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FLIGHT OPERATIONS & TRAINING STANDARDS

December 2024

Getting to Grips with Aircraft Performance

AIRBUS

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INTRODUCTION

The safety of air transportation is a combined effort, regulated by the State on one side, and used by the manufacturers, airlines and Air Traffic Controllers (ATC), on the other. It is the responsibility of the State to supervise civil aviation, to ensure that a high safety standard is maintained throughout the industry, and its primary method to implement this is via the definition, and the management of written regulations. The control process includes a fixed set of rules to ensure that all aircraft respect a minimum level of performance that therefore results in the definition of limitations.

The "State administration" generally includes the civil aviation authority that corresponds to the aircraft's country of registration. In the United States for example, this position is the responsibility of the Federal Aviation Administration (FAA). In France, it is the responsibility of the “Direction Générale de l’Aviation Civile” (DGAC).

Every country has its own regulations, but the international characteristics of air transportation takes into account that there are rules that must be followed worldwide. The International Civil Aviation Organization (ICAO) was therefore created in 1948, to provide a supranational council, to assist in the definition of the minimum recommended standards that must be complied with internationally. The Chicago Convention was signed on December 7, 1944, and has become the legal foundation for civil aviation worldwide.

In Europe, the regulations evolved over time, under different authorities: the Joint Aviation Authorities (JAA) requirements are now the European Aviation Safety Agency (EASA) regulatory measures. This document mentions the most updated EASA Certification Specifications (CS), but the applicable certification regulation can be different depending on the aircraft.

Although it is usual for each country to select the main airworthiness standards defined together with aircraft manufacturers (USA, Europe, Canada, etc.), every country has its own set of operational regulations. For example, some countries (mainly European) selected EASA Air OPS (formerly JAR-OPS), while some others follow the FAA FAR 121.

The "field of limitations" is therefore dependent on a combination of the following two areas:

- Airworthiness: This involves the design of the aircraft (limitations, performance data etc.), in relation to EASA CS 25 or FAA FAR 25.
- Operations: This involves the technical operating rules (takeoff and landing limitations, fuel planning, etc.), in relation to EASA AIR OPS or FAA FAR 121.

There are airworthiness and operational regulations for all aircraft types. This document is about Airbus aircraft, that is aircraft with a maximum takeoff weight that exceeds 57 000 kg. Airbus performance documentation is clearly divided into the two above-mentioned categories: Airworthiness and Operations.

- Airworthiness: The Airplane Flight Manual (AFM) is associated with the airworthiness certificate and contains certified performance data in compliance with EASA CS 25/FAA FAR 25.
- Operations: The Flight Crew Operating Manual (FCOM) can be seen as the AOM (aircraft-related portion of the Operations Manual), that contains all the necessary limitations, procedures and performance data for aircraft operation.

The following table (Table 1) illustrates the regulatory basis for large aircraft:

	ICAO	**EUROPE (EASA)**	**USA (FAA)**
Airworthiness	Annex 8 to the Chicago Convention	CS 25	FAR part 25
Operating Rules	Annex 6 to the Chicago Convention	AIR OPS	FAR part 121

Table 1: Large Aircraft Regulatory Requirements

Most Airbus aircraft are primarily CS 25 (or a previous applicable standard) certified. However, compliance with the operating rules remains under the responsibility of the airline.

This document is about the Airbus civil aircraft performance. The aircraft performance is the analysis of the payload capabilities of an aircraft (takeoff, in flight and landing), depending on several conditions.
It takes into account three different characteristics of aircraft performance:

- The physical characteristics: This document provides reminders about flight mechanics, aerodynamics, altimetry, influence of external parameters on aircraft performance, flight optimization concepts…
- The regulatory characteristics: The description of the main EASA and FAA certification and operating rules, that results in the establishment of limitations. For a clear understanding, regulatory extracts are quoted to help make a specific subject clear. In these cases, the text is written in italics and in blue (***certification***) or green (***operational***) color, and the exact references are clearly indicated to the reader.
- The operational aspect: The description of operational methods, operational procedures and pilot's actions.
- The ICAO guidelines: when applicable, the ICAO references are written in italics and in orange (***recommendations***).

A. AIRCRAFT LIMITATIONS

1. FLIGHT LIMITATIONS

1.1. LOAD FACTORS

Aircraft are designed to be resistant to several flight loads that mainly come from engines, wind gusts and maneuver cases. During the flight, load factors (n_z), e.g. maneuver and turbulence, may appear and increase loads on the aircraft. The load factors have an impact on the maximum weights and maximum speeds.

CS 25.301 Subpart C
CS 25.303 Subpart C
CS 25.305 Subpart C
CS 25.307 Subpart C
CS 25.321 Subpart C
CS 25.1531 Subpart G

FAR 25.301 Subpart C
FAR 25.303 Subpart C
FAR 25.305 Subpart C
FAR 25.307 Subpart C
FAR 25.321 Subpart C
FAR 25.1531 Subpart G

CS/FAR 25.301 Loads

"(a) Strength requirements are specified in terms of limit loads (the maximum loads to be expected in service) and ultimate loads (limit loads multiplied by prescribed factors of safety). Unless otherwise provided, prescribed loads are limit loads."

CS/FAR 25.321 Flight Loads

"(a) Flight Load Factors represent the ratio of the aerodynamic force component (acting normal to the assumed longitudinal axis of the airplane) to the weight of the airplane. A positive load factor is one in which the aerodynamic force acts upward with respect to the airplane."

$$n_z = \frac{Lift}{Weight}$$

Except when the lift force is equal to the weight (W) and n_z=1 (for example, in straight and level flight), the aircraft apparent weight (W_a) is different from its actual weight (mg):

$$W_a = n_z . m. g = Lift$$

In some cases, the load factor is more than 1 (bank turn, recovery, turbulence). In other cases, it may be less than 1 (clear air turbulence). The aircraft structure is designed to be resistant to load factors, as defined by the regulations. As a result, load factor limits are defined, so that an aircraft can operate within these limits without suffering permanent distortion of its structure. The extreme loads that can cause rupture, are usually 1.5 times the load factor limit.

CS / FAR 25.1531 Maneuvering flight load factors

"Load factor limitations, not exceeding the positive limit load factors determined from the maneuvering diagram in section 25.333 (b) must be established."

For all Airbus types, the load acceleration limits for flight maneuvering are established as follows:

Clean configuration...........................	$-1g \le n_z \le +2.5g$
Slats extended.................................	$0g \le n_z \le +2g$

1.2. Maximum Speeds

1.2.1. Maximum Airspeeds

CS 25.1501 Subpart G ***FAR 25.1501 Subpart G***

"(a) Each operating limitation specified in sections 25.1503 to 25.1533 and other limitations and information necessary for safe operation must be established."

CS 25.1503 Subpart G
CS 25.1505 Subpart G
CS 25.1507 Subpart G
CS 25.1511 Subpart G
CS 25.1515 Subpart G
CS 25.1517 Subpart G

FAR 25.1501 Subpart G
FAR 25.1505 Subpart G
FAR 25.1507 Subpart G
FAR 25.1511 Subpart G
FAR 25.1515 Subpart G
FAR 25.1517 Subpart G

CS/FAR 25.1503 Airspeed Limitations: General

"When airspeed limitations are a function of weight, weight distribution, altitude, or Mach number, the limitations corresponding to each critical combination of these factors must be established."

OPERATING LIMIT SPEED	DEFINITIONS	SPEED VALUE EXAMPLES FOR THE A320-200
VMO/MMO Maximum Operating Limit Speeds	***CS / FAR 25.1505 Subpart G*** V_{MO} or M_{MO} are the speeds that may not be intentionally exceeded in any phase of flight (climb, cruise, or descent).	**V_{MO} = 350 kt (IAS)** **M_{MO} = M0.82**
V_{FE} Flaps Extended Speeds	***CS / FAR 25.1511 Subpart G*** V_{FE} must be established, so that it does not exceed the design flap speed.	**CONF1 230 kt** **CONF1+F 215 kt** **CONF2 200 kt** **CONF3 185 kt** **CONFULL 177 kt**
V_{LO} / V_{LE} Landing Gear Speeds	***CS / FAR 25.1515 Subpart G*** V_{LO}: Landing Gear Operating Speed V_{LO} may not exceed the speed at which it is safe to extend and to retract the landing gear. If the extension speed is not the same as the retraction speed, the two speeds must be determined as $V_{LO(EXT)}$ and $V_{LO(RET)}$, respectively. ***CS / FAR 25.1515 Subpart G*** V_{LE}: Landing Gear Extended Speed V_{LE} may not exceed the speed at which it is safe to fly with the landing gear secured in the fully extended position. *Note: With the same considerations, Airbus also published Landing Gear Operating Mach (M_{LO}) and Landing Gear Extended Mach (M_{LE}).*	**$V_{LO\ RET}$** (landing gear operating: retraction) **220 kt (IAS)** **$V_{LO\ EXT}$** (landing gear operating: extension) **250 kt (IAS)** **V_{LE}** (landing gear extended) **280 kt / M 0.67**

Table A-1 Maximum Operating Speeds

The maximum speeds are indicated by a red and black strip on the PFD scale (Illustration A-1).

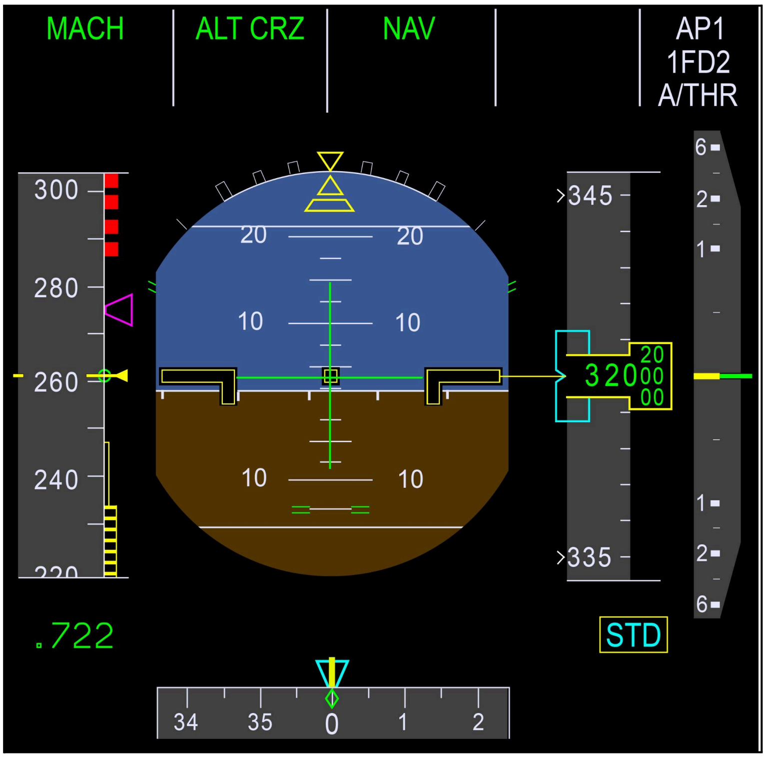


Illustration A-1: Maximum Speed on the PFD

1.2.2. Maximum Brake Energy Speed: V_{MBE}

Brakes require a minimum stopover time to cool and recover full efficiency after each use.

When the takeoff is rejected, brakes and the aerodynamic drag must absorb and eliminate the aircraft's kinetic energy. When rejected at V1, this energy corresponds to:

$$\left(\frac{1}{2} Weight \cdot V1^2\right)$$

CS 25.109 Subpart B ***FAR 25.109 Subpart B***

"(i) A flight test demonstration of the maximum brake kinetic energy accelerate-stop distance must be conducted with no more than 10% of the allowable brake wear range remaining on each of the aeroplane wheel brakes."

Brakes have a maximum energy absorbent capacity, known as the maximum brake energy. For certification purposes, this capacity must be demonstrated with worn brakes (only post-amendment FAR 25-42). As a result, the speed at which a full stop can be achieved, for a specific takeoff weight, is limited to a maximum value (V_{MBE}).

1.2.3. Maximum Tire Speed: V_{TIRE}

The tire manufacturer specifies the maximum ground speed, in order to limit the centrifugal forces and the heat generation that may damage the tire structure.

Note: For example, for A321XLR aircraft, V_{TIRE} = 235 mph published as 204 knots (ground speed) in Airbus documentation.

1.3. Minimum Speeds

1.3.1. Minimum Control Speed on the Ground: V_{MCG}

CS 25.149 Subpart B ***FAR 25.149 Subpart B***

"(e) V_{MCG}, the minimum control speed on the ground, is the calibrated airspeed during the take-off run, at which, when the critical engine is suddenly made inoperative, it is possible to maintain control of the aeroplane with the use of the primary aerodynamic controls alone (without the use of nose-wheel steering) to enable the take-off to be safely continued using normal piloting skill.
In the determination of V_{MCG}, assuming that the path of the aeroplane accelerating with all engines operating is along the centreline of the runway, its path from the point at which the critical engine is made inoperative to the point at which recovery to a direction parallel to the centreline is completed, may not deviate more than 30 ft laterally from the centreline at any point."

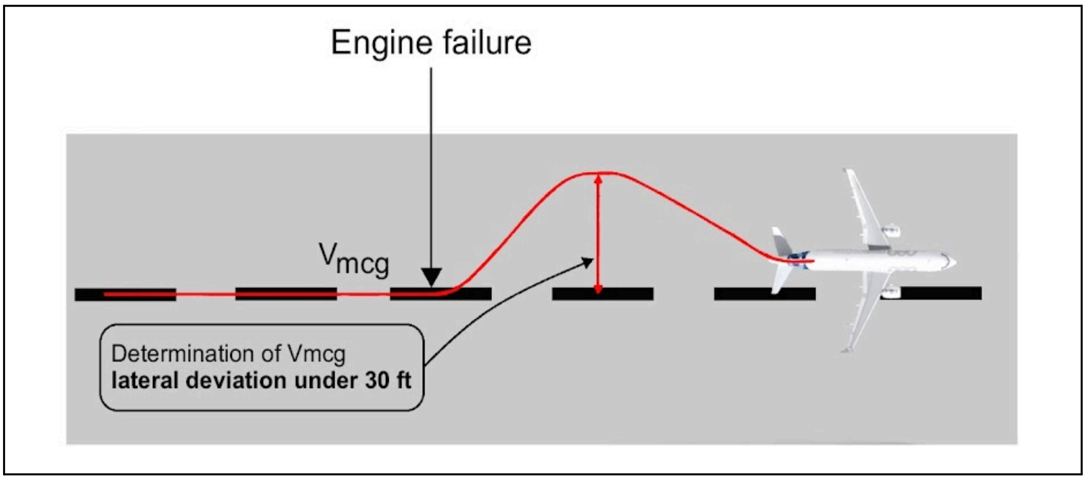


Illustration A-2: V_{MCG}

"V_{MCG} must be established with:
- *The aeroplane in each take-off configuration or, at the option of the applicant, in the most critical take-off configuration;*
- *Maximum available take-off power or thrust on the operating engines;*
- *The most unfavourable centre of gravity;*
- *The aeroplane trimmed for take-off; and*
- *The most unfavourable weight in the range of take-off weights."*

Note: For some aircraft models, the V_{MCG} may be increased for operations on narrow runways.

1.3.2. Minimum Control Speed in the Air: V_{MCA}

CS 25.149 Subpart B *FAR 25.149 Subpart B*

"(b) $V_{MC[A]}$ is the calibrated airspeed, at which, when the critical engine is suddenly made inoperative, it is possible to maintain control of the aeroplane with that engine still inoperative, and maintain straight flight with an angle of bank of not more than 5 degrees.

(c) $V_{MC[A]}$ may not exceed 1.13 V_{SR} with

- *Maximum available take-off power or thrust on the engines;*
- *The most unfavourable centre of gravity;*
- *The aeroplane trimmed for take-off;*
- *The maximum sea-level take-off weight*
- *The aeroplane in the most critical take-off configuration existing along the flight path after the aeroplane becomes airborne, except with the landing gear retracted; and*
- *The aeroplane airborne and the ground effect negligible*

(d) The rudder forces required to maintain control at VMC may not exceed 667 N (150 lbf) nor may it be necessary to reduce power or thrust of the operative engines. During recovery, the aeroplane may not assume any dangerous attitude or require exceptional piloting skill, alertness, or strength to prevent a heading change of more than 20°."

Note: Refer to the Takeoff section for "critical engine" definition.

1.3.3. Minimum Control Speed during Approach and Landing: V_{MCL}

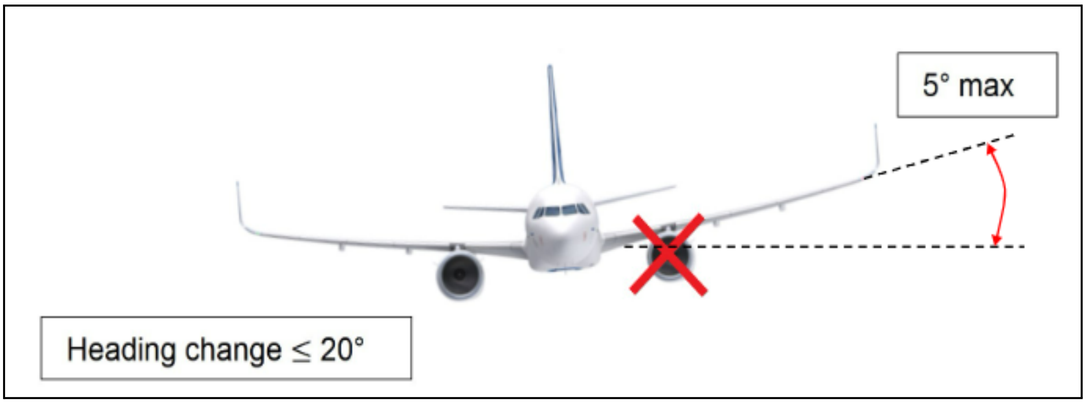


Illustration A-3: V_{MCA}

CS 25.149 Subpart B **FAR 25.149 Subpart B**

"(f) V_{MCL}, the minimum control speed during approach and landing with all engines operating, is the calibrated airspeed at which, when the critical engine is suddenly made inoperative, it is possible to maintain control of the aeroplane with that engine still inoperative, and maintain straight flight with an angle of bank of not more than 5º. V_{MCL} must be established with:

- *The aeroplane in the most critical configuration (or, at the option of the applicant, each configuration) for approach and landing with all engines operating;*
- *The most unfavourable centre of gravity;*
- *The aeroplane trimmed for approach with all engines operating;*
- *The most unfavourable weight, or, at the option of the applicant, as a function of weight.*
- *Go-around thrust setting on the operating engine(s)*

(g) For aeroplanes with three or more engines, V_{MCL-2}, the minimum control speed during approach and landing with one critical engine inoperative, is the calibrated airspeed at which, when a second critical engine is suddenly made inoperative, it is possible to maintain control of the aeroplane with both engines still inoperative, and maintain straight flight with an angle of bank of not more than 5°. V_{MCL-2} must be established with [the same conditions as V_{MCL}, except that]*:*

- *The aeroplane trimmed for approach with one critical engine inoperative*
- *The thrust on the operating engine(s) necessary to maintain an approach path angle of 3° when one critical engine is inoperative.*
- *The thrust on the operating engine(s) rapidly changed, immediately after the second critical engine is made inoperative, from the [previous] thrust to:*
    - *the minimum thrust [and then to]*
    - *the go-around thrust setting*

(h) In demonstrations of V_{MCL} and V_{MCL-2}, lateral control must be sufficient to roll the aeroplane from an initial condition of steady straight flight, through an angle of 20 degrees in the direction necessary to initiate a turn away from the inoperative engine(s) in not more than 5 seconds."

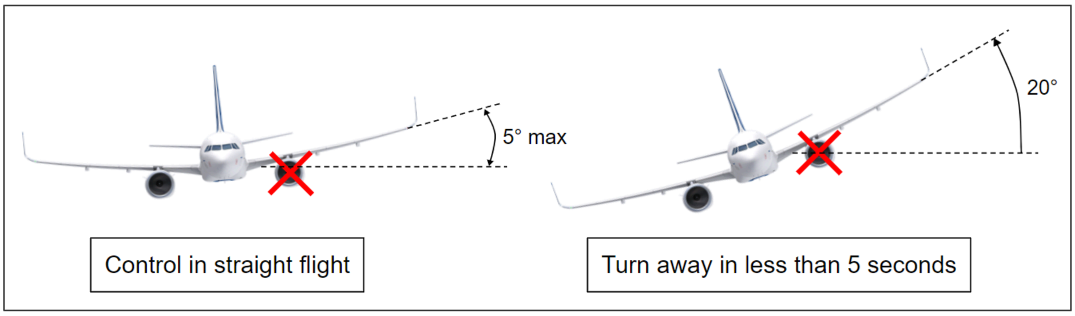


Illustration A-4: VMCL and VMCL-2

1.3.4. Minimum Unstick Speed: V_{MU}

CS 25.107 Subpart B *FAR 25.107 Subpart B*

"(d) V_{MU} is the calibrated airspeed at and above which the aeroplane can safely lift off the ground, and continue the take-off…"

VMU is the max between 2 speeds:

- The VLOF with the maximum pitch angle (*"...safely lift off the ground"*).
- The minimum speed ensuring a safe fly away from ground effects (*"...and continue the take-off"*).

During the flight test demonstration, at a low speed (80-100 kt), the pilot pulls the control stick to the limit of the aerodynamic capacity of the control surfaces. The aircraft achieves a slow rotation to an angle-of-attack at which the maximum lift coefficient is reached. For aircraft with geometric limitations, the aircraft achieves a slow rotation until the tail touches/comes into contact with the runway (the tail is protected by a device).

After, the pitch is maintained until liftoff.

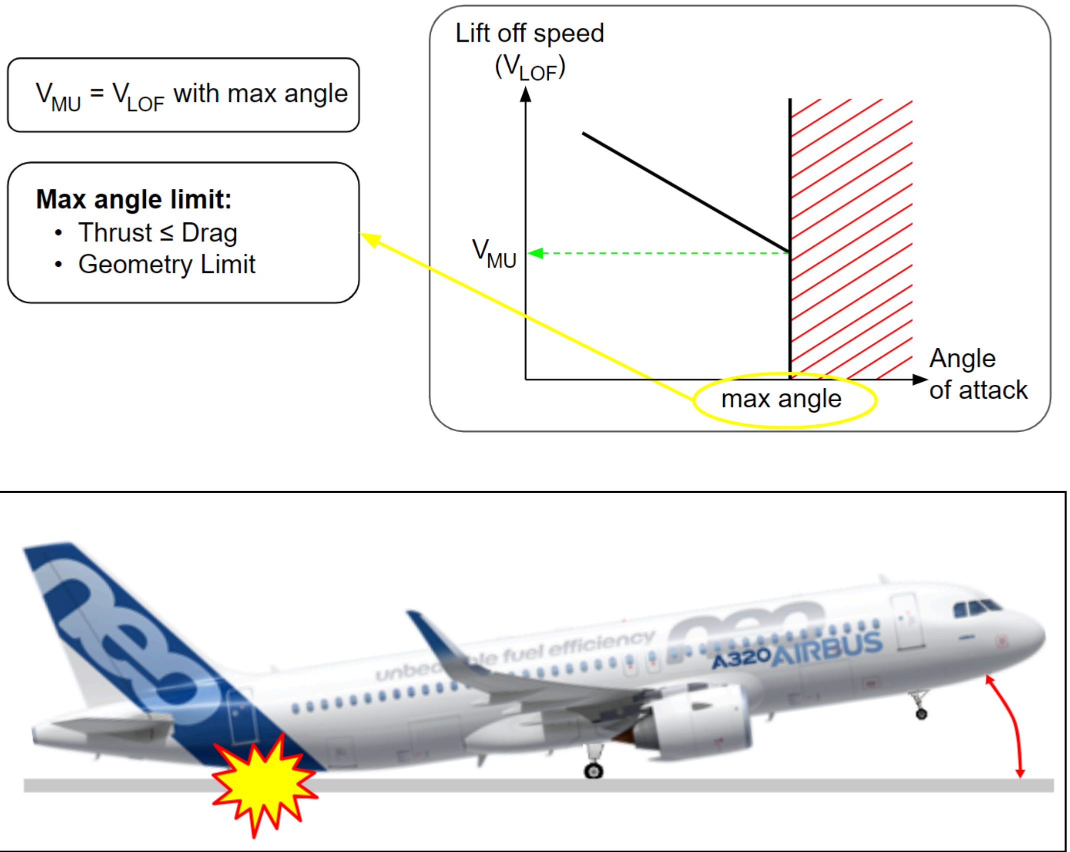


Illustration A-5: V_{MU} Demonstration (Geometrically-limited Aircraft)

In the case of One Engine Inoperative (OEI), the $V_{MU\ (N-1)}$ must ensure safe lateral control in order that the wing does not come into contact with the ground.

Illustration A-6: V_{MU} Risk of Wing in Contact with the Ground

Two Minimum Unstick Speeds (V_{MU}) must be determined:

- With all engines operatives: $V_{MU\ (N)}$
- With one engine inoperative: $V_{MU\ (N-1)}$

Note: $V_{MU\ (N)}$ is validated by flight test, $V_{MU\ (N-1)}$ is simulated by using a total thrust on both engines equivalent to OEI thrust.
Thrust generates some lift (see the result of the thrust on the vertical axis on illustration A-7).
With all engines operating, the lift generated by the thrust is greater than the lift with OEI.
This means that the lift generated by the wings must be higher, in the case of one engine failure. This increased lift can only be reached through a speed increase. This means that, usually, $V_{MU\ (N)}$ will be below $V_{MU\ (N-1)}$.

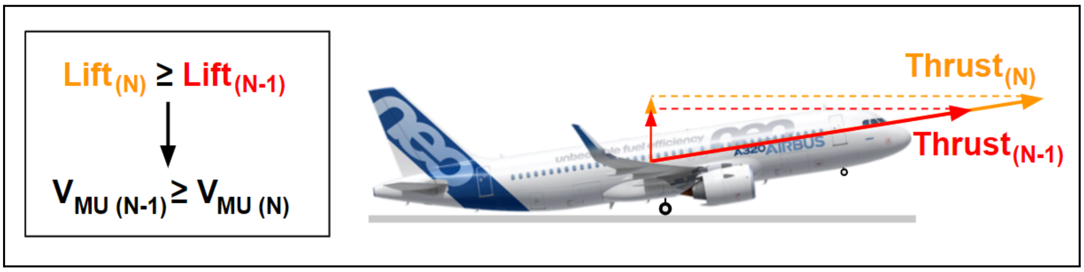


Illustration A-7: Engine Failure Effect on V_{MU}

1.3.5. Stall Speed

The stall speed definition changed since the A320 certification.

The stall speed can be explained as follows: when the angle-of-attack increases, the following events happen:

- Increase of the airflow speed over the wing (V in illustration A-8), and decrease of the airflow speed below the wing
- Decrease of the pressure over the wing
- Increase of the lift coefficient (C_L) and drag coefficient (C_D).

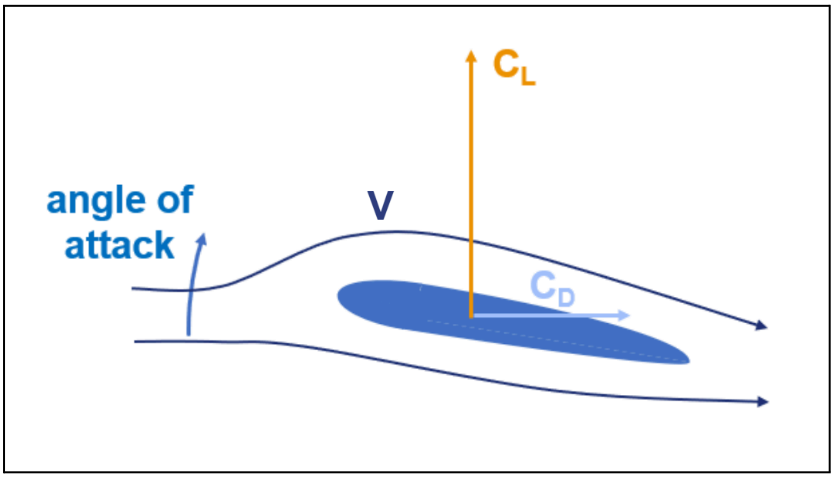


Illustration A-8:Low Angle of Attack - No Airflow Separation

The lift coefficient increases with the angle-of-attack. In level flight, the increase of the lift coefficient results in a decrease of the aircraft speed. The lift must balance the aircraft weight, that can be considered as constant at a specific time.

$$Angle\ of\ attack\ \nearrow \quad \Rightarrow \quad C_L\ \nearrow$$

$$Weight = \frac{1}{2}\rho\, S\, (TAS)^2\, C_L = constant$$

$$\rho = constant \qquad S = constant \qquad Lift = constant$$

$$C_L\ \nearrow \quad \Rightarrow \quad TAS\ \searrow$$

The speed cannot decrease beyond a minimum value. Above a certain angle-of-attack, the airflow starts to separate from the wing (Illustration A-9).

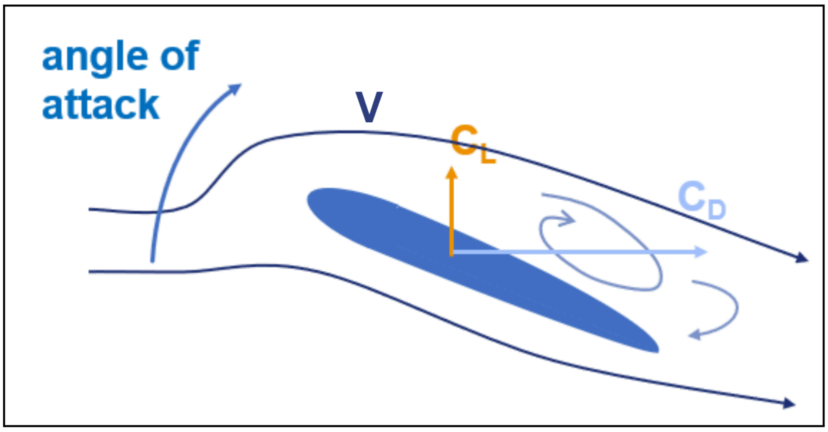


Illustration A-9: High Angle of Attack - Airflow Separation

Illustration A-10 demonstrates that the lift coefficient increases up to a maximum lift coefficient (C_{Lmax}), and suddenly decreases, when the angle-of-attack is increased above a specific value. This is a stall.

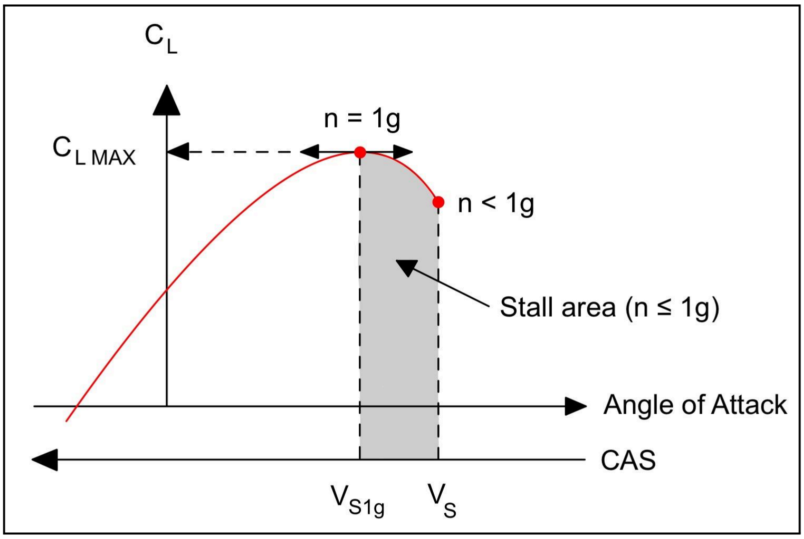


Illustration A-10: C_L versus Angle of Attack

There are two types of stall speed:

- V_{S1g} corresponds to the maximum lift coefficient (i.e. just before the lift starts to decrease). At this moment, the load factor is still equal to one.
- V_S corresponds to the conventional aerodynamic stall (i.e. when the lift suddenly collapses). At this moment, the load factor is always less than one.

CS 25.103 Subpart B ***FAR 25.103 Subpart B***

CS 25.103 Stall speed

"(a) The reference stall speed V_{SR} is a calibrated airspeed defined by the applicant. V_{SR} may not be less than a 1-g stall speed. V_{SR} is expressed as:

$$V_{SR} \geq \frac{V_{CLMAX}}{\sqrt{n_{zw}}}$$

Where:
V_{CLMAX} = [speed of maximum lift coefficient, i.e. V_{S1g}]
n_{zw} = Load factor normal to the flight path at V_{CLMAX}

(b) V_{CLMAX} is determined with:

- *Engines idling, or if that resultant thrust causes an appreciable decrease in stall speed, not more than zero thrust at the stall speed;*
- *The aeroplane, in other respects (such as flaps, landing gear and ice accretions) in the condition existing in the test or performance standard in which V_{SR} is being used;*

- *The weight used when V_{SR} is being used as a factor to determine compliance with a required performance standard;*
- *The centre of gravity position that results in the highest value of reference stall speed;*
- *The aeroplane trimmed for straight flight at a speed selected by the applicant, but not less than $1.13V_{SR}$ and not greater than $1.3V_{SR}$."*

Change 15 of JAR 25 of October 2000, established the idea of reference stall speed V_{SR} that is the same as V_{s1g}. The previous version of the JAR 25 provided a direct relationship between V_S and V_{S1g}, in order to ensure a consistency between aircraft models certified at V_s and those certified at V_{S1g}.

The 1-g stall speed, as the basis for compliance, was added to the Federal Aviation Requirements-25 (FAR-25), on November 26, 2002.

For the certification of the A320, the relationship between V_s and V_{s1g} was demonstrated as:

$$V_S = 0.94\ V_{S1g}$$

Based on this demonstration, the minimum V_2 (refer to the Takeoff section for the definition of V_2) was defined:

- For all Airbus aircraft models certified at V_{S1g}, $V_2 \geq 1.13\ V_{S1g}$
- For Airbus aircraft models certified at V_S (A300/A310), $V_2 \geq 1.2\ V_S$.

Note: In Airbus operational documentation, in addition to this brochure, V_{SR} is referred to as V_{S1g}.

Influence of CG in V_{s1g}

Based on CS 25.103, the worst CG for takeoff and landing calculations is a forward CG. As a result, a forward CG will result in a higher V_{S1g}.

2. Maximum Structural Weights

CS 25.25 Subpart B
CS 25.473 Subpart C
Air OPS Annex 1

FAR 25.25 Subpart B
FAR 25.473 Subpart C
AC 120-27C

2.1. Aircraft Weight Definitions

- **Manufacturer's Empty Weight (MEW)**: The weight of the structure, power plant, furnishings, systems and other items of equipment that are considered an integral part of the aircraft. It is a "dry" weight, and it only includes the fluids contained in closed systems (e.g. hydraulic fluid).

- **Operational Empty Weight (OEW)**: The MEW plus the Operator's items, (i.e. flight and cabin crew and their baggage, unusable fuel, engine oil, emergency equipment, toilet chemicals and fluids, galley structure, catering equipment, seats, documents, etc.).

- **Dry Operating Weight (DOW)**: The total weight of an aircraft ready for a specific type of operation without all usable fuel and traffic load. The OEW plus items that are specific to the type of flight (i.e. catering, newspapers, pantry equipment, etc.).

- **Zero Fuel Weight (ZFW)**: The weight obtained by the addition of the total traffic load (payload, in which are included cargo loads, passengers and passenger bags), and the DOW.

- **Landing Weight (LW)**: The weight at landing, at the destination airport. It is equal to the ZFW plus the fuel reserves.

- **Takeoff Weight (TOW)**: The weight at takeoff at the departure airport. It is equal to the LW at landing plus the trip fuel (fuel required for the trip), or to the ZFW plus the takeoff fuel (fuel required at the brake release point that includes reserves).

TOW = DOW + traffic load + fuel reserves + trip fuel

LW = DOW + traffic load + fuel reserves

ZFW = DOW + traffic load

Illustration A-11 illustrates the different aircraft weights, as defined in the regulations.

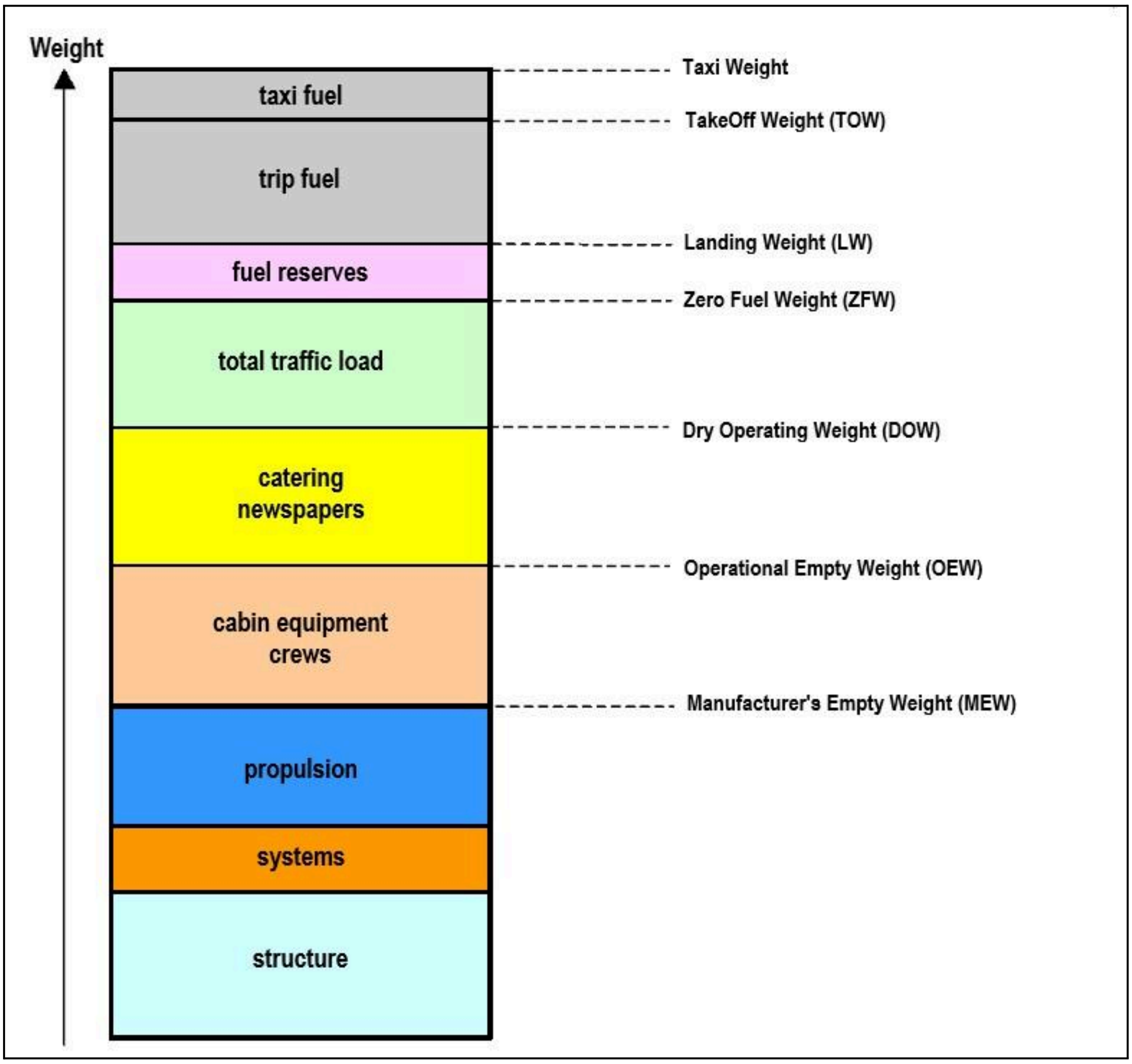


Illustration A-11: Aircraft Weights

2.2. Maximum structural Takeoff Weight (MTOW)

The TOW must never exceed the MTOW. The MTOW is determined during a landing impact with a vertical speed that is equal to -1.83 m/s (-360 ft/min), in accordance with the following:

- In-flight structure resistance criteria,
- Resistance of the landing gear,
- Structure criteria.

Note: Depending on the context, MTOW means either:

- The maximum weight limited by performance,
- The maximum weight limited by structure,
- The minimum between both limitations above.

2.3. Maximum Structural Landing Weight (MLW)

The LW is limited, with the assumption of a landing impact with a vertical speed equal to -3.05 m/s (-600 ft/min). The limit is the MLW. The landing weight must comply with the following:

$$\text{Actual } LW = TOW - \text{Trip Fuel} \leq MLW$$
or
$$\text{Actual } TOW \leq MLW + \text{Trip Fuel}$$

Note: Depending on the context, MLW means either:
- The maximum weight limited by performance,
- The maximum weight limited by structure,
- The minimum between both limitations above.

2.4. Maximum Zero Fuel Weight (MZFW)

Bending moments applied to the wing root, are at a maximum when the quantity of fuel in the wings is at a minimum (see Illustration A-12). During flight, the quantity of fuel in the wings, m_{WF}, decreases as fuel is burned. As a result, it is necessary to limit the weight when there is no fuel in the tanks. This limited weight is the Maximum Zero Fuel Weight (MZFW).

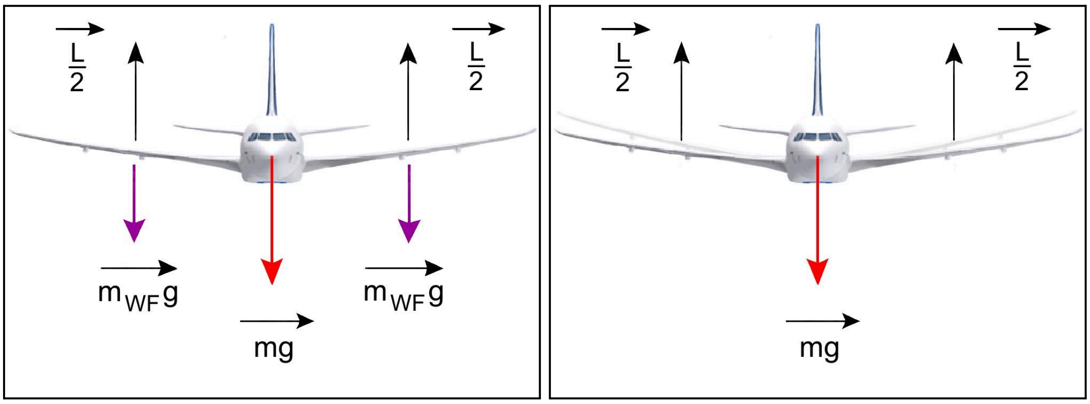


Illustration A-12: Wing Bending Relief Due to Fuel Weight

Therefore, the limitation is defined by:

$$\text{Current } ZFW \leq MZFW$$

The takeoff fuel is the sum of the trip fuel and the fuel reserves. As a result:

$$\text{Current } TOW \leq MZFW + \text{Takeoff Fuel}$$

2.5. Maximum Taxi Weight (MTW)

The MTW is limited by the stress on the shock absorbers, and possible bending of the landing gear, during turns on the ground.
However, the MTW is usually not a limitation factor, and is defined based on the MTOW, so that:

MTW – Taxi Fuel < MTOW

3. Minimum Structural Weight

CS 25.25 Subpart B ***FAR 25.25 Subpart B***

"(b) Minimum weight. The minimum weight (the lowest weight at which compliance with each applicable requirement of this CS-25 is shown) must be established so that it is not less than –

(1) The lowest weight selected by the applicant;
(2) The design minimum weight (the lowest weight at which compliance with each structural loading condition of this CS-25 is shown); or
(3) The lowest weight at which compliance with each applicable flight requirement is shown."

Usually, the gusts and turbulence loads are part of the criteria considered to determine the minimum structural weight.

4. Environmental Envelope

CS 25.1527 Subpart G ***FAR 25.1527 Subpart G***

"The extremes of the ambient air temperature and operating altitude for which operation is allowed, as limited by flight, structural, powerplant, functional, or equipment characteristics, must be established."

The result of this determination is the environmental envelope, and it includes the pressure altitude and the temperature limits. It is inside the environmental envelope that the aircraft performance is established and the aircraft systems achieve the certification requirements.

The AFM sets minimum and maximum Pressure Altitudes (MIN Zp and MAX Zp) and Temperatures (T_{MIN} and T_{MAX}).

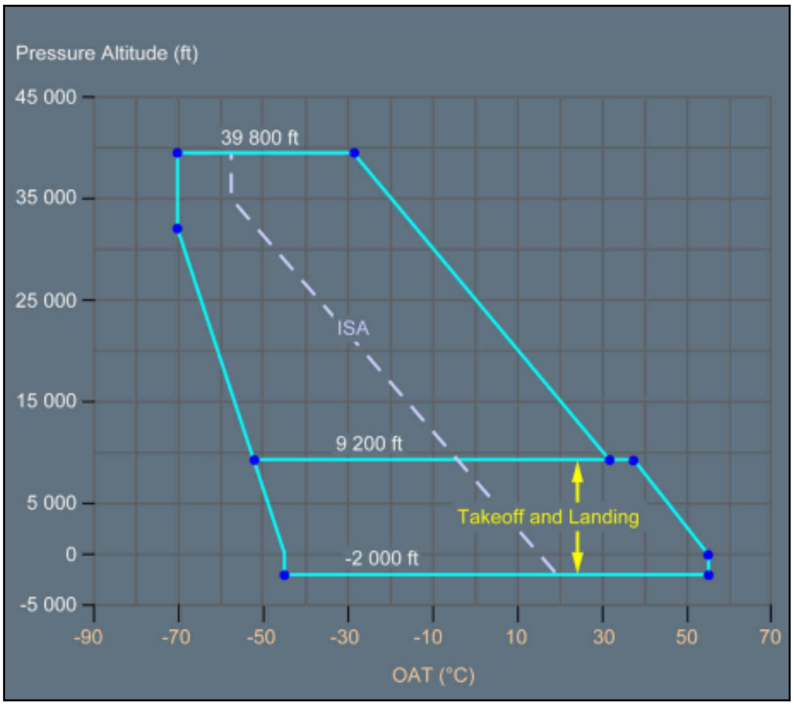


Illustration A-13: Example of an A320 Environmental Envelope

5. Engine Limitations

5.1. Thrust Setting and EGT Limitations

CS 25.1521 Subpart G
CS-E 490 and E 800

FAR 25.1521 Subpart G
FAR 33.87 and 33.88

The main cause of engine thrust limitations is the Exhaust Gas Temperature (EGT) limit.

The maximum thrust available for takeoff is the Takeoff/Go-Around (TOGA) thrust. It is certified for a maximum time of:

- 10 minutes, in the case of One Engine Inoperative (OEI) at takeoff, or
- 5 minutes with All Engines Operative (AEO).

The Maximum Continuous Thrust (MCT) is the maximum thrust that can be used without limitation in flight. It must be selected in the case of engine failure, when TOGA thrust is no longer permitted due to time limitation.

The Climb (CL) thrust is the maximum thrust available during the climb phase to the initial cruise flight level and to higher flight levels.

Note: The Takeoff/Go-Around (TOGA) thrust is the maximum thrust available for a Go-Around. The time limits are the same as for takeoff.

5.2. TAKEOFF THRUST LIMITATIONS

Illustration A-14 illustrates the influence that the pressure altitude and outside air temperature have on the maximum takeoff thrust, for a specific engine type.

At a specific pressure altitude, the Takeoff/Go-Around (TOGA) thrust remains constant (equal to the flat rated thrust), until the temperature reaches the flat rated temperature or reference temperature (T_{ref}). Above this reference temperature, the engine thrust is limited by the Exhaust Gas Temperature (EGT). The result is that the available thrust decreases as the temperature increases.

On the other hand, at a specific temperature, any increase in the pressure altitude decreases the available takeoff thrust.

