using the data for the MRJT 1 in CAP 696, what is the CG as a percentage of the MAC if the CG is 650 inches from the datum?**

    a. 17.03%
    b. 18.14%
    c. 19.25%
    d. 20.36%

14. **The datum has to be along the longitudinal axis:**

    a. between the nose and the tail
    b. between the leading and trailing edge of the MAC
    c. but does not have to be between the nose and the tail
    d. at the firewall

15. **The CG is:**

    a. the point on the aircraft where the datum is located
    b. the point on the aircraft at which gravity appears to act
    c. the point on the aircraft from where the dihedral angle is measured
    d. the point on the aircraft where the lift acts through

16. **The aircraft basic mass and CG position details are found on:**

    a. the weighing schedule and the aeroplane must be re-weighed if equipment change causes a change in mass or balance
    b. on the loading manifest and is DOM – traffic load
    c. on the loading manifest and is ZFM – useful load
    d. on the weighing schedule and in the aeroplane technical log, and are adjusted to take account of any mass changes

17. **When determining the mass of fuel/oil and the value of the SG is not known, the value to use is:**

    a. determined by the operator (and laid down in the aeroplane OPS Manual. A pilot simply has to look it up)
    b. set out in EU-OPS Section 1 Subpart J
    c. determined by the aviation authority
    d. determined by the pilot

18. **In mass and balance terms, what is an index?**

    a. A cut down version of a force
    b. A moment divided by a constant
    c. A moment divided by a mass
    d. A mass divided by a moment

19. **Standard masses for baggage can be used when there are:**

    a. 9 seats or more
    b. 20 seats or more
    c. 30 seats or more
    d. less than 30 seats

20. What is the zero fuel mass?

a. MSTOM minus fuel to destination minus fuel to alternative airfield
b. Maximum allowable mass of the aircraft with no usable fuel on board
c. Operating mass minus the fuel load
d. Actual loaded mass of the aircraft with no usable fuel on board

21. If an aeroplane comes into land below its MSLM but above the PLLM for the arrival airfield:

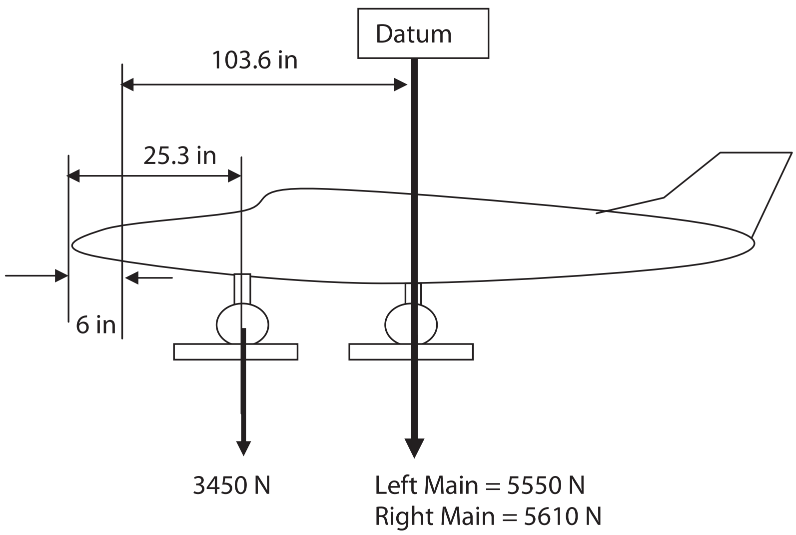
1. airframe structural damage will occur
2. tyre temperature limits could be exceeded
3. it might not have sufficient runway length in which to stop safely
4 a go-around might not be achievable
5. brake fade could occur

a. all the answers are correct
b. 3 and 4 only are correct
c. 2, 3, 4 and 5 only are correct
d. 1, 3, 4 and 5 only are correct

22. A twin engine aeroplane of mass 2500 kg is in balanced level flight. The CG limits are 82 in to 95 in from the nose position of the aeroplane and the CG is approximately mid range. A passenger of mass 85 kg, moves from the front seat 85.5 inches aft of the nose to the rear seat 157.6 inches from the nose. What is the new CG position approximately?

a. 2.5 inches
b. 87.5 inches
c. 91 inches
d. 92.5 inches

23. Calculate the Basic Empty Mass and CG position for the MEP1 shown below:



a. BEM = 1489 kg and CG is 20 inches forward of datum
b. BEM = 1456 kg and CG is 20 inches aft of the nose
c. BEM = 1489 kg and CG is 20 inches aft of datum
d. BEM = 1456 kg and CG is 89.6 inches aft of the nose

24. **A twin engine aeroplane is certified for a MSTOM and a MSLM of 58 000 kg and 55 000 kg respectfully. What is the limiting take-off mass for the aeroplane?**

PLTOM	**61 000 kg**
PLLM	**54 000 kg**
MZFM	**36 000 kg**
Operating mass	**55 000 kg**
Trip fuel	**36 000 kg**
Alternative fuel	**500 kg**
Final reserve	**500 kg**
Flight duration	**3 hours**
Fuel consumption	**500 kg per hour per engine**
Useful load	**41 500 kg**

a. 58 000 kg
b. 61 000 kg
c. 56 145 kg
d. 56 545 kg

Refer to CAP 696 for answers to 25, 26 and 27.

25. **With reference to CAP 696 figure 4.9, the centroid of the forward hold is:**

a. half way between stations 228 and station 500
b. 314.5 inches forward of the aft cargo bay centroid
c. 367.9 inches from the datum
d. 367.9 inches from the nose of the aeroplane

26. **The distance of the leading edge of the wing MAC from the datum is:**

a. undefined
b. 525.6 m
c. 625.6 in
d. 525.6 in

27. **What is the CG as a percentage of the MAC of the fully loaded aircraft?**

BEM	**12 000 kg**
Arm	**3 m**
CG	**25% MAC**
MAC	**2 m**
Item	**Balance arm**
Front seats	**2.5 m**
Rear seats	**3 m**
Fuel @ 0.74	**410 L**
Fuel arm	**2.5 m**
Rear seats	**Empty**
Pilot	**80 kg**
Front seat Pax	**80 kg**

a. 16%
b. 19%
c. 21%
d. 24%

28. The maximum aircraft mass excluding all usable fuel is:

a. fixed and listed in the aircraft's Operations Manual
b. variable and is set by the payload for the trip
c. fixed by the physical size of the fuselage and cargo holds
d. variable and depends on the actual fuel load for the trip

29. Just prior to take-off, a baggage handler put an extra box of significant mass into the hold without recording it in the LMCs. What are the effects of this action? The aeroplane has a normal, tricycle undercarriage.

1. VMC will increase if the extra load is forward of the datum
2. Stick forces in flight will decrease if the extra load is behind the datum
3. Stick forces at VR will increase if the box is forward of the main wheels
4. VMU will occur later
5. The safe stopping distance will increase

a. 3, 4 and 5 only
b. 2, 3 and 4 only
c. 1 and 5 only.
d. all the above

30. What is the maximum take-off mass given:

MSTOM	**43 000 kg**
MSLM	**35 000 kg**
PLLM	**33 000 kg**
MZFM	**31 000 kg**
DOM	**19 000 kg**
Total Fuel capacity	**12 500 kg**
Maximum Trip Fuel	**9000 kg**
Contingency fuel	**1000 kg**
Alternate fuel	**500 kg**
Final reserve fuel	**400 kg**

a. 43 000 kg
b. 42 000 kg
c. 41 000 kg
d. 40 000 kg

31. What is the maximum mass an aeroplane can be loaded to before it moves under its own power?

a. Maximum structural ramp mass
b. Maximum structural take-off mass
c. Maximum regulated ramp mass
d. Maximum regulated take-off mass

32. The weight of an aircraft in all flight conditions acts:

a. parallel to the CG
b. at right angles to the aeroplane's flight path
c. always through the MAC
d. vertically downwards

33. With reference to MRJT1 Load and Trim Sheet (CAP 696 Section 4 Page 11). If the DOM is 35 000 kg and the CG is 14%, what is the DOI?

a. 41.5
b. 33
c. 40
d. 30

34. If the CG moves rearwards during flight:

a. range will decrease
b. range will increase
c. stability will increase
d. range will remain the same but stalling speed will decrease

35. The CG of an aeroplane is situated at 115.8 arm and the mass is 4750 kg. A weight of 160 kg is moved from a hold situated at 80 arm to a hold at 120 arm. What would be the new CG arm?

a. 117.14
b. 118.33
c. 118.50
d. 120.01

36. What is the effect of moving the CG from the front to the rear limit at constant altitude, CAS and temperature?

a. Reduced optimum cruise range
b. Reduced cruise range
c. Increased cruise range
d. Increased stall speed

37. The baggage compartment floor-loading limit is 650 kg/m^2. What is the maximum mass of baggage that can be placed in the baggage compartment on a pallet of dimensions 0.8 m by 0.8 m if the pallet has a mass of 6 kg?

a. 416 kg
b. 1015 kg
c. 650 kg
d. 410 kg

38. An aeroplane of 110 000 kg has its CG at 22.6 m aft of the datum. The CG limits are 18 m to 22 m aft of the datum. How much mass must be removed from a hold 30 m aft of the datum to bring the CG to its mid point?

a. 26 800 kg
b. 28 600 kg
c. 86 200 kg
d. 62 800 kg

39. Where does the mass act through when the aircraft is stationary on the ground?

a. The centre of gravity
b. The main wheels
c. It doesn't act through anywhere
d. The aerodynamic centre

40. **If an aircraft is weighed prior to entry into service, who is responsible for doing the re-weigh to prepare the plane for operations?**

a. The manufacturer
b. The operator
c. The pilot
d. The flight engineer

41. **An aeroplane has a tank capacity of 50 000 imperial gallons. It is loaded with fuel to a quantity of 165 000 kg (790 kg/m³). What is the specific gravity of the fuel and approximately how much more fuel could be taken up given that mass limits would not be exceeded?**

a.	0.73	46 053 gallons
b.	0.81	4050 gallons
c.	0.72	46 000 gallons
d.	0.79	4056 gallons

42. **Define Balance Arm:**

a. BA = Mass / Moment
b. BA = Moment / Mass
c. BA = Mass / Distance
d. BA = Moment / Distance

43. **You have been given 16 500 litres of fuel at SG 0.78 but written down is 16 500 kg. As a result you will experience:**

a. heavier stick forces at rotation and improved climb performance
b. heavier stick forces on rotation and distance to take-off increases
c. lighter stick forces on rotation and calculated V_1 will be too high
d. lighter stick forces on rotation and V_2 will be too low

Answers

1	2	3	4	5	6	7	8	9	10	11	12
b	d	c	c	b	b	a	c	b	d	c	c

13	14	15	16	17	18	19	20	21	22	23	24
b	c	b	a	d	b	b	d	c	c	a	a

25	26	27	28	29	30	31	32	33	34	35	36
c	c	d	a	a	b	a	d	c	b	a	c

37	38	39	40	41	42	43
d	b	a	b	d	c	c

Specimen Examination Paper

1. **Define the useful load:**

    a. traffic load plus dry operating mass
    b. traffic load plus usable fuel mass
    c. dry operating mass plus usable fuel load
    d. that part of the traffic load which generates revenue

2. **Determine the position of the CG as a percentage of the MAC given that the balance arm of the CG is 724 and the MAC balance arms are 517 to 1706:**

    a. 14.2%
    b. 15.3%
    c. 16.3%
    d. 17.4%

3. **The distance from the datum to the CG is:**

    a. the index
    b. the moment
    c. the balance arm
    d. the station

4. **Use CAP 696, MRJT 1, fig 4.9. What is the balance arm, the maximum compartment load and the running load for the most aft compartment of the fwd cargo hold?**

a.	421.5 cm	3305 kg	13.12 kg per inch
b.	1046.5 inches	711 kg	7.18 kg per kg
c.	421.5 inches	2059 kg	13.12 kg per inch
d.	1046.5 m	711 kg	7.18 kg per in

5. **Individual aircraft should be weighed in an air conditioned hangar:**

    a. on entry into service and subsequently every 4 years
    b. when the effects of modifications or repairs are not known
    c. with the hangar doors closed and the air conditioning off
    d. all the above

6. **If a compartment takes a maximum load of 500 kg, with a running load limit of 350 kg/m and a distribution load limit of 300 kg/m² max, which of the following boxes, each of 500 kg, can be carried?**

    1. 100 cm × 110 cm × 145 cm
    2. 125 cm × 135 cm × 142 cm
    3. 120 cm × 140 cm × 143 cm
    4. 125 cm × 135 cm × 144 cm

    a. Any one of the boxes if loaded with due care as to its positioning
    b. Either of boxes 2, 3 and 4 in any configuration
    c. Box 2 with its longest length perpendicular to the floor cross beam or box 3 in any configuration
    d. Either of boxes 3 and 4 with their longest length parallel to the aircraft longitudinal axis

7. Use CAP 696, Section 4, MRJT1, as appropriate. Prior to departure an MRJT is loaded with maximum fuel of 20 100 L at an SG of 0.78. Calculate the maximum allowable traffic load that can be carried given the following data:

PLTOM	**67 200 kg**
PLLM	**54 200 kg**
DOM	**34 930 kg**
Taxi fuel	**250 kg**
Trip fuel	**9 250 kg**
Contingency and holding fuel	**850 kg**
Alternate fuel	**700 kg**

a. 13 092 kg
b. 12 442 kg
c. 16 370 kg
d. 16 842 kg

8. If the maximum structural landing mass is exceeded:

a. the aircraft will be unable to get airborne
b. the undercarriage could collapse on landing
c. no damage will occur providing the aircraft is within the regulated landing mass
d. no damage will occur providing the aircraft is within the performance limited landing mass

9. For a conventional light aeroplane with a tricycle undercarriage configuration, the higher the take-off mass:

1. stick forces at rotation will increase.
2. range will decrease but endurance will increase.
3. gliding range will reduce.
4. stalling speed will increase.

a. all statements are correct
b. statement 3 only is correct
c. statements 1 and 4 only are correct
d. statement 4 only is correct

10. Due to a mistake in the load sheet the aeroplane is 1000 kg heavier than you believe it to be. As a consequence:

a. V_1 will be later
b. V_{MU} will be later
c. V_R will be later
d. V_1, V_{MU}, V_R will all occur earlier

11. If the aeroplane was neutrally stable this would suggest that:

a. the CG is forward
b. the CG is in mid range
c. the CG is on the rear limit
d. the CG is behind the rear limit

12. **The CG position is:**

    a. set by the pilot
    b. set by the manufacturer
    c. able to exist within a range
    d. fixed

13. **Which of the following would not affect the CG position?**

    a. Cabin crew members performing their normal duties
    b. Fuel consumption during flight
    c. Horizontal stabilator trim setting
    d. Mass added or removed at the neutral point

14. **An aircraft is about to depart on an oceanic sector from a high elevation airfield with an exceptionally long runway in the tropics at 1400 local time. The regulated take-off mass is likely to be limited by:**

    a. MZFM
    b. Obstacle clearance
    c. Maximum certified take-off mass
    d. Climb gradient

15. **An aircraft is flying at 1.3V_{S1g} in order to provide an adequate margin above the low speed buffet and transonic speeds. If the 1.3V_{S1g} speed is 180 kt CAS and the mass increases from 285 000 kg to 320 000 kg, what is the new 1g stalling speed?**

    a. 146.7 kt, drag will increase and nautical mile per kg fuel burn will decrease
    b. 191 kt, drag will increase and range NM/kg will increase
    c. 191 kt, drag will increase and NM/kg fuel burn will decrease
    d. 147 kt, drag will remain the same and NM/kg fuel burn will increase

16. **The datum for the balance arms has to be along the longitudinal axis:**

    a. between the nose and the tail
    b. between the leading and trailing edge of the MAC
    c. but does not have to be between the nose and the tail
    d. at the fire wall

17. **The useful load is:**

    a. TOM – fuel mass
    b. BEM plus fuel load
    c. TOM minus the DOM
    d. TOM minus the operating mass

18. **In Mass & Balance terms, what is an index?**

    a. A cut down version of a force
    b. A moment divided by a constant
    c. A moment divided by a mass
    d. A mass divided by a moment

19. Standard masses for baggage can be used for aircraft with:

a. 9 seats or more
b. 20 seats or more
c. 30 seats or more
d. less than 30 seats

20. If an aeroplane comes into land below its MSLM but above the PLLM for the arrival airfield:

1. airframe structural damage will occur
2. tyre temperature limits could be exceeded
3. the runway length might be inadequate
4 a go-around might not be achievable
5. brake fade could occur

a. 1 and 5 only
b. 3 and 4 only
c. 2, 3, 4 and 5 only
d. 1, 3, 4 and 5 only

21. What is the zero fuel mass?

a. MSTOM minus fuel to destination minus fuel to alternative airfield
b. Maximum allowable mass of the aircraft with no usable fuel on board
c. Operating mass minus the fuel load
d. Actual loaded mass of the aircraft with no usable fuel on board

22. An aeroplane develops a serious maintenance problem shortly after take-off and has to return to its departure airfield. In order to land safely the aircraft must jettison fuel. How much fuel must be jettisoned?

a. Sufficient to reduce the mass to the zero fuel mass
b. The pilot calculates the amount of fuel to jettison to reduce the mass to a safe level at or below the RLM
c. The fuel system automatically stops the jettison at the RLM
d. As much as the pilot feels is just insufficient to land safely

23. Calculate the amount of cargo that could be loaded into the aircraft given the following information and using CAP 696, Section 4, MRJT1, as necessary:

Dry Operating Mass	**34 900 kg**
Performance Limited Landing Mass	**55 000 kg**
Trip Fuel	**9 700 kg**
Contingency Fuel	**1200 kg**
Alternate Fuel	**1400 kg**
130 passengers at 84 kg each	**10 920 kg**
130 bags at 14 kg each	**1820 kg**

a. 2860 kg
b. 3660 kg
c. 4660 kg
d. 5423 kg

Answers to Specimen Examination Paper

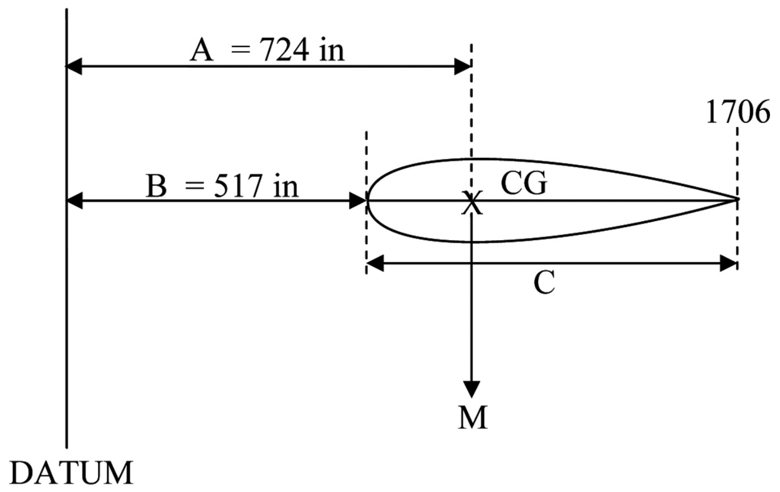
1	2	3	4	5	6	7	8	9	10	11	12
b	d	c	c	d	d	b	b	c	b	d	c

13	14	15	16	17	18	19	20	21	22	23
c	d	a	c	c	b	b	c	d	b	a

Debrief to Specimen Examination Paper

1. b. (See CAP 696 Section 1, General Notes, Page 3).

2. d.



$$C = 1706 - 517 = 1189$$

$$\% \text{ MAC} = \frac{A - B}{C} \times 100$$

$$= \frac{724 - 517}{1189} \times 100 = 17.4\%$$

3. c. (See CAP 696 Section 1, General Notes, Page 3).

4. c. See CAP 696 Section 4 - MRJT1 Page 5. Note the values have been placed in reverse order.

5. d. See EU-OPS 1, Subpart J 1.605.

6. d. Max running load $= \frac{\text{Load}}{\text{Min Length}}$

Therefore min length = 500 kg / 350 kg /m = 1.428 m
Thus, anything shorter than 1.428 m will exceed the maximum running load.

Max distribution load $= \frac{\text{Load}}{\text{Min Area}}$

Therefore min area = 500 kg/300 kg/m^2 = 1.66 m^2
Thus, any area less than 1.66 m^2 will exceed the max floor intensity.

Using the above, only boxes 3 and 4 meet the distribution load requirements but the load must be placed with its longest length parallel to the longitudinal axis to meet the running load requirement.

7.	b.	Ramp Fuel mass	=	20 100 l × 0.78	= 15 678 kg
		Take-off fuel	=	15 678 – 250 {start/taxi}	= 15 428 kg
		Fuel remaining	=	15 428 – 9250	= 6178 kg
		From CAP 696, MZFM	=	51 300 kg	
	1.	MZFM –DOM	=	51 300 – 34 930	= 16 370 kg

2. MSTOM is lower than PLTOM thus
MSTOM – DOM – TO Fuel = 62 800 – 34 930 – 15 428 = 12 442 kg

3. PLLM is lower than SLLM, thus
PLLM - DOM - Fuel Remaining = 54 200 – 34 930 – 6178 = 13 092 kg

Allowable TL = lowest of 1, 2 or 3 above = 12 442 kg

8. b. The Maximum Structural Landing Mass is set by the manufacturer to meet with the Design Limit Loads (DLL) of the structure. If exceeded, the structure will be subject to excessive fatigue and could even be permanently damaged.

9. c.
1. Stick forces at rotation will increase [weight is fwd of wheel rotation].
2. Range will decrease but endurance will increase [both will decrease].
3. Gliding range will reduce [gliding range is not affected by weight].
4. Stalling speed will increase [stalling speed increases with weight].

10.
a. Wrong. You will still believe it to be the speed you calculated because you are unaware of the error.
b. Correct. V_{MU} will be later (the extra mass will prolong the point of minimum lift-off).
c. Wrong. You will pull the stick back to rotate at the speed you originally calculated.
d. Wrong. They will all occur later.

11 d. the CG is behind the rear limit (review the Principles of Flight notes on Static Margin. If the CG were positioned on the neutral point and the aeroplane was disturbed in pitch by a gust of wind, it would retain the new attitude because the moments about the CG would all equal one another.)

12.
b. Wrong. The manufacturer sets the limits not the position.
c. Correct. Within the range set by the manufacturer.

13. c. Stabiliizer trim applies a balancing moment (about the CG) but does not move the CG position.

14. d. Oceanic means there are no obstacles to consider. Though we have an unlimited runway the high elevation of the airfield will result in a low air density. Also, the time, being at the hottest part of the day, will further reduce the air density. The reduced density will seriously reduce the engine performance limits. Weight would be limited in order to achieve a suitable climb gradient.

15. a. $1.3V_S$ = 180 kt, therefore $V_S = \frac{180}{1.3}$ = 138.46 kt

New V_S = Old $V_S \times \sqrt{}$(New weight/Old Weight)

= $138.46 \times \sqrt{(320\,000/285\,000)}$ = 146.7 kt

Assuming the aircraft continues to fly at $1.3V_S$ its new speed will be:

146.7 × 1.3 = 190.7 kt

Naturally, drag will increase and range (nautical miles per kg of fuel) will decrease).

16. c The datum does not have to be between the nose and the tail. (The datum can be anywhere in front of, on or behind the aircraft so long as it is on the longitudinal axis of the aeroplane).

17. c. TOM = DOM + Traffic Load + Fuel Load.
But, Traffic Load + Fuel Load = Useful Load.
Thus, TOM = DOM + Useful Load, Rearrange formula, UL = TOM – DOM

18. b. To simplify M&B calculations. See CAP 696 page 4.

19. b. See EU-OPS 1 Subpart J 1.620, para f.

20. c. 2, 3, 4 and 5 only.

In this example the performance limitation is not stated and could be anything from a runway length restriction, a sloping runway, an obstruction limitation and/or altitude/temperature limitations. The aeroplane might sustain a burst tyre, brake fade, and/or brake fire as a result of heavy braking. Tyre temperatures might exceed limits and delay the take-off time even if they do not burst. The climb slope for obstacle clearance during a go-around might be reduced. As the landing is below the MSLM, the structure itself should not suffer direct damage providing the aeroplane comes to a stop without hitting anything.

21. d. See CAP 696 Section 1, General Notes, Page 3, Para 4.1.

22. b. The pilot calculates the amount of fuel to jettison to reduce the mass to a safe level at or below the RLM. (Before jettisoning the fuel the pilot should attempt to declare an emergency if time permits and advise Air Traffic Control of his intensions).

23. a. When attempting this sort of question the golden rule is to work out the fuel states first. Once the fuel states are known you can simply use the three formulae to determine the answer.

TOF = 9700 + 1200 + 1400 = 12 300
FR = 1200 + 1400 = 2600
DOM = 34 900
MZFM = 53 000
RTOM = 62 800
RLM = 54 900

Formulae

1.	MZFM – DOM	=	53 000 - 34 900	= 18 100
2.	RTOM – DOM – TOF	=	62 800 - 34 900 - 12 300	= 15 600
3.	RLM – DOM – FR	=	54 900 - 34 900 - 2600	= 17 480

Allowable TL	=	Lowest of 1, 2, 3 Above	=	15 600 kg
Actual TL	=	PAX + Baggage	=	(130 × 84) + (130 × 14)
Actual TL	=	12 740 kg		

Difference Between Allowed TL and Actual TL = Underload

Cargo That Can Be Taken = Underload

Cargo = 15 600 – 12 740 = 2860 kg

Chapter

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CAE Oxford
Aviation Academy

PERFORMANCE
ATPL GROUND TRAINING SERIES

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ATPL Aircraft Performance

Introduction

Chapter

1

Performance - Introduction

Definitions

Absolute Ceiling The altitude at which the theoretical rate of climb, with all engines operating at maximum continuous power, is reduced to zero feet per minute

Accelerate-stop Distance Available The distance from the point on the surface of the aerodrome at which the aeroplane can commence its take-off run to the nearest point in the direction of take-off at which the aeroplane cannot roll over the surface of the aerodrome and be brought to rest in an emergency without the risk of accident. It is equal to TORA plus any available stopway.

Aerodrome Any area of land or water designed, equipped, set apart or commonly used for affording facilities for the landing and departure of aircraft and includes any area or space, whether on the ground, on the roof of a building or elsewhere, which is designed, equipped or set apart for affording facilities for the landing and departure of aircraft capable of descending or climbing vertically, but shall not include any area the use of which for affording facilities for the landing and departure of aircraft has been abandoned and has not been resumed.

Aerodrome Elevation The elevation of the highest point of the landing area.

Aerodrome Reference Point The aerodrome reference point is the geographical location of the aerodrome and the centre of its traffic zone where an ATZ is established.

Aerodynamic Ceiling The altitude, in unaccelerated 1g level flight, where the Mach number for the low speed and high speed buffet are coincident.

Aeroplane A power-driven heavier-than-air aircraft, deriving its lift in flight chiefly from aerodynamic reactions on surfaces which remain fixed under given conditions of flight.

Aircraft A machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the earth's surface.

Aircraft Classification Number (ACN) This is a value assigned to an aeroplane to show its load force. The aircraft classification number must be compared to the pavement classification number (PCN) of an aerodrome. The aircraft classification number may exceed the pavement classification number by as much as 50% but only if the manoeuvring of the aeroplane is very carefully monitored, otherwise significant damage may occur to both the aeroplane and the pavement.

Airframe The fuselage, booms, nacelles, cowlings, fairings, aerofoil surfaces (including rotors but excluding propellers and rotating aerofoils of engines), and landing gear of an aircraft and their accessories and controls.

Air Minimum Control Speed The minimum speed at which directional control can be demonstrated when airborne with the critical engine inoperative and the remaining engines at take-off thrust. Full opposite rudder and not more than 5 degrees of bank away from the inoperative engine are permitted when establishing this speed. V_{MCA} may not exceed $1.2V_{SI}$ or $1.13V_{SR}$.

Alternate Airport An airport at which an aircraft may land if a landing at the intended airport becomes inadvisable.

Altitude The altitude shown on the charts is pressure altitude. This is the height in the International Standard Atmosphere at which the prevailing pressure occurs. It may be obtained by setting the subscale of a pressure altimeter to 1013 hPa.

Angle of Attack The angle between the chord line of the wing of an aircraft and the relative airflow.

Apron A defined area on a land aerodrome provided for the stationing of aircraft for the embarkation and disembarkation of passengers, the loading and unloading of cargo, and for parking.

Auxiliary Power Unit Any gas turbine-powered unit delivering rotating shaft power, compressor air, or both which is not intended for direct propulsion of an aircraft.

Balanced Field A runway for which the Accelerate-stop Distance Available is equal to the Take-off Distance Available is considered to have a balanced field length.

Baulked Landing A landing manoeuvre that is unexpectedly discontinued.

Brake Horsepower The power delivered at the main output shaft of an aircraft engine.

Buffet Speed The speed at which the airflow over the wing separates creating turbulent airflow aft of the separation point which buffets the aeroplane.

Calibrated Airspeed The indicated airspeed, corrected for position and instrument error. It is equal to True Airspeed (TAS) at Mean Sea Level (MSL) in a Standard Atmosphere.

Climb Gradient The ratio, in the same units of measurement, expressed as a percentage, as obtained from the formula:- gradient = vertical interval ÷ horizontal interval × 100.

Clearway An area beyond the runway, not less than 152 m (500 ft) wide, centrally located about the extended centre line of the runway, and under the control of the airport authorities. The clearway is expressed in terms of a clearway plane, extending from the end of the runway with an upward slope not exceeding 1·25%, above which no object or terrain protrudes. However, threshold lights may protrude above the plane if their height above the end of the runway is 0·66 m (26 inches) or less and if they are located to each side of the runway.

Cloud Ceiling In relation to an aerodrome, cloud ceiling means the vertical distance from the elevation of the aerodrome to the lowest part of any cloud visible from the aerodrome which is sufficient to obscure more than one half of the sky so visible.

Contaminated Runway A runway is considered to be contaminated when more than 25% of the runway surface area is covered by surface water, more than 3 mm deep.

Continuous One Engine Inoperative Power Rating The minimum test bed acceptance power, as stated in the engine type certificate data sheet, when running at the specified conditions and within the appropriate acceptance limitations.

Continuous One Engine Inoperative Thrust Rating The minimum test bed acceptance thrust, as stated in the engine type certificate data sheet, when running at the specified conditions and within the appropriate acceptance limitations.

Continuous One Engine Inoperative Power The power identified in the performance data for use after take-off when a power unit has failed or been shut down, during periods of unrestricted duration.

Continuous One Engine Inoperative Thrust The thrust identified in the performance data for use after take-off when a power unit has failed or been shut down, during periods of unrestricted duration.

Critical Engine The engine whose failure would most adversely affect the performance or handling qualities of an aircraft.

Damp Runway A runway is considered damp when the surface is not dry, but when the moisture on it does not give it a shiny appearance.

Declared Distances The distances declared by the aerodrome authority for the purpose of application of the requirement of the Air Navigation Order.

Decision Speed The maximum speed in the take-off at which the pilot can take the first action (e.g. apply brakes, reduce thrust, deploy speed brakes) to stop the aeroplane within the accelerate-stop distance. It also means the minimum speed in the take-off, following a failure of the critical engine at V_{EF} at which the pilot can continue the take-off and achieve the required height above the take-off surface within the take-off distance.

Density Altitude The altitude in ISA, where the prevailing measured density occurs.

Drag That force on an aeroplane which directly opposes thrust.

Dry Runway A dry runway is one which is neither wet nor contaminated, and includes those paved runways which have been specially prepared with grooves or porous pavement and maintained to retain 'effectively dry' braking action even when moisture is present.

Elevation The vertical distance of an object above mean sea level. This may be given in metres or feet.

En Route The en route phase extends from 1500 ft above the take-off surface level to 1000 ft above the landing aerodrome surface level for Class B aeroplanes or to 1500 ft above the landing aerodrome surface level for Class A aeroplanes.

Equivalent Airspeed The calibrated airspeed corrected for compressibility at the particular pressure altitude under consideration. It is equal to Calibrated Airspeed in a Standard Atmosphere.

Exhaust Gas Temperature The average temperature of the exhaust gas stream.

Final En Route Climb Speed The speed of the aeroplane in segment four of the take-off flight path with one engine inoperative.

Final Segment Speed The speed of the aeroplane in segment four of the take-off flight path with one engine inoperative.

Final Take-off Speed The speed of the aeroplane that exists at the end of the take-off path in the en route configuration with one engine inoperative.

Fixed Pitch Propeller A propeller, the pitch of which cannot be changed.

Flap Extended Speed The highest speed permissible with wing flaps in a prescribed extended position.

Flight Level A surface of constant atmospheric pressure that is related to 1013.25 hPa. It is conventionally the pressure altitude to the nearest 1000 ft in units of 100 ft. For example, flight level 250 represents a pressure altitude of 25 000 ft.

Frangibility The ability of an object to retain its structural integrity and stiffness up to a specified maximum load but when subject to a load greater than specified or struck by an aircraft will break, distort or yield in such a manner as to present minimum hazard to an aircraft.

Go-around A procedure involving a decision to abort the landing and climb straight ahead to rejoin the circuit. Such a decision might be taken at any time during the final approach, the transition phase or even after initial touchdown.

Gross Height The true height attained at any point in the take-off flight path using gross climb performance. Gross height is used for calculating pressure altitudes for purposes of obstacle clearance and the height at which wing flap retraction is initiated.

Gross Performance The average performance that a fleet of aeroplanes should achieve if satisfactorily maintained and flown in accordance with the techniques described in the manual.

Ground Minimum Control Speed The minimum speed at which the aeroplane can be demonstrated to be controlled on the ground using only the primary flight controls when the most critical engine is suddenly made inoperative and the remaining engines are at take-off thrust. Throttling an opposite engine is not allowed in this demonstration. Forward pressure from the elevators is allowed to hold the nose wheel on the runway, however, nose wheel steering is not allowed.

Height The vertical distance between the lowest part of the aeroplane and the relevant datum.

Hydroplaning Speed The speed at which the wheel is held off the runway by a depth of water and directional control through the wheel is impossible.

ICAO Standard Atmosphere The atmosphere defined in ICAO Document 7488/2. For the purposes of Certification Specifications the following are acceptable:

- The air is a perfect dry gas
- The temperature at sea level is 15°C
- The pressure at sea level is 1013.2 hPa (29.92 in Hg)
- The temperature gradient from sea level to the altitude at which the temperature becomes –56.5°C is 0.65°C/100 m (1.98°C/1000 ft)
- The density at sea level under the above conditions is 1.2250 kg/m^3

IFR Conditions Weather conditions below the minimum for flight under visual flight rules.

Indicated Airspeed The speed as shown by the pitot/static airspeed indicator calibrated to reflect Standard Atmosphere adiabatic compressible flow at MSL and uncorrected for airspeed system errors.

Instrument A device using an internal mechanism to show visually or aurally the attitude, altitude, or operation of an aircraft or aircraft part. It includes electronic devices for automatically controlling an aircraft in flight.

Landing Distance Available The distance from the point on the surface of the aerodrome above which the aeroplane can commence its landing, having regard to the obstructions in its approach path, to the nearest point in the direction of landing at which the surface of the aerodrome is incapable of bearing the weight of the aeroplane under normal operating conditions or at which there is an obstacle capable of affecting the safety of the aeroplane.

Landing Gear Extended Speed The maximum speed at which an aircraft can be safely flown with the landing gear extended.

Landing Gear Operating Speed The maximum speed at which the landing gear can be safely extended or retracted.

Landing Minimum Control Speed The minimum speed with a wing engine inoperative where it is possible to decrease thrust to idle or increase thrust to maximum take-off without encountering dangerous flight characteristics.

Large Aeroplane An aeroplane of more than 5700 kg maximum certificated take-off weight. The category 'Large Aeroplane' does not include the commuter aeroplane category.

Lift That force acting on an aerofoil which is at right angles to the direction of the airflow.

Load Factor The ratio of a specified load to the total weight of the aircraft. The specified load is expressed in terms of any of the following: aerodynamic forces, inertia forces, or ground or water reactions.

Mach Number The ratio of true airspeed to the Local Speed of Sound (LSS).

Manoeuvre Ceiling The pressure altitude that provides a 0.3 g margin to both the high speed buffet and the low speed buffet.

Maximum Brake Energy Speed The maximum speed on the ground from which an aeroplane can safely stop within the energy capabilities of the brakes.

Maximum Continuous Power The power identified in the performance data for use during periods of unrestricted duration.

Maximum Continuous Thrust The thrust identified in the performance data for use during periods of unrestricted duration.

Maximum Structural Take-off Mass The maximum permissible total mass of an aeroplane at the start of the take-off run.

Maximum Structural Landing Mass The maximum permissible total mass of an aeroplane on landing (under normal circumstances).

Minimum Control Speed The minimum speed at which the aeroplane is directionally controllable with the critical engine inoperative and the remaining engines at take-off thrust.

Minimum Unstick Speed The minimum speed demonstrated for each combination of weight, thrust, and configuration at which a safe take-off has been demonstrated.

Missed Approach When an aircraft is caused to abort a landing after it has already started its landing approach. The aircraft has to follow a set missed approach procedure to leave the airspace surrounding the terminal.

Net Height The true height attained at any point in the take-off flight path using net climb performance. Net height is used to determine the net flight path that must clear all obstacles by the statutory minimum to comply with the Operating Regulations.

Net Performance Net performance is the gross performance diminished to allow for various contingencies that cannot be accounted for operationally e.g. variations in piloting technique, temporary below average performance, etc. It is improbable that the net performance will not be achieved in operation, provided the aeroplane is flown in accordance with the recommended techniques.

Outside Air Temperature The free air static (ambient) temperature.

Pitch Setting The propeller blade setting determined by the blade angle, measured in a manner and at a radius declared by the manufacturer and specified in the appropriate Engine Manual.

Pitch Motion of the aeroplane about its lateral axis.

Pitot Tube A small tube whose open end collects Total Pressure.

Pressure Altitude The altitude of an aircraft above the pressure level of 1013.25 hPa. This is achieved by setting the altimeter subscale to 1013 hPa and reading the altitude indicated.

Reference Landing Speed The speed of the aeroplane, in a specified landing configuration, at the point where it descends through the landing screen height in the determination of the landing distance for manual landings.

Rejected Take-off (RTO) A situation or event in which it is decided, for safety reasons, to abandon the take-off of an aircraft.

Roll Motion of the aeroplane about its longitudinal axis.

Rotation Speed The speed at which, during the take-off, rotation is initiated with the intention of becoming airborne.

Runway A defined rectangular area on a land aerodrome prepared for the landing and take-off run of aircraft along its length.

Runway Strip An area of specified dimensions enclosing a runway intended to reduce the risk of damage to an aircraft running off the runway and to protect aircraft flying over it when taking off or landing.

Runway Threshold The beginning of that portion of the runway usable for landing.

Screen An imaginary barrier, located at the end of the Take-off Distance Available (TODA) or the beginning of the Landing Distance Available (LDA). The screen is of no operational significance, but the test pilots use the height of the screen when assessing the performance of the aeroplane.

Service Ceiling The pressure altitude at which the rate of climb is reduced to a specified minimum value (approximately 300 ft/min).

Specific Fuel Consumption Fuel flow per unit thrust. The lower the value, the more efficient the engine.

Stopway An area beyond the take-off runway, no less wide than the runway and centred upon the extended centre line of the runway, able to support the aeroplane during an aborted take-off, without causing structural damage to the aeroplane, and designated by the airport authorities for use in decelerating the aeroplane during an aborted take-off.

Take-off Distance Available. It is equal to TORA plus any clearway and cannot be more than one and one half times the TORA, whichever is the less.

Take-off Mass The mass of an aeroplane, including everything and everyone contained within it, at the start of the take-off run.

Take-off Power The output shaft power identified in the performance data for use during take-off, discontinued approach and baulked landing:

i. for piston engines, it is limited in use to a continuous period of not more than 5 minutes;

ii. for turbine engines installed in aeroplanes and helicopters, limited in use to a continuous period of not more than 5 minutes; and

iii. for turbine engines installed in aeroplanes only (when specifically requested), limited in use to a continuous period of not more than 10 minutes in the event of a power unit having failed or been shut down.

Take-off Run Available The distance from the point on the surface of the aerodrome at which the aeroplane can commence its take-off run to the nearest point in the direction of take-off at which the surface of the aerodrome is incapable of bearing the weight of the aeroplane under normal operating conditions.

Take-off Safety Speed A referenced airspeed obtained after lift-off at which the required one engine-inoperative climb performance can be achieved.

Take-off Thrust The output shaft thrust identified in the performance data for use during take-off, discontinued approach and baulked landing:

i. for piston engines, it is limited in use to a continuous period of not more than 5 minutes;

ii. for turbine engines installed in aeroplanes and helicopters, limited in use to a continuous period of not more than 5 minutes; and

iii. for turbine engines installed in aeroplanes only, limited in use to a continuous period of not more than 10 minutes in the event of a power unit having failed or been shut down.

Taxiway A defined path on a land aerodrome established for the taxiing of aircraft and intended to provide a link between one part of the aerodrome and another.

Thrust That force acting on an aeroplane produced by the engine(s) in a forward direction.

True Airspeed The airspeed of an aircraft relative to undisturbed air.

Turbojet An aircraft having a jet engine in which the energy of the jet operates a turbine that in turn operates the air compressor.

Turboprop An aircraft having a jet engine in which the energy of the jet operates a turbine that drives the propeller. Turboprops are often used on regional and business aircraft because of their relative efficiency at speeds slower than, and altitudes lower than, those of a typical jet.

Variable Pitch Propellers A propeller, the pitch setting of which changes or can be changed, when the propeller is rotating or stationary.

V_{EF} The calibrated airspeed at which the critical engine is assumed to fail and is used for the purpose of performance calculations. It is never less than V_{MCG}.

V_1 Referred to as the decision speed. Engine failure prior to V_1 demands that the pilot must reject the take-off because there is insufficient distance remaining to enable the aircraft to safely continue the take-off. Engine failure at or faster than V_1 demands that the pilot must continue the take-off because there is insufficient distance remaining to safely bring the aircraft to a stop.

Wet Runway A runway is considered wet when the runway surface is covered with water, or equivalent moisture on the runway surface to cause it to appear reflective, but without significant areas of standing water.

Windshear Localized change in wind speed and/or direction over a short distance, resulting in a tearing or shearing effect that can cause a sudden change of airspeed with occasionally disastrous results if encountered when taking off or landing.

Yaw Motion of an aeroplane about its normal axis.

Zero Flap Speed The minimum safe manoeuvring speed with zero flap selected.

Abbreviations

AC	Air Conditioning
ACARS	Aircraft Communications Addressing and Reporting System
ACS	Air Conditioning System
ACN	Aircraft Classification Number
AFM	Aeroplane Flight Manual
AGL	Above Ground Level
AMSL	Above Mean Sea Level
ANO	Air Navigation Order
AOM	Airline Operation Manual
ASD	Accelerate-stop Distance
ASDA	Accelerate-stop Distance Available
ASDR	Accelerate-stop Distance Required
ATC	Air Traffic Control
AUW	All-up Weight
BRP	Brake Release Point
CAA	Civil Aviation Authority
CAP	Civil Aviation Publication
CAS	Calibrated Airspeed
C_D	Drag Coefficient
CI	Cost Index
C_L	Lift Coefficient
C of A	Certificate of Airworthiness
C of G	Centre of Gravity
C of P	Centre of Pressure
FMC	Flight Management Computer
FMS	Flight Management System

DOC	Direct Operating Cost
DOM	Dry Operating Mass
EAS	Equivalent Airspeed
EASA	European Aviation Safety Agency
ECON	Economic speed (minimum directing operating cost speed)
EGT	Exhaust Gas Temperature
EMD	Emergency Distance
EMDA	Emergency Distance Available
EMDR	Emergency Distance Required
ETOPS	Extended range with twin aeroplane operations
FAA	Federal Aviation Administration
FCOM	Flight Crew Operating Manual
FF	Fuel Flow (hourly consumption)
FL	Flight Level
G/S	Ground Speed
hPa	Hectopascal
IAS	Indicated Airspeed
IAT	Indicated Air Temperature
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
ISA	International Standard Atmosphere
JAA	Joint Aviation Authority
JAR	Joint Aviation Requirements
kg	Kilograms
km	Kilometres
kt	Nautical miles per hour (knots)
LCN	Load Classification Number

LDA	Landing Distance Available
LDR	Landing Distance Required
LRC	Long Range Cruise speed
MAT	Mass-altitude-temperature
M_{CRIT}	Critical Mach number
MCT	Maximum Continuous Thrust
MEL	Minimum Equipment List
M_{LRC}	Mach Number for Long Range Cruise
M_{MO}	Maximum Operating Mach number
M_{MR}	Mach of Maximum Range
MRC	Maximum Range Cruise Speed
MSL	Mean Sea Level
MTOM	Maximum Take-off Mass
MZFM	Maximum Zero Fuel Mass
N	All engines operating
NFP	Net Flight Path
NM	Nautical Mile
NOTAM	Notice to Airmen
N1	Speed rotation of the fan
N-1	One engine inoperative
N-2	Two engines inoperative
OAT	Outside Air Temperature
OEI	One Engine Inoperative
PA	Pressure Altitude
PCN	Pavement Classification Number
PFD	Primary Flight Display
PMC	Power Management Control
PNR	Point of No Return

psi	Pounds per square inch
QFE	The altimeter subscale setting which causes the altimeter to read zero elevation when on the airfield reference point or runway threshold
QNE	The indicated height on the altimeter at the aerodrome datum point with the altimeter subscale set to 1013.2 hPa
QNH	The altimeter subscale setting which causes the altimeter to read the elevation of the airfield above mean sea level when placed on the airfield reference point or runway threshold
RESA	Runway End Safety Area
RNP	Required Navigation Performance
RTO	Rejected Take-off
RZ	Reference Zero
SAR	Specific Air Range
SFC	Specific Fuel Consumption
SR	Specific Range
TAS	True Airspeed
TAT	Total Air Temperature
TOD	Take-off Distance/Top of Descent
TODA	Take-off Distance Available
TODR	Take-off Distance Required
TOGA	Take-off/Go-around thrust
TOR	Take-off Run
TORA	Take-off Run Available
TORR	Take-off Run Required
TOSS	Take-off Safety Speed
TOW	Take-off Weight
V_1	Decision speed
V_2	Take-off safety speed
V_{2MIN}	Minimum take-off safety speed
V_3	All engines operating steady initial climb speed

V_4	All engines operating steady take-off climb speed
V_A	Design Manoeuvring Speed
V_{EF}	The assumed speed of engine failure
V_{FE}	The maximum flap extended speed
VFR	Visual Flight Rules
V_{FTO}	Final take-off speed
V_{GO}	The lowest decision speed from which a continued take-off is possible within the TODA with one engine inoperative
V_{MD}	Velocity of Minimum Drag
V_{MP}	Velocity of Minimum Power
V_{LE}	The maximum speed with landing gear extended
V_{LO}	The maximum speed at which the landing gear may be lowered
V_{LOF}	Lift-off speed
V_{MBE}	Maximum brake-energy speed
V_{MC}	Minimum control speed with the critical power unit inoperative
V_{MCA}	Minimum control speed in the air (take-off climb)
V_{MCG}	Ground minimum control speed (at or near the ground)
V_{MCL}	Landing minimum control speed (on the approach to land)
V_{MO}	The maximum operating speed
V_{MU}	The minimum unstick speed
V_{NE}	Never exceed speed
V_P	Hydroplaning/Aquaplaning speed
V_R	Rotation Speed
V_{RA}	The turbulence speed or rough air speed
V_{REF}	The reference landing speed (Replaced VAT speed)
V_S	Stalling speed or minimum steady flight speed at which the aeroplane is controllable
V_{SR}	Reference stalling speed. Assumed to be the same as V_{S1g}
V_{SR0}	Reference stalling speed in the landing configuration

V_{SR1}	Reference stalling speed in the specified configuration
V_{S1g}	Stalling speed at 1g or the one-g stall speed at which the aeroplane can develop a lift force (normal to the flight path) equal to its weight. This is assumed to be the same speed as V_{SR}.
V_{S0}	The stalling speed with the flaps at the landing setting or minimum steady flight speed at which the aeroplane is controllable in the landing configuration
V_{S1}	The stalling speed for the configuration under consideration
V_{STOP}	The highest decision speed that an aeroplane can stop within ASDA
V_X	The speed for the best gradient or angle of climb
V_Y	The speed for the best rate of climb
V_{ZF}	The minimum safe manoeuvring speed with zero flap
WAT	Weight-altitude-temperature
ZFW/ZFM	Zero fuel weight/zero fuel mass
γ	Climb or descent angle
μ	Runway friction coefficient
θ	Aircraft attitude
ρ	Air density

EU-OPS Performance Classification

Performance Class A

Multi-engine aeroplanes powered by turbo-propeller engines with a maximum approved passenger seating configuration of more than 9 or a maximum take-off mass exceeding 5700 kg, and all multi-engine turbojet powered aeroplanes. Class A aeroplanes must abide by the Certification Specifications laid out in the document from EASA called CS-25.

Performance Class B

Propeller driven aeroplanes with a maximum approved passenger seating configuration of 9 or less, and a maximum take-off mass of 5700 kg or less. Class B aeroplanes must abide by the Certification Specifications laid out in the document from EASA called CS-23.

Performance Class C

Aeroplanes powered by reciprocating engines with a maximum approved passenger seating configuration of more than 9 or a maximum take-off mass exceeding 5700 kg.

Unclassified

This class is given to those aeroplanes whose performance characteristic is unique and special performance consideration is required. For example, the Unclassified class includes supersonic aeroplanes and sea planes.

	Multi-engine Jet	Propeller driven	
		Multi-engine Turboprop	**Piston**
Mass : > 5700 kg or Passenger Seats: > 9	A	A	C
Mass : ≤ 5700 kg and Passengers Seats : ≤9	A	B	B

Performance Expressions

Any class of aeroplane operated in the public transport role must adhere to the operational requirements set out in EU-OPS 1. EU-OPS 1 prescribes a minimum performance level for each stage of flight for Class A, Class B and Class C aeroplanes. The certification and operational regulations together aim to achieve a high standard of safety that has kept air travel as the safest form of travel. To achieve the required safety standard, the aviation authorities have added a safety margin into the aeroplane performance data. The application of these safety margins changes the expression of the performance data.

Measured Performance

This is the performance achieved by the manufacturer under test conditions for certification. It utilizes new aeroplanes and test pilots and is therefore unrepresentative of the performance that will be achieved by an average fleet of aeroplanes.

Gross Performance

Gross performance is the average performance that a fleet of aeroplanes should achieve if satisfactorily maintained and flown in accordance with the techniques described in the manual. Therefore, gross performance is measured performance reduced by a set margin to reflect average operating performance.

Net Performance

Net performance is the gross performance diminished to allow for various contingencies that cannot be accounted for operationally e.g. variations in piloting technique, temporary below average performance, etc. It is improbable that the net performance will not be achieved in operation, provided the aeroplane is flown in accordance with the recommended techniques. This level of performance is approximately 5 standard deviations from the average performance or gross performance. Therefore, 99.99994% of the time, the aeroplane will achieve net performance or better. However, there is less than one chance in a million that the aeroplane will not achieve the net performance. This is the safety standard which the aviation authorities aim to achieve.

Chapter 2

General Principles - Take-off

Take-off

The take-off part of the flight is the distance from the brake release point (BRP) to the point at which the aircraft reaches a defined height. This defined height is termed the "screen height". The screen height varies from 35 ft for Class A aeroplanes to 50 ft for Class B aeroplanes.

For any particular take-off, it must be shown that the distance required for take-off in the prevailing conditions does not exceed the distance available at the take-off aerodrome. However, there are various terms used to describe the available distances at an aerodrome.

Available Distances

Some aerodromes have extra distances associated with the main runway which are used in a variety of ways. Before we look at these distances, we need to define two areas associated with the runway.

Clearways

Clearways are an area beyond the runway, not less than 152 m (500 ft) wide, centrally located about the extended centre line of the runway, and under the control of the airport authorities. The clearway is expressed in terms of a clearway plane, extending from the end of the runway with an upward slope not exceeding 1.25%, above which no object or terrain protrudes. However, threshold lights may protrude above the plane if their height above the end of the runway is 0.66 m (26 inches) or less and if they are located to each side of the runway. Clearways are not physical structures; they are simply an area of defined width and length which are free of obstacles.

Figure 2.1 Clearways extend from the end of the runway with an upward slope not exceeding 1.25%, above which no object or terrain protrudes

Stopways

Stopways are an area beyond the take-off runway, no less wide than the runway and centred upon the extended centre line of the runway, able to support the aeroplane during a Rejected Take-off (RTO), without causing structural damage to the aeroplane, and designated by the airport authorities for use in decelerating the aeroplane during a rejected take-off. Stopways are physical structures and are usually paved. However, stopways are not as strong as the main length of runway and therefore are only used to help bring an aeroplane to a stop in the event of a rejected take-off. Stopways are identified by large yellow chevrons on either end of the main runway.

Figure 2.2 Stopways are able to support the aeroplane during a rejected take-off and are marked by large yellow chevrons

Understanding stopways and clearways is essential when examining the available distances published at aerodromes. There are four principal aerodrome distances, although only three will apply to the take-off and these are discussed next.

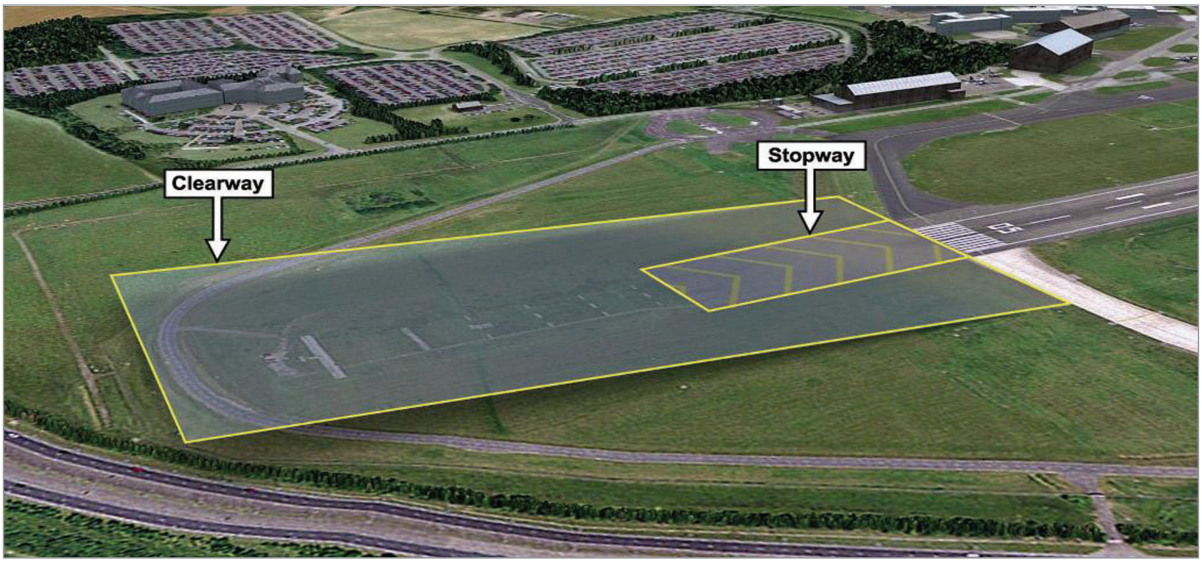


Figure 2.3 Illustrates the stopways & clearways that can be found at aerodromes

The Take-off Run Available (TORA)

The take-off run available is the distance from the point on the surface of the aerodrome at which the aeroplane can commence its take-off run to the nearest point in the direction of take-off at which the surface of the aerodrome is incapable of bearing the weight of the aeroplane under normal operating conditions. At most aerodromes the take-off run available is the length of the runway from threshold to threshold.

The Take-off Distance Available (TODA)

The take-off distance available is the take-off run available plus any clearway (TORA + clearway). If there is no clearway at the aerodrome then the take-off distance available will be the same length as the take-off run available.

The take-off distance available must be compared to the aeroplane's actual take-off distance. The requirements for take-off state that the aeroplane must be able to complete the take-off within the take-off distance available. Although clearways can be of any length, there is a limit to the amount of clearway that can be used when calculating the TODA. The maximum length of clearway in this case cannot be more than half the length of the TORA.

The Accelerate-stop Distance Available or Emergency Distance Available (ASDA/EMDA)

The accelerate-stop distance available is the length of take-off run available plus any stopway (TORA + stopway). If there is no stopway at the aerodrome then the accelerate-stop distance available will be the same length as the take-off run available.

The accelerate-stop distance available must be compared to the aeroplane's actual accelerate-stop distance. The requirements for take-off state that the aeroplane's accelerate-stop distance must not exceed the accelerate-stop distance available.

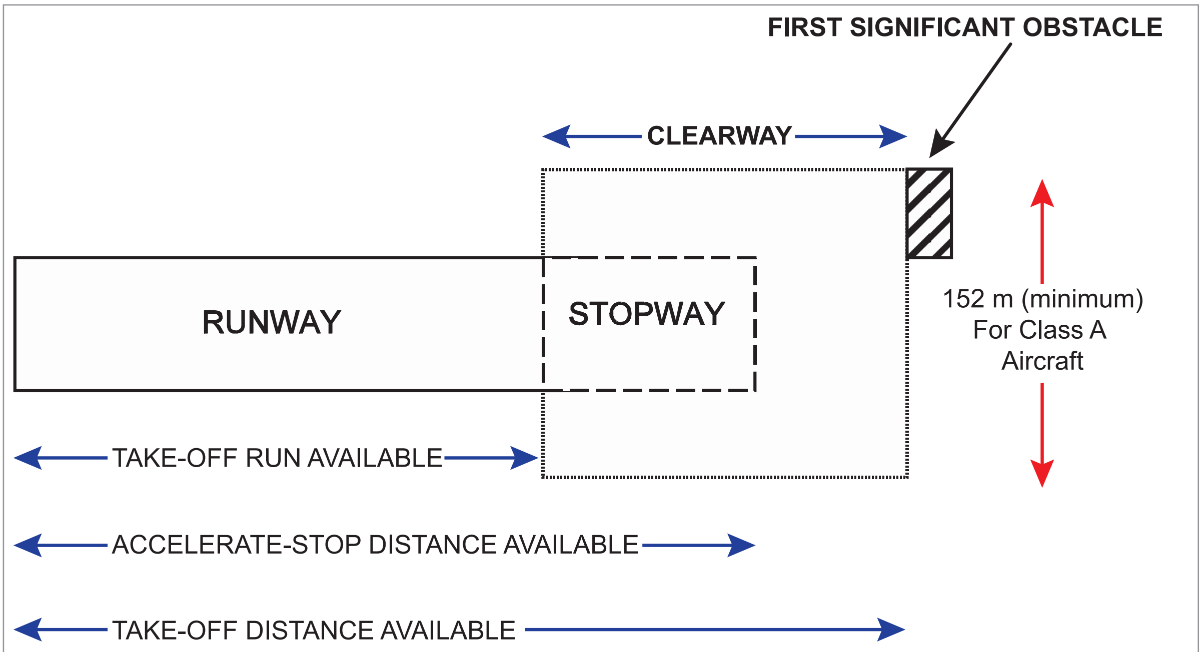


Figure 2.4 A summary of the available distances at an aerodrome

Required Distances

The distance required for take-off may be considered as two segments:

- The take-off roll or ground run.
- The airborne distance to a "screen" of defined height.

The total distance from the brake release point to the screen height is called the Take-off Distance (TOD). The speed at which the pilot will attempt to raise the nose wheel off the ground is called "V_R". This is the speed for rotation. At this speed the pilot will pull back on the control column and eventually the nose wheel will lift off the runway. This action will increase the lift and eventually the main wheels themselves will lift off the runway. The speed at which this occurs is called "V_{LOF}" which means the speed for lift-off.

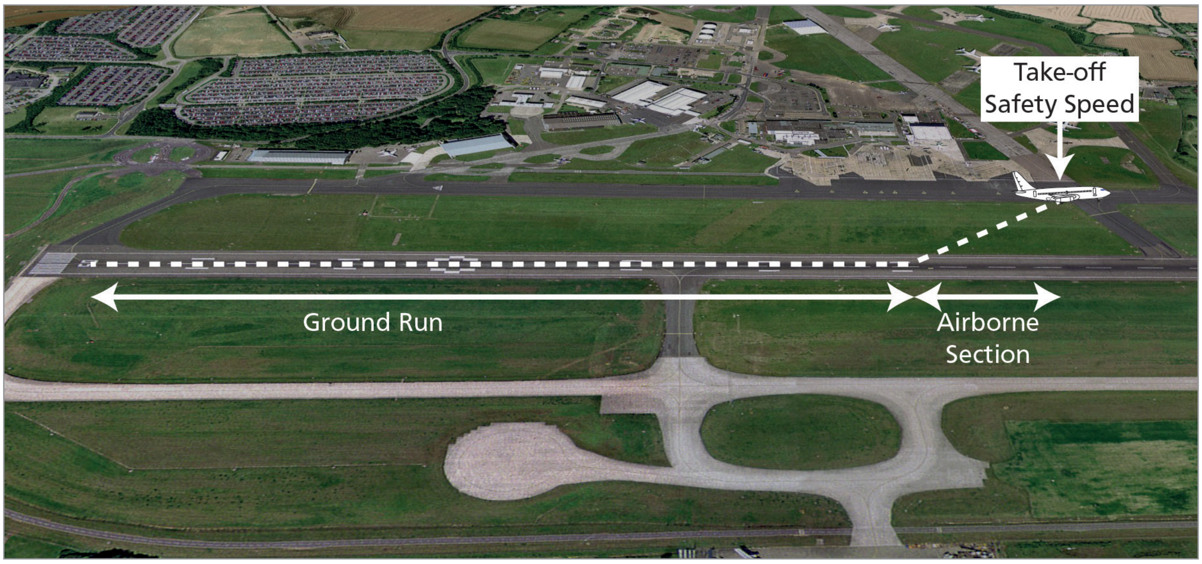


Figure 2.5 The take-off distance (TOD) is the total distance from brake release until the screen height

Calculating the take-off distance is an important consideration but it is essential to a pilot to understand that there is a chance, albeit a remote chance, that the actual calculated take-off distance will not be achieved. To this end, the aviation authorities have created a set of safety regulations to ensure that poor performance is accounted for in the calculations. These safety regulations require factors to be applied to the estimated distances to give a satisfactory safety margin. The application of safety factors changes the terminology used. The calculated take-off distance is called the Gross Take-off Distance, but applying the safety factors changes this to the Net Take-off Distance. The regulations and their associated safety factors will be discussed later in the relevant chapters on the different classes of aeroplanes.

Calculating the Take-off Distance

The two formulae shown below are used to help understand the key components in calculating the take-off distance. The upper formula is used to calculate the distance required (s) to reach a specified speed (V) with a given acceleration (a). Beneath the first formula is the formula to calculate that acceleration.

$$s = \frac{V^2}{a}$$

$$a = \frac{T - D_A - \mu\,(W - L)}{m}$$

Key:					
	s = Displacement	a = Acceleration	W = Weight	D_A = Aerodynamic Drag	m = Mass
	V = Speed	T = Thrust	L = Lift	μ = Coeffecient of Friction	

Figure 2.6 Forces in the take-off

For an aircraft taking off, the acceleration is thrust minus drag. However, both of these forces will change as the speed changes, and so the acceleration will not be constant during the take-off. Also, during the airborne part of the take-off, the laws of motion will be somewhat different, and the upper formula will change somewhat, but the distance required will still depend on the speed to be achieved and the acceleration.

Forces During Take-off

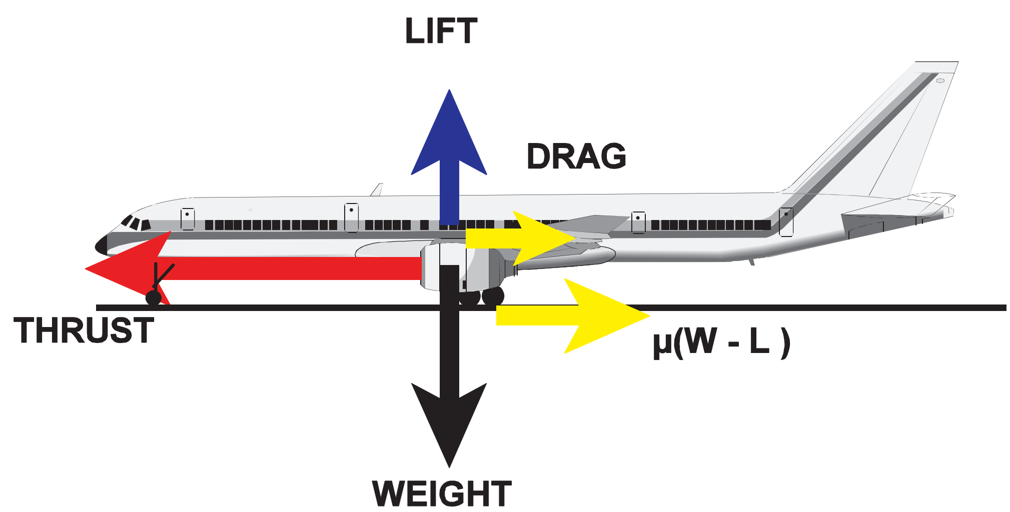


Figure 2.7 Forces in the take-off

Looking back at the formula for acceleration during take-off it can be seen that thrust and drag play a crucial part in the take-off performance. Therefore a little extra detail will be covered on these two important forces.

Thrust

The engine thrust will vary during take-off, and the variation of thrust with speed will be different for jet and propeller engines.

- **Jet engine.** For a jet engine the net thrust is the difference between the gross thrust and the intake momentum drag. Increasing speed increases the intake momentum drag, which reduces the thrust. However, at higher speeds the increased intake pressure due to ram effect helps to reduce this loss of thrust, and eventually at very high speeds it will cause the net thrust to increase again. During take-off the aeroplane speed is still low and as such the ram effect is insufficient to counteract the loss of thrust due to intake momentum drag, therefore during the take-off there will be a decrease of thrust. In later chapters and in some performance graphs you will notice that the assumption is made that jet thrust is constant with speed. This is done so as to simplify some of the teaching points.

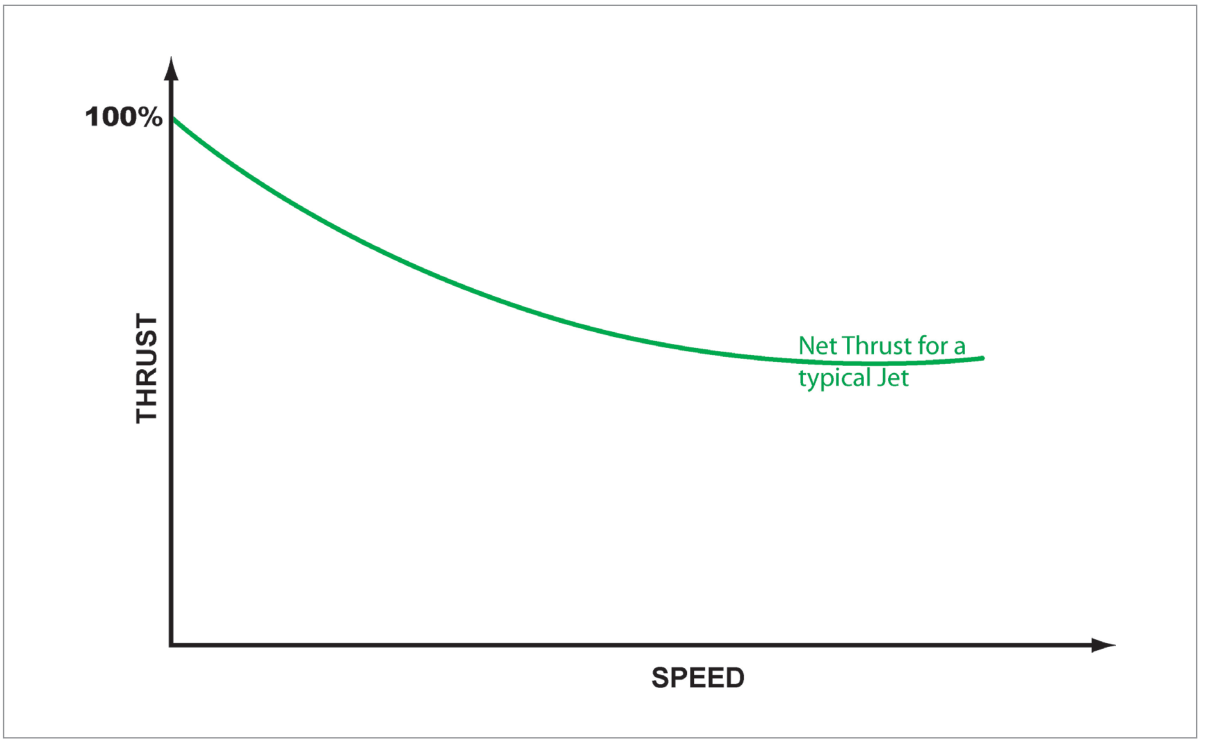


Figure 2.8 Net thrust with speed for a typical modern jet engine

- **Flat rated engines.** The thrust produced by an engine at a given rpm will depend on the air density, and hence on air pressure and temperature. At a given pressure altitude, decreasing temperature will give increasing thrust. However, many jet engines are "flat rated", that is, they are restricted to a maximum thrust even though the engine is capable of producing higher thrust. The reason being that at lower temperatures too much thrust may be generated and the pressures within the compressors may be exceeded. Consequently at temperatures below the flat rating cut off, (typically about ISA + 15°C) engine thrust is not affected by temperature.

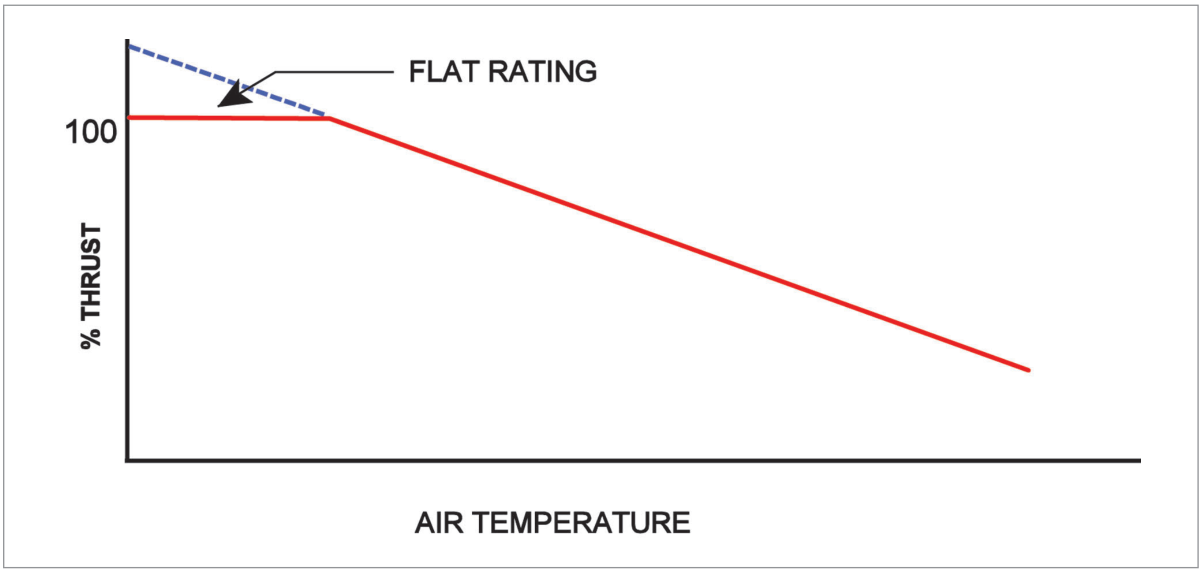


Figure 2.9 Typical thrust with air temperature from a flat rated engine

Propeller. For a propeller driven aircraft, thrust is produced by a propeller converting the shaft torque into propulsive force. For a fixed pitch propeller, angle of attack decreases as forward speed increases. Thrust therefore decreases with increasing speed. For a variable pitch propeller, the propeller will initially be held in the fine pitch position during take-off and the propeller angle of attack will decrease with increasing speed. Above the selected rpm the propeller governor will come into operation, increasing the propeller pitch, and reducing the rate at which the thrust decreases. In summary therefore, the thrust of a propeller aeroplane decreases with forward speed.

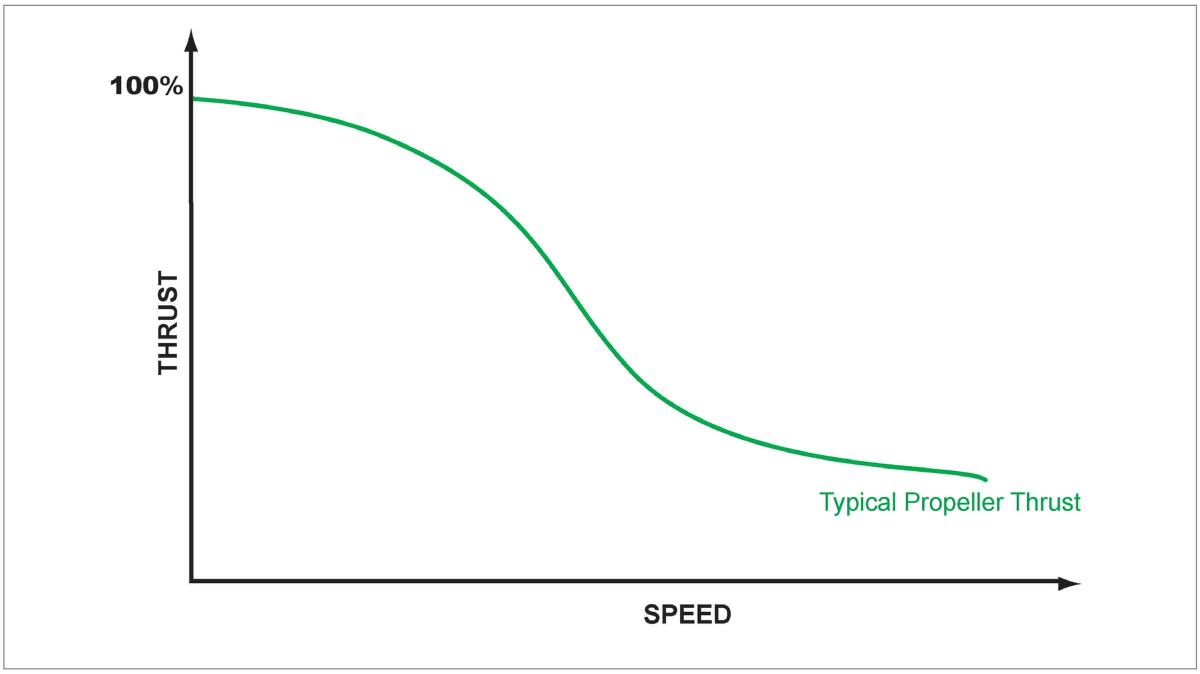


Figure 2.10 Typical thrust with speed from a propeller powered engine

Supercharged engines. If the engine is un-supercharged, the power produced will decrease with decreasing density (higher temperature or lower pressure). For a supercharged engine, power may be maintained with increasing altitude, up to the Full Throttle Height.

Drag

The total drag (D) of an aeroplane during take-off is a product of both aerodynamic drag (D_A) and wheel drag/wheel friction (μ) as shown in the formula below.

$$D = D_A + \mu(W - L)$$

- **Aerodynamic Drag.** There are principally two forms of aerodynamic drag, parasite drag and induced drag. Parasite drag is increased by the square of the speed, therefore this form of drag will increase during the take-off. Induced drag is a function of the angle of attack. This angle of attack is constant until the aeroplane rotates at which point the angle of attack increases dramatically. Therefore induced drag will increase during the take-off.

- **Wheel Drag.** The wheel drag depends on the load on the wheel (W - L) and the runway surface resistance (μ). At the start of the take-off the load on the wheels is the entire weight of the aeroplane, therefore wheel friction and wheel drag is high. However, as forward speed increases, lift starts to counteract the weight force and this reduces the load on the wheels. Therefore the wheel friction and the wheel drag will reduce, eventually being zero at lift-off.

The increase of aerodynamic drag is much higher than the decrease of wheel drag, therefore total drag during the take-off increases.

Summary of Forces

In summary then, for all aeroplanes during the take-off, thrust decreases and drag increases. The acceleration force is determined by subtracting the total drag from the total thrust. This is visually represented in the next graph by the area between the total drag line and the thrust line. When thrust is more than drag the term "excess thrust" is used. Excess thrust is what is needed to accelerate the aeroplane. You can see from the graph that the excess thrust and therefore the acceleration of the aeroplane decreases during the take-off. The term "excess thrust" will be used again when climb theory is introduced.

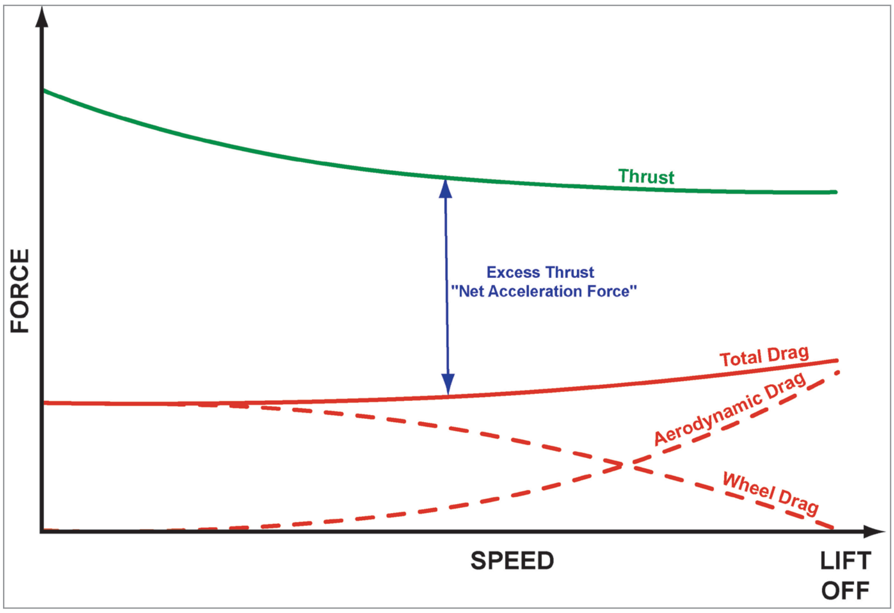


Figure 2.11 Variation of forces with speed during the take-off

Take-off Speed

The speed (V) in the take-off distance formula is True Ground Speed. When calculating the take-off run required, account must therefore be taken of the effect of density on TAS for a given IAS, and of the effect of wind on TGS for a given TAS.

The speed to be reached at the screen (the Take-off Safety Speed) is determined by the Regulations, and is required to be a safe margin above the stall speed and the minimum control speed, a speed that gives adequate climb performance, and that takes account of the acceleration that will occur after lift-off. It is very important to ensure this speed is achieved by the screen height.

Effect of Variable Factors on Take-off Distance

Mass

The mass of the aeroplane affects:

- The acceleration for a given accelerating force. This is the effect of inertia. An aeroplane with higher mass will have more inertia. Therefore as mass increases, acceleration will decrease which will increase the take-off distance.

- The wheel drag. Increased mass increases the load placed on the wheels and therefore increases the wheel friction. Because of the increased wheel friction, wheel drag will increase. Therefore, acceleration is reduced and the take-off distance will increase.

- The take-off safety speed. An aeroplane with a higher mass will have a greater force of weight. This must be overcome by greater lift. To gain this extra lift the aeroplane must be accelerated to a higher speed, which will of course increase the take-off distance.

- The angle of initial climb to the screen height. This effect will be better understood in the next chapter, but nonetheless a higher mass reduces the angle of the initial climb. This means that the aeroplane will use a greater horizontal distance to get to the screen height.

In summary then, increasing mass has four detrimental effects on the take-off distance.

Air Density

Density is determined by pressure, temperature and humidity. Density affects:

- The power or thrust of the engine. Reduced density will reduce combustion inside the engine and therefore reduce the thrust and/or power that the engine can generate. Therefore, acceleration will be less and the take-off distance will increase.

- The TAS for a given IAS. Reduced density will increase the true airspeed for a given indicated airspeed. For example, if the take-off safety speed was an indicated airspeed of 120 knots, then in low density this may represent a true airspeed of 130 knots. Getting to a true speed of 130 knots will require more distance. Therefore, low density will increase the take-off distance.

- The angle of the initial climb. Since there is less thrust and/or power in low density, the angle of climb will reduce. Therefore, getting to the screen height will require a longer horizontal distance.

Wind

Winds affect the true ground speed of the aeroplane for any given true airspeed.

Headwinds will reduce the ground speed at the required take-off airspeed and reduce the take-off distance. For example, with a headwind of 20 knots and a true airspeed for the take-off safety speed being 120 knots, the ground speed is only 100 knots. Getting to a true ground speed of only 100 knots will require less distance. Another benefit is that headwinds also increase the angle of the initial climb which will further reduce the required distance. Therefore, headwinds reduce the take-off distance and it is this reason why pilots always aim to take off into wind.

A tailwind does the opposite to a headwind. Tailwinds will increase the ground speed and increase the take-off distance.

The Regulations for all classes of aircraft require that in calculating the take-off distance, no more than 50% of the headwind component is assumed and no less than 150% of a tailwind component is assumed. This is to allow for variations in the reported winds during take-off.

For example, it would not be wise to plan a distance limited take-off with 10 knots headwind if at the actual time of take-off the wind was less than 10 knots. In this case, the aeroplane would not be able to complete the take-off within the available distance. Most aeroplane performance manuals and operating handbooks already have the wind rules factored into the take-off graphs or tables. In this case, simply use the forecast wind and the graph or table will automatically correct the take-off distance to account for the regulation on wind.

Note: For any headwind the distance required to take off will be less than the calculated distance, as only half the headwind is allowed for. Equally for any tailwind the distance required will be less, as a stronger tailwind is allowed for. If the wind is a 90° crosswind, the distance required to take off will be the same as the distance calculated for zero wind component.

Runway Slope

If the runway is sloping, a component of the weight will act along the longitudinal axis of the aeroplane. This will either augment thrust or augment drag which will increase or decrease the accelerating force. The amount of weight augmenting either thrust or drag is called either "weight apparent thrust" or "weight apparent drag." It can be calculated by multiplying the force of weight by the sine of the angle of the runway slope.

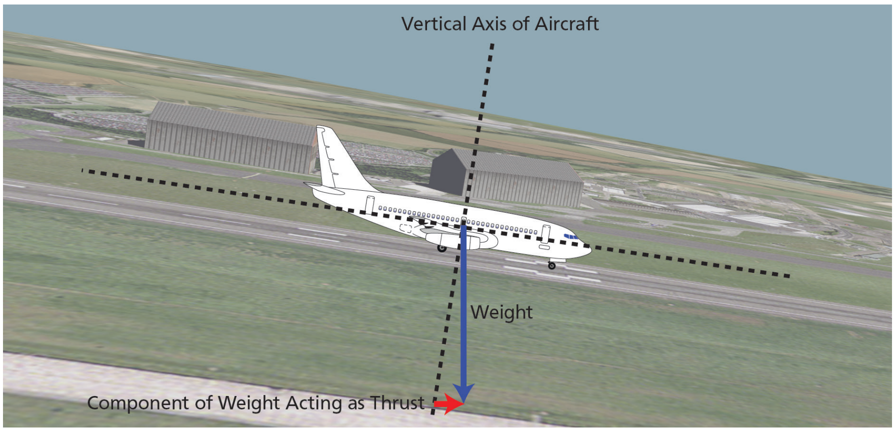


Figure 2.12 On a downslope a proportion of weight acts in the direction of thrust

A downhill slope will increase the accelerating force, and reduce the take-off distance, whereas an uphill slope will reduce the accelerating force and increase the take-off distance.

Runway Surface

Even on a smooth runway there will be rolling resistance due to the bearing friction and tyre distortion. If the runway is contaminated by snow, slush or standing water, there will be additional drag due to fluid resistance and impingement. This drag will increase with speed, until a critical speed is reached, the hydroplaning speed, above which the drag will start to decrease. Any contamination will increase the drag and hence increase the take-off distance.

If the take-off is rejected and braking is required, the coefficient of braking friction is severely reduced on a runway which is wet, icy or contaminated by snow or slush. This means that the brake pressure must be severely reduced to prevent skidding. Thus the stopping distance is greatly increased.

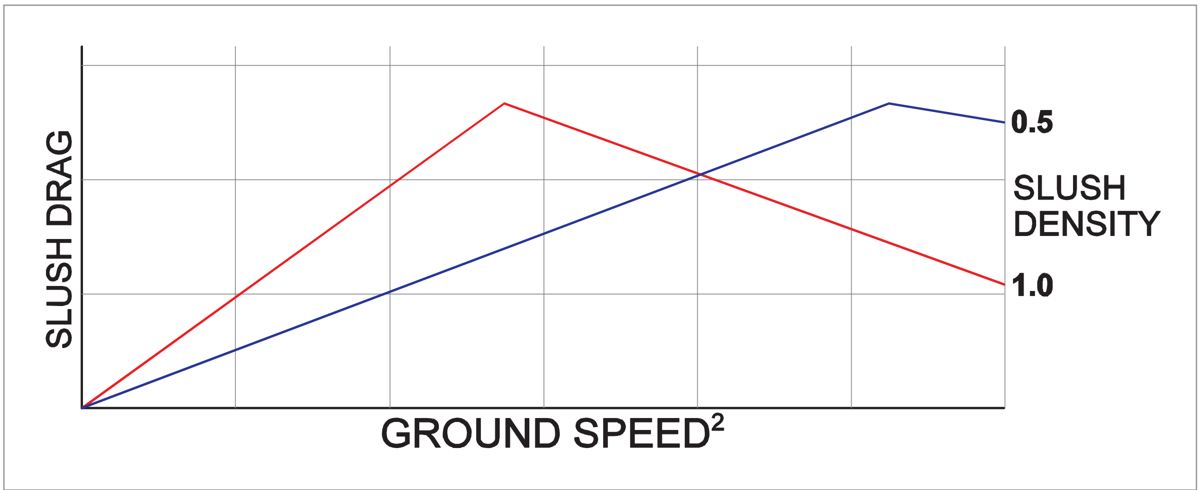


Figure 2.13 The effect of slush density on the slush drag

Airframe Contamination

The performance data given assumes that the aircraft is not contaminated by frost, ice or snow during take-off. In fact it is a requirement that at the commencement of take-off the aeroplane must be free of ice or snow. Snow and ice on the airframe will increase the drag, reduce the lift and increase the weight of the aeroplane. Therefore, if any of these contaminants are present, the performance of the aircraft will be reduced, and the take-off distance will be increased.

Flap Setting

Flaps affect:

- The C_{LMAX} of the wing
- The drag

Increasing flap angle increases C_{LMAX}, which reduces stalling speed and take-off speed. This reduces the take-off distance.

Increasing flap angle increases drag, reducing acceleration, and increasing the take-off distance. The net effect is that take-off distance will decrease with increase of flap angle but above a certain flap angle the take-off distance will increase again. An optimum setting can be determined for each type of aircraft, and any deviation from this setting will give an increase in the take-off distance.

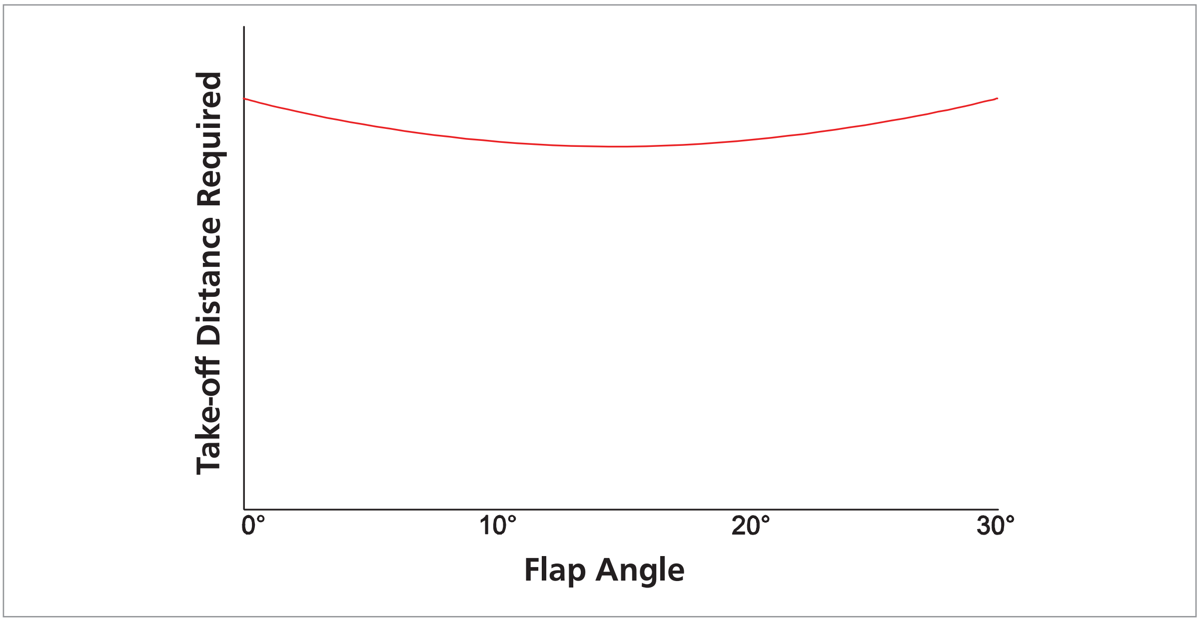


Figure 2.14 A graph showing the effect of the flap angle on the take-off distance required

The flap setting will also affect the climb gradient, and this will affect the Maximum Mass for Altitude and Temperature, which is determined by a climb gradient requirement, and the clearance of obstacles in the take-off flight path.Increasing the flap angle increases the drag, and so reduces the climb gradient for a given aircraft mass. The maximum permissible mass for the required gradient will therefore be reduced. In hot and high conditions this could make the Mass-Altitude-Temperature requirement more limiting than the field length requirement if the flap setting for the shortest take-off distance is used. A greater take-off mass may be obtained in these conditions by using a lower flap angle.

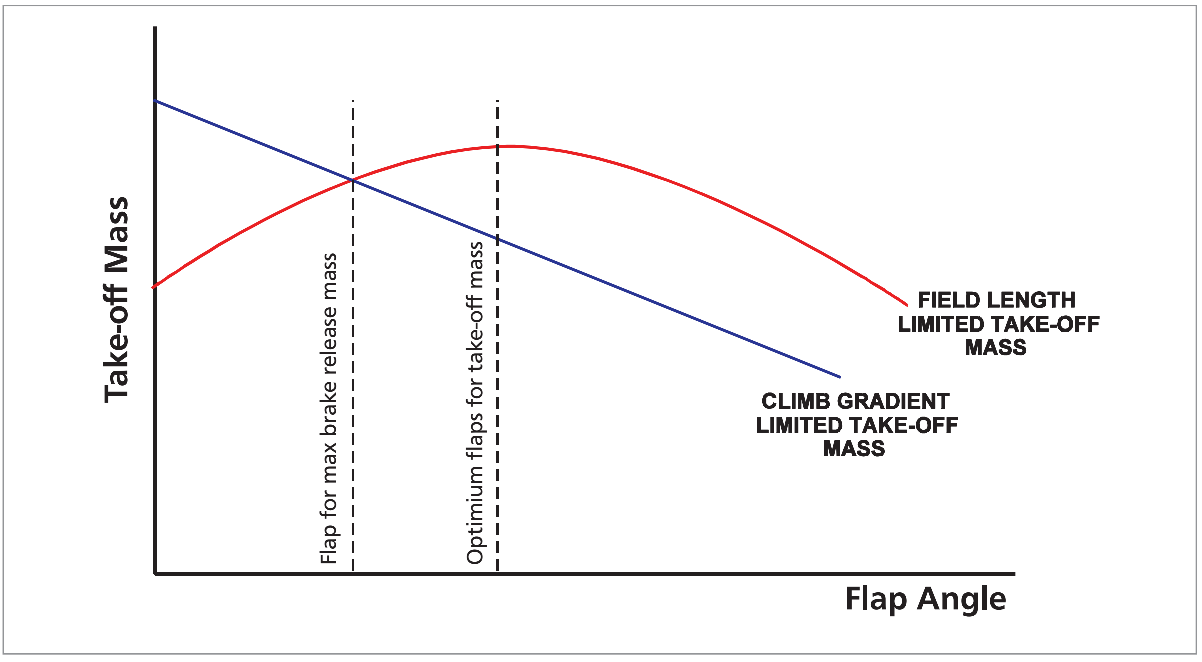


Figure 2.15 A graph showing the effect of the flap on the climb & field limit mass

If there are obstacles to be considered in the take-off flight path, the flap setting that gives the shortest take-off distance may not give the maximum possible take-off mass if the Take-off Distance Available is greater than the Take-off Distance Required. If close-in obstacles are not cleared, using a lower flap angle will use a greater proportion of the Take-off Distance Available but may give a sufficiently improved gradient to clear the obstacles

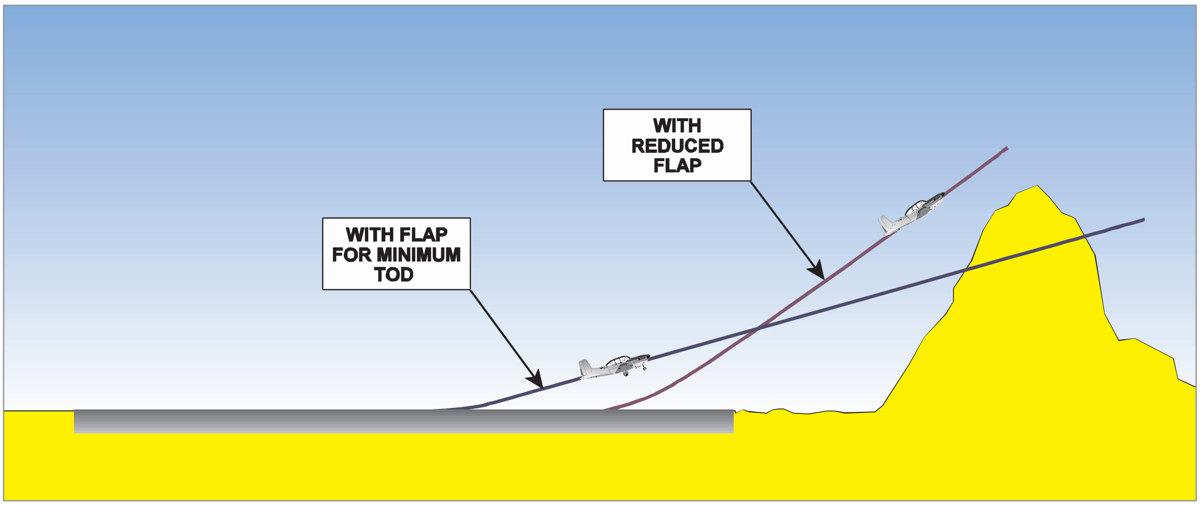


Figure 2.16 An illustration showing the effect of flap angle on obstacle clearance

Questions

1. **How is wind considered in the take-off performance data of the Aeroplane Operations Manuals?**

    a. Unfactored headwind and tailwind components are used
    b. Not more than 80% headwind and not less than 125% tailwind
    c. Since take-offs with tailwind are not permitted, only headwinds are considered
    d. Not more than 50% of a headwind and not less than 150% of the tailwind

2. **What will be the influence on the aeroplane performance if aerodrome pressure altitude is increased?**

    a. It will increase the take-off distance
    b. It will decrease the take-off distance
    c. It will increase the take-off distance available
    d. It will increase the accelerate-stop distance available

3. **The required Take-off Distance (TOD) and the field length limited Take-off Mass (TOM) are different for the zero flap case and take-off position flap case. What is the result of flap setting in take-off position compared to zero flap position?**

    a. Increased TOD required and decreased field length limited TOM
    b. Increased TOD required and increased field length limited TOM
    c. Decreased TOD required and decreased field length limited TOM
    d. Decreased TOD required and increased field length limited TOM

4. **During take-off, the thrust of a fixed pitch propeller:**

    a. increases slightly while the aeroplane speed builds up
    b. varies with mass changes only
    c. has no change during take-off and climb
    d. decreases while the aeroplane speed builds up

5. **What will be the effect on an aeroplane's performance if aerodrome pressure altitude is decreased?**

    a. It will increase the take-off distance required
    b. It will increase the take-off ground run
    c. It will decrease the take-off distance required
    d. It will increase the accelerate-stop distance

6. The take-off distance of an aircraft is 800 m in a standard atmosphere with no wind and at 0 ft pressure altitude. Using the following corrections:

± 20 m / 1000 ft field elevation
- 5 m / kt headwind
+ 10 m / kt tailwind
± 15 m / % runway slope
± 5 m / °C deviation from standard temperature

The take-off distance from an airport at 2000 ft elevation, temperature 21°C, QNH 1013.25 hPa, 2% upslope, 5 kt tailwind is:

a. 810 m
b. 970 m
c. 890 m
d. 870 m

7. An uphill slope:

a. increases the take-off distance more than the accelerate-stop distance
b. decreases the accelerate-stop distance only
c. decreases the take-off distance only
d. increases the allowed take-off mass

8. Other factors remaining constant and not limiting, how does increasing pressure altitude affect allowable take-off mass?

a. Allowable take-off mass remains uninfluenced up to 5000 ft pressure altitude
b. Allowable take-off mass decreases
c. Allowable take-off mass increases
d. There is no effect on allowable take-off mass

9. In reality, the net thrust of a jet engine at constant rpm:

a. does not change with changing altitude
b. is independent of the airspeed
c. decreases with the airspeed
d. increases with the airspeed

10. Which of the following are to be taken into account for the runway in use for take-off?

a. Airport elevation, runway slope, standard temperature, pressure altitude and wind components
b. Airport elevation, runway slope, outside air temperature, standard pressure and wind components
c. Airport elevation, runway slope, outside air temperature, pressure altitude and wind components
d. Airport elevation, runway slope, standard temperature, standard pressure and wind components

11. **For a take-off in slush, the slush drag:**

    a. will increase up to aquaplaning speed and then remain constant
    b. will increase up to aquaplaning speed and then decrease
    c. will increase up to aquaplaning speed and then increase at a greater rate
    d. will decrease progressively up to the lift-off speed

12. **With contamination on the aircraft wings and fuselage only:**

    a. the TODR will be unaffected
    b. the ASDR will decrease
    c. stalling speed is not affected
    d. the lift-off speed will be increased

13. **The gross take-off distance (TOD) is defined as being from brake release until:**

    a. the aeroplane's main wheel lifts off the runway
    b. the aeroplane has reached 35 ft
    c. the aeroplane has reached the screen height
    d. the aeroplane is safely off the ground

14. **The result of a higher flap setting up to the optimum at take-off is:**

    a. a higher V_R
    b. a longer take-off run
    c. a shorter ground roll
    d. an increased acceleration

15. **V_R is the speed at which:**

    a. the aeroplane nose wheel is off the ground
    b. the pilot initiates the action required to raise the nose wheel off the ground
    c. the main wheels lift off the ground
    d. the aeroplane rotates about the longitudinal axis

16. **During take-off:**

    a. the acceleration force decreases
    b. wheel drag increases
    c. thrust increases
    d. total drag decreases

17. **High altitudes, hot air and humid conditions will:**

    a. increase the take-off payload
    b. decrease the take-off mass
    c. increase the take-off performance
    d. decrease the take-off distance

18. **The main purpose for taking off into wind is to:**

    a. decrease the true ground speed
    b. decrease the aeroplane performance
    c. increase the true ground speed
    d. increase the take-off distance

19. What is the effect of a contaminated runway on the take-off?

a. Increases the take-off distance and greatly increases the accelerate-stop distance
b. Increases the take-off distance and decreases the accelerate-stop distance
c. Decreases the take-off distance and increases the accelerate-stop distance
d. Decreases the take-off distance and greatly decreases the accelerate-stop distance

20. Which of the following statements is correct?

a. If a clearway or a stopway is used, the lift-off point must be attainable at least by the end of the permanent runway surface
b. A stopway means an area beyond the take-off run available, able to support the aeroplane during a rejected take-off
c. An under-run is an area beyond the runway end which can be used for a rejected take-off
d. A clearway is an area beyond the runway which can be used for a rejected take-off

21. A 'balanced field length' is said to exist where:

a. the accelerate-stop distance available is equal to the take-off distance available
b. the clearway does not equal the stopway
c. the accelerate-stop distance is equal to the all engine take-off distance
d. the one engine out take-off distance is equal to the all engine take-off distance

22. The stopway is an area which allows an increase only in:

a. the accelerate-stop distance available
b. the take-off run available
c. the take-off distance available
d. the landing distance available

23. An airport has a 3000 metres long runway, and a 2000 metre clearway at each end of that runway. For the calculation of the maximum allowed take-off mass, the take-off distance available cannot be greater than:

a. 4000 metres
b. 3000 metres
c. 5000 metres
d. 4500 metres

24. Can the length of a stopway be added to the runway length to determine the take-off distance available?

a. Yes, but the stopway must be able to carry the weight of the aeroplane
b. Yes, but the stopway must have the same width as the runway
c. No
d. No, unless its centre line is on the extended centre line of the runway

25. **In relation to runway strength, the ACN:**

    a. must not exceed 90% of the PCN and then only if special procedures are followed
    b. may exceed the PCN by up to 10% or 50% if special procedures are followed
    c. may exceed the PCN by a factor of 2
    d. must equal the PCN

26. **The TODA is:**

    a. declared runway length only
    b. declared runway length plus clearway up to a maximum of 150% of TORA
    c. declared runway length plus stopway
    d. declared runway length plus clearway and stopway

27. **Take-off distance available is:**

    a. take-off run available plus clearway up to 50% of TORA
    b. take-off run minus the clearway, even if clearway exists
    c. always 1.5 times the TORA
    d. 50% of the TORA

28. **Can a clearway be used in the accelerate-stop distance calculations?**

    a. Yes
    b. No
    c. Only if the clearway is shorter than the stopway
    d. Only if there is no clearway

29. **The take-off distance available is:**

    a. the total runway length, without clearway even if one exists
    b. the length of the take-off run available plus any length of clearway available, up to a maximum of 50% of TORA
    c. the runway length minus stopway
    d. the runway length plus half of the clearway

30. **The stopway is:**

    a. at least as wide as the runway
    b. no less than 152 m wide
    c. no less than 500 ft wide
    d. as strong as the main runway

31. **Which class of aeroplane describes all multi-engine turbojet aeroplanes?**

    a. Unclassified
    b. Class C
    c. Class B
    d. Class A

32. A propeller aeroplane with nine or less passenger seats and with a maximum take-off mass of 5700 kg or less is described as:

a. unclassified
b. Class C
c. Class B
d. Class A

Answers

1	2	3	4	5	6	7	8	9	10	11	12
d	a	d	d	c	b	a	b	c	c	b	d

13	14	15	16	17	18	19	20	21	22	23	24
c	c	b	a	b	a	a	b	a	a	d	c

25	26	27	28	29	30	31	32
b	b	a	b	b	a	d	c

Chapter 3
General Principles - Climb

Climb

The climb section of aircraft performance deals with the analysis of that stage of flight from the end of the take-off phase to the beginning of the en route phase. There are two ways in which climbing needs to be examined; the angle of climb and the rate of climb.

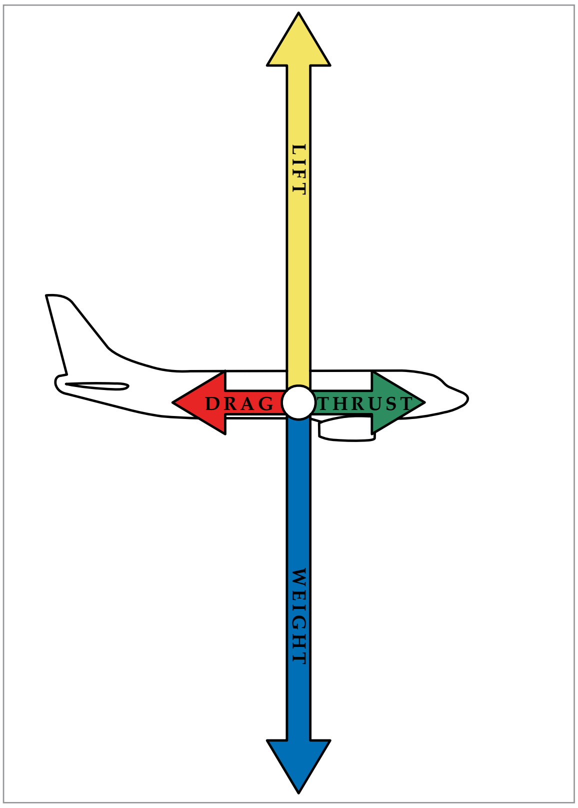


Figure 3.1

Angle of Climb

Angle of climb will be examined first. *Figure 3.1* shows an aircraft in unaccelerated level flight. Notice that the forward acting force, Thrust, balances the rearward acting force, Drag. Therefore, the aircraft will maintain a steady speed. How much Thrust is required for unaccelerated level flight? The same as the aerodynamic Drag. A frequently used alternative term for Drag is “Thrust Required”.

However, if the aircraft is placed in a climb attitude, as shown in *Figure 3.2,* a component of the aeroplane's Weight acts backwards along the flight path and is added to Drag.

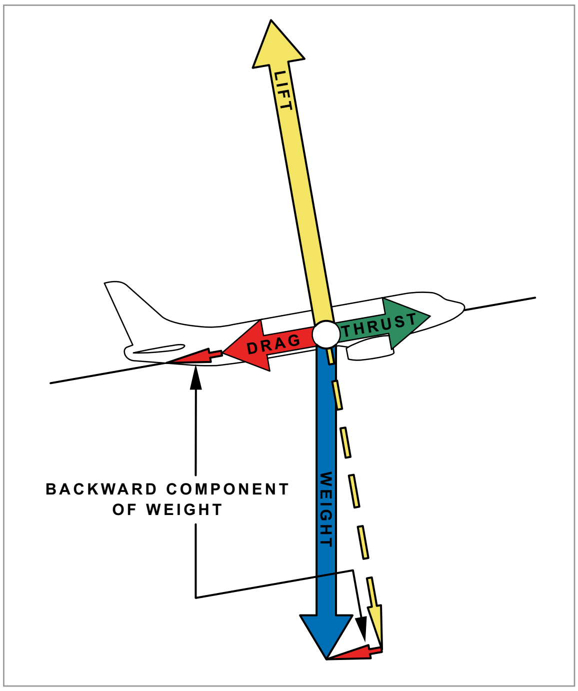


Figure 3.2

The larger the angle of climb, the larger the backward component of Weight, as shown in *Figure 3.3*. In both illustrations it is apparent that the sum of the two rearward acting forces is greater than the forward acting force. If this situation were left unchanged the aircraft would decelerate.

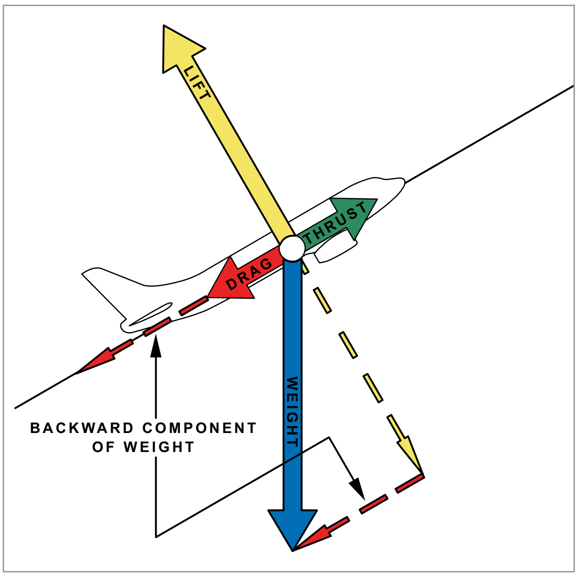


Figure 3.3

Excess Thrust

To maintain a steady speed along the flight path in a climb, additional Thrust is required to balance the backward component of Weight. This additional Thrust required is called Excess Thrust.

