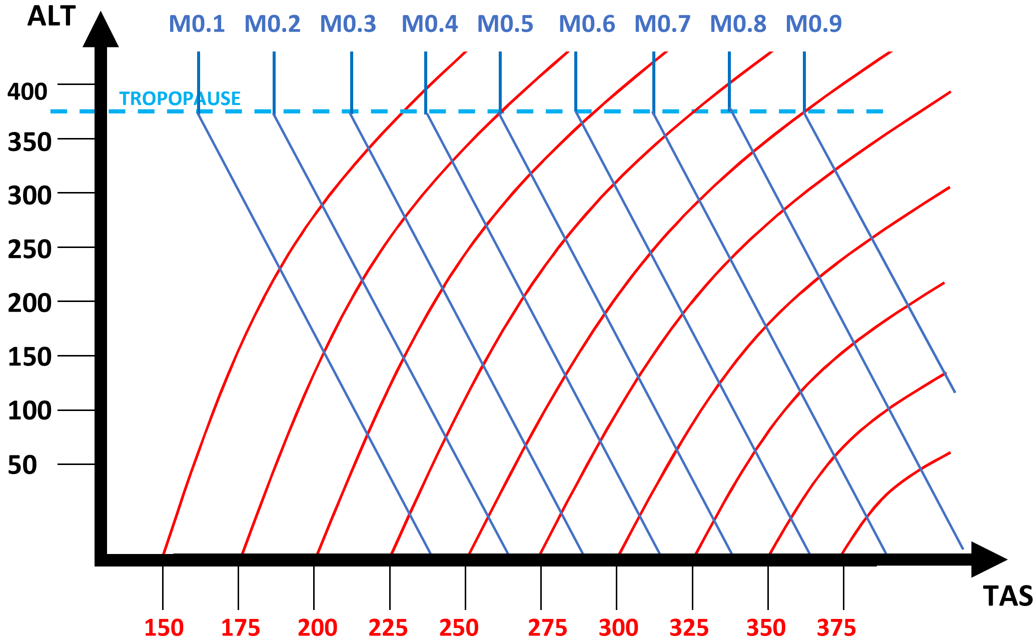
C) En-route

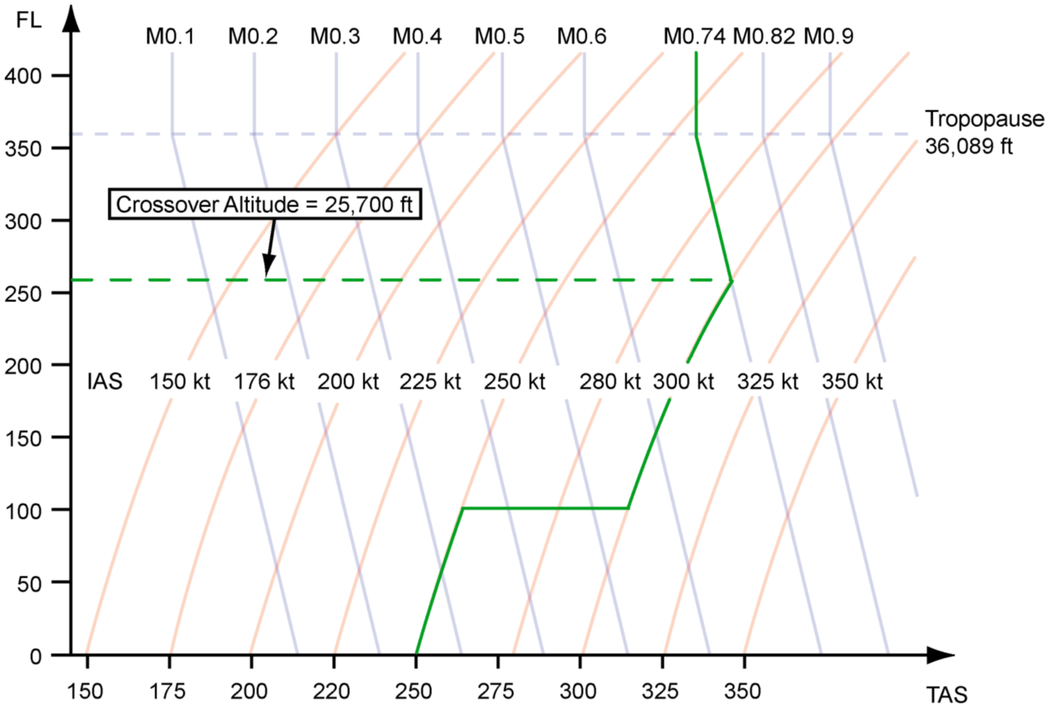
The en-route phase of flight starts at 1500 ft above the departure aerodrome and ends once the aeroplane has reached 1500 ft above intended destination aerodrome. The en route regulations account for engine failure.

