AEROPLANE PERFORMANCE

BOURNEMOUTH COMMERCIAL FLIGHT TRAINING

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The notes are also suitable for distant learning with appropriate
Instructor guidance and worksheets.
The layout and order of the notes follows a logical learning sequence and is based upon the structured JAR/EASA ATPL (A) learning objectives 2008 (NPA25)

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Introduction

EUOPS is specifically mentioned in the learning objectives (Lo's) and should be used for reference as required in regard to examination within EU Member States.

General

1. To fully appreciate and understand this subject 032 - Performance (Aeroplanes) the student should also have a good background knowledge in subject 081 - Principles of Flight (Aeroplanes).

2. For JAR-FCL standardisation purposes the following should be taken as definitions:

Climb Angle:-
This is assumed to be air mass related.

Flight Path angle:-
This is assumed to be ground related.

Screen Height for take-off:-
This is the vertical distance between the take-off surface and the take off flight path at the end of take off distance.

Screen Height for landing:-
This is the vertical distance between the landing surface and the landing flight path from which the landing distance starts.

3. For mass definitions refer to the syllabus for subject 031 – Mass and Balance

For the UK-CAA Examinations this document should be read alongside and with reference to CPA 698 – Aeroplane Performance Manual - Third Edition July 2006.

Section One Legislation and Performance Theory

Chapter 1 Performance legislation

1 Legislation

EASA have determined acceptable minimum levels of performance for each Class of aeroplane and for each phase of flight, these have been published in airworthiness requirements manuals (CS23 and CS25) and EUOPS.

The goal of this legislation is to produce a uniform safety standard across all classes of aeroplanes whilst engaged in Public Transport.

1.1 Airworthiness Requirements according to CS23 and CS25

These documents form the current regulatory publications for the operation of Public Transport aeroplanes and are mandatory for all passenger-carrying aeroplanes requiring registration in a European State.

CS23 is an airworthiness certification code applicable to:

1. Aeroplanes in the normal, utility and aerobatic categories that have a seating configuration, excluding the pilot seat(s), of nine or fewer and a maximum certified take-off weight of 5670 Kg (12,500 lb) or less; *and*
2. Propellor-driven twin-engined aeroplanes in the commuter category that have a seating configuration, excluding the pilot seat(s), of nineteen or fewer and a maximum certified take-off weight of 8618 Kg (19,000 lb) or less.

CS25 is an airworthiness certification code applicable to:

Turbine powered Large Aeroplanes.

1.2 Interpret the European airworthiness requirements according to CS 23 relating to aeroplane performance.

EASA CS-23 contains performance sections with the relevant details interpreted within these notes and UK-CAA CAP698.

1.3 Interpret the European airworthiness requirements according to CS 25 relating to aeroplane performance.

EASA CS-25 contains performance sections with the relevant details interpreted within these notes and UK-CAA CAP698.

1.4 Name the general differences between aeroplanes as certified under CS23 and CS25

From study of the above mentioned documents and these notes it will become apparent that CS23 code is used typically for small aeroplanes including a lot of twin engine propeller commuter types and a good number of 'light aircraft.'
CS25 code is used typically for the larger aeroplanes including most if not all passenger airliners powered by turbine engines.

2 Operational Regulations

Fundamental to all performance requirements and regulations is the 'Scale of Probabilities' shown below and is based on the statistics and analysis of past air accidents and incidents.
The objective with performance planning is the determination of the maximum TOM that will ensure full attainment of the predetermined safety levels in all the phases of flight.
Looking at the illustration below the 'Remote' probability of 10^{-6} is selected as the target value for all EASA public transport aircraft scheduled performance (performance planning).

Classification of failure conditions	CS 25 Probability	Effect on aircraft and occupants	Examples
Minor Likely to occur during the life of each aircraft.	Frequent – probable	Normal	Heavy landing
	10^{-3}		
Minor Unlikely to occur often during the life of each aeroplane.	Reasonably probable	Operating limitations emergency procedures	Engine failure
	10^{-6}		
Major Unlikely to occur to each aeroplane during its life, but may occur several times during the life of a number of aircraft of the type.	Remote – improbable	Significant reduction in safety margins. Difficult for crew to cope.	Low-speed overrun. Falling below the take-off net flight path. Minor damage. Possible passenger injuries.
	10^{-7}		
Hazardous Possible, but unlikely to occur in the total life of a number of aircraft of the same type.	Extremely remote – improbable	Large reductions in safety margins. Crew extended because of workload. Serious or fatal injuries to a small number of passengers.	High-speed overrun. Ditching. Extensive damage. Possible loss of life. Hitting obstacle in the take-off net flight path. Double engine failure on a twin.
	10^{-9}		
Catastrophic	Extremely Remote – Improbable	Aeroplane destroyed. Multiple deaths	Mid-air collision. Hitting terrain on approach to land.

2.1 Name and define the performance classes for commercial air transportation. According to EUOPS 1.470

Subpart F - Performance General of EUOPS refers and OPS1.470 gives applicability accordingly:

(1) An operator shall ensure that 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 5 700 kg, and all multi-engine turbojet powered aeroplanes are operated in accordance with Subpart G (**Performance Class A**).

(2) An operator shall ensure that propeller driven aeroplanes with a maximum approved passenger seating configuration of nine or less, and a maximum take-off mass of 5 700 kg or less are operated in accordance with Subpart H (**Performance Class B**).

(3) An operator shall ensure that aeroplanes powered by reciprocating engines with a maximum approved passenger seating configuration of more than nine or a maximum take-off mass exceeding 5 700 kg are operated in accordance with Subpart I (**Performance Class C**).

(4) Where full compliance with the requirements of the appropriate Subpart cannot be shown due to specific design characteristics (e.g. supersonic aeroplanes or seaplanes), the operator shall apply approved performance standards that ensure a level of safety equivalent to that of the appropriate Subpart

2.2 Interpret the European operating regulations according to EUOPS relating to aeroplane performance.

The operating regulations are set out in EUOPS in the following structure:

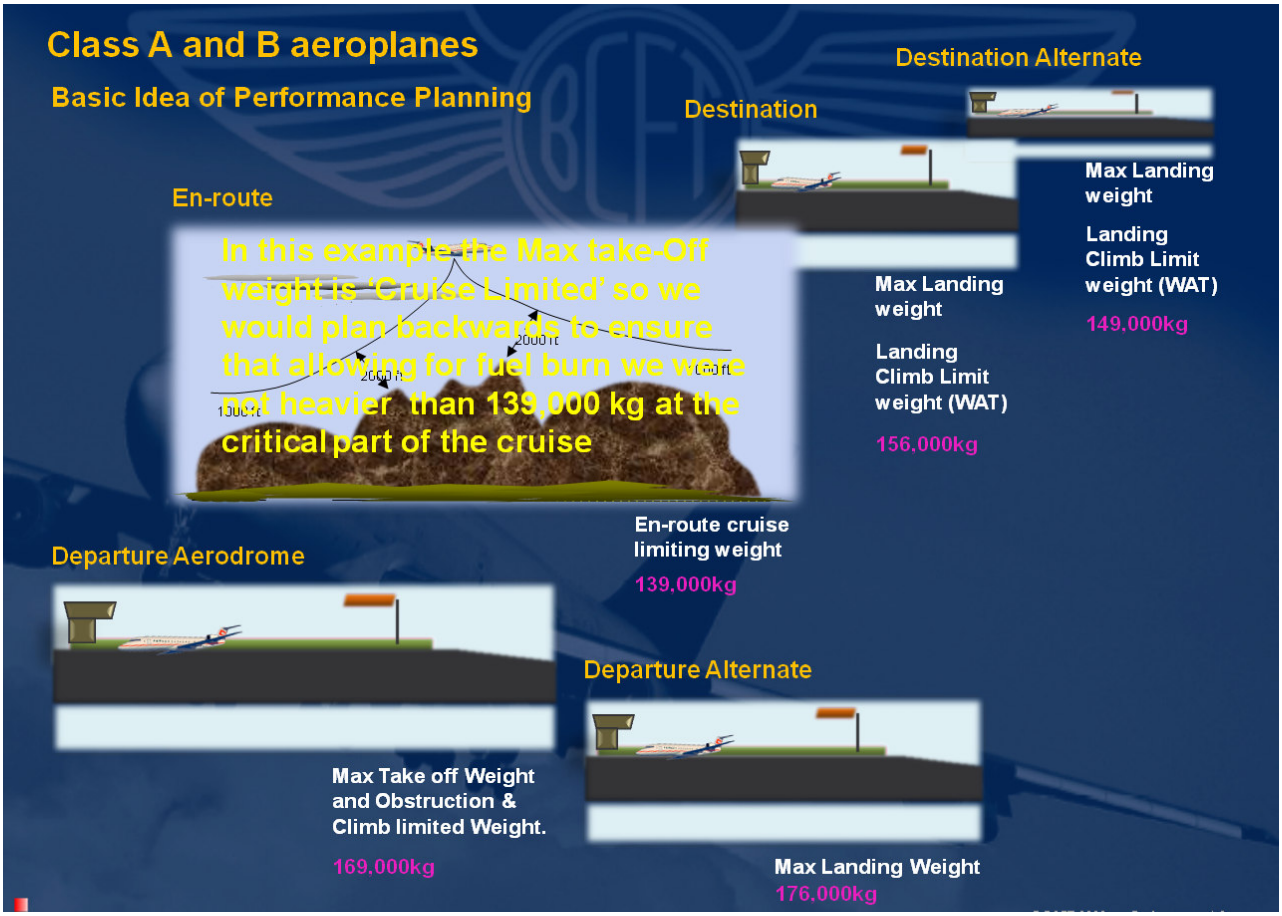
Subpart G	Performance **A**
Subpart H	Performance **B**
Subpart I	Performance **C**

The regulations are interpreted within these notes and UK-CAA CAP698.

3 *General Performance Theory*

3.1 *Stages of flight*

The following illustration depicts a typical flight and the performance planning involved



In performance planning we would start with considerations of the destination alternate to find the maximum landing weight and landing climb limit weight and working backwards through the planned flight, finding maximum weights for en-route stages and departure alternate and departure aerodromes along with their climb limited weights.

From the illustration above the lowest weight is for the en-route part of the flight and so will determine the maximum weight for that part of the route. In turn this will be a determining weight in respect to the take-off weight at point of departure.

Note: in the above we have used the term weight – however you may see that in CAP698 General Notes on page 3 the comments regarding the term weight, in CAP698 it should be considered that 'Mass' should have the same meaning.

Chapter 2 Performance Principles and Level un-accelerated flight

1 International Standard Atmosphere (ISA).

- The ISA assumes;

- Mean sea level values of a pressure of 1013.25 hPa
- Temperature of +15ºC
- Density of 1225 gm/cubic metre.
- The temperature is assumed to fall at a lapse rate of 1.98ºC/1000 ft up to 36,090 ft, where it remains constant at – 56.5ºC.
- For practical purposes, a lapse rate of 2ºC/1000 ft may be used.

1.1 Density Altitude

Density altitude is the altitude at which the air density equals that of the standard atmosphere.
As altitude increases in the troposphere, the pressure decreases.
This decrease of pressure will decrease the density.
As altitude increases temperature decreases up to the tropopause, any decrease in temperature will increase the density.
Density will however continue to decrease with an increase in altitude, because the overall effects of pressure are greater than that of temperature.
In ISA conditions the density altitude and the pressure altitude are the same, but they deviate from each other in non-standard conditions.

Density altitude is the pressure altitude corrected for the temperature deviation from ISA.

Note that aerodynamic performance depends on air density, whereas engine performance also depends on the air pressure.

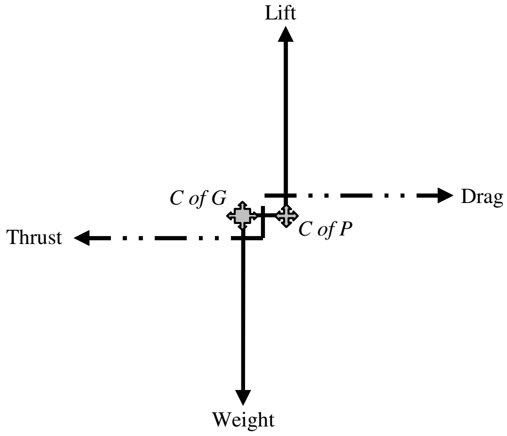
2 Effect of density altitude and aeroplane gross mass

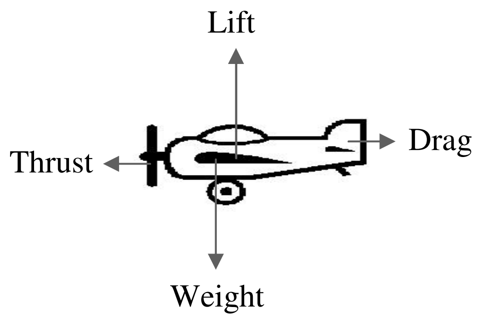
2.1 Explain the effect of altitude and temperature on cruise performance.

As altitude or temperature increases, the density will decrease, so the **'Density Altitude'** *increases*.
When an aeroplane is operating at a *higher* density altitude the TAS *increases* for a given IAS in order to maintain the same performance.
The overall effect is to limit the maximum IAS the aeroplane can achieve in straight and level flight although the TAS may well be higher.
For a given IAS the drag will remain the same therefore the thrust required will remain the same, but the power required will increase.
The power produced by both Piston and Jet engines will also decrease with increase in altitude

2.2 *Steady Level Un-accelerated Flight*

Un-accelerated Flight - In steady level flight the height and speed are constant, all the four forces on the aeroplane are in balance. Lift = Weight and Thrust = Drag. The lift and weight forces are much larger than the thrust and drag forces, and the aeroplane is not accelerating/decelerating or climbing/descending so:





Some conclusions from the above:

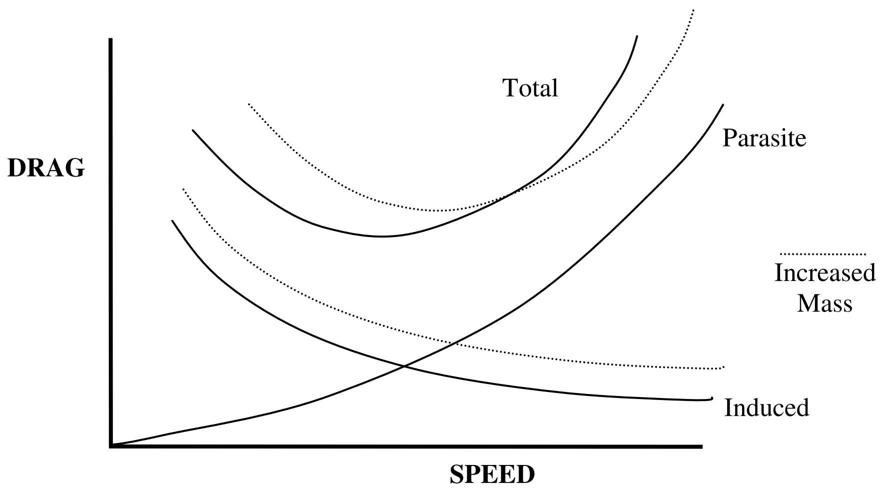
- Most large transport aeroplanes have C of G Forward of C of P.
- Lift acts through the centre of pressure (C of P) and is expressed as $C_L½\rho V^2S$ and level flight will only be achieved if the formula remains in balance.
- Weight acts through the centre of gravity (C of G)
- Drag in opposition to thrust and is expressed as $C_D½\rho V^2S$
- Thrust which is the force produced by the engines in Newtons, a calculation based upon Mass (Kg) multiplied by Acceleration (M/s^2)
- The rate of doing work is known as Power, being the product of thrust and speed and is a measure of the work done by the engines, often stated in Horse Power.
- Power required = Drag x TAS, and for given IAS, *drag is constant*.
- TAS increases with altitude increase for a given IAS, so *the power required increases with an increase in altitude.*
- Power Available from the engines reduces with increase in altitude, so as altitude increases the excess power available reduces. *When excess power is zero, the aeroplane has either reached it's maximum speed in level flight or it's absolute ceiling.*
- The absolute ceiling gradually increases, as the aeroplane becomes lighter due to fuel burn-off.
- A performance (or service) ceiling is defined as when the rate of climb falls to *100 ft/min for a piston aeroplane or 500 ft/min for a jet.*

2.3 Drag

The diagram below shows the Parasite Drag, Induced drag and the resultant total drag against their relationship with speed. The dotted lines indicate the effect of increased mass (Weight).

2.4 Explain the effect of mass on power required, drag and airspeed.

If the mass of an aeroplane is increased the power required for level flight will increase.
To produce the same total lift for a given speed, the 'Angle of Attack' must increase, therefore the drag will increase, needing more power.



2.5 Explain the effect of speed and angle of attack on the induced drag.

Trailing vortices modify the flow pattern. In particular, they alter the flow direction and speed in the vicinity of the wing and tail surfaces.
The trailing vortices therefore have a strong influence on the drag of an aeroplane.
Downwash also influences the flow over the wing itself, with important consequences.

- Firstly the angle of attack relative to the modified total airflow direction is reduced, this in effect is a reduction in angle of attack, and means that less lift will be generated unless the angle of attack is increased.
- The second consequence is that the lift vector is now tilted backward relative to the free stream flow. There is therefore a rearward component of the force which is known as 'Induced Drag' or 'Vortex Drag'.

As angle of attack is increased the lift vector is tilted further back and Induced drag increases

As speed increases the span-wise flow that causes the wingtip vortices decreases so Induced drag decreases

2.6 *Explain effect of altitude, mass and configuration on total drag.*

Altitude – As altitude increases, density decreases, but at a constant IAS the TAS increases. A look at the drag formula $D = C_D \frac{1}{2}\rho V^2 S$ will show that at a constant IAS total drag will not change with increasing altitude but will decrease with a constant TAS with increasing altitude.

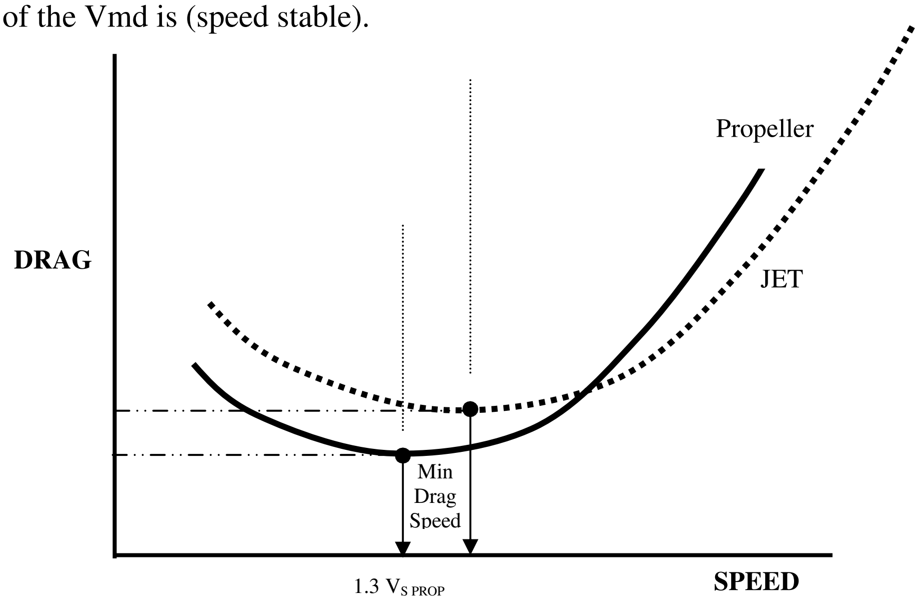
Mass – If the mass of an aeroplane is increased, then so must the lift. If the lift is to be increased then so must the angle of attack of the wing for a given airspeed. If the angle of attack is increased then so is the induced drag. Therefore for a higher mass, the total drag is increased.(Diagram above)

Configuration – Modern wings are designed to be very clean and efficient and therefore operate with a minimum of drag. Any change in configuration of the wing will increase the drag. Spoilers will increase parasite drag and flaps will increase lift therefore increase induced drag. Flaps will also increase the parasite drag by an amount depending on the deflection angle.

Lowering the undercarriage will increase parasite drag.

2.7 *Speed Stability*

Speed Stability – The Drag/EAS curve below is marked with 2 areas for both Propeller and Jet, the part to the left of the minimum drag speed (Vmd) is (speed unstable) and the part to the right of the Vmd is (speed stable).



$1.3\ V_{S\ PROP}$

$1.6\ V_{S\ JET}$

- **Consider the speed unstable area first;** if a sheer in headwind occurs the aeroplane EAS will decrease. If the EAS decreases in this area the drag will increase, with thrust constant. This means that thrust is now less than drag and the aeroplane continues to decelerate. The aeroplane is said to be speed unstable in this area. The slope of the curve indicates the level of speed instability. The steeper the slope the greater the degree of instability.

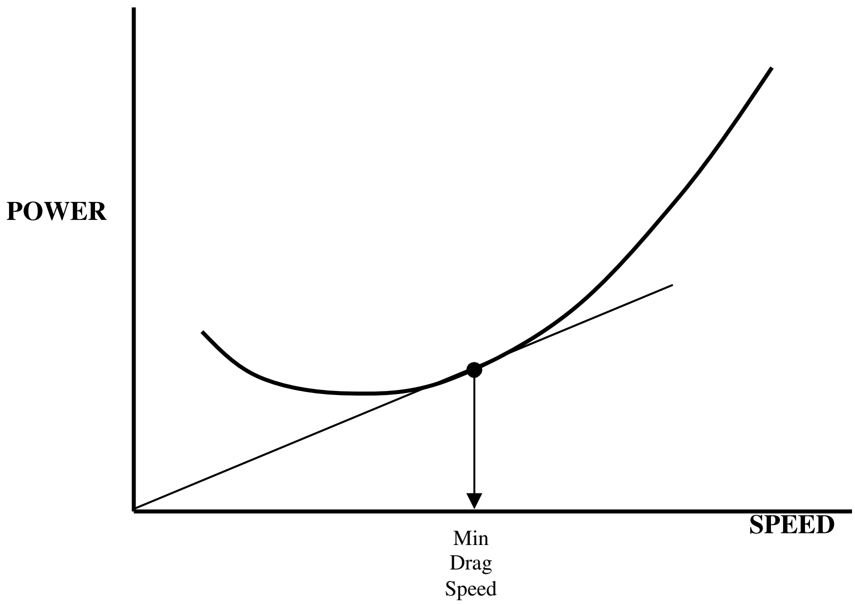
- **Considering the speed stable area;** if a sheer in headwind occurs EAS will again decrease. As the aeroplane slows down the drag now decreases, thrust is constant. The thrust now exceeds drag and the aeroplane will accelerate back to the original speed. This is speed stability, the slope of the curve again indicating the level of speed stability. The steeper the slope the greater the degree of stability.

2.8 Minimum drag speed

The speed / velocity for minimum drag will be at the lowest point of the total drag curve. Notice from the above diagram that the speed for a propeller driven aeroplane is about 1.3 V_S and that for a jet, it is faster: 1.6 V_S.
(V_S is the term often used for minimum steady flight speed or stall speed.)

This means that it is necessary to fly at a higher speed in a jet than a propeller driven aeroplane in order to maintain stability and steady flight.

If you plot this on a power curve it will appear tangential to the curve. As shown in the next diagram.



In regard to jet aeroplanes the minimum drag speed is greater than that found for minimum power.

2.9 Pressure Altitude and Temperature effects

Pressure Altitude. The performance of an aeroplane will decrease as pressure altitude increases. See the Power Curve on the next page, showing effect of high and lower altitude.

The decrease in pressure gives an increase in density altitude.

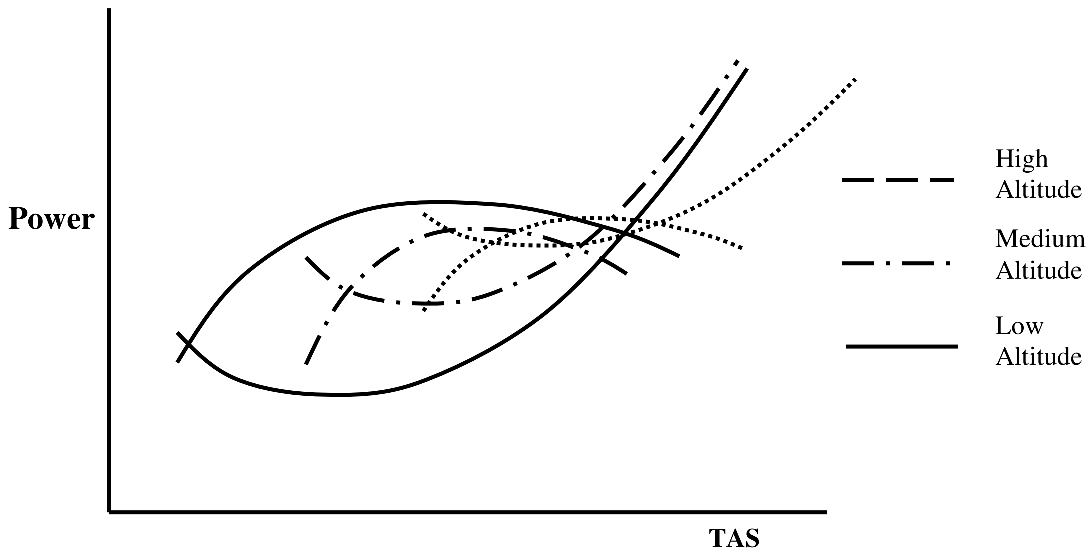
An increase in temperature gives an increase in density altitude

Both the thrust and the power available decrease with an increase in altitude, and the power that is required for level flight increases.

The amount of thrust available reduces from a maximum at the surface.

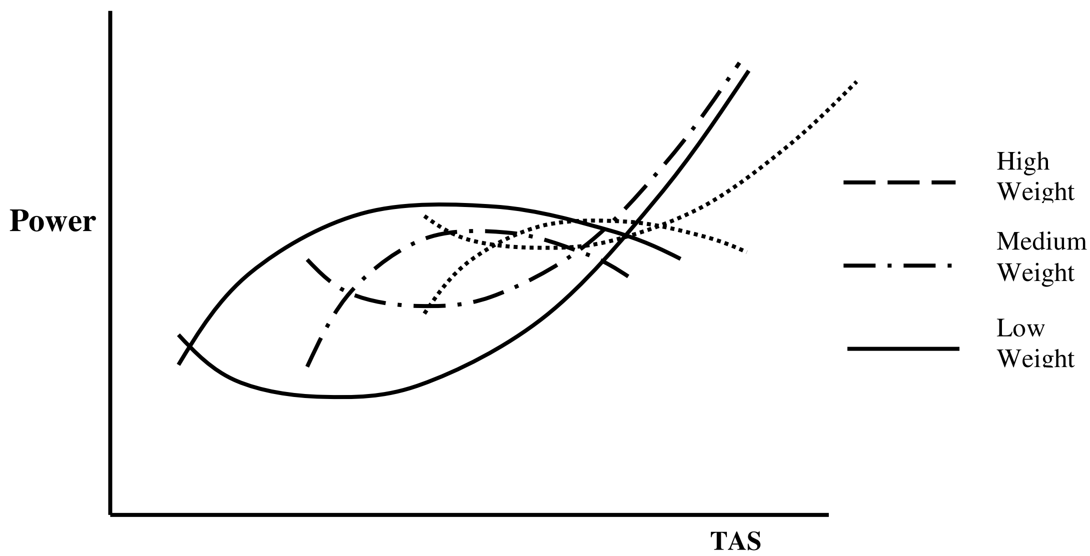
2.10 *Explain the effect of altitude and temperature on the power required curve.*

We have already seen that if altitude or temperature increases the density altitude will increase.
The effect of this can be seen on the following graph of power required and power available at low, medium and high altitude.



2.11 *Compare Power Curves showing effect of a higher and lower weight.*

Notice that in both these diagrams the curves have moved up and to the right, which would also indicate that speed used is TAS which also increases with altitude and weight!



3 Cruise altitude and altitude ceiling

3.1 Define service and absolute ceiling and optimum altitude.

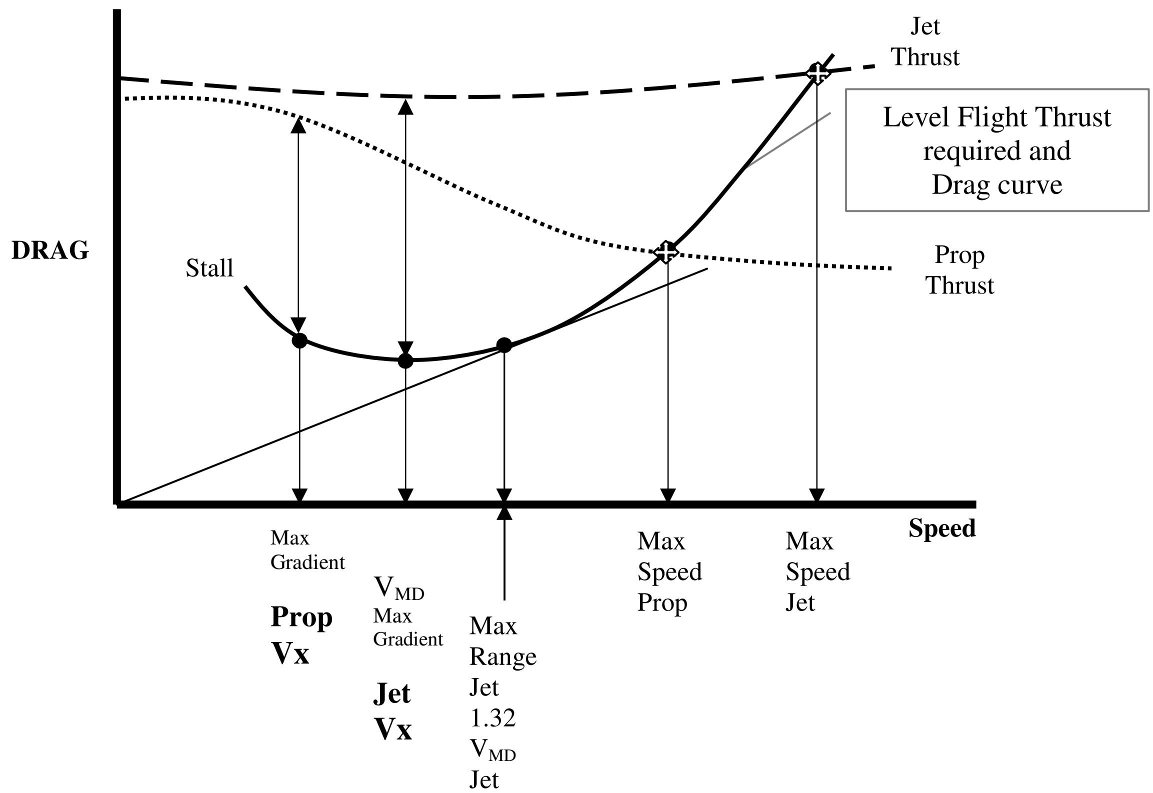
Service Ceiling – This is denoted where, at maximum power, the rate of climb of an aeroplane has fallen to 100 feet per minute for a piston aeroplane and 500 feet per minute for a jet aeroplane.

Absolute Ceiling – This is denoted by a rate of climb of zero feet per minute, that is, at full power, the aeroplane is only able to fly straight and level.

Optimum Altitude – For any given aeroplane weight there is an optimum altitude at which the sector should be flown. This is given in performance manuals and gives the best TAS to fuel flow ratio.

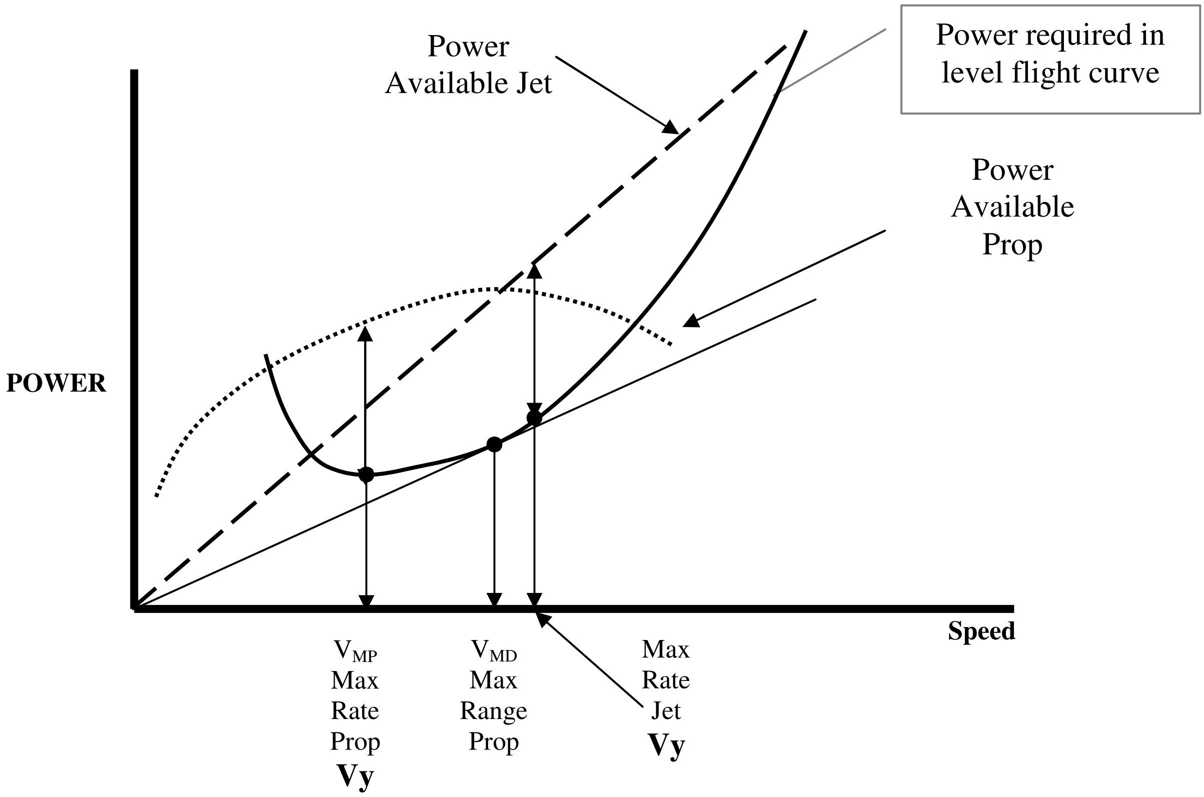
3.2 Interpret the thrust required and thrust available curves.

The thrust required curve for straight and level flight, is derived from the total drag curve as thrust must equal drag when in un-accelerated straight and level flight.
From these curves can be plotted V_{MD}, best angle of climb speed V_X, best range speeds and maximum speeds straight and level for both the Jet and piston / propeller



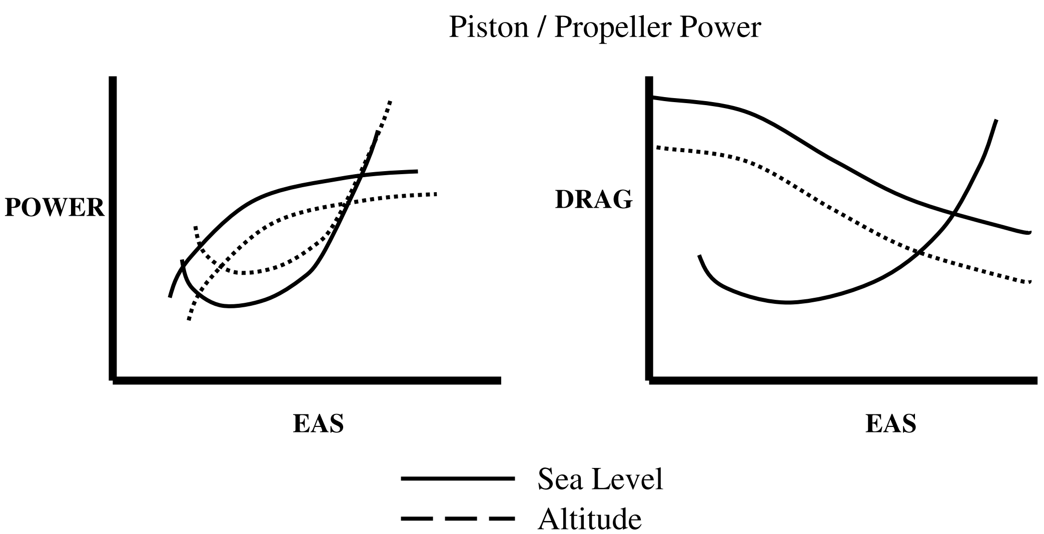
3.3 Interpret the power required and power available curves

From the power curves we can plot the speeds for the best rate of climb and the best range speed for a prop aeroplane and a jet.
Increases of altitude or mass will have an effect on the angles and rates of climb and descent due to the decreased thrust and power *available* and increased power *required.*



4 Compare Jet and Piston Propeller power / thrust availability

Although the graphs look different for a jet aeroplane, the effect is much the same as below.



4.1 Temperature.

The effect of temperature on performance is similar to increasing altitude.

An increase in temperature reduces the density of the air and therefore increases density altitude.

In addition, jet engines are limited to a maximum temperature, temperature rises as more fuel is pumped into the engine to produce more power.
Consider two jet engines operating in ambient temperature ranges say –10° C and +35° C. Both engines are limited to +600° C, the engine operating at -10° C can use the fuel to give a 610° C temperature rise.
The engine operating at +35° C can *only* use fuel to give a 565° C temperature rise.
The engine operating in the colder temperature not only has greater mass airflow, it can *use* more fuel.

4.2 A summary of the factors which affect the thrust/power available and thrust/power required curves in horizontal flight

Power available - Power available will decrease as pressure altitude and temperature increase
Power required - Power required for straight and level flight at constant IAS will increase as pressure altitude and temperature increase and decrease as aeroplane mass decreases.
Thrust available - Thrust available will decrease as pressure altitude and temperature increase.
Thrust required - Thrust required for straight and level flight at constant IAS will not vary with changes in altitude or temperature but will decrease as aeroplane mass decreases.

4.3 A summary of the relationship between mass vs minimum drag in steady horizontal flight

As mass is decreased in level flight, there is a decrease in angle of attack and a decrease in induced drag. This will reduce the total drag and also the minimum drag speed.

4.4 A summary of the relationship between airspeed and induced drag

Induced drag is inversely proportional to the airspeed, more simply put - the induced drag decreases as the airspeed increases.
Induced drag is lift dependant, more lift = more induced drag.
The converse is true for parasite drag, which increases proportionally to the square of the EAS, the combination of the two results in an overall drag value.

4.5 A summary of the lift / drag formula

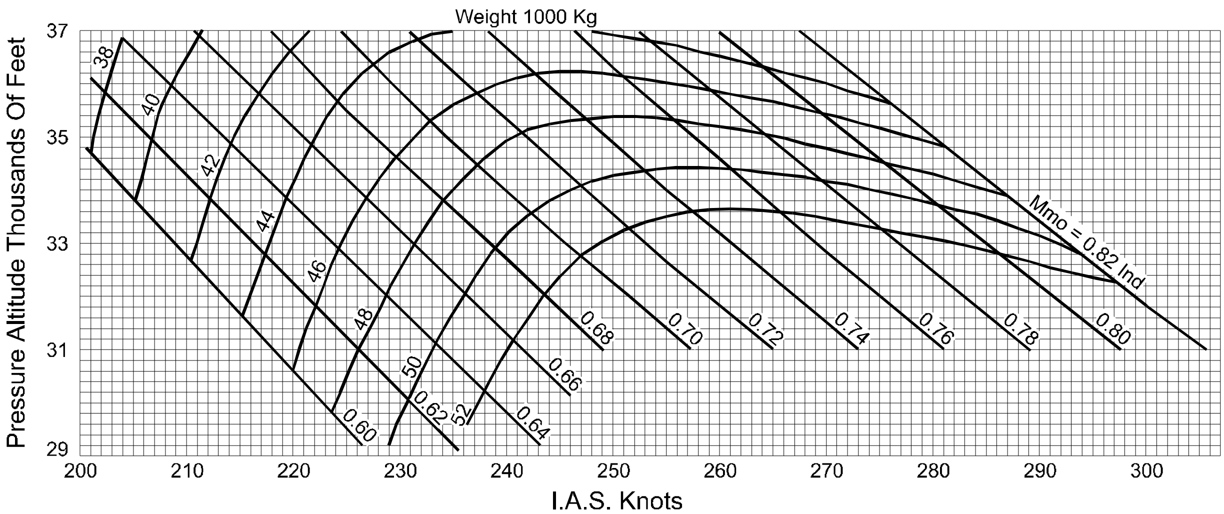
The drag formula $\mathbf{D = C_D \frac{1}{2} \rho V^2 S}$

The Lift formula $\mathbf{L = C_L \frac{1}{2} \rho V^2 S}$

5 *The Buffet Onset Boundary Chart (BOB-chart)*

Low speed buffet will occur in straight and level flight as the aeroplane approaches the stall speed.
High speed buffet will occur when the speed reaches the point where separation occurs because of shock wave formation.
The difference between these two speeds is called the buffet margin.
The effect of turning and load-factor is to increase the speed at which the low speed buffet will occur and decrease the speed at which the high speed buffet will occur.
This reduces the buffet margin. An increase in altitude will also reduce the buffet margin.

5.1 Interpret the buffet onset boundary chart (BOB chart).



Manoeuvring capability – The graph above is the BOB chart for a Boeing 737-200. The graph is entered with cruising altitude and aeroplane mass, and where the curve bends down at the left will give the IAS/Mach number where the pre-stall buffet will be felt, and to the right will give where the high-speed buffet will be felt. The aeroplane must have room for manoeuvring as it is impractical to assume that an aeroplane will not turn, so the graph allows for level turns using up to 45° angle of bank.

Effect of mass and bank angle – Assuming throughout that the cruising altitude is FL 340, it can be clearly seen that the higher the mass the more restrictive the operating range of the aeroplane;

At 50 tons: the low speed buffet will be felt at 246 IAS (0.716 Mach) and below, whilst the high-speed buffet will be felt at 275 IAS (0.789 Mach) and above.

At 48 tons: the low speed buffet will be felt at 235 IAS (0.685 Mach) and below, whilst the high-speed buffet will be felt at 285 IAS (0.816 Mach) and above, thus giving a larger range of speeds at which the aeroplane can be flown.

At 46 tons: the low speed buffet will be felt at 227 IAS (0.663 Mach) and below, whilst the high-speed buffet will not be felt before M_{MO} is reached.

Provided no more than 45° angle of bank is used (30° being the maximum that should be used with passengers embarked), the aeroplane should not encounter either pre-stall or high-speed buffet provided that it is operated in the range depicted by the graph.

Buffet onset gust factor – The graph also takes into account the possibility of encountering gusts, so when calculating the BOB limits there is no requirement to take this into account.

5.2 *State influence of bank angle, mass and 1.3g buffet onset factor on the step climb*

Bank angle decreases the buffet margin, therefore the higher the altitude the less margin available for load margins imposed by banking.

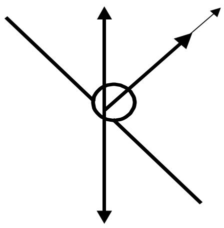
Mass an increase in mass will decrease the buffet margin so restricting the maximum altitude
1.3 Buffet Onset Factor this is a factor to allow for disturbances in flight increasing the load factor, altitude will be limited in order to maintain the factor.
The initial cruise altitude will have to take these influences into account, as will the time and altitude to step climb.

6 *Turning Flight*

6.1 *Explain the effect of Bank Angle at constant TAS on the load factor.*

As an aeroplane is banked the lift force must produce a vertical force to balance the weight, because the lift still acts normal to the lateral axis it must be increased. At a constant TAS lift is increased by increasing the angle of attack, as a consequence the stalling speed increases.

$$\text{Load Factor} = \frac{\text{Lift}}{\text{Weight}}$$

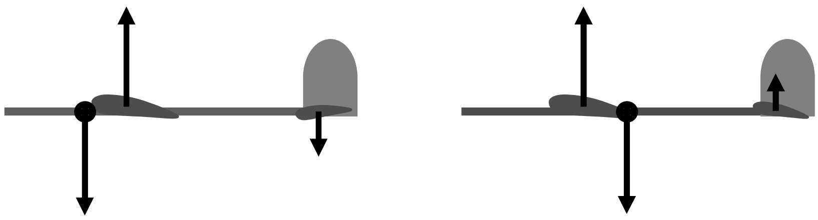


Therefore the Load Factor must increase.

7 *Centre of Gravity (C of G)*

7.1 *Explain the effect of centre of gravity on fuel consumption.*

An aeroplane at a given weight will require that amount of weight to be supported by the lift.



If the C of G is forward of the point of lift there is a nose down couple, this needs a down force at the tail.
This down force is in the same direction as weight and adds to the total weight the wings must support.
The further forward the centre of gravity the larger the down force from the tail to keep the aeroplane level this in turn requires more lift with the consequent increase in drag.

Therefore the further forward the centre of gravity the larger the fuel consumption in Flight, when compared to an aeroplane with an aft centre of gravity.

This will still be true of an aeroplane with the C of G behind the lift, as less lift is needed from the tail to prevent the nose up pitching moment.

8 *Summary of Definitions used this in this chapter*

IAS Indicated Airspeed
Derived from the Pitot Static system and calibrated to the standard atmosphere at sea level. It is uncorrected for any system errors. The IAS is a direct function of the dynamic pressure $½\rho V^2$.

$½\rho V^2$ Half rho V-squared
This governs generation of the aerodynamic forces – lift and drag there will therefore be aerodynamic limit speeds which will in turn be Indicated airspeeds.

CAS Calibrated Airspeed
The Calibrated or Rectified Airspeed (RAS) is IAS as corrected for the pitot static position error and instrument errors. In a standard atmosphere at sea level this will also be the same as TAS.

EAS Equivalent Airspeed
This is CAS (Calibrated Airspeed) as corrected for adiabatic compressibility for the given pressure altitude. This will be the same as the CAS in the Standard Atmosphere (ISA) at sea level.

TAS True Airspeed
This is EAS corrected for the density error and is the true speed of an aeroplane relative to the undisturbed air.

Mach No. A body passing through the air will generate small disturbances that will be transmitted as pressure waves (In effect sound waves), when considering the motion of a body it becomes convenient to express this as the ratio of the velocity of the body in question, to that of the pressure wave produced.
The formation of the pressure waves will be affected by the temperature and can be taken to move at the Local Speed of Sound (LSS).

$$\text{Mach No.} = \frac{TAS}{LSS}$$

V_X The speed to be used to obtain maximum (best) gradient (angle) of climb.