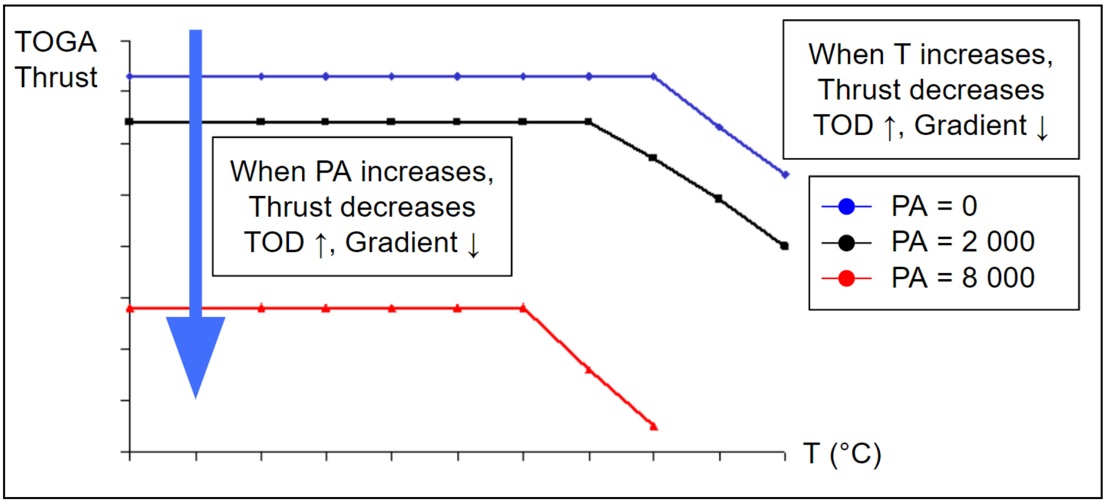


Illustration A-14: Engine Thrust VS. Pressure Altitude and Temperature

B. OPERATING SPEEDS

1. Common Speeds

1.1. Lowest Selectable Speed: VLS

CS 25.125 Subpart B *FAR 25.125 Subpart B*

As a general rule, during in-flight phases, pilots should not select a speed below V_{LS} (Lowest Selectable Speed). The V_{LS} definition depends on the flight phase. V_{LS} is at least 1.23 V_{S1g} in clean and landing configurations.

$$V_{LS} \geq 1.23\, V_{S1g}$$

For A300/A310, the V_{LS} is defined as

$$V_{LS} = 1.3\, V_S$$

Refer to the chapter Stall Speed.

The V_{LS} rule also applies for the landing phase. During landing, pilots must maintain a stabilized approach with a calibrated airspeed of no less than V_{LS} down to a height of 50 ft above the destination airport.

1.2. Minimum Flaps Speed: F

F speed is indicated by an “F” on the PFD speed scale (Illustration B-1).

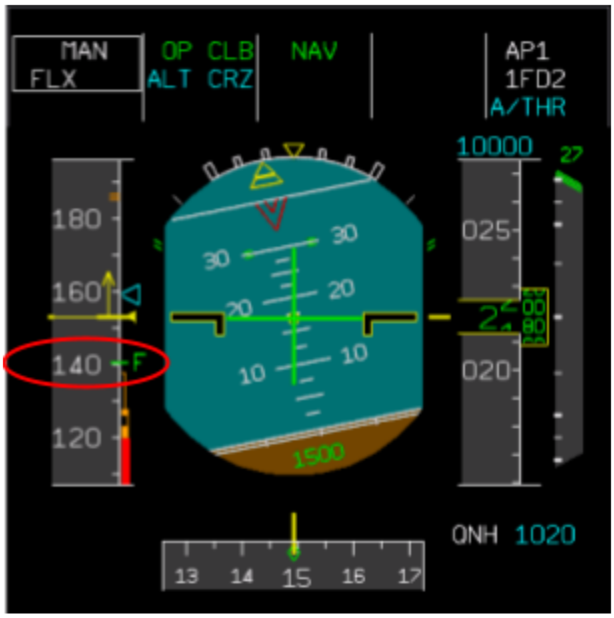


Illustration B-1: F Speed on PFD

F speed is not the same for takeoff and approach.

At takeoff: F speed is the minimum speed at which the flaps may be safely retracted to flaps lever position 1 during initial climb. F speed is designed to provide some margin compared to the V_{LS} of the configuration that corresponds to flaps lever position 1.

During approach: F speed is the recommended speed to select CONF 3 when the aircraft is in CONF 2, or the recommended speed to select CONF FULL when the aircraft is in CONF 3.

1.3. Minimum Slats Speed: S

S Speed is indicated by an "S" on the PFD speed scale (Illustration B-2).

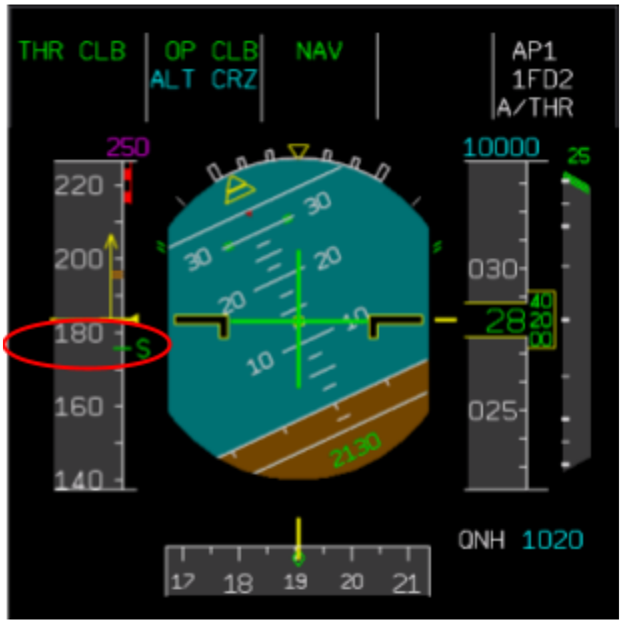


Illustration B-2: S Speed on the PFD

S speed is not the same for takeoff and approach.

At takeoff: S speed is the minimum speed at which the slats and flaps may be retracted to CONF clean. S speed is designed to provide some margin compared to the V_{LS} of the CONF clean.

During approach: S speed is the recommended speed to select CONF 2 when the aircraft is in CONF 1.

1.4. Green Dot Speed: GDS

The green dot speed is indicated by a green dot on the PFD scale (Illustration B-3).

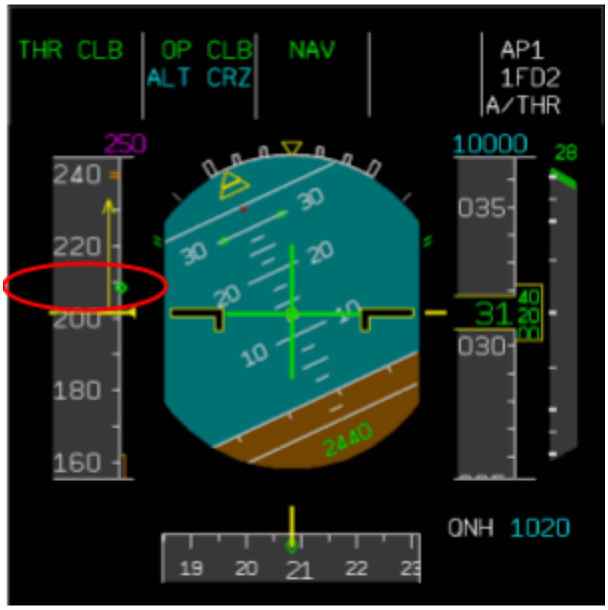


Illustration B-3: GDS on the PFD

The value of GDS displayed on the PFD can be different between AEO and OEI.

The GDS is a good compromise in order to enable the pilots to follow a speed very near to the best lift to drag ratio speed.
It is also used with OEI:

- To perform drift down since it results in the highest ceiling.
- As a target speed at the end of the segment at final takeoff, since it provides the best climb gradient at low speed.

1.5. Speed Reference System : SRS

The Speed Reference System (SRS) mode is a managed vertical mode. This mode is used during takeoff and during go-around.

SRS mode controls the speed via the elevators in order to control the aircraft along a vertical path.

For example, when the aircraft is on ground at takeoff, V_2 is the speed target. When the aircraft is airborne, V_2 + 10 kt becomes the speed target.
In case of engine failure, the SRS mode obtains and maintains the existing speed at the time of the engine failure or V_2, depending on which is higher. However, the speed target is limited by V_2 +15 kt.

The SRS guidance law includes:

- A limit for pitch altitude guidance, in order to not exceed a maximum pitch attitude.
- A vertical speed protection to ensure a minimum climb rate.

In any case, SRS will provide guidance to a speed equal or above V_{LS}.

2. Takeoff Speeds

2.1. Engine Failure Speed: V_{EF}

CS 25.107 Subpart B ***FAR 25.107 Subpart B***

"(a) V1 must be established in relation to VEF as follows:
(1) V_{EF} is the calibrated airspeed at which the critical engine is assumed to fail. V_{EF} must be selected by the applicant, but may not be less than V_{MCG}."

2.2. Decision Speed: V1

CS 25.107 Subpart B ***FAR 25.107 Subpart B***

V1 is the maximum speed at which the crew can decide to reject the takeoff, and still be able to stop the aircraft within the limits of the runway.

If the crew is aware of a failure before V1, the crew will safely abort the takeoff.
If the crew is aware of a failure after V1, the crew must complete the takeoff. From the point where the aircraft reaches V1, the aircraft is sure to reach the takeoff limited height: and the aircraft may be too fast to brake safely before the end of the stopway.

"CS/FAR 25.107
(a)(2) V_1, in terms of calibrated airspeed, is selected by the applicant; however, V_1 may not be less than V_{EF} plus the speed gained with the critical engine inoperative during the time interval between the instant at which the critical engine is failed, and the instant at which the pilot recognises and reacts to the engine failure, as indicated by the pilot's initiation of the first action (e.g. applying brakes, reducing thrust, deploying speed brakes) to stop the aeroplane during accelerate-stop tests."

The time that is considered between the critical engine failure at V_{EF}, and the pilot detection of the failure at V_1, is at least 1 second. Therefore:

$$V_{MCG} \leq V_{EF} < V_1 \leq V_{MBE}$$

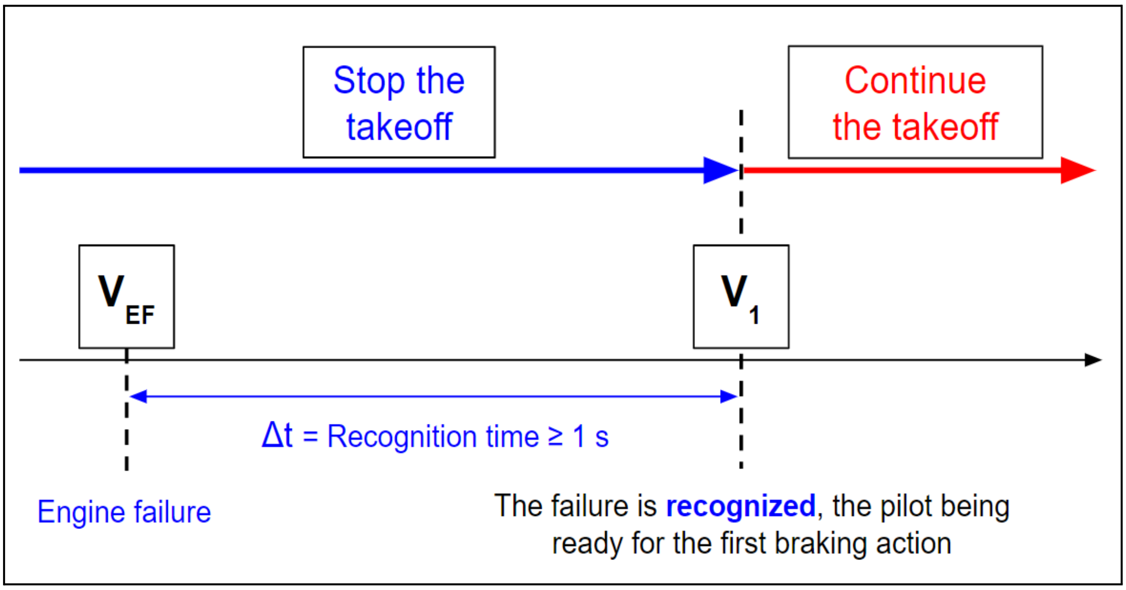


Illustration B-4: Decision Speed

This speed is entered by the crew in the FMS cockpit interface, e.g. Multipurpose Control and Display Unit (MCDU) for A320, during flight preparation. The speed is indicated by a “1” on the speed scale of the Primary Flight Display (PFD) during takeoff acceleration (see Illustration B-5). The V_2 Speed (see chapter Takeoff Climb Speed: V2) is indicated by a triangle in purple.

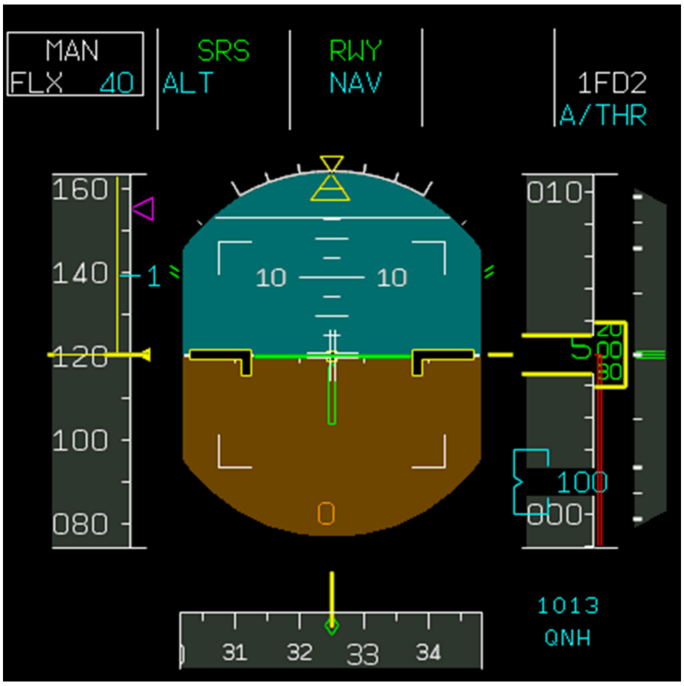


Illustration B-5: Information Provided by the PFD

2.3. ROTATION SPEED: VR

CS 25.107 Subpart B

FAR 25.107 Subpart B

V_R is the speed at which the pilot initiates the rotation, at the appropriate rate of approximately 3 ° per second.

"(e)(1) V_R may not be less than:

- *V_1,*
- *105% of V_{MCA}*
- *The speed that allows reaching V_2 before reaching a height of 35 ft above the take-off surface, or*
- *A speed that, if the aeroplane is rotated at its maximum practicable rate, will result in a [satisfactory] V_{LOF}".*

V_R is entered in the FMS cockpit interface by the crew during the flight preparation.

$$V_R \geq 1.05\, V_{MCA}$$

2.4. LIFT OFF SPEED: V_{LOF}

CS 25.107 Subpart B

FAR 25.107 Subpart B
FAR AC 25 7D

"(f) V_{LOF} is the calibrated airspeed at which the aeroplane first becomes airborne."

The lift off speed is the speed at which the aircraft lifts off the ground, i.e. when the lift force exceeds the aircraft weight.

"(e)(i) V_R may not be less than -
(iv) A speed, that if the aeroplane is rotated at its maximum practical rate will result in a V_{LOF} of not less than:

- *110% of V_{MU} in the all-engines-operating condition, and 105% of V_{MU} determined at the thrust-to-weight ratio corresponding to the one-engine-inoperative condition; or*
- *If the V_{MU} attitude is limited by the geometry of the aeroplane (ie. tail contact with the runway), 108% of V_{MU} in the all-engines-operating condition and 104% of V_{MU} determined at the thrust-to-weight ratio corresponding to the one-engine-operating condition."*

An aircraft is said to be geometry limited, when at its maximum pitch angle (the tail of the aircraft touches the ground while the main landing gear is still on ground). Therefore, the maximum lift coefficient (CL_{max}) is not reached, and the VMU speeds are limited by the aircraft's maximum pitch angle on the ground.
The regulations consider the specific case of aircraft for which the minimum possible VMU speeds are limited by the elevator efficiency at a high angle of attack, or that are limited by tail contact with the runway (referred to as geometry limited aircraft).

In these conditions, the margins can be reduced as follows:

EASA AMC 25.107 ***FAR AC 25-7D***

"For aeroplanes that are geometry limited (ie. the minimum possible V_{MU} speeds are limited by tail contact with the runway), CS 25.107 (e)(i)(iv) allows the V_{MU} to V_{LOF} speed margins to be reduced to 108% and 104 % for the all-engines operating and one-engine-inoperative conditions, respectively."

Airbus aircraft, as most commercial airplanes, are usually geometry limited.

For aircraft certified before the A380, certification rules are different between JAR or EASA CS and FAR, as summarized in Table B-1:

	JAR, EASA CS or FAR from A380	FAR before A380
Geometric Limitation	$V_{LOF} \geq 1.04\ V_{MU\ (N-1)}$ $V_{LOF} \geq 1.08\ V_{MU\ (N)}$	$V_{LOF} \geq 1.05\ V_{MU\ (N-1)}$ $V_{LOF} \geq 1.08\ V_{MU\ (N)}$
Aerodynamic Limitation	$V_{LOF} \geq 1.05\ V_{MU\ (N-1)}$ $V_{LOF} \geq 1.10\ V_{MU\ (N)}$	

Table B-1: V_{LOF} Limitation

And the upper limit is:

$$V_{LOF} \leq V_{TIRE}$$

VLOF depends on the aircraft configuration, the angle of attack and the takeoff weight.

2.5. Takeoff Climb Speed: V_2

V2 is the minimum climb speed that must be reached before a height of 35 ft above the runway surface, in case of an engine failure.

CS 25.107 Subpart B ***FAR 25.107 Subpart B***

"(b) V_{2min}, in terms of calibrated airspeed, may not be less than:
(1) 1.13 V_{SR} [...] for turbo-jet powered aeroplanes
[...]
(3) 1.10 times V_{MC}"

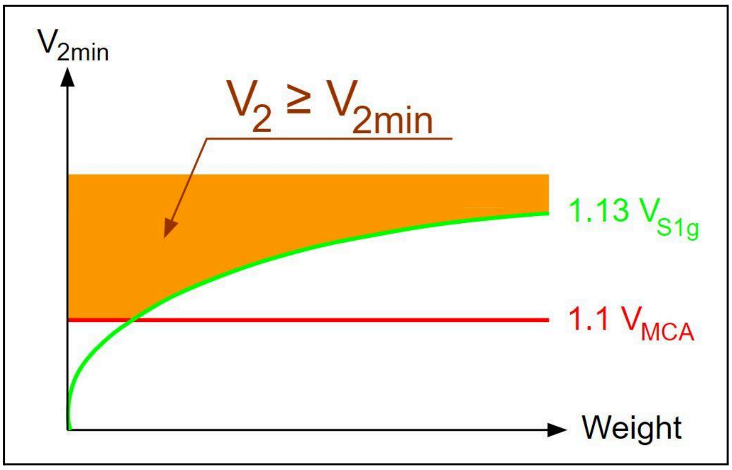


Illustration B-6: Definition of V_{2min}

"(c) V_2, in terms of calibrated airspeed, must be selected by the applicant to provide at least the gradient of climb required by CS/FAR 25.121(b) but may not be less than:

- *V_{2min}; and*
- *V_R plus the speed increment attained before reaching a height of 35 ft above the take-off surface.*

[...]"

This speed must be entered by the crew during flight preparation, and is indicated by a magenta triangle on the speed scale (see Illustration B-5).

$$V_2 \geq 1.1\,V_{MCA}$$

$$V_2 \geq 1.13\,V_{S1g}$$

(Airbus aircraft except A300/A310)

$V_2 \geq 1.2\,V_S$ (For A300/A310)

2.6. Takeoff Speed Summary

Illustration B-7 illustrates the relationships and the regulatory margins between the certified speeds (V_{S1G}, V_{MCG}, V_{MCA}, V_{MU}, V_{MBE}, V_{TIRE}), and the takeoff operating speeds (V_1, V_R, V_{LOF}, V_2) for Airbus aircraft.

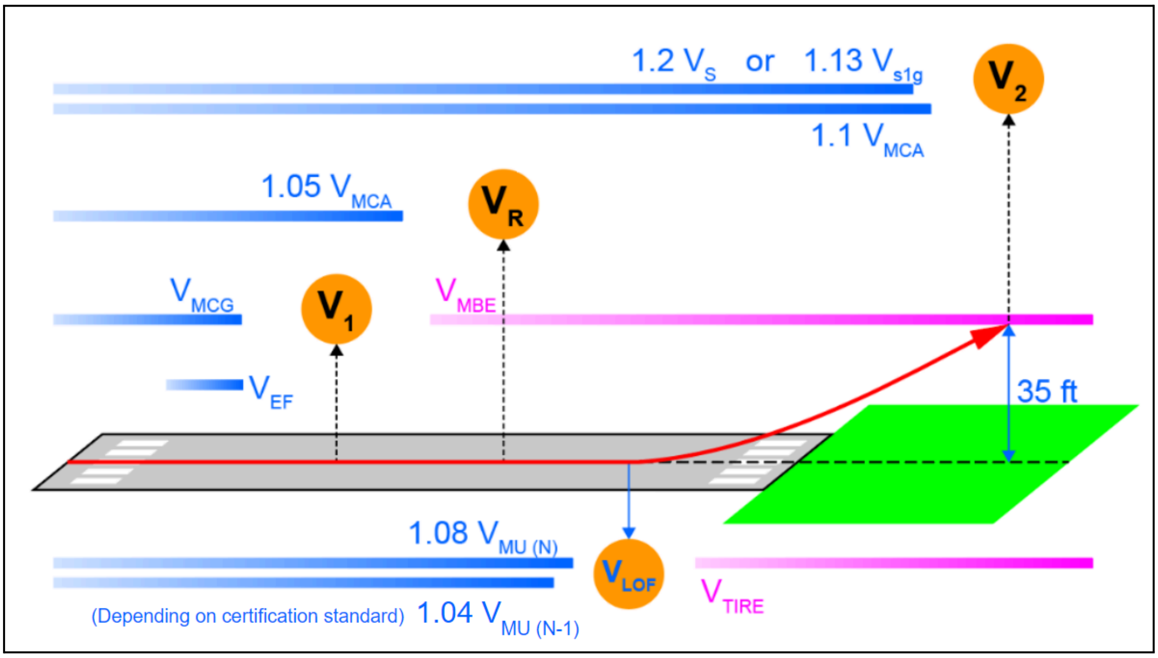


Illustration B-7: Takeoff Speed Summary and Limitations Related to V_1, V_R, V_{LOF} and V_2

3. Landing Speeds

3.1. Final Approach Speed: V_{APP}

V_{APP} is the aircraft speed during landing, 50 ft above the runway surface. The flaps/slats are in landing configuration, and the landing gears are extended.

V_{APP} is limited by V_{LS}:

$$V_{APP} \geq V_{LS}$$

It is normal to keep a margin on V_{LS} to define V_{APP}. For Airbus aircraft, in normal operations, the V_{APP} is defined by:c

$$V_{APP} = V_{LS} + Wind\ correction$$

Wind correction is limited to a minimum of 5[1] kt, and a maximum of 15 kt. V_{APP} is displayed on the Approach page of the FMS cockpit interface.

The FMGS and managed speed is used to define the $V_{APP\ TARGET.}$ It provides better speed guidance in approach with windy conditions, since it uses:

$$V_{APP\ TARGET} = GS\ mini + current\ headwind$$
$$GS\ mini = V_{APP} - tower\ wind$$

Current headwind is measured by ADIRS, and the tower wind is entered on the FMS cockpit interface.

[1] When the auto-thrust is used or to compensate for ice accretion on the wings

3.2. Reference Speed: V_{REF}

In case of failure in flight, emergency or abnormal configuration, performance computations are based on a reference configuration and on a reference speed, V_{REF}. V_{REF} means the landing approach speed is steady at the 50 ft point for a defined landing configuration. For Airbus aircraft, this configuration is CONF FULL.

That results in:

$$V_{REF} = V_{LS}\, in\, CONF\, FULL$$

In case of a system failure that affects landing performance, Airbus operational documentation (FCOM) indicates the correction to be applied to V_{REF} to take into account the failure:

$$V_{APP} = V_{REF} + \Delta V_{INOP}$$

Another speed increment can be added to V_{APP} to account for wind when required.

3.3. Go-Around Speed: V_{AC} and V_{GA}

For A220 aircraft, the V_{AC} is displayed on the PFD scale, V_{GA} is indicated by a magenta arrow.

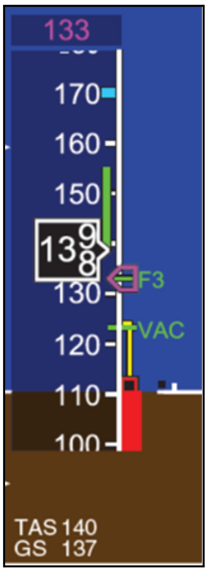


Illustration B-8: VAC on the A220 PFD

The V_{AC} is the approach climb speed of the aircraft also referred to as V_{2GA} or $V_{2\ GO\text{-}AROUND}$. That is the target climb speed to be achieved during a go-around with one engine inoperative
For A220 aircraft, the V_{GA} is the aircraft climb speed for all engines go-around.

For other Airbus aircraft, V_{GA} is the climb speed for go-around, regardless of the number of engines that are operative.

4. Cruise Speeds

There are two ways to operate the aircraft in cruise:

- By the direct selection of the speed by the crew: Selected speed.
- By the use of optimum speed computed by the FMS, based on the Cost Index (CI): Managed speed (refer to the chapter Cruise at Minimum Cost).

4.1. Managed Speed

A Flight Guidance (FG) mode is MANAGED when the FG manages the aircraft along the FMS F-PLN (e.g. NAV mode). A speed target is MANAGED when the speed value is computed by the FMS (e.g. ECON).

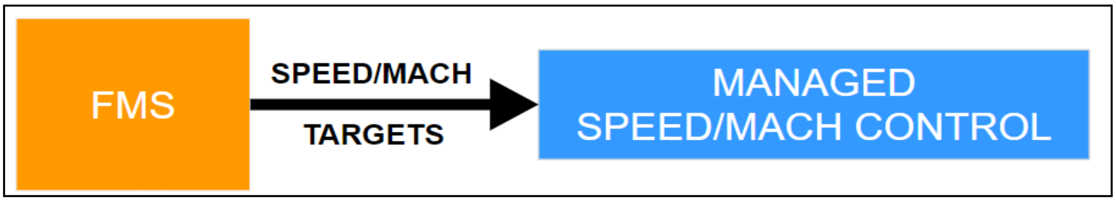


Illustration B-9: Managed Speed

4.2. Selected Speed

A Flight Guidance (FG) mode and its associated target are SELECTED when the FG manages the aircraft to a target selected by the pilot on the AFS CP (e.g. HDG). A speed target is SELECTED when directly selected by the pilot on the AFS CP. The speed target is used by the AP/FD and by the A/THR as a target.

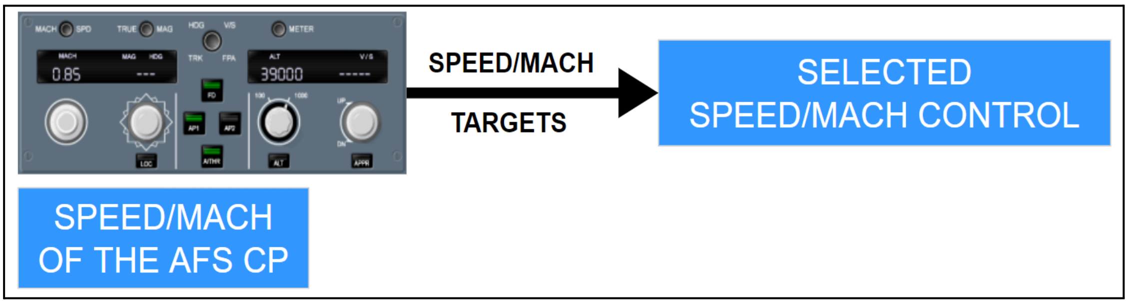


Illustration B-10: Selected Speed

C. TAKEOFF

1. INTRODUCTION

The takeoff is the flight phase that starts from brake release and ends at the beginning of climb, at 1 500 ft.
During the takeoff phase, the pilot must achieve the sufficient speed and angle-of-attack conditions to balance the lift and weight forces of the aircraft.

At the end of the ground acceleration phase, the pilot pulls back on the sidestick to start the rotation. During this phase, the acceleration is maintained and the angle-of-attack is increased, in order to increase the lift. The ground reaction forces gradually decrease until liftoff.

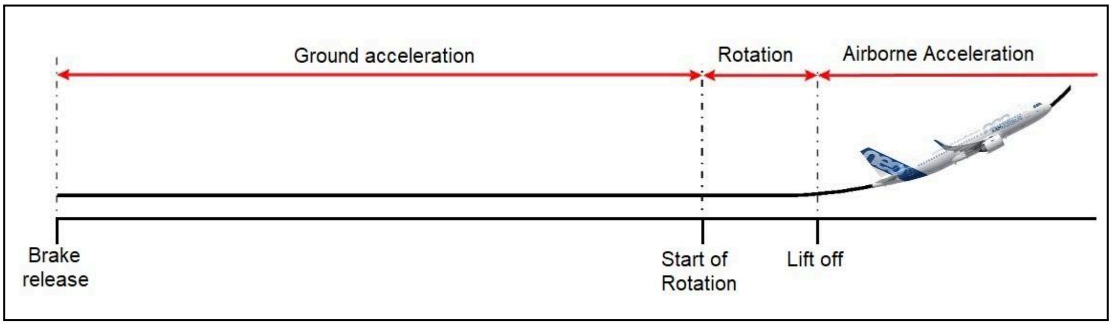


Illustration C-1: Takeoff Profile

The performance determination must take into account the possibility of an engine failure during the ground acceleration phase. For CS/FAR certified aircraft, the failure of the most critical engine must be considered.

CS Definitions ***FAR Definitions***

"'Critical Engine' means the engine whose failure would most adversely affect the performance or handling qualities of an aircraft."

On a jet aircraft with four engines, the critical engine is the outer engine. On Airbus jet aircraft with two engines, there is no critical engine.

2. Ground limitations

2.1. Takeoff Lengths

2.1.1. Runway

Air OPS Annex 1 Definitions **FAR 1.1 General Definitions**

Runway: "A defined rectangular area on a land aerodrome prepared for the landing and take-off of aircraft."

2.1.2. Stopway

Air OPS Annex 1 Definitions **FAR 1.1 General Definitions**

"The runway may be extended by an area called the stopway. The stopway is an area beyond the takeoff runway:
- *no less wide than the runway and centered upon the extended centerline of the runway,*
- *able to support the airplane during an aborted takeoff, without causing structural damage to the airplane, and*
- *designated by the airport authorities for use in decelerating the airplane during an aborted takeoff."*

Illustration C-2: Definition of Stopway

2.1.3. Clearway

Air OPS Annex 1 Definitions **FAR 1.1 General Definitions**

"The runway may be extended by an area called the clearway. The clearway is an area beyond the runway, which should have the following characteristics:
- *Be centrally located about the extended centerline of the runway, and under the control of the airport authorities.*
- *Be expressed in terms of a clearway plane, extending from the end of the runway with an upward slope not exceeding 1.25%.*
- *Have a minimum width not less than 152 m (500 feet) wide.*
- *Have no protruding objects or terrain. Threshold lights may protrude above the plane, if their height above the end of the runway is 0.66 m (26 in) or less, and if they are located on each side of the runway.*
- *In addition, clearway cannot exceed half the runway length (computation limitation)."*

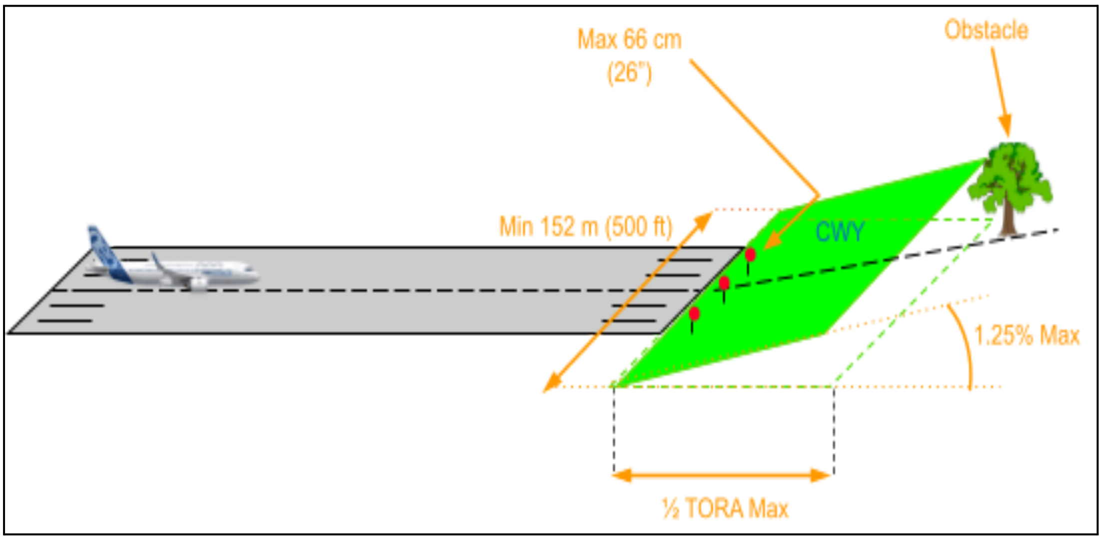


Illustration C-3: Definition of Clearway

2.2. Published Takeoff Distances

The takeoff distances defined in this section are published by the national aviation authorities in the Aeronautical Information Publications (AIP).
Refer to Appendix 6.

2.2.1. Takeoff Run Available (TORA)

Air OPS Annex 1 ***FAR 121.189***

*"**TakeOff Run Available (TORA)**: The length of runway which is declared available by the appropriate authority and suitable for the ground run of an aeroplane taking off."*

TORA is either equal to the runway length, or to the distance from the runway entry point (taxiway intersection) to the end of the runway (Illustration C-4).

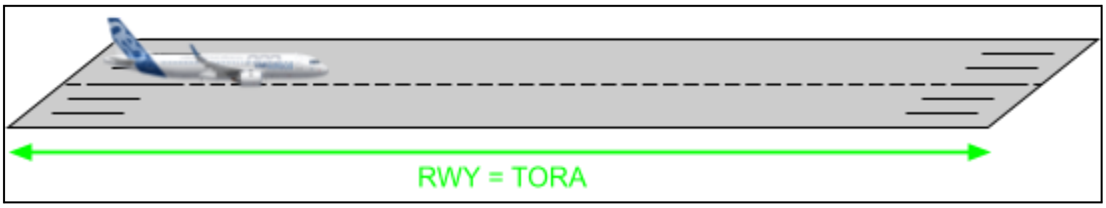


Illustration C-4: Definition of TORA

For airport authorities, the TORA is the part of the takeoff surface that is free from obstacles. It has a surface where the aircraft can maneuver under all normal operating conditions.

2.2.2. Takeoff Distance Available (TODA)

Air OPS Annex 1　　*FAR 121.189*

*“**Takeoff Distance Available (TODA)**: The length of the takeoff run available plus the length of the clearway available.”*

As displayed in Illustration C-5, the Takeoff Distance Available (TODA) corresponds to the Takeoff Run Available (TORA) plus the Clearway, if any.

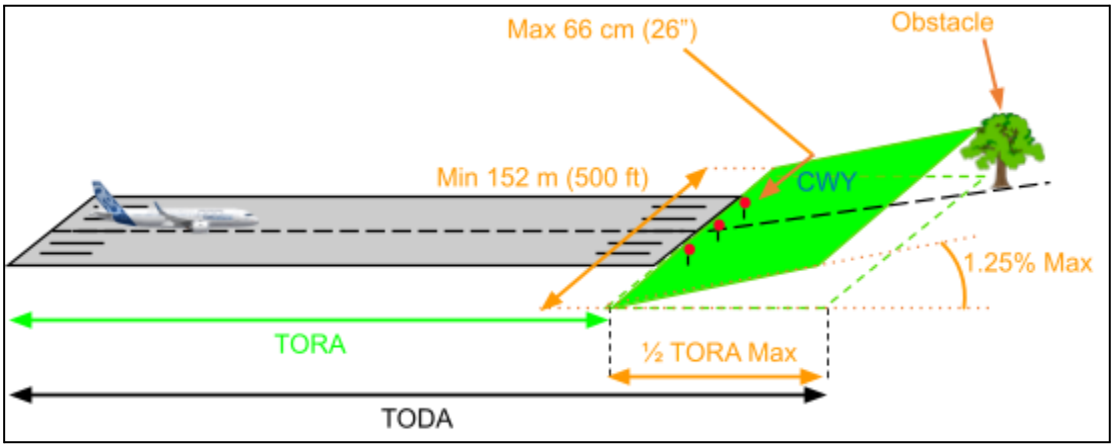


Illustration C-5: Definition of TODA

2.2.3. Accelerate-Stop Distance Available (ASDA)

Air OPS Annex 1　　*FAR 121.189*

*“**Accelerate-Stop Distance Available (ASDA)**: The length of the takeoff run available plus the length of the stopway, if such stopway is declared available by the appropriate Authority and is capable of bearing the mass of the aeroplane under the prevailing operating conditions.”*

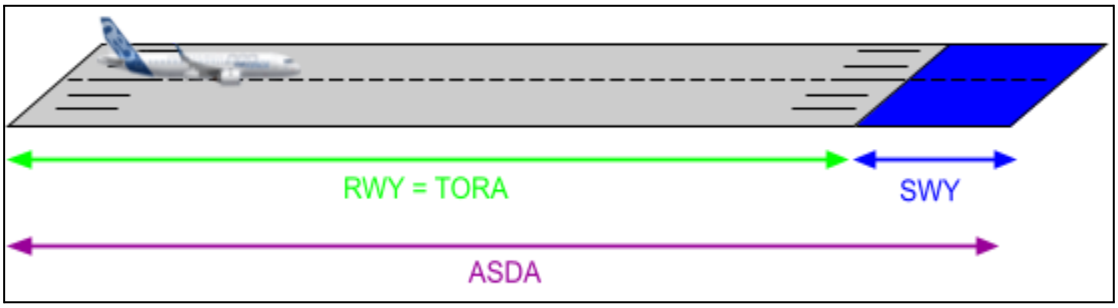


Illustration C-6: Definition of ASDA

Note: In some cases, the ASDA can be shorter than the TORA, as described in FAA AC 150/5300-13B Appendix H. This happens when the ASDA is reduced to include the Runway End Safety Area (RESA).

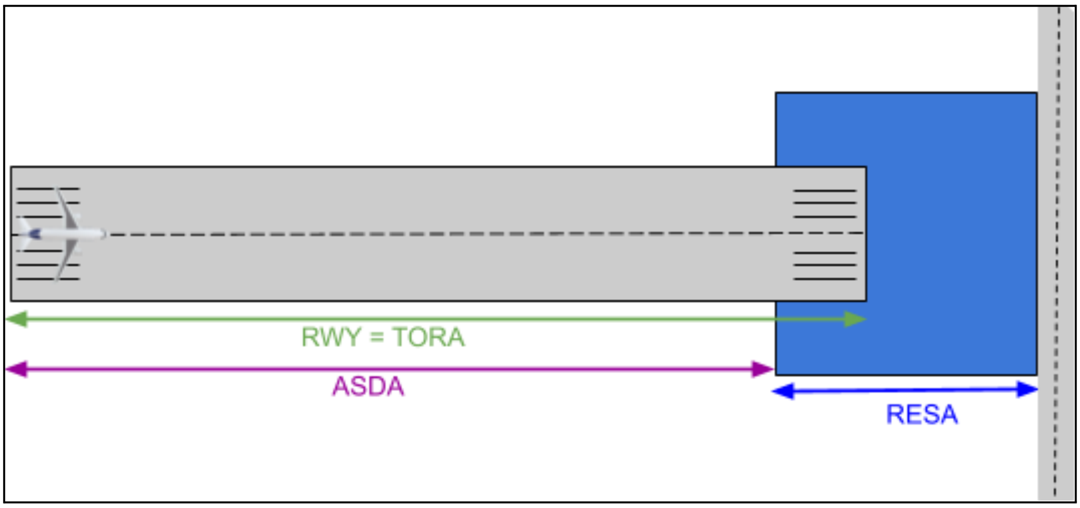


Illustration C-7: ASDA shorter than TORA

2.3. Departure Sector

2.3.1. Takeoff Funnel

The takeoff funnel is the area around the takeoff flight path. Obstacles identified inside the area must be considered. The limits of this area, also referred to as the departure sector, will be different depending on if they are published in the Air OPS or the FAA regulations. These differences will be described separately in the following sections.

2.3.2. Takeoff Funnel Air OPS Definition

Air OPS Subpart C
CAT.POL.A210

"The net takeoff flight path shall be determined in such a way that the aeroplane clears all obstacles by a vertical distance of at least 35 ft or by a horizontal distance of at least 90 m plus 0.125 x D, where D is the horizontal distance the aeroplane has travelled from the end of the take-off distance available (TODA) or the end of the take-off distance if a turn is scheduled before the end of the TODA. For aeroplanes with a wingspan of less than 60 m, a horizontal obstacle clearance of half the aeroplane wingspan plus 60 m, plus 0.125 x D may be used."

The semi-width at the start of the departure sector is 90 m, or smaller for aircraft with a wingspan of less than 60 m (e.g. A300/A310 or A320 Family).

CAT.POL.A.210
"(b)(6) For cases where the intended flight path does not require track changes of more than 15°, the operator does need not to consider those obstacles which have a lateral distance greater than:

- *300 m, if the pilot is able to maintain the required navigational accuracy through the obstacle accountability area; or*
- *600 m, for flights under all other conditions."*

CAT.POL.A.A210
"(b)(7) For cases where the intended flight path does require track changes of more than 15°, the operator does need not to consider those obstacles which have a lateral distance greater than:

- *600 m, if the pilot is able to maintain the required navigational accuracy through the obstacle accountability area; or*
- *900 m, for flights under all other conditions."*

AMC1 CAT.POL.A.A210

The required navigational accuracy is defined in AMC1 CAT.POL.A.A210. It can either be obtained via navigation aids, or via external references, in the case of Visual Course guidance.

The following Illustration C-8 and Illustration C-9 display the Air OPS departure sectors:

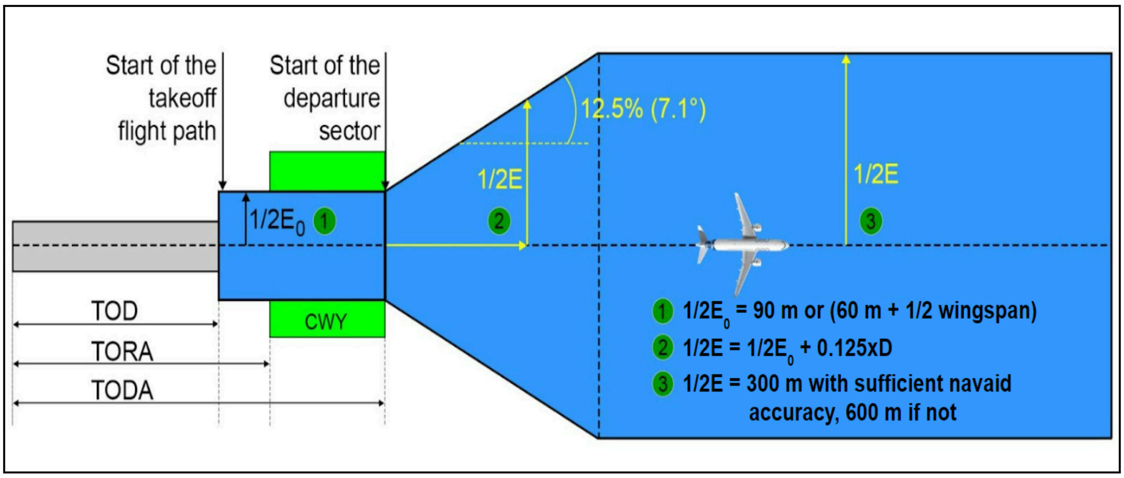


Illustration C-8: Air OPS Departure Sector (Track Change ≤ 15 º)

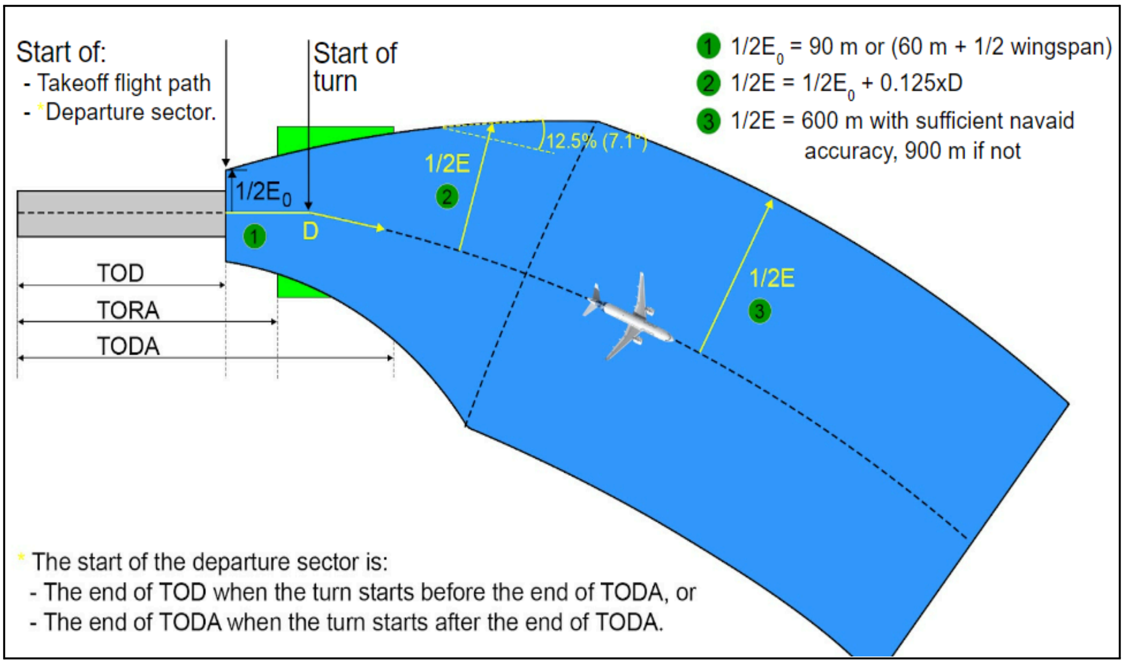


Illustration C-9: Air OPS Departure Sector (Track Change > 15 º)

Note: The ICAO recommendations for the departure sector (refer to Appendix 6) are the same as the ones provided by the Air OPS definitions.

2.3.3. Takeoff Funnel FAA Definition

FAA - AC 120-91A

"14.(a) Straight-Out Departures. During straight-out departures or when the intended track or airplane heading is within 15 degrees of the extended runway centerline heading, the following criteria apply:

(1) The width of the OAA is 0.0625D feet on each side of the intended track (where D is the distance along the intended flightpath from the end of the runway in feet), except when limited by the following minimum and maximum widths.

(2) The minimum width of the OAA is 200 feet on each side of the intended track within the airport boundaries, and 300 feet on each side of the intended track outside the airport boundaries.

(3) The maximum width of the OAA is 2,000 feet on each side of the intended track.

14.(b) Turning Departures. During departures involving turns of the intended track or when the airplane heading is more than 15 degrees from the extended runway centerline heading, the following criteria apply:

(1) The initial straight segment, if any, has the same width as a straight-out departure.

(2) The width of the OAA at the beginning of the turning segment is the greater of:

(a) 300 feet on each side of the intended track.

(b) The width of the OAA at the end of the initial straight segment, if there is one.

(c) The width of the end of the immediately preceding segment, if there is one, analyzed by the Flight Track Analysis Method.

(3) Thereafter in straight or turning segments, the width of the OAA increases by 0.125D feet on each side of the intended track (where "D" is the distance along the intended flightpath from the beginning of the first turning segment in feet), except when limited by the maximum width in subparagraph (4) below:

(4) The maximum width of the OAA is 3,000 feet on each side of the intended track."