CLIMB PROFILE / CLIMB SCHEDULE

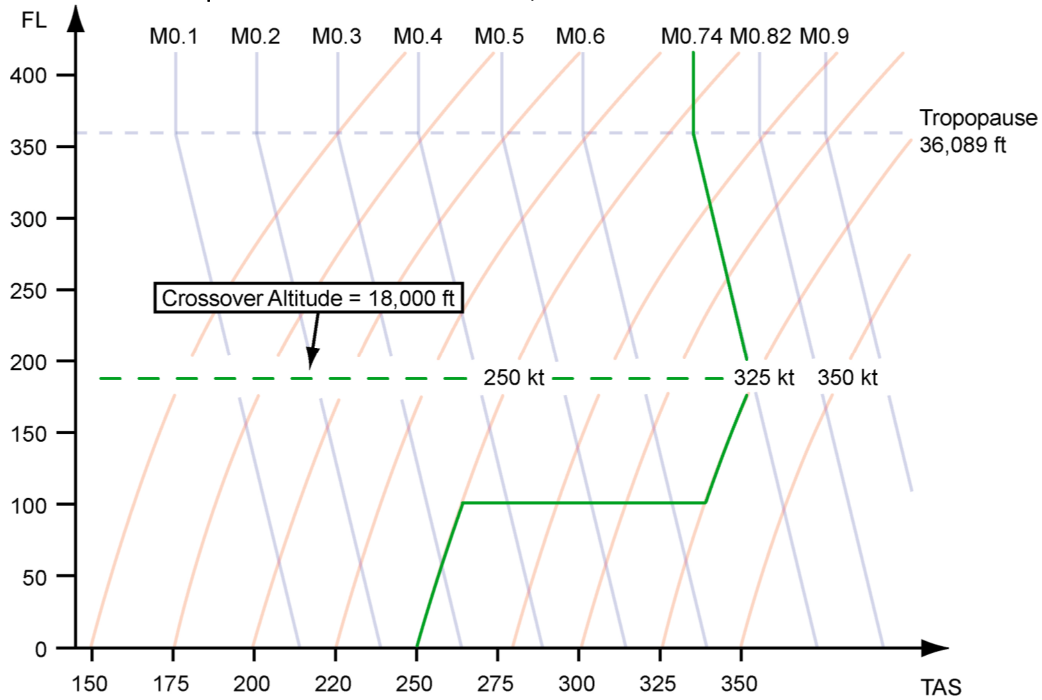
After a normal take-off, climbing to the en-route altitude is a straight forward affair. Once the aeroplane configuration is clean, a set climb profile or climb schedule will be flown. Initially the aeroplane climbs at a constant indicated airspeed. However, continuously climbing at a constant indicated airspeed causes the Mach number to rise. Beyond a certain altitude, the Mach number gets too high and serious aerodynamic forces start to affect the aeroplane, and the pilot must not exceed the Maximum Operation Mach Number (M_{MO}). Therefore, at some lower altitude the aeroplane needs to change its climb profile to a constant Mach number climb.
The altitude at which this change occurs is called **the cross over altitude** or **change-over altitude**.



A typical climb schedule for a 737 – 400



If a faster indicated airspeed climb is maintained, the crossover altitude is lower

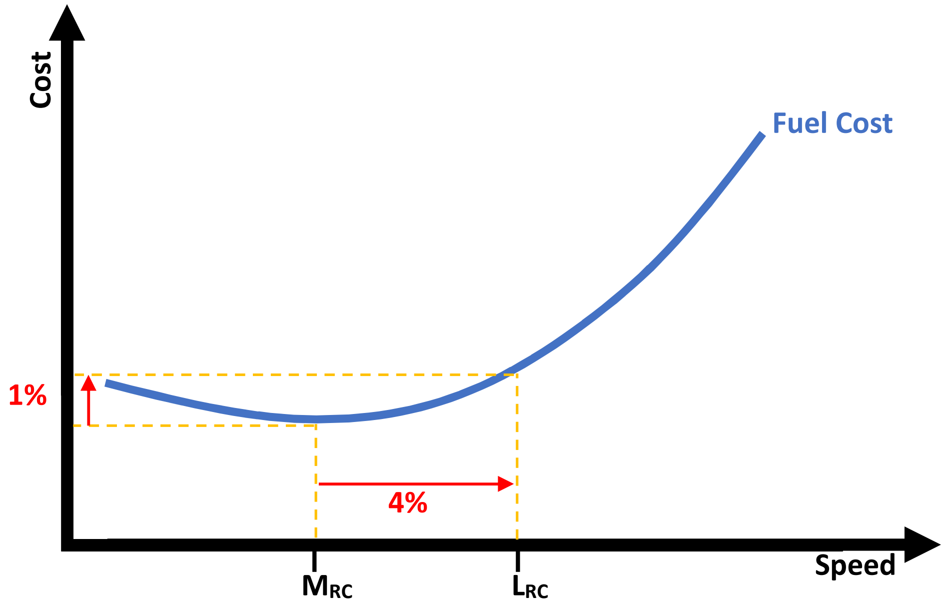


CRUISE SPEEDS

The first speeds to consider are the maximum operating speeds, either called V_{MO} when using indicated airspeed or M_{MO} when using mach numbers.

For the majority of the 737 family V_{MO} is 340 knots and M_{MO} is 0.82. Flying beyond these speeds in a commercial operational context is not permitted and may cause either structural damage or a high speed stall.

The next speeds to know are used in reference to describe the range of the aeroplane. Those are the Maximum Range Cruise speed, MRC, and Long Range Cruise speed, LRC.
When these speeds are referenced in terms of a Mach number the abbreviation is changed to M_{MR} and M_{LRC} respectively.



The advantage of flying at the maximum range speed is simply that the aeroplane will use the least amount of fuel and therefore have the least fuel cost for a given distance. However, operationally, the faster "long range cruise" is used. The simple reason why this speed is used is because by getting to destination more quickly; more revenue earning flights can be carried out in any given period.
In other words, over a given time, **4% more flights can be carried out with only a fuel consumption increase of 1%**.

The long range cruise speed does suffer from limitations. It doesn't consider the variable cost of fuel from day to day or month to month and neither does it account for the operational costs. When fuel prices are high, the extra fuel consumption may dramatically increase the overall cost of the flight and a more operationally economical speed may need to be flown.