V_{X1} As above, and in the case of an aeroplane having three or four engines with one engine inoperative.

V_Y The speed to be used to obtain maximum (best) rate of climb.

V_{Y1} As above, and in the case of an aeroplane having three or four engines with one engine inoperative.

V_{YSE} The speed to be used to obtain maximum (best) rate of climb in the case of an aeroplane having two engines with one engine inoperative.

MZFM Maximum Zero Fuel Mass
The maximum weight of the aeroplane, excluding the usable fuel within which its structural limitations will allow.

Gross Mass The mass of the aeroplane including everything and everybody carried in and on it at any particular time.

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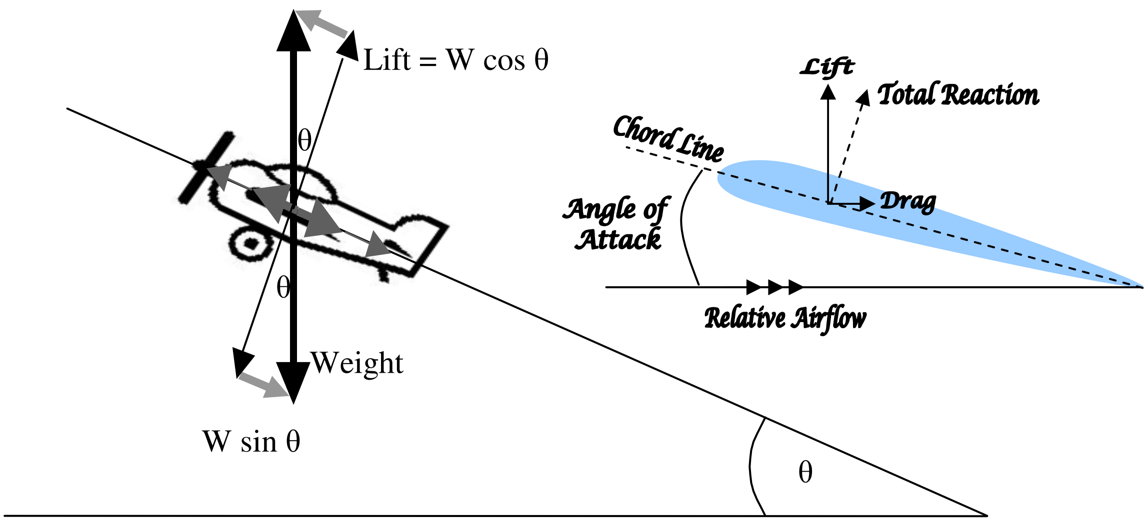
Chapter 3 Climbing Flight

1 Steady Climb

In a steady climb, TAS and climb angle (θ) are constant.



During a climb the lift continues to act at right angles to the flight path and the weight vertically downwards, however, the two are no longer directly opposed.
The weight must now be resolved into two components, one supported by lift, and the other acting in the opposite direction to the flight path.
Note that the lift required is now less than for level flight **(W Cos. θ)** although the thrust must now be increased to overcome the component of weight **(W Sin θ)** that is acting parallel to the flight path. (This can be termed weight apparent drag).

1.1 Total Reaction

Note also from the aerofoil section diagram above that:
Lift; is the component of the 'Total Reaction' at right angles or perpendicular to the relative airflow.
Drag; is the component of the 'Total Reaction' parallel to the relative airflow and opposing motion through the air.

2 The aeroplane's C_L/C_D curve for specified configurations.

The C_L/C_D curve is an important concept in aerodynamic and performance considerations. For a given configuration there will be an angle of attack that gives the largest gap between lift and drag.
This is the best lift to drag ratio. In terms of performance the major effects on the C_L/C_D curve is the use of flaps and slats for take-off.
To get the best climb performance it is best to fly at the speed and angle of attack which gives the best lift to drag ratio, this speed will vary depending on the configuration.
In general terms the best lift to drag ratio when comparing configurations is derived when the aeroplane is clean, so in terms of performance you will get the best climb rate when the aeroplane is clean.

2.1 Calculate the climb gradient for a given Lift/Drag ratio, thrust, mass and gravitational acceleration.

It can be accepted that:

$$\text{Thrust} = \text{Drag} + (\text{Weight} \times \text{Sin}\,\theta)$$

Therefore the Climb Gradient can be expressed as:

$$\text{Sin}\,\theta = \frac{\text{Thrust - Drag}}{\text{Weight}} \qquad or \qquad \text{Climb gradient (\%)} = \frac{\text{Thrust - Drag}}{\text{Weight}} \times 100$$

So from the above; if we are given the thrust, lift / drag ratio and mass (weight) then the gradient can be calculated.
For the small angles considered the 'Sin θ' can be accepted as being the same as 'Tan θ' which is the gradient of climb = γ (Gamma).

As an example from Principles of Flight:

An aircraft of mass 50,000kg with two engines of 60,000N thrust each, has a L/D ratio of 12:1.
Assuming g=10m/s2, calculate the one engine inoperative climb gradient.

From the information given, the weight of the aircraft can be calculated to be:

50,000kg x 10m/s2 = **500,000N**

With one engine inoperative, the thrust will only be 60,000N.

At small angles of climb, it has been shown that lift is slightly less than weight but for the purposes of these simple calculations it can be assumed that lift equals weight.

As the actual drag is unknown but the L/D ratio of 12:1 has been given, we can calculate drag to be 1/12 of the lift and as it has been assumed that lift equals weight, this will be:

500,000N ÷ 12 = **41,667N**

Therefore, using the formula sin γ = (T - D) ÷ W and substituting the required values:

$$\text{Climb Gradient (\%)} = \frac{60{,}000 - 41667}{500000}$$

From above, the climb gradient = sin γ x 100%

therefore: The one engine inoperative climb gradient = 0.0367 x 100% = **3.67%.**

From that we can also derive:

$$\frac{\text{Change in height (ft)}}{\text{Horizontal distance travelled Nm x 6080}} \text{ x 100 = \% Gradient}$$

This is a more useful way of calculating the climb gradient in % and this method can also be found in CAP 698 in the general notes section.

It should also be remembered that:

- **If thrust is increased the angle of climb will increase.**
- **If weight is increased the angle of climb will decrease.**

Weight, altitude and temperature, (WAT) are the three parameters which affect the climb gradient in still air for a given aeroplane and configuration, this is often referred to as the **'Climb Limit'** and may need calculating for 'Take off Climb' and also the 'Landing Climb' (In case of the go-around or 'Baulked Landing'.)
Minimum climb gradients in still air at various phases of the flight may be required. These gradient requirements will limit the weight (take-off and landing) for a given altitude and temperature, and this is known as the Climb Limit Mass.

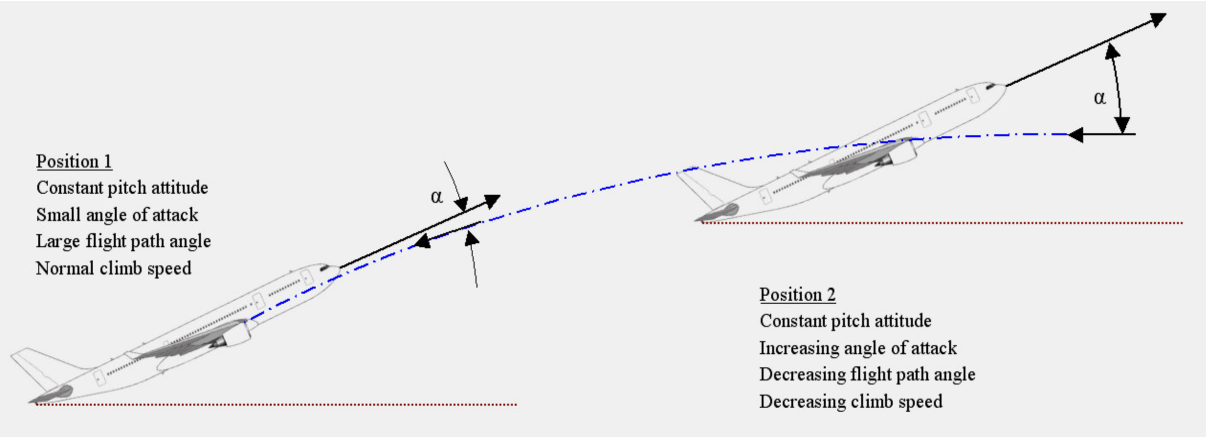
Headwind and tailwind components affect the gradient with respect to the ground, and thus affect the flight path and obstacle clearance considerations.
Headwinds give better clearance as the relative airflow at the same airspeed gives a lower groundspeed, which means that the ground distance covered is smaller for a given rate of climb than for a tailwind.
Tailwinds give a *worse clearance* as the relative airflow at the same airspeed gives a higher groundspeed, which means that the ground distance covered for a given rate of climb is larger than for a headwind.

Wind and the Maximum Climb Angle - The effective *angle* of climb will be increased by a headwind and decreased by a tailwind.

Please note that: The *rate* of climb will not be affected by either head or tailwind.

2.2 Define the terms flight path angle and flight path gradient

The flight path angle is the angle between the relative airflow and the horizon, in other words relative to the ground and accounting for head or tailwind.



The aircraft in the diagram above is being climbed at the recommended climb thrust setting and best rate of climb speed with the pilot holding the pitch attitude constant. At position 1 it can be seen that flight path angle is fairly steep and that the angle of attack is fairly small. As the aircraft ascends, the power from the engines starts to decay and the rate of climb starts to decrease, reducing the climb angle. As the pitch attitude is being held constant, the angle of attack is starting to increase and the speed is starting to bleed off. At position 2 with increased altitude, the flight path angle is now very small but because constant pitch attitude is being held, the angle of attack has increased significantly and with it the airspeed has decreased.

2.3 Explain the difference between climb/descent angle and flight path angle

Climb/descent performance is specified in terms of the climb/descent gradient, the ratio of climb/descent rate to forward speed. The following points apply:

- For small angles of climb/descent, the flight path gradient and the flight path angle are essentially the same.
- Climb/descent gradient is the flight path climb/descent angle expressed in percent, and equates to feet climbed/descended per 100 feet of horizontal distance travelled.
- Climb gradient is a direct measure of the take-off acceleration and climb capability of the aeroplane.
- Climb/descent gradient is used as a normalising parameter to simplify performance charts.

2.4 Explain the effect of temperature, wind and altitude on climb performance

To summarise from the last few pages:

- The effect of increased temperature on performance is similar to that of increasing altitude.
- An increase in temperature will reduce the density of the air. In other words an increase in the density altitude, equating to reduced performance.
- Headwind and tailwind components affect the gradient with respect to the ground, and thus affect the flight path and obstacle clearance considerations.
- Climb performance will reduce with the increase in density altitude until reaching absolute ceiling at which rate of climb will become zero.

2.5 *Define Best Angle(Max Gradient) and Best rate(Max Rate) climb speeds.*

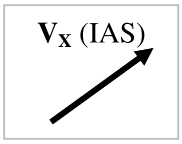
i. ***V_X*** This is the speed for ***'Best Angle of Climb'***.

For a given set of conditions there will be a speed that gives the best angle (gradient) of climb, this will be where ***the biggest surplus of <u>thrust</u> is available*** over that required for level flight.

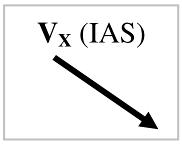
V_{MD} for a Jet aeroplane and less than V_{MD} for a Piston/Propeller aeroplane.

For any given mass (weight) the maximum climb gradient will be when the excess thrust is greatest.
Drag and thrust will vary with the airspeed so there must be one particular speed at which this occurs. This is called V_X.

<u>**Mass**</u>
Increased mass: = More drag for a given thrust so reduced climb gradient. Leading to increased V_X

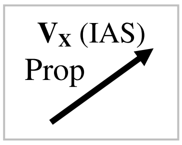


<u>**Flaps and Gear**</u>
Flaps and gear down: = More drag
Gear down Result: = V_{MD} decreases
Flaps selected Result: = V_X decreases and V_{MD} decreases



<u>**Density decreased or Altitude increased**</u>
For any given IAS the drag is not affected by changes of density, however the thrust will reduce with a density decrease, V_X (TAS) increases with increased altitude.

Decrease in density: = Decreased climb gradient
JET constant as V_X (IAS) = V_{MD} but increased as V_X (TAS)
Piston / propeller aeroplane V_X (IAS) increase with altitude



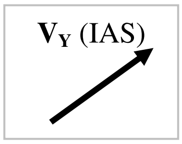
ii. ***V_Y*** This is the speed for ***'Best Rate of Climb'.***

For an aeroplane to climb at its fastest rate it will not be flying at the speed for its best angle. To attain the best rate of climb the aeroplane must be travelling at the speed which will give ***the biggest surplus in <u>power</u> available*** over that required for level flight.

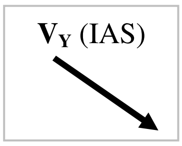
This speed is normally above that which gives the best angle.

For any given mass (weight) the rate of climb will be at a maximum when the excess power is greatest. This is called V_Y.

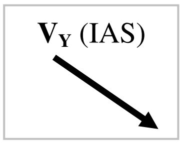
<u>**Mass**</u>
Increased mass: = more power required
= Excess power over that required is therefore reduced
= Rate of climb reduced for the given excess power available
Leading to increased V_Y



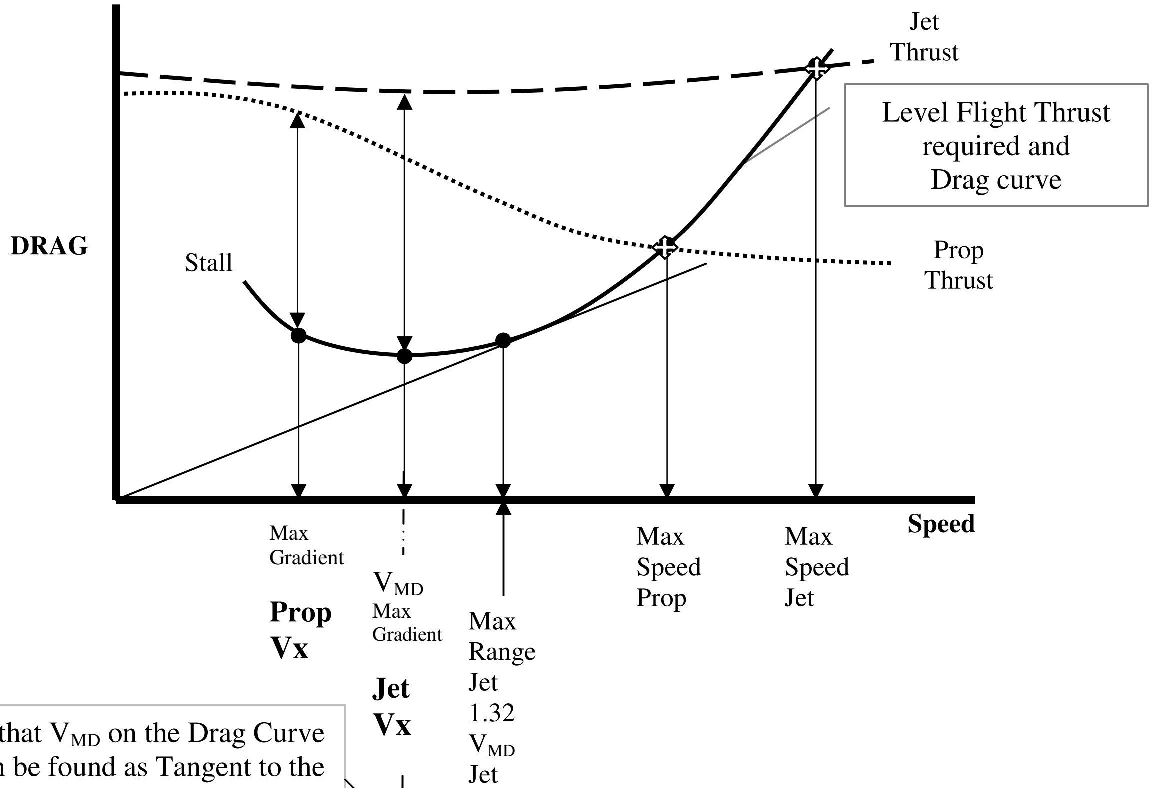
<u>**Flaps and Gear**</u>
Flaps and gear down: = More drag
Result = increased power required to compensate, if available
Flaps selected Result: = V_Y decreased



<u>**Density decreased or Altitude increased**</u>
Power available: = decreases
Power required: = increases
Result: = V_Y (IAS) decreases V_Y (TAS) increases

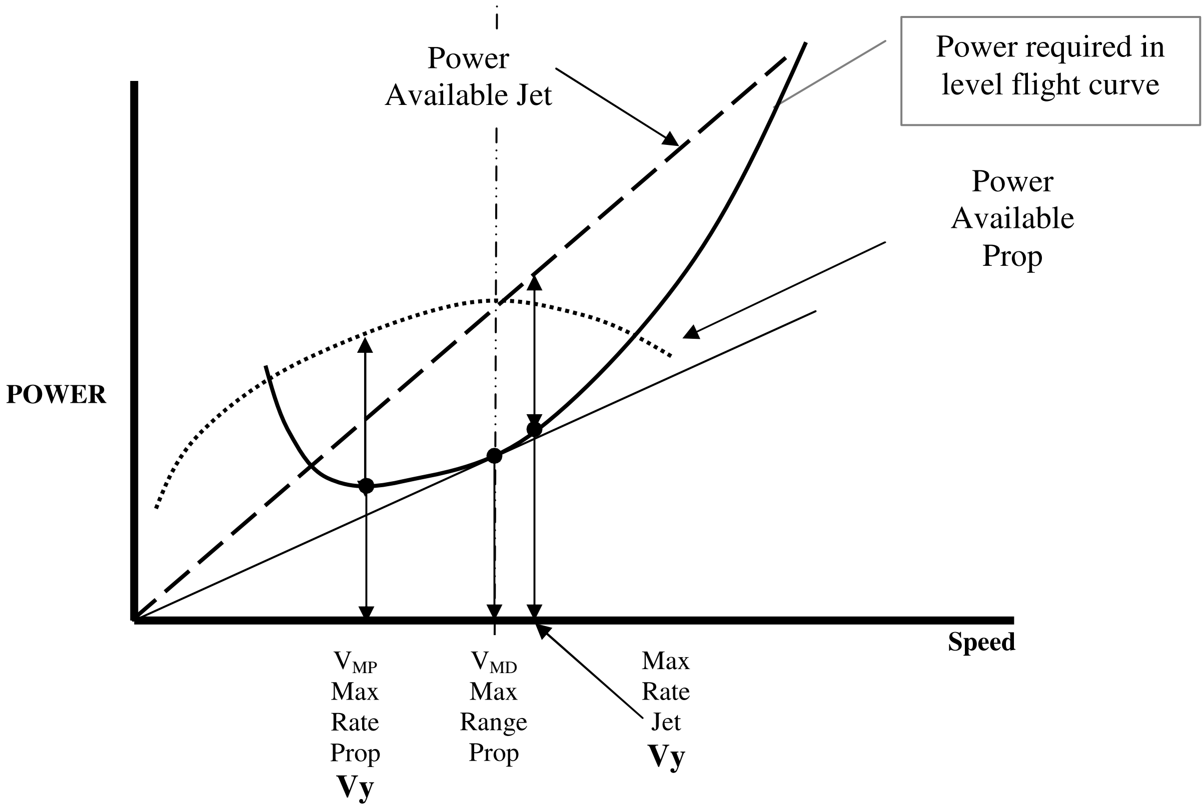


Maximum Climb Angle γ Gamma or Gradient (Max Excess Thrust) for Prop and Jet aeroplane



Notice that V_{MD} on the Drag Curve can be found as Tangent to the Power Curve.

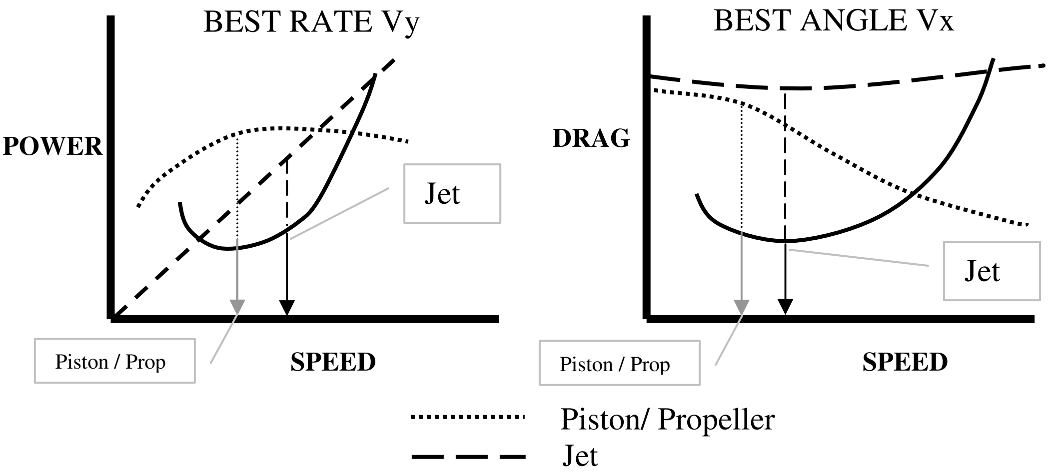
Maximum Rate of Climb (Max Excess Power) for Prop and Jet Aeroplane $\mathbf{V_Y}$



2.6 *V_x and V_y during the climb to Absolute Ceiling*

During the climb Best Gradient (angle) airspeed Vx increases with altitude.
Also when climbing Best Rate airspeed Vy decreases with altitude.
V_X and V_Y will meet with the same value when the aeroplane reaches its 'Absolute Ceiling'
In other words Vx and Vy will be will be the same at 'Absolute Ceiling'.

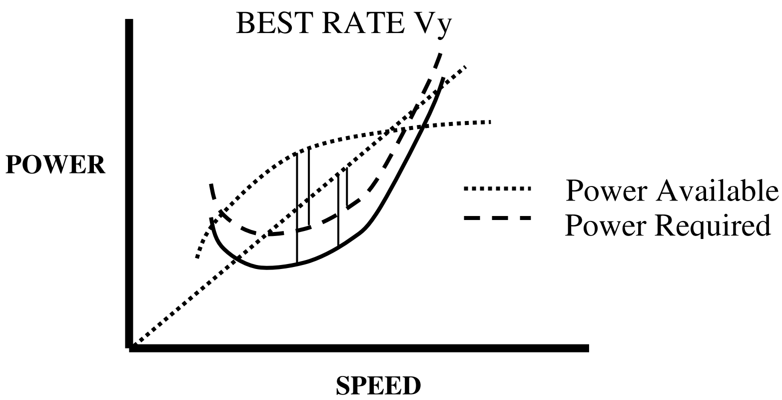
2.7 *Vy and Vx for Piston Propeller vs Jet.*



Notice from the Power and Drag curves shown above that both Vy and Vx are faster in regard to the Jet aeroplane.

2.8 *Explain the effect of mass on the best Rate of Climb (ROC) speed Vy*

As Mass is increased, so is the drag, more lift required therefore more induced drag. This increases the speed for best rate of climb for both piston / propeller and jet aeroplane.



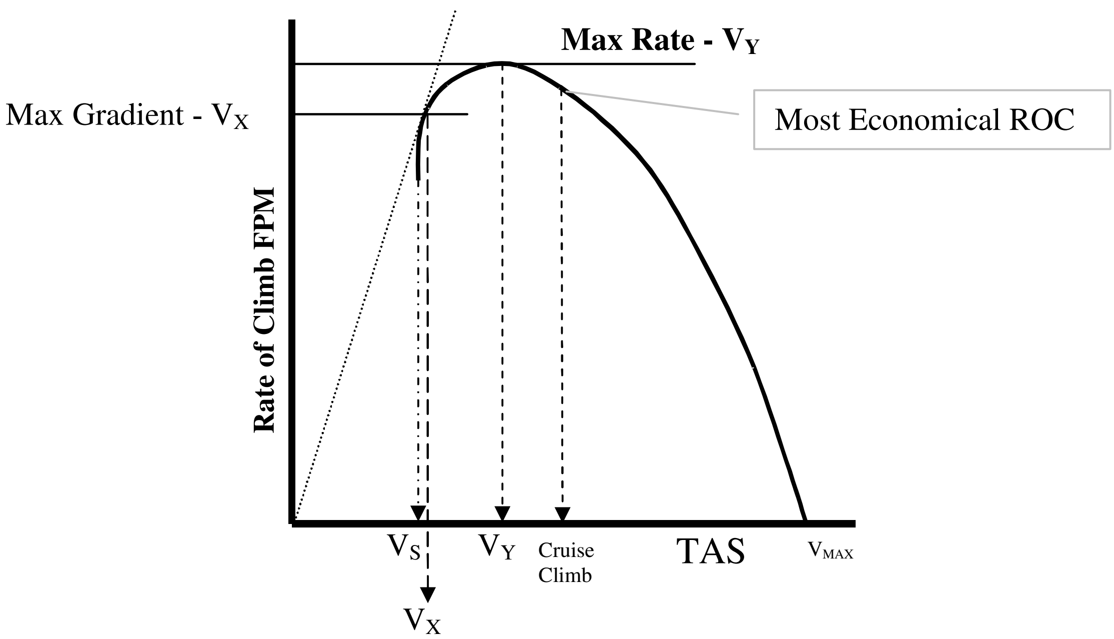
2.9 *State the effect of mass on V_X and V_Y.*

An increase of mass will increase the speed for best angle of climb (V_X) and best rate of climb (V_Y).
An increase of mass therefore effectively moving both the power and thrust required curves up and to the right with reference to TAS.

3 Rates of climb

3.1 The effect of selected power settings, speeds, mass and flaps on the rate of climb versus airspeed curve.

Power – Increasing the power in a climb will increase the rate of climb since rate of climb is proportional to power available less the power required (P_a – P_r divided by the Weight).
In practice, a commercially operated aeroplane will climb at V_Y, as this gives the best rate of climb for the lowest fuel consumption. (*Typically for a Boeing 737, this is 280 Kt.*).



Speed – From the above graph it can be seen that when you are flying at the maximum rate of climb speed Vy, and then increase or decrease the speed; it will reduce the rate of climb.
The most economical ROC will be at a speed slightly faster than V_Y

Mass – Increasing the mass of the aeroplane requires an increase in lift for a given thrust setting. The only way to achieve this is to fly at a higher IAS.
Therefore for an increase in mass, an aeroplane will climb slower, whereas a lighter aeroplane will climb quicker.

Flaps – With flaps lowered, lift is significantly improved but so is drag and the 'Lift : Drag Ratio' reduces.
Therefore climbing with flaps extended does not allow the aeroplane, as a whole, to climb efficiently.
The best rate of climb can always be achieved with a clean wing.
Therefore, having flap extended means that the rate of climb will decrease.

4 *Climbing with constant Mach Number vs the lift coefficient*

$$\text{Mach No} = \frac{\text{TAS}}{\text{LSS}}$$

If the Mach number remains constant with decreasing temperature, the IAS and TAS decrease.
As the IAS is decreasing the C_L (angle of attack) must be increased to maintain the lift.

4.1 *Explain the effect of climbing with constant IAS on the drag*

Total drag is found using the formula Drag = $C_D \frac{1}{2} \rho V^2 S$ from this we can see that with constant IAS in the climb the total drag will remain constant.

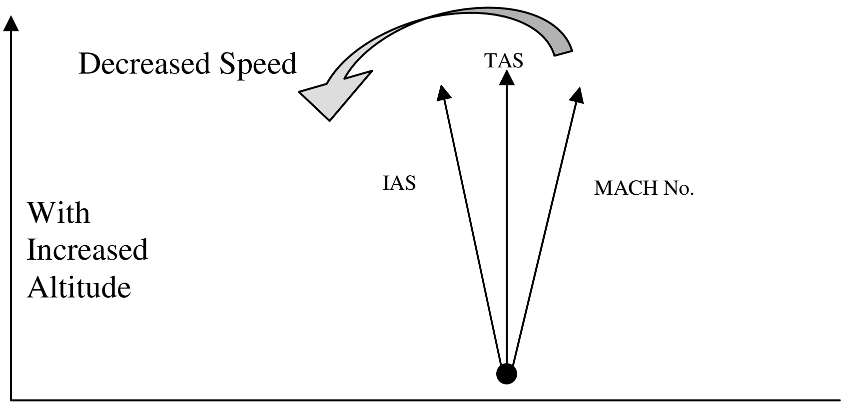
4.2 *Computation of the maximum climb speed by using performance data*

As an aeroplane is climbed at a constant IAS the TAS and Mach No. both increase.
Eventually a speed is reached where the Mach limit (M_{MO}) may be exceeded.
From this point on, the aeroplane will be climbed at a constant Mach No. and IAS will decrease.

The climb/descent schedule for the MRJT is 280 kts/Mach 0.74.

An illustration of the three speeds as affected by the climb.

Example, TAS Constant = IAS reducing and Mach No. Increasing:



4.3 *Elaborate on the cross over altitude, during a certain climb speed schedule (IAS-Mach Number)*

The flight planning graphs in CAP 697 show two figures for climb and descent; an airspeed and a Mach number. (e.g. 280 knots / Mach 0.74)
In the climb, the speed will initially be set at the airspeed figure with reference to the ASI.

As altitude increases; the TAS increases and the speed of sound decreases.

When the indicated airspeed equals the Mach number (e.g. 280 knots IAS = Mach 0.74) the aeroplane is passing the **'Cross-over Altitude'**, above this level the aeroplane speed is set with reference to the Mach No.

For a schedule of 280 knots / Mach 0.74 this altitude will be 30,000 ft

4.4 State the effect on TAS when climbing in and above the troposphere at constant Mach Number

In the troposphere, as altitude is increased at a constant Mach No. the TAS will decrease. Above the troposphere, because temperature remains constant, 'Local Speed of Sound' remains constant, therefore TAS will remain constant.

4.5 State the effect on the operational speed limit when climbing at constant IAS

The operational speed limit is normally given as a Mach number.
When climbing at constant IAS, the TAS is increasing and the Mach No is increasing.
If flying with reference to the ASI, the operational Mach No. limit must be calculated to ensure it is not exceeded. Note: "Coss-over Alitude" already referred to.
The reverse is true in the descent at constant Mach No. when the operational IAS limit may be exceeded.

5 Significant airspeeds for climb

5.1 The sequence of climb speeds for jet transport aeroplanes

The correct sequence is:

V_2 – (TOSS) - Best ROC IAS - Mach Schedule speed.

You will note from the graph on the preceding page that the V speeds for the rates of climb would fall into the following pattern:

V_S V_X V_Y $V_{CRUISE\ CLIMB}$ $V_{MAX\ (Horizontal\ flight)}$

Note that '**TOSS'**; 'Take-off Safety Speed' is used normally in regard to light twin engine aeroplane. The concept is based on V_2 considerations.

6 Summary of effect of Flaps and Acceleration on V_X and V_Y

6.1 State the effect of flaps on V_X and V_Y.

The effect of flap is always to reduce the climb performance (increase drag) – both rate and angle of climb.
Therefore the *speed* for best rate and angle of climb will decrease.

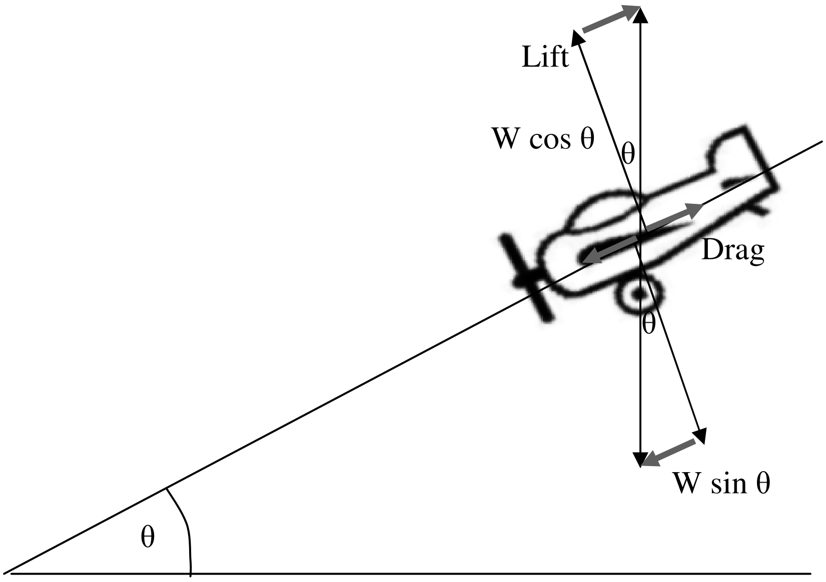
6.2 State the effect of acceleration on V_X and V_Y at a given constant power setting

With a fixed power setting, some of the thrust that has been used to climb the aeroplane will now be used in the acceleration, so the rate and angle of climb will be reduced.
Acceleration being a change in airspeed (TAS or Groundspeed).

Chapter 4 Descending Flight

1 Steady Glide

In a glide, TAS and Descent angle (θ) are constant.



The lift continues to act at right angles to the flight path and the weight vertically downwards, however, like in the example above, the two are no longer directly opposed.
The weight must now be resolved into two components, one supported by lift, and the other acting in the direction of the flight path.
Note that the lift required is now less than for level flight **(W Cos. θ)**
Weight acting along the glide path must now equal drag.

1.1 Explain the effect of mass on the speed for best angle, and best rate in the descent.

The forces in the descent can be determined from the diagram above;

In which the forces parallel to the flight path are:

Thrust = Drag – (Weight x Sin θ)

The forces perpendicular to the flight path are:

Lift = W Cos θ (Weight Apparent Lift)

In the glide (Zero Thrust)

Drag = W Sine θ (Weight Apparent Thrust)

Therefore;

Lift is less than Weight

Thrust is less than Drag

If weight is increased then the speed must be increased to maintain the best angle.

It can be accepted that:

$$\text{Drag} = \text{Thrust} + \text{Weight} \times \sin\theta$$

Therefore the Descent Gradient, like the Climb Gradient can be expressed as:

$$\sin\theta = \frac{T-D}{W}$$

Note however that in a glide the thrust, T is reduced to zero and the relationship between the forces is simplified as follows:

$$\sin\theta = \frac{D}{W}$$

The Rate of Descent is:

$$\text{R.O.D} = V \times \frac{D-T}{W}$$

Where V is velocity (TAS).

From that we can also derive the following:
'R.O.D. = V sine θ' therefore, ROD = TAS x Gradient ***'when angles are small'*****.**

ROC *or* ROD = TAS x GRADIENT

Therefore if the Velocity is increased to maintain optimum descent conditions, the rate of descent will increase. If the optimum conditions *are* maintained then drag and W sin θ will increase in the same proportion maintaining the glide angle.

1.2 Gliding for Max Range

The best range in the glide will be at the **'Best Lift : Drag ratio'**
The speed for best angle of descent is the minimum angle or gradient of descent when lift/drag ratio is at a maximum, $\mathbf{V_{MD}}$.

The angle of the glide is unaffected by changes in weight (Mass), provided that the speed is adjusted accordingly, '**faster when heavier and slower when lighter'**, thereby changing the time taken during descent. This not only presents a change in the R.O.D but also changes the total time that a head or tailwind component may affect the flight.

i. Head and Tail winds

The effect of wind is much the same as when in the climb, a headwind will increase the descent gradient and a tailwind will decrease the descent gradient. Appreciate that the ground distance travelled will also change to accommodate the changed descent angle, less ground distance into the headwind and greater with a tailwind. There is best range advantage in making slight adjustments to the TAS to help maintain the best L/D ratio; reduce TAS for the tailwind and to increase TAS when exposed to headwind.
If you are gliding into a headwind for best range, you are also better off being heavy, so it makes sense *not* to make the aeroplane any lighter. (Think of gliders and ballast or jettisoning fuel!)

1.3 Gliding for Endurance

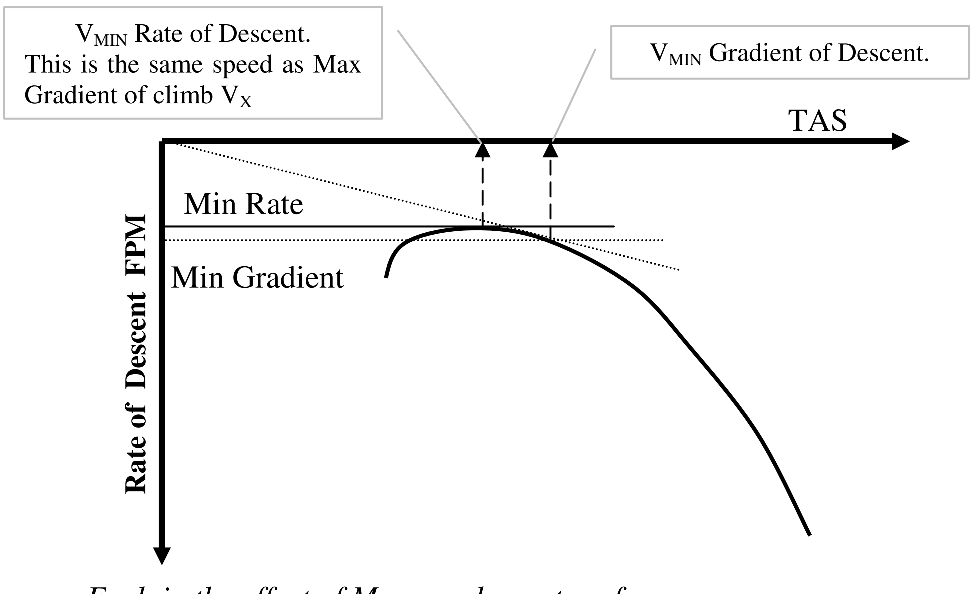
Minimum Rate of Descent will occur where the power required is at a minimum, V_{MP}. This is the speed found at the lowest point of the power required curve and will change with the weight (Mass).
The more the weight, the more the speed and the greater the rate of descent, the result being less Gliding Endurance.
A simple 'rule of thumb' to find the Minimum Rate of Descent airspeed is to use 75% of the speed required for minimum angle, tangent to the power curve. (V_{MD}).

2 Pitch angle, mass, airspeed and lift/drag ratio in a glide

The best (minimum) glide angle will be at the best lift / drag ratio, this will be at a specific angle of attack or pitch angle for a given configuration. In order to maintain the optimum condition when the mass is increased, the airspeed will have to be increased too. This will lead to a higher rate of descent but the same glide angle.

2.1 Describe effect of pitch changes on the glide distance

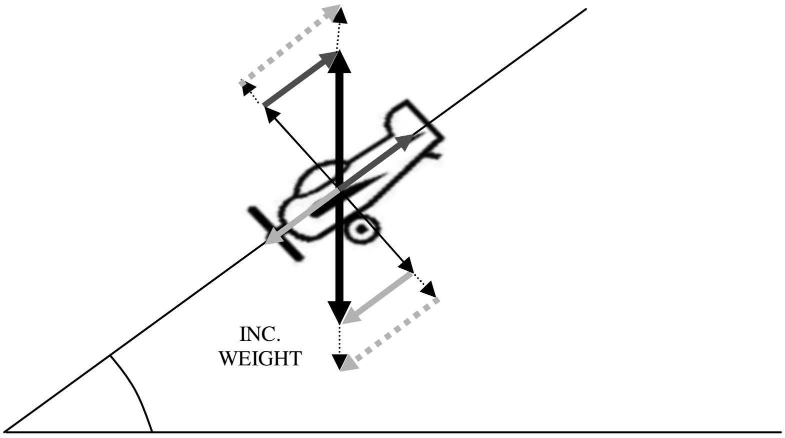
The maximum glide range will be achieved at the angle of attack which gives the best Lift / Drag ratio. An increase or decrease of pitch away from this optimum angle will decrease the range, change the glide angle and increase the rate of descent.



2.2 Explain the effect of Mass on descent performance.

Mass – The best angle of glide will be at the best 'Lift : Drag Ratio'.
A higher mass will increase the rate of descent and increase the optimum glide speed.
Providing the optimum Lift / Drag ratio is maintained; the glide angle and therefore glide range (in still air) will be unaffected.
So if we increase the mass; then the speed will *have* to increase to overcome the *extra drag*, (weight apparent drag) this in turn will require an *increase* in rate of descent.
The effect of head and tailwind components will also be affected by aeroplane weight, the higher airspeed of the heavier aeroplane will shorten the airborne time, this in turn will reduce the time when the aeroplane is under the influence of the wind component.

The glide endurance will also decrease with increasing weight due to the higher rate-of-descent.



2.3 Explain the influence of configuration, altitude on rate of descent, glide angle and lift/drag ratio

Configuration - The best lift / drag ratio of an aeroplane is always achieved in a clean configuration. The final stages of an approach, just before landing will normally be flaps and wheels down.

Flaps – The lowering of flaps causes a marked decrease in the 'Lift : Drag Ratio', this in turn will mean a steeper glide angle
Flaps increase the lift and in a powered approach the same glide angle can be maintained by increasing the pitch angle and decreasing the speed, however in a glide without power the glide angle will increase because of the reduced lift / drag ratio.

Altitude - Ignoring compressibility, drag is dependent on EAS.
'The optimum glide will still be at the best lift / drag ratio at any altitude'.
The main effect of altitude is at high altitude the TAS and rate of descent along the optimum glide path are increased but glide angle is unaffected.
At higher altitude due to the less dense air, the rate of descent will initially be quite high (approximately 2,500 feet per minute for a Boeing 737), though this will reduce in the lower atmosphere due to the increasing air density (to approximately 1,300 feet per minute for a Boeing 737).

3 Explain the effect of a descent at constant Mach Number

3.1 The margin to low speed and Mach buffet.

As an aeroplane descends at constant Mach number in ISA conditions the IAS is increasing, this will increase the margin to low speed buffet and decrease the high speed buffet margin.

3.2 Changes of lift coefficient in the glide at constant Mach.

As an aeroplane descends at constant Mach number in ISA conditions the IAS is increasing. To maintain a constant lift the C_L must decrease by decreasing the angle of attack.

Chapter 5 Range and Endurance

1 Endurance and the effects of power

Endurance is the maximum time an aeroplane can remain in the air on a given amount of fuel. This speed will be where fuel consumption per hour is at a minimum. We must also consider that this is not only a question of the airframe and overcoming the forces of drag but also the overall efficiency of the engines too. Factors such as the aeroplane weight, altitude and also how much useable fuel is carried also must be considered.

Piston / Propeller
The power required will increase with altitude as TAS increases with altitude overcoming the drag at a constant IAS.

Power Required = Drag x TAS

From this we should expect that Max Endurance will be found at the lowest usable altitude and where the best surplus of power available over power required can be found. This is roughly the same as the best rate of climb speed V_Y.

- Minimum power speed for a Piston/Propeller aeroplane where fuel flow is at minimum. $\mathbf{V_{MP}}$

Flying at this speed would produce a low IAS and a risk of controllability problems so it is usual for the aeroplane to be flown at a *slightly* faster speed.

Jet
With a jet engine the fuel flow and thrust produced are directly related and virtually in proportion with each other. The thrust required must be equal to the drag in level flight so minimum drag will require minimum thrust and a minimum fuel flow. The thrust will decrease with altitude so also will the fuel flow, and from that we may assume that the Max Endurance for a jet will be found at the highest usable altitude.

- Minimum drag speed for a jet aeroplane $\mathbf{V_{MD}}$

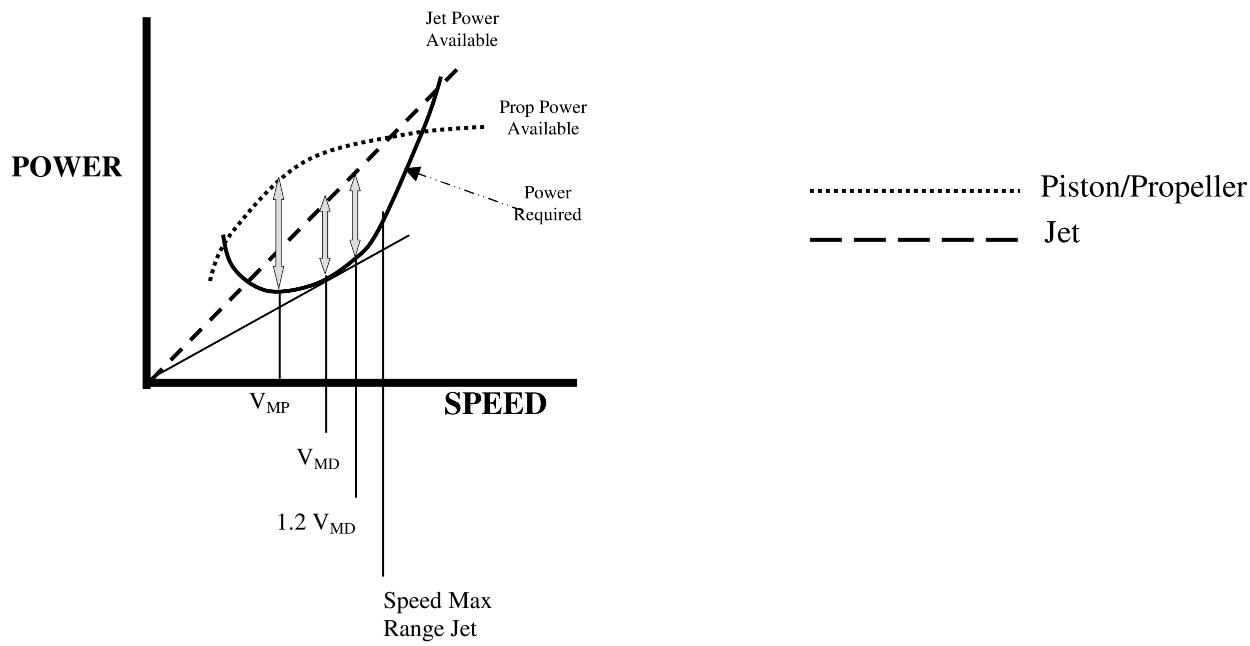
For controllability reasons the speed normally used is *slightly* higher than the speed of minimum drag.
Between V_{MD} and 1.2 V_{MD} the Jet power available over the power required changes very little so there is some flexibility in the choice of speed used.

1.1 Explain the effect of wind on the maximum endurance speed.

As endurance has no bearing on how far the aeroplane travels, the wind will have no effect on the speed to fly.