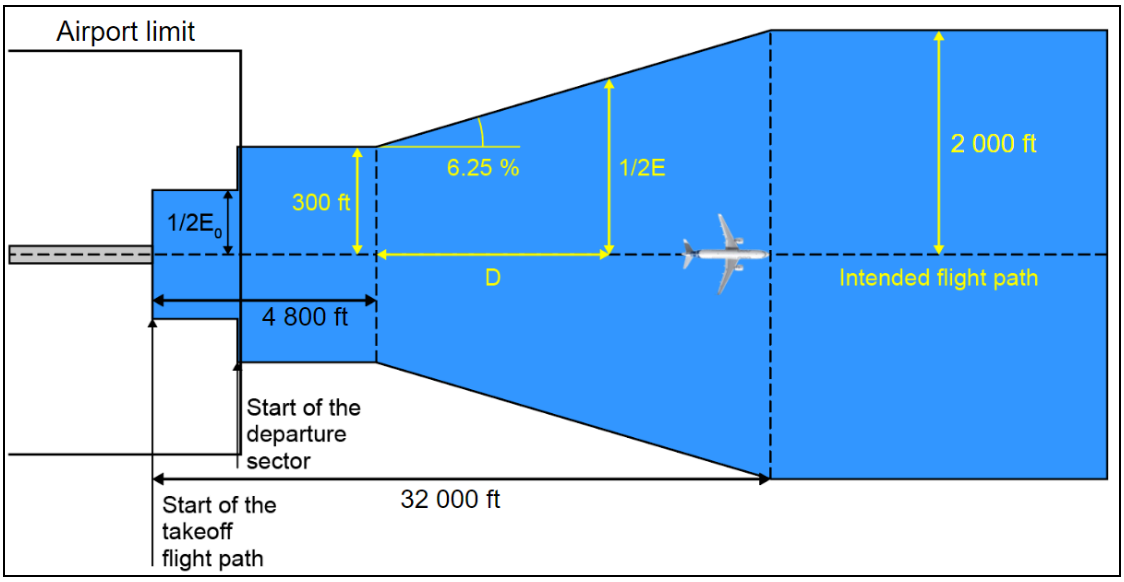


Illustration C-10: FAA Departure Sector (Track Change ≤ 15 º)

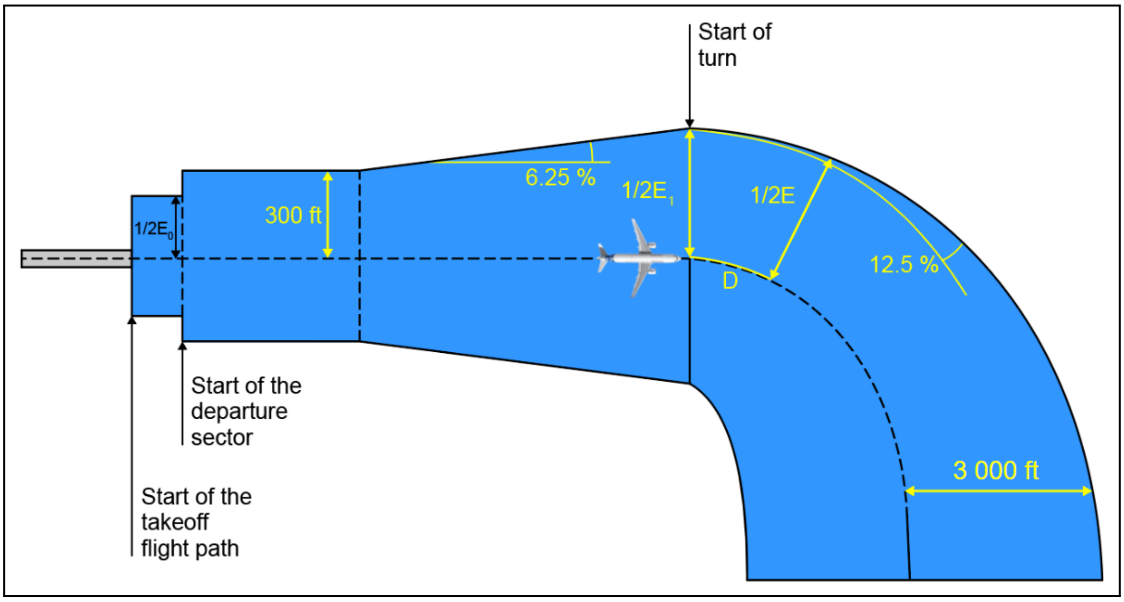


Illustration C-11: FAA Departure Sector (Track Change > 15 º)

3. Performance limitations

This paragraph contains limitations related to takeoff certification. For the definition of limiting and operating speeds, refer to the chapter Aircraft Limitations.

3.1. Takeoff Distances

3.1.1. Takeoff Distance (TOD)

CS 25.113 Subpart B   *FAR 25.113 Subpart B*

For specific operational conditions (e.g. temperature, pressure altitude, weight, etc.):

a) The takeoff distance on a dry runway is the higher of the following values:

- $TOD_{N-1\ dry}$ = The distance covered from the brake release to a point at which the aircraft is at 35 ft above the takeoff surface. This is based on the assumption that there is a failure of the critical engine at V_{EF}, and that it is detected at V_1.

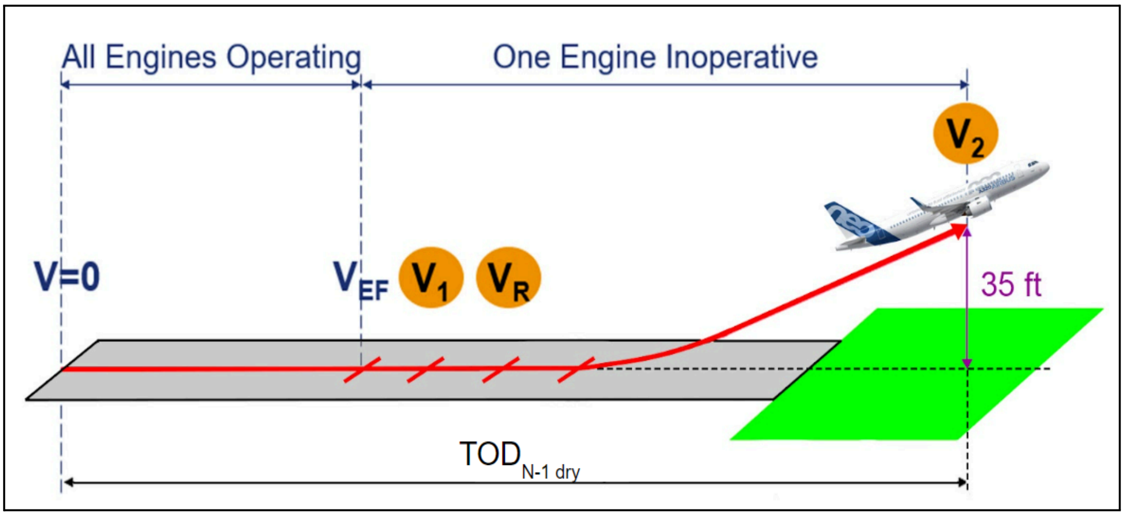


Illustration C-12: $TOD_{N-1\ dry}$

- 1.15 $TOD_{N\ dry}$ = 115 % of the distance covered from brake release to a point at which the aircraft is at 35 ft above the takeoff surface. This is based on the assumption that all engines are operating.

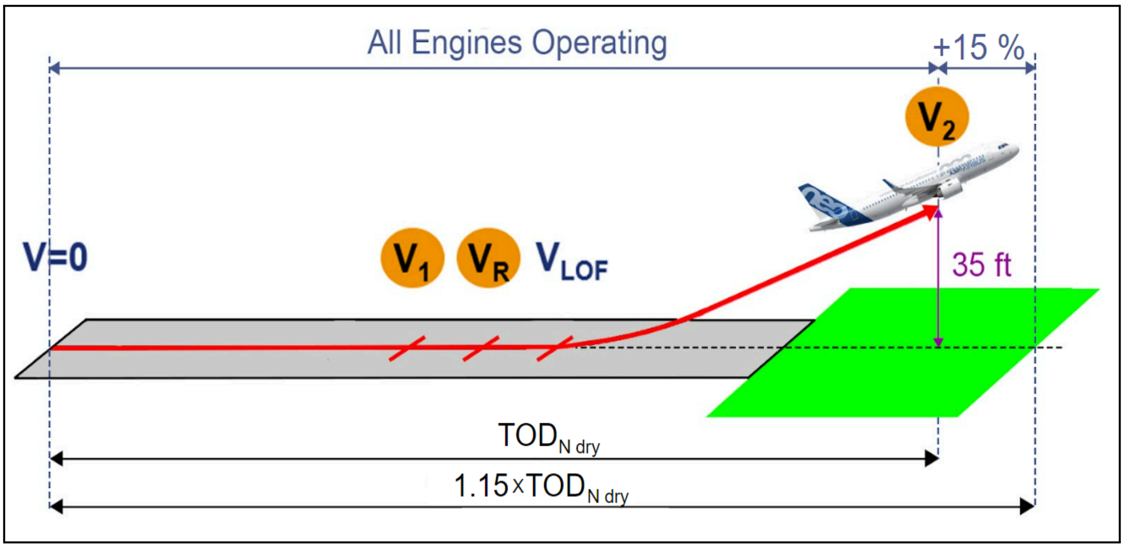


Illustration C-13: $TOD_{N\,dry}$

$$TOD_{dry} = max\ of\ \{TOD_{N-1\,dry},\ 1.15\,TOD_{N\,dry}\}$$

b) The takeoff distance on a wet runway is the higher of the following values:

- TOD_{dry} = Takeoff distance on a dry runway (see above)
- $TOD_{N-1\ wet}$ = Distance covered from brake release to a point at which the aircraft is at 15 ft above the takeoff surface, to ensure that the V_2 speed is achieved before the aircraft is 35 ft above the takeoff surface. This is based on the assumption that there is a failure of the critical engine at V_{EF} and that it is detected at V_1.

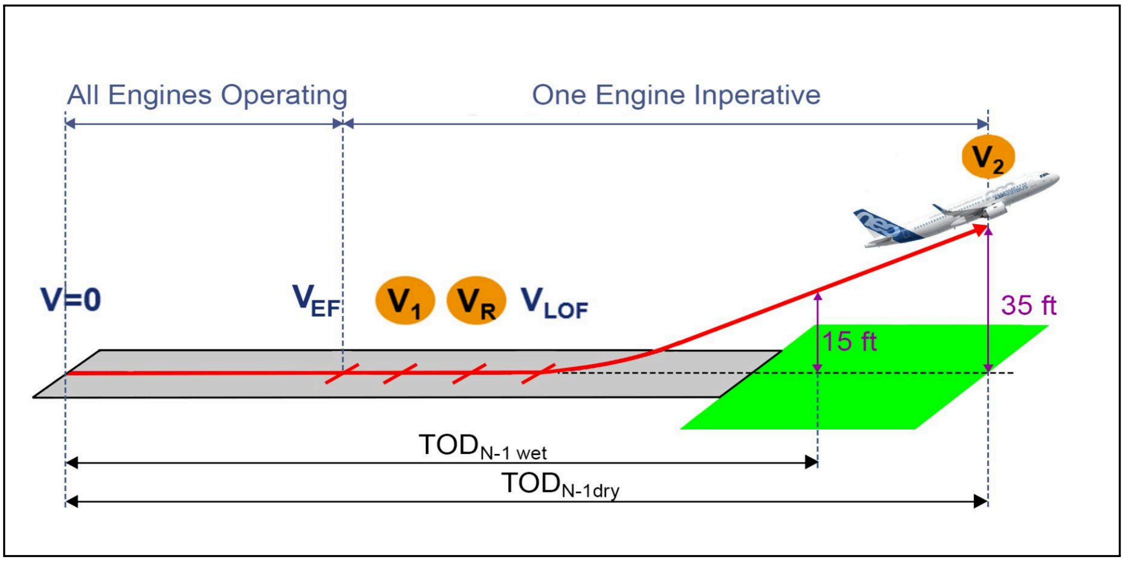


Illustration C-14: TOD_{wet}

$$TOD_{wet} = max\ of\ \{TOD_{dry},\ TOD_{N-1\,wet}\}$$

Air OPS CAT.POL.A.205

FAR 121.189 (c)(2) Subpart I

"Air OPS CAT.POL.A.205
(b)(2) The Takeoff distance shall not exceed the takeoff distance available (TODA), with a clearway distance not exceeding half of the takeoff run available (TORA)."

$$TOD \leq TODA$$

3.1.2. Takeoff Run (TOR)

3.1.2.1. Runway with Clearway

CS 25.113 Subpart B

FAR 25.113 Subpart B

a) The takeoff run on a dry runway is the higher of the following values (Illustration C-15):

- $TOR_{N-1\ dry}$ = The distance covered from brake release to a point of equal distance between the point at which V_{LOF} is reached, and the point at which the aircraft is 35 ft above the takeoff surface. This is based on the assumption that there is a failure of the critical engine at V_{EF}, and that it is detected at V_1.

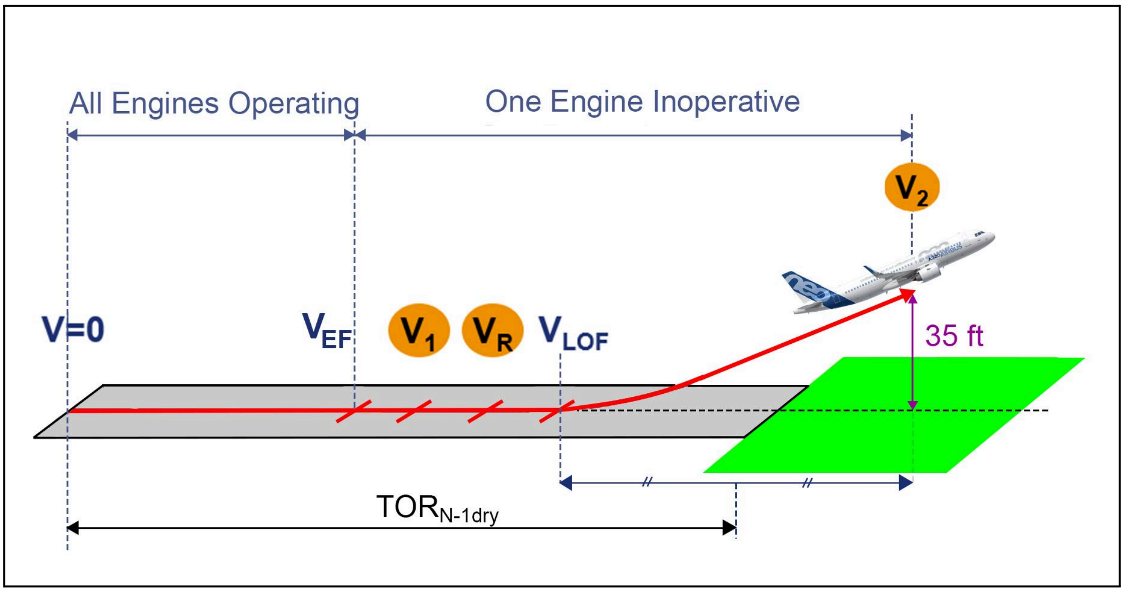


Illustration C-15: $TOR_{N-1\ dry}$

- $1.15\ TOR_{N\ dry}$ = 115 % of the distance covered from brake release to a point of equal distance between the point at which V_{LOF} is reached and the point at which the aircraft is 35 ft above the takeoff surface. This is based on the assumption that all engines are operating.

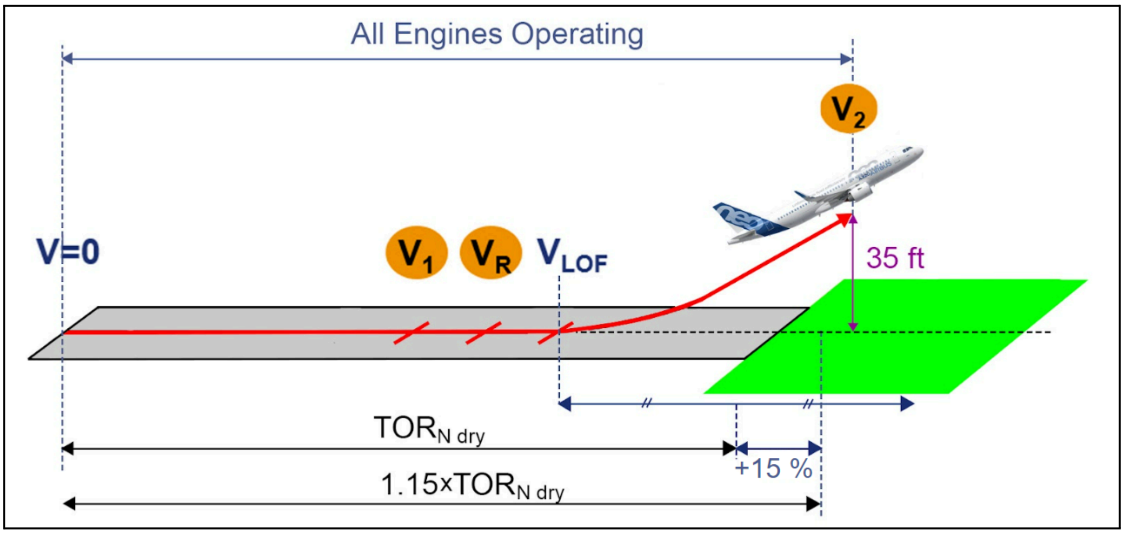


Illustration C-16: $TOR_{N\ dry}$

$$TOR_{dry} = max\ of\ \{TOR_{N-1\ dry},\ 1.15\ TOR_{N\ dry}\}$$

b) The takeoff run on a wet runway is the higher of the following values:

- $TOR_{N-1\ wet}$ = The distance covered from the brake release to a point at which the aircraft is at 15ft above the takeoff surface, to ensure that the V_2 speed will be achieved before the aircraft is 35 ft above the takeoff surface. This is based on the assumption that there is a failure of the critical engine at V_{EF}, and that it is detected at V_1. $TOR_{N-1\ wet}$ is equal to $TOD_{N-1\ wet}$.

- 1.15 $TOR_{N\ wet}$ = 115 % of the distance covered from brake release to a point of equal distance between the point at which V_{LOF} is reached, and the point at which the aircraft is 35 ft above the takeoff surface. This is based on the assumption that all engines are operating.

$$TOR_{wet} = max\ of\ \{TOR_{N-1\ wet},\ 1.15\ TOR_{N\ wet}\}$$

Air OPS CAT.POL.A.205 ***FAR 121.189 (c)(3) Subpart I***

"Air OPS CAT.POL.A.205
(b)(3) The takeoff run shall not exceed the takeoff run available (TORA)."

$$TOR \leq TORA$$

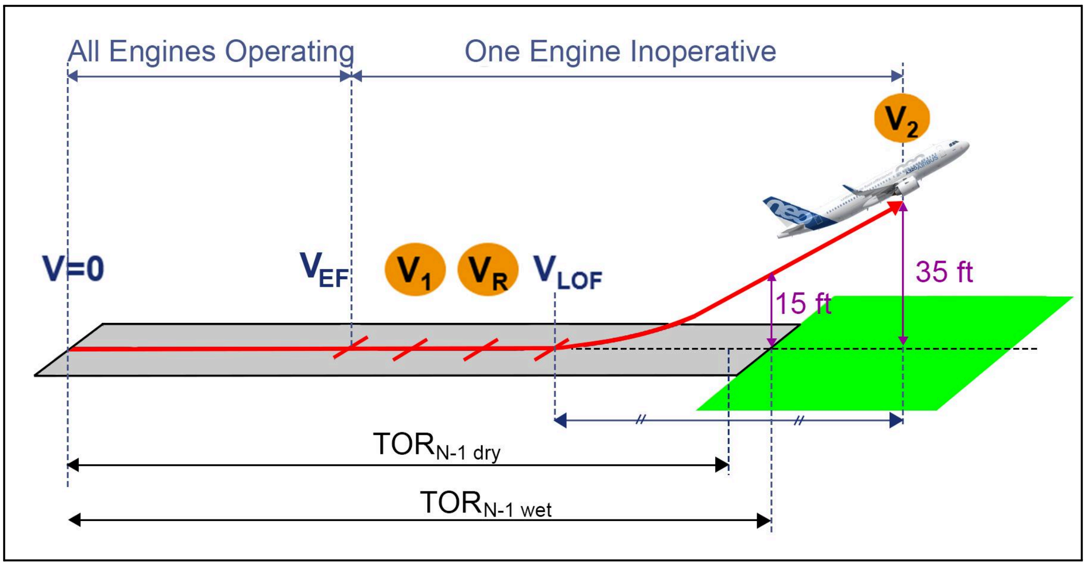


Illustration C-17: $TOR_{N\text{-}1\ dry}$ and $TOR_{N\text{-}1\ wet}$

3.1.2.2. Runway without Clearway

On runways without a clearway, the takeoff run is equal to the takeoff distance, regardless of the takeoff surface (dry or wet).

3.1.2.3. Clearway Influence on a Wet Runway

On a wet runway, the takeoff run with one Engine-Out (EO) is always equal to the takeoff distance with one EO (i.e. from brake release to 15 ft). Therefore, a clearway does not provide any performance advantages on a wet runway, because the TOR is always more restrictive (TORA less than TODA).

3.1.2.4. Accelerate Stop Distance (ASD)

CS 25.109 Subpart B ***FAR 25.109 Subpart B***

a) The Accelerate Stop Distance on a dry runway is the higher of the following values:

- $ASD_{N\text{-}1\ dry}$ = Sum of the distances necessary to:
  - Accelerate from a fixed start to V_{EF} with all engines at TOGA.
  - Accelerate from V_{EF} to V_1[2] under the assumption that the critical engine fails at V_{EF} and that the pilot takes the first action to reject the takeoff at V_1.
  - Come to a full stop[3;4] (all engines at idle), under the assumption that no deceleration means to retard the aircraft were applied before V_1.
  - Add a distance margin equal to 2 seconds, at constant[5] V_1 speed.

---

[2] Delay between V_{EF} and $V_1 \geq 1$ second.

[3] ASD must be established with the "wheel brakes at the fully worn limit of their allowable wear range"
[CS/FAR 25.101].

[4] ASD must not be determined with reverse thrust on a dry runway.

[5] Pre-amendment 42 does not consider the distance margin of 2 seconds at V1 (applicable to the A300, A300-600 and A310).

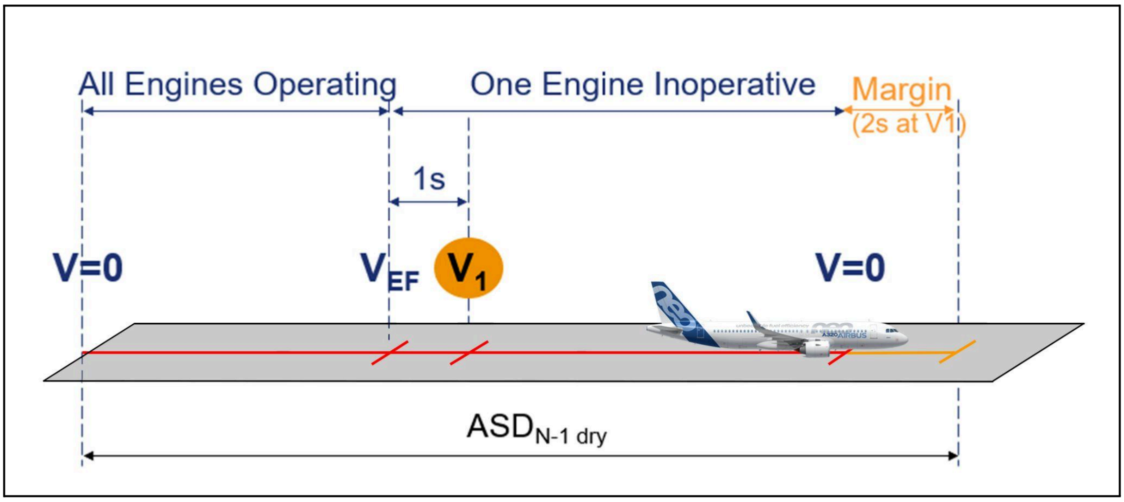


Illustration C-18: ASD$_{N-1\ dry}$

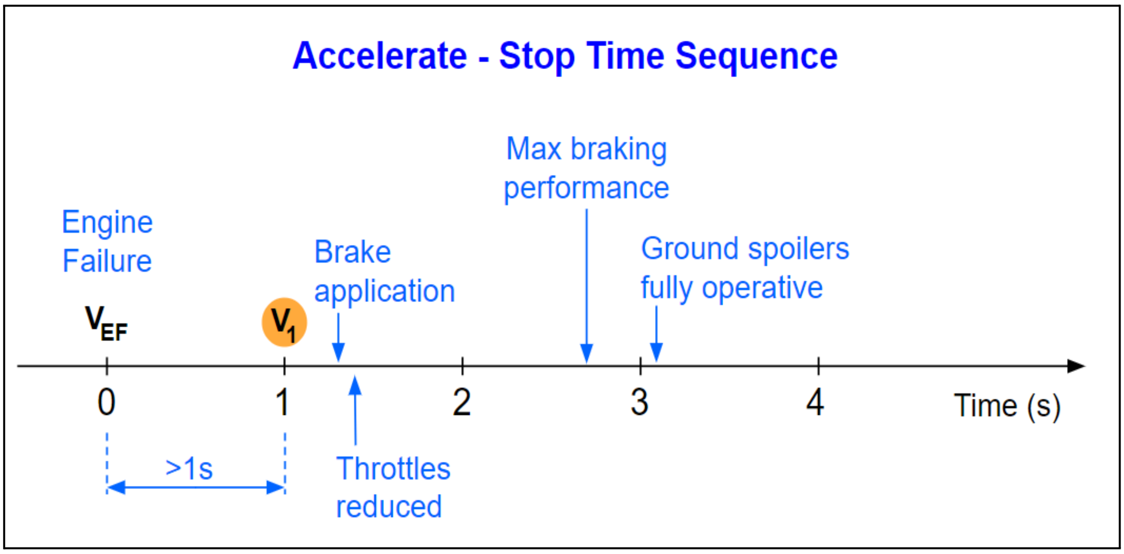


Illustration C-19: Example of Accelerate - Stop Time Sequence

- ASD$_{N\ dry}$ = Sum of the distances necessary to:
  - Accelerate from a fixed start to V_{EF} with all engines at TOGA.
  - Come to a full stop (all engines at idle), under the assumption that no deceleration means to retard the aircraft were applied before V_1.
  - Add a distance margin equal to 2 seconds, at constant V_1 speed.

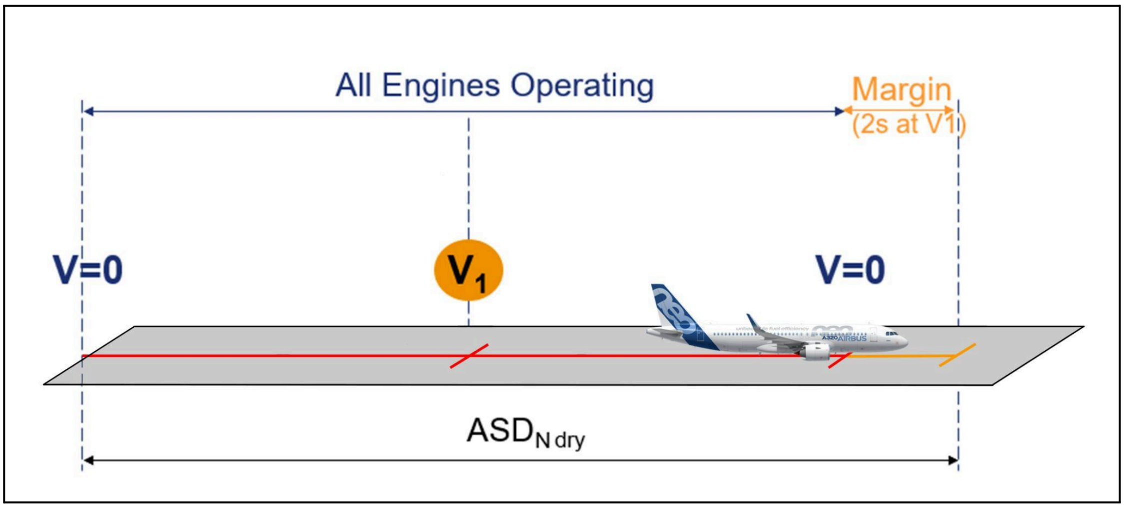


Illustration C-20: $ASD_{N\ dry}$

$$ASD_{dry} = max\ of\ \{ASD_{N-1\ dry}, ASD_{N\ dry}\}$$

The ASD with All Engines Operative (AEO) is considered to take into account some situations that should result in a decision to reject the takeoff without engine failure.
The ASD_N was included in the Amendment 42. Therefore, there is no ASD_N for A300, A300-600 and A310 aircraft.

b) The ASD on a wet runway is the higher of the following values:

- ASD_{dry}
- $ASD_{N-1\ wet}$ = same definition as $ASD_{N-1\ dry}$, except the runway is wet[6]
- $ASD_{N\ wet}$ = same definition as $ASD_{N\ dry}$, except the runway is wet

$$ASD_{wet} = max\ of\ \{ASD_{dry}, ASD_{N-1\ wet}, ASD_{N\ wet}\}$$

Air OPS 1.490 Subpart G ***FAR 121.189 (c)(1) Subpart I***

"CAR-OPS 1.490
(b)(1) The accelerate-stop distance shall not exceed the accelerate-stop distance available."

$$ASD \leq ASDA$$

[6] ASD determination on a wet runway may include the use of the reverse thrust provided that it is safe and reliable [CS/FAR 25-109 (e)(f)].

3.2. Takeoff Trajectory

The takeoff trajectory needs to comply with the following requirements:

- Operations with OEI, in compliance with airworthiness regulations (CS/FAR25) and operational regulations (AIR-OPS/FAR-121)
- Operations with AEO, in compliance with air traffic management and noise procedures published by the airport.

3.2.1. One Engine Inoperative - Takeoff Flight Path

3.2.1.1. Definitions

CS 25.111 Subpart B
CS 25.115 Subpart B

FAR 25.111 Subpart B
FAR 25.115 Subpart B

"CS/FAR 25.111
(a) The takeoff path extends from a standing start to a point at which the aeroplane is at a height:

- *Of 1500 ft above the takeoff surface, or*
- *At which the transition from the takeoff to the en-route configuration[7] is completed and the final takeoff speed[8] is reached,*

whichever point is higher".

"CS/FAR 25.115 (a)
The takeoff flight path must be considered to begin 11 m (35 ft) above the take-off surface at the end of the takeoff distance."

The takeoff flight path starts at the end of the TOD.
For aircraft limited by TOD_{N-1}, the regulatory definitions for the takeoff path and takeoff flight path consider that the aircraft accelerates on the ground to V_{EF}. At this point, the critical engine becomes inoperative, and remains inoperative for the rest of the takeoff. In addition, the V_2 speed must be reached before the aircraft is 35 ft above the takeoff surface. The aircraft must continue at a speed of not less than V_2, until at least 400 ft above the takeoff surface are reached.

3.2.1.2. Takeoff Segments and Climb Requirements

CS 25.121 Subpart B

FAR 25.121 Subpart B

Regulation defines the takeoff flight path by a number of segments.
Each segment is characterized by a specific change in:

- Configuration
- Thrust
- Speed.

The flight path performance computations must be based on the assumption of the aircraft out of ground effect. The aircraft is considered to be out of the ground effect when it reaches a height equal to its wing span.

[7] En route configuration: clean configuration, Maximum Continuous Thrust (MCT) setting.
[8] Final takeoff speed: speed above 1.25 Vs, chosen equal to Green Dot speed (best climb gradient speed).

The configuration, weight and thrust of the aircraft must correspond to the most critical condition in the segment.

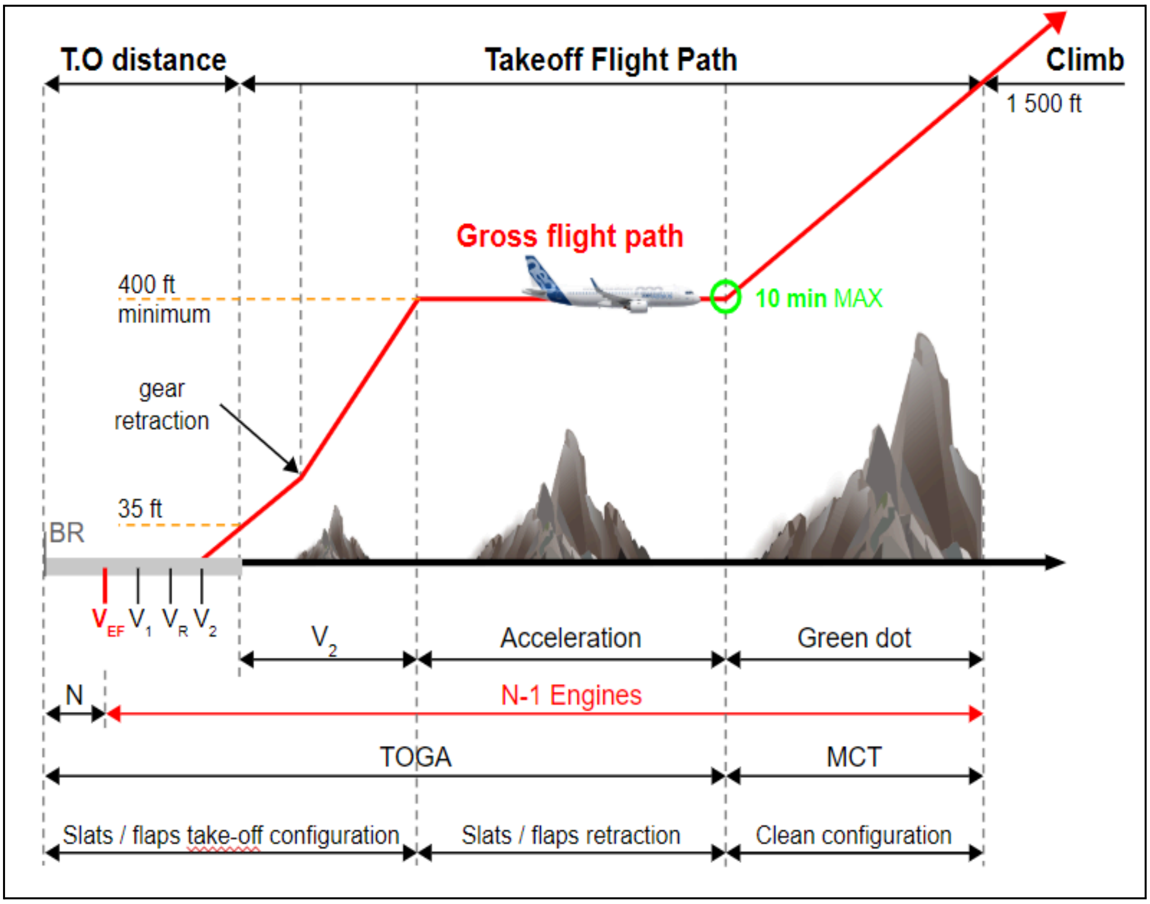


Illustration C-21: Takeoff Flight Path (example for TOD=TOD$_{N-1}$)

After an engine failure at V_{EF}, regardless of the operational conditions, the aircraft must satisfy minimum climb gradients, as required by CS/FAR 25.121.

The following table (Table C-1) summarizes the different requirements and the aircraft status during the four takeoff segments:

- The minimum required climb gradient with OEI
- The flaps / slats configuration
- The engine rating
- The speed reference
- The landing gear configuration.

		FIRST SEGMENT	SECOND SEGMENT	THIRD SEGMENT	FINAL SEGMENT
Minimum Climb Gradient (N-1) Engines	Twin	0.0 %	2.4 %	-	1.2 %
	Quad	0.5 %	3.0 %	-	1.7 %
Start When		V_{LOF} reached	Landing gear fully retracted	Acceleration height reached (min 400 ft)	En route configuration achieved
Slats/Flaps Configuration		Takeoff	Takeoff	Slats/Flaps retraction	Clean
Engine Rating		TOGA/FLEX /DERATE	TOGA/FLEX /DERATE	TOGA/FLEX /DERATE	MCT
Speed Reference		V_{LOF}	V_2	Acceleration from V_2 to Green Dot	Green Dot
Landing Gear		Retraction	Retracted	Retracted	Retracted
Weight Reference		Weight at the start of the landing gear retraction. *Note: for Airbus aircraft, Weight at brake release is considered.*	Weight when the landing gear is fully retracted	Weight at the start of the acceleration segment	Weight at the end of the acceleration segment
Ground Effect		Without	Without	Without	Without

Table C-1: Takeoff Segment Characteristics

3.2.1.3. Minimum and Maximum Acceleration Heights

Minimum Acceleration Height

CS 25.111 Subpart B ***FAR 25.111 Subpart B***

"(c)(2) The aeroplane must reach V_2 before it is 35 ft above the takeoff surface and must continue at a speed not less than V_2 until it is 400 ft above the take-off surface.

(c)(3) At each point along the takeoff flight path, starting at the point at which the aeroplane reaches 400 ft above the takeoff surface, the available gradient of climb may not be less than:

- *1.2 % for two-engined aeroplanes*
- *1.7 % for four-engined aeroplanes"*

This means that, below 400 ft, constant speed must be maintained, with a minimum speed of V_2.
Above 400 ft, the aircraft must achieve a minimum climb gradient or an equivalent acceleration capability, in level flight. Therefore, the regulatory acceleration height is fixed to a minimum 400 ft above the takeoff surface.

However, during the acceleration segment, obstacle clearance must be ensured at any moment. Therefore, the operational acceleration height must at least be equal to 400 ft.

Maximum Acceleration Height

The Maximum Takeoff Thrust (TOGA) is certified for use for a maximum of 10 minutes, in the case of an engine failure at takeoff, and for a maximum of 5 minutes with AEO.
The Maximum Continuous Thrust (MCT), that has no time limitation, can only be selected when the en route configuration is achieved (i.e. when the aircraft is in clean configuration at Green Dot speed).
As a result, the enroute configuration (end of the third segment) must be achieved within a maximum of 10 minutes after takeoff. This is in order to enable the determination of a maximum acceleration height.

3.2.1.4. Gross and Net Takeoff Flight Paths - Obstacle Clearance

The runway surroundings usually have obstacles that must be considered in the takeoff computation, to check for obstacle clearance.
A vertical margin must be considered between the aircraft and each obstacle in the takeoff flight path. This margin, based on a climb gradient reduction, results in the definitions of the Gross Takeoff Flight Path and the Net Takeoff Flight Path.

CS 25.115 Subpart B *FAR 25.115 Subpart B*

Gross Flight Path = The true flight path that the aircraft flies, i.e.:
"(a) The take-off flight path must be considered to begin 11 m (35 ft) above the take-off surface at the end of the takeoff distance [to the end of the takeoff path]"

Net Flight Path = Gross takeoff flight path minus a mandatory reduction.
"(b) The net take-off flight path data must be determined so that they represent the actual [Gross] takeoff flight paths [...] reduced at each point by a gradient equal to:
- *0.8 % for two-engined aeroplanes;*
- *1.0 % for four-engined aeroplanes."*

Net Gradient = Gross Gradient - Gradient Penalty

	Gradient Penalty
Aircraft with Two Engines	0.8 %
Aircraft with Four Engines	1.0 %

Table C-2: Values of Gradient Penalties

The gradient penalty between the Net and the Gross Flight Path must be considered during the first, second, and final takeoff segments (Illustration C-22).

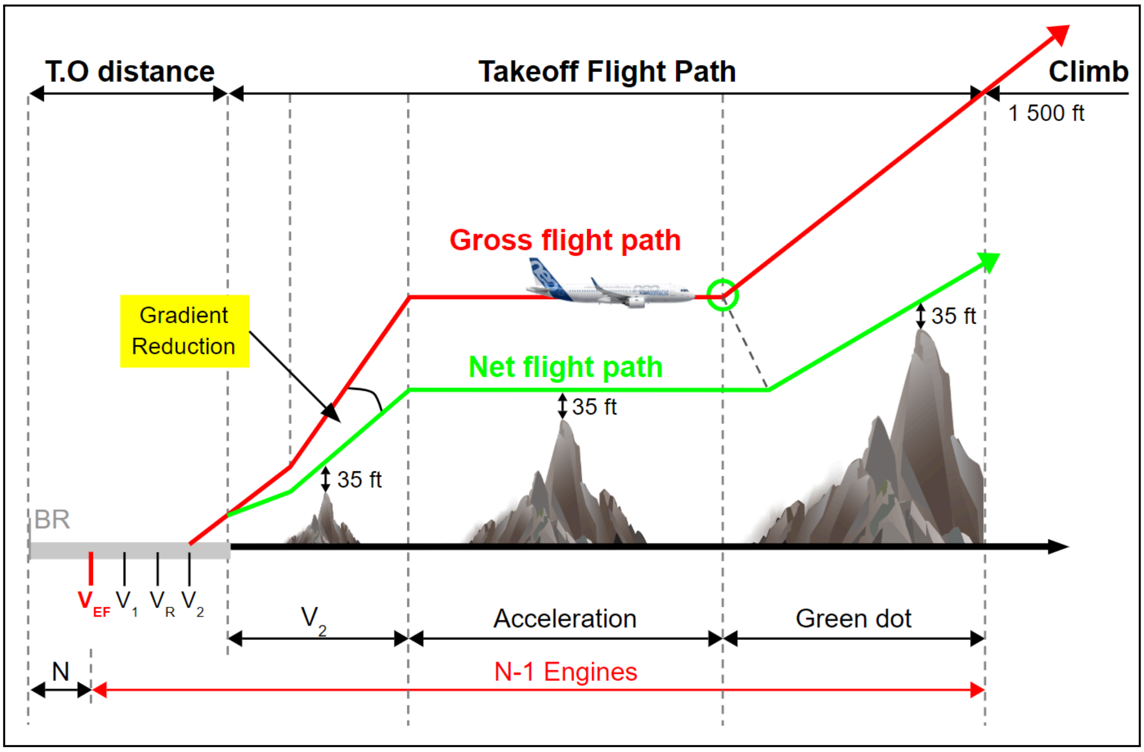


Illustration C-22: Takeoff Gross and Net Flight Path (example for TOD=TOD_{N-1})

Air OPS Subpart C CAT.POL.A.210

FAR 121.189 (d)(2) Subpart I

"(a) The net take-off flight path shall be determined in such a way that the aeroplane clears all obstacles by a vertical distance of at least 35 ft."

For example, the minimum climb gradient that is required during the second segment must be 2.4 % for an aircraft with two engines. But, as per regulation, the net flight path must clear any obstacle by at least 35 ft (Illustration C-22). This may sometimes require the second segment gradient to be more than 2.4 % and, as a result, the MTOW may need to be reduced accordingly. This is an example of obstacle limitation.
Obstacles below the third segment determine the minimum acceleration height. This height must be between 400 ft and the maximum acceleration height (10 min at TOGA). The minimum acceleration height ensures a vertical clearance of 35 ft (or 50 ft) between the net flight path and the obstacle.

3.2.1.5. Management of the Extended Final Segment

As described in the Definitions of this chapter, the CS/FAR 25.111 defines the end of the takeoff flight path at the higher of 1500 ft, or when the enroute configuration is achieved. The en route configuration needs to be achieved a maximum of 10 min after takeoff, due to the limitations of the use of TOGA. This results in a maximum acceleration height, as defined in the chapter Minimum and Maximum Acceleration Heights.
Therefore, for Airbus aircraft, the certified net flight path ends at the net height, achieved after 10 min. Any additional obstacles, after the end of the Net Takeoff Flight Path that is certified, should be checked with the Net en route Flight Path that is certified.

There is a difference between the obstacle clearance requirements for takeoff and en route. As explained in the chapter Takeoff Funnel Air OPS Definition, the Net Flight Path needs to clear obstacles, by either a lateral margin of at least 600 m, or by a vertical margin of at least 35 ft (refer to Air OPS Subpart C - CAT.POL.A.210).
For en route, the net flight path needs to clear obstacles by either a lateral margin of at least 5 nm, or by a vertical margin of at least 1 000 ft (refer to Air OPS CAT.POL.A.215), as described in the chapter Vertical Clearance.

For some airports, not all obstacles are cleared at the end of the Net Takeoff Flight Path. The use of the en route margins may have a high impact on the MTOW, because more obstacles need to be considered (due to the larger lateral margin) with a higher vertical margin. One option is to consider the extension of the Net Takeoff Flight Path beyond the CS25 definition.
The regulation does not define how to manage this difference between obstacle clearance during takeoff and en route.
Some documentation provides guidance on this subject.

For example the FAA Advisory Circular 120-91A explains that, for the purpose of the analysis of obstacle clearance, the takeoff flight path ends at one of the following:

- The Minimum Crossing Altitude (MCA) or the Minimum En Route Altitude (MEA), for a route to the expected destination, or
- A point where the requirements for en route obstacle clearance can be satisfied, or
- A point from which an approach may be initiated to the departure airport or to the departure alternate.

Operators can consider several methods for the gross/net flight path margin and the definition of minimum obstacle clearance, for the extended final segment. These can be checked with their local authorities:

1. A conservative method is to consider that far away obstacles are below the third segment, and that the net flight path clears the obstacles by at least 35 ft.

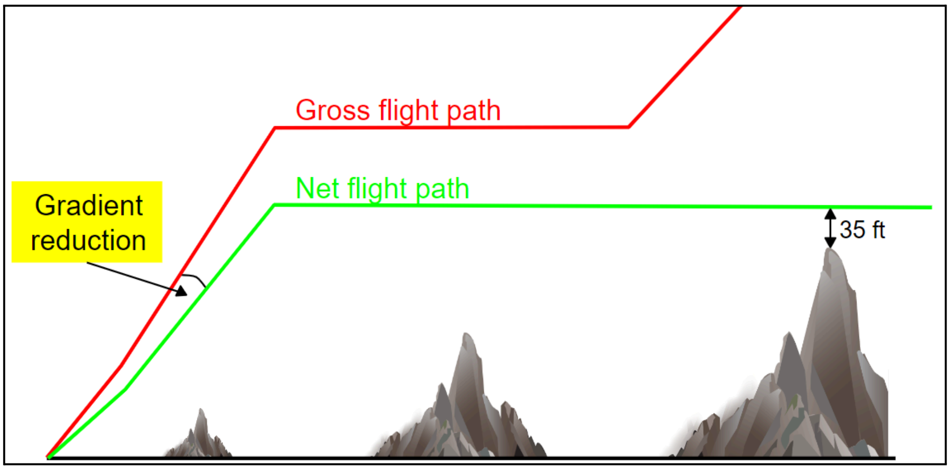


Illustration C-23: Method 1 for Obstacles Clearance

If this option has too many limitations for MTOW, one of the following options can be considered.

2. Apply a gradient reduction to the gross flight path for the final segment.

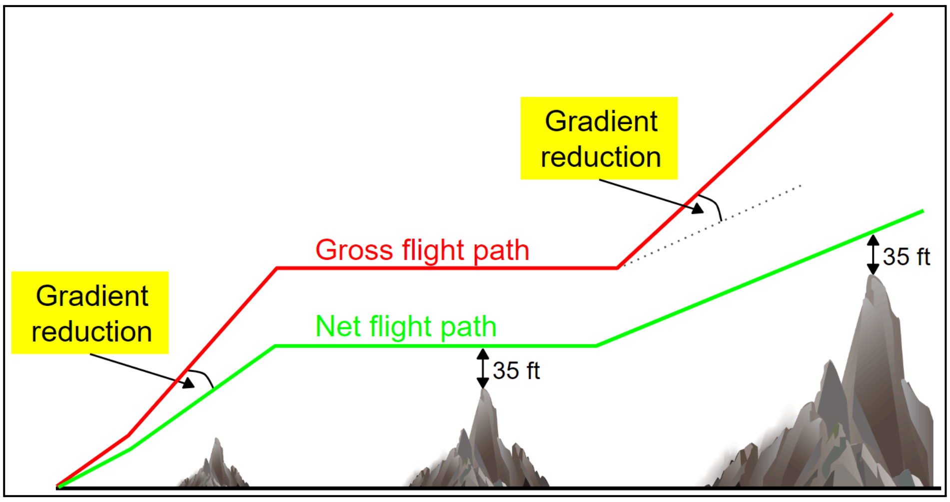


Illustration C-24: Method 2 for Obstacles Clearance

This results in the deviation between gross and net flight path as the aircraft climbs. For far away obstacles, the difference between the gross and net paths may be very large (Illustration C-24). The method, 3, below permits to avoid this.

Apply a gradient reduction to the gross flight path for the final segment, until the difference between the gross and the net flight path reaches a defined maximum value. As soon as the altitude difference between gross and net is equal to the defined maximum value, the net flight path becomes parallel to the gross, separated by the maximum value. Therefore, when the gross and the net flight paths are parallel, the minimum obstacle clearance between the gross flight path and the obstacle is at least the maximum value (Illustration C-25).