COST INDEX

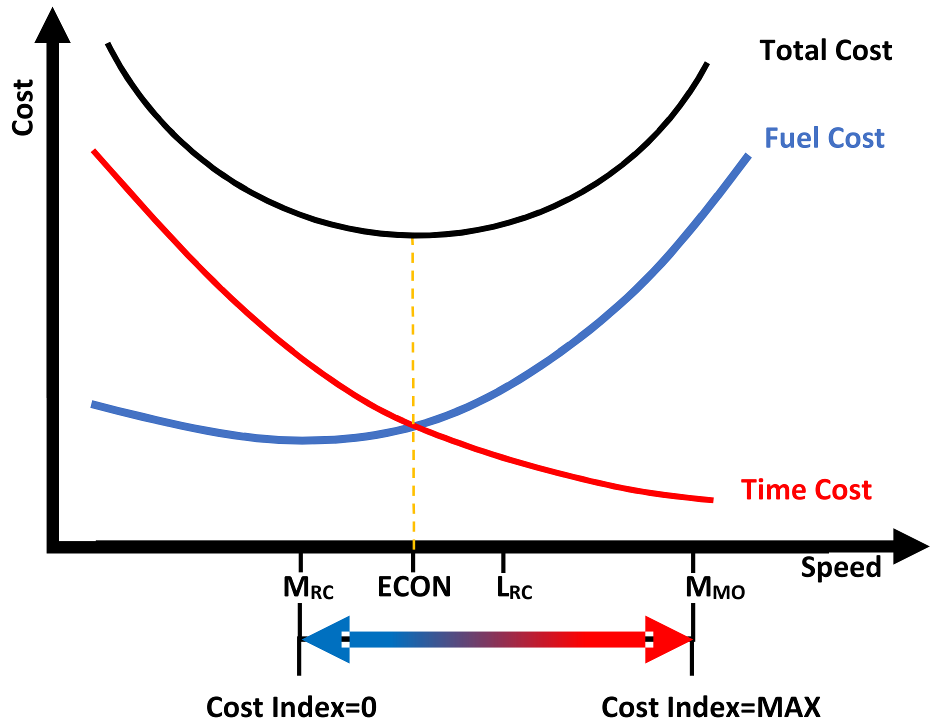
The cost index is used to take into account the relationship between fuel-and time-related costs. With time-related costs, the faster the aircraft is flown, the more money is saved in time costs. This is because the faster the aircraft is flown, the more operations it can cover. It also means that it can operate more between inspections when considering maintenance costs.

These costs are minimum at the maximum operating speed VMO/MMO. However, if the aircraft is flown at such a high speed the fuel burn increases and total fuel cost for the trip increases.

Fuel costs on the other hand will be minimum at the maximum range cruise speed (MRC) and maximum and the maximum operating speed.

Adding the time related costs and fuel related costs together, produces a total operating cost.

The flight management system (FMS) uses the time and fuel related costs to select the best speed to fly.



The total cost curve that the speed which gives the minimum total operating cost is the most economical speed to fly. This speed is called ECON, or the Minimum Cost Speed. The value of the ECON speed is worked out by the FMS based upon the value of the cost index.

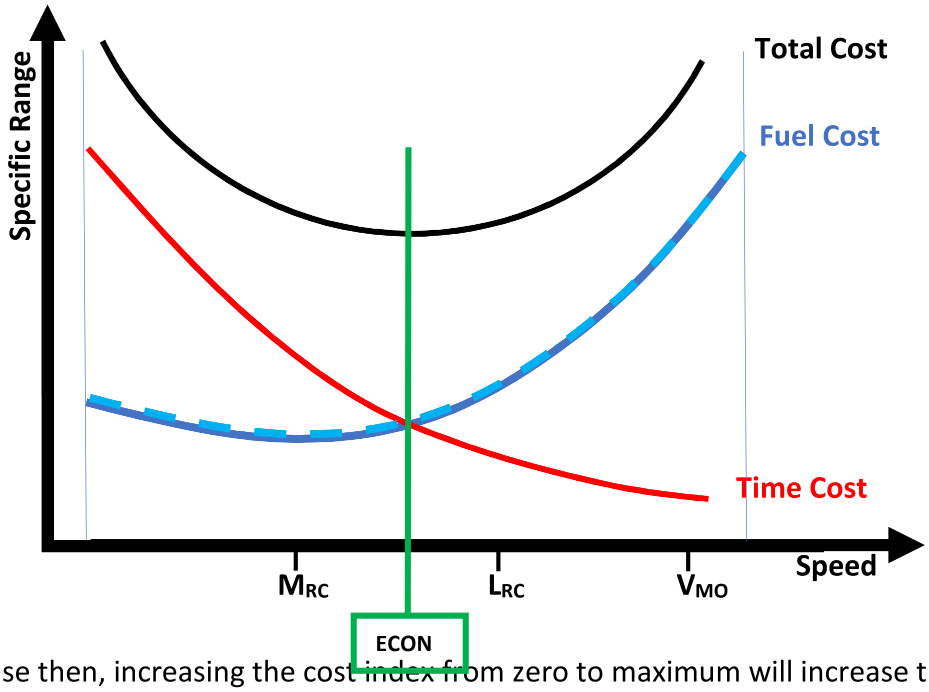
As a formula the cost index is a ratio of cost of time (CT) divided by the cost of fuel (CF).

$$Cost\ Index\ (CI) = \frac{Cost\ of\ Time\ (CT)}{Cost\ of\ Fuel\ (CF)}$$

Fluctuation of the fuel cost

When fuel costs are high and time cost are very low, the cost index would be almost zero and the black total cost line is moved to the left. The intersection point of the other cost lines will lie very close to the maximum range cruise speed and. With a cost index of zero, the ECON speed (found at the bottom of the blue line) would now be at the maximum range speed.

When time costs are high and fuel costs are low, the cost index would be very high, and the black total cost line moves to the far right of the graph. The ECON speed, found at the bottom of the blue curve would now be very close to the maximum operating speed.