Looking at the Power curve graph below it illustrates the following:

- For a piston/propeller: Max Endurance is at V_{MP}
- For a Jet: Max Endurance is at a faster speed being V_{MD}
  (Tangent to the Power Curve)
- All the above speeds are lower than the speed for Max Range Jet
  (Tangent to the Drag Curve)



1.2 Speed/Economy trade-off

1.3 Explain the correlation between maximum endurance and fuel consumption.

In order to achieve the 'Maximum Endurance' from a given amount of fuel, the fuel consumption must be at its *lowest*, which is when the aeroplane is at;

'Minimum Power Speed' (V_{MP}).

This will ensure that the, specific fuel consumption (SFC engines*) is at its lowest and the aeroplane will be able to remain airborne for the maximum period of time.
This is generally only used when the aeroplane is put into a hold, as this will enable the pilot to hold for the maximum period of time before low fuel quantity forces a diversion.

This should not be confused with range considerations, which is the distance that can be flown for a given amount of fuel which for a *piston* aeroplane, will be at a higher speed, the best ratio of speed to power. (Tangent to the power curve).

$$^{*}\quad SFC = \frac{\text{Fuel Flow/Hr}}{\text{Thrust}}$$

2 Range and the effects of power and wind.

2.1 Explain the effect of various power settings on the still air range.

Range is the maximum distance an aeroplane can fly on a given amount of fuel.

$$\text{Gross Fuel Flow (GFF)} = \frac{\text{The Fuel Flow}}{\text{Ground speed}}$$

For example it can be seen from the graph for range calculation in CAP 697 Fig 2.4, that the more power used, the less the range of the aeroplane.
This is simply that more fuel is required per revolution of the engine to maintain the higher power setting than a lower one.

2.2 The effect of wind.

A head wind will decrease the range and a tail wind will increase the range.

Looking at the Drag curve graph below it illustrates the following:

Piston / Propeller ($V_{MAX\ RANGE}$)

- For a piston/propeller Max Range is at V_{MD} or 'Tangent' to the power curve.

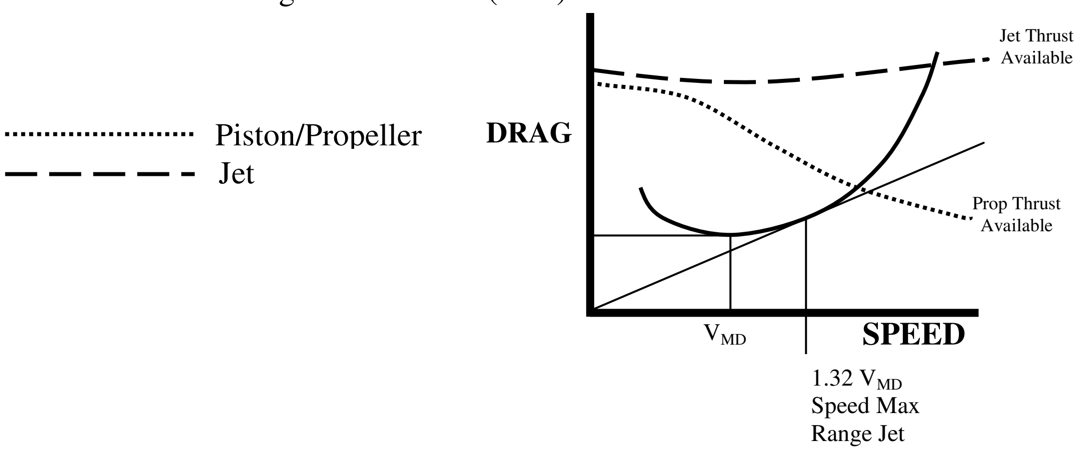
Flying at this speed would offer some controllability problems so it is usual to adopt a speed of 1.1 V_{MD}
Notice that the Prop Thrust available reduces as speed increases so the engine / propeller is most efficient at low IAS.

Jet ($V_{MAX\ RANGE}$)

- For a Jet Max Range speed will be the IAS found at 'Tangent' to the drag curve. *(This is normally about 1.32 V_{MD})*

This will equate to the maximum IAS for the minimum amount of drag.
Notice that the Jet Thrust available is virtually maintained across the speed range, with the result that all things considered, the jet engine is most efficient at high IAS.

As we have already stated that maximum range requires lowest gross fuel flow, the aeroplane should be flown at a high altitude where the IAS will give the best TAS.
At any given turbine RPM a reduction in the air density will result in a reduction in fuel flow, this is another advantage of high altitude flight that combined with the increase in TAS will give a reduction in the gross fuel flow. (GFF)



2.3 *The effect of Mass and Altitude*

- With an increase of mass, power required and drag are increased. More thrust is required therefore fuel flow increases and range decreases.
- For a jet aeroplane, if mass is increased by 10% then the speed for best range will increase by 5%, the fuel flow will increase by 10% and the SR will decrease by 5%.
- With an increase in altitude, range will increase until the optimum altitude is reached because of the increase in TAS and decrease in Specific Fuel Consumption (SFC).
- The optimum altitude is reached when the increase in TAS leads to compressibility problems with the consequent increase in drag.

2.4 *Explain the effect of airspeed on thrust of a jet engine aeroplane at constant RPM.*

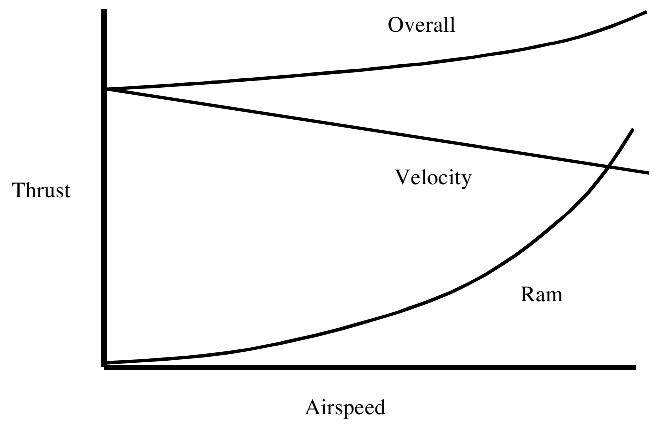
There are two major effects to consider as follows:

Ram Air – The principle of a Jet is to impart a large acceleration to a relatively small mass of air. As the airspeed increases air is effectively rammed into the intake by virtue of the forward motion of the aeroplane, for a given RPM this increases the mass airflow.

Inlet Velocity - It can be shown that with increasing speed, the increase in velocity at the inlet duct has the effect of decreasing the thrust. (Velocity increase - Pressure decrease)

Overall the ram effect on the thrust is greater than the velocity effect and thrust increases with an increase in airspeed.

Ram Air vs Velocity



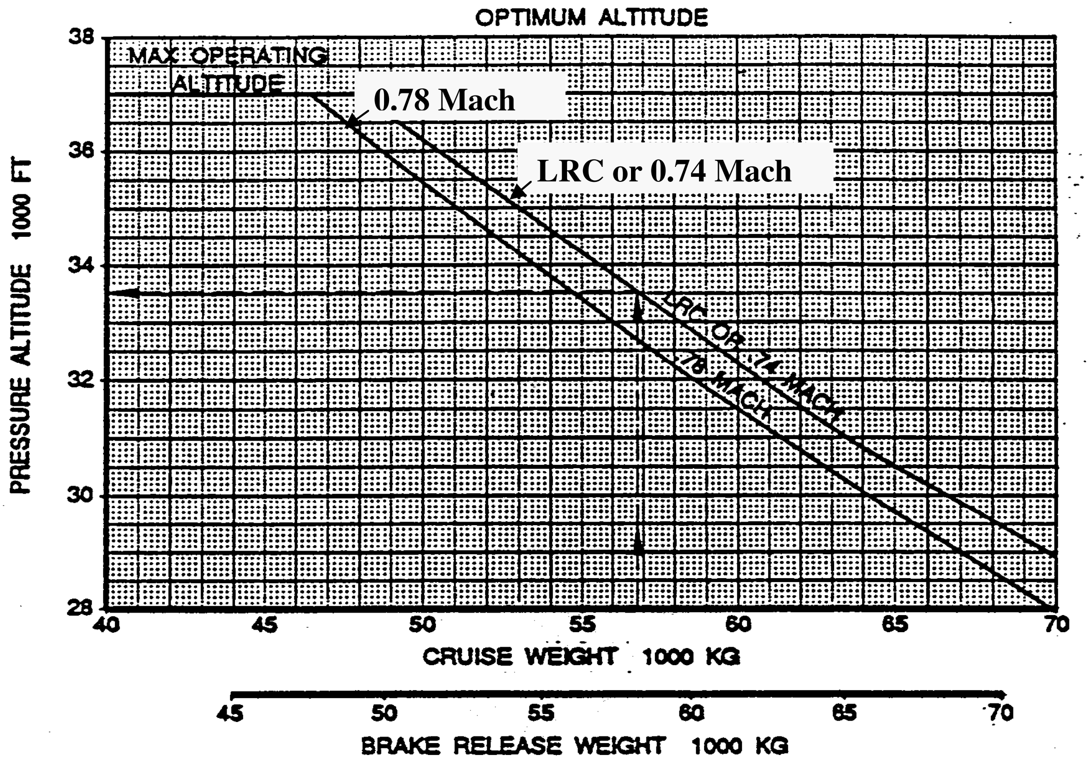
2.5 *Explain and state the factors which affect the optimum long range cruise altitude*

For any given aeroplane weight there is an optimum altitude at which the sector should be flown.
This is given in performance manuals and gives the best TAS to fuel flow ratio.
This altitude may well have to be revised, of course, due to meteorological conditions as at one altitude there may be a headwind, whilst at lower and therefore theoretically less efficient altitude there may be a tailwind which will more than compensate for the lack of efficiency.
An example of a Boeing 737 optimum altitude graph is shown on the next page (LRC is the abbreviation used for 'Long Range Cruise').

As we may see from the above, the main factor that affects optimum cruise altitude is aeroplane weight, however speed is also a factor and the graphs clearly show this.
Whilst it is always most efficient to fly at exactly the altitude given by the graph (refer also to the step-climb), the aeroplane will be limited to selecting the most appropriate semi-circular flight level for each part of the flight.

2.6 Explain and state factors which affect the choice of optimum altitude

The optimum cruise altitude charts are in CAP 697. There are two charts, one for short flights (up to 230 miles where lower altitudes are appropriate), the other for standard cruise flights.



Weight and wind are the main factors affecting optimum altitude

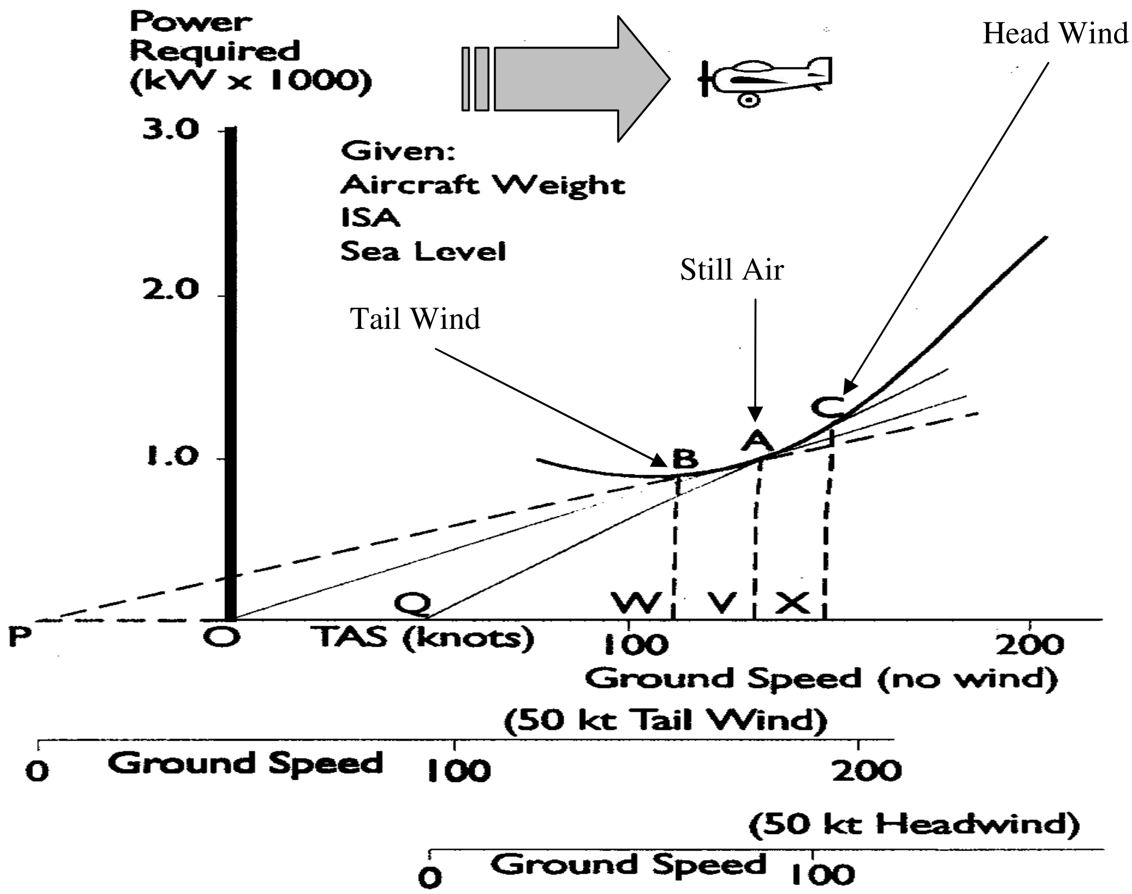
Whilst the charts give an optimum cruise altitude for aeroplane weights during the flight, wind and ground-speed are not considered. The table in CAP 697 gives the fuel mileage penalty figures for use when flying above or below the optimum level, using this with the forecast wind data can determine the best specific range. (Note that up to 4,000 ft below the optimum the penalty is relatively small).

2.7 Explain reasons for flying above or below optimum altitude

The primary reasons for flying above or below the optimum altitude are wind and turbulence. Groundspeed must be carefully considered as wind can be a greater benefit or detriment than the optimum altitude and in the case of a very strong tailwind it may be better to select an altitude up to 4000 ft lower than the optimum. It is also possible that turbulence at the optimum altitude is beyond an acceptable level and for safety / passenger comfort another level may be chosen. It may also be the case that starting the cruise higher than optimum will allow the reduced weight as fuel is burnt off to 'place the flight' at the optimum altitude.

2.8 *Explain the effect of wind on the maximum range speed.*

Maximum Range Speed - This is the maximum ground distance for a given amount of fuel. In zero wind a tangent to the curve from the origin, indicates the maximum range speed, this is line **'V'** in the figure below.
If there is a headwind the range speed alters as indicated by the tangent **'Q'** showing a speed increase at line **'X'**.
Conversely if there is a tailwind the tangent is line **'P'** indicating a speed decrease at line **'W'**.



From the above diagram note:

- A Slower TAS increases time of exposure to a tailwind with advantage of more energy gain.
- With a tailwind the TAS can therefore be reduced with a saving in the fuel due to the 'Free' energy available! = **MORE RANGE**

Conclusion - Wind will still often determine the best height to fly in order to take advantage of an increased tailwind or decreased head wind.

3 Centre of gravity and range and endurance

3.1 Explain the effects of Centre of Gravity (CG) position and actual mass of the aeroplane on range and endurance

The CG will have a ‘Safe forward and Aft limit for flight’ however the CG position will not remain fixed in flight; as the load is very likely to move forward and aft within its determined limits.
Fuel (mass) can be moved or used from different tanks in order to help compensate for in-efficient CG locations. A lack of efficiency will generally appear as resultant drag.

If drag or mass should be high then more thrust will be required and higher fuel flow will result, this will affect the range and endurance.

The CG is normally positioned toward the Aft limit of the envelope to assist rotation on take-off, throughout the flight the fuel should be managed and other loads, in such a way that the CG is maintained ‘just forward’ of the Aft limit.
By adopting this technique it reduces potential for trim drag.

Less drag results in less fuel flow, so range is increased and the stall speed is also reduced too. Given that the power settings were not adjusted then the IAS would be seen to increase due to the improved efficiency and as a result so would the TAS and the maximum range would increase.

Endurance is all about just staying airborne at minimum effort, so if you needed endurance the IAS should be maintained at its original figure and the power reduced which will again reduce the fuel flow.

3.2 Performance effects of CG at the Aft limit

- Less trim drag
- Decreased stall speed
- Decreased thrust required
- Decreased fuel flow
- Increased maximum endurance for a given fuel loading
- Increased maximum range for a given fuel loading

3.3 Performance effects of CG at the Forward limit

- More trim drag
- Increased stall speed
- More thrust required
- Increased fuel flow
- Decreased maximum endurance for a given fuel loading
- Decreased maximum range for a given fuel loading

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Section Two The Aeroplane within the Aerodrome limits

Chapter 6 Definitions of terms and distance and values used

1 Definitions

1.1 Aeroplane performance class / category definitions

This is referenced to EU-OPS and CS/FAR23 and CS25/FAR25

Class 'A'
An operator shall ensure that multi-engined aeroplanes powered by turbo propeller engines with a maximum approved passenger seating configuration of more than 9 or a maximum take-off mass exceeding 5,700 kg, and all multi-engined turbojet powered aeroplanes are operated in accordance with Subpart 'G' of EU-OPS. (Performance Class 'A').

Aircraft in this class can cope with an engine failure in any phase of flight between the start of the take-off run and the end of the landing run without a reduction in safety standards being below the acceptable level.

Commuter Category
The requirements for 'Commuter Category' aeroplanes are similar to those for Class 'A', requiring consideration of engine failure on take-off and acceleration stop performance.

Class 'B'
An operator shall ensure that propeller driven aeroplanes with a maximum approved passenger seating configuration of nine or less, and a maximum take-off mass of 5,700 kg are operated in accordance with Subpart 'H' of EU-OPS. (Performance Class 'B').

Performance accountability for an engine failure, on a multi engine aeroplane in this class, need not be considered below a height of 300 ft.

Class 'C'
An opertator shall ensure that aeroplanes powered by reciprocating engines with a maximum approved passenger seating configuration of more than nine or a maximum take-off mass exceeding 5,700 kg are opertade in accordance with Subpart 'I' of EU-OPS. (Performance class 'C').

1.2 Decision Speed

Class 'A' and Commuter Class Only!

In event of an engine failure being promptly recognised, V_1 is the speed at which the:

- Continued TODR will not exceed the TODA.
- Continued TORR will not exceed the TORA.
- ASDR will not exceed ASDA.

1.3 Summary of Performance Classes

This table is referenced to CS23 and CS25 (Note the difference with the weights and terms to those of EU-OPS!)

<table>
<tr><th rowspan="3">Aeroplane Category</th><th colspan="3">Aeroplane Power Plant configuration and Class</th></tr>
<tr><th colspan="2">Propeller</th><th rowspan="2">Multi-engined Jet</th></tr>
<tr><th>Single or Twin Engine Piston</th><th>Twin-engined Turbo - prop</th></tr>
<tr><td>Certified under CS23/FAR23 Normal, Utility and Aerobatic Commuter

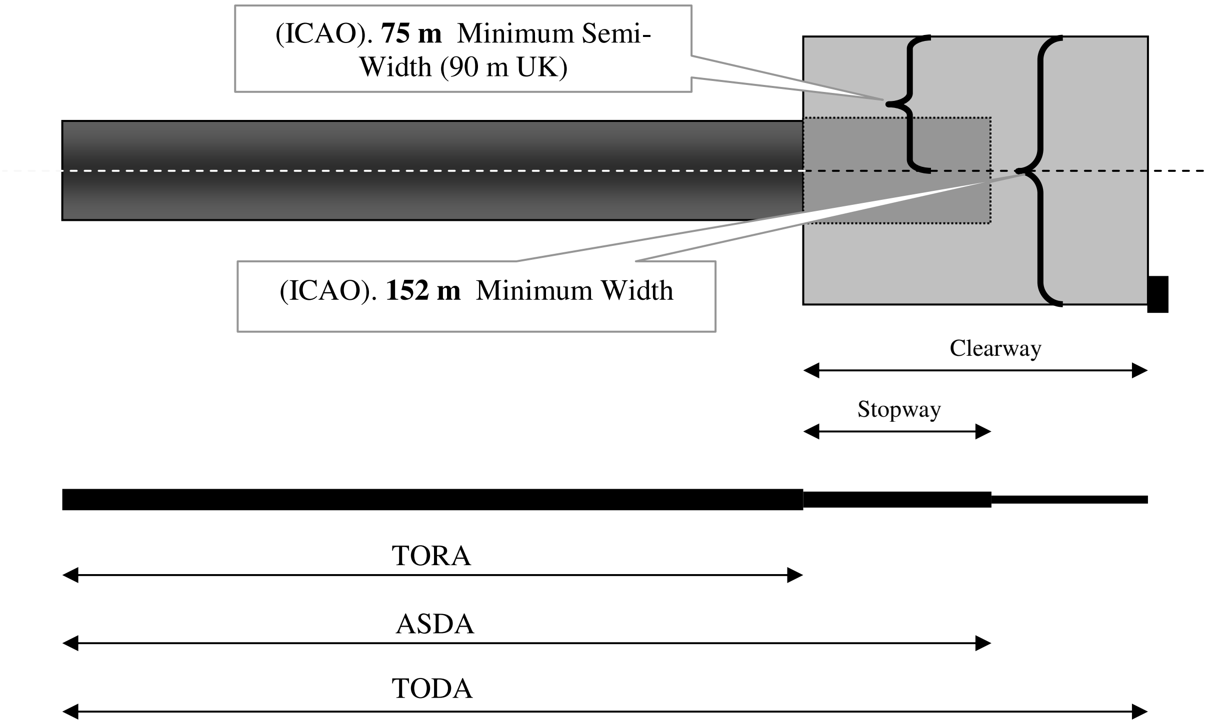
Weight: 5,670 Kgs (12,500 lbs) or less
Passengers seating: 9 or less (Excluding pilot seating)</td><td>B</td><td>B</td><td rowspan="2"></td></tr>
<tr><td>Certified under CS23/FAR23 Commuter

Weight: 8,618 Kgs (19,000 lbs) or less
Passengers seating: 19 or less (Excluding pilot seating)</td><td>Twin Engine only Piston
A</td><td>A</td></tr>
<tr><td colspan="4">Certified under CS25/FAR25
Turbine Powered - Large Aeroplanes</td></tr>
<tr><td rowspan="2">Weight: Greater than 5,700 Kgs
Passengers seating: More than 9</td><td rowspan="2"></td><td>A</td><td>A</td></tr>
<tr><td>*C</td><td></td></tr>
</table>

*Class 'C' Reciprocating Engines

Health warning!
(You will note that there are several differences between some of the definitions used in CS23/25 and those given in EU-OPS.)

1.4 The Runway Definitions



TORA - Take off run available. The length of runway which is declared by the state to be suitable for the ground run of an aeroplane taking off. In most cases this equates to the physical length of the runway pavement. The TORA must be equal or greater than the TORR.

TODA - Take off distance available: The length of the take-off run plus the length of the clearway available. TODA cannot exceed 1.5 x TORA.
The TORA must be equal or greater than the TORR.

ASDA - Accelerate stop distance available: The length of the take-off run plus the length of the stop-way available. The ASDA must be equal or greater than the ASDR.

CLEARWAY - A defined rectangular area, minimum width 152 metres (75m semi-width) for class A aeroplane, at the end of the runway and in the direction of take-off. It must be selected or prepared as a suitable area over which an aeroplane may make a portion of its initial climb to a specified height and must be under the control of the Competent Authority. The clearway can be no more than 50% of the TORA. It is also limited by any 'Non Frangible' obstruction encountered within its total width. (The small black rectangle extreme right in the above diagram).

LDA – Landing Distance Available. The length of runway which is declared by the state to be suitable for an aeroplane landing from a point 50 ft above the landing surface.

1.5 Explain the effect of clearway in take-off calculations.

Imagine a runway facing out to the pacific ocean, there is a defined amount of TORA (the concrete) and in theory, a very large clearway across the pacific.
The TORA + Clearway defines the TODA.
The aeroplane must reach the screen height by the end of the clearway.
This would foolishly enable *all* aeroplanes to take off at max weight in the knowledge that they can comply with the regulations.
However, there may not be enough concrete to allow the aeroplane to lift off at maximum take-off weight.
This means that;

The clearway as a declared distance is limited to 50% of the TORA making the TODA 150% of the TORA

This does not mean the aeroplane can *always* use all of the clearway as there is a 'Maximum Allowable' clearway depending on the TORA.

STOPWAY - A defined rectangular area on the ground at the end of a runway, in the direction of take-off, prepared by the competent authority as a suitable area in which an aeroplane can be stopped in the case of an interrupted take-off. The width is the same as the runway.

Runway Slope – EU-OPS and the range of slopes in the aeroplane flight manual account for runway slopes of +/- 2%.
Operation from runways outside of this range will need approval from 'the authority' dependant upon class of aeroplane and under what legislation the operation is taking place.
The runway slope often varies along its length and the average gradient is the value given to operators for application in landing and take-off calculations.

Basic Slope Calculation:

$$\text{Slope} = \frac{\text{CHANGE IN HEIGHT (ft)}}{\text{AVAILABLE RUNWAY LENGTH (ft)}} \times 100 = \%$$

There are many occasions where there will be a displaced threshold when the published TORA are of different lengths for opposite ends of the same runway. (The area of the displaced threshold being given as stopway for the other end of the runway!)
In this case the 'Shorter of the two TORA's' is used in the above calculation.
Remember also that there will usually be a mixture of units to contend with, elevation in feet and often TORA being given in metres.

Runway Slope (Accounting for displaced threasholds)

$$\frac{\text{Difference in threshold elevations}}{\text{Shorter of the two TORA x 3.28}} \times 100 = \%$$

1.6 Aerodrome Pressure Altitude

Field elevation - Density altitude affects aeroplane performance during all stages of flight, if an aerodrome is situated at a high elevation, the effect on take off performance must be accounted for. Density decreases with increasing altitude - reducing the efficiency of the engines and aerodynamic surfaces.
Performance charts allow for field elevation, no further calculations are usually necessary.

1.7 Balanced Field lengths

A Balanced Field is where;

- The available distance to continue the take-off is equal to the accelerate-stop distance, i.e. TODA = ASDA.
- If there is no stopway or clearway it is also a balanced field. (TORA = TODA)
- When ASDA is equal to TODA (This is when Clearway = Stopway or there is not a Clearway and Stopway).

This means a balanced field is where the stopway and clearway are equal and starting at the end of TORA.
It can also include an airfield where there is no clearway or stopway
(TODA = TORA = ASDA)

1.8 Assumed balanced field

An assumed balanced field can give a simpler calculation of the field length limit weight and take-off speeds than an unbalanced field.

If unbalanced field lengths are quoted as balanced field lengths by ignoring the extra stopway or clearway, this will give a lower field length limit take-off weight.

CAP 698 assumes balanced fields in its graphs.

1.9 Unbalanced field lengths

An unbalanced field is where;

- The TODA is determined by the Take Of Run Available (TORA) plus the Clearway with the Stopway being greater than the Clearway. ASDA is greater than TODA.
- The ASDA is determined by the TORA with no Stopway plus the clearway making TODA greater than ASDA
- The TORA plus the Clearway equals the TODA and the ASDA is greater than the TODA

This means an unbalanced field is where the stopway and clearway are not equal.
ASDA is not equal to TODA

2 *ACN and PCN*

PCN - Pavement Classification Number. A number expressing the bearing strength for unrestricted operations for aeroplane above 5700 kg MTWA. The PCN is a five-part code reported in the aerodrome section of the AIP for applicable runways. It will include the following:

- The PCN number;
- The type of pavement; **R** = rigid, **F** = flexible;
- The pavement sub-grade category; **A** = high, **B** = medium, **C** = low, **D** = ultra-low;
- The maximum tyre pressure authorised for the pavement; **W** = high, no limit, **X** = medium, limited to 217 psi, **Y** = low, limited to 145 psi, **Z** = very low, limited to 73 psi;
- Pavement evaluation method; **T** = technical evaluation, **U** = by experience of aeroplane actually using the pavement.

Example; PCN: 8O/R/B/W/T

This represents the bearing strength of a rigid pavement resting on a medium strength sub-grade and has been assessed by a technical evaluation to be a PCN of 80 and there is no tyre pressure limit.
If the PCN is equal to or greater than the ACN, unlimited runway use is permitted.
Individual aerodromes decide when to permit overload use (ACN > PCN).

An overload on <u>flexible pavements not exceeding 10%</u> should not adversely affect the pavement.
An overload on <u>rigid or composite pavements not exceeding 5%</u> should not adversely affect the pavement.
If the structure is not known the 5% limit should be used.

The annual number of overloads should not exceed 5% of the annual movements.

Overload use in excess of an ACN over PCN of 50% should be in an emergency only.

ACN - Aeroplane Classification Number. Calculated taking into account the weight of the aeroplane, the pavement type and the sub-grade category. ACN values are given in tables in the operating manual. The tables give ACN values for two weights, the MTWA and the operating weight empty.

- Max TOW Authorised — Rigid Pavements
- Operating Weight Empty — Rigid Pavements
- Max TOW Authorised — Flexible Pavements
- Operating Weight Empty — Flexible Pavements

if the aeroplane is operating at an intermediate weight, the ACN value can be obtained by linear interpolation, extrapolation is not permitted. (Boeing 757-535C has a maximum ACN of 29)

Chapter 7 Class A and B aeroplanes within the aerodrome

Screen Height – The height of an imaginary screen placed at the end of the take-off Distance Required (TODR) and at the beginning of the Landing Distance Required (LDR) which the aeroplane would only just clear when the wings were level and with the landing gear down.

Class	Take-off	Landing	EU-OPS (Class 'B') and EU-OPS (Class 'A')
'A'	35 ft	50 ft	With the approval of 'The Authority' Landing Screen height may be reduced but to not less than 35 ft.
'B'	50 ft	50 ft	

The speed definitions used in this chapter can also be found later in these notes, but basically:

V_{LOF} – Lift-Off Speed – This is the speed at which the main wheels leave the runway when the aircraft is rotated at V_R (Rotation Speed)

V_{EF} – *(Class A Only)* This is the calibrated speed (IAS) at which it is assumed the most critical engine fails.

V_I – *(Class A Only)* This is the speed at which, if an engine failure has been promptly recognised the aeroplane may still be brought safely to rest within the ASDA. When faster than this speed the aeroplane is committed to becoming airborne, even in the event that an engine fails.

V_2 – *(Class A Only)* This is the take-off safety speed, It is the speed that the aeroplane must legally attain by the time it reaches Screen Height with one engine inoperative and with the remaining engines set at maximum take-off power.

V_3 – *(Class A Only)* This is the steady initial climb speed with all engines operating to which the aeroplane naturally accelerates after V_{LOF}

Clear 50 ft speed (Screen Height Speed):- (*Class B Only*) This is the speed used instead of **V_3** for Class B aircraft. It is the lowest safe speed at which to climb with all engines operating and to which the aeroplane must naturally accelerate after lift-off to cross screen height at 50 ft. It gives options of continued flight (or land back if applicable) under all reasonably expected conditions, including turbulence and complete failure of the critical engine.

TORR - Take off run required: Calculated distance required for the take off run by the aeroplane, this must not exceed TORA.

TODR - Take off distance required: Calculated distance required for the take off run and climb to 50 ft / 35 ft screen height. TODR cannot exceed TODA.

ASDR - Accelerate stop distance required: ASDR cannot exceed ASDA. In class 'A' this is the distance required to accelerate the aeroplane to V_1 and, under the assumption of a failure of the critical engine, to decelerate to a complete stop within the published ASDA.
A transition phase of 2 seconds is included to account for the time taken to reach full braking (full brakes, full spoilers).

All of the above take-off distances will vary with environmental issues, runway surface condition, runway slope, aeroplane mass and in performance class A the selection of V_1.

HEIGHT – Vertical distance between the lowest part of the aeroplane and the specific pressure datum.

1.1 Class B Field length requirements

Looking at CAP698 these requirements are given for the SEP1 and MEP1 in accordance with EU-OPS.

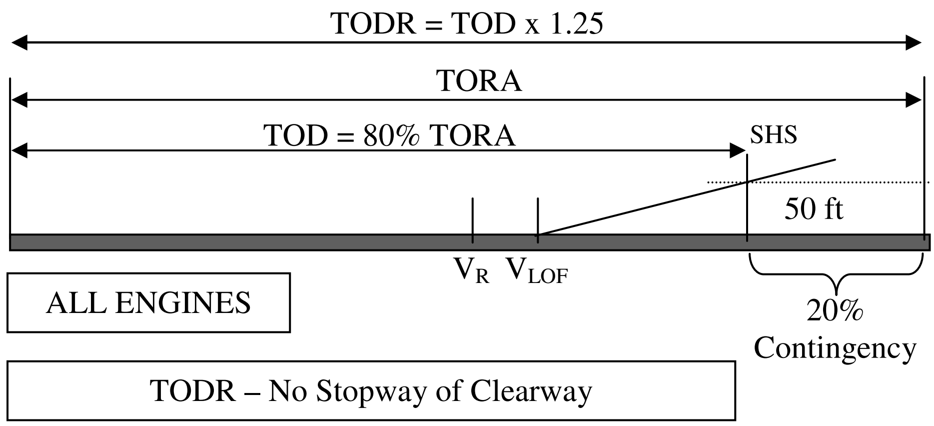
- **No Stopway or Clearway**: (Balanced Field)

i. The take off distance x 1.25 must not exceed TORA.

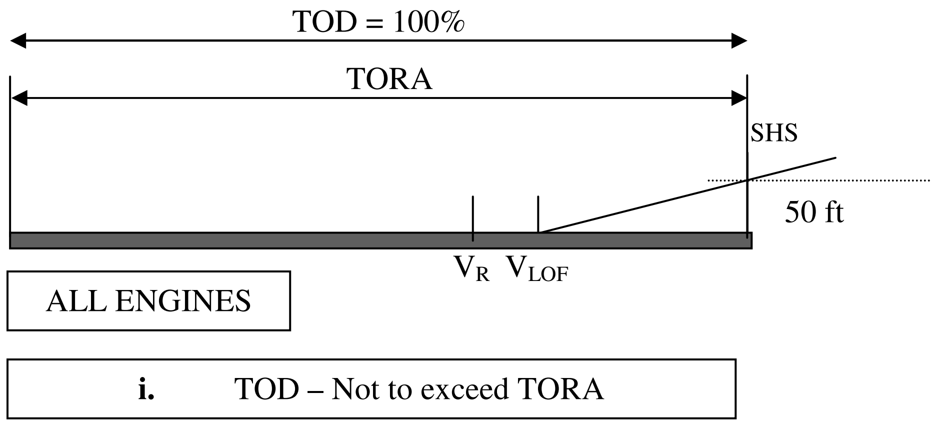
- **When Stopway and/or Clearway is available the take off distance must:**

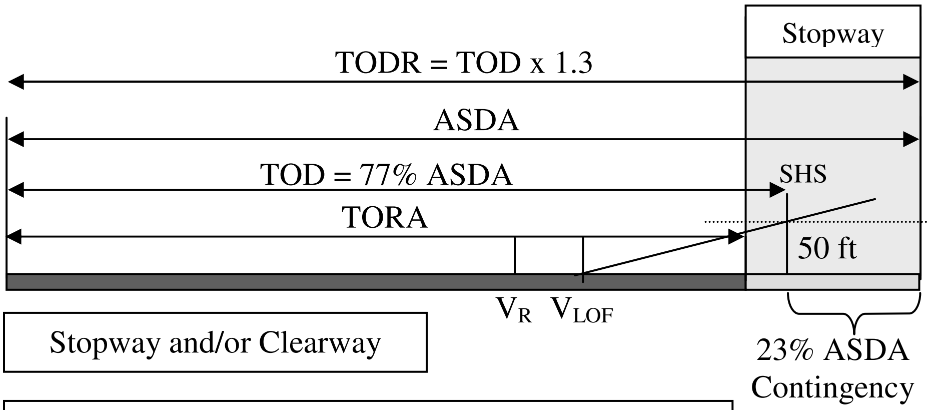
i. Not exceed TORA
ii. When multiplied by 1.3 not exceed ASDA
iii. When multiplied by 1.15 not exceed TODA

The diagrams that follow illustrate the cases for aeroplanes Class 'B' note that clear 50 ft or Screen Height Speed is shown as **SHS**.
In each case the runway surface condition is considered dry and paved.

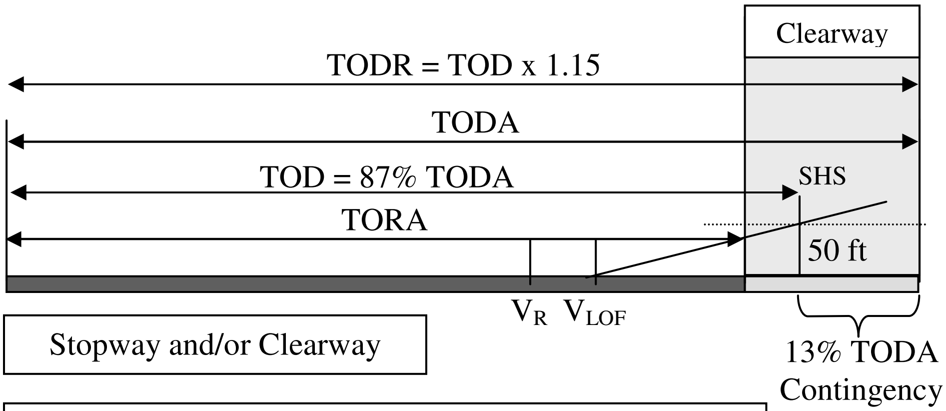


The following illustrate the three cases when Stopway and/or Clearway *is* available.





ii. When multiplied by 1.3 not to exceed ASDA



iii When multiplied by 1.15 not to exceed TODA

To find Take-off Distance (TODR)

It will be required to apply the factors as illustrated in the CAP698 using the 'Graphical Distance' from the take-off graph and multiplying by the surface factors as required.

There is also a note that refers and advises how to apply these 'Regulatory' factors as shown above.

To find Take-off Mass (TOM)

It will be required to apply the factors as illustrated in the CAP698 construction of a table as shown in the CAP698 will assist and taking the LOWEST of the DE-FACTORED (Divide by!) values of TORA, ASDA and TODA from the aerodrome data will provide the entry argument for the take-off graphs.

Note that in the table the 'Regulation Factors' have also been applied and the field length limited TOW is found by using the lowest result from the table.

2 *Class A Field length requirements as specified CS 25*

Take a look at the MRJT pages in CAP698 pages 7 – 8.

TORR Class 'A'; 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 35ft, all factorised by 1.15 to obtain the net TORR.

- One power unit inoperative (dry runway). The horizontal distance from the brakes release point (BRP) to a point equidistant between V_{LOF} and the point the aeroplane reaches 35 ft with the critical power unit inoperative.

- One power unit inoperative (wet runway). The horizontal distance from the brake release point (BRP) to the point at which the aeroplane is 15ft 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}.

TODR Class 'A' The take-off distance required is the *greatest* of the following three distances:

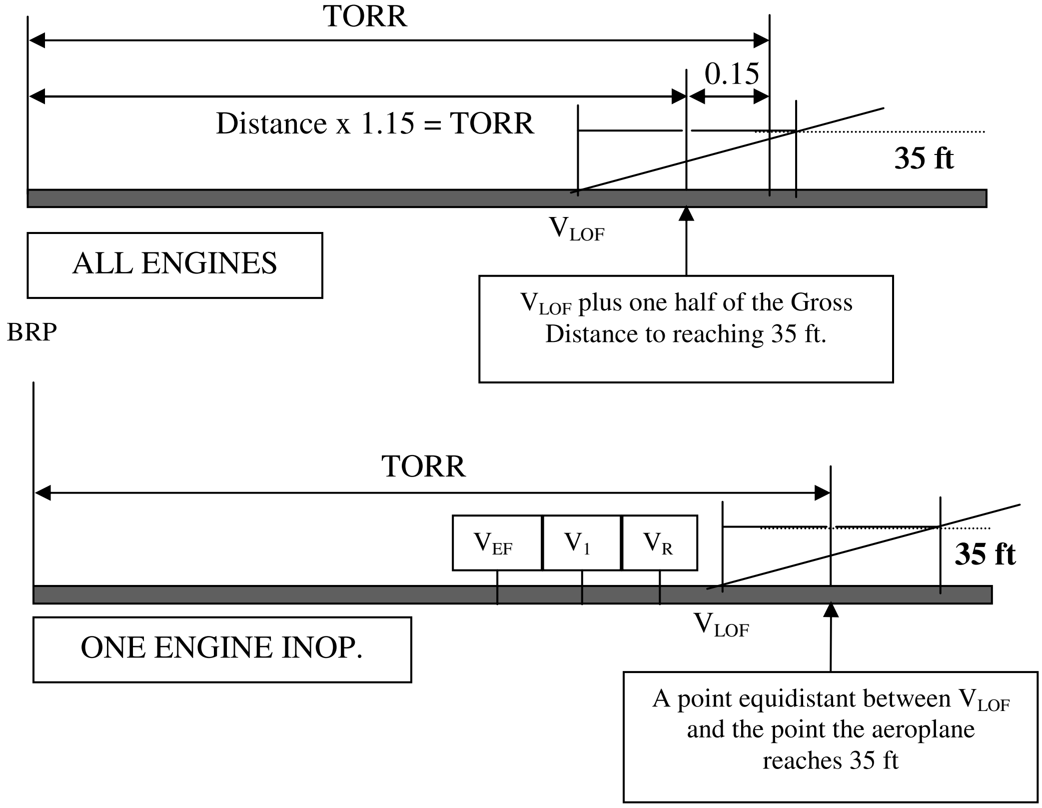
- *All engines operating.* 115% of the horizontal distance travelled, with all engines operating, to reach a screen height of 35 ft.
- *One engine inoperative (dry runway).* The horizontal distance from BRP to the point at which the aeroplane attains 35 ft., assuming the critical power unit fails at 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.

ASDR ***Class 'A'*** 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 runway 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.

Notice from the preceding page and also the CAP698 that in each case the resulting distance required will be the 'Greatest Of'.

The diagrams that follow illustrate TORR for aeroplanes Class 'A'.



3 Runway variables

3.1 Explain the effects of the following runway variables on take off performance

Dimensions - TORA, TODA and ASDA all affect the take-off calculations. The longer the distances available, the less restrictive the "Field Length Limitation (FLL)."

Note from the graph Fig. 4.4 on MRJT page 9 that increasing the field length distance has the direct effect of increasing the FLL take off weight.

Slope - Runway slope affects the take-off run required (TORR), take-off distance required (TODR) and Accelerate-stop distances required (ASDR).

- Down-slope will reduce all three, up-slope will increase them.
- The faster acceleration achieved on a down-slope results in an earlier lift-off point and hence reduces TORR and TODR.

The effect on the ASDR is less obvious - whilst increased acceleration can be achieved on a down-slope, it is also more difficult to stop!
The effect of increased acceleration is more significant than the "stopping" part of the equation – resulting in a reduction in the ASDR.
Slopes are corrected for on the Field Limit graph Fig. 4.4 .

Surface condition (damp, wet or contaminated) and **Influence of contamination** on friction coefficient.
A runway is considered dry if it is not wet or contaminated.
A damp runway has moisture present but this does not give it a gloss finish.
In performance considerations for operation from paved runways, damp conditions are treated as for "dry."
Contaminated runways are when more than 25% is covered with:

- Surface water greater than 3mm deep, or the equivalent of slush or loose snow.
- Compacted snow.
- Ice or wet ice.

Runways with porous surfaces, or grooves, to dissipate water can have similar braking action in both dry and wet conditions.

3.2 Acceleration and stopping on contaminated runways

The V-speed tables (MRJT pages 17 to 19 of CAP 698) give values for "Dry" runways only, corrections for wet and contaminated runways can be found on pages 24 to 27.
Inspection of these charts shows that reductions to the V_1 and take-off mass are required from contaminated runways.
Ideally runways should always be dry, the presence of water slows acceleration and increases braking distances. The effect is proportional to the amount of water, slush or snow.
Ice will seriously affect the stopping distance and corrections to the ASDR can be applied.

3.3 State the operational regulations for obstacle clearance of the net take-off flight path in the departure sector

Performance 'Class A' requires that the Net Take Off Flight Path (NTOFP) clears all relevant obstacles by at least 35 feet (50 feet if the aeroplane is turning).
Performance 'Class B' requires 50 feet at all times. See EU-OPS 1.495 (Perf. A) and EU-OPS 1.535 (Perf. B)

3.4 The Obstacle Accountability Area

CAP698 MEP1 Page 9 has the details and shows that obstacles qualify as being relevant if they fall within a sector (Obstacle domain) which begins at the end of the TODA.
The sector has an initial width either side of the extended centreline of:

90 m + 0.125 x D

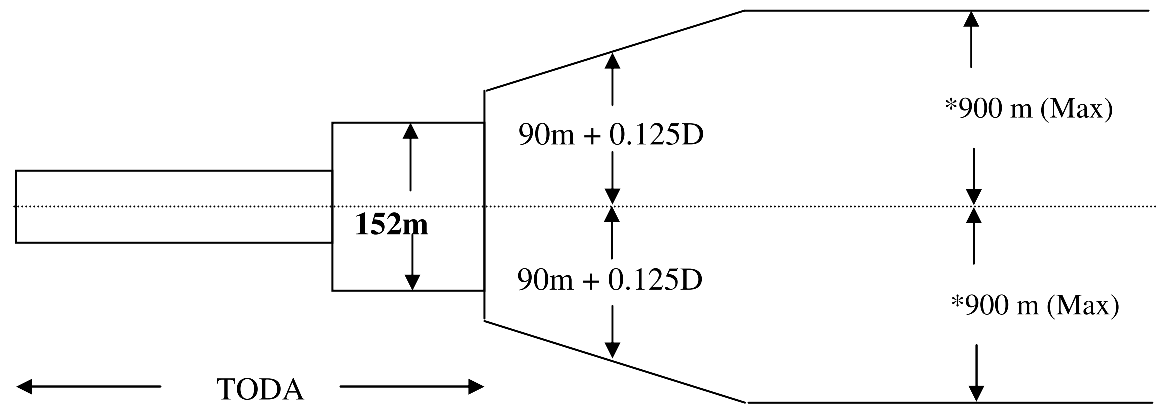
(and if the wingspan were less than 60 m, then half the wingspan + 60 m + 0.125 x D is to be used)

Where: **D = Horizontal distance travelled from the end of the TODA**

The sector expands: either side of the extended centreline at a distance to width ratio of:

8:1 - until reaching a maximum width of 900 metres.