Excess Thrust is the Thrust available from the engine(s) after aerodynamic Drag is balanced.

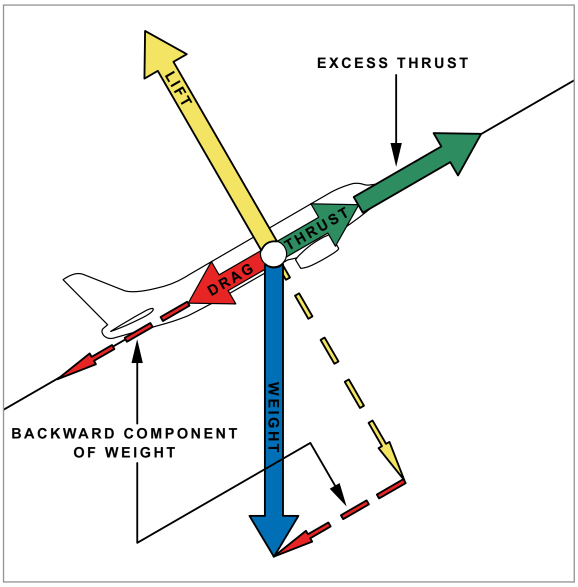


Figure 3.4

From *Figure 3.4* it can be seen that the forward acting force in green is now the same as the two rearward acting forces in red and the aeroplane will maintain a steady speed along its new flight path. To maintain a steady climb with no loss of speed, Thrust must balance not only the aerodynamic Drag, but also the backward component of Weight.

In *Figure 3.5* the aircraft only has a small amount of Excess Thrust available. Notice that there is too much backward component of Weight from the climb angle that has been set, so that climb angle can not be maintained.

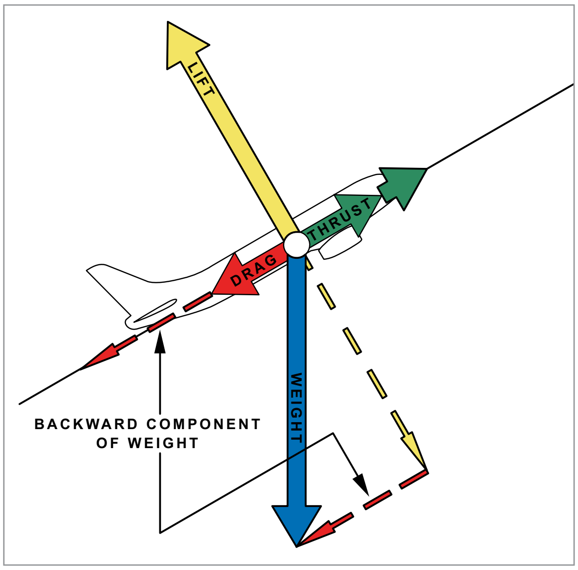


Figure 3.5

The angle of climb must be reduced to give a smaller backward component of Weight that matches the Excess Thrust available, as shown in *Figure 3.6.* The greater the Excess Thrust, the larger the backward component of Weight that can be balanced.

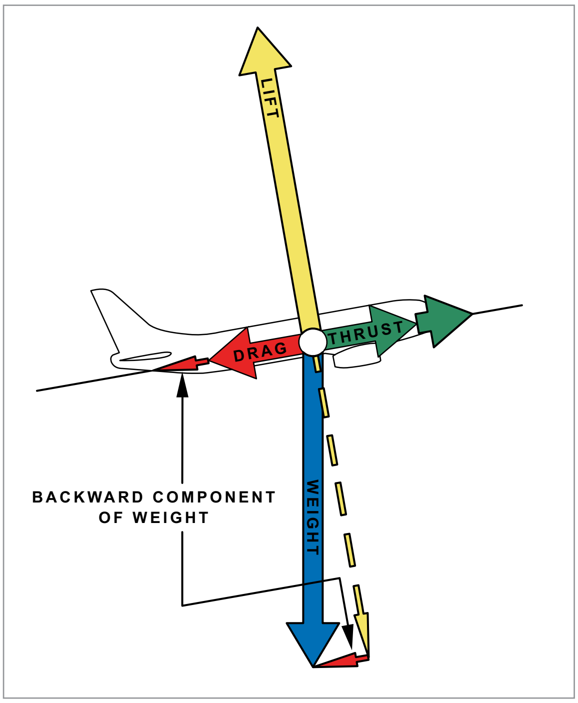


Figure 3.6

In other words, the more Excess Thrust available, the steeper the angle of climb or the greater the weight at the same climb angle.

The Effect of Weight on Climb Angle

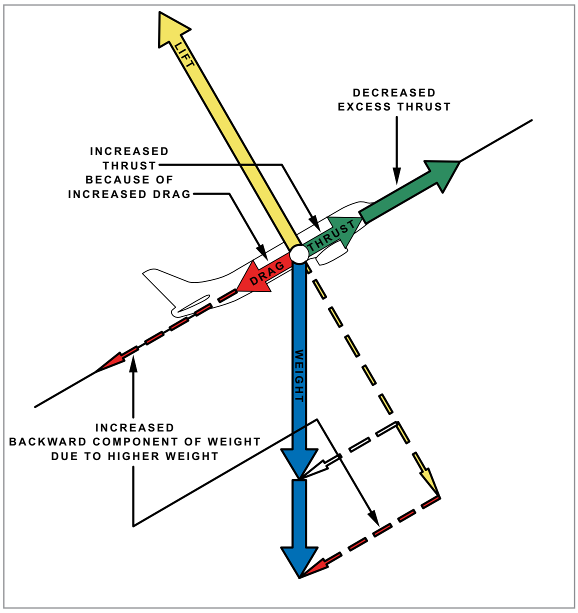


Figure 3.7

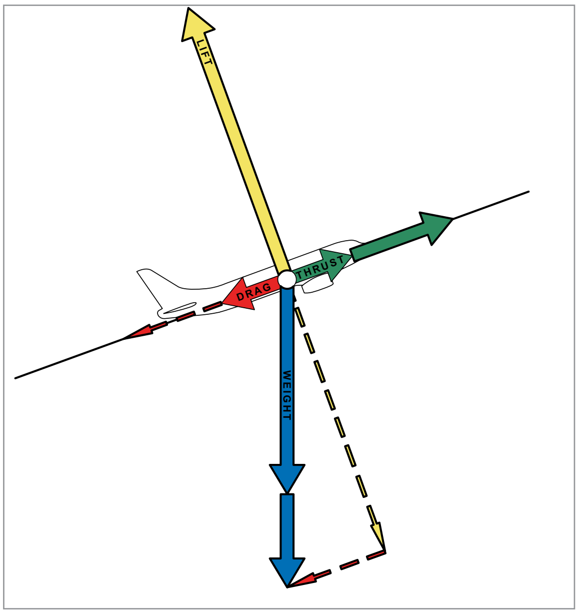


Figure 3.8

Weight has an influence on climb performance. *Figure 3.7* illustrates that if the aircraft tries to use the same climb angle as before, but at a higher weight, the backward component of weight will be greater and there is insufficient Excess Thrust to balance it. In addition, the higher weight will also generate increased aerodynamic Drag (Induced), which will further reduce Excess Thrust. Increased weight therefore decreases the maximum climb angle, as shown in *Figure 3.8.*

Thrust Available

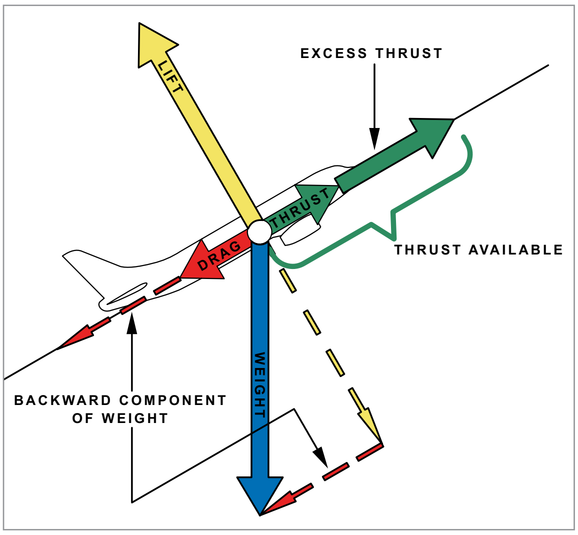


Figure 3.9

Figure 3.9 shows that Thrust Available is the total amount of Thrust available from the engine(s) and under a given set of conditions and in a steady climb the thrust available must be the same as the sum of the aerodynamic Drag (D) plus the backward component of Weight (W sin γ) .

Calculating Climb Gradient

If Thrust Available and aerodynamic Drag are known, the maximum backward component of Weight can be calculated by subtracting the aerodynamic Drag from Thrust Available. For most purposes, climb gradient is used rather than climb angle, but climb angle is still an important factor. Climb gradient is merely the percentage of the backward component of Weight to the aircraft Weight.

Shown here is the formula to calculate the percentage climb gradient. This formula is very significant.

$$\text{Gradient \%} \quad = \frac{T - D}{W} \times 100$$

Merely by looking at the above formula certain facts are self-evident:

- For a given weight, the greater the "Excess Thrust" (T – D) the steeper the climb gradient. The less the Excess Thrust the more shallow the climb gradient.

- For a given Excess Thrust (T – D), the greater the weight the more shallow the climb gradient. The less the weight the steeper the climb gradient.

If representative values of Thrust, Drag and Weight are known, the % climb gradient can be calculated. For example:

A twin engine turbojet aircraft has engines of 60 000 N each; its mass is 50 tonnes and it has a L/D ratio of 12:1, what is the % climb gradient? Use 'g' = 10 m/s/s.

From the above information the values to include in the formula have to be derived:

Thrust = 60 000 N × 2 engines = 120 000 N

Drag = Weight / 12

Weight = 50 tonnes × 1000 = 50 000 kg × 10 m/s/s = 500 000 N

Drag therefore = 500 000 N / 12 = 41 667 N

$$\frac{120\,000\text{ N} - 41\,667\text{ N}}{500\,000\text{ N}} \times 100 = \frac{78\,333\text{ N}}{500\,000\text{ N}} \times 100 = 15.7\%$$

Let us now consider the same values, but with one engine failed:

$$\frac{60\,000\text{ N} - 41\,667\text{ N}}{500\,000\text{ N}} \times 100 = 3.7\%$$

Thrust has decreased by 50%, but climb gradient has decreased by approximately 75% or to one quarter of the gradient possible with all engines operating. This fact is very significant. After losing 50% of the Thrust Available, why did the gradient decrease by 75%?

Note: *The aircraft data gave the L/D ratio from which the value of Drag was extracted, yet the value of Lift is obviously less than Weight when the aircraft is in a steady climb. Isn't this an inaccurate value? If the climb angle is less than approximately 20 degrees, and it always will be, the difference in the magnitude of Lift and Weight in a steady climb is insignificant and they can be considered (for purposes of these and other calculations) to be the same.*

Climbing after an Engine Failure

Consider *Figure 3.10*: Losing 50% of the Thrust Available reduces Excess Thrust by approximately 75% because the same value of aerodynamic Drag must still be balanced. *Figure 3.11* emphasizes that a two-engine aeroplane with one engine inoperative, has a severely reduced ability to climb.

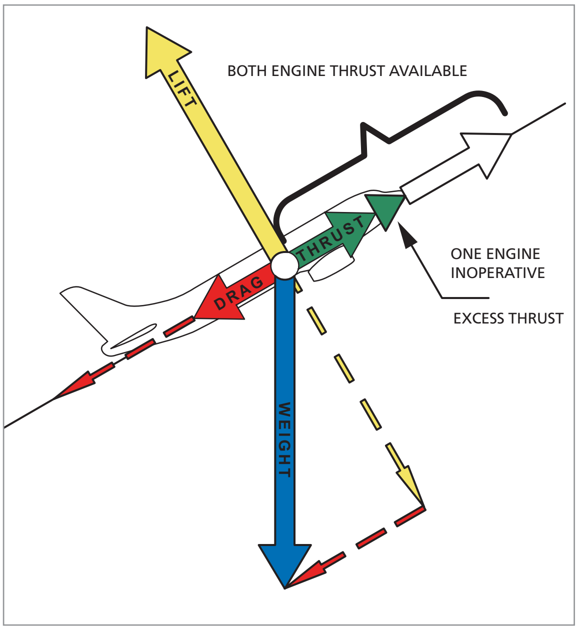


Figure 3.10

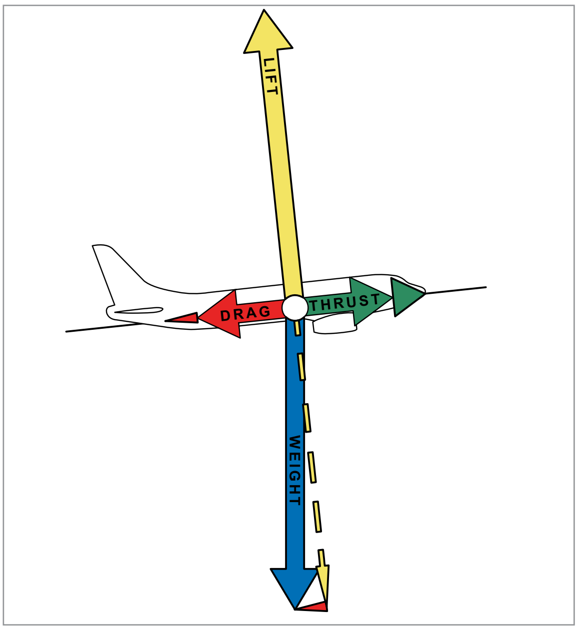


Figure 3.11

The Effect of Flaps on Climbing

High lift devices (flaps) increase aerodynamic Drag. From the study of Principles of Flight it was learned that the purpose of flaps is to reduce the take-off and landing run. *Figure 3.12* and *Figure 3.13* show it is obvious that flaps reduce the climb angle because they increase aerodynamic Drag and therefore decrease Excess Thrust.

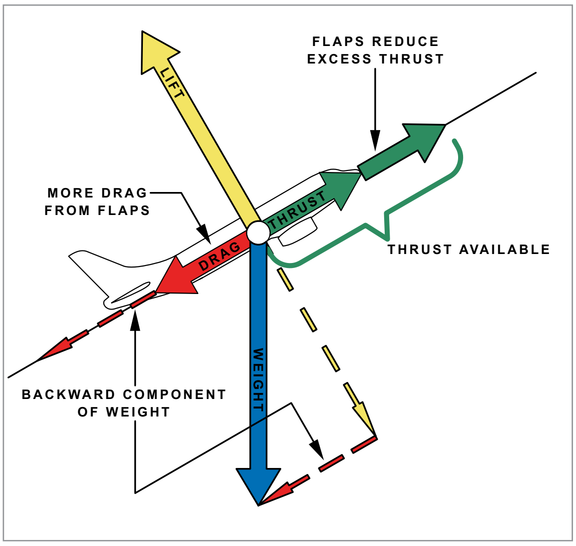


Figure 3.12

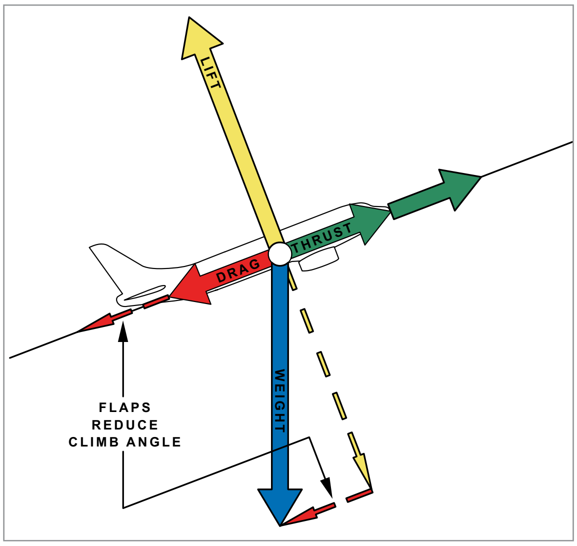


Figure 3.13

The Climb Angle - Gamma

Figure 3.14 includes the symbol used for climb angle, the Greek letter GAMMA (γ). Note that the angle between the horizontal and the flight path (climb angle) is exactly the same as the angle between the Weight vector and the transposed Lift vector. We will be using climb angle for the FREE AIR climb.

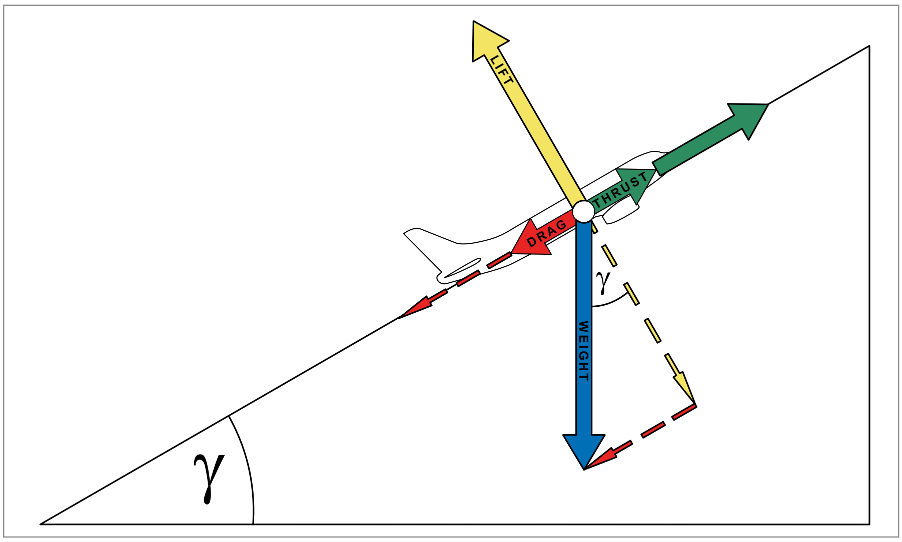


Figure 3.14

When an aeroplane is in a steady climb there will be a gain in height after a given horizontal distance travelled. This relationship is the % climb gradient. The calculation on *page 48* gave 15.7% climb gradient, all engines. From *Figure 3.14* it can be visualized that for 100 units of horizontal travel, the aeroplane will be 15.7 units higher. This is a fundamental concept.

For example: an aircraft with a climb gradient of 15.7% all engines operating, will be 314 ft higher after travelling 2000 ft horizontally, but the one engine inoperative climb gradient of 3.7%, will only give a height gain of 74 ft in the same distance.

Horizontal distance = 2000 ft

Gradient = 15.7% (For every 100 ft horizontally, a height gain of 15.7 ft)

$$\frac{2000 \text{ ft}}{100} = 20$$

$$20 \times 15.7 \text{ ft} = 314 \text{ ft (All engines)}$$

Gradient = 3.7% (For every 100 ft horizontally, a height gain of 3.7 ft)

$$20 \times 3.7 \text{ ft} = 74 \text{ ft (One engine inoperative)}$$

Parasite Drag Curve

An easy way to visualize how an aeroplane can maximize Excess Thrust and therefore its climb angle is to use a simple graph showing the relationship between Thrust and Drag under various conditions. But first, the parts of the Drag curve will be studied in detail.

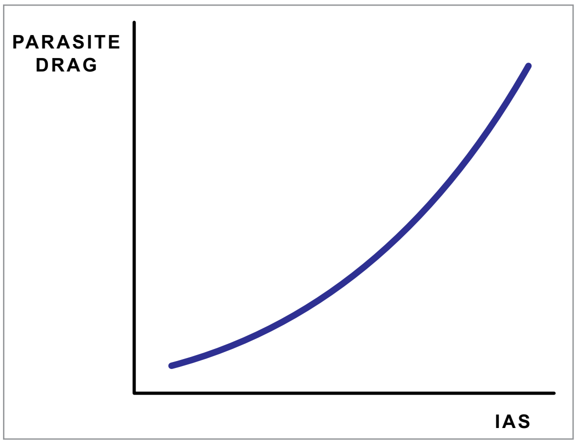


Figure 3.15

Figure 3.15 shows Parasite Drag increasing with the square of the IAS. (Parasite Drag is proportional to IAS squared). If IAS is doubled, Parasite Drag will be increased four times. Note that at low speed Parasite Drag is small, but reaches a maximum at high IAS. Parasite Drag will increase with increasing "Parasite Area" (flaps, undercarriage or speed brakes).

Induced Drag Curve

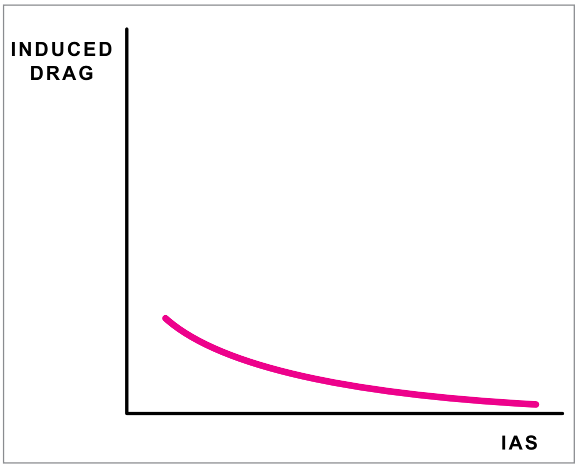


Figure 3.16

Figure 3.16 shows Induced Drag decreasing with IAS squared. (Induced Drag is inversely proportional to IAS squared). If IAS is doubled, Induced Drag will be decreased to one quarter of its previous value. Note that Induced Drag is at its highest value at low IAS, but decreases with increasing IAS. Induced Drag will vary with Lift production. Increasing the Weight or banking the aircraft will increase Induced Drag.

Total Drag Curve

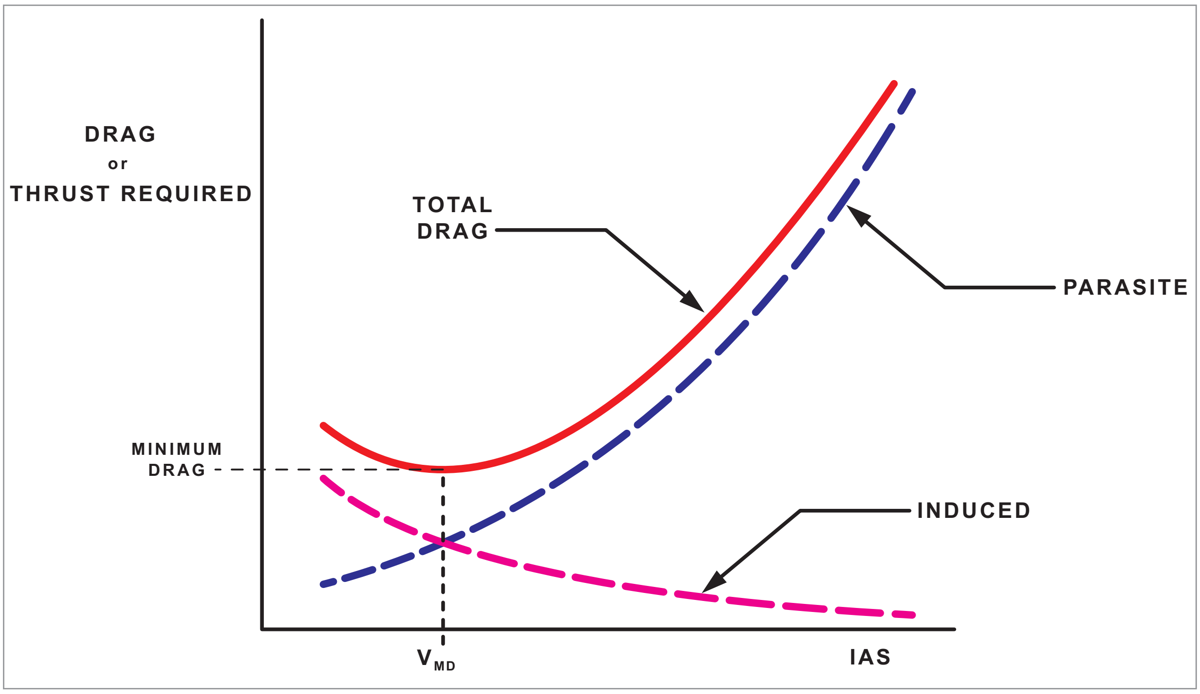


Figure 3.17

In flight, an aeroplane will experience both Parasite and Induced Drag. The sum of Parasite Drag and Induced Drag is called Total Drag. When only the word Drag is mentioned, the meaning is Total Drag. *Figure 3.17* shows a Total Drag curve:

- At any given IAS, Total Drag is the sum of Parasite Drag and Induced Drag.
- The IAS at which Parasite Drag is the same value as Induced Drag will generate minimum Total Drag.
- The IAS that gives minimum Total Drag, is called "The Minimum Drag Speed" and is called V_{MD}.
- Flying at an IAS slower than V_{MD} will generate more Drag and flying at an IAS faster than V_{MD} will also generate more Drag.

Whenever Drag is being considered it is an excellent idea to develop the habit of sketching the Total Drag curve, together with the Parasite Drag and Induced Drag curves. This enables the result of any variable to be included and the correct conclusion obtained.

The Effect of Weight or Bank Angle on Drag

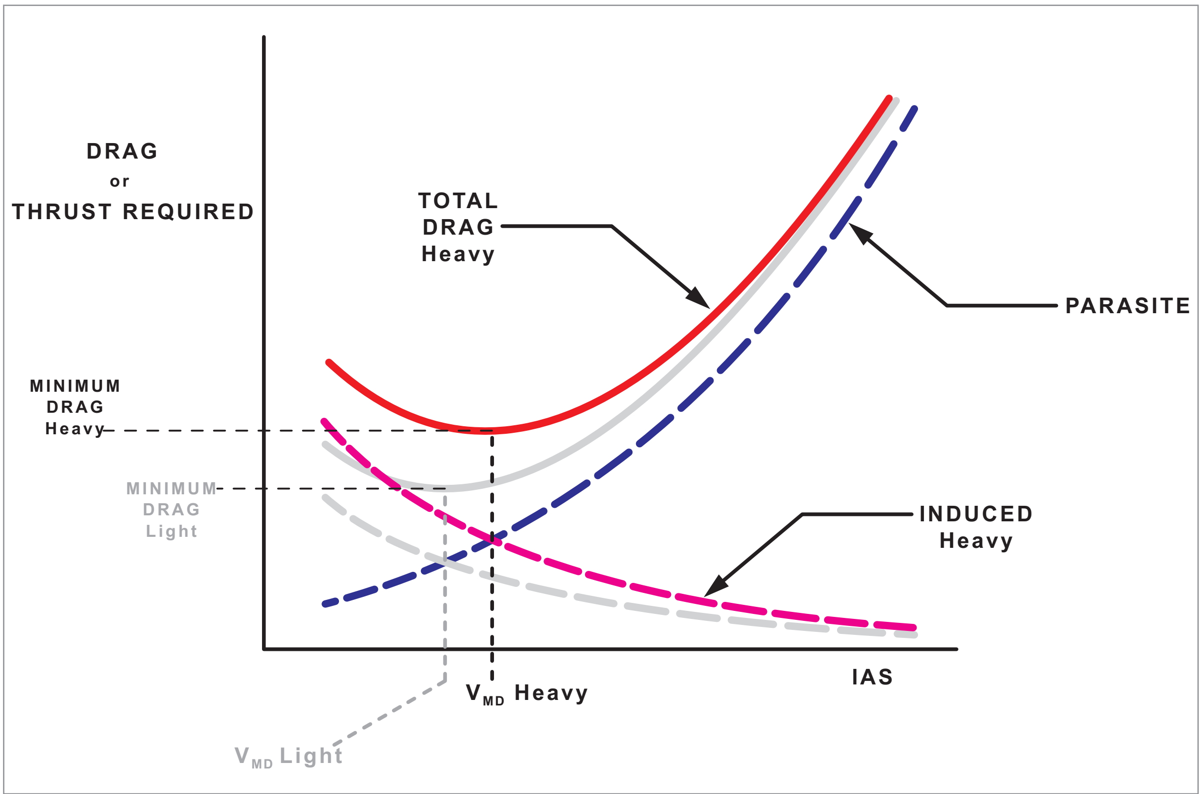


Figure 3.18

Figure 3.18 shows the effect of increased Weight and/or the effect of turning the aircraft. Induced Drag will be greater at a given IAS because Lift must be increased when the aircraft has more weight or when turning. The reason for the proportionally greater increase in Induced Drag at the low speed end of the graph is because Induced Drag is inversely proportional to IAS squared – therefore, at low speed the effect is greater.

The intersection of the Induced Drag curve and the Parasite Drag curve is further towards the high speed end of the graph and the sum of Induced Drag and Parasite is greater. Total Drag will increase and V_{MD} will be a faster IAS when an aircraft is operating at increased Weight or when turning.

Conversely, throughout flight Weight will decrease due to fuel use. As the aircraft becomes lighter, Total Drag will decrease and the IAS for V_{MD} will also decrease.

The Effect of Flaps or Gear on Total Drag

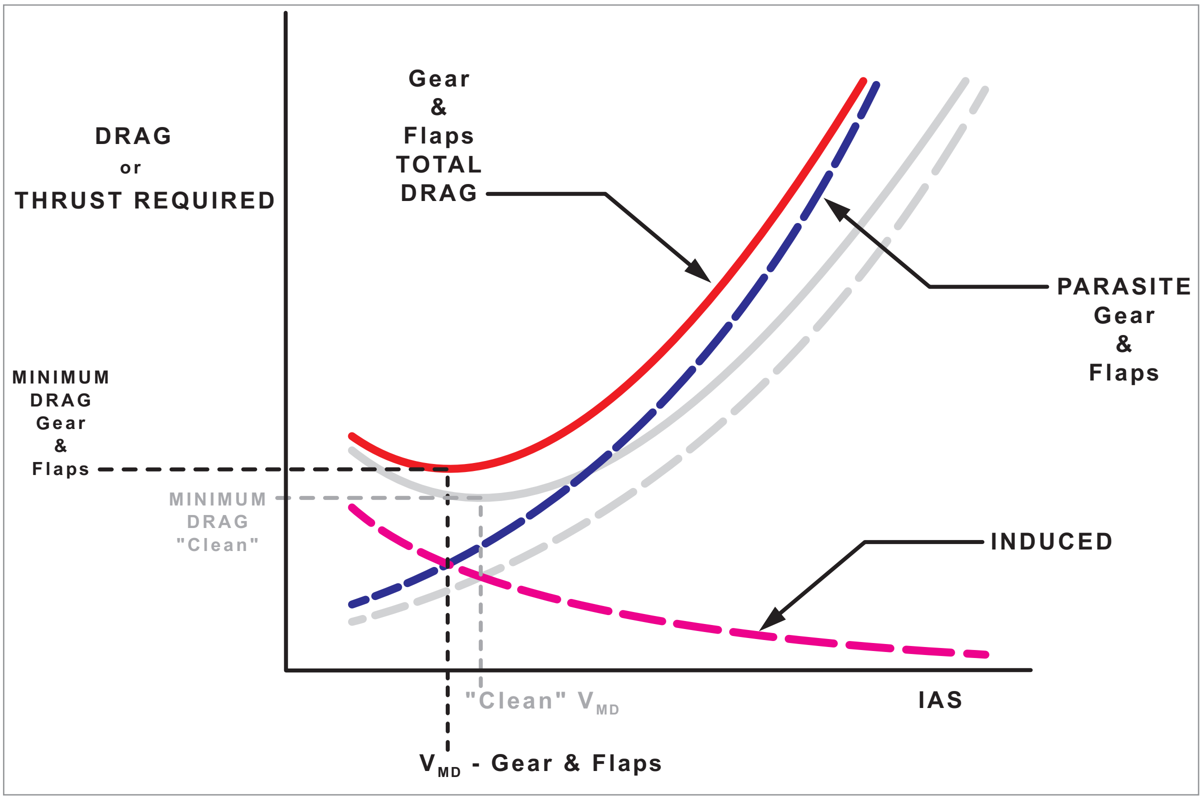


Figure 3.19

Figure 3.19 shows the effect of flaps or gear (undercarriage). Parasite Drag will be greater at a given IAS because the Parasite area will be increased. When both flaps and the gear are fully retracted, the aircraft is said to be in the Clean configuration or the aircraft is Clean. The reason for the proportionally greater increase in Parasite Drag at the high speed end of the graph is because Parasite Drag is proportional to IAS squared – therefore, at high speed, the effect is greater. The intersection of the parasite Drag curve and the Induced Drag curve is further towards the low speed end of the graph and the sum of Parasite Drag and Induced Drag is greater. Total Drag will increase and V_{MD} will be a lower IAS when either the flaps or gear are lowered.

Thrust

Thrust is the force required to balance aerodynamic Drag; plus the backward component of Weight when the aircraft is in a steady climb. A turbojet engine generates Thrust by accelerating a mass of air rearwards. The variation of **Thrust Available** with forward speed is relatively small and the engine output is nearly constant with changes in IAS.

Thrust Available = Mass Flow × Acceleration (Exhaust velocity - Intake velocity)

Since an increase in speed will increase the magnitude of intake velocity, constant **Thrust Available** will only be obtained if there is an increase in mass flow or exhaust velocity. When the aircraft is at low forward speed, any increase in speed will reduce the velocity change through the engine without a corresponding increase in mass flow and **Thrust Available** will decrease slightly. When the aircraft is flying at higher speed, the ram effect helps to increase mass flow with increasing forward speed and **Thrust Available** no longer decreases, but actually increases slightly with speed.

For a given engine rpm and operating altitude, the variation of turbo-jet Thrust with speed is shown in *Figure 3.20.*

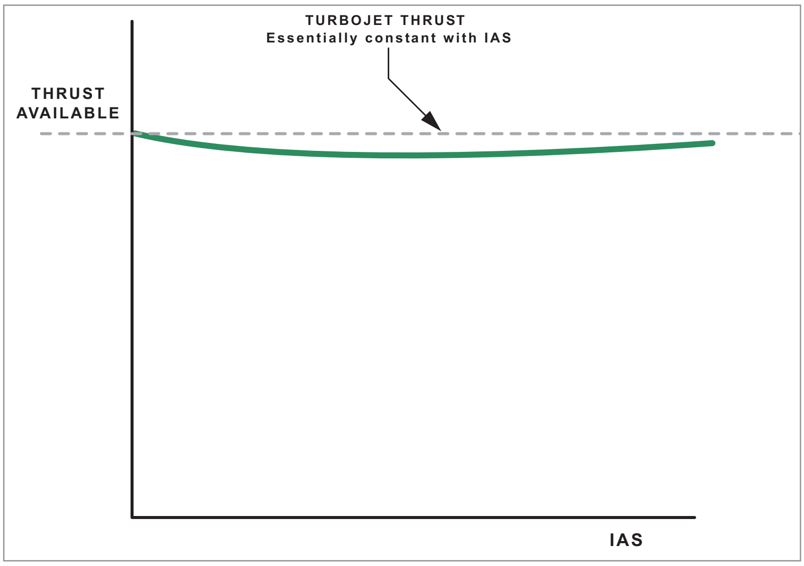


Figure 3.20

Because turbojet thrust is essentially constant with speed, unless the take-off run is being considered, future illustrations will display **Thrust Available** from the turbojet as a straight line.

Variation of Thrust with Density Altitude

A turbojet engine is un-supercharged. Increasing Density Altitude (lower air density) will reduce the mass flow through the engine and Thrust Available will decrease. Obviously, this will have an effect when climbing, but also when operating at airfields with a High Pressure Altitude and/or a high Outside Air Temperature (OAT). As a reminder, Pressure Altitude can be determined on the ground by setting 1013 hPa on the altimeter subscale. If the altimeter reads 1000 ft on the ground with 1013 on the subscale, the Pressure Altitude is 1000 ft, irrespective of the actual height of the airfield above sea level. (The aeroplane will experience the air pressure that corresponds to 1000 ft in the International Standard Atmosphere).

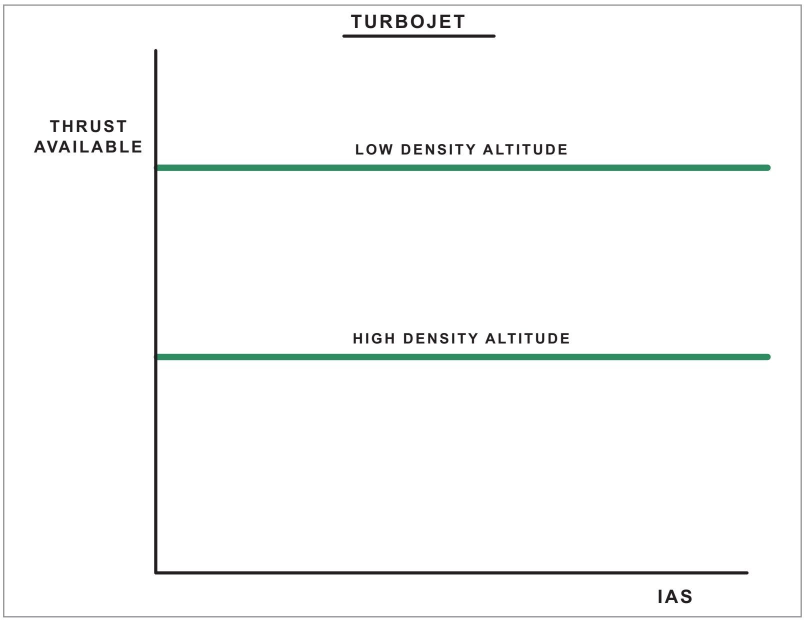


Figure 3.21

Figure 3.21 shows that **Thrust Available** has a lower value with increasing Density Altitude (lower air density).

Variations of Take-off Thrust with Air Temperature (OAT)

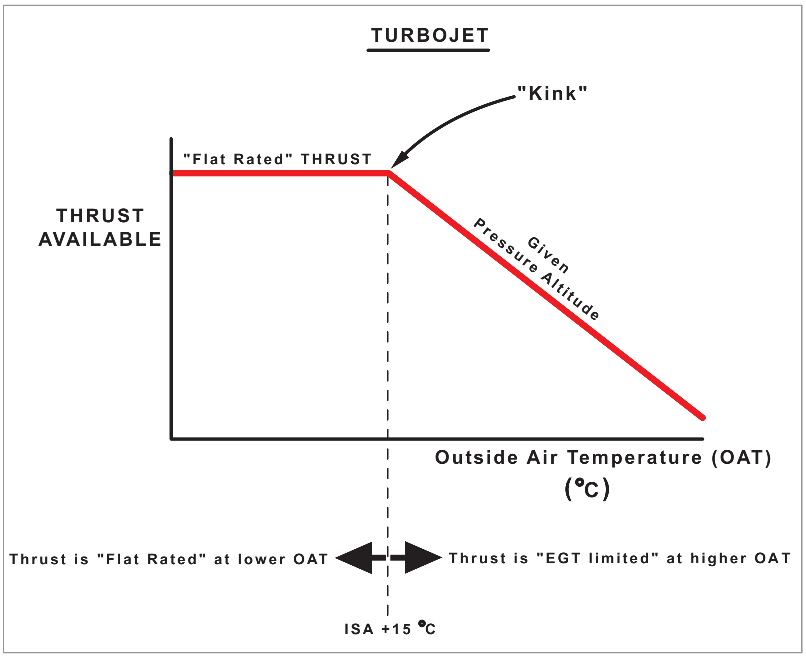


Figure 3.22

Generally, the Thrust of any turbojet engine is restricted by the maximum temperature the turbine blades can withstand. The more heat resistant the material from which the turbine blades are made and the more efficient the blade cooling, the higher the maximum turbine inlet temperature and therefore the greater the Thrust the engine can safely develop.

For a given engine, the higher the OAT the lower the mass air flow and therefore the lower the fuel flow before the maximum turbine inlet temperature is reached and consequently, the lower the Thrust the engine is able to develop – this is known as EGT limited Thrust.

Figure 3.22 should be read from right to left, and shows Thrust increasing with decreasing OAT at a given Pressure Altitude, but only down to an OAT of ISA + 15°C. Below ISA + 15°C Thrust remains constant. This is the engine's "Flat Rated" Thrust. At OATs below ISA + 15°C, Thrust is no longer limited by turbine inlet temperature but by the maximum air pressure the compressor is built to withstand. Below airport OATs of ISA + 15°C it does not matter how far the flight crew advance the throttle, the engine management computer will maintain "Flat Rated" Thrust – this is the maximum certified Thrust of the engine.

From a Performance point of view, if engines are not "Flat Rated" and the throttles are fully advanced at OATs below ISA + 15°C a lot more than maximum certified Thrust will be delivered. While this may not be immediately destructive to the engine if done occasionally, it completely compromises the certification of the aeroplane. Engine-out critical speeds (V_{MCG}, V_{MCA} and V_{MCL}) are based on the yawing moment generated at maximum certified Thrust. If significantly more Thrust is produced during one-engine-out flight with the IAS at the recommended minimum, directional control of the aeroplane will be lost.

Some Performance graphs incorporate the "Flat Rated" Thrust of the engine to allow determination of, for instance, the Climb Limit Take-off Weight. Climb Limit Take-off Weight will increase with decreasing OAT, but only down to ISA + 15°C. For each Pressure Altitude, an OAT lower than ISA + 15°C will not give an increase in Climb Limit Take-off Weight.

In the EASA Performance exam the ISA + 15°C temperature for each Pressure Altitude is referred to as the "kink" in the pressure altitude lines of *CAP 698, Figures 4.4, 4.5 and 4.29*. "The kinks in the pressure altitude lines indicate the temperature, individually for each altitude, below which the Thrust will not increase with an increase in density".

Region of Reverse Command

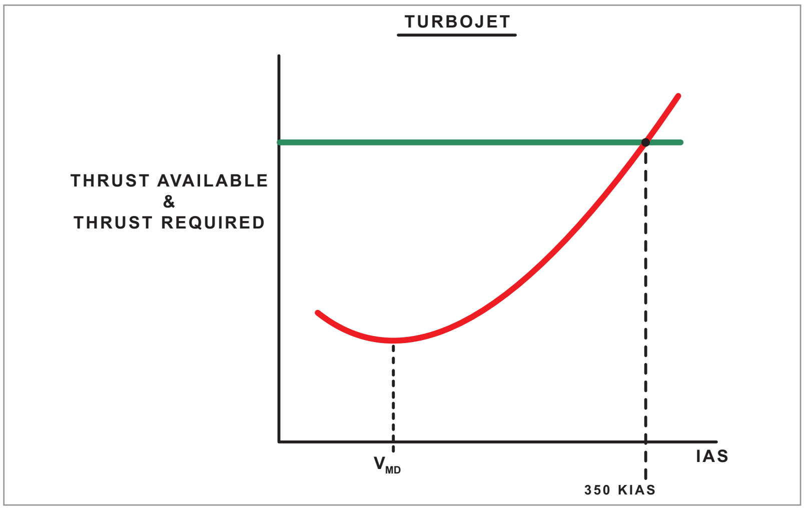


Figure 3.23

Thrust and Drag on the same graph will show the result of many variables. *Figure 3.23* shows Thrust Available in green and Thrust Required in red. The intersection of the two curves will result in unaccelerated flight at a high speed of 350 KIAS.

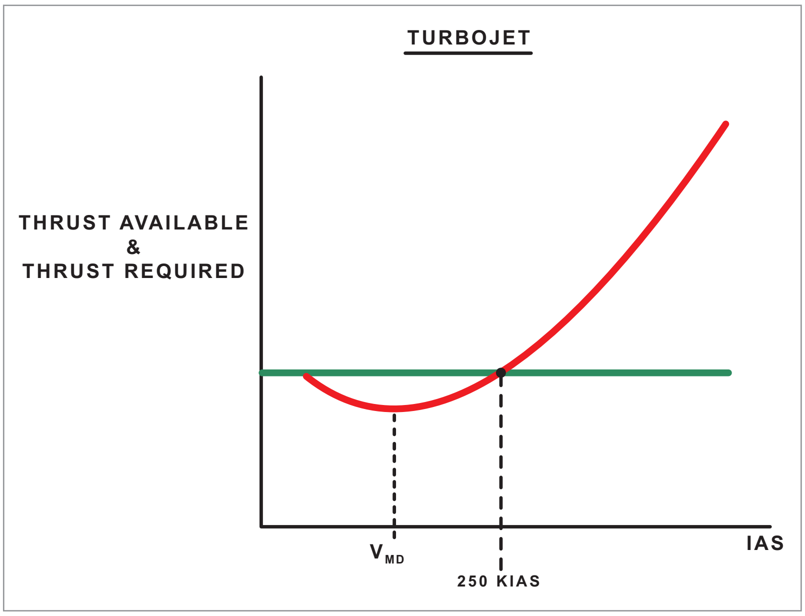


Figure 3.24

Figure 3.24 shows that to maintain unaccelerated flight at a lower speed of 250 KIAS, **Thrust Available** must be decreased and the aircraft slowed until **Thrust Required** reduces to the same value.

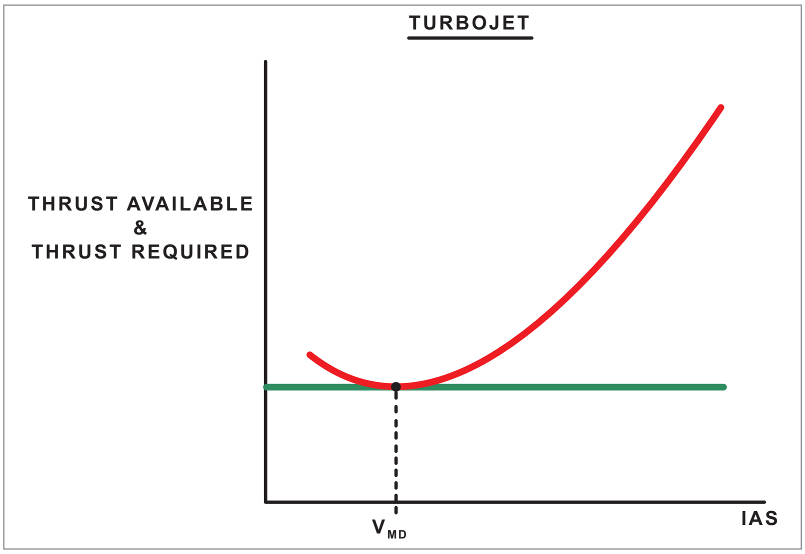


Figure 3.25

Figure 3.25 shows Thrust Available has been further reduced in order to maintain unaccelerated flight at V_{MD}, the minimum Drag speed.

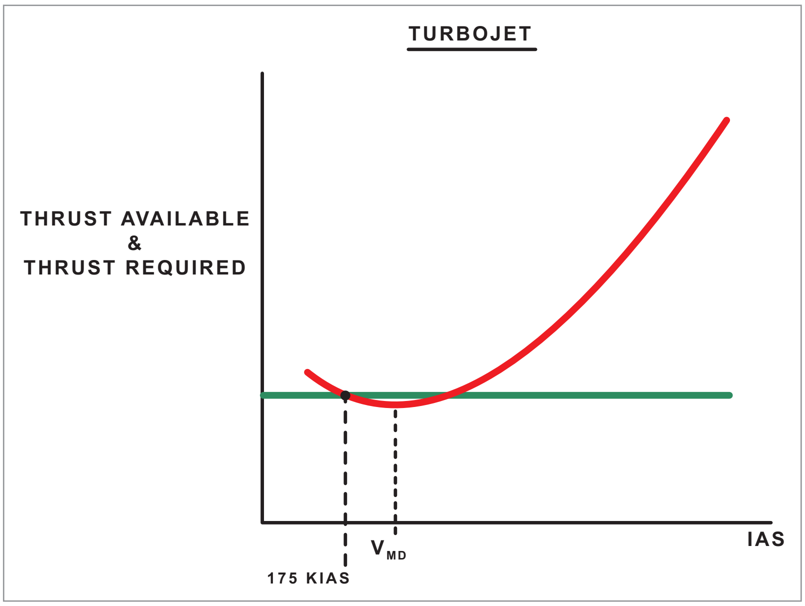


Figure 3.26

Figure 3.26 shows that to maintain unaccelerated flight at an IAS slower than V_{MD}, **Thrust Available** must be increased. This is because at speeds below V_{MD}, **Thrust Required** (Drag) increases. The speed region slower than V_{MD} has three alternative names:

- "The back-side of the Drag curve",
- "The speed unstable region" and, perhaps the most descriptive,
- "The region of Reverse Command": so called because to maintain unaccelerated flight at an IAS slower than V_{MD}, Thrust must be increased – the reverse of what is "Normally" required.

Best Angle of Climb Speed (V_X)

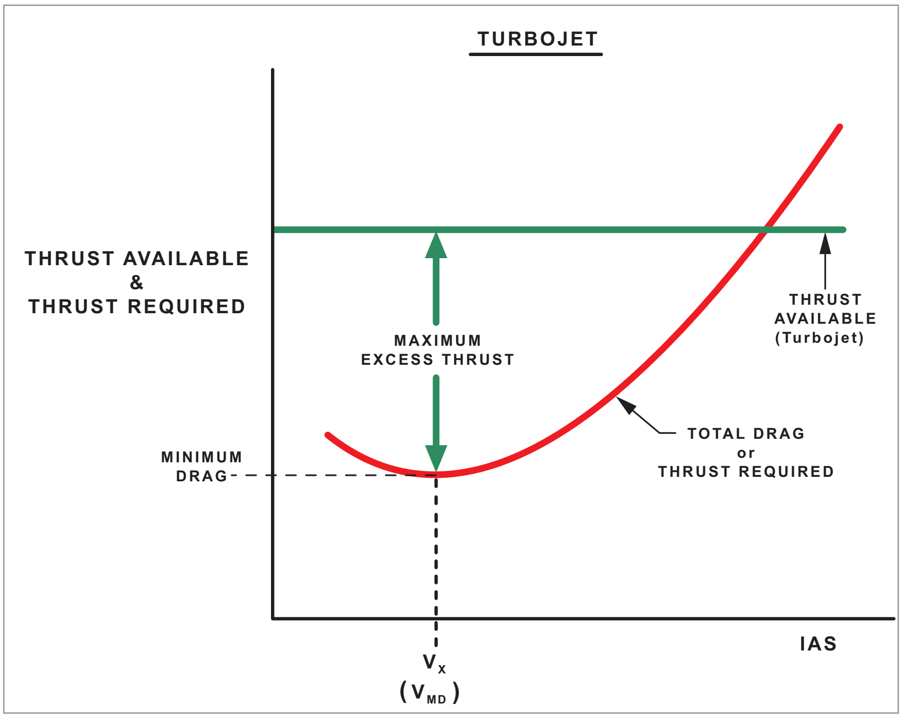


Figure 3.27

Figure 3.27 shows Thrust Required (Aerodynamic Drag) and Thrust Available (from the engines) for an aeroplane powered by turbojet engines.

Excess Thrust is the amount of Thrust that exceeds aerodynamic Drag. Excess Thrust can be seen on the graph as the distance between the Thrust Available and Thrust Required lines. You will recall that to maximize the climb gradient, Excess Thrust must be a maximum. Maximum Excess Thrust is obtained by flying at the IAS where the distance between the Thrust and the Drag lines is maximum.

Notice that maximum Excess Thrust is available only at one particular IAS, labelled V_X. At any other speed, faster or slower, the distance between the Thrust and Drag curves is smaller and Excess Thrust is less. Therefore, climbing at an IAS other than V_X will give a climb gradient less than the maximum possible.

The IAS at which the aeroplane generates the greatest amount of Excess Thrust and is therefore capable of its steepest climb gradient, is called V_X. (V_X is referred to as the Best Angle of Climb Speed). From *Figure 3.27*, it can be seen that for an aeroplane powered by turbojet engines, V_X is the same IAS as V_{MD}. V_X for a propeller aeroplane is less than V_{MD} and at low altitudes will be in the region of V_{MP}.

Factors Affecting Angle of Climb

The Effect of Weight

Viewing Thrust Required (Drag) and Thrust Available on the same graph will show any obvious changes in Excess Thrust and therefore maximum climb gradient. Any associated changes in the IAS for V_X can also be seen.

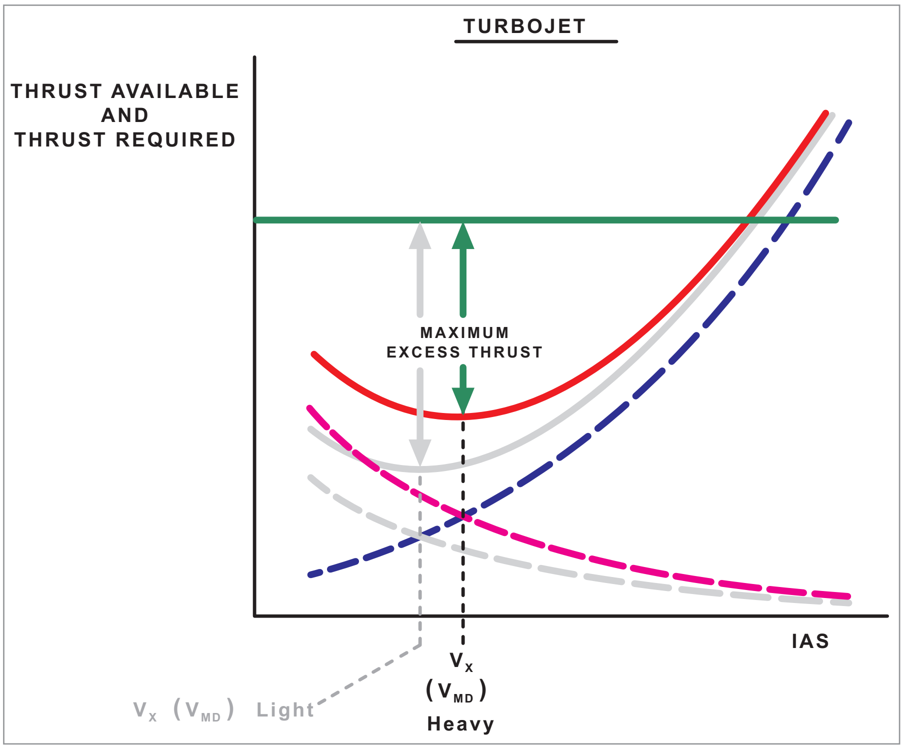


Figure 3.28

Figure 3.28 shows the result of increased weight on the steady climb. More weight requires more Lift, therefore Induced Drag will be greater. This moves the Total Drag curve up, but also to the right. Thrust Required is increased and V_X is a faster IAS. Because Thrust Required has increased, Excess Thrust is decreased, so maximum climb gradient is decreased.

Remember the formula to calculate climb gradient?

$$\text{Gradient \%} = \frac{(T - D)}{W} \times 100$$

Merely by looking at the above formula certain facts are self-evident:

- For a given Weight, the greater the "Excess Thrust" ($T - D$) the more times Weight will divide into the bigger value and therefore, the steeper the climb gradient. The less the **Excess Thrust** the more shallow the climb gradient.

- For a given **Excess Thrust** ($T - D$), the greater the Weight the fewer times Weight will divide into the same value and therefore, the more shallow the climb gradient. The less the weight the steeper the climb gradient.

Increased Weight reduces maximum climb gradient and increases V_X.

The Effect of Flaps (or Gear)

Another factor that affects maximum climb angle is aircraft configuration. Configuration means whether the flaps (or gear) are extended, or not. If flaps (and gear) are retracted, the aircraft is said to be in the clean configuration. If flaps (or gear) are extended, Parasite Drag will increase, but there will be no significant change in Induced Drag.

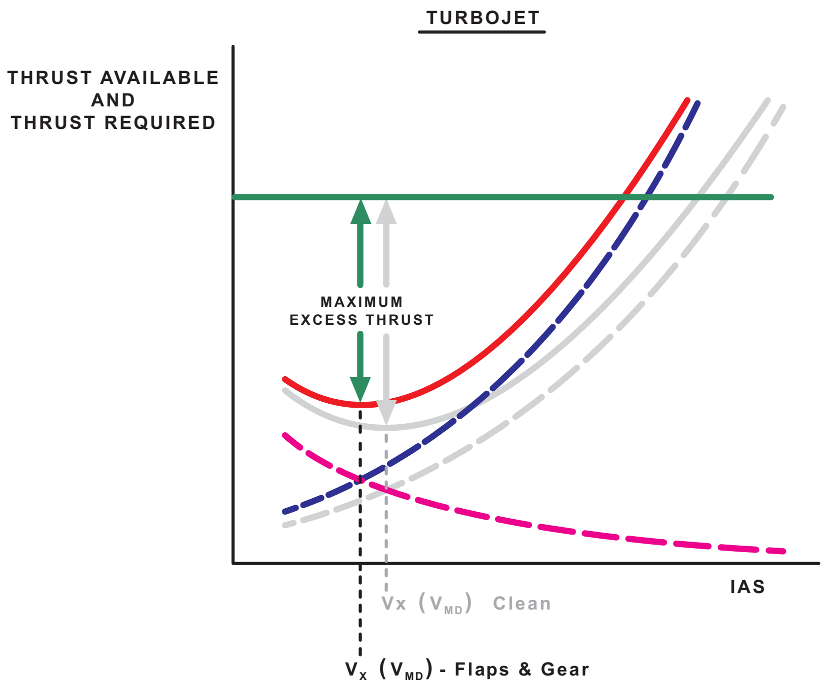


Figure 3.29

Figure 3.29 shows a steady climb with flaps (or gear) extended compared to the clean configuration. Parasite Area is increased, therefore Parasite Drag will be greater. This moves the Total Drag curve up, but also to the left. Thrust Required is increased and V_X is a slower IAS. Because Thrust Required has increased, Excess Thrust is decreased, so maximum climb gradient is decreased.

Flaps or gear reduce maximum climb gradient and decrease V_X.

It therefore seems a very good idea to retract the gear as soon as possible after lift-off, after a positive rate of climb is achieved, and also not to use flaps during a climb so that the climb angle is as large as possible. But, you may recall the purpose of flaps is to decrease the take-off and landing run. If it is necessary to use flaps for the take-off run, retract them in stages after take-off as soon as it is safe to do so. The regulatory flap retraction schedule will be discussed later.

The Effect of Air Density

- Air density affects the mass flow of air into the engine.
- A decrease in air density reduces Thrust Available, thus Excess Thrust is also decreased.

Therefore, the ability to climb decreases with decreasing air density.

Air density is presented on performance graphs as two components: Temperature and Pressure Altitude. (Pressure Altitude is the reading on the altimeter when 1013 hPa is set on the subscale). Any variation in atmospheric pressure or temperature will change air density and therefore Excess Thrust.

Relevant aircraft performance graphs contain a horizontal axis of temperature and a series of sloping Pressure Altitude guide lines. An intersection of these two values will provide the necessary compensation for Density Altitude.

Density Altitude

Now might be a good time to review the meaning of Density Altitude. The “official” definition can be confusing: “A high Density Altitude is one that represents a higher altitude in the International Standard Atmosphere”. A fair explanation when one already understands what is meant, but of little instructional value. Air density cannot be “sensed” or measured directly, but it can be calculated.

Let us say that you are on an airfield which is physically at sea level; the waves are lapping at the end of the runway. Due to existing meteorological conditions the air pressure is low (lower than Standard sea level atmospheric pressure of 1013 hPa), and with 1013 hPa set on the altimeter subscale the altimeter reads 1000 ft.

The reason the altimeter reads 1000 ft is because the actual air pressure is the same as that at 1000 ft in the International Standard Atmosphere - you are at “a high Pressure Altitude”. Reduced air pressure will give reduced air density (mass per unit volume). But air density is also affected by temperature. The “Standard” air temperature at 1000 ft is 13°C (Temperature lapse rate of 2°C per 1000 ft, so 15 - 2 = 13), yet for this example, the actual Outside Air Temperature is measured at 25°C. The actual air temperature is 12°C higher than “Standard” (25 - 13 = 12). This is referred to as ISA+12. Now, either a table or a circular slide rule can be used to accurately determine the Density Altitude; in this case: approximately 2400 ft. So, although the aircraft is physically at sea level, the air density is the same as that at approximately 2400 ft in the International Standard Atmosphere. A turbojet engine would theoretically generate less thrust and the TAS would need to be higher for a given IAS.

For take-off and initial climb from the same airfield, any increase in pressure altitude or air temperature due to local meteorological conditions will reduce Excess Thrust and therefore the ability to climb (or accelerate). This is in addition to the more obvious decrease in air density during a climb to high altitude.

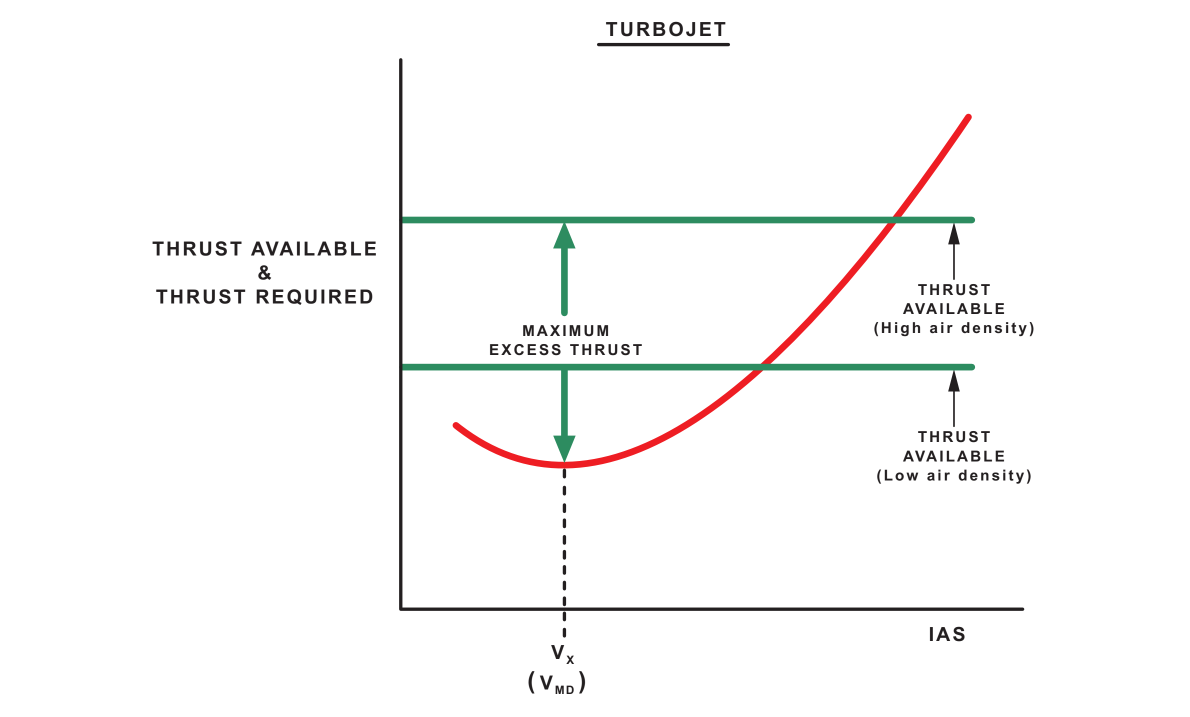


Figure 3.30

Any decrease in air density (increase in Density Altitude) will reduce Thrust Available and therefore move the Thrust line downwards, as shown on the graph in *Figure 3.30*.

Because decreased density reduces Excess Thrust, maximum climb angle will be reduced. Excess Thrust will continually decrease with increasing Density Altitude so the maximum angle of climb will continually decrease as the aircraft climbs. Note that V_X will remain constant with changes in air density, because at a constant IAS (V_X) Drag will not vary. However, you will recall that as air density decreases, True Airspeed must be increased to maintain the required dynamic pressure.

So although the IAS for V_X is constant with increasing Density Altitude, the TAS for V_X will of course increase.

You may recall from earlier lessons that high humidity will also decrease air density and will therefore also decrease aeroplane performance. This is already factored into performance charts, so is not something you need to allow for. However, basic theory questions in the exam may require your knowledge of the fact.

The Effect of Accelerating on Climbing

It has been stated that the ability of an aircraft to climb depends upon Excess Thrust, which is the amount of Thrust Available remaining after Drag is balanced. Hence an aircraft's maximum climb angle is limited by its maximum Excess Thrust. If there is a need to accelerate the aircraft while climbing or a need to climb while accelerating, some of the Excess Thrust must be used for the acceleration and therefore the maximum climb angle will be reduced.

The Effect of Bank Angle on Climbing

When an aircraft is banked, any increase in bank angle beyond approximately 15 degrees will significantly increase the amount of Lift that needs to be generated. Increased Lift will generate more Induced Drag, so Excess Thrust will be reduced and therefore maximum climb angle will be reduced.

The Effect of Wind on Climbing

The effect that wind has on climbing depends upon the type of climb gradient being considered, (wind being motion of a body of air over the ground). There are two types of climb gradient: Air gradient and Ground gradient. Air gradient is used by aviation authorities to lay down minimum climb performance limits. E.g. a Class 'A' aeroplane: *"..... starting at the point at which the aeroplane reaches 400 ft (122 m) above the take-off surface, the available gradient of climb may not be less than 1.2% for two-engined aeroplanes".*

Air Gradient

Air gradient is the vertical distance gained in a body of air divided by the horizontal distance travelled through the same body of air. The fact that the body of air might be moving over the ground is NOT considered. So wind has no effect on Air gradient.

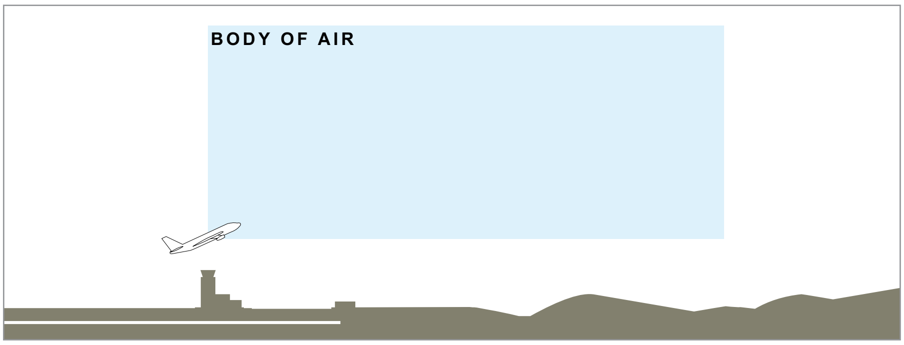


Figure 3.31

Figure 3.31 shows an aeroplane in the bottom left corner of a body of air, directly above the control tower on the ground.

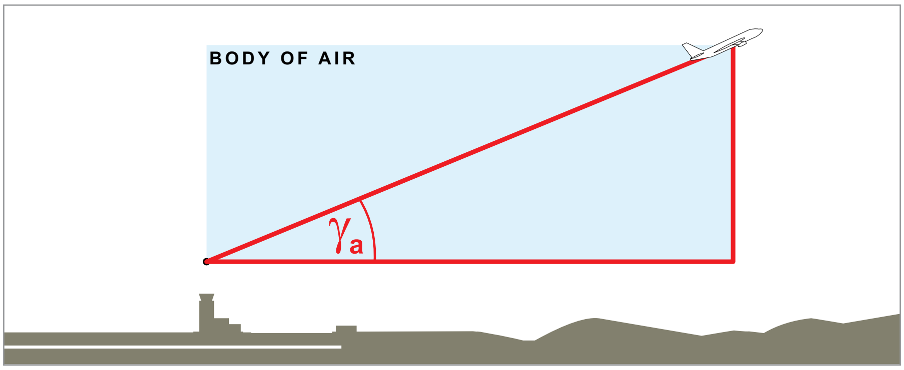


Figure 3.32

Figure 3.32 shows the body of air stationary relative to the ground; this is referred to as "Zero Wind" or "Still Air". The aeroplane has climbed to the top right corner of the body of air and the Air gradient is shown as Gamma 'a'.

Note: *To simplify the study of climbing, for climb angles less than approximately 20 degrees, it is considered that doubling the climb angle will double the climb gradient.*

Ground Climb Gradient

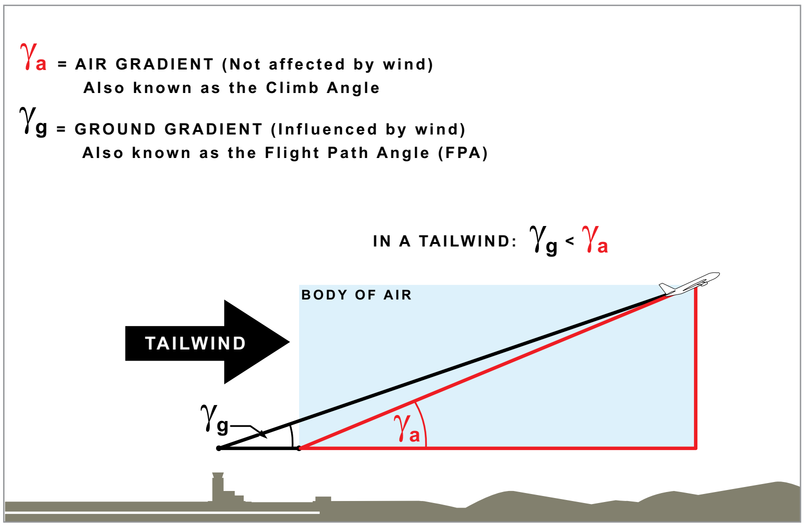


Figure 3.33

Figure 3.33 shows the effect of a tailwind. Because the body of air is moving over the ground in the direction of flight the Ground gradient is smaller than the Air gradient.

A tailwind does not change the Air gradient, but decreases the Ground gradient.

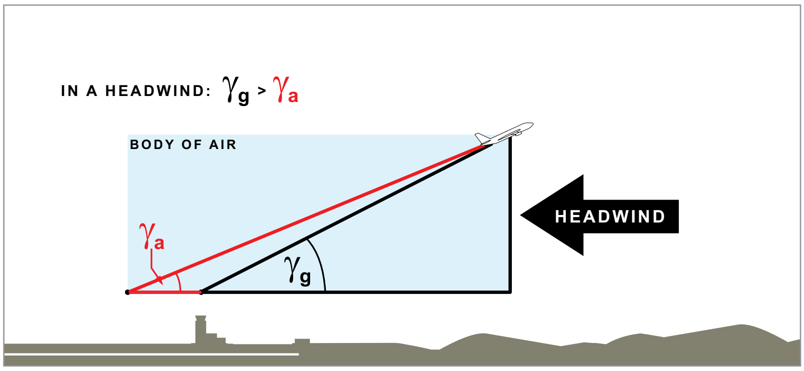


Figure 3.34

Figure 3.34 shows the effect of a headwind. Because the body of air is moving over the ground opposite to the direction of flight the Ground gradient is larger than the Air gradient.

A headwind does not affect the Air gradient, but increases the Ground gradient.

The only time wind is used to calculate climb gradient is when obstacle clearance is being considered. In all other cases of climbing, still air is used, even if a wind value is supplied.

Calculating Ground Gradient

It is possible to calculate the Ground gradient by using a "wind factor" to correct the Air gradient for wind. Any gradient is the vertical distance divided by the horizontal distance.

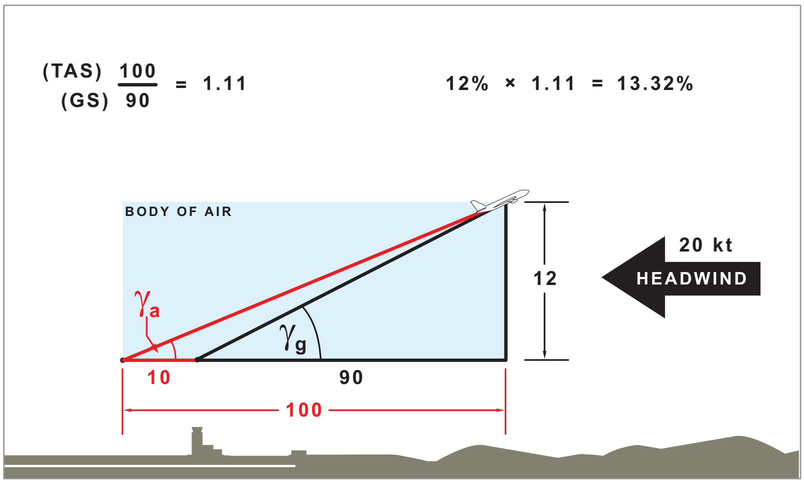


Figure 3.35

Headwind

Example 1: An aeroplane has an Air gradient of 12%, its TAS is 100 kt and the headwind is 20 kt. Calculate the Ground gradient. *(Figure 3.35)*.

Applying 50% of the 20 kt headwind makes the ground speed (GS) 90 kt (100 – 10 = 90).

100 kt TAS divided by 90 kt GS gives a wind factor of 1.11. Multiplying the Air gradient of 12% by the wind factor gives a Ground gradient of 13.32%.

Example 2: An Air gradient of 12% with a TAS of 160 kt and a headwind of 20 kt. 160 divided by 150 gives a wind factor of 1.07. Multiplying the Air gradient of 12% by the wind factor gives a Ground gradient of 12.8% (12 × 1.07 = 12.8).

Note: It is important to remember that if the Ground gradient is to be used for the calculation of obstacle clearance, the application of headwinds and tailwinds must include the 50% headwind and 150% tailwind rule.

Tailwind

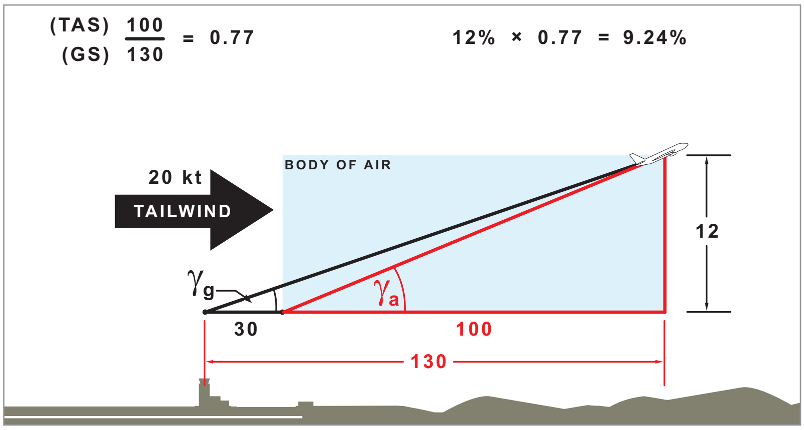


Figure 3.36

Example 3: The same Air gradient of 12% with a TAS of 100 kt but now a tailwind of 20 kt. In the above example, the 20 kt tailwind makes the ground speed (GS) 130 kt (100 + 30 = 130).

100 kt TAS divided by 130 kt GS gives a wind factor of 0.77. Multiplying the Air gradient of 12% by the wind factor gives a Ground gradient of 9.24% (12 × 0.77 = 9.24).

Example 4: An Air gradient of 12% with a TAS of 160 kt and a tailwind of 20 kt makes the ground speed (GS) 190 kt. 160 kt TAS divided by 190 kt GS gives a wind factor of 0.84. Multiplying the Air gradient of 12% by the wind factor gives a Ground gradient of 10.1% (12 × 0.84 = 10.1).

Having detailed the method of calculating Ground gradient from the Air gradient, we will now examine a typical climb gradient question.

Example 5: Determine the ground distance for a Class B aeroplane to reach a height of 2000 ft above Reference Zero in the following conditions:

OAT: 25°C
Pressure altitude: 1000 ft
Gradient: 9.4%
Speed: 100 KIAS
Wind component: 15 kt Headwind

The question mentions 2000 ft above Reference Zero; what is Reference Zero?

Reference Zero is the point on the runway or clearway plane at the end of the Take-off Distance Required *(Figure 3.37)*. It is the reference point for locating the start point of the take-off Flight Path.

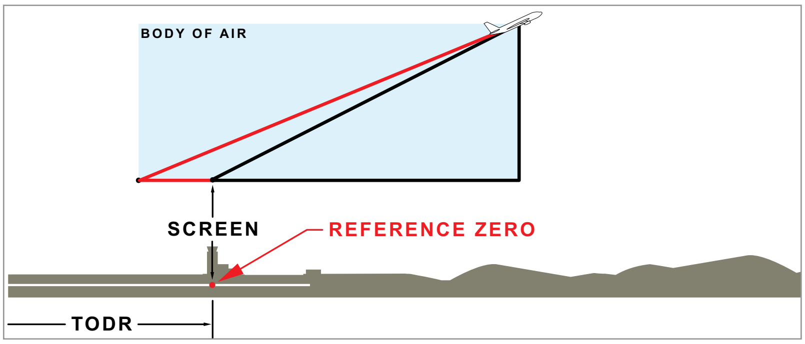


Figure 3.37

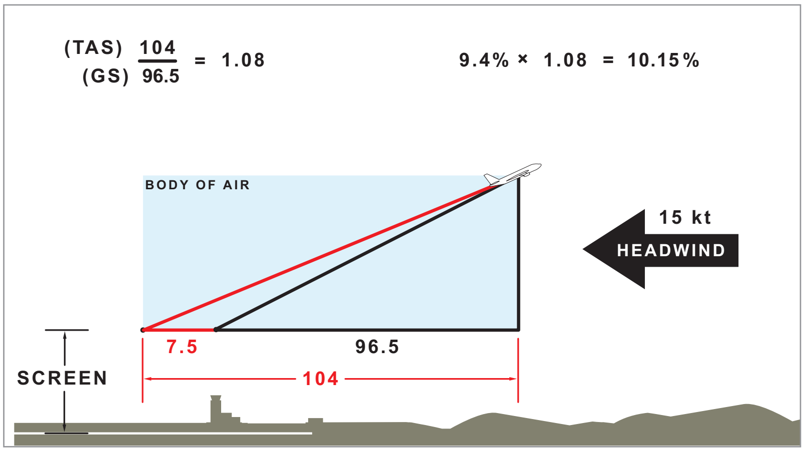


Figure 3.38

Figure 3.38 illustrates the data supplied in the question and calculation of the Ground gradient from the Air gradient.

1. The TAS is calculated from the KIAS using your circular slide rule. (At 1000 ft Pressure Altitude and 25°C, 100 KIAS = 104 KTAS)

2. Due to the 15 kt headwind, the ground speed will be (104 KTAS – 7.5 kt) = 96.5 KTAS. (Wind speed is always a TAS)

3. TAS divided by GS gives a wind factor of 1.08.

4. Multiplying the Air gradient by the wind factor gives a Ground gradient of 10.15% (Approximately).

It is always a good idea to "draw" the question. Once the triangle has been sketched and the known parameters included, the visual relationship can be more easily considered.

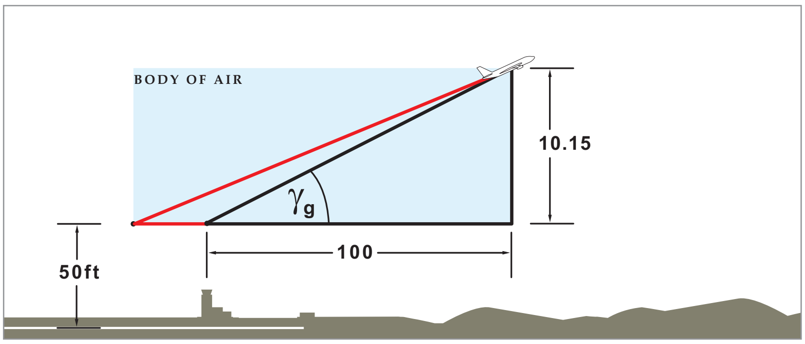


Figure 3.39

A Class B aeroplane is being considered, so the screen height is 50 ft. The climb segment begins at the screen height above Reference Zero. Therefore the aeroplane will only need to gain an additional 1950 ft to be 2000 ft above Reference Zero. A 10.15% gradient simply means that the aircraft will be 10.15 units higher after 100 units of horizontal travel.

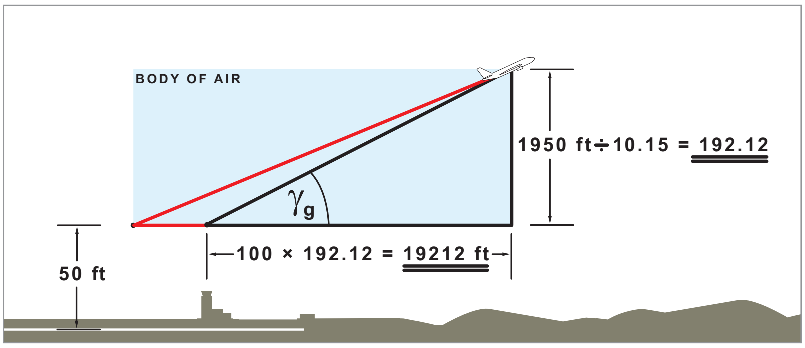


Figure 3.40

In this case the required vertical height gain is 1950 ft, so we need to discover how many times 10.15 will divide into 1950 ft (1950 ft / 10.15 = 192.12). This means that the vertical height gain is 192.12 times greater, so the horizontal distance will also be 192.12 times greater. Multiplying 100 by 192.12 will give the horizontal distance travelled in feet, in this case, 19 212 ft.

Example 6: Following take-off, a light twin-engine aeroplane has a 10% climb gradient. By how much will it clear a 900 m high obstacle situated 9740 m from the end of the Take-off Distance Available (TODA)?

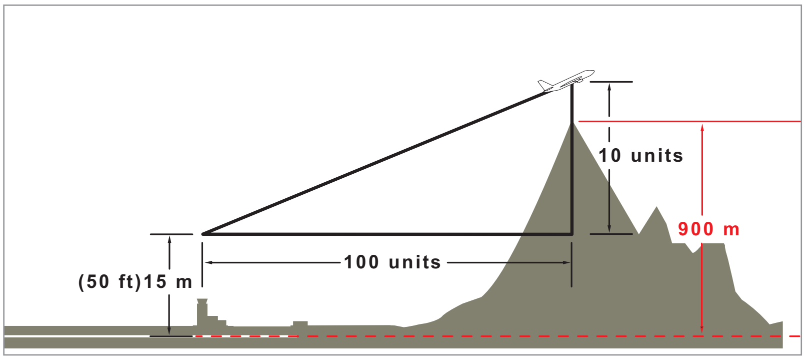


Figure 3.41

In order to find out by how much the aeroplane will clear the obstacle, it is necessary to calculate the height gain after covering a horizontal distance of 9740 m.

Remember: Percentage gradient is merely the vertical height for a horizontal distance travelled of 100 units. In this case the 10% gradient will give 10 units up for every 100 units along.

The primary data from the question has been included in *Figure 3.41*. This simple procedure allows you to see how the aircraft flight path relates to the obstacle. The height of the obstacle is above Reference Zero, as is the start of the climb segment.

For practical purposes a screen height of 50 ft is 15 m.

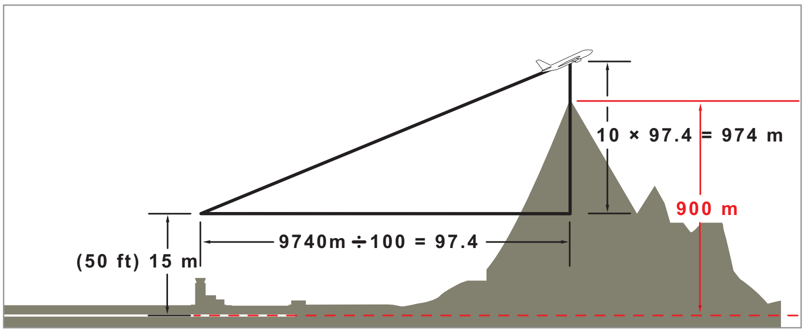


Figure 3.42

The distance of the obstacle from the end of the TODA is 9740 m, so we need to discover how many times the horizontal ratio of 100 will divide into that distance (9740 / 100 = 97.4). This means that the horizontal distance is 97.4 times greater, so the height gain will also be 97.4 times greater. Multiplying 10 by 97.4 will give the height gain in metres, (97.4 × 10 = 974 m) in this case, 974 m.

However, it must be remembered that the climb segment starts at 15 m (50 ft) above Reference Zero. So the screen height must be added to the height gain (974 m + 15 m = 989 m), in this example, 989 m.

The aircraft will clear the 900 metre obstacle by 89 metres.

Rate of Climb

We will now consider rate of climb and begin with an overview. There are many ways of learning. But once a concept has been explained and understood it must then be remembered. Some students manage to confuse angle of climb with rate of climb, so the following basic explanation is provided to help decide when and how to use rate of climb. (The same considerations can be used later with rate of descent).

POWER is the RATE of doing work. (Associate the word RATE with the word POWER).

Work = Force × Distance

Therefore:

$$\text{POWER} = \frac{\text{Force} \times \text{Distance}}{\text{Time}}$$

When considering rate of climb we need to do the maximum amount of work on the aeroplane in a given time.

Question: When climbing, what force must be balanced?

Answer: Drag!

The remaining product from the formula is distance divided by time, e.g. nautical miles per hour (kt).

Question: How many speeds are there?

Answer: One! The True Airspeed, the only speed there is, the speed of the aeroplane through the air.

Therefore: POWER REQUIRED = DRAG × TAS

If we take a Thrust Required (Drag) curve in sea level ISA conditions, and multiply the Drag at various airspeeds by the TAS and plot the resulting Power Required curve on the same piece of graph paper, the result will be that illustrated in *Figure 3.43.*

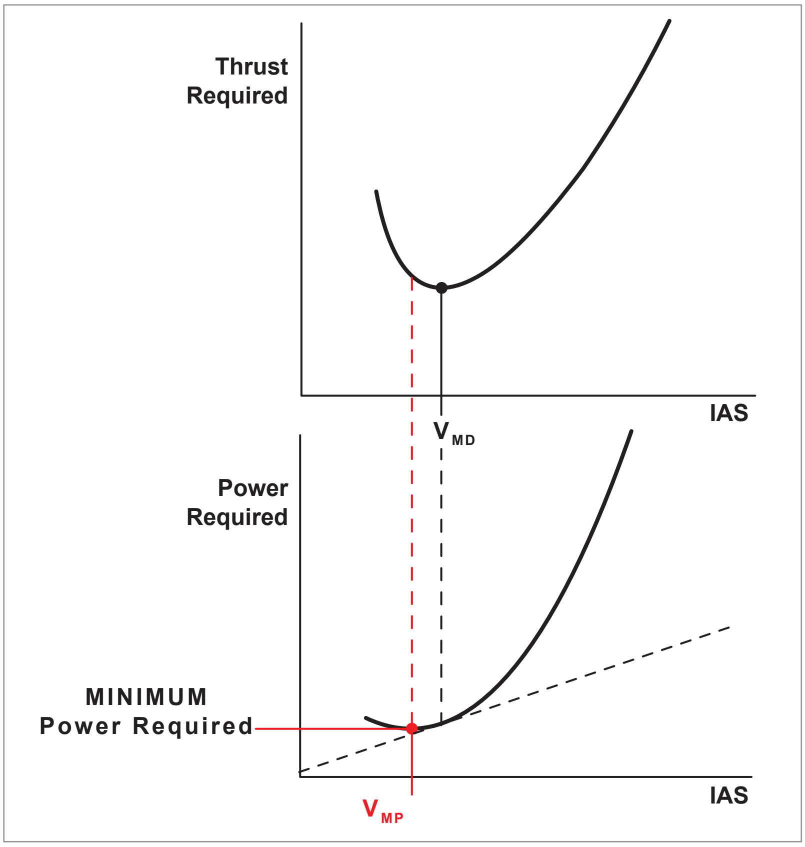


Figure 3.43

The shape of the Power Required curve is very similar to that of Thrust Required. The significant difference is that the Power Required curve is displaced to the left. Consequently, the speed for minimum Power Required (V_{MP}) is slower than the speed for minimum Thrust Required (V_{MD}).

It is essential to be able to visualize the Power Required curve relative to the Thrust Required curve, together with the V_{MP} and V_{MD} relationship. Associated data will be presented later.

To demonstrate one use of the (POWER REQUIRED = DRAG × TAS) formula; if an aircraft climbs at a constant IAS, Drag remains constant, but TAS must be increased to compensate for decreasing air density. Therefore, when climbing at a constant IAS, Power Required increases.

Rate of climb is the vertical speed of an aeroplane measured in feet per minute; it is displayed in the cockpit on the vertical speed indicator (VSI).

Another way to think of rate of climb is to consider it as the TAS of the aeroplane along a gradient.

Figure 3.44 shows two identical aeroplanes at the same angle of climb. The one on the right has a higher TAS along the gradient. In the same time, the aeroplane on the right will climb through a greater vertical distance than the aeroplane on the left. Therefore the aeroplane on the right has a higher rate of climb. This demonstrates that TAS is one important factor when considering rate of climb.

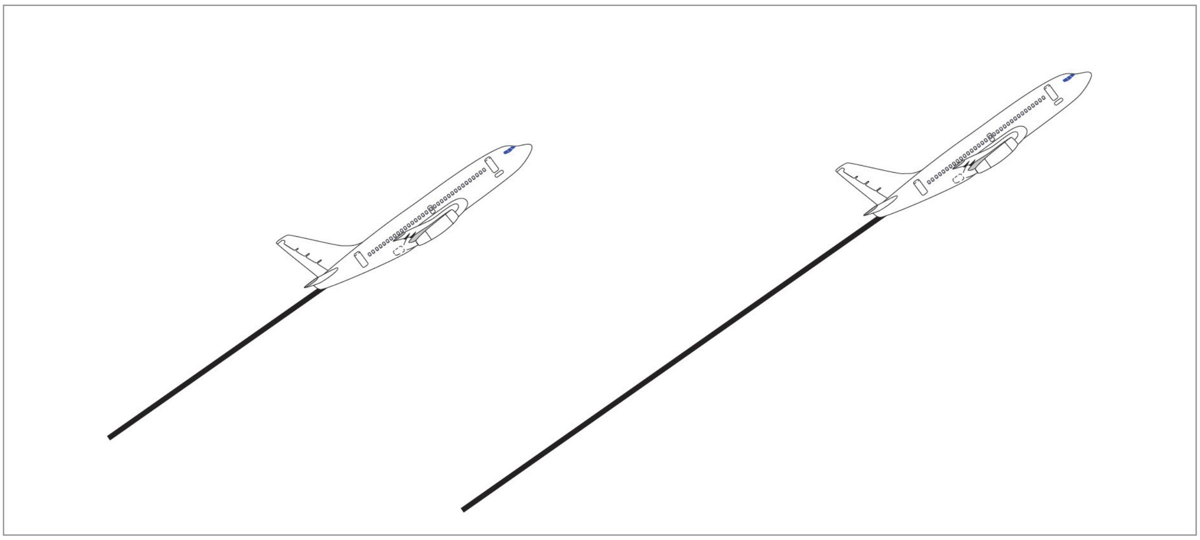


Figure 3.44

Figure 3.45 shows two identical aeroplanes at the same TAS. The aeroplane on the right is climbing at a steeper angle. In the same time, the aeroplane on the right climbs through a greater vertical distance than the aeroplane on the left. Therefore the aeroplane on the right has a higher rate of climb. This demonstrates that angle of climb is also an important factor in the rate of climb.

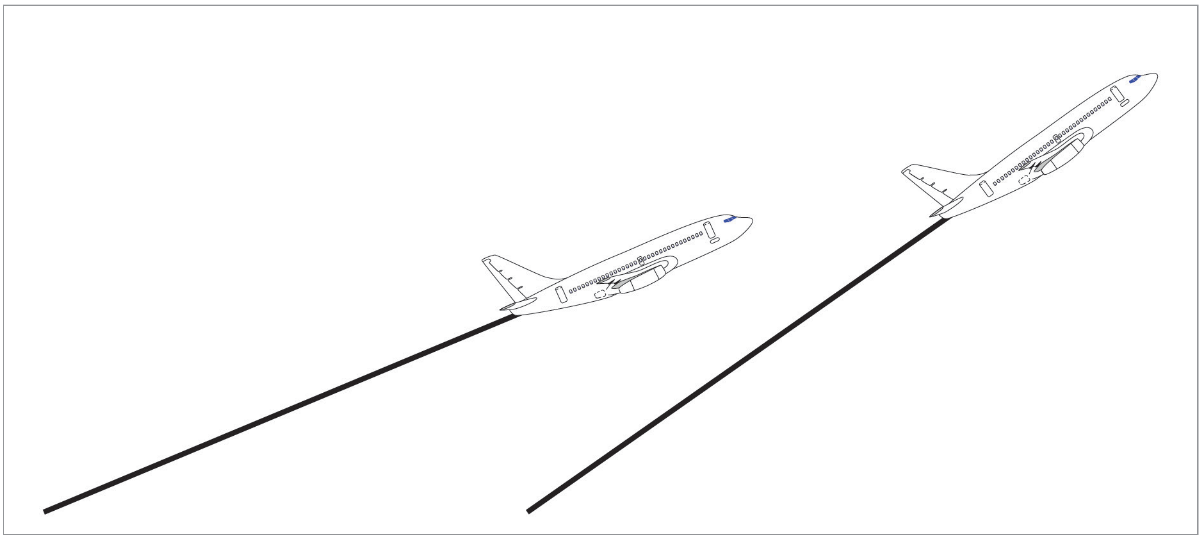


Figure 3.45

From *Figure 3.44* and *Figure 3.45* and the above explanation, it can be seen that rate of climb is a function of both angle of climb and TAS along the achieved gradient.

Sample Question

An aircraft with a gradient of 3.3% is flying at an IAS of 85 kt. At a Pressure Altitude of 8500 ft and an outside air temperature 15°C, the aircraft will have an ROC of:

a. 284 ft/min
b. 623 ft/min
c. 1117 ft/min
d. 334 ft/min

As Power Required is Drag × TAS, the IAS must be converted into TAS at the pressure altitude of 8500 ft and an OAT of 15 degrees C. Using a circular slide rule the TAS is 100 KTAS.

Note: *At climb angles less than approximately 20 degrees (and they always will be) the difference in length between the hypotenuse and the adjacent sides of a right angled triangle is so small that, for the sake of simplicity, it is disregarded in this type of calculation. So we do not need to worry about the fact that the aeroplane TAS is 'up' the hypotenuse. (EASA make the same assumption, so your answers will be correct)*

From our previous study of climb angle/gradient it is self-evident that use of percentage gradient allows us to visualize the ratio of 'up' to 'along'. In this case the climb gradient of 3.3% gives a horizontal component of 100 and a vertical component of 3.3. Because we are considering RATE of climb, the horizontal component is the TAS, which in this case is 100 KTAS; this must be converted into ft/min:

$$\frac{100 \text{ KTAS} \times 6080 \text{ ft}}{60 \text{ mins}} = 10\,133 \text{ ft/min}$$

$$\frac{10\,133 \text{ ft/min}}{100} = 101.33$$

$$101.33 \times 3.3 = 334 \text{ ft/min}$$

Let us return to the formula for the gradient of climb as shown below:

$$\text{Gradient} = \frac{(T - D)}{W}$$

Gradient is given by the formula Thrust Available minus Thrust Required divided by Weight. All that it is needed now for consideration of rate of climb is to add the velocity function, as shown below. This is now the formula for rate of climb.

$$\text{Rate of Climb} = \frac{(T - D)}{W} \times \text{TAS}$$

However, there is a little more detail to understand:

The velocity is True Airspeed, but Thrust and Drag are both forces and TAS is distance over time. Force multiplied by distance gives work and work divided by time gives power. This means that instead of Thrust multiplied by velocity, the formula now contains the expression Power Available, and instead of Thrust Required multiplied by velocity, the formula now has Power Required.

$$\text{Rate of Climb} = \frac{\underset{\text{(Excess Power Available)}}{\text{Power Available - Power Required}}}{W}$$

The rate of climb formula now reads Power Available minus Power Required (Excess Power Available), divided by Weight.

For any given Weight, the greater the Excess Power Available, the greater the rate of climb. Conversely, the less the Excess Power Available, the smaller the rate of climb. In order to maximize the aeroplane's rate of climb therefore, we need to maximize Excess Power. To understand how it is possible to obtain the greatest amount of Excess Power Available and therefore climb at the highest rate of climb it is necessary to look at some more graphs.

Excess Power Available (Jet)

Figure 3.46 shows a graph of Power Available and Power Required for a typical jet aeroplane. In order to provide some benchmarks it is necessary to locate the two reference speeds V_{MP} and V_{MD} that we mentioned earlier. The speed found at the bottom of the Power Required curve is called the velocity for minimum power or V_{MP}. There was another speed, slightly faster than V_{MP} called V_{MD}. This speed is the velocity for minimum drag and is found at the point of contact of the tangent from the origin to the Power Required curve.

Having analysed the reference speeds, the object now is to locate where Excess Power available is maximum.

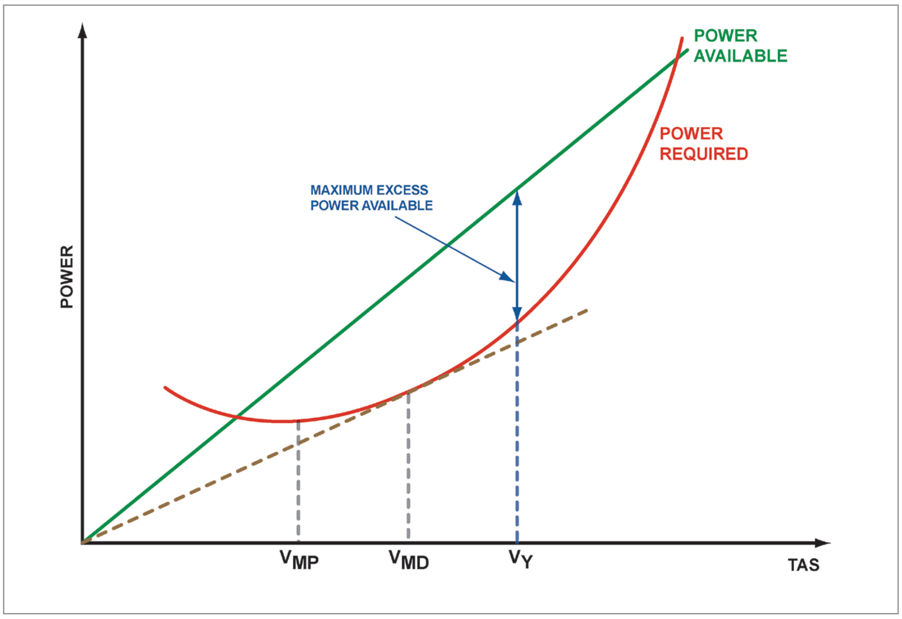


Figure 3.46 Maximum Excess Power available occurs at a speed faster than V_{MD} for jet aeroplanes

Looking at the graph, the area between the two curves represents the area of Excess Power available. On the graph the greatest amount of Excess Power available will be found where the distance between the curves is at its maximum. Notice that it occurs at a speed higher than V_{MD}. At any other speed, the Excess Power is less and the rate of climb will be less. The speed for the best rate of climb is called V_Y. Therefore for a jet aeroplane V_Y occurs at a speed higher than V_{MD}. V_Y is the airspeed to use to climb to the cruise or en route altitude as it will give the greatest height gain per unit time. In a typical 737-400 this speed is about 275 knots and is usually published in the aeroplane flight manual as an indicated airspeed.

Excess Power Available (Propeller)

Figure 3.47 is a graph of Power Available and Power Required for a typical propeller aeroplane. On the graph, the greatest amount of Excess Power available will be found where the distance between the curves is at its maximum.

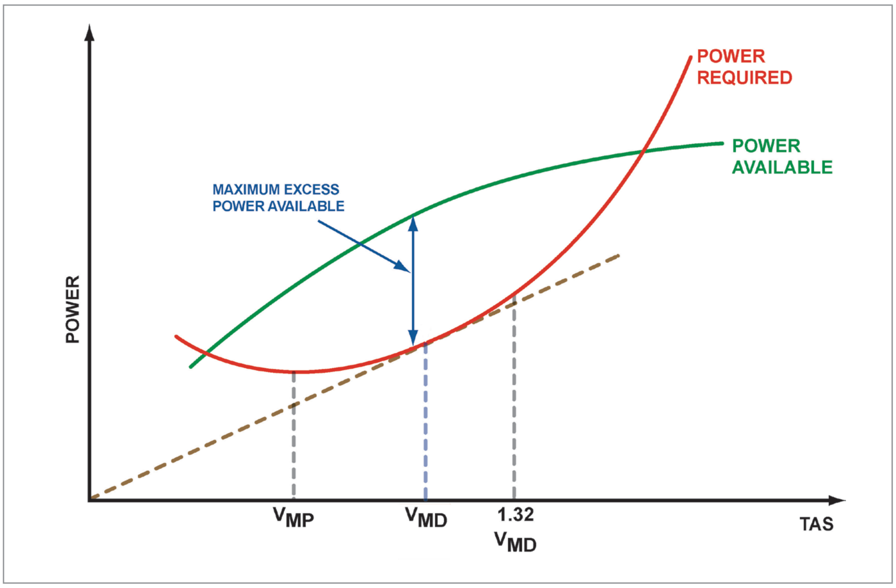


Figure 3.47 Maximum Excess Power available occurs at a speed higher than V_{MP} for propeller aeroplanes.

Notice that for a propeller aeroplane this occurs at a speed higher than V_{MP}. At any other speed, the Excess Power is less and the rate of climb less. As we have already learnt, V_Y is the speed for the best rate of climb. Therefore for a propeller aeroplane V_Y occurs at a speed higher than V_{MP}.

It is important to remember where V_Y is found for both jet and propeller aeroplanes. For example, looking at *Figure 3.47*, it can be seen that if a propeller aeroplane were climbing at a speed equal to V_{MP} and then selected a slightly higher speed, the Excess Power would increase and the rate of climb would increase. It is more obvious to see how speed changes affect both Excess Power and the rate of climb when the graph is used. Try and become aware of what the graphs look like so that you can use them to your advantage in test situations. Let us now examine what factors can influence the rate of climb for jet and propeller aeroplanes.

Factors Affecting Rate of Climb

Weight

You may recall that an increase in Weight creates more weight apparent Drag which reduces the angle of climb. For any given airspeed, if the angle of climb reduces, then so will the rate of climb because they are fundamentally linked. You can see this effect on the formula shown below. Simply by increasing the value of Weight, mathematically the rate of climb will reduce.

$$\text{Rate of Climb} = \frac{\text{Power Available - Power Required}}{W}$$

Weight has a further effect that we have already talked about. An increase in Weight will require an increase in Lift. Increasing Lift increases Induced Drag which causes the Drag curve to move up and right. The Power Required curve, shown in red in the following graph, is actually based upon Drag. Power Required is Drag multiplied by velocity.

So if the Drag curve moves up and right, so will the Power Required curve.

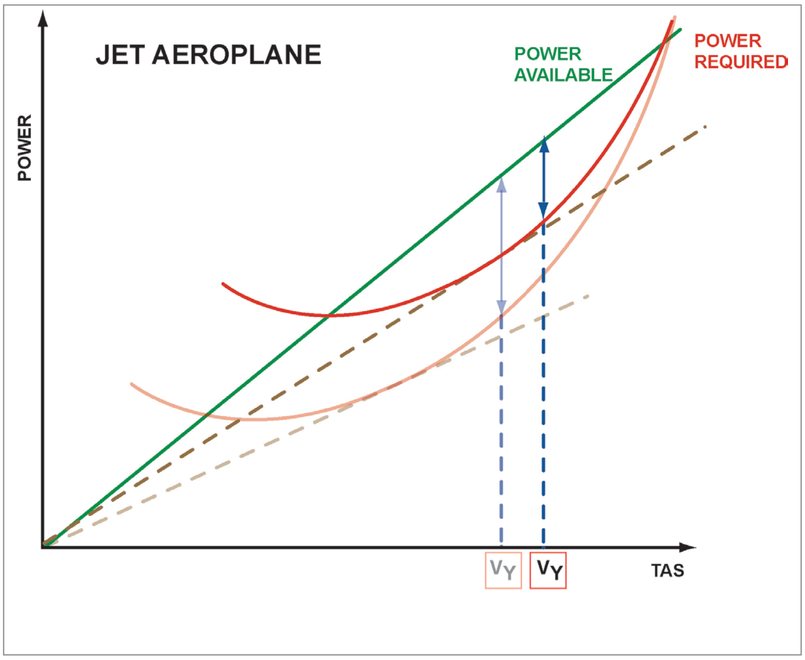


Figure 3.48 The effect of higher Weight is to move the Power Required curve up & right, reducing Excess Thrust & increasing V_Y.

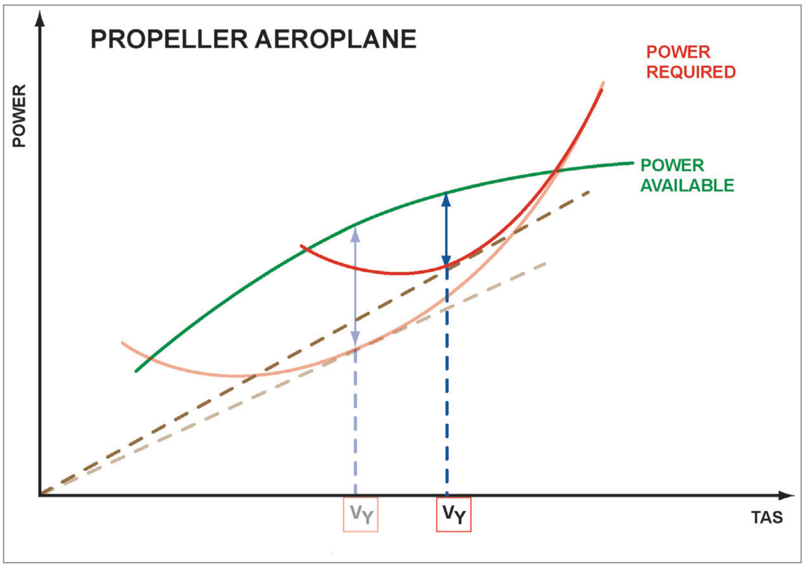


Figure 3.49 The effect of higher Weight is to move the Power Required curve up & right, reducing Excess Thrust & increasing V_Y.

As you can see from *Figure 3.48* for jet aeroplanes and *Figure 3.49* for propeller aeroplanes the power required curve moves up and right. Therefore, less Excess Power is available and therefore the rate of climb decreases. However, what is important to see is that the speed for maximum Excess Power available is no longer the same. It is now higher. So with higher Weight, the rate of climb is decreased but V_Y is increased.

Configuration

The next factor that affects the rate of climb is the configuration of the aircraft, in other words the use of flaps and gear.

If the gear and flaps are deployed then the profile drag of the aeroplane will increase. This increases total Drag and the Drag curve moves upwards and to the left.

The Power Required curves will follow the same movement as the Drag curve.

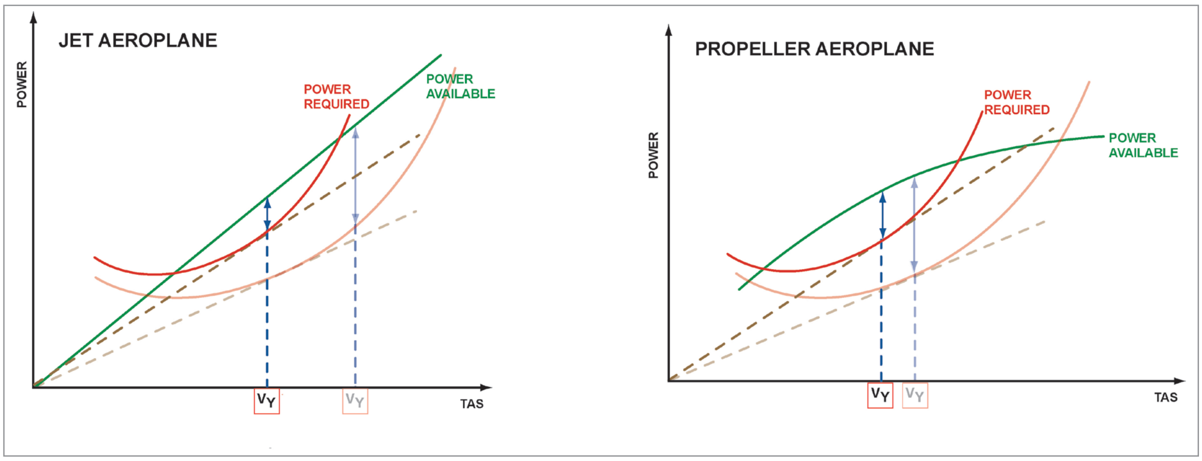


Figure 3.50 The effect of extending the gear or flaps is to move the Power Required curve up & left, reducing Excess Thrust & decreasing V_Y.