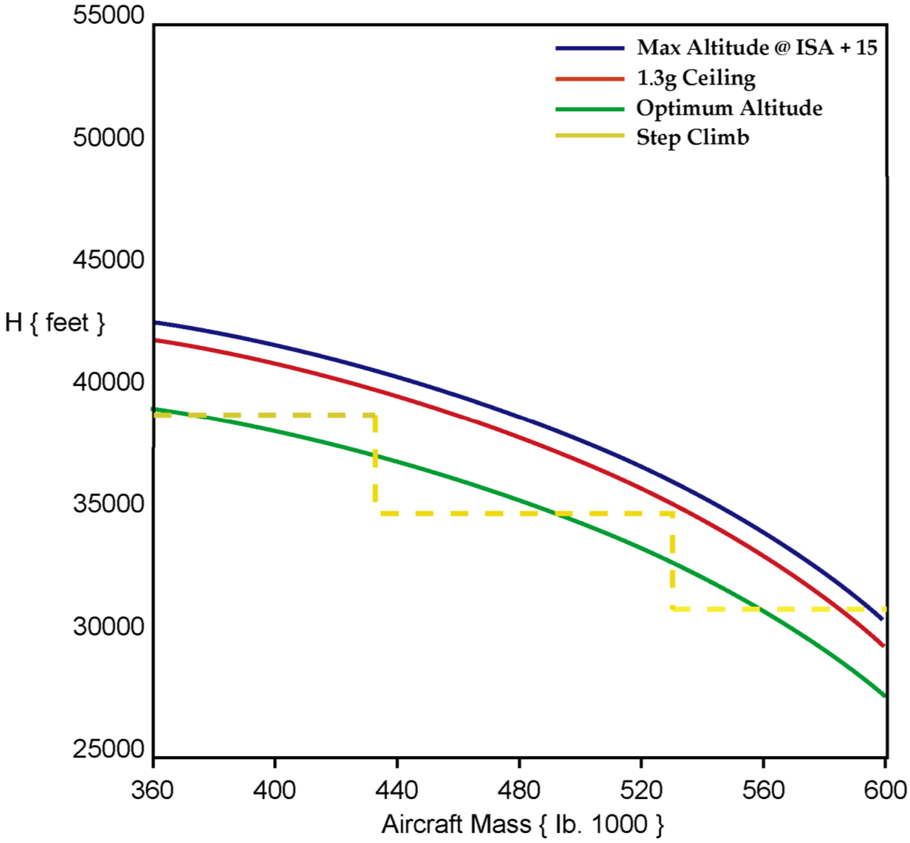


To summarise then, increasing the cost index from zero to maximum will increase the ECON speed from the maximum range speed to maximum operating speed. For most aeroplanes the cost index varies from 0 to 99 or from 0 to 999.

CRUISE ALTITUDES

Once the aeroplane has completed the climb profile and has reached the top of the climb, the aeroplane will level off at the appropriate altitude. This cruise altitude should ideally coincide with optimum altitude. You may recall that the optimum altitude was the altitude for maximum specific range or maximum fuel mileage.

this altitude is not constant. As weight decreases during the flight from fuel consumption, the optimum altitude increases.



Therefore, to constantly fly at the optimum altitude, the aeroplane will not actually fly level, but will in fact slowly be climbing in the cruise. On the other hand, ATC restrictions require level flight cruise to ensure vertical separations with other aeroplanes. To try an accommodate ATC in congested airspace aircraft must fly by segments of constant altitude which must be as close as possible to the optimum altitude.

The procedure is called the step climb which has been seen in GENERAL PERFORMANCE

There may be several step climbs during the flight and the aeroplane will be gaining altitude throughout this process. However, there is a limit to how high the aeroplane is permitted to operate and able to operate.

As the aeroplane altitude increases, the thrust that is required to maintain a given speed, increases. Eventually, there will be an altitude where the thrust is increased to its maximum cruise value and it would not be possible to climb any higher without exceeding the thrust limits. This altitude is called the **Maximum Altitude**

AERODYNAMIC CEILING AND MANOEUVRE CEILING

When the speed of the aeroplane is reduced, to still produce enough lift to balance weight, the angle of attack must increase. However, below a certain speed, the critical angle of attack of the wings is reached, the airflow over the wing separate from the boundary layer producing turbulent airflow. This turbulent airflow buffets on the elevator.

This phenomenon is called **the low-speed buffet**. Flying below this speed will dramatically decrease the lift and a full stall ensues.

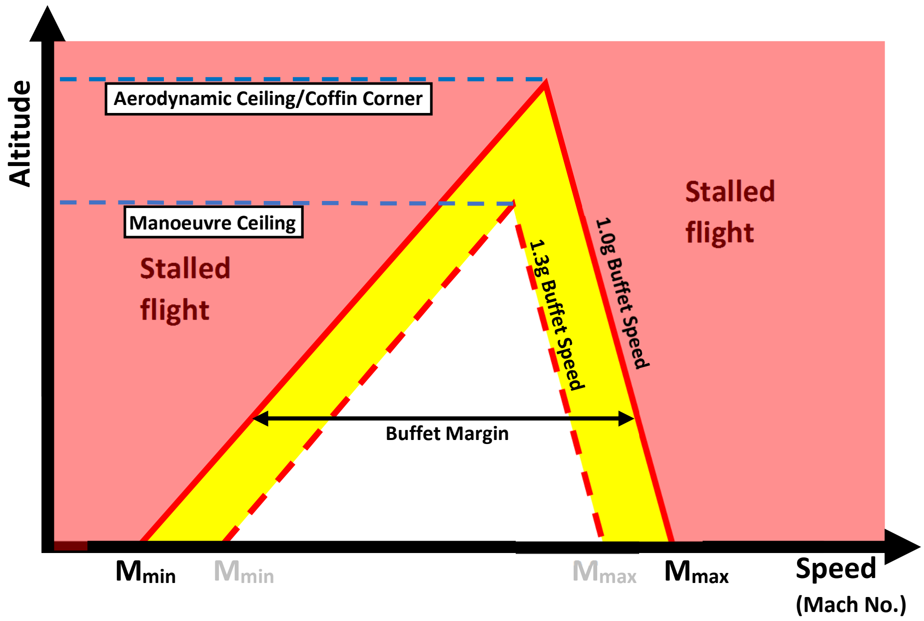
For a given weight and configuration, the aeroplane will always stall at the same indicated airspeed but the equivalent Mach number for the low speed buffet and stall increases with altitude

The Mach number for the low speed buffet is abbreviated to **M_{min}.**

A similar buffet can occur at high speed. At very high speeds, close to the speed of sound, the compressibility of the air ahead of the aeroplane leads to the formation of shockwaves or high pressure waves. These shock waves create a disturbance to the airflow over the wing causing it to separate and create turbulent airflow. Like the low speed buffet, this turbulent airflow will buffet the elevator.