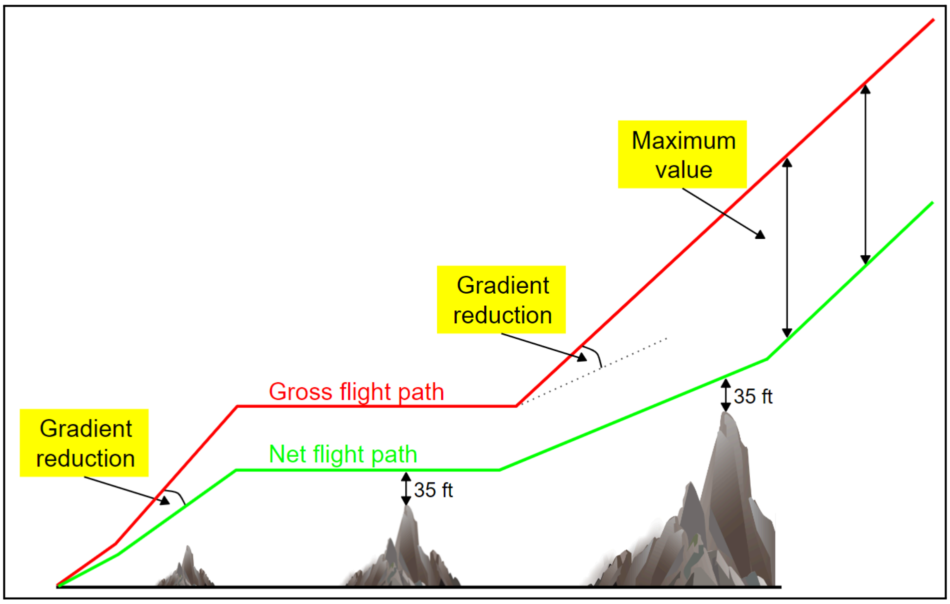


Illustration C-25: Method 3 for Obstacles Clearance

3. Build the net flight path depending on the true altitude of the aircraft and the related Minimum Obstacle Clearance Altitude (MOCA) that is required. (Illustration C-26) When the net flight path diverges from the gross flight path, the difference between the gross and the net flight path is limited, based on a specific table [true altitude; MOCA]. Refer to ICAO PANS-OPS Vol II (Doc 8168) for an example.

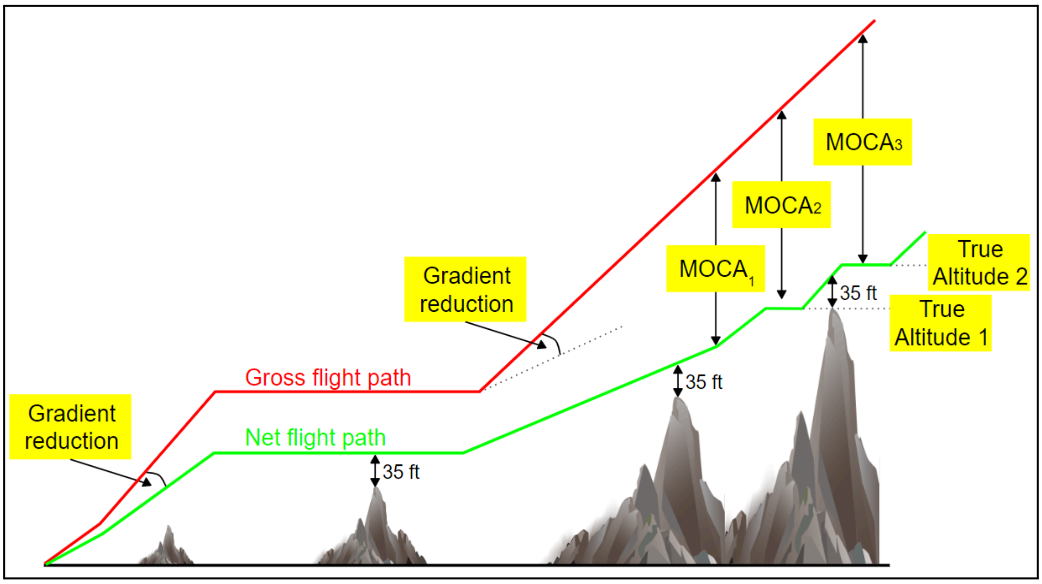


Illustration C-26: Method 4 for Obstacles Clearance

The use of these methods may help to increase the MTOW, when it is limited by a far away obstacle clearance. Since the methods described above are not defined by regulation, their use must be approved by local authorities.

3.2.1.6. Turn Limitations

Some airports define departure procedures that require a turn to avoid limiting obstacles. Regulation defines specific criteria applicable to turns for consideration in the net takeoff flight path computation.

The turn criteria is different depending on the regulation. The following paragraphs consider EASA and FAA regulation separately.

Air OPS Subpart C
CAT.POL.A.210

"(b)(2) Track changes shall not be allowed up to the point at which the net take-off flight path has achieved a height equal to one half the wingspan but not less than 50 ft above the elevation of the end of the TORA."

AIRCRAFT TYPE	WINGSPAN	Minimum Height above End of TORA to Start a Track Change = Max {Half of Wingspan, 50 ft}
A220	38.7 m (127 ft)	64 ft
A300-B2/B4/600	44.84 m (147 ft 1 in)	74 ft
A310-200/300	43.90 m (144 ft 1 in)	72 ft
A318/A319/A320/A321	34.10 m (111 ft 10 in)	56 ft
A330-200/300	60.30 m (197 ft 10 in)	99 ft
A330-800/900	64.00 m (210 ft)	105 ft
A340-200/300	60.30 m (197 ft 10 in)	99 ft
A340-500/600	63.50 m (208 ft 2 in)	104 ft
A350-900/1000	64.75 m (212 ft 5 in)	106 ft
A380-800	79.75 m (261 ft 8 in)	131 ft

Table C-3: Minimum Height to Initiate a Track Change

"(b)(2) Thereafter, up to a height of 400 ft it is assumed that the aeroplane is banked by no more than 15°. Above 400 ft height bank angles greater than 15°, but not more than 25° may be scheduled.

(c)(3) Operations that apply increased bank angles of not more than 20° between 200 ft and 400 ft, or not more than 30° above 400 ft, shall be carried out in accordance with CAT.POL.A.240."

Air OPS Subpart C
CAT.POL.A.240

"(a) Operations with increased bank angles require prior approval by the competent authority."

Maximum Bank Angle during a Turn (Air OPS)		
	Standard Procedure	Specific Approval
Below 200 ft	15 °	15 °
Between 200 ft and 400 ft	15 °	20 °
Above 400 ft	25 °	30 °

Table C-4: Maximum Bank Angle During a Turn

Note: Depending on the conditions, with an engine failure, the autopilot may limit the bank angle to 15 °.

The obstacle clearance margins, during a turn, are different, depending on if they are provided by Air OPS or FAR. The FAR regulation does not consider any additional vertical margin during a turn, because the bank angle is limited to 15 º. The following rule is then applicable to EASA Air Ops only.

Air OPS Subpart C
CAT.POL.A.210

"(b) (3) Any part of the net take-off flight path in which the aeroplane is banked by more than 15° shall clear all obstacles [...] by a vertical distance of at least 50 ft."

	Obstacle Clearance Margin
Bank Angle ≤ 15 °	35 ft
Bank Angle > 15 °	50 ft

Table C-5: Minimum Vertical Clearance Margin

FAR 121.189 Subpart I

"(f) For the purpose of this section, it is assumed that the airplane is not banked before reaching a height of 50 ft, […] and thereafter that the maximum bank is not more than 15 degrees[9]."

FAA - AC 120-91A

[9] The FAA rule is similar to the ICAO annex 6 recommendations.

“17.(b) Bank Angle. Sections 121.189, 135.379, and 135.398 assume that the airplane is not banked before reaching a height of 50 feet, and that thereafter, the maximum bank is not more than 15 degrees. Obstacle clearance at certain airports can be enhanced by the use of bank angles greater than 15 degrees. The following bank angles and heights may be used with OpSpec authorization (in accordance with § 121.173(f)). Any bank angles greater than the values shown in Table C-6 below require additional, specific FAA authorization.”

Maximum Bank Angles	
Height Above Departure End of Runway (ft)	Maximum Bank Angle
h > 400	25 °
400 > h > 100	20 °
100 > h > 50*	15 °
* Or ½ of wingspan, the highest of both.	

Table C-6: Maximum Bank Angles

3.2.2. All Engines Operative - Takeoff Flight Path

As described in the chapter One Engine Inoperative - Takeoff Flight path, for an OEI takeoff, the net flight path must ensure an obstacle clearance of at least 35 ft (refer to CAT.POL.A210 and FAR 121.189 (d)(2) Subpart I).

For the AEO operations, the certification and Air OPS regulations do not define requirements on the vertical and the lateral flight paths. By design, and as per the recommendations of the PANS-OPS (ICAO DOC 8168), operators must ensure that the gross AEO takeoff flight path will not cross the protection surface, published on the Standard Instrument Departure (SID) chart. As a result, operators must check for compliance with the operational constraints.

3.2.2.1. Flight Path

On Airbus aircraft, the typical trajectory with AEO procedure is described as follows:

- The aircraft maintains the takeoff thrust at a speed near to V_2+10 kt, until the thrust reduction altitude is reached.
- The aircraft still maintains a speed equal to V_2+10 kt with the climb thrust.
- The aircraft reaches the acceleration altitude.
- At the acceleration altitude, the aircraft retracts the flaps and the slats until the configuration is clean, and then accelerates to 250 kt.
- The aircraft climbs to 10 000 ft at a constant speed of 250 kt.

In the case of a specific takeoff procedure, for example the NADP2, the different takeoff segments will not be the same as those defined for a typical trajectory.

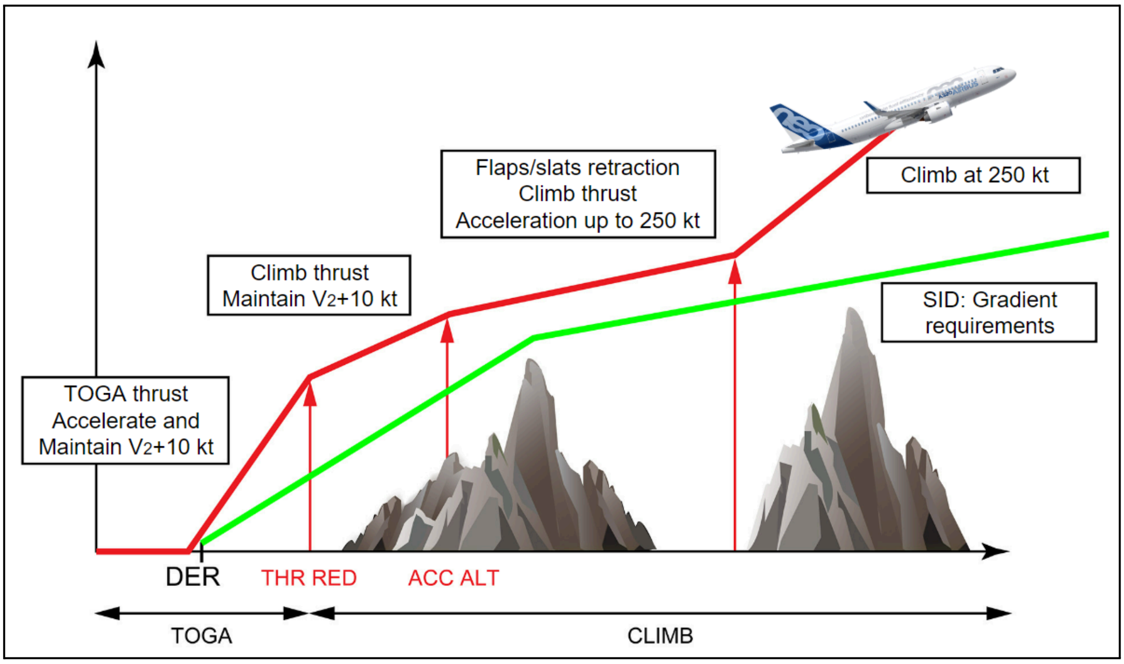


Illustration C-27: Typical Takeoff Vertical Flight with AEO

On the illustration C-27, the protection surface is displayed in green and the AEO gross takeoff flight is displayed in red.

3.2.2.2. Published Procedure

The ICAO PANS-OPS Vol II (Doc 8168) provides standards and recommendations for the people that create procedures, so that they can write the departure instrument procedures. The operators comply with the published procedures. SID procedures are published as part of the AIP, refer to Appendix 6.

ICAO PANS-OPS Vol II (Doc 8168)

Due to the recommendations and the standards described in the PANS-OPS, by design, a takeoff procedure with AEO must ensure that no obstacle enters a protection surface of 2.5 %. An additional margin of 0.8 % is applied. For this reason, when no climb gradient is published, operators must consider a surface of 3.3 % as a minimum protection surface .

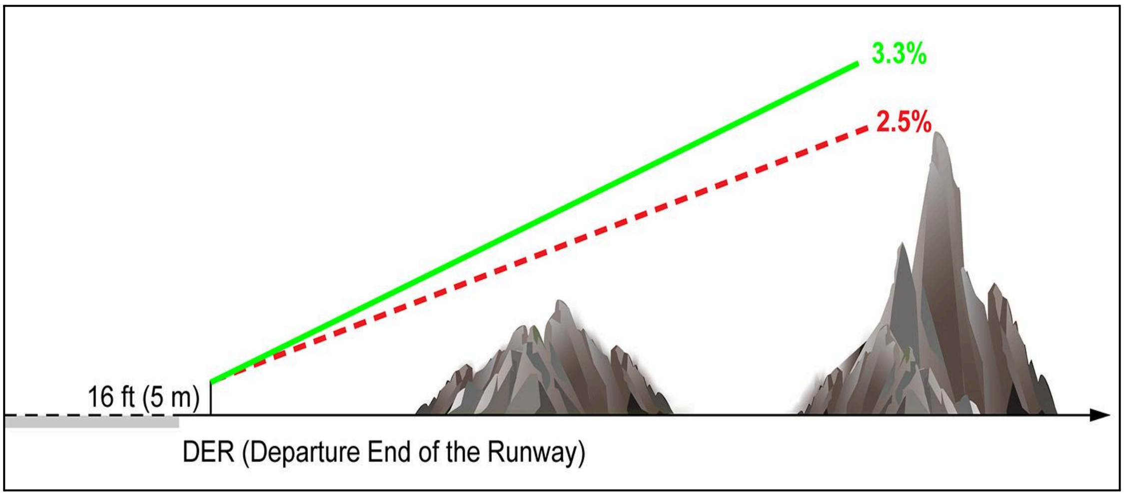


Illustration C-28: AEO Protection Surface

The minimum protection surface starts at 5 m above the departure end of the runway, and continues until the target altitude.

When the protection surface requires a higher gradient than the standard climb gradient of 3.3 %, this gradient and the target altitude are published on the chart.

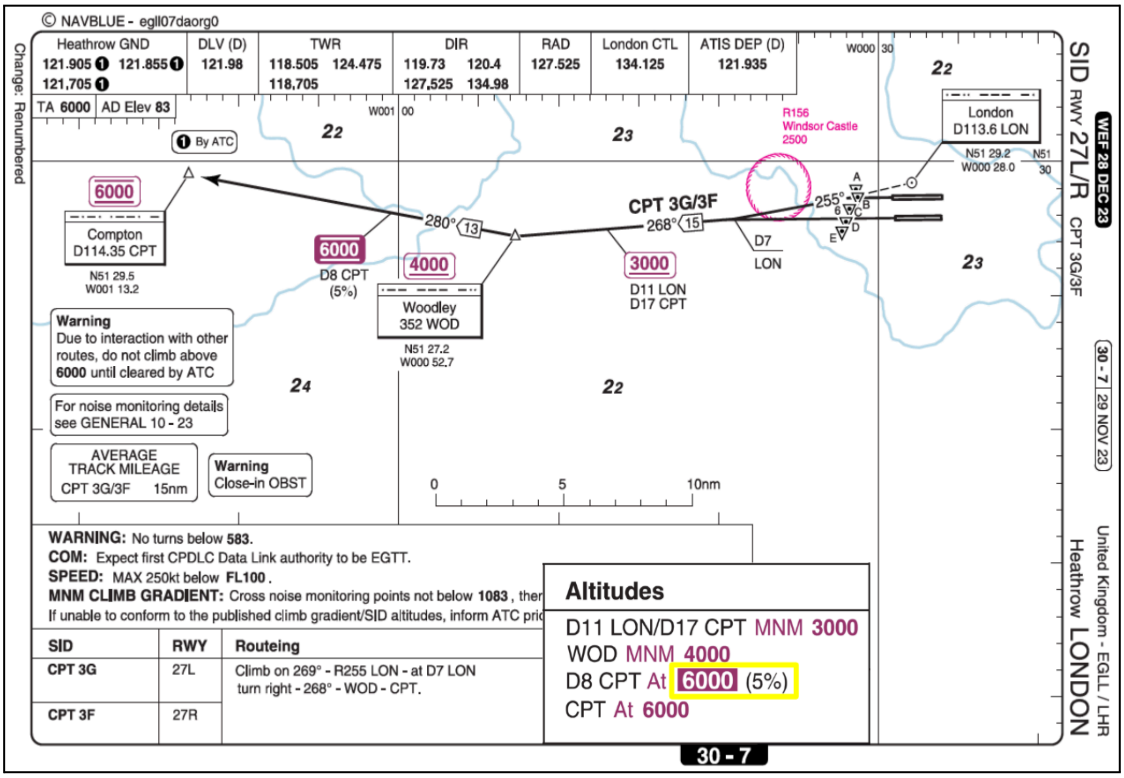


Illustration C-29: Example of a Climb Gradient Published on a Chart

On the chart, for the SID CPT 3F, an all engine climb gradient of 5 % up to 6 000 ft is required.

This published constraint means that the protection surface is as follows:

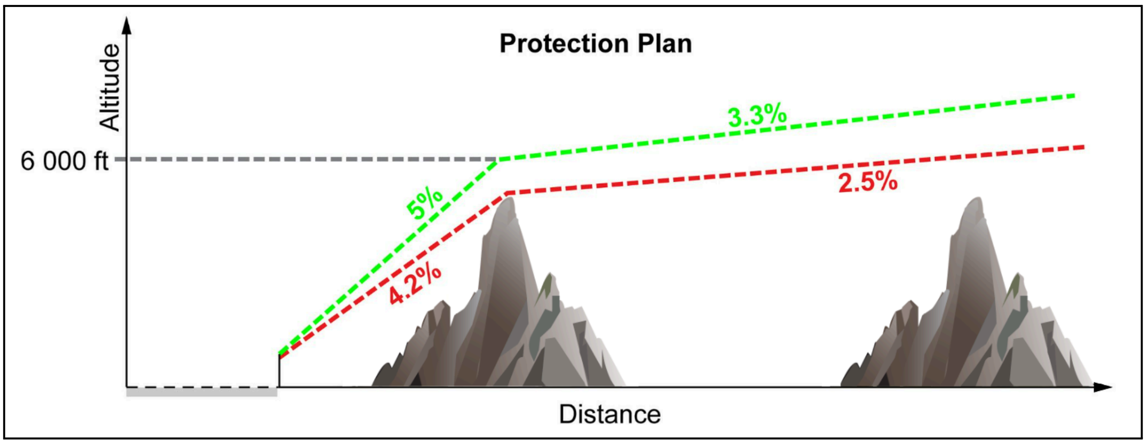


Illustration C-30: Protection Surface for a Published Climb Gradient of 5% up to 6 000 ft

3.2.2.3. Check for the All Engine Climb Gradient

As described in the IATA Operational Safety Audit (IOSA) Handbook, operators must provide the pilots with the all engine climb gradient, and publish it in the Operating Manual.

Operators can consider several options, in order to check the all engine climb gradient:

1. The first approach is to compute the gross trajectory of the aircraft with AEO, and to ensure that the AEO gross trajectory always remains above the protection surface.
   This method is precise, and may consider the cases where the protection surface is divided into several connected constraints (for example, 5.6 % until 2 500 ft and then 4.2 % until 6 000 ft).

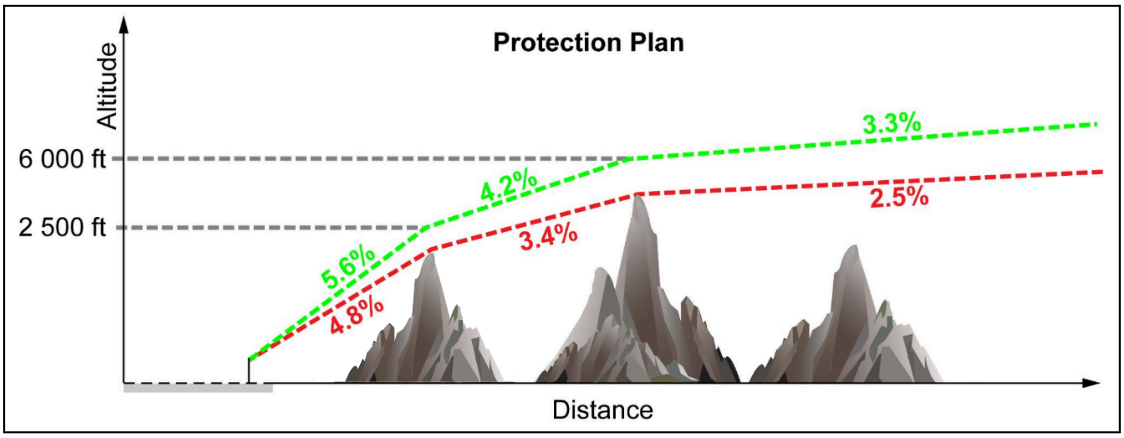


Illustration C-31: Example of Obstacle Protection Surface

   This method could be long and difficult to apply for operators with a large network.

The other alternative methods are to check an All Engine Climb Gradient (AECG) between the end of TOD and the target altitude, published on the SID charts.

2. A conservative method is to compute the AECG at the end of the first acceleration phase (i.e. the end of the third segment). This computation must be valid for a range of temperatures and takeoff weights and consider the most penalizing conditions:
   a. The minimum V_2 speed.
   b. The takeoff configuration with maximum slats/flaps extension.

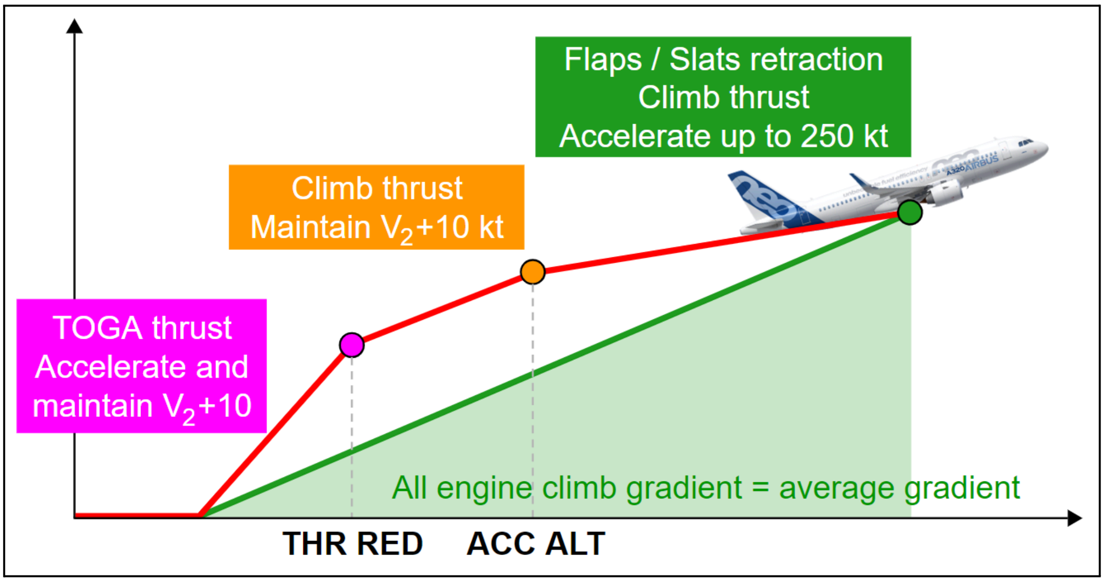


Illustration C-32: Typical Takeoff Flight Path and Associated all engine climb gradient

   On a typical AEO takeoff vertical trajectory, during the acceleration segment, the aircraft accelerates to 250 kt. As a result, the aircraft has a lower energy to climb and the AECG is also lower.

3. If operations are limited with method 2, it is necessary to compute the AECG with the conditions of the day. Some Electronic Flight Bag (EFB) providers include this functionality in the takeoff computation.

Note that with methods 2 & 3, it is not possible to take into account the different changes on the lateral track of the aircraft. This means that only the wind on the runway axis can be considered.

For the AEO operations, the thrust reduction altitude and the acceleration altitude are defining parameters:

- When the published AECG is too limiting, the best way to enhance the performance is to optimize the thrust reduction altitude and the acceleration altitude.
- When the takeoff is not limited by the published AECG, a reduction in fuel consumption and noise emission may be possible by:
  - The optimization of the thrust reduction altitude, and/or,
  - The optimization of the acceleration altitude.

Please refer to the “Getting to Grips with Fuel Economy & Emission Reduction” and to the “Getting to Grips with Noise”, available on Airbusworld.

4. FACTORS OF INFLUENCE

There are two types of factors of influence:

- Parameters that are external: temperature, pressure, runway conditions, runway slope, wind, alignment, air bleed and moisture.
- Parameters that can be selected: flaps setting, V_1 and V_2.

4.1. EXTERNAL PARAMETERS

The determination of the TOW limited by performance must be based on the external conditions of the day that are subject to frequent variation.

CS 25.105 Subpart B
CS 25.237 Subpart B

FAR 25.105 Subpart B
FAR 25.237 Subpart B

Air OPS Subpart C
CAT.POL.A.205

FAR 121.189 (e) Subpart I

“Air OPS Subpart C
CAT.POL.A.205
(c) When showing compliance with CAT.POL.A.205 (b), [requirements when determining the maximum permitted takeoff mass], the following shall be taken into account:
(1) The pressure altitude at the aerodrome;
(2) The ambient temperature at the aerodrome;
(3) The runway surface condition and the type of runway surface;
(4) The runway slope in the direction of the takeoff;
(5) Not more than 50% of the reported headwind component or not less than 150% of the reported tailwind component; and
(6) The loss, if any, of runway length due to alignment of the aeroplane prior to takeoff.”

4.1.1. Temperature and Pressure Altitude

Temperature (T) and Pressure Altitude (Zp) have an influence on aerodynamic performance and engine performance.

<u>Effect on Aerodynamics:</u>

At takeoff, Lift (L) must be higher than Weight (W):

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

As air density ρ decreases when T or Zp increases, the same lift can be obtained by an increase in the velocity (V).
As a result, the takeoff distances increase and the gradients decrease with increasing T and Zp.

Effect on Engines:

When the Zp or T increases, the available takeoff thrust is reduced, as described in the chapter Engine Limitations.
As a result, the takeoff distances increase and the gradients decrease with T and Zp.

4.1.2. Runway Condition

Refer to the chapter Takeoff on Wet or Contaminated Runways.

4.1.3. Runway Slope

A slope is usually defined as a percentage, with a plus sign before (when it is upward), or a minus sign before (when it is downward).

Airbus aircraft are certified for takeoff on runways with slopes between -2 % and +2 %. However, these values can be extended to higher limits for operations on specific runways that require certification of an AFM supplement, justified by analysis and flight testing.

An upward slope degrades the aircraft acceleration capability and, as a result, it increases the takeoff distance. On the other hand, the required distance to stop is reduced in the case of a rejected takeoff. For this reason, depending on the takeoff limitation, an upward slope may increase or decrease the MTOW.

Upward slope	⇒	Takeoff distances ↗ Accelerate stop distance ↘
Downward slope	⇒	Takeoff distances ↘ Accelerate stop distance ↗

4.1.4. Wind

Air OPS Subpart C CAT.POL.A.205

FAR 121.189 (e) Subpart I

The wind component along the runway axis is a factor that has an important influence on takeoff performance. The wind affects the true airspeed. The takeoff distances are reduced, in the case of headwind, and increased, in the case of tailwind.

The MTOW calculated before takeoff, must be determined based on 50 % of the current headwind component, or 150 % of the current tailwind component. This criteria is taken into account by the Airbus performance software, so that an Operator only needs to consider the current wind component for the determination of the MTOW.

CS 25.237 Subpart B *FAR 25.237 Subpart B*

"(a)(1) A 90° cross component of wind velocity, demonstrated to be safe for take-off and landing, must be established for dry runways and must be at least 37 km/h (20 kt) or 0.2 V_{SR0}[10], whichever is greater, except that it need not exceed 46 km/h (25 kt)."

The regulation requires the demonstration of a crosswind capability of up to at least 25 kt, but Airbus demonstrates maximum crosswind values above 25 kt.

On some aircraft, takeoff with high crosswind, or with tailwind, requires specific takeoff procedures that can affect the performance of the aircraft, due to the progressive application of the takeoff thrust. This is taken into account by the Airbus performance software.

In addition, the maximum recommended crosswind values are published for different runway states, considering handling quality criteria.

4.1.5. Alignment

Aircraft usually enter the takeoff runway from an intersecting taxiway. The aircraft must be turned in a way that the aircraft nose points toward the runway, in the direction for takeoff. The FAA regulations do not clearly require that the aircraft operators take into account the runway distance used to align the aircraft on the runway for takeoff. However, the EASA regulations require a lineup distance allowance to be considered.

Air OPS Subpart C
CAT.POL.A.205

Lineup corrections should be made, when the takeoff performance is computed, if runway access does not permit to position the aircraft at the threshold.
The Takeoff Distance/Takeoff Run (TOD/TOR) adjustment is based on the initial distance from the beginning of the runway to the main landing gear. This is because the screen height is measured from the main landing gear, as indicated by distance "A", in Illustration C-33. The Accelerate Stop Distance (ASD) adjustment is based on the initial distance between the beginning of the runway and the nose landing gear, as indicated by distance "B", in Illustration C-33.

[10] V_{SR0} is the reference stall speed in clean configuration.

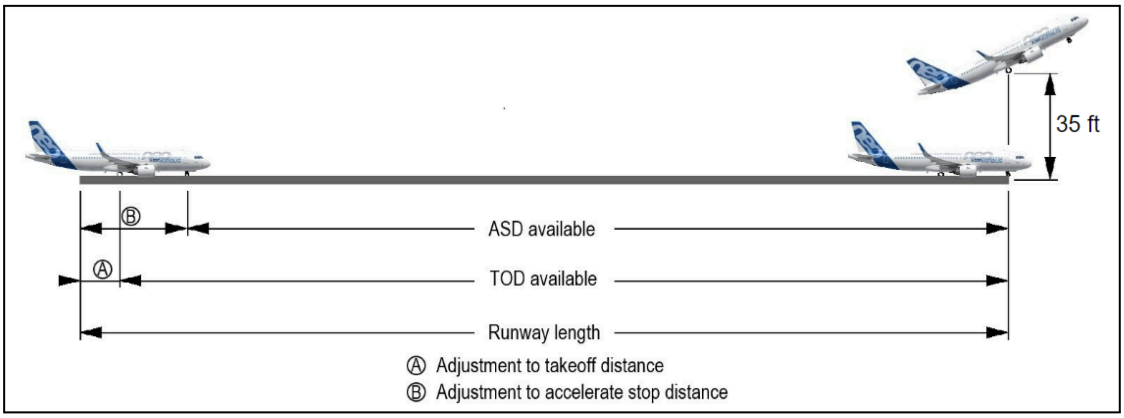


Illustration C-33: Lineup Corrections

Runways with a displaced takeoff threshold, or large turning aprons, should not need additional adjustment. An adjustment is usually required for a 90 ° taxiway entry to the runway, and for a 180 ° turnaround on the runway.

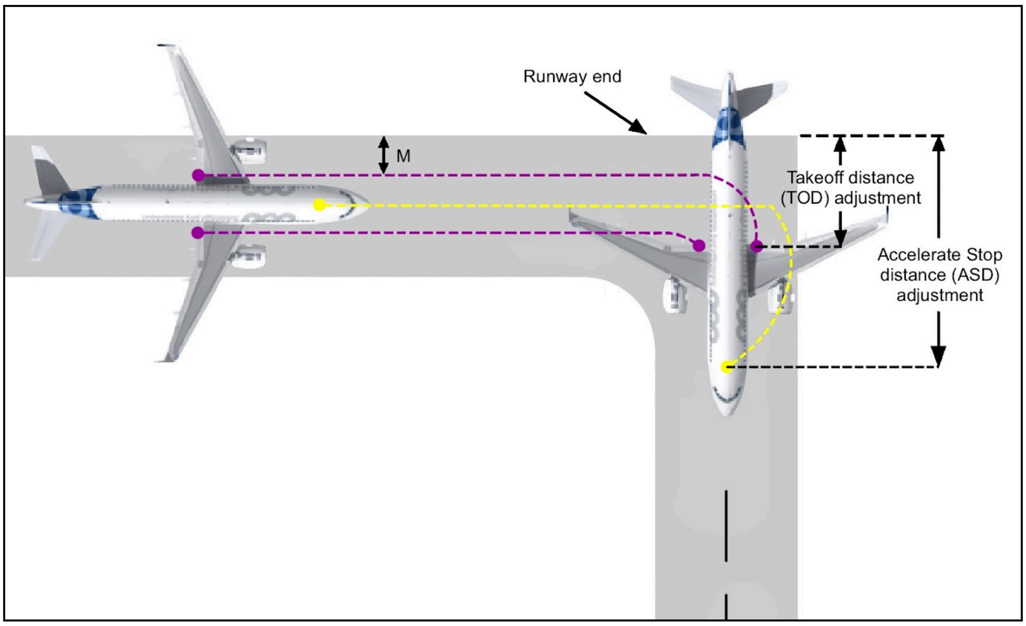


Illustration C-34: Example of 90° Taxiway Entry

The values of the distance corrections for the minimum lineup are available in the Airbus manuals (Aircraft Performance Data manuals), by aircraft model.

4.1.6. Air Bleed

When the air bleeds (i.e. air conditioning and anti-ice) are activated (set to ON), the takeoff distances increase and the gradients decrease, due to engine thrust reduction.

4.1.7. Moisture

CS 25.101 §b

FAR 25.101 §b

Performance must take into account the following variation of moisture:

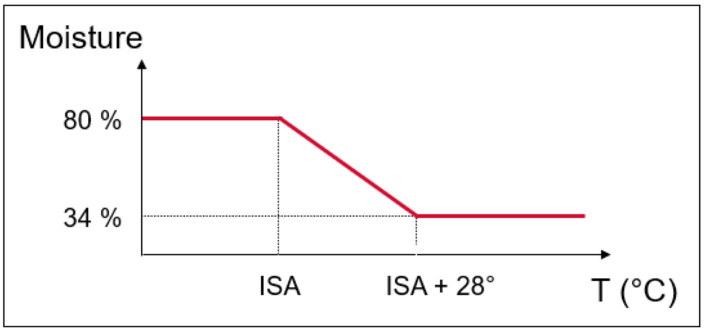


Illustration C-35: Variation of Moisture with Temperature

The influence of moisture is taken into account in the Airbus performance software.

4.2. Selected Parameters

4.2.1. Flap Setting

The deployment of flaps results in an increase in both lift and drag.
The increase in lift results in a reduction in the takeoff distances.
The increase in drag results in a reduction in the takeoff climb gradient.

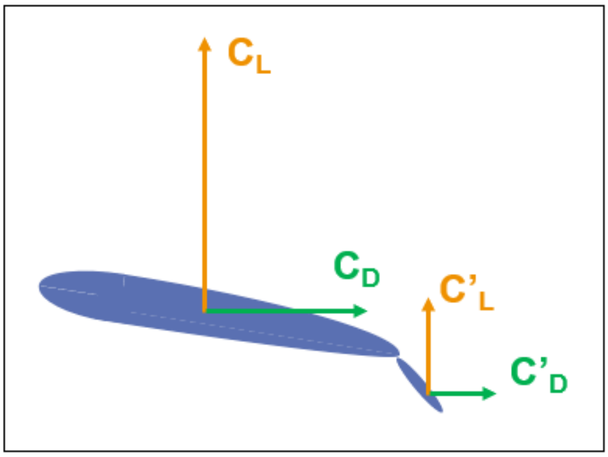


Illustration C-36: Effect of Flap in Lift and Drag

Takeoff flaps can be selected from several available takeoff configurations. For example, CONF 1+F, CONF 2 or CONF 3.

Each configuration is associated with a set of certified performance data, and it is, therefore, always possible to determine a MTOW for each takeoff configuration. As a result, the optimum configuration is the one that provides the highest MTOW.

As a general rule, CONF 1+F provides better performance on long runways (better climb gradients), while CONF 3 provides better performance on short runways (shorter takeoff distances). Sometimes, other parameters, like obstacles, can limit the performance. In this case, a compromise between climb and runway performance is required, and this makes intermediate configurations optimal for takeoff.

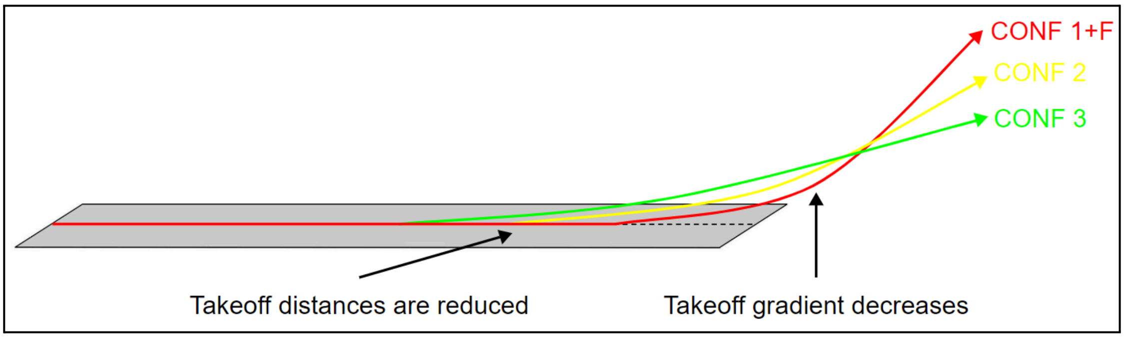


Illustration C-37: Effect of the Flap in the Takeoff Distance and in the Gradient

4.2.2. Decision Speed: V_1

For a specific takeoff weight, any increase in V_1 results in a reduction of both TOD_{N-1} and TOR_{N-1}. The all engines acceleration phase is longer with a higher V_1 speed. As a result, in the case of an engine failure at V_{EF}, the same V_2 speed can be achieved at 35 ft in a shorter distance.

The TOD_N and TOR_N are independent of V_1, because there is no engine failure and, therefore, no impact on the acceleration phase and on the necessary distance to reach 35 ft.

For a specific takeoff weight, any increase in V_1 results in an increase in both the ASD_{N-1} and ASD_N. With a higher V_1 speed:

- The acceleration distance from brake release to V_1 is longer
- The deceleration distance from V_1 to the complete stop is longer
- The distance at constant V_1 speed is longer.

As a result, the illustration C-38 with the takeoff/accelerate stop distances as a function of V_1 can be defined. This illustration clearly demonstrates that a minimum distance is achieved at a specific V_1 speed. This speed is the “balanced V_1”, and the corresponding distance is the “balanced field”.

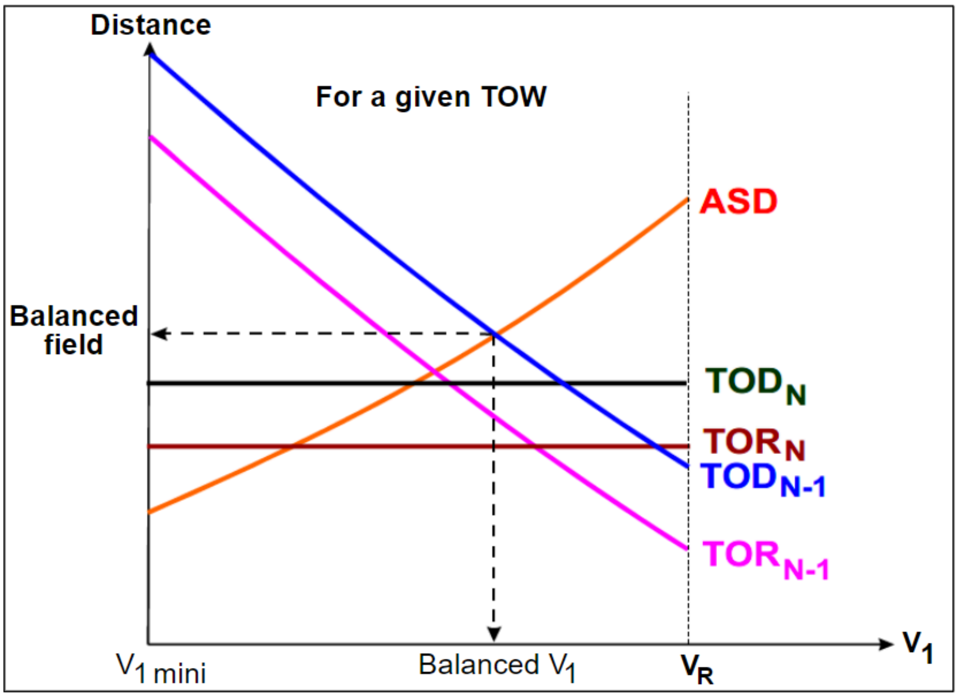


Illustration C-38: Influence of V_1 on Accelerate Go/Accelerate Stop Distances

4.2.3. Speed at 35 ft Height: V_2

V_2 is determined by V_R, as no takeoff parameters can be changed after liftoff:

$$\text{high } V_2 \Leftrightarrow \text{high } V_R$$

For a specific weight, a higher V_2 requires a higher V_R. Therefore, also a longer TOD because more distance is required to accelerate up to V_R. But, a higher V_2 will also enable the aircraft to have higher climb gradients (until a V_2/V_S maximal value, as demonstrated in the chapter Maximum Performance Takeoff Weight).

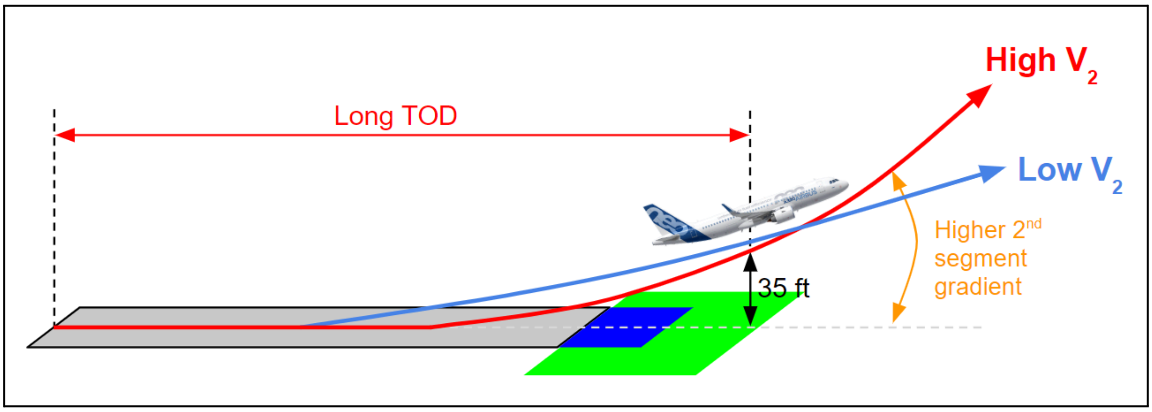


Illustration C-39: Influence of V2 on Second Segment Gradient for a Specific Weight

5. Maximum Performance Takeoff Weight

This section is specifically designed to explain the takeoff optimization principle. The optimization objective is to obtain the maximum takeoff weight permitted by the regulations. This means the highest takeoff weight that is limited by performance and complies with all airworthiness requirements.

Note: For takeoff configuration, refer to the chapter Factors of Influence.

5.1. Takeoff Speed Optimization

Takeoff speeds are the most important variables for the MTOW optimization. The following section demonstrates how this optimization is achieved using speed ratios (V_1/V_R and V_2/V_S).

5.1.1. Speed Ratios: V_1/V_R and V_2/V_S

5.1.1.1. V_1/V_R Range

The decision speed V_1 must always be less than the rotation speed V_R. But, as the V_R depends on weight, the maximum V_1 value is not fixed, while the maximum V_1/V_R ratio is equal to one (regulatory value).

In addition, it was demonstrated that a V_1 speed of less than 84% of the V_R makes the takeoff distances very long. Therefore, it does not have any takeoff performance advantages. As a result, the minimum V_1/V_R ratio is equal to 0.84 (manufacturer value).

The V_1/V_R ratio is used in the optimization process, because its range is well-identified:

$$0.84 \leq V_1/V_R \leq 1$$

Note: Any V_1/V_R increase (and respective decrease) should be considered to have the same effect on takeoff performance as a V_1 increase (and respective decrease).

5.1.1.2. V_2/V_S Range

CS 25.107 §b

The minimum V_2 speed is defined by the regulations :

$V_{2min} = 1.2\, V_s$ (A300/A310)	
$V_{2min} = 1.13\, V_{S1g}$ (Fly-By-Wire aircraft)	

→ $(V_2/V_S)_{min} = 1.2 \text{ or } 1.13$

The stall speed depends on weight. So that the minimum V_2 speed is not a fixed value, while the minimum V_2/V_S ratio is known for a specific aircraft type.

In addition, a high V2 speed results in longer takeoff distances, and a reduction of climb performance (Illustration C-40). As it does not provide any advantage, the V_2/V_S ratio is limited to a maximum value (V_2/V_S maxi) that depends on the aircraft type.

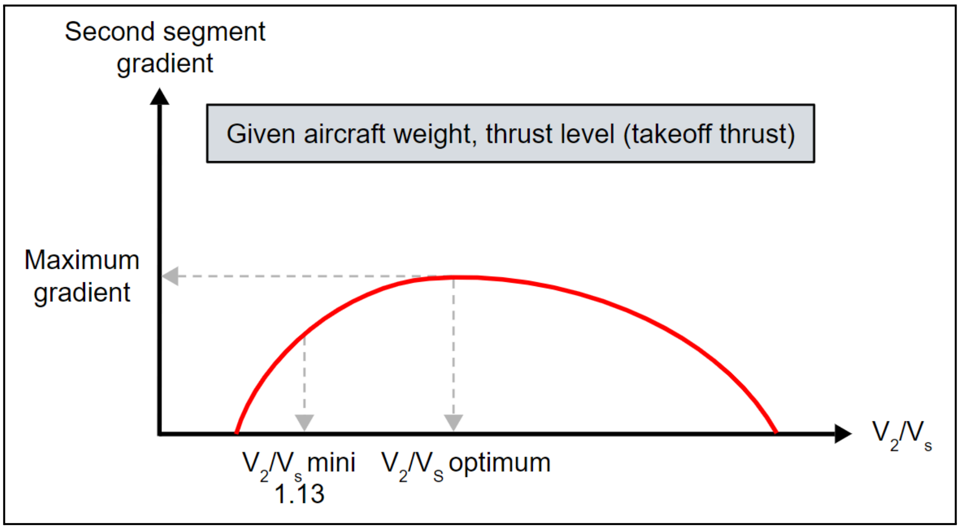


Illustration C-40 : 2nd Segment Climb Gradient variation with V_2/V_S Ratio

The V_2/V_S ratio is used in the optimization process, because its range is well-identified.

Note: Any V_2/V_S increase (and respective decrease) should be considered to have the same effect on the takeoff performance as a V_2 increase (and respective decrease).