Notice the reduction in Excess Power available as shown by the blue double headed arrows. You may recall that a reduction in Excess Power reduces your rate of climb.

However, the important effect here is that the speed for maximum Excess Power is no longer the same. It is now lower. So with the gear and/or flaps deployed, the rate of climb is decreased and V_Y is decreased. If you use flaps for take off, remove them in stages when you have attained a positive stable climb ensuring you check through the aeroplane flight manual for the correct actions for your aeroplane.

As you do so, the rate of climb and the speed to attain the best rate of climb will increase, so you should accelerate to ensure you remain at V_Y.

Density

Density is another important factor that affects the rate of climb. However, density affects a lot of the variables in the formula for the rate of climb.

Shown below is an expanded rate of climb formula, reminding you that Power Available is Thrust multiplied by true airspeed and that Power Required is Drag multiplied by true airspeed.

$$\text{Rate of Climb} = \frac{\text{Power Available (Thrust} \times \text{TAS) - Power Required (Drag} \times \text{TAS)}}{W}$$

Focusing on the Power Available for the moment, decreased density will decrease the Thrust but it will also increase the true airspeed. The overall effect is that the Thrust loss is more than the TAS gain, meaning, overall, that the Power Available decreases.

Looking at Power Required, decreased density will increase the true airspeed but have no effect on the Drag. Therefore the Power Required will increase.

Looking at *Figure 3.51* and using the graphs for the jet and propeller aeroplanes you can see that the Power Available curves move down and right, and the Power Required curves move up and right. You will notice that there is less Excess Power available and this causes a reduction in the rate of climb for both aeroplane types.

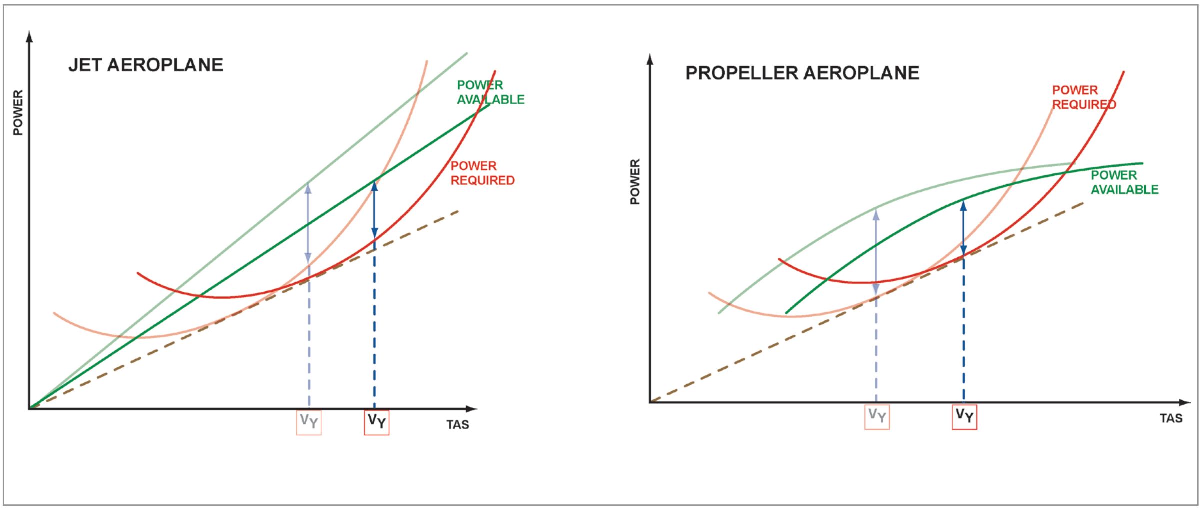


Figure 3.51 Decreasing density (high temperature/high altitudes/high humidity) reduces Excess Power available and increases V_Y (TAS).

Notice from the graphs that the true airspeed for V_Y increases a little with decreasing density or increasing altitude. However, as pilots we fly using indicated airspeeds and therefore it is important to understand what happens to the indicated airspeed of V_Y. In order that we may understand this, a further explanation is needed.

Using *Figure 3.52* you will notice that if the true airspeed increases only slightly with altitude, then the indicated airspeed will still fall. Therefore, although V_Y as TAS increases with decreasing density or increasing altitude, V_Y as an IAS decreases. In fact, V_Y will eventually fall to become the same value as V_X. So in summary, reduced density decreases the indicated airspeed of V_Y and decreases the rate of climb.

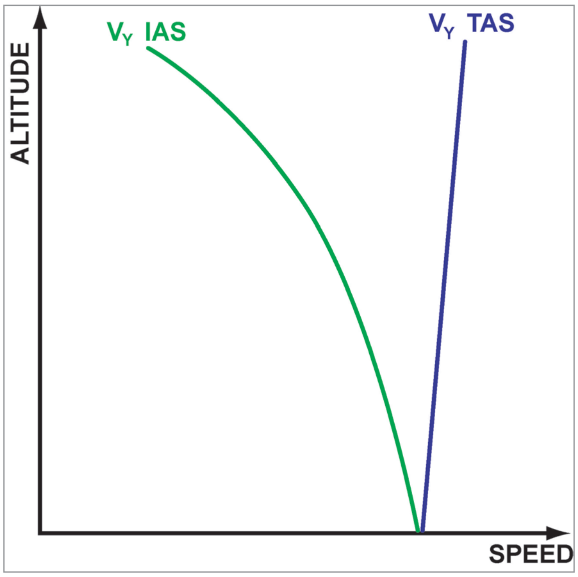


Figure 3.52 If the TAS of V_Y increases a little with reducing density or increasing altitude, the IAS of V_Y still falls.

In relation to altitude, as the aeroplane flies higher, the Excess Power available diminishes and therefore the maximum achievable rate of climb will decrease.

There will be an altitude where the Excess Power available decreases to zero, as shown in *Figure 3.53.* Therefore the rate of climb will also decrease to zero. This altitude is known as the absolute ceiling.

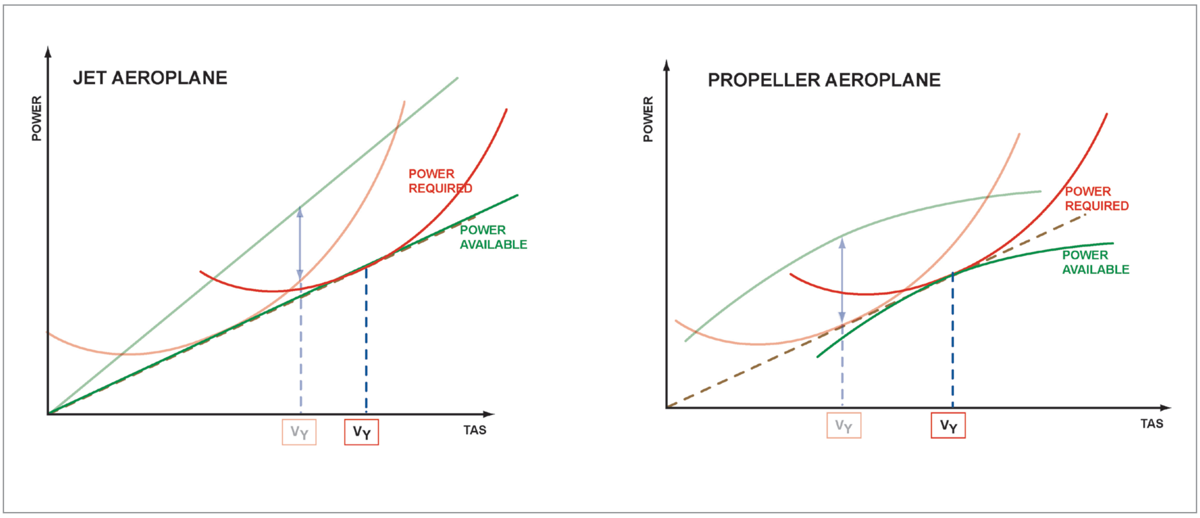


Figure 3.53 At a certain altitude or density, there is no more Excess Power available & therefore the rate of climb is zero

Figure 3.54 shows the excess of power for a typical aeroplane at various altitudes. Notice V_Y is the speed that gives the maximum Excess Power available and maximum achievable rate of climb. This is shown by the top of each curve. Also note that on this graph, V_X can be found where the tangent out of the origin touches each curve. As altitude increases, notice that the Excess Power available, achievable rate of climb and the indicated airspeed for V_Y decreases. Eventually there will be an altitude where V_X and V_Y are the same and there is no more Excess Power and, therefore, the rate of climb is zero. Remember that this altitude is called the absolute ceiling.

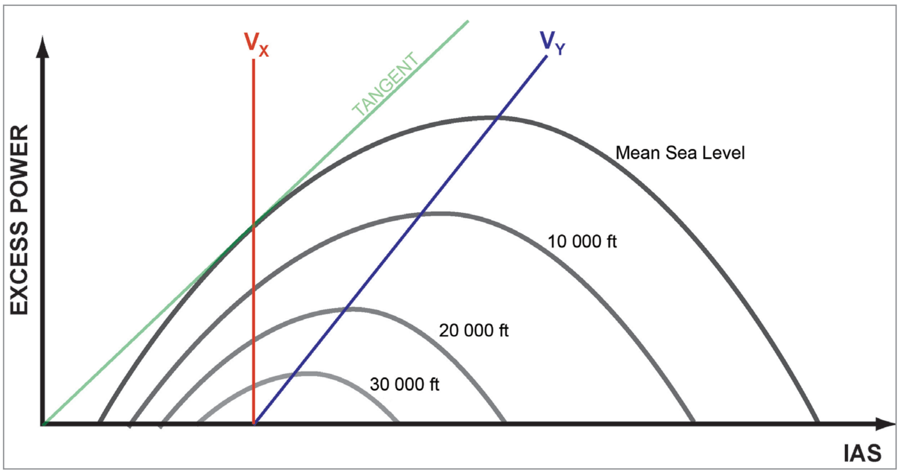


Figure 3.54 As altitude increases, the Excess Thrust reduces and V_Y as an IAS decreases to become the same speed as V_X at the absolute ceiling.

At its absolute ceiling, the performance of an aeroplane is so reduced that it is unable to manoeuvre. Therefore, absolute ceiling is a rather abstract concept for a pilot. It is more useful for a pilot to know his aeroplane's service ceiling. Service ceiling is defined by the manufacturers and aviation authorities as the maximum altitude where the best rate of climb airspeed will still produce a positive rate of climb at a specific number of feet per minute. The recommendation is to not exceed this altitude because the performance envelope of the aeroplane is very small. If the aeroplane were to climb higher, the rate of climb would fall to zero, the aeroplane would not be able to climb any higher and the absolute ceiling would be reached. At this altitude V_Y and V_X are the same speed. To find the absolute and service ceilings of your aeroplane, consult your flight manual and operate the aeroplane below the service ceiling to help maintain sufficient performance levels.

Wind

Wind is generally considered as horizontal movement of air. It cannot oppose or add to the vertical forces on the aeroplane. As such, wind has no effect on the rate of climb and therefore has no effect on the time to climb. However, vertical wind currents such as the ones found in microbursts or vertical windshear do affect the rate of climb of the aeroplane.

Questions

1. **What happens to the drag of a jet aeroplane if, during the initial climb after take-off, a constant IAS and constant configuration is maintained? (Assume a constant mass.)**

    a. The drag decreases
    b. The drag increases initially and decreases thereafter
    c. The drag remains almost constant
    d. The drag increases considerably

2. **The speed for best rate of climb is called:**

    a. V_O
    b. V_Y
    c. V_X
    d. V_2

3. **An increase in atmospheric pressure has, among other things, the following consequences on take-off performance:**

    a. a reduced take-off distance and degraded initial climb performance
    b. a reduced take-off distance and improved initial climb performance
    c. an increased take-off distance and degraded initial climb performance
    d. an increased take-off distance and improved initial climb performance

4. **A higher outside air temperature:**

    a. does not have any noticeable effect on climb performance
    b. reduces the angle of climb but increases the rate of climb
    c. reduces the angle and the rate of climb
    d. increases the angle of climb but decreases the rate of climb

5. **In unaccelerated climb:**

    a. thrust equals drag plus the uphill component of the gross weight in the flight path direction
    b. thrust equals drag plus the downhill component of the gross weight in the flight path direction
    c. lift is greater than the gross weight
    d. lift equals weight plus the vertical component of the drag

6. **A jet aeroplane is climbing at a constant IAS with maximum climb thrust. How will the climb angle / the pitch angle change?**

    a. Remain constant / decrease
    b. Remain constant / become larger
    c. Reduce / decrease
    d. Reduce / remain constant

7. Take-off performance data, for the ambient conditions, show the following limitations with flap 10° selected:

Runway or field limit mass: 5270 kg
Obstacle limit mass: 4630 kg

If the estimated take-off mass is 5000 kg, it would be prudent to consider a take-off with flaps at:

a. 20°, both limitations are increased
b. 5°, the obstacle limit mass is increased but the runway limit mass decreases
c. 5°, both limitations are increased
d. 20°, the obstacle limit mass is increased but the runway limit mass decreases

8. A four jet engine aeroplane whose mass is 150 000 kg is established on climb with engines operating. The lift over drag ratio is 14:1. Each engine has a thrust of 75 000 Newtons.
The gradient of climb is: (given: g = 10 m/s^2)

a. 12.86%
b. 27%
c. 7.86%
d. 92%

9. How does the best angle of climb and best rate of climb vary with increasing altitude?

a. Both decrease
b. Both increase
c. Best angle of climb increases while best rate of climb decreases
d. Best angle of climb decreases while best rate of climb increases

10. Following a take-off determined by the 50 ft (15 m) screen height, a light twin climbs on a 10% ground gradient. It will clear a 900 m high obstacle situated at 10 000 m from the 50 ft clearing point with an obstacle clearance of:

a. 85 m
b. It will not clear the obstacle
c. 115 m
d. 100 m

11. The rate of climb:

a. is approximately the climb gradient multiplied by the true airspeed divided by 100
b. is the downhill component of the true airspeed
c. is angle of climb multiplied by the true airspeed
d. is the horizontal component of the true airspeed

12. **Assuming that the required lift exists, which forces determine an aeroplane's angle of climb?**

a. Thrust and drag only
b. Weight and thrust only
c. Weight, drag and thrust
d. Weight and drag only

13. **Which of the following provides maximum obstacle clearance during climb?**

a. $1.2V_S$
b. The speed for maximum rate of climb
c. The speed at which the flaps may be selected one position further UP
d. The speed for maximum climb angle V_X

14. **Which speed provides maximum obstacle clearance during climb?**

a. The speed which gives maximum excess thrust
b. V_2 + 10 kt
c. The speed for maximum rate of climb
d. V_2

15. **Which of the equations below expresses approximately the unaccelerated percentage climb gradient for small climb angles?**

a. Climb Gradient = (Thrust - Drag)/Weight × 100
b. Climb Gradient = (Thrust + Drag)/Lift × 100
c. Climb Gradient = (Thrust - Mass)/Lift × 100
d. Climb Gradient = Lift/Weight × 100

16. **The absolute ceiling:**

a. is the altitude at which the best climb gradient attainable is 5%
b. is the altitude at which the aeroplane reaches a maximum rate of climb of 100 ft/min
c. is the altitude at which the rate of climb is theoretically zero
d. can be reached only with minimum steady flight speed

17. **The climb gradient of an aircraft after take-off is 6% in standard atmosphere, no wind, at 0 ft pressure altitude.**

Using the following corrections:

± 0.2% / 1000 ft field elevation
± 0.1% / °C from standard temperature
- 1% with wing anti-ice
- 0.5% with engine anti-ice

The climb gradient after take-off from an airport situated at 1000 ft, 17°C; QNH 1013.25 hPa, with wing and engine anti-ice operating for a functional check is:

a. 3.9%
b. 4.3%
c. 4.7%
d. 4.9%

18. As long as an aeroplane is in a positive climb:

a. V_X is always below V_Y
b. V_X is sometimes below and sometimes above V_Y depending on altitude
c. V_X is always above V_Y
d. V_Y is always above V_{MO}

19. A constant headwind component:

a. increases the angle of flight path during climb
b. increases the best rate of climb
c. decreases the angle of climb
d. increases the maximum endurance

20. A higher gross mass at the same altitude will cause:

a. V_Y and V_X to decrease
b. V_X to increase and V_Y to decrease
c. V_Y and V_X to remain constant since they are not affected by a higher gross mass
d. V_Y and V_X to increase

21. With a true airspeed of 194 kt and a vertical speed of 1000 ft/min, the climb gradient is approximately:

a. 3°
b. 3%
c. 5°
d. 8%

22. With take-off flaps set, V_X and V_Y will be:

a. lower than that for clean configuration
b. higher than that for clean configuration
c. the same as that for clean configuration
d. changed so that V_X increases and V_Y decreases compared to clean configuration

23. The maximum rate of climb that can be maintained at the absolute ceiling is:

a. 0 ft/min
b. 125 ft/min
c. 500 ft/min
d. 100 ft/min

24. A headwind will:

a. increase the rate of climb
b. shorten the time of climb
c. increase the climb flight path angle
d. increase the angle of climb

25. V_X is:

a. the speed for best rate of climb
b. the speed for best specific range
c. the speed for best angle of flight path
d. the speed for best angle of climb

26. The best rate of climb at a constant gross mass:

a. decreases with increasing altitude since the thrust available decreases due to the lower air density
b. increases with increasing altitude since the drag decreases due to the lower air density
c. increases with increasing altitude due to the higher true airspeed
d. is independent of altitude

27. With a jet aeroplane, the maximum climb angle can be flown at approximately:

a. $1.2V_S$
b. $1.1V_S$
c. the highest L/D ratio
d. the highest L/D^2 ratio

28. During a climb with all engines operating, the altitude where the rate of climb reduces to 100 ft/min is called:

a. thrust ceiling
b. maximum transfer ceiling
c. service ceiling
d. absolute ceiling

29. With all other factors remaining constant, how does increasing altitude affect V_X and V_Y as a TAS:

a. V_X will decrease and V_Y will increase
b. Both will increase
c. Both will remain the same
d. Both will decrease

30. Any acceleration in climb, with a constant power setting:

a. improves the climb gradient if the airspeed is below V_X
b. improves the rate of climb if the airspeed is below V_Y
c. decreases rate of climb and increases angle of climb
d. decreases the rate of climb and the angle of climb

31. For an aircraft maintaining 100 kt true airspeed and a climb gradient of 3.3% with no wind, what would be the approximate rate of climb?

a. 3.30 m/s
b. 33.0 m/s
c. 330 ft/min
d. 3300 ft/min

32. **During a climb to the cruising level, any headwind component:**

    a. decreases the climb time
    b. decreases the ground distance flown during that climb
    c. increases the amount of fuel for the climb
    d. increases the climb time

33. **The pilot of a single-engine aircraft has established the climb performance. The carriage of an additional passenger will cause the climb performance to be:**

    a. degraded
    b. improved
    c. unchanged
    d. unchanged, if a short field take-off is adopted

34. **A headwind component increasing with altitude, as compared to zero wind condition: (assuming IAS is constant.)**

    a. improves angle and rate of climb
    b. decreases angle and rate of climb
    c. has no effect on rate of climb
    d. does not have any effect on the angle of flight path during climb

35. **Which of the following combinations adversely affects take-off and initial climb performance?**

    a. High temperature and low relative humidity
    b. Low temperature and low relative humidity
    c. High temperature and high relative humidity
    d. Low temperature and high relative humidity

36. **A decrease in atmospheric pressure has, among other things, the following consequences on take-off performance:**

    a. a reduced take-off distance and degraded initial climb performance
    b. an increased take-off distance and degraded initial climb performance
    c. a reduced take-off distance and improved initial climb performance
    d. an increased take-off distance and improved initial climb performance

37. **The angle of climb with flaps extended, compared to that with flaps retracted, will normally be:**

    a. increased at moderate flap setting, decreased at large flap setting
    b. smaller
    c. larger
    d. not changed

38. **What is the effect of tailwind on the time to climb to a given altitude?**

    a. The time to climb increases
    b. The time to climb decreases
    c. The effect on time to climb will depend on the aeroplane type
    d. The time to climb does not change

39. Changing the take-off flap setting from flap 15° to flap 5° will normally result in:

a. a longer take-off distance and a better climb
b. a shorter take-off distance and an equal climb
c. a better climb and an equal take-off distance
d. a shorter take-off distance and a better climb

40. What is the influence of the mass on maximum rate of climb (ROC) speed if all other parameters remain constant?

a. The ROC is affected by the mass, but not the ROC speed
b. The ROC and the ROC speed are independent of the mass
c. The ROC speed increases with increasing mass
d. The ROC speed decreases with increasing mass

41. Following a take-off to the 50 ft (15 m) screen height, a light twin climbs on a gradient of 5%. It will clear a 160 m obstacle situated at 5000 m from the 50 ft point with an obstacle clearance margin of:

a. it will not clear the obstacle
b. 105 m
c. 90 m
d. 75 m

42. The climb "gradient" is defined as the ratio of:

a. true airspeed to rate of climb
b. rate of climb to true airspeed
c. the increase of altitude to horizontal air distance expressed as a percentage
d. the horizontal air distance over the increase of altitude expressed as a percentage

43. When flying an aircraft at:

i. V_X without flap.
ii. V_X with flap.
iii. V_Y without flap.
iv. V_Y with flap.

the aircraft should be achieving:

a. i. the best rate of climb
ii. the best rate of climb, but using a slightly faster speed than in (i)
iii. the best angle of climb
iv. the best angle of climb, but using a slightly faster speed than in (iii)

b. i. a good angle of climb
ii. the best angle of climb
iii. a good rate of climb
iv. the best rate of climb

c. i. the best angle of climb
ii. a slightly reduced angle of climb compared to (i) if using a slightly reduced speed than in (i)
iii. the best rate of climb
iv. a slightly reduced rate of climb compared to (iii) if using a slightly reduced speed than in (iii)

d. i. a good rate of climb
ii. the best rate of climb
iii. a good angle of climb
iv. the best angle of climb

Answers

1	2	3	4	5	6	7	8	9	10	11	12
c	b	b	c	b	c	b	a	a	c	a	c

13	14	15	16	17	18	19	20	21	22	23	24
d	a	a	c	a	a	a	d	a	a	a	c

25	26	27	28	29	30	31	32	33	34	35	36
d	a	c	c	b	d	c	b	a	c	c	b

37	38	39	40	41	42	43
b	d	a	c	b	c	c

Chapter

4

General Principles - Descent

Descent

Descent performance will focus mainly on the forces in the descent and what factors govern the descent. In a normal flight, the descent will occur at a point we define as "the top of descent" which may be up to 200 miles before the destination aerodrome. A descent will also be required following engine failure or depressurization. In this latter situation the descent is forced early and it is important for the pilot to be aware of what determines the characteristics of the descent so that obstacle clearance can be maintained. There are two ways of measuring the descent performance of an aircraft. Either by angle of descent, (sometimes called descent range) or rate of descent, (sometimes called descent endurance).

Angle of Descent

In order to initiate a steady descent, thrust is normally reduced. The forward force of thrust in now less than the rearward force of drag and the aircraft slows down. The value of drag that exceeds the thrust force is called excess drag. In order to balance the forces and maintain speed, the nose is lowered until the weight apparent thrust provides enough forward force to balance the excess of drag as can be seen in *Figure 4.1*. Now the aircraft will maintain this steady descent angle at a constant speed. The forward and rearward forces are in balance once again. Drag (D_A) is being balanced by the thrust (T) and the weight apparent thrust (W sin γ).

$$D_A = T + W \sin \gamma$$

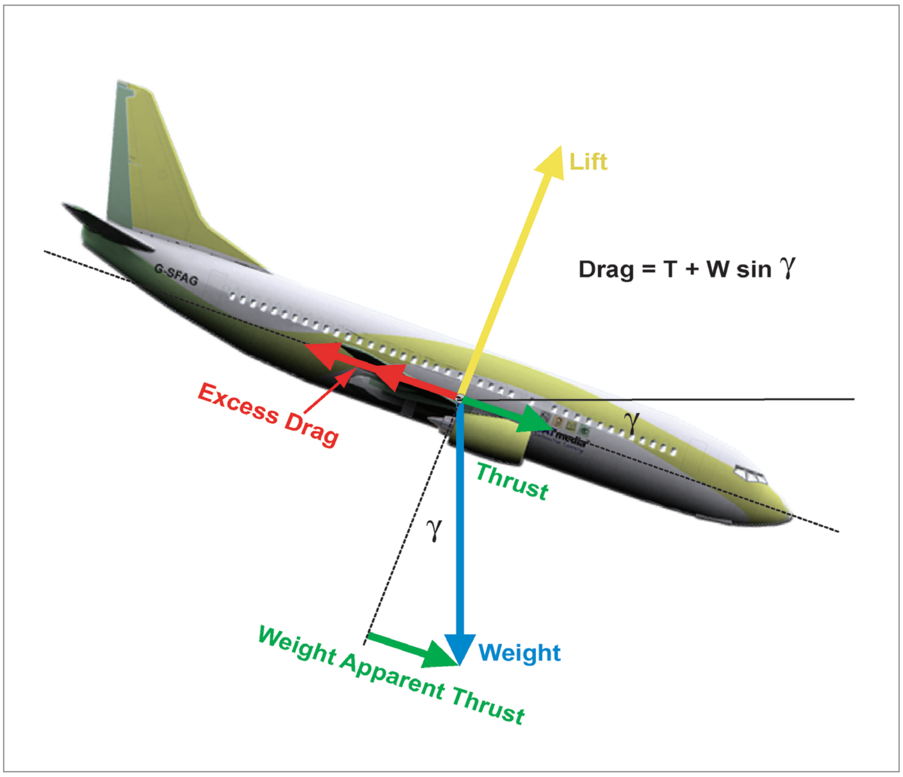


Figure 4.1 An illustration showing the balance of forces in normal powered descent

The weight apparent thrust can be calculated by multiplying weight by the sine of the angle gamma. If thrust were reduced even more as shown in *Figure 4.2*, then there would be a greater amount of excess drag. More weight apparent thrust is therefore needed to balance the greater amount of excess drag. To gain more weight apparent thrust the aeroplane nose must be lowered even more. The result is an increase in the descent angle. For the purpose of the examinations, lowering the nose is a decrease in pitch.

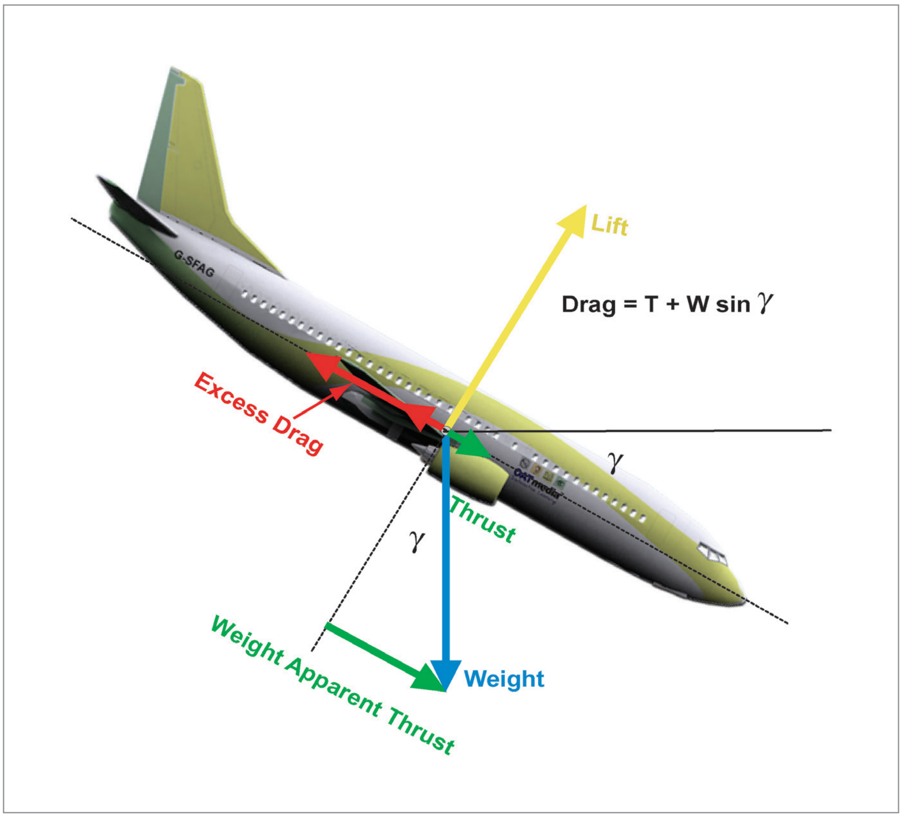


Figure 4.2 An illustration showing the balance of forces in low powered descent

From this demonstration it is clear that it is the excess drag which determines the angle of descent. Notice that the angle gamma is the same angle as the angle of descent.

Rearranging the formula shown in *Figure 4.1* and *Figure 4.2* ($D_A = T + W \sin \gamma$) so that angle gamma can be calculated gives us the formula for the angle or gradient of descent.

$$\text{Gradient of Descent (\%)} = \frac{(D - T)}{W} \times 100$$

Drag minus thrust will give excess drag. In summary then, the angle or gradient of descent is controlled by the excess drag. In order to visualize this excess drag, it is necessary to return to the thrust and drag graphs that were used in the climbing lesson.

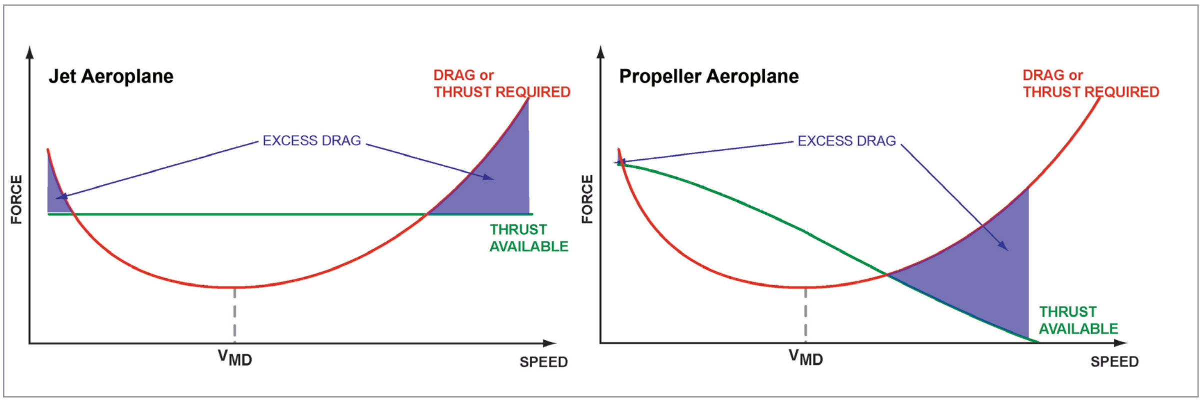


Figure 4.3 An illustration showing excess drag (D-T) for a jet & propeller aeroplane

Shown in *Figure 4.3* are the thrust and drag curves for a jet and propeller aeroplane. We have learnt that in order to descend, there has to be an excess of drag. On the graphs, excess drag can be found by taking the area beneath the drag curve and subtracting from it the area beneath the thrust curve. The solid purple highlighted areas represent excess drag. Notice that if thrust is reduced at any given speed, then excess drag increases, therefore the descent angle increases.

Maximum Angle of Descent

If it were a performance priority to maximize the angle of descent, then from the theory we have seen so far, we would have to maximize excess drag.

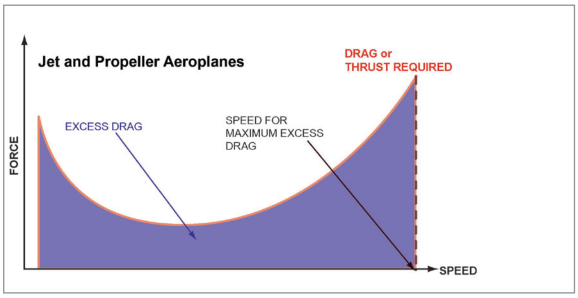


Figure 4.4 An illustration showing excess drag (D-T) for a jet & propeller aeroplane with zero thrust

If thrust is reduced to zero, notice that the excess drag area is a maximum, but to obtain the maximum excess drag, the aeroplane needs to be accelerated to a very high speed, as shown in *Figure 4.4*. This can be achieved by closing the throttles, and continuously lowering the nose of the aeroplane so as to cause the increasing amount of weight apparent thrust to accelerate the aeroplane. As speed rises even more, both the excess drag and the angle of descent will increase. The angle of descent, then, is a function of excess drag; the greater the excess drag the steeper the angle of descent. This angle could be increased even more if it were possible to increase the excess drag. This can be achieved by deploying drag devices such as the speed brakes and the undercarriage, but attention must be paid to their maximum deployment speeds. The practical side of increasing drag to increase your descent angle occurs mainly in training and occasionally in commercial operations after air traffic re-routes. Take note that any increase in excess drag either by deploying speed brakes or undercarriage, or by reducing thrust will steepen the angle of descent.

Minimum Angle of Descent

You have just learnt that to maximize the descent angle excess drag must be maximized. Following an engine failure the aim is to ensure that the aeroplane will cover the greatest horizontal distance so that the pilot has a large area in which to select a suitable landing field. This can only be achieved by using the smallest possible angle of descent sometimes referred to as the minimum glide angle. To descend at the smallest possible angle, excess drag must be minimum. This can be seen in *Figure 4.5*.

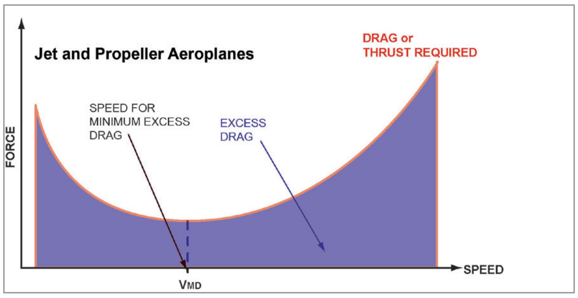


Figure 4.5 An illustration showing that excess drag (D-T) is minimum at V_{MD} for a jet & propeller aeroplane with zero thrust

Notice that V_{MD} is the speed found at the bottom of the drag curve. At V_{MD}, drag is at a minimum. Therefore, to descend at the minimum possible angle, the aeroplane must be flown at V_{MD} since, with no power, V_{MD} is the speed that gives minimum excess drag.

One of the other ways to examine glide performance is to consider the aeroplane's lift over drag ratio commonly referred to as the lift drag ratio. However, before we do this, there is a little more detail to discuss first. In the glide descent the resultant of drag and lift balances the force of weight. From your Principles of Flight lessons, the term for the resultant of lift and drag is total reaction. If the drag force line is moved upwards you can see that we now have a triangle of forces with the angle gamma being the angle between the lift and total reaction.

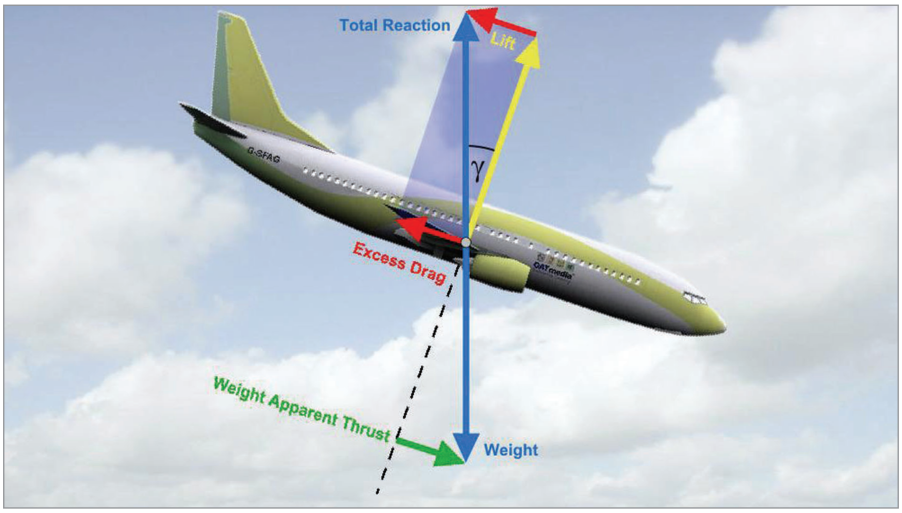


Figure 4.6 The value of drag (in red) & the value of lift (in yellow) determine the angle gamma, which is also the same as the angle of descent

Looking at *Figure 4.6,* if there were any change in the lift and/or drag values, both the angle gamma and the glide angle would change. A typical modern jet has a maximum lift drag ratio of about 19. Where this ratio reaches its maximum, the value of the angle gamma will be at its minimum. The lift drag ratio reaches its maximum value at 4 degrees angle of attack and is always at the speed V_{MD}. Therefore, V_{MD} is the speed for the minimum angle of descent or the minimum glide angle. V_{MD} is also known as the speed for L/D Max. The angle of attack at V_{MD} is fixed at 4 degrees. If the angle of attack is greater or less than 4 degrees, the speed will change, the lift drag ratio will decrease in value and consequently the angle of the glide will increase.

If, following an engine failure, you fly at V_{MD}, your aeroplane will be flying at the smallest possible glide angle. Never try to stretch the glide by raising the nose of the aeroplane. If you do so, the speed will decrease and the glide angle will steepen. At any speed other than V_{MD} your glide angle will be steeper than the optimal glide angle.

Shown in *Figure 4.7* is the angle of glide at V_{MD}.

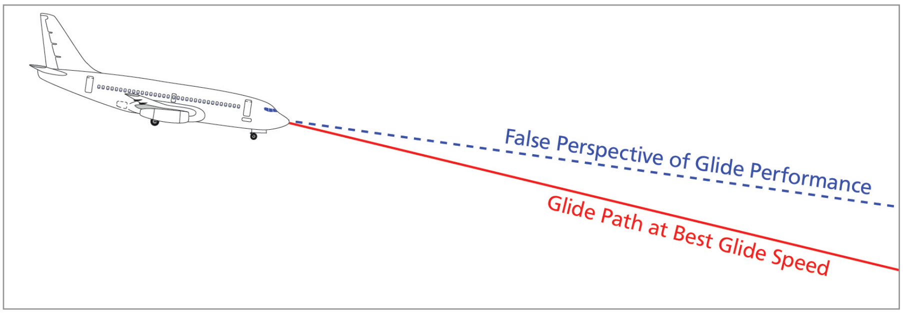


Figure 4.7 When flying at V_{MD}, if the nose is raised the aeroplane will slow down & therefore not be at V_{MD} anymore. The angle of descent will therefore steepen

The temptation is to raise the nose a little. This gives an impression from the cockpit that the glide is being extended. If the nose were raised, the weight apparent thrust would decrease and the aeroplane would slow down. As a result the aeroplane would not be flying at V_{MD}, and therefore not have the best lift drag ratio. The result would be a steeper descent angle despite the fact that the aeroplane had a slightly higher nose attitude. Be disciplined in following the procedures for flying at the optimum glide angle as laid down by the manufacturer or the operator in the aeroplane flight manual.

Rate of Descent

You may recall we mentioned at the beginning of the descent section that there were two ways of assessing the descent performance. We have covered the angle of descent or descent range; now let us consider the rate of descent or descent endurance.

You have already learnt in an earlier lesson that the rate of climb is a function of both climb angle and velocity. Similarly, the rate of descent is a function of descent angle and velocity. Shown below is the formula for the rate of descent.

$$\text{Rate of Descent} = \frac{DV - TV}{W}$$

You may recall that force and velocity gave us Power. So the correct formula for the rate of descent is shown below.

$$\text{Rate of Descent} = \frac{\overset{\text{(Excess Power Required)}}{\text{Power Required - Power Available}}}{W}$$

The rate of descent is equal to the power required minus the power available divided by the weight. Power required minus power available gives excess power required. So, for any given weight, the rate of descent is determined by the excess power required.

The greater the excess power required, the larger the achievable rate of descent, conversely the lesser the excess power required the smaller will be the rate of descent.

In an emergency descent, for instance a descent initiated by the pilot following depressurization, the aim is to reach FL100 as soon as possible. To achieve this requirement, the aeroplane would need to lose height with the maximum possible rate of descent which can only happen if the aeroplane has maximum excess power required. Shown in *Figure 4.8* is the power required and power available curves for both the jet and propeller aeroplane. The areas beneath the power required curves but above the power available curves represent the excess power required and are highlighted in purple. However, notice that there is not very much excess power required, but it is possible to generate more.

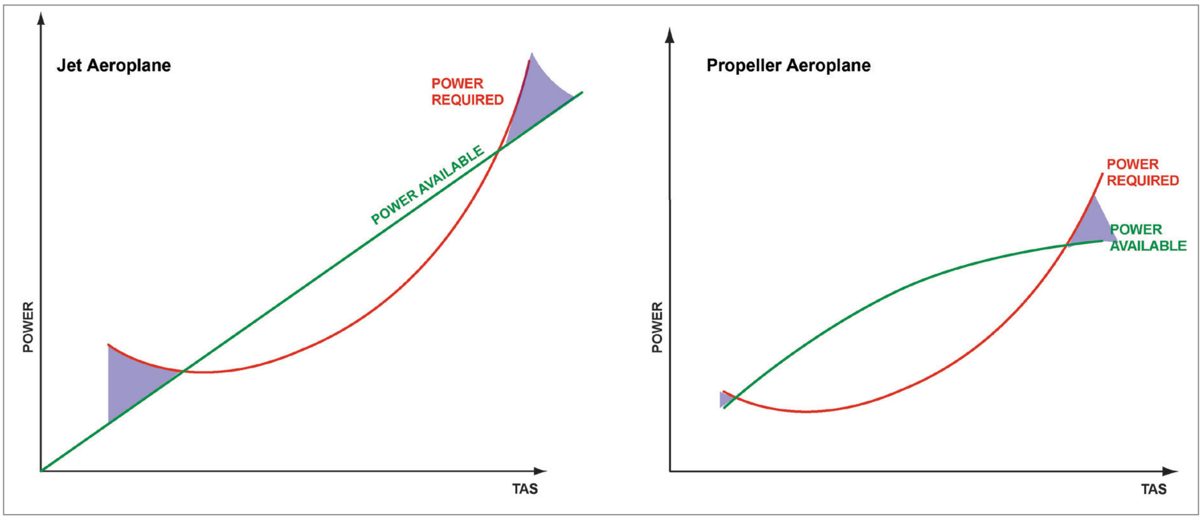


Figure 4.8 The area beneath the power required line but above the power available line represents the area for excess power required. This is shown by the purple shaded areas

In order to create the conditions of the greatest excess of power required, power available (represented by the green lines in the previous diagram) must be reduced to zero as shown by *Figure 4.9*.

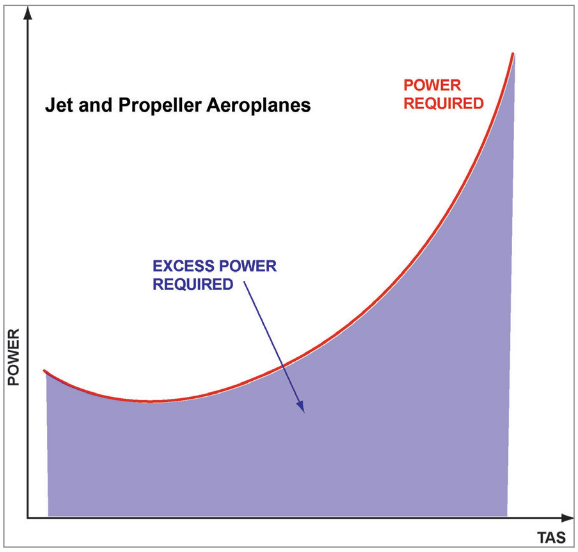


Figure 4.9 With no power available since the throttle is closed, all of the area beneath the power required curve becomes excess power required

Notice that the purple areas of excess power required, are now as large as possible. In order to achieve the greatest rate of descent the aeroplane needs to fly at a speed that achieves the greatest excess power required. It is obvious from the graph that this can only be achieved at very high speeds. Remember that power required is a function of speed and drag, therefore the aeroplane needs to be configured for high drag and high speed in order to achieve maximum power required. In fact, for a lot of

Class A aeroplanes, emergency descents are flown at maximum operating speeds with speed brakes deployed and thrust at idle.

If it were the aim to descend at the lowest rate of descent, the aeroplane would need to fly at a speed that gives the minimum excess power required. Looking at *Figure 4.9* this point is plain to see. In fact it is found at the very bottom of the power required curve. You may recall that this speed is called V_{MP}. So, to lose height at the slowest possible rate of descent the aeroplane would need to fly at V_{MP}. The lowest rate of descent is also known as maximum descent endurance, which essentially means the aeroplane will take the greatest time to descend. EASA sometimes refer to this as the speed for maximum glide endurance.

Factors Affecting Descent

Weight

For the effect of weight on the descent we shall only consider the effect in a glide, in other words with idle power. Let us firstly concentrate on the minimum angle of descent or the glide angle.

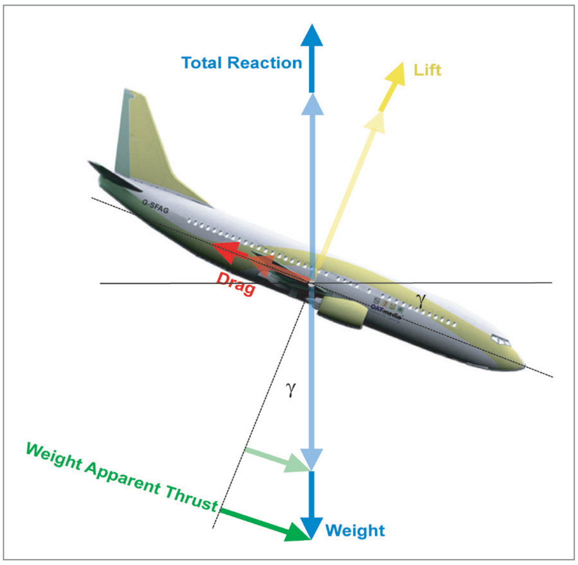


Figure 4.10 An illustration showing that with a higher weight the forward & rearward forces along the flight path are larger but the angle of glide remains unchanged

Looking at *Figure 4.10* you can see that an aeroplane with a higher weight will have a larger amount of weight apparent thrust, but if the aeroplane is still flying at V_{MD}, (which will be faster with a higher weight) it will also have a greater amount of drag. You will recall this from knowing that a higher weight moves the drag curve up and right. In *Figure 4.10* you will notice that the forward and rearward forces along the flight path are still balanced, albeit a bit longer. But crucially notice that the angle of descent is unchanged. It is important for you to understand that weight has no effect on the minimum angle of descent or glide angle but it will increase the speed of the descent.

In summary therefore, weight has no effect on the minimum angle of descent, but it will increase the speed along that descent gradient and therefore it will increase the rate of descent.

Configuration

The next factor to affect the angle and rate of descent is the aeroplane's configuration. As with the effect of weight, configuration changes are best understood when assuming idle thrust. Looking at *Figure 4.11*, if the flaps or undercarriage were deployed, then notice that excess drag increases. To balance this increase in excess drag, the nose is lowered. This action increases weight apparent thrust and a balance of forces is restored but, importantly the balance is achieved at a higher angle of descent and therefore a higher rate of descent.

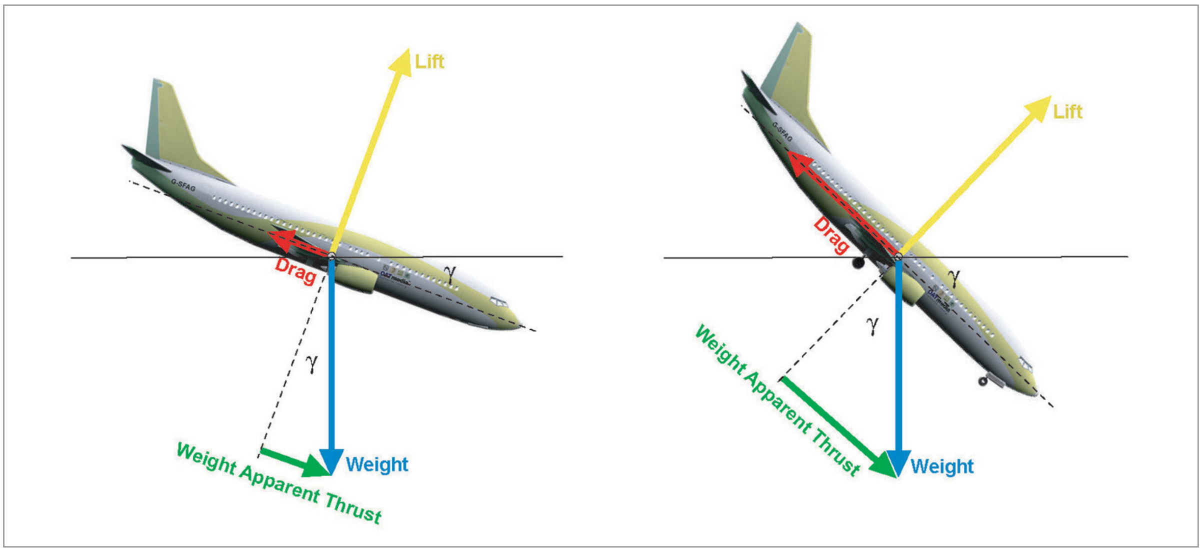


Figure 4.11 An illustration showing an increase in excess drag must be balanced by an increase in weight apparent thrust

The effect of configuration can also be seen using graphs. Shown below in *Figure 4.12* is the drag curve for the jet and propeller aeroplane with excess drag shown by the purple area. With flaps and undercarriage deployed, you will recall that the curves move up and left. This has the effect of increasing the excess drag and therefore increasing the angle of descent for any given speed. Notice too that the speed for the minimum angle of descent, V_{MD}, is lower.

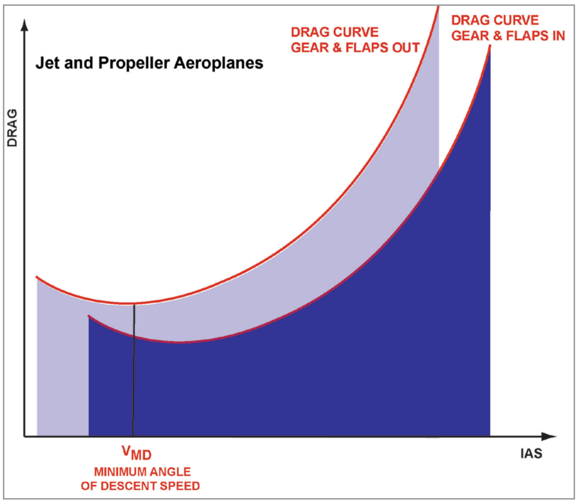


Figure 4.12 With gear & flaps deployed, the drag curve moves up & left showing an increase in excess drag & consequently an increase in glide angle

The same effect can be seen in *Figure 4.13* when examining the rate of descent and by using the power required graph. Similarly the purple area represents excess power required.

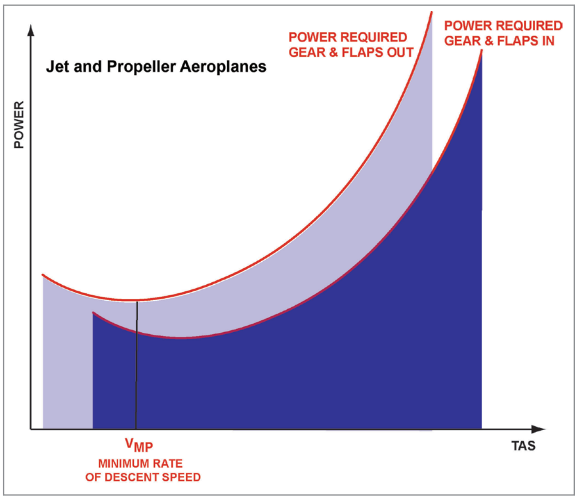


Figure 4.13 With gear & flaps deployed, the power required curve moves up & left showing an increase in excess power required & consequently an increase in the rate of descent

With flaps and gear deployed, you will recall that the power curves move up and left. This has the effect of increasing the excess power required and therefore increasing the rate of descent. Notice too that the speed for the minimum rate of descent, V_{MP}, is lower.

In summary then, with gear and flaps deployed the angle and rate of descent increase, but the speeds for minimum angle and minimum rate of descent decrease.

Wind

Figure 4.14 shows the effect of headwinds and tailwinds on the angle of descent. Headwinds steepen the glide angle and decrease the descent range whereas tailwinds decrease the glide angle but increase the descent range. However, notice that the aeroplane in a headwind or tailwind reaches the same descent altitude in the same time as the aeroplane flying in zero wind conditions. This demonstrates that a headwind or tailwind has no effect on the rate of descent.

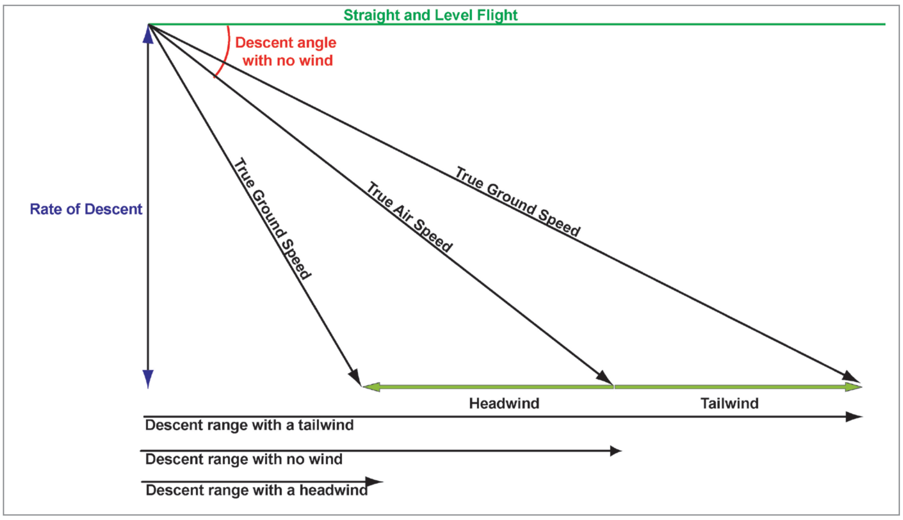


Figure 4.14 An illustration showing the effect of headwinds & tailwinds on the angle & rate of descent

The effect of the wind on the angle of descent can be examined a little further. Because of the adverse effect of the headwind on descent range, then in a glide, it would be of benefit to increase the aeroplane's forward speed slightly. This has the effect of reducing the time spent in the headwind. This means that the aeroplane will not be pushed back as much by the wind. Similarly with a tailwind; because a tailwind benefits the glide by increasing the descent range, it would be better to try and stay in this situation for longer. So this time the aeroplane's forward speed can be decreased so that the aeroplane can stay under the tailwind effect for longer and therefore be pushed further forwards.

When flying on a training sortie, make sure you know the wind speed and direction both for the surface and aloft. This will help you plan a better descent giving you more accurate circuit patterns. But more importantly, knowledge of what the wind is doing will ensure you obtain maximum descent performance if an engine failure should occur.

Questions

1. **Two identical aeroplanes of different masses are descending at idle thrust. Which of the following statements correctly describes their descent characteristics?**

   a. At a given angle of attack, both the vertical and the forward speed are greater for the heavier aeroplane
   b. There is no difference between the descent characteristics of the two aeroplanes
   c. At a given angle of attack the heavier aeroplane will always glide further than the lighter aeroplane
   d. At a given angle of attack the lighter aeroplane will always glide further than the heavier aeroplane

2. **In a steady descending flight equilibrium of forces acting on the aeroplane is given by: (T = Thrust, D = Drag, W = Weight, descent angle = GAMMA)**

   a. T + D = - W sin GAMMA
   b. T + W sin GAMMA = D
   c. T - W sin GAMMA = D
   d. T - D = W sin GAMMA

3. **Which of the following combinations has an effect on the angle of descent in a glide? (Ignore compressibility effects.)**

   a. Configuration and mass
   b. Configuration and angle of attack
   c. Mass and altitude
   d. Altitude and configuration

4. **Which statement is correct for a descent without engine thrust at maximum lift to drag ratio speed?**

   a. The mass of an aeroplane does not have any effect on the speed for descent
   b. The higher the gross mass the greater is the speed for descent
   c. The higher the gross mass the lower is the speed for descent
   d. The higher the average temperature (OAT) the lower is the speed for descent

5. **An aeroplane is in a power-off glide at best gliding speed. If the pilot increases pitch attitude, the glide distance:**

   a. increases
   b. remains the same
   c. may increase or decrease depending on the aeroplane
   d. decreases

6. **Is there any difference between the vertical speed versus forward speed curves for two identical aeroplanes having different masses? (Assume zero thrust and wind).**

   a. Yes, the difference is that the lighter aeroplane will always glide a greater distance
   b. Yes, the difference is that for a given angle of attack both the vertical and forward speeds of the heavier aeroplane will be larger
   c. No difference
   d. Yes, the difference is that the heavier aeroplane will always glide a greater distance

7. **Which statement is correct for a descent without engine thrust at maximum lift to drag ratio speed?**

   a. A tailwind component increases fuel and time to descent
   b. A tailwind component decreases the ground distance
   c. A tailwind component increases the ground distance
   d. A headwind component increases the ground distance

8. **An aeroplane executes a steady glide at the speed for minimum glide angle. If the forward speed is kept constant at V_{MD}, what is the effect of a lower mass on the rate of descent / glide angle / C_L/C_D ratio?**

   a. decreases / constant / decreases
   b. increases / increases / constant
   c. increases / constant / increases
   d. decreases / constant/ constant

9. **Which of the following factors leads to the maximum flight time of a glide?**

   a. Low mass
   b. High mass
   c. Headwind
   d. Tailwind

10. **A constant headwind:**

   a. increases the descent distance over ground
   b. increases the angle of the descent flight path
   c. increases the angle of descent
   d. increases the rate of descent

11. **An aeroplane carries out a descent maintaining a constant Mach number in the first part of the descent and then at a constant indicated airspeed in the second part of the descent. How does the angle of descent change in the first and in the second part of the descent?**

   Assume idle thrust and clean configuration and ignore compressibility effects.

   a. Increases in the first part; is constant in the second
   b. Increases in the first part; decreases in the second
   c. Is constant in the first part; decreases in the second
   d. Decreases in the first part; increases in the second

12. **During a glide at a constant Mach number, the pitch angle of the aeroplane will:**

   a. decrease
   b. increase
   c. increase at first and decrease later on
   d. remain constant

13. **Which of the following factors will lead to an increase of ground distance during a glide, while maintaining the appropriate minimum glide angle speed?**

   a. Headwind
   b. Tailwind
   c. Increase of aircraft mass
   d. Decrease of aircraft mass

14. A twin jet aeroplane is in cruise, with one engine inoperative, and has to overfly a high terrain area. In order to allow the greatest height clearance, the appropriate airspeed must be the airspeed:

a. giving the greatest C_D/C_L ratio
b. for long range cruise
c. of greatest lift-to-drag ratio
d. giving the lowest C_L/C_D ratio

15. What is the effect of increased mass on the performance of a gliding aeroplane at V_{MD}?

a. The lift/drag ratio decreases
b. The speed for best angle of descent increases
c. There is no effect
d. The gliding angle decreases

16. A twin-engine aeroplane in cruise flight with one engine inoperative has to fly over high ground. In order to maintain the highest possible altitude the pilot should choose:

a. the speed corresponding to the minimum value of lift / drag ratio
b. the speed at the maximum lift
c. the speed corresponding to the maximum value of the lift / drag ratio
d. the long range speed

17. With all engines out, a pilot wants to fly for maximum time. Therefore, he has to fly the speed corresponding to:

a. the minimum power required
b. the critical Mach number
c. the minimum angle of descent
d. the maximum lift

18. Descending from cruising altitude to ground level at a constant IAS in a headwind, compared to still air conditions, will:

a. reduce the time to descend
b. increase the time to descend
c. reduce the ground distance taken
d. reduce the fuel used in the descent

19. When descending at a constant Mach number:

a. the angle of attack remains constant
b. the IAS decreases then increases
c. the pitch angle will increase
d. the pitch angle will decrease

Answers

1	2	3	4	5	6	7	8	9	10	11	12
a	b	b	b	d	b	c	d	a	b	a	a

13	14	15	16	17	18	19
b	c	b	c	a	c	d

Chapter

5

General Principles - Cruise

Balance of Forces in Level Flight

This chapter will concentrate on the general performance principles of an aeroplane in the en route phase of flight. Performance in the en route phase can be measured using the aeroplane's range and endurance parameters. These will be discussed in detail later on in the chapter. Let us firstly examine the forces acting on an aircraft in the cruise.

These forces are split into couples and are shown in *Figure 5.1*.

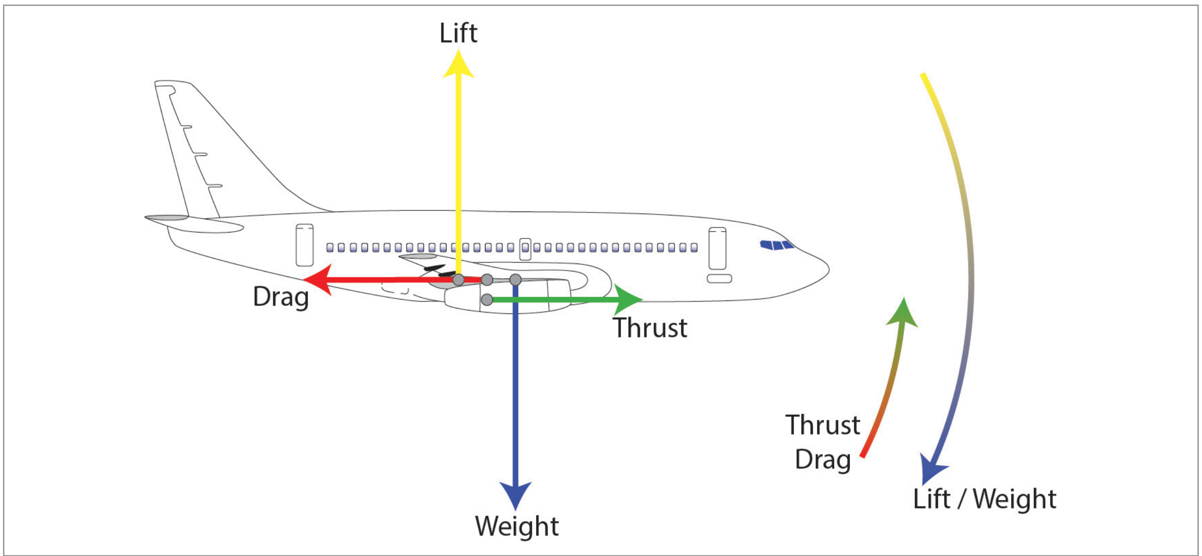


Figure 5.1 An illustration showing some of the forces in straight & level flight

The first of these couples is produced by lift and weight. Weight acts through the centre of gravity of the aeroplane directly towards the centre of the earth. Lift balances weight and acts through the centre of pressure. The effect of this couple on the aeroplane is to cause a nose-down pitching moment. The lift/weight couple is comparatively strong and thus the nose-down pitching moment is large as shown by the large arrow pointing downwards to the right of the aeroplane. As an example of the size of these forces, in a 737-800 series, the maximum structural mass is 79 000 kg. At this mass the aeroplane weighs about 770 000 Newtons. Obviously this weight will be balanced in cruising flight by an equal and opposite lift force of 770 000 Newtons.

The second couple acting upon an aeroplane in flight is that produced by the forces of thrust and drag. The effect of this couple is to cause a nose-up pitching moment as shown by the upward pointing red and green arrow to the right of the aeroplane. Notice though that this couple is far weaker than the lift/weight couple. The maximum thrust produced by the engines of a 737-800 is only 214 000 Newtons. This means that the nose-up pitching moment generated by the thrust/drag couple does not balance the stronger nose-down pitching moment of the lift/weight couple. As a result there is still a nose-down tendency as shown in *Figure 5.1*. In order to maintain level flight, we need somehow to generate an opposite moment which will balance the residual nose-down pitching tendency. This is achieved by the tailplane, or horizontal stabilizer, on the aeroplane's tail assembly. The horizontal stabilizer, or tailplane, must be set at an angle which will cause a nose-up pitching moment to balance the aeroplane, or more commonly expressed, to trim the aeroplane. Looking at *Figure 5.2*, notice that now, with the addition of the tailplane down force, the nose-up and nose-down pitching moments are in balance and level flight is possible. The down force generated at the tail is called tailplane down force or tail load.

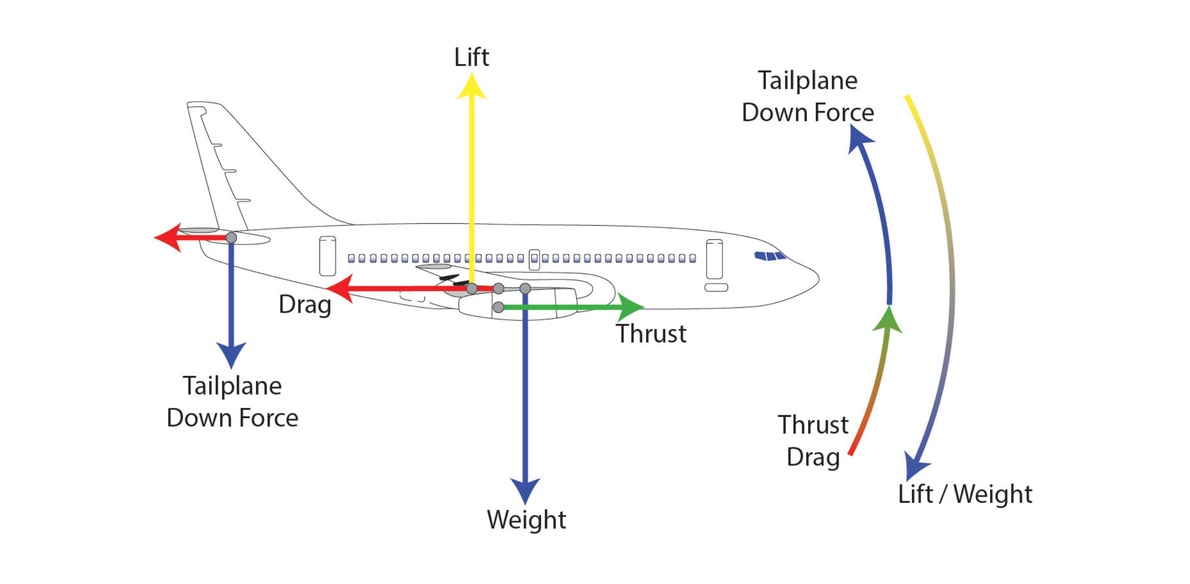


Figure 5.2 An illustration showing the complete balance forces in straight & level flight

Although such a force is necessary for level flight it does have two adverse effects on aircraft performance. Firstly, notice that the tailplane down force acts in the same direction as weight. It therefore increases the effective weight of the aircraft. The second adverse effect of the tailplane down force is its contribution to drag. The tailplane is an aerodynamic surface designed to produce lift. It will therefore produce induced drag as well as parasite drag. Therefore, the greater the amount of balancing force produced by the tailplane the greater the aeroplane aerodynamic drag and effective weight. We will shortly understand that the two additional forces provided by the tailplane are detrimental to the aeroplane's en route performance in terms of range and endurance.

Moving the Centre of Gravity

To some extent the amount of tailplane down force required for level flight can be manipulated by moving the centre of gravity. In flight this can be done in one of two ways. Firstly by selective fuel consumption, or secondly by fuel transfer. Consuming fuel in the tail first, or transferring fuel out of the tail to other tanks, will move the centre of gravity position forwards. Conversely, using fuel in the centre or forward tanks first, or transferring fuel out of these tanks will cause the centre of gravity to move aft. If the centre of gravity moves forwards, the magnitude of the lift/weight couple increases because the arm of the two forces is now longer. The greater strength from the lift/weight couple increases the nose-down pitching moment. This can be seen by comparing the length of the lift/weight pitching down arrows from *Figure 5.2* and *Figure 5.3*.

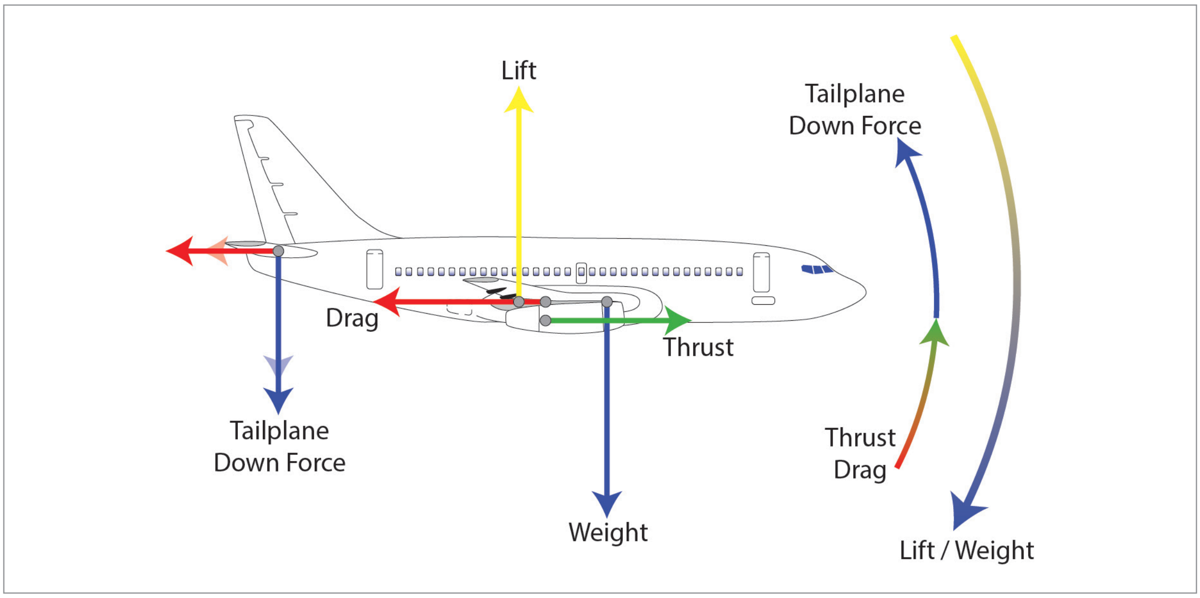


Figure 5.3 An illustration showing that with a more forward C of G the lift/weight couple increases & greater tail load is needed

To balance the greater nose-down pitching moment and maintain level flight, more tailplane down force is needed. You may recall that this had the effect of increasing the effective weight and the drag of the aeroplane which would have a detrimental effect on the aircraft's performance, reducing both its range and endurance. If the centre of gravity moves aft, the strength of the lift/weight couple is decreased because the arm of the two forces is now shorter. This decreases the nose-down pitching moment. To balance the nose-down pitching moment, less tailplane down force is needed to maintain level flight. Reducing tailplane down force reduces drag and effective weight which will increase both the aeroplane's range and endurance capability. Remember that, before you fly, when carrying out a weight and balance check, also ensure that the centre of gravity is still within the limits published in the aircraft manual. Be extra careful when handling data produced by countries whose units of measurement are different to those you are used to.

Aeroplane Speeds

This particular section of the chapter will deal with the aeroplane's speed, including maximum speed, minimum speed, and the relationship between the various expressions of speed such as indicated airspeed, calibrated airspeed, true airspeed, true ground speed and Mach number.

Firstly let us examine what we mean by an aeroplane's maximum speed. You will have learnt from earlier chapters that an aeroplane will remain at a constant speed when the forward and rearward forces are balanced, as shown in *Figure 5.4.*

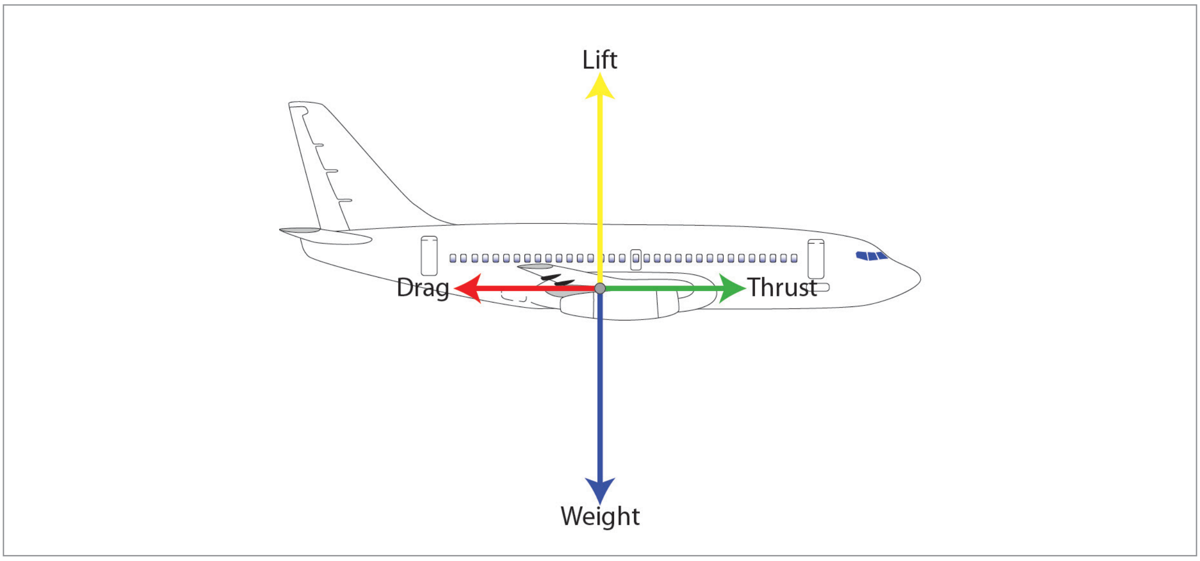


Figure 5.4 In straight & level flight a constant speed is maintained when the forward force of thrust balances the rearward force of drag

In this case, thrust is equal to drag. In order for the aeroplane to accelerate, thrust must exceed drag. This can be achieved by the pilot opening the throttle further. With thrust greater than drag the aeroplane will accelerate. As the aeroplane accelerates, drag will increase. When drag reaches a value which is the same as the thrust, acceleration will cease and the aeroplane will have achieved balanced flight once more, but now at a higher speed. Therefore, the highest level flight speed that can be flown by the aeroplane will be at a speed where thrust is maximum and drag is maximum. Let us look at what we have just learnt but this time using a graph. Shown in *Figure 5.5* are the thrust and drag curves for a typical jet aeroplane.

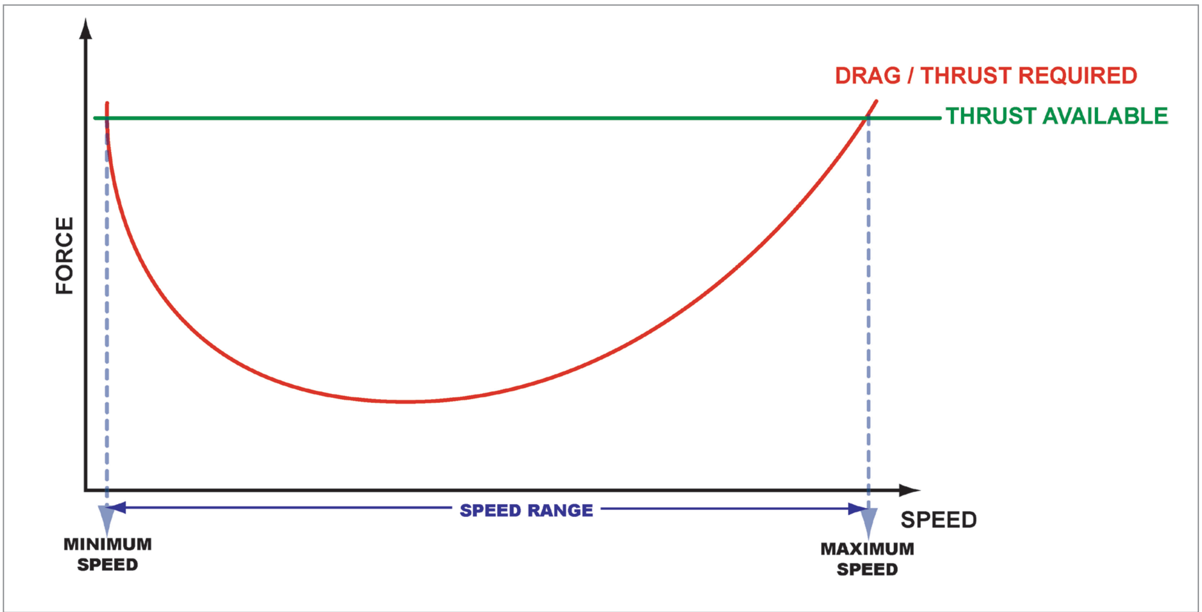


Figure 5.5 An illustration showing that the intersections of the thrust & drag curves represent the maximum & minimum straight & level flight speeds

Notice the maximum speed is achieved once thrust and drag are equal. It is impossible in straight and level flight to accelerate any faster since the drag would exceed the thrust. This speed is the fastest speed the aeroplane can achieve in level flight.

Look at the graph again and notice that there is another point on the curves where thrust and drag are equal. This point lies to the very left of the graph. The speed at this point represents the slowest speed that can be maintained. In level flight it would be impossible to fly any slower at this thrust setting since the rearward force of drag would exceed the force of thrust.

At high altitude the thrust produced by the engine decreases and therefore the green thrust line moves downwards.

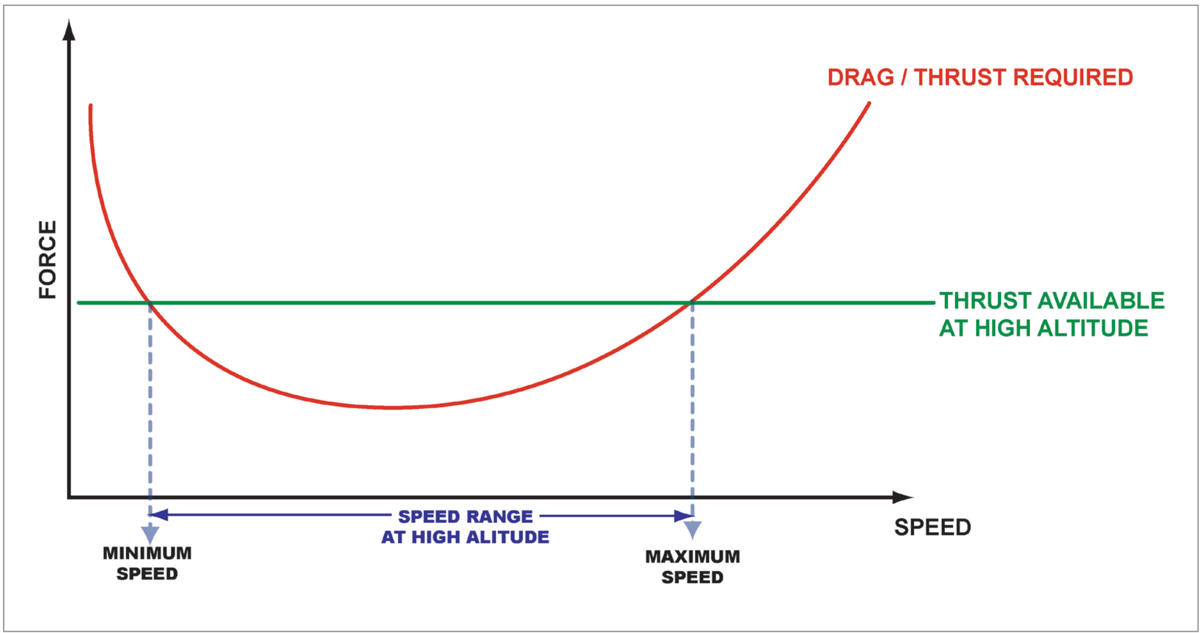


Figure 5.6 An illustration showing that at high altitudes, the level flight speed range decreases

Looking at *Figure 5.6* it is clear to see that at high altitude the maximum achievable level flight speed is slower and the minimum achievable level flight speed is faster than at lower altitudes, thus the range of speeds for the aeroplane is narrower.

This next part of the chapter will focus on the explanation of the various expressions of aeroplane speed.

Indicated Airspeed (IAS)

Different expressions of aeroplane speed are used for different purposes depending on whether we are concerned with aerodynamics, operations, navigation or even performance. In most cases aeroplane speed is measured using certain types of probes called the total pressure and static pressure probes. These probes help us to isolate dynamic pressure on which indicated airspeed is based. You can feel total pressure by simply putting your arm out of the window of a moving car. However, total pressure probes, sometimes called pitot probes, and static probes, suffer from errors. Without any correction to the errors, the speed which is obtained from the probes when dynamic pressure is being sensed is called the indicated airspeed, abbreviated to IAS. Indicated airspeed is the speed that is displayed on the airspeed indicator.

Calibrated Airspeed (CAS)

If the pressure probes are corrected for instrument and position errors, the speed is called calibrated airspeed, abbreviated to CAS. This speed is also known as rectified airspeed, or RAS but this expression will not be used in this book. Calibrated airspeed is more accurate than indicated airspeed. In large modern commercial aeroplanes, the air data computer automatically corrects the pressure probe data for these errors and displays the calibrated airspeed in the airspeed indicator rather than the indicated airspeed.

Equivalent Airspeed (EAS)

The final correction to make to the information received from the pressure probes is the correction to compensate for the effect of compressibility. Typically, at speeds beyond 220 knots, the air ahead of the aeroplane does not move out of the way. As a result, the air starts to build up and compress in front of the aeroplane. This build-up of air has an effect called the compressibility effect. If the probes are corrected for the compressibility error as well as position and instrument errors, the speed obtained is called equivalent airspeed, abbreviated to EAS. Equivalent airspeed is the most accurate of the speeds which are obtained from dynamic pressure. For the most part, this performance book will assume that indicated airspeed, calibrated airspeed and equivalent airspeed are the same. But, unless otherwise stated, assume any reference to aeroplane speed as being indicated airspeed.

True Airspeed (TAS)

The next speed to consider is true airspeed, abbreviated to TAS. True airspeed is the equivalent airspeed corrected for density error and as the name suggests is the true speed of the aircraft relative to the air through which the aeroplane is flying.

Below is a very simplified formula showing that true airspeed is proportional to the equivalent airspeed and inversely proportional to the density.

TAS is proportional to EAS ÷ DENSITY

If for a constant equivalent airspeed the density were to fall, the true airspeed would increase. This means that with increasing altitude at a constant equivalent airspeed, true airspeed increases, as shown by *Figure 5.7.*

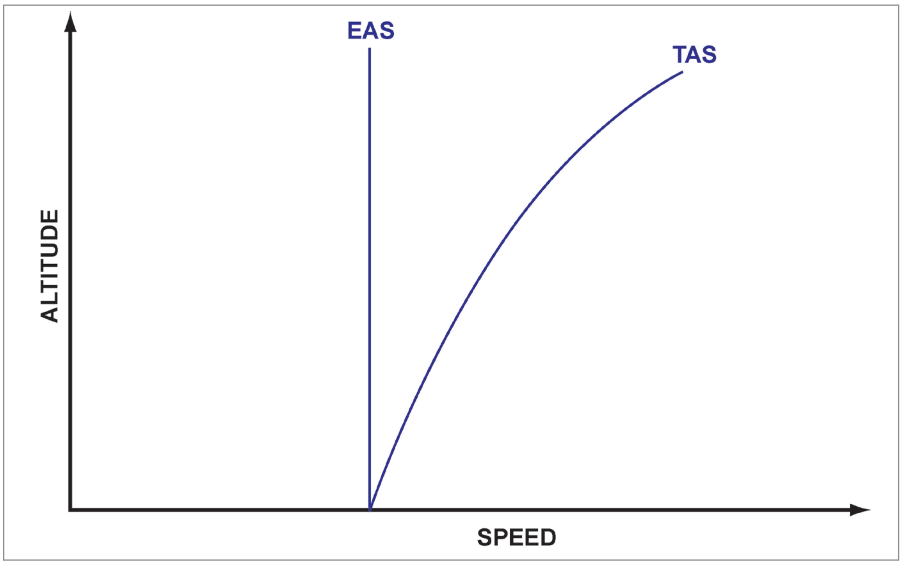


Figure 5.7 An illustration showing the relationship between EAS & TAS with altitude

True airspeed can be calculated by using the tables in the aeroplane flight manual, using a flight navigation computer or even using a calibration scale on the airspeed indicator. True airspeed is mainly used for navigation and flight planning purposes.

True Ground Speed (TGS)

The next speed to consider is the true ground speed, abbreviated to TGS or just GS. This represents the aeroplane's speed within a fixed ground reference system. Put more simply it is the aeroplane's velocity over the ground. The true ground speed is equal to the true airspeed plus or minus the wind component. If there is a tailwind then the aeroplane's speed over the ground will increase by a value equal to the speed of the tailwind. For example, if the true airspeed is 250 knots and the tailwind is 20 knots, the true ground speed is 270 knots. Conversely, if there is a headwind, the aircraft's speed over the ground will be reduced by a value equal to the speed of the headwind.

For example, if the true airspeed is 250 knots and the headwind is 30 knots, the true ground speed is 220 knots. If the headwind or tailwind components are not already known, these can be worked out using a flight navigation computer or by using graphs or tables in the aeroplane flight manual. *CAP 698, Section 4, Page 4, Figure 4.1* can also be used.

At speeds higher than about 220 knots, some of the energy of the aeroplane goes into compressing the air ahead of the aeroplane and locally increasing the density of the air. Compressibility affects the amount of drag force on the aeroplane and the effect becomes more important as speed increases. As the aeroplane moves through the air it makes noise simply by disturbing the air. This noise emanates outwards in the form of pressure waves. These pressure waves stream out away from the aircraft at the speed of sound in all directions acting just like the ripples through water when a stone is dropped in the middle of a still pond.

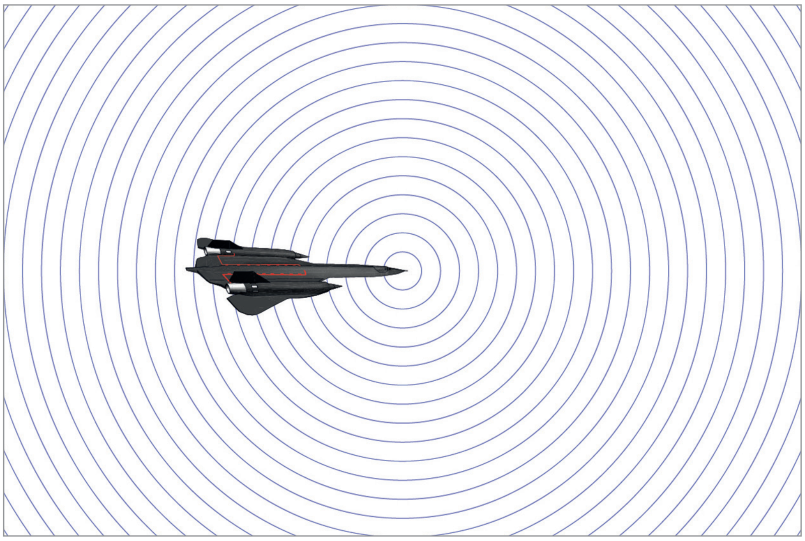


Figure 5.8 An illustration showing pressure waves emanating from a theoretically stationary aeroplane.

However, as the aeroplane approaches the speed of sound it actually starts catching up with its own pressure waves in front if it as can be seen in *Figure 5.9*. These pressure waves turn into one big pressure shock wave which causes a loud bang, called a sonic boom. The shock wave generated actually buffets the aeroplane and decreases the lift force.

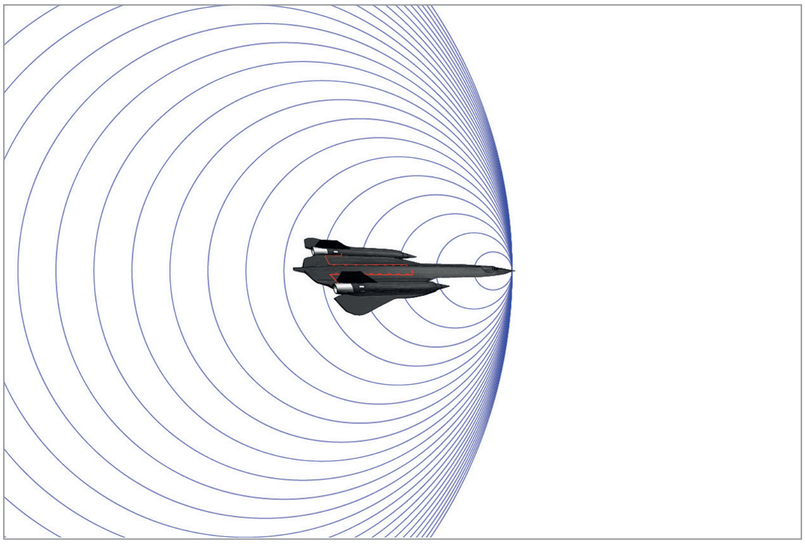


Figure 5.9 An illustration showing pressure waves emanating from an aeroplane flying at the speed of sound

Obviously, because of the increasing drag, decreasing lift and aeroplane buffet, pilots need to know when they are approaching the speed of sound.

Mach Number

The ratio of the speed of the aeroplane to the speed of sound in the air determines the magnitude and intensity of many of the effects of high speed flight. Because of the importance of this speed ratio, aerodynamicists have given it a special name called the Mach number in honour of Ernst Mach, a late 19th century physicist who studied gas dynamics. Mach number is not an actual speed as such; it is, as we have already said, the ratio of the true speed of the aeroplane to the local speed of sound. Mach number is best illustrated using an example. To calculate the Mach number, simply divide the true airspeed (TAS) by the local speed of sound (LSS).

MACH NUMBER = TAS ÷ LSS

At sea level in ISA conditions, the local speed of sound is 661 knots. If the true airspeed of the aeroplane is 510 knots, then the Mach number is 0.77. In other words, the aeroplane is travelling at about three quarters of the speed of sound. If the aeroplane were to fly faster, the Mach number would increase. If the aeroplane accelerated to 661 knots, then its speed would be equal to the speed of sound and the aeroplane would be at Mach 1. Aeroplanes flying between Mach 0.8 and Mach 1.2 are said to be in transonic flight.

The speed of sound varies with temperature. As altitude increases, the reducing temperature causes the local speed of sound to fall. At 30 000 ft the speed of sound is 590 knots. If the true airspeed of the aeroplane is kept constant at 510 knots, as a result of the falling local speed of sound with altitude, the Mach number will increase.

As the aeroplane's speed approaches Mach 1, the compressibility and approaching shock wave can have very detrimental effects on the aeroplane's performance if the aeroplane is not designed to mitigate such effects. As a result, most commercial aeroplanes in service today have a limit on the maximum Mach number they are allowed to fly at. This maximum operating Mach number is called M_{MO}. Having discussed all the relevant speeds of an aeroplane it is important to understand the relationship of these speeds with one another as altitude changes. This is best illustrated on a graph as shown in *Figure 5.10*.

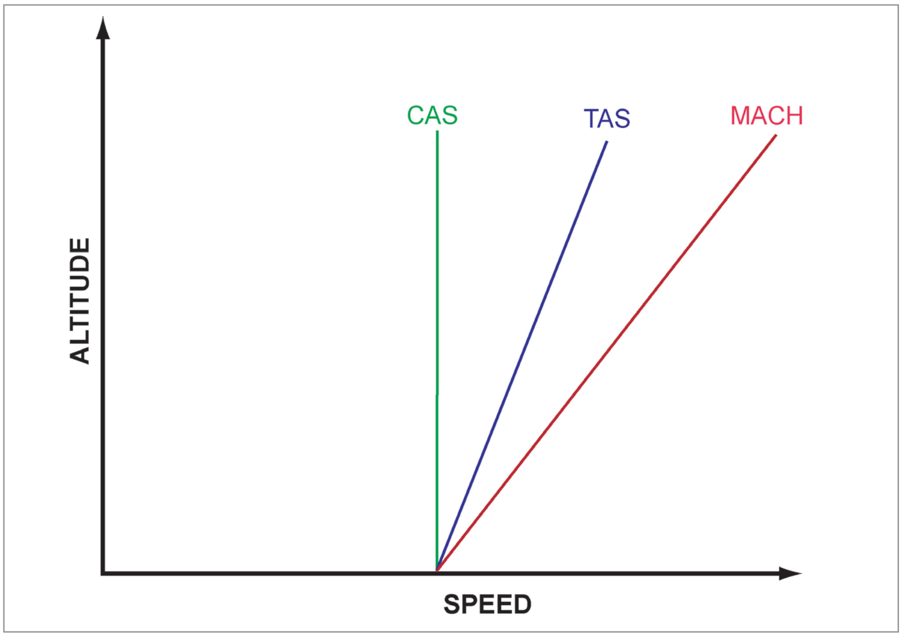


Figure 5.10 An illustration showing the relationship of the various speeds with altitude

If calibrated airspeed, or simply indicated airspeed is kept constant with increasing altitude, then as density falls the true airspeed will increase, as shown in *Figure 5.10*. But if true airspeed increases with increasing altitude, while the local speed of sound decreases, then the Mach number must increase. These lines representing these three speeds can be manipulated to help solve complex problems.

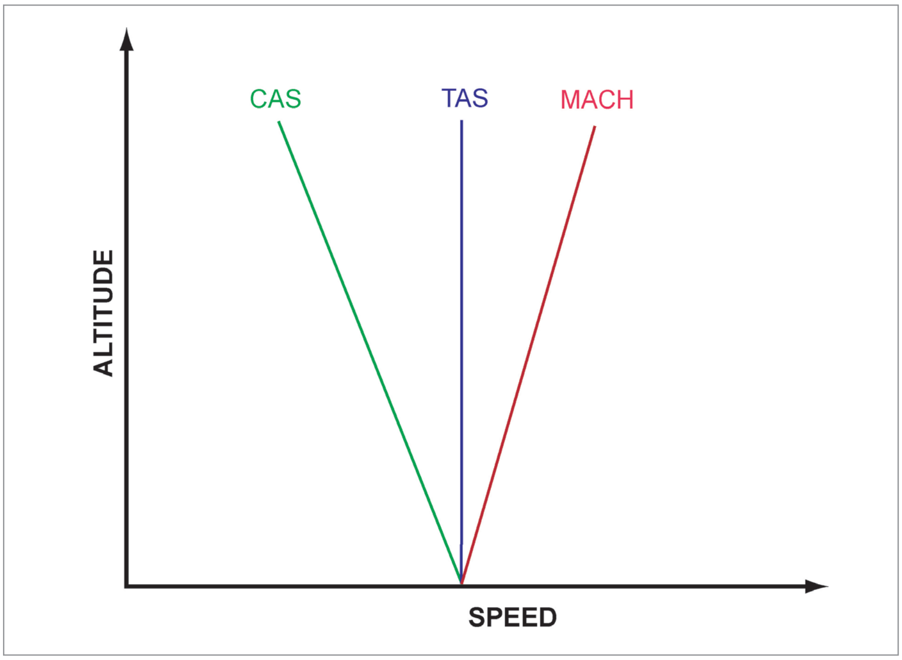


Figure 5.11 An illustration showing the relationship of the various speeds with altitude

If the true airspeed were to be kept constant with increasing altitude as shown in *Figure 5.11*, the TAS line would be drawn vertically and the CAS and Mach lines as shown. Now, calibrated airspeed decreases whilst Mach number increases.

If Mach number were to be kept constant, the diagram could be drawn so that the Mach line is straight up as illustrated in *Figure 5.12*. Notice that TAS and CAS decrease with increasing altitude.

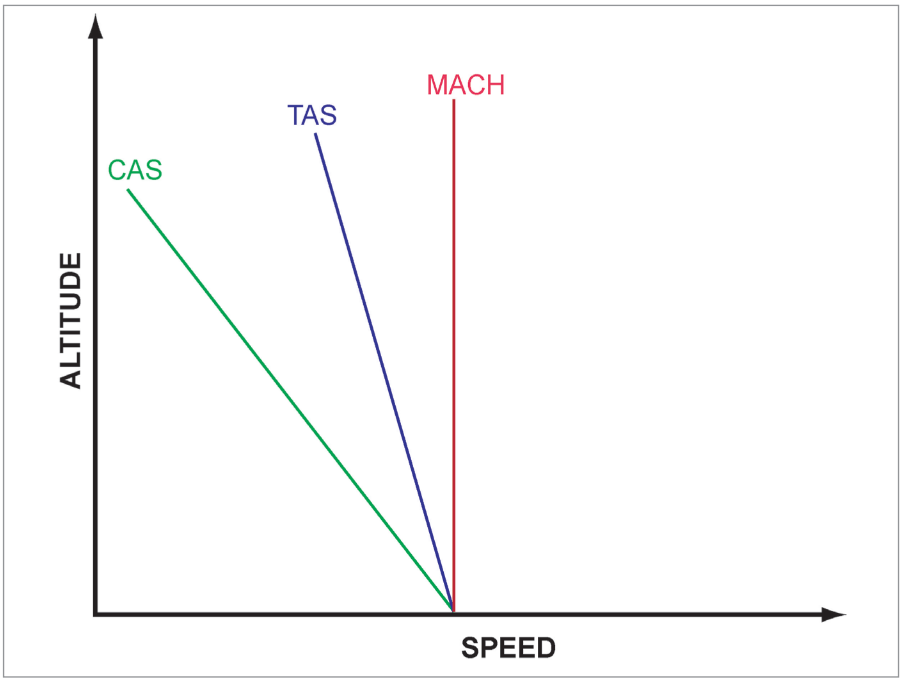


Figure 5.12 An illustration showing the relationship of the various speeds with altitude

These graphs can also be used to see the relationship between the speeds when descending, just ensure to follow the lines down not up. Therefore, looking at *Figure 5.12*, if the pilot was to descend at a constant Mach number, then the EAS and TAS will increase.

To help you remember how to draw the lines, C, T and M always appear from left to right. You can use Britain's favourite food "Chicken Tikka Masala" as an acronym for remembering C T and M and the order in which they appear in the graph.

Fuel Flow

In a turbojet, the fuel flow is proportional to thrust. Therefore, as thrust increases, fuel flow increases. For aeroplanes driven by a propeller regardless of engine type, fuel flow is proportional to power. Therefore when considering range and endurance, turboprop aeroplanes are treated as propeller aeroplanes.

Endurance

The next section of this chapter analyses the two cruise performance parameters: range and endurance. When flying for range we are asking the question - how much fuel will the aeroplane use per unit distance? When flying for endurance we are asking the question - how much fuel does the aeroplane use per unit time? Let us firstly deal with the endurance of the aeroplane.

The endurance of an aeroplane is the time it can remain airborne on a given quantity of fuel or, put another way, endurance can be expressed as fuel used over a given airborne time. The only time an aeroplane will be flown by the pilot for maximum endurance is when the aeroplane is in a holding pattern over its destination. For instance, when there are long landing delays running out of fuel starts to become a problem.

Endurance is defined to be the ratio of airborne time to fuel used for that time.

ENDURANCE = TIME (hr) ÷ FUEL (kg)

However, to use this formula a small adjustment needs to be made as shown:

SPECIFIC ENDURANCE (hr/kg) = 1 ÷ FUEL FLOW

This now becomes the formula for specific endurance. The units of specific endurance are airborne hours per kilogram of fuel consumed. The endurance of an aeroplane is simply a function of its fuel flow or fuel consumption. An aeroplane which can minimize its fuel flow will achieve maximum endurance. Therefore, when analysing the maximum endurance capability of an aeroplane it is necessary to understand what controls the fuel flow. You should note that fuel flow calculations are different for a jet and a propeller aeroplane. Let us examine the jet aeroplane first.

Jet Aeroplane Endurance

FUEL FLOW = FUEL FLOW PER UNIT THRUST × TOTAL THRUST

Here, fuel flow is a function of the fuel used per unit of thrust, multiplied by the total number of thrust units. Obviously if it were possible to reduce the fuel used per unit of thrust and the total number of thrust units required then the total fuel flow would be reduced. Fuel used per unit thrust is most commonly known as specific fuel consumption which is abbreviated to SFC. The formula for fuel flow should be as shown below.

FUEL FLOW = SFC × TOTAL THRUST

The specific fuel consumption needs to be small, in other words, the aim is to reduce the amount of fuel used to produce each thrust unit. For a jet engine this occurs when ambient temperature is very low and engine rpm is very high. This can only occur at high altitude. So, flying at high altitude, minimizes the fuel used per unit of thrust.

Having minimized the fuel used to produce each unit of thrust, the aim is now to fly the aeroplane using minimum possible total thrust because each unit of thrust requires fuel to be consumed. This problem is comparatively simple to solve. In level flight the forward acting force of thrust is controlled and balanced by the rearward acting force of drag. If drag is small, the aeroplane need fly with only a small amount of thrust. Looking at the formula below, thrust can be replaced by drag since the value of drag is equal and opposite to the value of thrust.

FUEL FLOW = SFC × TOTAL DRAG

To minimize drag, the jet aeroplane simply flies at the velocity for minimum drag. Therefore V_{MD} is the speed to fly for maximum endurance for a jet aeroplane.

In summary then, for a jet aeroplane to maximize its endurance by minimizing its fuel flow, the pilot would fly the aeroplane at V_{MD} and fly as high as possible.

Propeller Aeroplane Endurance

The situation with endurance and fuel flow for a propeller aeroplane is very similar to that for the jet aeroplane. There is just one small difference in the formula we use. Turboprop and piston engines first convert chemical energy in the fuel into power output on a shaft. The propeller then converts that power into thrust. Therefore, for a propeller aeroplane, since the fuel is used to generate power and not thrust, the formula for fuel flow is fuel used per unit of power multiplied by the total units of power.

FUEL FLOW = FUEL FLOW PER UNIT POWER × TOTAL POWER

Obviously to minimize the fuel flow, the fuel used per unit of power and the total number of power units must be kept to a minimum. Fuel used per unit power as you already know is called specific fuel consumption. Therefore, similar to a jet the formula for fuel flow for a propeller reads as below.

FUEL FLOW = SFC × TOTAL POWER

The specific fuel consumption value needs to be small but for the majority of propeller aeroplanes the value is more or less fixed. However, in very general terms it is safe to say that for piston engines specific fuel consumption is a minimum at lower altitudes, whereas for turbo-propeller engines specific fuel consumption is a minimum at middle to high altitudes. Since specific fuel consumption is more or less fixed, the only other way to minimize fuel flow is to use the minimum amount of power. This can be achieved by flying at the speed for minimum power required, or V_{MP}. Therefore note that, for a propeller aeroplane, it is V_{MP} that is the speed for maximum endurance, whereas for a jet it is V_{MD}.

Factors Affecting Endurance

Weight

Having studied how to achieve maximum endurance for both jet and propeller engines, let us now examine the factors that affect range. The first factor we must discuss is the effect of weight. You will recall that increasing the weight of the aeroplane increases induced drag and this moves the total drag curve and power required curve up and right. Looking at *Figure 5.13* you can see that for jet aeroplanes at higher weights, the aeroplane has more drag which will require more thrust and therefore require more fuel flow. In this situation the endurance will decrease.

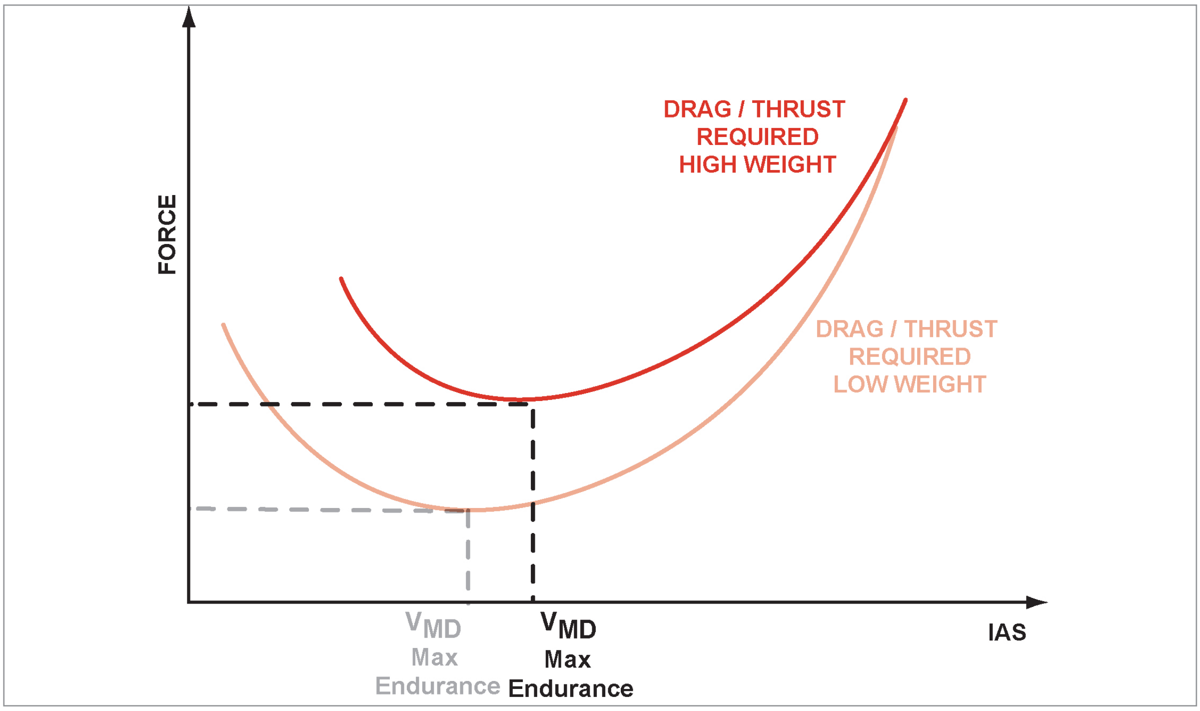


Figure 5.13 An illustration of the effect of weight on the drag & the speed for maximum endurance for a jet aeroplane

We must also note that the speed for maximum endurance, V_{MD} is now higher. For a propeller aeroplane the situation is similar. For a propeller aeroplane at higher weights, more power is required, therefore fuel flow increases and endurance decreases, but also the speed for best endurance, V_{MP} is higher. This can be seen in *Figure 5.14.*

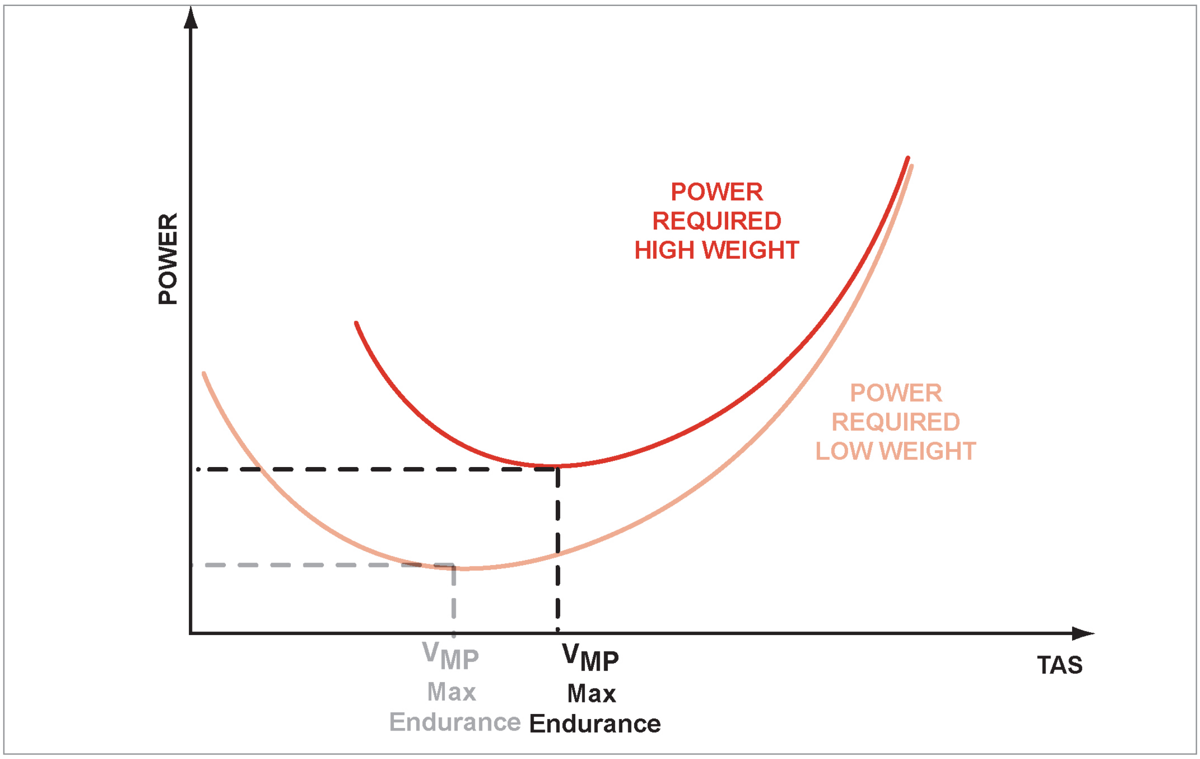


Figure 5.14 An illustration of the effect of weight on the power required & the speed for maximum endurance for a propeller aeroplane

There is one other effect that is seldom mentioned. At higher weights, operating altitudes are lower, which for a jet aeroplane means that the specific fuel consumption increases, because at lower altitudes, the jet engine is less efficient.