This phenomenon is called **the high-speed buffet** and the Mach number for the high speed buffet decreases with altitude. Flying faster than this speed may cause a high speed shock stall in an aeroplane whose wings are not designed to overcome such effects. The Mach number for the high speed buffet decreases with altitude, as shown.

This speed is commonly abbreviated to **M_{max}**



Taking into consideration both the Mach number for low speed and high speed buffet, it means that there are two mach numbers, below and above which the aeroplane is unable to fly.

This speed range between the Mach number for the low speed stall and high speed stall is called **the buffet margin.**

The buffet margin is the speed range between the low and speed and high speed buffet. The important point to understand is that the margin between the low speed and high speed buffet decreases with altitude.

Notice that there is an altitude with that the low speed and high speed buffets are coincident at the same velocity. It is impossible to fly higher than this altitude. Flying slower or faster than the speed shown will stall the aeroplane.
This altitude is called **the aerodynamic ceiling**, or **coffin corner**.

In fact, at the aerodynamic ceiling even manoeuvring the aeroplane will initiate a stall because manoeuvring the aeroplane will increase the effective weight (load factor g) and increase the stall speed. To prevent aeroplanes from operating too close to this altitude, an operational limit is set below this point. The aeroplane must manoeuvre up to 40° bank, which will produce:

$$\frac{1}{cos\ 40°} = 1{,}3\ g$$

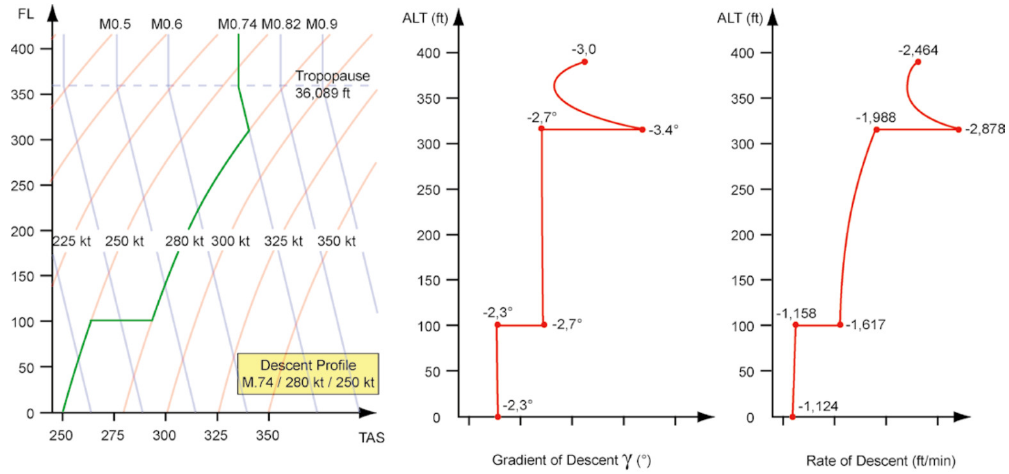
Aerodynamic ceiling is the altitude where the low speed and high speed buffets are coincident. Notice that a 1.3 g manoeuvre moves the buffet speed lines to the "dashed red" position.
Notice that now, the Mach number for the low and speed and high speed buffet are coincident at a lower altitude.
This altitude is called the **1.3 g buffet limit altitude** or **manoeuvre ceiling** and is usually about 4,000 to 6,000 ft below the aerodynamic ceiling.

NORMAL DESCENT

When the aeroplane gets close to the destination airfield it will reach a point which marks the beginning of the descent. This is called the top of descent. You may remember that in order to initiate a descent, firstly the thrust must be reduced, and then the nose is lowered to get weight to act forwards to balance the drag. The balance of forces ensures a constant speed can be maintained during the descent.

The descent profile is almost the reverse of the climb profile.
The descent is flown initially in Mach Number, then at the cross over altitude the speed in kept constant in IAS, but when 10,000ft is reached no more than 250 knots must be flown.

For a typical 737, the descent profile is almost the reverse of the climb profile.
The climb for a typical 737 is initially flown at 250 knots, then at 10,000 ft this changes to 280 knots and then at the cross over altitude mach 0.74 is maintained. The descent is flown initially and 0.74 mach, then at the cross over altitude the speed in kept constant at 280 knots, but when 10,000ft is reached no more than 250 knots must be flown.



EMERGENCY DESCENT

Following either depressurisation or engine failure in flight, the engine or pressurization failures force a premature descent and therefore the performance becomes very constraining over mountainous areas.

Engine Failure

In case of an engine failure during flight, the remaining thrust is no longer sufficient to balance the drag force and therefore the cruise speed cannot be maintained. The only solution is to descend to a lower flight altitude, where the remaining engine can provide enough thrust to balance the drag and allow level flight once more.

To achieve this, the aeroplane is allowed to decelerate from the selected cruise speed to the velocity of minimum drag, and then the nose is lowered to get weight apparent thrust to balance drag. As the aeroplane descends into the lower atmosphere where density is greater, the remaining engine can develop more thrust which will mean that weight apparent thrust can be slowly reduced until an altitude is reached where the remaining engine generates enough thrust to balance drag. At this altitude the aeroplane can level off.

This procedure is called the **Driftdown**, and it produces a Driftdown profile. This path must of course, be above all relevant obstacles.