5.1.2. V_1/V_R Ratio Influence

The objective of this section is to study the influence of V_1/V_R ratio variations on the takeoff performance, while the V_2/V_S ratio remains a constant. For that purpose, it is considered that the following parameters are fixed:

Fixed Parameters	
Runway Data	Elevation Runway Clearway Stopway Slope Obstacles
Outside Conditions	QNH Outside Air Temperature Wind component
Aircraft Data	Flaps/Slats Air conditioning Anti-ice Aircraft status (MEL/CDL) V_2/V_S

5.1.2.1. Runway Limitations

Any V_1/V_R increase results in (Illustration C-41):

- An increase in MTOW, limited by:
  - TOD_{N-1}
  - TOR_{N-1}
- A decrease in MTOW, limited by:
  - $ASD_{(N \text{ or } N-1)}$
- No influence on the MTOW, limited by:
  - TOD_N
  - TOR_N

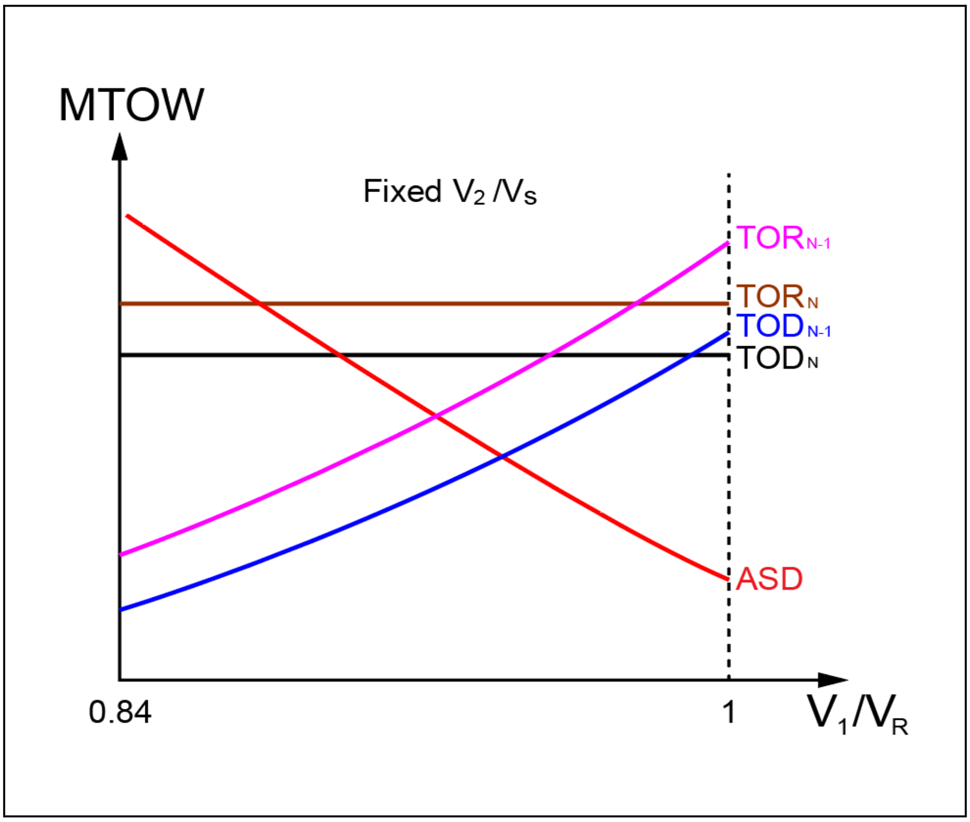


Illustration C-41 - Runway limited MTOW

5.1.2.2. Climb and Obstacle Limitations

The V_1 speed (recognition speed on ground) has no influence on climb gradients (first, second and final takeoff segments).

On the contrary, the obstacle-limited weight is increased with a higher V_1, because the takeoff distance is reduced. Therefore, the start of the takeoff flight path is obtained at a shorter distance, and this requires a lower gradient to clear the obstacles.

Any V_1/V_R increase results in (Illustration C-42):

- An increase in MTOW, limited by:
  - Obstacles.

- No influence on the MTOW, limited by the:
  - First segment
  - Second segment
  - Final takeoff segment.

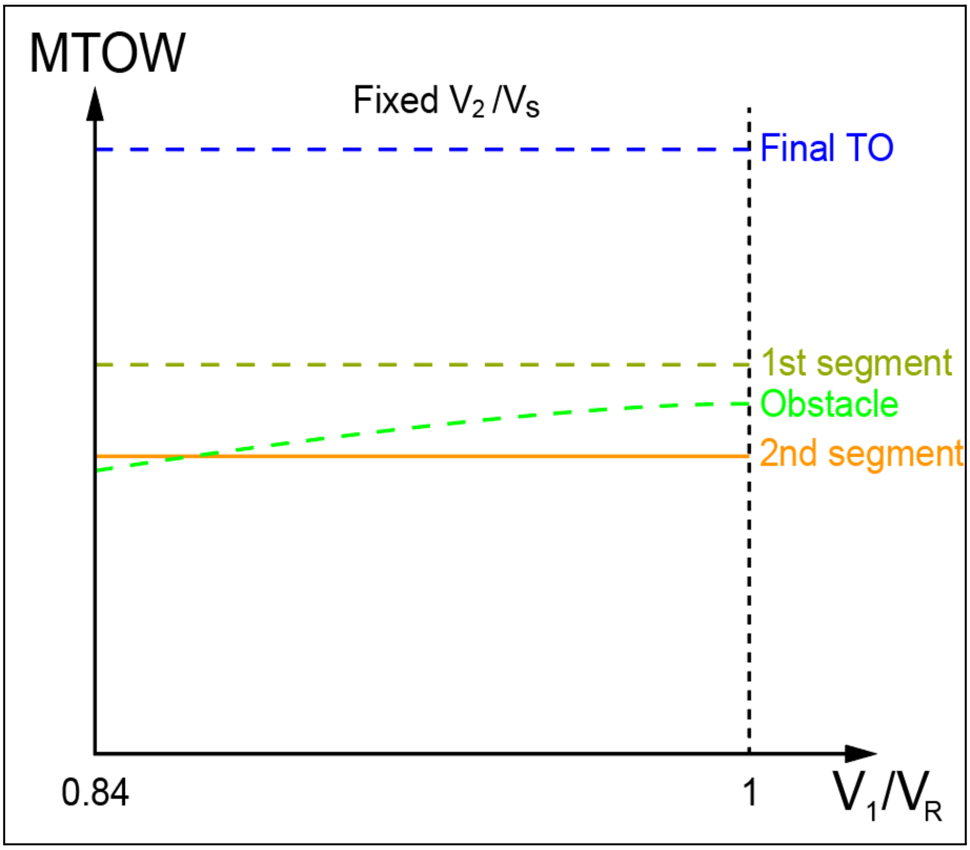


Illustration C-42: Climb and Obstacle limited MTOW

5.1.2.3. Brake Energy and Tire Speed Limitations

There is a maximum V_1 speed, limited by brake energy (V_{MBE}) for each TOW. To achieve a higher V_1 speed, it is necessary to reduce the TOW.

On the contrary, the decision speed does not have an influence on the tire speed limit.

Any V_1/V_R increase results in (Illustration C-43):

- A decrease in MTOW, limited by:
  - Brake energy.

- No influence:
  - Tire speed.

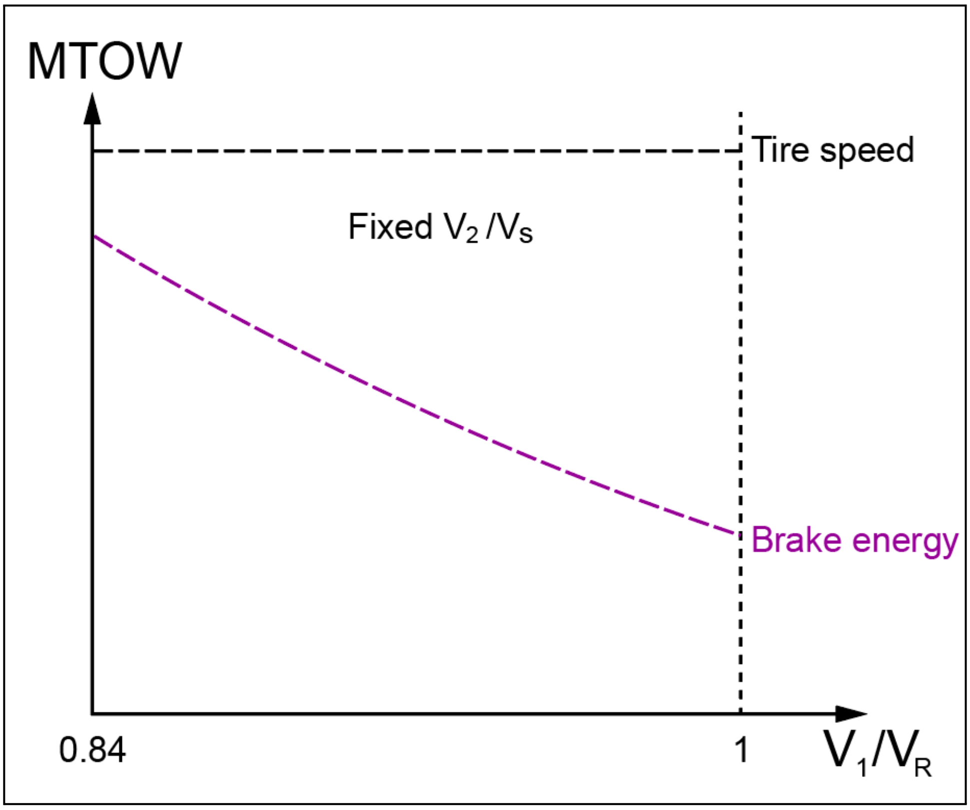


Illustration C-43: Brake energy and tire speed limited MTOW

5.1.2.4. All Limitations

The following Illustration (C-44) demonstrates that the highest of the maximum takeoff weights can be achieved at a specific optimum V_1/V_R ratio. This optimum point corresponds to the intersection between two limitation curves.

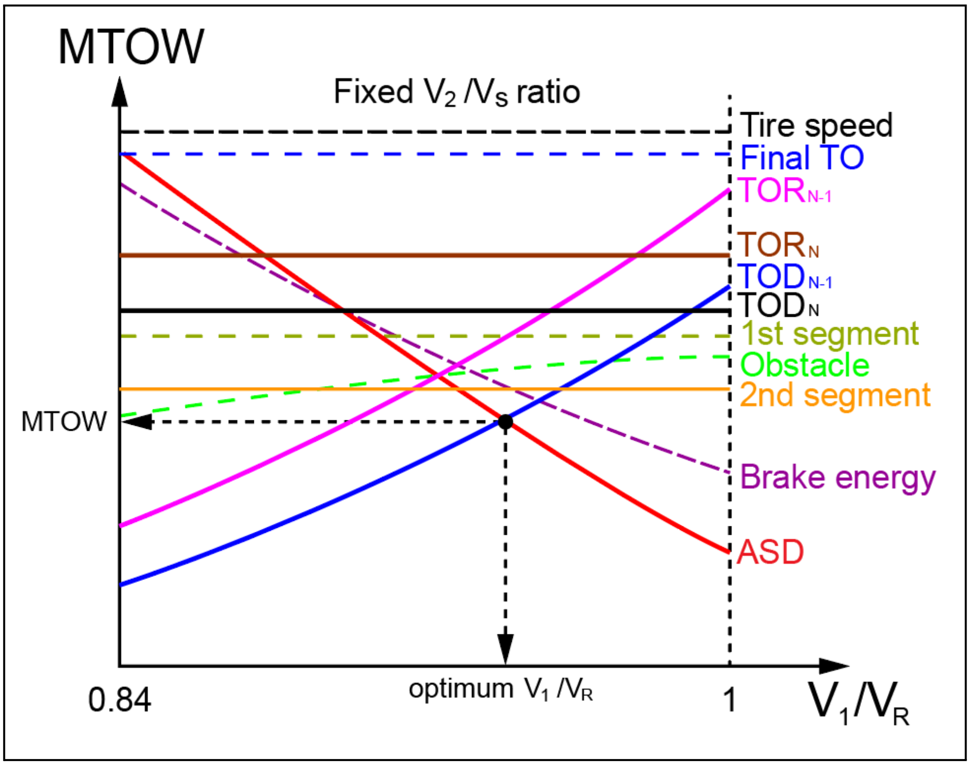


Illustration C-44: Optimum MTOW

The result of this optimization process is, for a specific V_2/V_S ratio, an optimum MTOW and an associated optimum V_1/V_R ratio.

5.1.3. V2/VS Ratio Influence

The purpose of this paragraph is to study the influence of V_2/V_S ratio variation on the takeoff performance, for a specific V_1/V_R ratio.

5.1.3.1. Runway Limitations

As a general rule, for a specific V_1/V_R ratio, any increase in the V_2/V_S ratio results in an increase in the OEI and AEO takeoff distances. In order to achieve a higher V_2 speed at 35 ft, the acceleration phase is longer.

On the contrary, the V_2 speed has no direct impact on the ASD. But, a higher V_2 speed results in a higher V_R speed and, therefore, for a specific V_1/V_R ratio, in a higher V_1 speed. Therefore, it has an effect on ASD.

Any V_2/V_S increase results in (Illustration C-45):

- A decrease in MTOW limited by:
  - TOD_{N-1} and TOD_N
  - TOR_{N-1} and TOR_N
  - ASD_{N-1} and ASD_N

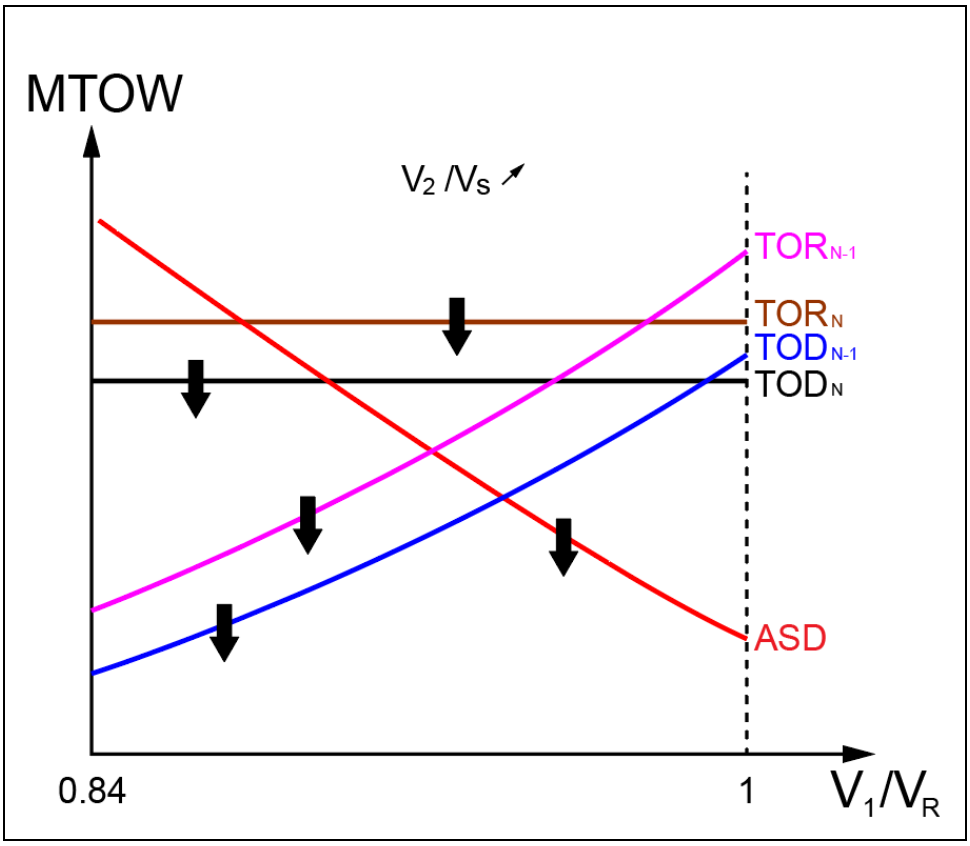


Illustration C-45: V_2/V_S Effect on the Runway Limitations

5.1.3.2. Climb and Obstacle Limitations

As shown in Illustration C-40, any V_2/V_S increase results in better climb gradients (first and second segment) and, therefore, in better climb limited MTOWs (first segment, second segment, obstacle).

On the other hand, as the aircraft flies the final takeoff segment at green dot speed, this segment is not affected by V_2 speed variations.

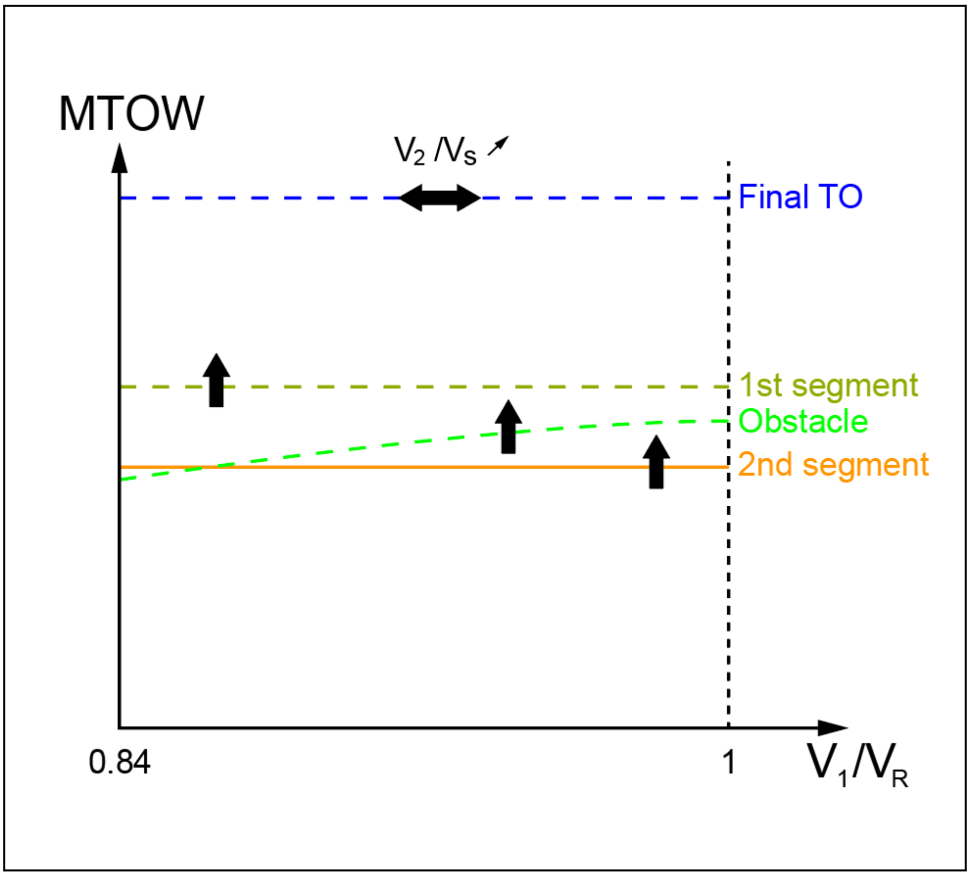


Illustration C-46: V_2/V_S Effect on the Climb and Obstacle Limitations

Any V_2/V_S increase results in (Illustration C-46):

- An increase in MTOW, limited by the:
  - First segment
  - Second segment
  - Obstacles.
- No influence on the MTOW, limited by the:
  - Final takeoff segment.

5.1.3.3. Brake Energy and Tire Speed Limitations

The V_2 speed does not have a direct impact on the brake energy limitation. However, any V_2 increase results in a V_R increase and, therefore, in a V_1 increase, at a fixed V_1/V_R ratio. Therefore, there is an effect on the brake energy limited weight.

The liftoff speed, V_{LOF}, is limited by the tire speed (V_{tire}). As a result, V_2 is limited to a maximum value. For this reason, any V_2/V_S increase is identical to a V_S reduction, because the V_2 is considered as fixed, and the tire speed limited TOW is also reduced.

Any V_2/V_S increase results in (Illustration C-47):

- A decrease in MTOW, limited by the:
  - Brake energy
  - Tire speed.

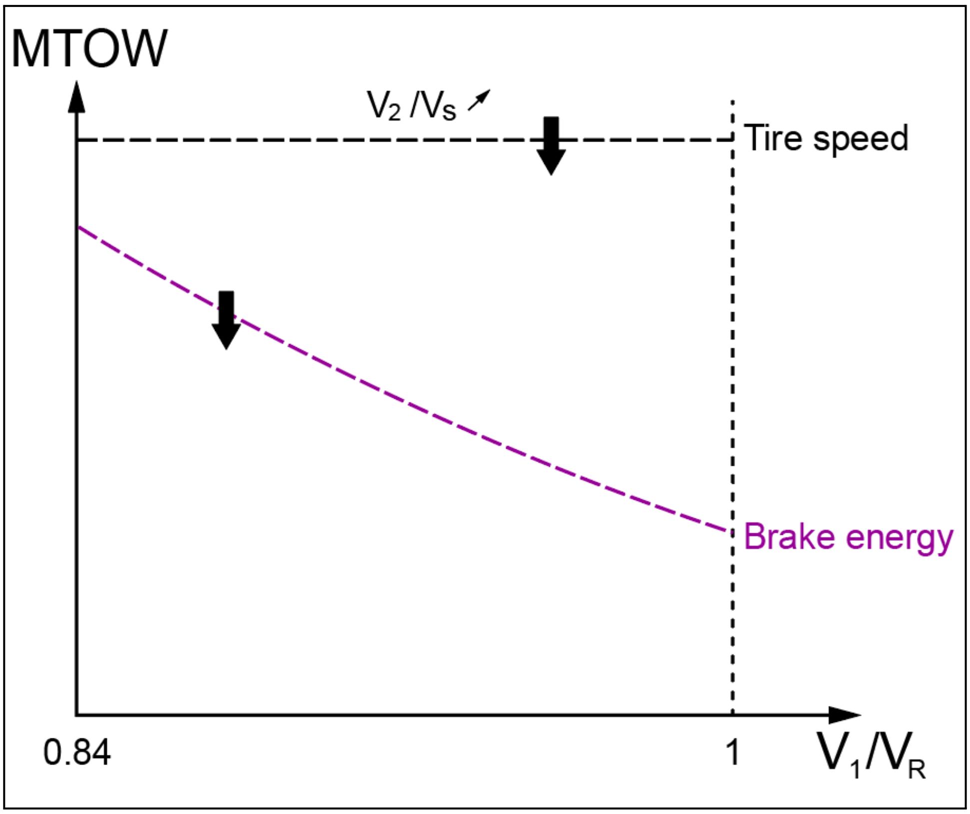


Illustration C-47: V_2/V_S Effect on the Brake Energy and Tire Speed Limitations

5.2. Result of the Optimization Process

5.2.1. Maximum Takeoff Weight

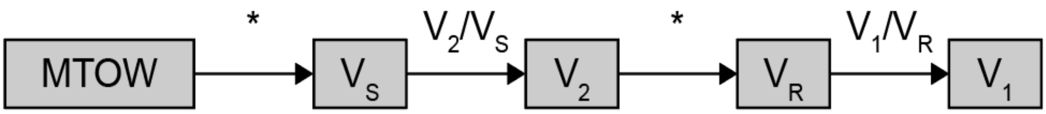
The previous section demonstrated how, for a specific V_2/V_S ratio, it is possible to find an optimum MTOW and its associated optimum V_1/V_R ratio.

This is determined for each V_2/V_S ratio between V_2/V_{smin} and V_2/V_{smax}. In the end, the highest of all the optimum MTOWs and associated optimum V_1/V_R is retained. Therefore, it corresponds to an optimum V_2/V_S ratio. The result of the optimization process, for a specific runway and takeoff conditions is as follows:

Result of the Optimization Process
• The highest possible MTOW • The optimum V_1/V_R ratio • The optimum V_2/V_S ratio

5.2.2. Takeoff Speeds and Limitations

The optimization process determines the MTOW, based on a single set of optimized takeoff speeds (V_1, V_R and V_2). The use of different speeds results in a TOW reduction.
When the optimum speed ratios (V_1/V_R and V_2/V_S) are obtained, the takeoff speeds are calculated as follows:



(*) Note: The certified aircraft model defines this relationship.
Most of the time, the MTOW is restricted by two regulatory limitations (Illustration C-48).

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5.2.3. MTOW with Two Limitations

Illustration C-48 illustrates that takeoff weight is limited by obstacles and by the Accelerate Stop Distance (ASD).

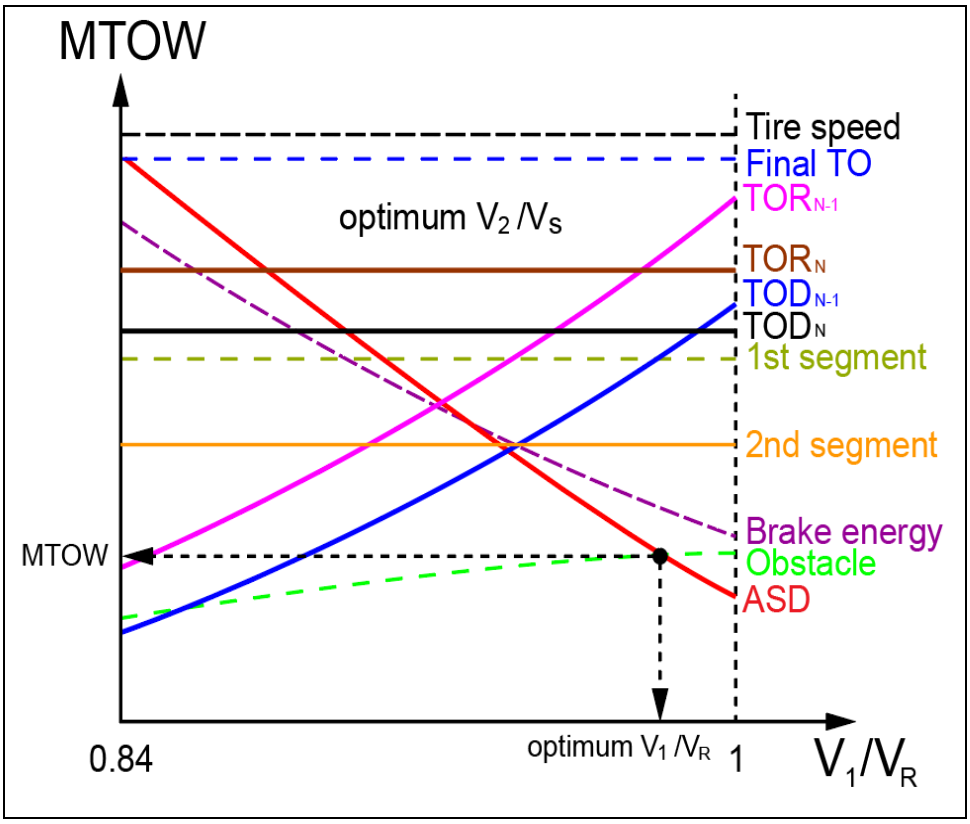


Illustration C-48: MTOW with Two Limitations

5.2.4. MTOW with One Limitation

In Illustration C-49, the takeoff weight is only limited by obstacles.

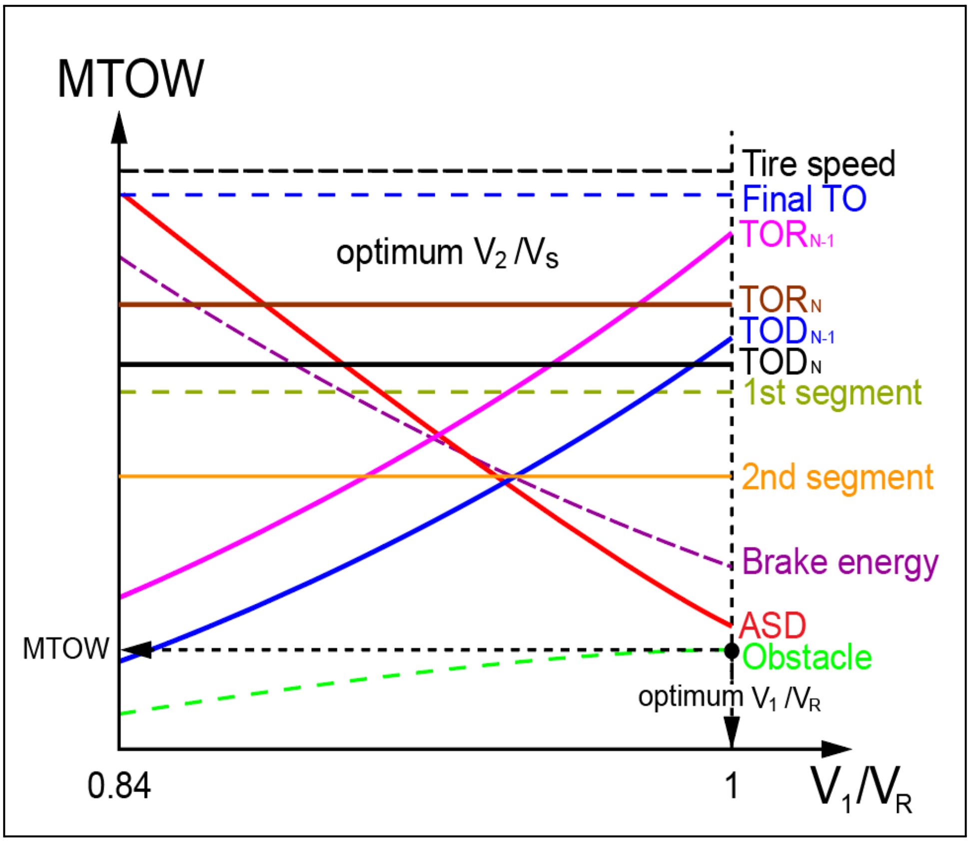


Illustration C-49: MTOW with One Limitation

5.2.5. MTOW with Three Limitations

In this specific case, there is a V_1 range. As a result, regardless of the selected V_1 speed (from the range between a minimum V_1 and a maximum V_1), the MTOW remains the same while the nature of the limitation changes. The selected takeoff V_1 speed remains at the Operator's discretion.

In Illustration C-50, the nature of the limitation depends on the V_1/V_R ratio:

- At V_1/V_{Rmin} (Point 1): The takeoff weight is limited by the TOD_{N-1} and by the second segment.
- Between V_1/V_{Rmin} and V_1/V_{Rmax}: The takeoff weight is only limited by the second segment.
- At V_1/V_{Rmax} (Point 2): The takeoff weight is limited by the second segment and by the brake energy.

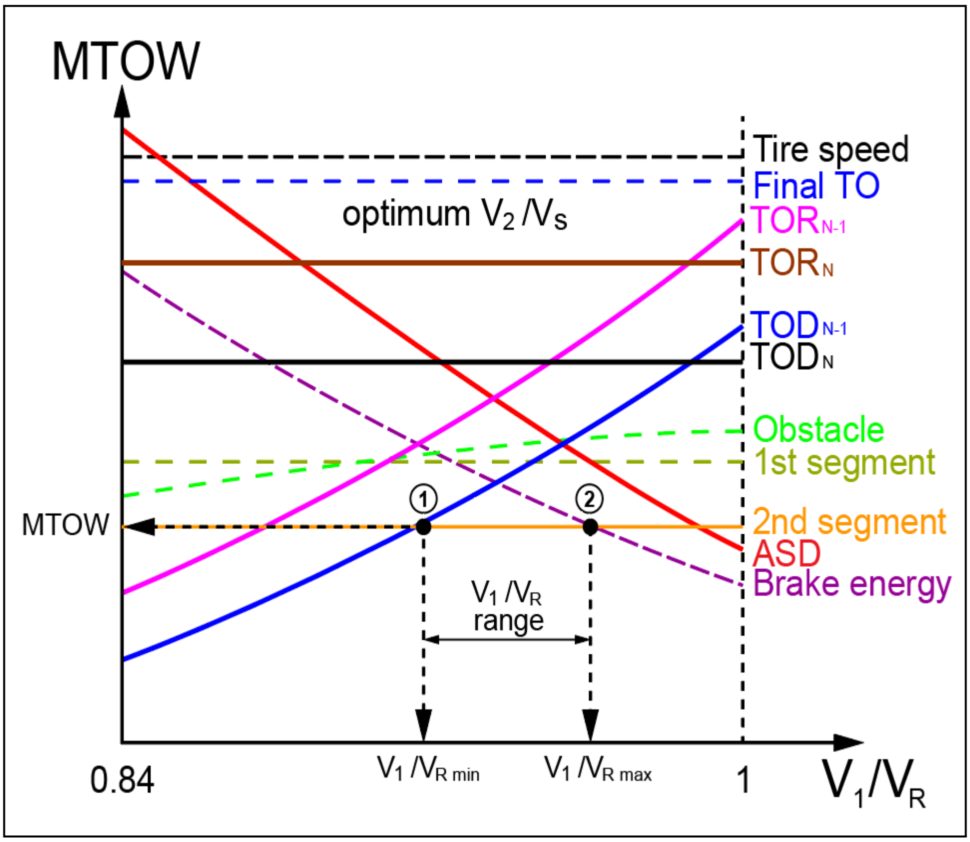


Illustration C-50: MTOW with Three Limitations

6. Takeoff on Wet or Contaminated Runways

6.1. Definitions of Contaminant

AMC 25.1591 §4.0 to §4.8

"The following definitions are a subset of the runway surface condition descriptors for which a representative take-off performance model may be derived using the methods contained in this AMC."

6.1.1. Frost

AMC 25.1591 §4.1

"Ice crystals formed from airborne moisture on a surface whose temperature is below freezing. Frost differs from ice in that frost crystals grow independently and, therefore, have a more granular in texture."

Airbus does not provide performance data for takeoff with frost.

6.1.2. Standing Water

AMC 25.1591 §4.1.a

"Water of a depth greater than 3 mm."

Standing Water is caused by heavy rainfall and/or not sufficient runway drainage, and with a depth of more than 3 mm (0.125 in).

6.1.3. Slush

AMC 25.1591 §4.2

"Snow that is so water-saturated that water will drain from it when a handful is picked up or will splatter if stepped on forcefully."

Slush occurs at temperatures of approximately 5 °C.

6.1.4. Wet Snow

AMC 25.1591 §4.3

"Snow that contains enough water to be able to make a well-compacted, solid snowball without squeezing out water."

6.1.5. Dry Snow

AMC 25.1591 §4.4

"Snow from which a snowball cannot readily be made."

Snow that, if compacted by hand, does not stay compressed when released.

6.1.6. Compacted Snow

AMC 25.1591 §4.5

"Snow that has been compacted into a solid-mass such that aeroplane tyres, at operating pressures and loadings, will run on the runway surface without significant further compaction or rutting of the runway surface."

6.1.7. Ice

AMC 25.1591 §4.6

"Water that has frozen or compacted snow that has transitioned into ice, in cold and dry conditions.
Note: this definition excludes wet ice that has a film of water on top of it or contains melting ice."

Airbus defines an ice-covered runway as ICE COLD and DRY.

6.1.8. Slippery Wet Runway

AMC 25.1591 §4.7

"A wet runway where the surface friction characteristics on a significant portion of the runway have been determined to be degraded."

6.1.9. Specially Prepared Winter Runway (SPWR)

AMC 25.1591 §4.8

"A runway, with a dry frozen surface of compacted snow and/or ice which has been treated with sand or grit or has been mechanically or chemically treated to improve runway friction. The runway friction is monitored and reported on a regular basis in accordance with national procedures."

6.2. Runway Condition

6.2.1. Definitions of Runway Condition

Air OPS ANNEX 1

"'Contaminated runway' means a runway of which a significant portion of its surface area (whether in isolated areas or not) within the length and width being used is covered by one or more of the substances listed under the runway surface condition descriptors."

FAR AC 25-31

"For purposes of condition reporting and airplane performance, a runway is considered contaminated when more than 25 percent of the runway surface area (within the reported length and the width being used) is covered by frost, ice, and any depth of snow, slush, or water."

Note: In FAR AC 25-31, for purposes of runway condition reporting and aircraft performance, water has a depth of more than 3 mm (⅛ inch).

Air OPS ANNEX 1

"'Wet runway' means a runway whose surface is covered by any visible dampness or water up to and including 3 mm deep within the area intended to be used."

AMC 25.1591 §2

"In line with International Civil Aviation Organization (ICAO) and Federal Aviation Administration (FAA) standards, EASA considers a depth of more than 3 mm for loose contaminant accountability in take-off performance assessments a reasonable lower threshold."

Note: A runway with surface water, slush or loose snow (with a depth of less than 3 mm) can be considered equal to a wet runway.

Air OPS ANNEX 1

"'Grooved runway' is a runway where the runway is grooved or the runway is treated with a porous friction course (PFC) or other materials. This is to improve the friction capability of the aircraft."

Air OPS ANNEX 1 ***FAR AC 25-31***

"'Damp runway' means a runway when the surface is not dry, but when moisture on it does give a shiny appearance."

The FAA and the EASA consider a damp runway as a wet runway.

Air OPS ANNEX 1 ***FAR AC 25-31***

"'Dry runway' means a runway whose surface is free of visible moisture and not contaminated within the area intended to be used."

6.2.2. Runway Condition Reporting

Procedures for Air Navigation Services (PANS) - Aerodromes (Doc 9981) - Part II, Chapter 1

The Runway condition is reported in SNOWTAMs. A SNOWTAM is a special NOTAM that provides a surface condition report, in a standard format. It notifies the presence or removal of runway contaminants (e.g. snow, ice, slush, frost, standing water) on the movement area.

The runway condition is reported for each runway third, and it contains (for each third) the following:

- The runway condition code (RWYCC) (refer to the section Landing)
- The percentage of the coverage by the contaminant
- The depth of loose contaminant
- The condition description
- The width of runway to which the runway condition code applies, if less than the published width.

Note: Airports in the United States report Field Conditions (FICONs), that contain the same information in a different format.

6.3. Contaminants Classification and Properties

AMC 25.1591 §5.0

6.3.1. Range of Contaminants

AMC 25.1591 §5.1

"Contaminants can be classified as being:

> *(i) Drag producing, for example by contaminant displacement or impingement,*
> *(ii) Braking friction reducing, or*
> *(iii) A combination of (i) and (ii)."*

AMC 25.1591 §5.1 Table 1

Contaminant Type	Range of Depths to be Considered — mm	Specific Gravity Assumed for Calculation	Is Drag Increased?	Is Braking Friction Reduced below Dry Runway Value?
Standing water, Flooded runway	More than 3 up to 15 (see Note 1)	1.0	Yes	Yes
Slush	More than 3 up to 15 (see Note 1)	0.85	Yes	Yes
Wet snow (see Note 2)	More than 3 up to 5 (see Note 1)		No	Yes
Wet snow (see Note 3)	More than 5 up to 30	0.5	Yes	Yes
Dry snow (see Note 2)	More than 3 up to 10 (see Note 1)		No	Yes
Dry Snow	More than 10 up to 130	0.2	Yes	Yes
Compacted snow at or below outside air temperature (OAT) of -15 °C/5 °F	0 (see Note 4)		No	Yes
Compacted snow above OAT of -15 °C/5 °F	0 (see Note 4)		No	Yes
Dry snow over compacted snow	More than 10 up to 130	0.2	Yes	Yes
Wet snow over compacted snow (see Note 3)	More than 5 up to 30	0.5	Yes	Yes
Ice (cold & dry)	0 (see Note 4)		No	Yes
Slippery wet	0 (see Note 4)		No	Yes
Specially prepared winter runway (see Note 5)	0 (see Note 4)		No	Yes

Table 1: Type of contaminants and their depth

"Note 1: Runways with water depths or slush depths or snow depths of 3 mm or less are considered wet."

"Note 2: Contaminant drag may be ignored."
In this case, Airbus does not take the drag into account.

"Note 3: For conservatism, the same landing gear displacement and impingement drag methodology is used for wet snow as for slush."

"Note 4: Where depths are given as zero, it is assumed that the aeroplane is rolling on the surface of the contaminant."

"Note 5: No default model is provided for specially prepared winter runways [...]. Such runway surfaces are specific, and their treatment may be of variable effectiveness. The competent authority of the State of operator should approve the related procedures and methods."

Airbus divides contaminants into loose and hard contaminants:

- Loose Contaminants:
  Contaminants, like standing water, slush and loose snow are considered loose contaminants, because they affect the acceleration and also the deceleration capability of the aircraft. This happens because they reduce the friction force, generate precipitation drag and cause the aircraft to aquaplane.

- Hard Contaminants:
  Contaminants like compacted snow and ice are termed as hard contaminants, because they only affect the deceleration capability of the aircraft. This occurs because they reduce the friction force.

6.3.2. Other Contaminants

The runway may be covered with sand, rubber deposits, volcanic ash etc. There is no regulatory definition of the contaminant type for these contaminants. Therefore, Airbus does not provide performance data for them.

6.4. Effect on Performance

CS 25.1591

"(a) Supplementary take-off performance information applicable to aeroplanes operated on slippery wet runways and on runways contaminated with standing water, slush, snow, or ice may be furnished at the discretion of the applicant."

Airbus certified contaminated performance for all aircraft models, except for the A300 and the A310.

The terms, defined in the chapter Takeoff Distances, for wet runways are applicable to contaminated runways. But the contaminants have an impact on the takeoff distances, due to their effect on:

- Drag
- Friction coefficient
- Aquaplaning.

Note: Wet runways, by definition, do not consider the drag effect.

AMC 25.1591 §6.2

6.4.1. Aquaplaning and Contaminant Drag - Standing Water, Slush, Wet Snow

AMC 25.1591 §7.1

"Total drag due to fluid contaminant	=	*Drag due to fluid displacement by tyres*	+	*Drag due to airframe impingement of fluid spray from tyres"*

The effect of these two drag components is twofold:

- The deceleration capability of the aircraft is better, that is advantageous for the accelerate stop performance.
- The acceleration capability of the aircraft is worse, that is not advantageous for the accelerate go performance.

The Airbus performance software takes this effect into account. However only specific contaminant depths are published. When the real contaminant depth is between two published values, it is not possible to know (without computation) what published contaminant depth will be the most penalizing. Therefore, the performance must be determined with both contaminant depths.

6.4.2. Aquaplaning Speed

At higher speeds, the build-up of contaminant can result in the absence of contact between the tire and the ground.

AMC 25.1591 §7.1.1

"An aeroplane will aquaplane at high speed on a surface that is contaminated by standing water, slush or wet snow."

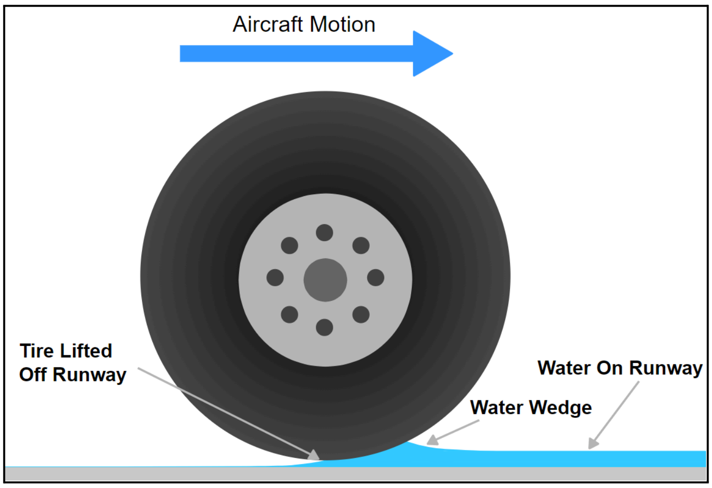


Illustration C-51: Aquaplaning Phenomenon

6.4.3. Displacement Drag

AMC 25.1591 §7.1.2

"[The Displacement Drag is] due to the wheel(s) running through the contaminant and doing work by displacing the contaminant sideways and forwards."

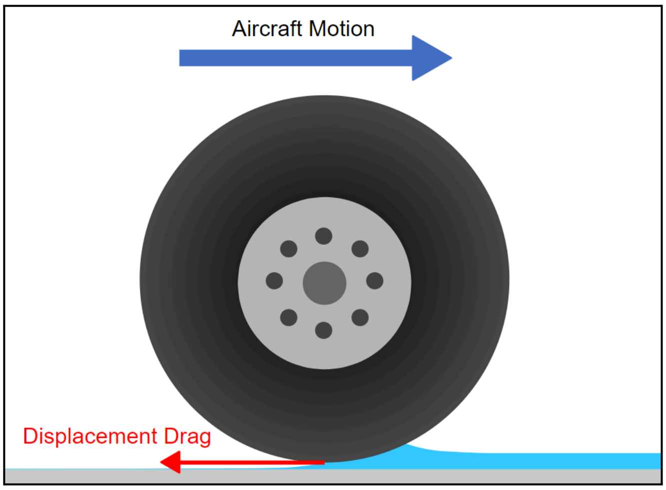


Illustration C-52: Displacement Drag

6.4.4. Spray Impingement Drag

AMC 25.1591 §7.1.3

"[The Spray Impingement Drag is] due to the projection of contaminant on the aircraft structure."

Flight test data indicates that the effect of precipitation drag is significant, and that it affects the performance of the aircraft.

Illustration C-53: Spray Impingement Drag

6.4.5. Contaminant Drag - Dry Snow

AMC 25.1591 §7.2

The model for the displacement drag with dry snow is different, as defined in the AMC 25.1591 chapter 7.2. The impingement drag can be neglected for dry snow.

6.4.6. Braking Friction (Wet and Contaminated Runways)

6.4.6.1. Definitions

AMC 25.1591 §7.3

- Braking Friction Force

The deceleration of the aircraft is assisted by a friction force between the tire and the runway, when the brakes are applied. This friction force acts in the area of contact between the tire and the runway, and it depends on the wheel speed and on the load applied on the wheel.

- Wheel Load

A load must be applied on the wheel, to increase the contact surface between the tire and the runway, in order to create a braking friction force. The greater the load on the wheel, the higher the friction force and the better the braking performance.

- Braking Friction Coefficient (μ_β)

The friction coefficient, μ_β, is defined as the ratio of the maximum tire friction force that is available and the vertical load that acts on the tire.

$$\mu_\beta = \frac{Friction\ Force}{Vertical\ Load}$$

μ_β changes with the aircraft speed, and flight tests help to establish a direct relation between μ_β and ground speed.

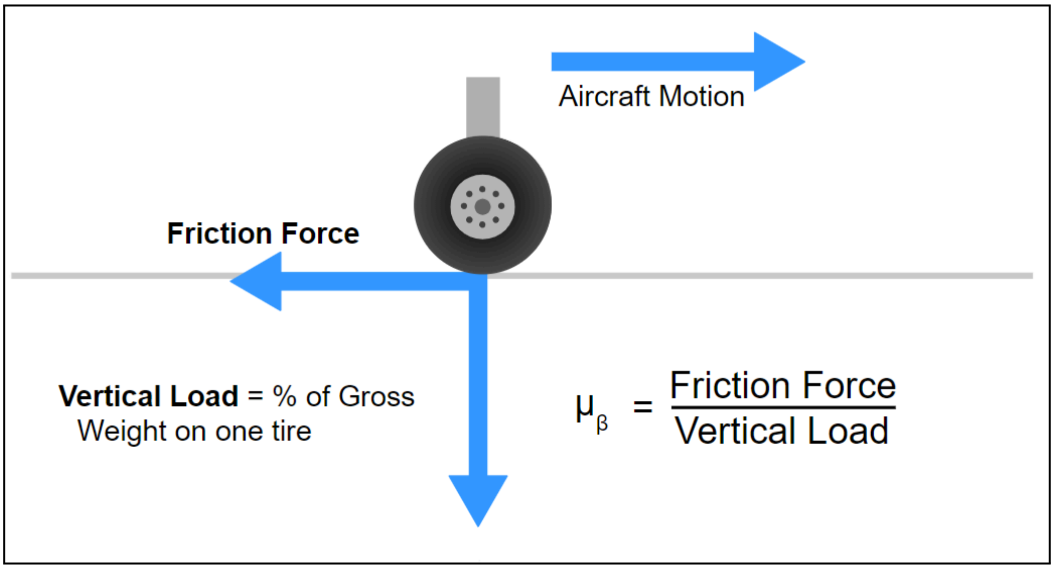


Illustration C-54: Effect of Load Distribution on Braking Performance

- Wheel Slip

Wheel speed is defined as the speed of the tire at the contact area between the tire and the runway.

The wheel speed range is from lockup speed (zero) to free rolling speed (equal to the aircraft speed).

Any intermediate speed causes the tire to slip over the runway surface, with a speed equal to: Aircraft speed minus speed of tire at the contact point. The slipping is often in percentage of aircraft speed.

$$Slip = \left(\frac{Aircraft\ speed - speed\ of\ tire\ at\ contact\ point}{Aircraft\ speed}\right)$$

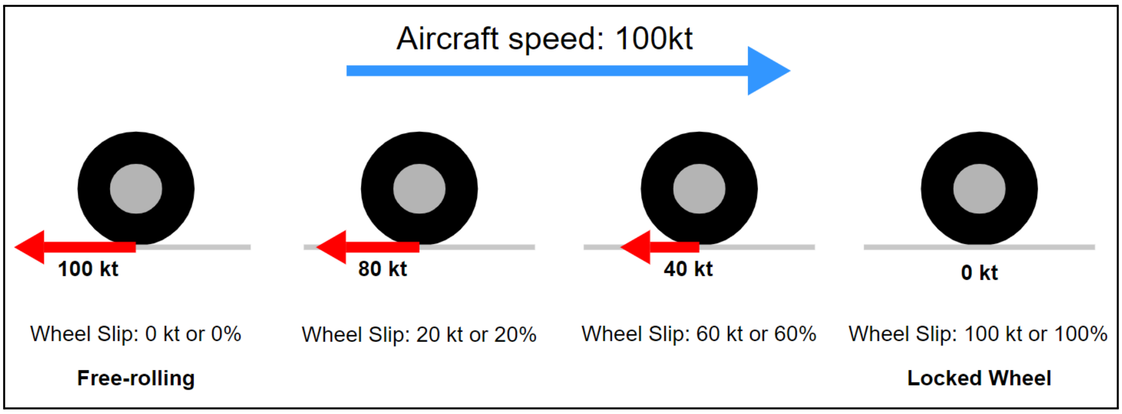


Illustration C-55: Wheel Slip

- Antiskid Efficiency

The braking friction force depends on the slip percentage, and the antiskid is designed to achieve the optimum slip ratio.