The sector ends: when the aeroplane passes through 1500 feet, (unless there are distant obstacles to clear), after which the aeroplane is considered to be in the en-route phase.
The domain within which an object can be considered accountable can therefore be plotted using the diagram.
If the aeroplane changes its direction of flight by more than 15°, the domain maintains the same dimensions but curves with the intended line of flight.



***Note that the absolute Max semi-width is 900 m, but may be less under certain conditions, as shown in the table below:**

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**

3.5 Take-off climb 'Accountable Obstructions'.

Example;

An aeroplane with a 48 m wingspan must fly a scheduled departure from an aerodrome where there is an obstruction at 336 m distance from the end of the TODA and displaced at 121 m to the left of the centre line, need this be accountable as a significant obstruction within the NTOFP Domain.

Solution;

The wing span is less than 60 m, so the funnel must start out at 60 + half wing span = 84 m

Semi-width of the funnel from an initial point of origin = Distance out 336 ÷ 8 = 42 m

(Or you can use 'D' x 0.125, for example 336 x 0.125 = 42 m)

Wing span inclusive semi-width 42m + 84 m = 126 m.

That puts the obstacle just inside the domain width of 126 m at 336 m distance 'D' by 5 m!

Answer:
Therefore this obstruction must be accounted for in the departure as it is positioned at:
5 m inside the domain.

It might just as well have been on the centre line in regard to the regulations!

Section Three Single-Engine (Light) Performance Class B.

Light Aeroplanes Not Certified Under CS/FAR 25

1 Definitions and general notes.

CAP698 The Generic Aeroplane:
Single – Engine Piston certified under CS23 (Light Aeroplanes) Performance Class B **SEP1**

This is a good time to take a good hard look at the CAP 698.

You will be given a 'CAA copy' of the CAP698 along with your performance examination paper by the invigilator.
Knowing this document and where to find information from it will save you a lot of time in the exam.

- Section 1 - 'General Notes' has some very useful data and definitions about all of the generic aeroplanes used in the CAP698 and also a list of acceptable conversions based on ICAO Annex 5.
- Section 2 - contains the 'Data for Single-Engine Piston Aeroplane (SEP1)'.
- Section 3 - deals with the 'Multi-Engined Piston Aeroplane (MEP1)'.
- Section 4 - contains information for the 'Medium Range Jet Transport Aeroplane (MRJT1)'.

It is very wise to become totally familiar with the aeroplanes described in the CAP698 as listed in the General Considerations, as if it were to be any other aeroplane that you intended to fly.
In the exam there may be references to these pages and you need to know where to find this information in case it is needed. Applicable definitions can be found in CAP698:

- Section 1 - General Notes pages 2, 3. and 4.
- Section 4 - MRJT pages 1,2 and 3.

1.1 Definitions of speeds used Class B

'Clear 50ft speed' or 'Screen Height Speed' - this is the minimum speed used at which to climb with all engines operating by class 'B' aeroplanes (*instead of* V_3) and required to be attained on reaching the screen height (50ft) and is the greatest of:

1. Single-engined aeroplanes:
   a. A safe speed under all reasonably expected conditions
   b. 1.2 V_{S1}
2. Twin-engined aeroplanes:
   a. A safe speed under all reasonably expected conditions
   b. 1.1 V_{MC}
   c. 1.2 V_{S1}

The take-off weight and the flap setting determine the exact speed and it will also vary with aerodrome elevation and temperature.

The screen height is the height of an imaginary screen that an aeroplane would just clear in an un-banked attitude, with the undercarriage extended, above the take-off surface level.
Because the take-off distance is not completed until the aeroplane reaches its screen height during the take-off, it is located at the end of the take-off distance required (TODR).

V_{REF} .-. (V_{AT0}) Reference Landing Speed - The reference landing speed is the speed which the aeroplane attains, in the specified landing configuration as it passes through the screen height (50ft) and is used to determine the landing distance for manual landings.
This speed is not less than 1.3_{VS0} following a steady descent gradient of 5%.
This is also termed the 'Barrier Speed', as often used in regard to light twins as in the MEP1 in the CAP698. It is the speed of the aeroplane, at screen height all engines operating.

Stall speeds

V_S - Means the stalling speed or minimum steady flight speed at which the aeroplane is controllable. The stalling speed is the greater of:

1. The minimum CAS obtained when the aeroplane is stalled (or the minimum steady flight speed at which the aeroplane is controllable with the longitudinal control on its stop).
2. A CAS equal to 94% of the one-g stall speed (V_{s1g}).

V_{S1g} - Means the 'One-g Stalling Speed' which is the minimum CAS at which the aeroplane can develop a lift force (normal to the flight path) equal to its mass while at an angle of attack not greater than that which the stall is identified.

V_{SO} - Means the stalling speed or the minimum steady flight speed for an aeroplane in the landing configuration. V_{so} at the maximum mass must not exceed 61kt for a class 'B' single-engined aeroplane or for a class 'B' twin-engined aeroplane of 2722Kg or less.

V_{S1} – Means the stalling speed or the minimum steady flight speed for an aeroplane in the configuration under consideration. *e.g. Flaps extended.*

Rotation Speed
V_R – This is the speed at which, in both all engines and the one-engine-inoperative configuration, the pilot should initiate a change to the aeroplane attitude during the ground run, by rotating the aircraft about its lateral axis for the purpose of taking-off.

1.2 Definitions of Take-off and Landing Distances

Take-off distance:-The distance taken by the aeroplane to accelerate from the brake release point to V_R and then climb to screen height in the prevailing conditions. (TOD is 'gross distance').
Landing distance:-The distance taken by the aeroplane from over the threshold at screen height to land and come to a complete halt. (LD is a 'gross distance').
Ground roll distance:-Ground roll distance is how far the plane rolls after you land or how far the plane rolls before take-off.
Maximum allowed take-off mass (Maximum Structural Take-off mass):- is the maximum permissible total aeroplane mass at the start of the take-off run.
Maximum allowed landing mass (Maximum Structural Landing Mass):- is the maximum permissible total aeroplane mass on landing under normal circumstances.

Chapter 8 Take-Off And Landing Performance SEP1

1 *Aeroplane mass, wind, density, altitude, runway slope, runway conditions*

1.1 *Effect Of Aeroplane Mass.*

The heavier an aeroplane is, the greater the take-off distance required (TODR). This is because:

- There will be less acceleration during the take-off roll.
  Since force in 'F = Mass * acceleration' will be constant, if the mass increases, the acceleration must decrease.
- The greater mass of a heavy aeroplane will impede the acceleration of an aeroplane due to the increased friction between the ground and the wheels.
- As heavier aeroplane have a higher stalling speed, a higher airspeed is required which takes longer to achieve due to the slower acceleration.
- The heavier an aeroplane is, the lower its climb gradient will be. Because it's rate of climb is less than for a lighter aeroplane, it will take longer to climb to screen height, which increases the distance travelled to reach screen height, which increases TODR

Take off distance will be increased by 20% for each 10% increase in mass (a factor of 1.2)

The heavier an aeroplane is, the greater the landing distance required (LDR). This is because:

- As heavier aeroplane have a higher stalling speed, a higher airspeed is required which means that a faster approach is required.
- Because of the faster approach, there is more energy to dissipate in order to slow the aeroplane down. This increases the heat generated by the brakes and also their wear and results in a longer landing roll than for a light aeroplane.

Landing distance will be increased by 10% for each 10% increase in mass (a factor of 1.1)

1.2 *Effect Of Wind.*

With a headwind, the TODR is shorter. This is because:

- The airspeed is higher relative to the groundspeed. Therefore the ground distance required to take off is shorter.
- The rate of climb of an aeroplane is unchanged by headwind. Although with the same rate of climb, the aeroplane has a lower groundspeed than in still air, which means that less ground is covered to climb to the same height.

The same is true for the effect on LDR for the same reasons, whilst the converse is true for the effects of a tailwind in that the TODR and LDR will be increased.

Landing and take off distance will be increased by 20% for a tailwind component of 10% of the landing or lift off speed (a factor of 1.2).

1.3 *Percentage of accountability for head and tailwind during take-off calculations.*

In the Performance data sheets, the wind speed grids have already been factored: **50% for headwinds and 150% for tailwinds.**

Therefore the grids may be entered with the reported, or calculated, along track components. Should the grids supplied not have been so factored, then the reported or calculated along track component will have to be factored, for ‘non public transport flights’ these values are also recommended.

NB – EU-OPS 1.530(c) states that not more than 50% of the headwind component and not less than 150% of the tailwind component is assumed. (Some manuals include this factoring).

CAP 698 charts include the factoring.

1.4 Effect Of Density.

An increase in air density will increase the aeroplane performance, whilst a decrease in density will cause a decrease in aeroplane performance. The increase in performance with increased air density is due to the number of air molecules that are available to provide lift for both the wings and the propeller.

An increase in altitude, temperature or relative humidity will cause density to decrease.

1.5 Effect Of Altitude.

Because an increase in altitude leads to a decrease in air density, an increase in airfield altitude will cause a decrease in aeroplane performance (see density above).

1.6 Effect Of Runway Slope.

A downward sloping runway will decrease the TODR and increase the LDR. This is because:

- On take-off, the down slope will assist the acceleration of the aeroplane so that less distance is required to get to take off speed and therefore less runway is used during the take-off roll.
- On landing, the down slope will hinder the stopping power of the brakes, and so a longer landing roll is required.

The reverse will be the case for an up slope take off or landing.

Note that CAP 698 SEP1 page 2 continuation of field length requirements d); states that the take-off distance should be increased by 5% for each 1% up slope, and that no allowance is permitted for down slope. Contrast that statement with the landing requirements e) SEP1 on page 9 where no allowance is permitted for upslope. In other words no factorisation is required when safe take off or landing is helpfully assisted by the runway slope!

Slope factor calculation:

$$\text{Factor} = \frac{\text{Slope x 5 +100}}{100}$$

1.5% slope, find the factor.

$$1.075 = \frac{1.5 \text{ x } 5 + 100}{100}$$

Note that this means for a 1.5% up/down slope the factor is 1.075.

1.7 Take-Off Requirements.

- The only take-off requirement for a single engine aeroplane is for the Field Length as detailed in this extract from CAP698 below. Unlike the MEP1 there is no take-off climb requirement.

The Field-Length Requirements CAP698 SEP1 Page 1 these are as set out in EU-OPS 1. Sometimes called Regulation Factors:

- When no stopway or clearway is available the take-off distance (TODR) when multiplied by 1.25 must not exceed TORA (the take-off run available).

- When a stopway and/or clearway is available the take-off distance must *not exceed*:

  i. TORA (take-off run available)
  ii. when multiplied by 1.3, ASDA (accelerate stop distance available)
  iii. when multiplied by 1.15, TODA (take-off distance available)

1.8 Effect Of Runway Conditions.

The performance data in CAP698 is based on paved level and dry surfaces.
If the surface is wet or consists of grass or wet grass, the TODR and LDR will both be increased. This is due to the increased drag on the wheels during take-off and the propensity for the wheels to lock and skid during the landing roll.
Note that the CAP 698 SEP1 page 2 states that if the runway surface is other than dry and paved, the following factors must be used when determining the TODR:

Surface Type	Condition	Factor
Grass (on firm soil) up to 20 cm long	Dry	**x 1.2**
	Wet	**x 1.3**
Paved	Wet	**x 1.0**

There is also a note following the table in the CAP698 that states: The same surface and slope correction factors should be used when calculating TOR or ASD.

2 Use of aeroplane flight data

2.1 Use of Graphs Fig.2.1 TOD Flaps up.

Following the example in the CAP698 SEP1 page 2 use the graph and see if you agree with the resulting 'Graphical Distance' 3450 ft.
This is the result of carefully following the graph reading procedure.
This can take some practice to perfect, a sharp pencil, a straight edge and a steady hand!
Looking at the example of Fig. 2.1 on the next page.
Basically, remember that operating the graph in this 'Forward' direction you must always work toward the 'Reference Line and then follow the 'Trade Line' up or down to some bisecting value.
This having entered the graph carefully with the given values.
Always check the values per square, they need not be the same throughout the graph!

Always check the associated conditions

The values used as the worked example in the CAP698

ASSOCIATED CONDITIONS

POWER........................ TAKE-OFF POWER SET BEFORE BRAKE RELEASE
MIXTURE...................... FULL RICH
FLAPS........................... UP
LANDING GEAR........... RETRACT AFTER POSITIVE CLIMB ESTABLISHED
COWL FLAPS............... OPEN
RUNWAY........................ PAVED, LEVEL, DRY SURFACE

EXAMPLE

OAT.. 15°C
PRESSURE ALTITUDE.......................... 5653 ft
TAKE-OFF MASS................................ 3650 lb
HEAD WIND COMPONENT.................. 10 kt

GROUND ROLL.................................. 1900 ft
TOTAL DISTANCE OVER 50 ft OBSTACLE.... 3450 ft
TAKE-OFF SPEED AT:
ROTATION.............................. 73 kt
50 ft....................................... 84 kt

MASS lb	TAKE-OFF SPEED kt	
	ROTATION	50 ft
3650	73	84
3600	72	83
3400	71	82
3200	70	80
3000	68	78
2800	65	75

Reference Line

Trade Lines

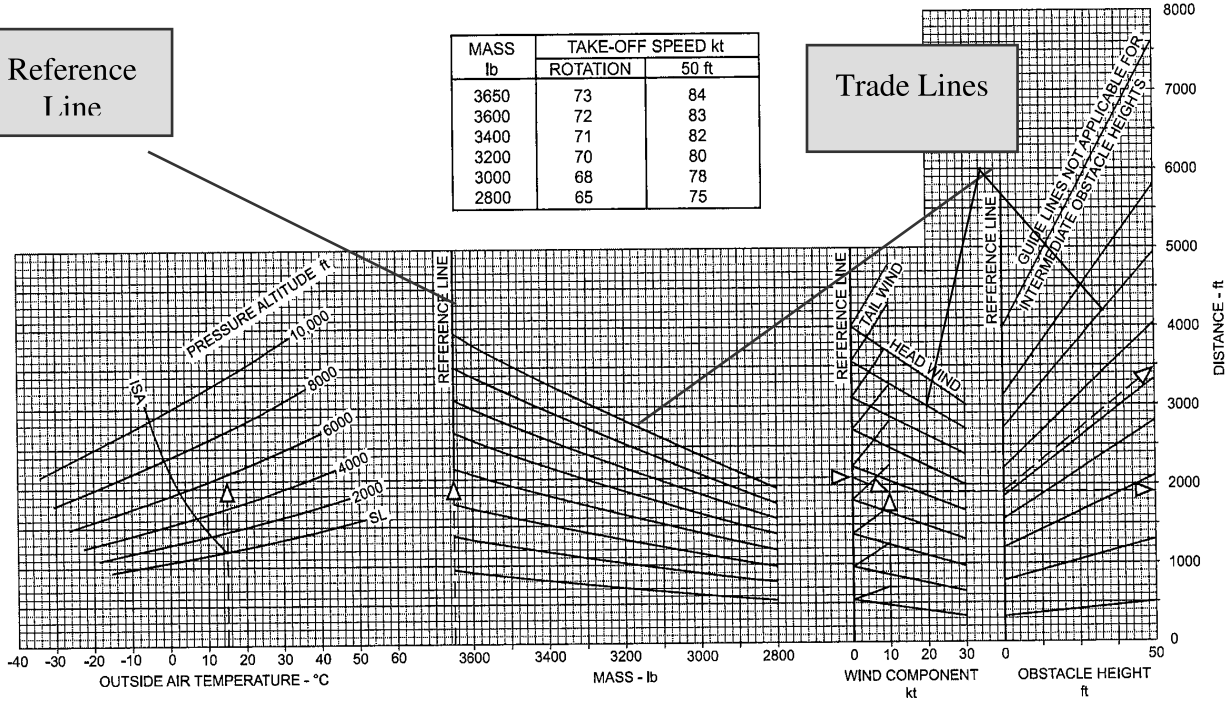


Figure 2.1 Take-Off Distance Flaps Up

i. What to do with the 'Graphical Distance' finding TOD

This is the output from the graph in assumed conditions as given in the associated conditions. These are unlikely to be found in the real world so some adjustment will be required.

Allowance must be made for slope, surface and runway condition.

Graphical Distance	3450 ft	
Slope	x 1.075	as calculated from 1.5% Uphill
Surface Wet Grass	x 1.3	from the table.
Take-off Distance	**4821 ft.**	

(Note. You must always work the factors as individual values-do not try to add them up!)

2.2 Mass Calculation Fig 2.1 Flaps up

It will often be required to find the Mass (weight) and in this case it will be necessary to start off with a 'Graphical Distance' and work from both ends of the graph to make it possible to determine the Take-off Mass from the centre web of Fig. 2.1.
Remember that operating the graph in this 'Reverse' direction you must always work toward and follow the 'Trade Line' up or down from some bisecting value to arrive at the 'Reference Line.

SEP1 page 4 outlines the procedure to be used.
Notice that in this case we must apply the requirements of EU-OPS in regard to slope, surface , condition and regulation.

In this example we have been given the details of the aerodrome assuming that in this case where we are planning a departure and needing to calculate the 'Field Length Limited' Take-off Mass (weight).

It will be required to find a suitable 'Graphical Distance' to enter the graph as a paved, level, dry surface, whilst complying with the regulations. (See SEP1 pages 1 and 2.)

i. De-factoring the distance.

	TORA	**ASDA**	**TODA**
Given Distances	4250 ft	4470 ft	4600 ft
Slope factor	÷1.1	÷1.1	÷1.1
Surface / Condition Factor	÷1.2	÷1.2	÷1.2
Regulation Factor	÷1.00	÷1.3	÷1.15
De-Factored Distance	3220 ft	**2605 ft**	3030 ft

The lowest of the above values will be the most limiting so it is that value that must be used as the 'Graphical Distance' entry argument for Fig. 2.1. (*I have added division signs to make the workings more apparent*).

2.3 Determine the take-off speeds. Fig 2.1 Flaps up

The take-off speeds are clearly laid down in the CAP 698 Fig 2.1:

	Take-Off Speed kt	
Mass lb.	Rotation	50 Ft.
3650	73	84
3600	72	83
3400	71	82
3200	70	80
3000	68	78
2800	65	75

NB – Round to nearest weight. (Do not interpolate)

In these calculations we have been looking at the case only for take-off with 'Flaps Up'.
Fig. 2.2 accounts for flaps approach, both graphs are used in the same way. Notice the lower speeds with approach setting.

2.4 Use of the Take-off Climb Graph Fig 2.3.

There are no obstacle clearance limits or minimum acceptable climb gradient required by EU-OPS 1.
The operation of the graph is well covered by the CAP698 SEP1 page 6.
This may be referred to in some performance manuals as the 'Weight Altitude and Temperature' (WAT) limit graph.
The output of the graph will be the Rate of Climb and also Climb Gradient. Examining the graph you will see that you will need the True Air Speed in order to read the gradient from the right hand web.
This can be calculated from the Navigation Computer (The CRP5 for example).

Distance to Reach given height
To calculate the ground distance travelled in order to obtain a given height above reference zero, see if you agree with the example in the CAP698 SEP1 Page 8:

- **i**. Convert the IAS 100 Kt to a TAS.
- **ii.** Apply the wind component to the TAS to obtain the groundspeed.
- **iii.** Determine the climb gradient from the graph.
- **iv.** Calculate the still air distance using the formula:

  $$\text{Still air distance} = \frac{\text{Height difference}}{\text{Gradient}} \times 100$$

- **v.** Finding the ground distance use the formula:

  $$\text{Ground distance} = \text{Still air distance} \times \frac{\text{Groundspeed}}{\text{TAS}}$$

2.5 Requirements for the Cruise

There are two requirements for the cruise, which are:

Firstly: The aeroplane may *not* be assumed to be flying above the altitude at which a rate of climb of 300 ft/minute is attained.

Secondly: The net gradient of descent, in the event of engine failure, is the gross gradient plus 0.5 %.

3 Landing

3.1 The requirements

SEP1 page 9 clearly sets out the requirements and calculation details for the landing.

3.2 Despatch rules

The despatch rules for scheduled (planned) landing calculations are in EU-OPS 1.550 (c).

These are operating regulations to be used at the planning / scheduling phase. **They do not apply to any landing performance calculations when in flight.**

The idea behind this is to attempt to ensure that at least one runway will be available at the destination without making unrealistic demands on the conditions or services likely to be available.
This practice then avoids the pilot having to make awkward performance calculations during a very demanding part of the flight.

The rules state:

> For despatching an aeroplane in accordance with EU-OPS 1.550 (a), (b), and (c) (*The regulations*).
>
> (1) The aeroplane will land on the most favourable runway, in still air; and
>
> (2) The aeroplane will land on the runway most likely to be assigned considering the probable wind speed and direction and the ground handling characteristics of the aeroplane, and considering other conditions such as landing aids and terrain. (See IEM OPS 1.550 (c).)
>
> If an operator is unable to comply with subparagraph (2) above for the destination aerodrome, the aeroplane may be despatched if an alternate aerodrome is designated which permits full compliance with EU-OPS 1.550 (a), (b), and (c) (*The regulations*).

3.3 Using the landing factors

Looking at the solution given in CAP698 SEP1 page 9 notice that from the 'Graphical Distance' obtained from Fig. 2.4 on the next page, each factor is applied individually including the regulatory factor of 1.43.

3.4 Wet Runway

The requirements state that if the METAR or TAF or a combination of both indicate that the runway may be wet at the estimated time of arrival, the landing distance should be multiplied by a factor of 1.15.

i. Definition of 'Wet Runway'

If a runway is covered with water less than 3 mm in depth it is considered as 'WET', or when there is enough moisture on the runway to cause it to appear reflective, but without significant areas of standing water.

ii. Definition of 'Water Contaminated Runway'

In the event that more than 25% of the runway surface is covered in water with a depth that exceeds 3 mm it will be considered as 'Contaminated'.

3.5 Wet Grass Runways

EU-OPS 1.555(a) considers wet grass runways.

> IEM OPS 1 .555(a) Has some advice about landing on 'Wet Grass Runways'.
>
> 1. When landing on very short grass which is wet, and with a firm subsoil, the surface may be slippery, in which case the distances may increase by as much as 60%. (1.60 factor).
>
> 2. As it may not be possible for a pilot to determine accurately the degree of wetness of the grass, particularly when airborne, in case of doubt, the use of the wet factor (1.15) is recommended.

Using this advice if the runway *is* of very short wet grass on a firm subsoil the 'Wet' factor of 1.15 should be replaced by the 'slippery' factor of 1.6.

3.6 Use of the Landing Field Length graph.

The Landing Field Length graph Fig. 2.4 on page 10 has instructions about its use on SEP1 page 9. The example in the CAP698 arrives at a LDR of 2979 ft.

3.7 Landing Mass

It would be quite likely that for given conditions it would be required to find the Landing Mass by using the graph in the 'Reverse' sense.
Note that it then becomes necessary to 'De-factor' the Landing Distance Available (LDA) to obtain the entry argument 'Graphical Distance', much the same as when determining the Take off Mass from Fig 2.1 or Fig. 2.2.

3.8 Landing Speeds

The IAS to be used for the approach to the 50 ft landing screen height are tabulated on Fig 2.4.

Mass lb	SPEED AT 50 ft kt
3650	79
3400	80
3200	81
3000	81
2800	78

Following the example in the CAP698 with a landing mass of 3479 lbs the approach speed is 80 kts (IAS)

4 Finding head and cross wind components

Fig. 4.1 from the MRJT1 section of the CAP698 page 4 may be used to determine head, tail and cross wind components. Instructions for its use are included on the same page.

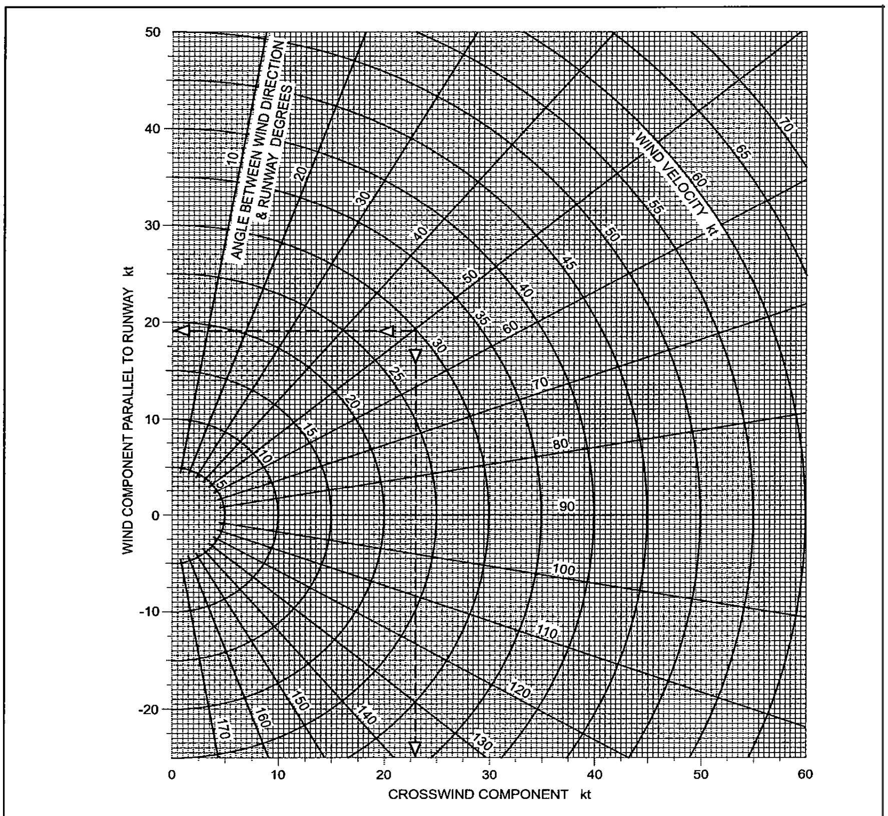


Figure 4.1 Wind Components for Take-Off and Landing

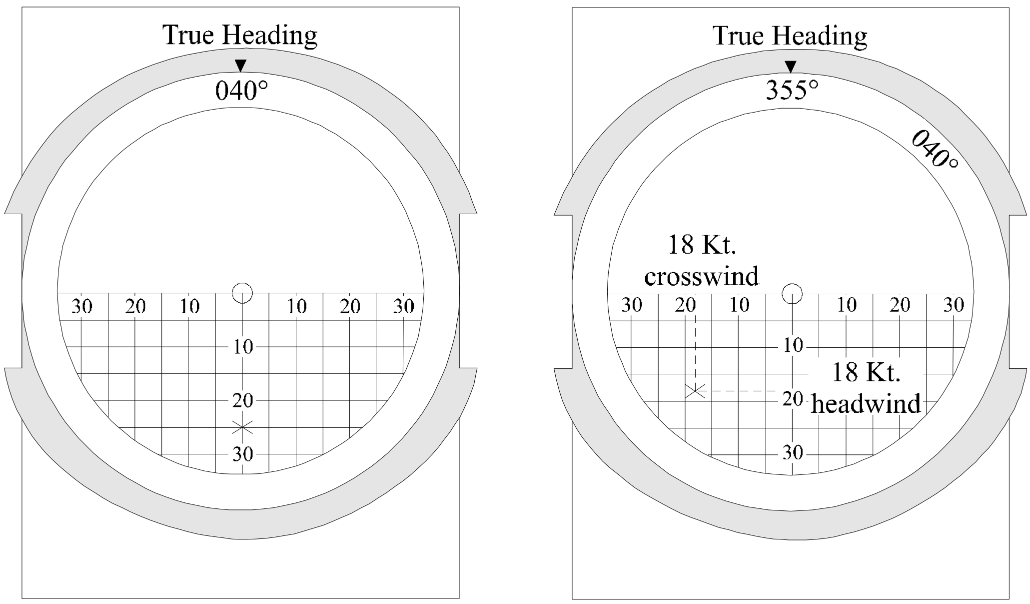
The head wind and cross wind components can also be calculated on the CRP 5 computer using the following technique:

i. Put the true wind direction under the True Heading index and mark off the wind velocity on the square grid using a suitable scale.

ii. Rotate the computer such that the runway QDM lies under the True Heading index.

iii. Read off the cross and head wind components.

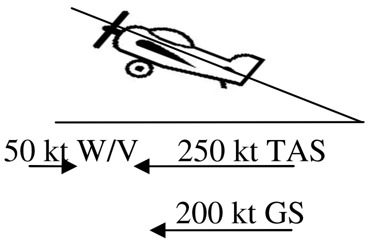
In the example below, the wind is 040º at 25 Kt., and the runway QDM is 355º, which gives a crosswind component of 18 Kt., and a head wind component of 18 Kt.



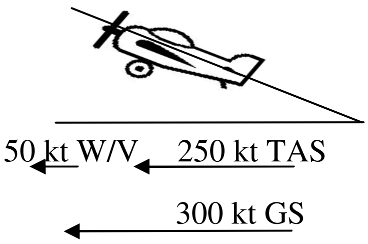
Chapter 9 Climb, Cruise and Descent Performance Calculations

1 Rate of climb, angle of climb, rate of descent and descent angle.

It is particularly important, however, to appreciate the relationship between the climb angle and the rate of climb and the rate of descent and the descent angle.
In a climb a headwind will increase the angle of climb and thus climb *higher* over a given distance on the ground than with a tailwind.
This is because for a given IAS the groundspeed is lower, so for a given rate of climb, the same height is achieved for less ground distance.



With a 200 kt groundspeed
the aeroplane covers 16.6 nm in
5 minutes and climbs 7,500 ft
at 1500 ft/min.
A climb gradient of 7.47%



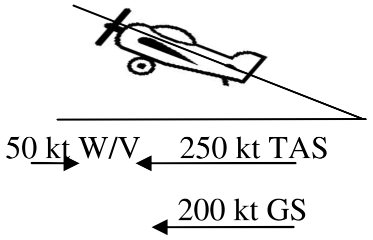
With a 300 kt groundspeed
the aeroplane covers 25 nm in
5 minutes and climbs 7,500 ft
at 1500 ft/min.
A climb gradient of 4.96%

The same is true for the descent angle with a given rate of descent with either a head wind or a tail wind.

Remember that a head or tailwind will change the *angle* but not the rate of climb or descent!

It is often necessary to use some basic calculations in order to assess the climb gradient (angle).
CAP698 illustrates most of the common formula with examples.
Over the next few pages we have brought together most of the often required formula and also illustrated some calculations based upon the above diagrams.

2 *Climb Example calculations*



With a 200 kt groundspeed the aircraft covers 16.6 nm in 5 minutes and climbs 7,500 ft at 1500 ft/min.
A climb gradient of 7.47%

2.1 *Find Climb Gradient.*

Rule of Thumb method:

$$\frac{ROC/ROD}{TAS} = \%\ \text{Still Air}$$

$$\frac{1500}{250-50} = 7.5\%$$

More accurately:

$$\frac{ROC/ROD}{TAS} \times \frac{6000}{6080} = \%\ \text{Still Air}$$

$$\frac{1500}{250-50} \times \frac{6000}{6080} = \mathbf{7.40\ \%}$$

Note from the above that when we use ground speed we get the flight path gradient, not still air gradient.

Also we can use:

$$\frac{\text{Distance climbed}}{\text{Distance travelled}} \times 100 = \%$$

$$\frac{7500}{16.6 \times 6080} \times 100 = \mathbf{7.431\%}$$

2.2 *Find Time to Climb (Seconds).*

$$\frac{\text{Height Difference}}{ROC/ROD} \times 60 = \text{Sec.}$$

$$\frac{7500}{1500} \times 60 = \mathbf{300\ Sec.}$$

2.3 *Find fuel to climb*

Knowing the time the fuel burn can be found using the CRP5 in the normal way!

2.4 *Find Distance (Nm) to Top Of Climb (TOC)*

$$\frac{\text{Height Difference}}{\text{ROC/ROD}} \times \frac{\text{Groundspeed}}{60} = \text{Nm}$$

$$\frac{7500}{1500} \times \frac{200}{60} = \mathbf{16.6Nm}$$

2.5 *Find the maximum rate of climb speed*

Remember what we found about climb speed from the power required and power available curves.
From the graphs it can be seen that when you are flying at the maximum rate of climb speed **Vy**, and then increase or decrease the speed; it will reduce the rate of climb.
The most economical ROC will be at a speed slightly faster than $\mathbf{V_Y}$

2.6 *Find Rates of Climb / Decent*

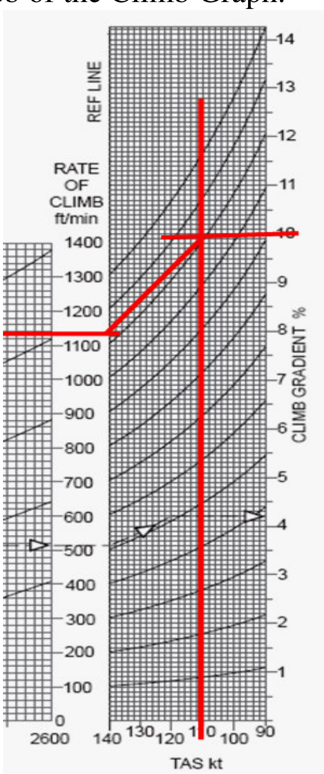
From the formula it can be seen that just by transposition, provided there is enough information the rate of climb can be found.

$$\frac{\text{GRADIENT x DISTANCE TRAVELLED (ft)}}{60 \text{ X } 100} = \text{ROC / ROD}$$

Rule of thumb <u>when angles are small!</u>

GRADIENT x TAS = ROC / ROD

In addition, looking at CAP698 Fig.2.3 SEP1 Page 7 the rate of climb can be obtained graphically from the right hand web of the Climb Graph.



3 *Useful Formula*

3.1 *Climb Gradients*

RULE OF THUMB

$$\text{Still Air} = \frac{\text{ROC/ROD}}{\text{TAS}} = \%$$

MORE ACCURATELY

$$\text{Still Air} = \frac{\text{ROC/ROD}}{\text{TAS}} \times \frac{6000}{6080} = \%$$

Or

$$\text{Still Air} = \frac{\text{ROC/ROD}}{\text{TAS} \times 6080 \div 60} \times 100 = \%$$

$$\text{The Gradient} = \frac{\text{CHANGE IN HEIGHT}}{\text{HORIZONTAL DISTANCE TRAVELLED}} \times 100 = \%$$

3.2 *Time to Climb*

$$\text{Time in seconds} = \frac{\text{Height Difference}}{\text{ROC/ROD}} \times 60 = \text{Sec.}$$

3.3 Distances

$$\text{Distance} = \frac{\text{Height Difference}}{\text{ROC/ROD}} \times \frac{\text{Groundspeed}}{60} = \text{Nm}$$

$$\text{Still Air Distance (ft)} = \frac{\text{CHANGE IN HEIGHT (ft)}}{\text{GRADIENT}} \times 100 = \text{ft}$$

$$\text{Ground Distance (ft)} = \frac{\text{Still Air Distance x Groundspeed}}{\text{TAS}} = \text{ft}$$

To convert to Nm use $\frac{\text{Ft}}{6080}$

3.4 Height Gain

$$\text{Height Gain ft} = \frac{\text{Dist (ft) x ROC x 60}}{\text{G/S x 6080}} = \text{ft}$$

$$\text{Height Gain ft} = \frac{\text{Distance ft}}{100} \times \text{Gradient} = \text{Ht in ft}$$

$$\text{Height Gain} = \frac{\text{Gradient x Distance}}{\text{TAS}} = \text{Height Gain}$$

$$\text{Still Air Height Gain} = \frac{\text{Distance Nm}}{\text{TAS} \div 60} \times \text{ROC} = \text{Ht in ft}$$

3.5 Rates of Climb / Decent

Rule of thumb <u>when angles are small!</u>

GRADIENT x TAS = ROC / ROD

3.6 Load factor

Load Factor = $\frac{\text{LIFT}}{\text{Weight}}$ = Load Factor

3.7 Obstacles

Percentage of Obstacle Height cleared =

$$\frac{\text{Distance to Obst. (feet) x R.O.C (feet)}}{\text{Distance Travelled (fpm) x Obstacle height (feet)}} \times 100 = \% \text{ of Obst Height}$$

3.8 Gradient to degrees

Rule of Thumb!

Basically 'half it and add a bit!'

Some examples:		
	3%	= **1.7°**
	5%	= **3°**
	10%	= **6°**
	20%	= **11°**

This seems to hold good even up to around 40% so should be adequate in most cases.

3.9 Lift and Drag formula

Where	$\mathbf{C_L}$	Coefficient of Lift
	ρ	Dynamic Pressure
	S	Surface area of the aerofoil
	$\mathbf{V^2}$	Air Velocity relative to the aerofoil Squared

3.10 The formula for Dynamic Pressure

Half Rho v Squared

Remember that this is defined as being common to all aerodynamic forces and fundamentally determines the air loads imposed on any object moving through the air; it must therefore be taken into account with lift and drag.

$$\frac{1}{2}\rho V^2$$

Lift = $C_L \frac{1}{2}\rho V^2 S$

Drag = $C_D \frac{1}{2}\rho V^2 S$

3.11 Formula for Descent

$$\text{ROD} = \text{TAS} \sin \theta$$

Also

$$\text{ROD} = \text{TAS x Gradient}$$

(When angles are small)

Gradient:

$$\frac{\text{Total Drag – Total Thrust}}{\text{Mass}} \times 100 = \text{Gradient}$$

Rate of Descent fpm:

$$\frac{\text{Total Drag – Total Thrust}}{\text{Mass x TAS}} = \text{ROD fpm}$$

Still air Gradient:

$$\frac{\text{ROD fpm}}{\text{TAS kts x } 6000 \div 6080} = \text{Still air Gradient}$$

Wind affected Gradient (*flight path gradient*):

$$\frac{\text{ROD fpm}}{\text{G/S kts x } 6000 \div 6080} = \text{Flight Path Gradient}$$

3.12 Find the difference between still air distance Nautical Air Miles (NAM) and ground distance (NGM)

This is fully covered in the JAR Flight Planning Syllabus and summarised here.
Much of the flight planning calculations require air distances. Knowing the route distance (over the ground), the change to air distance requires the true airspeed and the groundspeed. One way to do so is:

- Find the time taken to cover the ground, by dividing the distance by groundspeed.
- Multiply that time by the true airspeed to find the air distance.

This whole process can be summarized into a single formula, which is provided on page 26 of CAP 697. Multiply the distance in NGM by the average TAS divided by the TAS plus or minus the wind component, (which is groundspeed), to find the distance in NAM.

$$NAM = NGM \times \frac{TAS_{(average)}}{TAS \pm WC}$$

The formula can be re-arranged to find NGM:

$$NGM = NAM \times \frac{TAS \pm WC}{TAS_{(average)}}$$

(Note that the CAP 697 is not required for the Performance Examination.)

Section Four Multi-Eng. Aeroplanes (Light) Performance Class B

Light Twin Engine Aeroplane not certified under CS25/FAR 25

Chapter 10 Definitions of terms and speeds

1 The Multi-Engine Aeroplane.

As configured in CAP 698 it is a low wing monoplane with retractable undercarriage, powered by twin reciprocating engines both supercharged, they drive counter rotating constant speed propellers. The maximum take off mass is **4,750 lbs**, the maximum landing mass is **4,513 lbs**. The runway crosswind limitation is **17 kts**.

2 Definitions

Critical Engine – Is the engine that, if it were to fail, would cause the most performance or handling penalties.

3 Terms used for multi-engine aeroplane performance

The following are some widely used terms often used in regard to multi-engined aeroplanes.

3.1 Explain the effect of the critical engine inoperative on the power required and the total drag.

In a piston aeroplane the critical engine will normally be the one which would cause the worst yaw.
When an engine fails the following can be expected:

- The drag caused by the windmilling propeller causes the assymetric drag to rise significantly.
- Induced drag has also increased because of the rudder input to correct the yaw.
- The power on the live engine is increased to provide the power to overcome the loss of power from the failed engine and the increased drag.
- But the total power available will be reduced as the live engine is unlikely to be able to double its power.
- Total drag will have increased and the power required will have increased at the same time as the power available has decreased.

Some jets will also have a critical engine, if, for example, one engine powered a particular system and gave a performance penalty on failure.

3.2 Class B Take off 'V' speeds

The following is a list of V speeds with a brief resume of each. The list is in the correct order as they occur from the '**Brake Release Point**' (BRP).

Note that speeds applicabel to Class 'B' are given here, for more V speeds, refer to Class 'A' section in these notes.

V_S This is the stalling speed or minimum steady flight speed at which the aeroplane is controllable.

V_{SR} This is the reference stall speed, the CAS selected by the manufacturer and is used as the basis for the calculation of other speeds it's about 6% greater than V_S

V_{MC} The minimum control speed

V_{MCG} The minimum CAS (RAS) during the take off run when, if the critical engine fails, it is possibe to maintain control of the aeroplane without deviating more than 30 ft from the centreline using 'Primary Aerodynamic Controls' (nosewheel steering off) alone.

V_{MCA} The minimum flight speed with maximum power for take off set, if the critical engine fails, it is possible to keep the aeroplane within +/- 20 degrees and then maintain heading using no more than 5° angle of bank. This is the minimum control speed in the take off climb.

V_{MU} The minimum unstick speed. This is used to establish V_R and is not calculated by the pilot.

V_R The speed at which the pilot starts to rotate the aeroplane, V_R Class 'B' may not be less than;

- Single engined aeroplanes - Vs_1.
- Twin engined aeroplanes - 1.05 V_{MCA} - or 1.1 Vs_1

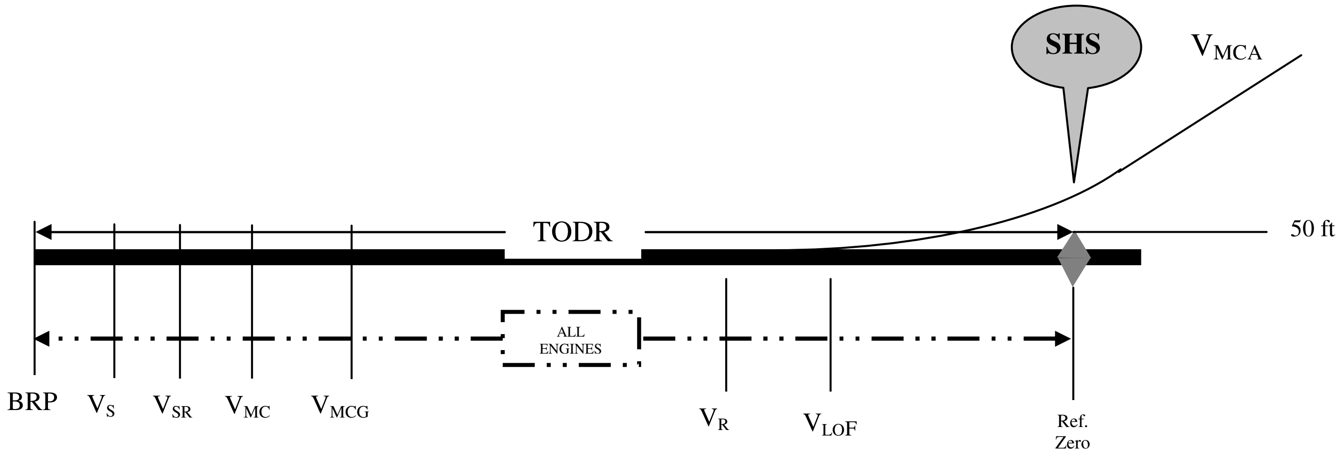
However it must be:

- Fast enough to reach screen height at Screen Hieght Speed (Clear 50 ft speed)

V_{LOF} The speed at which the aeroplane leaves the runway if the aeroplane is rotated at V_R.

V_5 After an engine failure, when the aeroplane is clean this is the max continuous power climb speed until the minimum safe altitude.

V_{ER} '**V** **e**n-**r**oute' is the speed to climb with an engine inoperative above the minimum safe altitude or the speed at which to drift down from altitude in the event of a failure of an engine.



3.3 Explain the parameters, which must be maintained at V_{MCA} in case of an engine failure.

The aeroplane will yaw markedly with drag on one side and take-off thrust set on the other.
The pilot must be able to fly the aeroplane safely using aerodynamic means only.
Remmeber also that with normal pilot reaction the max deviation in aeroplane heading is +/- 20 degrees.
The pilot must then be able to regain control without having to use more than 5 degrees of bank angle.

3.4 Explain the effect of engine failure on controllability under given conditions.

For performance considerations it is assumed the take off will be all engine operating until an assumed engine failure point, from then on the performance is considered with one engine inoperative.

3.5 Engine failure and controllability with varied runway surface conditions

Dry – Controllability is defined by the minimum control speeds.
V_{MCG} when on or near the ground, V_{MCA} when in the air after take off and V_{MCL} in the approach and landing configuration.
In Class 'A' It is important to understand that V_{MCG} and V_{MCA} are used to define a *minimum* V_1 and a *minimum* V_2 respectively. If an engine failure occurs below these speeds then the aeroplane may be uncontrollable.

Wet – Very little difference to the dry conditions as the control is primarily by aerodynamic means.

Icy – There are no manufacturer or performance guarentees as to the controllability!
In Class 'A' If the runway is icy then there are different problems, the normal concept of V_1 does not apply and instead a recommended '**Maximum Abandonment Speed**' is calculated (**V_{STOP}**).
This could leave a gap where the aeroplane can not get airborne in the distance available nor can it safely stop!

3.6 Difference between propeller and light twin jet

As a general rule, the propellor causes a lot more initial drag until feathered and the engine is more often displaced further from the aeroplane centre line than a light jet, the engines of which are often mounted on the fuselage. These two factors combine to make the V_{MCG} and the V_{MCA} of a propeller aeroplane *higher* than a jet of equivalent weight.

3.7 Name the limits for $V_{MAX\ TYRE}$.

The calculated V speeds must not exceed the capabilities of the aeroplane's tyres.
This is not normally a problem for a lower performance aeroplane as the speeds are lower.
As the weight of the aeroplane increases, it is possible on long runways at high altitude and high temperature for the take of speed to exceed the tyre limit.
Tyres are rated in (MPH) Miles per Hour, and may be found as a code letter imprinted upon the tyre wall.
The tyre speed for the Medium Range Jet Transport **(MRJT)** in CAP 698 is **225 MPH**.

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Chapter 11 Take-off variables - Multi-engined aeroplanes.