Configuration

The next factor which affects endurance is the aeroplane's configuration. While it seems an obvious point that the gear and/or flaps should not be deployed in the cruise, there will be occasions when a pilot will find himself stacked with other aeroplanes in a holding pattern over the destination airfield. As the aeroplane at the lowest level exits the hold to land, the other aeroplanes will have to descend to a lower hold and eventually prepare for the landing by deploying gear and flaps. You will recall that deploying the flaps and undercarriage increases parasite drag and thus causes the total drag curve and power required curve to move up and left. Looking at *Figure 5.15* which is for a jet aeroplane and uses the drag curve, you can see that with the gear and flaps deployed, the aeroplane has more drag and therefore requires greater fuel flow, but notice that the speed for maximum endurance, V_{MD} is now lower.

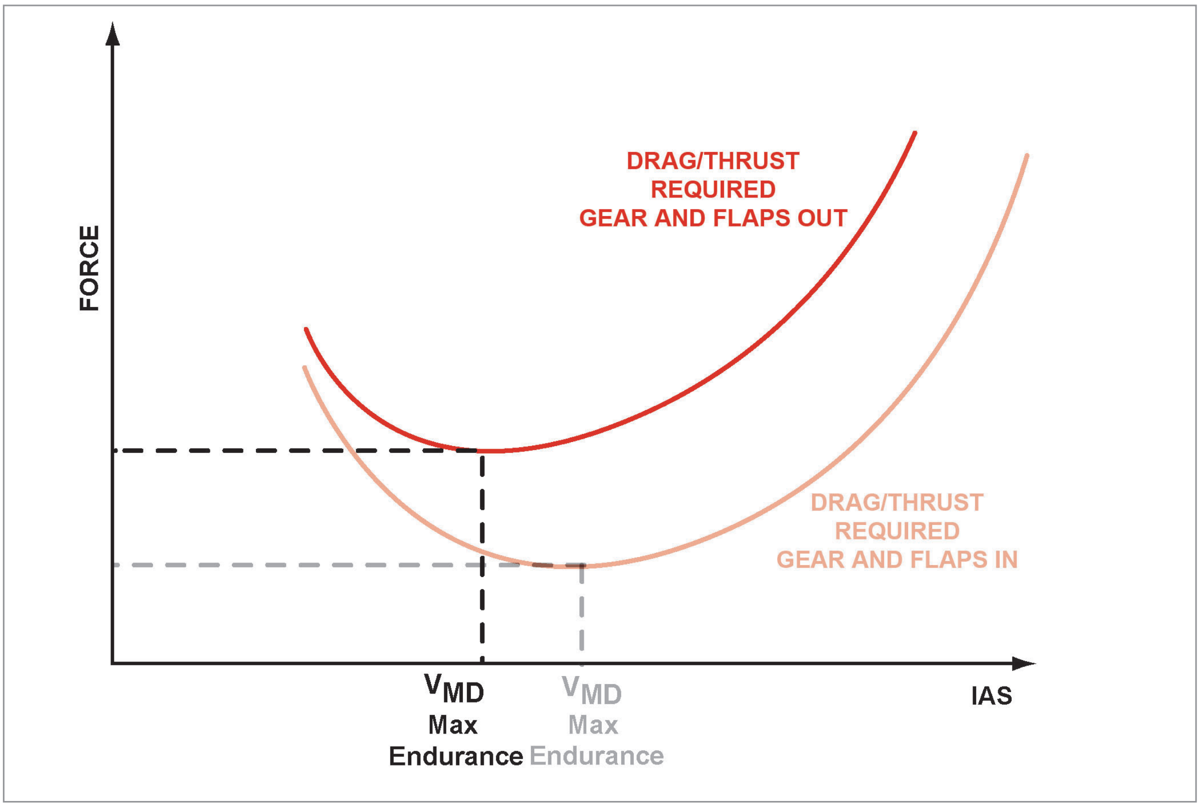


Figure 5.15 An illustration of the effect of gear & flaps on the drag & the speed for maximum endurance for a jet aeroplane

Using *Figure 5.16* which is for a propeller aeroplane, it is much the same. With gear and flaps deployed, more power is required, therefore fuel flow increases and endurance decreases, but also the speed for best endurance, V_{MP} is lower.

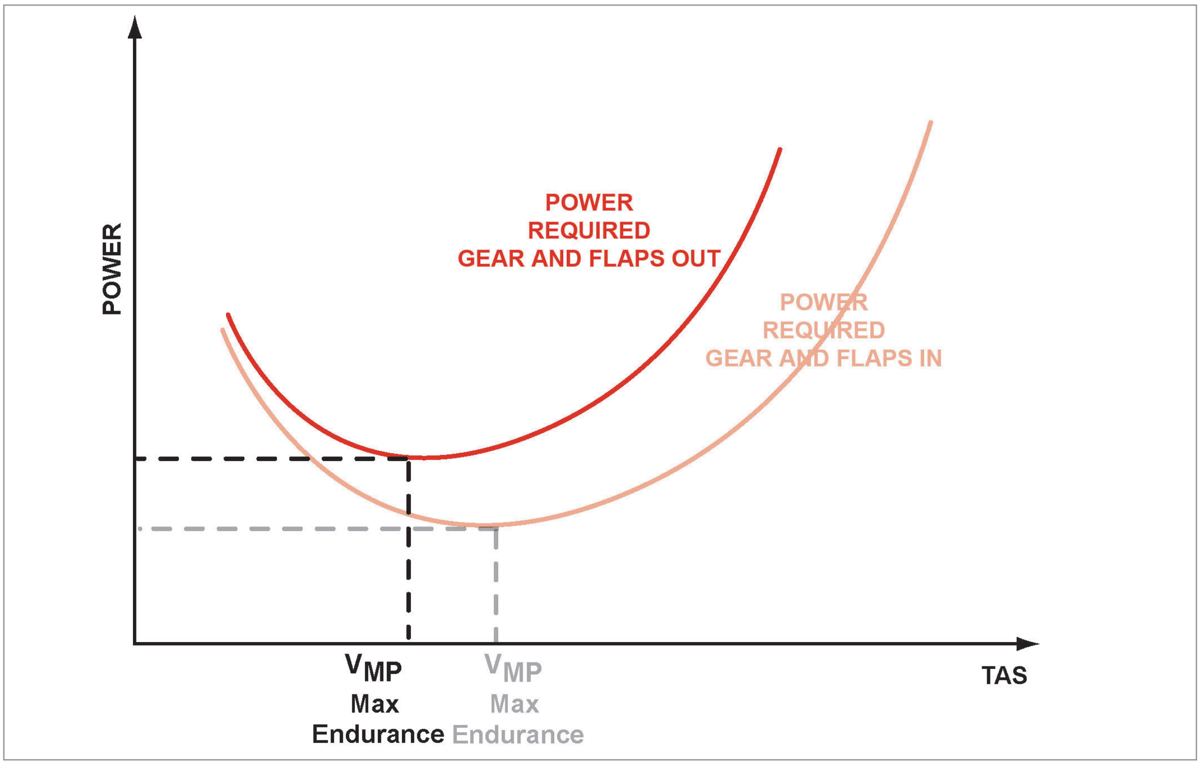


Figure 5.16 An illustration of the effect of gear and flaps on the power required & the speed for maximum endurance for a propeller aeroplane

Fuel flow in the landing configuration can increase by 150% compared to a clean configuration, so it important not to deploy gear or flaps too early and unnecessarily increase the fuel costs for the flight.

Wind and Altitude

The case of wind is quite simple. It has no effect on endurance. You will remember that maximum endurance is concerned with minimizing fuel flow. It should be obvious that wind does not affect the fuel flow into the engine. Endurance is about time in the air, not distance covered. Whatever the effect of wind, an aeroplane will still remain airborne only for as long as it has usable fuel in its tanks.

Altitude however, does affect endurance. Its effect though is a little complicated and is very dependent on engine type. Generally jet aeroplanes become more efficient as altitude increases partly due to the decreasing ambient temperature, but also because of the increasing rpm required to maintain thrust. Therefore, theoretically, the maximum endurance of a jet aeroplane will be achieved when flying at or above the tropopause where the ambient air temperature is lowest.

Turbo-propeller aeroplanes function in a similar way to a jet since they are, in essence, jet engines with a propeller attached to a geared shaft. However, even though the turbo-propeller engine gains efficiency with altitude, the power required increases due to the rising TAS offsetting the efficiency gains. This means that for the majority of modern turbo-propeller aeroplanes, maximum endurance is achieved at around 10 000 ft or less.

Piston engine aeroplanes are most efficient at sea level when the manifold pressure is high and rpm is low, provided that the mixture has been leaned correctly.

In summary then, jet aeroplanes achieve maximum endurance at or above the tropopause; turbo-propeller aeroplanes reach maximum endurance at about 10 000 ft and piston engine aeroplanes have their maximum endurance at sea level.

Range

You have learnt that there are two performance parameters in the cruise: range and endurance. Let us now consider range. Range is a more useful performance parameter than endurance, and one that aircraft designers continually try to improve. Whereas endurance is about airborne time, range is more concerned with distance covered and it is, therefore, sometimes referred to as "fuel mileage". For range, not only is the concern to minimize the fuel flow, but more importantly to maximize the speed. This will allow the aeroplane to travel a greater distance.

Maximum range can be defined as being the maximum distance an aeroplane can fly for a given fuel quantity consumed or to put it another way, the minimum fuel used by an aeroplane over a given distance. This latter expression of range is more commonly used for commercial operations. As a formula, range is simply the distance in nautical miles divided by fuel quantity in kilograms.

RANGE = DISTANCE (NM) ÷ FUEL (kg)

However, in the same way as we did for the formula for endurance we must adjust our range formula needs in order for it to give us useful information. The range that an aeroplane can achieve is determined by the speed of the aeroplane and the fuel flow. The top line of the formula is nautical air miles per hour (TAS) and the bottom line of the formula is kilograms of fuel per hour. Thus the formula now reads true airspeed divided by fuel flow.

SPECIFIC RANGE (SR) = TAS ÷ FUEL FLOW

This is the formula for specific air range. The formula shows that specific air range is defined as the ratio of true airspeed to the fuel flow. You may recall from the endurance section that fuel flow is specific fuel consumption multiplied by drag for a jet and specific fuel consumption multiplied by power required for a propeller driven aeroplane. Looking at the formulae it is now obvious that in order to maximize the specific range of the aeroplane, true airspeed must be high, and the fuel flow must be low.

JET SPECIFIC RANGE (SR) = TAS ÷ (SFC × DRAG)

PROPELLER SPECIFIC RANGE (SR) = TAS ÷ (SFC × POWER REQUIRED)

Jet Aeroplane Range

Let us now focus on the specific air range of the jet aeroplane. We stated earlier that to maximize the range, the TAS must be high, and the specific fuel consumption and the drag must be low. Shown in *Figure 5.17* is a drag curve for a jet aeroplane. If the aeroplane were to fly at V_{MD} then of course the drag force would be at its lowest.

If we look at the formula for specific range as shown in the graph, it seems we have solved one of the points, namely how to make drag as low as possible. However, notice that because the drag curve is fairly flat at the bottom, the speed may be increased significantly from V_{MD} for only a small drag penalty.

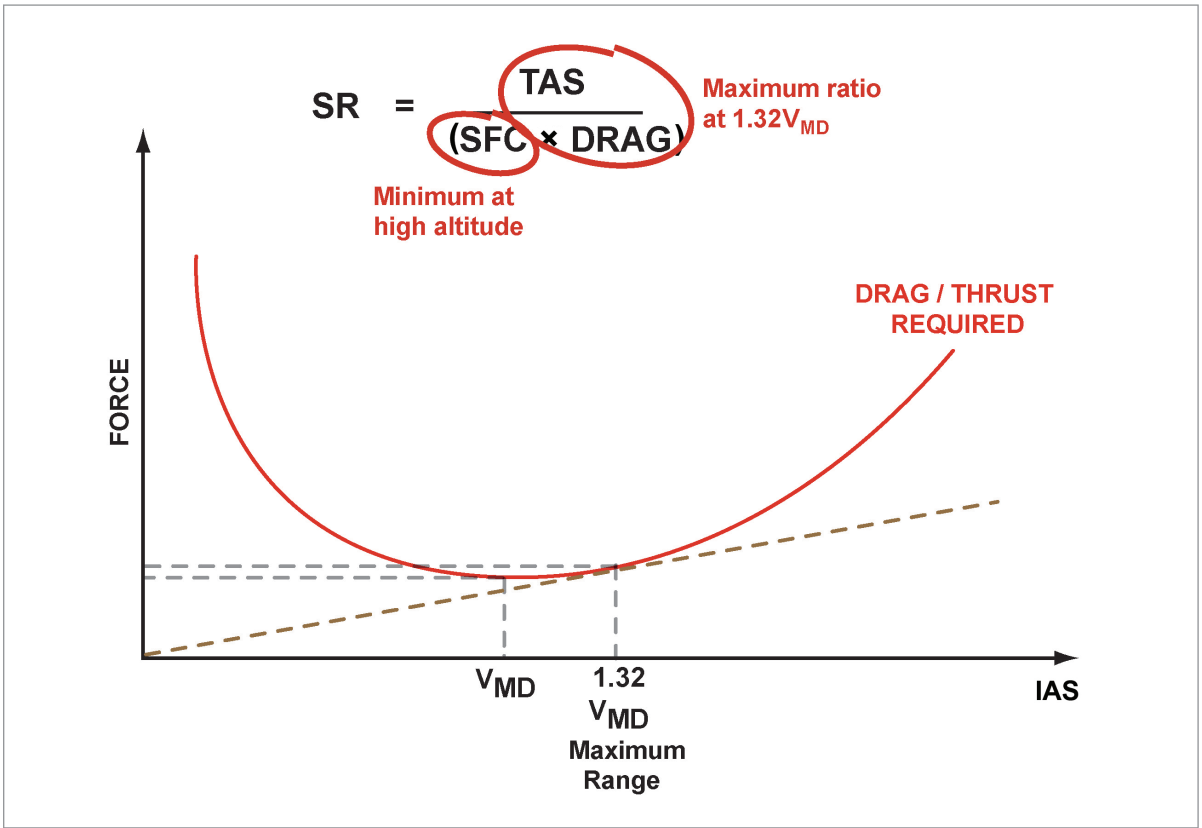


Figure 5.17 A graph showing the speed for maximum range for a jet aeroplane

We can therefore see that whilst drag has increased a little, which is bad for range, the airspeed has increased significantly, which is good for range. Consequently the overall effect is that there is an increase in specific range.

The speed at which the speed over drag ratio is maximized may be read from the graph at the point of contact of the tangent from the origin to the curve. You may recall that this speed was $1.32V_{MD}$. Therefore it is $1.32V_{MD}$ that is the speed for maximum range for a jet aeroplane.

There is now only one remaining item left in the formula which still needs to be resolved. In order to increase range even more, specific fuel consumption must be decreased. You may recall that the only way to do this for a jet aeroplane is to operate at as high an altitude as possible. Operating as high as possible will give us a higher true airspeed for any given indicated airspeed which, again, will improve the specific range.

Propeller Aeroplane Range

Having completed the analysis of range for a jet aeroplane, let us now examine specific air range for a propeller aeroplane. We stated earlier that to maximize the specific range, the TAS must be high, and the specific fuel consumption and the power required must be low. Shown in *Figure 5.18* is the power required curve for a propeller aeroplane. If the aeroplane were to fly at V_{MP} then of course its engine would be delivering minimum power required for level flight. It seems, then, that we have solved one of the components, namely to make power required as small as possible.

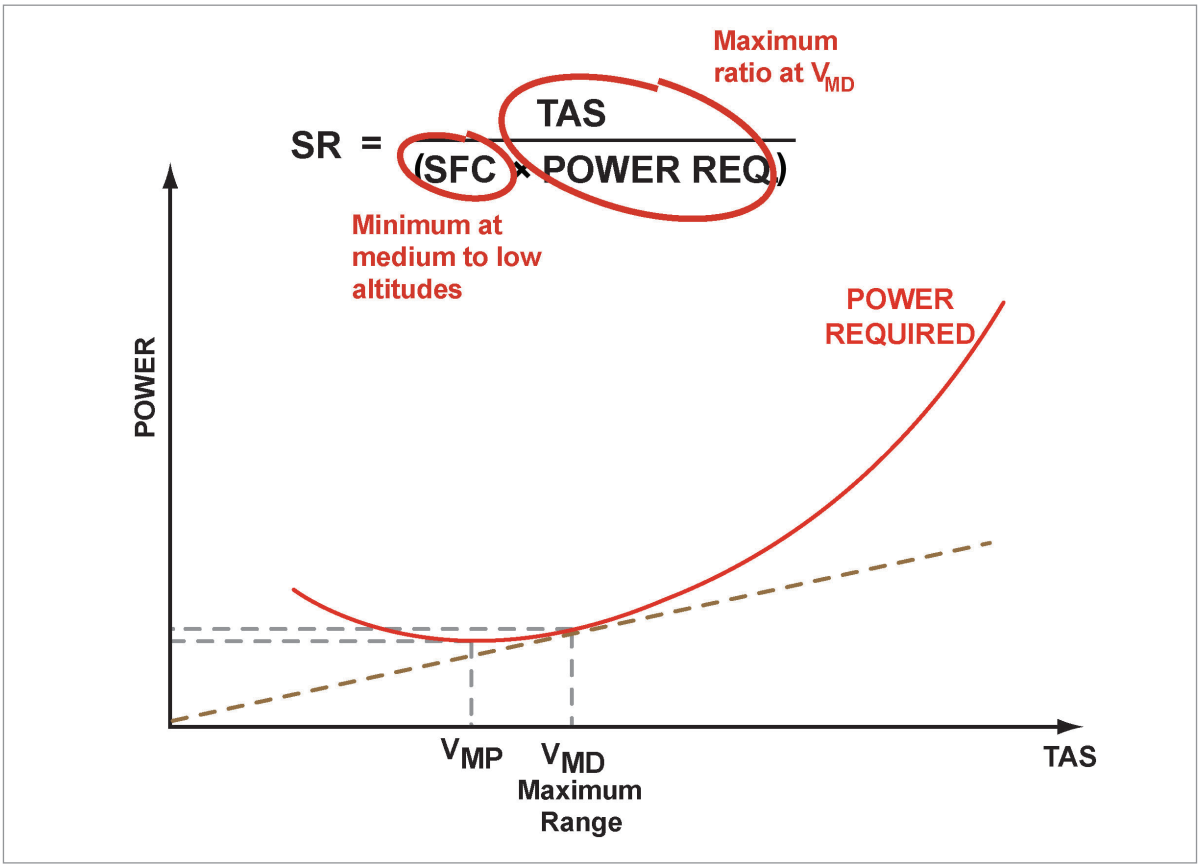


Figure 5.18 A graph showing the speed for maximum range for a propeller aeroplane

However, looking at the graph, you will notice, like for the jet aeroplane, that because the power required curve is fairly flat at the bottom, the aeroplane speed may be increased significantly from V_{MP} for only a small penalty increase in the power required. You can see that whilst power required has increased a little, which is bad for range, the airspeed has increased significantly, which is good for range. Consequently the overall effect is an increase in the range. The point at which the speed power ratio is at a maximum is the point of contact of the tangent from the origin to the curve. You may recall that this speed is V_{MD}. Therefore it is V_{MD} that is the speed for maximum range for a propeller aeroplane.

There is now only one remaining item left in the formula which still needs to be resolved. In order to maximize range even more, specific fuel consumption must be decreased. However, you may remember that specific fuel consumption for piston aeroplane is more or less best at low altitudes, whereas for turbo-propeller aeroplanes which use jet engines, the specific fuel consumption decreases with altitude up to a point about halfway up the troposphere.

Factors Affecting Range

Weight

Having studied how to achieve maximum range for both jet and propeller engines, let us now examine the factors that affect range. The first of the factors to discuss is the effect of weight. You will recall that increasing the weight of the aeroplane increases induced drag and thus moves the total drag curve and power required curve up and right.

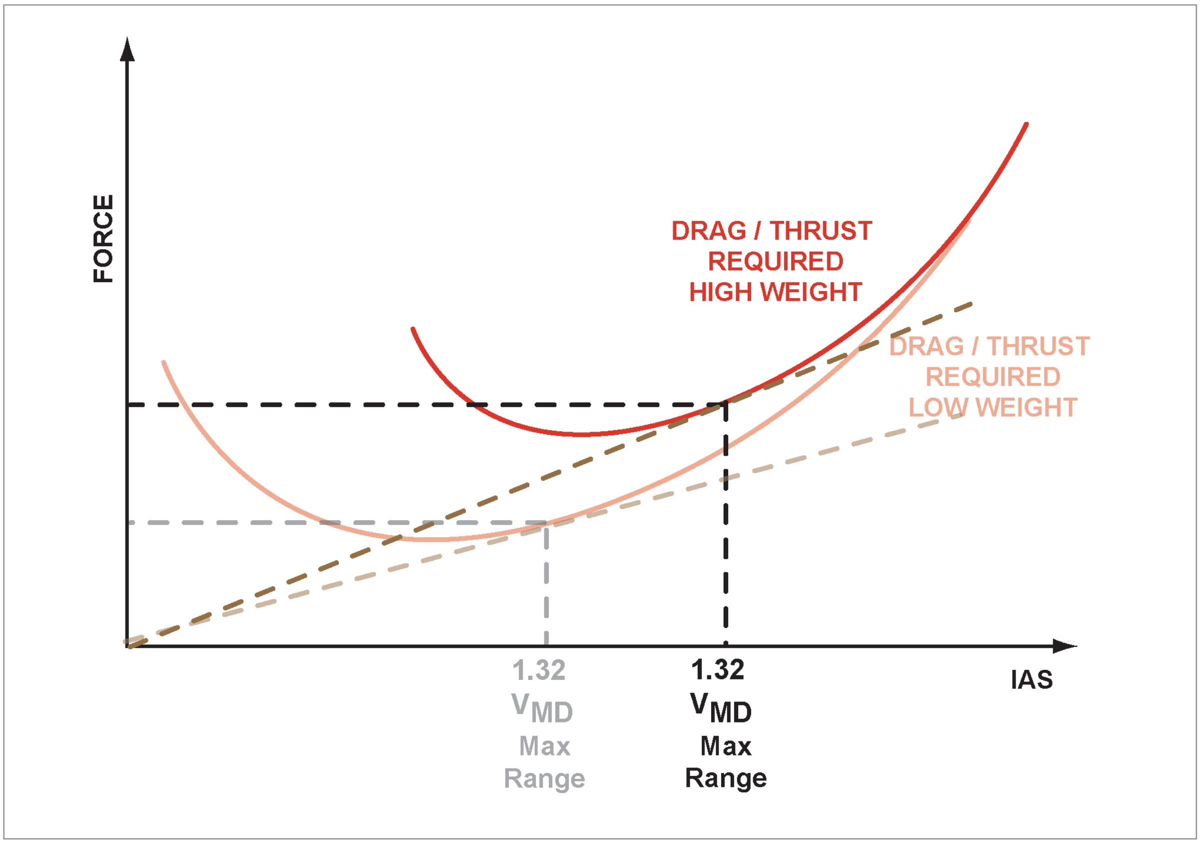


Figure 5.19 A graph showing the effect of weight on drag & the speed for maximum range for a jet aeroplane

Looking at *Figure 5.19* which is for a jet aeroplane, you can see for higher weights, the aeroplane is subject to a higher drag force and therefore requires a higher rate of fuel flow. This will decrease specific range. However, notice that the speed for maximum range, $1.32V_{MD}$, is now higher.

Figure 5.20 A graph showing the effect of weight on power required & the speed for maximum range for a propeller aeroplane

Using *Figure 5.20* which is for a propeller driven aeroplane, it is much the same as the jet. At higher weights, more power is required, therefore fuel flow increases and range decreases. However, notice too, that the speed for best range, V_{MD}, is higher.

Remember also that at higher weights, the operating altitudes are reduced, which for a jet aeroplane means that the specific fuel consumption increases, because at lower altitudes, the jet engine is less efficient.

There is a linear relationship between weight and fuel flow – assuming identical aeroplanes, at the same altitude and the same specific fuel consumption.

If we know the fuel flow for an aeroplane at one weight we can calculate the fuel flow at an alternate weight.

For example; an aeroplane has a weight of 120 000 kg with a fuel flow of 4400 kg/hr. An identical aeroplane at the same altitude and specific fuel consumption but weighing 110 000 kg would have a fuel flow of:-

4400/120 000 = .03666 then multiplied by 110 000 kg gives 4033.33 kg/hr.

In other words; the percentage change in the fuel flow is proportional to the percentage change in aircraft weight.

Payload vs Range

One of the most important issues that airline operators need to consider is the choice of the aeroplane they operate. This choice is mainly based upon the required aeroplane's payload and range. These requirements can be best described by going through a typical example. Shown in *Figure 5.21* is the payload range graph for a Boeing triple seven. On the vertical axis is the payload in thousands of kilograms and the horizontal axis shows the aeroplane range in thousands of nautical miles.

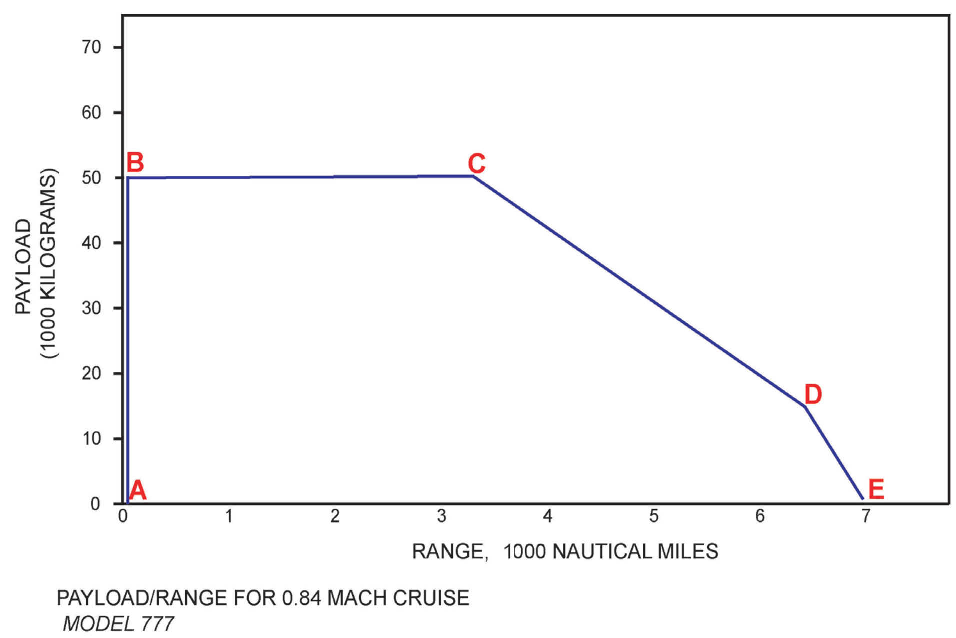


Figure 5.21 A graph showing the payload versus the range of a typical Boeing 777

Using *Figure 5.21*, as the payload is initially added to the aeroplane the marker moves from point A to point B. However, payload will reach a maximum when either there is no more space on the aeroplane or the aeroplane has reached its zero fuel mass (ZFM). Notice that the range at point B is zero because no fuel has been added yet. Fuel is now added to the aeroplane and the blue marker line moves to the right showing an increase in range. Adding fuel can continue until the maximum structural take-off mass is achieved. This is shown by point C on the graph. Although maximum mass has been reached, it is unlikely that the tanks are full at this stage. To increase range further, more fuel must be added. But since the maximum mass has been achieved, the only way to add more fuel is if some of the payload is exchanged for fuel. Now the marker will start to move down and right. This shows that range is increasing but the payload is decreasing. Swapping payload for fuel in this way can continue only until the tanks are full, as shown by point D. From point C to point D the total mass of the aeroplane has remained constant since we are simply swapping payload for fuel.

The only way to increase the range beyond point D, even though the tanks are full, is to remove the rest of the payload. You will recall that reducing weight increases range. Reducing the payload completely moves the marker line from point D to point E. At point E, the aeroplane has full tanks, maximum range but no payload.

In the majority of airlines the trade-off between range and payload is carried out on initial aeroplane purchase and, thereafter, during in-flight planning. As a pilot it is unlikely you will be required to work through these graphs other than to check and confirm the data that has been prepared in advanced for you.

Configuration

Another factor affecting the range is the aeroplane's configuration. You will recall that deploying the flaps and gear increases parasite drag and thus moves the total drag curve and power required curve up and left, as shown in *Figure 5.22*.

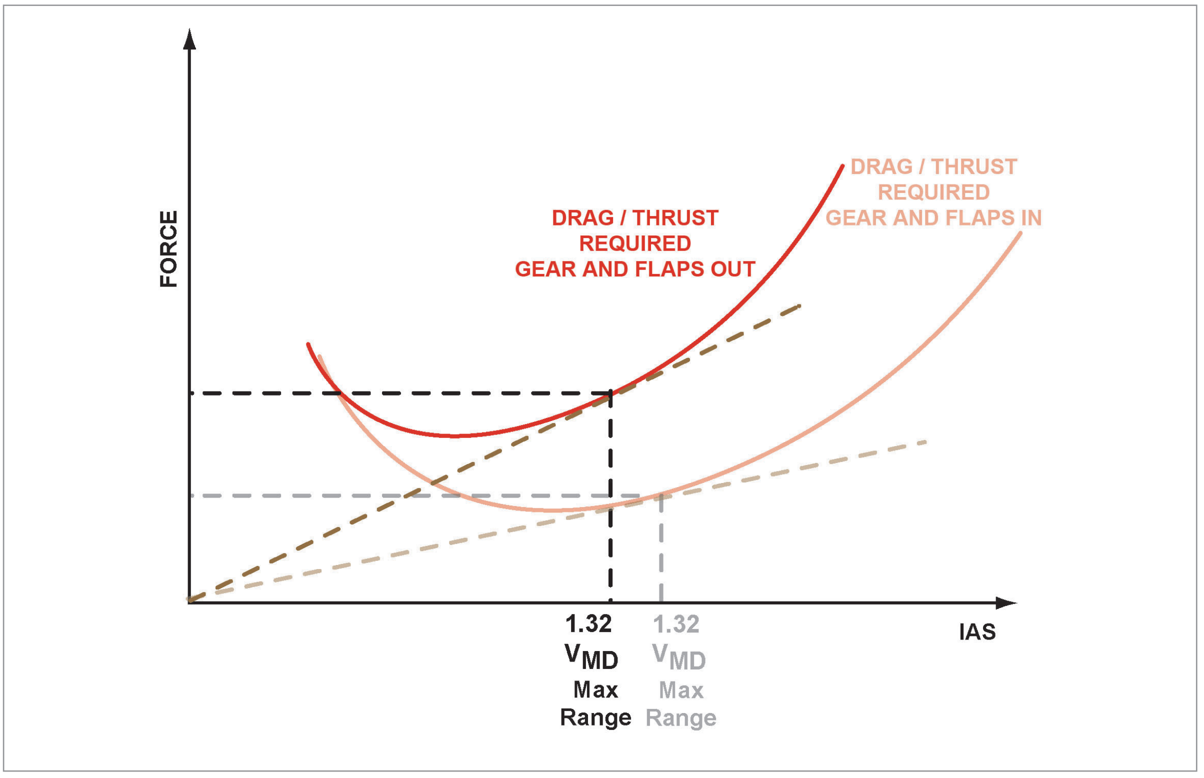


Figure 5.22 A graph showing the effect of configuration on drag & the speed for maximum range for a jet aeroplane

You can see that with the gear and flaps deployed, the aeroplane has more drag and therefore needs more thrust which, in turn, requires greater fuel flow. This will decrease the range. However, notice that the speed for maximum range, $1.32V_{MD}$, is now lower.

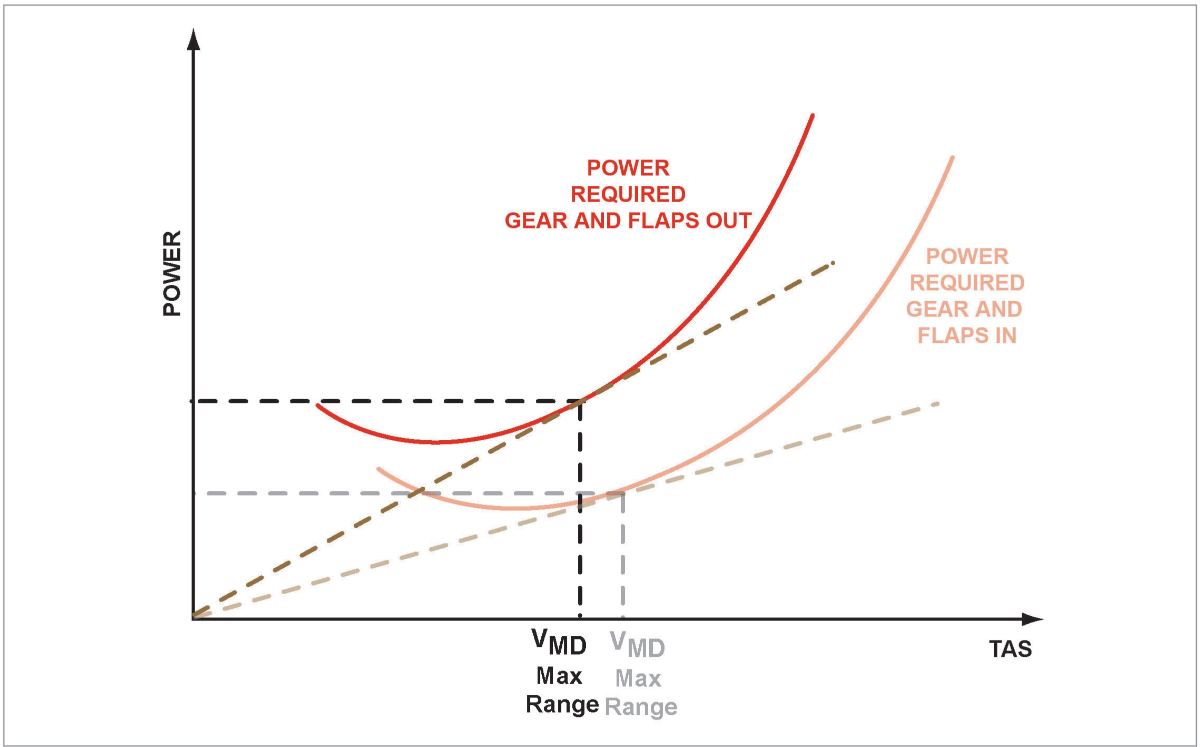


Figure 5.23 A graph showing the effect of configuration on power required & the speed for maximum range for a propeller aeroplane

Looking at *Figure 5.23* which is the range graph for a propeller aeroplane you can see that matters are much the same. With gear and flaps deployed, more power is required. Therefore fuel flow increases and range decreases. But also notice that the speed for best range, V_{MD}, is lower.

A point always to bear in mind in the cruise is that any increase in parasite drag will be detrimental to range and endurance. Increases in parasite drag can be caused by any number of things such as damaged and misaligned surfaces. The extra drag created by misaligned or misrigged airframe surfaces creates a type of drag called excrescence drag. This can be more than 4% of the aeroplane's total drag. Careful preflight inspection should reveal misaligned or misrigged surfaces.

An important point to consider over which the pilot has direct control is aeroplane trim. A pilot must periodically check the aileron and rudder trim, the spoiler misfair and the trailing edges to ensure that the aeroplane is "in trim" and is in balanced flight. Monitoring the aeroplane's control surfaces will help to reduce the extra drag and extra fuel consumption that out of trim and unbalanced flight can cause.

Lastly, contamination on the airframe from airframe icing can affect fuel flow. This icing will not only change the shape of the wing, making it less efficient at producing lift, but it will also increase weight and drag. All this is detrimental to aircraft performance and will reduce the aeroplane's range.

Wind

Wind is the next of the major factors affecting the range of an aeroplane. Headwinds will cause the aircraft to travel slower over the ground and therefore cover less distance for a given level of fuel consumption. Thus, in headwinds range is reduced. In order to minimize this effect the speed of the aeroplane is increased by a margin slightly less than the amount of the headwind. The increase in speed will increase the thrust and the power required and therefore the fuel consumption, but on a positive side the aeroplane will be exposed to the headwind for a shorter time period if it is flying faster. This higher speed then recovers some of the range loss caused by the headwind. On the contrary, a tailwind will increase the ground speed and increase the distance covered for a given level of fuel consumption, thereby increasing range. For maximum range with a tailwind, the speed for the best range should be decreased slightly so as to reduce the thrust and power required. This will therefore reduce the fuel flow and increase the range a little more. The reduction in speed is slightly less than the speed of the tailwind component being experienced.

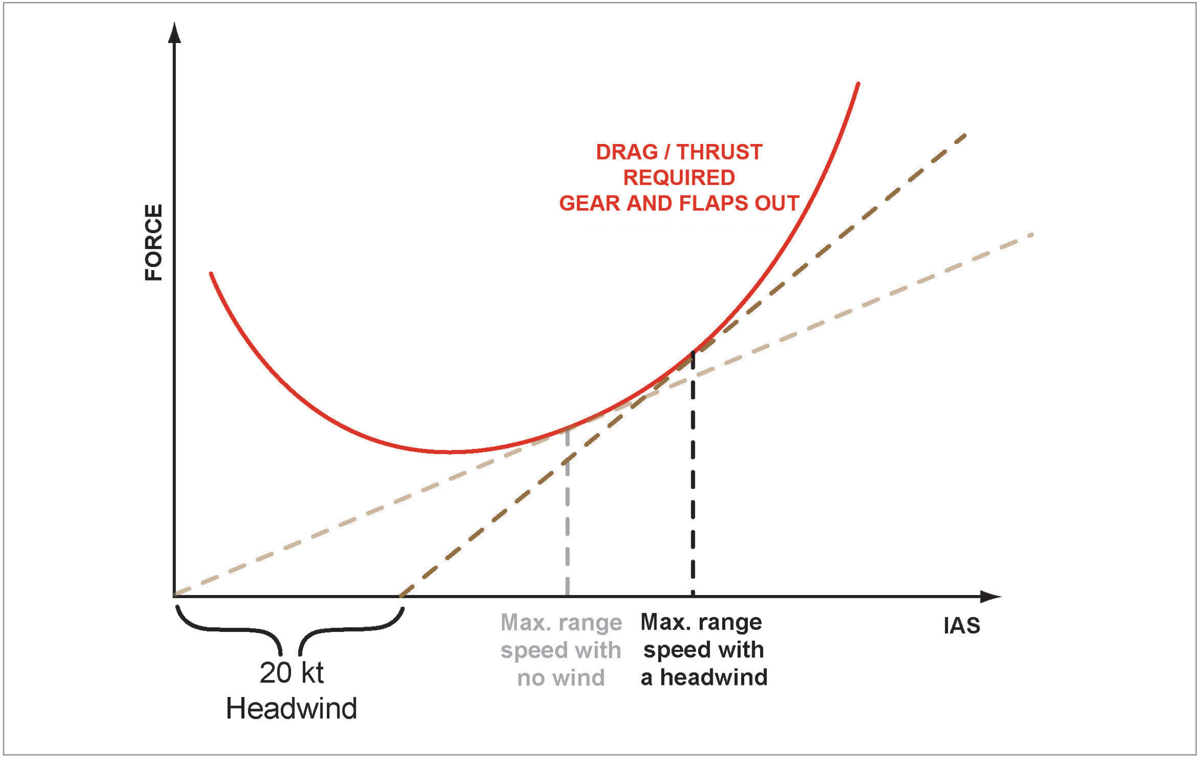


Figure 5.24 A graph showing the effect of a headwind on the speed for maximum range for a jet aeroplane

The headwind and tailwind speed changes can be seen on the drag and power curves for the jet and propeller aeroplane. However, to simplify things, we will just concentrate on the drag curve for the jet aeroplane.

Looking at *Figure 5.24*, with a 20 knot headwind, the origin of the tangent line moves 20 knots to the right. Notice that the tangent meets the curve at a point corresponding to a higher speed, thus confirming that in a headwind the speed for best range is higher. The opposite is the case in a tailwind scenario. With a tailwind of 20 knots, the origin of the tangent line moves 20 knots left. The tangent meets the curve at a point corresponding to a lower speed. This confirms that in a tailwind the speed for best range is lower than in conditions of zero wind.

Altitude (Jet Aeroplanes)

The effect of altitude on the range of an aeroplane is important, especially for a jet aeroplane. Below is the formula for the specific air range for a jet aeroplane. Let us examine how the variables change with increasing altitude.

SPECIFIC RANGE (SR) = TAS ÷ (SFC × DRAG)

As aeroplane operating altitude increases, the colder air and requirement for increasing rpm cause the specific fuel consumption to decrease which will help to increase the specific air range. However, there are two other variables left to consider, namely the true airspeed and the drag.

Let us deal with true airspeed first. If you think back to the part of the lesson where we were analysing the effects of altitude on the various speeds, you will recall that if the aeroplane operates at higher and higher altitudes at the constant indicated or calibrated airspeed of $1.32V_{MD}$, the true airspeed increases. The effect of increasing altitude and therefore increasing true airspeed acts together with the reducing specific fuel consumption to help increase the specific range. Therefore, specific range increases with altitude.

However, the last element of the formula to consider is drag. You will recall that with altitude, as the true airspeed increases and the local speed of sound decreases, the Mach number increases. This means that the aeroplane is approaching the speed of sound and approaching its maximum operating Mach number, M_{MO}. The problem with this is that beyond a certain Mach number, the compressibility factor and approaching shock wave will cause drag to increase. This will be detrimental to the specific range as you can see by the formula. However, it is a little more complicated. As altitude increases, if the Mach number is allowed to get too high, the penalty due to drag will start to outweigh the benefits of increasing TAS and reducing specific fuel consumption. It is at this point that the specific air range will start to reduce. Using the left hand blue line in the graph in *Figure 5.25* you can see that initially specific range increases with altitude but then above a certain altitude the specific range decreases.

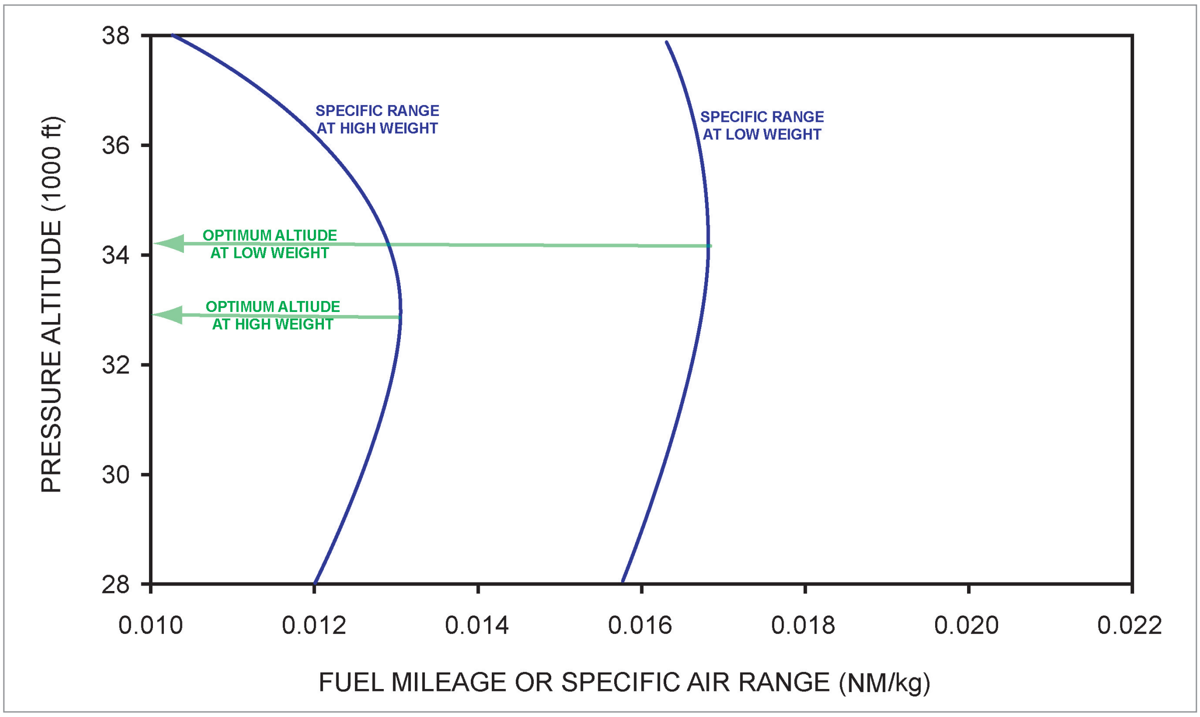


Figure 5.25 A graph showing the effect of altitude on specific range for a jet aeroplane at high & low weights

Optimum Altitude

Using the left hand blue line in *Figure 5.25* you will notice that there is an altitude at which the specific range is greatest; in our example this is just below 33 000 ft. This altitude is called the optimum altitude. It is defined as being the pressure altitude which provides the greatest specific range or fuel mileage at a given weight and speed. Flying higher or lower than the optimum altitude will decrease the range of the aeroplane.

It is important to understand that the optimum altitude is not fixed. You will recall that as the weight decreases through fuel burn, the drag curve moves down and left. Therefore, the best range speed, $1.32V_{MD}$, falls and the total drag decreases. Therefore, with decreasing weight the aeroplane needs to slow down to maintain the best range speed. As it does so, the Mach number will also decrease meaning that the aeroplane is not limited by the high Mach number and corresponding high drag. This fact allows the aeroplane to climb a little. As the aeroplane climbs, the Mach number will increase again to its previous limiting value and drag will increase back to its previous value. But more importantly the higher altitude has decreased the specific fuel consumption. Therefore, the specific air range increases during this little climb. This means that over time, as the weight decreases with fuel burn, the optimum altitude increases. You can see this in *Figure 5.25* by comparing the specific range line for high and low weight. Notice too that as the optimum altitude increases, the specific range increases. Plotting the change of the optimum altitude over time can be seen in *Figure 5.26*.

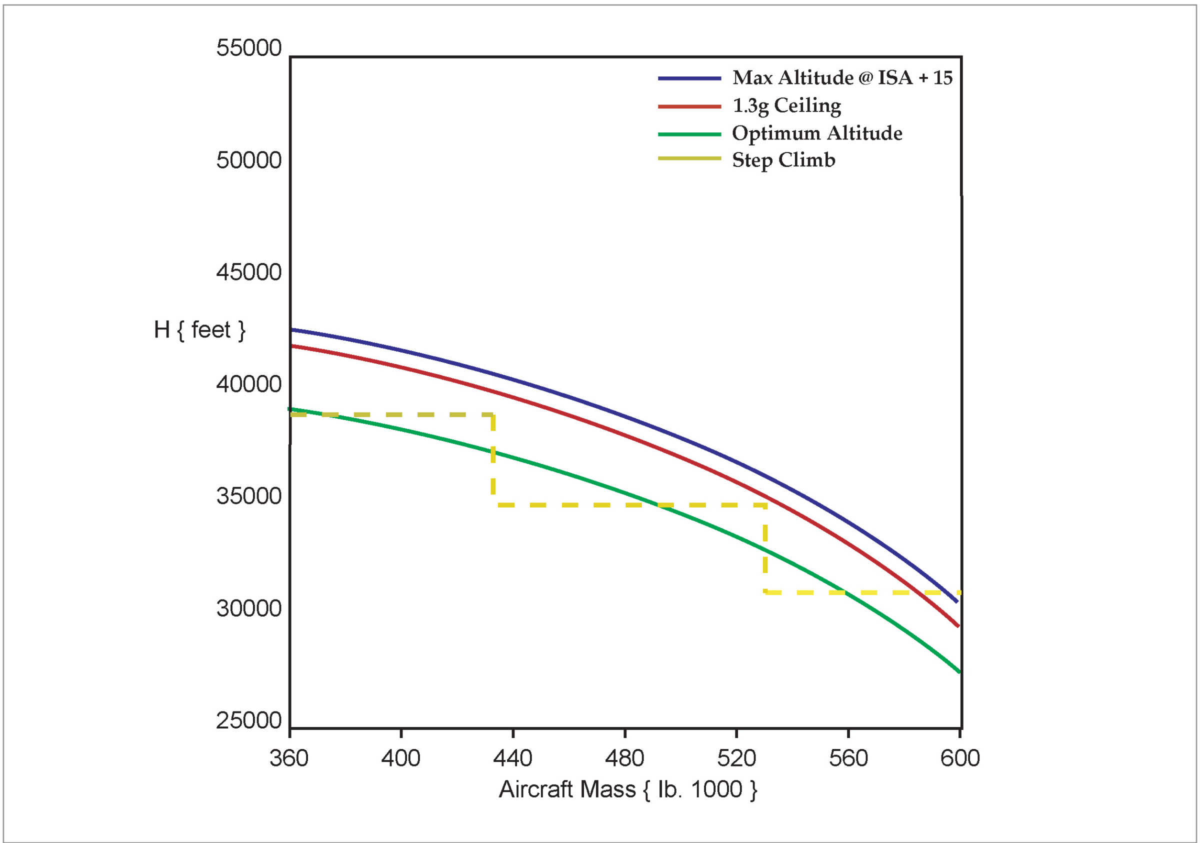


Figure 5.26 A graph showing the optimum altitude increasing with a reduction in weight as the flight progresses for a typical jet aeroplane

In order for the aeroplane to maximize the specific range the aeroplane must stay with the optimum altitude as the optimum altitude slowly increases, in other words the aeroplane must climb along the green line shown in *Figure 5.26*. Climbing in this way is sometimes called a "cruise climb". But carrying out a cruise climb is not always possible, since air traffic control and airspace congestion may predetermine flight cruising levels. If this is the case, in order to stay close to the optimum altitude, step climbs may be performed and are shown by the dashed yellow line in *Figure 5.26*.

Step Climbs

Step climbs essentially mean that the aeroplane climbs to about 2000 ft above the optimum altitude and levels off. As fuel is used and weight falls, the optimum altitude will increase to a point where it is again 2000 ft above the aeroplane's current level but it can take up to 3 hours for it to do so. At its current level the aeroplane can then climb 4000 ft and level off so that it will once again be 2000 ft above the optimum altitude. But, if the last step climb is within 200 NM of the top of descent, then the fuel saving is negated and the aeroplane should remain level.

The step climb process can be repeated throughout the cruise and it helps to explain why the cruise altitudes at the end of the flight are higher than at the start.

Carrying out step climbs in this way, rather than always staying with the optimum altitude, will increase fuel consumption by about 1% and therefore decrease the maximum range by 1%. This may not sound like much, but over a year a typical 747 would have used an extra 34 000 tonnes of fuel. If an aeroplane did not even step climb and simply remained at a constant altitude during the cruise, then the aeroplane would increase its fuel consumption by 10% compared to flying constantly at the optimum altitude. This demonstrates just how important altitude and speed control are in the cruise for a typical commercial flight.

Altitude (Propeller Aeroplanes)

Having discussed the effect of altitude on the jet aeroplane, let us now consider the effect of altitude on the propeller aeroplane. In general though, we may say that most turbo-propeller aeroplanes operate significantly lower than their jet counterparts. Turbo-propeller aeroplanes seldom operate above 30 000 ft, and therefore never really suffer from the effects of getting close to the speed of sound. Turbo-propellers are based on the same engine design as a pure jet, therefore, the effect of altitude on the turbo-propeller is very similar to the jet aeroplane. As altitude, increases the increasing TAS and slightly decreasing specific fuel consumption help to improve the specific range. However, this benefit is offset a little by the increasing power required at higher altitude. So whilst specific range does improve with altitude, above 10 000 ft it only improves by a small amount. The choice of altitude may depend more on the wind considerations and the time and fuel considerations involved in climbing to the selected altitude.

The other type of propeller aeroplane is that driven by a piston engine. You will recall that the piston engine aeroplane has a more or less fixed specific fuel consumption even though specific fuel consumption is lowest at high manifold pressures, low rpm and with the mixture correctly set. Therefore, the only remaining variables in the specific air range formula for the piston engine aeroplane are the true airspeed and the power required.

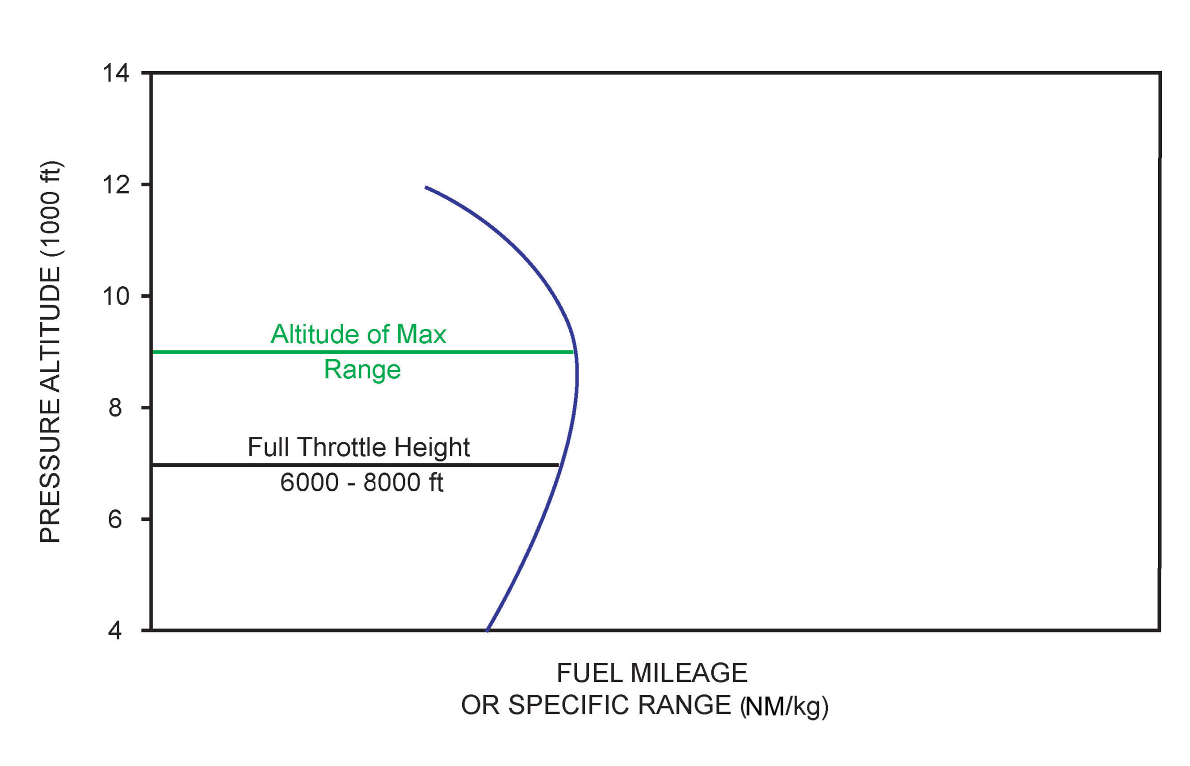


Figure 5.27 A graph showing the specific range with altitude for a typical piston propeller driven aeroplane

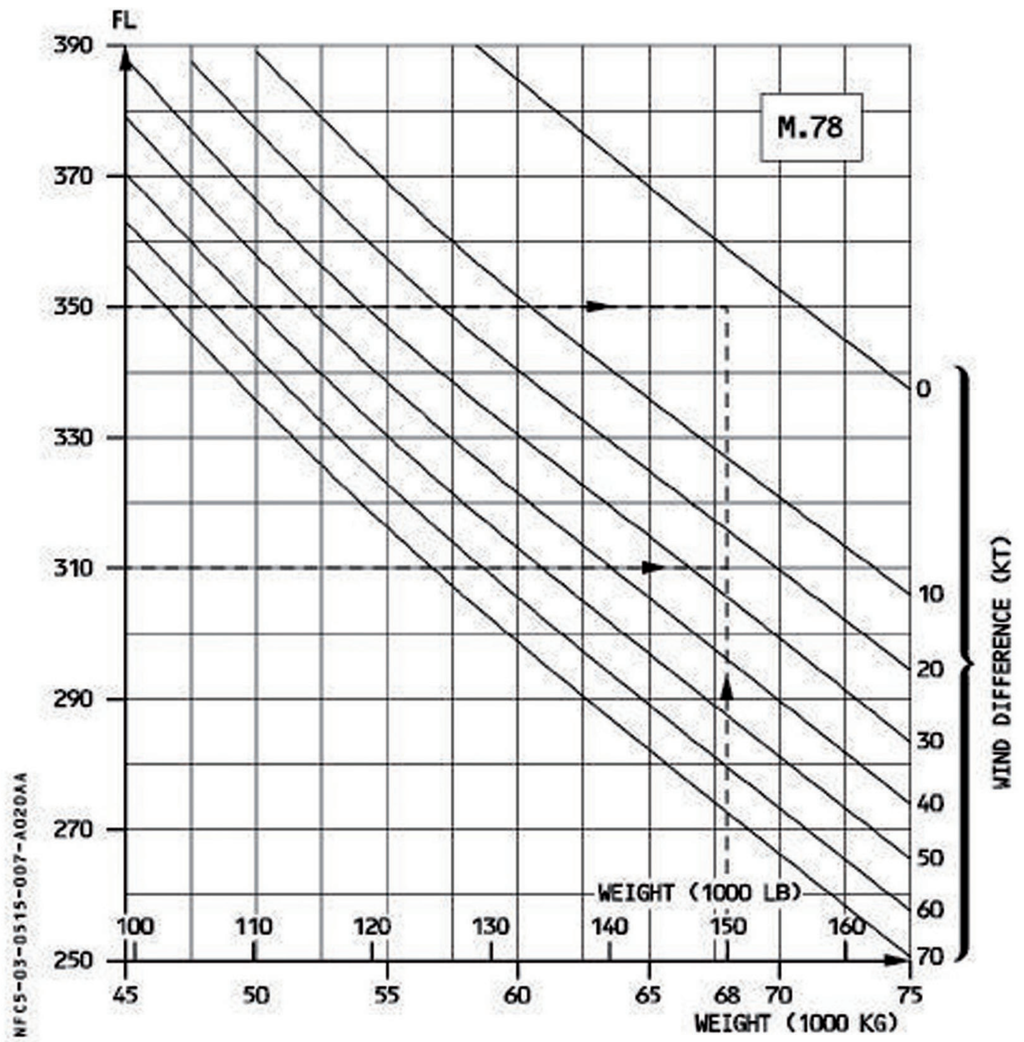
As the aeroplane operates at higher and higher altitudes the power required to maintain the range speed will increase. This of course is detrimental to range. However, as altitude increases, true airspeed increases for any given indicated airspeed and this is good for range. This fact slightly more than offsets the increase of power required and therefore the specific range slowly increases with altitude. However, the aeroplane will reach an altitude where the throttle needs to be fully advanced to maintain the selected speed. This altitude is called the full throttle height and it is shown in *Figure 5.27*. Beyond this altitude the selected power and selected airspeed cannot be maintained and the aeroplane will slow down. Very soon after this altitude, the true airspeed will also start to fall despite the decreasing density. This fact, combined with the constantly increasing amount of power required, means that the specific range will decrease. As a result, maximum specific range will be attained just after full throttle height.

Wind Altitude Trade-Off

The effect of headwinds and tailwinds on the range of the aeroplane can play a significant role in the choice of cruising altitude. For example, if there is a considerable headwind at the selected cruising altitude, this will be detrimental to the range. In this case, it may be beneficial to operate at a different altitude where the winds might be more favourable. In large commercial operations most of these considerations are dealt with prior to the flight by the flight planning personnel. However, in smaller operations, and if conditions change in flight, a pilot may have to carry out a wind altitude trade-off calculation. Information enabling the pilot to do this is usually given in the aeroplane flight manual, an example of which is shown in *Figure 5.28*.

A319/320/321 FLIGHT CREW OPERATING MANUAL	IN FLIGHT PERFORMANCE CRUISE	3.05.15 SEQ 020	P 7 REV 24

WIND ALTITUDE TRADE FOR CONSTANT SPECIFIC RANGE



GIVEN	: Weight : 68000 kg (150 000 lb) Wind at FL350 : 10 kt head
FIND	: Minimum wind difference to descend to FL310 : (26 − 3) = 23 kt
RESULTS	: Descent to FL310 may be considered provided the tail wind at this altitude is more than (23 − 10) = 13 kt.

Figure 5.28 An illustration of a typical wind altitude trade-off graph for an Airbus aeroplane

Long Range Cruise (LRC)

Figure 5.29 shows the relationship between the speed of the aeroplane and its range. The top of the blue curve represents the point of maximum range and the speed at which this is found. For a jet aeroplane you will recall this speed is $1.32V_{MD}$. In commercial operations this speed is more commonly referred to as the Maximum Range Cruise or MRC.

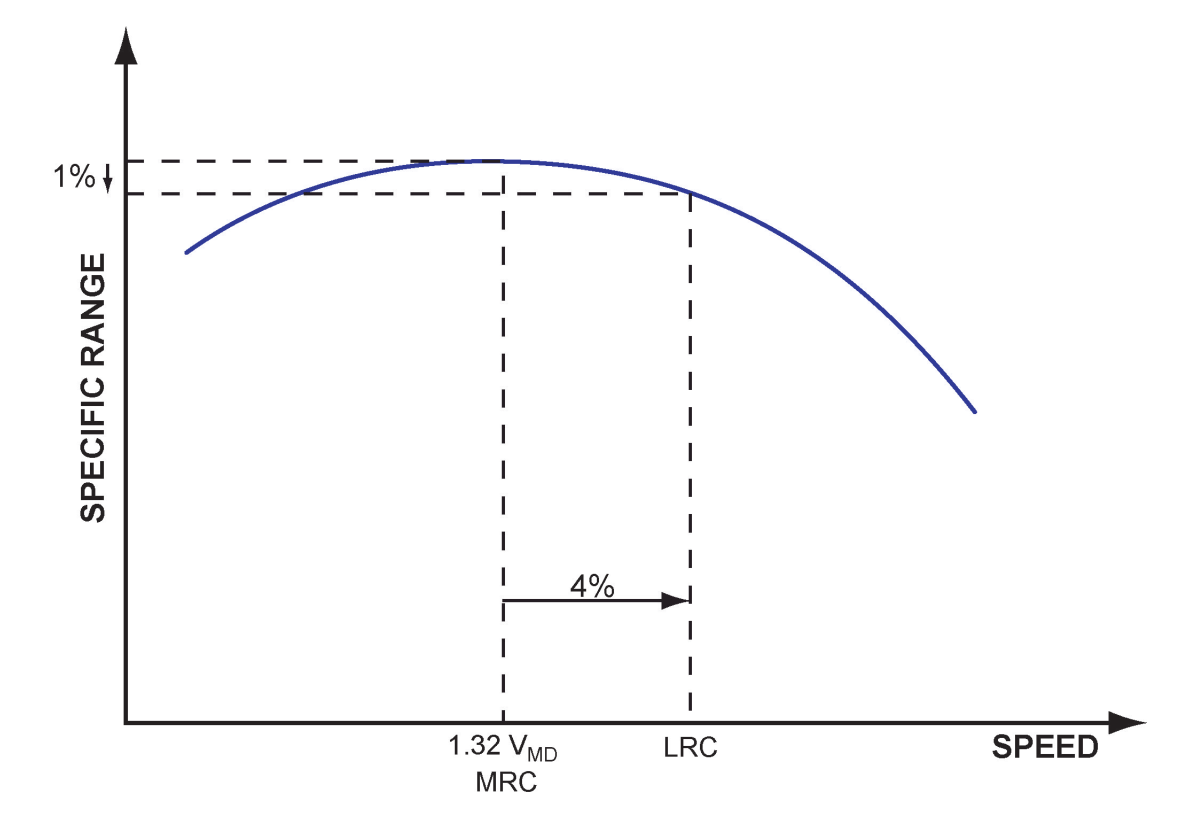


Figure 5.29 A graph showing the relationship between aeroplane speed & range

However, maximum range cruise speed is seldom flown. Usually, a higher speed is used. Looking at the top of the graph, you will notice the line is fairly flat. This means that a significant speed increase can be achieved with only a small compromise in range. This higher speed is called the Long Range Cruise (LRC). The long range cruise speed is about 4% higher than the maximum range cruise speed, and as such the specific range reduces by about 1%. The reason for using this higher speed is simply that there are costs other than fuel which need to be considered in commercial operations. A more detailed explanation of the relationships of these costs and how they affect the operations will be dealt with later on.

Questions

1. On a reciprocating engine aeroplane, with increasing altitude at constant gross mass, constant angle of attack and configuration, the power required:

a. remains unchanged but the TAS increases
b. increases and the TAS increases by the same percentage
c. increases but TAS remains constant
d. decreases slightly because of the lower air density

2. Moving the centre of gravity from the forward to the aft limit: (gross mass, altitude and airspeed remain unchanged).

a. increases the power required
b. affects neither drag nor power required
c. increases the induced drag
d. decreases the induced drag and reduces the power required

3. For jet engine aeroplanes operating below the optimum altitude, what is the effect of increased altitude on specific range?

a. It does not change
b. Increases only if there is no wind
c. Increases
d. Decreases

4. If the thrust available exceeds the thrust required for level flight:

a. the aeroplane accelerates if the altitude is maintained
b. the aeroplane descends if the airspeed is maintained
c. the aeroplane decelerates if it is in the region of reversed command
d. the aeroplane decelerates if the altitude is maintained

5. Given a jet aircraft, which order of speeds is correct?

a. V_S, Maximum range speed, V_X
b. Maximum endurance speed, Maximum range speed, V_X
c. V_S, V_X, Maximum range speed
d. Maximum endurance speed, Long range speed, Maximum range speed

6. The pilot of a light twin engine aircraft has calculated a 4000 m service ceiling with a take-off mass of 3250 kg, based on the general forecast conditions for the flight. If the take-off mass is 3000 kg, the service ceiling will be:

a. less than 4000 m
b. unchanged, equal to 4000 m
c. only a new performance analysis will determine if the service ceiling is higher or lower than 4000 m
d. higher than 4000 m

7. **Consider the graphic representation of the power required for a jet aeroplane versus true airspeed (TAS). When drawing the tangent out of the origin, the point of contact determines the speed of:**

   a. critical angle of attack
   b. maximum endurance
   c. minimum power
   d. maximum specific range

8. **In the drag versus speed curve for a jet aeroplane, the speed for maximum range corresponds with:**

   a. the point of contact of the tangent from the origin to the drag curve
   b. the point of intersection of the parasite drag curve and the induced drag curve
   c. the point of contact of the tangent from the origin to the parasite drag curve
   d. the point of contact of the tangent from the origin to the induced drag curve

9. **The speed V_S is defined as the:**

   a. speed for best specific range
   b. stalling speed or minimum steady flight speed at which the aeroplane is controllable
   c. safety speed for take-off in case of a contaminated runway
   d. design stress speed

10. **What is the effect of a headwind component, compared to still air, on the maximum range speed (IAS) and the speed for maximum climb angle respectively?**

    a. Maximum range speed decreases and maximum climb angle speed decreases
    b. Maximum range speed increases and maximum climb angle speed increases
    c. Maximum range speed increases and maximum climb angle speed stays constant
    d. Maximum range speed decreases and maximum climb angle speed increases

11. **A jet aeroplane is flying at the long range cruise speed at the optimum altitude. How does the specific range / fuel flow change over a given time period?**

    a. Decrease / decrease
    b. Increase / decrease
    c. Increase / increase
    d. Decrease / increase

12. **The maximum indicated airspeed of a piston engine aeroplane, in level flight, is reached:**

    a. at the service ceiling
    b. at the practical ceiling
    c. at the lowest possible altitude
    d. at the optimum cruise altitude

13. **The optimum cruise altitude increases:**

a. if the aeroplane mass is decreased
b. if the temperature (OAT) is increased
c. if the tailwind component is decreased
d. if the aeroplane mass is increased

14. **What effect has a tailwind on the maximum endurance speed?**

a. No effect
b. Tailwind only affects holding speed
c. The IAS will be increased
d. The IAS will be decreased

15. **Which of the equations below defines specific air range (SR)?**

a. SR = Ground speed/Total Fuel Flow
b. SR = True Airspeed/Total Fuel Flow
c. SR = Indicated Airspeed/Total Fuel Flow
d. SR = Mach Number/Total Fuel Flow

16. **Which of the following statements, with regard to the optimum altitude (best fuel mileage), is correct?**

a. An aeroplane usually flies above the optimum cruise altitude, as this provides the largest specific range
b. An aeroplane sometimes flies above the optimum cruise altitude, because ATC normally does not allow an aeroplane to fly continuously at the optimum cruise altitude
c. An aeroplane always flies below the optimum cruise altitude, as otherwise Mach buffet can occur
d. An aeroplane always flies on the optimum cruise altitude, because this is most attractive from an economy point of view

17. **The optimum altitude:**

a. is the altitude up to which cabin pressure of 8000 ft can be maintained
b. increases as mass decreases and is the altitude at which the specific range reaches its maximum
c. decreases as mass decreases
d. is the altitude at which the specific range reaches its minimum

18. **A lower airspeed at constant mass and altitude requires:**

a. less thrust and a lower coefficient of lift
b. more thrust and a lower coefficient of lift
c. more thrust and a lower coefficient of drag
d. a higher coefficient of lift

19. **The point at which a tangent out of the origin touches the power required curve:**

a. is the point where drag coefficient is a minimum
b. is the point where the lift to drag ratio is a minimum
c. is the maximum drag speed
d. is the point where the lift to drag ratio is a maximum

20. **In relation to the speed for maximum range cruise (MRC), the long range cruise speed (LRC) is:**

a. Lower
b. Dependent on the OAT and net mass
c. Dependent on density altitude and mass
d. Higher

21. **The maximum horizontal speed occurs when:**

a. the thrust is equal to minimum drag
b. the thrust does not increase further with increasing speed
c. the maximum thrust is equal to the total drag
d. the thrust is equal to the maximum drag

22. **Under which condition should you fly considerably lower (4000 ft or more) than the optimum altitude?**

a. If at the lower altitude either more headwind or less tailwind can be expected
b. If at the lower altitude either considerably less headwind or considerably more tailwind can be expected
c. If the maximum altitude is below the optimum altitude
d. If the temperature is lower at the low altitude (high altitude inversion)

23. **The optimum cruise altitude is:**

a. the pressure altitude up to which a cabin altitude of 8000 ft can be maintained
b. the pressure altitude at which the TAS for high speed buffet is a maximum
c. the pressure altitude at which the best specific range can be achieved
d. the pressure altitude at which the fuel flow is a maximum

24. **Maximum endurance for a piston engine aeroplane is achieved at:**

a. the speed that approximately corresponds to the maximum rate of climb speed
b. the speed for maximum lift coefficient
c. the speed for minimum drag
d. the speed that corresponds to the speed for minimum rate of descent

25. **On a long distance flight the gross mass decreases continuously as a consequence of the fuel consumption. The result is:**

a. the speed must be increased to compensate the lower mass
b. the specific range increases and the optimum altitude decreases
c. the specific range decreases and the optimum altitude increases
d. the specific range and the optimum altitude increase

26. **A jet aeroplane is climbing at constant Mach number below the tropopause. Which of the following statements is correct?**

a. IAS decreases and TAS decreases
b. IAS increases and TAS increases
c. IAS decreases and TAS increases
d. IAS increases and TAS decreases

27. Why are 'step climbs' used on long distance flights?

a. Step climbs do not have any special purpose for jet aeroplanes; they are used for piston engine aeroplanes only
b. ATC do not permit cruise climbs
c. To fly as close as possible to the optimum altitude as aeroplane mass reduces
d. Step climbs are only justified if at the higher altitude less headwind or more tailwind can be expected

28. Which of the following sequences of speed for a jet aeroplane is correct? (From low to high speeds.)

a. Maximum endurance speed, maximum range speed, maximum angle of climb speed
b. Maximum endurance speed, long range speed, maximum range speed
c. V_S, maximum angle climb speed, maximum range speed
d. V_S, maximum range speed, maximum angle climb speed

29. The pilot of a jet aeroplane wants to use a minimum amount of fuel between two airfields. Which flight procedure should the pilot fly?

a. Maximum endurance
b. Holding
c. Long range
d. Maximum range

30. Long range cruise is selected as:

a. the higher speed to achieve 99% of maximum specific range in zero wind
b. the speed for best economy (ECON)
c. the climbing cruise with one or two engines inoperative
d. specific range with tailwind

31. The optimum long range cruise altitude for a turbojet aeroplane:

a. is only dependent on the outside air temperature
b. increases when the aeroplane mass decreases
c. is always equal to the powerplant ceiling
d. is independent of the aeroplane mass

32. Maximum endurance:

a. is the same as maximum specific range with wind correction
b. can be flown in a steady climb only
c. can be reached with the 'best rate of climb' speed in level flight
d. is achieved in unaccelerated level flight with minimum fuel consumption

33. For a piston engine aeroplane, the speed for maximum range is:

a. that which gives the maximum lift to drag ratio
b. that which gives the minimum value of power
c. that which gives the maximum value of lift
d. 1.4 times the stall speed in clean configuration

34. **The speed for maximum endurance:**

a. is always higher than the speed for maximum specific range
b. is always lower than the speed for maximum specific range
c. is the lower speed to achieve 99% of maximum specific range
d. can either be higher or lower than the speed for maximum specific range

35. **The intersections of the thrust available and the drag curves are the operating points of the aeroplane:**

a. in unaccelerated climb
b. in unaccelerated level flight
c. in descent with constant IAS
d. in accelerated level flight

36. **For a jet transport aeroplane, which of the following is the reason for the use of 'maximum range speed'?**

a. Minimizes specific fuel consumption
b. Minimizes fuel flow for a given distance
c. Longest flight duration
d. Minimizes drag

37. **The centre of gravity moving near to, but still within, the aft limit:**

a. increases the stalling speed
b. improves the longitudinal stability
c. decreases the maximum range
d. improves the maximum range

38. **A jet aeroplane is performing a maximum range flight. The speed corresponds to:**

a. the minimum drag
b. the minimum required power
c. the point of contact of the tangent from the origin to the power required versus TAS curve
d. the point of contact of the tangent from the origin to the Drag versus TAS curve

39. **During a cruise flight of a jet aeroplane at a constant flight level and at the maximum range speed, the IAS / the drag will:**

a. increase / increase
b. decrease / increase
c. decrease / decrease
d. increase / decrease

40. **Which of the following is a reason to operate an aeroplane at 'long range speed'?**

a. The aircraft can be operated close to the buffet onset speed
b. In order to prevent loss of speed stability and tuck-under
c. It offers greatly reduced time costs than with maximum range speed
d. In order to achieve speed stability

41. **Long range cruise is a flight procedure which gives:**

a. an IAS which is 1% higher than the IAS for maximum specific range
b. a specific range which is 99% of maximum specific range and a lower cruise speed
c. a specific range which is about 99% of maximum specific range and higher cruise speed
d. a 1% higher TAS for maximum specific range

42. **The lowest point of the drag or thrust required curve of a jet aeroplane is the point for:**

a. minimum drag and maximum endurance
b. maximum specific range and minimum power
c. minimum power
d. minimum specific range

43. **If other factors are unchanged, the fuel mileage or range (nautical miles per kg) is:**

a. independent of the centre of gravity position
b. lower with an aft centre of gravity position
c. higher with a forward centre of gravity position
d. lower with a forward centre of gravity position

44. **To achieve the maximum range over ground with headwind the airspeed should be:**

a. lower compared to the speed for maximum range cruise with no wind
b. reduced to the gust penetration speed
c. higher compared to the speed for maximum range cruise with no wind
d. equal to the speed for maximum range cruise with no wind

45. **When utilizing the step climb technique, one should wait for the weight reduction, from fuel burn, to result in:**

a. the aerodynamic ceiling to increase by approximately 2000 ft above the present altitude, whereby one would climb approximately 4000 ft higher
b. the optimum altitude to increase by approximately 2000 ft above the present altitude, whereby one would climb approximately 4000 ft higher
c. the manoeuvre ceiling to increase by approximately 2000 ft above the present altitude, whereby one would climb approximately 4000 ft higher
d. the en route ceiling to increase by approximately 2000 ft above the present altitude, whereby one would climb approximately 4000 ft higher

46. **Which of the following statements is true regarding the performance of an aeroplane in level flight?**

a. The maximum level flight speed will be obtained when the power required equals the maximum power available from the engine
b. The minimum level flight speed will be obtained when the power required equals the maximum power available from the engine
c. The maximum level flight speed will be obtained when the power required equals the minimum power available from the engine
d. The maximum level flight speed will be obtained when the power required equals the power available from the engine

Answers

1	2	3	4	5	6	7	8	9	10	11	12
b	d	c	a	c	d	b	a	b	c	b	c

13	14	15	16	17	18	19	20	21	22	23	24
a	a	b	b	b	d	d	d	c	b	c	d

25	26	27	28	29	30	31	32	33	34	35	36
d	a	c	c	d	a	b	d	a	b	b	b

37	38	39	40	41	42	43	44	45	46
d	d	c	c	c	a	d	c	b	a

Chapter 6

General Principles - Landing

Landing Distance

The landing stage of flight is defined as being that stage of flight commencing from 50 ft above the landing threshold and terminating when the aeroplane comes to a complete stop as shown by *Figure 6.1.* The 50 ft point is sometimes referred to as the landing screen height. The landing screen height is fixed at 50 ft for all classes of aeroplane unlike the take-off screen height which is 35 ft for Class A aeroplanes and 50 ft for Class B aeroplanes.

From the approach down to the landing screen height the aeroplane must have attained the landing reference speed, known as V_{REF}. V_{REF} for Class A aeroplanes must be no less than the greater of 1.23 times the stall reference speed in the landing configuration ($1.23V_{SR0}$) and the velocity of minimum control in the landing configuration (V_{MCL}). V_{REF} for all other classes of aeroplane must be no less than 1.3 times the stall speed ($1.3V_{S0}$) in the landing configuration. V_{REF} is a very important speed to attain since the landing distances in the aeroplane flight manual are based on aeroplanes flying at V_{REF}. Therefore, if a landing aeroplane is not at V_{REF}, the landing distance given by the manual will not be achieved by the pilot. A landing carried out at a speed other than V_{REF} could seriously jeopardize the safety of the landing.

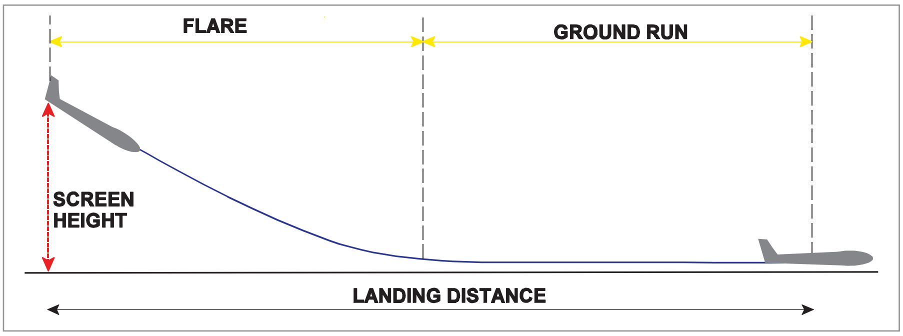


Figure 6.1 Landing distance

The landing can be divided into two parts. We call these the airborne section and the ground run or landing roll. The first part, the airborne section, starts from the landing screen height of 50 ft and ends when the aeroplane's main wheels touch the landing surface. The airborne section is usually given as being about 1000 ft in length. Within the airborne section certain critical actions take place. On descending through the screen height the thrust is reduced to zero and the aeroplane pitch attitude is increased slightly so that the aeroplane is in a slight nose-up attitude. The increase in pitch attitude helps to arrest the rate of descent and the reduction in thrust to zero reduces the speed. This procedure of reducing thrust and increasing pitch is known as the landing flare, although other terms like "roundout" are commonly used. The landing flare will allow the aeroplane to touch down onto the runway using the main wheels first. It is important to understand that the technique of flaring the aeroplane differs from one aeroplane to another and especially so between light general aviation aeroplanes and large commercial jet airliners.

The second part of the landing is the ground run, ground roll or landing roll. This is the distance covered from touchdown until the aeroplane comes to full stop. As with the airborne section, there are a few critical actions that are carried out. Once the main wheels have settled onto the landing surface reverse thrust and lift spoilers can be activated and as the speed decreases further, the nose wheel will then settle onto the landing surface. Braking force is now applied and the aeroplane will slow to a stop. However, in normal operations, the aeroplane does not stop on the runway; rather the aeroplane is slowed to a safe speed where it can then be steered off the runway and taxied to the disembarkation point or ramp.

The combined length of the 'airborne section' and the 'ground run or 'landing roll' is known as the "landing distance required". Pilots need to make sure that the landing distance required does not exceed the landing distance available.

Landing Distance Available (LDA)

The landing distance available is the distance from the point on the surface of the aerodrome above which the aeroplane can commence its landing, having regard to the obstructions in its approach path, to the nearest point in the direction of landing at which the surface of the aerodrome is incapable of bearing the weight of the aeroplane under normal operating conditions or at which there is an obstacle capable of affecting the safety of the aeroplane.

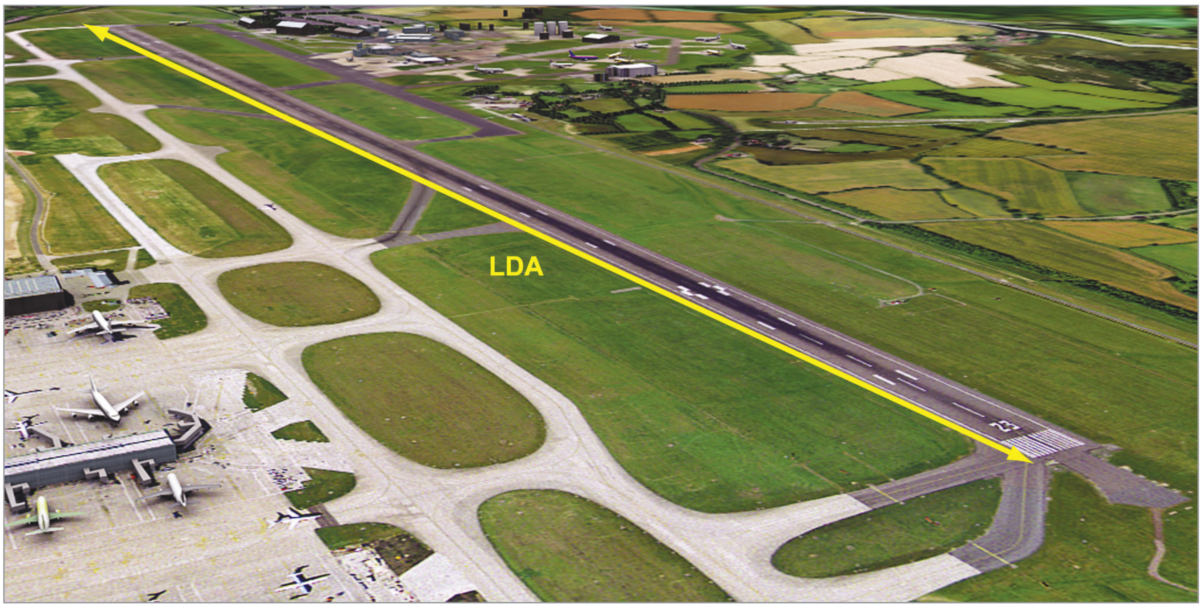


Figure 6.2 Landing distance available

In short, the landing distance available is the length of runway from one threshold to another. These are not always at the end of the runway, sometimes there are displaced thresholds which are some way in from the end of the paved surface. You will recall that the landing distance starts at 50 ft. This point must be directly above the threshold. Landing on the threshold is not the aim of the landing.

Lift and Weight

In order to better understand landing performance we need to analyse the forces acting upon the aeroplane, and how these forces might be modified throughout the landing. The first of the forces that we will consider is weight. As you have learnt already, weight acts vertically downwards towards the centre of the earth from the centre of gravity. During flight, weight is mainly balanced by lift. However, once the aeroplane is on the ground weight is balanced by the reaction of the ground acting up through the wheels on the undercarriage. The weight of the aeroplane on landing will be less than at take-off due to the fact that fuel has been consumed. There is, however, a maximum structural landing mass which must not be exceeded. Let us now consider lift. Whilst lift helps to balance weight when in the air, once the aeroplane is on the ground, lift is no longer required. In fact during the landing roll, lift is detrimental to the landing performance. Producing lift will reduce the load placed on wheels and therefore decrease the braking effect. In large commercial aeroplanes once the main wheels have settled on the runway the lift spoilers or lift dumpers are deployed which act very quickly to disrupt the airflow over the wing and destroy lift.

Reverse Thrust

Whilst in level flight the forward acting force of thrust is essential to maintain sufficient speed for the wings to provide lift. During landing, because the aim is to bring the aeroplane to a stop, the thrust force must be reduced to zero. Any residual thrust would be detrimental to the landing performance. However, large propeller and jet aeroplane engines have the capability of redirecting the force of thrust in order to generate a braking effect on the aeroplane. This is known as reverse thrust. Reverse thrust helps to reduce the aeroplane's forward speed. Reverse thrust capability is especially important in conditions where braking force is reduced due to ice or water contamination on the runway.

Jet Engines

Jet engines produce reverse thrust by using one of several methods, but all jet engines follow the same basic principle which is to redirect the jet efflux in a forwards direction. Many modern aeroplanes have a safety device whereby reverse thrust is not activated until a certain value of the aeroplane's weight is pressing down on the main wheels and until the wheels have reached a certain speed of rotation. Once the aeroplane's reverse thrust system has detected this, reverse thrust is activated and the engine will reconfigure itself so that the exhaust gas flow can be redirected forwards. You can see the extent of the reconfiguration in *Figure 6.3*.

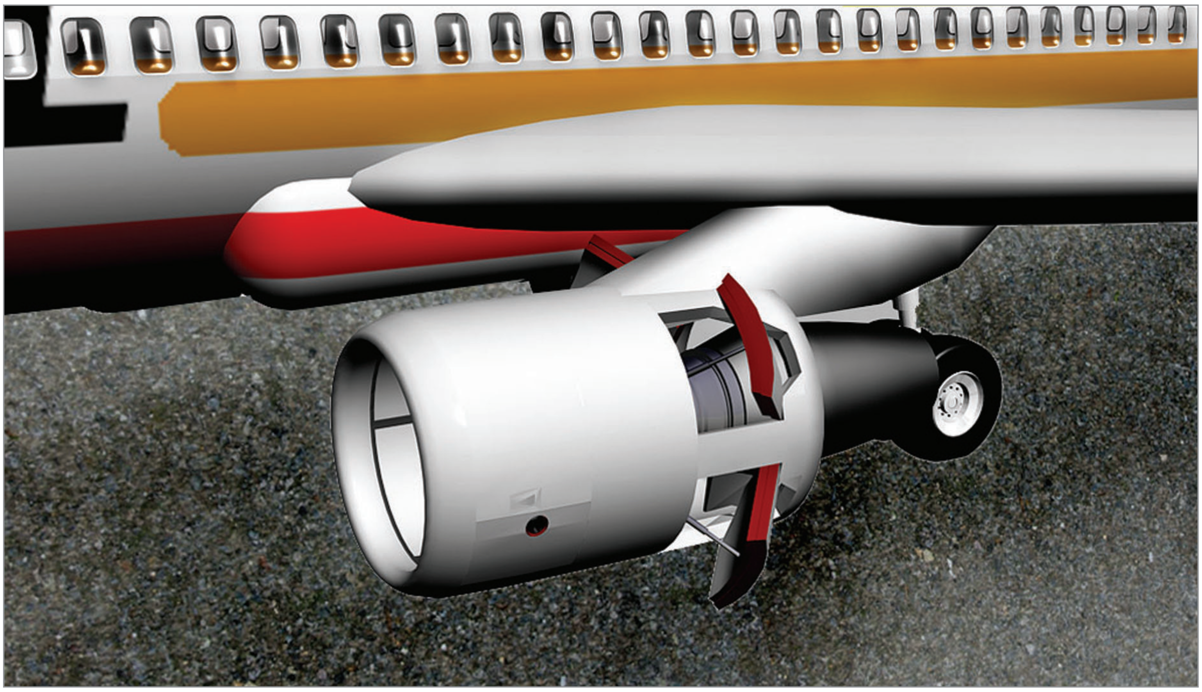


Figure 6.3 An illustration of a jet engine during reverse thrust mode

However, pilots need to recognize that the process of getting the engines reconfigured to generate full reverse thrust takes time, and so the aeroplane will have travelled a small distance from the touchdown point before reverse thrust takes effect. This fact reduces the effective time period during which reverse thrust can be used. Therefore, the effectiveness of reverse thrust on landing is reduced.

It is important to note too that jet engine reverse thrust cannot be maintained right up to the point when the aeroplane comes to a full stop. Reverse thrust must be deactivated before the forward speed reduces to a minimum value. As the aeroplane slows down the redirected airflow may start to be re-ingested into the compressor. This means that the jet engine recycles its own gas flow which significantly increases the engine temperatures but it also means that debris on the runway can be sucked into the engine, potentially causing major damage. As a result of this danger to the engines at low forward speeds reverse thrust must be deactivated below about 50 kt.

The combined effect of late reverse thrust activation and early reverse thrust deactivation means that the time period for which reverse thrust can be used may be quite short.

Propeller Aeroplanes

Large turbo-propeller aeroplanes are also able to generate reverse thrust by redirecting the air flow forwards, but they do so in a very different way than that employed by a jet engine. For forward flight the propeller blade is angled in such a way as to displace air backwards thus producing forward thrust. In order for the propeller blade to direct air forwards and create a rearward acting force, the blade angle must change. The blade angle required for the propeller to generate reverse thrust is known as reverse pitch. Because only a change of blade angle is required, a propeller aeroplane can switch from forward to reverse thrust far quicker than a jet aeroplane. This means that a propeller aeroplane can use reverse thrust earlier in the landing roll than a jet aeroplane.

A propeller aeroplane can also maintain reverse thrust until the aeroplane comes to a full stop. This capability gives the propeller aeroplane a greater braking advantage over the jet aeroplane during landing.

In summary, the usable period of reverse thrust in the landing roll is shorter for a jet aeroplane than for a propeller aeroplane. For this reason, the authorities have laid down less stringent landing performance regulations for propeller aeroplanes. The precise nature of these regulations will be discussed later.

Drag

Let us now consider the action of the drag force during landing. You may recall that there are several forms of drag. The main types of drag are parasite drag and induced drag. However, whilst the aeroplane is on the ground, during take-off and landing, wheel drag must be considered alongside the aerodynamic drag. The aim of the landing is to bring the aeroplane to a stop safely within the confines of the runway. In order to decelerate, sufficient rearward directed forces need to act on the aeroplane. Consequently, in addition to reverse thrust aerodynamic drag plays a crucial role in landing.

Induced Drag

Of the two types of aerodynamic drag, we will deal with induced drag first. Induced drag is dependent on lift and is proportional to angle of attack. During the airborne section of the landing, there is still a large amount of lift being generated and the angle of attack is relatively high. This means that induced drag is far higher than in cruising flight. However, when the aeroplane nose wheel touches the runway, the angle of attack is almost nil. Induced drag is consequently reduced to zero.

Parasite Drag

The second form of aerodynamic drag is parasite drag. Parasite drag is a function of the aeroplane's forward facing cross-sectional area, more accurately known as form drag, and of the aeroplane's forward speed. The configuration of the aeroplane for landing is such that the flaps and slats are fully extended which significantly increases the aeroplane's form drag and therefore significantly increases parasite drag. Once the aeroplane touches down and the spoilers and speed brakes are deployed, parasite drag increases even further. However, as the speed rapidly decays after touchdown, so will the parasite drag; eventually decreasing to zero once the aeroplane reaches a full stop.

In summary then, the aerodynamic drag comprising induced drag and parasite drag will be very high during the early part of the landing, but very soon after touchdown will decay rapidly.

Wheel and Brake Drag

Having discussed aerodynamic drag, let us now consider wheel drag and brake drag. Wheel drag is the friction force between the wheel and the runway and with the wheel bearings, whereas brake drag is the friction force between the brake discs and the brake pads. Wheel drag will come into play as soon as the aeroplane touches down on the runway. However, as friction is a function of the force pushing two surfaces together, because there is still a lot of lift being generated, wheel load is small during the initial part of the landing run, and therefore wheel drag is also small. As speed reduces and as lift is destroyed by the spoilers, the wheel load increases which in turn increases the wheel drag. Therefore, wheel drag increases throughout the landing roll and will reach a maximum value just before the aeroplane comes to rest.

Brake drag is by far the most important and the most effective of the various drag forces during the landing since it provides the greatest retarding force. However, brake drag is only effective if there is also sufficient wheel drag or wheel friction between the tyres and the runway. If wheel drag is low, brake drag will also be low. Consequently, the brakes are effective only if there is sufficient friction between the tyres and the runway. During the early part of the landing run there is not much load on the wheels and therefore not much wheel friction. Brake drag is consequently ineffective in slowing down the aeroplane. However, as the lift reduces and more weight is placed on the wheels, brake drag does become more effective in slowing down the aeroplane. Therefore, brake drag increases as the landing roll progresses. This concept explains why pilots need to destroy lift as soon as possible after touchdown so that the braking action can be at its peak effectiveness early on in the landing.

In most large commercial aeroplanes, however, the braking action may not actually be carried out by the pilots. Instead it can be carried out by a highly effective automatic anti-skid braking system. This braking system can be set to low, medium or high braking levels, or levels 1 through to 3, and it is especially important to use it when landing on contaminated runways.

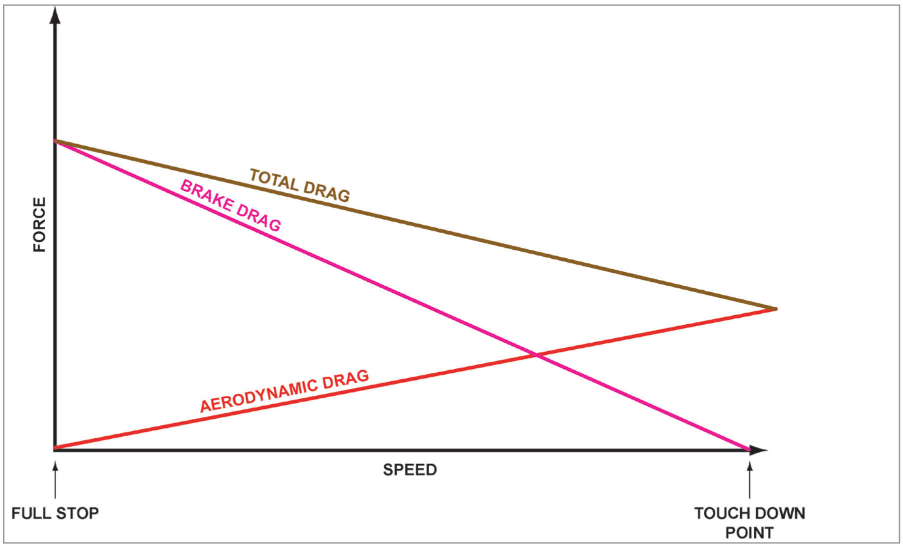


Figure 6.4 A graph showing the variations in drag through the landing roll

In summary then, the first of the drag forces we discussed was aerodynamic drag. As speed decreased during the landing run, aerodynamic drag comprising parasite and induced drag decreased.

Brake drag on the other hand increased during the landing roll as more load was placed on the wheels. Notice that during the early part of the landing roll, aerodynamic drag provides the majority of the drag, whereas once the speed has dropped below 70% of the landing speed, brake drag provides the majority of the drag.

The last line on the graph is total drag. From this line you can see that during the landing roll, total drag increases. Overall, you can see how important brake drag is. If the brakes were to fail, or the landing surface is very slippery, then the loss of braking would cause the landing performance to massively deteriorate therefore increasing the landing distance.

Landing Distance Formula

Now we will examine what determines the landing distance, and also what roles the four forces play. In order to do this, let us briefly detail the formula that is used to calculate the landing distance. In *Figure 6.5* you can see the landing distance formula. The letter "s" is the displacement or distance required to stop from a specified speed which is "V" with a given deceleration "d". Deceleration is force divided by mass. The force is aerodynamic drag, plus the braking coefficient which is a function of wheel load, minus thrust, or in the case of reverse thrust, plus thrust.

$$s = \frac{V^2}{d}$$

$$d = \frac{D_A + \mu\,(W - L) + T_R}{m}$$

Key: s =Displacement d = Deceleration W = Weight D_A = Aerodynamic Drag m = mass
V = Speed T_R = Thrust Reverse L = Lift μ = Coefficient of friction

Figure 6.5 The expanded landing distance formula

Expanding the formula in this manner allows you to see how a change in one of the variables has a knock-on effect on the landing distance. We will now analyse in detail all the factors that can affect the landing, with our principal concern being how these factors affect the landing distance.

Effect of Variable Factors on Landing Distance

Weight

The mass of the aeroplane affects:

- the stalling speed and hence V_{REF}
- the deceleration for a given decelerating force
- the wheel drag

Increased mass increases stalling speed, and reduces the deceleration for a given decelerating force, both effects increasing the landing distance. Increased mass increases the brake drag available (if not torque limited) and this decreases the landing distance. The net effect is that the landing distance will increase with increasing mass, but to a lesser degree than the increase of take-off distance with increasing mass.

Density
The air density affects:

- the TAS for a given IAS
- the thrust or power of the engine

As thrust is small the main effect will be on the TAS. Low density (high temperature, low pressure or high humidity) will give an increase in the landing distance due to the higher TAS, but again to a lesser degree than for the take-off distance.

Wind
You will recall that headwinds decrease the true ground speed of the aeroplane for any given indicated airspeed. Thus, during a headwind, the forward speed over the landing surface is much less and as a result the distance required to bring the aeroplane to rest is decreased.

A tailwind will have the opposite effect and it will increase the ground speed for a given indicated airspeed. Thus, during a tailwind, the forward speed over the landing surface is much greater and as a result the distance required to bring the aeroplane to rest is increased.

When examining the effects that winds have on landing performance, it is recommended that you do not use the actual wind that is given just in case the wind changes to a worse condition than the one you have planned for.

When calculating actual landing distances, it is recommended that you assume only 50% of the headwind component, and 150% of the tailwind component. Most performance graphs that calculate the landing distance have the 50% headwind and 150% tailwind recommendations already applied.

An important note is that there is no allowance for crosswinds and therefore no safety factor for crosswinds. Crosswinds present an additional complication because of the effect of potentially crossed controls which would have to be applied because the wind will tend to push the aeroplane off the centre line. These issues mean that aeroplanes are given maximum crosswind limits.

Flap Setting
Flaps are devices used to increase the camber of the wing and generate more lift, thereby reducing the landing speed. However, the use of a lot of flap will dramatically increase aerodynamic drag as well. This is a benefit in landing and helps to slow the aeroplane down. Let us take a look at how different flap angles can affect the landing distance.

With no flap the aircraft will have a much faster approach speed, and have very little aerodynamic drag, therefore the landing distance will be large. However, with some flap selected, the approach speed is less, there will be more aerodynamic drag and consequently the landing distance will be smaller. However, with full flap, the approach speed is minimized and the aerodynamic drag is maximized. Therefore, the landing distance will be least compared to other flap settings. Having full flap selected for landing allows the aeroplane to maximize its landing mass. However, there is a disadvantage with having full flap if there was a situation where the aeroplane needed to abort the landing and go-around for another attempt. You will recall that large flap angles greatly deteriorate the climb performance compared to no flaps. Therefore in a go-around, after the climb has been established, retract the flaps as soon as possible in the manner prescribed in the aeroplane flight manual.

Runway Slope

The next factor that can affect the landing performance is the slope of the runway. Slope has an impact on the landing distance because of its effect on how the component of weight acts along the longitudinal axis of the aeroplane. When the aircraft is on an upslope, the weight still acts towards the centre of the earth, but there is a component of weight which acts in the direction of drag, that is, backwards along the longitudinal axis. This will increase the deceleration of the aeroplane and therefore decrease the landing distance. Conversely when the aeroplane is on a downslope, the weight component now acts in the direction of thrust. This adds to the forward force, therefore it will decrease the deceleration and increase the landing distance.

A rough calculation to help quickly quantify the effect of slope is to assume that for every 1% slope, the landing distance is affected by 5%, or a factor of 1.05. The slope at some airfields means that the landing may only be possible in one direction. These are called unidirectional runways. Treat these runways with extra caution and always check that the current wind velocity will still allow a safe landing since you may be forced to land with a tailwind.

Runway Surface

Most landing performance graphs assume a paved hard surface. If the condition of the runway is not like this, then the effect on the landing distance needs to be understood and corrections applied.

Grass

A lot of small airfields have grass runways. The grass will increase the drag on the wheels. This is known as impingement drag and it will help to decelerate the aeroplane. However, grass severely reduces the wheel friction to the runway compared to a paved runway and therefore the wheel cannot be retarded efficiently by the brakes, otherwise the wheel will lock and the wheel friction with the runway will reduce even further.

Figure 6.6 An illustration showing that for the wheel to advance grass must be pushed out of the way

The overall effect is that grass runways will increase the landing distance. In light general aviation aeroplanes, this increase in landing distance is about 15% compared to a landing on a paved surface. However, most landings that you will carry out throughout your professional career will undoubtedly be on hard paved runways.

Contaminations

If the runway is covered partially or fully by contaminants such as standing water, snow, slush or ice, then pay special attention to the effect that they will have on the landing distance. These substances will have two main effects.

The first effect is that they will create impingement drag, much like grass did, but more importantly, the second effect is that these substances will substantially reduce the friction between the wheel and the runway. Therefore the wheel cannot be retarded efficiently by the brakes. As a result of the reduced friction and therefore the subsequent reduced braking action, any contamination of the runway due to water, snow, slush or ice will significantly increase the landing distance. You can see the effect of the various contaminations to the landing distance in *Figure 6.7*.

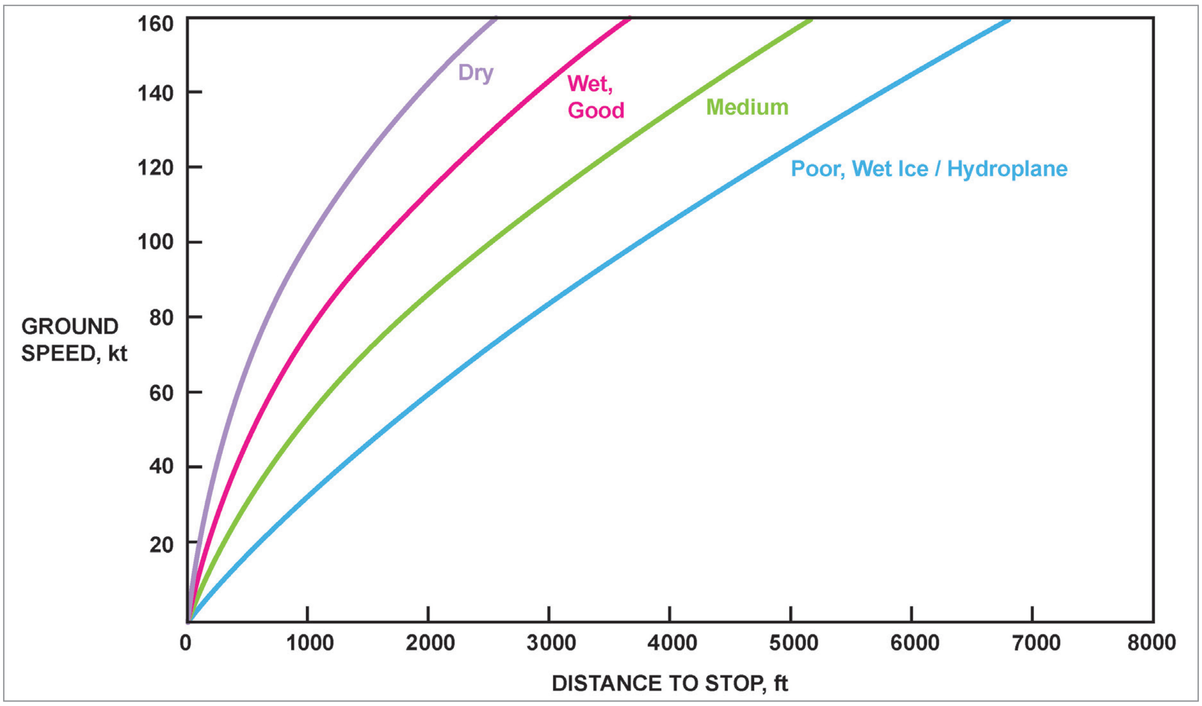


Figure 6.7 A graph showing the effect of contamination on the landing distance

Typically on a dry runway the braking coefficient of friction is between 0.8 to 1.0, but on wet, slippery or icy runways, the braking coefficient of friction can fall to less than 0.2. Because of the lack of effective braking on slippery surfaces, the aerodynamic drag and reverse thrust become more important in bringing the aeroplane to a stop as shown in *Figure 6.8*. On flooded or icy runways, reverse thrust accounts for 80% of the deceleration force.

Figure 6.8 Various codes & terminology associated with runway contaminations

An important point to note is that there is a distinction between the definitions of a damp, wet or contaminated runway. A runway is considered to be damp when there is moisture present on the surface which changes its colour, but insufficient moisture to produce a reflective surface.

A wet runway is one whose moisture level makes the runway appear reflective, but there are no areas of standing water in excess of 3 mm deep. Wet runways can cause the average dry landing distance to increase by as much as 50%.

A contaminated runway is one where more than 25% of the runway is covered in a layer of moisture, whose specific gravity is equivalent to a depth of 3 mm or more of water. The importance of runway contamination cannot be stressed enough, as many fatal accidents may have been avoided had due account been taken of the situation.

From what you have learnt so far it is vital that the pilot be aware of the type of runway contamination, its depth, its extent, its effect on the braking and of course its overall effect on the operation concerned, in this case, the landing. The information on the runway contamination and braking effect can be given to the pilot through a report. These reports are either by SNOWTAM, runway state code PIREPS or spoken by air traffic control and may include braking action or braking coefficient. Use any runway reports together with your aeroplane flight manual or standard operating procedure to best gauge the landing technique and landing performance.

Hydroplaning

There are three principal types of aquaplaning or hydroplaning as it is now more commonly known.

Dynamic Hydroplaning

The first is dynamic hydroplaning. When an aircraft lands fast enough on a wet runway with at least 3 mm of standing water, inertial effects prevent water escaping from the footprint area, and the tyre is buoyed or held off the pavement by hydrodynamic force. Most people have experienced this type of hydroplaning when they have driven over a patch of water at high speed. The speed at which dynamic hydroplaning occurs is called V_P. There is a simple formula to help calculate the dynamic hydroplaning speed.

For rotating tyres the dynamic hydroplaning speed in knots is equal to 9 times the square root of the tyre pressure in psi. For a typical 737 the dynamic hydroplaning speed is between 90 and 120 knots.

However, for non-rotating tyres the dynamic hydroplaning speed is equal to 7.7 times the square root of the tyre pressure.

The danger from hydroplaning is the virtually nil braking and steering effect. The most positive methods of preventing this type of hydroplaning are to groove the tyres, transversely groove the runway, ensure the runway pavement is convex from the centre line and ensure the runway has a macro-texture.