The antiskid system compares the speed of each wheel of the main landing gear at the contact point (measured by a tachometer) with the reference speed of the aircraft. When the wheel speed drops below a threshold value, the antiskid system commands the release of the brake pressure, in order to maintain the slip at optimum value, and to prevent skidding or locking up of the wheels.

The maximum antiskid efficiency (η) is demonstrated by flight tests.

6.4.6.2. Default Values

AMC 25.1591 §7.3.1

“To enable aeroplane performance to be calculated conservatively in the absence of any direct test evidence, default wheel-braking coefficient values as defined in Table 2 may be used. These values represent the maximum effective wheelbraking coefficient of a fully modulating anti-skid controlled braked wheel/tyre.”

Contaminant	Default Wheel-Braking Coefficient μ
Standing water and slush	$= -0.0632\left(\frac{V}{100}\right)^3 + 0.2683\left(\frac{V}{100}\right)^2 - 0.4321\left(\frac{V}{100}\right) + 0.3485$ where V is ground speed in knots Note: For V greater than 85 % of the aquaplaning speed (V_P), use the μ = 0.05 constant. At the discretion of the applicant, the wheel-braking coefficient as defined for runway condition codes (RWYCC) 2 in AMC 25.1592 may be applied.
Wet snow above 3 mm depth	0.16
Dry snow above 3 mm depth	0.16
Wet snow over compacted snow	0.16
Dry snow over compacted snow	0.16
Compacted snow below outside air temperature (OAT) of -15 °C	0.20
Compacted snow above OAT of -15 °C	0.16
Ice	0.07
Slippery wet	0.16

Table 2: Default Wheel-Braking Coefficient

Note: Aircraft certified before the Amdt27 to CS 25 are based on a 0.2 braking coefficient for Compacted Snow above OAT of -15 °C.

CS 25.109 Subpart B

FAR 25.109 Subpart B

"(c) The wet runway braking coefficient of friction for a smooth wet runway is defined as a curve of friction coefficient versus ground speed and must be computed as follows: "

Tyre Pressure (psi)	Maximum Braking Coefficient (tyre-to-ground)
50	$\mu_{t/gMAX} = -0{\cdot}0350\left(\frac{V}{100}\right)^3 + 0{\cdot}306\left(\frac{V}{100}\right)^2 - 0{\cdot}851\left(\frac{V}{100}\right) + 0{\cdot}883$
100	$\mu_{t/gMAX} = -0{\cdot}0437\left(\frac{V}{100}\right)^3 + 0{\cdot}320\left(\frac{V}{100}\right)^2 - 0{\cdot}805\left(\frac{V}{100}\right) + 0{\cdot}804$
200	$\mu_{t/gMAX} = -0{\cdot}0331\left(\frac{V}{100}\right)^3 + 0{\cdot}252\left(\frac{V}{100}\right)^2 - 0{\cdot}658\left(\frac{V}{100}\right) + 0{\cdot}692$
300	$\mu_{t/gMAX} = -0{\cdot}0401\left(\frac{V}{100}\right)^3 + 0{\cdot}263\left(\frac{V}{100}\right)^2 - 0{\cdot}611\left(\frac{V}{100}\right) + 0{\cdot}614$

where:

Tyre Pressure = maximum aeroplane operating tyre pressure (psi)

$\mu_{t/gMAX}$ = maximum tyre-to-ground braking coefficient

V = aeroplane true ground speed (knots); and

Linear interpolation may be used for tyre pressures other than those listed.

Note: For Airbus aircraft[11] certified before the AMC 25.1591 (§7.3.1), the performance on wet and contaminated runways was based on the same accelerate stop time sequence used for dry runways (refer to the chapter Accelerate Stop Distance (ASD)):

- Wet runway: $\mu_{wet} = \mu_{dry}/2$ (limited to 0.4)
- Contaminated runway: $\mu_{conta} = \mu_{dry}/4$
- Runway covered in compacted snow: $\mu_{snow} = 0.2$
- Icy runway: $\mu_{icy} = 0.05$
- The aquaplaning phenomenon is considered.

6.4.7. Operation on Grooved or PFC Runways

Specific runway surface preparation may enhance the braking friction coefficient for wet runways. This can be achieved by runway grooving or by the use of porous surfaces.
To take advantage of this enhancement:
- The airport must declare the characteristic of the runway, and perform the necessary maintenance to achieve the expected friction coefficient.
- The AFM must provide the related performance information.
- The Operator should obtain the approval from the National Aviation Authorities.

6.4.8. Specially Prepared Winter Runway Surfaces

AMC 25.1591 §7.3.4

"At the discretion of the applicant, take-off performance data may be provided for specially prepared winter runway surfaces. This may include icy surfaces that have been treated with sand or gravel in such a way that a significant improvement of friction may be demonstrated. The applicant should apply a reasonable margin to the observed braking action in performance computations for such surfaces, and assume wheel-braking coefficients no greater than 0.20 for fully modulating anti-skid systems."

[11] Refer to Performance Program Manual (PPM) - Tyre/Runway Friction Coefficient for the performance model for all Airbus aircrafts.

7. Reduced Takeoff Thrust

7.1. Principle of Thrust Reduction

The actual takeoff weight of the aircraft is often below the maximum regulatory takeoff weight. Therefore, in certain cases, it is possible to comply with all the takeoff regulatory constraints at a thrust below the maximum takeoff thrust. It is advantageous to adjust the thrust to the real need, because it increases the life and the reliability of the engine, while it reduces maintenance and operating costs.

Reduced thrust takeoff operations are usually divided into two categories:

- Operations that use the reduced thrust concept, known as flexible takeoffs at Airbus
- Operations that use a specific derated thrust level, i.e. derated takeoffs.

7.2. Flexible Takeoff

7.2.1. Definition

CS 25 AMC 25.13 ***FAR AC 25-13***

"(4)(c) Reduced takeoff thrust, for an aeroplane, is a takeoff thrust less than the takeoff (or derated takeoff) thrust. The aeroplane takeoff performance and thrust setting are established by approved simple methods, such as adjustments, or by corrections to the takeoff or derated takeoff thrust setting and performance. [In this case,] the thrust for takeoff is not considered as a takeoff operating limit."

As displayed in the Illustration C-56 below, the actual takeoff weight is below the maximum takeoff weight permitted by the regulations. Therefore, it is possible to determine the outside temperature at which the required thrust is the maximum takeoff thrust for this temperature. This temperature is referred to as "flexible temperature (T_{Flex})" or "assumed outside temperature".

In addition, per CS 25 AMC 25-13/AC 25-13:

"(5)(a) The reduced takeoff thrust setting

(2) Is based on an approved takeoff thrust rating or derated for which complete aeroplane performance data is provided.

(3) Enables compliance with the applicable engine operating and aeroplane controllability requirements in the event that takeoff thrust or derated takeoff thrust is applied at any point in the takeoff path

(4) Is at least 60% of the maximum takeoff thrust (no derate) for the existing ambient conditions."

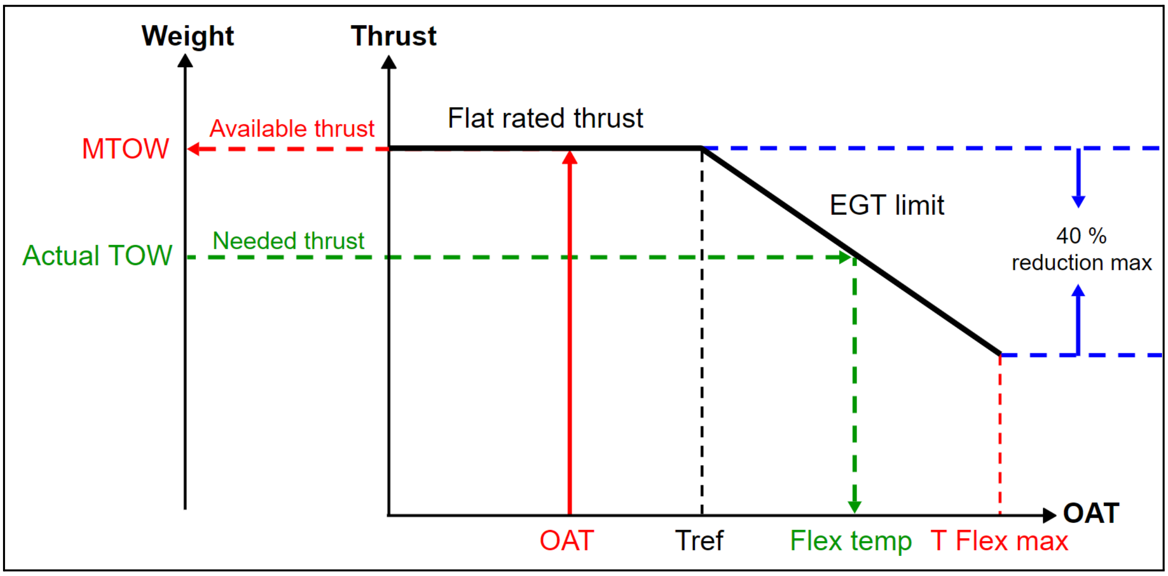


Illustration C-56: Flexible Temperature Principle

As a result, the flexible temperature is the input parameter through which the FADEC adapts the thrust to the actual takeoff weight. This method is derived from the approved rating for maximum takeoff thrust and, for this reason, the minimum control speeds (V_{MCG}, V_{MCA}) are the same as for TOGA thrust.

In addition, the thrust reduction cannot exceed 40 % of the maximum takeoff thrust.
Each aircraft is certified with a maximum thrust reduction. This maximum thrust reduction results in a maximum flexible temperature.

To comply with the above requirements, a flexible takeoff is only possible when the flexible temperature satisfies the three following conditions:

$$T_{Flex} > T_{REF}$$
$$T_{Flex} > OAT$$
$$T_{Flex} \leq T_{Flex\,Max}$$

Regulations require that the operators perform periodic takeoff demonstrations, with the maximum takeoff thrust setting, in order to check the takeoff parameters (i.e. N1, N2, EPR, EGT). The time interval between takeoff demonstrations may be extended, provided that the Operator uses an approved program to monitor the engine condition.

7.2.2. Flexible Takeoff and Runway State

CS 25 AMC 25.13 ***FAR AC 25-13***

“(5)(f) The AFM states that [reduced thrust takeoffs] are not authorised on runways contaminated with standing water, snow, slush, or ice, and are not authorised on wet runways, including slippery wet runways, unless suitable performance accountability is made for the increased stopping distance on the wet surface."

The Airbus operational tools and documentation (e.g. EFB, FCOM) provide performance information for flexible takeoffs on wet runways. As a result, a flexible takeoff is permitted on wet runways, while it is prohibited on contaminated runways.

7.2.3. Flexible Takeoff Procedure

Use of flex takeoff thrust is at the discretion of the pilot. To perform a flexible takeoff, a flexible temperature must be computed. Then, this temperature value must be entered in the dedicated cockpit interface (e.g. MCDU on the A320), during the takeoff preparation phase. At takeoff, the thrust levers must be set to the FLX detent, as per the Standard Operating Procedure (SOP). TOGA thrust remains available at any moment during the takeoff phase. However, in the event of an engine failure after V_1, TOGA selection is not required.

Illustration C-57: FMS Cockpit Interface Takeoff Performance

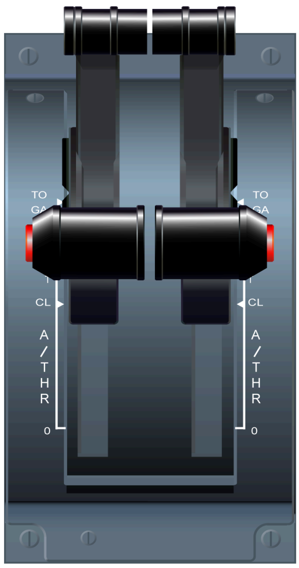


Illustration C-58: Thrust Throttles Positions

7.3. Derated takeoff

7.3.1. Definition

CS 25 AMC 25.13 **FAR AC 25-13**

"(4)(b) Derated takeoff thrust, for an aeroplane, is a takeoff thrust less than the maximum takeoff thrust, for which exists in the AFM a set of separate and independent, or clearly distinguishable, takeoff limitations and performance data that complies with all the takeoff requirements of CS-25.
[In this case,] the thrust for takeoff is considered as a normal takeoff operating limit."

For a derated takeoff, the limitations, the procedures and the performance data must be included in the AFM.

Note: The derated thrust is an option on some Airbus aircraft.

7.3.2. Minimum Control Speeds with Derated Thrust

A derate level corresponds to the basic maximum thrust minus a specific percentage. Therefore, the new maximum available thrust, at any point of the takeoff flight path, is reduced, when compared with the non-derated thrust. Then, new minimum control speeds (V_{MCG}, V_{MCA}) are established, as per CS/FAR 25.149.

Sometimes, a reduction in the minimum control speeds generates a takeoff performance advantage (i.e. higher MTOW), for takeoffs on a short or contaminated runway. The decision speed V_1 is the maximum speed at which it is still possible to reject the takeoff, and stop the aircraft within the runway distance available. However, V_1 must be above V_{MCG}, and the ASD is often the limiting criteria on a short runway. A reduction of the V_{MCG} can permit a reduction of the ASD for a determined takeoff weight, and result is better takeoff performance, when the MTOW without derate is limited by ASD (i.e. V_{MCG}).

7.3.3. Derated Takeoff and Runway State

A derated takeoff is considered a normal takeoff with the engines at their normal operating limits. New limitations, procedures, and performance data are provided in the AFM for each derate level and for each runway surface. Therefore, it is possible to determine the MTOW on a dry, wet, or contaminated runway, via the EFB.
So, a derated takeoff is permitted on both wet and contaminated runways.

7.3.4. Derated Takeoff Procedure

When derated takeoff is available, there are several certified levels, depending on the aircraft models. This means that the AFM must contain a set of performance data for TOGA, and a set for each derate level. The derate name is approximately the percentage of thrust reduction compared to TOGA (e.g. D04 is approximately TOGA-4%).

Then, the derate level computed by the EFB is entered in the FMS cockpit interface during the takeoff preparation phase. At the brake release point, the thrust levers must be set to FLX/MCT.

<u>Important</u>: In the case of engine failure during a derated takeoff, TOGA thrust must never be selected until the aircraft becomes airborne and the speed is above a minimum safe speed. The reason for this is to ensure a speed above VMCA for TOGA.

Illustration C-59: FMS Cockpit Interface Takeoff Performance

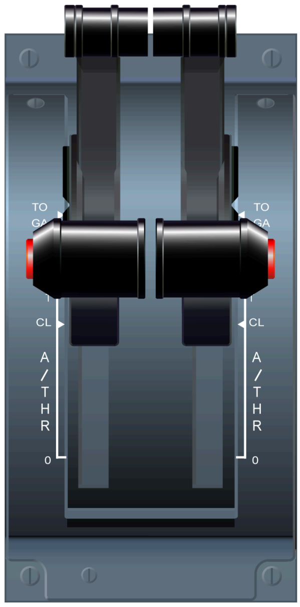


Illustration C-60: Thrust Throttles Positions

<u>Note</u>: On the A220, a flexible takeoff and a derated takeoff can be performed at the same time. This is not the case for other Airbus aircraft.

7.4. ATTCS/APR Systems

Some aircraft are equipped with the Automatic Take-off Thrust Control System (ATTCS) or the Automatic Power Reserve (APR) system. In case of OEI, these systems increase the thrust available on the remaining engine. These systems enable the engine to reach a lower thrust level for takeoff (i.e. a higher Flex temperature, or a derate level).

7.5. Conclusion

Both the flexible takeoff and the derated takeoff significantly reduce the engine stress, and this results in:

- A reduction of the probability of a failure (increased safety)
- A reduction of the engine degradation rate and its associated maintenance costs (reduced costs).

The main differences between a flexible and a derated takeoff are the following:

Flexible Takeoff	Derated Takeoff
- Possibility to recover TOGA at any moment - Not allowed on contaminated runways - No performance enhancement	- TOGA selection not possible (except above "F" speed) - Permitted on contaminated runways - Increased takeoff weight on short and contaminated runways V_{MCG} limited

8. SPECIFIC GUIDANCE FOR ENGINE FAILURE PROCEDURE

8.1. PUBLISHED DEPARTURE PROCEDURE

The Aeronautical Information Publication (AIP) is the main source of airport data. It contains published departure procedures (e.g. SID, RNAV, etc.). For additional information, refer to Appendix 6.

The published departure provides the all engine operative procedures for each runway, usually based on recommendations and standards defined in the PANS-OPS Vol II (Doc 8168).
A departure procedure is a designed IFR route, connected to an aerodrome with a specified point, at which the en route phase of the flight starts. The published departure procedure:

- Is designed to ensure an acceptable clearance above obstacles during the departure phase
- Takes into account noise, ATC constraints and airspace restrictions.

In order to ensure an acceptable obstacle clearance, a gradient requirement at a specific distance or altitude is published for the departure procedure. If no gradient is published, a 3.3% minimum gradient is applicable. The published gradient is an average gradient requirement.

8.2. ENGINE FAILURE PROCEDURE

As previously referred in the Introduction of this chapter, the possibility of engine failure during takeoff must always be considered. The crew must be provided with a safe path to fly in the event of an engine failure.

Because the published departure procedure is designed for normal operations (i.e AEO), in terms of performance, it is not acceptable to check if the gradient on the published departure procedure can be achieved with OEI. This is too restricted for the computation of the maximum takeoff weight.

Note: It is not conservative to check if the second segment gradient is above the published gradient.

Air OPS Subpart C
CAT.POL.A.210

"(c) The operator shall establish contingency procedures to satisfy the requirements in (a) and (b) and to provide a safe route, avoiding obstacles, to enable the aeroplane to either comply with the en-route requirements of CAT.POL.A.215, or land at either the aerodrome of departure or at a take-off alternate aerodrome."

An Engine Failure Procedure (EFP) must be defined for each departure procedure to ensure the use of a specific OEI departure routing, in the event of an engine failure that deviates from the normal routing during takeoff. Therefore, obstacle clearance must be ensured on the EFP, in accordance with the regulatory requirements described in the chapters Departure Sector and One Engine Inoperative - Takeoff Flight Path.

Note: Engine Failure Procedure (EFP) is also known as:
- Engine Out Standard Instrument Departure (EOSID)
- Engine Out Procedure (EOP)

8.3. Obstacle Data

For normal AEO operations, the obstacle clearance is ensured by compliance with the minimum gradient requirement, published on the departure procedure. The obstacles considered to define the gradient requirement are based on ICAO PANS-OPS procedure design recommendations. Therefore, the limiting obstacles may be outside the takeoff funnel described in the chapter Departure Sector.
The obstacles that were considered for the published departure procedure are not published.
The Aeronautical Information Publication (AIP) may contain a set of data for obstacles and terrain. However, this obstacle database is not associated with a specific EFP.

8.4. Strategy to Design an EFP

One of the strategies that may be considered for an EFP is a straight takeoff, along the extended runway centreline. The Operator must comply with the regulatory obstacle clearance that is previously described.
As referred in the chapter Management of the Extended Final Segment, the takeoff flight path ends either:
- At the Minimum Crossing Altitude (MCA) or the Minimum Enroute Altitude (MEA) for a route to the intended destination, or
- At a point where enroute obstacle clearance requirements can be satisfied, or
- At a point from which an approach may be initiated to the departure airport or to the departure alternate.

The list of obstacles provided in the AIP may not be sufficient, because the obstacles are identified based on a limited distance from the departure end of the runway. Therefore, the Operator must ensure that the obstacles used for the performance computation are considered until the end of the takeoff flight path.

At some airports, particularly those close to mountain areas, a straight takeoff in the case of an engine failure can result in performance penalties, due to the obstacle limitation.
In that case, it is possible to select one published departure procedure, as the EFP, in order to avoid obstacles. If the takeoff performance is still too limiting, a specific path can be defined, avoiding the most limiting obstacles

It is possible that several obstacles cannot be avoided with the minimum lateral distance defined by the regulations, as described in the chapter Departure Sector. The Operator must consider obstacles that are in the corridor of the trajectory that the aircraft flies. The vertical clearance with the obstacle, that is described in the chapter One Engine Inoperative - Takeoff Flight Path, must be checked. If the MTOW is calculated with a straight trajectory, the obstacle height needs to be adjusted, to consider the loss of height during the turn.

8.5. Loss of Climb Gradient During a Turn

During a turn, the forces acting on the aircraft include not only the weight of the aircraft acting downwards but also a horizontal acceleration force (F_a). The resultant force is the “apparent weight” (W_a), with a magnitude equal to the load factor (n_z) times the weight of the aircraft.

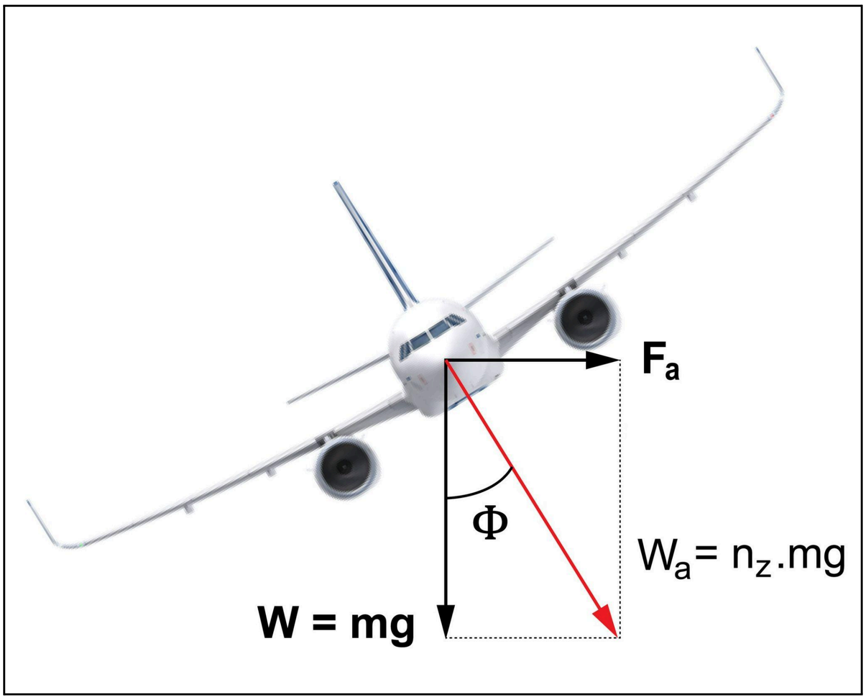


Illustration C-61: Load Factor in a Turn

Based on Illustration C-61, the load factor (n_z) and the bank angle (Φ) are related as follows:

$$n_Z = \frac{1}{\cos\Phi}$$

When the aircraft enters into a banked turn, the load factor goes above n_z=1. The increased load factor results in a loss of climb gradient. The climb angle can be defined as follows (refer to the chapter Climb):

$$\gamma = \frac{Thrust}{n_Z \bullet Weight} - \frac{1}{\frac{L}{D}}$$

As observed in the above equation, the increase in load factor increases the apparent weight, that must be supported by an increase in lift. The increase in lift results in an increase in the drag and therefore a reduction in the climb gradient.

Air OPS Subpart C
AMC2 CAT.POL.A.210

"(a) The Aeroplane Flight Manual generally provides a climb gradient decrement for a 15° bank turn. For bank angles of less than 15°, a proportionate amount should be applied, unless the manufacturer or AFM has provided other data."

For some Airbus aircraft, there is no correction published in the AFM. The climb gradient reduction can be computed via two different methods:

1. The use of the certified Flight Manual module in the Performance Engineer's Programs (PEP) software that contains the computation of the net flight path, with or without turns, or
2. The use of a conservative loss of gradient vs. the bank angle chart that is provided in the Airbus Performance Program Manual (PPM) of PEP. See example in Illustration C-62.

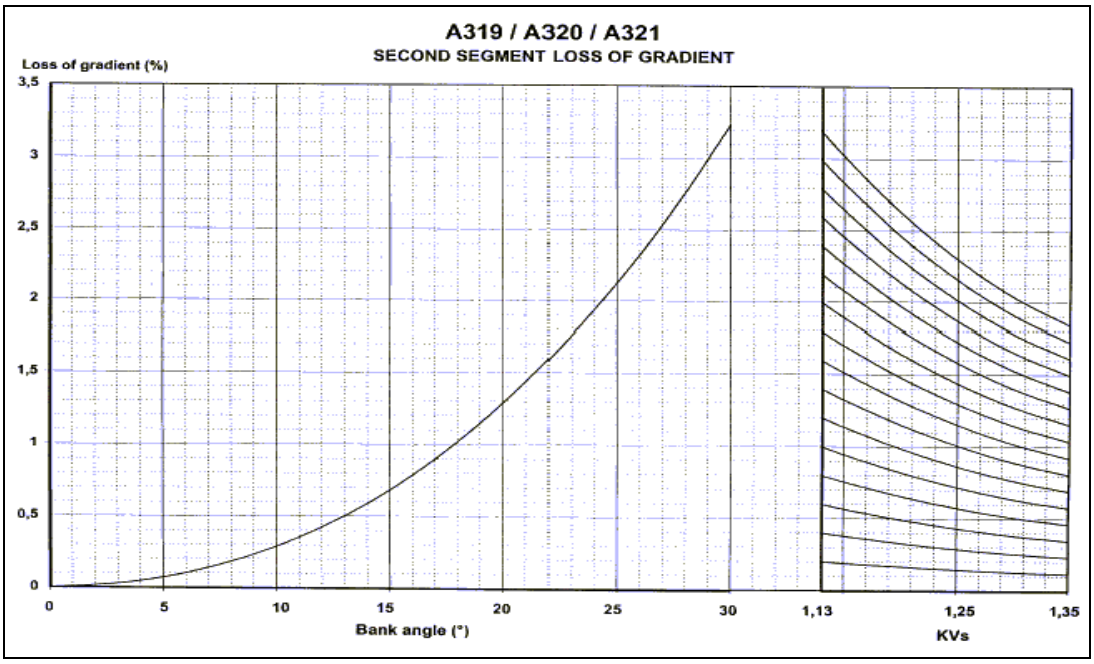


Illustration C-62: Loss of Gradient VS. Bank Angle (A320 Family Example)

8.6. Turn Bank Angle

As referred to in the chapter Turn Limitations and with reference to the CAT.POL.A210, if a turn with a bank angle above 15 ° is required, the net takeoff flight path must clear all obstacles located inside the departure sector by 50 ft. In addition, the maximum bank angle is limited, depending on the height of the aircraft above the ground. A specific approval must be obtained from local authorities to increase the maximum bank angle above the standard maximum values permitted by the regulation.

In addition, on Airbus Fly-By-Wire aircraft, the autopilot limits the bank angle at takeoff with one engine inoperative, depending on the margin vs. the maneuverability speeds.

The margin vs. the maneuverability speeds may change depending on the environmental conditions. Therefore, it is a correct assumption to consider the most limited value for the maximum bank angle in autopilot: 15 °.

An EFP may require that a turn is performed with a bank angle above 15 °. When a turn with a bank angle above 15 ° must be performed, the procedure may be designed to fly the turn manually. If the autopilot must be used in combination with a bank angle above 15 °, the Operator must evaluate the autopilot capability to fly the designed EFP. To achieve this, the Operator must ensure enough margin vs. maneuvering speeds.

8.7. Decision Point and Deviation Point

Air OPS Subpart C
GM1 CAT.POL.A.210

"Take-off obstacle clearance:
If compliance with CAT.POL.A.210 is based on an engine failure route that differs from the all engine departure route or SID normal departure, a 'deviation point' can be identified where the engine failure route deviates from the normal departure route. Adequate obstacle clearance along the normal departure route with failure of the critical engine at the deviation point will normally be available. However, in certain situations the obstacle clearance along the normal departure route may be marginal and should be checked to ensure that, in case of an engine failure after the deviation point, a flight can safely proceed along the normal departure route."

If the critical engine fails at V_1, the aircraft will follow the EFP flight path where the obstacle clearance must be ensured as described in the chapters One Engine Inoperative - Takeoff Flight Path and Departure Sector. Then, the obstacle clearance along the EFP is ensured, if the engine failure happens between V_{EF} and the deviation point.

The deviation point is the most distant and common point between the published departure procedure and the EFP. If the engine failure happens after the deviation point, the aircraft flies on the trajectory of the published departure procedure.

The decision point is the point at which the flight crew can decide to follow the published departure procedure or the EFP. The decision cannot occur after the deviation point. Therefore, the obstacle clearance along the published departure procedure must be checked with the assumption of an engine failure at the decision point.

The decision point is defined by the Operator. Preferably, it must be far enough to ensure that obstacles are cleared with an engine failure on the trajectory for the published departure procedure. But it also must enable the flight crew to detect the engine failure and activate the EFP procedure, in the case of an engine failure at the decision point.

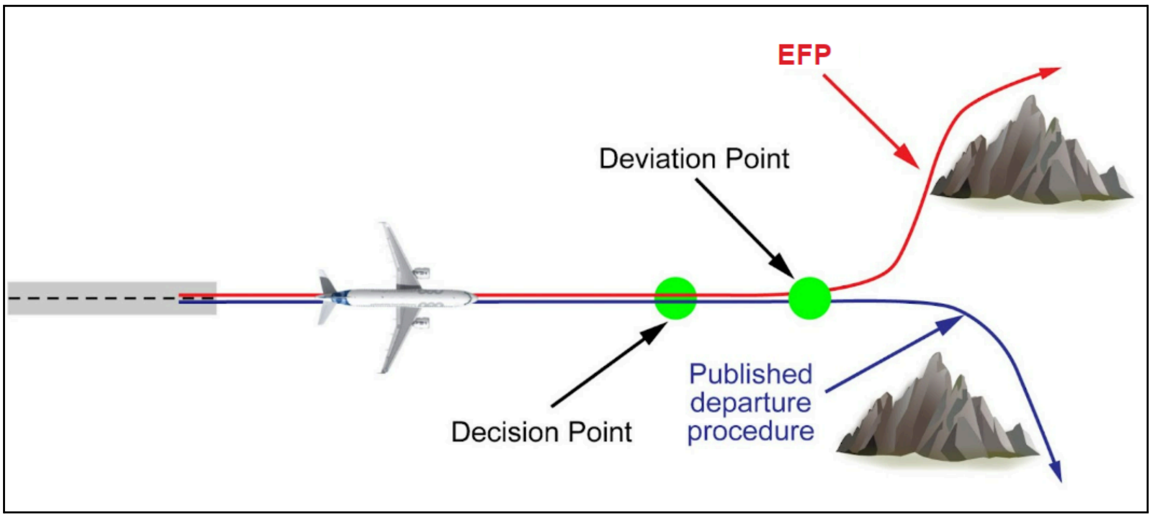


Illustration C-63: Decision Point and Deviation Point

On Illustration C-63, the MTOW is computed with the following assumptions:
- An engine failure at V_{EF}
- The obstacle clearance along the EFP trajectory satisfies the regulatory requirements.

Then, with the assumption of an engine failure at decision point, the obstacle clearance along the published departure procedure must be checked.

9. RETURN TO LAND

In emergency situations, the flight crew may need to land shortly after takeoff, at a weight above the Maximum Landing Weight (MLW).

The reasons for a return to land may include medical emergencies, onboard fire, or aircraft failures.
Only a reduced number of cases require an immediate return to land, and most of the scenarios enable the flight crew to compute the landing performance and evaluate the need to make a diversion.

In the case of immediate return to land, the flight crew does not have time to check the performance of the aircraft. To handle these situations, the certification standard expects the aircraft to be able to land or to go-around with OEI on the departure runway, in an overweight landing situation.

In this case, in addition to the overweight landing procedure and the associated performance impact, specific go-around and landing performance must be considered.

For the go-around, the minimum certified air climb gradients must be checked.
For certain aircraft types, the go-around can be performed in CONF 1+F, if the climb gradient cannot be achieved in CONF 2. The landing configuration is, then, CONF 3.
This is possible when V_{S1g} (CONF 1+F) < 110 % V_{S1g} (CONF 3).
In order to reduce the go-around constraints, a jettison system may be required.

CS 25.1001 Subpart E

FAR 25.1001 Subpart E

"(a) A fuel jettisoning system must be installed on each aeroplane unless it is shown that the aeroplane meets the climb requirements of [Landing Climb gradient] and [Approach Climb gradient] at maximum take-off weight, less the actual or computed weight of fuel necessary for a 15-minute flight comprised of a take-off, go-around, and landing at the airport of departure with the aeroplane configuration, speed, power, and thrust the same as that used in meeting the applicable take-off, approach, and landing climb performance requirements of this CS/FAR-25."

For the landing capability, the following performance limitations should be considered:

- Maximum brake energy
- Maximum tire speed
- Landing distances.

The certification assessment checks the capability of the Airbus aircraft for an immediate return to land, in the case of:

- An emergency with no reduction to the performance of the aircraft (e.g. medical emergency), or
- An engine failure.

In the case of a return to land, the landing distances are checked with the following assumptions:

- ALD or LDTA, depending on the certification standard - refer to the section Landing
- without operational margins
- on the same runway used for takeoff
- in dry and in wet conditions.

If the operational conditions have more constraints than the certification conditions (for example, published gradient), the Operator should determine, before takeoff, the capability of the aircraft to immediately return to land.
The Operator should limit the takeoff weight, or consider the use of a takeoff alternate airport, if this requirement is not achieved.

Air OPS CAT.OP.MPA.182

"(b) At the planning stage, to allow for a safe landing in case of an abnormal or emergency situation after take-off, the operator shall select and specify in the operational flight plan a take-off alternate aerodrome if either:

(1) the meteorological conditions at the aerodrome of departure are below the operator's established aerodrome landing minima for that operation; or

(2) it would be impossible to return to the aerodrome of departure for other reasons."

The takeoff alternate airport must be located within:

- One hour flying time, at OEI cruising speed, in still air, for non-ETOPS twin engine aircraft,
- Up to a maximum of two hour flying time, at OEI cruising speed, in still air, for ETOPS twin engine aircraft,
- Two hour flying time, at AEO cruising speed, in still air, for four engine aircraft.

D. IN FLIGHT PERFORMANCE

This section describes the in-flight performance optimization and limitations with all engines operating. Certification standards take into account failure cases in flight, and abnormal operations. These in-flight failures can be found in the In Flight Performance With Failure section of this document.

1. CLIMB

1.1. CLIMB MANAGEMENT

1.1.1. Thrust Setting

The standard climb rating is called "Maximum Climb Thrust". At the thrust reduction altitude (THR RED), pilots must reduce thrust from takeoff power to climb power by setting the thrust levers to the climb (CL) gate (Illustration D-1). This must be completed before a maximum time of 5 minutes after brake release.

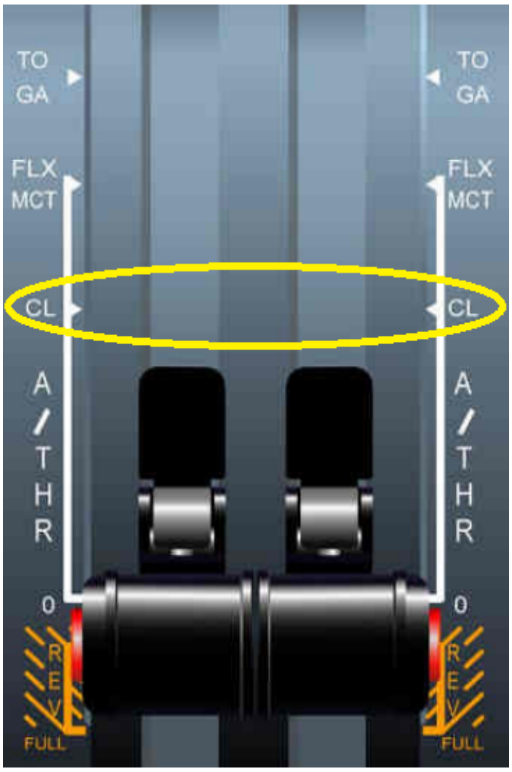


Illustration D-1: Climb Power

1.1.2. Derated Climb Thrusts

Derated or auto-derated climb thrust is available on some aircraft models, and have thrust ratings that are reduced for maximum climb thrust. These ratings can be used when there are no operational constraints to take into account, along the flight path.

When derated climb thrust is available, the flight crew must select the applicable derated climb level before takeoff via the FMS cockpit interface.

Derated climb thrust results in a slight increase in fuel and time, but reduced maintenance costs.

Some aircraft models have an auto-derated thrust function that automatically reduces the thrust during the climb phase. The reduced thrust level is computed by the FMGS to have a similar performance level as a reference case, and corresponds to the climb to REC MAX ALT at MTOW with Maximum Climb Thrust. The function reduces the thrust as much as possible to provide the same time to climb to the cruise altitude as the reference case. It also guarantees a minimum climb capability and a limited impact on the fuel consumption.

The derated and auto-derated climb offers the following economical advantages:
- Increased engine life
- Better engine reliability
- Direct reduction in maintenance costs.

1.1.3. Energy Sharing

Aircraft energy is provided by the engines. To fly, an aircraft needs:
- Kinetic energy: Energy necessary to accelerate.
- Potential energy: Energy necessary to climb.

The sum of the kinetic energy and the potential energy cannot exceed the total aircraft energy. As a result, when the aircraft needs to climb and accelerate, the total energy must be divided between the requirement for speed and the requirement for altitude.

The FMGS manages this energy sharing during the climb (60% for speed, 40% for altitude). As a result, at a defined thrust, when:
- TAS increases: The climb gradient and the rate of climb (RC) decrease, because potential energy is changed into kinetic energy.
- TAS decreases: The climb gradient and rate of climb increase, because kinetic energy is changed into potential energy.

1.1.4. Climb Ceiling

The climb can continue until the aircraft levels off (i.e. when the rate of climb is near zero). However, as it will use both time and fuel to reach the zero rate of climb condition, the FMGS displays a maximum recommended altitude. In general, this maximum recommended altitude corresponds to the climb ceiling, defined by a rate of climb of 300 ft/min.

1.2. Climb Speeds

1.2.1. Climb at Selected Speeds

For aircraft not equipped with FMS economical speed management, the climb is operated at a constant Indicated Air Speed (IAS) and Mach Number. For example, a climb profile for the A320 family is:

250 kt / 300 kt / M0.78

Therefore, the climb phase is divided into three phases (Illustration D-2):

- Below 10 000 ft: Climb at constant IAS = 250 kt. The speed is limited by Air Traffic Control (ATC) laws.
- Above 10 000 ft: Climb at constant IAS = 300 kt (limited to M0.78). At 10 000 ft, the aircraft accelerates to a more optimum climb speed (300 kt), that is maintained as long as the mach number remains under 0.78.
- Above the crossover altitude: Climb at constant Mach = M0.78. The crossover altitude is the altitude where 300 kt IAS is equal to M0.78. Above this altitude, a constant ratio between the TAS and the sound velocity must be maintained to avoid high speed buffeting.

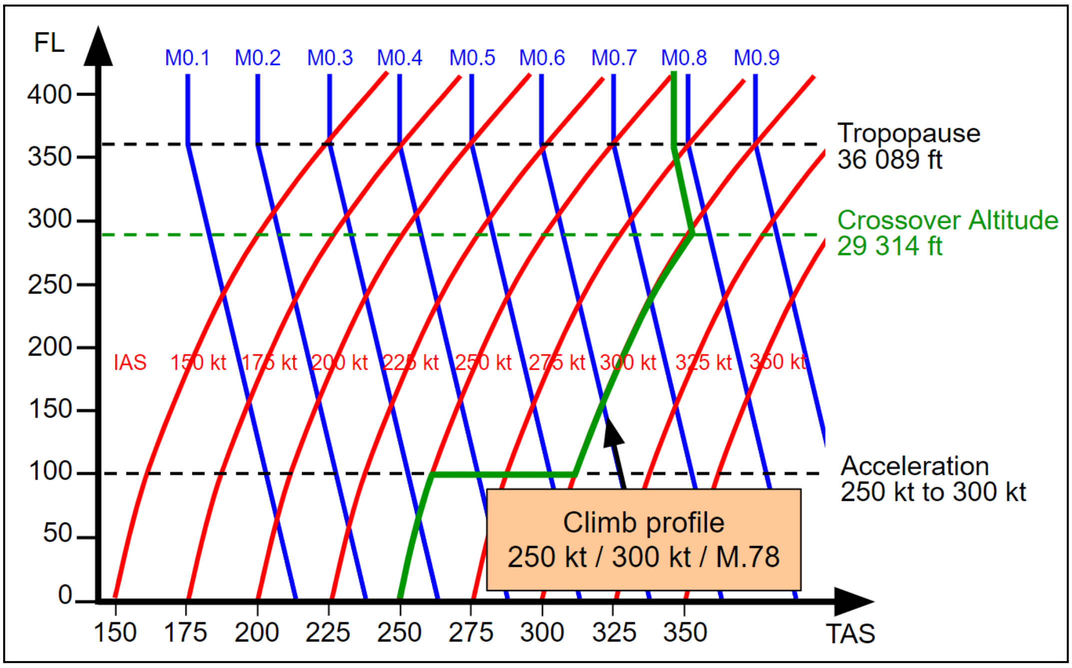


Illustration D-2: Climb Profile at IAS/MACH Law

1.2.2. Climb at Maximum Gradient

The maximum climb gradient is achieved at Green Dot speed. Climb at Green Dot speed enables a target altitude to be achieved over the shortest distance.

Green Dot speed is computed by the Flight Management System based on aircraft weight and altitude, and is indicated by a green circle on the Primary Flight Display (PFD) as soon as the aircraft is in clean configuration. Consequently, the flight crew can easily fly Green Dot speed in manual mode. Green Dot is the target speed, in case of an engine failure after takeoff.

1.2.3. Climb at Minimum Cost

The cost index aims to minimize direct operating costs (refer to the chapter Cruise at Minimum Cost for cost index description). As a result, for a selected cost index, an optimum climb speed (IAS_{ECON}) and an optimum climb mach number ($Mach_{ECON}$) are calculated by the FMGS to optimize the climb profile. The climb is then performed in managed mode, based on the following IAS/Mach law:

$$\mathbf{250\ kt\ /\ IAS_{ECON}\ /\ Mach_{ECON}}$$

To minimize the global fuel consumption during flight, a low cost index must be used. It is advantageous to minimize climb duration to minimize the fuel consumption. This is achieved at the maximum rate of climb speed.

$$\mathbf{CI = 0 \ \Rightarrow IAS_{ECON} = \text{Maximum rate of climb speed}}$$

Contrary to this, a higher cost index provides a higher climb speed, therefore the rate of climb lowers. But the distance covered during the climb is longer, therefore the cruise phase and total flight time are reduced. In general, the maximum climb speed is limited to VMO - 10 kt.

$$\mathbf{CI = CI_{max} \Rightarrow IAS_{ECON} = VMO - 10\ kt}$$

Flight at a selected cost index provides the advantage that the overall costs for the entire flight are optimized while the crew workload is kept low. Flight at a given cost index in climb is one of the recommendations of the Green Operating Procedures available in the FCTM. In addition, the use of the same cost index for the entire flight is recommended in the FCTM Standard Operating Procedures for Cruise.

When applying a different strategy, the Operator needs to consider the overall costs and crew workload. Optimizing just one flight phase may not be globally efficient.

1.2.4. Climb at Maximum rate

Climb at the maximum rate of climb speed enables a target altitude to be reached in the shortest time.
The maximum rate of climb speed is not indicated on the PFD. However, a climb at maximum rate can be performed in managed mode (refer to the chapter Climb at minimum cost).

1.3. Cabin Climb

Since the cabin is pressurized, a cabin pressurization system adjusts cabin altitude to maintain a good level of passenger comfort during the flight.
During normal operations, the cabin altitude is limited to a maximum value that depends on the aircraft type. The purpose of the maximum cabin altitude is to limit differential pressure, DP, between the cabin pressure and the outside atmospheric pressure to a maximum value. For example, Max cabin altitude on A350 is 6 000 ft and DP_{max} = 620 hPa (9.4 PSI).

Cabin altitude changes based on a predefined law, in order to reach the scheduled cabin altitude at the top of climb that is defined by the FMGS cruise FL. For fly-by-wire aircraft, the cabin rate of climb is limited to 1 000 ft per minute.

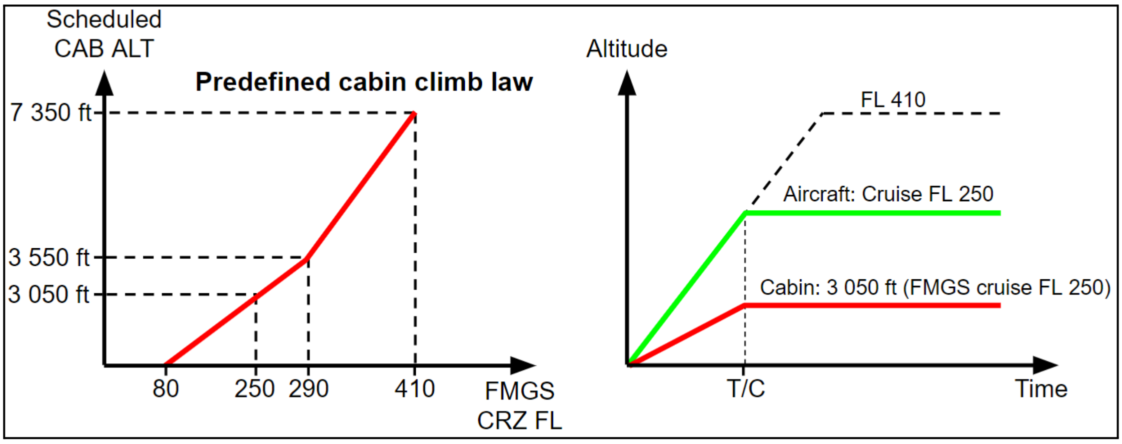


Illustration D-3: A340-200/300 Cabin Climb Law Example

In the above illustration (D-3): for example, when the FMGS cruise level is FL250, the cabin altitude remains at 3 050 ft during the cruise phase at this altitude.

1.4. Factors of Influence

1.4.1. Altitude Effect

Due to air density reduction when pressure altitude increases, climb thrust and drag decrease. However, since the drag force decreases at a lower rate than the available thrust, the difference between thrust and drag decreases. Therefore, the climb gradient and the rate of climb decrease with pressure altitude, due to a lower excess thrust.

ZP ↗ ⇒	Climb gradient ↘ Rate of climb ↘

1.4.2. Temperature Effect

When the temperature increases, thrust decreases due to a lower air density. As a result, the effect is the same as for the altitude.

Temperature ↗ ⇒ Climb gradient ↘
Rate of climb ↘

1.4.3. Weight Effect

As detailed in Appendix 5, the climb gradient (γ_{rad}) and rate of climb are defined as follows:

$$\gamma_{rad} = \frac{\text{Thrust - Drag}}{\text{Weight}}$$

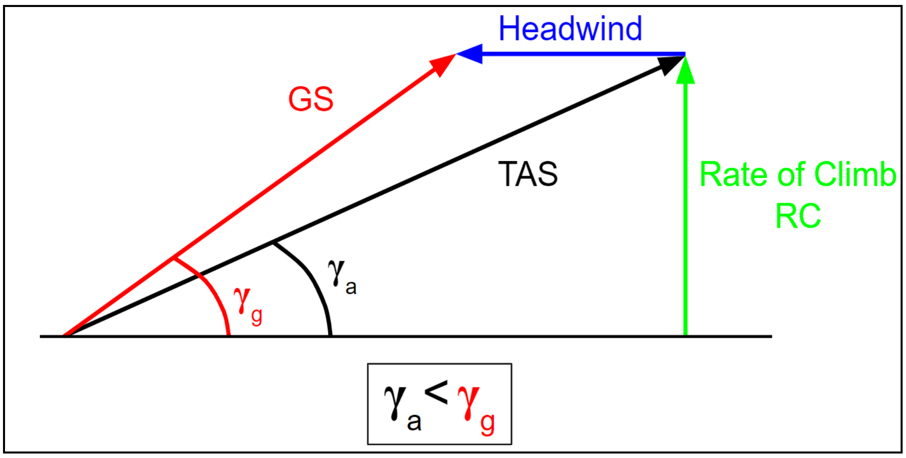
$$\mathbf{RC} = \mathbf{TAS} \cdot \frac{\text{Thrust - Drag}}{\text{Weight}}$$

Therefore, at a defined engine thrust, altitude, and climb speed (TAS), any increase in weight results in a decrease in the climb gradient and rate of climb.