Performance calculations are vital to the safe and efficient operation of aeroplane. There are many variables which can effect the performance, these variables are considered in an objective manner to define weights, thrust and V speeds to ensure the aeroplane performs within the defined parameters for transport aeroplane operation.
Under normal conditions performance is determined using the aeroplane's handbook or performance manual.

1 Determination of performance under normal conditions

1.1 Explain the effect of flap setting on the ground roll distance.

The main influence of the flap setting is to alter the rotation speed V_R, the greater the flap setting the more lift created at a given airspeed.

A greater flap setting (within the take off range) will give a lower speed and a shorter ground run.

Although the drag is increased this is not too significant at low airspeeds, the conclusion is that if rolling resistance is high the flap setting should be high to shorten the roll. The advantage of lower flap settings is a better rate and angle of climb.
Too much flap (outside the take off range) will increase the take off run because of the very large increases in drag.

1.2 For both fixed and constant speed propellers, explain the effect of airspeed on thrust during the take-off run.

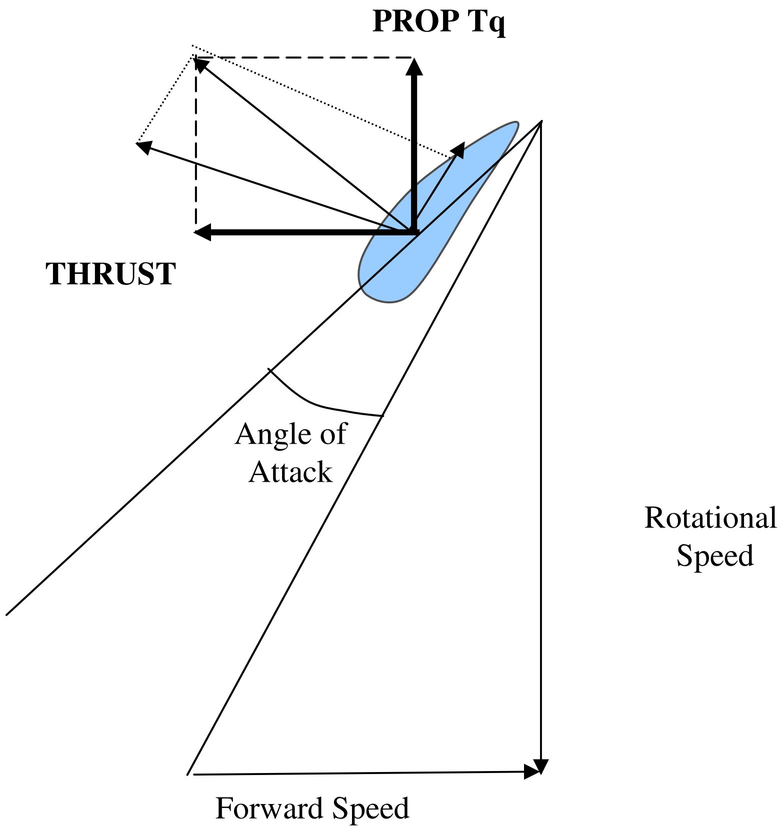
On the next page is a diagram of the vectors involved when considering propeller aerodynamics.
The important area for our consideration is the angle of attack.
The larger the angle of attack the more thrust produced up to the point of the stall.

Fixed pitch - From the diagram it can be seen that the blade angle and angle of attack at the start of the take off run will be high, decreasing as forward speed increases. Therefore;

- Thrust will be decreasing.
- Efficiency, thrust to torque ratio will be increasing but not reaching its peak until cruise speed is reached.

Constant speed - On a constant speed propeller the blade angle can be changed to give maximum thrust or maximum efficiency at any speed.

Forces on the Propeller:



2 Effects of wind, mass, slope sfc conditions temp and Press. Alt.

Wind. Wind is important to aeroplane performance, a headwind increasing and a tailwind decreasing performance.
Simply stated; if Screen Height Speed (Clear 50 ft speed) is say 100 kts and you have a 20 kt HWC, then the effort expended i.e. the work done, is equivalent to 80 kts, the extra 20 kts of speed have been provided 'FREE' by nature.

A HWC allows us to select a higher weight for take off than would otherwise be allowed at a particular field length.

Aeroplane Mass. We not only want to calculate a weight that allows safe performance we want to calculate the *maximum* weight that allows safe performance *and* complies with the performance regulations.
This determines the amount of payload that can be carried and in turn determines the revenue (Our job security and wages!).

As the weight of the aeroplane is increased it will eventually reach a limiting factor as follows:

- **Field Length** – The TORA and TODA are not unlimited and there will be a weight beyond which the declared distance for take-off is not enough.
- **Weight Altitude Temperature (WAT)** – These three aspects all combine to determine the rate of climb. There is a minimum acceptable rate of climb and weight is the only variable under pilot control. This means that, in conditions of high altitude and or high temperature, the weight will be *limited* to enable climb performance to comply with the regulations. This is the so called '**Climb Limit**'.
- **Obstacles** – The net aeroplane must be able to clear obstacles, in the event of a power unit becoming inoperative, by a specified margin. Climb performance is reduced as weight increases, there will be a weight that does not give an adequate climb gradient to clear any obstacles present in the take off flight path.
- **Brake Energy** – Brakes stop the aeroplane by converting the aeroplane's kinetic energy into heat energy. The brakes can only accept a certain amount of heat energy which in turn limits the kinetic energy. Kinetic energy is a function of the aeroplane's weight and speed, speed for take-off rises as weight increases so the kinetic energy to dissipate in the event of an aborted take-off rises. There is a limit to the brakes ability to stop the aeroplane which is much reduced by down slope and down wind. Ultimately for a given altitude, temperature, slope and wind there will be a brake energy limited weight.
- **Tyre Speeds** – Tyres are rated to a maximum speed, if the take-off weight requires speeds in excess of the maximum the tyres can accept then the weight must be reduced.

Runway Slope – Runway slope affects performance as follows;
A down slope assists the acceleration which reduces take off run but, in the event of an aborted take off, the down slope increases the distance needed to stop the aeroplane.
Conversely accelerating up slope increases the take-off roll but in the event of an aborted take-off the up slope aids braking and decreases the stopping distance.

Runway Aerodrome Conditions – This subject is quite large and covered in depth as performance unfolds.
In summary, anything, be it water, snow or slush impinging the aeroplane adds to the total drag and reduces the acceleration.
The contamination will also have profound effects on the ability to stop the aeroplane in the event of an aborted take off.
Control in cross winds is difficult and is usually strictly limited to quite low crosswind levels around 10Kts. Virtually all take-off or landings on contaminated runways are on the edge of the aeroplane's and crews abilities, this reduces the margin for error and increases the risk factor.

i. Effect of runway contamination on the take-off distance.

Runway contamination will increase the take-off distance considerably. Spray will impinge upon the wheels and flaps causing additional drag and slower acceleration.
In addition it is possible for the wheels to aquaplane and stop rotating causing additional drag and control problems.

Weight for take off is not exclusively about the aeroplane's ability to fly, the commander must consider the aeroplane's ability to stop in the event of a malfunction. In general terms there is no V-Go, but there will be a recommended abandon speed (V_{STOP}) at which the aeroplane should be able to stop.
This speed will be well below a speed where a decision to go can be made. This can leave a significant gap where the aeroplane cannot stop or continue and get airborne.
An engine failure during this time will result in potential disaster.

ii. The effect of temperature on the brake energy limited take-off mass.

This applies to hot days. The brakes are designed to be able to stop the aeroplane at maximum take-off weight under ISA conditions in nil wind.
This condition normally places the aeroplane on or near to the brake energy limit.
If the temperature is high this affects the brake energy in two ways as follows;

- The brakes are operating from a higher start point reducing the amount of kinetic energy they can absorb.
- The V speeds required for the take off will be higher. As the air is less dense the reduction in performance is compensated for by an increase in velocity.

iii. The effect of pressure altitude on the field length limited take of mass.

Compare two aeroplane of identical weight and performance at different altitudes, with runway lengths identical.

- At the higher altitude density is reduced, which means the take off speeds have to be increased and more distance is needed to accelerate to the higher speeds.
- To reach these higher speeds the aeroplane needs a longer runway.
- If the aeroplane, when at the lower altitude, is using all the runway there will be insufficient field length available at the higher altitude.

The result must therefore be a reduction in weight to reduce the take off distance required at the higher aerodrome.

Chapter 12 Additional Elements of Performance theory.

1 Certified engine thrust rating.

The certified engine thrust rating is the minimum test bed acceptance thrust as stated in the engine type certificate, when running at specified conditions and within the appropriate acceptance limitations.
Performance calculations work on the assumption that the engines will be producing the thrust specified for certification.

1.1 The effect of temperature and altitude on the fuel flow for jet engine aeroplanes in given conditions.

The effects are as follows:

Temperature – At low temperatures the density of the air increases, so the mass of air entering the engine at a given speed is greater, this means the thrust is greater.
The engine will require higher fuel flow to maintain the engine speed as the drag is higher due to the denser air.
At high temperatures the density decreases reducing the mass of air entering the engine and consequently reduces the thrust.
As the air is less dense the drag on the compressor is less and the fuel flow is reduced.

Altitude – With increasing altitude the ambient air pressure and temperature decreases.
The fall in pressure reduces the air density and therefore the mass air flow entering the engine.
This would cause the thrust to reduce, the drag is also reduced and the fuel flow reduces to maintain a constant speed.

The decrease in temperature with increasing altitude increases the air density.
This increases the mass air flow entering the engine, it compensates for some of the loss in thrust and reduction in fuel consumption due to altitude, but;

The dominant factor is the altitude.

It is also worth remembering that that the temperature is constant above the tropopause where thrust and fuel flow decrease as a result of the pressure drop, without cooling to help compensate.

The subject would not be complete without bringing together the factors and examining the overall fuel flow. The reduction in mass airflow with altitude through the engine means that the engine has to work harder to produce the same thrust. This makes the engine more efficient as well as giving a reduction in fuel flow due to the reduction in compressor drag.
It is important to realise that the air is very thin and the drag against the aeroplane is much reduced so the reduced thrust is in effect compensated for.

2 Aeroplane Flight Data

Aeroplane Flight Data to calculate TAS, MAP, climb distance and range predictions are all contained in the CAP 697.
There are four tables based on an aeroplane with a mass of 3,400 lbs. and using cruise lean mixture.
It would be a good idea to take a look at the way the tables and graphs operate and also to note the effects of altitude and temperature which support points already made.

Fuel, Time & Distance To Climb, Range and endurance profile graphs can all be found in CAP697 with examples.

Given the cruise height, the throttle setting and the RPM setting, the maximum range or the maximum endurance can be calculated.

2.1 Payload/range trade-off and the payload-range diagram

No graph is provided in CAP 698 for payload against range but see Figure 3.2 in CAP 697.
On a commercial aeroplane, it is seldom possible to take a full fuel load as well as a maximum payload.
The range between the two points is known and so a fuel figure can be derived, taking into account approximate weight, cruising altitude, diversion requirements, holding and meteorological considerations such as head/tailwind.
Once this fuel figure is known, the maximum payload can be calculated taking into consideration the most limiting of the maximum take-off mass, maximum zero fuel mass and maximum landing mass.

Not all aeroplanes have a payload-range diagram published because they are seldom operated near that limit.
However, for planning considerations, a graph or diagram may be produced that will show the possible ranges with a given payload in zero wind conditions.
It is also worth updating the meteorological information once airborne, as a headwind may be present at the optimum cruising altitude, but a much more favourable tailwind at either a higher or lower altitude that may increase the groundspeed.

These topics are covered in the Flight Planning notes and associated training.

CAP697 is <u>not required</u> for the aeroplane performance exam!

Chapter 13 Using performance graphs and tabulated data Class 'B' MEP

Using the CAP 698 practice the following examples along side the given examples in the CAP 698. Take note of the procedure for finding the information from the available data.

1 Examples

EXAMPLE 1 Find MTOM (FLL Weight) MEP

Short field T/O

PA	6000 ft	TORA	2100 ft
OAT	+30°C	ASDA	2800 ft
Wind	10Kts HWC	TODA	2900 ft
Slope	1.5% UP		
SFC Type	Grass		
SFC Condition	Dry		

Find: Field Length Limited TOM

Given Distances	TORA	ASDA	TODA
	2100	2800	2900
Slope Factor	1.075	1.075	1.075
Sfc Factor	1.2	1.2	1.2
Reg Factor	1.0	1.3	1.15
Defactored Distance	**1628**	*1670*	*1955*

Using 1628

Fig 3.3 = MTOM = FLL 4550 lbs

1.1 Effect of brake release, before take-off power is set, on ASDA

i. Fig 3.2 and Fig 3.4

Two accelerate and stop distance graphs are given in the CAP 698 One considers the flaps 0º take-off figure 3.2, and the other a flaps 25º take-off figure 3.4.
Note the extra distance required to accelerate and stop when conducting a flaps 0º take-off.
The conditions for the use of both graphs assume that full power is applied on both the engines *before* brake release.
Should full power not be set before brake release, the distance obtained from the graphs is invalid as the actual accelerate and stop distance may be considerably longer, and no correction data is given in this Performance Manual for that event.
Releasing the brakes with idle power set will mean that the aeroplane is moving forward and the distance taken to reach V_R will be longer.

EXAMPLE 2 — Find MTOM (FLL Weight) — MEP

Short field T/O

PA	4000 ft	TORA	2000 ft
OAT	+25°C	ASDA	2300 ft
Wind	5Kts TWC	TODA	2600 ft
Slope	1.2% Down		
SFC Type	Grass		
SFC Condition	Wet		

Find FLL TOM

Given Distances	**TORA**	**ASDA**	**TODA**
	2000	2300	2600
Slope Factor	1.0	1.0	1.0
Sfc Factor	1.3	1.3	1.3
Reg Factor	1.0	1.3	1.15
Defactored Distance	*1538*	**1361**	*1739*

Using 1361

Fig 3.3 = MTOM = FLL 3390 lbs

EXAMPLE 3 Find MTOM (FLL Weight) MEP

Normal T/O

PA	1000 ft	TORA	2230 ft
OAT	+15°C	Stopway	None
Wind	5Kts HWC	Clearway	None
Slope	1.5% UP		
SFC Type	Grass		
SFC Condition	Dry		

Find FLL TOM

Given Distances	TORA	ASDA	TODA
	2230		
Slope Factor	1.075		
Sfc Factor	1.2		
Reg Factor	1.25		
Defactored Distance	**1383**		

No Stopway or Clearway

Balanced Field

Using 1383

Fig 3.1 = MTOM = FLL 3250 lbs

EXAMPLE 4 Take off Climb Performance MEP

Given;

Aerodrome PA	4500 ft
OAT	–10°C
Take-off Mass	4650 Lbs
Gear	UP
Flaps	Zero
Climb Speed	92 Kts IAS
Wind Component	6.5 Kts Tail
Cloud Base	800 ft above Ref. Z.

There is an obstacle in the domain, **800 ft** above Ref.Z, at **1.8 nm** from the end of TODR.

1. What is the vertical clearance at the obstacle by the aeroplane?
2. Find the distance from the end of TODR to 1500 ft.

SOLUTION

I. Find the TAS and Ground Speed: **TAS = 95.6 Kts**
(It's a tail wind so use 150%) TWC 6.5 x 150% = 9.75 Kts = **G/S 105 Kts**

II. **Fig. 3.6** @ OAT –10°C, PA 4500 ft, TOM 4650 Lbs =

Both Eng. ROC *1480 f/pm*

One Eng INOP ROC *265 f/pm*

III. **Fig 3.7** @ OAT –10°C, PA 4500 ft, TOM 4650 Lbs =

One Eng INOP ROC (Max Cont. Pwr) *225 f/pm*

IV. Time to Cloud Base (Both Eng ROC)

$$\frac{\text{Diff in height X 60}}{\text{ROC}} = \text{Seconds} \qquad \frac{\text{800-50 (Screen Ht) x 60}}{\text{1480 fpm}} = 30.4 \text{ sec}$$

V. Time Cloud base up-to 1500 ft (One Eng. INOP ROC)

$$\frac{\text{Diff in height X 60}}{\text{ROC}} = \text{Seconds} \qquad \frac{\text{1500-800 (In cloud) x 60}}{\text{265 fpm (SE)}} = 158.5 \text{ sec}$$

VI Total time so far:

Time to Cloud Base =30.4 sec
Plus: Cloud base up to 1500 ft =158.5 sec
Total =188.9 ÷ 60 = **3.14 minutes**

Time is OK as <u>within 5 min</u> Max T/O power!

VII. Horizontal Distance to Cloud Base

$$\frac{\text{Diff in height X G/S}}{\text{ROC X 60}} \text{ X 6080 X 1.3 = ft}$$

JAR OPPS 1-H-1
Regulatory Factor:
0.77% or factor = 1.3

$$\frac{800\text{-}50 \times 105}{1480 \times 60} \text{ X 6080 X 1.3 = } \mathbf{7009\ ft}$$

VIII. Horizontal Distance from Cloud base to the obstruction

1.8 nm x 6080 = 10944 ft from 'Ref. Zero'.

10944 – 7009) = **3935 ft**

IX. (Q1): Height gain from Cloudbase (*and top of obstruction in this question!*).

$$\frac{\text{Distance X ROC}}{\text{G/S}} \text{ X 60 = ft} \qquad \frac{3935 \times 265}{105 \times 6080} \text{ X 60 = } \mathbf{98\ ft}$$

X. Horizontal Distance to Cloud entry

Result of stage VII 7009 ft ÷ 6080 **= 1.15 nm**

XI. Horizontal Distance from Cloud entry (800ft) up-to 1500 ft.

$$\frac{\text{Diff in height X G/S}}{\text{ROC X 60}} \text{ = Nm} \qquad \frac{1500 - 800 \times 105}{265 \times 60} = \mathbf{4.62\ Nm}$$

XII. (Q2): Total distance from end of TODR to 1500 ft.

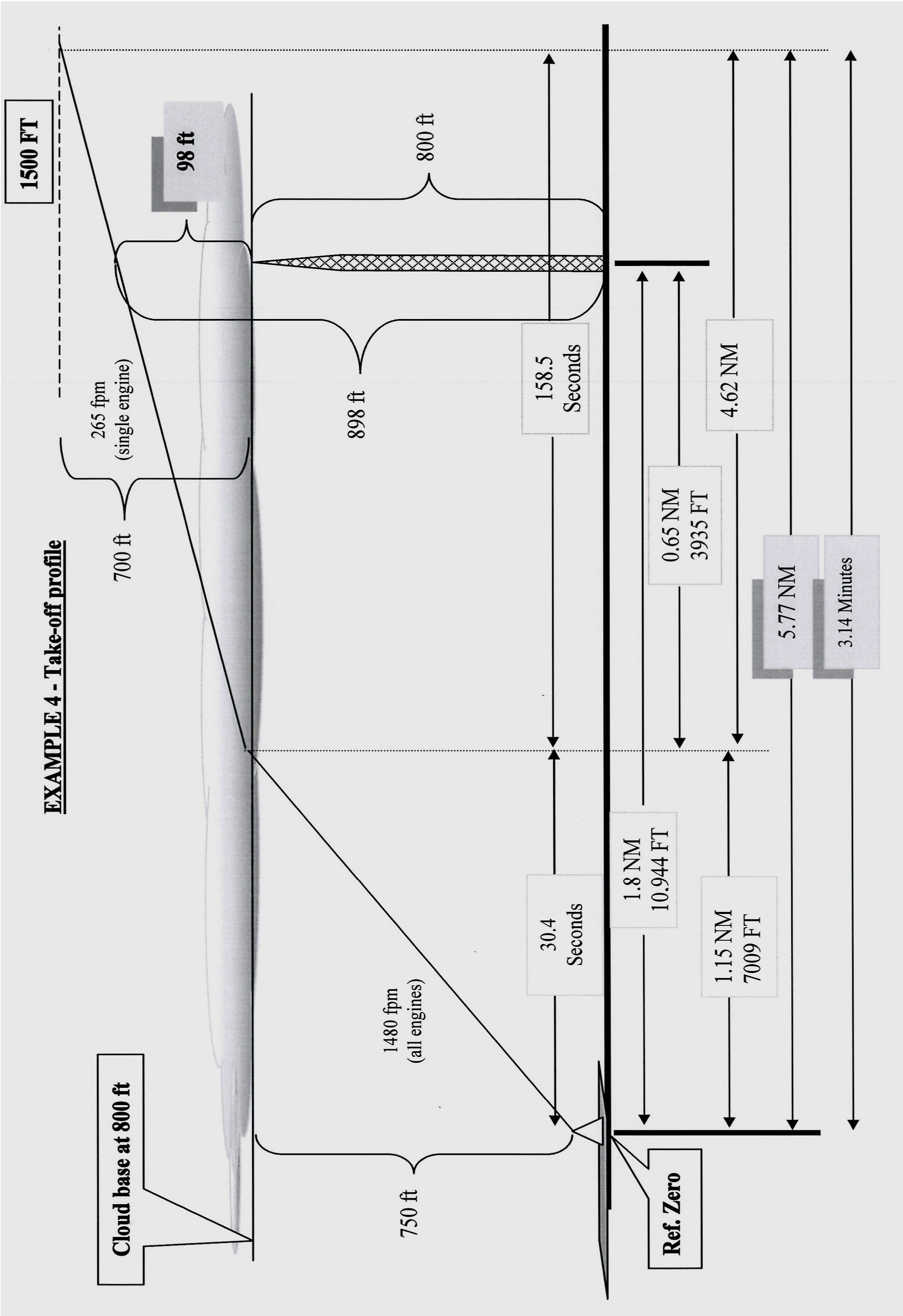
Result from stage X plus stage XI = 1.15 + 4.62 = **5.77 nm**

XIII. Clearance

In this example this will be the answer found at stage IX = **98 ft.**

NB. *Always check to see if this takes you over the 'Five Minute' period.!! If so round again using the reduced climb of 225 f/pm from Fig. 3.7*
In this example we are OK!

The diagram below shows the take-off profile and values determined from Example 4.



EXAMPLE 5 Take off Climb Performance MEP

Given;

Aerodrome PA	5000 ft
OAT	+20°C
Take-off Mass	4500 Lbs
Gear	UP
Flaps	Zero
Climb Speed	92 Kts IAS
Wind Component	20 Kts Head
Cloud Base	600 ft above Ref. Z.

There is an obstacle in the domain, **650 ft** above Ref.Z, at **15000 ft** from the end of TODR.

Question 1. What is the vertical clearance at the obstacle by the aeroplane?
Question 2. Find the distance from the end of TODR to 1500 ft.

SOLUTION

I. Find the TAS and Ground Speed: **TAS = 102 Kts**
(It's a Head wind so use 50%) HWC 20 x 50% = 10 Kts = **G/S 92 Kts**

II. **Fig. 3.6** @ OAT +20°C, PA 5000 ft, TOM 4500 Lbs =

Both Eng. ROC *1500 f/pm*

One Eng INOP ROC *260 f/pm*

III. **Fig 3.7** @ OAT +20°C, PA 5000 ft, TOM 4500 Lbs =

One Eng INOP ROC (Max Cont. Pwr) *220 f/pm*

IV. **Time to Cloud Base** (Both Eng ROC)

$$\frac{\text{Diff in height X 60}}{\text{ROC}} = \text{Seconds} \qquad \frac{600\text{-}50 \text{ (Screen Ht) x } 60}{1500 \text{ fpm}} = 22 \text{ sec}$$

V. **Time Cloud base up-to 1500 ft** (One Eng. INOP ROC)

$$\frac{\text{Diff in height X 60}}{\text{ROC}} = \text{Seconds} \qquad \frac{1500\text{-}600 \text{ (In cloud) x } 60}{260 \text{ fpm (SE)}} = 207.7 \text{ sec}$$

VI. **Total time so far:**

Time to Cloud Base	=22 sec
Plus: Cloud base up to 1500 ft	=207.7 sec
Total	=229.7 ÷ 60 = **3.82 minutes**

Time is OK as within 5 min Max T/O power!

VII. Horizontal Distance to Cloud Base (Both Eng ROC)

$$\frac{\text{Diff in height X G/S}}{\text{ROC X 60}} \text{ X 6080 X 1.3 = ft}$$

JAR OPPS 1-H-1
Regulatory Factor:
0.77% or factor = 1.3

$$\frac{600\text{-}50 \text{ x } 92}{1500 \text{ x } 60} \text{ X 6080 X 1.3 = } \mathbf{4444 \text{ ft}}$$

VIII. Horizontal Distance from Cloud base to the obstruction

(Obst dist from end TODR) – (Horiz. Dist to Cloud Base from step VII)

(15000) – (4444) = **10556 ft ÷ 6080 = <u>1.73 nm</u>**

IX. Height gain from Cloudbase to the obstruction (One Eng. INOP ROC)

$$\frac{\text{Distance X ROC}}{\text{G/S}} \text{ X 60 = ft} \qquad \frac{10556 \text{ x } 260}{92 \text{ x } 6080} \text{ X 60 = } \mathbf{294 \text{ ft}}$$

X. Horizontal Distance to Cloud entry

From step VII. = **4444 ÷ 6080 = <u>0.73 nm</u>**

XI. Horizontal Distance from Cloud entry up-to 1500 ft. (One Eng. INOP ROC)

$$\frac{\text{Diff in height X G/S}}{\text{ROC X 60}} \text{ = Nm} \qquad \frac{1500 - 600 \text{ x } 92}{260 \text{ x } 60} \mathbf{= 5.30 \text{ Nm}}$$

XII. Total distance from end of TODR to 1500 ft.

(Horiz Dist. to Cloud Base from step VII) + (Dist. from Cloud Base to 1500 ft from step XI)

(0.73 nm) + (5.30 nm) = <u>6.03 nm Answer Question 2</u>

XIII. Height at the obstacle

(Cloudbase) + (Height gain from step IX)

(600 ft) + (294 ft) = 894 ft

XIV. Clearance

(Height at the obst. From step XIII) – (Actual Obst. Height)

(894 ft) – (650 ft) = <u>244 ft Answer Question 1</u>

NB. *It may be required to check to see if this takes you over the 'Five Minute' period from step 'V'!! If so round again using the reduced climb of 220 f/pm from Fig. 3.7*

1.2 Find the accelerate-go distance as well as the accelerate-stop distance

CAP 698 includes the Accelerate/Stop Distance Graph – Flap zero which is figure 3.2 MEP1 Page 5.

The text on page MEP1 Page 2 refers in paragraph 2.2:

Use of Take-Off Graphs
There are two sets of take-off graphs: one for a "normal" take-off with 0° flap and the other for a "maximum effort" (short field) take-off with 25° flap. Each set comprises two graphs, one for determining the take-off run and take-off distance, the other for calculating the accelerate-stop distance.

The entry procedure for all three of these graphs is basically the same as given in the example procedure on MEP1 Page 2.

EXAMPLE 6 Find Landing Dist. Req. MEP

Given;

Normal Landing

PA	5000 ft	**Landing Mass**	3200 Lbs
OAT	+20°C	**IAS**	V_{REF} 85 Kts
Wind	10Kts HWC		
Slope	1% Down		
SFC Type	Paved		
SFC Condition	Dry		

Question 1. Find Baulked Landing Climb Gradient
Question 2. Find Missed Approach Climb Gradient
Question 3. Find Landing Distance Required (LDR)
Question 4. Find Ground Roll
Question 5. Find Barrier Speed

I. Fig 3.8 Balked Landing Climb

Graphical ROC = 780 f/pm

II. Find TAS = 94 Kts (Based on V_{REF})

III. Find Still Air Climb Gradient

Ans Q.1

$$\frac{\text{ROC X 6000}}{\text{TAS X 6080}} = \%\ \text{Grad} \qquad \frac{780 \text{ X } 6000}{94 \text{ X } 6080} = \mathbf{8.1\%\ Grad}$$

OK This is more than Regulatory ROC 2.5%

IV. Fig. 3.7 Find missed approach gradient of climb (Max Continuous Power)

Graphical ROC = 600 f/pm

V. Find TAS = Note that the graph states the best single engine climb speed = 92 Kts IAS

TAS = 102 Kts

VI. Find Still Air Climb Gradient

Ans Q.2

$$\frac{\text{ROC X 6000}}{\text{TAS X 6080}} = \%\ \text{Grad} \qquad \frac{600 \text{ X } 6000}{102 \text{ X } 6080} = \mathbf{5.8\%\ Grad}$$

OK This is more than Regulatory ROC 0.75%

VII. Fig 3.9 Landing Distance 'Normal'

Graphical Distance	**2000 ft**	Ground Roll **1000 ft**	**Ans Q.4**
Slope 1% down	x Factor 1.05		
Surface Paved	x Factor 1.00		
Condition Dry	x Factor 1.00		
Regulatory	x Factor 1.43		
LDR	**3003 ft**	**Ans Q.3**	
Barrier Speed	**77.5 Kts**	**Ans Q.5**	

EXAMPLE 7 Find FLL Landing Mass MEP

Normal Landing

PA	1000 ft	IAS	V_{REF} 85 Kts
OAT	+33°C	LDA	3960 ft
Wind	5Kts HWC		
Slope	2% Down		
SFC Type	Grass		
SFC Condition	Dry		

Question 1. Find Baulked Landing Climb Gradient
Question 2. Find FLL Landing Mass
Question 3. Find Landing Ground Roll
Question 4. Find Barrier Speed
Question 5. Find Missed Approach Climb Gradient

I. Fig 3.8 Balked Landing Climb

Graphical ROC = 820 f/pm

II. Find **TAS = 89.5 Kts (Based on V_{REF})**

Ans Q.1

$$\frac{\text{ROC X 6000}}{\text{TAS X 6080}} = \text{\% Grad} \qquad \frac{820 \text{ X } 6000}{89.5 \text{ X } 6080} = \mathbf{9.04 \text{ \% Grad}}$$

OK This is more than Regulatory ROC 2.5%

III. Defactor LDA

Landing Distance Available : 3960

Slope 2% down	÷ Factor 1.10
Surface Grass	÷ Factor 1.00
Condition Dry	÷ Factor 1.15
Regulatory Factor	÷ Factor 1.43
De-factorised LDA	= **2189**

Entry Argument for Fig. 3.9

Field Length Limiting Landing Mass = 3350 lbs

IV. Fig 3.9 Using distance found from Step III @ OAT/PA/Wind.

Question 2. Find FLL Landing Mass = 3350 lbs

Question 3. Find Landing Ground Roll = 1080 ft

Question 4. Find Barrier Speed = 79 Kts

V. Fig. 3.7 Find missed approach gradient of climb (Max Continuous Power)

Graphical ROC = 600 f/pm

VI. Find TAS = Note that the graph states the best single engine climb speed = 92 Kts IAS

TAS = 97 Kts

VII. Find Still Air Climb Gradient

Ans Q.5

$$\frac{\text{ROC X 6000}}{\text{TAS X 6080}} = \text{\% Grad} \qquad \frac{600 \text{ X } 6000}{97 \text{ X } 6080} = \mathbf{6.1\%\ Grad}$$

OK This is more than Regulatory ROC 0.75%

2 *LDR (dry and wet) for destination and alternate airports.*

There follows some extracts with our notes in *italics* from EU-OPS 1 pages 1-H-2 and 1-H-3, para: 1.545, 1.550 and 1.555 which state the case for *all* Class 'B' operations, *basically*:

2.1 For Dry Runways

(a) An operator shall ensure that the landing mass of the aeroplane, determined in accordance with EU-OPS 1.475(a), for the estimated time of landing at the destination aerodrome and at any alternate aerodrome allows a full stop landing from 50 ft (or not less than 35 ft with the approval of the Authority) above the threshold:

- within 70% of the landing distance available. (Factor 1.43)

(b) When showing compliance with the above, an operator shall take into account the following:

i. The altitude at the aerodrome.
ii. Not more than 50% of the head-wind component or not less than 150% of the tailwind component.
iii. The runway surface condition and the type of runway surface. (See AMC OPS 1.550(b) (3))
iv. The runway slope in the direction of landing adjusted for down slope and if greater than ±2% only with the acceptance of the Authority. (See AMC OPS 1.550(b) (4))

2.2 Despatch rules

(c) For despatching an aeroplane in accordance with sub-paragraph (a) above, it must be assumed that:

- The aeroplane will land on the most favourable runway, in still air.
- The aeroplane will land on the runway most likely to be assigned considering the probable wind speed and direction and the ground handling characteristics of the aeroplane, and considering other conditions such as landing aids and terrain. (See IEM OPS 1.550(c).)
- If an operator is unable to comply with the sub-paragraph above for the destination aerodrome, the aeroplane may still be despatched if an alternate aerodrome is designated which permits full compliance with sub-paragraphs (a), (b) and (c) above.

2.3 For Wet Runways

(a) An operator shall ensure that when the appropriate weather reports or forecasts, or a combination thereof, indicate that the runway at the estimated time of arrival may be wet:

The landing distance available is equal to or exceeds (*greater than!*) the required landing distance, determined in accordance with EU-OPS 1.550. *in other words it should be*:

….at least 115% of the required landing distance, (Factor 1.15)
as determined in accordance with EU-OPS 1.550.
IEM OPS 1.555(a) also refers.

(b) An operator shall ensure that when the appropriate weather reports or forecasts, or a combination thereof, indicate that the runway at the estimated time of arrival may be contaminated, the landing distance determined by using data acceptable to the Authority for these conditions, does not exceed the landing distance available.

(c) A landing distance on a wet runway shorter than that required by sub-paragraph (a) above, but not less than that required by EU-OPS 1.550(a), may be used if the Aeroplane Flight Manual includes specific additional information about landing distances on wet runways. *In other words it should be:*

….at least 115% (Factor 1.15) of the landing distance determined in accordance with approved contaminated landing distance data or equivalent, and be acceptable by the Authority.

2.4 Class B Landing speeds

$\mathbf{V_{REF}}$ the speed the aeroplane should be at, as it descends through the screen height after a descent gradient not exceeding 5%, and should not be less than:

The greater of V_{MC} or 1.3 x V_{S0}.
(Class 'A' aeroplanes use not less than 1.23 V_{SRO} or V_{MCL}).

This speed is used to determine the landing distance for manual landings.

$\mathbf{V_{AT}}$ the Target Threshold Speed the speed at which the pilot aims to cross the threshold when landing based on 1.3 x V_{S0}.

2.5 Approach speeds

During the approach the speed is gradually reduced to $\mathbf{V_{REF}}$ and/or (V_{AT})

The approach speed is based on 1.33 V_{S0}

2.6 Barrier Speed

This is shown as the speed to be attained over the 50 ft Barrier or screen height on the landing graphs CAP698 MEP1 page 21 and page 23.

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Section Five Aeroplanes Performance Class A

Aeroplane certified under JAR/FAR 25/CS25

Chapter 14 Introduction

The basic requirement for a transport aeroplane is that it should proceed safely from the departure point to the destination. In order to do this it must have sufficient fuel and power, these requirements are met by Fuel Planning and Performance Planning.

In simple terms the aeroplane must be able to remain in safe flight if a critical engine fails at any stage of the flight.

Performance planning is part of the flight plan and is concerned solely with the safety of the aeroplane.

The object is to ensure that the space required for manoeuvre is never greater than the space available.

The space required by an aeroplane for a particular manoeuvre depends on and increases with weight.

Performance planning consists of fitting the space required into the space available and, since weight is the major variable, the principal end product will be the maximum permissible take-off weight.

The fuel plan and time scheduling both depend on take-off weight, therefore it is always necessary to do the performance planning first.

Performance Class A aeroplane must also meet these requirements:
An aeroplane with a maximum certificated take-off weight exceeding 5700 kg and with a performance level such that at whatever time a power unit fails, a forced landing should not be necessary.

For performance planning a flight is divided into four distinct phases :

- **Take Off** : From brakes off, to the point where the aeroplane reaches the screen height of 35 feet.
- **Net Take Off Flight Path** : From 35 feet to 1500 feet above the aerodrome
- **En Route** : From 1500 feet above the departure aerodrome, to 1500 feet above the destination or alternate aerodrome.
- **Landing** : From 1500 feet above the destination or alternate aerodrome, to the point where the aeroplane stops at the end of the landing run.

In order to establish that all phases can be safely conducted, the 'Net Performance Data' must be used to establish the most restrictive take-off weight after consideration of :

- Aeroplane structural limitations
- Climb performance Net Take-Off Flight Path (NTOFP) – obstacle clearance
- En-route terrain clearance
- The landing weight at destination or alternate (including airfield criteria and climb performance for a go-around.

Other factors which may limit the take-off or landing weights may be:

- Brake heating limitations
- Tyre speed and pressure limitations
- Crosswind limitations
- Reduced performance due to standing water, slush or snow
- Aerodrome pavement strength
- Noise abatement regulations
- Inoperative systems : Anti-skid, reverse thrust
- Flap settings

1 Take – off

1.1 A Reminder of the essential forces affecting the aeroplane during take-off until lift off

Thrust : Providing the acceleration force moving the aeroplane forward.

Drag : The component of total reaction acting back along the flight path

Weight : The mass of the aeroplane acting vertically downwards

Lift : Component of the total reaction acting at right angles to the flight path.

As speed increases during the take off run the lift and drag will be increasing until just at the point of lift off when lift will equal the weight.

1.2 State the effects of angle of attack, thrust-to-weight ratio and flap-setting on acceleration distance

Angle of Attack: An aeroplane, with tricycle undercarriage, on the ground will present the aerodynamic surfaces at an angle of attack close to zero. This minimises the effects of drag during the ground roll. The acceleration will be better and ground roll reduced at minimum angle of attack. The acceleration to V_2 will also be better at a low angle of attack

Thrust to weight ratio: Directly affects aeroplane acceleration on the ground and in the air. The greater the thrust available for a given weight, the better the acceleration. The greater the aeroplane weight for a given thrust setting, the slower the aeroplane will accelerate.

Flap Setting: For take-off, relatively small angles of flap are used. This is to minimise the drag effects of high flap angles that would seriously affect acceleration. *Importantly an aeroplane must not attempt a take off with a flap setting greater than allowed in the aeroplane flight manual.*

2 *Definitions of terms and speed used*

2.1 Define the following speeds:

STALL SPEEDS

V_S The calibrated stalling speed or minimum steady flight speed for the configuration under consideration at which a/c is controllable. It is the greater of:

- The minimum CAS in level flight
- 94% of the 1g stall speed (V_{S1G})

V_{S0} The stalling speed (Or given that no stall can be obtained, the minimum steady flight speed) with flaps in the landing setting.

V_{S1} The stalling speed (Or given that no stall can be obtained, the minimum steady flight speed) in the configuration under consideration, for example with flaps extended

V_{S1G} This is the '1-g stalling speed', which is the minimum CAS at which the aeroplane can develop a lift force being normal to the flight path and equal to its mass, while at an angle of attack not greater than that which the stall is identified.

V_{SR} Reference stalling speed which is a calibrated airspeed selected by the manufacturer and used as the basis for calculation of other speeds. It is approximately 6% greater than V_S.

V_{SR0} Reference stalling speed; in the landing configuration.

V_{SR1} Reference stalling speed: in a specific configuration under consioderation.

V_{MS} The lowest possible stall speed. This is V_S but for any combination of mass and atmospheric conditions with no power, at which large and short term controllability problems arise in pitch and roll.

V_{MS0} The lowest possible stall speed. This is V_{S0} (Or given that no stall can be obtained, the minimum steady flight speed) with flaps in the landing setting, for any combination of mass and atmospheric conditions.

V_{MS1} The lowest possible stall speed. This is V_{S1} (Or given that no stall can be obtained, the minimum steady flight speed) in the configuration under consideration, for any combination of mass and atmospheric conditions.

CONTROL SPEEDS

V_{MC} Minimum control speed. The lowest calibrated airspeed at maximum take-off power at which it is possible to maintain control of the aeroplane, following a sudden critical engine failure. It must be possible to regain control maintaining heading within 20° of the original by using no more than 5° angle of bank. Note also that:

V_{MC} may not exceed:

- Class 'A' — 1.13 V_{SR} at maximum take-off mass at MSL.
- Commuter Class & Class 'B' — 1.2 V_{S1}

V_{MCG} Minimum control speed ground: The minimum control speed being the CAS on the ground with maximum take-off power, at which it is possible to suffer a critical power unit failure and maintain control using aerodynamic means only. Note also that:

- V_{MCG} is never greater than V_{MC}
- It does not account for use of nose wheel steering.
- It does allow for normal piloting skills.
- The aeroplane to remaining parallel within 30 feet of the original path.

V_{MCA} Minimum control speed air: The minimum speed in the air in a take-off climb configuration at which it is possible to suffer the critical power unit failure and maintain control using aerodynamic means alone, using no more than 5° of bank.

V_{MCL} Is the minimum control speed during the approach and landing with all engines operating. It is the lowest CAS at which, with the aeroplane in its most critical configuration, for example the landing configuration, it is possible to maintain control:

1. With the critical engine failed, feathered and/or secured and the operating engine at go-around power/ thrust:
    - Whilst able to maintain straight flight with no more than 5º Bank
    - With ability to roll through 20º from straight flight away from the operative engine in five seconds.
2. Assuming the engine fails while at the power/thrust setting to maintain a 3º approach.

TAKE-OFF SPEEDS

V_{EF} Engine failure speed: The calibrated airspeed at which the most critical power unit failure is *assumed* to occur as applicable to performance calculations of V_1 and allowing a 1 second interval in calculations between the two speeds to help account for pilot recognition.

Class 'A' aeroplanes:

- V_{EF} is never less than V_{MCG}
- V_{EF} is never greater than V_1

Commuter aeroplanes:

- V_{EF} is never less than 1.05 V_{MC}
- V_{EF} is never greater than V_{MCG}

V_{STOP} The highest decision speed at which the aeroplane can safely stop within the ASDA. In the event of the take-off being abandoned.

V_{GO} This is the lowest decision speed from which a continued take-off is possible within the take-off distance available (TODA).

V_1 Take off decision speed: The speed above which, in the event of a power unit failure, take off must be continued and below which the take off must be abandoned. It is the speed at which the aircraft could continue the take-off or be safely able to stop in the runway length available.

- V_1 cannot be less than V_{MCG}
- V_1 cannot be more than V_R and V_{MBE}
- V_1 is never less than V_{EF} in addition to the speed increase from the time of the failure to the time of the pilot application of the first means of retardation.
- V_1 has a 'built in' 2 second allowance for the delay in pilot reaction time to the failure.
- V_1 is determined from the aircraft configuration, take-off mass and the relative field lengths.

Range of V_{1s} A range of V_{1s} can be available for use in the event that the field length limited take-off mass is greater than the actual take-off mass that is being used.

- Piston engine aeroplanes and Turbo-prop normally use the higher field length value.
- Turbo-jet aeroplanes normally use the lower take-off mass value.

V_1 / V_R ratio The power failure speed ratio. This is often seen in flight manuals as a method of presenting data. V_1 is as defined above, but V_R is dependant upon the aeroplanes configuration and take-off mass, so given that the take-off mass is known and also the V_1 / V_R ratio, it can simplify the calculation of a V_1.

V_R Rotation speed: The speed at which the pilot initiates a change in aeroplane attitude with the intention of leaving the ground. It should be such that the aeroplane becomes airborne and rapidly attaining V_2 by the screen height 35ft.

- V_R is not less than 1.1 V_{MU} all engines.
- V_R is not less than 1.05 V_{MU} one-engine inoperative.
- V_R is never less than V_1 or 1.05 V_{MC}

Commuter aeroplanes use the value of V_R being:

- V_R is never less than V_1 or 1.05 V_{MC}
- not less than 1.1 V_{S1}

V_{MU} The lowest possible un-stick speed: The minimum demonstrated speed at which it is possible to safely leave the ground climbing to screen height with all power units operating, for any combination of mass and atmospheric conditions.
There would usually be an allowance of 5 kts between the lowest speed for raising the nose wheel and V_R.

V_{LOF} Lift off speed or unstick-speed: The calibrated airspeed at which the aeroplane main wheels will leave the ground, having rotated at V_R.

V_{MBE} Max brake energy speed: The maximum speed on the ground from which a stop can be accomplished within the energy capabilities of the brakes. It may limit the upper values of V_1 in the case of and for combinations of:

- High Take-off Mass. (TOM)
- High Temperature
- High Altitude
- Down Slope
- Tail wind.

$V_{MAX\ TYRE}$ Max tyre speed: The maximum speed allowed using the speed rating of the tyres fitted.

V_2 This is sometimes called the Take of Safety Speed (TOSS) or 'Free Air Safety Speed' (FASS).
It is defined as the speed the Class 'A' or Commuter aeroplane must be able to attain at the screen height after sufferring an engine failure. It allows for the natural acceleration obtained after rotation at V_R and lifting off at V_{LOF}. As a CAS this will be the lowest safe climb speed with one-engine inoperative, that can achieve the minimum climb gradient requirements.

Class 'A' aeroplanes V_2 must not be less than:

- $V_{2\ MIN}$
- V_R plus the speed increment gained before reaching the screen height
- The speed that provides manoeuvring capability

Commuter aeroplanes

- 1.1 V_{MCA}
- 1.2 V_{S1}

V_2 is used to the point where flap retraction is initiated and is used as the flap retraction reference speed.
It will change value depending on take-off mass, density, and flap setting.
V_2 is a lower CAS than Vx or Vy and so is not the most efficient climb speed, but will meet the required minimum climb gradients.

2.2 Define $V_{2\ MIN}$.

$V_{2\ min}$ The minimum take-off safety speed. This is the lowest value for V_2 as a CAS in any environmental condition or configuration that allows for V_R plus an increment attained, before reaching the screen height with the operational engines set at maximum take-off power.

$V_{2\ min}$ not less than $1.13V_{SR}$ for;

- two engined and three engined turbo-prop aeroplanes.
- Turbo-jet aeroplanes that do not have provision for obtaining a significant reduction in the one-engine-inoperative stalling speed with power on.

$V_{2\ min}$ not less than $1.08V_{SR}$ for;

- Turbo-prop aeroplanes with four power plants.
- Turbo-jet aeroplanes that shall have provision for obtaining a significant reduction in the one-engine-inoperative stalling speed with power on.

$V_{2\ min}$ not less than 1.1 V_{MC}

2.3 V2 as defined by V_{MCA} and V_{MC}

With an engine inoperative the climb to flap retraction is flown at V_2, if this V_2 is determined to be below V_{MCA} then V_{MCA} becomes the minimum value for V_2.
Therefore: V_{MCA} also defines $V_{2\ MIN}$.
Additionally; it's worth noting that in some ambient conditions of low aerodrome pressure altitude coupled with low temperature and low aeroplane mass V_{MC} may also pose a restriction on the minimum value of V_2.