Viscous Hydroplaning

The second type of hydroplaning is called viscous hydroplaning. It occurs because of the viscous properties of water acting like a lubricant. A thin film of fluid not more than 0.03 mm deep cannot be penetrated by the tyre in the footprint area and the tyre rolls on top of the film. Viscous hydroplaning can occur at a much lower speed than dynamic hydroplaning, but it requires a smooth surface.

The most positive method of preventing this type of hydroplaning is to provide a micro-texture to the pavement surface which breaks up the film of water allowing it to collect into very small pockets. This means that the tyre footprint will sit on the peaks of the textured surface and not the film of water.

Reverted Rubber Hydroplaning

Reverted rubber hydroplaning is a complex phenomenon which over the years has been the subject of a variety of explanations. Reverted rubber hydroplaning requires a prolonged, locked wheel skid, reverted rubber, and a wet runway surface. The locked wheels create enough heat to vaporize the underlying water film forming a cushion of steam that lifts the tyre off the runway and eliminates tyre to surface contact. The steam heat reverts the rubber to a black gummy deposit on the runway. Once started, reverted rubber skidding will persist down to very low speeds, virtually until the aircraft comes to rest. During the skid there is no steering capability and the braking effect is almost nil. Reverted rubber hydroplaning is greatly reduced in modern aeroplanes due to the standardization of advanced anti-skid braking systems which prevent wheel lock up.

Landing Technique on Slippery Runways

Detailed below is some advice and guidance on how to land on contaminated runways.

Firstly, check the current weather, and the runway conditions using the most accurate information possible. Once this has been done, completely reassess the landing performance data to ensure satisfactory compliance to the regulations.

Ensure you are at V_{REF} at the landing screen height and prepare to land the aircraft in the touchdown zone within the 1000 ft target of the airborne segment.

Land on the centre line with minimal lateral drift and without excess speed.

Arm auto spoilers and auto brakes as appropriate which ensures prompt stopping effort after touchdown. For aeroplanes fitted with automatic anti-skid brakes, the brakes will be applied above the dynamic hydroplaning speed, but for aeroplanes without this system, only apply the brakes below the dynamic hydroplaning speed.

The flare should lead to a firm touchdown, sometimes described as flying the aeroplane onto the runway. Positive landings will help place load on the wheels which will increase braking effectiveness and squeeze out the water from the tyre footprint area.

Do not allow the aeroplane to float and do not attempt to achieve a perfectly smooth touchdown. An extended flare will extend the touchdown point. Soft touchdowns will delay wheel spin up and delay oleo compression which is needed for auto brake and auto spoiler activation.

After main gear touchdown, do not hold the nose wheel off the runway. Smoothly fly the nose wheel onto the runway by relaxing aft control column pressure.

Deploy spoilers as soon as possible after touchdown or confirm auto spoiler deployment. If the aeroplane does not have auto brake then initiate braking once spoilers have been raised and nose wheel has contacted the runway.

Apply brakes smoothly and symmetrically.

Initiate reverse thrust as soon as possible after touchdown of the main wheels and target the rollout to stop well short of the end of the runway.

Leave a margin for unexpectedly low friction due to wet rubber deposits or hydroplaning.

Microbursts and Windshear

Of all the phases of flight it is the landing phase which is the most susceptible to severe weather conditions. The low altitude, low speed, low thrust settings and high drag during the landing phase mean that the aeroplane is at its most vulnerable. Landing when windshear is observed or forecast should be avoided, but if conditions are within limits, then landing at a higher speed should be used, but caution should be exercised since the higher landing speed will greatly increase the distance of the airborne section and ground roll of the landing.

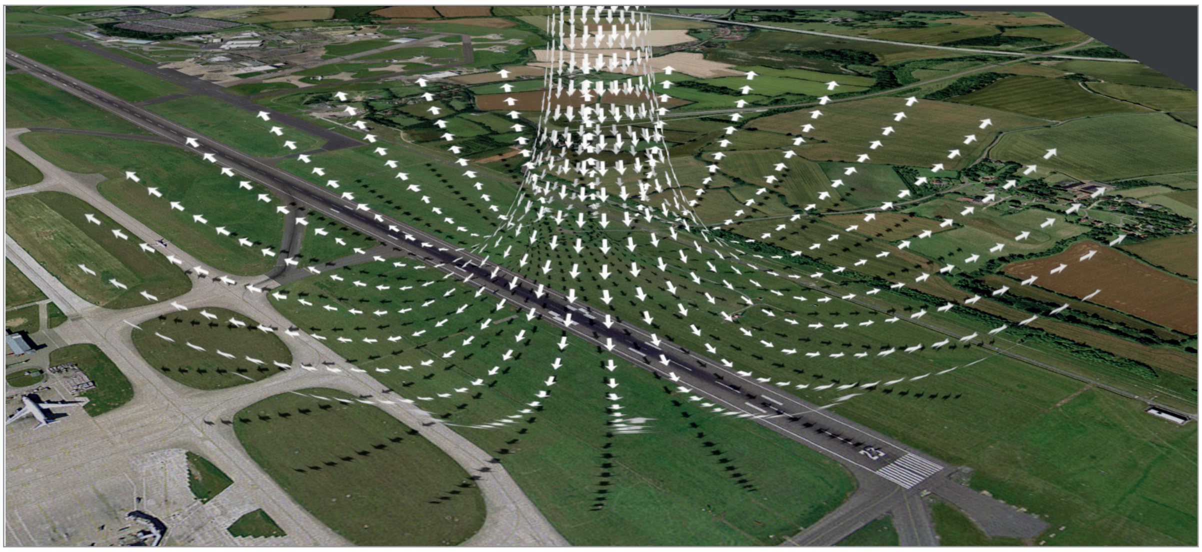


Figure 6.9 An illustration of a microburst at an airfield

The microburst is the single most hazardous weather phenomenon to aeroplanes close to the ground, particularly during the landing phase. However, there are certain clues which can give a pilot advance warning. The most obvious clue to a potential microburst are the tendrils of rain found beneath a storm cloud which are called virga or fallstreaks. Virga is precipitation falling but evaporating before it reaches the ground.

In the absence of specific guidance, here are some suggested techniques for identifying and dealing with a microburst encounter whilst on the approach to land. Using *Figure 6.10* you can see that initially there will be an increase in airspeed and a rise above the approach path caused by the increasing headwind. On modern aeroplanes a windshear alert is usually given. This should be seen as the precursor to the microburst. Any hope of a stabilized approach should be abandoned and a missed approach should be initiated. Without hesitation the power should be increased to go-around power, the nose raised and the aeroplane flown in accordance with the missed approach procedure. Typically the nose attitude will be about 15° and the control column should be held against the buffet or stick shaker. The initial bonus of increased airspeed may now be rapidly eroded as the downdraught is encountered. Airspeed will fall and the aeroplane may start to descend despite high power and high pitch angle.

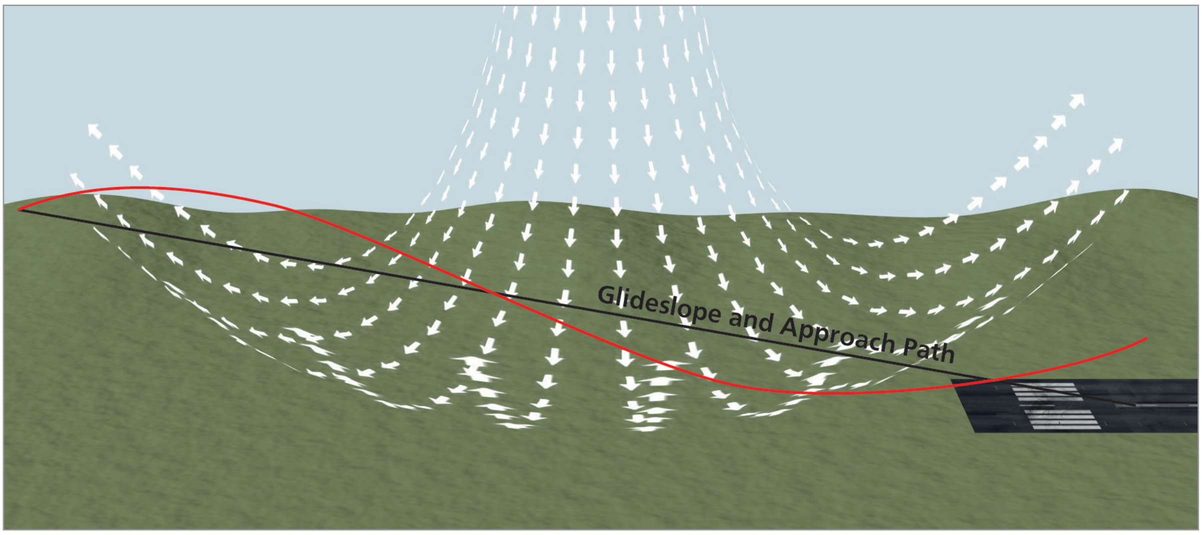


Figure 6.10 An illustration showing the flight path of a typical aeroplane on the approach to land during a microburst encounter

The point at which the tailwind starts to be encountered may be the most critical. The rate of descent may reduce, but the airspeed may continue to fall and any height loss may now break into obstacle clearance margins. Maximum thrust is now usually needed and the nose attitude kept high on the stall warning margins to escape the effects of the tailwind. Had the go-around not been initiated at the early warning stage, then it is highly unlikely that the aeroplane would survive the encounter. Because windshear, heavy rain, poor visibility, runway contamination and microbursts are hazards very closely associated with thunderstorms, it is advisable never to land with a thunderstorm at or in the immediate vicinity of the aerodrome. Delay the landing or consider diverting. There are too many cases to list of pilots who have attempted to land in bad weather and they have sadly perished along with many passengers. Most of these occurrences were avoidable had due account been taken of the situation.

Questions

1. **The landing reference speed V_{REF} has, in accordance with international requirements, the following margins above the stall speed in landing configuration for a Class B aeroplane:**

   a. 15%
   b. 20%
   c. 10%
   d. 30%

2. **At a given mass, the stalling speed of a twin engine, Class B aeroplane is 100 kt in the landing configuration. The minimum speed a pilot must maintain in short final is:**

   a. 130 kt
   b. 115 kt
   c. 125 kt
   d. 120 kt

3. **The stalling speed or the minimum steady flight speed at which the aeroplane is controllable in landing configuration is abbreviated as:**

   a. V_{S1}
   b. V_{S}
   c. V_{MC}
   d. V_{S0}

4. **What margin above the stall speed is provided by the landing reference speed V_{REF} for a Class B aeroplane?**

   a. $1.10V_{S0}$
   b. $V_{MCA} \times 1.2$
   c. $1.30V_{S0}$
   d. $1.05V_{S0}$

5. **An increase in atmospheric pressure has, among other things, the following consequences on landing performance:**

   a. a reduced landing distance and degraded go-around performance
   b. a reduced landing distance and improved go-around performance
   c. an increased landing distance and degraded go-around performance
   d. an increased landing distance and improved go-around performance

6. **The landing distance of an aircraft is 600 m in a standard atmosphere, with no wind and at a pressure altitude of 0 ft. Using the following corrections:**

± 20 m / 1000 ft field elevation
- 5 m / kt headwind
+ 10 m / kt tailwind
± 15 m / % runway slope
± 5 m / °C deviation from standard temperature

The landing distance at an airport of 1000 ft elevation, temperature 17°C, QNH 1013.25 hPa, 1% upslope, 10 kt tailwind is:

a. 555 m
b. 685 m
c. 725 m
d. 785 m

7. **To minimize the risk of hydroplaning during the landing the pilot of a modern airliner should:**

a. make a "positive" landing and apply maximum reverse thrust and brakes as quickly as possible
b. use maximum reverse thrust, and should start braking below the hydroplaning speed
c. use normal landing, braking and reverse thrust techniques
d. postpone the landing until the risk of hydroplaning no longer exists

8. **An aircraft has two certified landing flaps positions, 25° and 35°. If a pilot chooses 25° instead of 35°, the aircraft will have:**

a. a reduced landing distance and better go-around performance
b. an increased landing distance and degraded go-around performance
c. a reduced landing distance and degraded go-around performance
d. an increased landing distance and better go-around performance

9. **May anti-skid be considered to determine the take-off and landing data?**

a. Only for take-off
b. Only for landing
c. Yes
d. No

10. **An aircraft has two certified landing flaps positions, 25° and 35°. If a pilot chooses 35° instead of 25°, the aircraft will have:**

a. an increased landing distance and better go-around performance
b. a reduced landing distance and degraded go-around performance
c. a reduced landing distance and better go-around performance
d. an increased landing distance and degraded go-around performance

Answers

1	2	3	4	5	6	7	8	9	10
d	a	d	c	b	c	a	d	c	b

Chapter

7

Single-engine Class B Aircraft - Take-off

Performance Class B

Just to remind yourself, single-engine Class B aeroplanes are propeller driven aeroplanes with a maximum approved passenger seating configuration of 9 or less, and a maximum take-off mass of 5700 kg or less.

CS-23 contains requirements for normal, utility, and aerobatic category aeroplanes, and also for commuter category aeroplanes.

General Requirements (EU-OPS 1.525)

These requirements can be found in CAP 698 on page 1 of section 2 under paragraph 1.2. There are four general requirements about operating single-engine Class B aeroplanes for commercial air transport purposes.

- The first is that this aeroplane shall not be operated at night.
- The second that the aeroplane must not be operated in instrument meteorological conditions (IMC) except under special visual flight rules (SVFR).
- The third is that it must not be operated unless suitable surfaces are available en route which permit a safe forced landing to be made should engine failure occur at any point on the route.
- Lastly, that this type of aeroplane must not be operated above a cloud layer that extends below the relevant minimum safe altitude.

The reason why the latter regulation exists is quite easy to understand. If the engine were to fail during these conditions, it would be almost impossible for a pilot to be able to see the landing surface and therefore impossible for the pilot to carry out a safe forced landing.

Take-off Distance (CS-23.51 & 23.53)

The gross take-off distance for Class B aeroplanes (other than those in the commuter category) is the distance from the start of take-off to a screen height of 50 ft above the take-off surface, with take-off power set, rotating at V_R and achieving the specified speed at the screen.

The rotation speed V_R must not be less than V_{S1}

The take-off safety speed (screen height speed) must be not less than the greater of:

- a speed that is safe under all reasonably expected conditions

or

- $1.2V_{S1}$

Take-off Requirements / Field Length Requirements

There is only one take-off requirement for single-engine Class B aeroplanes. The requirement is that the mass of the aeroplane must be such that the take-off can be completed within the available distances. In other words, the take-off must be complete within the field length available. This requirement is called the "Field Length Requirement".

The Field Length Requirements are detailed below and you can find them in *CAP 698 under paragraph 2.1.1 of page 1 and 2 of section 2.*

- When no stopway or clearway is available, the take-off distance when multiplied by 1.25 must not exceed TORA (Gross TOD × 1.25 must not exceed the TORA)

- When a stopway and/or clearway is available the take-off distance must:

  - not exceed TORA (Gross TOD must not exceed the TORA)
  - when multiplied by 1.3, not exceed ASDA (Gross TOD × 1.3 must not exceed the ASDA)
  - when multiplied by 1.15, not exceed TODA (Gross TOD × 1.15 must not exceed the TODA)

To understand these requirements it might be easier to work through an example.

EXAMPLE: Let us assume that the aeroplane flight manual gives the take-off distance as 3000 ft and that there is no stopway or clearway available at the airport. What is the net take-off distance or the minimum length or TORA?

In this case we must satisfy the requirement that "when no stopway or clearway is available, the take-off distance when multiplied by 1.25 must not exceed TORA (Gross TOD × 1.25 must not exceed the TORA)"

To carry out the calculation, multiply 3000 ft by 1.25 which gives us a value of 3750 ft. Essentially this means that the runway must be at least 3750 ft long, or, more correctly, the take-off run available (TORA) must be at least 3750 ft long.

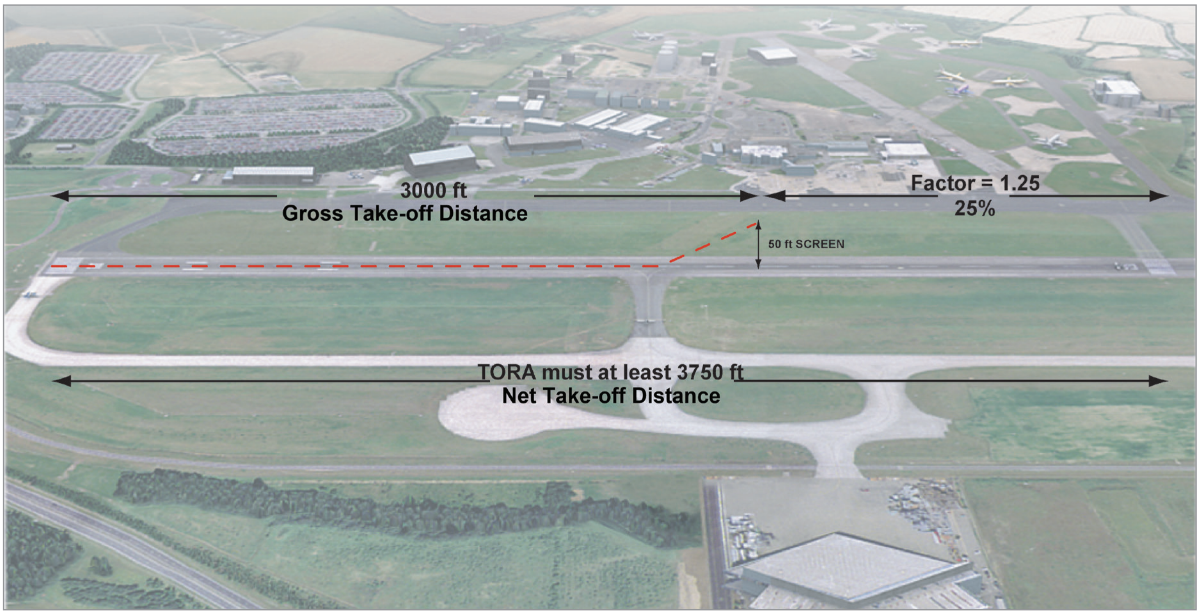


Figure 7.1 The gross take-off distance multiplied by 1.25 must not exceed the TORA

This rule ensures that once the aeroplane has completed the take-off, that is, at the screen height, there should be at least 25% of the runway remaining. Therefore the regulation requirement provides an adequate safety margin for the take-off. We discussed these safety concerns during the lesson on performance standards. To interpret the regulation, although the actual take-off distance is 3000 ft, the authorities are suggesting the worse case in a million would be a take-off that is 3750 ft long. This helps us again to see the difference between net and gross performance. Here the gross performance for the take-off is 3000 ft but the net performance, which is always worse performance, is 3750 ft.

Factors to Be Accounted for

The regulations in CS-23 state that when calculating the gross take-off distance, in other words, before we add the factors mentioned previously, certain details must be accounted for. These are listed below.

The gross take-off distance required shall take account of:

- the mass of the aeroplane at the start of the take-off run
- the pressure altitude at the aerodrome
- the ambient temperature at the aerodrome
- the runway surface conditions and the type of runway surface
- the runway slope
- not more than 50% of the reported headwind component or not less than 150% of the reported tailwind component

Surface Condition Factors

Concentrating on runway surface, conditions and slope, the regulations stipulate that due account must be taken of the runway condition. Most performance data in the aeroplane flight manual assumes a level, dry and hard runway. Therefore, correction factors must be applied to the gross take-off distance when the runway conditions are different. There are various correction factors such as for grass runways, wet runways and runways which are sloped. These factors are detailed next.

At the top of page 2 section 2 under section c) in CAP 698 it states that if the runway is other than dry and paved the following correction factors must be used when determining the take-off distance. These are shown for you in *Figure 7.2.*

Surface Type	Condition	Factor
Grass (on firm soil) up to 20 cm long	Dry	× 1.2
	Wet	× 1.3
Paved	Wet	× 1.0

Figure 7.2 The correction factors that need to be applied to the gross take-off distance when the runway is other than dry and paved

As you have learnt already, grass runways will increase the take-off distance compared to paved runways. Here the factor to use to account for the effect of dry grass is 1.2 and 1.3 if the grass is wet.

At the top of page 2 section 2 underneath the table, point "d" details the corrections to be applied if there is a slope to the runway. It states that a pilot must increase the take-off distance by 5%, or by a factor of 1.05, for every 1% upslope. However, it also states that "no factorization is permitted for downslope". In other words, when an aeroplane may be taking off on a downwards sloping runway no correction factor is to be applied for the downslope. The reason for ignoring the downslope is because a downslope will decrease the take-off distance. This helps to add a little extra safety to the take-off distance calculation.

Presentation of Data

The take-off distance required is usually presented in graphical form. You can see such a graph by looking at *Figure 2.1 on page 3 of section 2 in CAP 698*. Firstly, the title of the graph indicates that the graph is for calculating the gross take-off distance with no flaps selected. For other flap settings you may have to consult another graph.

Take a look at the associated conditions paying particular notice to the power and flap settings as shown at the top of *Figure 2.1 in CAP 698*. Also notice that this graph assumes a runway that is paved, level and dry. If the runway conditions required for a given calculation are different to those specified, then corrections will need to be made to the values this graph will give. We briefly saw these correction factors earlier. Notice a small box in the middle of the graph which highlights the rotation and screen height speeds for different weights. A pilot must adhere to these accurately because they are the speeds which have been used to construct this graph. If a pilot were to deviate from these speeds, the required aircraft performance would not be achieved.

Having looked at the various bits of information around the graphs let us now examine the graph itself. The left hand carpet of the graph involves the variations of temperature and pressure altitude. This part of the graph accounts for the effect of air density on the take-off distance. The middle carpet accounts for the effect of the mass and to the right of this carpet is the wind correction carpet. Notice the differences in the slope of the headwind and tailwind lines. This means the 150% and 50% wind rules have been applied. The last carpet on the far right of the graph is labelled "obstacle height". Although there is no "obstacle" as such at the end of the take-off run, you will recall that the take-off is not complete until a screen height of 50 ft is reached.

Using an example we will work through the graph so that you are able to see how the take-off distance is calculated. For this example, follow through the red line in *Figure 7.3.*

In the example we will assume a temperature of 15°C at a given airfield 4000 ft above mean sea level. To use the graph then, move upwards from 15°C until you have reached the 4000 ft pressure altitude line. Then move right until you meet the first reference line. The next variable is mass; in our example let us assume a mass of 3400 lb. From the reference line we must move down along the sloping guidelines until we reach 3400 lb as shown here. From this point we go horizontally to the right until the next reference line. The next variable is wind.

In our example we will assume a 10 knot headwind. Notice though that the slopes of the headwind and tailwind lines are different. We therefore recognize that the 150% tailwind and 50% headwind rules that you learnt about in the general principles for take-off lesson have already been applied. Travel down the headwind line until you reach 10 knots headwind and then move horizontally right once more, up to the last reference line. Remember that the take-off is not complete until the aeroplane has reached the 50 ft screen height, so from this point on the graph we must move up the guidelines to the end. The take-off distance in our example, then, is approximately 2300 ft from brake release to the 50 ft screen.

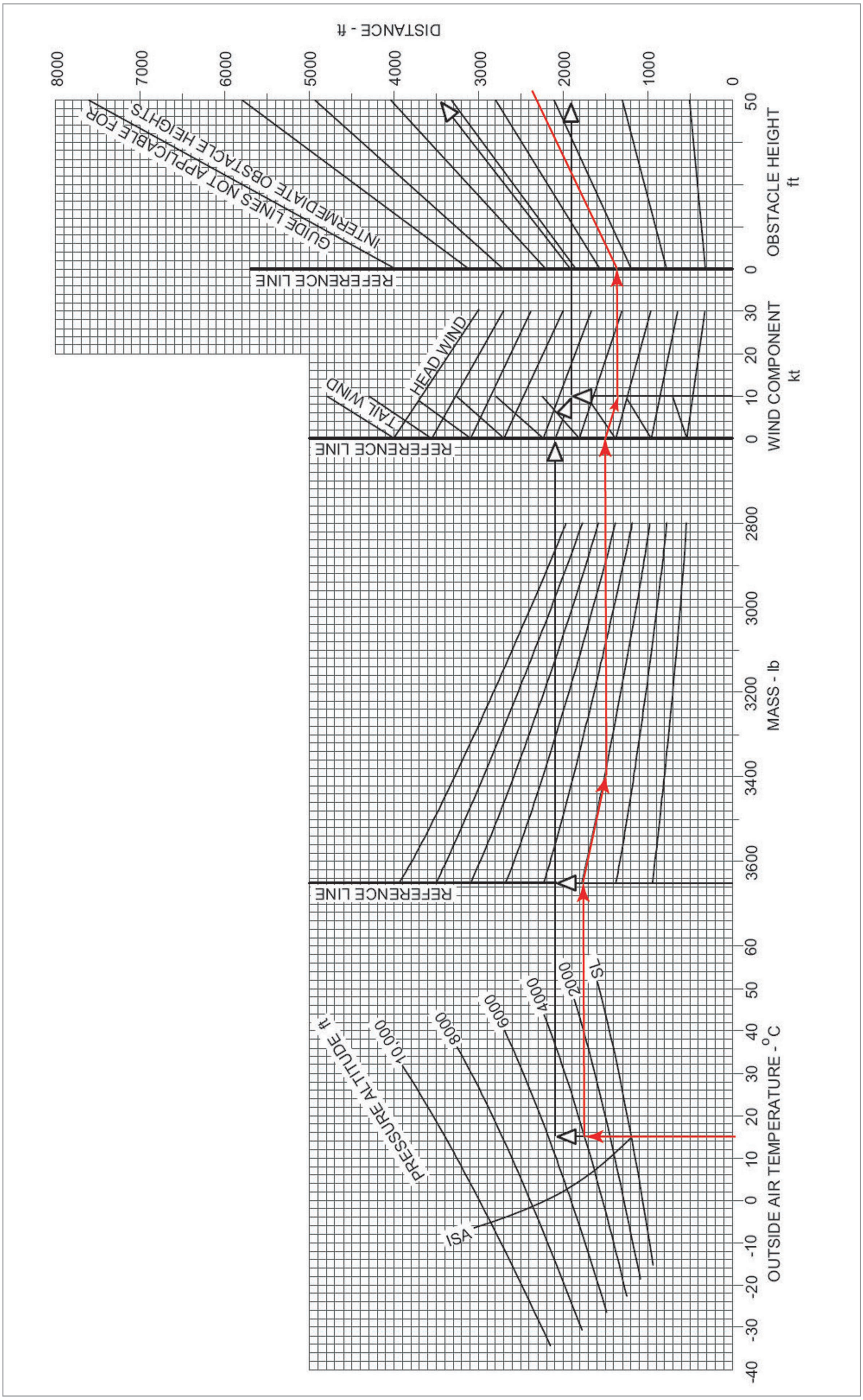


Figure 7.3 An example take-off distance calculation.

However, let us now assume that the runway has a grass surface and that the grass is wet. Remember that both these variables cause an increase in the take-off distance. Since the graph assumes a paved dry runway we will have to make a correction to the take-off distance for the different conditions. You may recall that wet grass increases the distance by 30% or by a factor of 1.3. Our calculated take-off distance was 2300 ft, but correcting it for wet grass would now make the take-off distance 2990 ft.

Let us now assume the runway has an upslope of 1%. You may recall this would increase the take-off distance by 5% or by a factor of 1.05.

This now makes the total gross take-off distance 3140 ft. To comply with the field length requirements and to obtain a net take-off distance, you may recall that the take-off distance must be compared to the available distances at the airfield to ensure it does not exceed the limits laid down by the authorities. To remind you of these regulations turn to page 1 section 2 in CAP 698.

Certification Requirements

The last part of the lesson will focus on some of the certification specifications for single-engine Class B aeroplanes. These can be found in the document from EASA called CS-23. There are only two main specifications that apply to the take-off phase of flight and these specifications concern the take-off speeds.

The first of these certification specifications concerns V_R. You may recall that V_R is the speed at which the pilot makes a control input with the intention of getting the aeroplane out of contact with the runway.

The certification specifications state that for the single-engine aeroplane, the speed V_R must not be less than V_{S1}. V_{S1} being the stall speed or the minimum steady flight speed of the aeroplane obtained in a specified configuration. The configuration concerned is that configuration used for the take-off.

The second of the certification specification concerns the speed of the aeroplane at the screen height. The specifications state that the speed at 15 m or 50 ft above the take-off surface must be more than the higher of a speed that is safe under all reasonably expected conditions, and $1.2V_{S1}$. You will recall from an earlier lesson that the speed that must be attained at the screen height is commonly referred to as the take-off safety speed.

The certification regulations about V_R and the take-off safety speed are not found in CAP 698 and therefore must be committed to memory.

Questions

1. **For a single-engine Class B aeroplane, how does runway slope affect allowable take-off mass, assuming other factors remain constant and not limiting?**

   a. An uphill slope decreases take-off mass
   b. Allowable take-off mass is not affected by runway slope
   c. A downhill slope decreases allowable take-off mass
   d. A downhill slope increases allowable take-off mass

2. **For this question use Performance Manual CAP 698 SEP1 Figure 2.1.**

   With regard to the take-off performance chart for the single-engine aeroplane, determine the take-off speed for (1) rotation and (2) at a height of 50 ft.

   Given:

   OAT: ISA + 10
   Pressure Altitude: 5000 ft
   Aeroplane Mass: 3400 lb
   Headwind Component: 5 kt
   Flaps: up
   Runway: Tarred and Dry

   a. 73 and 84 kt
   b. 68 and 78 kt
   c. 65 and 75 kt
   d. 71 and 82 kt

3. **For this question use Performance Manual CAP 698 SEP1 Figure 2.2.**

   With regard to the take-off performance chart for the single-engine aeroplane determine the take-off distance over a 50 ft obstacle height.

   Given:
   OAT: 30°C
   Pressure Altitude: 1000 ft
   Aeroplane Mass: 2950 lb
   Tailwind Component: 5 kt
   Flaps: Approach setting
   Runway: Short, wet grass, firm subsoil
   Correction Factor: 1.25 for the current runway conditions

   a. 1700 ft
   b. 2500 ft
   c. 2200 ft
   d. 1900 ft

4. **For this question use Performance Manual CAP 698 SEP1 Figure 2.1.**

With regard to the take-off performance chart for the single-engine aeroplane determine the maximum allowable take-off mass.

Given:

OAT: ISA
Pressure Altitude: 4000 ft
Headwind Component: 5 kt
Flaps: up
Runway: Tarred and Dry
Factored Runway Length: 2000 ft
Obstacle Height: 50 ft

a. 3000 lb
b. 2900 lb
c. 3650 lb
d. 3200 lb

5. **For this question use Performance Manual CAP 698 SEP1 Figure 2.1.**

With regard to the take-off performance chart for the single-engine aeroplane determine the take-off distance to a height of 50 ft.

Given:
OAT: 30°C
Pressure Altitude: 1000 ft
Aeroplane Mass: 3450 lb
Tailwind Component: 2.5 kt
Flaps: up
Runway: Tarred and Dry

a. approximately : 2200 ft
b. approximately : 2400 ft
c. approximately : 1400 ft
d. approximately : 2800 ft

6. **For this question use Performance Manual CAP 698 SEP1 Figure 2.2.**

With regard to the take-off performance chart for the single-engine aeroplane determine the take-off distance to a height of 50 ft.

Given:
OAT: -7°C
Pressure Altitude: 7000 ft
Aeroplane Mass: 2950 lb
Headwind Component: 5 kt
Flaps: Approach setting
Runway: Tarred and Dry

a. approximately : 1150 ft
b. approximately : 2450 ft
c. approximately : 1500 ft
d. approximately : 2100 ft

7. **For this question use Performance Manual CAP 698 SEP1 Figure 2.1.**

With regard to the take-off performance chart for the single engine aeroplane determine the take-off distance to a height of 50 ft.

Given:
Airport characteristics: hard, dry and zero slope runway
Pressure altitude: 1500 ft
Outside air temperature: +18°C
Wind component: 4 knots tailwind
Take-off mass: 1270 kg

a. 520 m
b. 415 m
c. 440 m
d. 615 m

8. **For this question use Performance Manual CAP 698 SEP1 Figure 2.2.**

With regard to the take-off performance chart for the single-engine aeroplane determine the take-off distance to a height of 50 ft.

Given:
OAT: 38°C
Pressure Altitude: 4000 ft
Aeroplane Mass: 3400 lb
Tailwind Component: 5 kt
Flaps: Approach setting
Runway: Dry Grass
Correction Factor: 1.2

a. approximately : 3250 ft
b. approximately : 4200 ft
c. approximately : 5040 ft
d. approximately : 3900 ft

9. **For a Class B aircraft at an aerodrome with no stopway or clearway, the minimum length of take-off run that must be available to satisfy the take-off requirements:**

a. must not be less than the gross take-off distance to 50 ft
b. must not be less than 1.15 times the gross take-off distance to 50 ft
c. must not be less than 1.25 times the gross take-off distance to 50 ft
d. must not be less than 1.3 times the gross take-off distance to 50 ft

10. **For a single-engine Class B aircraft, the rotation speed V_R:**

a. must not be less than $1.1V_{S1}$
b. must not be less than V_{S1}
c. must not be less than $1.2V_{MC}$
d. must not be less than V_{MC}

11. For a single-engine Class B aircraft at an aerodrome with stopway:

a. the TOD × 1.3 must not exceed the ASDA
b. the TOD must not exceed the ASDA × 1.3
c. the TOD × 1.25 must not exceed the ASDA
d. the TOD must not exceed the ASDA × 1.25

Answers

1	2	3	4	5	6	7	8	9	10	11
a	d	c	d	b	d	a	d	c	b	a

Chapter

8

Single-engine Class B - Climb

Climb Performance

The take-off climb requirements for single-engine Class B aeroplanes are stated in EU-OPS, but, again, as for the take-off requirements, the climb regulations can be found in CAP 698, on page 6 of section 2. At the top of page 6 of section 2 under point 3.1 we read that there are no obstacle clearance limits, or minimum acceptable climb gradients. Let us break down the two elements in this statement.

The regulations state that there is no requirement for a single-engine Class B aeroplane to demonstrate that it can clear an obstacle within the take-off flight path. However, other classes of aeroplane have to demonstrate that obstacles within the take-off flight path can be cleared by a set limit of 50 ft or 35 ft. It seems strange, then, that there is no regulatory requirement for obstacle clearance in the case of a single-engine Class B aeroplane. But, surely the idea of the regulations is to enforce a safety margin? What must be understood here, though, is that the pilot of a single-engine Class B aeroplane must, at all times, have visual contact with the ground. Consequently the pilot will at all times be able to identify the obstacle within the take-off path and, therefore, avoid it. However, you may judge it prudent to carry out an obstacle clearance calculation if there were known obstacles in the take-off flight path.

The second part of the regulation states that there is no minimum acceptable climb gradient for a single-engine Class B aeroplane. Again, this seems strange; the idea of the operational regulations is to enforce a safety margin. However, the reason why there is no operational regulation on the climb performance is that the certification specifications for this type of aeroplane, as stated in CS-23, are stringent enough on their own.

Even though there is no operational requirement for a minimum climb performance, it would not be safe to operate the aeroplane in such a manner that its performance is so poor it is barely able to climb. Therefore, it is important as a pilot operating this class and type of aeroplane to know what climb performance would be achieved so that the aeroplane will at least be able to climb sufficiently.

Presentation of Data

Provided in most pilot operating manuals or aeroplane flight manuals are climb graphs that help the pilot to calculate the gradient of climb. Such a graph can be found in *CAP 698 in section 2 page 7 figure 2.3*. As with any graphs, before you use it, ensure you are familiar with the associated conditions of that graph. In this graph the throttles are at maximum, mixture is rich, flaps and gear are up and the cowl flaps set as required. The climb speed for the graph is taken to be 100 knots indicated airspeed for all masses.

The graph has an example that you can follow using the dashed black lines so that you can practise on your own. Graph accuracy is very important so try and be as careful as possible when using them. Be especially careful when working out your true airspeed which is needed when you approach the right hand side of the graph. You may need your navigation computer to do this as it might not be given to you, such as the case in the example.

Use of the Climb Graph Data

There will be two main uses of the climb graph. The first main use of the graph is to calculate the time to climb to the cruise altitude. For this, the pilot would need to know the cruise altitude and the rate of climb. However, if the gradient from this graph is used for the calculation of obstacle clearance or the ground distance, then the gradient must be adjusted for the effect of wind. This particular climb graph makes no correction for wind. The reason why the gradient must be corrected for wind is because obstacle clearance calculations or ground distance calculations use ground gradients, that is gradients measured relative to the ground and ground gradients are affected by wind.

If you need to refresh your memory on the difference between ground gradients and air gradients and the effects of wind, then go back to the general performance principles climb chapter.

Examples in CAP 698

There are some example calculations in CAP 698 for you to work through and practise. For example, on page 6 of section 2 there is an example on how to calculate the climb gradient using the graph. Just below this, there is another example to determine what the maximum permissible mass is in order to achieve a 4% climb gradient. This maximum permissible mass is sometimes referred to as the MAT or WAT limit.

On page 8 of section 2 is another example. This is an example of how to calculate the horizontal ground distance required to climb to a given height.

Questions

1. **For this question use Performance Manual CAP 698 SEP1 Figure 2.3.**

   Using the climb performance chart, for the single-engine aeroplane, determine the rate of climb and the gradient of climb in the following conditions:

   Given:
   OAT at take-off: ISA
   Airport pressure altitude: 3000 ft
   Aeroplane mass: 3450 lb
   Speed: 100 KIAS

   a. 1310 ft/min and 11.3%
   b. 1130 ft/min and 10.6%
   c. 1030 ft/min and 8.4%
   d. 1140 ft/min and 11.1%

2. **For this question use Performance Manual CAP 698 SEP1 Figure 2.3.**

   Using the climb performance chart, for the single-engine aeroplane, determine the ground distance to reach a height of 1500 ft in the following conditions:

   Given:
   OAT at take-off: ISA
   Airport pressure altitude: 5000 ft
   Aeroplane mass: 3300 lb
   Speed: 100 KIAS
   Wind component: 5 kt Tailwind

   a. 19 250 ft
   b. 14 275 ft
   c. 14 925 ft
   d. 15 625 ft

3. **For this question use Performance Manual CAP 698 SEP1 Figure 2.3.**

   With regard to the climb performance chart for the single-engine aeroplane determine the climb speed (ft/min).

   Given:
   OAT: ISA + 15°C
   Pressure Altitude: 0 ft
   Aeroplane Mass: 3400 lb
   Flaps: up
   Speed: 100 KIAS

   a. 1150 ft/min
   b. 1290 ft/min
   c. 1370 ft/min
   d. 1210 ft/min

4. **For this question use Performance Manual CAP 698 SEP1 Figure 2.3.**

Using the climb performance chart, for the single-engine aeroplane, determine the ground distance to reach a height of 2000 ft in the following conditions:

Given:
OAT at take-off: 25°C
Airport pressure altitude: 1000 ft
Aeroplane mass: 3600 lb
Speed: 100 KIAS
Wind component: 15 kt Headwind

a. 14 500 ft
b. 18 750 ft
c. 16 850 ft
d. 15 750 ft

Answers

1	2	3	4
b	d	b	c

Chapter

9

Single-engine Class B - En Route and Descent

En Route Section

This chapter will focus on the single-engine Class B performance requirements for the en route and descent stages of flight.

Essentially the en route part of the flight is considered to be from 1500 ft above the airfield from which the aeroplane has taken off to 1000 ft above the destination airfield. Although the CAP 698 manual does show the en route performance requirements these requirements are scattered through the document, which does not make for ease of reference.

En Route and Descent Requirements

EU-OPS 1.542 states that "an operator must ensure that the aeroplane, in the meteorological conditions expected for the flight, and in the event of engine failure, is capable of reaching a place at which a safe forced landing can be made." In order to be able to comply with the rule, an operator has to know certain details about the route to be flown and the performance of the aeroplane. First of all, of course, for any given route, an operator must know the safe forced landing areas. The next detail that the operator needs to know is whether his aeroplane will be able to reach these areas if the engine were to fail while en route. Whether or not this is possible will depend on two things;

- the altitude chosen for the flight
- the descent gradient of the aeroplane following engine failure

If these two parameters are known, it is possible to calculate how far the aeroplane will travel following engine failure. So, let us work through an actual example.

Let us assume a cruise altitude of 10 000 ft and a gradient of descent of 7% following an engine failure. What is the descent range?

We can work out the horizontal distance travelled or descent range by taking the height of the aeroplane above the ground, dividing this by the gradient and then multiplying by 100.

Horizontal Distance = Vertical/Gradient × 100

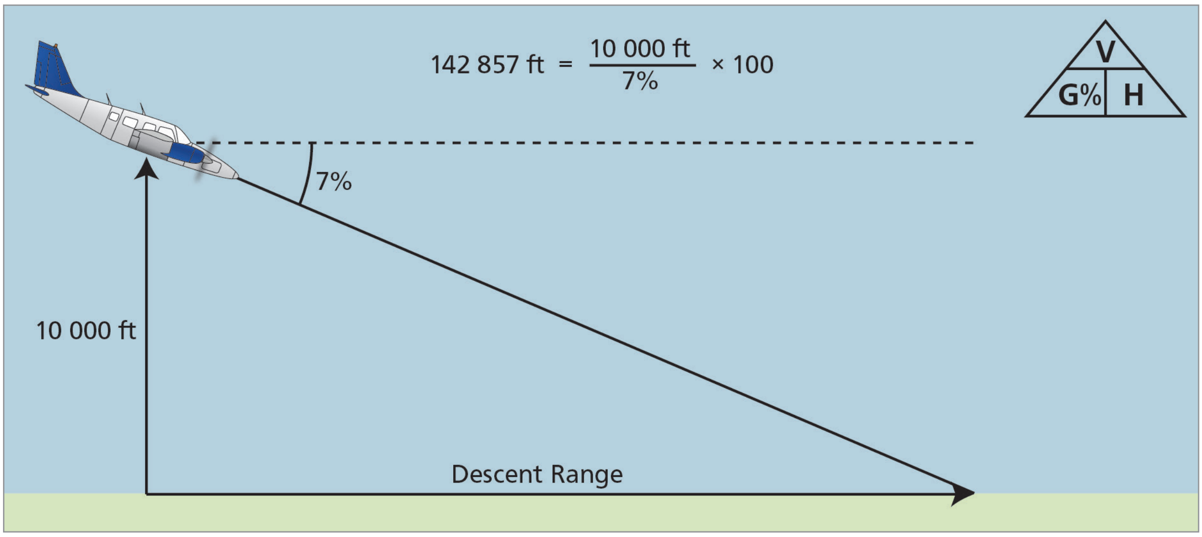


Figure 9.1 An illustration showing an example descent range calculation

In this case we see that in still air the aeroplane will cover in the glide a horizontal distance of 142 857 ft or roughly 23.5 NM following engine failure. This means that the aeroplane must not pass further away than 23.5 NM from any safe forced landing locations. So then draw a circle of 23.5 NM radius, around each of the safe forced landing locations (the yellow dots) as you can see in *Figure 9.2*. Then draw a track line from Airfield A to Airfield B that is within each circle. If the flight track falls outside of the circles then, following engine failure, the aeroplane will not make it to a safe forced landing area.

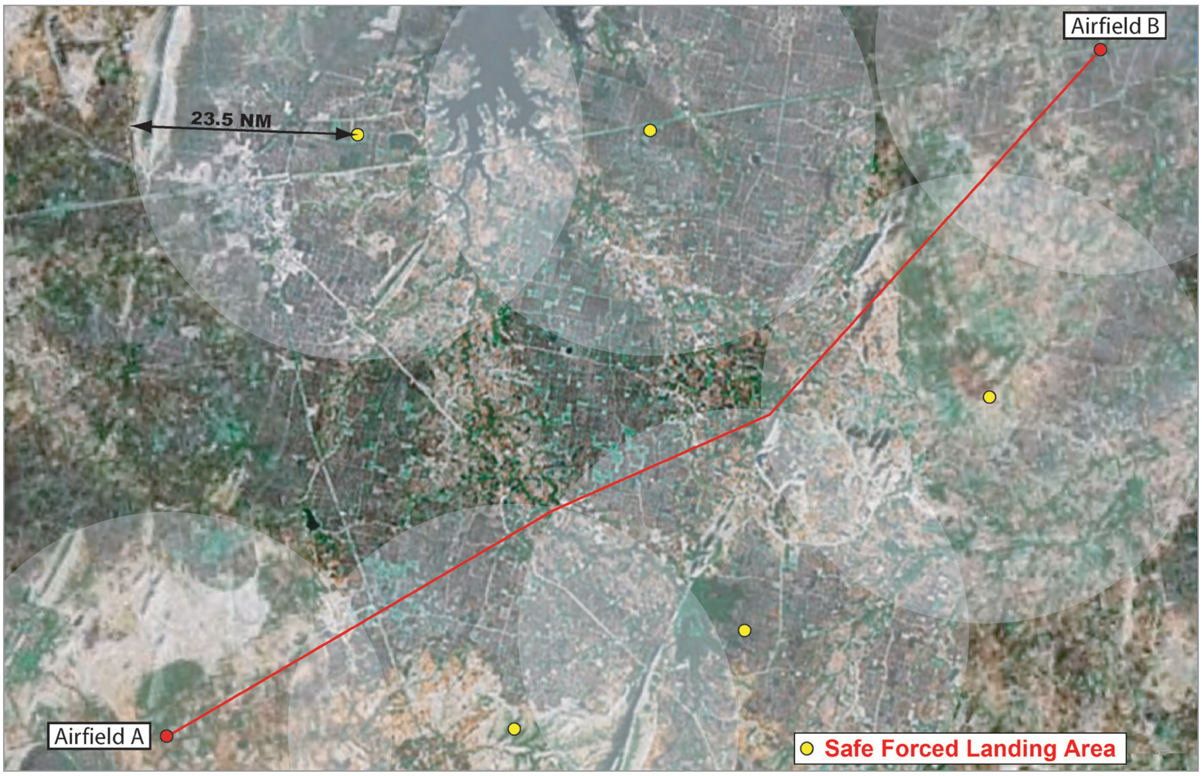


Figure 9.2 An illustration showing the glide descent range around each forced landing area & the subsequent track that is required to remain within glide range of each field

If the aeroplane were to operate at a higher altitude, then it would be able to cover a greater distance in the glide following an engine failure. For example, operating at 15 000 ft instead of 10 000 ft would increase the aeroplane's still air glide range to 35 nautical miles. Therefore the circles around each forced landing location will grow as shown in *Figure 9.3.*

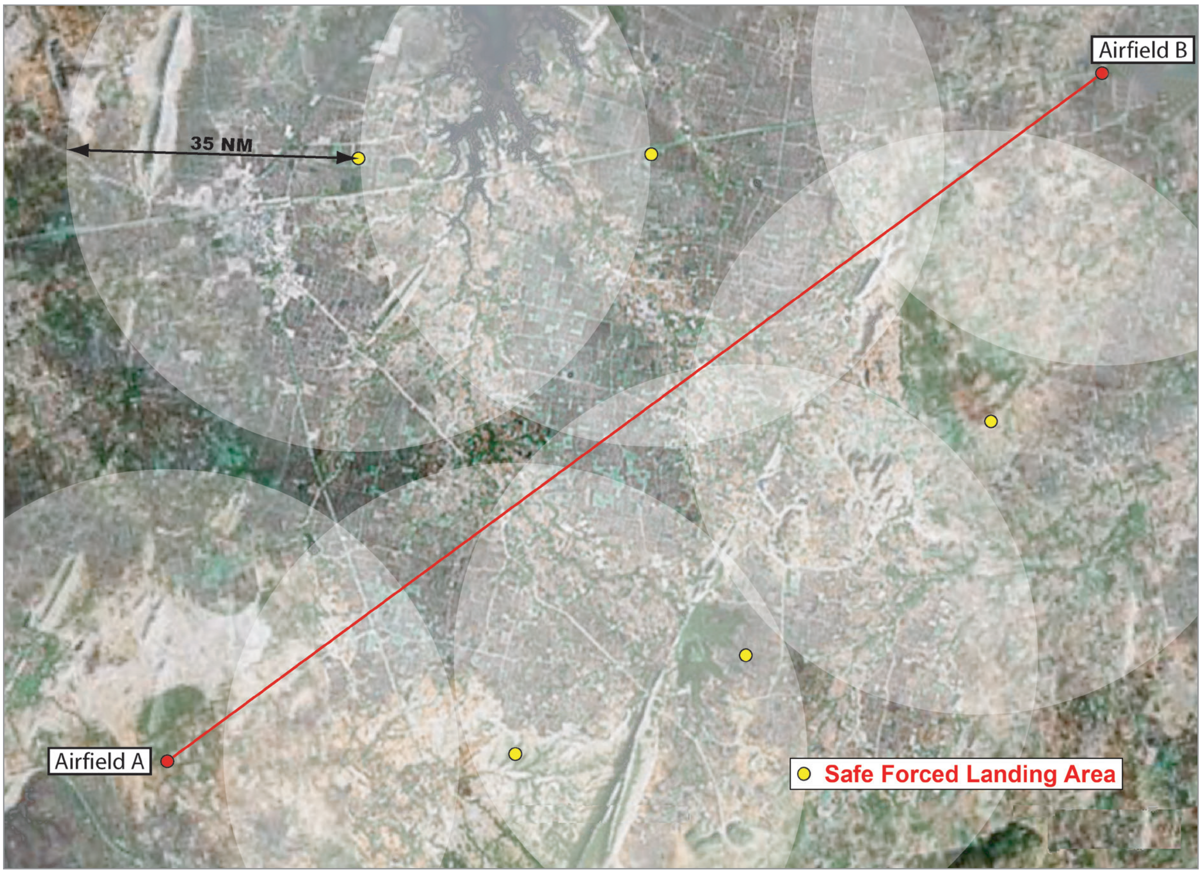


Figure 9.3 An illustration showing the glide descent range around each forced landing area & the subsequent track that is required to remain within glide range of each field

Notice that now the aeroplane can fly along a straight track to airfield B because at all times throughout the flight, the aeroplane is within glide range of a suitable forced landing location. Consequently, small piston engine aeroplanes should be flown at their maximum altitudes so that direct routes can be achieved. However, when planning the altitude, another regulation must be borne in mind.

EU-OPS 1.542 (b) (1) states, that when complying with the safe forced landing rule the aeroplane must not be assumed to be flying with the engine operating at maximum continuous power at an altitude exceeding that at which the aeroplane's rate of climb equals 300 ft per minute. What this rules effectively does, is to limit the maximum altitude that can be used in order to comply with the forced landing rule. An aeroplane may operate at a higher altitude than this regulation prescribes but the operator may not use the higher altitude in his calculation of glide range to a safe landing area.

There is one last detail to be considered about complying with the forced landing rule. EU-OPS 1.542 (b) (2) states, that in order to comply with the safe forced landing rule the assumed en route gradient shall be the gross gradient of descent, increased by a gradient of 0.5%. In our example we had a gradient of descent of 7%, unfortunately though, as we have seen, the regulations do not permit this gradient to be used in our calculation. The gradient must be increased by 0.5% to 7.5% as shown in *Figure 9.4*.

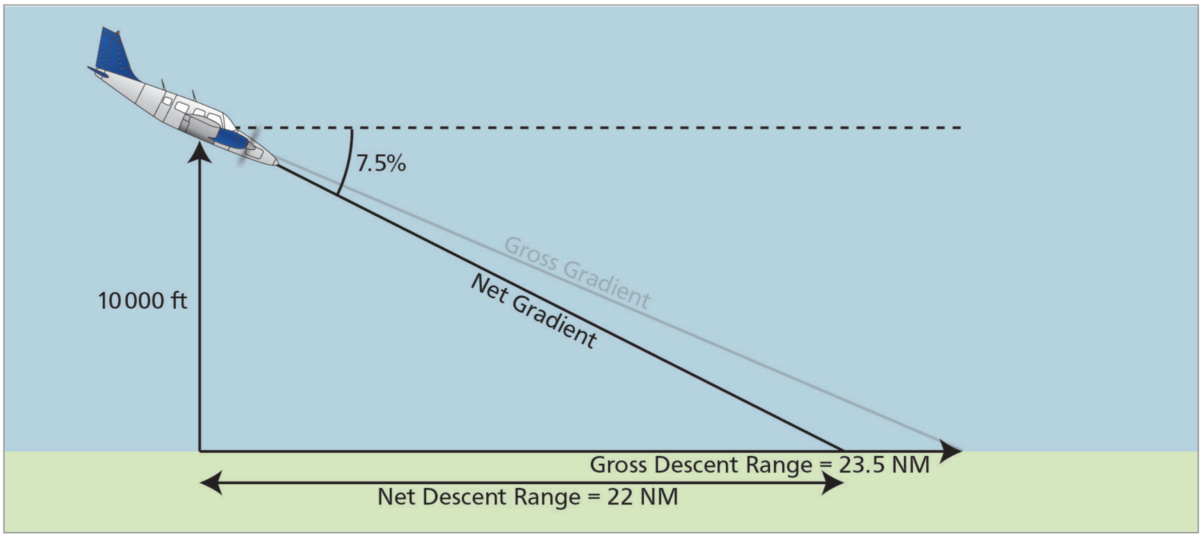


Figure 9.4 An illustration showing an example descent range calculation

This will lower the assumed descent performance of the aeroplane. The new deteriorated gradient that the regulations insist we use is called the net gradient, and in our case this is 7.5%.

If this net gradient has to be used, the glide distance will reduce to 22 NM. So, although the aeroplane may achieve 23.5 NM following an engine failure, it must be assumed to glide only 22 nautical miles.

Looking at *Figure 9.5*, this means that the circles around each safe landing area must reduce to a radius of 22 NM.

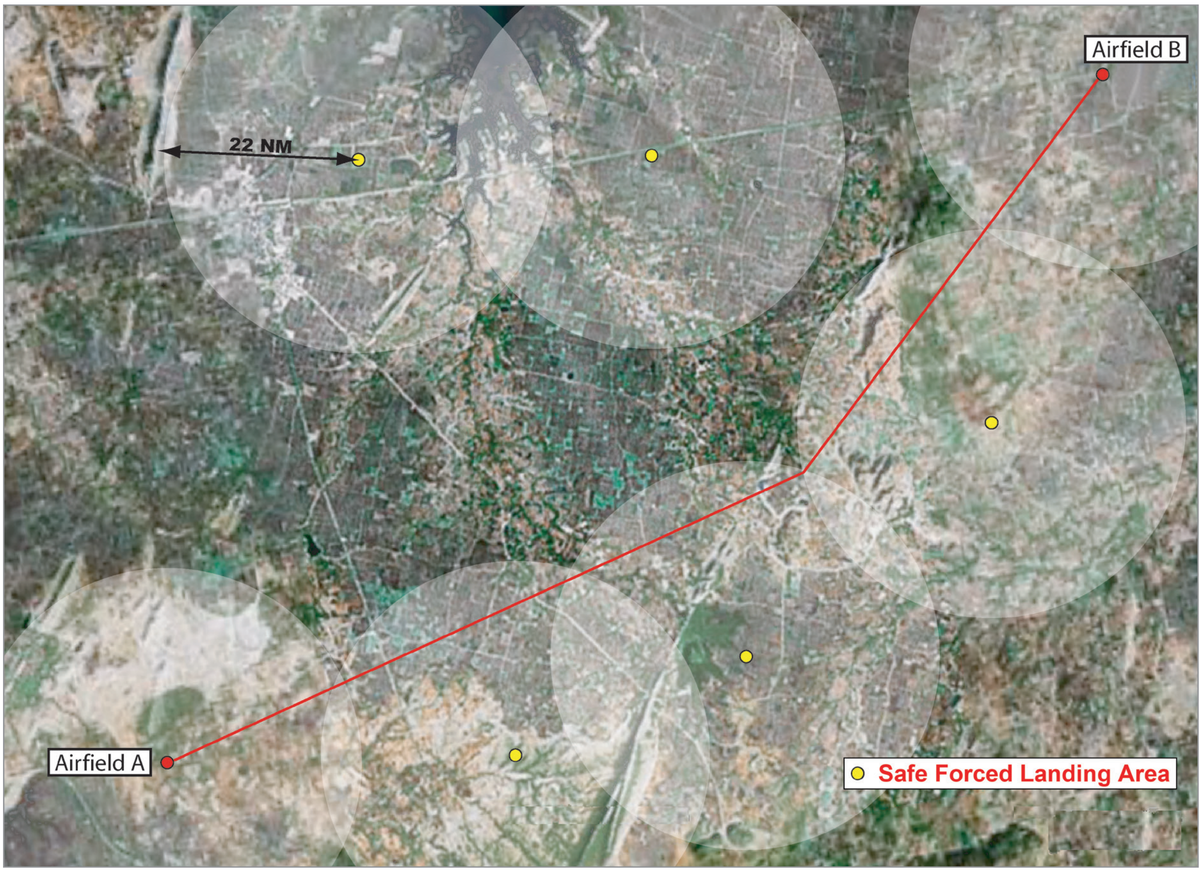


Figure 9.5 An illustration showing the net track that is required to remain within net glide range of each safe forced landing area

Thus the planned track will have to change slightly so that at all points along the route, the aeroplane is no further than 22 NM from a safe forced landing area. The track shown in *Figure 9.5* meets the entire set of requirements as stated in EU-OPS.

Information in CAP 698

It was mentioned at the beginning of the chapter that CAP 698 has the en route regulations in it for you, but that they were scattered through the manual and not conveniently collected in one place.

On page 1 of section 2 in the general requirement paragraph, point c) is the regulation about ensuring that the aeroplane is not operated unless surfaces are available which permit a safe forced landing to be carried out in the event of engine failure. However, the other regulations about complying with this rule are a few pages further on. You will find the remaining en route requirements at the bottom of page 8 of section 2.

The first part of the regulations to be found here states that the aeroplane may not be assumed to be flying above the altitude at which a rate of climb of 300 feet per minute can be achieved. Underneath that rule you can see the requirement which states that the net gradient of descent, in the event of engine failure, is the gross gradient + 0.5%.

Although the concepts of range and endurance have been covered in a previous lesson, it is important for the pilot to be able to use the information in the aeroplane flight manual so that he may calculate the range and endurance of the aeroplane. In the aircraft manual there are graphs and tables which help you calculate the endurance and range of your aeroplane under various conditions.

Typical Range and Endurance Graphs

Shown in *Figure 9.6* is a typical endurance graph for a light single-engine Class B aeroplane. As an example let us assume a cruise altitude of 7000 ft with an outside air temperature of 7°C at 65% power. Working through the graph hopefully you see that the endurance of the aircraft allowing 45 minutes of reserve fuel is 6.6 hours, or 7.4 hours allowing for no reserves.

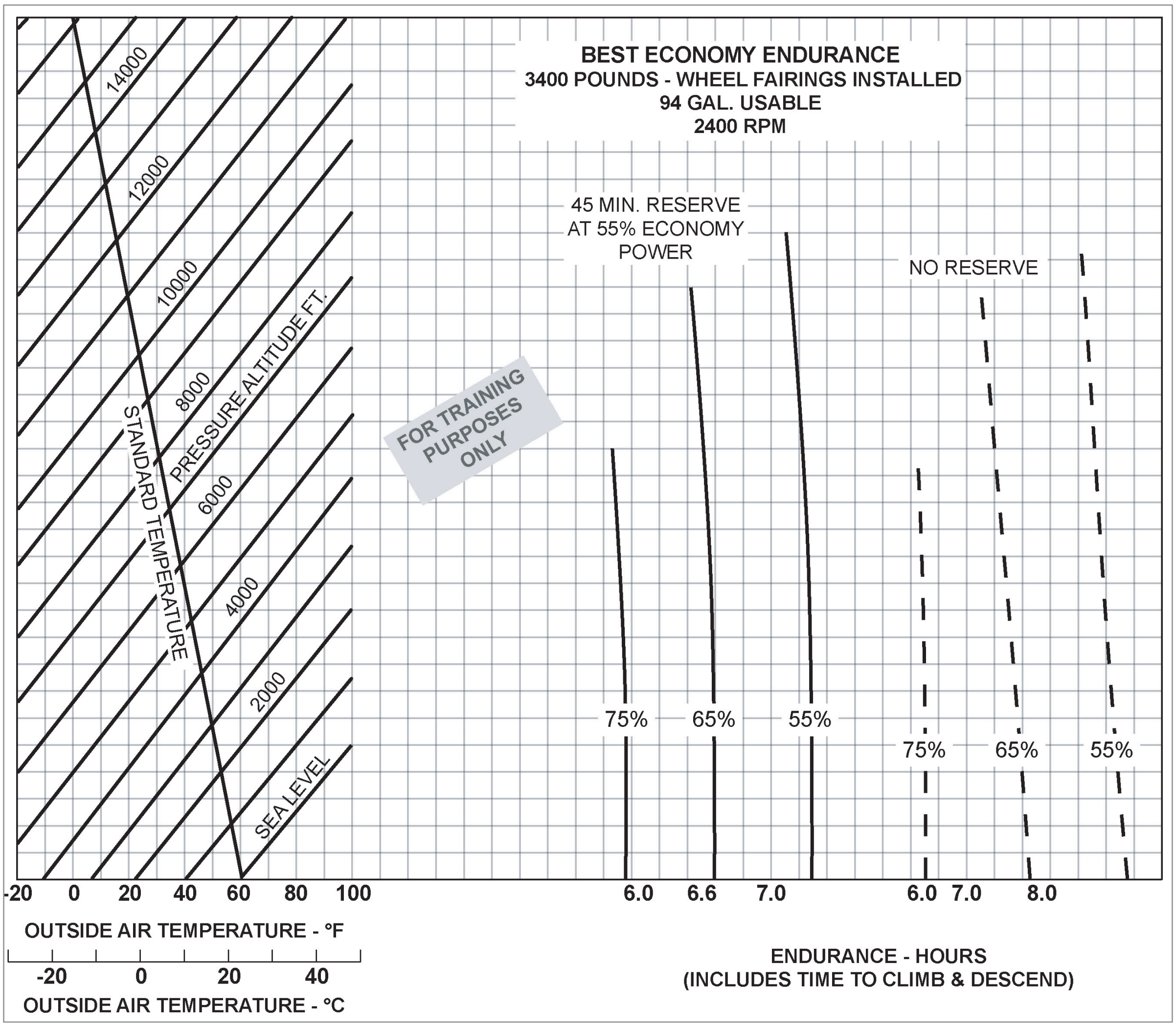


Figure 9.6 A typical endurance graph for a light single-engine aeroplane

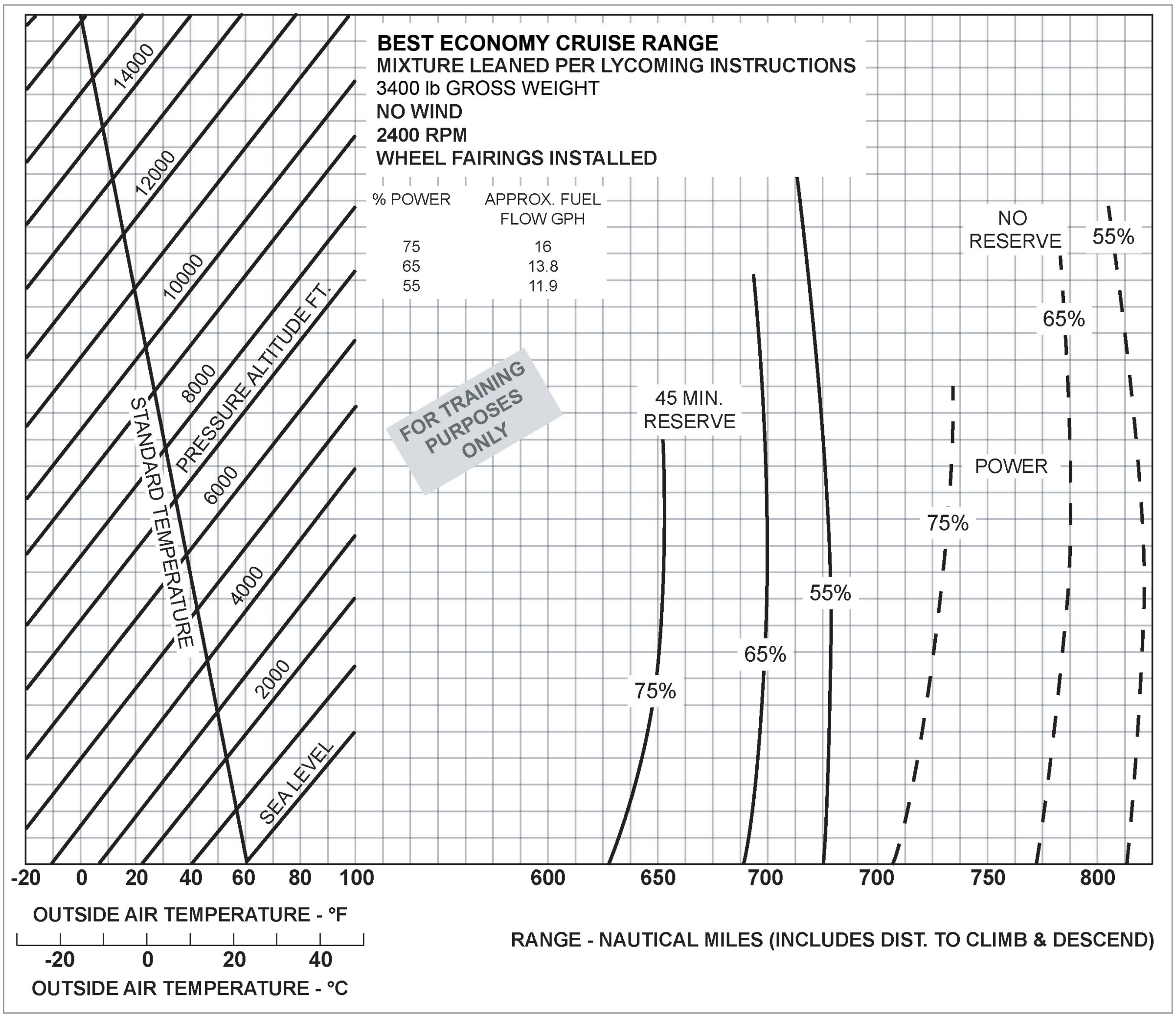


Figure 9.7 A typical range graph for a light single-engine aeroplane

Figure 9.7 is for calculating the aircraft range and it works in exactly the same way as the endurance graph except that instead of working out airborne time, distance flown is shown.

To achieve these range and endurance figures, be careful to follow the techniques described in the manual, especially with regard to correctly leaning the mixture.

Questions

1. **Which of the following statements correctly describes one of the general requirements about the operation of single-engine Class B aeroplanes in the public transport category?**

    a. They may fly at night
    b. They must be flown so that an airfield can be reached following engine failure
    c. They are not to operate in IMC, except under special VFR
    d. They must not be operated over water

2. **According to the information in a light aircraft manual, which gives two power-settings for cruise, 65% and 75%, if you fly at 75% instead of 65%:**

    a. cruise speed will be higher and SFC will be the same
    b. cruise speed will be higher and SFC will be lower
    c. cruise speed will be higher and SFC will be higher
    d. cruise speed will be the same and SFC will be the same

3. **According to the information in a light aircraft manual, which gives two power settings for cruise, 65% and 75%, if you fly at 65% instead of 75%:**

    a. endurance will be higher and SFC will be the same
    b. endurance will be higher and SFC will be lower
    c. endurance will be higher and SFC will be higher
    d. endurance will be the same and SFC will be the same

4. **For the purpose of ensuring compliance with the en route regulations, up to what maximum altitude is the aeroplane assumed to operate?**

    a. The altitude where the rate of climb falls to 300 ft/min with maximum continuous power set
    b. With maximum take-off power set, the altitude where the rate of climb exceeds 300 ft/min
    c. With maximum continuous power set, the altitude where the rate of climb exceeds 300 ft/min
    d. The altitude where the rate of climb increases to 300 ft/min with maximum take-off power set

5. **For the purpose of ensuring compliance with the en route regulations, the en route descent gradient must be:**

    a. the gross gradient of descent decreased by 0.5%
    b. the net gradient of descent decreased by 0.5%
    c. the gross gradient of descent increased by 0.5%
    d. 0.5%

6. **To ensure a piston engine Class B aeroplane can glide the furthest distance following engine failure, what speed must be flown?**

    a. V_{MP}
    b. $1.32V_{MD}$
    c. $0.76V_{MD}$
    d. V_{MD}

7. Following engine failure, to maximize the descent range of a small piston engine aeroplane the aeroplane must be flown at:

a. the speed for the maximum lift over drag ratio
b. V_{MP}
c. the speed for minimum lift over drag ratio
d. a speed equal to the aeroplane's best angle of climb

Answers

1	2	3	4	5	6	7
c	c	b	a	c	d	a

Chapter

10

Single-engine Class B - Landing

Landing Requirement

This lesson will focus on the single-engine Class B performance requirements for the landing stage of flight. There is actually only one regulation requirement for landing a single-engine Class B aeroplane. This requirement is that the landing distance must not exceed the landing distance available. In other words, the aeroplane must be able to land within the length of the runway. In order to comply with this regulation, certain points must be taken into account. These will all be discussed in this lesson.

As with other regulations we have dealt with in this course, the requirements relevant to the landing of single-engine Class B aeroplanes can be found in CAP 698. EU-OPS states that an operator must ensure that the landing mass of the aeroplane, for the estimated time of arrival, allows a full stop landing from 50 ft above the threshold within 70% of the landing distance available at the destination aerodrome and at any alternate aerodrome. This means that the aeroplane must be able to land within 70% of the landing distance available. The factor to use for such calculation is 1.43.

Example Landing Requirement

To help clarify this, let us work through an example and use *Figure 10.1*. If the landing distance available at the destination airfield is 2200 ft, then obviously the aeroplane must be able to land within 70% of 2200 ft. To calculate this value, we must divide 2200 ft by a factor of 1.43. Carrying out this simple calculation, gives us an answer of 1538 ft. 1538 ft is 70% of 2200 ft. Therefore, the aeroplane must be able to achieve a full stop landing within 1538 ft.

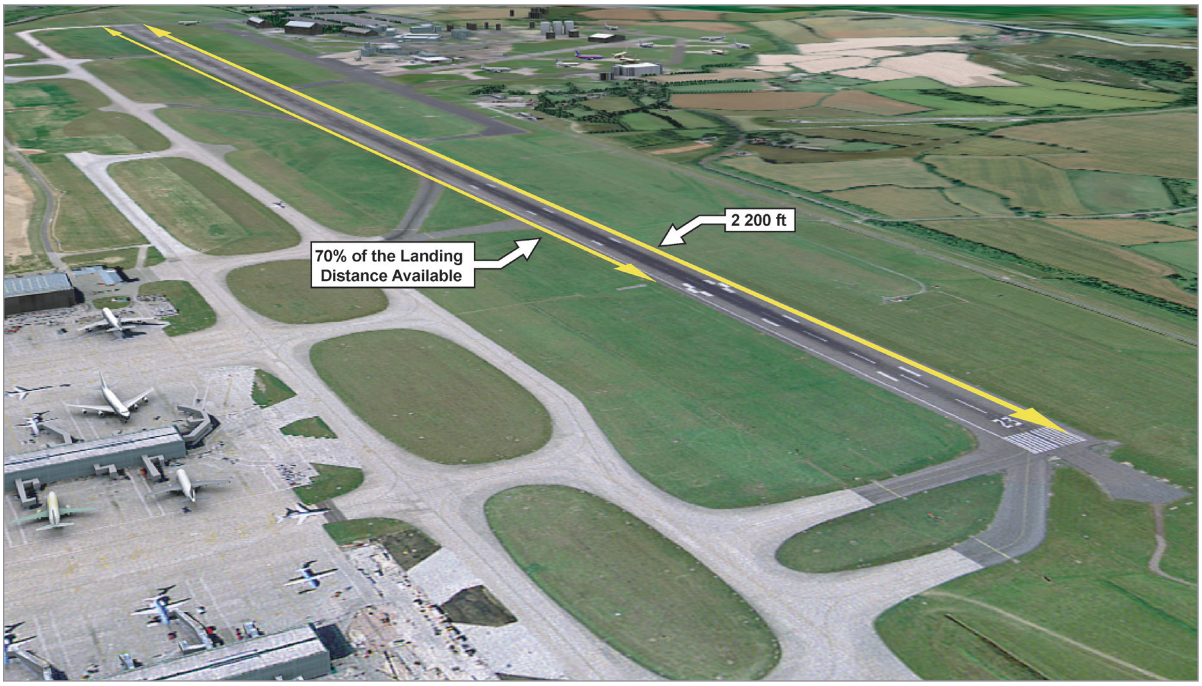


Figure 10.1 An illustration showing that the aeroplane must demonstrate it can come to a full stop within 70% of the landing distance available

There is another way to look at the landing requirement. If the landing distance of the aeroplane is calculated to be 1200 ft, what is the minimum length of the landing distance available which will allow a pilot to comply with the 70% rule?

Use *Figure 10.2* to help. In this case we simply multiply 1200 ft by 1.43. This gives us an answer of 1716 ft. Therefore, the landing distance available must be at least 1716 ft long. If the destination aerodrome has a runway with a landing distance available in excess of 1716 ft, the aeroplane will be able to land within 70% of the landing distance available and therefore satisfy the regulation requirement.

Figure 10.2 To obtain the minimum length of runway required, multiply the gross landing distance by 1.43.

The 70% landing regulation helps us to see the difference between net and gross performance. The gross performance is 1200 ft, but the net performance, which is always worse than the gross performance and is the one in a million worse case scenario, is 1716 ft.

The landing regulation we have just been discussing can be found in CAP 698 in section 2 at the top of page 9. The regulation states that the landing distance, from a screen height of 50 ft, must not exceed 70% of the landing distance available. If the aeroplane cannot come to a full stop within this length, then the landing distance must be reduced, either by selecting a higher flap setting or simply by reducing the mass of the aeroplane.

Factors to Be Accounted for

The regulations in CS-23 state that when calculating the gross landing distance, certain details must be accounted for. These are listed below.

The gross landing distance shall take account of:

- the pressure altitude at the aerodrome
- standard temperature
- the runway surface conditions and the type of runway surface
- the runway slope
- not more than 50% of the reported headwind component or not less than 150% of the reported tailwind component
- the despatch rules for scheduled or planned landing calculations EU-OPS 1.550 (c).

Correction Factors

Having discussed the regulation requirements detailing the maximum landing distance that must be available at a destination airfield or alternate airfield, we will now examine in detail the regulations governing how the gross landing distance is calculated given non-standard conditions like grass runways, wet runways and sloping runways.

Grass

In CAP 698 section 2, at the top of page 9 under point (b) we read that if the runway is of grass up to 20 cm high, the landing distance should be multiplied by a factor of 1.15. This would increase the landing distance by 15%.

Wet

If there is an indication that the runway may be wet at the estimated time of arrival, the landing distance should be multiplied by a factor of 1.15. Again, multiplying the calculated landing distance by a factor of 1.15 will increase the landing distance by 15%. If the aeroplane manual gives additional information on landing on wet runways, this may be used even if it gives a lesser distance than that from the above paragraph.

Slope

Point (d) in CAP 698 section 2 page 9 states that no allowance is permitted for upslope. The reason for this is that upslope will reduce the landing distance. If a pilot were to ignore the reduction in the landing distance then a margin of safety would be incorporated into the landing distance calculation. The landing distance should be increased by 5% for each 1% downslope. This means that for a 1% downslope the landing distance should be multiplied by a factor of 1.05. Therefore for a 2% downslope the factor would be 1.1.

Despatch Rules

Lastly, point (e) states that there must be compliance with the despatch rules for scheduled or planned landing calculations and that these can be found in EU-OPS 1.550 (c).

The despatch rules, found in EU-OPS 1.550 (c), state that for despatching an aeroplane, it must be assumed that:

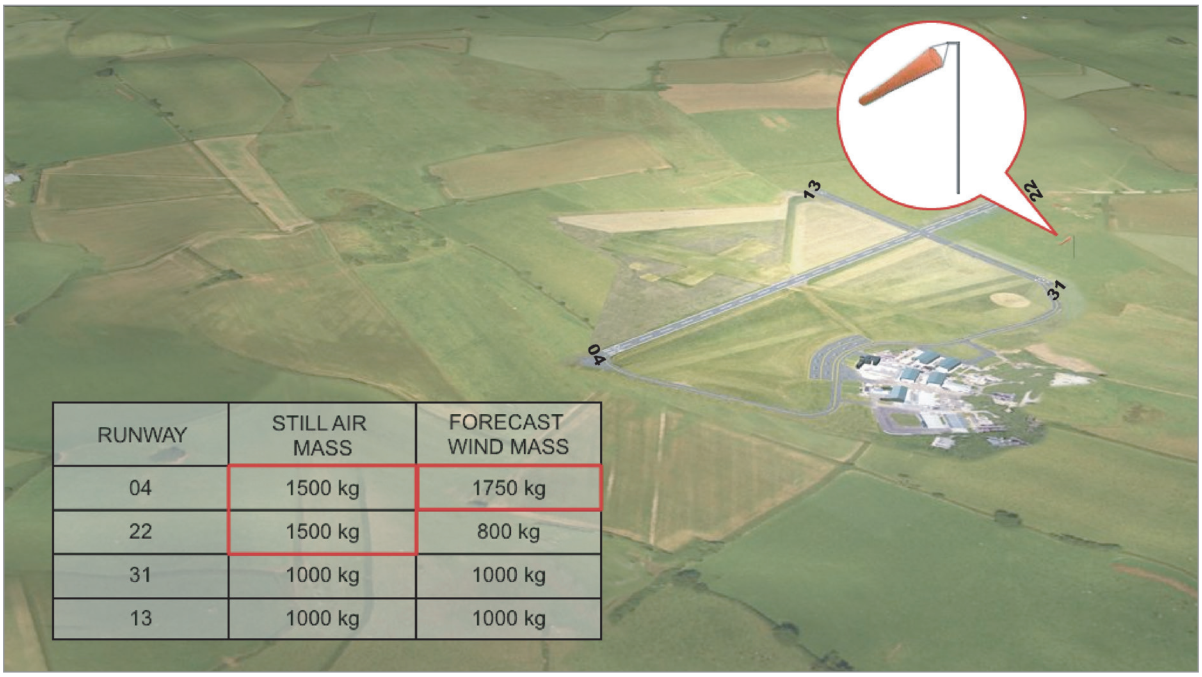
- The aeroplane will land on the most favourable runway at the destination airfield in still air, and

- The aeroplane will land on the runway most likely to be assigned considering the probable wind speed and direction.

If this second assumption cannot be met, the aeroplane may be despatched only if an alternate aerodrome is designated at which full compliance of the regulatory despatch requirements can be met.

The first assumption is that the aeroplane will land on the most favourable runway, in still air or zero wind. This means that, assuming zero wind at the destination airfield, the runway which would accommodate the largest possible landing mass would be selected since that is the most favourable runway.

Using an example which you see in *Figure 10.3*, firstly we try and understand the first rule. Assuming zero wind and focusing on the column “STILL AIR MASS”, runway 04 and runway 22 both allow a maximum landing mass of 1500 kg but runway 31 and runway 13, being much shorter runways, allow a maximum landing mass of only 1000 kg. Therefore, the most favourable runway in still air is either runway 04 or 22, which both allow a maximum landing mass of 1500 kg. These two masses have been highlighted in red.



RUNWAY	STILL AIR MASS	FORECAST WIND MASS
04	1500 kg	1750 kg
22	1500 kg	800 kg
31	1000 kg	1000 kg
13	1000 kg	1000 kg

Figure 10.3 An illustration showing example landing masses of an aeroplane based upon no wind & the forecast wind condition

The second despatch assumption is that the aeroplane will actually land on the most likely runway to be assigned considering the probable wind speed and direction. Now focus on the second column “FORECAST WIND MASS”. In this case, runway 04 has a strong headwind for the landing which will allow the aeroplane to land at a much greater mass than if there were no wind. In our example the headwind has increased the maximum landing mass to 1750 kg. However, runway 22 has a tailwind, which will decrease the maximum landing mass to 800 kg. Runway 31 and runway 13 both have a full cross wind; therefore, the maximum landing mass for these two runways will be the same as for still air. If the second despatch assumption is that the aeroplane will land on the runway most likely to be assigned considering the probable wind speed and direction, then it would have to be runway 04 with a maximum landing mass of 1750 kg. This mass is highlighted in red.

In summary then, the first assumption requires that the pilot select runway 04 or 22 for a maximum still air landing mass of 1500 kg, and the second assumption will require the pilot to select runway 04 for a maximum landing mass of 1750 kg.

Now we need to consider what to use as the despatch mass of the aeroplane. If the aeroplane was despatched at 1750 kg mass, and then on arrival at the airfield the wind was less than 15 knots, the aeroplane would not be able to land. Therefore, the aeroplane must be despatched with a mass of 1500 kg. Despatching the aeroplane with this mass would mean that, no matter what wind conditions prevail at the destination airfield, the aeroplane will have a mass which will allow it to land at the airfield.

The way to simplify the despatch rule is to always consider the greatest mass in still air and the greatest mass in the forecast wind conditions and, of the two, take the lesser mass as the despatch mass. Of the two, it is the still air mass that is usually the lesser mass, as shown in our example. The exception is when there is a tailwind on a unidirectional runway. A unidirectional runway is a runway whose direction for take-off and landing is fixed in one direction. And in this case the maximum landing mass in the tailwind will be less than the maximum landing mass in still air.

Reference Landing Speed (V_{REF})

You may recall that the regulatory speed at the landing screen height is called V_{REF} and, for a single-engine Class B aeroplane it had to be no less than 1.3 times the stall speed in the landing configuration, ($1.3V_{S0}$). A pilot must adhere to the V_{REF} speeds because they are the speeds which have been used to construct the landing graphs or table in the aeroplane flight manual. If a pilot were to deviate from these speeds, the required aircraft performance would not be achieved.

Presentation of Landing Data / Using the Graphs

This part of the chapter will deal with how the aeroplane's landing distance can actually be calculated. All aeroplanes will have either a pilot operating handbook or an aeroplane flight manual. The purpose of these manuals is not only to show how to operate the aeroplane but also to detail the aeroplane's performance.

The example graph we will use is *figure 2.4 on page 10 of section 2 in CAP 698*. Always take a look at the associated conditions first, paying particular attention to the power and flap settings as shown at the top of the graph. Also notice that this graph assumes a runway which is paved, level and dry. If the runway conditions required for a given calculation are different to those specified, corrections will need to be made to the values that this graph will give. We saw these correction factors earlier.

The left hand carpet of the graph involves the variations in temperature and pressure altitude. This part of the graph accounts for the effect of air density on the landing distance. The middle carpet accounts for the effect of the mass and to the right of this carpet is the wind correction carpet. Notice the differences in the slope of the headwind and tailwind lines. This means the 150% and 50% wind rules have been applied. The last carpet on the far right of the graph is labelled "obstacle height". Although there is no "obstacle" as such you will recall that the landing starts at a height of 50 ft above the landing surface.

Follow through the example that has been carried out for you in the graph. This will help you to use the graph correctly. Not only is there an example on the graph itself, but if you look at the bottom of *page 9 of section 2 in CAP 698* you will see another example which you can work through. Use the examples; they are there to help you. If you need practice on working through the graphs, use the questions at the end of the chapter.

Questions

1. **For this question use Performance Manual CAP 698 SEP1 Figure 2.4.**

   With regard to the landing chart for the single-engine aeroplane determine the landing distance from a height of 50 ft.

   Given:
   OAT: 27°C
   Pressure altitude: 3000 ft
   Aeroplane mass: 2900 lb
   Tailwind component: 5 kt
   Flaps: landing position (down)
   Runway: tarred and dry

   a. approximately : 1120 ft
   b. approximately : 1700 ft
   c. approximately : 1370 ft
   d. approximately : 1850 ft

2. **For this question use Performance Manual CAP 698 SEP1 Figure 2.4.**

   With regard to the landing chart for the single-engine aeroplane determine the landing distance from a height of 50 ft.

   Given:
   OAT: ISA +15°C
   Pressure altitude: 0 ft
   Aeroplane mass: 2940 lb
   Headwind component: 10 kt
   Flaps: landing position (down)
   Runway: short and wet grass with firm soil base
   Correction factor (wet grass): 1.38

   a. approximately : 1300 ft
   b. approximately : 2000 ft
   c. approximately : 1450 ft
   d. approximately : 1794 ft

3. **For this question use Performance Manual CAP 698 SEP1 Figure 2.4.**

   With regard to the landing chart for the single-engine aeroplane determine the landing distance from a height of 50 ft.

   Given:
   OAT: ISA +15°C
   Pressure altitude: 0 ft
   Aeroplane mass: 2940 lb
   Tailwind component: 10 kt
   Flaps: landing position (down)
   Runway: tarred and dry

   a. approximately : 950 ft
   b. approximately : 1900 ft
   c. approximately : 750 ft
   d. approximately : 1400 ft

4. **For this question use Performance Manual CAP 698 SEP1 Figure 2.4.**

   With regard to the graph for landing performance, what is the minimum headwind component required?

   Given:
   Actual landing distance: 1300 ft
   Runway elevation: MSL
   Weather: assume ISA conditions
   Mass: 3200 lb

   a. no wind
   b. 5 kt
   c. 15 kt
   d. 10 kt

5. **For this question use Performance Manual CAP 698 SEP1 Figure 2.4.**

   With regard to the landing chart for the single-engine aeroplane determine the landing distance from a height of 50 ft.

   Given:
   OAT: 0°C
   Pressure altitude: 1000 ft
   Aeroplane mass: 3500 lb
   Tailwind component: 5 kt
   Flaps: landing position (down)
   Runway: tarred and dry

   a. approximately : 1480 ft
   b. approximately : 940 ft
   c. approximately : 1770 ft
   d. approximately : 1150 ft

6. **For this question use Performance Manual CAP 698 SEP1 Figure 2.4.**

   Using the Landing Diagram, for single-engine aeroplane, determine the landing distance (from a screen height of 50 ft) required, in the following conditions:

   Given:
   Pressure altitude: 4000 ft
   OAT: 5°C
   Aeroplane mass: 3530 lb
   Headwind component: 15 kt
   Flaps: approach setting
   Runway: tarred and dry
   Landing gear: down

   a. 1550 ft
   b. 1020 ft
   c. 1400 ft
   d. 880 ft

7. **For this question use Performance Manual CAP 698 SEP1 Figure 2.4.**

With regard to the landing chart for the single-engine aeroplane determine the landing distance from a height of 50 ft.

Given:
OAT: ISA
Pressure altitude: 1000 ft
Aeroplane mass: 3500 lb
Tailwind component: 5 kt
Flaps: landing position (down)
Runway: tarred and dry

a. approximately : 1800 ft
b. approximately : 1150 ft
c. approximately : 1500 ft
d. approximately : 920 ft

8. **The landing distance available at an aerodrome is 2000 ft. For a Class B aircraft, what distance should be used in the landing distance graph to obtain the maximum permissible landing weight, if the runway has a paved wet surface with a 1% uphill slope?**

a. 1398 ft
b. 1216 ft
c. 1850 ft
d. 2000 ft

9. **At an aerodrome, the landing distance available is 1700 ft. For a single-engine Class B aircraft, what must be the actual landing distance in order to comply with the landing regulations?**

a. 1033 ft
b. 1478 ft
c. 2431 ft
d. 1189 ft

10. **By what factor must the landing distance available for a single-engine Class B aeroplane be multiplied in order to find the maximum allowable landing distance?**

a. 0.70
b. 1.67
c. 1.43
d. 0.60

11. **The landing field length required for single-engine Class B aeroplanes at the alternate aerodrome is the demonstrated landing distance plus:**

a. 92%
b. 43%
c. 70%
d. 67%

12. The calculated dry landing distance of a single-engine Class B aeroplane is 1300 ft. What is the minimum landing distance available to comply with the landing regulations? (runway is wet at the estimated time of arrival.)

a. 1495 ft
b. 2138 ft
c. 1859 ft
d. 1130 ft

Answers

1	2	3	4	5	6	7	8	9	10	11	12
d	d	b	d	c	c	a	b	d	a	b	b

Chapter

11

Multi-engine Class B - Take-off

Take-off Requirements

The take-off requirements for multi-engine Class B aircraft (other than those in the commuter category) are the same as for single-engine aircraft except that multi-engine Class B aeroplanes must additionally demonstrate a minimum climb gradient performance and an obstacle clearance capability.

Gradient Requirement EU-OPS 1.530

Three climb gradient requirements must be considered, and the most limiting will determine the maximum permissible mass. You can find these in *CAP 698 under paragraph 3.1.2* on page 9 of section 3.

- **ALL ENGINES OPERATING**
  A minimum climb gradient of 4% is required with:

  - take-off power on each engine
  - landing gear extended, except that if the landing gear can be retracted in not more than 7 seconds, it may be assumed to be retracted
  - the wing flaps in the take-off position
  - a climb speed of not less than the greater of $1.1V_{MC}$ and $1.2V_{S1}$

- **ONE ENGINE INOPERATIVE**
  The climb gradient at an altitude of 400 ft above the take-off surface must be measurably positive with:

  - the critical engine inoperative and its propeller in the minimum drag position
  - the remaining engine at take-off power
  - the landing gear retracted
  - the wing flaps in the take-off position
  - a climb speed equal to that achieved at 50 ft

  The climb gradient must not be less than 0.75% at an altitude of 1500 ft above the take-off surface, with:

  - the critical engine inoperative and its propeller in the minimum drag position
  - the remaining engine at not more than maximum continuous power
  - the landing gear retracted
  - the wing flaps retracted
  - a climb speed not less than $1.2V_{S1}$

Field Length Requirements

The Field Length Requirements are the same as for the single-engine aeroplane and are detailed below. You can also find them in *CAP 698 under paragraph 2.1.1 of pages 1 and 2 of section 3.*

- When no stopway or clearway is available, the take-off distance when multiplied by 1.25 must not exceed TORA (Gross TOD × 1.25 must not exceed the TORA)

- When a stopway and/or clearway is available the take-off distance must:

  - not exceed TORA (Gross TOD must not exceed the TORA)

  - when multiplied by 1.3, not exceed ASDA (Gross TOD × 1.3 must not exceed the ASDA)

  - when multiplied by 1.15, not exceed TODA (Gross TOD × 1.15 must not exceed the TODA)

Factors to Be Accounted for

The regulations in CS-23 state that when calculating the gross take-off distance, in other words, before we add the factors mentioned previously, certain details must be accounted for. These are listed below.

The gross take-off distance required shall take account of:

- the mass of the aeroplane at the start of the take-off run

- the pressure altitude at the aerodrome

- the ambient temperature at the aerodrome

- the runway surface conditions and the type of runway surface

- the runway slope

- not more than 50% of the reported headwind component or not less than 150% of the reported tailwind component

Surface Condition Factors

From the list above, the regulations stipulate that due account must be made of the runway condition. Most performance data in the aeroplane flight manual assumes a level, dry and hard runway. Therefore, correction factors must be applied to the gross take-off distance when the runway conditions are different. There are various correction factors such as for grass runways, wet runways and runways which are sloped. These factors are detailed next.

At the top of *page 2 section 2 under paragraph c) in CAP 698* it states that if the runway is other than dry and paved the following correction factors must be used when determining the take-off distance. These are shown for you in *Figure 11.1*.

Surface Type	Condition	Factor
Grass (on firm soil) up to 20 cm long	Dry	× 1.2
	Wet	× 1.3
Paved	Wet	× 1.0

Figure 11.1

As you have learnt already, grass runways will increase the take-off distance compared to paved runways. Here the factor to use to account for the effect of dry grass is 1.2 and 1.3 if the grass is wet.

At the *top of page 2 section 3, point d)* details the corrections to be applied if there is a slope to the runway. It states that a pilot must increase the take-off distance by 5%, or by a factor of 1.05, for every 1% upslope. However, it also states that "no factorization is permitted for downslope". In other words, when an aeroplane may be taking off on a downwards sloping runway no correction factor is to be applied for the downslope. The reason for ignoring the downslope is because a downslope will decrease the take-off distance. This helps to add a little extra safety to the take-off distance calculation.

Presentation of Take-off Data

Shown in *CAP 698 on pages 3 and 7 of section 3* are the take-off distance graphs for a typical multi-engine Class B aeroplane. The one on page 3 is "normal take-off" and the one on page 7 is a "maximum effort" take-off, in other words a short field take-off. There are several examples in CAP 698, one at the bottom of page 2 and the other at the top of page 6 in section 3. Ensure you go through these examples to help you with your graph work and to help you to know when to apply the various factors.

Accelerate-stop Distance Requirements

Other than for commuter category aircraft, there is no requirement for accelerate-stop distance, but the data may be given. Shown in *CAP 698 on pages 5 and 8 of section 3* you can see the accelerate-stop distance graphs for a typical multi-engine Class B aeroplane. As with other graphs, there are examples which you should go through.

For commuter category aircraft, the accelerate-stop distance is the sum of the distances necessary to:

- accelerate the aircraft to V_{EF} with all engines operating
- accelerate from V_{EF} to V_1 assuming the critical engine fails at V_{EF}
- come to a full stop from the point at which V_1 is reached

Take-off Speeds

The gross take-off distance required is the distance from the start of take-off to a point 50 ft above the take-off surface, with take-off power on each engine, rotating at V_R and achieving the specified speed at the screen.

V_R The rotation speed, must not be less than:

- $1.05V_{MC}$
- $1.1V_{S1}$

The speed at 50 ft (the take-off safety speed) must not be less than:

- a speed that is safe under all reasonably expected conditions
- $1.1V_{MC}$
- $1.2V_{S1}$

V_{MC} for take-off must not exceed $1.2V_{S1}$

These speeds are not found in CAP 698 and must be committed to memory.

Obstacle Clearance Requirements (EU-OPS 1.535)

Multi-engine Class B aircraft must demonstrate clearance of obstacles after take-off up to a height of 1500 ft. All the obstacle clearance requirements can be found in *CAP 698* and therefore they **do not** need to be learnt. You can find them all on *page 9 of section 3*.

Obstacles must be cleared by:

- a vertical margin of at least 50 ft or
- a horizontal distance of at least 90 m + 0.125D where D is the distance from the end of the TODA, or the end of the TOD if a turn is scheduled before the end of the TODA. For aeroplanes with a wingspan of less than 60 m the horizontal distance may be taken as 60 m + half the wingspan + 0.125D.

The following conditions must be assumed:

- the flight path begins at a height of 50 ft above the surface at the end of the TODR and ends at a height of 1500 ft above the surface.
- the aeroplane is not banked before it has reached the height of 50 ft, and thereafter that the angle of bank does not exceed 15°.
- failure of the critical engine occurs at the point on the all engine take-off flight path where visual reference for the purpose of avoiding obstacles is expected to be lost.
- the gradient to be assumed from 50 ft to the point of engine failure is equal to the average all engine gradient during climb and transition to the en route configuration, multiplied by a factor of 0.77.
- the gradient from the point of engine failure to 1500 ft is equal to the one engine inoperative en route gradient.

If the flight path does not require track changes of more then 15°, obstacles do not need to be considered if the lateral distance is greater than 300 m if in VMC or 600 m for all other conditions. If the flight path requires track changes of more than 15°, obstacles need not be considered if the lateral distance is greater than 600 m in VMC or 900 m for all other conditions.

Take-off Flight Path

The flight path profile performance should take account of:

- the mass of the aeroplane at the commencement of the take-off run
- the pressure altitude at the aerodrome
- the ambient temperature
- not more than 50% of the reported headwind component and not less than 150% of the reported tailwind component

Construction of the Flight Path

The flight path profile will depend on whether or not visual reference is lost before reaching 1500 ft.

- **VISIBILITY CLEAR TO 1500 ft**
    - Determine the TOD required for the take-off mass
    - Determine the all engines net gradient (gross gradient × 0.77)
    - Divide the height gain (1450 ft) by the gradient to determine the distance travelled (feet) from 50 ft to 1500 ft.
    - The profile may be plotted as shown in *Figure 11.2* and clearance of obstacles assessed.

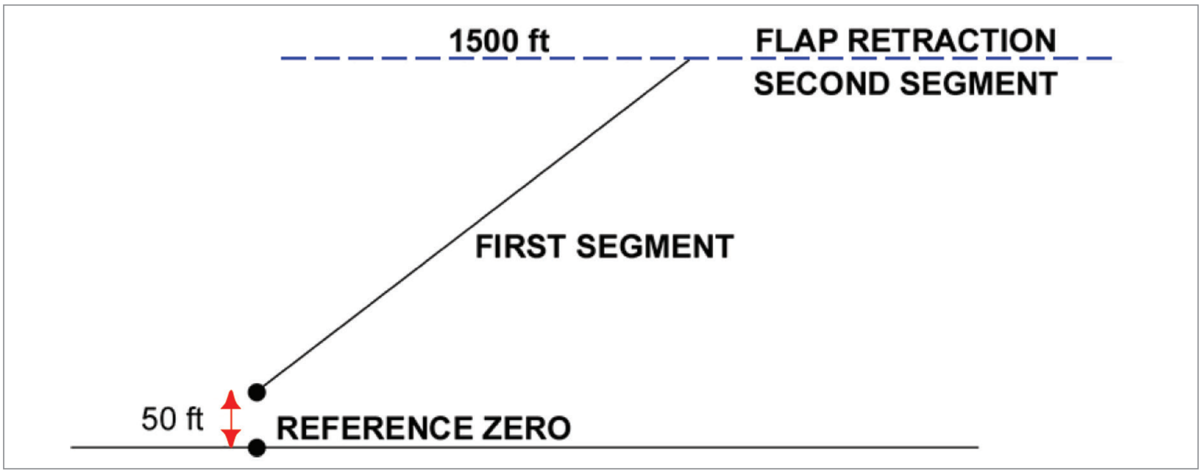


Figure 11.2 The obstacle clearance climb profile if there is no cloud

Alternatively for a single obstacle, find the TOD req. and gradient as above, then multiply the distance from reference zero to the obstacle by the gradient to find the height gain, and add 50 ft to find the aeroplane height at the obstacle distance. This must exceed the obstacle height by 50 ft.

If the obstacle is not cleared by 50 ft, a lower take-off mass must be assumed and a revised height calculated. The maximum mass which will just clear the obstacle by 50 ft can then be determined by interpolation.

- **CLOUD BASE BELOW 1500 ft**

If visual reference is lost before 1500 ft, the flight path will consist of two segments.

Segment 1 (From 50 ft to cloud base)

Distance from 50 ft to cloud base = height gain ÷ all engine net gradient × 100

Height gain = cloud base - 50 ft

Segment 2 (From cloud base to 1500 ft)

Distance = height gain ÷ gross gradient with one engine inoperative × 100

The profile may be plotted as shown in *Figure 11.3* and clearance of obstacles assessed. If the required clearance is not achieved, a reduced take-off mass must be assumed and a second flight path calculated. As before, the maximum permissible weight may be determined by interpolation.

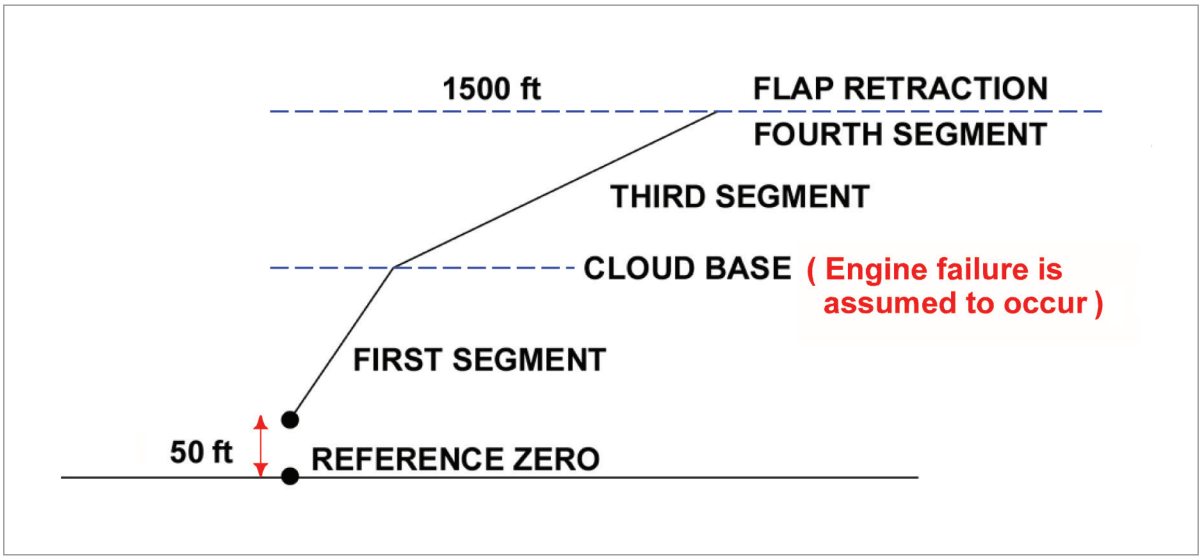


Figure 11.3 The obstacle clearance climb profile if there is cloud

If the climb data is given in terms of rate of climb, this can be converted to gradient:

Gradient% = Rate of Climb (ft/min) ÷ Aircraft True Ground Speed × 100

Alternatively the time on each segment can be calculated:

Time (mins) = Height Gain (ft) ÷ Rate of Climb (ft/min)

and the distance on each segment obtained from:

Distance (ft) = Aircraft True Ground Speed (ft/min) × Time (min)

Questions

1. **For a multi-engine Class B aeroplane at an aerodrome with no stopway or clearway, the length of take-off run that must be available for take-off, to satisfy the requirements:**

   a. must not be less than the gross take-off distance to 50 ft
   b. must not be less than 1.15 times the gross take-off distance to 50 ft
   c. must not be less than 1.25 times the gross take-off distance to 50 ft
   d. must not be less than 1.3 times the gross take-off distance to 50 ft

2. **For a multi-engine Class B aircraft, the rotation speed V_R:**

   a. must not be less than either $1.1V_{S1}$ or $1.05V_{MC}$
   b. must not be less than V_{S1}
   c. must not be less than $1.05V_{S1}$ or $1.1V_{MC}$
   d. must not be less than V_{MC}

3. **For a multi-engine Class B aircraft, the take-off safety speed must:**

   a. not be less than either $1.1V_{S1}$ or $1.05V_{MC}$
   b. be greater than $1.2V_{MC}$ or $1.1V_{S1}$
   c. not be less than either $1.2V_{S1}$ or $1.1V_{MC}$
   d. be greater than V_{S1}

4. **For this question use Performance Manual CAP 698 MEP1 Figure 3.4.**

   Determine the accelerate-stop distance from brake release to a full stop given an abort speed of 64 KIAS and a reaction time of three seconds.

   Given:
   OAT: 27°C
   Pressure altitude: MSL
   Aeroplane mass: 3750 lb
   Tailwind component: 5 kt
   Flaps: 25°
   Runway: paved, level and dry

   a. 2200 ft
   b. 1800 ft
   c. 3300 ft
   d. 2400 ft

5. **For this question use Performance Manual CAP 698 MEP1 Figure 3.2.**

Determine the maximum permissible mass that will allow the aeroplane to come to full stop given an accelerate-stop distance available of 3200 ft.

Given:
OAT: ISA
Pressure altitude: MSL
Headwind component: 5 kt
Flaps: 0°
Runway: paved, level and dry

a. 3550 lb
b. 4100 lb
c. 4250 lb
d. 3000 lb

6. **For this question use Figure 3.2 in CAP 698. With regard to the graph for the light twin aeroplane, will the accelerate-stop distance be achieved in a take-off where the brakes are released before take-off power is set?**

a. It does not matter which take-off technique is being used
b. No, the performance will be worse than in the chart
c. Performance will be better than in the chart
d. Yes, the chart has been made for this situation

7. **When assessing obstacle clearance after take-off for a twin-engine Class B aircraft, the climb from 50 ft to 1500 ft:**

a. is always assumed to take place with all engines operating
b. assumes that an engine fails at the point where visual reference of the obstacle is lost
c. always assumes that an engine has failed at 50 ft
d. assumes that an engine fails at 400 ft above ground level

8. **A light twin-engine aircraft is climbing from the screen height of 50 ft, and has an obstacle 10 000 m along the net flight path. If the net climb gradient is 10%, there is no wind and the obstacle is 900 m above the aerodrome elevation then what will the clearance be?**

a. The aircraft will not clear the object
b. 85 m
c. 100 m
d. 115 m.

9. **By what vertical margin must a multi-engine Class B aeroplane clear an obstacle in the take-off flight path?**

a. 35 ft
b. 50 ft
c. There is no obstacle clearance requirement
d. 60 m + 0.125D

10. **Regarding the take-off climb requirements for a multi-engine Class B aeroplane, what is the minimum all engine climb gradient after take-off?**

a. 0.75%
b. >0%
c. 4%
d. 2.4%

11. **If a multi-engine Class B aeroplane is unable to achieve the required vertical clearance over an obstacle, by what minimum horizontal margin must the obstacle be cleared? (assume wing span < 60 m.)**

a. 60 m + 1/2 wingspan + 0.125D
b. 90 m + 0.125D
c. 60 m / D + 0.125
d. There is no minimum horizontal clearance requirement

12. **What is the maximum bank angle permitted within the take-off flight path up to 1500 ft for a multi-engine Class B aeroplane?**

a. 25°
b. 10°
c. 5°
d. 15°

13. **By what regulatory factor must the all engine climb gradient of a multi-engine Class B aeroplane be multiplied in order to comply with the obstacle clearance requirements?**

a. 0.5%
b. 0.5
c. 0.77
d. 1.43

Answers

1	2	3	4	5	6	7	8	9	10	11	12
c	a	c	d	b	b	b	d	b	c	a	d

13
c

Chapter

12

Multi-engine Class B - En Route and Descent

En Route Requirements

This chapter will focus on the multi-engine Class B performance requirements for the en route and descent stages of flight. The en route part of the flight is considered to be from 1500 ft above the airfield from which the aeroplane has taken off, to 1000 ft above the destination airfield.

As with all the other requirements we have come across, the en route and descent requirements are written in EU-OPS and incorporated into CAP 698.

Looking at CAP 698 at the top of page 17 of section 3 you can see the en route requirements. The first sentence simply reminds you what the en route stage of flight is. These requirements are listed below.

- An operator shall ensure that the aeroplane, in the meteorological conditions expected for the flight, and in the event of the failure of one engine, with the remaining engines operating within the maximum continuous power conditions specified, is capable of continuing flight at or above the relevant minimum altitudes for safe flight stated in the operations manual to a point 1000 ft above an aerodrome at which the performance requirements for landing can be met.

This requirement is almost identical to the single-engine aeroplane, the only difference being that whereas the single-engine aeroplane has to be capable of landing in a suitable field after engine failure, the multi-engine aeroplane must be capable of a higher performance level and therefore continue flight and land at a suitable airfield. Therefore, in the event of engine failure, the multi-engine aeroplane should have a level of performance such that it can, even with an engine failure, get to an airfield to land. However, as with other requirements we have covered, the en route requirements do have some compliance rules. In fact, these compliance rules are very similar to the ones we mentioned in the single-engine en route lesson.

In order for the pilot to be able to abide by the regulation, the descent range with one engine inoperative must be known as well as the one engine inoperative cruise range. Once these have been calculated, a flight track must be plotted that will ensure an airfield is always within the total one engine inoperative descent distance. Herein lies the compliance rules because the compliance rules relate to how that descent range is calculated.

- When showing compliance with the rules shown above:
  - The aeroplane must not be assumed to be flying at an altitude exceeding that at which the rate of climb equals 300 ft/min with all engines operating within the maximum continuous power conditions specified; and
  - The assumed en route gradient with one engine inoperative shall be the gross gradient of descent or climb, as appropriate, respectively increased by a gradient of 0.5%, or decreased by a gradient of 0.5%.

What the first compliance rule means is that the aeroplane must not use the extra altitude above the 300 feet per minute altitude to gain extra range to help comply with landing at an airfield after engine failure.

The second compliance rule is saying that when calculating the descent range to work out if the aeroplane can make it to an airfield, the gross gradient of descent must be increased by 0.5%. This adjusted gradient is the net gradient and it is simply adding a safety margin into the aeroplanes descent range. In this case an airfield must be within the net descent range and not the gross descent range.