Weight ↗ ⇒ Climb gradient ↘
Rate of climb ↘

1.4.4. Wind Effect

A constant wind component has no influence on the rate of climb, but changes the flight path.



GS = Ground Speed

TAS = True Air Speed

γ_g = Ground climb gradient

γ_a = Air climb gradient

Illustration D-4: Headwind Component in Climb

As indicated in Illustration D-4, the air climb gradient remains the same, regardless of the wind component. Therefore, the fuel and time to the Top Of Climb (T/C) does not change.

Headwind[1] ↗	⇒	Rate of climb → Fuel and time to T/C → Flight path angle (γ_g) ↗ Ground distance to T/C ↘
Tailwind ↗	⇒	Rate of climb → Fuel and time to T/C → Flight path angle (γ_g) ↘ Ground distance to T/C ↗

2. Cruise

In cruise, the objective is to optimize speed and altitude to save on fuel, time or total cost.

2.1. Fuel Consumption Definition

2.1.1. Fuel Flow (FF)

The fuel flow (FF) corresponds to the fuel consumption of the aircraft per unit of time. In general, Fuel Flow units are:

- kg / h, or
- lb / h

2.1.2. Specific Consumption (SFC)

The Specific Consumption (SFC) introduces the concept of engine efficiency to the Fuel Flow. The Specific Consumption is equal to:

$$SFC = \frac{FF}{Ta}$$

With Ta = Thrust available

SFC units are:

- kg / h.N, or
- lb / h.lbf

2.1.3. Distance Consumption (Cd)

The distance consumption (Cd) is the fuel consumption per unit of distance. It is equal to:

$$Cd = \frac{FF}{GS}$$

With GS = Ground Speed. GS is equal to True Air Speed (TAS) if the wind velocity is 0.

The distance consumption units are:
- kg / nm, or
- lb / nm

2.1.4. Specific range (SR)

The specific range (SR) is the distance covered per unit of fuel.
The specific range is equal to:

$$SR = \frac{1}{Distance\ Consumption\ (Cd)}$$

The SR units are NM/kg or NM/ton.

The specific range (SR) indicates how far the aircraft can fly. The Fuel Flow (FF) indicates how long the aircraft can remain airborne.

In addition, SR depends on aerodynamic characteristics (Mach and L/D), engine performance (Specific Fuel Consumption)[12], aircraft weight (mg) and sound velocity at sea level (a_0).

$$SR_{(Air)} = \frac{true\ air\ speed\ (TAS)}{Fuel\ Consumption\ per\ hour\ (FF)}$$

With the formulas established above:

And:

$$TAS = a.M = a_0.M.\sqrt{\frac{T}{T_0}}$$

$$FF = SFC.T_a = SFC.\frac{mg}{\frac{L}{D}}$$

Therefore,

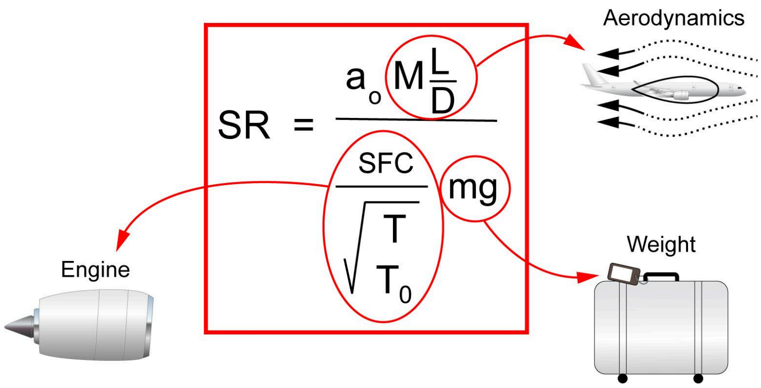
$$SR = \frac{a_0 . M . \frac{L}{D}}{\frac{SFC}{\sqrt{\frac{T}{T_0}}} . mg}$$

[12]The Specific Fuel Consumption (SFC) is equal to the fuel flow (FF) divided by the available thrust. It is expressed in kg/h.N (kilogram per hour per Newton) and represents the fuel consumption per thrust unit.

Where:

- a_0: The sound velocity at Mean Sea Level
- M: Mach Number
- L/D: Lift over drag ratio
- SFC: Specific consumption
- m: Weight
- g: Gravitational acceleration
- T: Temperature
- T0: Temperature at Mean Sea Level

Based on this equation, the SR depends on three domains: aerodynamics, engine and weight.



M . L/D ↗	⇨	SR ↗
m ↗	⇨	SR ↘
SFC ↗	⇨	SR ↘

Specific range will increase with aerodynamic efficiency. Higher specific consumption and weights degrade the specific range.

In All Engines Operating conditions, the aircraft should remain in Clean configuration, and the speed should remain between the Green Dot speed and VMO/MMO.

2.2. Cruise at Minimum Fuel Consumption

Maximum Range Mach Number (M_{MR})

Illustration D-5 indicates the variation of specific range as a function of Mach number for a defined weight at a constant altitude.

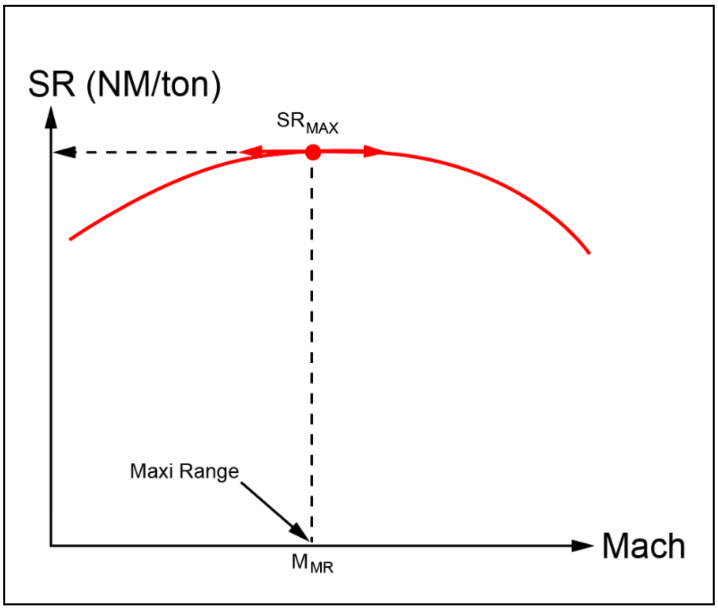


Illustration D-5: M_{MR} at Fixed Altitude and Weight

As a result, for a defined weight, a maximum specific range value exists and the corresponding Mach number is called Maximum Range Mach number (M_{MR}).

The advantage of the Maximum Range Mach number is that the fuel consumption for a defined distance is at a minimum. It also corresponds to the maximum distance an aircraft can fly with a defined fuel quantity.

During the cruise flight phase, the weight of the aircraft decreases due to fuel burn. At the same time, the specific range increases, but M_{MR} decreases (Illustration D-6). Therefore, the Mach number must be adjusted to compensate for weight changes during the entire flight at constant altitude.

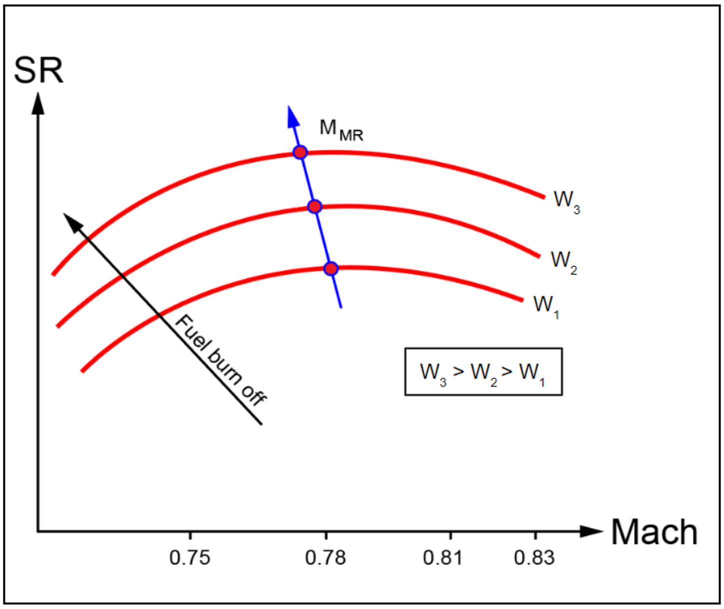


Illustration D-6: M_{MR} versus Weight at Fixed Altitude

Despite its advantage of minimum fuel consumption, the cruise speed associated with M_{MR} is relatively slow. As a result, the trip time is relatively long.

2.3. Time Constraints

2.3.1. Long Range Cruise Mach Number (M_{LRC})

An alternative to M_{MR} is to increase cruise speed with only a slight increase in fuel consumption. Typically, the Mach number for long-range cruise (M_{LRC}) provides this possibility.

At the Mach number for long-range cruise, the specific range corresponds to 99% of the maximum specific range (Illustration D-7). In terms of cost, the 1% loss compared to the maximum specific range results in a large increase of the cruise speed due to the flat shape of the SR vs. Mach curve.

$$M_{LRC} > M_{MR}$$

$$SR_{long\ range} > 0.99\ X\ SR_{max\ range}$$

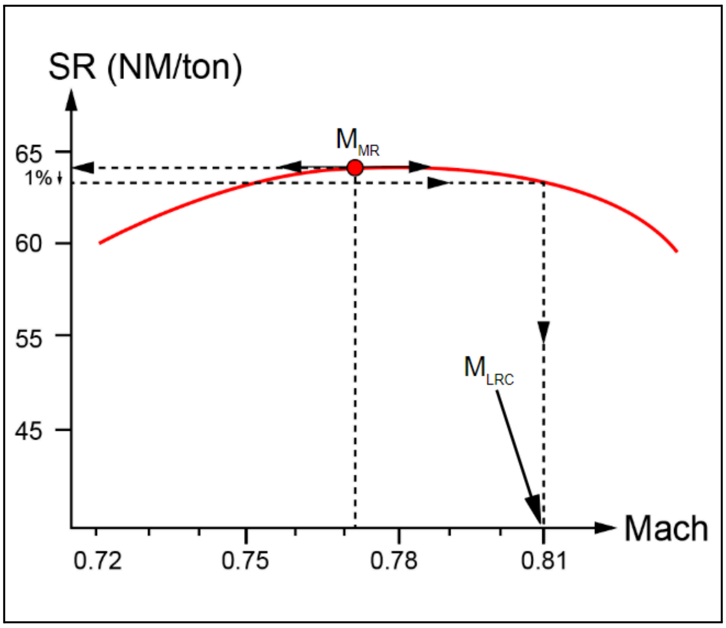


Illustration D-7: M_{LRC} at Fixed Altitude and Weight

In relation to the Mach number for Maximum Range, the Mach number for long range Cruise also decreases when weight decreases, as indicated in Illustration D-8.

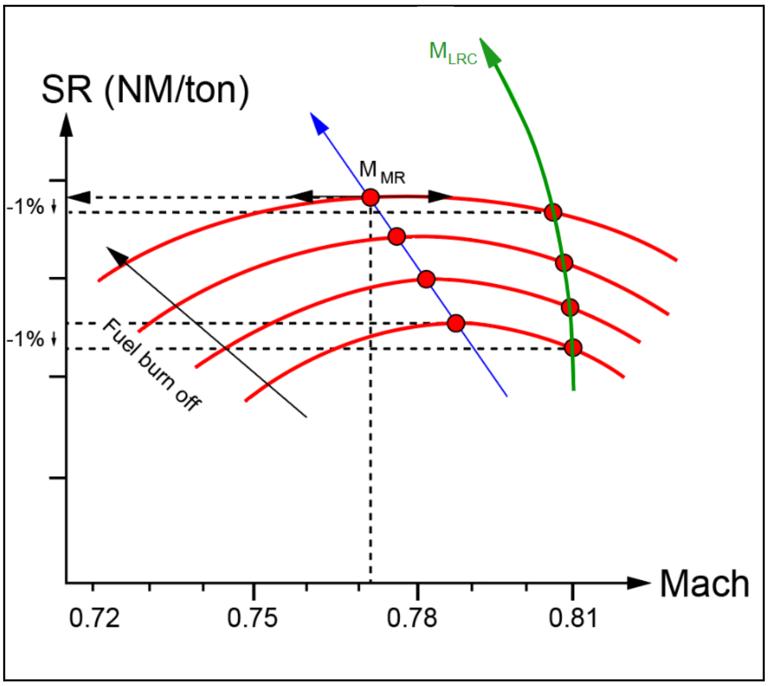


Illustration D-8: M_{LRC} versus Weight at Fixed Altitude

Zp = constant	Weight ↘	⇨	**LRC ↘**
weight = constant	Zp ↗	⇨	**LRC ↗**

2.3.2. Constant Mach Number

The aircraft may also be operated at a constant Mach number. Since the cruise speed is fixed, it is easier to manage the flight.

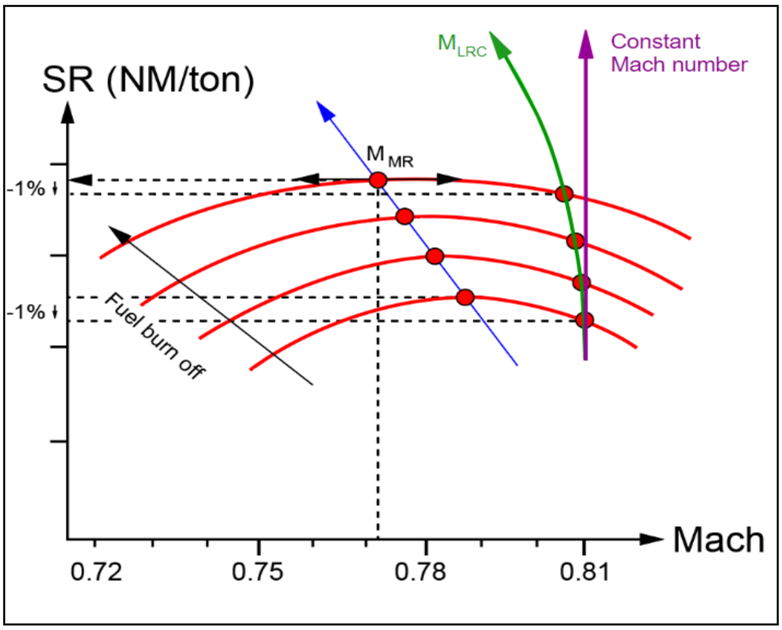


Illustration D-9: SR Evolution at Constant Mach Number and Fixed Altitude

However, when the aircraft weight decreases, the difference between the selected Mach and the M_{MR} increases. As a result, fuel consumption increases beyond the optimum.

2.4. Cruise at Minimum Cost

Economic Mach Number (M_{ECON})

Before cost index introduction, the Mach number for Long-range Cruise was considered as a minimum fuel Mach number. If we consider the Direct Operating Cost (DOC) instead, the Economic Mach number (M_{ECON}), can be established.

As indicated in the below equation, DOCs have fixed, flight-time related and fuel-consumption related costs. As a result, for a trip, DOC can be defined as:

$$DOC = C_C + C_F . \Delta F + C_T . \Delta T$$

That is:
C_C = fixed costs
C_F = cost of fuel unit

ΔF = trip fuel

C_T = time related costs per flight hour

ΔT = trip time

Since DOCs are calculated per nautical mile, it is possible to plot fuel-related costs, flight-time related costs, and direct operating costs based on the Mach number (Illustration D-10).

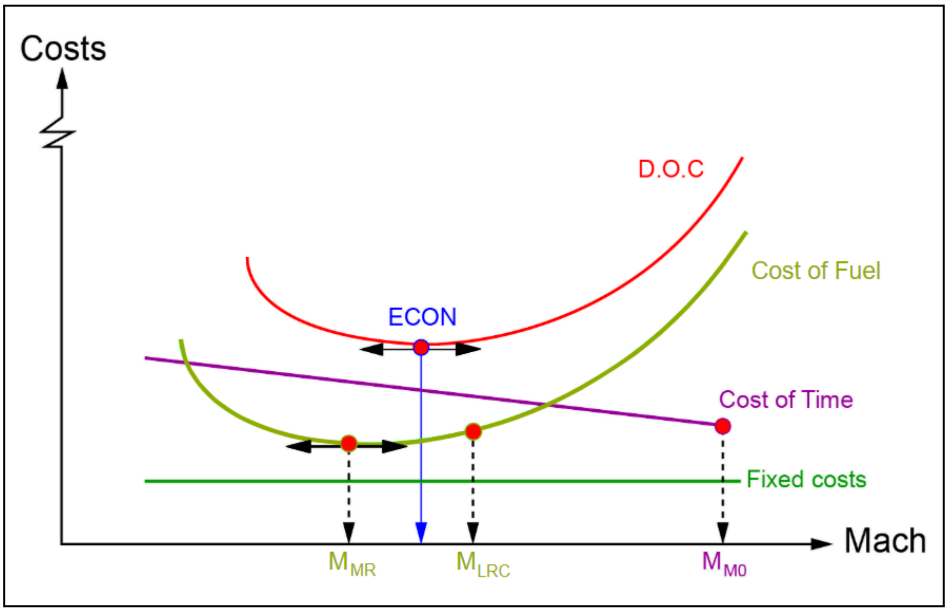


Illustration D-10: Mach Number and Costs

Minimum fuel costs correspond to the Maximum Range Mach number. The minimum DOC corresponds to a specific Mach number, referred to as Econ Mach (M_{ECON}).

Zp = constant	Weight ↘	⇨	M_{ECON} ↘
weight = constant	Zp ↗	⇨	M_{ECON} ↗

The M_{ECON} value depends on the time and fuel cost ratio. This ratio is called cost index (CI). The units of cost index usually are kg/min or 100lb/h. However to avoid to interpret cost index as a fuel flow, CI are often published without units:

$$Cost\ Index\ (CI) = \frac{Cost\ of\ time}{Cost\ of\ fuel} = \frac{C_T}{C_F}$$

When C_T is fixed and C_F increases, it becomes advantageous to decrease fuel consumption. Therefore, when CI decreases, Econ Mach decreases.

CI ↗	⇨	M_{ECON} ↗
CI ↘	⇨	M_{ECON} ↘

The range of CI values are as follows:

- **CI = 0**: Flight time costs are equal to zero (fixed wages), therefore M_{ECON} = M_{MR} (lowest boundary).
- **CI = CI_{max}**: Flight time costs are high and fuel costs are low, therefore M_{ECON} = MAX SPEED in order to have a trip with a minimum flight time. In general, the maximum speed (MMO - 0.02) or (VMO - 10kt).

For example, a cost index of 30 kg/min means that the cost of one flight minute is the same as the cost of 30 kg of fuel. This does not mean the fuel flow is 30 kg/min.

2.5. Altitude Optimization

2.5.1. Optimum Cruise Altitude

In fixed speed strategy, the optimum altitude corresponds to the altitude at which the maximum Specific Range (SR) is reached.

As established in the chapter Fuel Consumption definition, the Specific Range is:

$$SR = \frac{a_0 \cdot M \cdot \frac{L}{D}}{\frac{SFC}{\sqrt{\frac{T}{T_0}}} \cdot mg}$$

For Optimum Cruise altitude, we consider the following assumptions:

- Fixed speed (constant Mach number)
- Low variations of specific fuel consumption
- Fixed weight

Therefore, the Specific Range follows L/D variations.

In level flight, the weight compensates the lift. From the following flight mechanics equation and with the above assumptions taken into account:

$$mg = \frac{1}{2} \cdot \gamma \cdot S \cdot P \cdot C_L \cdot M^2$$

It is found that to remain at level flight at a higher altitude (where the pressure decreases), the lift must be increased.

From the review of SR changes with the altitude at a constant Mach number, it is visible that, for each weight, there is an altitude where SR is maximum. This altitude is referred to as “optimum altitude” (see Illustration D-11).

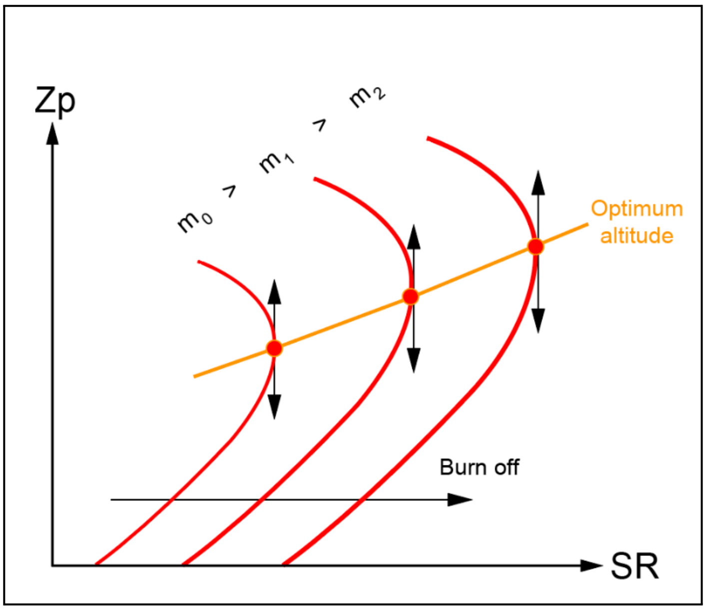


Illustration D-11: Optimum Altitude at Fixed Mach Number

When the aircraft flies at the optimum altitude, it operates at the maximum lift to drag ratio corresponding to the selected Mach number (as in Illustration D-12).

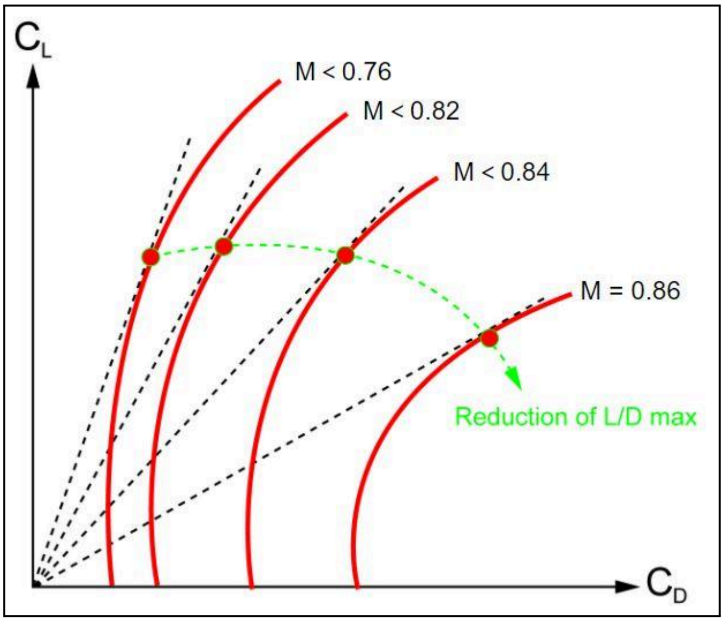


Illustration D-12: High Speed Polar Curve

When the aircraft flies at high speed, the polar curve depends on the indicated Mach number, and decreases when the Mach increases. Therefore, for each Mach number, there is a different value of L/D, that is lower as the Mach number increases, as displayed in Illustration D-12.

When the aircraft is in cruise at the optimum altitude for a specific Mach, C_L is fixed and corresponds to L/D of the selected Mach number. As a result, variable parameters are weight and outside static pressure (P_s) of the optimum altitude. The formula for a cruise at optimum altitude is:

$$\frac{Weight}{P_s} = constant$$

The optimum altitude curve, displayed in Illustration D-13, is directly extracted from Illustration D-11.

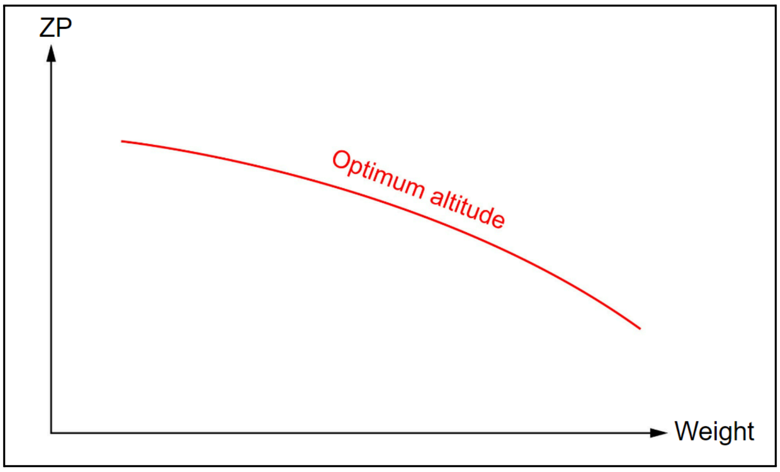


Illustration D-13: Optimum Altitude and Weight at Fixed Mach Number

Summary:

For a fixed ZP

Weight ↘ ⇨ [optimum altitude ↗ ; specific range ↗]

Optimum altitude curves for ISO Mach number are all almost parallel (Illustration D-14).

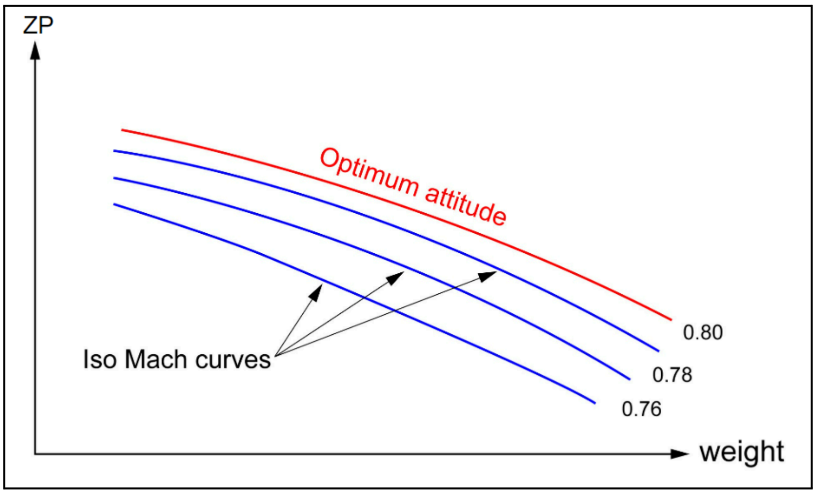


Illustration D-14: Curves of ISO Mach Number

2.5.2. Wind Influence

The M_{MR} (or M_{LRC} or M_{ECON}) value varies with headwind or tailwind, due to changes in the ground SR. Illustration D-15 displays the Maximum Range Mach number with wind variations.

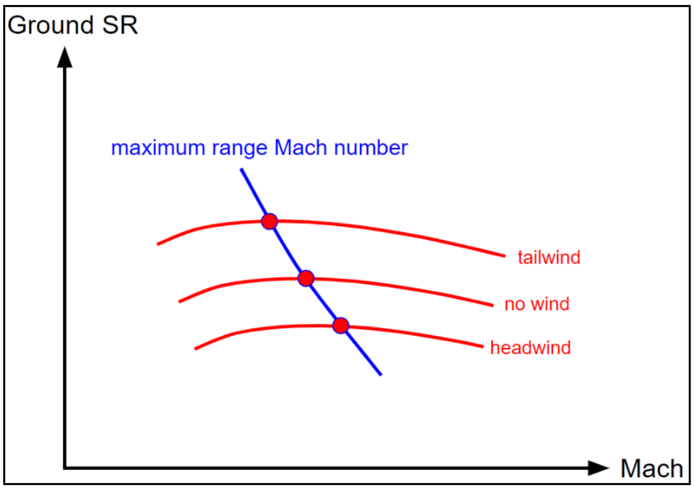


Illustration D-15: M_{MR} and Wind Influence at Fixed Weight and Zp

As a result:

Tailwind ⇨	Ground SR	↗
	M_{MR}	↘
Headwind ⇨	Ground SR	↘
	M_{MR}	↗

The wind can be different at different altitudes. For a specific weight, when cruise altitude is lower than optimum altitude, the specific range decreases (Illustration D-10). However, it is possible that at a lower altitude with wind, the ground specific range increases. When the wind difference between the optimum altitude and a lower altitude reaches a specific value, the ground-specific range at lower altitude is higher than the ground-specific range at optimum altitude. As a result, in these conditions, the ground specific range is higher for cruise at the lower altitude.

2.5.3. Maximum Altitude

The maximum altitude is the lowest of:

- Climb ceiling
- Maximum Cruise Altitude

2.5.3.1. Climb Ceiling

As previously established in the “Climb” section, the climb gradient and the rate of climb decrease with pressure altitude, due to lower excess of thrust. The climb ceiling corresponds to the maximum altitude at which the aircraft can maintain a vertical speed of 300 ft/min at Maximum Climb thrust.

2.5.3.2. Limit Mach Number at Constant Altitude

Each engine has a limited Max-Cruise rating. This rating depends on the maximum temperature that the turbines can sustain. As a result, when outside temperature increases, maximum thrust decreases (see Illustration D-16).

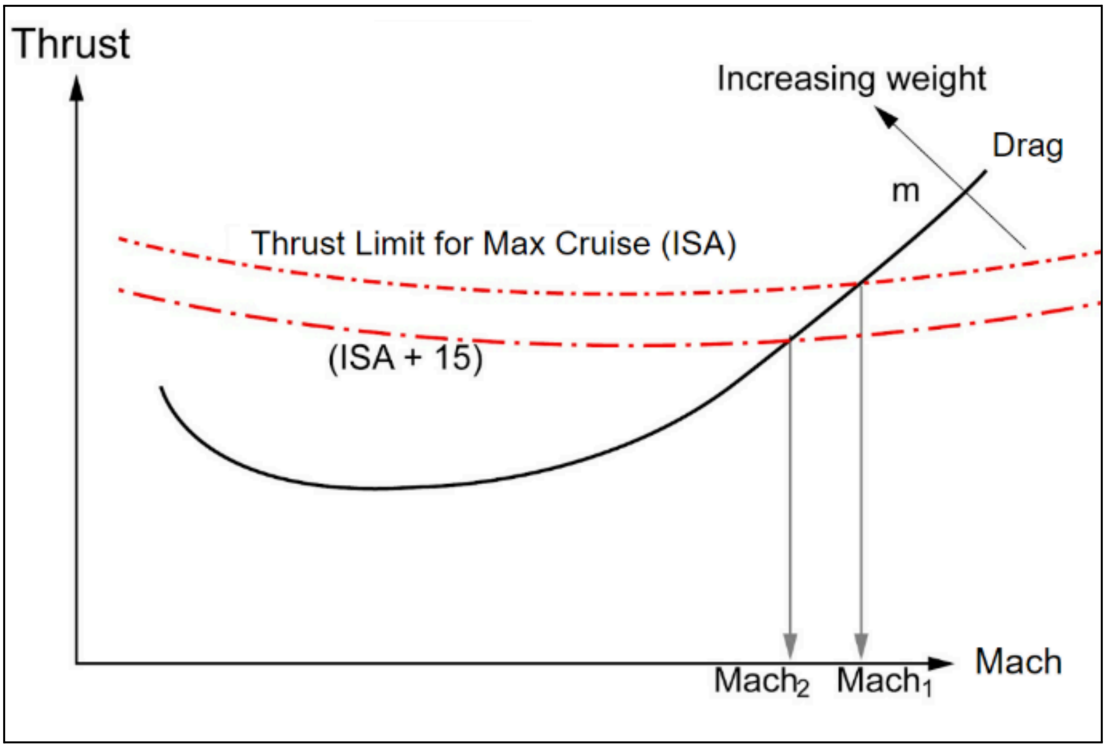


Illustration D-16: Influence of Temperature on Limit Mach Number at Fixed Altitude

Illustration D-16 displays the maximum Mach number possible, as a function of temperature at a specific altitude and weight.

Therefore, in summary, the change in limit Mach number at constant altitude is:

For a specific weight: Temperature ↗	Limit Mach number ↘
For a specific temperature: Weight ↗	Limit Mach number ↘

2.5.3.3. Maximum Cruise Altitude

For a specific weight and Mach number, the maximum cruise altitude is the maximum altitude that an aircraft can maintain at maximum cruise thrust. The maximum cruise thrust is the maximum thrust considered by the FMS in managed mode.

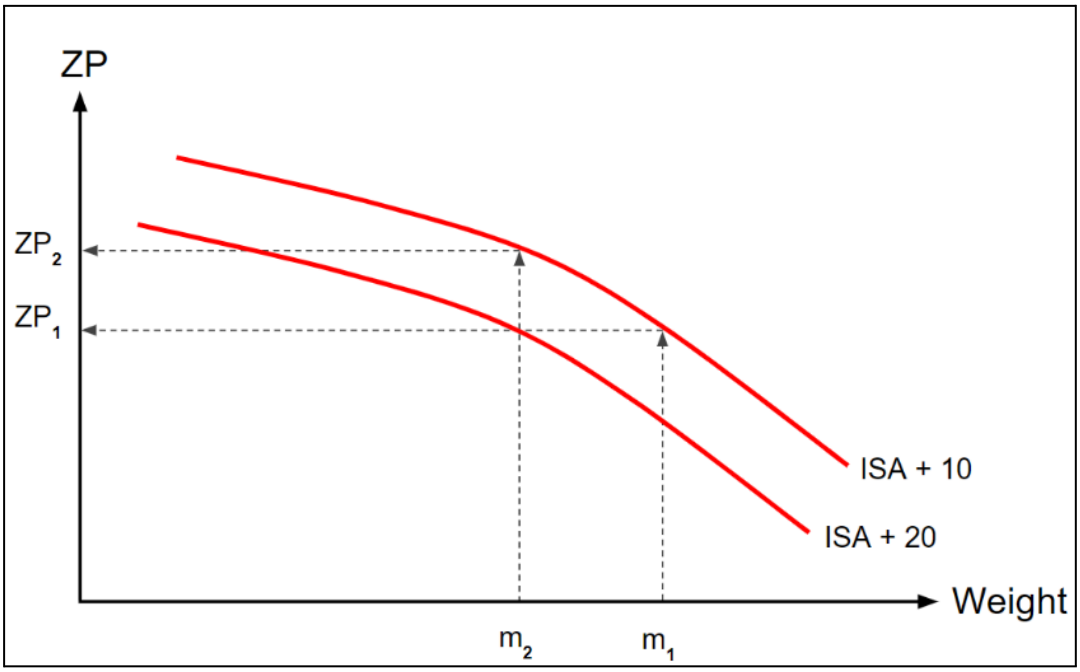


Illustration D-17: Zp curve VS. Weight at Fixed Mach Number

From Illustration D-17:

- At m_1, the maximum altitude is Zp_1 for temperatures less than ISA + 10
- At m_2, the maximum altitude is Zp_2 for temperatures less than ISA + 10, but Zp_1 for temperatures equal to ISA + 20.

In summary, maximum cruise altitude variations are:

Weight	↗	⇒	Maximum cruise altitude	↘
Temperature	↗	⇒	Maximum cruise altitude	↘
Mach number	↗	⇒	Maximum cruise altitude	↘

2.5.4. En Route Maneuver Limits

2.5.4.1. Lift Range

In level flight, lift balances weight and, when C_L equals C_{Lmax}, the lift limit is reached. At this point, if the angle of attack increases, level flight is no longer possible.

Lift limit equation:

$$mg = 0.7\ S\ P_S\ C_{Lmax}\ M^2$$

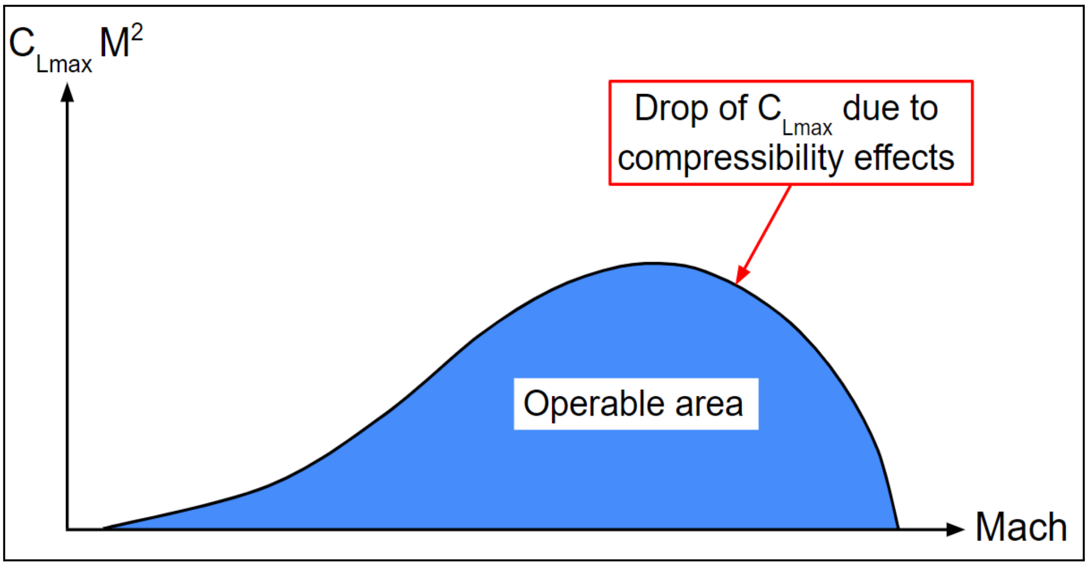


Illustration D-18: $C_{Lmax} M^2$ Curve VS. Mach Number

At a specific weight, based on the lift limit equation, each $C_{Lmax}.M^2$ value corresponds to a static pressure (P_s) value, that is, a pressure altitude (Zp). Therefore, there is a direct relationship between $C_{Lmax}.M^2$ and Zp.

Illustration D-19 displays that, for a specific Zp, flight is possible between M_{min} and M_{max}. When the Zp increases, the Mach range decreases until it is reduced to a single point corresponding to the lift ceiling (Zp_{max}).

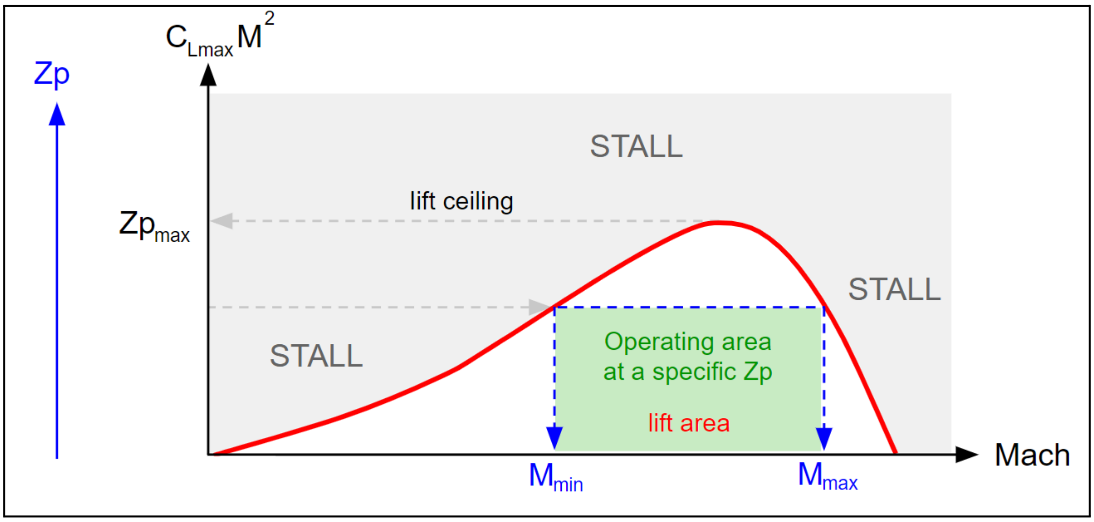


Illustration D-19: Lift Area Definition at a Fixed Weight

2.5.4.2. Operating Maneuver Limitations

2.5.4.2.1. Buffet Phenomenon

For the low Mach number limit, when speed decreases, the angle of attack must be increased in order to increase the lift coefficient, to balance the lift equation.

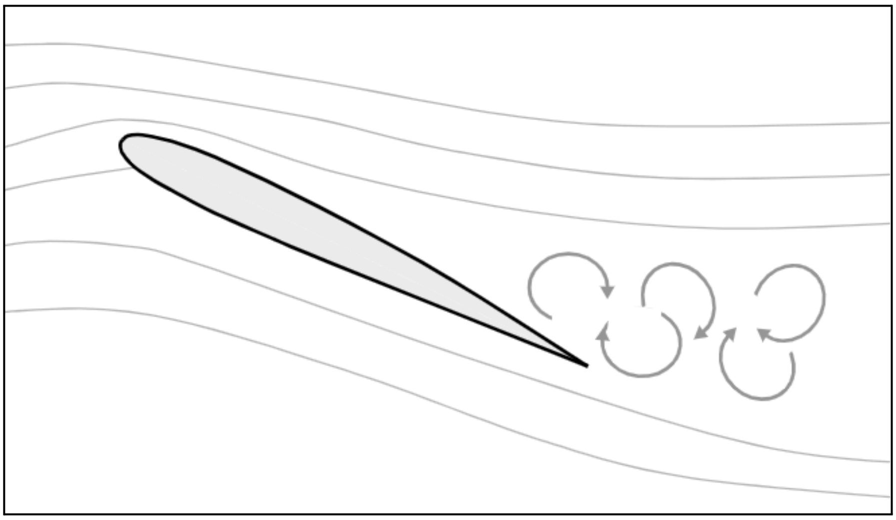


Illustration D-20: Low Speed Buffet

However, it is not possible to increase the angle of attack (AoA) indefinitely. At a high AoA, the airflow separates from the upper wing surface. If the AoA continues to increase, the point of airflow separation becomes unstable and rapidly moves back and forth. As a result, the pressure distribution changes continuously and also changes the position and magnitude of the lift. This effect is called buffeting and is indicated by severe vibrations.

When the AoA reaches a maximum value, the separation point moves forward and results in total flow separation of the wing upper surface. This results in a significant loss of lift, referred to as a stall.

The phenomenon for high Mach number limit is different. At high speed, compressibility effects produce shock waves on the wing upper surface. When the Mach number, and/or AoA increase, the airflow separates from the wing upper surface behind the shock wave, becomes unstable and induces buffeting of the same type as encountered in the low speed case.

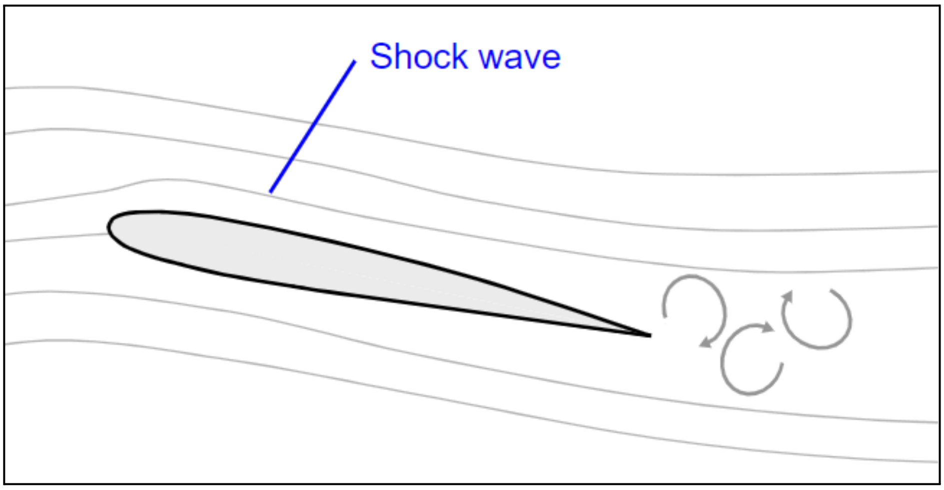


Illustration D-21: High Speed Airflow

2.5.4.2.2. Buffet Limit

In operation, the aircraft is subject to a load factor (n):

$$n = \frac{\text{Lift}}{\text{Weight}}$$

During banked turns, the load factor value mainly depends on the bank angle, as displayed in Illustration D-22. In level flight, n = 1/cos(bank angle).

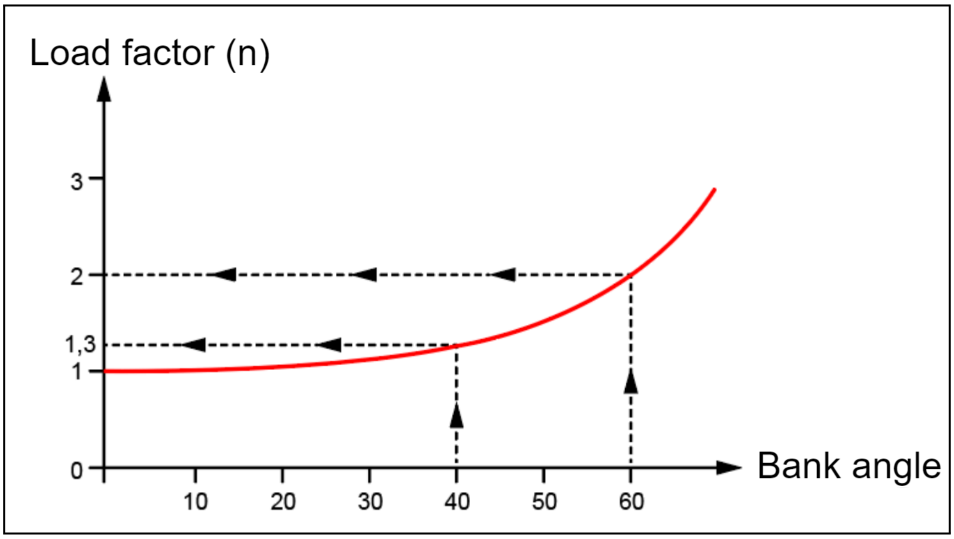


Illustration D-22: Load Factor variation with Bank Angle

At the lift limit:

$$n = \frac{0.7\, S\, P_S\, C_{Lmax}\, M^2}{m\, g}$$

At a specific pressure altitude (P_s) and specific weight (mg), one load factor corresponds to each $C_{L\ max}\ M^2$. Therefore, a curve that displays load factor vs. Mach number will have the same form as the one displayed in Illustration F17.

The Mach number range in operation is the range for which buffeting does not occur.

Illustration D-23 displays the buffet limit, and for n = 1 (level straight flight), a minimum Mach number is associated with low speed buffet and a maximum Mach number is associated with high speed buffet. When n increases, the Mach number range decreases, and when $n = n_{max}$, $M_{min} = M_{max}$.

Therefore, n_{max} is the maximum load factor that is acceptable at this weight and altitude, and the corresponding Mach number (M) permits the highest buffet limit margin.

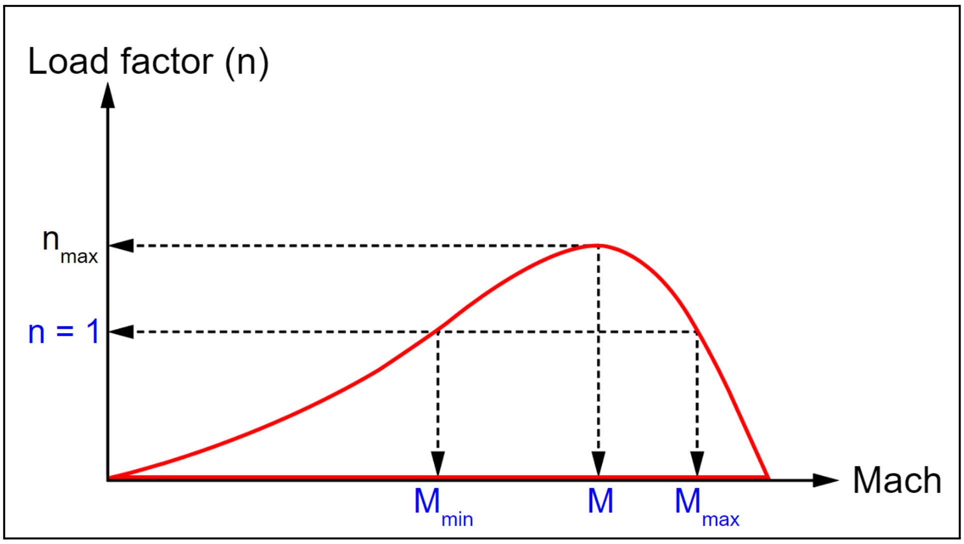


Illustration D-23: Load Factor and Lift Area at Fixed Weight and Zp

2.5.4.2.3. Pressure Altitude Effect

Illustration D-24 illustrates the effects of pressure altitude on the lift area. It appears that for a specific weight:

Pressure altitude ↗	n_{max} ↘ lift range ↘

When n_{max} = 1, the aircraft reaches the lift ceiling. For example, in Illustration D-24, pressure altitude Zp_3 corresponds to the lift ceiling at a specific weight.