Cabin Depressurisation

With a pressurization failure the procedure is little different. At high altitude, following depressurization, the air in the cabin escapes and very quickly the cabin air becomes the air same as outside. At high altitude the problem is that there is very little oxygen to breathe. Therefore oxygen must be carried on board and supplied to crew and passengers through oxygen masks.

However, the amount of oxygen carried is limited, therefore the aeroplane must descend, as rapidly as possible to 10,000 ft where there is sufficient oxygen, before the oxygen supply runs out. The procedure involves configuring the aeroplane for the maximum rate of descent. In order to achieve a maximum rate of descent, excess power required has to be a large as possible. Therefore, drag must be high and speed must be high. As a result, the first actions of the pilot are to:

- don the oxygen masks
- initiate descent
- close the throttles apply the speed brakes,

then allow the aeroplane to accelerate to maximum operating speed which is either V_{MO} or M_{MO}. This configuration is then maintained till at least 10,000 ft, or minimum safe en-route altitude, where there is sufficient oxygen to breathe.

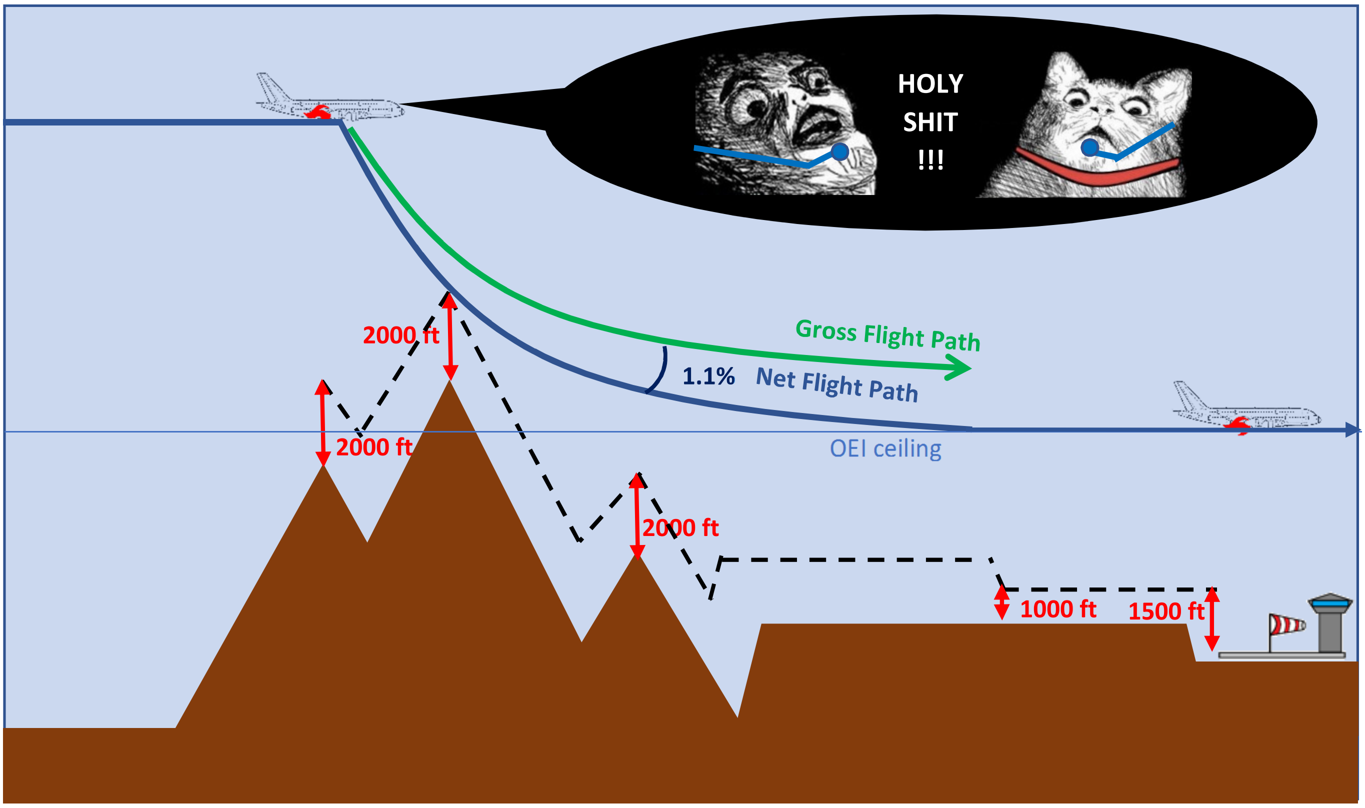
OBSTACLE CLEARANCE REQUIREMENTS

One of crucial points about the Driftdown procedure is the clearance of obstacles. Because the aeroplane is forced to descend, terrain, like mountains may present a flight hazard. When assessing the terrain hazard a safety margin must be introduced.

When planning routes and planning the flight profile, it is not the gross flight profile that must assumed, but rather the net flight profile. In other words, the flight profile must be made worse by a safety factor. This safety factor is based on assuming a gradient of descent that is worse than the aeroplane can achieve.

The gross gradient of descent is increased by

- 1.1% for 2 engines aeroplanes with one engine inoperative
- 1.4% for 3 engines aeroplanes
- 1.6% for 4 engine aeroplanes.



According to CAT.POL.A.215 En-route — one-engine-inoperative (OEI)

(a) The OEI en-route net flight path data shown in the AFM, appropriate to the meteorological conditions expected for the flight, shall allow demonstration of compliance with (b) or (c) at all points along the route. The net flight path shall have a positive gradient at 1500 ft above the aerodrome where the landing is assumed to be made after engine failure. In meteorological conditions requiring the operation of ice protection systems, the effect of their use on the net flight path shall be taken into account.

(b) The gradient of the net flight path shall be positive at least 1 000 ft above all terrain and obstructions along the route within 9,3 km (5 NM) on either side of the intended track.