The Drift Down

Calculating the descent range of a twin-engine aeroplane after engine failure is not as easy as it was for the single-engine aeroplane. For the single-engine aeroplane, to calculate the descent range it was simply the height of the aeroplane divided by the descent gradient and multiplied by 100.

However, the gradient of descent of a twin-engine aeroplane following engine failure is constantly changing. Let us explain why. In straight and level flight the forward force of thrust balances the rearward force of drag. When the engine fails, there is more rearward force than forward force, and, as a result of the excess drag the aeroplane will slow down if level flight is maintained. To maintain the speed, which should be kept at V_{MD}, the thrust force generated by the remaining live engine must be augmented so that the forces can once again be balanced.

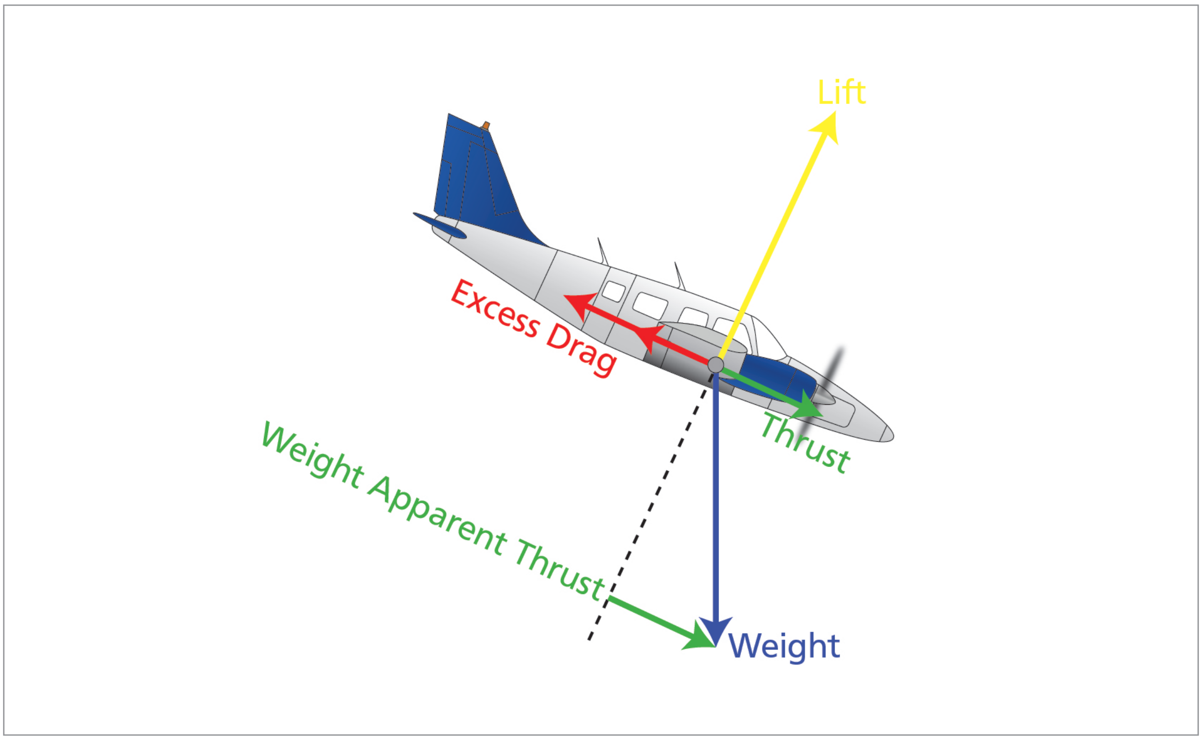


Figure 12.1 The forces on an aeroplane in the early part of the drift down

The only way to do this is to lower the nose so that weight can act forward and provide enough weight apparent thrust to balance the excess drag. If the nose is lowered by a sufficient amount then the forces will once again balance and V_{MD} can be maintained. The only side effect is that the aeroplane is descending. However, as the aeroplane descends in the atmosphere, the air density increases. This means that the thrust being produced by the remaining engine increases which reduces the excess drag. Now there is no need for so much weight apparent thrust since the excess drag has reduced. To reduce the amount of weight apparent thrust, the nose is raised a little.

This process can continue until the remaining engine generates sufficient thrust to balance the drag without any need for weight apparent thrust. At the altitude where this balance occurs the aeroplane is able to level off.

In summary then, after engine failure in the cruise, the aeroplane is forced to descend, but as it descends the aeroplane can slowly reduce the descent angle until the aeroplane can once more fly level. This procedure is known as the drift down procedure and it produces a drift down flight profile similar to the one shown in *Figure 12.2*.

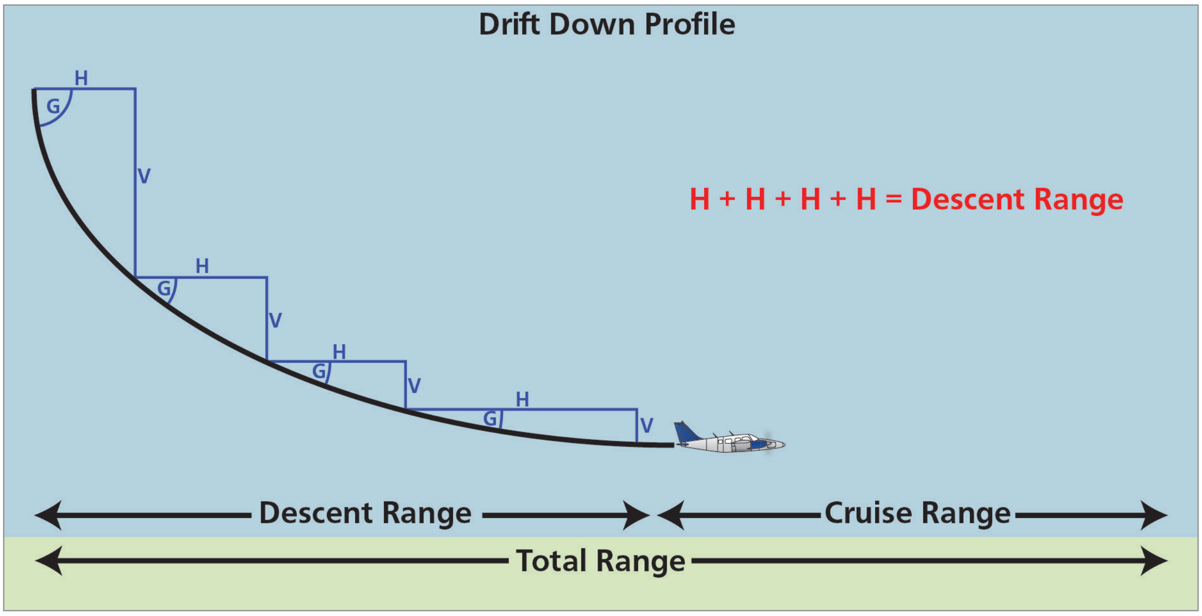


Figure 12.2 The drift down profile split into manageable segments for easy calculation of the descent range

Construction of the Drift Down Profile

It was stated that calculating the descent range for a twin-engine aeroplane after engine failure was complicated, and the reason, which is now hopefully apparent, is that the descent gradient or descent angle is constantly changing. In the absence of a drift down graph, the only feasible way of calculating the descent range is to break down the profile into manageable segments and carry out several calculations, as shown in *Figure 12.2*.

Each of these calculations will need the net descent gradient at that attitude and the vertical interval of that segment. This will give the horizontal distance covered for that segment. To find the descent range, simply add all the horizontal distances in all the segments. After the descent range has been calculated and the aeroplane is able to fly straight and level, the last thing to do is find out the one engine inoperative cruise range. Once this is known, it can be added to the descent range of the drift down profile to give the total range of the aeroplane following engine failure. Therefore, at any point along the flight there must be an airfield at which a landing can be made within the range of the aeroplane after engine failure. To ensure this, a circle, whose radius is the total single-engine range, is drawn around each airfield between the departure and destination points. To comply with the regulations, the aeroplane track must fall inside these circles. In doing so the aeroplane will comply with EU-OPS which states that in the event of engine failure the aeroplane is capable of continuing flight to an aerodrome where a landing can be made.

Questions

1. **For a multi-engine Class B aeroplane, the en route phase extends from:**

   a. 1000 ft above the take-off surface to 1500 ft above the landing surface
   b. 1500 ft above the take-off surface to 1000 ft above the landing aerodrome level
   c. from the start of level flight to the end of level flight
   d. 50 ft above the take-off surface to 1500 ft above the landing aerodrome level

2. **Following engine failure in the cruise, what is the name given to the descent procedure from the cruise altitude to the one engine inoperative ceiling?**

   a. Descent profile
   b. Descent procedure
   c. Drift down
   d. Emergency descent

3. **Why does the descent profile of the drift down procedure steadily become shallower?**

   a. As density increases, the remaining engine generates more thrust
   b. Drag starts to decrease towards the end of the drift down procedure
   c. Weight apparent thrust decreases with increasing density
   d. The increase in gravitational acceleration causes the weight apparent thrust to increase

4. **Which of the statements below correctly describes the en route requirements for a multi-engine Class B aeroplane?**

   a. In the event of engine failure, the aeroplane is capable of reaching a place at which a safe forced landing can be made
   b. In the event of the failure of one engine, the aeroplane is capable of continuing flight to an aerodrome
   c. The aeroplane must not be operated unless a landing into safe forced landing areas can be made
   d. The aeroplane cannot operate above an altitude where the rate of climb is less than 300 ft/min

5. **Following engine failure in a multi-engine Class B aeroplane at cruise altitude, why is the aeroplane forced to descend?**

   a. There is insufficient oxygen at high altitude to support the passengers
   b. Drag increases so that it exceeds the thrust available
   c. The one engine inoperative ceiling is lower than the two engine operative ceiling
   d. There is insufficient thrust to balance drag

6. **For a multi-engine Class B aeroplane, following engine failure, what speed should be used during the descent to the one engine inoperative ceiling?**

   a. V_{MD}
   b. V_{MP}
   c. $1.32V_{MD}$
   d. V_X

Answers

1	2	3	4	5	6
b	c	a	b	d	a

Chapter

13

Multi-engine Class B - Landing

Landing Requirements

This chapter will focus on the multi-engine Class B performance requirements for the landing stage of flight. There are two main regulation requirements.

1) The first requirement is that the landing distance must not exceed the landing distance available. In other words, the aeroplane must be able to land within the length of the runway. This requirement can be called the landing distance requirement.

2) The second requirement is that should the aeroplane be unable to land, it must be able to climb away from the aerodrome with an adequate climb gradient. This latter requirement can be called the landing climb requirement.

As with other regulations we have dealt with, the requirements relevant to the landing of multi-engine Class B aeroplanes can be found in CAP 698. However, caution must be exercised since CAP 698 contains very abbreviated versions of the requirements and therefore may be misleading. CAP 698 is, after all, supposed to contain supplementary information for examination purposes only.

Landing Climb Requirements / Gradient Requirement

If, for whatever reason, a landing was not possible, then the aeroplane should have a level of performance that would enable it to climb safely away from the airfield. This must be possible with either both engines operating or with one engine inoperative.

The landing climb requirements originate from the certification specification rules in CS-23 but are adopted in a brief format into EU-OPS 1. EU-OPS 1 divides the landing climb requirements into all engines operating and one engine inoperative. You can find these requirements in *CAP 698 at the bottom of page 17 and the top of page 18 of section 3* so you do not need to commit these requirements to memory.

All Engines Operating / Baulked Landing Requirement

With all engines operating, the steady gradient of climb must be at least 2.5%. This gradient must be achieved with:

- The power developed 8 seconds after moving the power controls to the take-off position.
- The landing gear (undercarriage) extended.
- Flaps at the landing setting.
- Climb speed equal to V_{REF}.

Note: In order to demonstrate this climb capability for certification and for operational purposes, the undercarriage is assumed to be extended and the wing flaps in the landing position.

One Engine Inoperative / Missed Approach Requirements

With the critical engine inoperative, the gradient of climb must not be less than 0.75% at an altitude of 1500 ft above the landing surface. This gradient must be achieved with:

- the critical engine inoperative and the propeller feathered
- the live engine set at maximum continuous power
- the landing gear (undercarriage) retracted
- the flaps retracted
- climb speed not less than $1.2V_{S1}$

Notice this time that in order to demonstrate this climb capability for certification and for operational purposes, the undercarriage and wing flaps are assumed to be retracted. The reason that the critical engine inoperative gradient requirement is much less than the all engine climb gradient requirement and that the aeroplane configuration is cleaner is because the failure of the critical engine results in an approximate 75% loss of climb gradient. Setting too high a level of regulation would impact on the operational capability of the aeroplane in terms of its payload because if the aeroplane is unable to attain these gradients, then the weight of the aeroplane must be reduced to an amount which can allow the gradient requirements to be met.

The term used to describe the maximum mass that can be carried and still attain the minimum gradient is called the **Landing Climb Limit Mass**.

The climb gradient requirements mentioned here are specific to aeroplanes in the normal, utility and aerobatic category of more than 2722 kg and therefore only represent a portion of the requirements for multi-engine Class B aeroplanes.

An example of a landing climb performance graph is on *page 19 of section 3 in CAP 698*. This graph is for the baulked landing, in other words an all engine full power go-around. However, notice that the graph only gives you a rate of climb. Therefore, in order to know if the aeroplane is achieving the minimum required gradient of 2.5% you must convert the rate of the climb into a gradient. An example of such a calculation is shown for you at the bottom of *page 18 of section 3 in CAP 698*.

Landing Distance Requirements EU-OPS 1.550

The landing distance requirements for multi-engine Class B aircraft are the same as for single-engine aircraft (see Chapter 10). You can see these requirements in *CAP 698 in the middle of page 17 of section 3.*

EU-OPS 1.550 states that an operator must ensure that the landing mass of the aeroplane, for the estimated time of arrival, allows a full stop landing from 50 ft above the threshold within 70% of the landing distance available at the destination aerodrome and at any alternate aerodrome.

This means that the aeroplane must be able to land within 70% of the landing distance available. The factor to use for such calculations is 1.43.

Factors to Be Accounted for

The regulations in CS-23 state that when calculating the gross landing distance, certain details must be accounted for. These are listed below.

The gross landing distance shall take account of:

- the pressure altitude at the aerodrome
- standard temperature
- the runway surface conditions and the type of runway surface
- the runway slope
- not more than 50% of the reported headwind component or not less than 150% of the reported tailwind component
- the despatch rules for scheduled or planned landing calculations EU-OPS 1.550 (c).

Correction Factors

Having discussed the regulation requirements detailing the maximum landing distance that must be available at a destination airfield or alternate airfield, we will now examine in detail the regulations governing how the gross landing distance is calculated given non-standard conditions like grass runways, wet runways and sloping runways.

Grass

In *CAP 698 section 3, in the middle of page 17 under point (b),* we read that if the runway is of grass up to 20 cm high on firm soil, the landing distance should be multiplied by a factor of 1.15. This would increase the landing distance by 15%.

Wet

Point (c) states that if there is an indication that the runway may be wet at the estimated time of arrival, the landing distance should be multiplied by a factor of 1.15. Again, multiplying the calculated landing distance by a factor of 1.15 will increase the landing distance by 15%. If the aeroplane manual gives additional information on landing on wet runways, this may be used even if it gives a lesser distance than that from the above paragraph.

Slope

Point (d) states that the landing distance should be increased by 5% for each 1% downslope. This means that for a 1% downslope the landing distance should be multiplied by a factor of 1.05. Therefore for a 2% downslope the factor would be 1.1. Point (d) also states that no allowance is permitted for upslope. The reason for this is that upslope will reduce the landing distance. If a pilot were to ignore the reduction in the landing distance then a margin of safety would be incorporated into the landing distance calculation.

Despatch Rules

Lastly, point (e) states that there must be compliance with the despatch rules for scheduled or planned landing calculations and that these can be found in EU-OPS 1.550 (c). The despatch rules, found in EU-OPS 1.550 (c), state that for despatching an aeroplane, it must be assumed that:

1) the aeroplane will land on the most favourable runway at the destination airfield in still air, and

2) the aeroplane will land on the runway most likely to be assigned considering the probable wind speed and direction.

If this second assumption cannot be met, the aeroplane may be despatched only if an alternate aerodrome is designated at which full compliance of the regulatory despatch requirements can be met.

Reference Landing Speed (V_{REF})

You may recall that the regulatory speed at the landing screen height is called V_{REF}, and for a single-engine Class B aeroplane it had to be no less than 1.3 times the stall speed in the landing configuration, ($1.3V_{S0}$). A multi-engine aeroplane must also be above V_{MCL} during the approach and landing phase to ensure that the aeroplane has sufficient rudder and aileron authority to maintain directional and lateral control. A pilot must adhere to the V_{REF} speeds because they are the speeds which have been used to construct the landing graphs or table in the aeroplane flight manual. If a pilot were to deviate from these speeds, the required aircraft performance would not be achieved.

Presentation of Landing Data / Using the Graphs

This part of the chapter will deal with how the aeroplane's landing distance can actually be calculated. All aeroplanes will have either a pilot operating handbook or an aeroplane flight manual. The purpose of these manuals is not only to show how to operate the aeroplane but also to detail the aeroplane's performance.

The example graph we will use is *Figure 3.9 on page 21 of section 3 in CAP 698*. Always take a look at the associated conditions first, paying particular attention to the power and flap settings as shown at the top of the graph. Also notice that this graph assumes a runway which is paved, level and dry. If the runway conditions required for a given calculation are different to those specified, corrections will need to be made to the values that this graph will give. We saw these correction factors earlier.

The left hand carpet of the graph involves the variations in temperature and pressure altitude. This part of the graph accounts for the effect of air density on the landing distance. The middle carpet accounts for the effect of the mass and to the right of this carpet is the wind correction carpet. Notice the differences in the slope of the headwind and tailwind lines. This means the 150% and 50% wind rules have been applied. The last carpet on the far right of the graph is used because you will recall that the landing starts at a height of 50 ft above the landing surface. If you travel straight through the last carpet, you will only calculate the landing roll, which in the example on the graph is 1120 ft.

Follow through the example that has been carried out for you in the graph. This will help you to use the graph correctly. Not only is there an example on the graph itself, but if you look at the bottom of *page 20 of section 3 in CAP 698* you will see another example which you can work through. Use the examples; they are there to help you. If you need practice on working through the graphs, use the questions at the end of the chapter.

Questions

1. **The landing distance available at an aerodrome is 2500 ft. For a Class B aircraft, what distance should be used in the landing distance graph to obtain the maximum permissible landing weight, if the runway has a paved wet surface with a 1% downhill slope?**

   a. Approximately : 1665 ft
   b. Approximately : 1447 ft
   c. Approximately : 1748 ft
   d. Approximately : 2500 ft

2. **A runway is contaminated with 0.5 cm of wet snow. Nevertheless, the flight manual of a light twin authorizes a landing in these conditions. The landing distance will be, in relation to that for a dry runway:**

   a. reduced
   b. substantially decreased
   c. increased
   d. unchanged

3. **For this question use Performance Manual CAP 698 MEP1 Figure 3.9.**

   With regard to the normal landing chart for the multi-engine aeroplane determine the landing distance from a height of 50 ft.

   Given:

   OAT: 30°C
   Pressure altitude: 0 ft
   Aeroplane mass: 4500 lb
   Headwind component: 10 kt
   Flaps: 40°
   Runway: paved, level and dry

   a. approximately : 1300 ft
   b. approximately : 2050 ft
   c. approximately : 2395 ft
   d. approximately : 2475 ft

4. **For this question use Performance Manual CAP 698 MEP1 Figure 3.9.**

   With regard to the graph for normal landing performance, what is the maximum allowable landing mass in order to comply with the landing regulations?

   Given:
   Runway length (unfactored): 3718 ft
   Runway elevation: 4000 ft
   Weather: assume ISA conditions
   Runway: paved, level and dry
   Headwind component: 4 kt

   a. approximately : 4000 lb
   b. approximately : 3500 lb
   c. approximately : 4500 lb
   d. approximately : 3600 lb

5. **At an aerodrome, the landing distance available is 3700 ft. For a multi-engine Class B aircraft, what must be the actual landing distance in order to comply with the landing regulations?**

a. 5291 ft
b. 2587 ft
c. 2249 ft
d. 3700 ft

6. **By what factor must the landing distance available for a multi-engine Class B aeroplane be divided in order to find the maximum allowable landing distance?**

a. 0.70
b. 1.67
c. 1.43
d. 0.60

7. **The landing field length required for multi-engine Class B aeroplanes at the alternate and destination aerodromes is the demonstrated or actual landing distance plus:**

a. 92%
b. 43%
c. 70%
d. 67%

8. **The landing climb requirements state that the all engines operating climb gradient for a multi-engine Class B aeroplane, in the event of a baulked landing, must be at least:**

a. 0.75%
b. 2.7%
c. 4%
d. 2.5%

Answers

1	2	3	4	5	6	7	8
b	c	d	a	b	c	b	d

Chapter

14

Class A Aircraft - Take-off

Introduction

The specimen aeroplane used for Class A performance is the Boeing 737-400 series. Just to remind you, Class A aeroplanes are defined as being any multi-engine jet, or any turbo-propeller aeroplane with a mass of more than 5700 kilograms OR 10 seats or more.

Because of the high passenger capacity and high speed of these aeroplanes, they must have the highest safety standards. Safety standards are enforced in two ways. Firstly by the certification requirements, which are laid down in CS-25, and secondly by the operational requirements which are laid down in EU-OPS 1. The operational requirements have one unique detail regarding Class A aeroplanes that is very different when compared to Class B aeroplanes. This difference is that the requirements state that for Class A aeroplanes engine failure must be considered for all stages of flight, whereas for multi-engine Class B aeroplanes, engine failure was not assumed below 300 ft. Assuming engine failure for Class A aeroplanes adds an extra dimension to understanding and assessment of the aeroplane's performance. Because of this, a lot of new terms and concepts will be introduced which you will need to become very familiar with before a full appreciation can be made of Class A aeroplane performance.

Operational Requirements

However, before we detail these new terms and concepts, let us examine what the operational requirements are. EU-OPS 1.490 states that an operator must ensure the take-off mass does not exceed the maximum take-off mass as published in the aeroplane flight manual. When calculating the maximum take-off mass, the accelerate-stop distance must not exceed the accelerate-stop distance available, the take-off distance must not exceed the take-off distance available, and lastly the take-off run must not exceed the take-off run available. To comply with the regulations we must use a single V_1 speed, which will be examined later, and account must be taken of the aerodrome conditions. To determine the maximum permissible mass for take-off it is necessary to consider the limits set by:

- the aerodrome distances available (Field Limit Mass)
- the climb requirements (Climb Limit Mass)
- obstacle clearance (Obstacle Limit Mass)
- brake energy limitations (V_{MBE})
- tyre speed limitations (Tyre Speed Limit Mass)
- runway strength limitation (ACN/PCN)
- maximum structural mass

Field Length Requirements

Next it is important to find out how the take-off run, take-off distance and accelerate-stop distance are calculated and what safety margins the authorities have included. In other words, how the net distances are worked out. These distances are defined in CS-25 and cover the cases of take-off with all engines operating and take-off with engine failure, for both dry and wet runways. You can see abbreviated versions of these requirements in *CAP 698 on page 7 of section 4 under paragraph 2.1.2*. Do not try and commit these requirements to memory; CAP 698 explains the requirements quite suitably and they are listed over the page and in CAP 698.

Net Take-off Run Required

If the take-off distance includes a clearway, the take-off run is the greatest of:

- **All power units operating (dry and wet runway).** The total of the gross distance from the start of the take-off run to the point at which V_{LOF} is reached, plus one half of the gross distance from V_{LOF} to the point at which the aeroplane reaches 35 ft, all factored by 1.15 to obtain the net TORR.

  As an example, let us assume the distance from brake release to halfway between V_{LOF} and 35 ft is 1747 metres. This is then multiplied by 1.15. Multiplying 1747 metres by 1.15 makes the total distance 2009 metres.

- **One power unit inoperative (dry runway).** The horizontal distance from the brake release point (BRP) to a point equidistant between V_{LOF} and the point at which the aeroplane reaches 35 ft with the critical power unit inoperative.

  As an example, let us assume that this distance is 1950 metres.

- **One power unit inoperative (wet runway).** The horizontal distance from the brake release point (BRP) to the point at which the aeroplane is 15 ft above the take-off surface, achieved in a manner consistent with the attainment of V_2 by 35 ft, assuming the critical power unit inoperative at V_{EF}.

  Lastly, as an example, let us assume that this distance is 2001 metres

Once these three distances have been calculated by the manufacturer, the greatest of the three is then published as the certified net take-off run required. In our example, the net take-off run required is 2009 metres. In the exam you will be presented with various distances and you must be able to work out which of the distances is selected as the net take-off run required.

Net Accelerate-stop Distance Required

The accelerate-stop distance on a wet runway is the greatest of:

- **All engines operating**. The sum of the distances required to accelerate from BRP to the highest speed reached during the rejected take-off, assuming the pilot takes the first action to reject the take-off at the V_1 for take-off from a wet runway and to decelerate to a full stop on a wet hard surface, plus a distance equivalent to 2 seconds at the V_1 for take-off from a wet runway.

- **One engine inoperative**. The sum of the distances required to accelerate from BRP to the highest speed reached during the rejected take-off, assuming the critical engine fails at V_{EF} and the pilot takes the first action to reject the take-off at the V_1 for take-off from a wet runway with all engines operating and to decelerate to a full stop on a wet hard surface with one engine inoperative, plus a distance equivalent to 2 seconds at the V_1 for take-off from a wet runway.

- **The accelerate-stop distance on a dry runway.**

Net Take-off Distance Required
The take-off distance required is the greatest of the following three distances:

- **All engines operating.** The horizontal distance travelled, with all engines operating, to reach a screen height of 35 ft multiplied by 1.15

- **One engine inoperative (dry runway).** The horizontal distance from BRP to the point at which the aeroplane attains 35 ft, assuming the critical power unit fails at V_{EF} on a dry, hard surface.

- **One engine inoperative (wet runway).** The horizontal distance from BRP to the point at which the aeroplane attains 15 ft, assuming the critical power unit fails at V_{EF} on a wet or contaminated hard surface, achieved in a manner consistent with the achievement of V_2 by 35 ft.

Note: The reduction of the screen height from 35 ft to 15 ft is to help reduce the take-off mass penalties that a wet runway will undoubtedly cause.

The V Speeds

V_{MCG} - Ground Minimum Control Speed
V_{MCG} is short for the ground minimum control speed, and it is described for you in *CAP 698 at the bottom of page 3 section 4*. It states V_{MCG} is the minimum speed on the ground at which the take-off can be safely continued, when the critical engine suddenly becomes inoperative with the remaining engine(s) at take-off thrust. Let us try and understand what this actually means.

When an engine fails, the remaining engine(s) still generates thrust and this causes the aeroplane to yaw away from the live engine. The amount of yaw is a function of the amount of thrust the live engine is generating. Greater thrust from the live engine would generate more yaw. The only way to counteract this is to use the ailerons and the rudder to try and steer the aeroplane in the right direction. However, when the aeroplane is on the ground, you cannot use the ailerons to control the yaw otherwise you might bank the wing into the ground. Therefore the only available aerodynamic surface left to control the asymmetric yaw is the rudder. However, for the rudder to be effective enough at controlling the yaw, there must be sufficient airflow over it to ensure it has the required aerodynamic force. This minimum airflow speed over the rudder is V_{MCG}. If the engine were to fail below this speed, then there is insufficient flow over the rudder to counteract the asymmetric yaw and therefore it is not possible to continue the take-off.

The only factor that controls the value of V_{MCG} is thrust, and since take-off thrust is more or less constant, then the only variable on the amount of take-off thrust generated is air density. The higher the air density, the more thrust that can be generated and therefore the more yaw that is generated when the engine fails, therefore the airflow over the rudder must be faster to make the rudder effective enough to counteract the yaw.

The effect of air density on V_{MCG} can be seen by looking at the second table from the bottom on *pages 18 and 19 of section 4 in CAP 698*. This table shows the variable of temperature on one side and the variable of pressure altitude on the other. Look at the V_{MCG} in the table and notice that at low temperatures and low pressure altitudes where the air density would be high, the value of V_{MCG} is also high. Therefore we can say that as density increases, V_{MCG} increases.

V_{EF}

The calibrated airspeed at which the critical engine is assumed to fail. It is used for the purpose of performance calculations. It is never less than V_{MCG}.

The speed V_{EF} is a rather strange one. As per the certification specification definition, V_{EF} means the speed at which the critical engine is assumed to fail during take-off. V_{EF} is selected by the aeroplane manufacture for purposes of certification testing, primarily to establish the range of speeds from which V_1 may be selected and secondly to help determine the accelerate-stop distance required. Lets us try and explain what V_{EF} is all about.

The definition of V_1 is the speed at which, if the failure of the critical engine was recognized, there is sufficient distance remaining to either reject the take-off or continue the take-off. However, recognizing that the engine has failed does take time, in fact it takes about 1 second. Therefore to recognize the engine failure at V_1, the engine must have failed about 1 second before V_1. The speed, at which the critical engine fails, so that it may be recognized at V_1, is called V_{EF} .

V_1 - Decision Speed

This is by far the most important speed in the take-off for Class A aeroplanes. V_1 is called the decision speed. It is so called because V_1 determines the outcome of a critical decision that must be made following an engine failure or other major critical systems failure.

V_1 is defined as being the maximum speed at which the pilot must take the first action in order to stop the aeroplane within the remaining accelerate-stop distance. V_1 is also the minimum speed following engine failure that the pilot is able to continue the take-off within the remaining take-off distance.

V_{GO} is the lowest decision speed from which a continued take-off is possible within the take-off distance available. V_{STOP} is the highest decision speed from which the aeroplane can stop within the accelerate-stop distance available. These two speeds are the extremes of V_1.

There are some rules about the speed for V_1. These are shown in *CAP 698 on page 2 of section 4* alongside the V_1 definition. It states that V_1:

- may not be less than V_{EF} plus the speed gained with the critical engine inoperative for the time between engine failure and the point at which the pilot applies the first means of retardation
- must not exceed V_R
- must not exceed V_{MBE}
- must not be less than V_{MCG}

If the engine were to fail before V_1, then the decision would be to abort the take-off. The reason is because, with only one engine operating, there would be insufficient take-off distance left to accelerate the aeroplane to the screen height. If the engine were to fail after V_1, the decision is to continue the take-off. The reason is because the aeroplane is travelling too fast to be able to stop within the remaining accelerate-stop distance available. In order to understand how V_1 is derived, we need to consider a graph which is shown in *Figure 14.1*. This graph plots the take-off distance required and accelerate-stop distance required based on a varying engine failure speed.

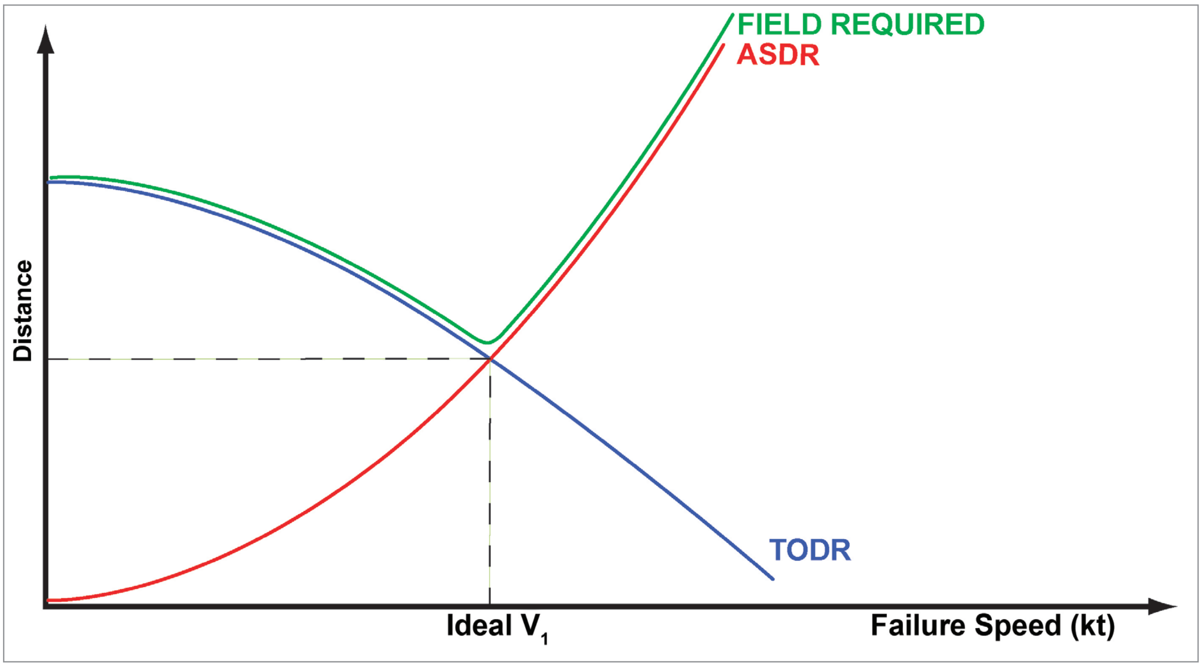


Figure 14.1 A graph showing the ideal position of V_1.

Looking at the graph you can see that a V_1 at the intersection point of the graph is the best V_1 to use, simply because a V_1 at that speed requires the least amount of field required or the least amount of runway. The V_1 at the intersection point of the curves is sometimes called the "Idealized V_1". It is also the V_1 which makes the take-off distance required be the same length as the accelerate-stop distance required, and therefore, this V_1 speed is also called the "Balanced V_1" since it balances the required distances for the aeroplane. What this graph is also useful for is to see the effect of using a higher or lower V_1.

For example, if for whatever reason V_1 was increased, notice that the accelerate-stop distance required increases, the take-off distance required decreases and the total field required increases. However, should V_1 be reduced from the intersection point, the accelerate-stop distance decreases, the take-off distance increases and the total field required increases. Trying to figure these points out without the use of this simple graph would not be easy. So use this graph to help you understand the effect of increasing or decreasing V_1.

Factors Affecting V_1

It is important to detail what factors can influence V_1. In essence, whatever factors change either the accelerate-stop distance required or the take-off distance required curves shown in *Figure 14.1*, will affect V_1. However, there is a simpler way to go through the list of factors affecting V_1. In every aeroplane flight manual there will be a set of tables and/or graphs which will allow you to calculate what V_1 should be on any given day. On *page 18 and 19 of section 4 in CAP 698* are such tables. Turn to page 18 and look at the second table from the top of the page where you see a column "A" and "B" etc. This table lists the three V speeds, including V_1 against the aeroplane mass. This table can show us what the effect of certain factors are.

- MASS For example, let us look at what aeroplane mass does to V_1. Look under column A and under V_1. If the aeroplane mass was 50 000 kg, V_1 would be 129 knots, but if the mass was increased to 65 000 kg then V_1 would increase to 151 knots. Therefore, increasing mass increases V_1.

- CONFIGURATION The next factor to affect V_1 is the aeroplane configuration. *Page 18* lists the V speeds for 5 degrees of flap and page 19 lists the V speeds with 15 degrees of flap. Therefore, comparing the speeds from these two pages should tell us the effect of the flaps. On *page 18*, which is 5 degrees of flap and using column A again, a 55 000 kg mass requires a V_1 speed of 137 knots, but on page 19, which is 15 degrees of flap and for the same mass of 55 000 kg, the V_1 speed is now 130 knots. Therefore we can see that increasing the flap angle decreases V_1.

- DENSITY The next factor to affect V_1 is density, but this is a little harder to observe than the previous two factors. On *page 17 of section 4* is a small table, which has temperature on one axis and pressure altitude on the other. This is the density accountability table. Under low altitudes and low temperatures is band A. This is a high density band, whereas band F is situated at higher temperatures and higher altitudes which equates to much lower densities. We can now use these bands to see the effect density has on V_1. Returning to page 18, notice that bands A, B, C, D, E and F are in the speed tables. Taking a mass of 50 000 kg in band A, which is high density, V_1 is 129 knots, but in bands B, C, D and E, the value of V_1 is increasing. Therefore, as density falls, shown by going through bands A to E, V_1 increases.

- SLOPE AND WIND The last two factors that affect V_1 are runway slope and wind. Notice that at the *top of pages 18 and 19* there is a table which is titled "Slope and Wind V_1 adjustment". If there were a downslope of 2%, then with an aeroplane mass of 70 000 kg, V_1 would have to be reduced by 3 knots, whereas if the runway had an upslope of 2%, with the same mass, V_1 must be increased by 4 knots. Therefore, downslopes reduce V_1 and upslopes increase V_1. The right hand side of the table is the correction for wind. So, for example, if there was a 15 knot tailwind, then with a mass of 70 000 kg, V_1 would have to be reduced by 3 knots, whereas if there was a headwind of 40 knots for the same mass, V_1 would have to increase by 1 knot. Therefore, tailwinds reduce V_1, and headwinds increase V_1.

Having finished discussing the main factors affecting V_1, there are other influences, however, which may or may not change the value of V_1. Two influences on V_1 in particular are the speeds V_{MCG} and V_{MBE}. In *CAP 698 on page 2 of section 4* we see the definition of V_1, but more importantly, at the end of the paragraph we read that V_1 must not be less than V_{MCG}, and not greater than V_R and not greater than V_{MBE}. Since V_1 must be between V_{MCG}, V_R and V_{MBE}, then depending on the values of these speeds, they may or may not push V_1 to be higher or lower than the ideal V_1 speed.

V_{MBE} - Maximum Brake Energy Speed

We stated that there were two particular speeds that can influence V_1. One of them was V_{MCG}, which we discussed earlier, the other was V_{MBE}. Turning back to the top of *page 3 of section 4 of CAP 698* you can see the description of V_{MBE}. V_{MBE} is the maximum brake energy speed and it represents the maximum speed on the ground from which an aeroplane can safely stop within the energy capabilities of the brakes. Essentially this means that if the take-off was rejected at a speed higher than V_{MBE}, and maximum braking force was applied, the brakes would not be able to safely bring the aeroplane to a stop regardless of how much runway was left. The brakes would most probably catch fire, melt and/or disintegrate.

You do need to be aware of the factors that control V_{MBE}, but luckily, most manuals, and indeed *CAP 698* has a V_{MBE} graph or table with all the variables and factors on it that can affect V_{MBE}. The graph concerned is on *page 15 of section 4*. If you need to see the effect of a variable, for example, mass, simply work through the graph but use two different masses. In this case the heavier mass has reduced V_{MBE}. The variables that affect V_{MBE} are pressure altitude, ambient air temperature, mass, slope and wind. Carefully examine each of these factors so you can see for yourself how they change V_{MBE}. Remember, *CAP 698* is for use in the exam, so if there are any questions which relate to V_{MBE}, you can rest assured that a lot of information on V_{MBE} is already in front of you.

The relationship between V_{MCG}, V_1 and V_{MBE}

Having looked at V_{MBE} and V_{MCG} we are now better placed to understand why these two speeds play a role in influencing V_1. According to the rule, V_1 must not be less than V_{MCG}, as shown in *Figure 14.2*.

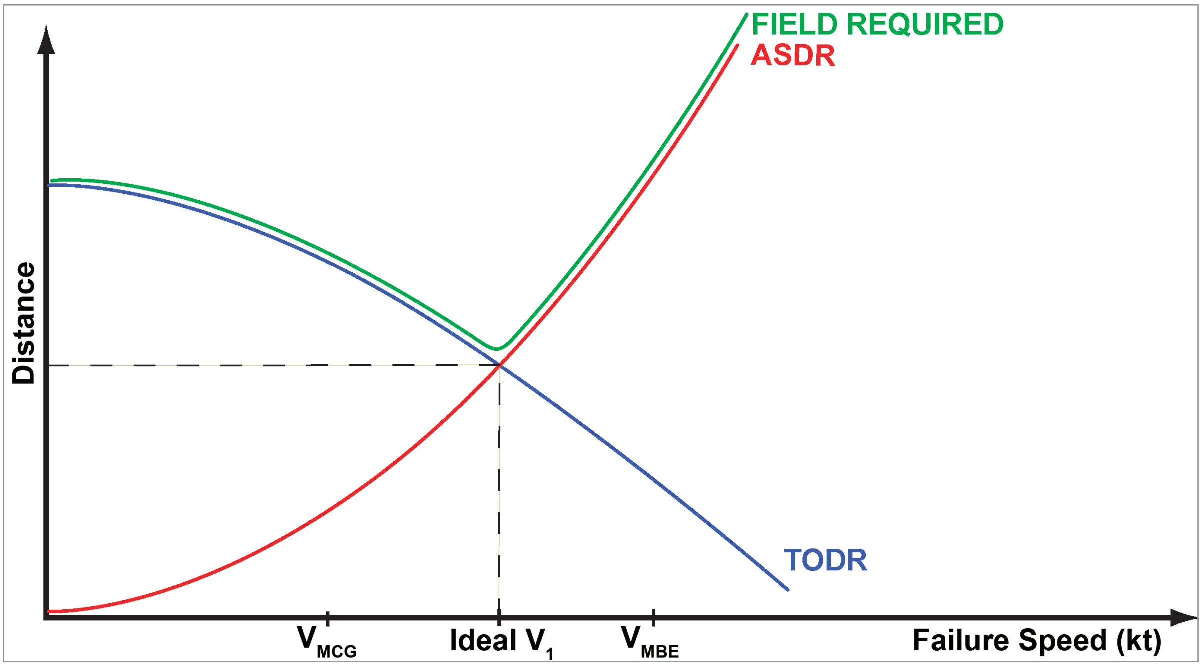


Figure 14.2 The relationship of V_1 with V_{MCG} and V_{MBE}.

V_1 cannot be allowed to be less than V_{MCG} because engine failure below V_{MCG} means the aeroplane is uncontrollable and the definition of V_1 is that the take-off can be continued following engine failure.

The rule also stated that V_1 must not be greater than V_{MBE}. Again, this makes sense, because at V_1 the aeroplane must be able to stop or continue the take-off, but above V_{MBE} it is impossible to bring the aeroplane safely to a stop.

Let us look at a scenario, where due to high density the value of V_{MCG} is higher than the idealized V_1. In this case, take-off is prohibited. However, this problem is solvable. The chosen V_1 can simply be increased until it is equal to or more than V_{MCG}. However, notice that the accelerate-stop distance increases, the take-off distance decreases and more importantly, the total field length required increases. So long as the runway is as long as the total field required, then moving V_1 to this point is not a problem. Hopefully, by understanding this graph you are able to see the consequences to the required distance should V_1 need to be moved from its ideal or balanced position due to pressure from V_{MCG} and V_{MBE}.

V_{MU} - Minimum Unstick Speed

The speed V_{MU} is defined as the minimum unstick speed. V_{MU} is the slowest calibrated airspeed at which the aeroplane can safely lift off the ground, and continue the take-off. However, despite V_{MU} being the lowest speed the aeroplane can safely lift off the runway, in actual operating conditions, the aeroplane does not lift off at this speed. The aeroplane is flown so that it actually lifts off at a slightly faster speed. The reason is because V_{MU} is very close to the stall speed, the aeroplane controllability is very "sloppy", and lastly, in order to actually lift off at V_{MU} some fairly dramatic actions take place which may be uncomfortable for the passengers.

It may seem strange, but the aeroplane is actually able to lift off at a speed where lift is less than weight.

The reason being because, so long as the nose can be raised to a high enough attitude, there is a vertical component of thrust which, together with lift, balances weight. The amount of this vertical thrust is controlled in part by the amount of thrust generated, but also by the amount of nose-up attitude the aeroplane can attain. This nose-up attitude may be limited by the power of the elevator to push the tailplane down, or by the tailplane striking the runway in what is described as a tail strike.

Hopefully now you are able to realize why it is unwise in operational conditions to lift the aeroplane off the ground at V_{MU}. The actual speed the aeroplane will lift off, in operational flights, is called V_{LOF} and we will discuss this speed later.

V_{MCA} / V_{MC} - Air Minimum Control Speed

The air minimum control speed. The minimum flight speed at which the aeroplane is controllable, with a maximum of 5° bank, when the critical engine suddenly becomes inoperative with the remaining engine(s) at take-off thrust. Although V_{MCA} is the minimum control speed in the air, the factors that affect V_{MCA} can for the purpose of the exam, be assumed to be the same as for V_{MCG}.

V_R - Rotation Speed

Rotation speed, V_R, is the speed at which the pilot initiates action to raise the nose gear off the ground, with the intention of becoming airborne. The pilot action is to pull back on the control column. This action deflects the elevators to create a downward aerodynamic force. This force rotates the aeroplane about its lateral axis and will raise the nose wheel off the ground.

V_R may not be less than:

- V_1
- $1.05V_{MC}$
- a speed such that V_2 may be attained before 35 ft.
- a speed such that if the aeroplane is rotated at its maximum practicable rate the result will be a V_{LOF} of not less than $1.1V_{MU}$ (all engines operating) or $1.05V_{MU}$ (engine inoperative) [if the aeroplane is geometry limited or elevator power limited these margins are $1.08V_{MU}$ (all engines) and $1.04V_{MU}$ (engine inoperative)]

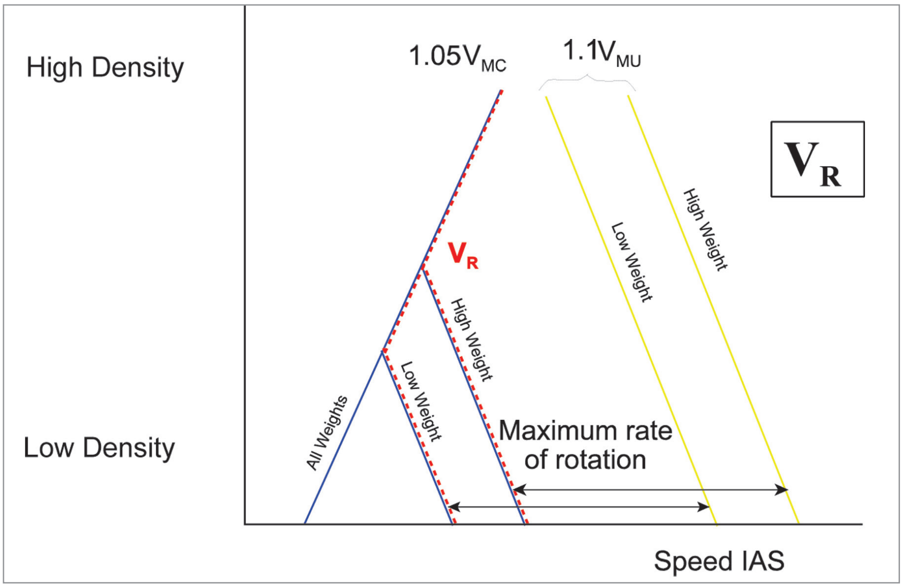


Figure 14.3

Lastly, as with other speeds, we need to examine the factors that affect V_R. However, this is made easy for you. As with V_1, all the factors that can affect V_R can be found by examining *pages 18 and 19 of section 4 in CAP 698*. On *pages 18 and 19* examine the second table from the top. This table lists the three V speeds, including V_R, against the aeroplane mass. This table can show us what the effect of certain factors is. For example, let us look at what aeroplane mass does to V_R.

If the aeroplane mass was 50 000 kg, V_R would be 131 knots under density column A, but if the mass was increased to 65 000 kg then V_R would increase to 155 knots. Therefore, increasing mass increases V_R.

The next factor to affect V_R is the aeroplane configuration. Page 18 lists the V speeds for 5 degrees flaps and page 19 lists the V speeds with 15 degrees of flap. Therefore, comparing the speeds from these two pages should tell us the effect of the flaps. On page 18, which is 5 degrees of flap, a 55 000 kg mass requires a V_R speed of 139 knots, but on page 19, which is 15 degrees of flap and for the same mass of 55 000 kg, the V_R speed is now 131 knots. Therefore we can see that increasing the flap angle decreases V_R.

The next factor to affect V_R is density. On *page 17 of section 4* is the density graph. You may recall that band A is a high density band, whereas band F equates to lower density. We can now use these bands to see the effect density has on V_R. Returning to page 18, taking a mass of 50 000 kg in band A, which is high density, V_R is 131 knots, but in bands B, C, D and E, the value of V_R is increasing. Therefore we can state that as density decreases, V_R increases.

In modern airliners, V_R is calculated not by looking at speed tables, but it will be computed by the aeroplane once the relevant data is inserted in the flight management computer or multipurpose computer display unit. Once V_1 and V_R have been calculated by the pilots, they can be entered into the Flight Management System and thereafter shown to the pilots in the speed scale on the left hand side of the Primary Flight Display (PFD) or Electronic Attitude Director Indicator (EADI).

Effects of early and over-rotation

If the aircraft is rotated to the correct attitude but at too low a speed, lift-off will not occur until the normal V_{LOF}, but there will be higher drag during the increased time in the rotated attitude, giving increased distance to lift-off. Rotation to an attitude greater than the normal lift-off attitude could bring the wing close to its ground stalling angle. Ground stall should not be possible with leading edge devices correctly set, so it is of extreme importance that these devices are set to the take-off position.

CS-25.107 requires:

- the take-off distance using a rotation speed of 5 knots less than V_R shall not exceed the take-off distance using the established V_R
- reasonable variations in procedures such as over-rotation and out of trim conditions must not result in marked increases in take-off distance.

Note: *The expression 'marked increase' in the take-off distance is defined as any amount in excess of 1% of the scheduled distance.*

V_{LOF} - Lift-off Speed

V_{LOF} means the lift-off speed. V_{LOF} is the calibrated airspeed at which the aeroplane first becomes airborne which is at the moment when the main wheels have left the runway. V_{LOF} should be faster than the minimum unstick speed V_{MU}. The margin above V_{MU} is determined by several factors.

For example, V_{LOF} must not be less than 110% of V_{MU} in the all engines operating condition and 105% of V_{MU} in the one engine inoperative condition. However, if the attitude of the aeroplane in obtaining V_{MU} was limited by the geometry of the aeroplane (i.e. tail contact with the runway), V_{LOF} must not be less than 108% of V_{MU} in the all engines operating condition and 104% of V_{MU} in the one engine inoperative condition.

Tyre Speed Limit

Aeroplane tyres are designed to carry very high loads and operate at very high speeds. It is common for a jet aeroplane tyre to carry loads as heavy as 27 000 kilograms while operating at ground speeds up to 235 miles per hour or ground speeds of 204 knots. Tyres are carefully designed and tested to withstand operation up to, but not necessarily beyond, these ratings.

V_{2MIN}

The minimum take-off safety speed, with the critical engine inoperative.

V_{2MIN} may not be less than:

- $1.13V_{SR}$ for 2 and 3 engine turboprops and all turbojets without provision for obtaining a significant reduction in the one engine inoperative power-on stalling speed OR $1.08V_{SR}$ for turboprops with more than 3 engines and turbojets with provision for obtaining a significant reduction in the one engine inoperative power-on stalling speed.
- $1.1V_{MC}$

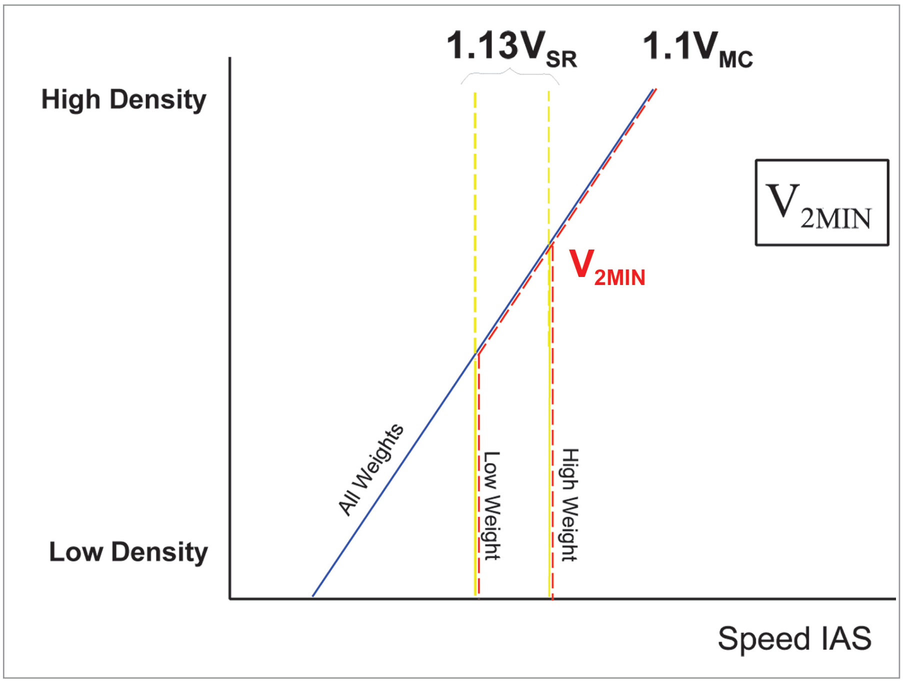


Figure 14.4

V_2 - Take-off Safety Speed

The speed V_2 is called the take-off safety speed. On *page 3 of section 4 of CAP 698* it states that V_2 is the target speed to be attained with one engine inoperative. In other words, V_2 must be reached at or prior to the screen height. Why is V_2 called the take-off safety speed, what is safe about reaching it?

There are two main speeds which when flying close to, may be unsafe. The first of these is stall speed and the second is the minimum control speed. Therefore, in order for V_2 to be called a safe speed it must be faster than these speeds. There is another reason why V_2 is called the take-off safety speed. In the event of engine failure, V_2 must be flown until the aeroplane reaches 400 ft. Therefore, the other safe feature about V_2 is that the aeroplane is able to achieve a positive climb. In fact, V_2 is the slowest speed which will enable the aeroplane to have sufficient excess thrust to climb above the minimum acceptable climb gradients.

V_2 may not be less than:

- V_{2MIN}
- V_R plus the speed increment attained up to 35 ft.

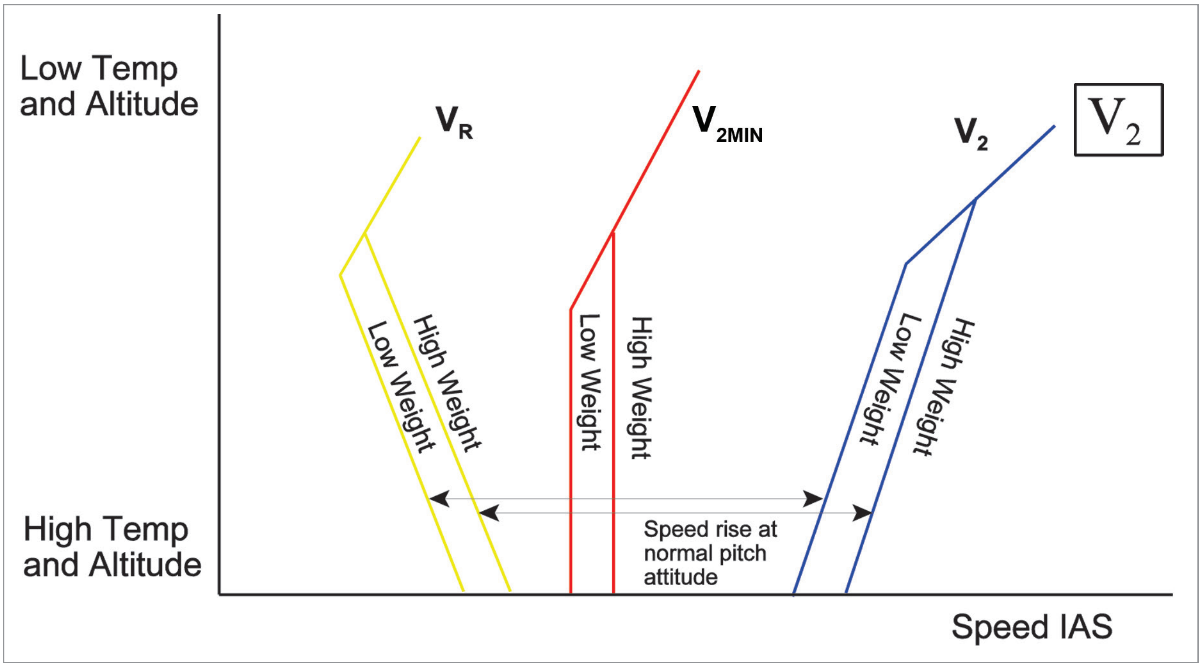


Figure 14.5

To analyse all the factors that can affect V_2 turn to *pages 18 and 19 of section 4 in CAP 698*. You will recall from similar discussions on V_1 and V_R that these pages can show the effect of mass, configuration and density on V_2. So ensure you can use these pages to see for yourself how these factors change V_2.

Once V_2 is calculated by the pilots it can be entered into the flight management computer just like V_1 and V_R were. Having done this, V_2 will be displayed to the pilots in the speed scale on the left hand side of the Primary Flight Display or Electronic Attitude Director Indicator.

V_3

The steady initial climb speed with all engines operating.

Presentation of Data

A complete analysis of take-off performance requires account to be taken of any stopway and clearway available. As this is time consuming and will often give a maximum permissible take-off mass in excess of that required, simplified data is often presented to permit a rapid assessment of the take-off mass. One method of doing this is to use balanced field data.

Balanced Field

A balanced field exists if the take-off distance is equal to the accelerate-stop distance. An aerodrome which has no stopway or clearway has a balanced field. For an aeroplane taking off, if an engine failure occurs, the later the engine fails, the greater will be the accelerate-stop distance required but the less will be the take-off distance required At some speed the two distances will be equal. *Figure 14.6* shows the variation of these distances graphically.

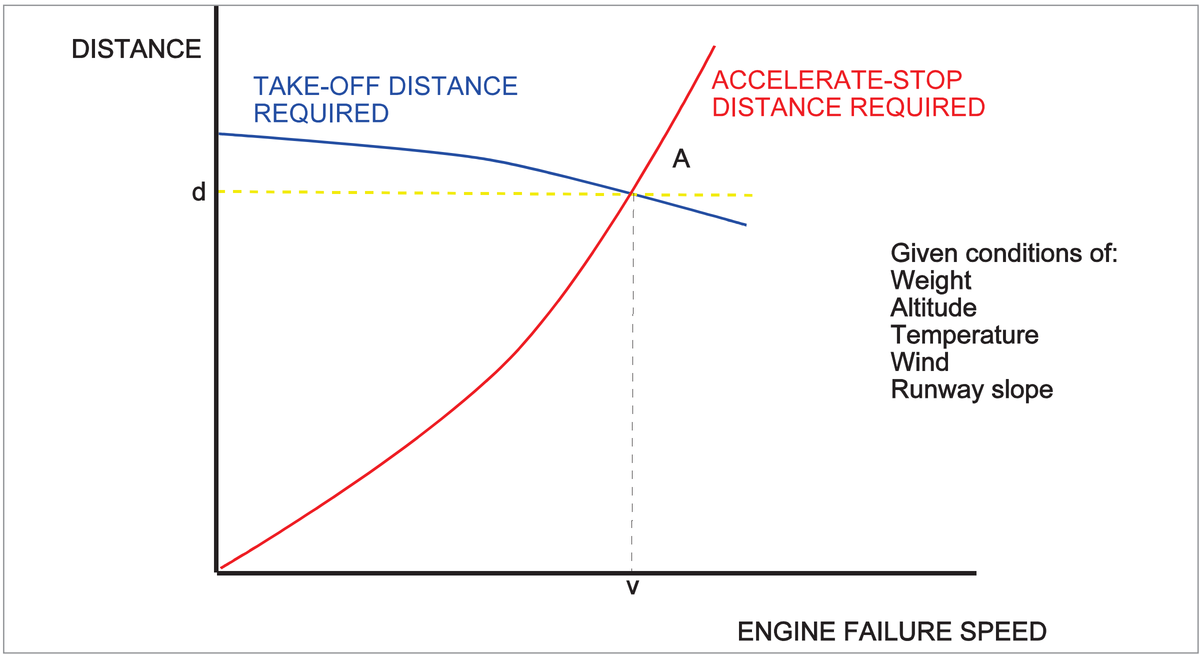


Figure 14.6

The distance, point A in *Figure 14.6*, is the balanced field length required for the prevailing conditions. It represents the maximum distance required for those conditions, because at whatever speed the engine fails, the distance is adequate, either to stop if the failure occurs before V_1 or to complete the take-off if the failure occurs after V_1.

Unbalanced Field

For a given weight and conditions, the balanced field V_1 will give the optimum performance, since the TODR and the ASDR are equal. In some circumstances, however, this V_1 will not be acceptable, as V_1 must lie within the limits of V_{MCG}, V_R and V_{MBE}. The following situations will give an unbalanced field:

- V_1 less than V_{MCG}

  At low weights and altitudes V_1 for the balanced field may be less than V_{MCG}. In this case V_1 would have to be increased to V_{MCG} and so the TODR would be less, and the ASDR would be greater than the balanced field length. The field length required would be equal to the ASDR at V_{MCG}.

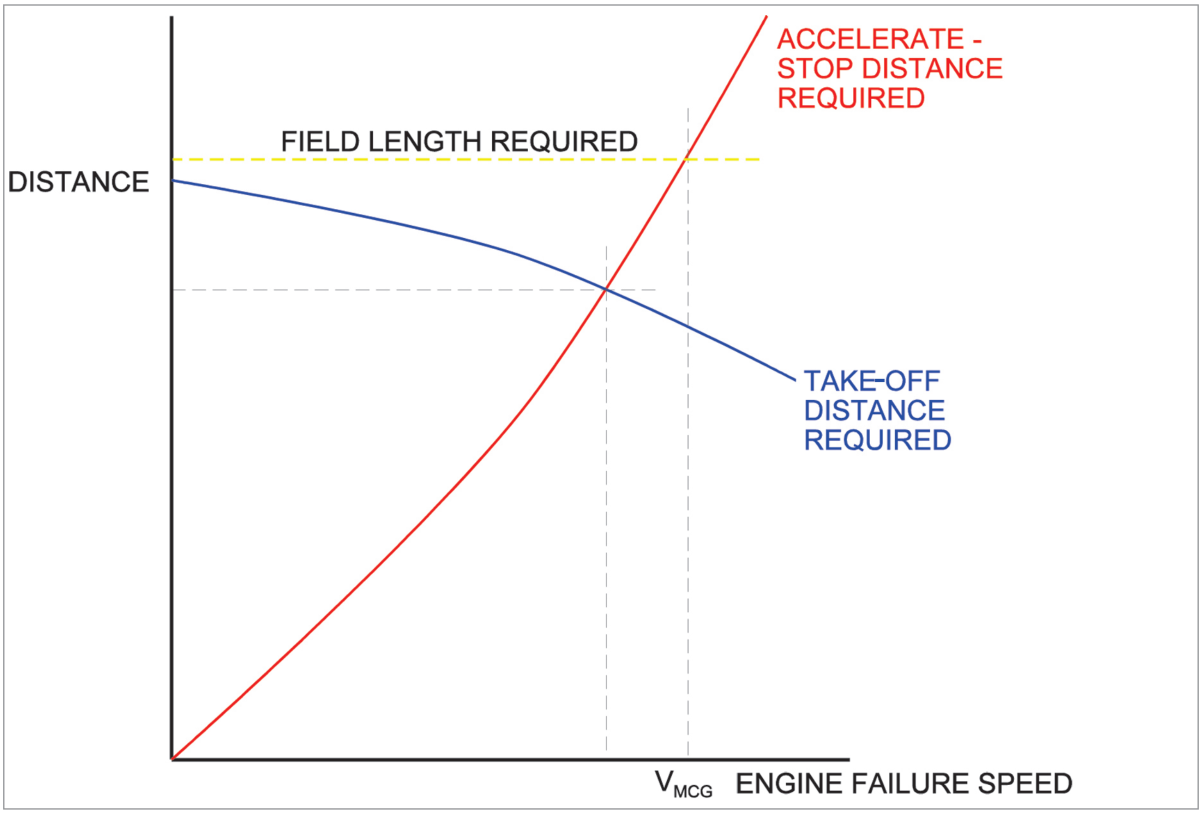


Figure 14.7

- V_1 greater than V_{MBE}

  At high weight, altitude and temperature, the balanced field V_1 may exceed the V_{MBE}. V_1 would have to be reduced to V_{MBE} giving a TODR greater, and an ASDR which is less, than the balanced field length. The field length required would be equal to the TODR at V_{MBE}.

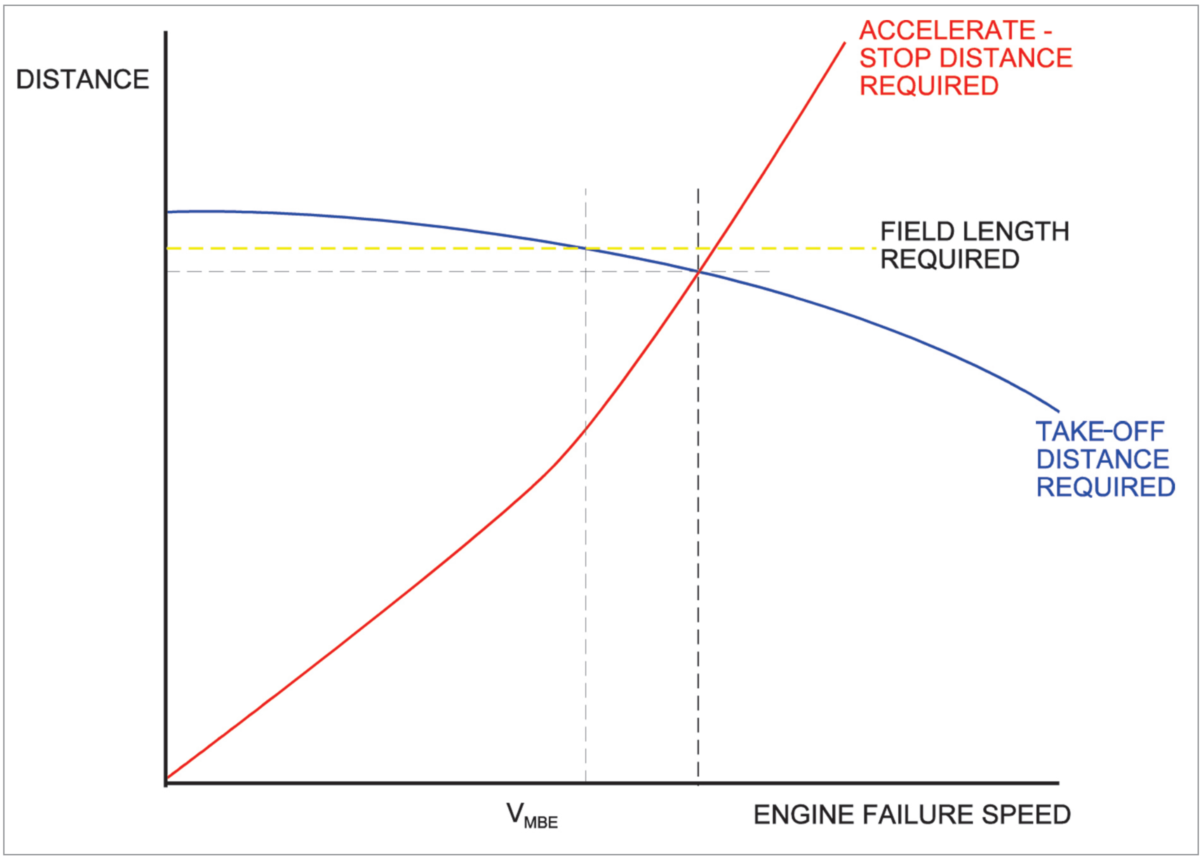


Figure 14.8

- V_1 greater than V_R

  For aircraft with good braking capabilities, the stopping distance will be short, giving a high balanced field V_1 speed. If this exceeds V_R for the weight, V_1 will have to be reduced to V_R and the field length required will be equal to the TODR at V_R.

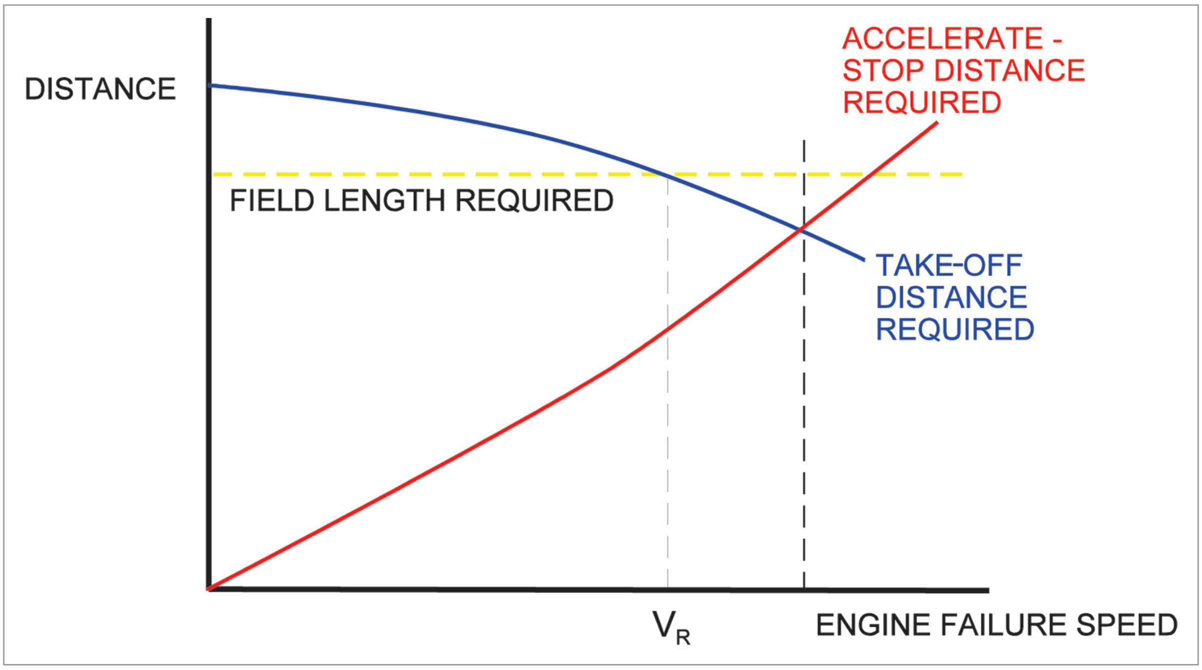


Figure 14.9

V_1 Range

If the balanced field available is greater than the balanced field required for the required take-off mass and conditions, there will be a range of speed within which V_1 can be chosen. This situation is illustrated in *Figure 14.10*.

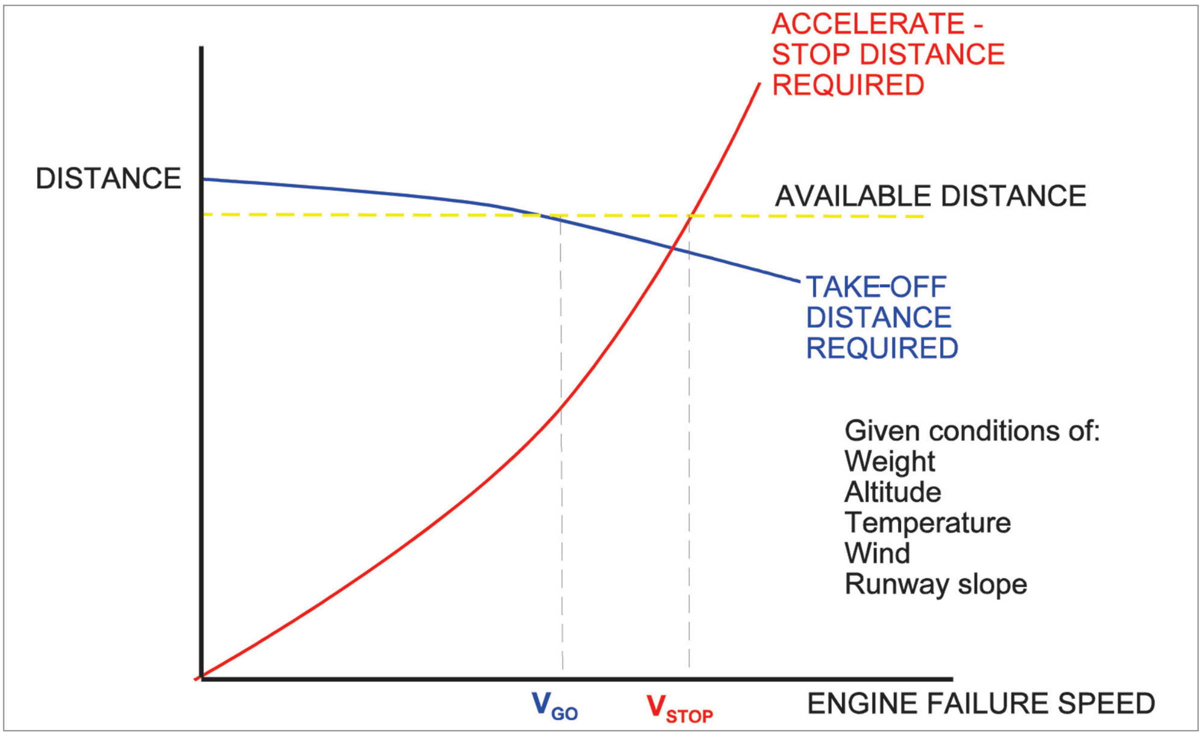


Figure 14.10

V_{GO} is the first speed at which the take-off can be completed within the distance available, and V_{STOP} is the last speed at which the accelerate-stop could be completed within the distance. The V_1 speed can therefore be chosen anywhere between V_{GO} and V_{STOP}.

Take-off from an Unbalanced Field

If the take-off aerodrome is not a balanced field, the balanced field data can be used by assuming a balanced field equal to the lesser of the Take-off Distance Available and the Accelerate-stop Distance Available. This distance may exceed the Take-off Run Available unless the TORA becomes limiting. The take-off mass obtained will of course be less than that which could have been obtained by taking account of stopway and clearway, but if the mass is sufficient for the flight, it will not be necessary to go into a more detailed analysis.

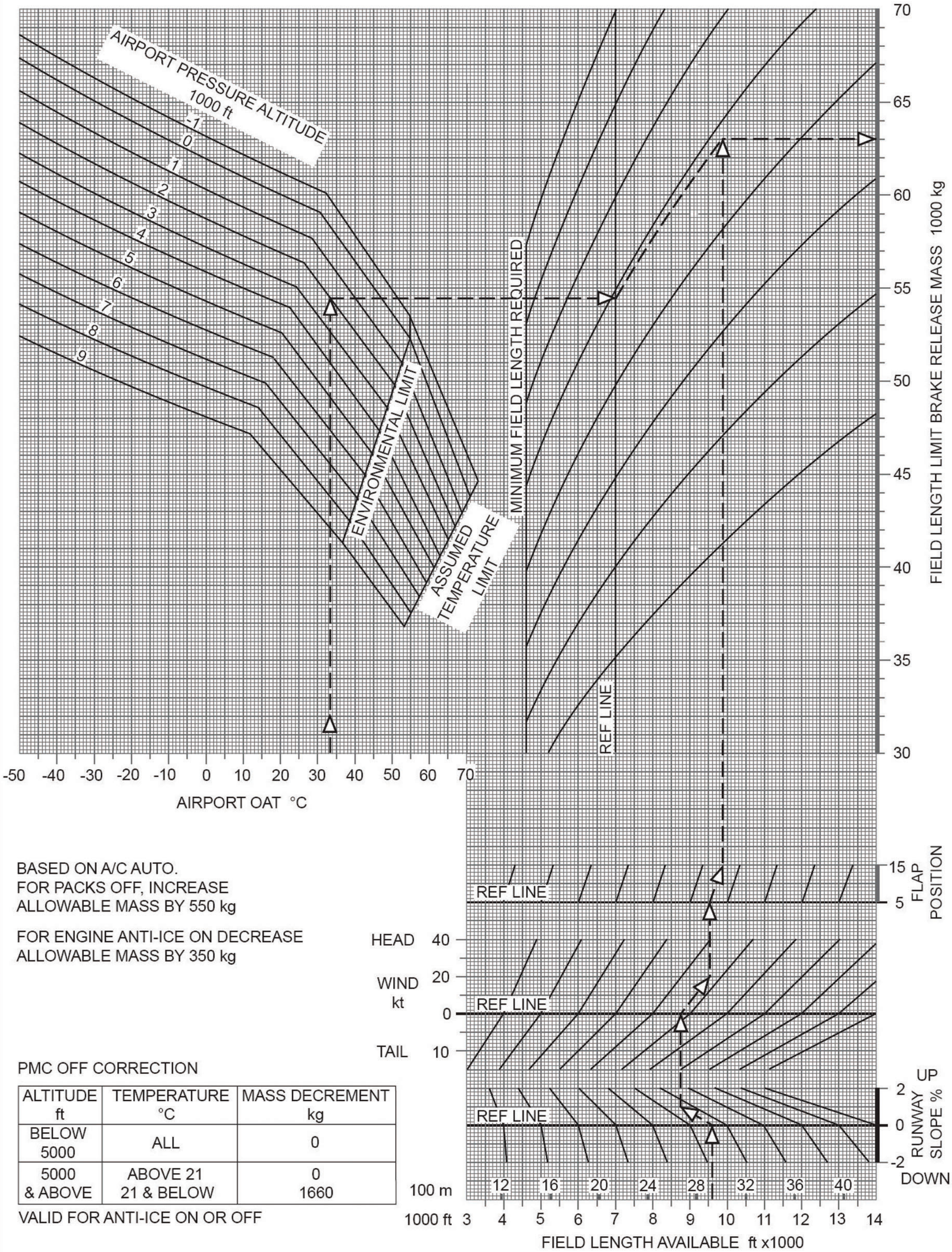
Field Limit Brake Release Mass / Field Limit Mass

This section of the chapter will focus on calculating the various limiting masses for take-off. Class A aeroplanes have data presented to the pilot in a different way than smaller Class B aeroplanes. Whereas Class B aeroplane data for take-off would show what length of runway would be used for any given mass, Class A aeroplane data shows what maximum mass could be taken for a given runway length. This makes sense since Class A aeroplanes are used commercially and the interest of the airlines is to carry the maximum payload possible for the flight. Therefore, most performance graphs or tables will give a mass as their outcome. The first of these performance masses is the field limit brake release mass.

The field limit brake release mass is the maximum mass that will allow the aeroplane to meet its field length requirements at the airfield concerned. Therefore, to be heavier than the field limit mass would mean that either the one engine inoperative or the all engine operative take-off run, take-off distance or accelerate-stop distance exceeds the available distance at the airfield.

If you remember, airfields can have different lengths of take-off run, take-off distance and accelerate-stop distance available. Therefore, there should be many mass graphs. There should be mass graphs for ensuring that the mass is such that the take-off run required is within the take-off run available, that the take-off distance required is within the take-off distance available and lastly another mass graph to ensure the accelerate-stop distance required is within the accelerate-stop distance available. However, there is only one graph and only one assumed available distance to calculate the field limit mass. The reason is for simplicity. The graph assumes that the take-off run available, the take-off distance available and the accelerate-stop distance available are the same length even though the take-off distance available and accelerate-stop distance available may be longer. Therefore no stopways or clearways are accounted for. When the take-off distance available and the accelerate-stop distance available are the same, the field is described as being balanced. In this case the balanced field length also happens to be the same length as the take-off run available because there are no stopways or clearways. To use the graph, make sure you only enter the take-off run available as the length of field available.

An example of a typical balanced field length graph is shown in *Figure 14.11*. This graph is exactly like the one shown in *CAP 698 on page 9 of section 4*. Notice at the bottom of the graph there is only one field distance to enter the graph with but, of course, an airfield has many distances, such as the TODA and the ASDA. Because there is only one distance to enter into the graph it must be balanced field length. The introduction to the graph is at the top of *page 7 of section 4 in CAP 698* and it reiterates that the graph assumes a balanced field. For unbalanced fields use the information under *paragraph 2.5.1 on page 16 of section 4*. This latter information is for adjusting V_1 when the field is unbalanced.



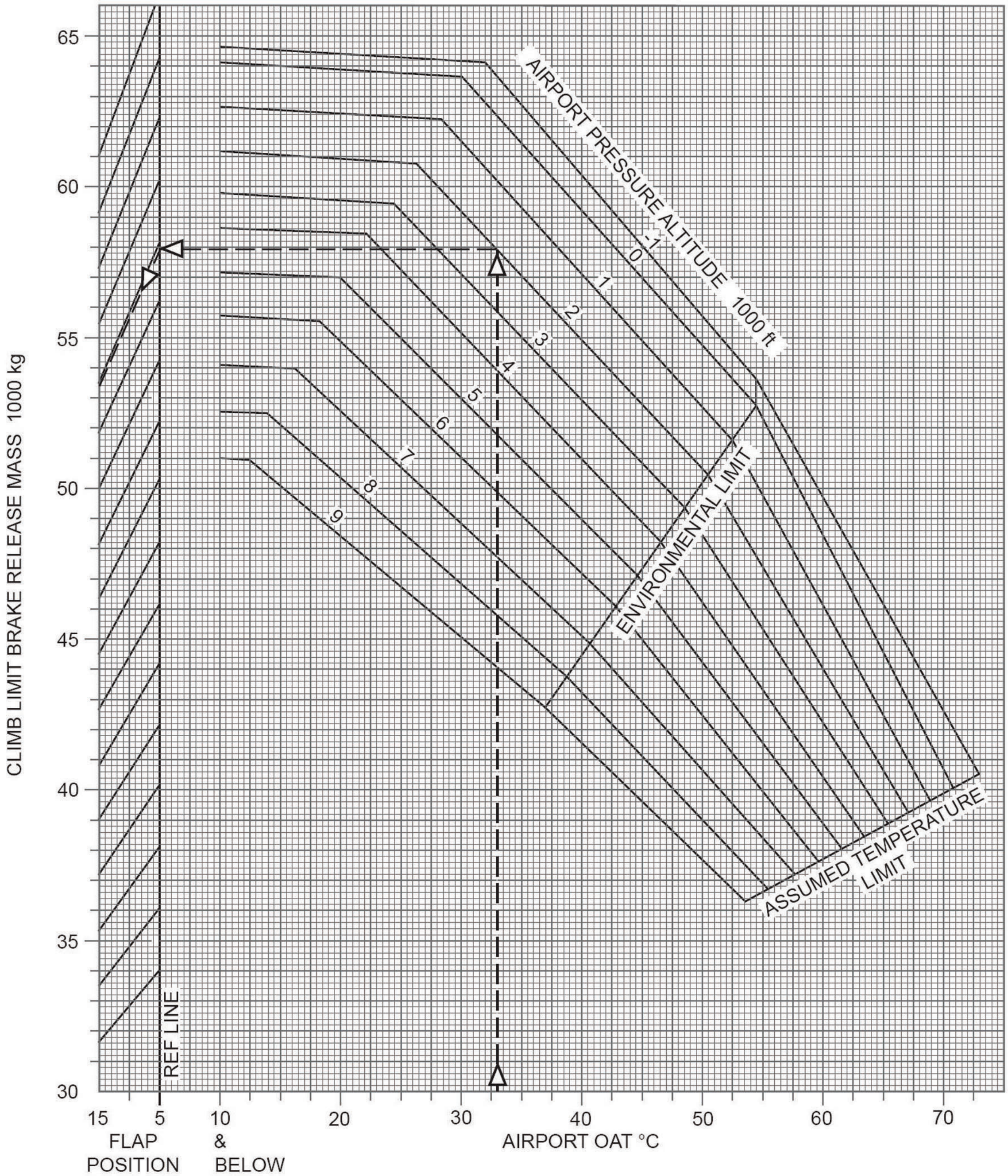
ALTITUDE ft	TEMPERATURE °C	MASS DECREMENT kg
BELOW 5000	ALL	0
5000 & ABOVE	ABOVE 21 21 & BELOW	0 1660

VALID FOR ANTI-ICE ON OR OFF

Figure 14.11 Field limit mass.

Climb Gradient Limit Mass

The field limit mass is not the only mass that must be considered in the take-off, there are several more. The next mass to consider is the climb limit brake release mass. The graph for calculating this mass is *Figure 4.5 which is on page 11 of section 4 in CAP 698*. The climb limit mass is sometimes referred to as the Weight Altitude Temperature or Mass Altitude Temperature limit, abbreviated to the WAT or MAT limit. Before we work though the climb limit mass graph let us try and understand what this mass means. The climb limit mass is the maximum mass that will enable the aeroplane to achieve a certain minimum climb performance. This minimum climb performance is the most severe of the climb gradient requirements. The most severe climb gradient requirement is in fact 2.4% which will be covered later. In other words, if the mass of the aeroplane was greater than the climb limit mass then the aeroplane may still be able to climb, but it will not achieve the minimum air gradients that the authorities have laid down. In other words the aeroplane would not achieve the climb requirements. The gradients for the climb requirements will be discussed in the next chapter but remember that these gradients are air gradients and are therefore unaffected by wind. *Figure 14.12* shows a typical presentation of the climb limited take-off mass and is found in *CAP 698 on page 11 of section 4*.



BASED ON A/C AUTO WITH APU ON OR OFF. FOR PACKS OFF, INCREASE ALLOWABLE MASS BY 900 kg.
FOR OPERATION WITH ENGINE ANTI-ICE ON SUBTRACT 190 kg WHEN AIRPORT PRESSURE ALTITUDE IS AT OR BELOW 8000 ft OR 530 kg WHEN AIRPORT PRESSURE ALTITUDE IS ABOVE 8000 ft.

PMC OFF CORRECTION

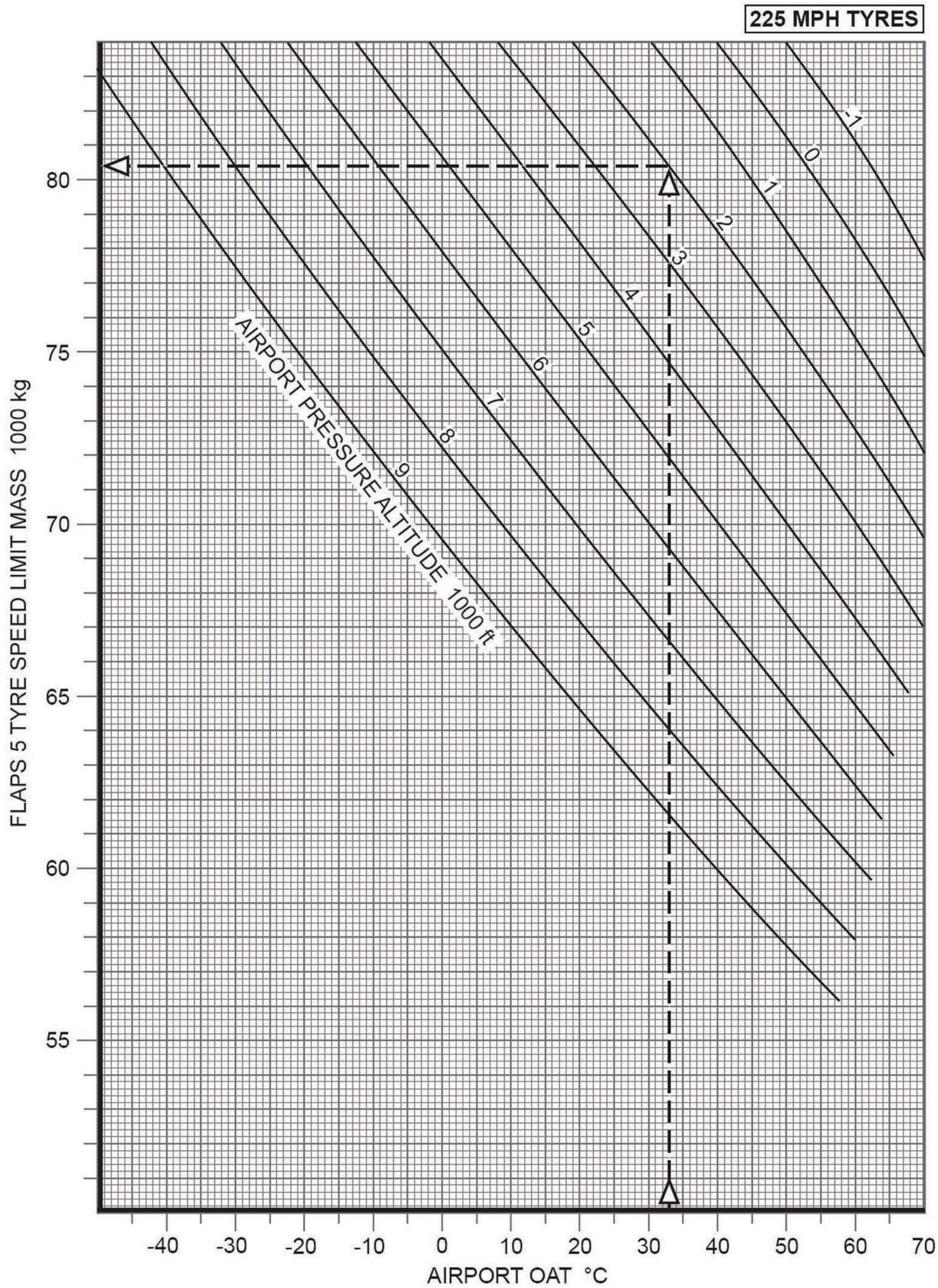
ALTITUDE ft	TEMPERATURE °C	MASS DECREMENT kg
BELOW 5000	ALL	0
5000 & ABOVE	ABOVE 21 21 & BELOW	0 1860

Figure 14.12 Take-off climb limit/climb limit mass.

Tyre Speed Limit Mass

The reason for a tyre speed limit is because naturally there is resistance between the wheel and the runway. As the wheel rotates this resistance generates heat. The greater the wheel speed and/or the greater the load on the wheel, the greater the heat generated. Too much heat will not only disintegrate the tyre but it may also expand the air within the tyre and may over pressurize it. This is dangerous and may result in a tyre blow out, although there are fusible plugs in modern tyres to help prevent this. As you can now understand, there is a maximum ground speed and maximum mass that the wheels can be subject to. The maximum ground speed that the tyre will experience will be at V_{LOF}, and as a result, tyre speed limits are designed to be greater than or equal to the fastest V_{LOF}.

For most medium range jets the maximum tyre speed limit is set at 195 knots which is about 225 miles per hour. *Figure 14.13* shows a typical presentation of the tyre speed limited take-off mass graph found in *CAP 698 on page 13 of section 4*.



CONDITIONAL DEVIATION	CORRECTION
15° Flap	+ 6600 kg
210 mph Tyres	- 9600 kg
15° Flap + 210 mph Tyres	- 1500 kg
Headwind	+ 400 kg per kt
Tailwind	-650 kg per kt

PMC OFF CORRECTION

ALTITUDE ft	TEMPERATURE °C	MASS DECREMENT kg
Below 5000	Above 21 21 & Below	250 210
5000 & Above	Above 21 21 & Below	200 270

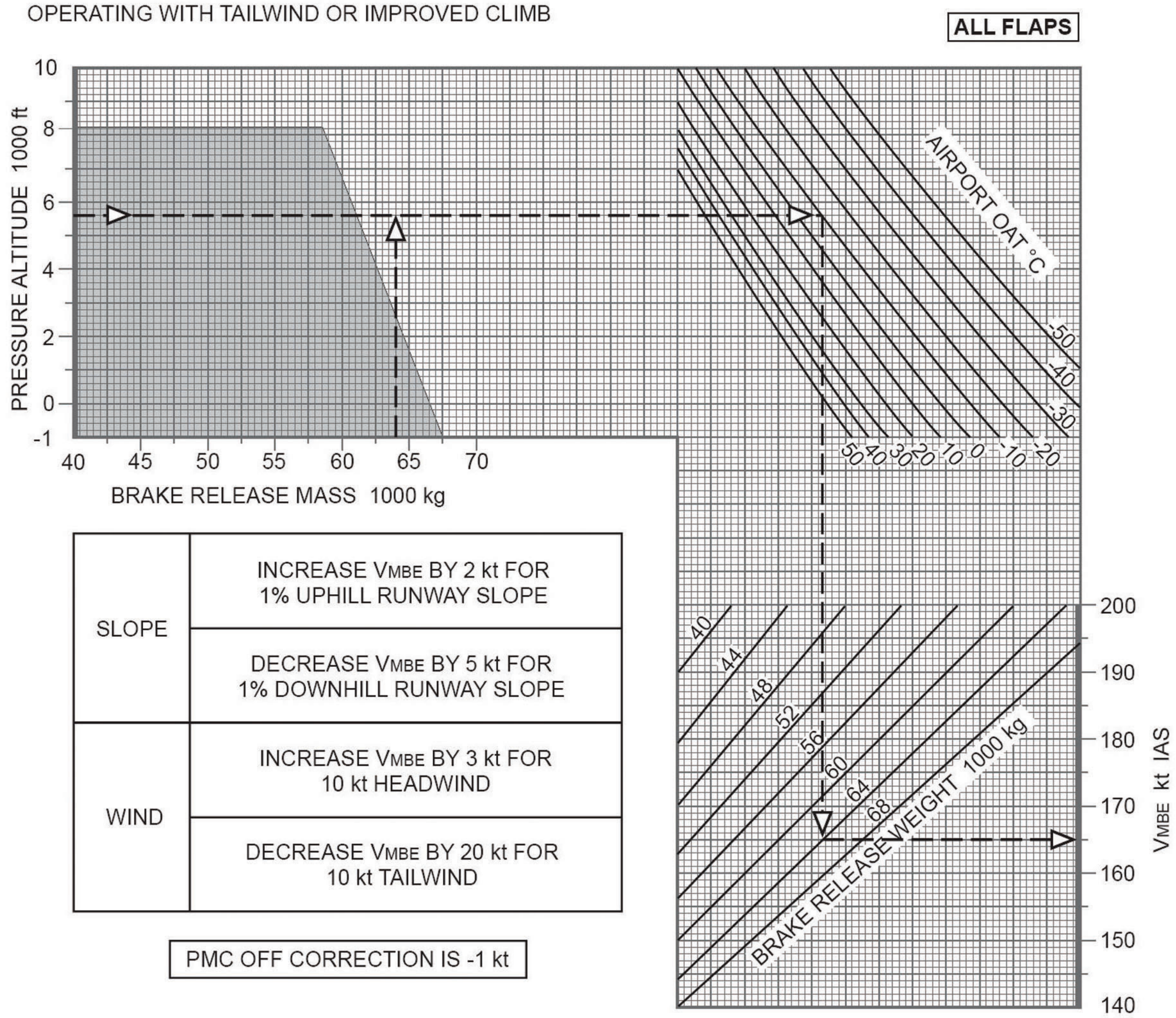
Figure 14.13 Tyre speed limit mass

Brake Energy Limit

For an aircraft of mass M, travelling at a true speed of V, the kinetic energy is ½ MV^2. If the aircraft is braked to a stop from this speed, a large proportion of this energy will go into the brakes as heat. The energy capacity of the brakes is limited and so for a given mass there will be a limiting speed from which a stop can be made. This will be a True Ground Speed, and so the corresponding IAS will vary with altitude, temperature and wind. Runway slope will also affect the speed, as a change in height involves a change in potential energy.

The brake energy limit speed V_{MBE} must not be less than the V_1 speed. If it is, the mass must be reduced until V_1 and V_{MBE} are the same. The flight manual will give the amount of weight to be deducted for each knot that V_1 exceeds V_{MBE}. For most aircraft, V_{MBE} will only be limiting in extremely adverse conditions of altitude, temperature, wind and runway slope. In fact if you look at *Figure 14.14* you will notice a grey area in the graph on the top left hand side. If the mass and pressure altitude falls within this grey area then V_{MBE} will not be limiting, unless operating with a tailwind or improved climb performance. The same graph can be seen in *CAP 698 on page 15 of section 4*.

CHECK V_{MBE} WHEN OUTSIDE SHADED AREA OR WHEN OPERATING WITH TAILWIND OR IMPROVED CLIMB



SLOPE	INCREASE V_{MBE} BY 2 kt FOR 1% UPHILL RUNWAY SLOPE
	DECREASE V_{MBE} BY 5 kt FOR 1% DOWNHILL RUNWAY SLOPE
WIND	INCREASE V_{MBE} BY 3 kt FOR 10 kt HEADWIND
	DECREASE V_{MBE} BY 20 kt FOR 10 kt TAILWIND

PMC OFF CORRECTION IS -1 kt

ADJUST V_{MBE} FOR SLOPE AND WIND

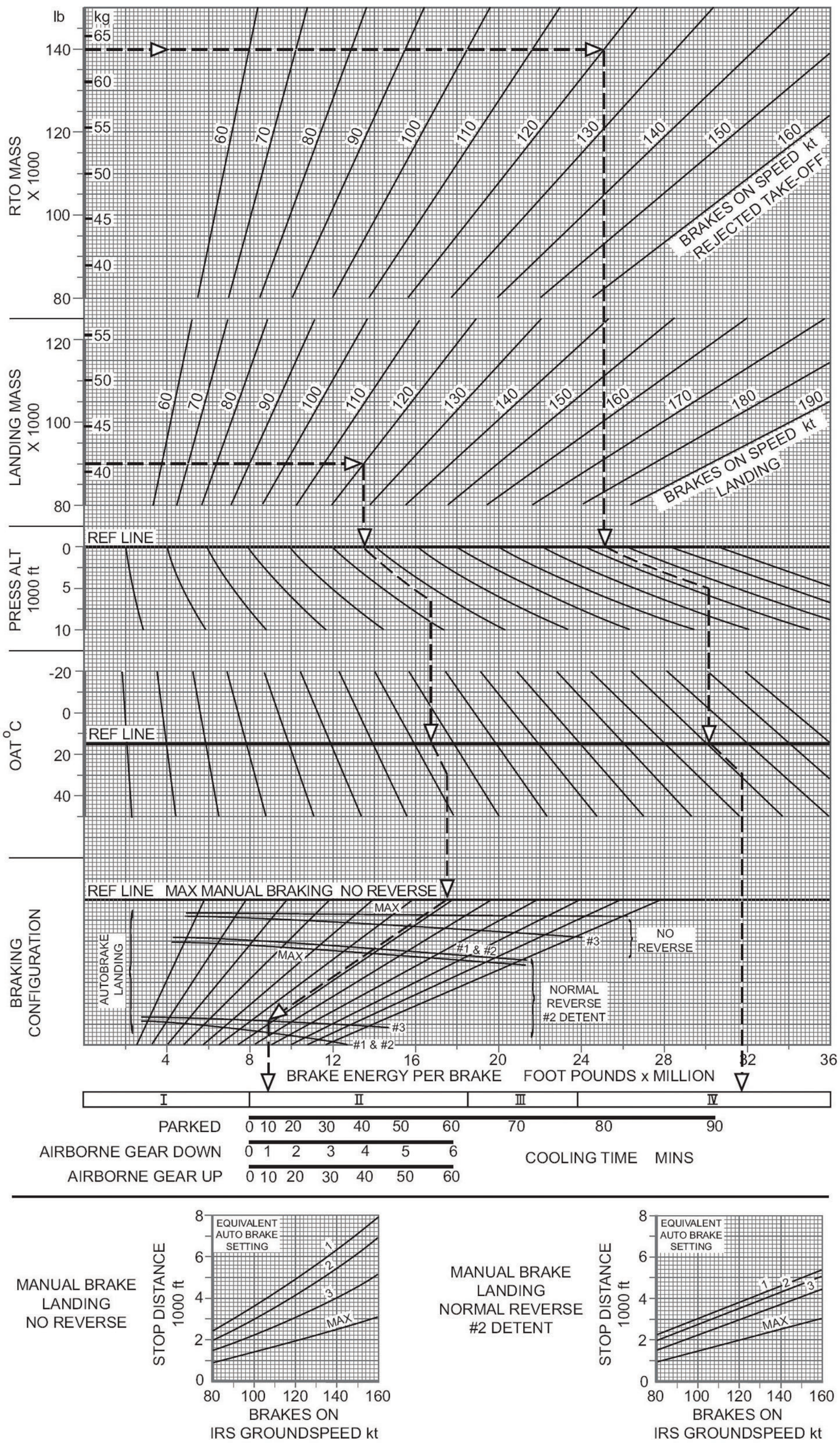
NORMAL TAKE-OFF: DECREASE BRAKE RELEASE MASS BY 300 kg FOR EACH KNOT V_1 EXCEEDS V_{MBE}. DETERMINE NORMAL V_1, V_R, V_2 SPEEDS FOR LOWER BRAKE RELEASE MASS

IMPROVED CLIMB TAKE-OFF: DECREASE CLIMB MASS IMPROVEMENT BY 160 kg FOR EACH KNOT V_1 EXCEEDS V_{MBE}. DETERMINE V_1, V_R, V_2 SPEED INCREMENTS FOR THE LOWER CLIMB MASS IMPROVEMENT

Figure 14.14 Brake energy limit

Brake Cooling

The value of V_{MBE} obtained from the data assumes that the brakes are at ambient temperature before the start of take-off. If a take-off is rejected following a recent landing, or after prolonged taxiing, the brakes will already be at a fairly high temperature, and their ability to absorb further energy will be reduced. Data is given in the manual to show the time to be allowed for the brakes to cool. An example of a brake cooling graph is shown in *Figure 14.15* and it can also be found in *CAP 698 on page 50 of section 4*.



I	NORMAL	No special procedure required.
II	COOLING RECOMMENDED	Cool as scheduled. Ground cooling schedule recommended prior to take-off.
III	CAUTION	Wheel fuse plugs may melt. Delay take-off and inspect after 30 minutes. After take-off, extend gear for at least 7 minutes.
IV	FUSE PLUG MELT	No reverse thrust or braking configuration credit allowed in this area. Clear runway immediately. Do not set parking brake. Do not approach gear or attempt taxi or subsequent take-off before waiting mandatory time shown on quick turnaround limit chart. Alert fire equipment.

Figure 14.15 Shows a typical brake cooling schedule.

Runway Strength

The operating mass of the aircraft may be limited by runway strength considerations. The bearing strength of a pavement is expressed by a PCN (Pavement Classification Number) and this is compared to the ACN (Aircraft Classification Number). The UK system of classification is the LCN (Load Classification Number) but this can be converted into the PCN system. The PCN is compared to the ACN. Operation on the pavement is permissible if the ACN is less than or equal to the PCN. Because the PCN includes a safety factor, a 10% increase of ACN over PCN is generally acceptable for pavements that are in good condition and occasional use by aircraft with ACNs up to 50% greater than the PCN may be permitted. In such circumstances the movement of the aircraft must be very closely monitored for damage to the aeroplane and pavement.

Maximum Take-off Mass

Consideration of the mass determined by the field length available, the climb requirement, the tyre speed limit, and the brake energy limit will determine the maximum performance mass for take-off. It will be the lowest of the masses given by the above limitations. This mass is called the performance limited mass. The performance limited mass must then be compared to maximum structural mass and the lower of the two masses is then selected as the take-off mass. This mass is known as the regulated take-off mass.

If there are obstacles to be considered on the take-off flight path, this may determine a further limitation on take-off mass. Analysis of obstacle clearance limited mass is examined in Chapter 15.

Calculating Take-off Speeds and Thrust Settings

When the maximum permissible take-off mass (regulated take-off mass) has been determined, it is necessary to find the corresponding take-off speeds and thrust settings. *CAP 698 on pages 17, 18, 19 and 20 of section 4* show the presentation of the take-off speeds V_1, V_R and V_2 and the % N1 for take-off.

Take-off Speeds

Having chosen the regulated take-off mass, which for the purpose of an example we shall assume is 57 900 kg, we are now able to select the take-off V speeds of V_1, V_R and V_2. Before we calculate these speeds the speed band needs to be selected. At the bottom of *page 17 of section 4 of CAP 698* is a small table and this is reproduced in *Figure 14.16*. This graph is the density correction graph for the take-off V speeds. As an example, let us assume a temperature of 25 degrees Celsius at an aerodrome pressure altitude of 2000 ft. In our example, the speed band to use is speed band B.

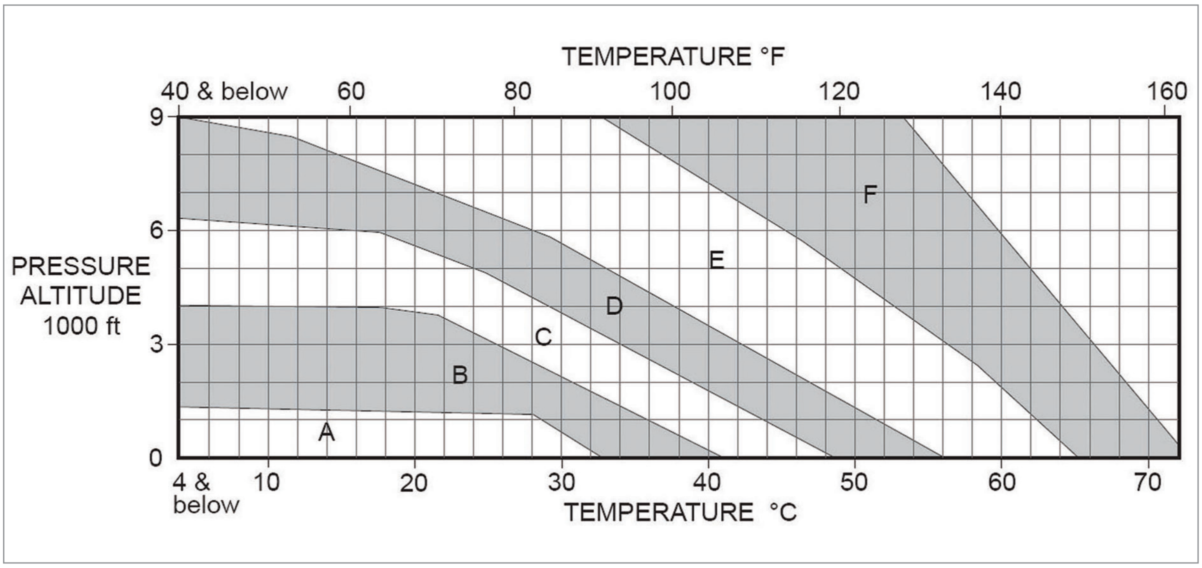


Figure 14.16 The density band selection for the take-off V speeds.

Turning over the page in *CAP 698 from page 17 of section 4 to pages 18 and 19* you can see the speed tables. There are two sets of speed tables. The one on page 18 is for a 5 degrees of flap setting and page 19 is for a 15 degrees of flap setting. For our example we will assume 5 degrees of flap with a regulated take-off mass of 57 900 kg. Using the speed tables for 5 degrees of flap *(page 18 section 4)* identify the column for speed band B (should be roughly in the middle of the page). This is reproduced for you in *Figure 14.17* and the areas to concentrate on are highlighted in red for you.

Mass (1000 kg)	A			B			C		
	V_1	V_R	V_2	V_1	V_R	V_2	V_1	V_R	V_2
70	158	163	168	158	164	169			
65	151	155	161	152	156	162	153	157	162
60	144	148	155	145	148	155	146	149	155
55	137	139	149	138	140	149	138	141	148
50	129	131	142	130	132	142	131	133	142
45	121	123	136	122	124	135	122	125	135
40	113	114	130	113	116	129	113	116	128

Figure 14.17

The left hand scale of the speed table is mass. Notice that our example regulated take-off mass of 57 900 kg lies between the 55 000 kg and 60 000 kg marks. Therefore interpolation must be used when working out our V speeds. V_1 for 55 000 kg is 138 knots and for 60 000 kg V_1 is 145. Correct interpolation for 57 900 kg would make V_1 equal to 142.06 knots which should be rounded but we will do this shortly.

Carrying out the same exercise for V_R and V_2 makes V_R for 57 900 kg equal to 145 knots and V_2 equal to 152 knots.

However, V_1 must be corrected for slope and wind as shown in the table at the top of the page 18 and this is reproduced for you in *Figure 14.18*.

Slope/Wind V_1 adjustment						
Mass (1000 kg)	Slope %			Wind kt		
	DOWNSLOPE -2	0	UPSLOPE 2	TAILWIND -15	0	HEADWIND 40
70	-3	0	4	-3	0	1
60	-2	0	2	-3	0	1
50	-2	0	1	-4	0	1
40	-2	0	1	-4	0	1

* V_1 not to exceed V_R

Figure 14.18 Slope & wind adjustment for V_1.