CLIMB SPEEDS

V_3 The steady initial climb speed with all engines operating, achieved by the screen height. This is the speed to which the aeroplane must naturally accelerate after V_{LOF}. Given that there is not an engine failure.

- V_3 is based upon V_2 + 10kts

V_4 The all engines steady take-off climb speed, used to a point where acceleration to flap retraction speed is initiated. V4 should be attained by a gross height of 400 feet using the scheduled techniques.

- V_4 is not less than 1.2 V_{MC}
- V_4 is not less than 1.3 V_{MS1}

LANDING SPEEDS

V_{REF} This is the speed of the aeroplane, in the specific landing configuration, at screen height, which is used to determine the landing distance for manual landings.

Class 'A' aeroplanes:

- V_{REF} is not less than 1.23 V_{SRO} or V_{MCL}

Commuter aeroplanes:

- V_{REF} is not less than 1.05 V_{MC} or 1.3 V_{SO}

3 *Aeroplane variables*

3.1 *Explain the effects of the following aeroplane variables on take off performance*

Mass - Increasing the aeroplane take-off mass (TOM):

- Increases the stalling speed, thereby increasing the take-off run
- Increases the aeroplane inertia - reducing acceleration and deceleration (ASDA increases)
- Reduces the rate of climb
- Reduces manoeuvrability and asymmetric performance

Configuration - Optimum flap/slat angles reduce the required take off distances and speeds. In general there will be one or two allowable take of flap settings.
Low flap settings give better acceleration (less drag) and better climb rates.
High flap settings give more lift and a shorter ground roll.

Reduced thrust take off - (Also termed Variable Power or Assumed Temperature take-off.) Whilst it is normally preferable to use full available power for take-off, there are occasions when less than maximum can be used safely.
The main benefit is that it extends engine life, there are also noise abatement advantages. Procedures will have strict limitations and conditions.
See CAP 698 MRJT1 page 31 to 33 for full procedures, also further explained later in these notes.

Serviceability of high lift devices - Any deviation from the recommended configuration will affect the take-off performance – increasing take off distances and speeds required.

Application of reverse thrust - Reverse thrust would only be used during an abandoned take-off and part of the "maximum retardation available:" If unavailable the stopping distance will be increased. corrections are required to allow for this.
Typically reverse thrust accounts for 10-20% of the aeroplane braking.
Only symmetrical reverse thrust is allowed in the case of a single engine failure on a multi engined aeroplane.

i. *The effect of thrust reverser on take-off mass calculations.*

'Boeing' states, for its aeroplane, that the use of thrust reverser during a rejected take-off is "free". This means that all Boeing supplied performance data has assumed that thrust reverser has NOT been used during a rejected take-off. On many Boeing aeroplane, auto-brakes are installed, and the action off pressing a Reject Take-off Button will close the throttles automatically and apply full anti-skid braking. Using the thrust reverser in these conditions does not necessarily increase the rate of retardation as the auto-brakes have been programmed with a set rate of retardation and will therefore produce less force on the brakes for the same level of overall retardation.
This, however, is not the case for all makes of aeroplane. In some cases, if a thrust reverser is unserviceable the maximum take-off mass calculations will have to be factored to account for the lose of retardation. This is because the performance data for the given length of runway available will have been calculated for a rejected take-off at V1, using all available means of

braking (lift dump, thrust reverser and wheel brakes). From this calculation, the maximum take-off mass for that runway is derived and if a single means of braking is lost, then the maximum take-off mass must be re-factored.

Brakes - The main method of retardation during an abandoned take-off.
Under normal conditions the energy absorption of the brakes will be adequate to stop the aeroplane, however conditions can exist (high ambient air temperature, down slope and tail-wind) where the capacity of the brakes can be exceeded.
In this case the take-off weight can be limited by V_{MBE}.

Use of 'Anti-Skid' devices - Braking systems have integral anti-skid devices that safely maintain braking close to the maximum available for the conditions.
If these systems are inoperative the braking distances required are markedly increased – typically by 50% . See CAP 698 page 34 for the calculations required when anti-skid is inoperative.

PMC (Power Management Computer)

Affords protection through:

1. Electronic Engine Computer (EEC)

To provide an EPR (Engine Pressure Ratio) Limitation

2. Engine Limiting Computer (ELC)

To provide an N_1 (Compressor RPM) Limitation

Either both or none are selected via the PMC.
One cannot be used without the other.

If PMC is selected 'OFF' there is a resulting reduction in power as shown on the graphs and tables in the CAP 698

Anti-icing Systems: There will be an adverse affect on aeroplane performance due to selection of 'Anti-ice' particularly in the event of an engine failure.
During the cruise and drift down calculations, adjustment must be made for 'Anti-ice on/off'

Air-Conditioning system: There will be an adverse affect on aeroplane performance when selected 'ON' due to the use of 'Bleed Air' from the engines, thereby reducing efficiency. With the reduction in the power available a lengthening of the TORR and TODR accompanied by a reduction in the climb gradient.

Bleed Air: As might be expected any other use of engine bleed air will have a performance penalty due to loss of thrust.

4 Meteorological variables

4.1 Explain the effects of the following meteorological variables on take off performance

Wind components (along and across runway). Headwind components reduce the take-off distances required, tailwinds increase them.
Both headwind component (50%) and tailwind component (150%) are factored in the performance graphs.
The aeroplane crosswind limitation should not be exceeded. See CAP 698 MRJT1 pages 1 and 4, for calculation of headwind and crosswind components.

Precipitation. The effects of precipitation on runways are covered in the previous paragraphs. The effect of precipitation on the aeroplane is not usually significant unless it results in icing conditions.
The requirement to switch on engine anti-ice systems reduces engine efficiency – and therefore thrust available.
In very heavy rain it may be necessary to operate the engines with continuous 'Igniters'
Precipitation reduces visibility especially at night. This effect can ground an aeroplane if something as simple as the windscreen wipers are inoperative!

Temperature - Ambient temperature affects the density altitude – the hotter it is the thinner the air. A look through the CAP 698 performance graphs will show that most include an adjustment for Outside Air Temperature (OAT). It affects the mass air flow and therefore thrust, and as density is a part of the lift formula it can be seen that a reduced density reduces lift.

Humidity - Increasing humidity reduces air density (water molecules are less dense than oxygen and nitrogen molecules). Increasing humidity therefore will reduce take off performance.

Pressure Altitude – This is the altitude reading with 1013 set on the altimeter subscale. The altitudes in the graphs of the CAPs are pressure altitudes.
Increase in pressure altitude will increase TODR.

Wing icing - The effects of airframe icing due to increased weight and reduced aerodynamic efficiency can seriously affect the performance of the aeroplane.
Even relatively thin accretions of airframe ice have been known to cause accidents on take off. **All ice should be removed**.
De-icing and anti-icing systems may not be available for the take-off due to the use of the engine bleeds, causing a reduction in engine power.
On some aeroplanes they can be used during taxi but switched off for the take-off, then on again in the climb.

Windshear - Term used to describe the variation of wind-speed and direction with height. Many factors can cause the variation of wind with height.
Wind speed can change suddenly by a significant amount and a large decrease in headwind component will adversely affect the take off performance.

5 *Take off speeds*

5.1 Explain the significance and applicability of the take off and initial climb 'V' speeds for specified conditions and configuration, for all engines operating and one engine inoperative

In the CAP 698 calculation of the V speeds is set out on MRJT1 page 17.
As there will be an environmental issue to account for in regard to the V speeds, a 'Density Sub Graph' is provided to determine which columns to use; A, B, C, D, E, or F of the tables on the following pages.
Corrections and adjustments for brake energy limit V_{MBE} are detailed on MRJT1 pages 14 & 15 remember that V_1 should never exceed V_{MBE}.
Page 16 details adjustment to the V_1 for Clearway & stopway being present it reminds us that the CAP698 assumes a balanced field! At the foot of the lower table it also reminds us that:

'In no circumstances may V_1 be less than the V_{MCG} nor may it exceed V_R or V_{MBE}'.

MRJT1 pages 24 to 27 contain advisory information about contaminated runways, water & slush.

All applicable to a take-off where the critical engine fails at the worst possible moment - V_1

5.2 State V1 , VR , V2 , V2 + increment , V4, landing gear and flap/slat retraction speeds

V_1 - is the decision speed and depends on many factors. CAP 698 MRJT1 pages 17, 18 and 19 give the basic V_1 speed. Allowing for balanced field, OAT, pressure altitude, weight, runway slope and wind component.

V_R - varies with aeroplane weight, for a given weight, altitude and temperature V_R is virtually constant.
The V_R is relevant for an all-engines-take-off <u>or</u> if a critical engine failure occurs after V_1 but before V_R.
V_R values can be found on MRJT1 pages 18 to 19 of CAP 698.

V_2 - is the minimum speed required at the screen height of 35 feet. assuming a critical engine failure. It is also used as the reference speed for flap/slat retraction.
V_2 values can be found on MRJT1 pages 18 to 19 of CAP 698.

V2 + Increment. CAP 698 MRJT1 pages 28, 29 & 30 detail the procedure for increasing V2 to improve the climb gradient or increase the take-off weight.
This is only applicable if there is excess field length over that which is required.

Landing Gear Retraction: The landing gear is normally retracted as the aeroplane accelerates during the **"First segment"** of the climb.
The penalty for late retraction will be a reduced acceleration due to the additional parasite drag.

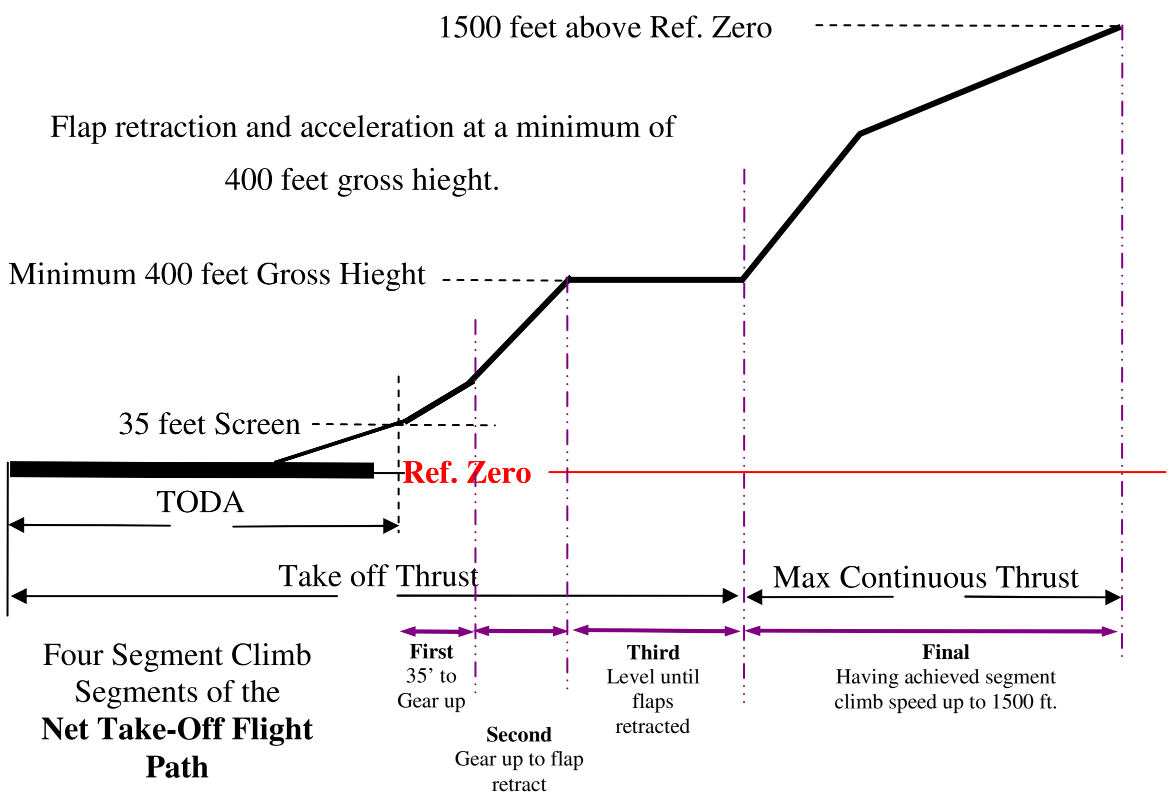
Flap/Slat Retraction : There is a legal requirement that the aeroplane configuration (apart from undercarriage) and thrust setting even allowing for the use of water methanol, cannot be changed until the aeroplane is at a Gross height greater than 400 feet above the take-off surface and **Reference Zero.**

- For all engine operation the aeroplane will be at V_4 (all engine steady initial climb speed) as it passes 400 feet gross.
- With a critical engine inoperative the aeroplane will stay at take-off flap whilst the aeroplane is flown at V_2.
- The time, and height attained, during the V_2 phase can vary between 400 feet and the position the aeroplane can achieve at maximum take-of thrust:

Not more than 5 minutes from the break release point.

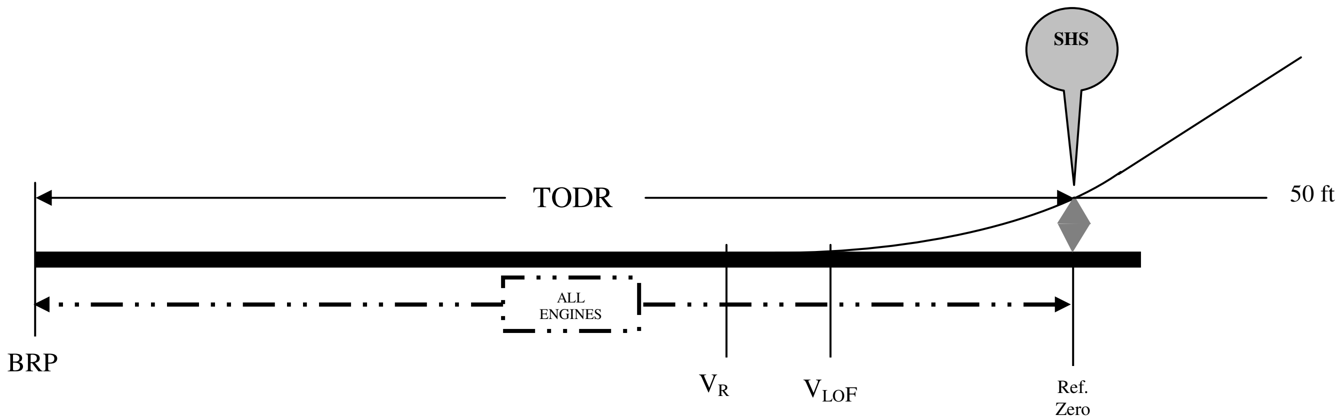
- V_2 is always used as the reference speed for calculating the flap retraction speeds, (e.g. V_2 + 20 kts), the aeroplane will be accelerated to the appropriate speed before retraction is initiated.
- In some performance manuals, V_2 is also used as the reference speed for all the speeds used during the climb to 1,500 ft.

Typical Take-off Climb Segments for a Turbo-Jet aeroplane are illustrated below and will be covered later in more detail.

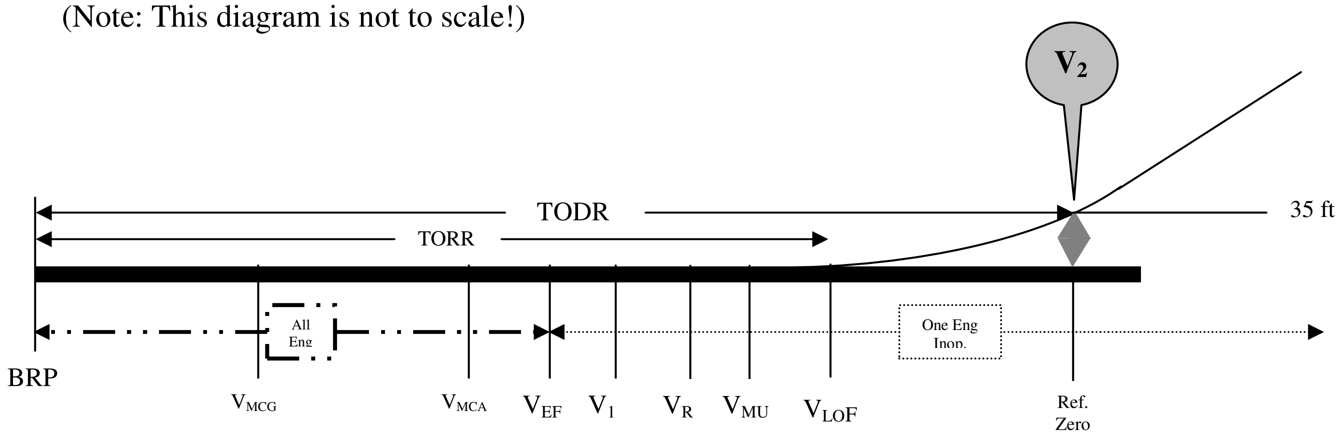


It is useful to compare the take-off speeds for both classes of aeroplane. Note the order in both cases – just in case you are ever asked!

The Take-off CLASS 'B'
(Note: This diagram is not to scale!)



The Take-off CLASS 'A'
(Note: This diagram is not to scale!)



5.3 Summary of upper and lower limits of the take off speeds V1 , VR and V2

V_1 cannot be less than V_{MCG}, or greater than V_R or V_{MBE}

V_R must be greater than V_1, Field length limitations will determine the maximum V_R, tyre speed limitations may also be relevant.

V_2 can vary between that required to attain the legal clearance at screen height and the maximum increment to achieve obstacle clearance. (see CAP 698 MRJT1 page 28).

5.4 State the reaction time between engine failure and recognition

The time allowed between an engine failure occurring and it being recognised is **2 seconds**. The point at which it is recognised is when the pilot takes the first action to deal with the emergency, CAP 698 MRJT1 Page 7.

5.5 Elaborate on factors which affect V_2

The value of V_2 will be governed by: Pressure altitude, OAT and aeroplane weight.
V_2 can be increased when there is runway available to achieve the higher speed (i.e. not Field Length limited), this allows for an increase in take-off weight or improves the second segment climb gradient - and therefore obstacle clearance.
The increased V_2 procedure is detailed on CAP 698 MRJT1 Pages 28, 29, and 30.

5.6 State mass, temperature, elevation and the effect on flap setting

Inspection of the take-off performance charts shows that the 15° flap setting has the effect of increasing the Field Limit take-off weight compared with the 5° setting.
However 15° of flap reduces the climb limit take-off weight. The ambient temperature and airfield elevation (pressure altitude) affect both the Field and Climb limit weights.
The decision on which flap setting to use will depend on the requirement to reduce the take-off run compared with the necessity to achieve climb performance.

5.7 Explain the effect of pressure altitude on V_{MCA}

V_{MCA} is the speed at which, in the event of an engine failure, the forces from the control surfaces are *just sufficient* to balance the yaw moment of the asymmetric engine thrust and maintain control of the aeroplane, within the stated parameters.
With increasing altitude the density of the air is reducing and therefore the control effectiveness is reduced.
At the same time the engine power is reduced giving less yawing moment.
The engine loss is greater than control loss therefore:

- **V_{MCA} is decreased with an increase in pressure altitude.**
- Note also that: **V_{MCG} is also decreased for the same reason.**

Take a look at CAP 698 MRJT1 pages 18 and 19 and check the V_{MCG} speed tables for temperature and pressure altitude, the table appears again on page 34.

5.8 Explain the effect of increasing altitude on the stall speed (IAS)

The Indicated airspeed at which an aeroplane will stall remains constant ($\frac{1}{2}\rho V^2$). Until at high altitudes and mach numbers, when it increases because of compressibility effects.

5.9 Explain the effect of slope on V_1

Take a look at CAP698 Fig. 4.8 or Fig. 4.9 which shows a reduction of 3Kts for a 2% down slope at 70,000 Kgs.

5.10 Explain the effect of changes in Mass, Flaps and pressure altitude on V_2

Take another look at CAP698 Fig. 4.8 or Fig. 4.9 which shows a permitted reduction in V_2 for a reduction in Mass.
An allowable reduction in V_2 for an increased flap setting from 5° to 15°.
Only small changes of V_2 are tabulated for changes in pressure altitude and temperature.

6 Take off distance

6.1 Explain the significance and applicability of the take off distances for specified conditions and configuration for all engines operating and one engine inoperative

The TODA is published in planning documents and will only change if there is a change to the runway. (e.g. change in runway length or change to clearway dimensions.) The TODR is calculated using the particular variables relevant to each take-off.
The resultant TODR will account for the possibility of an engine failure, to ensure that the take off can be accomplished safely.

The influence of 'Aeroplane Variables' is as follows:

Take off Weight: Increasing weight will result in increasing TODR due to the following:

- Force = Mass x Acceleration. Therefore with fixed engine power an increase in mass will reduce acceleration.
- Increased weight increases wheel friction, which resists acceleration.
- The higher the weight, the higher the stalling speed – and therefore the lift-off speed.
- At higher weights the rate of climb reduces, therefore the distance required to achieve screen height is greater.

Flap settings:
Take-off flap settings 5° and 15° as in CAP 698 MRJT1 reduce the stalling speed and therefore the lift-off speed.
Above these settings the lift/drag ratio will become unfavourable, Drag will significantly increase whilst the lift benefits are comparatively small.
The effect on take off is that the aeroplane accelerates more slowly – and therefore requires a greater distance to achieve the V speeds – leading to a greater TODR.
Recommended settings will give optimum take-off performance.

The influence of 'Runway Variables':

- **Runway length & Clearway:** TODR cannot exceed TODA
- **Slope:** Up-slope increases TODR but down-slope decreases TODR.
- **Pressure Altitude / Airfield elevation:** Increasing Pa. = Inc Da = Inc TODR

The influence of 'Meteorological Variables' is as follows:

- **Wind:** Increasing headwind decreases TODR
- **Temperature:** Increasing temp. = Inc Da = Inc TODR
- **Humidity:** Increasing humidity. = Inc Da = Inc TODR

(Please note: Da = Density Altitude and Pa = Pressure Altitude)

6.2 The effect of early/late rotation of the aeroplane

V_R is calculated as the point where the aeroplane has accelerated to an appropriate speed for take off and the requirements to achieve V_2 at screen height are met.
Rotating the aeroplane at any other speed will result in an increased TODR - which may then exceed the TODA!

Rotating before V_{MU}: will result in the aeroplane remaining on the runway on the main wheels until a lift-off speed is reached, the increase in drag caused by the nose-up attitude will reduce the aeroplane acceleration and additional runway will be required.

Rotating before V_R: will get the aeroplane airborne earlier, however the reduced airspeed and acceleration will result in a shallow climb angle and the required screen height may not be met.

Delaying rotation: holding the aeroplane on the ground until a speed higher than the calculated V_R will use more runway before lift off.
The subsequent climb angle may provide better middle distance obstacle clearance (see Increased V_2 procedure) however the height at the screen and near distance obstacles may be adversely affected.

6.3 The effect of too high and too low rotation angle

The correct attitude (rotation angle) that is required for aeroplanes of a particular type to leave the ground will be the same for all masses with adjustments made in the speeds determined from the performance calculations. It is fundamental that rotation is achieved at the correct speed, rate and attitude (rotation angle).

6.4 The effect of too high and too low rotation rate

If the aeroplane is rotated at too high a rate (a sudden and fast rotation) than that required by the conditions and configuration, it can lead to the stall condition due to the high angle of attack at low speed. There is also the possibility of a tail strike.
The gradient and rate of climb will be poor at speeds close to the stall and if the take-off is abandoned an increase in the stopping distance is most likely.

If the rotation rate is too low (a lazy and slow rotation) even if at the correct speed and perhaps slowly adopting the correct attitude, this will badly affect the scheduled performance calculations, such as to make them null and void!
A longer than expected distance will be travelled down the runway and toward the ends of all the declared distances and putting the aircraft closer to any obstruction in the take-off flight path.

6.5 Explain the effect of using clearway on the TODR

The Take-off field length limit graph Fig 4.4, in CAP 698 MRJT1 page 9 assumes that there is no stopway or clearway and Para. 2.1 on MRJT1 page 9 explains the implications.
Adjustments to V_1 for maximum allowable clearway are on MRJT1 page 16 with an explanation in para. 2.5.
The existence of a clearway affects the length of the TODA, it increases the distance available for the aeroplane to achieve screen height.
Without a clearway, screen height must be achieved as the aeroplane over-flies the upwind end of the runway.

With an increase in TODA (using a clearway), the TODR can be adjusted, which may allow an increase in take-off weight.

6.6 Explain the effect of miscalculation of V_1 on the TODR

The TODR is calculated on the basis that an engine fails at V1.

V_1 is less than the optimum:
If an engine fails the take-off might be continued when it should have been abandoned. In which case the aeroplane may not attain screen height by the end of the TODA.

V_1 is higher than the optimum:
Assuming that the correct V_R is used, a continued take-off should be achieved safely. However, if any attempt to abandon the take off is made at or before V_1 the aeroplane could be travelling too fast to stop by the end of the ASDA.

6.7 Explain the effect of using a higher or lower V_1 than the balanced V_1 on the TODR

When the planned take-off weight is neither field limited nor obstacle limited, V_1 may be raised or lowered to suit operating conditions – within the restrictions imposed by the TORA, V_{MCG}, V_R and V_{MBE}.
If V_1 is increased the TODR must remain within the TODA. The presence of clearway may allow an increase in V_1.
Reducing V_1 may ensure that the aeroplane will achieve screen height within the TODA.
However it should be remembered that the lower limit is set by the ability of the remaining engine(s) to accelerate the aeroplane to the correct V_R and V_2 . The upper limit is set by the ability to stop the aeroplane within the ASDA and brake energy limits.
This procedure can provide for a 'Range of V_1's' to be available.

6.8 Explain the effect of miscalculation of V_1 on ASDA

The ASDR is calculated on the basis that an engine fails at V_1.

V_1 is less than the optimum:
An abandoned take off will not require the full stopping distance available.

V_1 is higher than the optimum:
An abandoned take off may over-run the end of the runway, ASDA will have become inadequate.

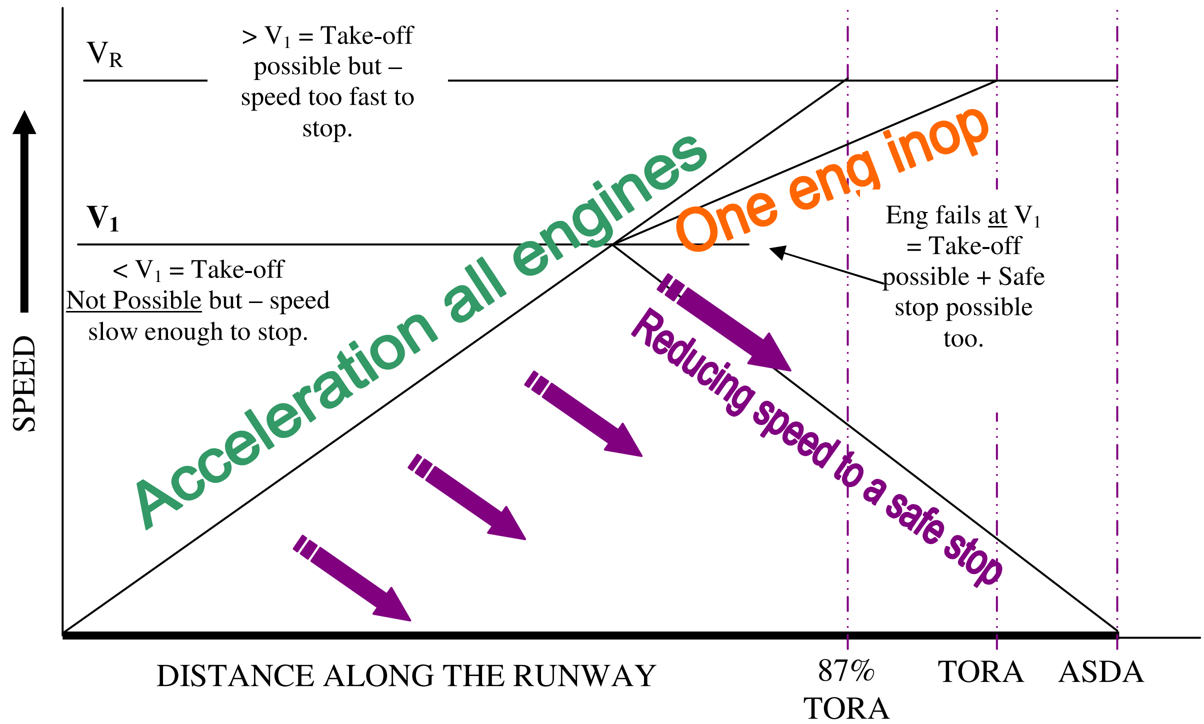
6.9 Explain the effect of using a higher or lower V_1 than the balanced V_1 on the accelerate-stop distance and action(s) to be taken in case of engine failure below V_1

When the planned take-off weight is neither field limited nor obstacle limited, V_1 may be raised or lowered to suit operating conditions – within the restrictions imposed by the available runway length, V_{MCG}, V_R and V_{MBE}.

If V_1 is increased the ASDR must not be greater than ASDA.
The presence of a stopway *may* allow an increase in V_1.

Reducing V_1 will ensure that the aeroplane will stop within the ASDA.
When an engine failure is recognised prior to V_1 the take-off should be abandoned using standard procedures.
(Maximum wheel braking, ground spoilers and reverse thrust applied as soon as possible.)

The following diagram helps to illustrate some of the parameters of V_1



Note that 87% TORA refers to EU-OPS 'All – engines operating' being 115% of take-off distance travelled. CAP 698 MRJT1 page 7.

7 Accelerate-stop distance

7.1 Explain the significance and applicability of the accelerate-stop distance for specified conditions and configuration for all engines operating and one engine inoperative.

The ASDA is published in planning documents, and will only change if there is a change to the runway length or change to stopway length.

ASDA = TORA + Stopway (if Available)

The ASDR is calculated using the particular variables relevant to each take-off

7.2 Explain the influence of aeroplane, runway and meteorological variables

The influence of the 'Aeroplane Variables':

- **Take off Weight:** Increasing weight = increasing ASDR
- **Flaps down (within take off limits):** = decrease ASDR

The influence of 'Runway Variables':

- **Runway length & Clearway:** ASDR must not exceed ASDA
- **Slope:** Up-slope decreases Stop distance and down-slope increases ASDR.
- **Pressure Altitude / airfield elevation:** Inc Pa. = Inc Da = Inc ASDR.

The influence of 'Meteorological Variables':

- **Wind:** Increasing headwind decreases ASDR
- **Temperature:** Increasing temp. = Inc Da = Inc ASDR.
- **Humidity:** Increasing humidity. = Inc Da = Inc ASDR

(Da = Density Altitude and Pa = Pressure Altitude)

7.3 Explain the effect of using a stopway on the ASDR

The Take-off field length limit graph Fig 4.4, in CAP 698 MRJT1 page 9 assumes that there is no stopway or clearway and paragraph 2.1 of page 7 explains the implications.
The existence of stopway affects the length of the ASDA, it increases the distance available for the aeroplane to stop following an abandoned take-off.
Without a stopway, the aeroplane must stop by the upwind end of the runway.

With an increase in ASDA, the ASDR can be adjusted, which may allow an increase in take-off weight.

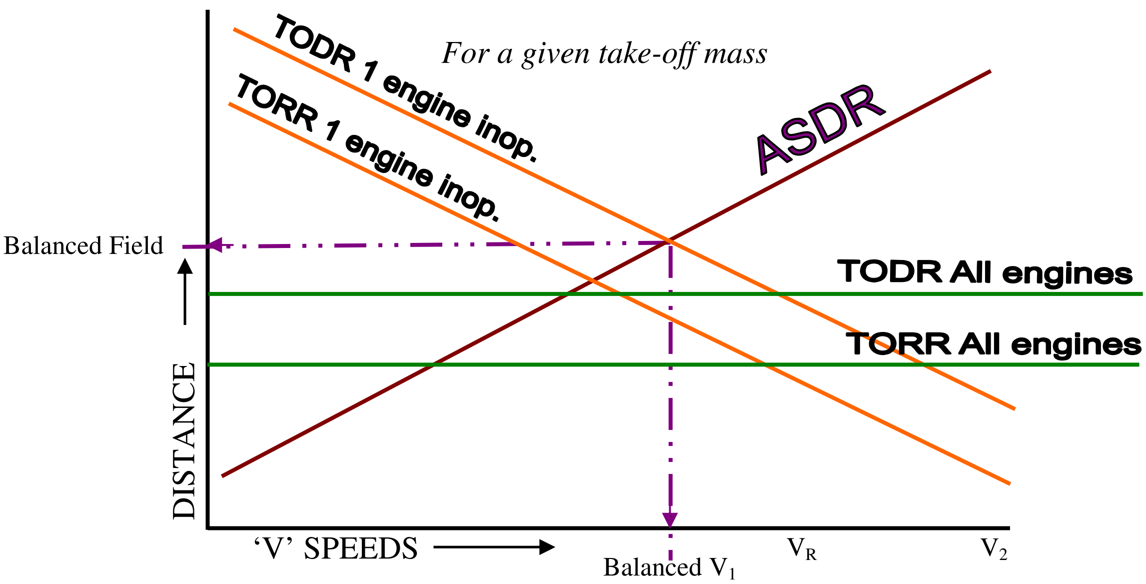
8 *Balanced and unbalanced field lengths*

A balanced Field is when ASDA is equal to TODA (i.e. Clearway = Stopway **or** no Clearway or Stopway).
Any other combination of clearway and stopway will be an Unbalanced Field.

The graphs, for a balanced field are simplified, however if these are used when the field is unbalanced (by reducing TODA to equal ASDA), the resultant T/O mass will be less than if the additional distances are taken into account.

The following graph illustrates take-off distances required as a function of V_1. It shows that a minimum distance is achieved at a particular speed, known as 'Balanced V_1'. The distance corresponds to 'Balanced Field' found at the bisection of one engine inoperative TODR and ASDR.

If the TODR and ASDR are greater than the equal value of TODA and ASDA the take-off mass will have to be reduced.



Increased V_1	TODR and TORR	REDUCED
Increased V_1	All engines acceleration phase is longer therefore V_2 achieved in a shorter distance to Ref Zero.	

<u>However</u>

Increased V_1	ASDR	INCREASED

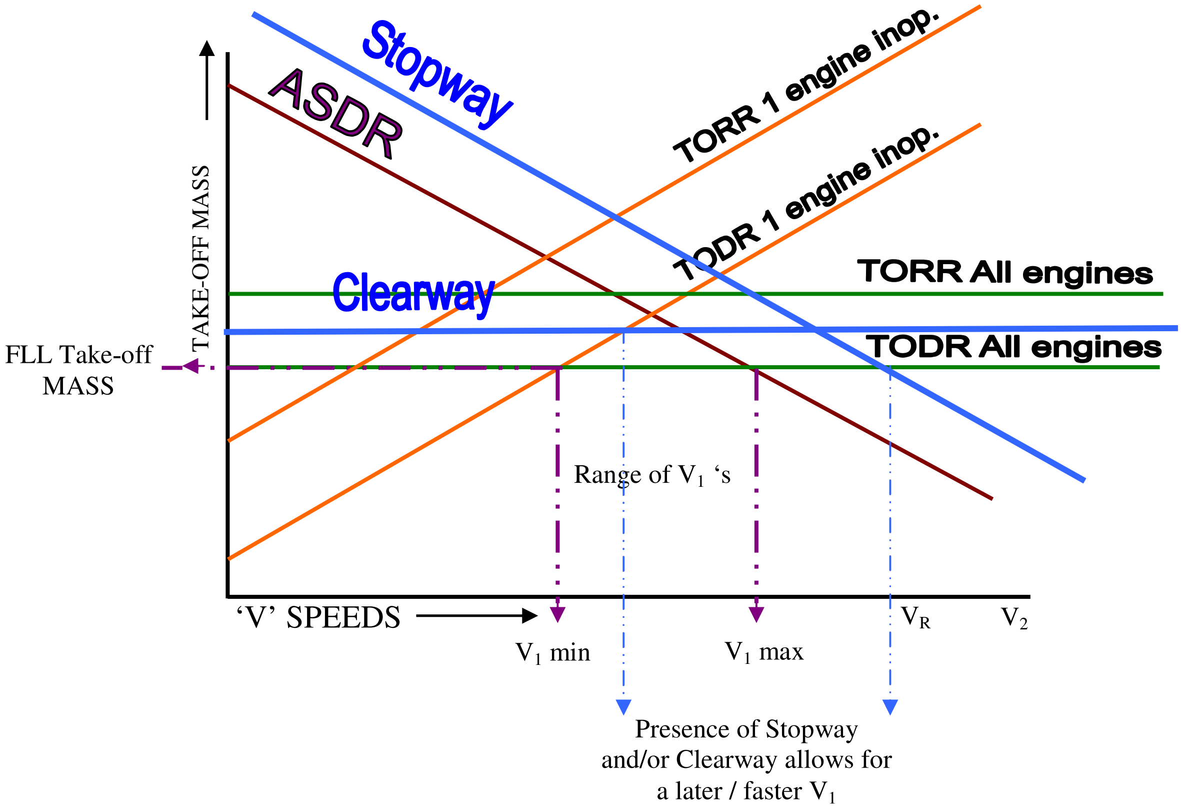
Note that the 'all engines' TODR and TORR are <u>not related</u> to V_1 as there is no consideration of an engine failure!

8.1 Unbalanced Fields using balanced field graphs and tables

To achieve the maximum T/O mass for an unbalanced field, corrections for the clearway and stopway must be applied - see CAP 698 MRJT1 page 7 para. 2.1 and also page 16.

8.2 Explain the effect of a stopway on the allowed take off mass and appropriate V_1

For a fixed T/O mass, the presence of a stopway allows for a later V_1 - a take off can be abandoned later because there is more distance available to stop.
It may allow for a range of V_1 speeds for a given take-off weight.
If the T/O mass might be limited by field length if no stopway were available, the increase in ASDA provided by a stopway would allow an increase in T/O mass and V_1.



8.3 Explain the effect of a clearway on the allowed take off mass and appropriate V_1

For a fixed T/O mass, the presence of a clearway allows for a later V_1 - there is more distance available to achieve the screen height and V_2.
It may allow for a range of V_1 speeds for a given take-off weight.
If the T/O mass is limited by field length without clearway, the increase in TODA provided by a clearway allows an increase in T/O mass.

8.4 State relation of take off distance, accelerate stop distance and V_1

For a balanced field, longer take-off distances and accelerate/stop distances will allow an increase in maximum V_1.
The presence of a stopway only will increase the distance that the aeroplane has for an abandoned take-off, therefore it can achieve a higher V_1 and still stop within the distance available.

8.5 Elaborate on the runway length limited take-off mass (RLTOM)

A safe take-off requires the aeroplane to leave the ground within the TORA and reach V2 and 35 feet within the TODA. If there is a short runway and maximum clearway, the length of pavement available may be more restrictive on the take-off weight than the field limit.
In this case the TORR must be within the TORA.

The requirement to individually consider TORA, ASDA and TODA is only applicable to unbalanced fields.

8.6 Explain the effect of runway slope on V_1

We have mentioned this on previous pages in these notes but again looking at CAP698 Fig. 4.8 or Fig. 4.9 which shows a reduction of 3Kts for a 2% down slope at 70,000 Kgs.

Remember too, that if you have down slope it becomes more difficult to stop within the ASDA so any extra speed is a disadvantage!
Recall that V_1 is also derived in consideration of the ability to stop within ASDA and also to be fast enough to achieve the minimum value of V_2 by screen height.

Chapter 15 CAP 698 and deceleration within ASDA

1 Determination of ASDA, decision time and deceleration procedures.

CAP 698, MRJT1 Fig 4.4 page 9 can be used to determine the field length limit.
As the TORA, ASDA and TODA are assumed to be equal, the ASDR for a particular take-off weight can also be found from the chart.
On page 7 the Field Length Requirements are given, note the decision time is assumed to be 2 seconds from the power unit failing to initial actions being taken.
Deceleration procedures will vary between aeroplane type and are detailed in operating manuals.
Procedures will always aim to stop the aeroplane in the shortest distance - using maximum possible retardation.

1.1 Explain time-to-decide allowance, use of brakes, use of reverse thrust, brake energy absorption limits, delayed temperature rise and tyre limitations - fuse plug limit

The 'time-to decide allowance' is relevant to the stopping distance, as continued take-off procedures for all engines and with one failed are essentially the same up to achieving V_2. The 2-second allowance is in the calculation of the accelerate-stop distances.

The calculation of stopping distances will assume that:

- Maximum available braking is applied.
- The anti-skid system is operative.
- The thrust reverser on the failed power unit is not available. The remaining thrust reversers must be used symmetrically.

The capacity of the wheel brakes should be adequate for most circumstances. The chance of a V_{MBE} limitation is increased when a combination of the following factors exists:

- High pressure altitude - (Increased approach speed)
- High ambient temperature - (Increased approach speed & reduced heat dissipation)
- High landing weight - (Increased approach speed)
- Downhill slope - (Increased landing run)
- Tailwind – (Increased approach speed and landing run)

Following a landing the maximum temperature that the brake units will reach will occur well after the aeroplane has parked, typically around 15 minutes later.
The Brake Cooling Schedule CAP698 MRJT1 Fig. 4.31 page 50 is used to avoid brake overheat problems.
Thermal, or fusible, plugs are fitted to wheels with tubeless tyres.
The temperature of the inflation gas in the tyre will rise during prolonged taxiing and heavy braking, which could ultimately burst the tyre.
The thermal plugs melt if the gas temperature rises above a set figure, allowing the tyre to deflate.
If the temperature reaches a high figure (but not enough to melt the plug,) which causes damage to the tyre, the plugs protrude to indicate that replacement is necessary. It must be noted that the plugs do not protect against a burst if the tyre has been over-inflated!

Correct operation is <u>temperature sensitive</u> not pressure!

1.2 Explain the effect of anti-skid 'unserviceable' during take-off

The anti-skid is relevant to the abandoned take-off part of the V_1 calculation. The anti-skid makes a big difference to the effectiveness of the brakes, typically increasing braking distances by 30-50% if inoperative.
The procedure for applying corrections is on CAP698 MRJT1 page 34. It should be remembered that: **full anti skid braking is the most efficient way of stopping an aeroplane.**

1.3 Ground Spoilers and Lift Dumpers

The purpose of spoilers is to destroy lift whilst increasing the drag for the same angle of attack. You may have already seen in the study of Principles of Flight that the spoiler is basically an arrangement of flat plates mounted on the upper surface of the wings, on deployment; they stand upward into the airflow thus destroying the lift.
Dependant on design, some are engaged by the pilot, others may have automatic deployment.
One aspect of the ground spoiler or lift dumper is that sensors in the undercarriage (Squat switches) enable the ground spoilers *only* to be deployed when the aircraft has landed or is on the ground prior to take-off.
Destruction of the lift places the whole mass of the aeroplane firmly onto the undercarriage. This increases braking efficiency.
During landing when the aeroplane is still moving at high speed, the lift dumpers also reduced the possibility of the aeroplane becoming airborne again, in gusty conditions.

In an abandoned take-off correct procedures should be followed in the use of ground spoilers to help stop the aeroplane within the distances available.

1.4 Explain the effects of runway, aeroplane and meteorological variables on the tyre speed limited take off

Runway variables:

None are listed in the CAP, the limitation depends on aeroplane speed only.
However, tyres are often re-treads and a prudent commander will take account of the quality of the runway surface.

The Take-off tyre speed limited procedure and graph Fig. 4.6 can be found in CAP 698 MRJT1 pages 12 and 13.

Aeroplane Variables:

- Take-off mass: The higher the TOM, the higher the speed required for take-off.
- Flap setting: Higher approved flap increases the TOM. (Reduced lift off speed.)
- Tyre speed rating: Higher speed ratings allow for increased TOM.
- PMC On / Off: PMC ***ON*** increases TOM and PMC *OFF* decreases it.

Meteorological Variables:

- Headwind / Tailwind: Headwind increases TOM, tailwind reduces it. (Affects ground speed.)
- Airfield pressure altitude: Increasing altitude reduces the Tyres limited TOM. (Density alt.)
- Ambient temperature - Increasing temperature reduces the Tyres limited TOM. (Density alt.)

Chapter 16 Initial climb

1 *Define gross,- and net take-off flight path with one engine inoperative*

The 'Gross Take off Flight Path' is that which an average aeroplane, of that type, should achieve under a particular set of conditions.
We cannot plan on always being in an aeroplane that will meet or exceed the average performance so a factor is applied.

This factor reduces the "gross gradients" by a fixed amount, these are then referred to as "net gradients."

This is the minimum standard of performance and is based on an incident probability rate of one in a million (= 1 : 1,000,000).
It is a legal requirement that all performance planning should be conducted to net performance considerations.

The JAR factor for converting to net gradients, for a two engine jet aeroplane, is to reduce gross gradients by 0.8%.

The most restrictive conditions during climb-out will be following the failure of a critical power unit, therefore all climb-out planning is done assuming that this has occurred.

Gross Gradients: Govern the time spent in each climb segment.
They are used to determine the '**Actual Heights'** at which transition from one segment to another occurs.

Net Gradients: Used for plotting the net flight path for obstacle clearance, a net gradient is considered to be the worst case.

1.1 *State distinct differences in climb gradient requirements for various types of aeroplanes during climb-out*

JAR/CS 25 regulations require minimum gradients that must be achieved during the take-off and climb-out, with all engines operating, or with one engine inoperative.

CLIMB GRADIENTS FOR DIFFERENT AEROPLANE TYPES					
Flight Phase	**Configuration**	**Number of Power plants**	**Min Gradient Required**		
			Gross	**Gross to Net Factor**	Net
1^{st} Segment	Take-off thrust set, from lift off to gear up, T/O flap setting, V_{LOF} to V_2.	***2 Engines***	***-0.8 Positive rate of climb***		
		3 Engines	0.3%	-0.6	Positive at all points
		4 Engines	0.5%	-0.5	
2^{nd} Segment	Steady climb, Take-off thrust set, Gear up, T/O flap setting, V_2, Outside ground effect (Height > wingspan)	***2 Engines***	***2.4%***	***–0.8%***	***1.6%***
		3 Engines	2.7%	–0.9%	1.8%
		4 Engines	3.0%	–1.0%	2.0%
Final Take-off climb	Steady climb Final climb speed (not less than 1.25 V_S), Maximum continuous thrust set. Flaps & Gear up.	***2 Engines***	***1.2%***	***–0.8%***	***0.4%***
		3 Engines	1.5%	–0.9%	0.6%
		4 Engines	1.7%	–1.0%	0.7%

The third segment is a level/acceleration segment. Gradients are those used for final segment but must be an equivalent attainable to allow for acceleration.