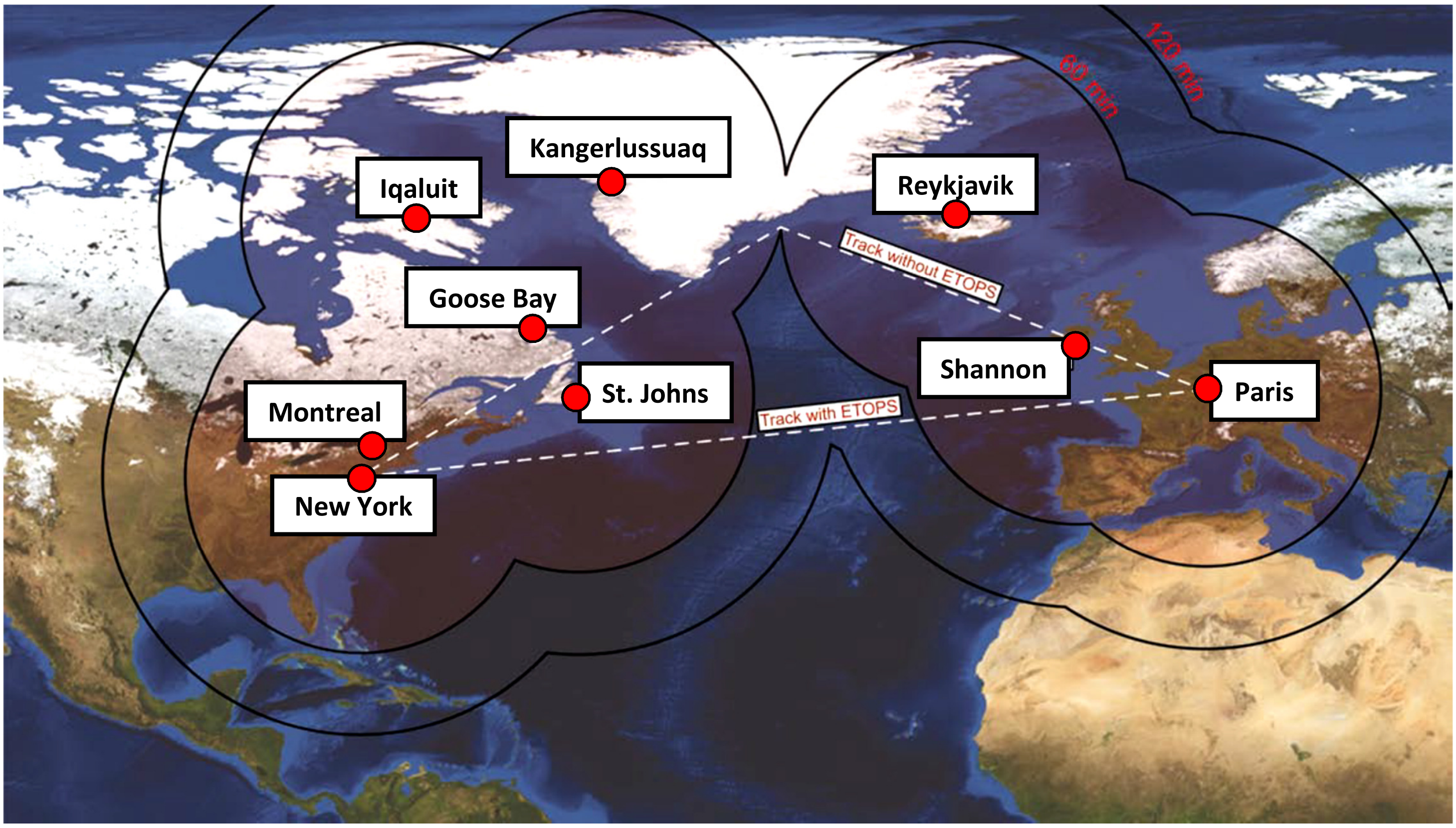
(c) The net flight path shall permit the aeroplane to continue flight from the cruising altitude to an aerodrome where a landing can be made in accordance with CAT.POL.A.225 or CAT.POL.A.230, as appropriate. The net flight path shall clear vertically, by at least 2 000 ft, all

terrain and obstructions along the route within 9,3 km (5 NM) on either side of the intended track in accordance with the following:
(1) the engine is assumed to fail at the most critical point along the route;
(2) account is taken of the effects of winds on the flight path;
(3) fuel jettisoning is permitted to an extent consistent with reaching the aerodrome with the required fuel reserves, if a safe procedure is used; and
(4) the aerodrome where the aeroplane is assumed to land after engine failure shall meet the following criteria:
(i) the performance requirements at the expected landing mass are met; and
(ii) weather reports and/or forecasts and field condition reports indicate that a safe landing can be accomplished at the estimated time of landing.

PRESENTATION OF DATA

RANGE LIMIT FOLLOWING ENGINE FAILURE

After engine failure, the lower operating altitude significantly decreases the engines efficiency so much so that the fuel-flow on the remaining engine is almost as much as the fuel flow with both engines operating at high altitude.
This fact, together with the reduced true airspeed, means that the specific range is dramatically decreased. As a result of the reduced range it is now not possible to reach the destination airfield and in fact the priority now is to find an alternate airfield to land before the fuel runs out. This issue is of such importance that is was necessary to regulate it.
The regulation states that twin engine aeroplanes beyond a certain size must be no further away from a suitable aerodrome than the distance flown in 60 minutes using the one engine operative cruise speed as TAS in still air. For aeroplanes with 3 or more engines the time is increased to 90 minutes.
Therefore at all points on the route, a twin engine aeroplane must be within 60 minutes of an alternate airfield.
This regulation has a significant impact on flight routes, especially over the sea. To comply with the 60 minute rule, the aeroplane track must all times be within the 60 minute range limit of a suitable alternate airfield. For example, a direct track to North America from Europe is not possible.