For a 2% upslope and a mass of 57 900 kg, interpolation shows that V_1 must be increased by 1.79 knots. For a 20 knot headwind, V_1 must be increased by 0.5 of a knot. Therefore the total correction to V_1 is to increase it by 2.29 knots. Adding 2.29 knots to the original V_1 of 142.06 that we calculated earlier makes V_1 to be 144.35 knots, which is rounded to 144 knots. Having finished with V_1, V_R and V_2, there are two other speeds to check. The first is V_{MCG}.

Looking further down the page you can see the table for calculating V_{MCG} which is reproduced for you in *Figure 14.19*.

V_{MCG}

Actual OAT		Press. Alt × 1000 ft				
°C	°F	0	2	4	6	8
55	131	104				
50	122	107	103			
40	104	111	107	103	99	94
30	86	116	111	107	104	98
20	68	116	113	111	107	102
10	50	116	113	111	108	104
-50	-58	118	115	112	109	105

For A/C packs 'off' increase V_{MCG} by 2 knots

Figure 14.19 The V_{MCG} table

Using 25°C and 2000 ft as our pressure altitude would make V_{MCG} to be 112 knots. Remember from our theory that V_1 must not be less than V_{MCG} and in our example it is not.

Lastly the speed V_{MBE} also needs calculating. The graph for this is on *page 15 of section 4 of CAP 698*. We have already described this graph and how to use it. Using *Figure 14.14*, if we use our example airfield conditions of 2000 ft pressure altitude, 25°C and our regulated take-off mass of 57 900 kg then the graph would not be applicable as we are in the shaded area. But as an example, V_{MBE} is 175 knots. However, there are some corrections to make. In our example we had a 2% upslope, and this means we need to increase V_{MBE} by 4 knots. There is also a wind correction to be made. In our example we assume a 20 knot headwind and this means V_{MBE} must increase by 6 knots. The total correction would increase V_{MBE} to 185 knots.

All the relevant take-off V speeds have now been calculated based upon our regulated take-off mass of 57 900 kg.

Correction for Stopway and Clearway

The speeds shown in the tables that we have just used are based on a balanced field length (TORA = TODA= ASDA) and are not valid if the take-off mass has been derived using stopway or clearway. Where this is the case the V_1 may be adjusted for the effects of stopway or clearway from the table below.

	Normal V_1 KIAS			
Clearway Minus Stopway (ft)	**100**	**120**	**140**	**160**
800	-	-	-3	-2
600	-	-3	-2	-1
400	-4	-3	-2	-1
200	-2	-1	-1	0
0	0	0	0	0
-400	1	1	1	1
-800	1	1	1	1

Maximum Allowable Clearway

Field Length (ft)	Maximum Allowable Clearway for V_1 Reduction (ft)
4000	400
6000	500
8000	550
10000	600
12000	700
14000	750

Figure 14.20

Thrust Setting (% N1)

The thrust setting values are as shown in CAP 698 on pages 20, 21, 22 and 23 of section 4. Use the tables on these pages to select the appropriate thrust setting for take-off and for the climb using the conditions at the airfield.

Stabilizer Trim Setting

The stabilizer trim setting appropriate to the CG position and take-off mass can be read from the table below and are shown in CAP 698 at the bottom of pages 18 and 19 of section 4.

Flaps 5°   Stabilizer Trim Setting

CG.% MAC	6	10	14	18	22	26	30
Stab. Trim	5½	5	4½	3¾	3¼	2¾	2¼

For masses at or below 45 350 kg subtract ½ unit
For masses at or above 61 250 kg add ½ unit
Stab trim settings must be between 1 and 5 ¾ units

Figure 14.21

Questions

1. For a given take-off mass, the maximum brake energy limit speed (V_{MBE}), as an indicated airspeed, will:

a. decrease with increasing altitude, and decrease with increasing temperature
b. increase with increasing altitude and increase with increasing temperature
c. decrease with increasing altitude, and increase with increasing temperature
d. not change with altitude, but decrease with increasing temperature

2. Provided all other parameters stay constant, which of the following statements will decrease the take-off ground run?

a. Decreased take-off mass, increased pressure altitude, increased temperature
b. Decreased take-off mass, increased density, increased flap setting
c. Increased pressure altitude, increased outside air temperature, increased take-off mass
d. Increased outside air temperature, decreased pressure altitude, decreased flap setting

3. A multi-engine aeroplane is flying at the minimum control speed (V_{MCA}). Which parameter(s) must be maintainable after engine failure?

a. Heading, altitude and a positive rate of climb of 100 ft/min
b. Altitude
c. Straight flight
d. Straight flight and altitude

4. How is V_{MCA} influenced by increasing pressure altitude?

a. V_{MCA} decreases with increasing pressure altitude
b. V_{MCA} increases with pressure altitude higher than 4000 ft
c. V_{MCA} increases with increasing pressure altitude
d. V_{MCA} is not affected by pressure altitude

5. Which of the following speeds can be limited by the 'maximum tyre speed'?

a. Lift-off ground speed
b. Lift-off IAS
c. Lift-off TAS
d. Lift-off EAS

6. A higher outside air temperature (OAT):

a. decreases the brake energy limited take-off mass
b. increases the field length limited take-off mass
c. increases the climb limited take-off mass
d. decreases the take-off distance

7. **The take-off performance requirements for Class A transport category aeroplanes are based upon:**

a. failure of critical engine
b. failure of critical engine or all engines operating whichever gives the largest take-off distance
c. all engines operating
d. only one engine operating

8. **Maximum and minimum values of V_1 can be limited by:**

a. V_R and V_{MCG}
b. V_2 and V_{MCA}
c. V_R and V_{MCA}
d. V_2 and V_{MCG}

9. **During the certification flight testing of a twin-engine turbojet aeroplane, the actual demonstrated take-off distances are equal to:**

1547 m with all engines operating
1720 m with failure of the critical engine at V_1 and with all other things remaining unchanged.
The take-off distance adopted for the certification file is:

a. 1547 m
b. 1720 m
c. 1779 m
d. 1978 m

10. **The minimum value that V_2 must exceed "air minimum control speed" is by:**

a. 15%
b. 20%
c. 30%
d. 10%

11. **With regard to a take-off from a wet runway, which of the following statements is correct?**

a. Screen height cannot be reduced
b. The screen height can be lowered to reduce the mass penalties
c. When the runway is wet, the V_1 reduction is sufficient to maintain the same margins on the runway length
d. In case of a thrust reverser inoperative, the wet runway performance information can still be used

12. **Balanced V_1 is selected:**

a. for a runway length limited take-off with a clearway to give the highest mass
b. if it is equal to V_2
c. if the accelerate-stop distance required is equal to the one engine out take-off distance required
d. for a runway length limited take-off with a stopway to give the highest mass

13. **How is V_2 affected if take-off flaps at 20° is chosen instead of take-off flaps at 10°?**

a. V_2 increases in proportion to the angle at which the flaps are set
b. V_2 has no connection with take-off flap setting, as it is a function of runway length only
c. V_2 decreases if not restricted by V_{MCA}
d. V_2 has the same value in both cases

14. **Which statement regarding the influence of a runway downslope is correct for a balanced take-off? Downslope:**

a. increases V_1 and reduces the accelerate-stop distance required (ASDR)
b. reduces V_1 and increases the accelerate-stop distance required (ASDR)
c. increases V_1 and increases the take-off distance required (TODR)
d. reduces V_1 and reduces take-off distance required (TODR)

15. **Ignoring the minimum control speed limitation, the lowest take-off safety speed (V_{2min}) is:**

a. $1.15V_S$ for all turbojet aeroplanes
b. $1.20V_S$ for all turboprop powered aeroplanes
c. $1.13V_{SR}$ for two-engine and three-engine turbo-propeller powered aeroplanes
d. $1.13V_{SR}$ for turbo-propeller powered aeroplanes with more than three engines

16. **During the flight preparation a pilot makes a mistake by selecting a V_1 greater than that required. Which problem will occur when the engine fails at a speed immediately above the correct value of V_1?**

a. The stop distance required will exceed the stop distance available
b. The one engine out take-off distance required may exceed the take-off distance available
c. V_2 may be too high so that climb performance decreases
d. It may lead to over-rotation

17. **The speed V_2 of a jet aeroplane must be greater than: (assume the aeroplane has provisions for obtaining a significant reduction in the one engine inoperative power-on stall speed.)**

a. $1.13V_{MCG}$
b. $1.05V_{LOF}$
c. $1.3V_1$
d. $1.08V_{SR}$

18. **When an aircraft takes off with the mass limited by the TODA or field length:**

a. the actual take-off mass equals the field length limited take-off mass
b. the distance from brake release to V_1 will be equal to the distance from V_1 to the 35 ft point
c. the "balanced take-off distance" equals 115% of the "all engine take-off distance"
d. the end of the runway will be cleared by 35 ft following an engine failure at V_1

19. **A runway is contaminated by a 0.5 cm layer of wet snow. The take-off is nevertheless authorized by a light-twin's flight manual. The take-off distance in relation to a dry runway will be:**

    a. very significantly decreased
    b. increased
    c. unchanged
    d. decreased

20. **What will be the influence on the aeroplane performance at higher pressure altitudes?**

    a. It will increase the take-off distance
    b. It will decrease the take-off distance
    c. It will increase the take-off distance available
    d. It will increase the accelerate-stop distance available

21. **During certification test flights for a turbojet aeroplane, the actual measured take-off runs from brake release to a point equidistant between the point at which V_{LOF} is reached and the point at which the aeroplane is 35 ft above the take-off surface are:**

    1747 m, all engines operating
    1950 m, with the critical engine failure recognized at V1, and all the other factors remaining unchanged.
    Considering both possibilities to determine the take-off run (TOR), what is the correct distance?

    a. 1950 m
    b. 2009 m
    c. 2243 m
    d. 2096 m

22. **Given that:**
    V_{EF} = Critical engine failure speed
    V_{MCG} = Ground minimum control speed
    V_{MCA} = Air minimum control speed
    V_{MU} = Minimum unstick speed
    V_1 = Take-off decision speed
    V_R = Rotation speed
    V_{2MIN}. = Minimum take-off safety speed

    The correct formulae are:

    a. $1.05V_{MCA}$ is less than or equal to V_{EF}, V_{EF} is less than or equal to V_1
    b. $1.05V_{MCG}$ is less than V_{EF}, V_{EF} is less than or equal to V_R
    c. V_{2MIN} is less than or equal to V_{EF}, V_{EF} is less than or equal to V_{MU}
    d. V_{MCG} is less than or equal to V_{EF}, V_{EF} is less than V_1

23. **If the field length limited take-off mass has been calculated using a balanced field length technique, the use of any additional clearway in take-off performance calculations may allow:**

    a. a greater field length limited take-off mass but with a higher V_1
    b. the obstacle clearance limit to be increased with no effect on V_1
    c. the obstacle clearance limit to be increased with a higher V_1
    d. a greater field length limited take-off mass but with a lower V_1

24. **The result of a higher flap setting up to the optimum at take-off is:**

a. a higher V_1
b. a longer take-off run
c. a shorter ground roll
d. an increased acceleration

25. **For Class A aeroplanes the take-off run is:**

a. the horizontal distance along the take-off path from the start of the take-off to a point equidistant between the point at which V_{LOF} is reached and the point at which the aeroplane is 35 ft above the take-off surface
b. 1.5 times the distance from the point of brake release to a point equidistant between the point at which V_{LOF} is reached and the point at which the aeroplane attains a height of 35 ft above the runway with all engines operative
c. 1.15 times the distance from the point of brake release to the point at which V_{LOF} is reached assuming a failure of the critical engine at V_1
d. the distance of the point of brake release to a point equidistant between the point at which V_{LOF} is reached and the point at which the aeroplane attains a height of 50 ft above the runway assuming a failure of the critical engine at V_1

26. **Which statement is correct for a Class A aeroplane?**

a. V_R must not be less than $1.05V_{MCA}$ and not less than $1.1V_1$
b. V_R must not be less than $1.05V_{MCA}$ and not less than V_1
c. V_R must not be less than V_{MCA} and not less than $1.05V_1$
d. V_R must not be less than $1.1V_{MCA}$ and not less than V_1

27. **During certification flight testing on a four engine turbojet aeroplane the actual take-off distances measured are:**

2555 m with all engines operating
3050 m with failure of the critical engine recognized at V_1 and all other things being equal.

The take-off distance adopted for the certification file is:

a. 3050 m
b. 3513 m
c. 2555 m
d. 2938 m

28. **When the outside air temperature increases, then:**

a. the field length limited take-off mass decreases but the climb limited take-off mass increases
b. the field length limited take-off mass increases but the climb limited take-off mass decreases
c. the field length limited take-off mass and the climb limited take-off mass decreases
d. the field length limited take-off mass and the climb limited take-off mass increases

29. **In case of an engine failure which is recognized at or above V_1:**

a. the take-off should be rejected if the speed is still below V_R
b. the take-off must be continued
c. the take-off must be rejected if the speed is still below V_{LOF}
d. a height of 50 ft must be reached within the take-off distance

30. **V_R cannot be lower than:**

a. 105% of V_1 and V_{MCA}
b. $1.2V_S$ for twin and three engine jet aeroplane
c. $1.15V_S$ for turboprop with three or more engines
d. V_1 and 105% of V_{MCA}

31. **If the performance limiting take-off mass of an aeroplane is brake energy limited, a higher uphill slope would:**

a. have no effect on the maximum mass for take-off
b. decrease the required take-off distance
c. increase the maximum mass for take-off
d. decrease the maximum mass for take-off

32. **In which of the following distances can the length of a stopway be included?**

a. In the accelerate-stop distance available
b. In the one-engine failure case, take-off distance
c. In the all engine take-off distance
d. In the take-off run available

33. **In the event of engine failure below V_1, the first action to be taken by the pilot in order to decelerate the aeroplane is to:**

a. apply wheel brakes
b. deploy airbrakes or spoilers
c. reduce the engine thrust
d. reverse engine thrust

34. **Which is the correct sequence of speeds during take-off?**

a. V_1, V_R, V_2, V_{MCA}
b. V_{MCG}, V_1, V_R, V_2
c. V_1, V_{MCG}, V_R, V_2
d. V_1, V_R, V_{MCG}, V_2

35. **Which of the following distances will increase if you increase V_1?**

a. All engine take-off distance
b. Take-off run
c. Accelerate-stop distance
d. Take-off distance

36. **If the value of the balanced V_1 is found to be lower than V_{MCG}, which of the following is correct?**

a. The ASDR will become greater than the one engine out take-off distance
b. The take-off is not permitted
c. The one engine out take-off distance will become greater than the ASDR
d. The V_{MCG} will be lowered to V_1

37. **For this question use Figure 4.4 in CAP 698 Section 4.**

For an example twin engine turbojet aeroplane two take-off flap settings (5° and 15°) are certified.

Given:
Field length available = 2400 m
Outside air temperature = - 10°C
Airport pressure altitude = 7000 ft
The maximum allowed take-off mass is:

a. 55 000 kg
b. 70 000 kg
c. 52 000 kg
d. 56 000 kg

Answers

1	2	3	4	5	6	7	8	9	10	11	12
a	b	c	a	a	a	b	a	c	d	b	c

13	14	15	16	17	18	19	20	21	22	23	24
c	d	c	a	d	a	b	a	b	d	d	c

25	26	27	28	29	30	31	32	33	34	35	36
a	b	a	c	b	d	c	a	c	b	c	b

37
d

Chapter

15

Class A - Additional Take-off Procedures

Non-standard Take-off Procedures

The procedure to determine the take-off mass, take-off speeds, and thrust settings for the normal take-off procedure is given in the previous chapter. Chapter 15 gives additional procedures to cover:

- take-off with contaminated runway
- take-off with increased V_2 speed
- take-off with reduced thrust
- take-off with anti-skid inoperative

However, most of these procedures can be found in *CAP 698 on pages 24 to 34 of section 4*. Do not worry about having to remember too much about these procedures, CAP 698 adequately details and describes not only the theory of the procedures but also the methodology of each procedure.

Contaminated Runways

This procedure is detailed on *page 24 of section 4 in CAP 698*. A runway is considered to be contaminated when more than 25% of the runway surface area (whether in isolated areas or not) within the required length and width being used is covered by surface water, more than 3 mm deep, or by slush or loose snow, equivalent to more than 3 mm of water.

Slush, loose snow or standing water on the runway will affect both the take-off distance required and the accelerate-stop distance required. The take-off distance required will increase because of the additional wheel drag and impingement drag. The accelerate-stop distance will increase because of the increased distance to accelerate and the increased distance to stop resulting from the reduced runway coefficient of braking friction. For given distances available, the maximum take-off mass and V_1 will therefore be reduced compared to the dry runway. The greater the depth of contamination, the greater the mass reduction and the less the V_1 reduction.

The supplementary performance information required by EU-OPS 1 should include accelerate-stop distance, take-off distance and take-off run appropriate to the relevant contaminant, derived in a similar manner to those distances with a wet runway.

The acceleration distance should take account of the additional drag due to the gear displacement drag, and the spray impingement drag, and the decrease of drag which occurs above the aquaplaning speed. For rotating tyres or tyres going from a dry surface to a flooded surface, the hydroplaning speed (V_P) is calculated using the formula below

$$9\sqrt{\text{TYRE PRESSURE (psi)}}$$

Figure 15.1

The hydroplaning speed for non-rotating tyres or to find the speed below which the aquaplaning will stop is shown below.

$$7.7\sqrt{\text{TYRE PRESSURE (psi)}}$$

Figure 15.2

Procedure

Use either *Figure 15.3* or the tables shown in *CAP 698 on pages 25, 26 and 27 of section 4* for the following description of the procedure to follow for contaminated runways.

The determination of take-off mass

a) Calculate the normal limiting take-off mass for a dry runway i.e. field length limit, climb limit or obstacle limit.

b) Select the table(s) appropriate to the depth of contaminant (interpolating if necessary).

c) Enter the left column of the top table at the normal limiting take-off mass, travel right to the aerodrome pressure altitude column. Interpolate for mass and pressure altitude, if necessary. Extract the mass reduction. Calculate maximum take-off mass for a contaminated runway by subtracting the mass reduction from the normal performance limiting take-off mass.

d) If in the shaded area, proceed to the bottom table. Enter the left column with the take-off run available (TORA), move right to the appropriate aerodrome pressure altitude column. Interpolate as necessary. Extract the maximum permissible take-off mass. Make $V_1 = V_{MCG}$.

e) The lower of the two values from c) and d) above is the maximum take-off mass for a contaminated runway.

f) Calculate all the V speeds for the actual take-off mass as given in e).

g) If not in the shaded area in c) above, then re-enter the top table at the actual mass to determine the V_1 reduction to be made.

h) Apply the reduction to V_1. If adjusted V_1 is less than V_{MCG}, take-off is not permitted.

0.08 Inch (2 mm) Slush/Standing Water Depth

Mass × 1000 kg	Mass and V_1 Reductions			
	Press Alt (ft)	0	4000	8000
40	1000 kg KIAS	2.9 22	3.4 21	4.0 19
44	1000 kg KIAS	3.7 22	4.2 21	4.9 18
48	1000 kg KIAS	4.3 21	5.0 19	5.8 17
52	1000 kg KIAS	4.9 20	5.7 18	6.5 15
56	1000 kg KIAS	5.6 18	6.3 16	7.0 14
60	1000 kg KIAS	6.1 16	6.8 15	7.3 12
64	1000 kg KIAS	6.6 16	7.2 13	7.6 10
68	1000 kg KIAS	6.9 13	7.5 11	8.2 8

Field Length Available (ft) (TORA)	$V_1 = V_{MCG}$ Limit Mass 1000 kg		
	Pressure Altitude (ft)		
	0	4000	8000
5600 5800 6000	39 42 45	- 34 37	- - -
6200 6400 6600	49 52 55	39 42 45	- - 36
6800 7000 7200	59 62 65	47 50 53	39 41 43
7400 7600 7800	69 - -	56 59 62	46 48 51
8000 8200 8400	- - -	65 68 71	53 56 58
8600 8800 9000	- - -	- - -	61 64 66

Figure 15.3 Sample data for a runway with 2 mm contamination.

Take-off with Increased V_2 Speed

This particular procedure is used when the performance limited mass is the climb limit mass. In other words, the climb performance is poor and is severely restricting the potential mass of the aeroplane. Before we start, it is important to understand that in the event of engine failure, the initial climb out speed is V_2. However, V_2 is not the best climb angle speed. V_2 is considerably slower than the best angle of climb speed, which, if you recall, is called V_X. As an example, for a typical new generation 737, V_X is 80 knots faster than V_2; therefore, climbing out at V_2 produces a climb angle much less than if the aeroplane were to climb out at V_X.

What the improved climb procedure aims to achieve is to increase V_2 to be closer to V_X. This will greatly enhance the climb performance. Understanding the concepts of the increased V_2 procedure would be best illustrated by working through an example where the field limit mass is 61 000 kg and the climb limit mass is 52 000 kg. The performance limited mass is always the lower mass and therefore the mass for take-off must be 52 000 kg. This is a shame, since the runway can allow a far greater mass. Therefore, taking off with only 52 000 kg would mean there would be a significant proportion of the runway left. This can provide a clue as to the solution.

With all the excess of runway it would be possible to stay on the runway for longer during the take-off to build up more speed; this will ensure that at rotation and at the screen height, a faster V_2 will be reached and this faster V_2 will be much closer to V_X. This ensures that the climb performance significantly improves. As a result of the improved climb performance, the climb limit mass can increase, which would increase the performance limited take-off mass and provide an improved regulated take-off mass.

The information at the top of page 28 of section 4 in CAP 698 introduces the concept of the procedure very well, so use this introduction in the exam if you are unsure of what the procedure entails. Below this introduction is the detailed methodology of the procedure itself which is reproduced in the next paragraph.

Procedure

Use the graphs shown in *CAP 698 on pages 29 and 30 of section 4* for the following procedure for an increased V_2 take-off.

a) Select the set of graphs appropriate to the flap setting on the "improved climb performance field length limit" graph *(CAP 698 Figure 4.15)*.

b) Enter the relevant left-hand graph with the value of the field length limit mass minus the climb limit mass. Travel vertically up to the normal 'climb limit' mass line.

c) From this intersection move horizontally left to the vertical axis to read the climb mass improvement and horizontally right to the vertical axis to read the increase to apply to V_1.

d) Continue horizontally right to the reference line of the right-hand graph. From this point interpolate and follow the grid lines to reach a vertical input in the right-hand graph of the normal climb limit mass.

e) From this intersection, travel horizontally right to the vertical axis to read the increase to apply to V_R and V_2.

f) Repeat this process in the improved climb performance tyre speed limit graph *(CAP 698 Figure 4.16)* except that the initial entry point is the tyre limit mass minus the climb limit mass.

g) The lower of the two mass increases is that which must be used together with its associated speed increases.

h) Add the mass increase to the normal climb mass limit.

i) Determine the V speeds for this increased mass.

j) Apply the speed increases to the appropriate speeds. Check V_{MBE}.

Take-off with Reduced Thrust

The third additional type of procedure is probably the most common and it is referred to by many different names and is detailed on *page 31 of section 4 in CAP 698*. Use this page to help you, it describes all the relevant information you need. So again, do not worry about having to remember all the information about it.

This third procedure is referred to as the reduced thrust take-off, variable thrust take-off or assumed temperature take-off. However, Airbus uses the term flexible take-off. The main reason for doing this procedure is to preserve engine life and also to help reduce noise. The procedure can be used any time the actual take-off mass is less than the maximum permissible take-off mass and there is an available distance that greatly exceeds that which is required. The maximum reduction in thrust from the full rated take-off thrust value is 25%.

Take-off with reduced thrust is not permitted with:

- icy or very slippery runways
- contaminated runways
- anti-skid inoperative
- reverse thrust inoperative
- increased V_2 procedure
- PMC off

Reduced thrust take-off procedure is not recommended if potential windshear conditions exist.

Procedure

Essentially this procedure assumes that the temperature is a lot hotter than it actually is. Imagine for the moment that the outside air temperature was continually increasing and as a result the thrust produced by the engines continually decreasing. There will eventually be a temperature beyond which there will be insufficient thrust to complete a take-off. This temperature is then used as the assumed temperature and the thrust equating to this temperature is then set as the take-off thrust.

The procedure described below can also be found in *CAP 698 on page 31 of section 4*.

It is first necessary to determine the most limiting performance condition. The only common parameter to enable comparison is that of temperature. Thus the maximum permissible temperature must be calculated for the actual take-off mass from each of the following:

- field limit graph
- climb limit graph
- tyre speed limit graph
- obstacle limit graph

From these temperatures, select the lowest and ensure that it does not exceed the environmental limit. If it does, then the environmental limit becomes the assumed temperature.

a) Calculate the maximum assumed temperature from *CAP 698 Figure 4.17a* or *4.17b*, as appropriate. Enter the left column with the actual ambient temperature and read the maximum temperature in the column appropriate to the aerodrome pressure altitude.

b) From *CAP 698 Figure 4.17c* on the bottom line, determine the minimum assumed temperature for the aerodrome pressure altitude.

c) From the same table, for the assumed temperature to be used, determine the maximum take-off % N1. Add 1.0% N1 if air conditioning packs are off. The assumed temperature used must neither exceed the maximum from paragraph a) above nor be below the minimum from paragraph b) above.

d) Enter the left column of *CAP 698 Figure 4.17d* with assumed temperature minus ambient temperature. Travel right along the line to the column appropriate to the ambient temperature, interpolating if necessary. Read the % N1 adjustment.

e) Subtract the value determined at paragraph d) from that at paragraph c) to determine the % N1 to be set at take-off.

De-rate

Both Airbus and Boeing use De-rated thrust which will reduce engine thrust by a fixed percentage, for example De-rate 1 will reduce thrust by 4% and De-rate 2 by 10%.

When De-rate thrust is used it provides a fixed reduction of thrust and because it is fixed then V_{MCG} and V_{MCA} can also be reduced which can help increase take-off mass on a short runway. However, once De-rate is selected thrust cannot be increased until the aeroplane is accelerated during flap retraction.

Take-off with Anti-skid Inoperative

(Simplified Method)

The last additional take-off procedure is that used when the anti-skid system is inoperative. You may think that this is not important for take-off, but bear in mind, Class A aeroplanes have to demonstrate that in the event of engine failure, the aeroplane is able to stop within the confines of the runway. Therefore, the accelerate-stop distance required must be less than or equal to the field available. If the anti-skid system does not work, then the stopping ability will be severely reduced and will cause the accelerate-stop distance to increase dramatically. To solve the problem, V_1 is reduced. You may recall that reducing V_1 decreases the accelerate-stop distance, but the side effect is that it increases the take-off distance *(Figure 14.1)*. To resolve this, the mass of the aeroplane is reduced, which will decrease both the accelerate-stop distance and take-off distance required so that they remain within the available field lengths.

In summary then, with the anti-skid system inoperative, V_1 and aeroplane mass must be decreased.

The anti-skid inoperative procedure is detailed on *page 34 of section 4 in CAP 698*. At the top of that page is a very clear introduction to the procedure and below this is the method of calculating the mass and V_1 reduction.

Questions

1. **With regard to a take-off from a wet runway, which of the following statements is correct?**

   a. Screen height cannot be reduced
   b. The screen height can be lowered to reduce the mass penalties
   c. When the runway is wet, the V_1 reduction is sufficient to maintain the same margins on the runway length
   d. In case of a thrust reverser inoperative, the wet runway performance information can still be used

2. **For a take-off from a contaminated runway, which of the following statements is correct?**

   a. Dry snow is not considered to affect the take-off performance
   b. A slush covered runway must be cleared before take-off, even if the performance data for contaminated runway is available
   c. The performance data for take-off is determined in general by means of calculation, only a few values are verified by flight tests
   d. The greater the depth of contamination at constant take-off mass, the more V_1 has to be decreased to compensate for decreasing friction

3. **Reduced take-off thrust is prohibited when:**

   a. it is dark
   b. the runway is wet
   c. obstacles are present close to the end of the runway
   d. the runway is contaminated

4. **If the anti-skid system is inoperative, which of the following statements is true?**

   a. It has no effect on the accelerate-stop distance
   b. Take-off with anti-skid inoperative is not permitted
   c. The accelerate-stop distance increases
   d. The accelerate-stop distance decreases

5. **A runway is contaminated by a 0.5 cm layer of wet snow. The take-off is nevertheless authorized by a light-twin's flight manual. The take-off distance in relation to a dry runway will be:**

   a. very significantly decreased
   b. increased
   c. unchanged
   d. decreased

6. **Reduced take-off thrust is prohibited when:**

   a. the runway is wet
   b. the OAT is ISA +10°C
   c. anti-skid is unserviceable
   d. it is dark

7. **Reduced take-off thrust should normally not be used when:**

a. it is dark
b. the runway is dry
c. the runway is wet
d. windshear is reported on the take-off path

8. **When V_1 has to be reduced because of a wet runway, the one engine out obstacle clearance/ climb performance:**

a. increases / increases
b. remains constant / remains constant
c. decreases / decreases
d. decreases / remains constant

9. **The climb limited take-off mass can be increased by:**

a. selecting a lower V_R
b. a lower flap setting for take-off and selecting a higher V_2
c. selecting a lower V_1
d. selecting a lower V_2

10. **Due to a lot of standing water on the runway the field length limited take-off mass will be:**

a. only higher for three and four engine aeroplanes
b. lower
c. higher
d. unaffected

11. **Reduced take-off thrust:**

a. can be used if the headwind component during take-off is at least 10 kt
b. has the benefit of improving engine life
c. can be used if the actual take-off mass is higher than the performance limited take-off mass
d. is not recommended at very low temperatures

12. **Which statement about reduced thrust is correct?**

a. In case of reduced thrust V_1 should be decreased
b. Reduced thrust can be used when the actual take-off mass is less than the field length limited take-off mass
c. Reduced thrust is primarily a noise abatement procedure
d. Reduced thrust is used in order to save fuel

13. **What is the effect of a greater contamination depth on the reduction to the take-off mass and the reduction to V_1 respectively?**

a. Increase, decrease
b. Decrease, decrease
c. Increase, increase
d. Decrease, increase

Answers

1	2	3	4	5	6	7	8	9	10	11	12
b	c	d	c	b	c	d	d	b	b	b	b

13
a

Chapter

16

Class A - Take-off Climb

Take-off Climb

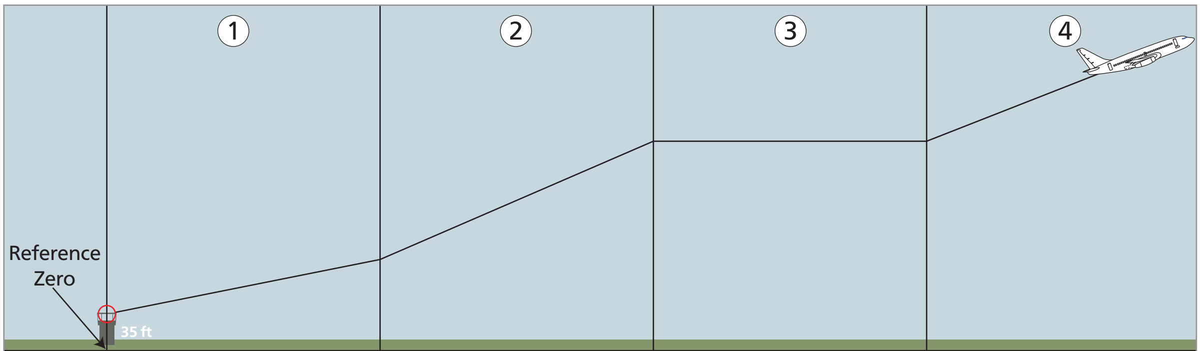
The take-off climb or take-off flight path extends from 35 ft above the take-off surface to 1500 ft above the take-off surface. However, with a contaminated runway take-off, the take-off climb begins at 15 ft and not 35 ft. The point on the ground directly below the 35 ft screen is called “reference zero”. There are two main requirements that must be met within the take-off climb and these requirements are based upon an engine failure occurring at V_{EF}. Remember that performance of Class A aeroplanes must account for engine failure in all flight phases.

The first requirement is that the aeroplane must be able to achieve the minimum climb gradients and secondly the aeroplane must be able to maintain sufficient obstacle clearance. Remember that the climb gradient requirements are air based gradients and the obstacle clearance requirement use ground based gradients.

When assessing compliance with the regulations, the manufacturer or operator may either use a continuous demonstrated take-off climb or a segmented take-off climb. Segmenting the take-off climb does make the requirements and the procedure a little easier to comprehend; therefore, we will use a segmented take-off climb profile as do most operators and manufacturers.

Segments of the Take-off Climb

The take-off climb is generally split into four unique segments and these are shown in *Figure 16.1.* Each segment is characteristic of a distinct change in aeroplane configuration, speed and/or thrust with various actions and climb gradient requirements. Generally there are four segments and you will need to learn what unique characteristics define each segment.



Starts	35 ft	Gear Up	> 400 ft AGL	Flaps Up V_{FTO} MCT
Actions	Select Gear Up	Climb to > 400 ft AGL	Retract Flaps Accelerate to V_{FTO} Set MCT	Climb to 1500 ft AGL
Speed	V_2	V_2	V_2 V_{ZF} V_{FTO}	V_{FTO}
Ends	Gear Up	> 400 ft AGL	Flaps Up V_{FTO} MCT	1500 ft AGL
Gradient for 2 Engines	> 0%	≥ 2.4%	N/A	≥ 1.2%
Gradient for 3 Engines	> 0.3%	≥ 2.7%	N/A	≥ 1.5%
Gradient for 4 Engines	> 0.5%	≥ 3.0%	N/A	≥ 1.7%

Figure 16.1 The segments of the take-off climb for a typical Class A aeroplane

Segment 1

The take-off flight path starts once the take-off is complete, in other words at 35 ft with the aeroplane at V_2 with one engine inoperative. The 35 ft screen marks the start point of segment 1. The objective at this point is to climb, as expeditiously as possible, which is difficult because of the lack of excess thrust due to the large amount of drag created by the gear and flaps and the fact that one engine is deemed inoperative. Therefore, the strategy is to retract the gear and flaps as soon as possible. Since retracting flaps at low speeds close to the ground is dangerous, the only option is to retract the gear.

Once the gear is up and locked then the first segment is finished. During this segment the steady gradient of climb must be positive.

Segment 2

The second segment starts at the end of the first segment, i.e. when the gear is up. The objective now is to retract the flaps. However, flap retraction is not permitted below 400 ft, therefore the action by the pilot is simply to climb, at no less than V_2, until 400 ft is reached. Once 400 ft is reached and flap retract can commence, segment 2 ends. Since the aeroplane has had the main source of drag removed, the minimum gradient requirement is more severe at no less than 2.4%.

Segment 3

Segment three starts at or above 400 ft and is the flap retraction and acceleration segment. However, retracting the flaps will increase the stall speed. This reduces the aeroplane's safety margin. Therefore, the aeroplane must accelerate during flap retraction from V_2 to the zero flap speed and then to the final take-off speed. The final take-off speed is also called the final segment speed and is intended to be the one engine inoperative best angle of climb speed. Once this has happened, thrust can be reduced from maximum take-off thrust, TOGA, to maximum continuous thrust, MCT. In fact, maximum take-off thrust is limited to only 10 minutes, therefore, acceleration and flap retraction must be complete by then. We require excess thrust to enable us to climb or accelerate and as our priority in this segment is to accelerate there is no minimum climb gradient required. The only way we can quantify this acceleration requirement, is by stating that the excess thrust available would be equivalent to a minimum climb gradient of 1.2%.

Segment 4

The fourth segment starts when the flaps are retracted, the final segment speed is achieved and the thrust is set to maximum continuous thrust. From this point the aeroplane is climbed to above 1500 ft where the take-off flight path ends. The pilot will either recover to the airfield or continue to his take-off alternate. The climb gradient for this last stage must not be less than 1.2%.

The gradient requirements for Class A aeroplanes with more than two engines form part of the syllabus and therefore they need to be remembered as well. Although we have already mentioned it in the previous chapter, the climb limit mass tells us what the maximum mass of the aeroplane can be in order to achieve the minimum gradient requirements. Having a mass greater than the climb limit mass would mean that the aeroplane will not have sufficient performance in the event of engine failure to achieve the climb gradient requirements. The graph to calculate the climb limit mass is on *page 11 of section 4 in CAP 698*. We have worked through an example in the previous chapter, but none the less ensure you are confident in being able to use this graph. The introduction to the climb section, shown on page 10 of section 4 reiterates the climb requirements and it states that during the take-off climb the aeroplane must:

a. Attain the most severe gradient requirement of the take-off net flight path, and

b. Avoid all obstacles in the obstacle accountability area by the statutory minimum vertical interval.

Both these requirements have already been mentioned at the beginning of this chapter. The climb limit mass deals with point a. In other words, being at or below the climb limit mass guarantees attainment of the most severe gradient requirement of the take-off flight path. What is the most severe angle of the take-off flight path? The most severe gradient requirement is in segment 2, which for a twin engine jet aeroplane is 2.4%. Therefore the climb limit mass ensures that the aeroplane, in the event of engine failure is able to attain a 2.4% gradient or more. Remember that these climb gradients are air based and therefore independent of the effect of wind. Looking through the climb limit mass graph confirms this since there is no wind component shown.

Obstacle Clearance

Having discussed the minimum climb gradient requirements and how to ensure the aeroplane attains them, we need to focus on the obstacle clearance requirements. In EU-OPS it states that an operator must ensure that the net take-off flight path must clear all obstacles by a vertical margin of at least 35 ft. If the aeroplane is unable to do so it must turn away from the obstacle and clear it by a horizontal distance of at least 90 m plus 0.125 × D, where D is the horizontal distance the aeroplane has travelled from the end of the take-off distance available.

90 m + 0.125D

For aeroplanes with a wingspan of less than 60 m a horizontal obstacle clearance of half the aeroplane wingspan plus 60 m, plus 0.125 × D may be used.

60 m + ½ wing span + 0.125D

However, obstacles further away than the values shown below need not be considered.

Condition	Maximum Semi-width	
Change of Track Direction	**0° to 15°**	**Over 15°**
Able to Maintain Visual Guidance or same Accuracy	300 m	600 m
All Other Conditions	600 m	900 m

We have seen this horizontal clearance information before when we were discussing multi-engine Class B obstacle clearance. However, there are two crucial points to consider when trying to work out the vertical clearance.

The first relates to climb gradient, which, if you remember, is a ground based gradient. In order to work out the obstacle clearance of the aeroplane, the climb gradient needs to be known. But EU-OPS states that the climb gradient to use for the purpose of calculating obstacle clearance must be the net climb gradient. Remember that the net gradient is the gross gradient diminished by a safety factor. In this case the safety factor changes depending on the number of engines.

The net gradient is the gross gradient reduced by:

0.8% for 2-engine aircraft
0.9% for 3-engine aircraft
1.0% for 4-engine aircraft

Using the net gradient instead of the gross gradient in the take-off flight path will produce a net take-off flight path. As we stated at the beginning, the net take-off flight path must clear all obstacles by 35 ft.

The second point to consider is the effect of wind on the ground gradient. Headwinds will increase the ground gradient and improve obstacle clearance, whereas tailwinds will decrease the ground gradient and deteriorate the obstacle clearance. EU-OPS states that when adjusting for wind to calculate the ground gradient, no more than 50% of the reported headwind and no less than 150% of the reported tailwind must be used. Carrying out this rule simply adds another safety margin into the calculation.

We stated that if the aeroplane is unable to clear the obstacle vertically, then it can turn away from the obstacle and clear it horizontally. However, there are restrictions on how much the aeroplane is allowed to turn. Clearly it is not safe if the aeroplane needs to bank sharply to clear the obstacle by the regulatory margins. Turning can increase the effective weight by imposing extra g loads and therefore the climb gradient is reduced and stall speeds are increased. Allowance must be made for the effect of the turn on the climb gradient and speed. The flight manual usually gives a gradient decrement for a 15° banked turn at V_2. For greater bank angles:

- For 20° bank, use 2 × gradient decrement and V_2 + 5 kt
- For 25° bank, use 3 × gradient decrement and V_2 + 10 kt

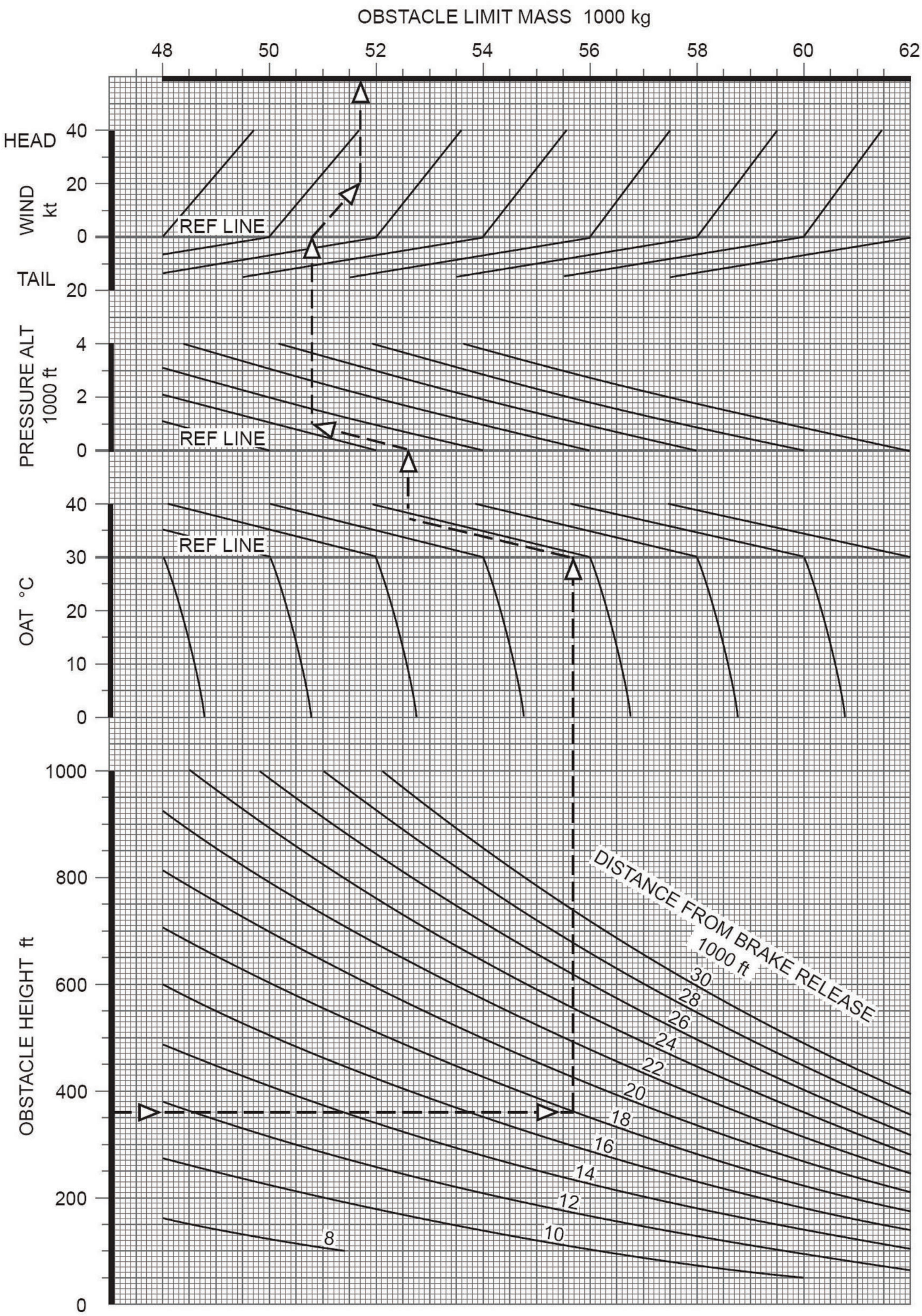
Turns on the Flight Path

- Turns are not allowed below a height of half the wingspan or 50 ft whichever is greater.
- Up to 400 ft, bank angle may not be more than 15°.
- Above 400 ft, bank angle may not be more than 25°.

EU-OPS 1.495 does permit operators to exceed these bank angles providing that the operator uses special procedures and that these procedures have been approved by the relevant authority. The special procedures must take account of the gradient loss from such bank angles and these must be published in the aeroplane flight manual. The maximum bank angles that the special procedures allow are up to 20° between 200 and 400 ft and up to 30 ° between 400 and 1500 ft.

If any turn of more than 15° is required at any point in the take-off flight path, then the vertical clearance is increased to 50 ft instead of 35 ft. Manually working out the obstacle clearance capability of the aeroplane could take a long time, since there are so many points to bear in mind and the calculation itself is quiet lengthy. Thankfully, most operators and manufactures have produced either rapid look-up tables or graphs to quickly enable the pilot to work out if an obstacle in the take-off climb will be cleared by the relevant vertical margins following engine failure. These tables or graphs will produce a mass. This mass is called the obstacle limit mass and an example is shown in *Figure 16.2* which can also be found in *CAP 698 on pages 36 and 37 of section 4*. It is the maximum mass that will allow the aeroplane, in the event of engine failure, to clear the obstacle by the relevant vertical margin.

Notice that winds are included on the graph. This is important because obstacle clearance calculations must use ground gradients and these are dependent on wind. In fact, remember that EU-OPS had a rule about the wind. It stated that when using the winds to work out the ground gradient only use 50% of headwinds and no less than 150% tailwinds. Notice the slope of the headwind and tailwind lines. This shows that the graph applies the wind rule for you. Therefore, if you enter the graph with the actual reported wind, the graph corrects it automatically so you do not need to.



PMC OFF CORRECTION

TEMPERATURE °C	MASS DECREMENT kg
21.1 & BELOW	4970
ABOVE 21.1	4420

OBSTACLE HEIGHT MUST BE CALCULATED FROM THE LOWEST POINT OF THE RUNWAY TO CONSERVATIVELY ACCOUNT FOR RUNWAY SLOPE

Figure 16.2 Obstacle limit mass

Once the details of the obstacle have been entered, as shown by the example, the obstacle limit mass can be read off, and, in the example on the graph itself the obstacle limit mass is 51 700 kg. Taking off with a higher mass than this would not ensure adequate vertical clearance. However, if this mass unduly restricts the take-off mass, then the aeroplane may be despatched with a greater mass so long as the aeroplane turns around the obstacle, clearing it by the relevant horizontal margins and does not exceed the turn restrictions when trying to do so.

Noise Abatement Procedures

Aeroplane operating procedures for the take-off climb shall ensure that the necessary safety of flight operations is maintained whilst minimizing exposure to noise on the ground.

The first procedure (NADP 1) is intended to provide noise reduction for noise-sensitive areas in close proximity to the departure end of the runway *(see Figure 16.3).* The second procedure (NADP 2) provides noise reduction to areas more distant from the runway end *(see Figure 16.4)*. The two procedures differ in that the acceleration segment for flap/slat retraction is either initiated prior to reaching the maximum prescribed height or *at* the maximum prescribed height. To ensure optimum acceleration performance, thrust reduction may be initiated at an intermediate flap setting.

NADP 1

This procedure involves a power reduction at or above the prescribed minimum altitude and the delay of flap/slat retraction until the prescribed maximum altitude is attained. At the prescribed maximum altitude, accelerate and retract flaps/slats on schedule whilst maintaining a positive rate of climb, and complete the transition to normal en route climb speed.

The noise abatement procedure is not to be initiated at less than 800 ft above aerodrome elevation. The initial climbing speed to the noise abatement initiation point shall not be less than V_2 plus 20 km/h (10 kt). On reaching an altitude at or above 800 ft above aerodrome elevation, adjust and maintain engine power/thrust in accordance with the noise abatement power/thrust schedule provided in the aircraft operating manual. Maintain a climb speed of V_2 plus 20 to 40 km/h (10 to 20 kt) with flaps and slats in the take-off configuration.

At no more than an altitude equivalent to 3000 ft above aerodrome elevation, whilst maintaining a positive rate of climb, accelerate and retract flaps/slats on schedule. At 3000 ft above aerodrome elevation, accelerate to en route climb speed.

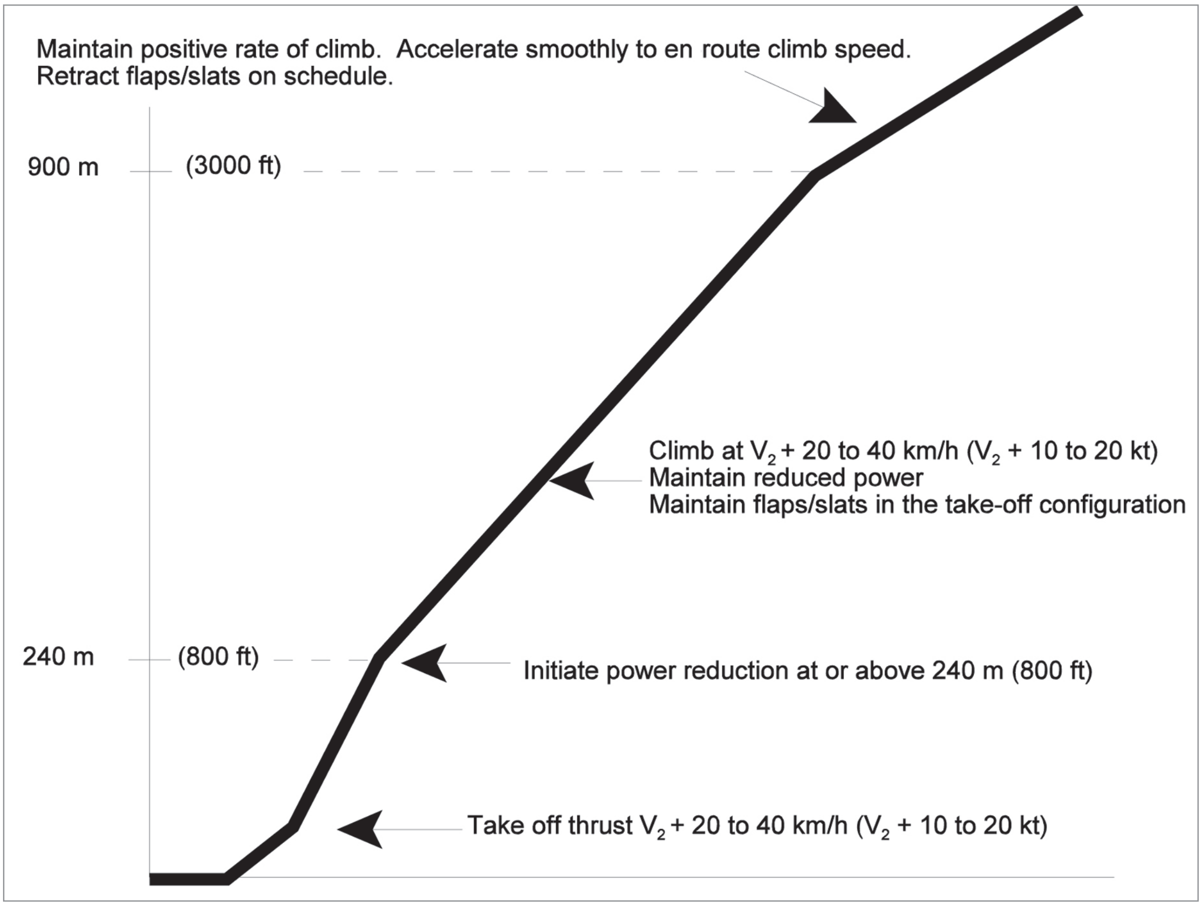


Figure 16.3 Noise abatement take-off climb - example of a procedure alleviating noise close to the aerodrome (NADP 1)

NADP 2

This procedure involves initiation of flap/slat retraction on reaching the minimum prescribed altitude. The flaps/slats are to be retracted on schedule whilst maintaining a positive rate of climb. The power reduction is to be performed with the initiation of the first flap/slat retraction or when the zero flap/slat configuration is attained. At the prescribed altitude, complete the transition to normal en route climb procedures.

The noise abatement procedure is not to be initiated at less than 800 ft above aerodrome elevation. The initial climbing speed to the noise abatement initiation point is V_2 plus 20 to 40 km/h (10 to 20 kt). On reaching an altitude equivalent to at least 800 ft above aerodrome elevation, decrease aircraft body angle/angle of pitch whilst maintaining a positive rate of climb, accelerate towards V_{ZF} and either:

- reduce power with the initiation of the first flap/slat retraction; or
- reduce power after flap/slat retraction.

Maintain a positive rate of climb, and accelerate to and maintain a climb speed of V_{ZF} + 20 to 40 km/h (10 to 20 kt) to 3000 ft above aerodrome elevation. On reaching 3000 ft above aerodrome elevation, transition to normal en route climb speed.

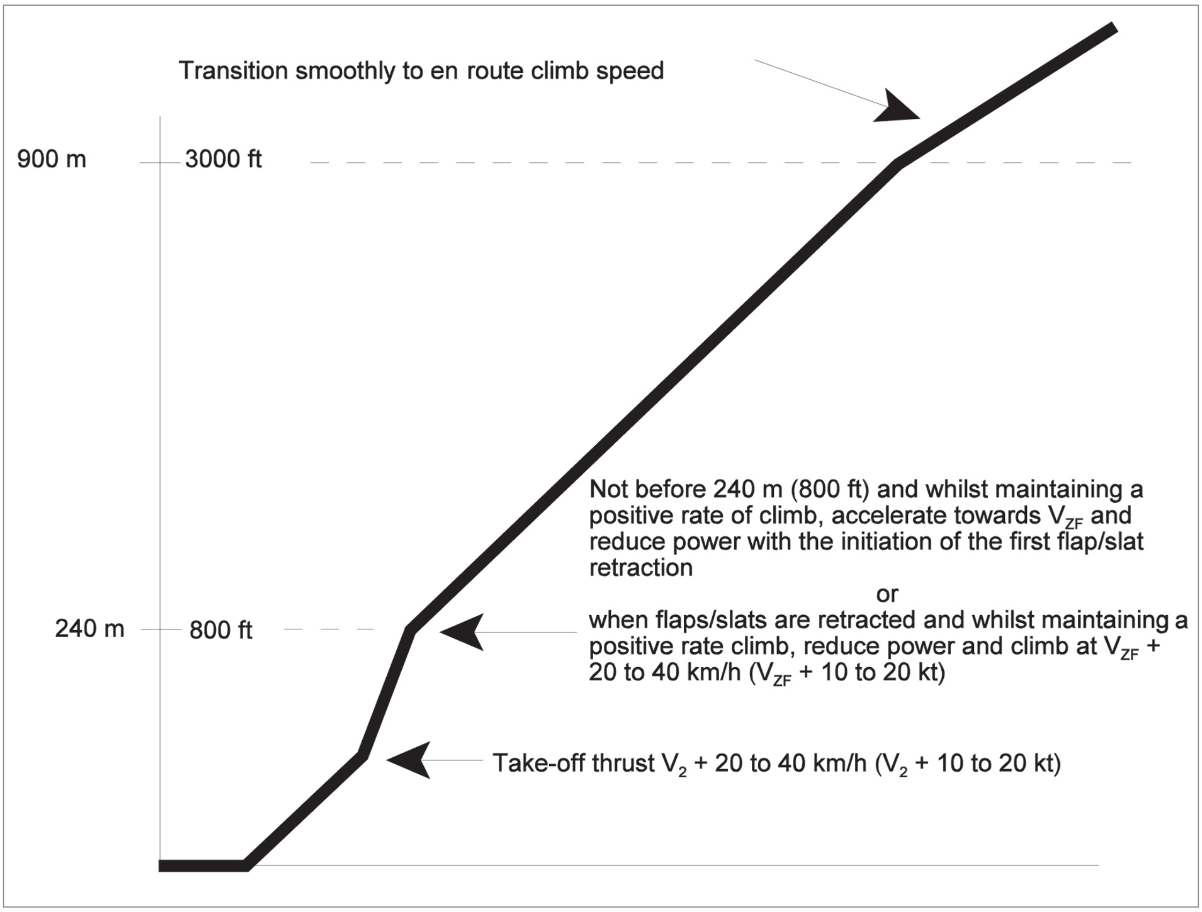


Figure 16.4 Noise abatement take-off climb - example of a procedure alleviating noise distant from the aerodrome (NADP 2)

Questions

1. **The net flight path climb gradient after take-off compared to the gross climb gradient is:**

    a. larger
    b. equal
    c. depends on type of aircraft
    d. smaller

2. **Given that the characteristics of a three-engine turbojet aeroplane are as follows:**

    Thrust = 50 000 N per engine
    g = 10 m/s²
    Drag = 72 569 N
    Minimum gross gradient (2nd segment) = 2.7%

    The maximum take-off mass under segment two conditions in the net take-off flight path conditions is:

    a. 101 596 kg
    b. 286 781 kg
    c. 74 064 kg
    d. 209 064 kg

3. **During the flight preparation the climb limited take-off mass (TOM) is found to be much greater than the field length limited TOM using 5° flap. In what way can the performance limited TOM be increased? There are no limiting obstacles.**

    a. By selecting a higher flap setting
    b. By selecting a higher V_2
    c. By selecting a lower V_2
    d. By selecting a lower flap setting

4. **An operator shall ensure that the net take-off flight path clears all obstacles. The half-width of the obstacle-corridor at the distance D from the end of the TODA is at least:**

    a. -90 m + 1.125D
    b. 90 m + D/0.125
    c. 90 m + 0.125D
    d. 0.125D

5. **The 'climb gradient' is defined as the ratio of:**

    a. true airspeed to rate of climb
    b. rate of climb to true airspeed
    c. the increase of altitude to horizontal air distance expressed as a percentage
    d. the horizontal air distance over the increase of altitude expressed as a percentage

6. **Which of the following statements, concerning the obstacle limited take-off mass for performance Class A aeroplanes, is correct?**

a. It should not be corrected for 30° bank turns in the take-off path
b. It should be calculated in such a way that there is a margin of 50 ft with respect to the "net take off flight path"
c. It cannot be lower than the corresponding climb limited take-off mass.
d. It should be determined on the basis of a 35 ft obstacle clearance with the respect to the "net take-off flight path"

7. **The determination of the maximum mass on brake release, of a certified turbojet aeroplane with 5°, 15° and 25° flaps angles on take-off, leads to the following values, with wind:**

Flap angle:	**5°**	**15°**	**25°**
Runway limitation:	**66 000**	**69 500**	**71 500**
2nd segment slope limitation:	**72 200**	**69 000**	**61 800**

Wind correction: Headwind: + 120 kg per kt OR Tailwind: - 360 kg per kt

Given that the tailwind component is equal to 5 kt, the maximum mass on brake release and corresponding flap angle will be:

a. 67 700 kg / 15 deg
b. 69 000 kg / 15 deg
c. 72 200 kg / 5 deg
d. 69 700 kg / 25 deg

8. **The requirements with regard to take-off flight path and the climb segments are only specified for:**

a. the failure of two engines on a multi-engine aeroplane
b. the failure of the critical engine on a multi-engine aeroplane
c. the failure of any engine on a multi-engine aeroplane
d. 2 engine aeroplane

9. **The first segment of the take-off flight path ends:**

a. at completion of gear retraction
b. at completion of flap retraction
c. at reaching V_2
d. at 35 ft above the runway

10. **Which statement, in relation to the climb limited take-off mass of a jet aeroplane, is correct?**

a. 50% of a head wind is taken into account when determining the climb limited take-off mass
b. On high elevation airports equipped with long runways the aeroplane will always be climb limited
c. The climb limited take-off mass decreases with increasing OAT
d. The climb limited take-off mass is determined at the speed for best rate of climb

11. Which one of the following is not affected by a tailwind?

a. The field limited take-off mass
b. The obstacle limited take-off mass
c. The take-off run
d. The climb limited take-off mass

12. How does TAS vary in a constant Mach climb in the troposphere?

a. TAS increases
b. TAS is constant
c. TAS is not related to Mach Number
d. TAS decreases

13. For this question use Figure 4.5 in CAP 698 Section 4.
With regard to the take-off performance of a twin jet aeroplane, why does the take-off performance climb limit graph show a kink at 30°C, pressure altitude 0 ft?

a. At lower temperatures one has to take the danger of icing into account
b. The engines are pressure limited at lower temperatures, at higher temperatures they are temperature limited
c. At higher temperatures the flat rated engines determines the climb limit mass
d. At higher temperatures the V_{MBE} determines the climb limit mass

14. Which of the following sets of factors will increase the climb limited take-off mass (TOM)?

a. High flap setting, low PA, low OAT
b. Low flap setting, high PA, high OAT
c. Low flap setting, high PA, low OAT
d. Low flap setting, low PA, low OAT

15. For this question use Figure 4.5 in CAP 698 Section 4.
Consider the take-off performance for the twin jet aeroplane climb limit chart. Why has the wind been omitted from the chart?

a. There is a built-in safety measure
b. The climb limit gradient requirements are taken relative to the air
c. The effect of the wind must be taken from another chart
d. There is no effect of the wind on the climb angle relative to the ground

16. Which of the following statements is applicable to the acceleration height at the beginning of the 3rd climb segment?

a. The minimum legally allowed acceleration height is at 1500 ft
b. There is no minimum climb performance requirement when flying at the acceleration height
c. The minimum one engine out acceleration height must be maintained in case of all engines operating
d. The maximum acceleration height depends on the maximum time take-off thrust may be applied

17. **In relation to the net take-off flight path, the required 35 ft vertical distance to clear all obstacles is:**

a. based on pressure altitudes
b. the height by which acceleration and flap retraction should be completed
c. the height at which power is reduced to maximum climb thrust
d. the minimum vertical distance between the lowest part of the aeroplane and all obstacles within the obstacle corridor

18. **Which of the following statements is correct?**

a. The performance limited take-off mass is independent of the wind component
b. The accelerate-stop distance required is independent of the runway condition
c. The take-off distance with one engine out is independent of the wind component
d. The climb limited take-off mass is independent of the wind component

19. **Which of the following statements with regard to the actual acceleration height at the beginning of the 3rd climb segment is correct?**

a. The minimum value according to regulations is 1000 ft
b. There is no legal minimum value, because this will be determined from case to case during the calculation of the net flight path
c. The minimum value according to regulations is 400 ft
d. A lower height than 400 ft is allowed in special circumstances e.g. noise abatement

20. **For take-off obstacle clearance calculations, obstacles in the first segment may be avoided:**

a. by banking not more than 15° between 50 ft and 400 ft above the runway elevation
b. by banking as much as needed if aeroplane is more than 50 ft above runway elevation
c. only by using standard turns
d. by standard turns – but only after passing 1500 ft

21. **The second segment begins:**

a. when landing gear is fully retracted
b. when flap retraction begins
c. when flaps are selected up
d. when acceleration starts from V_2 to the speed for flap retraction

22. **At which minimum height will the second climb segment end?**

a. 1500 ft above field elevation
b. 400 ft above field elevation
c. 35 ft above ground
d. When gear retraction is completed

23. On a segment of the take-off flight path an obstacle requires a minimum gradient of climb of 2.6% in order to provide an adequate margin of safe clearance. At a mass of 110 000 kg the gradient of climb is 2.8%. For the same power and assuming that the angle of climb varies inversely with mass, at what maximum mass will the aeroplane be able to achieve the minimum gradient?

a. 121 310 kg
b. 106 425 kg
c. 118 461 kg
d. 102 142 kg

24. During take-off, the third segment begins:

a. when acceleration to flap retraction speed is started
b. when landing gear is fully retracted
c. when acceleration starts from V_{LOF} to V_2
d. when flap retraction is completed

25. If there is a tailwind, the climb limited take-off mass will:

a. increase
b. decrease
c. increase in the flaps extended case
d. not be affected

26. A higher pressure altitude at ISA temperature:

a. has no influence on the allowed take-off mass
b. decreases the field length limited take-off mass
c. decreases the take-off distance
d. increases the climb limited take-off mass

27. The minimum climb gradient required on the 2nd flight path segment after the take-off of a jet aeroplane is defined by the following parameters:

1. Gear up
2. Gear down
3. Wing flaps retracted
4. Wing flaps in take-off position
5. All engines at the take-off thrust
6. One engine inoperative, remainder at the take-off thrust
7. Speed equal to V_2 + 10 kt
8. Speed equal to $1.3V_S$
9. Speed equal to V_2
10. At a height of 35 ft above the runway

The correct statements are:

a. 2, 3, 6, 7
b. 1, 4, 5, 10
c. 1, 5, 8, 10
d. 1, 4, 6, 9

28. **In the event that the take-off mass is obstacle limited and the take-off flight path includes a turn, the maximum bank angle is:**

a. 10 degrees up to a height of 400 ft
b. 20 degrees up to a height of 400 ft
c. 25 degrees up to a height of 400 ft
d. 15 degrees up to height of 400 ft

29. **Up to which height in noise abatement departure procedure 1 (NADP 1) must V_2 + 10 to 20 kt be maintained?**

a. 1500 ft
b. 3000 ft
c. 800 ft
d. 500 ft

30. **Reference point zero refers to the:**

a. point where the aircraft lifts off the ground
b. point where the aircraft reaches V_2
c. point on the ground where the aircraft reaches 35 ft
d. point where gear is selected up

31. **A Boeing 737 has a wingspan of 28.9 m. An obstacle is situated at a distance of 4264 ft from the end of the TODA. What is the minimum horizontal obstacle clearance?**

a. 607.45 m
b. 252.50 m
c. 236.95 m
d. 240 m

Answers

1	2	3	4	5	6	7	8	9	10	11	12
d	a	a	c	c	d	a	b	a	c	d	d

13	14	15	16	17	18	19	20	21	22	23	24
b	d	b	b	d	d	c	a	a	b	c	a

25	26	27	28	29	30	31
d	b	d	d	b	c	c

Chapter

17

Class A - En Route

En Route Phase

The en route phase of flight starts at 1500 ft above the departure aerodrome and ends once the aeroplane has reached 1500 ft above the intended destination aerodrome. As with other phases of flight for Class A aeroplanes, the en route regulations account for engine failure. Therefore, manufacturers and operators of Class A aeroplanes must ensure that the performance of the aeroplane subsequent to engine failure is still able to meet the regulation requirements.

Firstly we will discus the climb to the en route altitude, then we will detail the en route altitudes and how they are calculated as well as discussing various flight speeds. Lastly we will detail the descent, both normal descent, and the descent forced by either engine failure or depressurization.

Climb Profile / Climb Schedule

After a normal take-off, climbing to the en route altitude is a straightforward affair. Once the aeroplane configuration is clean, a set climb profile or climb schedule will be flown. Initially the aeroplane climbs at a constant indicated airspeed. However, continuously climbing at a constant indicated airspeed causes the Mach number to rise. Beyond a certain altitude, the Mach number gets too high and serious aerodynamic forces start to affect the aeroplane. In the 737 family the maximum Mach number, M_{MO} is 0.82. Therefore, at some lower altitude the aeroplane needs to change its climb profile to a constant Mach number climb. The altitude at which this change occurs is called the crossover or changeover altitude.

In brief summary then, the climb profile involves the aeroplane initially climbing at a constant indicated airspeed, and then at the crossover altitude, the aeroplane climbs at a constant Mach number. However, ICAO limits the maximum indicated airspeed to 250 knots below 10 000 ft. For the majority of the 737 family, the climb profile is 250 knots indicated airspeed up to 10 000 ft, then the aeroplane is accelerated to 280 knots and the climb continued at 280 knots. As the aeroplane climbs, the Mach number will increase and when the Mach number reaches 0.74, the aeroplane maintains a climb speed of 0.74 until the en route cruise altitude. Using *Figure 17.1* you will notice that the crossover altitude is at about 25 700 ft.

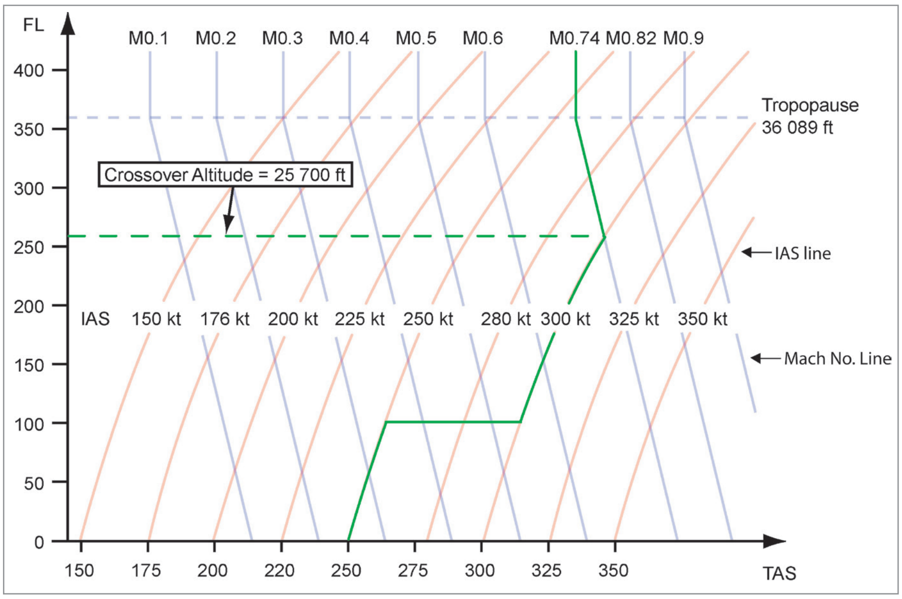


Figure 17.1

However, you need to understand what happens to the crossover altitude if a faster indicated airspeed climb is maintained, and for this example we will increase the second part of the indicated airspeed climb from 280 to 325 knots. Looking at *Figure 17.2*, initially the aeroplane will still climb at 250 knots, but, once reaching 10 000 ft the aeroplane will be accelerated to 325 knots and then climb at 325 knots. Once the Mach number has increased to 0.74, then the aeroplane climbs at 0.74. Notice now the crossover altitude is lower at 18 000 ft. Therefore if the indicated airspeed is increased in the climb profile, the crossover altitude decreases to a lower altitude.

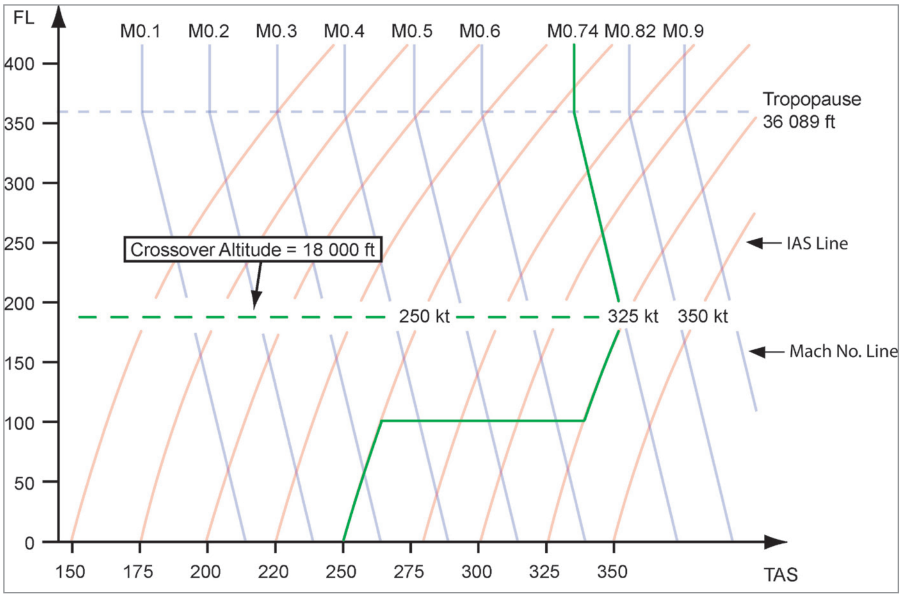


Figure 17.2 A typical climb schedule using a faster indicated airspeed

Cruise Speeds

Before we proceed to discuss the en route altitude, it is important at this point to briefly detail a few important speeds, most of which you have already covered. These speeds are commonly expressed as Mach numbers. The first of these speeds is the maximum operating speed, either called V_{MO} when using indicated airspeed or M_{MO} when using Mach numbers. For the majority of the 737 family V_{MO} is 340 knots and M_{MO} is 0.82. Flying beyond these speeds in a commercial operational context is not permitted and may cause either structural damage or a high speed stall.

The next two speeds are used in reference to describing the range of the aeroplane and were mentioned in the en route chapter of the general performance principles section. These two speeds are the maximum range cruise speed, MRC, and long range cruise speed, LRC. When these speeds are referenced in terms of a Mach number the abbreviation is changed to M_{MR} (Mach number for maximum range) and M_{LRC} (Mach number for long range cruise) respectively.

As you can see from *Figure 17.3*, plotting cost and speed, the advantage of flying at the maximum range speed is simply that the aeroplane will use the least amount of fuel and therefore have the least fuel cost for a given distance. However, operationally, the faster “long range cruise” is used. The simple reason why this speed is used is because by getting to destination more quickly, more revenue earning flights can be carried out in any given period. In other words, over a given time period 4% more flights can be carried out with only a fuel consumption increase of 1%. The long range cruise speed does suffer from limitations. It does not take into account the variable cost of fuel from day to day or month to month and neither does it account for the operational costs. When fuel prices are high, the extra fuel consumption may dramatically increase the overall cost of the flight and a more operationally economical speed may need to be flown. The relationship of these costs is explained by the use of a cost index and the speed flown based upon the cost index is called “ECON”. This will be discussed next.

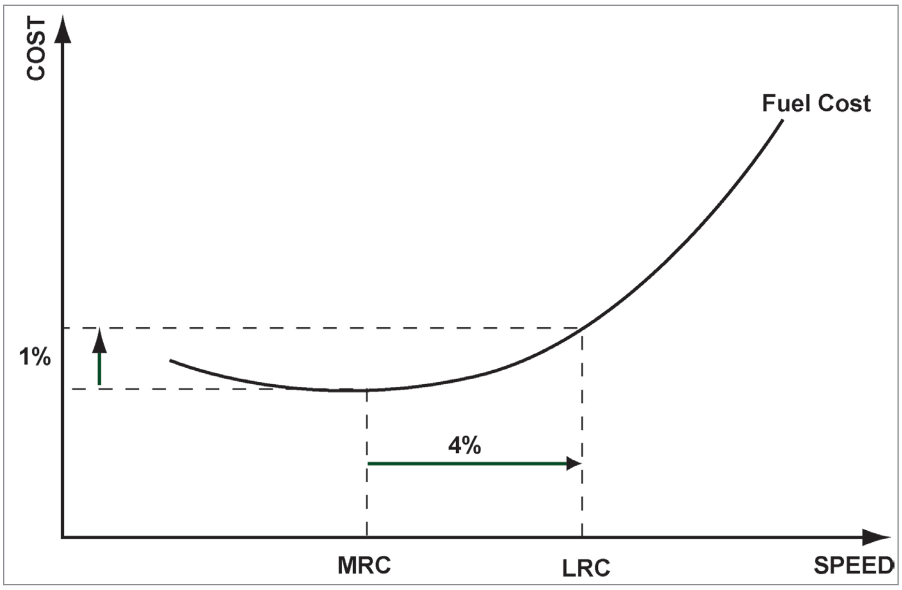


Figure 17.3 A graph showing the relation between the long range cruise speed (LRC) & the maximum range cruise speed (MRC)

Cost Index

The fundamental rationale of the cost index concept is to achieve minimum operation trip cost by means of a trade-off between time-related costs and fuel-related costs. The cost index is used to take into account the relationship between fuel-related costs and time-related costs. With time-related costs, the faster the aircraft is flown, the more money is saved in time costs. This is because the faster the aircraft is flown, the more miles can be flown for time-related components. It also means that more miles can be flown between inspections when considering maintenance costs. These costs are minimum at the maximum operating speed V_{MO}/M_{MO}. However, if the aircraft is flown at such a high speed, the fuel burn increases and total fuel cost for the trip increases. Fuel costs on the other hand will be minimum at the maximum range cruise speed (MRC) and maximum at the maximum operating speed. Adding the time-related costs and fuel-related costs together produces a direct operating cost, or more simplistically, a total operating cost. The flight management system uses the time and fuel-related costs to help select the best speed to fly.

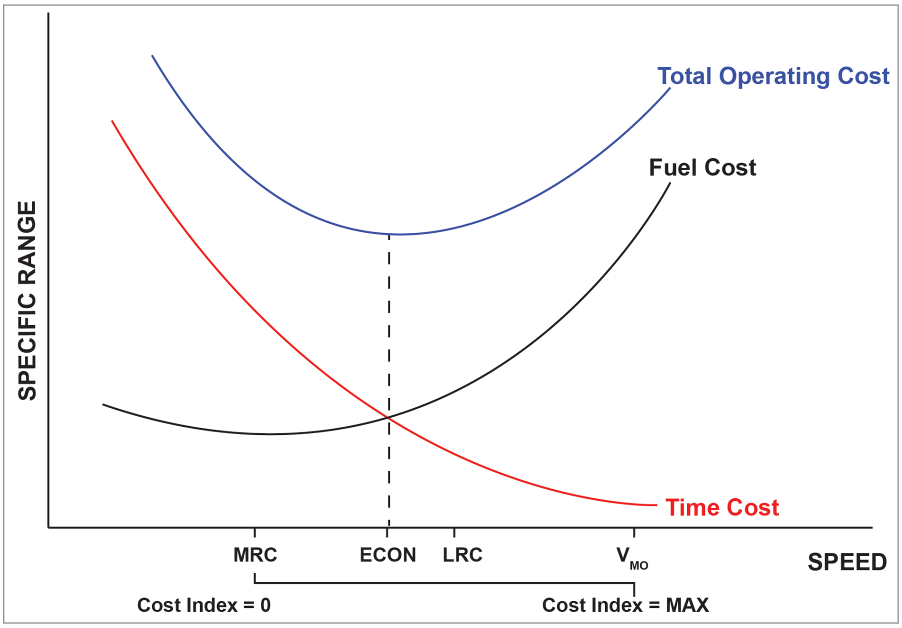


Figure 17.4 A graph plotting the operating costs of the aeroplane against the aeroplane speed

Looking at *Figure 17.4* you can see from the total cost curve that the speed which gives the minimum total operating cost is the most economical speed to fly. This speed is called ECON, in other words the minimum cost speed. The value of the ECON speed is worked out by the flight management system based upon the value of the cost index. As a formula the cost index is a ratio of cost of time, CT, to the cost of fuel, CF.

$$\text{COST INDEX (CI)} = \frac{\text{COST OF TIME(CT)}}{\text{COST OF FUEL(CF)}}$$

When fuel costs are high and time costs are very low, the cost index would be almost zero and the blue total cost line is moved to the left. The intersection point of the other cost lines will lie very close to the maximum range cruise speed giving a cost index of zero. The ECON speed (found at the bottom of the blue line) would now be at the maximum range speed *(see Figure 17.5)*. When time costs are high and fuel costs are low, the cost index would be very high and the blue total cost line moves to the far right of the graph. The ECON speed, found at the bottom of the blue curve would now be very close to the maximum operating speed *(see Figure 17.6)*.

To summarize then, increasing the cost index from zero to maximum will increase the ECON speed from the maximum range speed to maximum operating speed. For most aeroplanes the cost index varies from zero to 99 or from zero to 999.

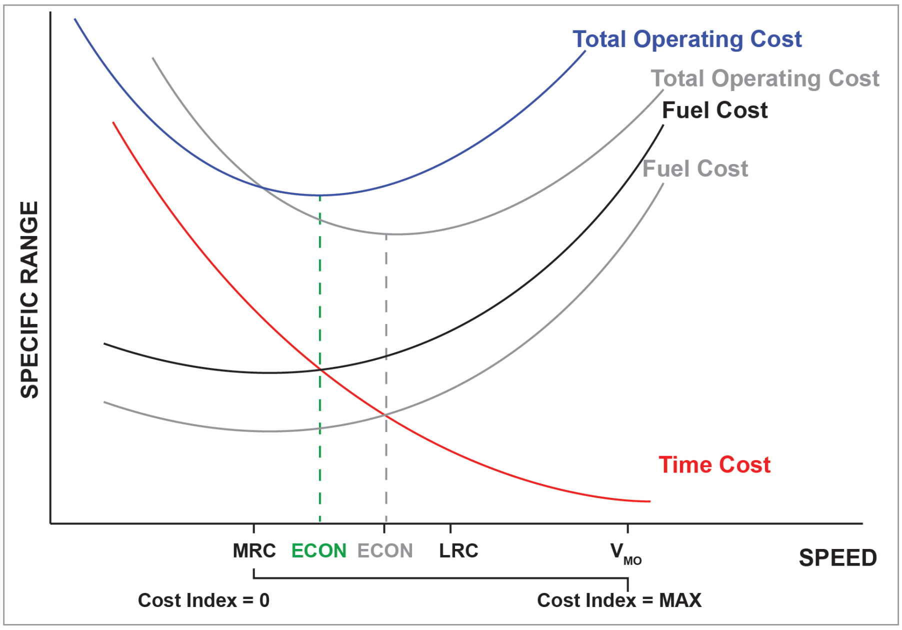


Figure 17.5 A graph plotting the operating cost of the aeroplane against the aeroplane speed

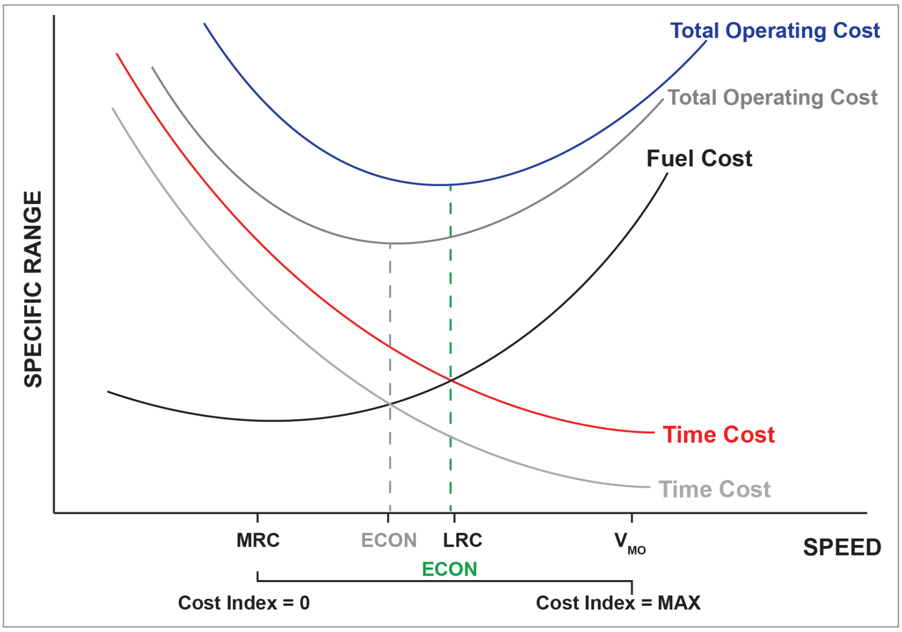


Figure 17.6 A graph plotting the operating cost of the aeroplane against the aeroplane speed

Cruise Altitudes

Once the aeroplane has completed the climb profile and has reached the top of the climb, the aeroplane will level off at the appropriate altitude. This cruise altitude should ideally coincide with optimum altitude. You may recall that the optimum altitude was the altitude for maximum specific range or maximum fuel mileage. As a general rule, this altitude is not constant. As weight decreases during the flight from fuel consumption, the optimum altitude increases, as illustrated in the *Figure 17.7*.

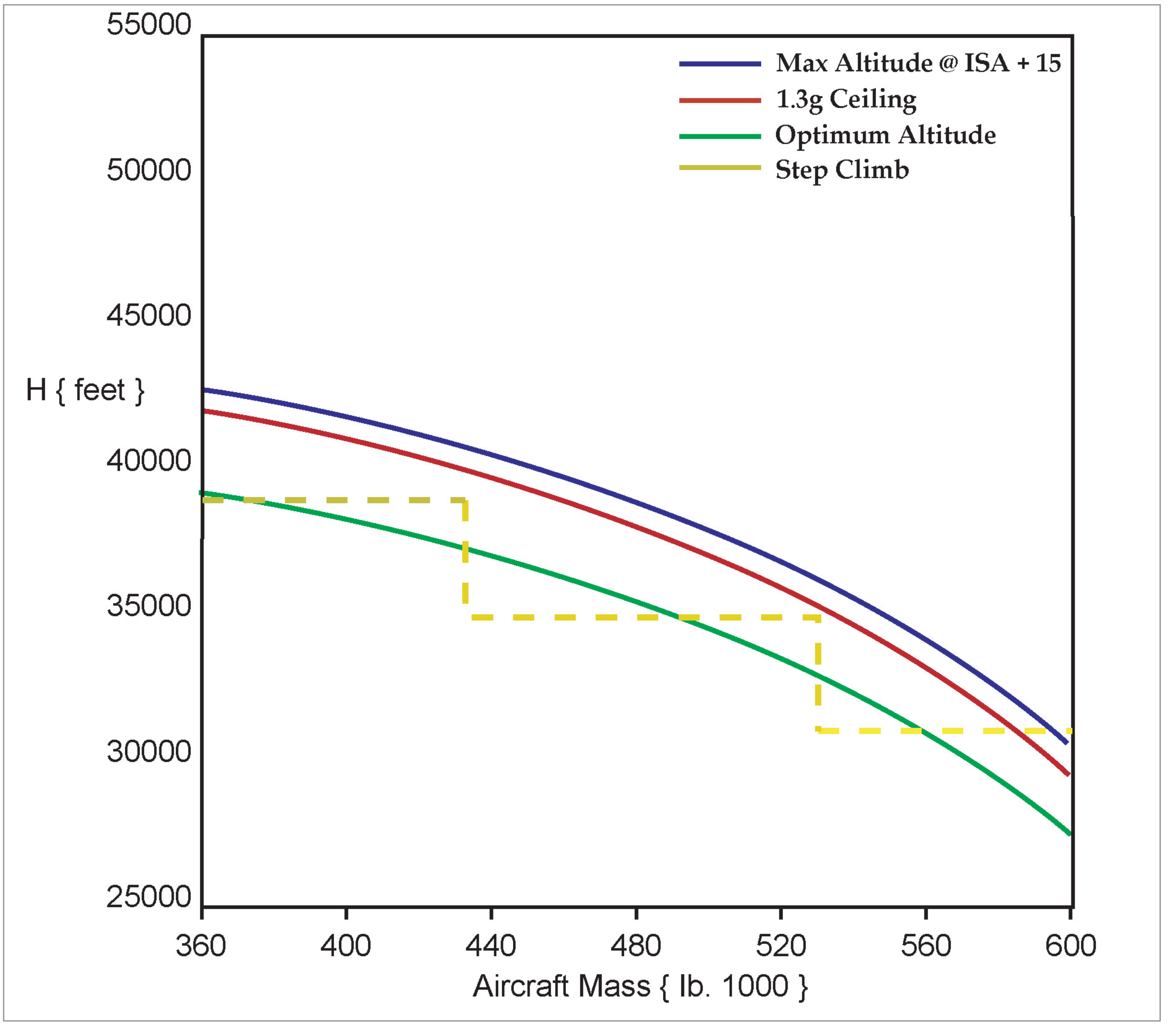


Figure 17.7 A graph showing important altitudes for a typical medium range jet

Therefore, to constantly fly at the optimum altitude, the aeroplane will not actually fly level, but will in fact slowly be climbing in the cruise. On the other hand, ATC restrictions require level flight cruise to ensure vertical separation with other aeroplanes. To try and accommodate ATC in congested airspace aircraft must fly by segments of constant altitude which must be as close as possible to the optimum altitude. The level segments are established within 2000 ft from the optimum altitude. The procedure is called the step climb which you have seen in the General Principles-Cruise chapter. Remaining within 2000 ft of the optimum altitude ensures the range is 99% of the maximum specific range. There may be several step climbs during the flight and the aeroplane will be gaining altitude throughout this process. However, there is a limit to how high the aeroplane is permitted to operate and able to operate.

As the aeroplane altitude increases, the thrust that is required to maintain a given speed increases. Eventually, there will be an altitude where the thrust is increased to its maximum cruise value and it would not be possible to climb any higher without exceeding the thrust limits. This altitude is called the maximum altitude and is shown in *Figure 17.7*. However, the hotter the atmosphere, the lower this altitude becomes and in exceptionally hot atmospheres the maximum altitude is almost the same as the optimum altitude. Although the aeroplane cannot operate above the maximum altitude, there are other altitude limits placed upon the aeroplane.

Aerodynamic Ceiling and Manoeuvre Ceiling

Before we can discuss the other limits on the operating altitude of an aeroplane it is important to discuss aeroplane stalling. When the speed of the aeroplane is reduced, in order to still produce enough lift to balance weight, the angle of attack must increase. However, below a certain speed, the angle of attack on the wings is such that the flow of air over the wing starts to separate from the boundary layer producing turbulent air flow. The separation point fluctuates back and forth along the wing making strong eddies in the turbulent airflow. These strong eddies buffet the elevators or tailplane. This phenomenon is called the low speed buffet. Flying below this speed will dramatically decrease the lift and a full stall ensues.

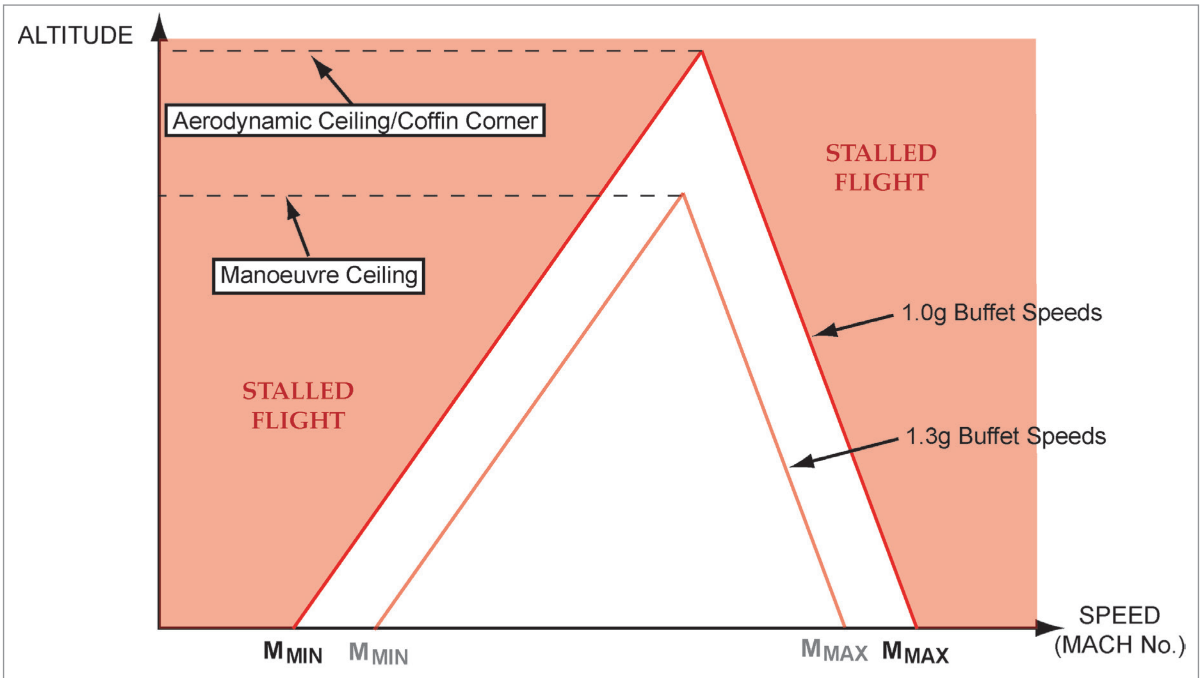


Figure 17.8 The relationship of the Mach number for the low speed & high speed buffets with altitude

For a given weight and configuration, the aeroplane will always stall at the same indicated airspeed but the equivalent Mach number for the low speed buffet and stall increases with altitude as illustrated by a simplistic graph shown in *Figure 17.8*. The Mach number for the low speed buffet is abbreviated to M_{MIN}. A similar buffet can occur at high speed. At very high speeds, close to the speed of sound, the compressibility of the air ahead of the aeroplane leads to the formation of shock waves or high pressure waves. These shock waves create a disturbance to the flow of air over the wing causing it to separate and create turbulent eddies. Similar to the low speed buffet these eddies will buffet the elevator. This phenomenon is called the high speed buffet. Flying faster than this speed may cause a high speed shock stall in an aeroplane whose wings are not designed to overcome such effects. The Mach number for the high speed buffet decreases with increasing altitude, as shown. This speed is commonly abbreviated to M_{MAX} and is shown by the backward sloping red line to the right of the graph in *Figure 17.8*.

Taking into consideration the Mach numbers for both low speed and high speed buffet, it means that there are two Mach numbers, below and above which the aeroplane is unable to fly. This speed range between the Mach numbers for the low speed stall and high speed stall is called the buffet margin. The important point to understand is that the margin between the low speed and high speed buffets decreases with increasing altitude. There is an altitude where the low speed and high speed buffets are equal under 1g conditions and it is impossible to fly higher than this altitude. Flying slower or faster than the speed shown will stall the aeroplane. In fact, even manoeuvring the aeroplane will initiate a stall because manoeuvring the aeroplane will increase the effective weight and increase the stall speed. This altitude is called the aerodynamic ceiling, or coffin corner. To prevent aeroplanes from operating too close to this altitude, an operational limit is set below this point. Notice that a 1.3g manoeuvre moves the buffet speed lines to the faded red position in *Figure 17.8*. Notice also that now, the Mach numbers for the low speed and high speed buffets are coincident at a lower altitude. This altitude is called the 1.3g buffet limit altitude or manoeuvre ceiling and is usually about 4000 to 6000 ft below the aerodynamic ceiling.

Buffet Onset

To more accurately calculate the high and low speed buffets or the buffet boundary, a pilot uses the buffet onset chart found within the aircraft flight manual. An example of such a chart, taken from Airbus, is shown in *Figure 17.9*. The following information describes the process of calculating the Manoeuvre (1.3g) and Aerodynamic Ceilings (1.0g).

1.3g Altitude (1g + 0.3g = 1.3g): At this altitude a 'g' increment of 0.3 can be sustained without buffet occurring. Using the data supplied:

> Follow the vertical solid red line upwards from 1.3g to the 110 tons line, then horizontally to the 30% CG vertical line, then parallel to the CG reference line, again horizontally to the M 0.8 vertical line. The altitude curve must now be 'paralleled' to read off the flight level of 405. The 1.3g altitude is 40 500 ft.

If the aircraft is operated above FL405 at this mass and CG, a gust, or bank angle of less than 40°, could cause the aircraft to buffet. (40° of bank at high altitude is excessive, a normal operational maximum at high altitude would be 10° to 15°).

Buffet restricted speed limits: Using the data supplied:

> Follow the vertical dashed red line upwards from 1g to the 110 tons line, then horizontally to the 30% CG vertical line, then parallel to the CG reference line. Observe the FL 350 curve. The curve does not reach the horizontal dashed red line at the high speed end because M 0.84 (M_{MO}) is the maximum operating speed limit. At the low speed end of the dashed red line, the FL350 curve is intersected at M 0.555. Thus under the stated conditions, the low speed buffet restriction is M 0.555 and there is no high speed buffet restriction because M_{MO} is the maximum operating Mach number which may not be exceeded under any circumstances.

Aerodynamic ceiling: at 150 tons can be determined by:

Initially following the vertical dashed red line vertically upwards from 1g, continue to the 150 tons plot, then move horizontally to the left to M 0.8 (via the CG correction). The interpolated altitude curve gives an aerodynamic ceiling of FL390.

Load factor and bank angle at which buffet occurs: Using the data supplied:

From M 0.8, follow the dashed blue line to obtain 54° bank angle or 1.7g.

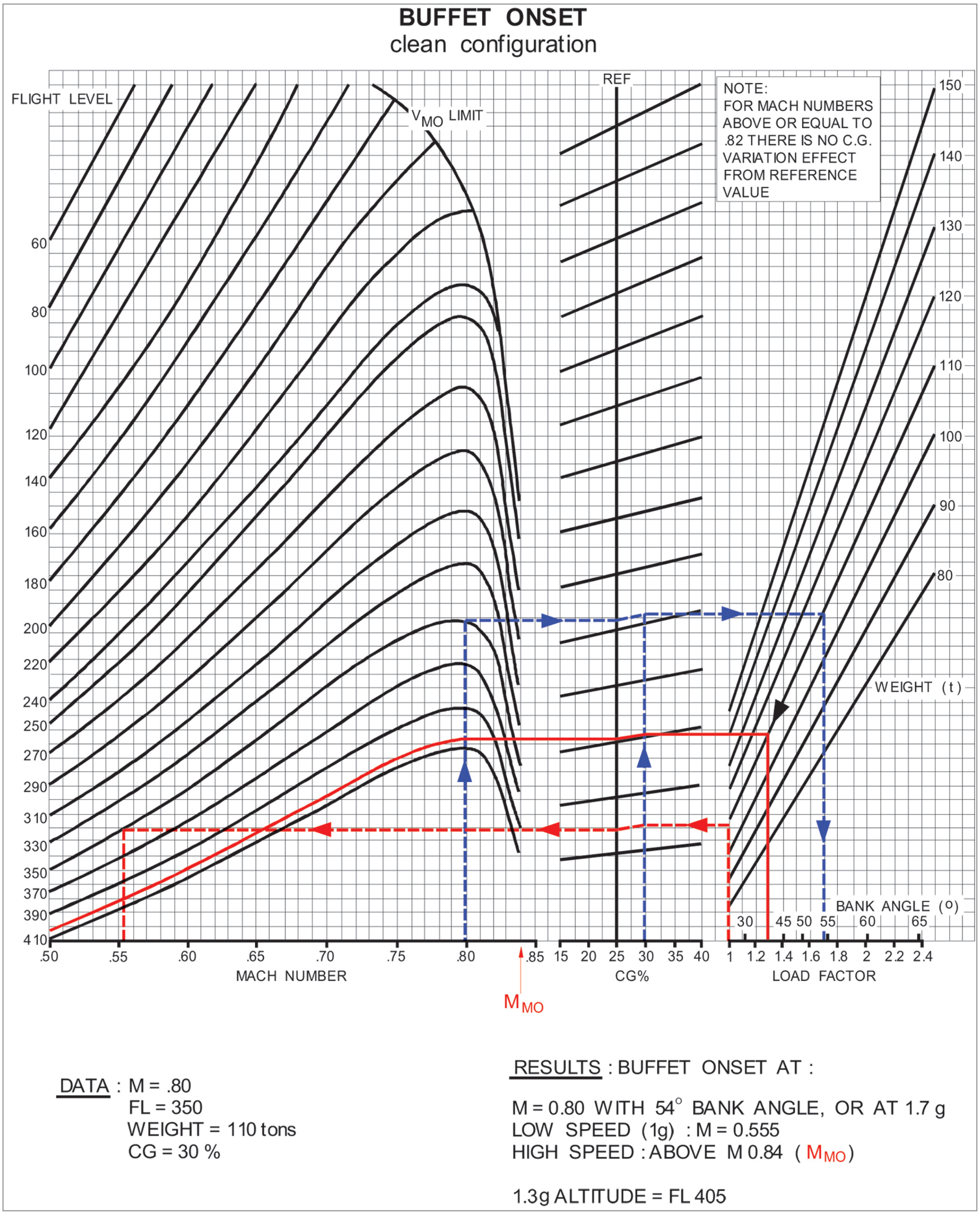


Figure 17.9 Example of a buffet onset chart.

Normal Descent

When the aeroplane gets close to the destination airfield it will reach a point which marks the beginning of the descent. This is called the top of descent. You may remember that in order to initiate a descent, firstly the thrust must be reduced, and then the nose is lowered to get weight to act forwards to balance the drag. The balance of forces ensures a constant speed can be maintained during the descent. The descent profile is almost the reverse of the climb profile. The climb for a typical 737 is initially flown at 250 knots, then at 10 000 ft this changes to 280 knots and then at the crossover altitude Mach 0.74 is maintained. The descent is flown initially at Mach 0.74, then at the crossover altitude the speed is kept constant at 280 knots, but when 10 000 ft is reached no more than 250 knots must be flown.

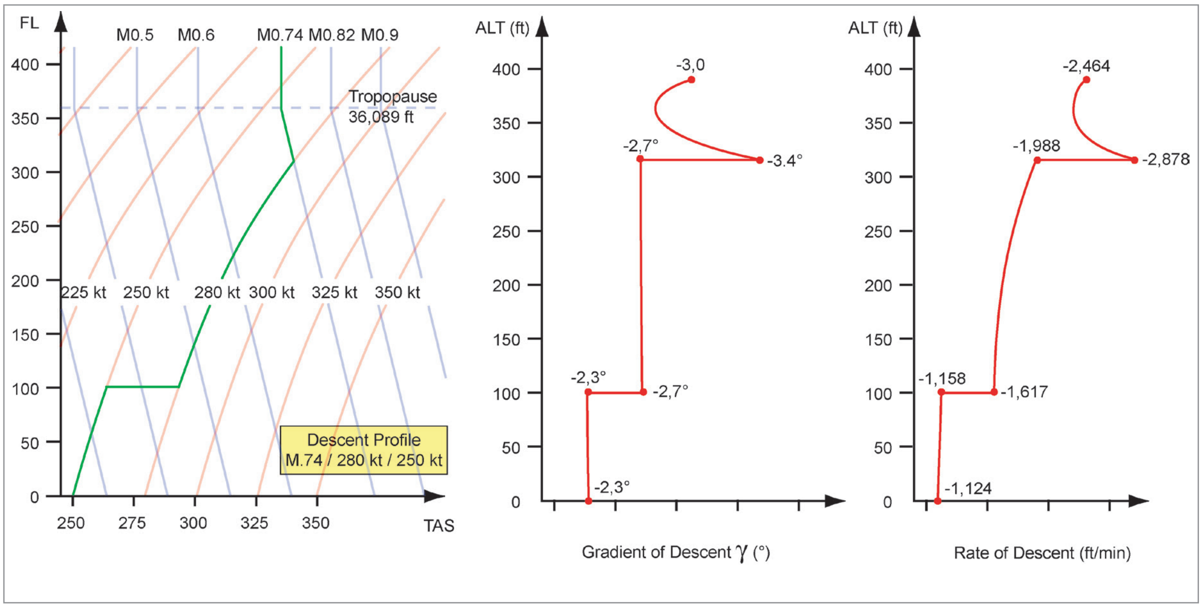


Figure 17.10 A typical descent profile for a medium range jet

Shown in *Figure 17.10* are the characteristics of the descent so you can see what happens to the gradient and rate of descent throughout the descent profile. If at any point air traffic control asks the pilots to expedite the descent, then the only action by the pilots would be to deploy the speed brakes.

This increases the drag, which must be balanced by more weight apparent thrust, therefore the nose is lowered which increases both the angle and rate of descent as per the instruction of air traffic control.

The next descent to consider is the descent characteristic following either depressurization or engine failure. In flight, engine or pressurization failures force a premature descent and therefore the performance becomes very constraining over mountainous areas.

Depressurization

When we suffer a pressurization failure the procedure is a little different from the engine failure case. At high altitudes the oxygen pressure in the cabin will be insufficient to support life so oxygen will be provided for both crew and passengers through oxygen masks. However, the amount of oxygen carried is limited, therefore the aeroplane must descend, as rapidly as possible to 10 000 ft where there is sufficient oxygen pressure, before the oxygen supply runs out. The procedure involves configuring the aeroplane for the maximum rate of descent. You may recall that in order to achieve a maximum rate of descent, excess power required has to be as large as possible. Therefore drag must be high and speed must be high. As a result, the first actions of the pilots are to don the oxygen masks, close the throttles, apply the speed brakes and then lower the nose to allow the aeroplane to accelerate to maximum operating speed which is either V_{MO} or M_{MO}. This configuration is then maintained till at least 10 000 ft, or minimum safe en route altitude, where there is sufficient oxygen to breathe.

Engine Failure and Drift Down

In the case of an engine failure during flight, the remaining thrust is no longer sufficient to balance the drag force and therefore the cruise speed cannot be maintained. The only solution is to descend to a lower flight altitude, where the remaining engine can provide enough thrust to balance the drag and allow level flight once more. To achieve this, the aeroplane is initially flown level to allow the aeroplane to decelerate from the cruise speed to the velocity of minimum drag. At V_{MD} the nose is lowered to maintain V_{MD} , which can now be thought of as the "speed for minimum excess drag" as shown by *Figure 17.11*. As the aeroplane descends into the lower atmosphere where density is greater, the remaining engine can develop more thrust which will eventually equal drag; this is the GROSS level-off altitude, but would give no performance margin, so the DRIFT DOWN PROCEDURE is continued to a lower altitude, the NET level-off altitude. *Figure 17.12* is a graph which allows flight crew to determine distance flown, and gross altitude, following engine failure. The current lines are the drift down profiles for various aircraft weights.

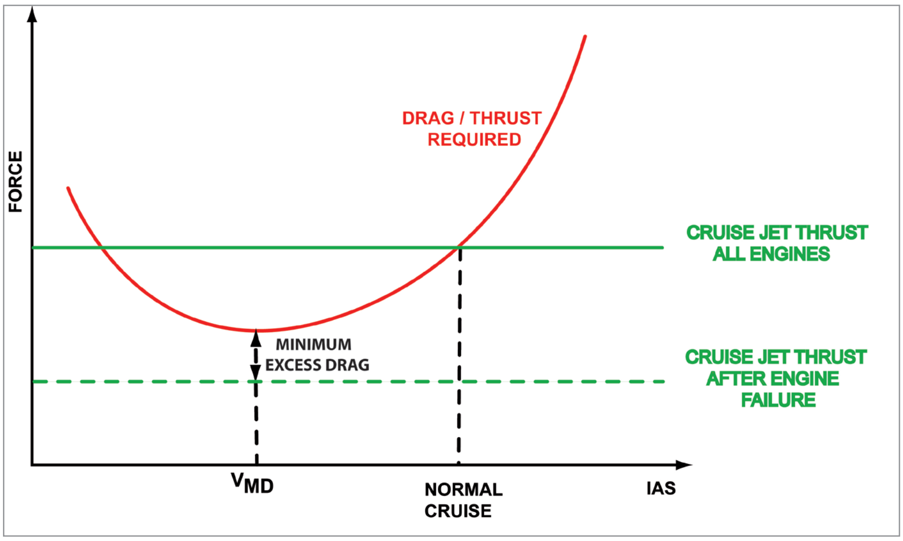
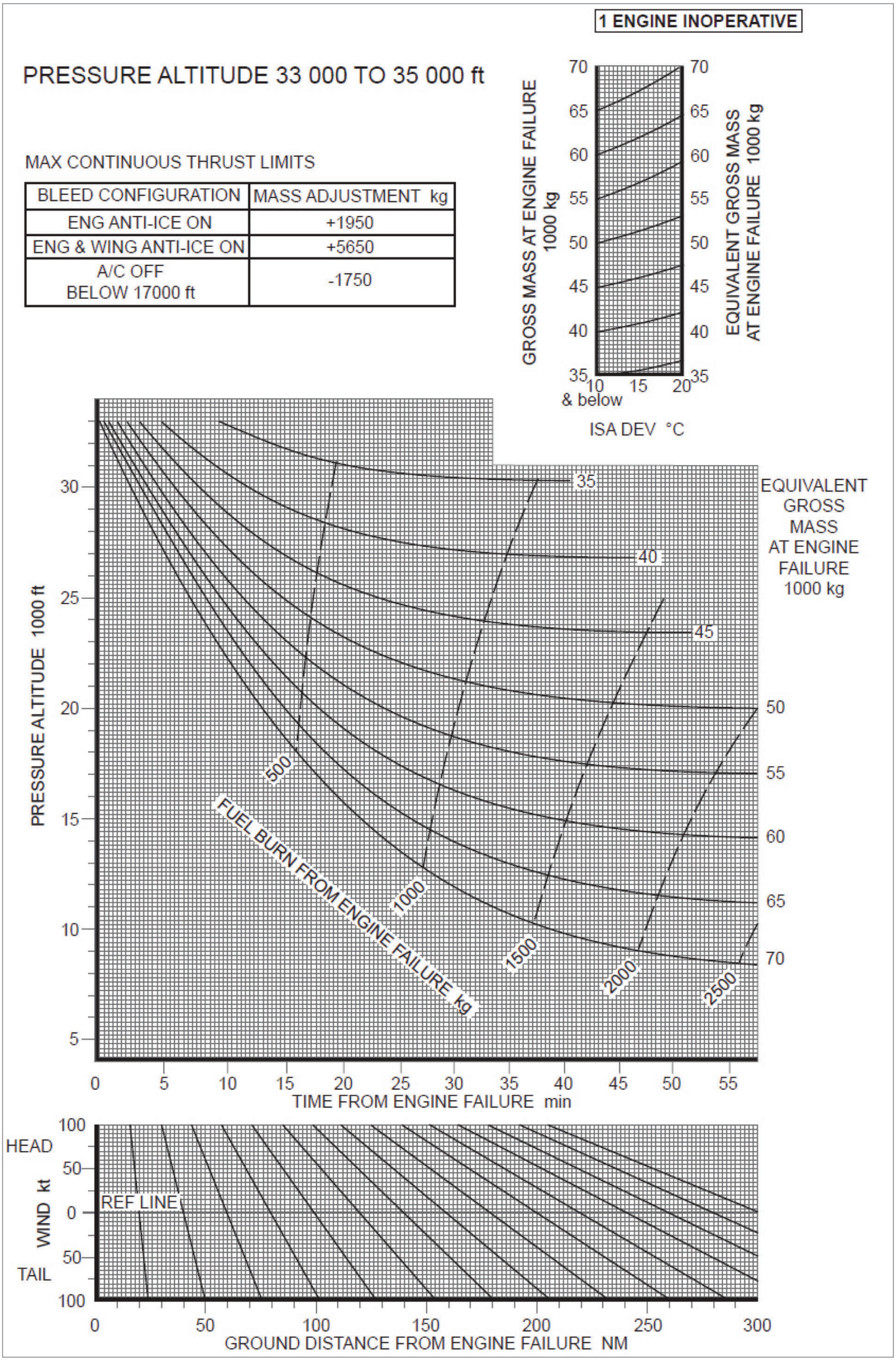


Figure 17.11 *Changes to thrust & drag after engine failure*

This procedure is called the drift down, and it produces a drift down profile. This path must, of course, be above all relevant obstacles, but this will be discussed later.