2 *Variables on determination climb and obstacle limited take-off mass.*

2.1 CLTOM (Climb Limited Take-off Mass):

Runway variables:
None, the take off climb graphs (CAP698 MRJT1 Fig. 4.5 page 11) do not account for the variations in runway length or slope.
However, if take of mass is limited by obstacle or climb limit considerations, an increased V_2 will allow a better CLTOM and OLTOM.
This can only occur if the mass is not runway length limited.

Aeroplane Variables:
- ***T/O Weight*** - Increasing weight increases take-off distance (reducing the horizontal distance between the lift-off point and the obstacle) and reduces the rate of climb.
- ***Flap setting & Retraction heights*** **–** Whilst increased flap reduces the take-off run and speeds, it also reduces climb gradients. Using the same parameters on both the 5° and 15° of flap graphs will show that the obstacle-clearance weight at 5° is appreciable higher than at 15°.

The minimum height for flap retraction is 400 feet gross.

- ***Air conditioning packs on / off*** - Packs off allows higher take-off weight, or a better gradient at a lower weight.
- ***Engine Anti-icing on / off*** - Anti-ice on reduces take-off weight, and reduces the gradient.
- ***PMC on /off*** - PMC off reduces take-off weight.

Meteorological Variables:
- ***Headwind / Tailwind*** - Headwind improves the angle of climb, tailwind reduces it.
- ***Airfield pressure altitude*** -Increasing altitude reduces the CLTOM. (Increased density alt.)
- ***Ambient temperature*** - Increasing temperature reduces the CLTOM. (Increased density alt.)
- ***Humidity*** - Increasing humidity reduces the CLTOM. (Increased density alt.)

2.2 OLTOM (Obstacle Limited Take-off Mass) :

Runway variables:
- ***Runway length / Take off Distance:***

Obstacles in the take off flight path are measured in distance and height from a point on the surface; called Reference Zero.
- ***Reference Zero.***

It is a point **'on the surface'** at the end of the published TODA and will be 35 feet below an aeroplane which is field length limited (TODR = TODA).
If the maximum T/O weight is limited by something other than field length, then less of the TODA is used. In which case the aeroplane gets airborne sooner and this effectively makes the obstacle further away, having moved Ref. Zero back toward the brake release point.
If the whole of the TODA is *not* used, then improved second segment climb gradient can be achieved using the Increased V_2 procedure, see CAP 698 MRJT1 page 28.

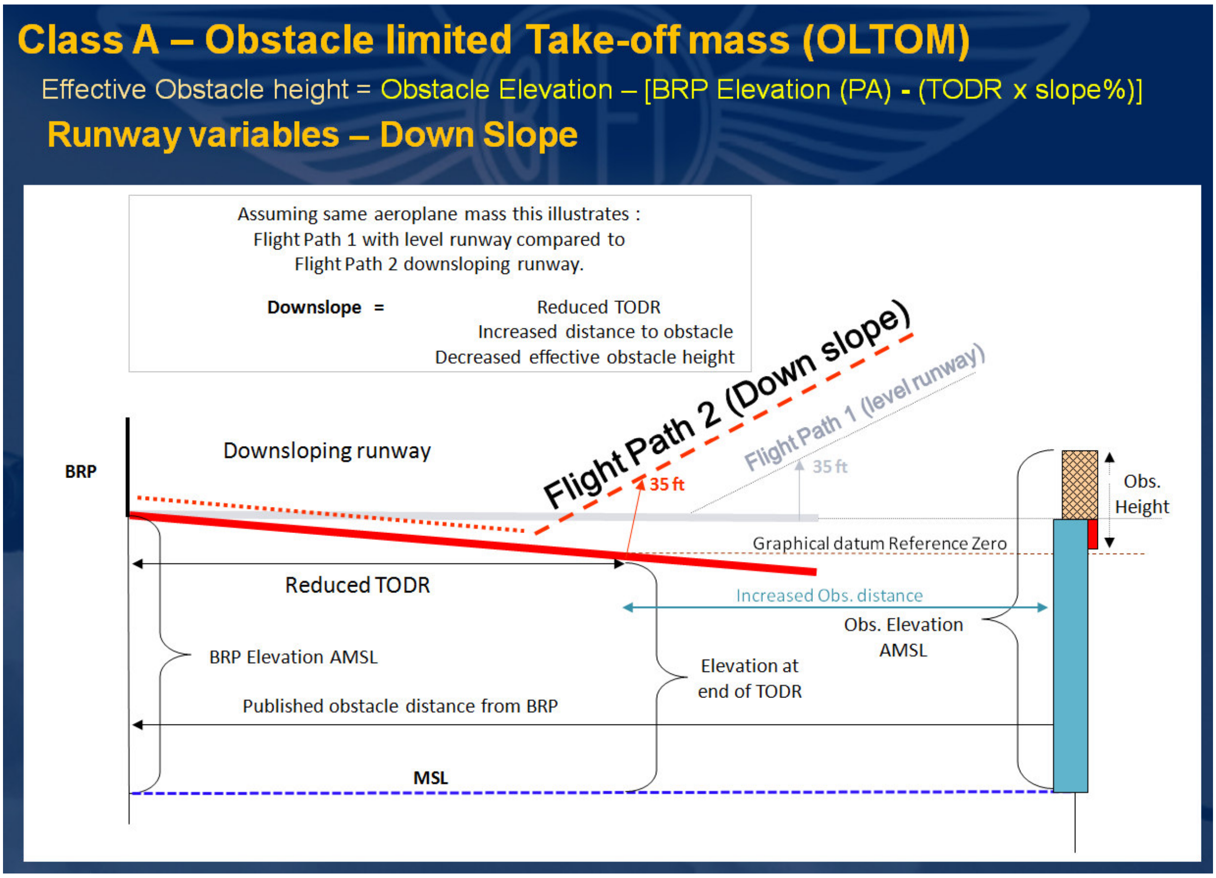
- *Runway Slope:*

The effect of slope is two-fold; it affects the take-off distances required and changes the effective obstacle height relevant to the flight path.
Down-slopes always have an advantageous effect on take-off performance, up-slopes have the potential of causing a dangerous situation if not properly accounted for.

Slope will alter the field length required, down-slope for example has the effect of reducing the TORR, TODR.
In this case the aeroplane has become airborne earlier and therefore effectively increased the distance from any obstacles, that might be assessed as a distance from the end of TODA.
Additionally the elevation of the BRP will not be the same as the elevation at Ref. Zero when there is a sloping runway, so there will also be a need to account for the runway elevation at the end of TODR. Remember too, that the NTOFP is referred to Ref. Zero, not AMSL.

The diagram below illustrates that the aeroplane taking off at Flight Path 1 with downslope, will clear the obstacle by a greater amount. In some performance calculations this is accounted for as a change in the effective height of the obstacle.
A down-slope effectively reduces the obstacle height and an up-slope increases it.
This can be remembered by:

Downslope downsize the obstacle - Upslope upsize the obstacle



In regard to Class 'A' the maximum average slope permitted for use on runways for large aeroplanes CS25 is 2% (*in the UK only 1%*)

In CAP698 the method of determining the effects of slope; is to find the Pressure Altitude of Reference Zero (RZ). Then to find the obstacle height above RZ, and using these values to enter figure 4-20 or 4-21 to find the Obstacle limited Take-off mass.

The obstacle chart procedure CAP 698 MRJT1 Page 35 to 37 accounts for runway slope as given in their example on page 35.

The CAP uses the following formula:
Note that there is no correction for upslope:

Obstacle Elevation - [Aerodrome Pressure Altitude – (TODR x Slope)]

1160 ft – [1,000 ft – (10,000 ft x 2%)] = **360 ft.**

The 360 ft is the entry argument for Figure 4-20 as the example states 'Flaps 5º'. In the CAP698 they are using aerodrome pressure altitude rather than the pressure altitude of reference zero.

The example in CAP698 shows only a limited amount of information, so included here is a further illustration on how some of these figures can be derived:

To find the 'Obstacle Height values for entry into Figures 4-20 or 4-21 to account for the slope the following routine is adopted:

I. Find elevation of Reference Zero:

BRP Elevation – (TODR x Slope)

II. Find PA of Reference Zero:

RZ Elevation + [(1013-QNH)x30)]

III. Find obstacle Height above Reference Zero

Obstacle Elevation- Elevation of RZ

As an example:

The BRP elevation at an aerodrome is 1000 ft with a TODR of 6400 ft. There is 2% down slope.
The obstacle elevation is 1300 ft and the QNH is given as 993 hPa.

Find:

Question 1. Elevation of RZ
Question 2. PA of RZ (*The 'PA' entry argument for the graph*)
Question 3. Obstacle Height above RZ (*The 'Height' entry argument for the graph*)

Elevation of RZ : 1000 – (6400 x 2%) = **872 ft**

PA of RZ: 872 + [(1013-993)x30)] = **1472 ft**

Obstacle Height above RZ 1300 – 872 = **428 ft**

This is the entry argument for figures 4-20 or 4-21 along with the values of:
OAT, Aerodrome Pressure altitude and Wind and distance from brake release to find the 'Graphical Obstacle Limited Mass'

Corrections for Power Management Computer (PMC) on or off must be applied to obtain the 'Corrected Obstacle Limited Take off Mass'.

EXAMPLE 8 Take-off Performance (OLTOM) MRJT1

Finding the Obstacle limited TOM

BRP Elevation	1200 ft	TODR	6800 ft
OAT	+20°C	PMC	'OFF'
Wind	20 Kts HWC	QNH	1008 hPa
Slope	2% Down		
SFC Type	Concrete		
SFC Condition	Dry	Anti-ice	'OFF'
Flap	5°	Packs	'OFF'
Rwy in use	26		

There is an obstacle at 24,000 ft distance from the BRP, with an elevation of 1500 ft.
(Assume 1 hPa = 30 ft)

Given the above find;

Question 1. Obstacle Limited Take-off Mass

I. Find Graphical Obstacle Height - for entry into Figure 4-20 (Flaps 5º).

Elevation of RZ : 1200 – (6800 x 2%) = 1064 ft

II. Find PA of RZ - for entry into Figure 4-20.

PA of RZ: 1064 + [(1013-1008)x30)] = **1214 ft**

Obstacle Height above RZ: 1500 – 1064 = **436 ft**

III. Find Graphical Obstacle Limit TOM

Fig. 4-20 @ Obstacle height, distance from brake release, OAT, pressure altitude and wind component.

Graphical Obstacle limited TOM: **= 56,540 Kg.**

IV. Find PMC Corrected Obstacle Limited TOM

Apply correction (Tabled on the graph)

PMC 'OFF' @ temperature +20°C, this is below 21.1ºC so a decrement of 4970 kg.

56,540 – 4970 = 51,570 Kg.

Obstacle limited TOM. **Ans. Question 1 = 51,570 kg.**

Aeroplane Variables:

- *T/O Weight:*

Increasing weight increases take-off distance (reducing the horizontal distance between the lift-off point and the obstacle) and reduces the rate of climb.

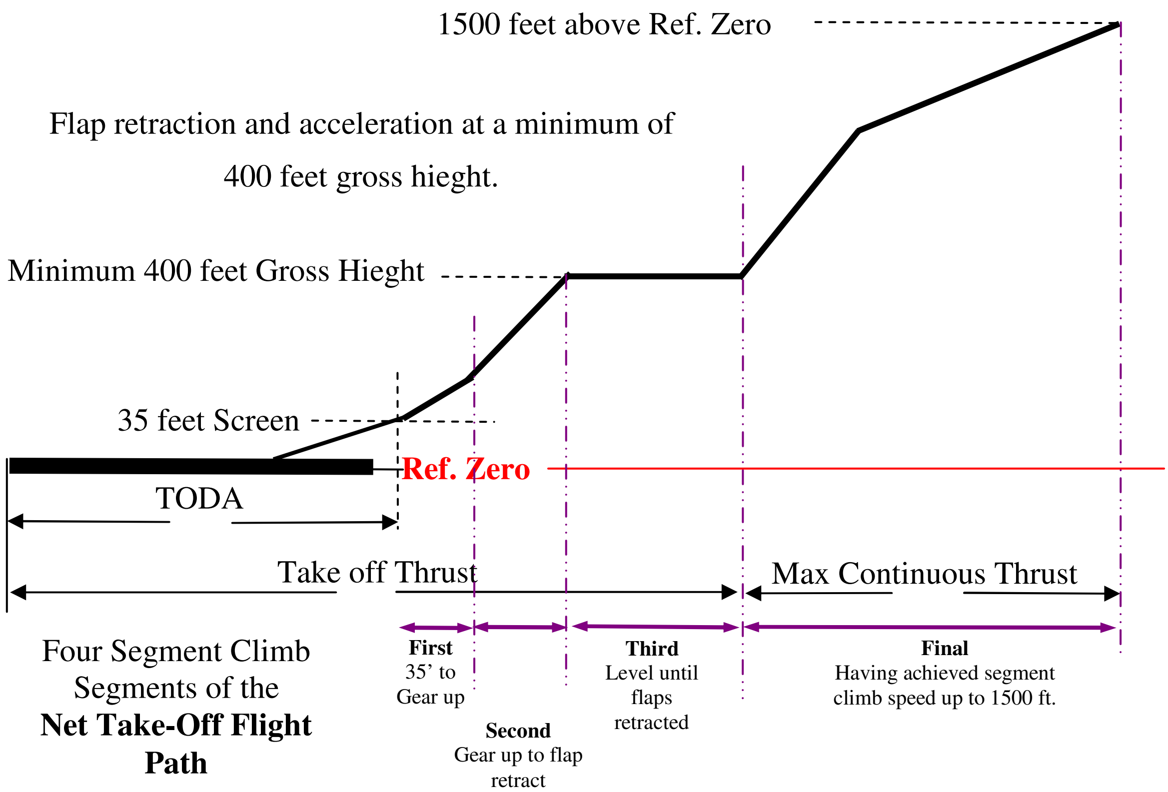
- *Flap setting & Retraction heights:*

Same as for CLTOM.

Meteorological Variables

Same as for CLTOM.

3 Climb segments



3.1 Define the segments along the gross take-off flight path (GFP)

The above diagram shows the segments along the GFP which assumes a failure of the critical engine at V_1.

These gross gradients are further diminished to Net values NTOFP and in the case of the Class 'A' twin engined aeroplane this is by 0.8%.

3.2 State distinct changes in the configuration, power or thrust, and speed.

The take-off flight path begins at the brake release point (standing start). Once airborne the flight path is divided into distinct climb phases, each with a particular combination of thrust and configuration.
Assuming that an engine failure occurs at V_1 on the runway, the climb segments would be as follows:

First Segment: The aeroplane starts the first segment at the end of TODA, where it should be at 35 feet and V_2 above the surface position of Ref. Zero.
This segment is flown at V_2 whilst the landing gear is retracted.

Second Segment: Flown at V_2 with T/O flap and thrust set.
Starts at the gear up point (end of the first segment) and extends to the point where the aeroplane is accelerated and the flaps are retracted (*third or 'level' segment*).
The second segment can be a climb to the minimum (normal) flap retraction height (400 feet gross) or can be extended if there are close in obstacles requiring clearance.
Extended V_2 climbs can be to a point where the 3rd segment is performed within the 5 minute T/O thrust limit, or *continued until the 5 minute point*.

Third Segment: Starts at the end of the second segment, the aeroplane is accelerated horizontally whilst the flaps are retracted. If this segment is completed at the normal flap retraction height, or within the 5-minute power limit, it is flown with T/O thrust set. The highest point where the acceleration is commenced is referred to on some charts as the Maximum Level-off Height.
This term could be confusing as it can be permissible to extend the V_2 climb until the 5-minute take-off thrust limit point, the third segment is then flown with maximum continuous power set.

Fourth (Final) Segment : Starts at the end of the 3rd segment with the aeroplane in a clean configuration, at the climb speed with maximum continuous power set.
The take off flight path ends at 1500 feet, or a higher altitude if there are distant obstacles to clear. (On the take off phase the net clearance for obstacles is 35 feet, once on the en-route phase clearance is 2000 feet.)

En-route phase: On completion of the take off flight path at 1500 feet above Ref. Zero, the en-route requirements become relevant.

3.3 Explain the use of 35 ft vertical distance over obstacles and equivalent reduction in acceleration at the point at which the aeroplane is accelerated in level flight

The net clearance of obstacles during the take-off flight path is 35 feet, however the flight path is determined by using the gross flight path gradient reduced by an appropriate factor **(0.8% for a twin engine aeroplane).**

If the net factor were to be applied to the level acceleration phase, this would become a descent!
In order to keep the net flight path level during the third segment, a correction due to the acceleration as flaps are retracted is applied as an equivalent reduction.

4 State maximum bank angle when flying at V_2

When the aeroplane is at V_2 the remaining engine(s) will be operating at maximum power. The airspeed must remain at V_2 until the flap retraction height, therefore the lift cannot be increased.

Banking the aeroplane will therefore reduce the rate of climb, which could be critical during this phase of flight.

A common procedure is given below:

At V_2 the bank angle is limited to a maximum of 15°
At 20° bank decrease gradient by 2 x Flight Manual decrement and use V2 + 5kt
At 25° bank decrease gradient by 3 x Flight Manual decrement and use V2 + 10kt

4.1 Determine the climb limited take-off mass (CLTOM) given relevant data

CAP 698 MRJT1 pages 10 and 11 give the CLTOM, the relevant graph is figure 4.5. The graph at figure 4.5 guarantees attainment of the most severe gradient requirement of the net flight path.

It does not guarantee obstacle clearance!

CAP 698 includes instructions on the use of the graphs.

5 Climb Variables

5.1 Explain the effects of aeroplane and meteorological variables on the initial climb

There are a large number of variables that affect the initial climb. These will effectively be the same as for all engine climb, except that the maximum available thrust will be reduced so *reducing the angle and rate of climb* when compared to the all engine climb.

5.2 Consider influence of airspeed selection, acceleration and turns on the climb gradients, best rate of climb speed and best angle of climb speed

Airspeed selection – The initial climb speed will be the calculated V_2. This will be maintained until the selected flap-retraction height, when the aeroplane is accelerated.
V_2 is a slightly lower speed than the best climb speed so once in the clean configuration, the aeroplane will accelerate to the best climb speed to achieve the required gradient, angle and or rate of climb.

Remember that the best ROC speed for a Jet - Vy is normally more than the minimum drag (Best Angle of climb) Vx speed.

Acceleration - The *rate of climb* depends on the margin between the power available and power required.
During acceleration some of the power available is used to increase the aeroplane speed, this results in a reduction in the rate of climb.
The faster the acceleration, the greater the reduction in the ROC.
Acceleration has the same effect on gradient and angle of climb

Turns: - Turns during the initial climb with one engine inoperative will decrease the gradient, angle and rate of climb, obstacles in the net take off flight path to be cleared by 35ft or:

50ft when turning.

At 15° of bank the load factor is 1.035 so at Angles of Bank of less than 15° the effect is considered to be negligible.

5.3 Explain the effect of meteorological variables on the ground distance during climb

Wind: The distance over the ground during a climb will be reduced by headwind component and increased by a tailwind.
Pressure Altitude and Temperature: The higher the density altitude, the lower the climb rate and angle of climb. Low angles of climb require longer distance to achieve a given height, compared with high climb angles.

5.4 State the effect of meteorological variables on the climb speeds

Wind - Wind will have no effect on the *speed* for best rate or angle of climb these are performance related.
Density Altitude - As density altitude increases the *speed* for best rate and angle of climb will increase. Power required increases/Power available decreases and Thrust available decreases.

5.5 Computation of maximum take-off mass at a given minimum gross gradient (2nd segment) sine of angle of climb, thrust per engine, G and drag

With an engine failure the minimum gross gradient is 2.4% on the aeroplane considered in CAP 698.
If, on using the graphs, the gradient calculated for a specified weight is say 2.0% then a suitable weight can be calculated using:

$$\frac{2.0}{2.4} \times 100 = 83.33\% \text{ of original weight}$$

6 Obstacle clearance requirements

6.1 Distinguish difference between the Obstacle Limited Take off mass (OLTOM) and Climb Limited Take off mass (CLTOM)

The EU-OPS requirements for minimum climb gradients to be achieved during the climb are shown in the table in Chapter 15 page 15-1. The maximum aeroplane weight at which the minima can be achieved is the climb limited take-off mass ‘CLTOM’.
These gradients will not necessarily provide obstacle clearance in the take-off path, the maximum aeroplane weight at which the obstacle clearance requirements can be achieved is the obstacle limited take-off mass ‘OLOTM’.

CAP698 MRJT1 pages 35 to 37 contain procedures and graphs for use to ensure that Obstructions may be cleared.

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Chapter 17 Noise Abatement

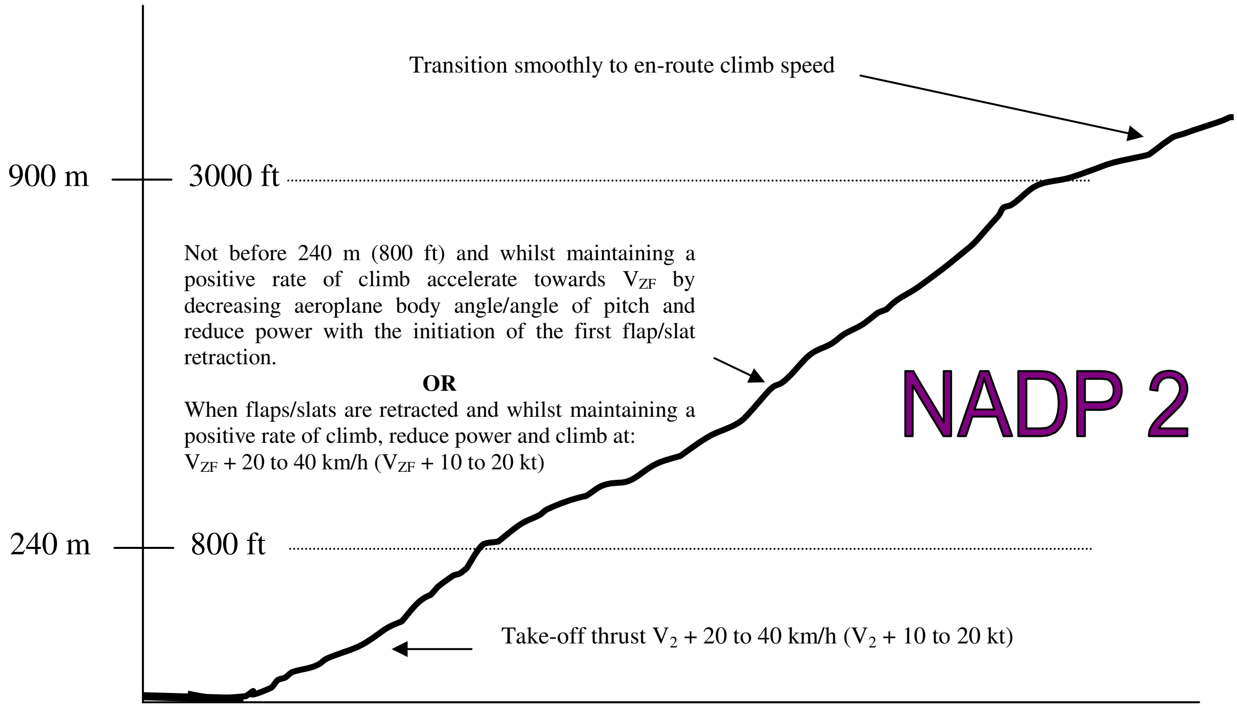
1 NADP 2 and NADP 1 during take-off ICAO Doc 8168

The aeroplane operating procedures for the take-off climb have been developed so as to ensure that the necessary safety of flight operations is maintained whilst minimising exposure to noise on the ground.
One of the two procedures contained should be applied routinely for all take-offs.
NADP 2 formerly known as 'Procedure A' results in noise relief during the latter part of the procedures whereas **NADP 1** formerly known as 'Procedure B' provides relief during that part of the procedure, close to the airport. The procedure selected for use will depend on the noise distribution required and the type of aeroplane involved.

2 NADP 2 - Later Noise relief

This procedure involves initiation of flap/slat retraction on reaching the minimum prescribed altitude.
They should be retracted on schedule while 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.

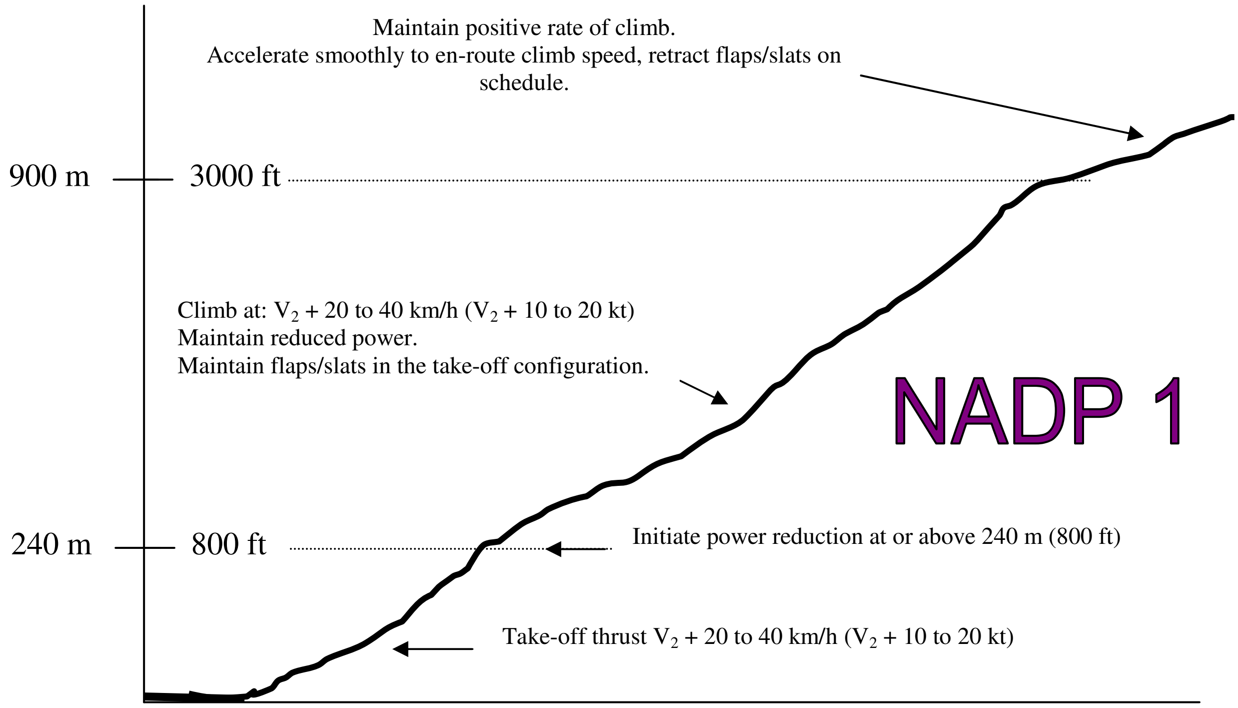
Note: $\mathbf{V_{ZF}}$ This is the 'Zero Flap' minimum safe manoeuvring speed.



Noise abatement take-off climb – Example of a procedure alleviating noise distant from the aerodrome.

3 NADP 1 - *Earlier Noise Relief*

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 while maintaining a positive rate of climb, and complete the transition to normal en-route climb speed.



Noise abatement take-off climb – Example of a procedure alleviating noise close to the aerodrome.

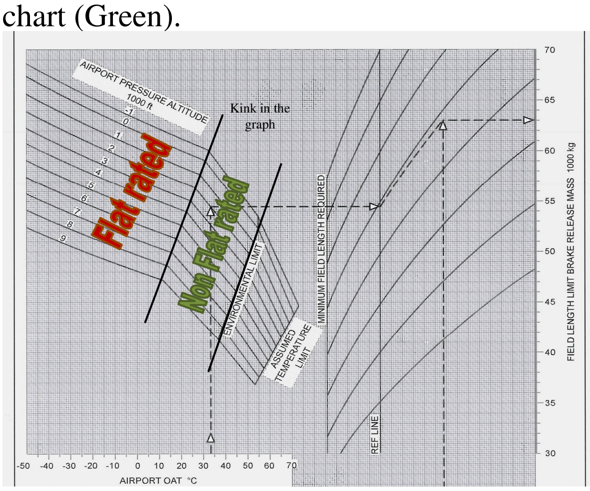
Chapter 18 Using flight manual take-off charts Class 'A' MRJT1

1 Practice performance calculations and comments on the graph's

Using the CAP 698 practice the following examples alongside the given solutions in the CAP. Take note of the procedure for finding the information from the available data.

1.1 Distinguish the difference between the flat rated and non flat rated part in performance charts

The Take-Off performance field length limit graph (Fig 4.4 - MRJT1 P9) includes performance information based on lines on the left hand side of the chart where the gradient of the lines changes significantly at certain points (kinks).
These kinks in the lines indicate changes in the operational characteristics of the engines.
Three distinct "zones" can be seen, as identified on the chart below. These are as labelled on this section from the graph below for explanation.
The first zone (Red) is the Flat-Rated power zone. At any combination of ambient temperature and pressure altitude within this zone, the engines will be operating such that the power management computer can adjust the fuel flow to maintain the thrust setting requested by the pilot.
As air density changes, fuel flow is adjusted to maintain the thrust requested.
If air density were to increase, thrust would normally increase so the PMC would reduce the fuel flow to reduce the actual thrust produced to maintain the thrust requested.
If air density were to decrease, thrust would normally decrease so the PMC would increase fuel flow to increase the actual thrust produced and therefore maintain the thrust requested.
As you can see from this, within the flat rated zone the PMC can increase or decrease fuel flow to maintain constant thrust.
Remember from gas turbine theory that when you increase fuel flow to increase thrust, this is achieved by raising the temperature of the engine (due to the additional fuel burn).
The amount of additional fuel that can be fed to the engine to increase thrust is limited to that which increases the engine temperature to its maximum operating temperature. Any further fuel to the engine would raise the temperature further and therefore exceed the engine maximum temperature. The engine has become "temperature limited". From this point onwards, any decrease in air density will result in a decrease in power as the PMC can no longer increase the fuel flow to the engine. The engine is now operating in the Non-flat-rated zone of the performance chart (Green).



Summary of Flat rated and non flat rated

Flat rated power is the maximum power that an engine can achieve under ISA conditions, non flat rated is everything else.

Fig 4.4 on page 9 in CAP 698 shows a 'kink' in the lines towards the top (e.g. +20°C and 5,000 ft PA), up to that point the engine can achieve the flat rated power.
Above and beyond that point the engine will be power limited.

The same effect is shown on the Climb Limit chart Fig. 4.5 page 11.

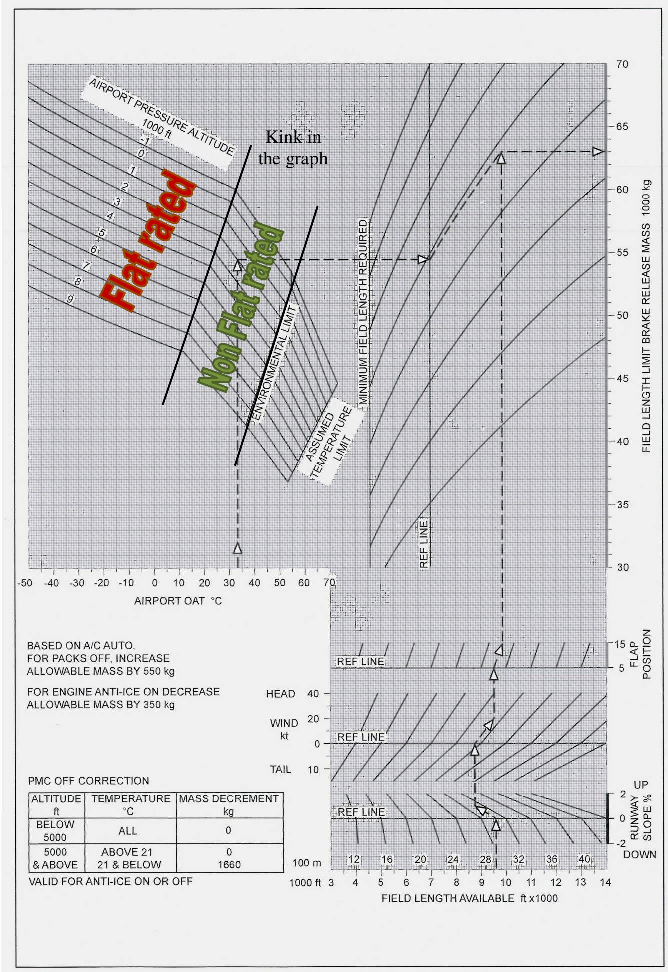


Figure 4.4 Take-Off Performance – Field Length Limit Graph

So in summary – In the flat-rated area, thrust remains constant (maintained by PMC).

In the non-flat rated area, if density decreases thrust will decrease. If density increases, thrust will increase.

Notice also from the chart that the temperature at which the MRJT1 engines become non-flat-rated is ISA+15°C.
(Check the position of the kink for the 'Zero Pressure Altitude line – temperature indicated is +30ºC, so that's ISA+15).

1.2 Explain the typical form of the wind guide lines in the performance charts

Wind grid lines can be found on the Field Limit graph Fig 4.4. (above). There are four points to note about the wind corrections:

1. Always go up to the reference line first when starting from the bottom of the page, then apply the correction. (A tail-wind correction is down and left from the ref line.)
2. The wind component adjustments have already been incorporated in the graphs. (50% for head-winds, 150% for tailwinds.)
3. The headwind and tailwind scales are different, this makes it easy to make a mistake in interpreting the graph.
4. **Note that one large square on the graph represents 20 knots of headwind and 10 knots of tailwind!!**

EXAMPLE 9 **Take-off Performance** **MRJT1**

PA	4500 ft	TORA	8500 ft
OAT	+22°C	Stopway	None
Wind	280/20 Kts	Clearway	None
Slope	0%	PMC	'OFF'
SFC Type	Concrete		
SFC Condition	Dry	Anti-ice	'OFF'
Flap	15°	Packs	'OFF'
Rwy in use	22		

No Stopway or Clearway

Balanced Field

Given the above find;

Question 1. FLL Brake Release Mass.
Question 2. Climb Limited Brake Release Mass
Question 3. From the above information the TOM.

Don't forget that the aircraft has a 'Maximum Structural take-off mass;

For the MRJT1 it is **62800 Kgs.**

I. **Find HWC**

Use CRP 5 or:

Fig. 4.1 @ 60° off and 20 Kts **= 10 Kts HWC**

II. **Find FLL Brake Release Mass.**

Fig. 4.4 @ OAT, PA, Wind, Flap, RWY Slope,.

FLL Break Release Mass (TOM) **= 60,000 Kgs**

III. **Apply Corrections (Tabled on the graph).**

1. **PMC** **'OFF'** No Change
2. **Packs** **'OFF'** **Increase by 550 Kg**
3. **Anti-Ice** **'OFF'** No Change

BRAKE RELEASE MASS Ans. Question 1 = **60,550 Kgs**

IV. **Find Climb Limited Break Release Mass (Take-off WAT limit)**

Fig. 4.5 @ OAT, PA, Flap.

Climb Limit (WAT) **53,000 Kgs**

V. **Apply Corrections (Tabled on the graph).**

1.	**PMC**	'OFF'	No Change
2.	**Packs**	'OFF'	Increase by 900 Kg
3.	**Anti-Ice**	'OFF'	No Change

CLIMB LIMITED MASS Ans. Question 2 = **53,900 Kgs**

VI. **Take-off Mass from the above information – take the lowest;**

Structural Limit for Take-off (Aircraft Limitations)	62,800 Kgs
Brake Release Mass (Step III)	60,550 Kgs
Climb Limit Mass (Step V)	**53,900 kGS**

Take-off is Climb Limited to; Ans. Question 3 = **53,900 Kgs**

EXAMPLE 10 Full Take-off – No obstructions MRJT1

Normal T/O

PA	2000 ft	TORA	9600 ft
OAT	+33°C	Stopway	None
Wind	20 Kts HWC	Clearway	None
Slope	1.0% UP	PMC	'ON'
SFC Type	Concrete	Tyres	'210 mph'
SFC Condition	Dry	Anti-ice	'OFF'
Flap	15°	Packs	'ON'

C/G 18% MAC
No Obstructions

No Stopway or Clearway

Balanced Field

Given the above find;

Question 1. Take off mass (TOM)
Question 2. V speeds
Question 3. Stab Trim setting.
Question 4. Take-off %N_1

Structural Limit for Take-off **= 62,800 Kgs**

Fig. 4.4 FLL TOM **= 63,000 Kgs**

Fig. 4.5 Climb Limit (WAT) **= 53,400 Kgs**

Fig. 4.6 Tyres = 80,400 Kgs
Less 1,500 Kgs Decrement for 210 Mph Tyres
Plus……..8,000 Kgs 20 Kts HWC @ 400 Kg / Knt

=86,900 Kgs

Fig. 4.7 Vmbe Not Limiting (In shaded area)

Take the lowest mass.

Climb Limited TOM Ans. Question 1. **53,400 Kgs**

V SPEEDS

(Note page numbers refer to CAP 698 MRJT1)

Page 16 **Para. 2.5.1** V1 Adjustment for clearway – '**Not required'**

Para. 2.5.2 Density Sub-Graph **'C'**

V Speeds **Find by interpolation from table** @ 'C' and 53,400 Kgs, Flap 15°.

(Note that Fig 4.8 Flap 5° and 4.9 Flap 15°)

Fig. 4.9 (Flap 15°) Page 65 / 19

Part of Fig 4.9	**C**		
1000'sKg	$\mathbf{V_1}$	$\mathbf{V_R}$	$\mathbf{V_2}$
Mass 55	131	133	140
TOM 53.4	$\frac{7}{5}$ X 3.4 = ***4.76***	$\frac{8}{5}$ X 3.4 = ***5.44***	$\frac{6}{5}$ X 3.4 = ***4.08***
Mass 50	124	125	134
Add Interpolate	+4.76	+5.44	+4.08
Speeds	$\mathbf{V_1 128.76}$	**Vr 130.44**	$\mathbf{V_2 138.08}$

SLOPE (Adjustment to V_1) @ 1% Up

Mass 60	0	+1	+2
TOM 53.4	0	*+0.75*	+1.5
Mass 50	0	+0.5	+1

WIND (Adjustment to V_1) @ 20 Kts HWC

Wind Kts	0	*20Kts*	40Kts
Mass 60	0	+0.5	+1
TOM 53.4	0	*+0.5*	
Mass 50	0	+0.5	+1

MIN V_1 (V_{MCG}) @ Pa 2000 ft OAT +33°C

Actual OAT 40°C 107

This Take off OAT 33°C $\frac{4}{10}$ X 3 = **1.2**

Actual OAT 30°C 111

– 1.2

109.8 V_{MCG} (Min V1)

V1	= 128.76 Kts
Correction Slope	= +0.75
Correction Wind	= +0.5
Total	= **130.01 Kts**
Check < than V_R	**Ok**
Check > than V_{MCG}	**Ok**

Therefore V1 = 130.01 Kts

Ans. Question 2.

V1	**130.01**
VR	**130.44**
V2	**138.08**

Flap 15° Stab Trim @ 18% Mac.

Stab Trim = **3**

Weight adjustment for 53,400 Kgs **No correction Required**.

Stab Trim therefore set at '3'

Ans. Question 3.

%N_1 Values

Fig 4.11 Page 21 (Note that this table is 'Packs On')

Take-Off %N_1 @ +33°C, 2000 ft, Anti-ice 'Off', Packs 'On' PMC ' On'.

Temp/PA 2000 ft

Airport OAT 35°C 95.6

This Take-off OAT 33°C $\frac{0.4}{5}$ X 3 = **0.24**

Airport OAT 30°C 96.0

–0.24

95.76

Ans. Question 4.

Take-off = 95.76%N_1

2 *Take-off performance wet and contaminated runways*

In Chapter 7 under runway variables were considerations of runway surface conditions, EU-OPS state:

Contaminated runways are when more than 25% is covered with:

- Surface water greater than 3mm deep, or the equivalent of slush or loose snow.
- Compacted snow.
- Ice or wet ice.

2.1 *Explain the differences between the take-off performance determination on a wet or contaminated runway and a dry runway.*

Class 'B' aeroplanes use a table of factors to adjust the performance calculations accordingly and it is very evident from those that the only 'good' runway is **dry and paved!**

In Class 'A' and the higher speeds involved these problems become very difficult to predict accurately and you will notice that the tables in CAP 698 MRJT1 Pages 25 – 27 all carry the warning that these figures are: 'Advisory Information'.

Some of the problems likely to be encountered are:

- Loss of friction when decelerating
- Impingement drag due to accelerating through the contaminant
- Displacement of the contaminant during acceleration / deceleration resulting in steering problems and skidding.
- As surface friction is poor a greater tendency to weathercock into strong winds.
- TODR and ASDR are likely to increase due to slower acceleration
- LDR will increase due to poor braking action.
- Hydroplaning (Aquaplaning) may take place. (See Chapter 20 of these notes).

Tables (Figures.4.14) in CAP698 assume an engine failure at V_1 and address these problems in three ways:

- A means of reduction of the dry runway Take-off Mass.
- A means of reduction of V_1
- The three tables allow for varying depths of contaminant and interpolation may be required across the tables.

In the top tables the pressure altitude columns of these tables have a shaded area as a warning that the TOM may be limited by V_{MCG} so if the table entry falls into this region, it becomes necessary to enter the lower table with the TORA to find the TOM as limited by V_{MCG}.
In which case V_1 becomes limited by V_{MCG}

Note that : The V_1 calculated by this method is not a true value in the normally accepted definition as there is <u>absolutely no guarantee that the aeroplane would actually stop before the end of the stopway!!</u>
Therefore it is referred to by a more correct term known as:

'**Maximum Abandonment Speed'**

3 *Use of Reduced and Derated Thrust*

3.1 *Explain advantages, disadvantages and differences between using reduced and derated thrust*

The main advantages of both Reduced and Derated thrust are those of reduced engine noise and preservation of engine life, it also helps decrease repair and servicing costs.

To comply with CS25 take-off performance and limitations, data is presented in the AFM for 'Derated Thrust', as the thrust output level is less than that of the maximum take-off thrust normally achievable.
In effect, the derated case presents the aeroplane with less powerful engines.
The thrust setting chosen for take-off is an 'operating limitation' and made clear in the AFM.
Aerodrome pressure altitude, ambient temperature and how much thrust is used determine the values of V_{MC} and V_{MCG} these values are lower for the derated thrust take-off than for the full thrust case.
However, due to the reduced thrust to mass ratio; V_1 V_R V_2 will all be higher than would be the case for a normal full thrust take-off.

Principally on a contaminated runway; it is most likely that the take-off mass will be restricted by V_{MCG} so in this case, using the derated thrust setting for take-off will overcome the restriction and provide the opportunity for a higher TOM than that normally achievable for a 'contaminated runway - full thrust take-off'.

3.2 *Explain when reduced and derated thrust may and may not be used*

Reduced Thrust
The reduced thrust take-off procedure is referred to by a number of different names:

- Variable Thrust Take-off
- Assumed Temperature Take-off

In the case of the Reduced Thrust take-off there are several restriction on its use, CAP698 list some of the following:

A reduced thrust take-off is <u>not permitted</u> with:

- Icy or very slippery runways
- Contaminated runways
- Wind-shear within the take-off flight path
- Anti-skid unserviceable
- Reverse thrust unserviceable
- Increased V_2 procedure
- The PMC 'Off'.

In addition this procedure can only be used when the available distance 'Greatly Exceeds' that which is required. The maximum reduction in thrust permitted is 25% of that required for a normal take-off.

Derated Thrust
The derated thrust take-off and Climb technique was largely developed due to the fact that the reduced thrust procedure cannot be used on a contaminated runway or when the normal take-off mass is restricted by $V_{MCG.-}$
Some of the advantages of using the derated trust procedure are given below:

- when the normal TOM is limited by V_{MCG}
- take-off from contaminated runways
- V_{MC} and V_{MCG} are reduced

3.3 *Explain the effect of using reduced and derated thrust on take-off performance, including: take-off speeds, take-off distance, Climb performance and obstacle clearance.*

Reduced Thrust
Because the 'assumed temperature' is higher than ambient, it means that if an engine failure occurs at V_1 the 'reduced thrust' is still adequate to ensure compliance with the requirements for take-off and climb. Interestingly, due to the actual air density being higher than assumed; the aeroplanes actual performance is slightly enhanced.
However despite the above fact, it is recommended that the thrust on the good engine/s is increased to full take-off power.
Take-off V speeds and distances:

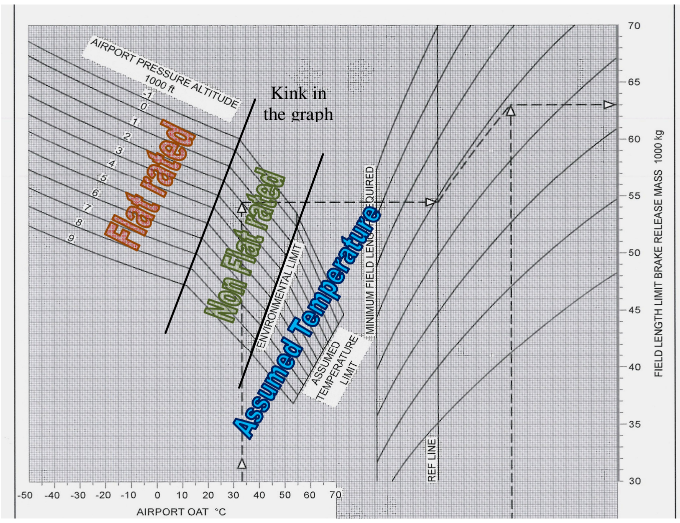
- V_{MC} / V_{MCG} – Normal - as with full thrust
- V_1 V_R V_2 - Normal - as with full thrust
- Take-off distance - Less
- Reverse thrust - Greater effect; stopping distances reduced

Derated Thrust
If there should be an engine failure when the derated thrust procedure is adopted, the aeroplane performance will still be adequate to comply with the field length and climb requirements without increase of thrust on the good engine/s.
Take-off V speeds and distances:

- V_{MC} / V_{MCG} – Significantly Lower
- V_1 V_R V_2 - Slightly Higher
- Take-off distance - Longer

3.4 Explain the assumed temperature method for determining reduced thrust performance

Looking at the blue labelled zone on Figure 4.4 this includes temperature and altitude combinations at which the aircraft has not actually been flown – these temperatures and altitudes are therefore beyond the "environmental limit" demonstrated for the engines, but are still theoretically possible.
These temperatures and pressures can be used for "assumed temperature" take offs.