However, as more and more reliable and efficient aeroplanes are produced, an extension to the 60 minutes rule has been introduced.

ETOPS - Extended range with Twin engine aircraft OPerationS

The extension to the 60 minutes rule is called "ETOPS" and hugely increases the operational capability of twin engine aeroplanes where only 3 or more engine aeroplanes could operate. However, ETOPS must be applied for by the airlines concerned and approval gained from the appropriate aviation authority.

To gain ETOPS approval, a greater range of performance parameters must be known and these accompany the application and are eventually published in the operating manual. These include extra data for

- Area of operation
- Critical Fuel Reserves
- Net Level-off Altitudes

Gaining an ETOPS approval of 120 minutes for example will greatly benefit flight tracks across the Atlantic Ocean, the route from Paris to New York for example, can now be flown direct by a twin jet aeroplane.

Previously, the longest ETOPS approval was 180 minutes and even for 207 minutes over the Pacific.

However, the approval never ceases to increase. In the future ETOPS may be evolving into a newer system, called LROPS. LROPS stands for Long Range Operational Performance Standards, which will affect all aircraft, not just those with a twin-engine configuration.

Example of possible certification per type of aircraft

ETOPS 120
Airbus A300
ATR 42 and 72
Boeing 737 Classic + BBJ
Tupolev Tu-204

ETOPS 180
Airbus Family A320: A318, A319, A320, A321.
Airbus A300-600/600R7, Airbus A3107 and A330-200F
Airbus A330 MRTT
Boeing 737 NG
Boeing 757, 767 and 777
Bombardier Global 5000

ETOPS 240
Airbus A330

ETOPS 330
Boeing 787 : ETOPS330 instead of ETOPS1809
Boeing 777 (since 2011): ETOPS330 instead of ETOPS180
Boeing 747-8 (FAA regulation)

ETOPS 370
Airbus A350 XWB (expected ETOPS420)

D) Landing

LANDING CONSIDERATION

The maximum mass for landing is the lesser of:

- the climb limit mass
- the field length limit mass
- the structural limit mass

LANDING CLIMB REQUIREMENTS

LANDING CLIMB (All engines operating)

- A gradient of not less than 3.2% with,
- All engines operating at the power available 8 seconds after initiation of movement of the thrust control from the minimum flight idle to the take-off position
- Landing configuration.
- Aerodrome altitude.
- Ambient temperature expected at the time of landing.
- A climb speed which is:
  - Not less than 1.13 V_{SRO} (may be 1.15 V_{SRO} for 4 engine aircraft if application of power results in significant reduction in stalling speed)
  - Not less than V_{MCL}
  - not more than 1.23 V_{SRO}

DISCONTINUED APPROACH CLIMB (One engine inoperative)

- A climb gradient not less than:
  - 2.1% for 2 engined aircraft
  - 2.4% for 3 engined aircraft
  - 2.7% for 4 engined aircraft

With:

- The critical engine inoperative and the remaining engines at the available take-off thrust.
- Landing gear retracted
- Flaps approach configuration, provided that the approach flap V_S does not exceed 110% of landing flap V_S
- Aerodrome altitude
- Ambient temperature
- Speed: Normal approach speed but not greater than 1.41 V_{SRO}.

The more limiting of the landing climb and the approach gradient requirements will determine the maximum mass for altitude and temperature at the landing aerodrome.

PRESENTATION OF DATA

DISCONTINUED APPROACH INSTRUMENT CLIMB

For instrument approaches with decision heights below 200ft, an operator must verify that the approach mass of the aeroplane, taking into account the take-off mass and the fuel expected to be consumed in flight, allows a missed approach gradient of climb, with the critical engine failed and with the speed and configuration used for go-around of at least 2.5%, or the published gradient, whichever is the greater.

LANDING DISTANCE REQUIREMENTS

The landing distance required on a dry runway for destination and alternate aerodromes, from 50 ft to a full stop must not exceed:

- **60% of the Landing Distance Available for turbo-jet aeroplanes**
- **70% of the Landing Distance Available for turbo-prop aeroplanes**

(Short landing and steep approach procedures may be approved based on lower screen heights, but not less than 35 ft)

Turbo-jet	$LD \leq 0.6\ LDA$	*or*	$1{,}67\ LD \leq LDA$
Turbo-prop	$LD \leq 0.7\ LDA$	*or*	$1{,}43\ LD \leq LDA$

The landing distance required is based on:

- the aeroplane in the landing configuration
- the speed at 50ft not less than 1.23 V_{SRO}
- aerodrome pressure altitude
- standard day temperature (ISA)
- factored winds (50% headwind, 150% tailwind)
- the runway slope if greater than ± 2%

RUNWAY SELECTION

WET RUNWAYS

If the runway is forecast to be wet at the estimated time of arrival the Landing Distance Available must be at least 115% of the dry runway landing distance required. However, a lesser factor may be used so long as it is published in the Aeroplane Flight Manual and the authority has approved such a factor.

Wet	$1.15\ LD \leq LDA$
Turbo-jet	$1{,}92\ LD \leq LDA$
Turbo-prop	$1{,}64\ LD \leq LDA$

PRESENTATION OF DATA

DESPATCH RULES

Landing must be considered both in still air and in the forecast wind.

1) Still air: The most favourable runway in still air may be selected.
2) Forecast wind: The runway most likely to be used in the forecast wind.

The lower of the two masses obtained from 1) and 2) above must be selected as the limiting mass for the field lengths available.

NON-COMPLIANCE

- If the still air requirement cannot be met at an aerodrome with a single runway, that is, landing can only be made if there is an adequate wind component, the aircraft may be dispatched if 2 alternate aerodromes are designated at which full compliance is possible.

- If the forecast wind requirement cannot be met, the aeroplane may be dispatched if an alternate is designated at which all the landing requirements are met.