BLEED CONFIGURATION	MASS ADJUSTMENT kg
ENG ANTI-ICE ON	+1950
ENG & WING ANTI-ICE ON	+5650
A/C OFF BELOW 17000 ft	-1750

Figure 17.12 Drift down profiles - net flight path.

Obstacle Clearance Requirements

One of the crucial points about the drift down procedure is the clearance of obstacles. Because the aeroplane is forced to descend, terrain, such as mountains, may present a flight hazard. When assessing the terrain hazard a safety margin must be introduced. When planning routes and planning the flight profile, it is not the gross flight profile that is used, but rather the net flight profile. In other words, the flight profile must be made worse by a safety factor. This safety factor is based on assuming a gradient of descent that is worse than the aeroplane can actually achieve. For two-engine aeroplanes with one engine inoperative the gross gradient of descent is increased by 1.1%. This increases to 1.4% for 3-engine aeroplanes and 1.6% for four-engine aeroplanes.

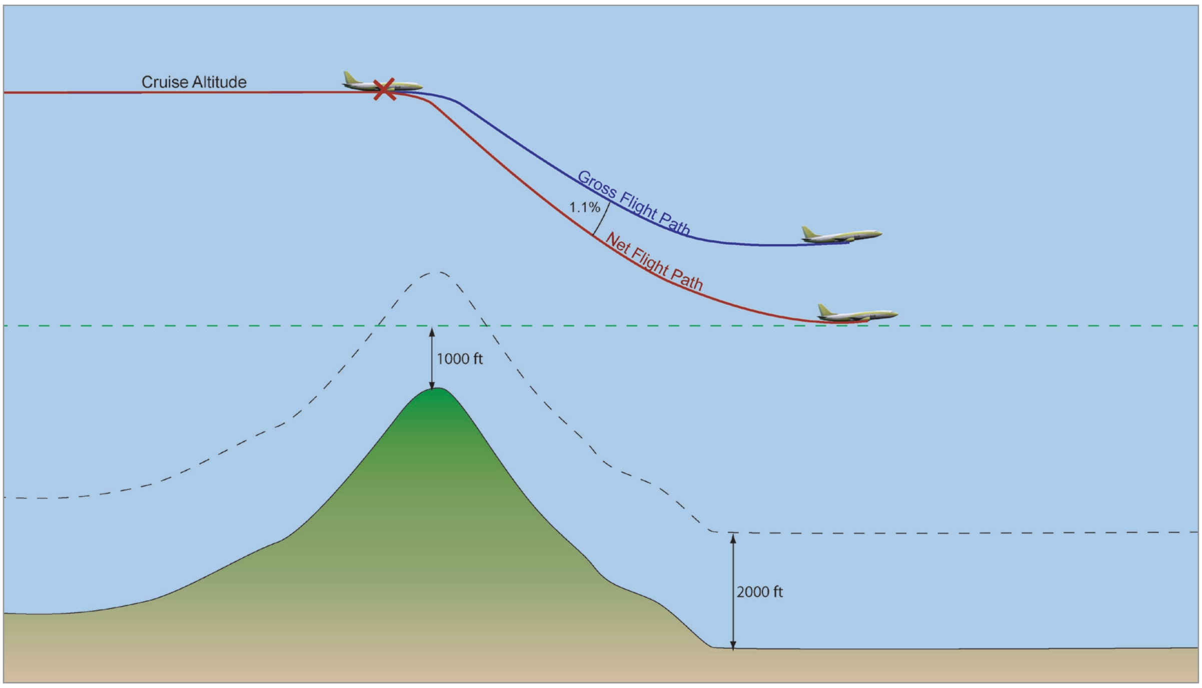


Figure 17.13 Net & gross descent profiles for a typical twin-engine medium range jet.

EU-OPS regulations state (in part):

The one engine inoperative en route net flight path must comply with either sub-paragraph (a) or (b) at all points along the route.

(a) The gradient of the net flight path must be positive at at least 1000 ft above all terrain and obstructions along the route within 5 NM on either side of the intended track.

If an aeroplane is unable to satisfy this restriction, or when it would be too limiting in terms of weight, a drift down procedure should be worked out, as detailed below:

(b) The net flight path must permit the aeroplane to continue flight from the cruising altitude to an aerodrome where a landing can be made, [...], the net flight path clearing vertically, by at least 2000 ft, all terrain and obstructions along the route within [the prescribed corridor].

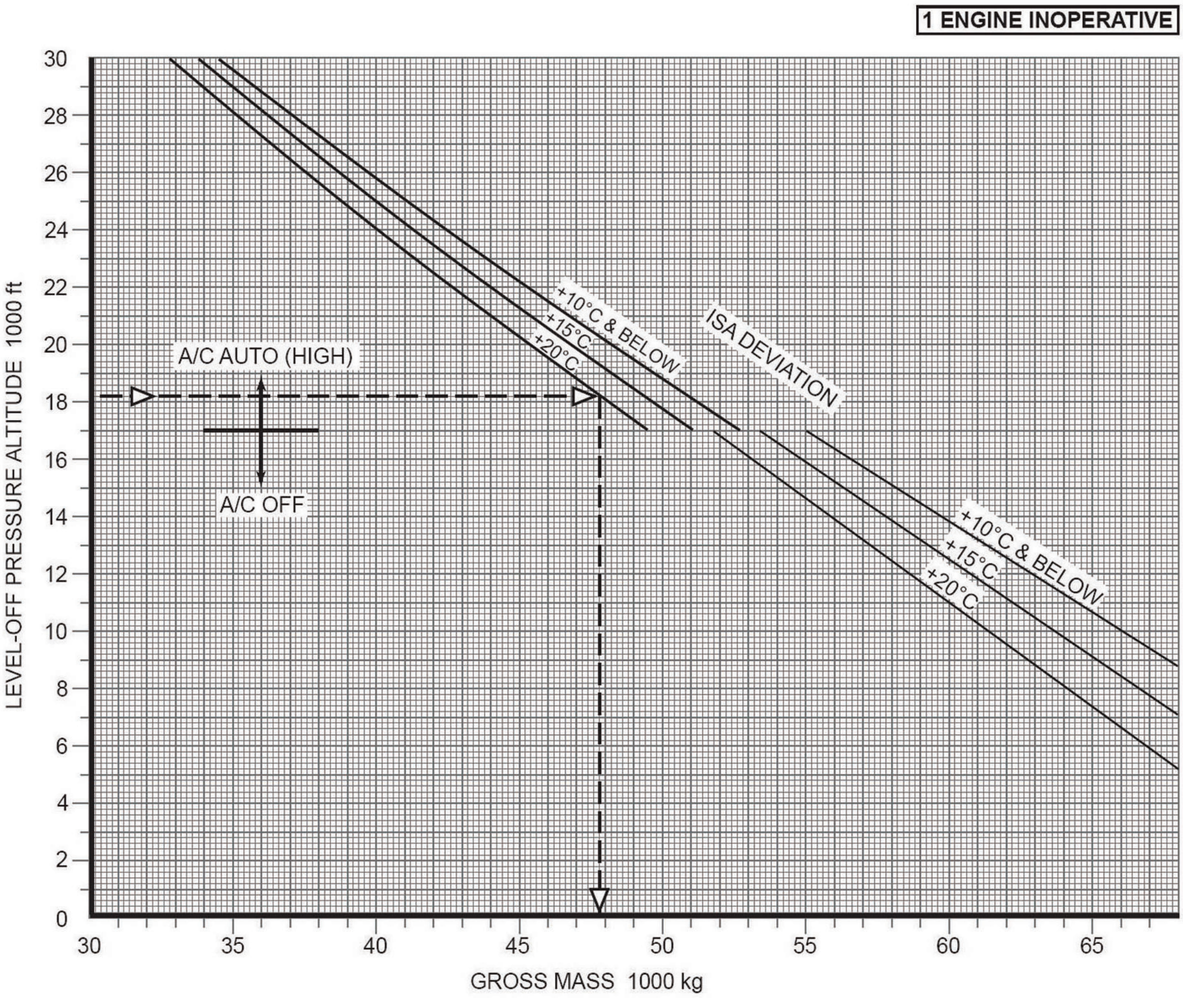
In addition:

The net flight path must have a positive gradient at 1500 ft above the aerodrome where the landing is assumed to be made after engine failure.

AND

Fuel jettisoning is permitted to an extent consistent with reaching the aerodrome with the required fuel reserves.

In order to find out if the aeroplane is able to level off at 1000 ft above an obstacle, use the graph in *CAP 698 on page 40 of section 4*. This has been reproduced in *Figure 17.14*.



BLEED CONFIGURATION	MASS ADJUSTMENT kg
ENG ANTI-ICE ON	-1950
ENG & WING ANTI-ICE ON	-5650
A/C AUTO (HIGH) BELOW 17 000 ft	-2500

Figure 17.14 A graph to calculate the maximum mass for a given net level-off altitude

Simply enter the graph with the level-off altitude that is required (obstacle height AMSL + 1000 ft) and the graph will show the mass that the aeroplane will need to be at in order to level off at that altitude. In the example on the graph, in order to level off at 18 000 ft in an ISA + 20 atmosphere the aeroplane would need to have a mass of just less than 48 000 kg. If this is not possible, then other graphs, shown on *pages 41 to 44 of CAP 698* must be used.

These graphs are more complicated, but, importantly, they will enable the pilot to work out if the aeroplane can clear any obstacle in the flight path by 2000 ft. When using these graphs be careful to adjust the weight of the aeroplane for any non-standard conditions and anti-ice use. Notice that the heavier the aeroplane the longer and lower the drift down procedure is.

Range Limit Following Engine Failure

After engine failure, the lower operating altitude significantly decreases the engine's efficiency. So much so that the fuel-flow on the remaining engine is almost as much as the fuel flow with both engines operating at high altitude. This fact, together with the reduced true airspeed, means that the specific range is dramatically decreased. As a result of the reduced range it may not be possible to reach the destination airfield and in fact the priority now is to find an alternate airfield to land before the fuel runs out. This issue is of such importance that it was necessary to regulate it. The authorities have to set a safety standard that in the event of engine failure the aeroplane must have the capability of reaching a suitable airfield within a certain time period.

EU-OPS 1.245 states that twin engine aeroplanes beyond a certain size must be no further away from a suitable aerodrome than the distance flown in 60 minutes using the one engine operative cruise speed as TAS in still air. For aeroplanes with 3 or more engines the time is increased to 90 minutes. Therefore, at all points on the route a twin-engine aeroplane must be within 60 minutes of an alternate airfield.

This regulation has a significant impact on flight routes, especially over the sea. In the example in *Figure 17.15* you can see that to comply with the 60 minute rule the aeroplane track must at all times be within the 60 minute range limit of a suitable alternate airfield. From the diagram in *Figure 17.15*, a direct track to North America from Europe is not possible.

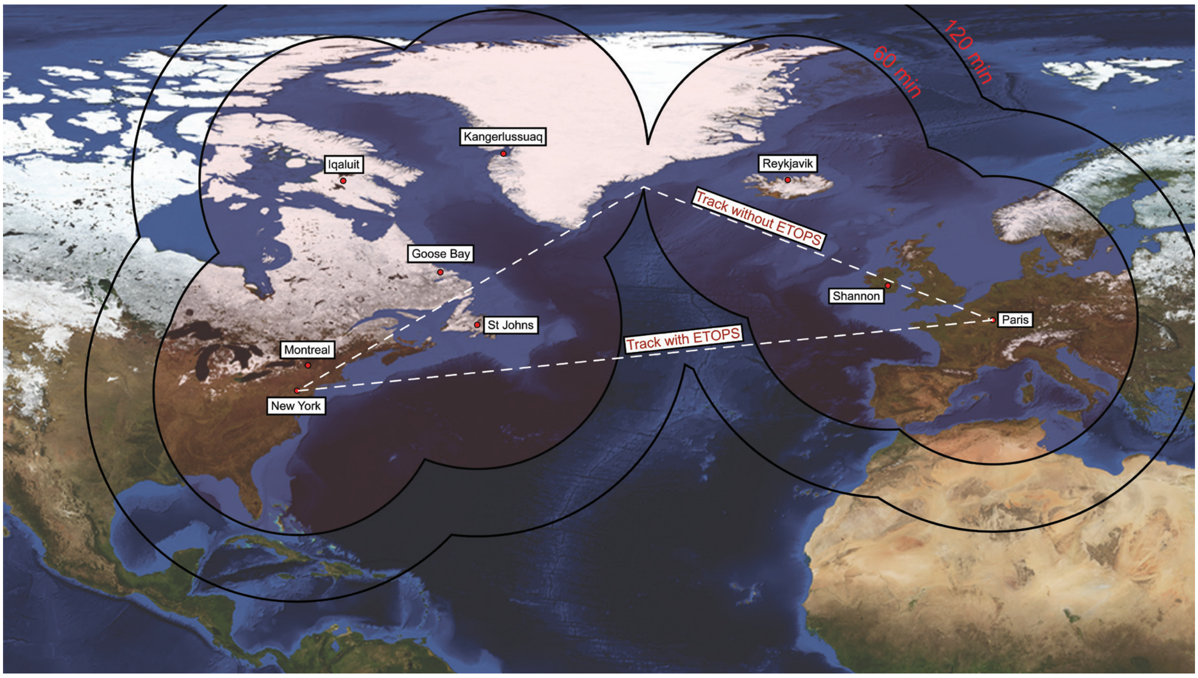


Figure 17.15 Range limits on twin medium range jets

However, as more and more reliable and efficient aeroplanes are produced, an extension to the 60 minute rule has been introduced.

ETOPS

The extension to the 60 minute rule is called "ETOPS" and it stands for **E**xtended-range **T**win-engine **O**perational **P**erformance **S**tandards. It hugely increases the operational capability of twin-engine aeroplanes where previously only aeroplanes with three or more engines could operate. However, ETOPS must be applied for by the airlines concerned and approval gained from the appropriate aviation authority.

To gain ETOPS approval, a greater range of performance parameters must be known and these accompany the application and are eventually published in the operating manual. These include extra data for

- Area of Operation
- Critical Fuel Reserves
- Net Level-off Altitudes

Gaining an ETOPS approval of 120 minutes for example will greatly benefit flight tracks across the Atlantic Ocean, as shown in *Figure 17.15*. The route from Paris to New York, for example, can now be flown direct by a twin jet aeroplane. Currently, the longest ETOPS approval is given to the Boeing 777. It holds an approval of 180 minutes with contingencies for 207 minutes over the Pacific.

In the future ETOPS may be evolving into a newer system, called LROPS. LROPS stands for Long Range Operational Performance Standards, which will affect all aircraft, not just those with a twin-engine configuration.

Questions

1. **Which statement with respect to the step climb is correct?**

   a. A step climb provides better economy than a cruise climb
   b. Performing a step climb based on economy can be limited by the 1.3g altitude
   c. In principle a step climb is performed immediately after the aircraft has exceeded the optimum altitude
   d. A step climb may not be performed unless it is indicated in the filed flight plan

2. **Which statement with respect to the step climb is correct?**

   a. A step climb is executed because ATC desires a higher altitude
   b. A step climb is executed in principle when, just after levelling off, the 1.3g altitude is reached
   c. Executing a desired step climb at high altitude can be limited by buffet onset at g-loads larger than 1
   d. A step climb must be executed immediately after the aeroplane has exceeded the optimum altitude

3. **The lift coefficient decreases during a glide at a constant Mach number, mainly because the:**

   a. TAS decreases
   b. glide angle increases
   c. IAS increases
   d. aircraft mass decreases

4. **An aeroplane carries out a descent from FL410 to FL270 at cruise Mach number, and from FL270 to FL100 at the IAS reached at FL270. How does the angle of descent change in the first and in the second part of the descent? Assume idle thrust and clean configuration and ignore compressibility effects.**

   a. Increases in the first part; is constant in the second
   b. Increases in the first part; decreases in the second
   c. Is constant in the first part; decreases in the second
   d. Decreases in the first part; increases in the second

5. **During a glide at constant Mach number the pitch angle of the aeroplane will:**

   a. decrease
   b. increase
   c. increase at first and decrease later on
   d. remain constant

6. **If a flight is performed with a higher "Cost Index" at a given mass, which of the following will occur?**

   a. A better long range
   b. A higher cruise Mach number
   c. A lower cruise Mach number
   d. A better maximum range

7. **During a descent at constant Mach Number, the margin to low speed buffet will:**

   a. decrease, because the lift coefficient decreases
   b. increase, because the lift coefficient decreases
   c. remain constant, because the Mach number remains constant
   d. increase, because the lift coefficient increases

8. **A jet aeroplane is climbing with constant IAS. Which operational speed limit is most likely to be reached?**

   a. The stalling speed
   b. The minimum control speed air
   c. The Mach limit for the Mach trim system
   d. The maximum operating Mach number

9. **ETOPS flight is a twin-engine jet aeroplane flight conducted over a route where no suitable airport is within an area of:**

   a. 75 minutes flying time at the approved one engine out cruise speed
   b. 60 minutes flying time in still air at the approved one engine out cruise speed
   c. 60 minutes flying time in still air at the normal cruising speed
   d. 30 minutes flying time at the normal cruising speed

10. **The danger associated with low speed and/or high speed buffet:**

    a. limits the manoeuvring load factor at high altitudes
    b. can be reduced by increasing the load factor
    c. exists only above M_{MO}
    d. has to be considered at take-off and landing

11. **Which data can be extracted from the buffet onset boundary chart?**

    a. The value of the Mach number at which low speed and shock stall occur at various weights and altitudes
    b. The values of the Mach number at which low speed buffet and Mach buffet occur at various masses and altitudes
    c. The value of maximum operating Mach number (M_{MO}) at various masses and power settings
    d. The value of the critical Mach number at various masses and altitudes

12. **Which of the following factors determines the maximum flight altitude in the "buffet onset boundary" graph?**

    a. Aerodynamics
    b. Theoretical ceiling
    c. Service ceiling
    d. Economy

13. **The optimum cruise altitude increases:**

    a. if the aeroplane mass is decreased
    b. if the temperature (OAT) is increased
    c. if the tailwind component is decreased
    d. if the aeroplane mass is increased

14. **Which of the following statements with regard to the optimum cruise altitude (best fuel mileage or range) is correct?**

a. An aeroplane usually flies above the optimum cruise altitude, as this provides the largest specific range
b. An aeroplane sometimes flies above or below the optimum cruise altitude, because ATC normally does not allow aeroplanes to fly continuously at the optimum cruise altitude
c. An aeroplane always flies below the optimum cruise altitude, as otherwise Mach buffet can occur
d. An aeroplane always flies on the optimum cruise altitude, because this is most attractive from an economy point of view

15. **The optimum altitude:**

a. is the altitude up to which cabin pressure of 8000 ft can be maintained
b. increases as mass decreases and is the altitude at which the specific range reaches its maximum
c. decreases as mass decreases
d is the altitude at which the specific range reaches its minimum

16. **Under which condition should you fly considerably lower (4000 ft or more) than the optimum altitude?**

a. If, at the lower altitude, either more headwind or less tailwind can be expected
b. If, at the lower altitude, either considerably less headwind or considerably more tailwind can be expected
c. If the maximum altitude is below the optimum altitude
d. If the temperature is lower at the low altitude (high altitude inversion)

17. **What happens to the specific range with one or two engines inoperative?**

a. At first improved and later reduced
b. It decreases
c. It increases
d. Unaffected by engine failure

18. **The optimum cruise altitude is:**

a. the pressure altitude up to which a cabin altitude of 8000 ft can be maintained
b. the pressure altitude at which the speed for high speed buffet as TAS is a maximum
c. the pressure altitude at which the highest specific range can be achieved
d. the pressure altitude at which the fuel flow is a maximum

19. **The maximum operating altitude for a certain aeroplane with a pressurized cabin:**

a. is dependent on aerodynamic ceiling
b. is dependent on the OAT
c. is only certified for four-engine aeroplanes
d. is the highest pressure altitude certified for normal operation

20. **Why are 'step climbs' used on long distance flights?**

a. Step climbs do not have any special purpose for jet aeroplanes; they are used for piston engine aeroplanes only
b. To respect ATC flight level constraints
c. To fly as close as possible to the optimum altitude as aeroplane mass reduces
d. Step climbs are only justified if, at the higher altitude, less headwind or more tailwind can be expected

21. **Long range cruise (LRC) instead of best range speed (MRC) is selected because LRC:**

a. is 4% faster and achieves 99% of maximum specific range in zero wind
b. is the speed for best range
c. is the speed for best economy
d. gives higher specific range with tailwind

22. **What happens when an aeroplane climbs at a constant Mach number?**

a. IAS stays constant so there will be no problems
b. The "1.3g" altitude is exceeded, so Mach buffet will start immediately
c. The lift coefficient increase
d. The TAS continues to increase, which may lead to structural problems

23. **The speed range between low speed buffet and high speed buffet:**

a. decreases with increasing mass and is independent of altitude
b. is only limiting at low altitudes
c. increases with increasing mass
d. narrows with increasing mass and increasing altitude

24. **A jet aeroplane descends with constant Mach number. Which of the following speed limits is most likely to be exceeded first?**

a. Maximum Operational Mach Number
b. Maximum Operating Speed
c. Never Exceed Speed
d. High Speed Buffet Limit

25. **With respect to the optimum altitude, which of the following statements is correct?**

a. An aeroplane always flies below the optimum altitude, because Mach buffet might occur
b. An aeroplane always flies at the optimum altitude because this is economically seen as the most attractive altitude
c. An aeroplane flies most of the time above the optimum altitude because this yields the most economic result
d. An aeroplane sometimes flies above or below the optimum altitude because optimum altitude increases continuously during flight

26. **The aerodynamic ceiling:**

a. is the altitude at which the aeroplane reaches 50 ft/min
b. is the altitude at which the speeds for low speed buffet and for high speed buffet are the same
c. depends upon thrust setting and increases with increasing thrust
d. is the altitude at which the best rate of climb theoretically is zero

27. **An aeroplane operating under the 180 minutes ETOPS rule may be up to:**

a. 180 minutes flying time to a suitable airport in still air with one engine inoperative
b. 180 minutes flying time to a suitable airport under the prevailing weather condition with one engine inoperative
c. 180 minutes flying time from suitable airport in still air at a normal cruising speed
d. 90 minutes flying time from the first en route airport and another 90 minutes from the second en route airport in still air with one engine inoperative

28. **If the climb speed schedule is changed from 280/.74 to 290/.74 the new crossover altitude is:**

a. unchanged
b. only affected by the aeroplane gross mass
c. lower
d. higher

29. **The drift down procedure specifies requirements concerning the:**

a. engine power at the altitude at which engine failure occurs
b. climb gradient during the descent to the net level-off altitude
c. weight during landing at the alternate
d. obstacle clearance during descent to the net level-off altitude

30. **For this question use Figure 4.24 in CAP 698 Section 4.**

With regard to the drift down performance of the twin jet aeroplane, why does the curve representing 35 000 kg gross mass in the chart for drift down net profiles start at approximately 3 minutes at FL370?

a. Because at this mass the engines slow down at a slower rate after failure, there is still some thrust left during four minutes
b. Due to higher TAS at this mass it takes more time to develop the optimal rate of descent, because of the inertia involved
c. All the curves start at the same point, which is situated outside the chart
d. Because at this mass it takes about 3 minutes to decelerate to the optimum speed for drift down at the original cruising level

31. **Which of the following statements is correct?**

a. An engine failure at high cruising altitude will always result in a drift down, because it is not permitted to fly the same altitude as with all engines operating
b. When determining the obstacle clearance during drift down, fuel dumping may be taken into account
c. The drift down regulations require a minimum descent angle after an engine failure at cruising altitude
d. The drift down procedure requires a minimum obstacle clearance of 35 ft

32. **The drift down requirements are based on:**

a. the actual engine thrust output at the altitude of engine failure
b. the maximum flight path gradient during the descent
c. the landing mass limit at the alternate
d. the obstacle clearance during a descent to the new cruising altitude if an engine has failed

33. **If the level-off altitude is below the obstacle clearance altitude during a drift down procedure:**

a. fuel jettisoning should be started at the beginning of drift down
b. the recommended drift down speed should be disregarded and it should be flown at the stall speed plus 10 kt
c. fuel jettisoning should be started when the obstacle clearance altitude is reached
d. the drift down should be flown with flaps in the approach configuration

34. **After engine failure the aeroplane is unable to maintain its cruising altitude. What is the procedure which should be applied?**

a. Emergency descent procedure
b. ETOPS
c. Long range cruise descent
d. Drift down procedure

35. **For this question use Figure 4.24 of CAP 698 Section 4.**

With regard to the drift down performance of the twin jet aeroplane, what is meant by "equivalent gross weight at engine failure"?

a. The increment accounts for the higher fuel flow at higher temperatures
b. The equivalent gross weight at engine failure is the actual gross weight corrected for OAT higher than ISA +10°C
c. The increment represents fuel used before engine failure
d. This gross weight accounts for the lower Mach number at higher temperatures

36. **'Drift down' is the procedure to be applied:**

a. to conduct a visual approach if VASI is available
b. after engine failure if the aeroplane is above the one engine out maximum altitude
c. after cabin depressurization
d. to conduct an instrument approach at the alternate

37. **In a twin-engine jet aircraft with six passenger seats, and a maximum certified take-off mass of 5650 kg, what is the required en route obstacle clearance, with one engine inoperative during drift down towards the alternate airport?**

a. 2000 ft
b. 1500 ft
c. 1000 ft
d. 50 ft or half the wingspan

38. **Below the optimum cruise altitude:**

a. the IAS for long range cruise increases continuously with decreasing altitude
b. the Mach number for long range cruise decreases continuously with decreasing altitude
c. the Mach number for long range cruise decreases continuously with an increasing mass at a constant altitude
d. the Mach number for long range cruise increases continuously with decreasing mass at a constant altitude

39. **How does the long range cruise speed (LRC) change?**

a. LRC Mach number decreases with decreasing altitude
b. LRC Mach number decreases with increasing altitude
c. LRC indicated airspeed increases with increasing altitude
d. LRC true airspeed decreases with increasing altitude

40 **If a flight is performed with a higher "cost index" at a given mass, which of the following will occur?**

a. A better maximum range
b. A higher cruise Mach number
c. A lower cruise Mach number
d. A better long range

41. **The effect of flying at the long range cruise speed instead of the maximum range cruise speed is:**

a. fuel flow is reduced and speed stability is improved
b. fuel flow is reduced and speed stability is reduced
c. fuel flow is increased and speed stability is improved
d. fuel flow is increased and speed stability is reduced

42. **An aircraft's descent speed schedule is M 0.74 / 250 KIAS. During the descent from 30 000 ft to sea level, the angle of attack will:**

a. decrease, then remain constant
b. increase, then remain constant
c. remain constant
d. decrease

43. **During a drift down following engine failure, what would be the correct procedure to follow?**

a. Begin fuel jettison immediately, commensurate with having required reserves at destination
b. Do not commence fuel jettison until en route obstacles have been cleared
c. Descend in the approach configuration
d. Disregard the flight manual and descend at V_S + 10 kt to the destination

Answers

1	2	3	4	5	6	7	8	9	10	11	12
b	c	c	a	a	b	b	d	b	a	b	a

13	14	15	16	17	18	19	20	21	22	23	24
a	b	b	b	b	c	b	c	a	c	d	b

25	26	27	28	29	30	31	32	33	34	35	36
d	b	a	c	d	d	b	d	a	d	b	b

37	38	39	40	41	42	43
a	b	a	b	c	a	a

Chapter

18

Class A - Landing

Landing Considerations

The maximum mass for landing is the lesser of:

- the landing climb limit mass (maximum mass to achieve landing climb requirements)
- the field length limit mass
- the structural limit mass

Landing Climb Requirements

LANDING CLIMB (All engines operating CS-25.119)
A gradient of not less than 3.2% with:

- All engines operating at the power available 8 seconds after initiation of movement of the thrust control from the minimum flight idle to the take-off position
- Landing configuration
- Aerodrome altitude
- Ambient temperature expected at the time of landing
- A climb speed of V_{REF}

  $V_{REF:}$
  - not less than V_{MCL}
  - not less than $1.23V_{SR0}$
  - provides the manoeuvring capability specified in CS-25.143 (h)

DISCONTINUED APPROACH CLIMB (One engine inoperative CS-25.121 (d))

A climb gradient not less than:

- 2.1% for 2 engine aircraft
- 2.4% for 3 engine aircraft
- 2.7% for 4 engine aircraft

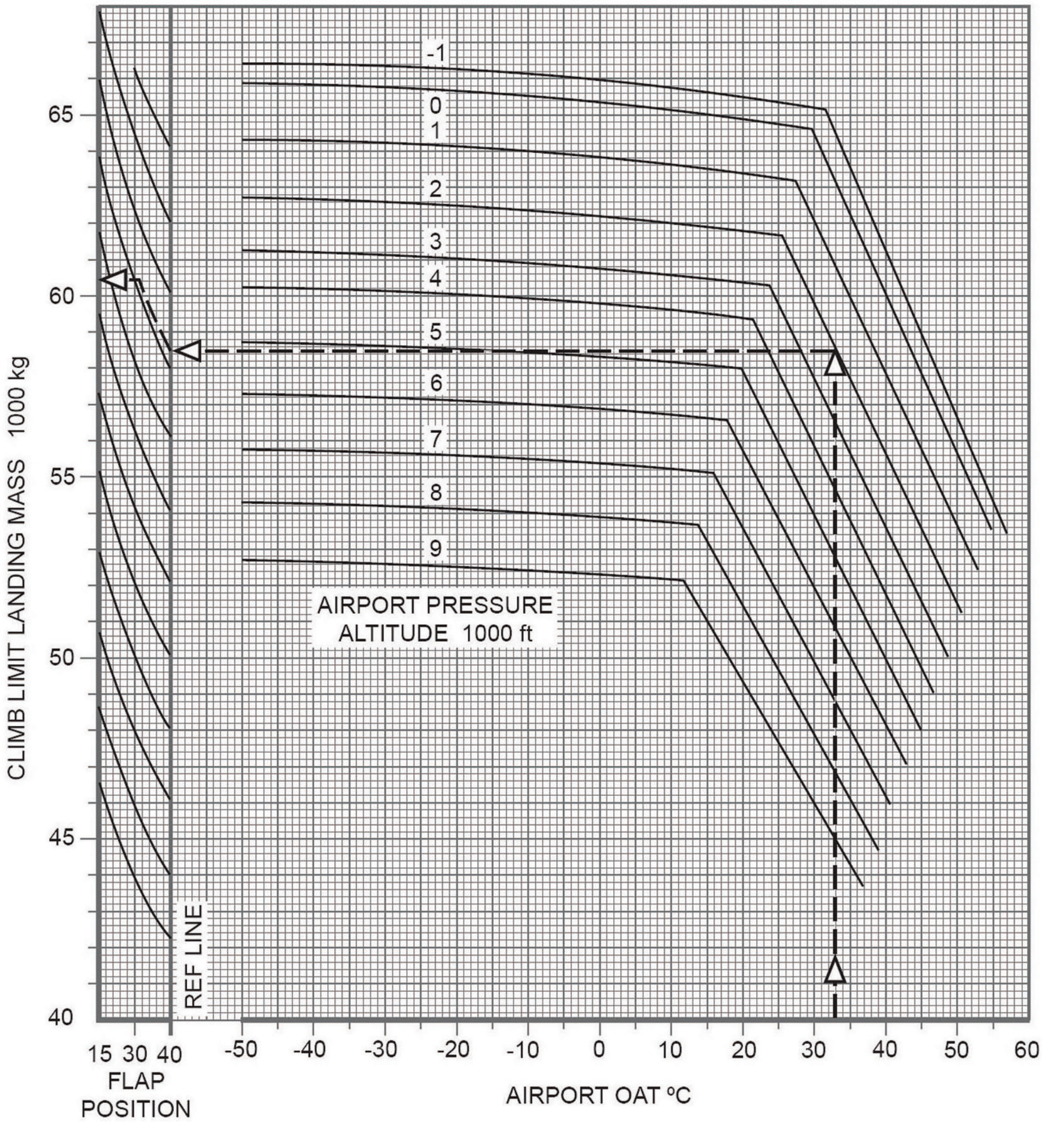
With:

- The critical engine inoperative and the remaining engines at go-around thrust
- Landing gear retracted
- Flaps in the approach configuration, provided that the approach flap V_{SR} does not exceed 110% of landing flap V_{SR}
- Aerodrome altitude
- Ambient temperature
- Speed: Normal approach speed but not greater than $1.4V_{SR}$.
- Maximum landing weight

The more limiting of the landing climb and the approach gradient requirements will determine the maximum mass for altitude and temperature at the landing aerodrome. *Figure 18.1* shows a typical presentation of this data.

Discontinued Approach Instrument Climb. (EU-OPS 1.510)

For instrument approaches with decision heights below 200 ft, an operator must verify that the approach mass of the aeroplane, taking into account the take-off mass and the fuel expected to be consumed in flight, allows a missed approach gradient of climb, with the critical engine failed and with the speed and configuration used for go-around of at least 2.5%, or the published gradient, whichever is the greater.



BASED ON A/C AUTO. FOR PACKS OFF INCREASE:
THE FLAPS 40 ALLOWABLE MASS BY 1250 kg,
THE FLAPS 30 ALLOWABLE MASS BY 1310 kg, OR
THE FLAPS 15 ALLOWABLE MASS BY 1440 kg

IF OPERATING IN ICING CONDITIONS DURING ANY PART OF THE FLIGHT WHEN THE FORECAST LANDING TEMPERATURE IS BELOW 8°C:
REDUCE THE FLAPS 40 CLIMB LIMIT MASS BY 4830 kg,
REDUCE THE FLAPS 30 CLIMB LIMIT MASS BY 4730 kg, OR
REDUCE THE FLAPS 15 CLIMB LIMIT MASS BY 4960 kg

FOR ANTI-ICE OPERATION, DECREASE ALLOWABLE MASS BY THE AMOUNT SHOWN IN THE TABLE BELOW

ANTI-ICE OPERATION DECREMENT kg		
FLAPS	ENGINE ONLY	ENGINE & WING
15	650	5800
30	600	5350
40	550	5250

* NOTE:
ANTI-ICE BLEED SHOULD
NOT BE USED ABOVE 10°C

Figure 18.1 Landing performance climb limit

Landing Distance Requirements EU-OPS 1.515

The landing distance required on a dry runway for destination and alternate aerodromes, from 50 ft to a full stop must not exceed:

- 60% of the landing distance available for turbojet aeroplanes
- 70% of the landing distance available for turboprop aeroplanes

(Short landing and steep approach procedures may be approved based on lower screen heights, but not less than 35 ft)

The landing distance required is based on:

- the aeroplane in the landing configuration
- the speed at 50 ft not less than $1.23V_{SR0}$ or V_{MCL}
- aerodrome pressure altitude
- standard day temperature (ISA)
- factored winds (50% headwind, 150% tailwind)
- the runway slope if greater than ± 2%

V_{SR0} is the stall reference speed in the landing configuration.

V_{MCL}, the minimum control speed during approach and landing with all engines operating, is the calibrated airspeed at which, when the critical engine is suddenly made inoperative, it is possible to maintain control of the aeroplane with that engine still inoperative, and maintain straight flight with an angle of bank of not more than 5° towards the live engine(s).

Runway Selection / Despatch Rules

Landing must be considered both in still air and in the forecast wind.

a. Still air: The most favourable runway in still air may be selected.
b. Forecast wind: The runway most likely to be used in the forecast wind.

The lower of the two masses obtained from a. and b. above must be selected as the limiting mass for the field lengths available.

Non-compliance

- If the still air requirement cannot be met at an aerodrome with a single runway, that is, landing can only be made if there is an adequate wind component, the aircraft may be despatched if 2 alternate aerodromes are designated at which full compliance is possible.

- If the forecast wind requirement cannot be met, the aeroplane may be despatched if an alternate is designated at which all the landing requirements are met.

Wet Runways

If the runway is forecast to be wet at the estimated time of arrival, the landing distance available is at least 115% of the required landing distance. However, a lesser factor may be used so long as it is published in the aeroplane flight manual and the authority has approved such a factor.

Presentation of Data

The example graph in *Figure 18.2* can be found in *CAP 698 on page 46 of section 4*. Work through the example shown in the graph which is detailed on page 40 of section 4. Practise by using the questions at the end of the chapter and remember that you will need to work through these graphs both in the normal way as illustrated by the arrow heads in the example, but also in reverse.

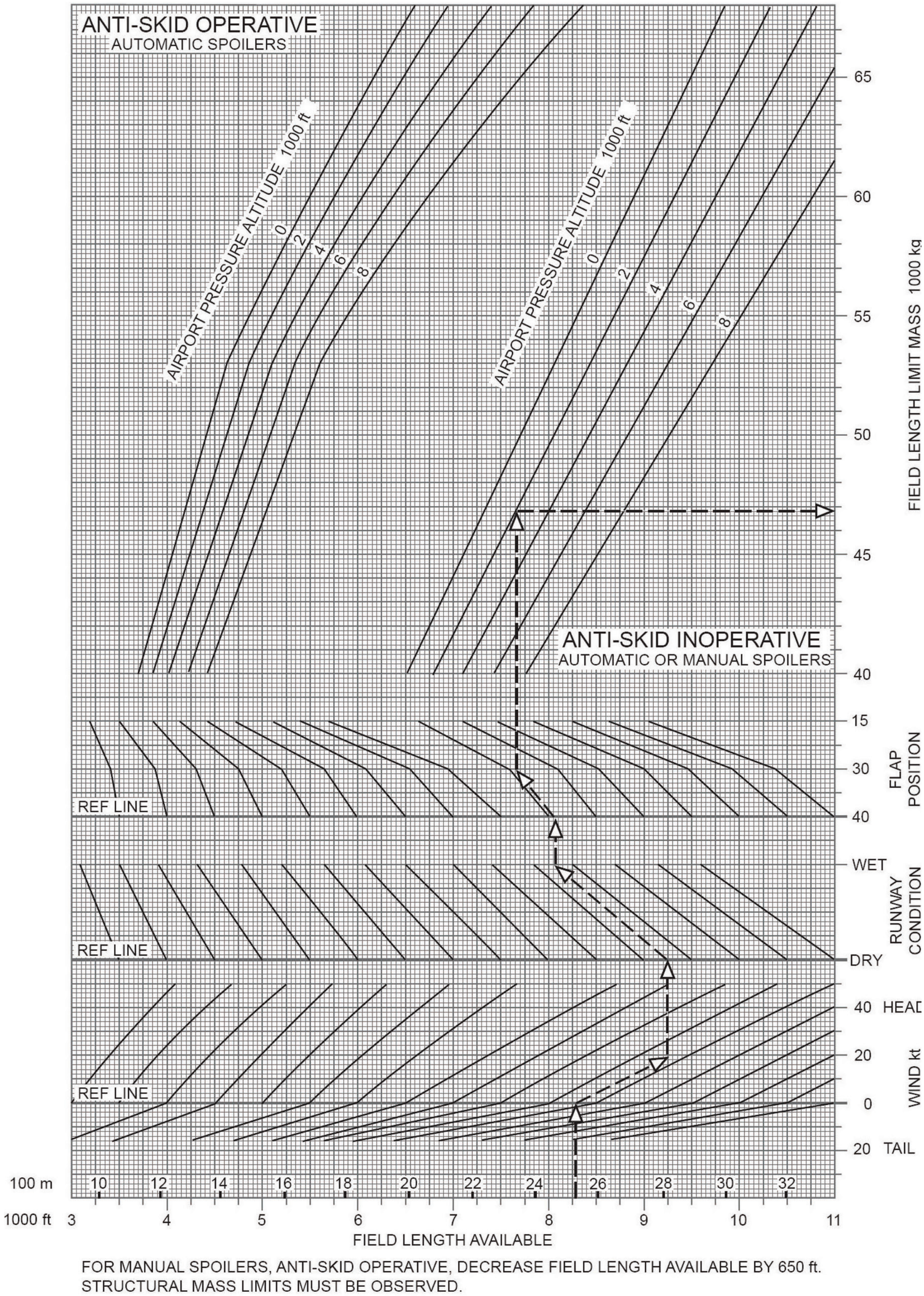


Figure 18.2 Shows a typical presentation of landing distance data

Questions

1. The approach climb requirement has been established to ensure:

a. minimum climb gradient in case of a go-around with one engine inoperative
b. obstacle clearance in the approach area
c. manoeuvrability in case of landing with one engine inoperative
d. manoeuvrability during approach with full flaps and gear down, all engines operating

2. The maximum mass for landing could be limited by:

a. the climb requirements with all engines in the landing configuration but with gear up
b. the climb requirements with one engine inoperative in the approach configuration
c. the climb requirements with one engine inoperative in the landing configuration
d. the climb requirements with all engines in the approach configuration

3. Which of the following is true according to EU-OPS regulations for turbo-propeller powered aeroplanes not performing a steep approach?

a. Maximum take-off run is 0.5 × runway length
b. Maximum use of clearway is 1.5 × runway length
c. Maximum landing distance at the destination aerodrome and at any alternate aerodrome is 0.7 × LDA (landing distance available)
d. Maximum landing distance at destination is 0.95 × LDA (landing distance available)

4. For a turboprop powered aeroplane, a 2200 m long runway at the destination aerodrome is expected to be "wet". To ensure the wet landing distance meets the requirement, the "dry runway" landing distance should not exceed:

a. 1540 m
b. 1147 m
c. 1339 m
d. 1771 m

5. A flight is planned with a turbojet aeroplane to an aerodrome with a landing distance available of 2400 m. Which of the following is the maximum landing distance for a dry runway?

a. 1437 m
b. 1250 m
c. 1090 m
d. 1655 m

6. **According to EU-OPS, which one of the following statements concerning the landing distance for a turbojet aeroplane is correct?**

   a. The landing distance is the distance from 35 ft above the surface of the runway to the full stop
   b. When determining the maximum allowable landing mass at destination, 60% of the available landing runway length should be taken into account
   c. Reverse thrust is one of the factors always taken into account when determining the landing distance required
   d. Malfunctioning of an anti-skid system has no effect on the required runway length

7. **By what factor must the landing distance available (dry runway) for a turbojet powered aeroplane be multiplied to find the maximum landing distance?**

   a. 1.15
   b. 1.67
   c. 60/115
   d. 0.60

8. **The landing field length required for jet aeroplanes at the alternate in wet conditions is the demonstrated landing distance plus:**

   a. 92%
   b. 43%
   c. 70%
   d. 67%

9. **The landing field length required for turbojet aeroplanes at the destination in wet condition is the demonstrated landing distance plus:**

   a. 67%
   b. 70%
   c. 43%
   d. 92%

10. **For a turbojet aeroplane, what is the maximum landing distance for wet runways when the landing distance available at an aerodrome is 3000 m?**

   a. 2070 m
   b. 1562 m
   c. 1800 m
   d. 2609 m

11. **If the airworthiness documents do not specify a correction for landing on a wet runway, the landing distance must be increased by:**

   a. 10%
   b. 20%
   c. 15%
   d. 5%

12. **Required runway length at destination airport for turboprop aeroplanes:**

a. is the same as at an alternate airport
b. is less then at an alternate airport
c. is more than at an alternate airport
d. is 60% longer than at an alternate airport

13. **For this question use Figure 4.28 in CAP 698 Section 4.**

What is the minimum field length required for the worst wind situation, landing a twin jet aeroplane with the anti-skid inoperative?

Elevation: 2000 ft
QNH: 1013 hPa
Landing mass: 50 000 kg
Flaps: as required for minimum landing distance
Runway condition: dry
Wind: Maximum allowable tailwind: 15 kt
Maximum allowable headwind: 50 kt

a. 2600 m
b. 2700 m
c. 2900 m
d. 3100 m

14. **Compared to the landing distance available, the maximum landing distance for a turbo-propeller and turbojet aircraft are:**

a. 60%, 60%
b. 70%, 70%
c. 70%, 60%
d. 60%, 70%

15. **The landing climb gradient limit mass is determined by:**

a. a gradient of 3.2% with one engine inoperative, the other engines at take-off power in the landing configuration
b. a gradient of 3.2% with all engines operating at take-off power, in the landing configuration
c. a gradient of 2.1% with all engines operating at take-off power, with landing gear retracted, and approach flap
d. a gradient of 3.2% with all engines operating at take-off power, with landing gear retracted and approach flap

Answers

1	2	3	4	5	6	7	8	9	10	11	12
a	b	c	c	a	b	d	a	d	c	c	a

13	14	15
d	c	b

Chapter 19 Revision Questions

19 Revision Questions

Questions

1. **What happens to the speed for V_X and V_Y with increasing altitude?**

    a. Both remain constant
    b. V_X remains constant and V_Y increases
    c. V_X increases and V_Y remains constant
    d. V_X remains constant and V_Y decreases

2. **The effects of a contaminated runway on take-off are:**

    a. decreased weight, increased V_1, increased V_R
    b. decreased weight, same V_1, increased V_R
    c. decreased weight, same V_1, same V_R
    d. decreased weight, decreased V_1, decreased V_R

3. **When operating with anti-skid inoperative:**

    a. both landing and take-off performance will be affected
    b. only landing performance will be affected
    c. only take-off performance will be affected
    d. neither take-off nor landing performance will be affected

4. **When comparing V_X to V_Y:**

    a. V_X will always be greater than V_Y
    b. V_Y will always be greater than or equal to V_X
    c. V_Y will always be greater than V_X
    d. V_X will sometimes be greater than V_Y, but sometimes be less than V_Y

5. **Referring to Fig. 4.24 in CAP 698. Why does the curve for an equivalent weight of 35 000 kg only start 4 mins after engine failure?**

    a. All the curves start at the same point higher up
    b. At that altitude the engine takes longer to spool down after failure
    c. At that weight the aircraft has a higher TAS and therefore more momentum
    d. At that weight the aircraft takes longer to slow down to the optimum drift down speed

6. **With which conditions would one expect V_{MC} to be the lowest?**

    a. Cold temp, low altitude, low humidity
    b. Hot temp, low pressure altitude, high humidity
    c. Hot temp, high pressure altitude, high humidity
    d. Cold temp, high altitude, low humidity

7. **Give the correct order for the following:**

a. V_{MCG}, V_R, V_1, V_2
b. V_{MCG}, V_1, V_R, V_2
c. V_1, V_{MCG}, V_R, V_2
d. V_{MCG}, V_1, V_{MCA}, V_R, V_2

8. **If the C of G moves aft from the most forward position:**

a. the range and the fuel consumption will increase
b. the range and the fuel consumption will decrease
c. the range will increase and the fuel consumption will decrease
d. the range will decrease and the fuel consumption will increase

9. **Descending below the tropopause from FL370 to FL250 at a steady Mach Number, then FL250 to FL100 at a constant CAS, what happens to descent angle?**

a.	Increase	Increase
b.	Increase	Constant
c.	Decrease	Decrease
d.	Constant	Constant

10. **With a constant weight and Mach No., a higher altitude will require:**

a. lower C_L
b. lower C_D
c. higher AoA
d. no change

11. **When approaching a wet runway, with the risk of hydroplaning, what technique should the pilot adopt with an inoperative anti-skid system?**

a. Positive touchdown, full reverse and brakes as soon as possible
b. Smoothest possible touchdown, full reverse and only brakes below V_P
c. Positive touchdown, full reverse and only brakes below V_P
d. Normal landing, full reverse and brakes at V_P

12. **An aircraft with a grad of 3.3%, flying at an IAS of 85 kt. At a P.ALT of 8500′ with a temp of +15°C will have an ROC of:**

a. 284′/min
b. 623′/min
c. 1117′/min
d. 334′/min

13. **An aircraft with a mass of 110 000 kg is capable of maintaining a grad of 2.6%. With all the atmospheric variables remaining the same, with what mass would it be able to achieve a grad of 2.4%?**

a. 119 167 kg
b. 101 530 kg
c. 110 000 kg
d. 121 167 kg

14. Give the correct sequence:

a. V_S, V_X, V_Y
b. V_X, V_S, V_Y
c. V_S, max range speed, max endurance speed
d. max endurance speed, V_S, max range speed

15. Flying at an altitude close to coffin corner gives:

a. max speed
b. less manoeuvrability
c. greater 1 engine inoperative range
d. greater 1 engine inoperative endurance

16. The main reason for using the step climb technique is to:

a. decrease sector times
b. increase endurance
c. adhere to ATC procedures
d. increase range

17. Ignoring the effect of compressibility, what would C_L do with an increase in altitude?

a. Increase
b. Decrease
c. Remain the same
d. Increase, then decrease

18. In climb limited mass calculations, the climb gradient is a ratio of:

a. height gained over distance travelled through the air
b. height gained over distance travelled across the ground
c. TAS over rate of climb
d. TGS over rate of climb

19. In a twin-engine jet aircraft with six passenger seats, and a maximum certified take-off mass of 5650 kg, what is the required en route obstacle clearance, with one engine inoperative during drift down towards the alternate airport?

a. 2000 ft
b. 1500 ft
c. 1000 ft
d. 50 ft or half the wingspan

20. When does THRUST = DRAG?

a. Climbing at a constant IAS
b. Descending at a constant IAS
c. Flying level at a constant IAS
d. All of the above

21. **When take-off mass is limited by V_{MBE}, an increase in the uphill slope will:**

a. have no effect
b. require a decrease in the mass
c. allow an increase in the mass
d. decrease the TODR

22. **SFC will:**

a. increase if C of G is moved further forward of the C of P
b. decrease if C of G is moved further forward of the C of P
c. not be affected by C of G position
d. only be affected by C of G position if it is behind the C of P

23. **Reference point zero refers to the:**

a. point where the aircraft lifts off the ground
b. point where the aircraft reaches V_2
c. point where the aircraft reaches 35 ft
d. point where gear is selected up

24. **To maintain the same angle of attack and altitude at a higher gross weight an aeroplane needs:**

a. less airspeed and same power
b. the same airspeed
c. more airspeed and less power
d. more airspeed and more power

25. **The coefficient of lift may be increased by lowering the flaps or:**

a. increasing CAS
b. reducing nose-up elevator trim
c. increasing angle of attack
d. increasing TAS

26. **An aircraft is certified to land with flaps at either 25 or 35 degrees of flap. If the pilot selects the higher setting there will be:**

a. increased landing distance and reduced go-around performance
b. increased landing distance and improved go-around performance
c. reduced landing distance and improved go-around performance
d. reduced landing distance and reduced go-around performance

27. **Which conditions are most suited to a selection of lower flap for take-off?**

a. Low airfield elevation, close obstacles, long runway, high temperature
b. Low airfield elevation, no obstacles, short runway, low temperature
c. High elevation, no obstacles, short runway, low temperature
d. High airfield elevations, distant obstacles, long runway, high ambient temperature

28. During the certification of an aeroplane, the take-off distance with all engines operating and the take-off distance with one engine inoperative are:

1547 m
1720 m

What is the distance used in the aircraft certification?

a. 1547 m
b. 1779 m
c. 1720 m
d. 1798 m

29. V_{2MIN} is determined by: (excluding V_{MCA})

a. $1.08V_{SR}$ for 4 engine turboprops with $1.13V_{SR}$ for 2 and 3 engine turboprops.
b. $1.2V_S$ for all turbojets
c. $1.2V_{SR}$ for all turboprops and $1.15V_{SR}$ for all turbojets
d. $1.15V_S$ for all aeroplanes

30. If the flap setting is changed from 10 degrees to 20 degrees, V_2 will:

a. not change
b. decrease if not limited to V_{MCA}.
c. increase
d. increase or decrease depending on weight

31. For a turbojet aeroplane the second segment of the climb begins when:

a. accelerating from V_2 to flap retraction speed begins
b. the landing gear is fully retracted
c. flap retraction begins
d. the flaps are fully retracted

32. For a turbojet aeroplane the third segment of climb begins when:

a. acceleration to flap retraction speed begins (min 400 ft)
b. the landing gear is fully retracted
c. acceleration from V_{LOF} to V_2 begins
d. the flaps are fully retracted

33. The buffet onset boundary chart tells the pilot the:

a. critical Mach number for various masses and altitudes
b. values for low speed stall and Mach buffet onset for various masses and altitudes
c. Mach number for low speed buffet and shock buffet for various masses and altitudes
d. maximum operating M_{MO} for various masses and altitudes

34. **Two identical turbojets are holding at the same altitude and have the same specific fuel consumption. Aeroplane 1 weighs 130 000 kg and fuel flow is 4300 kg/hr. If aeroplane 2 weighs 115 000 kg what is the fuel flow?**

a. 3 804 kg/hr
b. 4 044 kg/hr
c. 3 364 kg/hr
d. 3 530 kg/hr

35. **The speed for minimum power required in a turbojet will be:**

a. slower than the speed for minimum drag
b. faster than the speed for minimum drag
c. slower in a climb and faster in the decent
d. same as speed for minimum drag

36. **In wet conditions, what extra percentage over the dry gross landing distance must be available for a turbojet?**

a. 43%
b. 92%
c. 67%
d. 15%

37. **In dry conditions, when landing at an alternate airport in a turbojet by what factor should the landing distance available be divided to give landing distance?**

a. 0.6
b. 1.0
c. 1.67
d. 1.43

38. **What landing distance requirements need to be met at an alternate airfield compared to a destination airfield for a turboprop?**

a. Less than destination
b. More than destination
c. Same as destination
d. None applicable

39. **For a twin-engine aircraft, which can use either 5 or 15 degrees flap setting, using MRJT fig 4.4 what is the maximum field limited take-off mass?**

Pressure Altitude	**7000'**
OAT	**-10°C**
Length available	**2400 m**
Slope	**Level**
Wind	**Calm**

a. 55 000 kg
b. 56 000 kg
c. 44 000 kg
d. 52 000 kg

40. **Absolute ceiling is defined by:**

a. altitude where theoretical rate of climb is zero
b. altitude at which rate of climb is 100 fpm
c. altitude obtained when using lowest steady flight speed
d. altitude where low speed buffet and high speed buffet speeds are coincident

41. **V_{REF} for a Class B aircraft is defined by:**

a. $1.3V_S$
b. $1.2V_S$
c. $1.3V_{MCL}$
d. $1.2V_{MCL}$

42. **V_R for a jet aircraft must be faster than, the greater of:**

a. $1.05V_{MCA}$ and V_1
b. V_{MCA} and $1.1V_1$
c. V_{MBE} and V_1
d. V_1 and $1.1V_{MCA}$

43. **Landing on a runway with 5 mm wet snow will:**

a. increase landing distance
b. decrease landing distance
c. not affect the landing distance
d. give a slightly reduced landing distance, due to increased impingement drag

44. **Take off on a runway with standing water, with a depth of 0.5 cm. Compared to a dry runway, field length limited mass will:**

a. increase, with a reduced V_1
b. remain the same, with a reduced V_1
c. decrease, with an increased V_1
d. decrease, with a decreased V_1

45. **A balanced field length is when:**

a. distance taken to accelerate to V_1 and distance to stop are identical
b. TORA × 1.5 = TODA
c. $V_1 = V_R$
d. ASDA equals TODA

46. **Increased ambient temperature will result in:**

a. increased field length limited mass
b. decreased maximum brake energy limited mass
c. increased climb limited mass
d. increased obstacle limited mass

47. **Pitch angle during decent at a constant Mach number will:**

a. increase
b. decrease
c. increase at first then decrease
d. stay constant

48. **At maximum range speed in a turbojet the angle of attack is:**

a. the same as L/D max
b. less than L/D max
c. maximum
d. more than L/D max

49. **If there is an increase in atmospheric pressure and all other factors remain constant, it should result in:**

a. decreased take-off distance and increased climb performance
b. increased take-off distance and increased climb performance
c. decreased take-off distance and decreased climb performance
d. increased take-off distance and decreased climb performance

50. **Climbing to cruise altitude with a headwind will:**

a. increase time to climb
b. decrease ground distance covered to climb
c. decreased time to climb
d. increased ground distance covered to climb

51. **Requirements for the third segment of climb are:**

a. minimum acceleration altitude for one engine inoperative should be used
b. a climb gradient of 5% is required in the third segment
c. level acceleration with an equivalent gradient of 1.2%
d. legal minimum altitude for acceleration is 1500 ft

52. **If the calculations for an aeroplane of 3250 lb indicate a service ceiling of 4000 m, what will the service ceiling be when the actual take-off mass is 3000 lb?**

a. Higher
b. Lower
c. Higher or lower, more calculations will have to be done
d. The same

53. **Why is there a requirement for an approach climb gradient?**

a. So that an aircraft falling below the glide path will be able to re-intercept it
b. Adequate performance for a go-around in the event of an engine failure
c. So that the aircraft will not stall when full flap is selected
d. To maintain minimum altitude on the approach

54. The drift down is a procedure applied:

a. after aircraft depressurization
b. for a visual approach to a VASI
c. for an instrument approach at an airfield without an ILS
d. when the engine fails above the operating altitude for one engine inoperative

55. A light twin-engine aircraft is climbing from the screen height of 50 ft, and has an obstacle 10 000 m along the net flight path. If the net climb gradient is 10%, there is no wind and obstacle is 900 m above the aerodrome elevation then what will the clearance be?

a. The aircraft will not clear the object
b. 85 m
c. 100 m
d. 115 m

56. The dry net take-off run required (TORR) for a jet aircraft, with all engines operating is:

a. brake release point to midpoint between V_{LOF} and 35 ft
b. brake release point to 35 ft
c. brake release point to 15 ft
d. the same as for all engines

57. A jet aircraft's maximum altitude is usually limited by:

a. its certification maximum altitude
b. its pressurization maximum altitude
c. the altitude at which low and high-speed buffet will occur
d. thrust limits

58. With respect to en route diversions (using drift down graph), if you believe that you will not clear an obstacle do you:

a. drift down to clearance height and then start to jettison fuel
b. jettison fuel from the beginning of the drift down
c. asses remaining fuel requirements, then jettison fuel as soon as possible
d. fly slight faster

59. With respect to field length limit, fill in the blanks in the follow statement.

"The distance to accelerate to ...., at which point an engine fails, followed by the reaction time of .... and the ensuing deceleration to a full stop must be completed within the ...."

a. V_R, 2 sec, TORA
b. V_1, 2 sec, ASDA
c. V_{EF}, 2 sec, TORA
d. V_{GO}, 2 sec, ASDA

60. **How does the power required graph move with an increase in altitude?**

a. Straight up
b. Straight down
c. Up and to the right
d. Straight across to the right

61. **What factors would cause V_2 to be limited by V_{MCA}?**

a. Flaps at high settings
b. With high pressure
c. With low temperature
d. Combination of the above

62. **In a climb, at a constant IAS / Mach No. 300 kt / M 0.78, what happens at the changeover point (29 500 ft, ISA)?**

a. Accelerate from the IAS to the Mach number, and therefore rate of climb will decrease
b. No change in rate of climb since TAS remains constant
c. Find that rate of climb would start to increase, because TAS starts to increase
d. Find that rate of climb would start to decrease, because TAS would start to decrease

63. **If not V_{MBE} or V_{MCG} limited, what would V_1 be limited by?**

a. V_2
b. V_{MC}
c. V_R
d. V_{MU}

64. **What procedure is likely to require V_1 to be reduced?**

a. Improved climb procedure
b. Reduced thrust take-off
c. When ASDA is greater than TODA
d. Take off with anti-skid inoperative

65. **Which of the following is not affected by a tailwind?**

a. Landing climb limit mass
b. Obstacle limit mass
c. V_{MBE}
d. Tyre speed limit mass

66. **When flying an aircraft on the back of the drag curve, maintaining a slower speed (but still faster than V_S) would require:**

a. more flap
b. less thrust due to less parasite drag
c. more thrust
d. no change

67. During certification test flights for a turbojet aeroplane, the measured take-off runs from brake release to a point equidistant between the point at which V_{LOF} is reached and the point at which the aeroplane is 35 ft above the take off surface are:

1530 m with all engines operating.
1810 m with the critical engine failure recognized at V_1, other factors remaining unchanged.

What is the correct value of the take-off run?

a. 1759 m
b. 1810 m
c. 1950 m
d. 2081 m

68. Taking into account the following, what would be the minimum required headwind component for landing? (Using fig 2.4 in CAP 698.)

Factored landing distance of 1300 ft.
ISA temperature at MSL.
Landing mass of 3200 lb.

a. 8 kt
b. 5 kt
c. 0 kt
d. 15 kt

69. Two identical aircraft at different masses are descending at idle thrust. Which of the following statements correctly describes their descent characteristics?

a. There is no difference between the descent characteristics of the two aeroplanes
b. At a given angle of attack, the heavier aeroplane will always glide further than the lighter aeroplane
c. At a given angle of attack, the lighter aeroplane will always glide further than the heavier aeroplane
d. At a given angle of attack, both the vertical and the forward speeds are greater for the heavier aeroplane

70. When flying in a headwind, the speed for max range should be:

a. slightly decreased
b. slightly increased
c. unchanged
d. should be increased, or decreased depending on the strength of the wind

71. V_{LO} is defined as:

a. the actual speed that the aircraft lifts off the ground
b. the minimum possible speed that the aircraft could lift off the ground
c. the maximum speed for landing gear operation
d. the long range cruise speed

72. When flying at the optimum range altitude, over time the:

a. fuel consumption gradually decreases
b. fuel consumption gradually increases
c. fuel consumption initially decreases then gradually increases
d. fuel consumption remains constant

73. What happens to the field limited take-off mass with runway slope?

a. It increases with a downhill slope
b. It is unaffected by runway slope
c. It decreases with a downhill slope
d. It increases with an uphill slope

74. For a given aircraft mass, flying with a cost index greater than zero set will result in:

a. a cruise at a slower Mach number than the best range Mach number for a given altitude
b. a cruise at the maximum endurance speed
c. climb at the slowest safe speed, taking into account stall and speed stability
d. a cruise at a faster Mach number than the Mach number giving best air nautical miles per kg ratio for a given altitude

75. Cruising with 1 or 2 engines inoperative at high altitude, compared to all engines operative cruise, range will:

a. increase
b. decrease
c. not change
d. decrease with 1 engine inoperative, and increase with 2 engines inoperative

76. Taking into account the values given below, what would be the maximum authorized brake release mass?

Flap:	5°	10°	15°
Field limited mass:	49 850 kg	52 500 kg	56 850 kg
Climb limited mass:	51 250 kg	49 300 kg	45 500 kg

a. 56 850 kg
b. 49 300 kg
c. 49 850 kg
d. 51 250 kg

77. **A turboprop aircraft with a maximum all up mass in excess of 5700 kg is limited to:**

a. 10° angle of bank up to 400 ft
b. 15° angle of bank up to 400 ft
c. 20° angle of bank up to 400 ft
d. 25° angle of bank up to 400 ft

78. **With regards to the optimum altitude during the cruise, the aircraft is:**

a. always flown at the optimum altitude
b. always flown 2000 ft below the optimum altitude
c. may be flown above or below the optimum altitude, but never at the optimum altitude
d. flown as close to the optimum altitude as ATC will allow

79. **A tailwind on take-off will not affect:**

a. climb limit mass
b. obstacle clearance
c. field limit mass
d. V_{MBE}

80. **When climbing at a constant Mach number through the troposphere, TAS:**

a. increases
b. decreases
c. remains constant
d. increases then decreases

81. **Concerning landing gear, which factors limit take-off performance?**

a. Brake temperature
b. Tyre speed and V_{MBE}
c. Tyre temperature
d. Brake wear

82. **In a glide (power-off descent) if pitch angle is increased, glide distance will:**

a. increase
b. decrease
c. remain constant
d. depend on the aircraft

83. **With which conditions would the aircraft need to be flown, in order to achieve maximum speed?**

a. Thrust set for minimum drag
b. Best lift - drag ratio
c. Maximum thrust and maximum drag
d. Maximum thrust and minimum drag

84. If a jet engine fails during take-off, before V_1:

a. the take-off can be continued or aborted
b. the take-off should be aborted
c. the take-off should be continued
d. the take-off may be continued if aircraft speed is above V_{MCG} and lies between V_{GO} and V_{STOP}

85. Up to which height in NADP 1 noise abatement procedure must V_2 + 10-20 kt be maintained?

a. 1500 ft
b. 3000 ft
c. 1000 ft
d. 500 ft

86. At MSL, in ISA conditions.
Climb gradient = 6%

What would the climb gradient be if:

P.altitude 1000 ft
Temperature 17°C
Engine anti-ice on.
Wing anti-ice on.
(- 0.2% engine anti-ice, - 0,1% wing anti-ice, ± 0.2% per 1000 ft P.altitude, ± 0.1 % per 1°C ISA deviation)

a. 5.1%
b. 6.3%
c. 3.8%
d. 5.5%

87. An aircraft with 180 minutes approval for ETOPS must be:

a. no more than 180 minutes from a suitable alternate, in still air, at the one engine inoperative TAS
b. no more than 180 minutes from a suitable alternate, in still air, at the all engine TAS
c. no more than 90 minutes from a suitable alternate, and 90 minutes from departure, at the one engine inoperative TAS
d. no more than 180 minutes from a suitable alternate, at the one engine inoperative TGS

88. In a balanced turn load factor is dependent on:

a. radius of turn and aircraft weight
b. TAS and bank angle
c. radius of turn and bank angle
d. bank angle only

89. Putting in 16 500 litres of fuel with an SG of 780 kg/m², and writing 16 500 kg of fuel on the load sheet will result in:

a. TOD increasing and ASD decreasing, and the calculated V_2 being too fast
b. TOD and ASD decreasing, and the calculated V_2 being too fast
c. TOD and ASD remaining constant, if the calculated speeds are used
d. TOD and ASD increasing, if the calculated speeds are used

90. If V_1 is found to be lower than V_{MCG}, which of the following statements will be true?

a. V_{MCG} must be reduced to equal V_1
b. TOD will be greater than ASD
c. ASD will be equal to TOD
d. Take-off is not permitted

91. When gliding into a headwind airspeed should be:

a. reduced to gust penetration speed
b. the same as the max. range glide speed in still air
c. lower than the max. range glide speed in still air
d. higher than the max. range glide speed in still air

92. How does the slush thickness affect the V_1 reduction required?

a. Greater reduction if thicker
b. Smaller reduction if thicker
c. No effect if mass is reduced
d. No effect at all

93. Which denotes the stall speed in the landing configuration?

a. V_{S0}
b. V_{S1}
c. V_S
d. V_{S1g}

94. When in a gliding manoeuvre, in order to achieve maximum endurance the aircraft should be flown at:

a. the speed for max. lift
b. the speed for min. drag
c. the speed for max. lift / drag
d. the speed for min. power

95. When descending below the optimum altitude at the long range cruise speed:

a. Mach number decreases
b. TAS increases
c. Mach number remains constant
d. Mach number increases

96. **What does density altitude signify ?**

a. Pressure altitude
b. Flight levels
c. ISA altitude
d. An accurate indication of aircraft and engine performance

97. **For a turboprop aircraft, the LDA at an aerodrome is 2200 m. If the conditions are indicated as wet, what would the equivalent dry LDA be ?**

a. 1451 m
b. 1913 m
c. 1538 m
d. 1339 m

98. **During aircraft certification, the value of V_{MCG} is found with nose wheel steering inoperative. This is because:**

a. nose wheel steering does not affect V_{MCG}
b. V_{MCG} must be valid in both wet and dry conditions
c. nose wheel steering does not work after an engine failure
d. the aircraft may be operated even if the nose wheel steering is inoperative

99. **Referring to CAP 698 Fig 4.28.**

What would the landing distance required be for an MRJT aircraft with anti-skid inoperative if:

Pressure altitude 2000 ft.
Mass 50 000 kg
Flaps for short field.
15 kt Tailwind
Dry runway.

a. 1700 m
b. 2500 m
c. 1900 m
d. 3100 m

100. **Which is true regarding a balanced field?**

a. Provides largest gap between net and gross margins
b. Provides minimum field length required in the case of an engine failure
c. Take-off distance will always be more than stopping distance
d. Distances will remain equal, even if engine failure speed is changed

101. **Climbing in the troposphere at a constant TAS:**

a. Mach number increases
b. Mach number decreases
c. CAS increases
d. IAS increases.

102. When an MRJT aircraft descends at the maximum range speed:

a. IAS increases
b. CAS increases
c. Mach number decreases
d. Mach number increases

103. What condition is found at the intersection of the thrust available and the drag curve?

a. Unaccelerated flight in a climb
b. Accelerated climb
c. Unaccelerated level flight
d. Accelerated level flight

104. Out of the four forces acting on the aircraft in flight, what balances thrust in the climb?

a. Drag
b. Weight
c. W Sin γ
d. Drag + W Sin γ

105. The information in a light aircraft manual gives two power settings for cruise, 65% and 75%. If you fly at 75% instead of 65%:

a. cruise speed will be higher, fuel consumption will be higher
b. cruise speed will be the same, fuel consumption will be the same
c. cruise speed will be higher, fuel consumption will be lower
d. cruise speed will be higher, fuel consumption will be the same

106. With a downward sloping runway:

a. V_1 will increase
b. V_1 will decrease
c. V_R will increase
d. V_R will decrease

107. How is fuel consumption affected by the C of G position, in terms of air nautical miles per kg?

a. Increases with a forward C of G
b. Decreases with an aft C of G
c. Decreases with a forward C of G
d. Fuel consumption is not affected by the C of G position

108. Rate of Climb 1000 ft/min
TAS 198 kt
What is the aircraft's gradient ?

a. 5.08%
b. 3%
c. 4%
d. 4.98%

109. The reduced thrust take-off procedure may not be used when:

a. runway wet
b. after dark
c. temperature varies by more than 10°C from ISA
d. anti-skid unserviceable

110. If the maximum take-off mass is limited by tyre speed, what effect would a down sloping runway have?

a. No effect
b. Always increase the mass
c. Only increase the mass if not limited by any other limitation
d. Decrease the mass

111. With an obstacle which is 160 m above the airfield elevation and 5000 m away from the end of the take-off distance (screen height 50 ft), what would the obstacle clearance be with a gradient of 5% ?

a. 105 m
b. 90 m
c. 250 m
d. 265 m

112. Prior to take-off the brake temperature needs to be checked, because:

a. they indicate the state of the fusible plugs
b. if the brakes are already hot, they may fade / overheat during a RTO
c. they would work better if they were warm
d. they may need to be warmed up to prevent them from cracking during a RTO

113. A turbojet is flying at a constant Mach number in the cruise. How does SFC vary with OAT in Kelvin?

a. Unrelated to T
b. Proportional to T
c. Proportional to 1/T
d. Proportional to $1/T^2$

114. If an aircraft has a stall speed of 100 kt, what would the speed on short finals have to be?

a. 100 kt
b. 115 kt
c. 130 kt
d. 120 kt

115. When descending at a constant Mach number, which speed is most likely to be exceeded first?

a. Max operating speed
b. M_{MO}
c. High speed buffet limit
d. V_{MO}

116. What is meant by 'equivalent weight' on the drift down profile graph?

a. Weight compensated for fuel reduction prior to engine failure
b. Weight compensated for temperature of ISA +10°C and above
c. Weight compensated for density at different heights
d. Weight compensated for temperature at different heights

117. What happens to the speeds V_X and V_Y when lowering the aircraft's undercarriage?

a. V_X increases, V_Y decreases
b. V_X decreases, V_Y decreases
c. V_X increases, V_Y increases
d. V_X decreases, V_Y increases

118. Maximum endurance:

a. can be achieved in level unaccelerated flight with minimum fuel consumption
b. can be achieved by flying at the best rate of climb speed in straight and level flight
c. can be achieved in a steady climb
d. can be achieved by flying at the absolute ceiling

119. What factors affect descent angle in a glide?

a. Configuration and altitude
b. Configuration and angle of attack
c. Mass and attitude
d. Mass and configuration

120. What is meant by balanced field available?

a. TORA = TODA
b. ASDA = ASDR and TODA =TODR
c. TODA = ASDA
d. TORA = ASDA

121. **For a piston engine aeroplane at a constant altitude, angle of attack and configuration, an increased weight will require:**

a. more power but less speed
b. more power and the same speed
c. more power and more speed
d. the same power but more speed

122. **In the climb an aircraft has a thrust to weight ratio of 1:4 and a lift to drag ratio of 12:1. While ignoring the slight difference between lift and weight in the climb, the climb gradient will be:**

a. 3.0%
b. 8.3%
c. 16.7%
d. 3.3%

123. **Which of the following will not decrease the value of V_S?**

a. The C of G in an aft position within the C of G envelope
b. Increased altitude
c. Decreased weight
d. Increased flap setting

124. **All other factors being equal, the speed for minimum drag is:**

a. constant for all weights
b. a function of density altitude
c. proportional to weight
d. a function of pressure altitude

125. **Taking into account the values given below, what would be the maximum authorized brake release mass with a 10 kt tailwind?**

Flap :	**5°**	**10°**	**15°**
Field limited mass :	**49 850 kg**	**52 500 kg**	**56 850 kg**
Climb limited mass :	**51 250 kg**	**49 300 kg**	**45 500 kg**

Assume 370 kg per kt of tailwind.

a. 56 850 kg
b. 49 850 kg
c. 52 500 kg
d. 48 800 kg

126. If a turn is commenced during the take-off climb path:

(i) the load factor.
(ii) the induced drag.
(iii) the climb gradient.

	(i)	(ii)	(iii)
a.	increases	decreases	decreases
b.	decreases	increases	increases
c.	increases	increases	decreases
d.	decreases	decreases	increases

127. What effect does an increase in weight have on V_1?

a. It will cause it to increase
b. It will cause it to decrease
c. It will have no effect
d. It will cause it to decrease by the same percentage as the weight increase

128. V_R for a Class A aeroplane must not be less than:

a. 10% above V_{MU}
b. 5% above V_{MCA}
c. 5% above V_{MCG}
d. 10% above V_{MCA}

129. As speed is reduced from V_{MD} to V_{MP}:

a. power required decreases and drag decreases
b. power required decreases and drag increases
c. power required increases and drag increases
d. power required increases and drag decreases

130. The maximum induced drag occurs at a speed of:

a. V_{MD}
b. V_{MP}
c. V_{S0}
d. $1.32V_{MD}$

131. Profile drag is:

a. inversely proportional to the square root of the EAS
b. directly proportional to the square of the EAS
c. inversely proportional to the square of the EAS
d. directly proportional to the square root of the EAS

132. Losing an engine during the take-off above V_{MCA} means the aircraft will be able to maintain:

a. altitude
b. straight and level flight
c. heading
d. bank angle

133. The best EAS / drag ratio is approximately:

a. $1.3V_{MD}$
b. $1.32V_{MD}$
c. $1.6V_{MD}$
d. $1.8V_{MD}$

134. The effect an increase of weight has on the value of stalling speed (IAS) is that V_S:

a. increases
b. decreases
c. remains constant
d. increases or decreases, depending on the amount of weight increase

135. Which one of the following statements is true concerning the effect of changes of ambient temperature on an aeroplane's performance, assuming all other performance parameters remain constant?

a. An increase will cause a decrease in the landing distance required
b. An increase will cause a decrease in take-off distance required
c. A decrease will cause an increase in the climb gradient
d. A decrease will cause an increase in the take-off ground run

136. What percentages of the headwind and tailwind components are taken into account, when calculating the take-off field length required ?

a. 100% headwind and 100% tailwind
b. 150% headwind and 50% tailwind
c. 50% headwind and 100% tailwind
d. 50% headwind and 150% tailwind

137. For a turbojet aircraft planning to land on a wet runway, the landing distance available:

a. may be less than 15% greater than the dry landing distance if the flight manual gives specific data for a wet runway
b. may be less than 15% greater than the dry landing distance if all reverse thrust systems are operative
c. may be less than 15% greater than the dry landing distance if permission is obtained from the relevant aerodrome authority
d. must always be at least 15% greater than the dry landing distance

138. The effect of installing more powerful engines in a turbojet aircraft is:

a. to increase the aerodynamic ceiling and increase the performance ceiling
b. to decrease the aerodynamic ceiling and increase the performance ceiling
c. to increase the performance ceiling but not affect the aerodynamic ceiling
d. to decrease both the aerodynamic and the performance ceilings

139. In relation to runway strength, the ACN:

a. may not exceed 90% of the PCN
b. may exceed the PCN by up to 10%
c. may never exceed the PCN
d. may exceed the PCN by a factor of 2

**140. An aerodrome has a clearway of 500 m and a stopway of 200 m.
If the stopway is extended to 500 m the effect will be:**

a. the maximum take-off mass will increase, and V_1 will decrease
b. the maximum take-off mass will increase and V_1 will remain the same
c. the maximum take-off mass will remain the same and V_1 will increase
d. the maximum take-off mass will increase and V_1 will increase

141. An aircraft is climbing at a constant power setting and a speed of V_x. If the speed is reduced and the power setting maintained, the:

a. climb gradient will decrease and the rate of climb will increase
b. climb gradient will decrease and the rate of climb will decrease
c. climb gradient will increase and the rate of climb will increase
d. climb gradient will increase and the rate of climb will decrease

142. When an aircraft is climbing in a standard atmosphere above the tropopause at a constant Mach number:

a. the IAS decreases and TAS remain constant
b. the IAS and TAS remain constant
c. the IAS decreases and TAS decreases
d. the IAS remains constant and TAS increases

143. An aircraft is climbing at a constant IAS, below the Mach limit. As height increases:

a. drag decreases, because density decreases
b. drag remains constant, but the climb gradient decreases
c. drag increases, because TAS increases
d. drag remains constant and the climb gradient remains constant

144. Optimum altitude can be defined as:

a. the highest permissible altitude for an aeroplane type
b. the altitude at which an aeroplane attains the maximum specific air range
c. the altitude at which the ground speed is greatest
d. the altitude at which specific fuel consumption is highest

145. If an aircraft is descending at a constant Mach number:

a. the IAS will increase and the margin to low speed buffet will decrease
b. the IAS will increase and the margin to low speed buffet will increase
c. the IAS will decrease and the margin to low speed buffet will decrease
d. the IAS will decrease and the margin to low speed buffet will increase

146. For a given flight level, the speed range determined by the buffet onset boundary chart will decrease with:

a. decreased weight
b. decreased bank angle
c. a more forward CG position
d. increased ambient temperature

147. Which of the following variables will not affect the shape or position of the drag vs. IAS curve, for speeds below M_{CRIT}?

a. Aspect ratio
b. Configuration
c. Altitude
d. Weight

148. Which of the following would give the greatest gliding endurance?

a. Flight at V_{MD}
b. Flight at $1.32V_{MD}$
c. Flight at the best C_L / C_D ratio
d. Flight close to C_{LMAX}

149. The tyre speed limit is:

a. V_1 in TAS
b. Max V_{LOF} in TAS
c. Max V_{LOF} in ground speed
d. V_1 in ground speed

150. What gives one the greatest gliding time?

a. Being light
b. A headwind
c. A tailwind
d. Being heavy

151. For take-off performance calculations, what is taken into account?

a. OAT, pressure altitude, wind, weight
b. Standard temperature, altitude, wind, weight
c. Standard altitude, standard temperature, wind, weight
d. Standard temperature, pressure altitude, wind, weight

152. **Which 3 speeds are effectively the same for a jet aircraft?**

a. ROC, range, minimum drag
b. Range, best angle of climb, minimum drag
c. Best angle of climb, minimum drag, endurance
d. Best angle of climb, range, endurance

153. **The long range cruise speed is a speed that gives:**

a. a 1% increase in range and a decrease in IAS
b. a 1% increase in TAS
c. a 1% increase in IAS
d. gives 99% of best cruise range, with an increase in IAS

154. **When an aircraft takes off at the mass it was limited to by the TODA:**

a. the end of the runway will be cleared by 35 ft following an engine failure just before V_1
b. the actual take-off mass equals the field length limited take-off mass
c. the distance from BRP to V_1 is equal to the distance from V_1 to the 35 ft screen
d. the balanced take-off distance equals 115% of the all engine take-off distance

155. **Which of the following speeds gives the maximum obstacle clearance in the climb?**

a. V_Y
b. $1.2V_{S1}$
c. V_X
d. V_{FE}

156. **The tangent from the origin to the power required curve gives:**

a. Minimum drag coefficient
b. L/D Minimum
c. D/L Maximum
d. L/D Maximum

157. **For a jet flying at a constant altitude, at the maximum range speed, what is the effect on IAS and drag over time?**

a. Increase, Increases
b. Decrease, Constant
c. Constant, Decrease
d. Decrease, Decrease

158. **If an aircraft descends at a constant Mach number, what will the first limiting speed be?**

a. Max operating speed
b. Never exceed speed
c. Max operating Mach number
d. Shock stall speed

159. For an aircraft gliding at its best glide range speed, if AoA is reduced:

a. glide distance will increase
b. glide distance will remain unaffected
c. glide distance will decrease
d. glide distance will remain constant, if speed is increased

160. If an aircraft's climb schedule was changed from 280 / M 0.74 to 290 / M 0.74, what would happen to the changeover altitude?

a. It would remain unchanged
b. It could move up or down, depending on the aircraft
c. It will move down
d. It will move up

161. What happens to the cost index when flying above the optimum long range cruise speed?

a. Cost index is not affected by speed
b. Cost index will increase with increased speed
c. Cost index will decrease with increased speed
d. It all depends on how much the speed is changed by

162. For an aircraft flying at the long range cruise speed, (i) specific range and (ii) fuel to time ratio:

a.	(i) decreases	(ii) increases
b.	(i) increases	(ii) increases
c.	(i) decreases	(ii) decreases
d.	(i) increases	(ii) decreases

163. By what percentage should V_2 be greater than V_{MCA}?

a. 30%
b. 10%
c. 20%
d. 15%

164. If a turboprop aircraft has a wet LDA of 2200 m, what would the equivalent dry landing distance allowed be?

a. 1540 m
b. 1148 m
c. 1913 m
d. 1339 m

165. If a TOD of 800 m is calculated at sea level, on a level, dry runway, with standard conditions and with no wind, what would the TOD be for the conditions listed below?

2000 ft Airfield elevation
QNH 1013.25 hPa
Temp. of 21°C
5 kt of tailwind
Dry runway with a 2% upslope.

(Assuming: ±20 m/1000 ft elevation, +10 m/1 kt of reported tailwind, ±5 m/1°C ISA deviation and the standard slope adjustments).

a. 836 m
b. 940 m
c. 1034 m
d. 1095 m

166. At a constant mass and altitude, a lower airspeed requires:

a. more thrust and a lower coefficient of lift
b. less thrust and a lower coefficient of lift
c. more thrust and a lower coefficient of drag
d. a higher coefficient of lift

167. On a piston engine aeroplane, with increasing altitude at a constant gross mass, angle of attack and configuration, the power required:

a. decreases slightly because of the lower air density
b. remains unchanged but the TAS increases
c. increases but the TAS remains constant
d. increases and the TAS increases

168. Reduced take-off thrust:

a. can be used if the headwind component during take-off is at least 10 kt
b. can be used if the take-off mass is higher than the performance limited take-off mass
c. is not recommended at very low temperatures
d. has the benefit of improving engine life

169. Reduced take-off thrust:

a. can only be used in daylight
b. can not be used on a wet runway
c. is not recommended when wind shear is expected on departure
d. is not recommended at sea level

170. May the anti-skid be considered in determining the take-off and landing mass limits?

a. Only landing
b. Only take-off
c. Yes
d. No

171. Climb limited take-off mass can be increased by:

a. lower V_2
b. lower flap setting and higher V_2
c. lower V_R
d. lower V_1

172. An operator shall ensure that the aircraft clears all obstacles in the net take-off flight path.

The half-width of the obstacle accountability area (domain) at distance D from the end of the TODA is:

a. 90 m + (D / 0.125)
b. 90 m + (1.125 × D)
c. 90 m + (0.125 × D)
d. (0.125 × D)

173. The take-off performance for a turbojet aircraft using 10° flap results in the following limitations:

Obstacle clearance limited mass:	**4630 kg**
Field length limited mass:	**5270 kg**

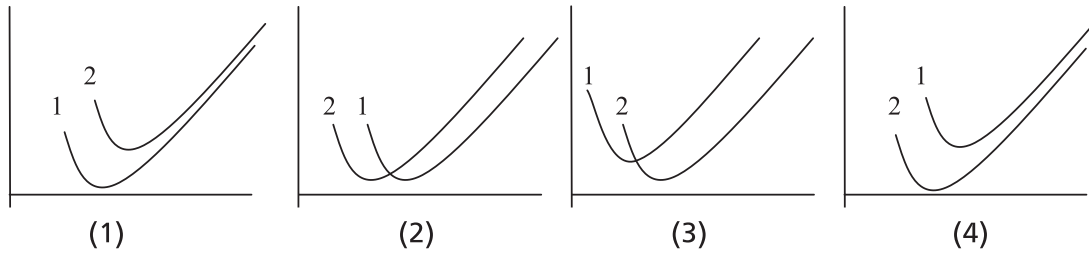
Given that it is intended to take-off with a mass of 5000 kg, which of the following statements is true?

a. With 5° flap the clearance limit will increase and the field limit will decrease.
b. With 15° flap both will increase
c. With 5° flap both will increase
d. With 15° flap the clearance limit will increase and the field limit will decrease

174. Induced drag:

a. increases with increased airspeed
b. decreases with increased airspeed
c. independent of airspeed
d. initially increases and then decreases with speed

175. Which of these graphs shows the relationship that thrust required has with decreased weight?



a. 1
b. 2
c. 3
d. 4

176. What is the formula for specific range?

a. Ground speed divided by fuel flow
b. True airspeed divided by fuel flow
c. Fuel flow divided by SFC
d. Ground speed divided by SFC

177. When does the first segment of the take-off climb begin?

a. When V_2 is reached
b. When 35 feet is reached
c. When flaps are up
d. When gear and flaps are up

178. A headwind component:

a. increases climb flight path angle
b. decreases climb flight path angle
c. increases best rate of climb
d. decreases rate of climb

179. V_1 is limited by:

a. V_{MCG} and V_R
b. V_{MCA} and V_R
c. V_2 and V_R
d. $1.05V_{MCA}$

180. V_R is:

a. less than V_1
b. more than V_2
c. less than V_{MCG}
d. equal to or more than V_1

181. What is the effect of an increase in pressure altitude?

a. Increased take-off distance with increased performance
b. Decreased take-off distance and increased performance
c. Increased take-off distance and decreased performance
d. Decreased take-off distance with decreased performance

182. What affects endurance?

a. Speed and weight
b. Speed and fuel on board
c. Speed, weight and fuel on board
d. None of the above

183. What degrades aircraft performance?

a. Low altitude, low temperature, low humidity
b. High altitude, high temperature, high humidity
c. Low altitude, high temperature, low humidity
d. High temperature, high altitude, low humidity

184. If your take-off is limited by the climb limit mass, what is the effect of a headwind?

a. No effect
b. Increased mass
c. Decreased mass
d. Dependant on the strength of the headwind

185. What is the effect on accelerate-stop distance of the anti-skid system being inoperative?

a. Increased
b. Decreased
c. Constant
d. Unable to be determined without further information

186. What is V_{REF} for Class A aircraft?

a. $1.3V_S$
b. $1.13V_{SR0}$
c. $1.23V_{SR0}$
d. $1.05V_{MCL}$

187. During planning V_{MCG} is found to be greater than V_1. If V_1 is adjusted to equal V_{MCG} and engine failure occurs at the new V_1, then:

a. ASDR is smaller than TODR
b. ASDR is larger than TODR
c. ASDR is the same as TODR
d. the aircraft weight must be reduced in order to permit take-off

188. Refer to CAP 698 Fig 2.1. What is the Gross TODR for an aircraft in the following conditions:

A/C TOM 1591 kg
Field elevation 1500 ft (QNH 1013)
OAT is +18°C
16 kt Headwind Component
1% downhill slope
Paved, dry surface
No stopway or clearway

a. 335 m
b. 744 m
c. 555 m
d. 595 m

189. What is the take-off run defined as for a Class A aircraft:

a. the distance from brakes release to V_{LOF}
b. the distance from brakes release to a point on the ground below which the aircraft has cleared a screen height of 35 ft
c. the distance from brakes release to a point on the ground below which the aircraft has cleared a screen height of 50 ft
d. the distance from brakes release to a point half way between where the aircraft leaves the ground and the point on the ground above which it clears a height of 35 ft

Answers

1	2	3	4	5	6	7	8	9	10	11	12
d	d	a	b	d	c	b	c	b	c	c	d

13	14	15	16	17	18	19	20	21	22	23	24
a	a	b	d	c	a	a	c	c	c	c	d

25	26	27	28	29	30	31	32	33	34	35	36
c	d	a	b	a	b	b	a	c	a	a	b

37	38	39	40	41	42	43	44	45	46	47	48
c	c	b	a	a	a	a	d	d	b	b	b

49	50	51	52	53	54	55	56	57	58	59	60
a	b	c	a	b	d	d	a	c	c	b	c

61	62	63	64	65	66	67	68	69	70	71	72
d	d	c	d	a	c	b	a	d	b	c	a

73	74	75	76	77	78	79	80	81	82	83	84
a	d	b	c	b	d	a	b	b	b	c	b

85	86	87	88	89	90	91	92	93	94	95	96
b	a	a	d	b	d	d	b	a	d	a	d

97	98	99	100	101	102	103	104	105	106	107	108
d	b	d	b	a	c	c	d	a	b	c	d

109	110	111	112	113	114	115	116	117	118	119	120
d	a	a	b	b	c	d	b	b	a	b	c

121	122	123	124	125	126	127	128	129	130	131	132
c	c	b	c	d	c	a	b	b	c	b	c

133	134	135	136	137	138	139	140	141	142	143	144
b	a	c	d	a	c	b	d	b	a	b	b

145	146	147	148	149	150	151	152	153	154	155	156
b	c	c	d	c	a	a	c	d	b	c	d

157	158	159	160	161	162	163	164	165	166	167	168
d	a	c	c	b	a	b	d	c	d	d	d

169	170	171	172	173	174	175	176	177	178	179	180
c	c	b	c	a	b	d	b	b	a	a	d

181	182	183	184	185	186	187	188	189
c	c	b	a	a	c	b	c	d

Specimen Examination Paper

40 Questions, 40 Marks
Time Allowed: 1 hour

1. **A turbo-propeller aircraft is certified with a maximum take-off mass of 5600 kg and a maximum passenger seating of 10. This aircraft would be certified in:**

a. Class A
b. Class B
c. Class C
d. Either Class A or Class B depending on the number of passengers carried
(1 mark)

2. **How does the thrust from a fixed propeller change during the take-off run of an aircraft?**

a. It remains constant
b. It increases slightly as the aircraft speed builds up
c. It decreases slightly as the aircraft speed builds up
d. It only varies with changes in mass
(1 mark)

3. **The take-off run is defined as:**

a. distance to V_1 and then to stop, assuming the engine failure is recognised at V_1
b. distance from brake release to the point where the aircraft reaches V_2
c. the horizontal distance from the start of the take-off roll to a point equidistant between V_{LOF} and 35 ft
d. the distance to 35 ft with an engine failure at V_1 or 1.15 times the all engine distance to 35 ft
(1 mark)

4. **What effect does a downhill slope have on the take-off speeds?**

a. It has no effect on V_1
b. It decreases V_1
c. It increases V_1
d. It increases the IAS for take-off
(1 mark)

5. **Which of the following combinations most reduces the take-off and climb performance of an aircraft?**

a. High temperature and high pressure
b. Low temperature and high pressure
c. Low temperature and low pressure
d. High temperature and low pressure
(1 mark)

6. **Density altitude is:**

a. the true altitude of the aircraft
b. the altitude in the standard atmosphere corresponding to the actual conditions
c. the indicated altitude on the altimeter
d. used to calculate en route safety altitudes
(1 mark)

7. **The take-off climb gradient:**

a. increases in a headwind and decreases in a tailwind
b. decreases in a headwind and increases in a tailwind
c. is independent of the wind component
d. is determined with the aircraft in the take-off configuration
(1 mark)

8. **The effect of changing altitude on the maximum rate of climb (ROC) and speed for best rate of climb for a turbojet aircraft, assuming everything else remains constant, is:**

a. as altitude increases the ROC and speed both decrease
b. as altitude increases the ROC and speed both increase
c. as altitude increases the ROC decreases but the speed remains constant
d. as altitude increases the ROC remains constant but the speed increases
(1 mark)

9. **A runway at an aerodrome has a declared take-off run of 3000 m with 2000 m of clearway. The maximum distance that may be allowed for the take-off distance is:**

a. 5000 m
b. 6000 m
c. 3000 m
d. 4500 m
(1 mark)

10. **An aircraft may use either 5° or 15° flap setting for take-off. The effect of selecting the 5° setting as compared to the 15° setting is:**

a. take-off distance and take-off climb gradient will both increase
b. take-off distance and take-off climb gradient will both decrease
c. take-off distance will increase and take-off climb gradient will decrease
d. take-off distance will decrease and take-off climb gradient will increase
(1 mark)

11. **The use of reduced thrust for take-off is permitted:**

a. if the field length limited take-off mass is greater than the climb limited take-off mass
b. if the actual take-off mass is less than the structural limiting mass
c. if the actual take-off mass is less than the field length and climb limited take-off masses
d. if the take-off distance required at the actual take-off mass does not exceed the take-off distance available
(1 mark)

12. **Planning the performance for a runway with no obstacles, it is found that the climb limiting take-off mass is significantly greater than the field limiting take-off mass with 5° flap selected. How can the limiting take-off mass be increased?**

a. Use an increased V_2 procedure
b. Increase the flap setting
c. Reduce the flap setting
d. Reduce the V_2
(1 mark)

13. **The maximum and minimum values of V_1 are limited by:**

a. V_R and V_{MCG}
b. V_2 and V_{MCG}
c. V_R and V_{MCA}
d. V_2 and V_{MCA}
(1 mark)

14. **If the TAS is 175 kt and the rate of climb 1250 ft per minute, the climb gradient is approximately:**

a. 7%
b. 14%
c. 12%
d. 10%
(1 mark)

15. **A pilot inadvertently selects a V_1 which is lower than the correct V_1 for the actual take-off weight. What problem will the pilot encounter if an engine fails above the selected V_1 but below the true V_1?**

a. The accelerate-stop distance required will exceed the distance available
b. The climb gradient will be increased
c. The take-off distance required will exceed that available
d. There will be no significant effect on the performance
(1 mark)

16. **A turbojet is in a climb at a constant IAS. What happens to the drag?**

a. It increases
b. It decreases
c. It remains constant
d. It increases initially then decreases
(1 mark)

17. **Comparing the take-off performance of an aircraft from an aerodrome at 1000 ft to one taking off from an aerodrome at 6000 ft, the aircraft taking off from the aerodrome at 1000 ft:**

a. will require a greater take-off distance and have a greater climb gradient
b. will require a greater take-off distance and have a lower climb gradient
c. will require a shorter take-off distance and have a lower climb gradient
d. will require a shorter take-off distance and have a greater climb gradient
(1 mark)

18. **Which is the correct sequence of speeds?**

a. V_S, V_Y, V_X
b. V_X, V_Y, V_S
c. V_S, V_X, V_Y
d. V_X, V_Y, V_S
(1 mark)

19. **Which of the following will increase the accelerate-stop distance on a dry runway?**

a. A headwind component
b. An uphill slope
c. Temperatures below ISA
d. Low take-off mass, because of the increased acceleration
(1 mark)

20. **A turbojet aircraft is climbing at a constant Mach number in the troposphere. Which of the following statements is correct?**

a. TAS and IAS increase
b. TAS and IAS decrease
c. TAS decreases, IAS increases
d. TAS increases, IAS decreases
(1 mark)

21. **The induced drag in an aeroplane:**

a. increases as speed increases
b. is independent of speed
c. decreases as speed increases
d. decreases as weight decreases
(1 mark)

22. **The speed range between low speed and high speed buffet:**

a. decreases as altitude increases and weight decreases
b. decreases as weight and altitude increase
c. decreases as weight decreases and altitude increases
d. increases as weight decreases and altitude increases
(1 mark)

23. **Thrust equals drag:**

a. in unaccelerated level flight
b. in an unaccelerated descent
c. in an unaccelerated climb
d. in a climb, descent or level flight if unaccelerated
(1 mark)

24. **A higher mass at a given altitude will reduce the gradient of climb and the rate of climb. But the speeds:**

a. V_X and V_Y will decrease
b. V_X and V_Y will increase
c. V_X will increase and V_Y will decrease
d. V_X and V_Y will remain constant
(1 mark)

25. **If the other factors are unchanged, the fuel mileage (NM per kg) is:**

a. independent of the centre of gravity (C of G)
b. lower with a forward C of G
c. lower with an aft C of G
d. higher with a forward C of G
(1 mark)

26. **Concerning maximum range in a turbojet aircraft, which of the following is true?**

a. The speed to achieve maximum range is not affected by the wind component
b. To achieve maximum range speed should be increased in a headwind and reduced in a tailwind
c. To achieve maximum range speed should be decreased in a headwind and increased in a tailwind
d. The change in speed required to achieve maximum range is dependent on the strength of the wind component acting along the aircraft's flight path and may require either an increase or decrease for both headwind and tailwind
(1 mark)

27. **V_1 is the speed:**

a. above which take-off must be rejected if engine failure occurs
b. below which take-off must be continued if engine failure occurs
c. below which if an engine failure is recognized, take-off must be rejected and above which take-off must be continued
d. that we assume the critical engine will fail
(1 mark)

28. A constant headwind in the descent:

a. decreases the angle of descent
b. increases the rate of descent
c. increases the angle of the descent flight path
d. increases the ground distance travelled in the descent
(1 mark)

29. For a turbojet aircraft what is the reason for the use of maximum range speed?

a. Greatest flight duration
b. Minimum specific fuel consumption
c. Minimum flight duration
d. Minimum drag
(1 mark)

30. Why are step climbs used on long range flights in jet transport aircraft?

a. To comply with ATC flight level constraints
b. Step climbs have no significance for jet aircraft, they are used by piston aircraft
c. To fly as close as possible to the optimum altitude as mass reduces
d. They are only justified if the actual wind conditions differ significantly from the forecast conditions used for planning
(1 mark)

31. The absolute ceiling of an aircraft is:

a. where the rate of climb reaches a specified value
b. always lower than the aerodynamic ceiling
c. where the rate of climb is theoretically zero
d. where the gradient of climb is 5%
(1 mark)

32. In the take-off flight path, the net climb gradient when compared to the gross gradient is:

a. greater
b. the same
c. smaller
d. dependent on aircraft type
(1 mark)

33. To answer this question use CAP 698 SEP1 figure 2.1. Conditions: aerodrome pressure altitude 1000 ft, temperature +30°C, level, dry, concrete runway and 5 kt tailwind component. What is the regulated take-off distance to 50 ft for an aircraft of weight 3500 lb if there is no stopway or clearway?

a. 2800 ft
b. 3220 ft
c. 3640 ft
d. 3500 ft
(1 mark)

34. **To answer this question use CAP 698 MRJT figure 4.4. Conditions: Pressure altitude 5000 ft, temperature −5°C, balanced field length 2500 m, level runway, wind calm. What is the maximum field length limited take-off mass and optimum flap setting?**

a. 59 400 kg, 15°
b. 60 200 kg, 5°
c. 59 400 kg, 5°
d. 60 200 kg, 15°
(1 mark)

35. **The effect of a headwind component on glide range is:**

a. the range will increase
b. the range will not be affected
c. the range will decrease
d. the range will only be affected if incorrect speeds are flown
(1 mark)

36. **Refer to CAP 698 MRJT figure 4.24. At a mass of 35 000 kg, why does the drift down curve start at approximately 3 minutes at an altitude of 37 000 ft?**

a. The origin of the curve lies outside the chart
b. At this altitude it takes longer for the engines to slow down, giving extra thrust for about 4 minutes
c. Because of inertia at the higher TAS it takes longer to establish the optimum rate of descent
d. It takes about this time to decelerate the aircraft to the optimum speed for drift down
(1 mark)

37. **A twin engine turbojet aircraft having lost one engine must clear obstacles in the drift down by a minimum of:**

a. 35 ft
b. 1000 ft
c. 1500 ft
d. 2000 ft
(1 mark)

38. **The landing speed, V_{REF}, for a single-engine aircraft must be not less than:**

a. $1.2V_{MCA}$
b. $1.1V_{S0}$
c. $1.05V_{S0}$
d. $1.3V_{S0}$
(1 mark)

39. **What factor must be applied to the landing distance available at the destination aerodrome to determine the landing performance of a turbojet aircraft on a dry runway?**

a. 1.43
b. 1.15
c. 0.60
d. 0.70
(1 mark)

40. **An aircraft is certified to use two landing flap positions, 25° and 35°. If the pilot selects 25° instead of 35° then the aircraft will have:**

a. an increased landing distance and reduced go-around performance
b. a reduced landing distance and reduced go-around performance
c. an increased landing distance and increased go-around performance
d. a reduced landing distance and increased go-around performance
(1 mark)

Answers to Specimen Examination Paper

1	2	3	4	5	6	7	8	9	10	11	12
a	c	c	b	d	b	c	a	d	a	c	b

13	14	15	16	17	18	19	20	21	22	23	24
a	a	c	c	d	c	b	b	c	b	a	b

25	26	27	28	29	30	31	32	33	34	35	36
b	b	c	c	b	c	c	c	b	d	c	d

37	38	39	40
d	d	c	c

Explanations to Answers – Specimen Exam Paper

1. The requirement for an aircraft to be certified in performance Class B is that the maximum certified take-off mass must not exceed 5700 kg AND the certified maximum number of passengers must not exceed 9. If both these conditions are not met then the aircraft will be certified in Class A.

2. c. As speed increases then the angle of attack and hence the thrust of the propeller decrease.

3. c.

4. b. With a downhill slope the effort required to continue acceleration after V_{EF} is less than the effort required to stop the aircraft because of the effect of gravity. Hence take-off can be achieved from a lower speed, but stopping the aircraft within the distance available can only be achieved from a lower speed.

5. d. The lowest take-off performance will occur when air density is at its lowest, hence high temperature and low pressure.

6. b. see definitions.

7. c. In determining take-off climb performance, the still air gradient is considered.

8. a. As altitude increases the speed for best gradient of climb remains constant, but the speed for best rate of climb decreases until the two speeds coincide at the absolute ceiling.

9. d. TODA is limited by the lower of TORA plus clearway and 1.5 × TORA.

10. a. With a reduced flap setting the lift generated decreases and the stalling speed increases, so a greater take-off speed is required increasing the take-off distance. The reduced flap setting reduces the drag so the climb gradient increases.

11. c. The use of reduced thrust means that the take-off distance will be increased and the climb gradient reduced, so neither of these can be limiting.

12. b. Increasing the flap setting will reduce the TODR so the weight can be increased, but the climb gradient will reduce with the increased flap setting.

13. a. see CAP 698 page 62, paragraph 2.5.1.

14. a. Gradient of climb can be approximated to rate of climb divided by TAS.

15. c. The decision to continue the take-off will be made, but because the speed is below the normal V_1, the distance required to accelerate will be greater, so the TODA may well be exceeded.

16. c. At a constant IAS drag will remain constant.

17. d. The air density is greater at the lower aerodrome so the performance will be better in terms of acceleration and gradient.

18. c. All speeds must be greater than V_S.

19. b. Although an uphill slope will enhance the deceleration, the effect on the acceleration to V_1 will result in increased distances.

20. b. Temperature is decreasing; therefore, the speed of sound and the TAS will decrease, and as altitude increases the IAS will also decrease.

21. c. As speed increases, the induced drag reduces proportional to the square of the speed increase.

22. b. As altitude increases at a given weight, the IAS for the onset of high speed buffet decreases and the IAS for the onset of low speed buffet remains constant, hence the speed range decreases. As weight increases at a given altitude, the IAS for the onset of low speed buffet increases and there is a small decrease in the IAS for the onset of high speed buffet so once again the speed range decreases.

23. a. In the climb and descent an element of gravity acts along the aircraft axis either opposing (climb) or adding to (descent) the thrust, so only in level unaccelerated flight will the two forces be equal.

24. b. An increase in weight causes induced drag to increase and moves the total drag curve up and to the right. This will reduce the gradient and rate of climb and increase the speeds for V_X and V_Y.

25. b. As the C of G moves forward, the download on the tail increases, so the lift required also increases. To create the extra lift either speed or angle of attack must increase. In either case, more thrust is required and the fuel required per NM will increase.

26. b. The speed for maximum range in a jet aircraft is found where the line from the origin is tangential to the drag curve. With a headwind the origin moves to the right by the amount of the wind component so the line from the origin will be tangential at a higher speed, and to the left with a tailwind giving a lower speed.

27. c. V_1 is the decision speed. If engine failure is recognized below V_1, take-off must be rejected, and if engine failure recognized above V_1, take-off must be continued.

28. c. The rate of descent is independent of the wind, but the descent path is modified by the wind, the angle increasing with a headwind because of the reduced ground distance covered.

29. b. The maximum range speed is the speed at which the greatest distance can be flown, which means the lowest possible fuel usage. To achieve this implies we must have the lowest specific fuel consumption.

30. c. The most efficient way to operate a jet aircraft is to cruise climb, that is to set optimum cruise power and fly at the appropriate speed and allow the excess thrust as weight decreases to climb the aircraft. For obvious safety reasons this is not possible, so the aircraft operates as close as possible to the optimum altitude by using the step climb technique.

31. c. The absolute ceiling is the highest altitude to which the aircraft could be climbed, where, at optimum climb speed, thrust = drag, so with no excess of thrust the rate (and gradient) of climb will be zero.

32. c. Net performance is gross (i.e. average) performance factored by a regulatory amount to give a 'worst case' view. Therefore, the worst case for the climb gradient will be a lower gradient than it is expected to achieve.

33. d. Gross take-off distance from the graph is 2500 ft. There is no stopway or clearway so the factor to apply is 1.25 to get the minimum TOR. (see CAP 698, page 19)

34. d. The maximum take-off mass will be achieved with the higher flap setting because the take-off speeds will be reduced. As ever, take care when using the graphs.

35. c. With a headwind component the glide performance will not be affected but the distance covered will reduce because of the reduced ground speed.

36. d. The aircraft will be allowed to slow down to the optimum drift down speed before commencing descent which will take an amount of time dependent on weight and altitude.

37. d. This is the EU-OPS regulatory requirement.

38. d. Again the EU-OPS regulatory requirement.

39. c. The EU-OPS regulatory requirement.

40. c. With a reduced flap setting the stalling speed and hence the V_{REF} will increase, so a greater landing distance will be required. With a reduced flap setting the drag will decrease, so the climb gradient will be better.

Chapter

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