An assumed temperature take off is where the take off mass is well below the field length limited mass and less thrust is required for take-off.
By telling the engines that the aircraft is taking off on a warmer day that is actually the case, the PMC will reduce the fuel flow to the engines so as not to exceed the maximum engine operating temperature based on the assumed temperature.
As the actual ambient temperature at take off is less than the assumed temperature, this results in a reduction of thrust during take-off. Assumed temperature take-off values are calculated and tabulated for the aircraft to achieve the relevant reduced thrust required.
Note that the reduction in thrust cannot exceed 25% of maximum take off thrust (in other words, the lowest reduced take off thrust setting achieved would be 75% of maximum take off thrust).

The procedure for reduced thrust take-off is detailed in CAP698 MRJT1 Page 31

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Chapter 19 Cruise

1 Cruise factors

1.1 Explain the factors which might affect or limit the maximum operating altitude

Operating Ceiling - When the aeroplane reaches an altitude where the all engines climb performance limitation is reached (500ft/min ROC for jet aeroplane), or with one engine inoperative (100ft/min ROC.)
Environmental Envelope - Limitations on the combination of altitude and temperature.
Pressurisation - The required cabin pressure cannot be achieved / maintained. (For instance, following the failure of an Air Conditioning pack.)
Icing Limitations - Unlikely for a Performance 'A' aeroplane but could affect an aeroplane with limited icing clearance.

1.2 Explain the purpose of step climbs used on long distance flights

The higher the aeroplane weight, the lower the absolute ceiling and optimum range altitude.
At the top of the climb a cruise altitude will be selected appropriate to the aeroplane weight.
As fuel is burnt off the optimum cruise altitude will increase.
On a long flight the ideal would be for the aeroplane to steadily climb as fuel is used. Because of ATC restrictions the system of climbing to the next appropriate FL, when weight allows, is used.
This is known as 'Step climb' and the relevant data can be found in CAP 697, where charts allow for steps of 4000 feet; from 2000 feet below to 2000 feet above the optimum altitude.

1.3 Computation of fuel consumption in relation to different aeroplane masses

Calculation of fuel consumption is covered during the flight planning stages where all the data required is covered. Mass is an important part of the calculation:

The greater the mass the more fuel used to transport the aeroplane over a given distance.

Take a look at CAP 697 which contains fuel consumption tables.

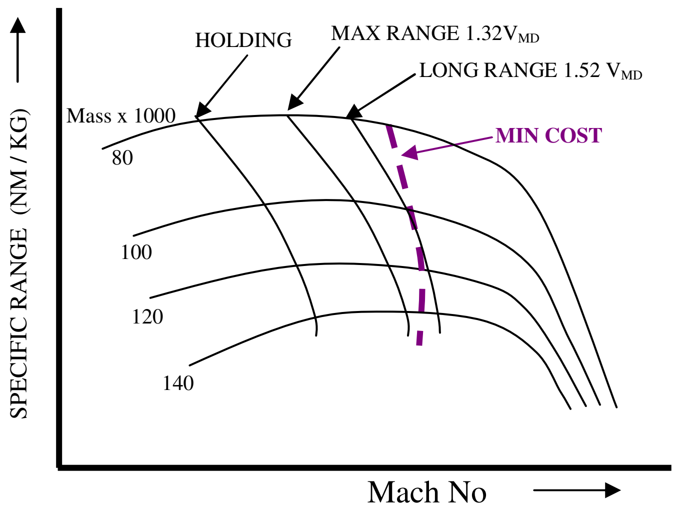
2 *Cruise control*

2.1 *Explain differences in flying V long range and V max range with regard to fuel flow and speed stability*

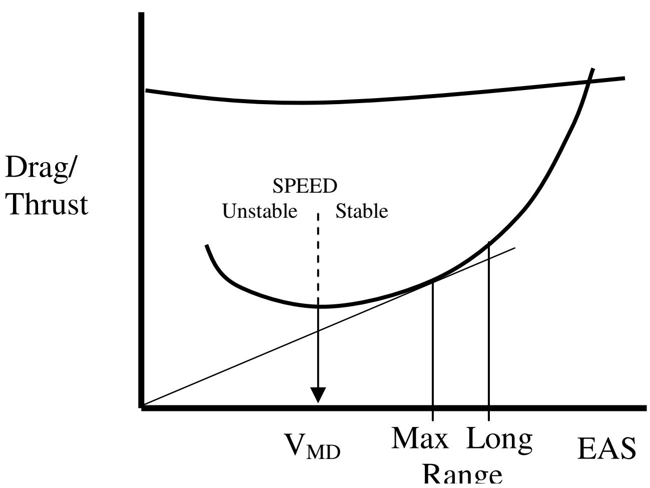
V max range: is used to fly the aeroplane the furthest distance with the available fuel.

V long range: is used to decrease the time taken to reach the destination and make more efficient use of the aeroplane. V_{LRC} achieves 99% of max range but at a higher speed.

- To achieve this it is flown at a *higher speed* than V max range and a *higher fuel* flow is accepted.
- Total fuel used may be less and maximum possible range will be less.
- Speed stability is enhanced at 'V. Long Range'



Speed Stability will be increased at V long range



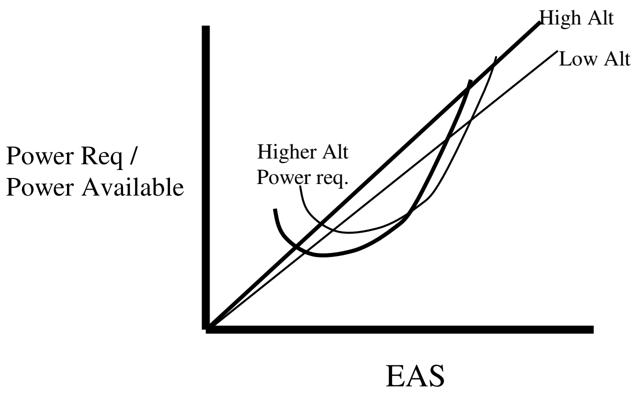
(NB V max endurance: is NOT a **cruise** speed (/regime), so not mentioned here!).

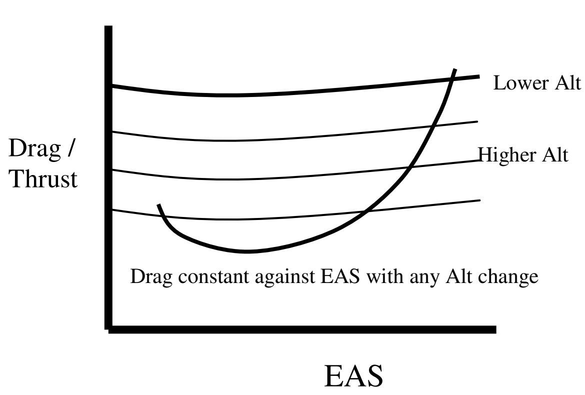
2.2 *Discuss 'thrust/power available and required' curves in horizontal flight*

At sea level the power available is at a maximum and the power required is at a minimum.
As altitude increases the power available reduces and the power required increases.

Remember that eventually an altitude is reached where the power required is equal to the power available, this is the *absolute ceiling* and the aeroplane cannot fly any higher.

For performance planning the service ceiling is defined as the altitude where the maximum rate of climb achievable is **100 feet / per minute for piston aeroplane** and **500 feet / per minute for jet aeroplane.**





The above graphs also show how the range of available speeds reduces as altitude increases. On the Power Req / Power Available graph, the minimum speed is where the power required and available curves cross on the left of the graph, the maximum speed where they cross on the right.
As altitude increases the envelope of speeds reduces until the absolute ceiling is reached, where theoretically there is only one available speed.

On the Drag/Thrust graph, as altitude increases the drag remains the same at a constant EAS, therefore the thrust required remains constant.
The thrust available however, reduces as altitude increases. This again decreases the range of speeds available.

2.3 *Explain the difference between Specific Fuel Consumption (SFC) and Specific Range (SR)*

Specific Range: This can be defined as the maximum distance which can be flown for a given amount of fuel and is the Velocity divided by the Fuel Flow per Hour in still air.
To maximise the SR the drag must be minimised, this can be done in flight by moving the Centre of Gravity towards the aft limit.
The MRJT1 typically uses 2000-2500 Kgs per hour in the cruise.

$$\text{Specific Range} = \frac{\text{Ground Nautical miles/hr}}{\text{Fuel flow kg/hr}}$$

or;

$$\text{Specific Range} = \frac{\text{Velocity, knots}}{\text{Fuel flow kg/hr}}$$

Specific Fuel Consumption (engine): This is equal to the Fuel Flow per Hour divided by the Thrust and is the proportion found between fuel flow in kg/hr and thrust in kg.

$$SFC = \frac{\text{Fuel flow kg/hr}}{\text{Thrust kg}}$$

Example $$\frac{6{,}000 \text{ kg/hr}}{5{,}000 \text{ kg}} = \text{SFC } 1.2 \text{ kg/hr}$$

Constant Mach number: FF decreased with increased altitude.
FF decreased with increased temperature.

Constant thrust and Altitude: FF slight increase with an increase in IAS

BUT

Thrust decreases with: Decreased RPM
Increased Altitude
Increased Temperature

In overall terms however, the SFC (engine) will decrease with decreased ambient temperature and with increased RPM.
There is not a dramatic change in the SFC with changes in cruise speeds.

2.4 Explain the effect on fuel consumption of altitude and aeroplane mass

The higher the altitude the greater the fuel used per hour, but the higher the TAS. So as altitude increases Specific Fuel Consumption increases and Specific Range increases.

2.5 Computation of fuel mileage

If we calculate that the aeroplane would use 1250 Kgs of fuel and travel 300 Ground Nautical Miles (Gnm), the fuel used is divided by the distance.
This giving the fuel used per ground nautical mile flown . **In this case 4.16 kg / Gnm**

3 *En-route - One Engine Inoperative*

3.1 Identify factors which affect the en-route net flight path

The drift-down flight path is affected by the following factors:

- **Aeroplane weight:** The higher the weight, the higher the rate-of-descent and the lower the stabilising altitude.
- **Engine power:** The remaining engine(s)will be set to maximum continuous power, however the power available will be affected by the bleed air systems (Anti-icing and Air Conditioning Packs.)
- **Altitude at which the engine failure occurs:** In the CAP698 pages 41 to 44 illustrate the profiles.
- **Temperature deviation from ISA:** Higher temperatures mean higher density altitude, this effectively increases the aeroplane weight.
- **Headwind and tailwind components:** Affect the angle of descent and ground-speed.

3.2 State minimum obstacle clearance height prescribed in EU-OPS 1.505

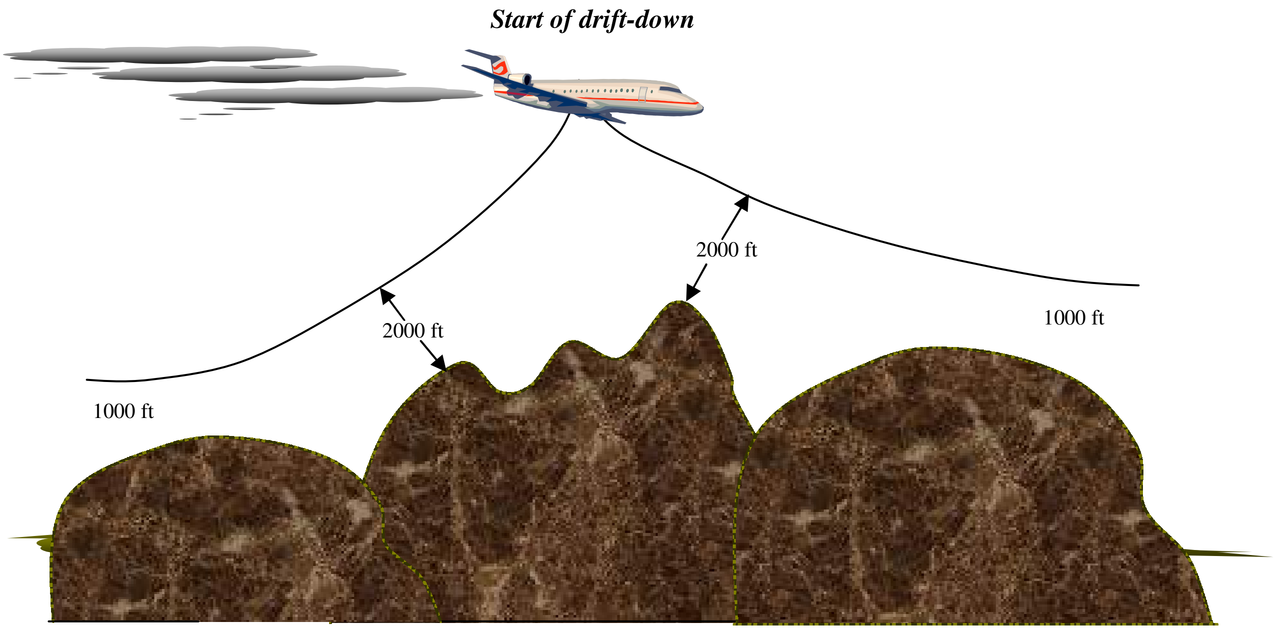
Following the failure of a critical power unit at the most critical point along the route, the net en-route flight path (within 5 nm of intended track and after accounting for wind) must clear obstacles by at least:

i. 1,000 ft when the rate of climb is zero or greater.

Or,

ii. 2,000 ft when the rate of climb is less than zero (decending).

In addition the aeroplane must be capable of a positive climb gradient at 1500 feet above the landing aerodrome.
The rate of climb is taken to be 150 ft/min *less* than the gross rate.
Study the diagram below which attempts to illustrate the above regulation.



3.3 Explain in detail the drift-down procedure

Following an engine failure at cruise altitude the aeroplane will not be able to maintain the cruise level and will be forced to descend.
The aeroplane mass will affect the optimum drift-down speed and the "stabilising altitude" where the aeroplane can level off.
CAP 698 MRJT1 provides tables on page 39 that give power setting, drift-down airspeed and level off data.
The graph on page 40 gives net level off altitudes with the AC packs on/off, and on pages 41 to 44 are graphs giving the drift down profiles for various pressure altitudes.

These graphs show the shape of the drift-down flight path, initially steep with the aeroplane heavy and in thin air, and becoming progressively shallower as fuel is burnt off and the density altitude reduces.
Once stabilised at the level off altitude, maximum range is achieved by cruise climbing the aeroplane as fuel is burnt off during the remainder of the route.

3.4 Explain influence of deceleration on the drift-down profiles

When an engine failure occurs in cruise flight the airspeed will be significantly higher than the optimum drift-down speed required.
In the initial stage some of the aeroplane kinetic energy is used to optimise the range achieved during drift-down, a gradual reduction in speed will do this more efficiently than a rapid deceleration. During this period, the lighter the aeroplane the longer the descent can be delayed.
This is shown by the start points of the profiles at differing weights. The tabulated optimum drift-down speed will give the shallowest overall drift-down angle. Reducing the speed below the optimum speed, may give a temporary reduction in the rate of descent, however the lower resulting airspeed will increase the descent angle.

3.5 Explain the effect of one engine inoperative at high altitudes on the SFC and SR and drift-down speed

'Specific Fuel Consumption is Fuel Flow divided by Thrust'.
Following an engine failure both the thrust and fuel flow will reduce.
Initially the remaining engines will be operating efficiently as max continuous power is close to the optimum operating power, however the aeroplane is descending and decreasing speed.

As the aeroplane descends into warmer air, the thermal efficiency of the engine will reduce and SFC will increase.

'The Specific Range (SR) is the distance travelled per unit of fuel used'.
SR is dependent on the 'TAS **:** Drag' ratio.
This ratio depends on the aeroplane speed, altitude and weight, it is optimum at high altitudes and high cruising speeds.

As the aeroplane descends and slows after an engine failure, the increase in SFC and reduction in 'TAS **:** Drag' ratio both serve to reduce the SR.
If one (or more) engines fail at high altitude the specific range will always be reduced.
The loss in range depends on the amount of height lost, the height loss being governed by the reserve of thrust available from the remaining engine(s).

3.6 Obstacle clearance en-route

Still considering the engine failure case, the aeroplane must be able to clear obstacles during drift down by a minimum of 2,000 ft and by 1,000 ft after reaching the level off altitude for the rest of the route or en route to the alternate.
Therefore the level off altitude cannot be below the safety altitude.(see EU-OPS 1.580).

4 En-route – Airplanes with three or more Engines, two engines inoperative

4.1 Analyse critical situation

Dealing with the aeroplane emergency	Complete all procedures and checks to secure the failed engines.
The aeroplane cannot maintain height.	Is the current flight path safe to clear the immediate terrain? What is the descent gradient and stabilising altitude? Are there obstacles further on the route to be cleared? Is an alternate flight path required to avoid obstacles or terrain?
The aeroplane range is reduced	Can the original destination be reached? Where are possible diversion airfields?
Aeroplane handling considerations	Can a normal approach and landing be carried out?
Reduced Landing performance	Analysis of aerodrome & aeroplane performance data.
Meteorological Situation	Weather & cross-wind suitable to comply with landing minima.
Aeroplane system limitations	Reduction in the electrical, hydraulic and pneumatic power available to aeroplane systems, limiting performance or operations.
Communications	Pan / Mayday. Amending flight plan, informing appropriate agencies.

4.2 Find one-engined out service ceiling, range and endurance, given engine inoperative charts.

4.3 Find maximum continuous power/thrust settings given engine inoperative charts.

4.4 Determine all engines and one engine inoperative descent rates, time and distance for descent, fuel used in descent.

The above objectives are covered within Flight Planning CAP 697 and also with reference in CAP 698.
Take a look at CAP698 En-route section MRJT1 page 39 and onward through the section on drift down, noting the effects and chart procedures.

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Chapter 20 Descent and landing

1 The Descent for approach.

1.1 Explain the effects on Mach Number and airspeed (IAS) during a descent schedule

The descent schedule is designed to allow the aeroplane to glide with the throttles closed to a point where the selection of the landing gear and approach flap will require power to overcome the drag.
From high altitude the aeroplane will descend at a constant Mach number (IAS increasing), converting to a constant IAS when the increasing IAS is reaching the optimum. Beyond this point there is a possibility that V_{MO} could be exceeded if a constant Mach descent was continued.
In the constant IAS descent; the Mach No. will be decreasing.

1.2 Explain the effect of mass on the vertical speed and forward speed at given conditions

The forces in a powered descent are similar to those in a glide, as described in the previous section.
The power effectively offsets the drag and results in a shallower descent angle.
The effect of increasing weight will be to increase the ROD and descent speed, the descent angle will be largely unaffected.

2 Significant V speeds for decent and landing

2.1 Identify the difference between V_{MO} - V_{NE} - M_{MO}

V_{MO} Maximum Operating limit airspeed.
V_{NE} Never Exceed Speed
M_{MO} Maximum Operating limit Mach number

(The 'V' refers to the CAS/RAS. The 'M' refers to Mach No.)

V_{MO} is the maximum operating *speed* and is not to be deliberately exceeded in any regime of flight (climb cruise or descent). It makes allowance for upsets due to turbulence etc. V_{MO} allows the crew to operate to a defined speed, the designers having built the aeroplane to withstand the stress of operating at V_{MO} for about 10% of the aeroplane's expected life.

V_{NE} is the Velocity never to exceed. V_{NE} is the structural limit of the aeroplane, exceeding this speed may cause overstressing of structural components such as controls, surfaces, aerials etc.

M_{MO} is the maximum operating Mach No. with the same parameters as V_{MO}. Whether V_{MO} or M_{MO} is the limiting speed depends on which is critical at that altitude.

2.2 *State the requirements for establishing V_{REF} and V_T*

CAP 698 MRJT1 page 3. defines the speeds and further references will also be found in these notes.

V_T the speed at which the pilot should aim to cross the runway threshold for landing in relatively favourable conditions to achieve the scheduled landing field length. It is calculated for all engines operating (V_{TO}) and with one engine inoperative (V_{T1})

VT_{MAX} the maximum threshold speed, above which the risk of exceeding the scheduled landing field length is unacceptably high – normally assumed to be VT_0 + 15 knots.

V_{REF} the speed the aeroplane should be at to determine the landing distances for manual landings in the specific landing configuration (*all engines*), as it descends through the screen height (50 ft) after a stable approach and descent gradient not exceeding 5%, and should not be less than:

Class 'A' aeroplanes:

- V_{REF} is not less than 1.23 V_{SRO} or V_{MCL}

Commuter aeroplanes:

- V_{REF} is not less than 1.05 V_{MC} or 1.3 V_{SO}

2.3 *Explain the factors used in determination of V_T*

V_T is the threshold speed and is varied by the following factors:

Mass: Higher mass = *higher stall speed = higher VT*
Flap: Greater flap deflection = *lower stall speed = lower VT*
Density: Lower density = *higher VT*

2.4 *Describe the landing distance determined according to CS25.125 (Demonstrated Landing Distance)*

CS25.125 covers the procedures to be included in performance considerations for landing 'Large Aeroplanes'.
Like the other aspects of CS25 that form the foundation of performance calculations, you will notice many similarities to the construction of all Class 'A' performance planning.

Demonstrated landing distance: Landing distance is the total distance required to clear an imaginary screen, 50 feet or 15 metres high at threshold, touch down and bring the aircraft to a stop with normal braking in nil wind conditions.
The manufacturer's 'demonstrated' landing distance has been achieved by an experienced test pilot in favourable conditions, during many (*at least six landings*) and type certification tests. The landing distance required by the average pilot and aeroplane, flown in other than ideal conditions may be considerably greater.
As extra contingency the regulations require that the planned landing distance should be 60% longer than the demonstrated distance to stop the aircraft.
See the table on page 20-5 and note what happens when it's a wet runway!

2.5 *State the requirements for the approach,- and landing climb limits*

The steady climb gradients may not be less than that specified in the table below.
In the 'Landing Climb' configuration the gradient is calculated on the thrust available at 8 seconds after the selection of go around power or thrust.

Descent phase	**Configuration**				**Minimum Climb 'Gross Gradient'**		
					No of Engines		
	Gear	Flaps	Thrust	Speed	**2**	**3**	**4**
Approach Climb	Up	Approach	Critical engine inoperative, the remaining at go around thrust	Not more than: **Commuter** 1.5 V_{S1} **Class 'A'** 1.4 V_{SR}	***2.1%***	2.4%	2.7%
Landing Climb *(After a Baulked Landing)*	Down	Landing	Go around thrust *(All engines operating)*	Equal to V_{REF}	***3.2%***	3.2%	3.2%

3 *Missed Approach*

Reference should also be made to IEM OPS 1.510(b) which states;
In the event that the approach is made on instruments with a decision height below 200 ft, the aeroplane must be able to achieve a minimum gross gradient of 2.5%.
The missed approach procedure of an instrument approach as shown on instrument approach charts is normally based on an obstacle clearance surface having a slope of 2.5%, but should it be greater than this the aeroplane must be able to attain the higher value.
This cannot be achieved by all aeroplanes when operating at or near maximum certified landing mass and in engine-out conditions.
Operators of such aeroplane should consider mass, altitude and temperature limitations and wind for the missed approach at aerodromes which are critical due to obstacles in the missed approach areas.

An increase in the decision altitude/height or minimum descent altitude/height may, as a result, be required.

3.1 State the requirements for the maximum landing distance (dry and wet) applicable for turbo propeller and turbojet aeroplanes at both destination and alternate

This is laid down in EU-OPS 1.510, 1.515 and 1.520 which state:

For Dry Runways

An operator shall ensure that the landing mass of the aeroplane, determined in accordance with EU-OPS 1.475(a), for the estimated time of landing at the destination aerodrome and at any alternate aerodrome allows a full stop landing from 50 ft but not less than 35 ft above the threshold:

- **Turbo-jet powered aeroplanes:**
  Within 60% of the landing distance available **Factor 1.67**
- **Turbo-propeller powered aeroplanes:**
  Within 70% of the landing distance available **Factor 1.43**

When showing compliance with the above, an operator must take account of the following:

i. The altitude at the aerodrome.
ii. Not more than 50% of the head-wind component and not less than 150% of the tailwind component.
iii. The runway slope in the direction of landing if greater than ±2%.

Also, it must be assumed that:

- The aeroplane will land on the most favourable runway, in still air.
- The aeroplane will land on the runway most likely to be assigned considering the probable wind speed and direction and the ground handling characteristics of the aeroplane, and considering other conditions such as landing aids and terrain. (See IEM OPS 1.515(c).)

For Wet Runways

An operator shall ensure that when the appropriate weather reports or forecasts, or a combination thereof, indicate that the runway at the estimated time of arrival may be wet:

The landing distance available is **at least 115% of the required dry runway landing distance** determined in accordance with EU-OPS 1.515.

This is the Dry Runway Landing Distance Required (LDR)
multiplied by: **Factor 1.15**

An operator shall ensure that when the appropriate weather reports or forecasts, or a combination thereof, indicate that the runway at the estimated time of arrival may be contaminated:

The landing distance available must be at least the landing distance determined in accordance with the above, or:

at least 115% (Factor 1.15) of the landing distance determined in accordance with approved contaminated landing distance data or equivalent, accepted by the Authority, whichever is greater.

A landing distance on a wet runway shorter than that required, but not less than that required by EU-OPS 1.515(a), may be used if the Aeroplane Flight Manual includes specific additional information about landing distances on wet runways.

Landing on Contaminated Runways
A landing distance on a specially prepared contaminated runway shorter than that required by the above, but not less than that required by EU-OPS 1.515(a), may be used if the Aeroplane Flight Manual includes specific additional information about landing distances on contaminated runways.
See EU-OPS 1.510, 1.515 and 1.520 for full details.

In summary; the following table may be helpful:

	Jet Aeroplane		**Turbo-prop Aeroplane**	
	DRY	Wet	DRY	Wet
Landing Distance Required =	Within 60% LDA LD x 1.67 = LDR	LDA = 115% Factor 1.15 1.15 x 1.67	Within 70% LDA LD x 1.43 = LDR	LDA = 115% Factor 1.15 1.15 x 1.43
Wet Runway factors	**To find LDR use 1.92**		**To find LDR use 1.64**	
Exceptions		If the flight manual has specific charts for wet and contaminated runways		If the flight manual has specific charts for wet and contaminated runways
Alternate Aerodrome	Same as destination		Alternate scales on performance charts may be used.	

4 *Landing considerations*

4.1 *Demonstrate knowledge of brake energy limited landing weight - overweight landing - flap placard speed - limiting bank angle - landing distance required*

Brake Energy limited LW: The main method of retardation during landing are the brakes. Under normal conditions the energy absorption of the brakes will be adequate to stop the aeroplane, however conditions can exist (high ambient air temperature, down slope and tail-wind) where the capacity of the brakes can be exceeded.
In this case the landing mass can be limited by $\mathbf{V_{MBE}}$.

Overweight Landing: An overweight landing is an emergency procedure, the consequences of which depend on the nature of the emergency, the landing distance available and the amount of overweight. In general terms the overweight landing compounds the problems and the risk of an overrun, brake fire, undercarriage collapse
The landing mass directly affects the landing distance required so increased weight means increased stall speed and therefore a higher approach speed. Increased weight will increase the landing roll and demand greater brakes energy absorption.

Note that for the aeroplane in the CAP 698 the MLM is **54,900 Kg.**

Flap Placards: A placard showing the maximum airspeeds for flap extension for take-off, approach and landing must be installed in clear view of each pilot. The company may choose to operate at lower limits, it is the manufacturers maximum limits that must be in view. (Note the effects of flap during the landing and go-around.)

Limiting Bank Angle: At the slow approach speeds the aeroplane is close to the stall speed. Increasing bank angles increase the stall speed and stalling close to the ground is likely to have disastrous results. Bank angles will be limited by airspeed and configuration.

Landing Distance Required: The horizontal distance to land and come to a complete stop from a point 50 feet above the landing surface with the aeroplane in the landing configuration.

4.2 *State three types of hydroplaning*

Dynamic: Standing water lifts the tyre off the runway
Viscous: Occurs on damp smooth surfaces (particularly associated with touch down zones where the rubber deposits smooth the surface), a very thin layer of water separates the tyre and the runway. Can happen at speeds lower than for dynamic hydroplaning. (***The most common!***)
Reverted rubber: The tyre rubber is damaged during a long skid on a wet runway. The heat generated produces steam which “reverts” the rubber, making it soft and tacky. The reverted rubber forms an effective seal which stops the steam escaping from under the tyre, this lifts the tyre from the runway.

4.3 Explain the effect of hydroplaning on landing distance required

Hydroplaning, also termed Aquaplaning, prevents the tyre from being in contact with the runway – hence making braking ineffective and increasing the landing distance required. Corrections should be applied to establish the additional distance required when conditions for aquaplaning exist.

5 Suitability of selected landing runway landing distance available

When calculating the LDR for a wet/dry runway, in addition to the requirements tabulated earlier, the following factors must be taken into account (EU-OPS 1.515):

- The airfield altitude / elevation
- Not more than 50% of the headwind component.
- Not less than 150% of the tailwind component.
- The runway slope in the direction of landing if greater than ±2° (Not required if runway can be used in both directions)
- The aeroplane must be able to land on the most favourable runway in still air and on the most likely landing runway in the forecast wind.

6 Computation of maximum landing mass for the given runway conditions

The maximum landing mass will be the lower of the two figures obtained from the Landing Field Length and Landing Climb Limit charts CAP 698 MRJT1 pages 46 and 47. The Landing Climb limit ensures that the necessary climb gradient is achieve if the aeroplane has to go around from the approach.
If the landing mass calculated by the above is greater than the maximum structural landing mass of 54,900 Kg, then this figure becomes the limiting landing mass.

The variables applicable to the Landing Field Length limit are:

- Field length.
- Airfield pressure altitude.
- Headwind / tailwind component.
- Wet / dry runway surface.
- Flap position.
- Anti-skid operative.
- Automatic / manual spoilers.

The variables applicable to the Landing Climb limit are:

- Airfield pressure altitude
- Temperature.
- Flap position
- Anti-icing on / off.

For a jet aeroplane the regulations require that at the destination and alternate aerodromes :

- The landing distance required must not exceed the landing distance available on at least one runway in still air conditions.
- The landing distance required must not exceed the landing distance available on at least one runway in the forecast (factored) conditions.

In order to determine the scheduled maximum landing weight at an aerodrome with multiple runways, the charts must be entered for each in turn to ascertain the appropriate still air and forecast wind values.
This process can be shortened by the application of a little logic:

- The longest runway will always give the best still air value.
- Generally the still air case will be the most limiting, unless there is a tailwind or the forecast wind puts the longer runway out of crosswind limits.

6.1 Determine, using aeroplane performance data sheets, the maximum landing mass for specified runway and environmental conditions

The procedure for determining the maximum landing mass is found in CAP 698 MRJT1 on page 45 Fig. 4.28. and page 47 Fig. 4.29.
Some points of note are:

- When starting from the bottom of the FLL chart with the field length available; always move up vertically to each reference line, then apply the correction using the guide lines.
- The FLL chart wind correction scale is linear. (whereas the T/O FLL chart it is not!)
- The FLL chart has two scales for airfield pressure altitude, the applicable one depends on whether the anti-skid is operative or not.
- The labelling of these scales could be slightly confusing, the right hand scale is only used when the anti-skid is inoperative, the correction for manual spoilers is stated at the bottom of the chart.
- The flap position scales are not linear on either chart.

Always check the notes at the bottom of the chart to see if there are applicable corrections.

7 Finding minimum field length for a given aeroplane mass condition.

7.1 State the requirements for determination of minimum field length for landing.

The same graphs are used if the landing mass is already known, however the starting point and method of applying the corrections will entail different application of the graph and any correction factors that may be involved.

Basically the graph will be operated in the reverse sense.

7.2 Determine, using aeroplane performance data sheets, the minimum runway length for a specified landing mass, runway and environmental conditions

The basic principle is to use the Landing FL chart to apply appropriate corrections which will give a minimum landing distance for a given landing weight.
The procedure is as follows:

Fig. 4.28 Landing FL Chart:

i. Enter the chart on the right hand side with the given landing mass.
ii. Move across to the appropriate pressure altitude line, then vertically down towards the flap correction lines. (Take care to use the correct web - operative or inoperative Anti-skid.)
iii. When starting with the field length, we always went to the reference line first, when working the chart the other way we must go to the guide lines first and then move across to the reference line. This is merely the same process in reverse, however it is easy to make mistakes. Tailwind corrections can be slightly confusing because the reference line has to be crossed vertically first, then the correction applied up-and-right ; back to the reference line.
iv. Read off the Field Length distance,
v. Note the comments at the foot of the page about manual spoilers, anti-skid operative and the decrease in field length of 650 ft to be applied if applicable.

Fig. 4.29 Landing Climb Chart:

- Use the given meteorological data to check that the given landing weight is within the climb limitations.

Aeroplane Limitation:

- Check that the weight obtained is less than the aeroplane C-of-A landing limitation maximum structural landing mass of 54,900 Kg.

7.3 Explain the effect of runway slope, surface conditions and wind and how each factor modifies the maximum landing mass for given runway distance and landing distance required for given landing mass.

- **Runway slope:** is not considered or corrected by the landing FLL chart. The effect of down-slope is to increase the landing distance and landing run required. The landing mass will be decreased.
- **Surface condition:** anything that leads to a contaminated runway will have an effect on the landing distance and especially the landing run and braking. This in turn will reduce the landing mass.
- **Wind:** a head wind will increase the landing mass and a tail wind will decrease the landing mass because of the change in groundspeed on landing.

7.4 Explain the effect of temperature and pressure altitude and how they modify the maximum landing mass for given runway distance and landing distance required for given landing mass

If you use the principle that aeroplane fly best at slow speed when the air is thick and cold (low density altitude), the effect of increasing altitude and temperature (high density altitude) will always be detrimental when the aeroplane is landing.

The aeroplane has to fly faster in thin air to provide a given amount of lift, whilst the indicated airspeed may be similar the TAS – and of more relevance to landing *the ground-speed will be higher*. This means that either an increase in landing distance required or a reduction in landing weight is necessary.

7.5 Explain the effect of temperature and pressure altitude on approach and landing climb performance

Aeroplane performance will be best at low density altitudes. With any increase in pressure altitude or increase in temperature the performance will decrease and decrease the maximum landing mass.

7.6 Define the quick turnaround limits and explain their purpose

To be economical and efficient with a public transport operation the amount of time spent on the ground between sectors is lost revenue, so the shorter period of time this occupies the better.
During landing the tyres will have become heated particularly when the following occur together or singularly:

- High landing mass
- Tail wind
- High aerodrome elevation
- High OAT is high
- Runway down slope
- Low flap settings

The tyres will have a design maximum temperature and thermal plugs which will indicate by melting or protruding that the temperatures have been exceeded.
CAP 698 refers to this procedure on MRJT1 Page 45, with suitable tables figure 4.30 MRJT1 page 48.

Note that if the landing mass exceeds the values given, you have to wait 53 minutes then check to see what has happened to the thermal plugs before considering a take-off.

7.7 Determine the maximum quick turnaround mass and time under given conditions from the aeroplane performance data sheets.

Examination of the tables MRJT1 page 48 in the CAP698 reveals the values of mass for the variable parameters as discussed in the last objective, note the additional adjustments to account for slope and wind at the foot of the page.

Chapter 21 Use of flight manual landing charts Class 'A' MRJT1

Using the CAP 698 practice the following example alongside the given solution in the CAP. Take note of the procedure for finding the information from the following data.

EXAMPLE 11 Find Landing Mass. MRJT1

PA	2000 ft	LDA	8905 ft
OAT	+33°C	Flap Setting	30°
Wind	20 Kt Head	Anti-skid System	Inoperative
Runway Condition	Wet	Spoilers	Automatic
Runway Slope	0.5% Up Slope	Air Conditioning	Auto
		Icing	None forecast

Question 1. Find maximum landing mass.
Question 2. Find maximum Quick Turn Round mass.

I. **Fig 4.28 Field length limited landing mass:**

Note that a correction of 650 ft is not required to LDA before graph entry when anti-skid inoperative.

FLL = 51,000 Kgs

II. **Fig. 4.29 Climb Limited landing mass (Landing WAT):**

Note the corrections required – none applicable in to-days landing.

CLLM = 60,400 Kgs

III. **Structural Limited Landing mass:**

MRJT1 = 54,900 Kgs

IV. **Select the lowest:**

Ans. Question 1: Maximum Landing Mass = **51,000 Kgs**

V. **Fig. 4.30 Quick Turnaround Limit** @ 30° Flaps, PA, OAT, Wind and Slope

Interpolate to find QTL (Take care to use the correct temp. scale!)

Quick Turnaround Limit = 52,455 Kgs
Slope adjustment 0.5% = ADD 175 Kgs
Wind adjustment 20 Kts HWC = ADD 2200 Kgs
Ans. Question 2: Maximum Quick Turnaround Mass **54,830 Kgs**

This is not limiting at our Maximum Landing Mass of 51,000 Kgs

1 *Summary of some frequent landing Computations*

1.1 Landing mass

This must be carried out in the pre-flight planning phase to ensure that the aeroplane does not arrive at the destination overweight.

1.2 Approach and landing speeds

The major consideration when computing landing speeds are V_T and V_{REF}. (See below)

1.3 Using aeroplane performance data sheets determine approach and landing speeds for specified landing masses, configuration and conditions

CAP 698 makes no reference to landing speeds. Maximum landing mass can be calculated but not converted to a speed. An aeroplane performance manual will contain the appropriate data.

2 *Summary of alternate landing considerations*

2.1 Explain the requirements for alternate aerodromes

The requirements are laid down in EU-OPS and include, aerodrome, fuel and performance considerations.
Clearly the aeroplane must have the fuel to get to the planned alternate. The aerodrome must be suitable to operate the type of aeroplane in exactly the same way a destination is.
In addition the weather at the alternate must be suitable.

2.2 State the destination and alternate aerodrome landing distance requirements for turbojet and turbo-prop aeroplane

This was covered earlier in this Chapter - pause to revise!

2.3 State the limitations on dispatching an aeroplane if the landing requirements at the destination aerodrome are not met

If the aeroplane is unable to comply with the still air landing requirements at the destination, two alternative aerodromes must be designated where all the landing criteria are met.
If the aeroplane is unable to comply with the into-wind landing requirements at the destination, one alternative aerodrome must be designated where all the landing criteria are met.

3 *Summary of the requirements of the landing approach*

3.1 *State the requirements for landing with all engine operating and one engine inoperative*

The take-off, climb and en-route planning ensures that an aeroplane can arrive safely at 1500 feet above the landing point – even if a critical power unit is lost.
From the 1500 feet point the aeroplane will fly a normal approach whether it has all engines working or one inoperative.
As long as the landing climb performance and landing distance criteria are met, a normal approach configuration is appropriate.
In order to have maximum power available form the remaining engine(s), the bleed air systems should be switched off for the landing.

3.2 *State the requirements for the approach configuration with all engines operating and one engine inoperative*

The approach configuration all engines operating, will allow the selection of go around flap and the required performance for the subsequent climb. Exactly the same requirement is demanded from engine inoperative approaches, therefore the approach must be flown at a speed and configuration that allows safe selection of the flap required for a single engine go around.

4 *Summary of Landing climb performance*

4.1 *State the minimum performance requirement for landing climb*

The landing performance climb limit chart Fig. 4.29 is in CAP 689 MRJT1 page 47 and this gives the maximum landing mass for the aeroplane to comply with the climb-out gradient requirements. (A table on an earlier page of this chapter also refers.)

4.2 *Explain the requirements and aeroplane configuration for the discontinued Approach Climb.*

Climb performance must be achievable:

i. At the maximum landing weight.
ii. With the landing gear retracted, in a configuration where V_{S1} does not exceed 110% of the landing configuration V_{S0}.
iii. With one engine inoperative, other engine(s) at take-off power.
At a climb speed not exceeding 1.5 V_{S1}. for the Commuter class and 1.4 V_{SR} for Class ‘A’.

4.3 The minimum steady gradient of Approach Climb, critical engine inoperative CS25.121:

i. ***Two Engine Aeroplane : 2.1%***
ii. Three Engine Aeroplane : 2.4%
iii. Four Engine Aeroplane : 2.7%

4.4 Explain the requirements and aeroplane configuration for the landing Climb all engines CS25.119

Landing climb performance must be achieved with the aeroplane in the landing configuration and all engines operating.
The minimum steady gradient of climb not less than **3.2%** with :

i. All engines at a power that can be achieved 8 seconds after applying power from idle.
ii. A climb speed of 1.2 V_S (1.15 V_S for 4 engine aeroplane) and not less than $V_{MCL.}$
iii. Not less than the greater of 1.3V_S and $V_{MCL.}$

5 Landing distance, dry, wet and contaminated runways

This has already earlier in this chapter – pause to revise!

5.1 Explain the factors to be considered in determining the landing distance required for dry, wet and contaminated runways

The landing performance chart Fig: 4.28 in the CAP 698 includes correction for dry (zero correction) and wet (full correction) runways.
Water and contamination will degrade the braking performance and can result in aquaplaning (or hydroplaning).

Chapter 22 Practical application of an airplane performance manual

1 Typical turbojet or turboprop Perf. Manual for Take off Climb

- Take-off, en-route and landing mass calculation
- Take-off data computations
- Effects of runway variables, aeroplane variables and meteorological variables
- Computation of the relevant 'V' speeds for take-off and initial climb
- Computation of runway distance factors
- Determination of rate and gradient of initial climb
- Determination of obstacle clearance
- Appropriate engine out calculations
- Climb computations

All the above objectives are based on the use of the pages in CAP 698, which also contains the relevant instructions and examples.

2 Cruise computations

Power settings and speeds for maximum range, maximum endurance, high speed and normal cruise

2.1 Explain the effect on aeroplane range, endurance and fuel consumption of power setting/speed options

The subject of range and endurance is based upon an understanding of the aeroplane drag curve. The power setting and therefore fuel is directly related to overcoming the drag.
If endurance is required, for example when flying in a hold, the best speed and configuration is clean and at the very bottom of the drag curve.
This gives the minimum power consumption just to stay airborne.
When considering range it is based upon the maximum number of miles covered for a given amount of fuel. This can be described using simple maths.

Example

An aeroplane uses 100 Kg of fuel per hour to fly at 100 Kts and therefore covers 100 Nm in an hour.

This gives a fuel flow of **1 kg/Nm**.

The aeroplane increases speed to 120 Kts and the fuel flow is 110 Kg per hour.

This gives a fuel flow of **0.916 Kg / Nm**.
Given a tank of 200 Kg useable fuel at 100 kts the aeroplane could cover 200 Nm and at 120 Kts the aeroplane can cover 218 Nm.
To further increase the speed the aeroplane uses 140 Kg per hour to fly at 130 Kts, this gives a fuel flow of **1.076 Kg / Nm**.
Given the tank size the aeroplane would fly 186 Nm.

Obviously it would cover the distance at a greater rate but using more fuel.

The best speed drag combination is a tangent to the drag curve, this gives the best fuel flow per Nm flown i.e. 'Maximum Range.'

2.2 State the factors involved in the selection of cruise technique accounting for cost indexing, passenger requirements against company requirements

The factors involved are laid down by company policy.
When establishing a cruise speed modern computers can derive a speed power combination that will give the best range for the aeroplane and therefore the lowest fuel used to arrive at the destination. This will take more time than if cruising at the maximum speed and arriving at the destination early, which in effect costs more.

2.3 Cost Index

The speed the computer selects is based on a ***'cost index'*** inserted into the system. The cost index is a complex calculation based on the operating cost per hour (not including fuel) and the fuel cost.
Getting behind on a schedule can be more costly than the extra fuel used to catch up. For example, businessmen will change carrier, passengers will be given drink and food vouchers, hotel accommodation, compensation and ultimately the cost of a charter airline if another carrier is employed to do the schedule.
Therefore from (CAP 697):

An increase in the cost index will normally mean an increase in TAS and fuel burn.

2.4 Extract the power settings and speeds from the aeroplane performance data sheets

This objectives will have been fully covered in Flight Planning using CAP 697

2.5 Fuel consumption

This objectives will have been fully covered in Flight Planning using CAP 697

2.6 Effects of Engine inoperative flight and pressurisation failure on consumption

Interestingly the fuel consumption is effected by the following:

- **Engine Failure:** The fuel consumption drops when using one engine, this is due to greater efficiency as the one engine is operated at higher power. It should be remembered that 40-50% of the power available in the fuel is used to drive the compressor, as only one compressor is being run the fuel consumption drops.
- **Pressurisation failure:** This means operating at or below FL 80, this will drastically increase fuel flow to the extent that destination will almost certainly not be obtainable and the aeroplane would divert.
  Any reduction in altitude from the optimum would increase fuel flow, unless the winds are more favourable to compensate.

3 Extended Twin Operations (ETOPS)

3.1 State the additional factors to be considered for ETOPS

ETOPS, also referred to as EROPS, is the approval for an aeroplane to fly routes at greater distances from suitable alternate aerodromes.
In the event of an engine failure, or decompression, the aeroplane is likely to have a considerably longer transit to reach a suitable landing runway.
The ETOPS approval has stringent requirements that ensure that the safety factors are adequate to ensure the safe arrival and landing.
Initially three and four engine aeroplane only could meet the ETOPS requirements.
The technology and safety factors now being incorporated in large twin-engine airliners (e.g. Boeing 777) allow for ETOPS approval to be achieved.

ETOPS allows aeroplane to fly more direct transits outside the usual oceanic airways and routes. These may be across remote and arctic regions where ATC and navigational aids are sparse.
Should an aeroplane carry out a forced landing, or ditch, it could take a long time for rescue services to reach survivors.
The ETOPS requirements include minimum navigational and survival equipment.

3.2 Additional consideration concerning fuel consumption

An alternate airfield has to be within 60 minutes flying time for 'Non-ETOPS' approved aeroplane, this is extended to 120 minutes for ETOPS approved aeroplane.
Both are at one engine inoperative cruise speed in still air.
The effect of this is to increase the time at one engine inoperative fuel burn for an ETOPS aeroplane at the flight planning stage.

3.3 Fuel for holding, approach and cruise to alternate

This is not covered in CAP 698 and will be covered in Flight Planning.

END OF NOTES