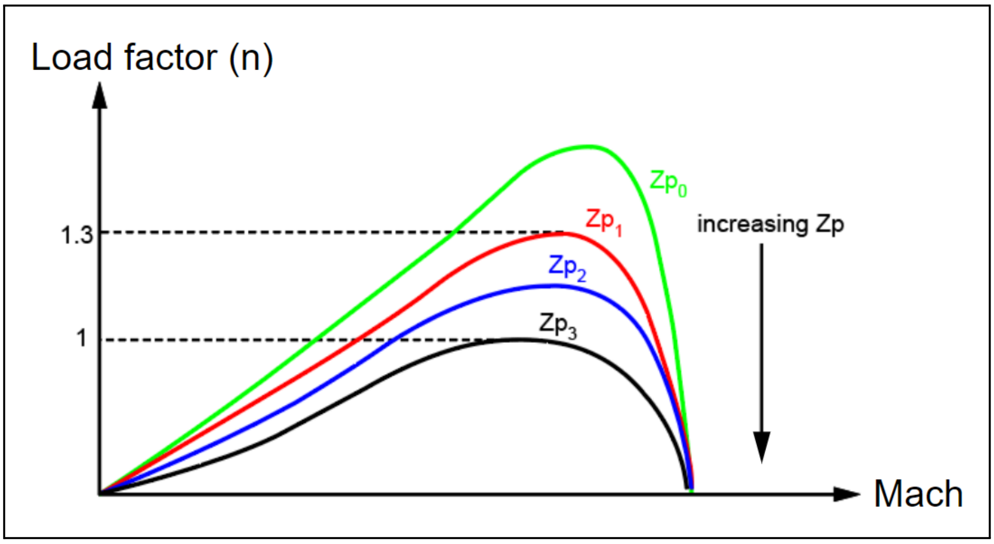


Illustration D-24: Influence of Pressure Altitude on the Lift Limit at Fixed Weight

At pressure altitude Zp_1 (Illustration D-24), n_{max} = 1.3. This means that it is possible to sustain a load factor equal to 1.3, or make a 40° bank turn before buffeting occurs.

In order to maintain a minimum margin against buffeting and to ensure good aircraft maneuverability, it is necessary to determine an acceptable load factor limit below which buffeting will never occur. In general, this load factor limit is fixed to 1.3. This value is an operating limitation, but not a regulatory limitation. The corresponding altitude is referred to as the “1.3 g buffet limited altitude” or “buffet ceiling”. The usual limit for load factor is 1.4 g in turbulent conditions.

For a specific Mach number, Illustration D-25 displays the 1.3 g buffet limited altitude variation with weight. At a specific Mach number, when weight decreases, the buffet limited altitude increases.

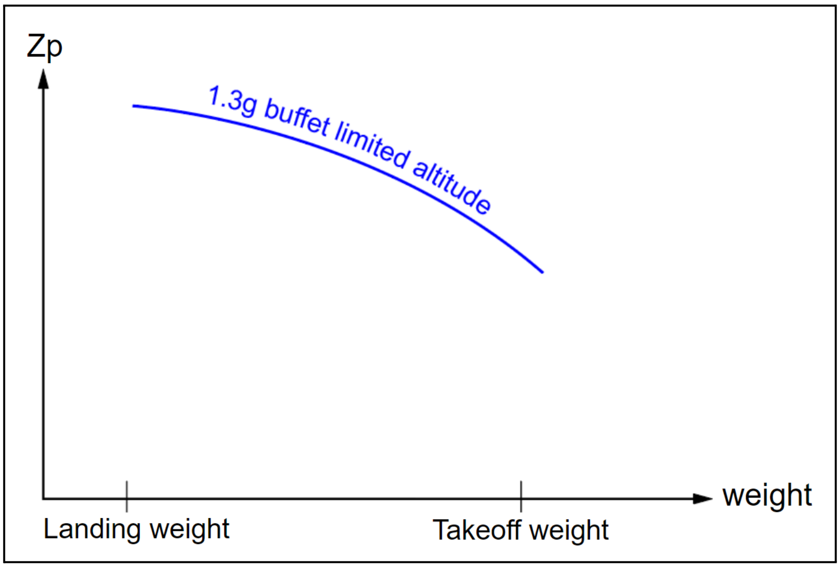


Illustration D-25: 1.3g Buffet Limited Altitude at Fixed Mach

2.5.4.2.4. A320 example

Illustration D-26 displays how buffet limitations are illustrated in an A320 AFM.

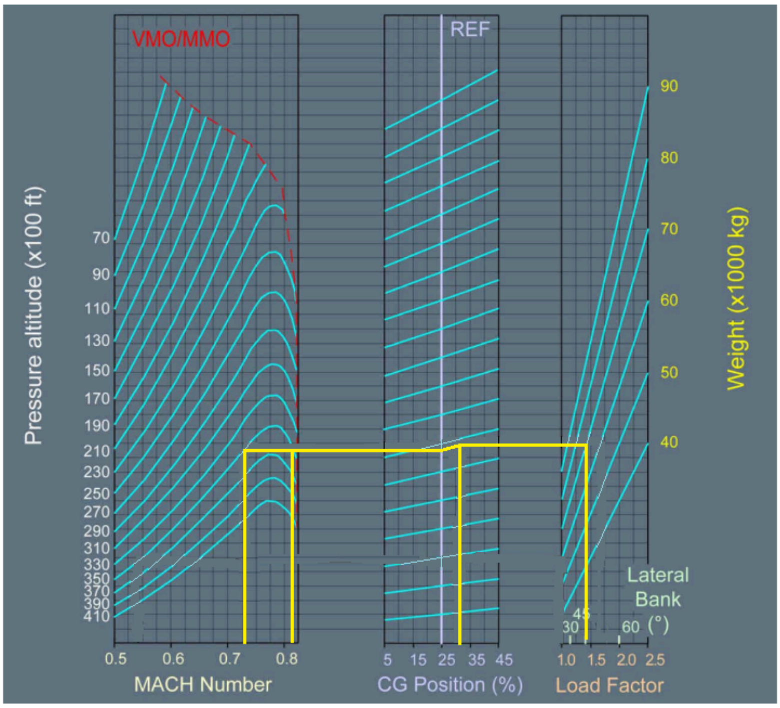


Illustration D-26: Buffet Onset

Assumptions:	**Results:**
n = 1.3	Speed range:
FL330	Mmin = M0.73
CG position: 31%	Mmax = M0.82
Weight: 70 t	

For a specific weight, the load factor limitation (1.3g) is taken into account as follows:

- At a fixed FL, the cruise Mach range is determined for n = 1.3g,
- At a fixed cruise Mach, the maximum FL (buffet ceiling) is determined for n = 1.3g.

2.5.5. Recommended Maximum Altitude

The Recommended Maximum (REC MAX) altitude is provided by the FMS. It is the lowest of the following maximum altitudes:

- 1.3g buffet limited altitude
- Maximum cruise altitude at maximum cruise thrust in level flight
- Maximum Climb altitude at maximum climb thrust with 300 ft/min vertical speed
- Maximum certified altitude.

The speed considered for REC MAX altitude computation is the speed between Green Dot and VMO/MMO that maximizes the altitude. This speed mainly depends on the current gross weight of the aircraft and the ΔISA.

2.5.6. Cruise Optimization : Step Climb

Optimum cruise should ideally coincide with optimum altitude. As a general rule, this altitude is not constant, but increases as weight decreases during cruise. However, ATC restrictions require level flight cruise. Aircraft must fly by segments of constant altitude that should, ideally, be as near as possible to the optimum altitude.

In accordance with the separation of aircraft by flight level, the level segments are established at ± 2 000 ft from the optimum altitude in Reduced Vertical Separation Minima (RVSM) airspace. In general, it is seen that in these conditions:

$$SR \geq 99\%\ SR_{max}$$

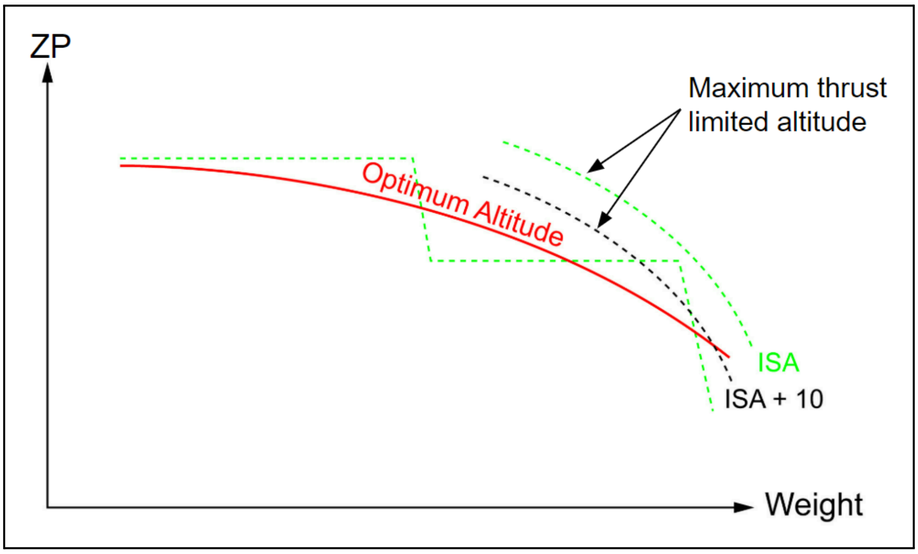


Illustration D-27: A Step Climb Cruise Profile

As a result, the following profile is obtained for a step climb (Illustration D-27).

Step Climb
2,000 ft under FL 290
4,000 ft above FL 290
or
2,000 ft in RVSM area

Flight levels are selected in accordance with temperature conditions. Usually, the first step starts at the first usable flight level that is compatible with maximum cruise altitude. This is the case with the example of cruise at ISA condition in Illustration D-27.

3. Descent/Holding

3.1. Descent Management

3.1.1. Thrust setting

The standard engine rating for descent is “Flight Idle Thrust”. For fly-by-wire aircraft, the thrust lever position does not change when autothrust is engaged. At THR RED, the throttle levers are set to the “CL” (climb) gate for the entire flight (Illustration D-28). The Full Authority Digital Engine Control (FADEC), adjusts the thrust level to the required value.

In case of an altitude constraint or a repressurization segment (see the chapter Cabin Descent), the vertical speed of the aircraft may have to be limited during descent. This is achieved at a thrust called “Adapted Thrust”. The adapted thrust may change between flight idle thrust and maximum cruise thrust. It is provided by the engines when autothrust is engaged, when the aircraft descent speed and one of the two descent parameters (gradient or rate) remain fixed.

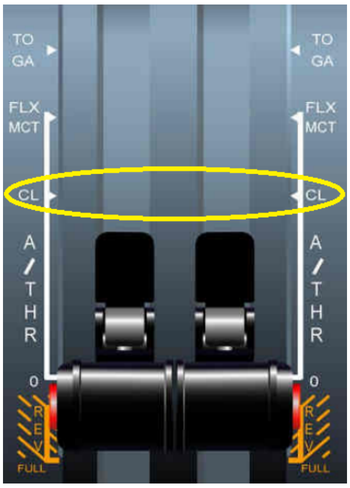


Illustration D-28: CL Gate is the Thrust Throttles Position During Descent with Auto-Thrust

3.2. Descent Speeds

3.2.1. Descent at Selected Speed

For a descent performed at a speed selected by the flight crew, the descent is operated at a constant Mach Number and Indicated Air Speed (IAS). For example, a typical descent profile for the A320 family is:

M0.78 / 300 kt / 250 kt

TAS variations during descent are indicated in Illustration D-29. For more details, refer to the chapter Climb.

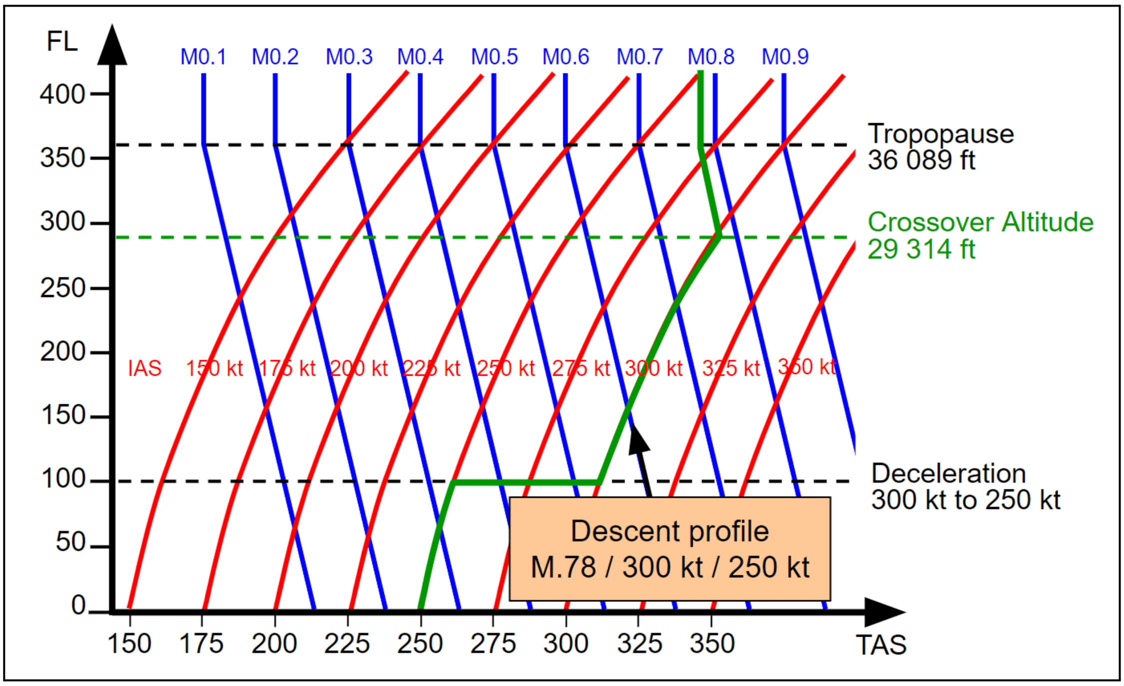


Illustration D-29: Descent Profile at Given MACH/IAS Law

3.2.2. Descent at Minimum Gradient (Drift Down)

The descent gradient is at a minimum when speed is set to Green Dot speed. Descent at Green Dot speed enables the highest possible altitude to be maintained for the longest distance (without any fuel consumption impact considered).

A Green Dot speed descent is not recommended in normal operations, because it results in increased flight time. On the other hand, it is very important in case of an engine failure during cruise over mountainous terrain, because it increases obstacle clearance margin and offers more escape solutions than higher speeds. A Green Dot speed descent with one engine inoperative is referred to as drift down procedure (refer to the chapter Obstacle/Drift Down Strategy).

3.2.3. Descent at Minimum Rate

The minimum rate of descent speed is lower than Green Dot. As a result, a descent at minimum rate is of no use in operations, compared to a descent at Green Dot. The time needed to reach a specific altitude is longer than at Green Dot and the distance covered is shorter. For this reason, and as a general rule, it is not advantageous to descend at a speed lower than Green Dot.

3.2.4. Descent at Minimum Cost

The cost index aims to lower direct operating costs for a specific flight. For a specific cost index, an optimum descent Mach ($Mach_{ECON}$) and an optimum descent speed (IAS_{ECON}) are calculated by the FMGS to optimize the descent. The descent is then performed in managed mode, based on the following MACH/IAS law:

$Mach_{ECON}$ / IAS_{ECON} / 250 kt

To minimize global fuel consumption for a flight, a low cost index must be used. Since the descent phase is performed at idle thrust, it is advantageous to maximize its duration, because it minimizes fuel consumption. This is achieved at a low descent speed, that depends on the aircraft type (e.g. 250 kt for the A320 family). However, the descent speed must remain above Green Dot.

$CI = 0 \Rightarrow IAS_{ECON}$ = Minimum descent speed (depends on A/C type)

On the contrary, a high cost index is required when the global flight time needs to be reduced for cost reasons. In this case, the descent must be as fast as possible (i.e. at the maximum rate of descent speed). The maximum rate is obtained at a speed that is, in general, limited to VMO – 10 kt in normal operations.

$CI = CI_{max} \Rightarrow IAS_{ECON}$ = VMO – 10 kt

Flight at a given cost index in descent is one of the recommendations of the Green Operating Procedures in the FCTM. In addition, the use of the same cost index for the entire flight is recommended in the FCTM Standard Operating Procedures for Cruise.

3.2.5. Emergency Descent

An emergency descent must be performed in case of a cabin pressurization failure. The objective is to reach FL100 as soon as possible due to oxygen constraints. In case of pressurization failure over mountainous terrain with high obstacles, the objective is to first descend to a lower flight level that permits obstacle clearance. After the obstacles are cleared, the objective is then to descend to FL100.

MMO/VMO is the best speed schedule, because it enables the most rapid rate of descent possible. This rate of descent is increased when the airbrakes are extended as requested by emergency descent procedure.

3.3. Vertical Profile Management

3.3.1. Cabin Descent

The cabin pressure rate is optimized during descent so that it reaches the landing field pressure + 0.1 psi just before landing.

Depending on the initial cabin and destination airport altitudes, the FMGS calculates the necessary cabin descent time. This time is obtained from the selected cabin rate of descent, defaulted to -350 ft per minute in the FMGS, but which can be modified up to a maximum of -750 ft per minute.

As soon as the cabin descent time is longer than the aircraft descent time, a repressurization segment is necessary, during which the aircraft vertical speed is limited to permit cabin repressurization (Illustration D-30).

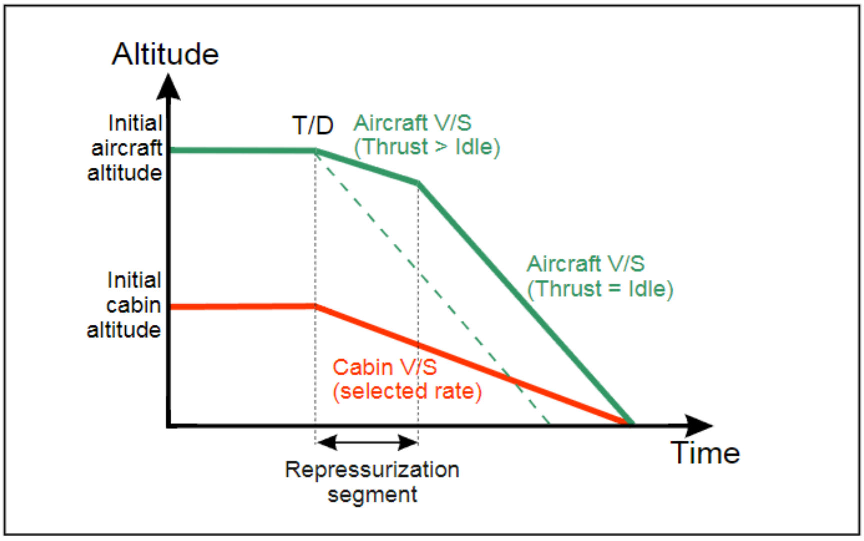


Illustration D-30: Cabin Repressurization Segment

In some specific cases (landing at high altitude airports) , the cabin pressure at cruise level is higher than the pressure at the landing airport. Therefore, the cabin pressure must decrease during descent, and this means that the vertical speed of the cabin is positive while the vertical speed of the aircraft is negative.

3.3.2. Top of Descent

The FMGS calculates the position of the Top of Descent point and takes into account speed and altitude constraints. The FMGS makes the assumption that the aircraft flies the segment at idle thrust with the use of idle thrust plus a small thrust margin. This provides the flight crew with some flexibility to keep the aircraft on the descent path if engine anti-ice is used (this increases idle thrust), or if there is a variation in the wind. This small extra amount of thrust also results in small differences in the vertical profile that can be seen between a theoretical profile at idle thrust and the profile computed by FMGS.
Operators can use the Idle Factor to adjust the Top of Descent computation on each aircraft. The real idle thrust of each aircraft can change compared to theoretical idle thrust, and this can cause flight crews to notice that the Top of Descent is too early or too late. More information on the Idle Factor value update can be found in the FCOM manual.

3.3.3. Continuous Descent Approach

Some aircraft are equipped with the function for continuous descent approach. A continuous descent will minimize the time that the aircraft is at a not optimum altitude and therefore results in fuel savings. The FMGS computes the continuous descent profile from the Top of Descent to 1 000 ft above ground level.
The possibility to perform a continuous descent approach at a specific airport needs to be confirmed with ATC.

3.4. Holding Management

When holding is required, it is usually performed on a “race track pattern”, that has two straight legs plus two 180 degree turns. When the aircraft makes a turn, the distance covered is not the primary objective. However, the maximum holding time (maximum endurance) is an important factor for any diversion decision. As a result, it is important during holding to try to minimize fuel consumption with time as much as possible, or to just minimize fuel flow (kg per hour or lb per hour).

The speed for minimum fuel consumption is somewhere between the minimum drag speed and the maximum lift-to-drag ratio (Green Dot) speed, that are quite similar in value. As a result, in clean configuration the standard holding speed is based on Green Dot.

Holding patterns may result in limitations around specific airports due to obstacle proximity. Green Dot speed is sometimes too high, particularly during turns that require high bank angles. Since it is not possible to significantly reduce the speed below Green Dot in clean configuration, slats may be extended and a holding performed in CONF1 at “S” speed[13].

Green Dot and S speeds are easy to fly in selected mode, since they are indicated on the Primary Flight Display (PFD), as a function of aircraft weight and configuration:

- In clean configuration: “Green Dot”.
- In configuration 1: “S speed”.

3.5. Factors of Influence

3.5.1. Altitude Effect

During the descent phase, air density increases, so for a specific aircraft weight and a specific true air speed, the drag force increases. The descent gradient and rate of descent are proportional to drag (as detailed in Appendix 5), and therefore, an increase in both descent gradient and descent rate is observed.

However, because the descent is never performed at a constant TAS, but at a constant Mach or a constant IAS, it is not possible to conclude. The following graph (Illustration D-31) illustrates the variation of the descent gradient (γ) and rate of descent (RD), with altitude for a descent profile M0.82 / 300 kt / 250 kt.

[13] S speed = Minimum slat retraction speed (from CONF1 to CONF CLEAN)

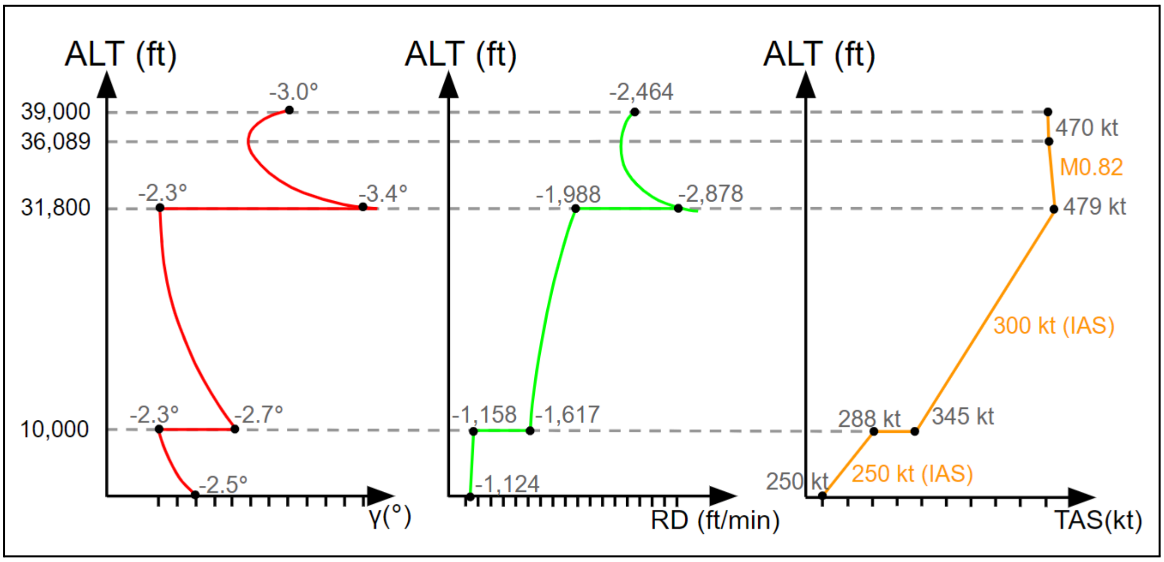


Illustration D-31: A330 example - Descent Gradient (γ) and RD variation with Altitude and TAS

Contrary to the climb phase, it is difficult to evaluate descent parameters (gradient and rate), because they only depend on drag and not on thrust (that is considered to be set to idle).

3.5.2. Temperature Effect

Similarly to the pressure altitude, the temperature effect is difficult to evaluate. At a specific altitude, an increase in temperature causes a reduction in air density. As a result, drag also decreases, and it may be convenient to consider that the magnitude of the gradient and rate of descent are reduced.

However, the TAS is not constant during the descent. For a specific Mach or IAS, TAS increases with temperature, and therefore compensates for drag reduction. This is the reason that descent parameter variations with temperature are not significant.

3.5.3. Weight Effect

Green Dot speed (for minimum gradient in descent) is a function of weight and altitude. Illustration D-32 indicates that, in the standard descent speed range (Green Dot to VMO), the rate and gradient of descent reduce at higher weights.

The balance of forces during descent indicates that:

$$\text{Lift} = \text{Weight}.\cos\gamma = \tfrac{1}{2}\,\rho.S.TAS^2.C_L$$

At a specific TAS in the standard speed range, a higher weight means that a higher lift coefficient (C_L) is required to maintain the balance of forces. This is achieved by an increase in the angle of attack (α) and a reduction in the descent gradient, γ. Since RD = TAS.γ, the rate of descent is also reduced at higher weights.

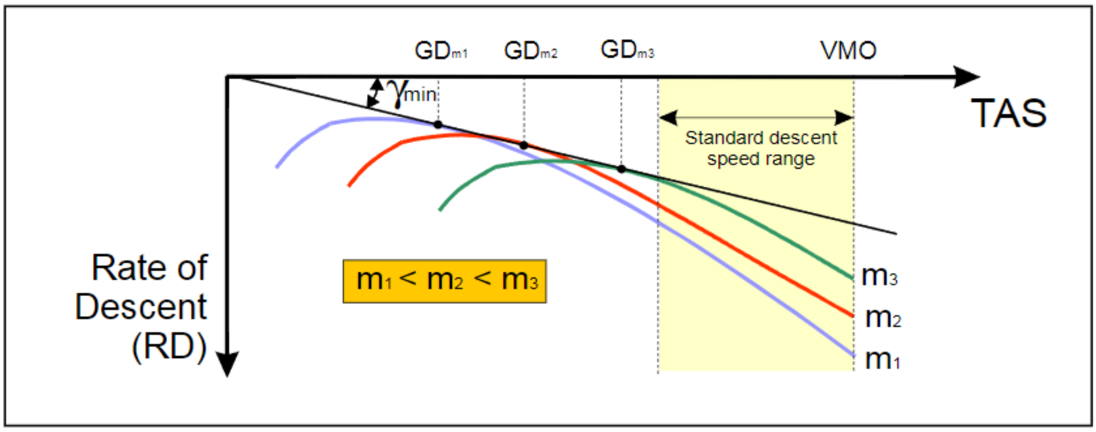


Illustration D-32: Gradient and Rate of Descent variation with Speed and Weight

Therefore, in the speed range for standard descent:

Weight ↗ ⇒	descent gradient ↘
	rate of descent ↘

3.5.4. Wind Effect

As displayed in Illustration D-33, the air descent gradient (γ_a) remains the same, regardless of the wind component. Therefore, the fuel and time necessary to descend from the Top of Descent (T/D) to the final level remain the same.

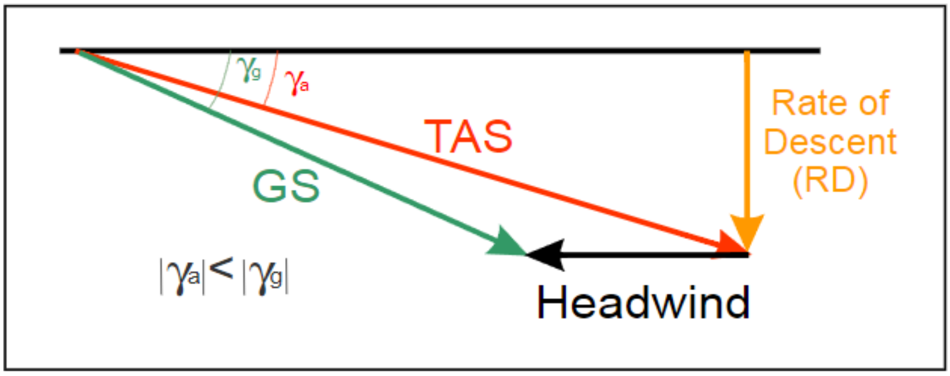


Illustration D-33: Headwind Effect on Descent Flight Path

Headwind ↗ ⇒	Rate of descent →
	Fuel and time from T/D →
	Flight path angle $|\gamma_g|$ ↗
	Ground distance from T/D ↘

Tailwind ↗ ⇒	Rate of descent →
	Fuel and time from T/D →
	Flight path angle $|\gamma_g|$ ↘
	Ground distance from T/D ↗

E. IN FLIGHT PERFORMANCE WITH FAILURE

1. ENGINE FAILURE

1.1. PROBLEM CREATED BY LOSS OF POWER

In case of an engine failure during flight, the remaining thrust is no longer sufficient to balance the drag force and to maintain the cruise speed. The thrust necessary to fly at the initial altitude suddenly becomes higher than the available thrust delivered by the operative engines, with Maximum Continuous Thrust (MCT) rating. The only solution is to then descend to a lower flight level, where the available thrust can equal the required thrust, this therefore enables the aircraft to level off.

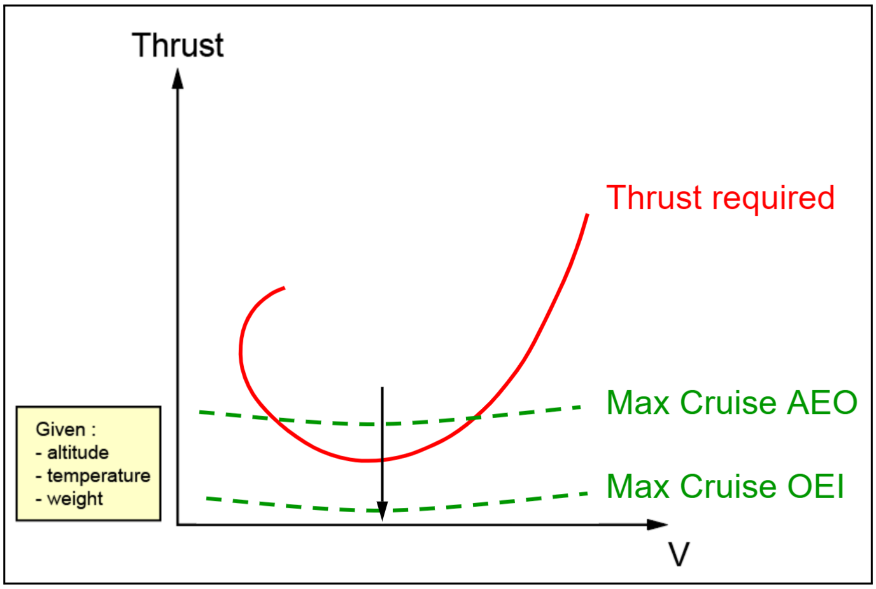


Illustration E-1: Thrust versus Velocity

1.2. GENERAL DEFINITIONS

CS 25.123 Subpart B ***FAR 25.123 Subpart B***

1.2.1. Gross Drift Down Flight Path

The Gross Drift Down Flight Path is the flight path that the aircraft flies after an engine failure (Illustration E-2). Regulations require that operators be provided with drift down performance information, as described below:

"(a) For the en-route configuration, the [gross drift down] flight path must be determined at each weight, altitude, and ambient temperature […]. The variations of the weight along the flight path, accounting for the progressive consumption of fuel […] by the operating engines, may be included in the computation. The flight paths must be determined at any selected speed, with:
- *The most unfavourable centre of gravity*
- *The critical engine inoperative."*

1.2.2. Net Drift Down Flight Path

The Net Drift Down Flight Path is the Gross Flight Path minus a regulatory reduction (Illustration E-2).

"(b) The one-engine-inoperative net flight path data must represent the actual climb performance diminished by a gradient of climb of

- *1.1% for two-engined aeroplanes*
- *1.6% for four-engined aeroplanes."*

(c) The two-engine-inoperative net flight path must represent the actual climb performance diminished by a gradient of climb of

- *0.5% for four-engined aeroplanes."*

Net Gradient = Gross Gradient – Gradient Penalty

	Gradient penalty	
	Two-engine aircraft	Four-engine aircraft
Net flight path (one engine out)	1.1%	1.6%
Net flight path (two engines out)	-	0.5%

Table E-1: Gradient Penalties Between Gross and Net Drift Down Flight Paths

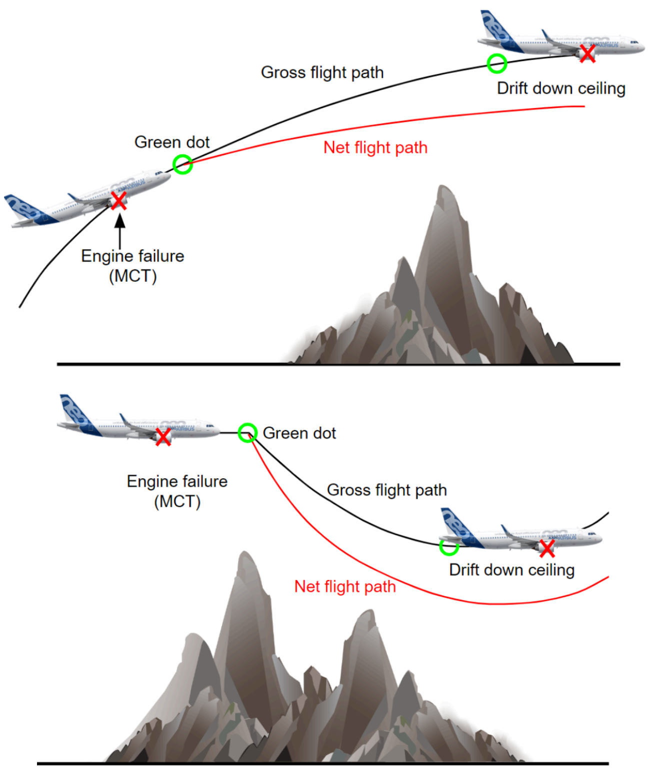


Illustration E-2: Gross and Net Drift Down Flight Paths (Climb and Descent)

1.3. En route Obstacle Clearance – One Engine Inoperative

1.3.1. Lateral Clearance

Obstacle clearance must be ensured throughout the route in case of an engine failure. The objective is to identify the obstacles that must be cleared based on regulatory criteria:

Air OPS CAT.POL.A.215 ***FAR 121.191 Subpart I***

"(c) The net flight path shall permit the aeroplane to continue flight from the cruising altitude to an aerodrome where landing can be made […] clearing […] all terrain and obstructions along the route within 9.3 km (5 nm) on either side of the intended track"
(d) […] an operator must increase the widths margins […] to 18.5 km (10 nm) if the navigational accuracy does not meet at least navigation specification RNAV5"
(Illustration E-3).

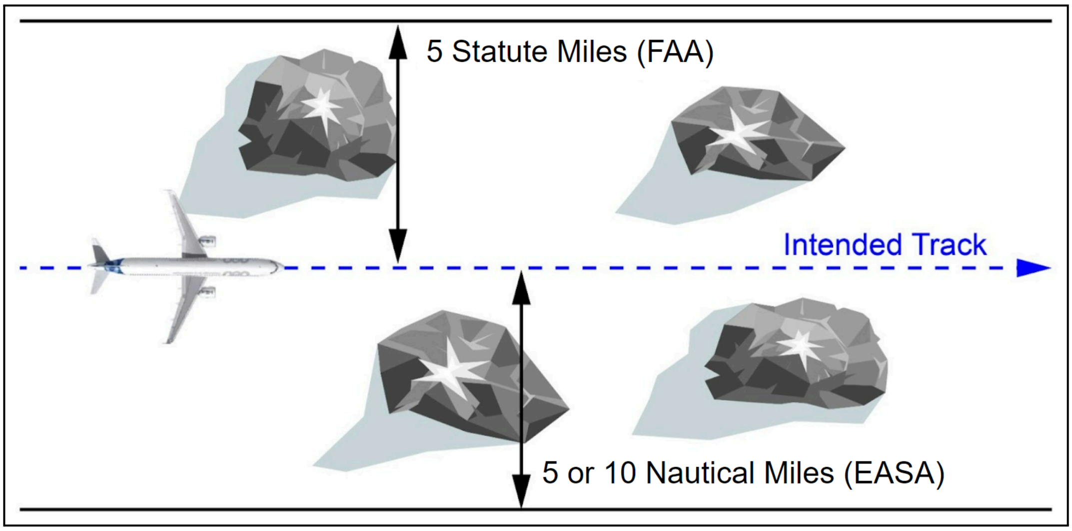


Illustration E-3: Lateral Clearance

The FAR regulation is similar, except that it requires a lateral margin of 5 statute miles on each side of the intended track. In addition, the FAR regulation specifies that a "different procedure" approval is required when the aircraft is nearer to the critical obstruction it has to pass over, than to the nearest approved radio navigation fix.

To perform a detailed route study (engine failure case), topographic data must be used and the highest obstacles inside the required corridor width determined.
Another, more rapid, but less accurate method, consists of the use of the published Minimum Flight Altitudes that usually account for a margin of 2 000 ft on the obstacles (refer to the chapter Minimum Flight Altitudes).

1.3.2. Vertical Clearance

Vertical clearance is defined as a margin between the net flight path and the obstacles. The en route net flight path must be determined from the Aircraft Flight Manual, and must take into account the expected meteorological conditions (wind and temperature) along the route. In addition, if icing conditions can be expected at the diversion level, the effect of the anti-ice system must be considered on the net flight path.

Air OPS CAT.POL.A.215 *FAR 121.191 Subpart I*

Any route study should be performed by a check of one of the following two conditions for vertical clearance. When Condition 1 cannot be met, or when it appears to have too many penalties in terms of weight, a detailed study must then be performed based on Condition 2.

Condition 1: 1 000 ft Clearance Margin

"CAT.POL.A.215
(b) The gradient of the en-route 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." (Illustration E-4)

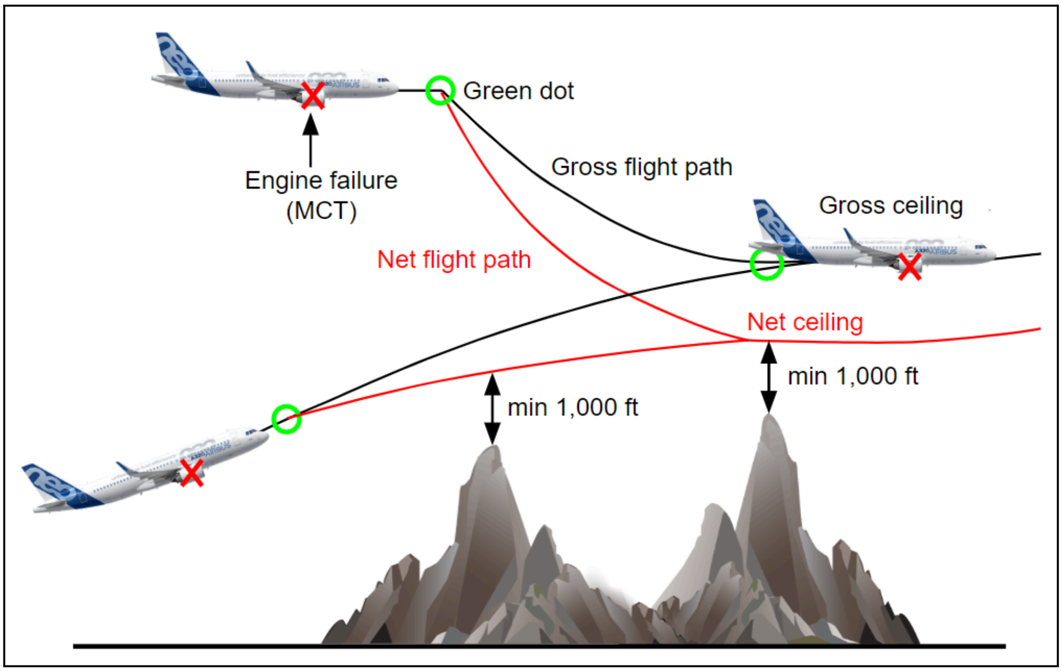


Illustration E-4: Vertical Clearance (1,000 feet)

<u>Condition 2: 2 000 ft Clearance Margin</u>

Condition 2 is related to the case of an engine failure during the cruise phase. When Condition 1 is not satisfied, or when it has too many limitations in terms of weight, a drift down procedure should be established, as detailed below:

Air OPS CAT.POL.A.215 ***FAR 121.191 Subpart I***

"(c) The net flight path shall permit the aeroplane to continue flight from cruising altitude to an aerodrome where a landing can be made, […] shall clear vertically, by at least 2,000 ft all terrain and obstructions along the route within [the prescribed corridor]." (Illustration E-5).

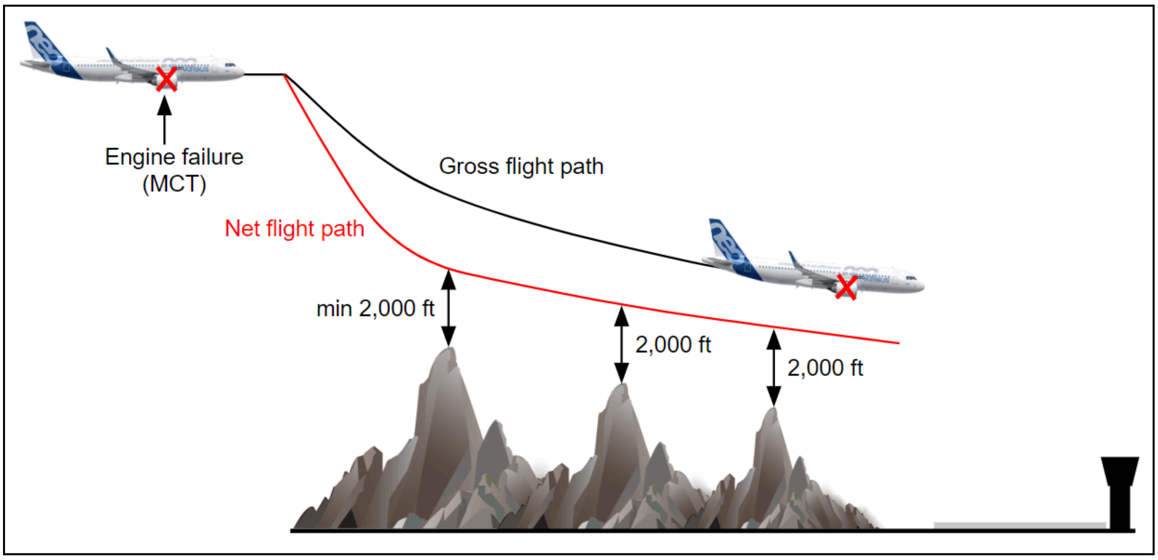


Illustration E-5: Vertical Clearance (2,000 feet)

At any point of a critical area on the route, it must always be possible to escape and ensure, during descent, the obstacle clearance margin of 2 000 ft on the net flight path. The following three escape procedures are available: Turn back, Divert, or Continue.

1.3.3. Diversion Airfield

Air OPS CAT.POL.A.215 ***FAR 121.191 Subpart I***

"(a) The net flight path shall have a positive gradient at 1,500 ft above the aerodrome where the landing is assumed to be made after an engine failure." (Illustration E-6)

The route study must indicate the different diversion airfields that are possible en route, associated with the various diversion scenarios. The gradient of the net flight path should be positive at 1 500 ft (at least) above the airport where the landing is expected. For that purpose, fuel jettisoning can be considered, when the system is available.

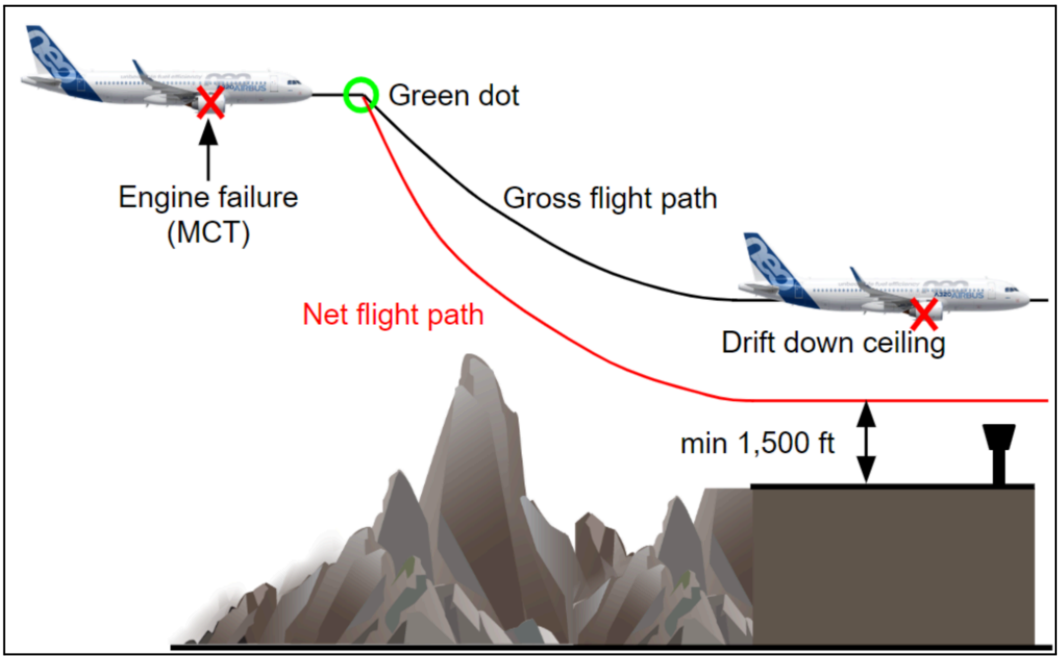


Illustration E-6: Performance Requirement Above Diversion Airport

In addition:
"(c)(4) The aerodrome where the aeroplane is assumed to land after engine failure shall meet the following criteria:

- *The performance requirements at the expected landing mass are met*
- *Weather reports or forecasts, or any combination thereof, and field condition reports indicate that a safe landing can be accomplished at the estimated time of landing."*

Alternate airports must be clearly identified at dispatch, and must comply with the prescribed weather minimums for the approach category. If these minimums are not satisfied, the associated diversion procedures are no longer possible.

1.4. Obstacle Clearance – Two Engines Inoperative

For 4 engine aircraft, when more than 90 min from a diversion airfield, the double engine failure must be considered.

Air OPS CAT.POL.A.220 (a) ***FAR 121.193 Subpart I***

Following a double engine failure, obstacles must be cleared by either a lateral or vertical margin.

1.4.1. Lateral Clearance

The regulations define the corridor width in which obstacles must be taken into account, as follows:

Air OPS CAT.POL.A.220   *FAR 121.193 Subpart I*

"(b) The two engines inoperative en-route net flight path data shall allow the aeroplane to continue the flight, in the expected meteorological conditions, from the point where two engines are assumed to fail simultaneously, to an aerodrome at which it is possible to land, […] clearing all terrain and obstructions along the route within 9.3 km (5 nm)[14] on either side of the intended track. […] If the navigational accuracy does not meet at least navigation specification RNAV 5, the operator shall increase the prescribed width margin […] to 18.5 km (10 nm)[15]."

1.4.2. Vertical Clearance

Vertical clearance is defined as a margin between the net flight path with two engines inoperative and the obstructions. The en route net flight path with two engines inoperative must be determined from the Aircraft Flight Manual, and must take into account:

- The expected meteorological conditions (wind and temperature) along the route,
- The use of ice protection systems, if required.

Air OPS CAT.POL.A.220   *FAR 121.193 Subpart I*

"The net flight path shall clear vertically, by at least 2,000 ft all terrain and obstructions along the route within [the prescribed corridor]."

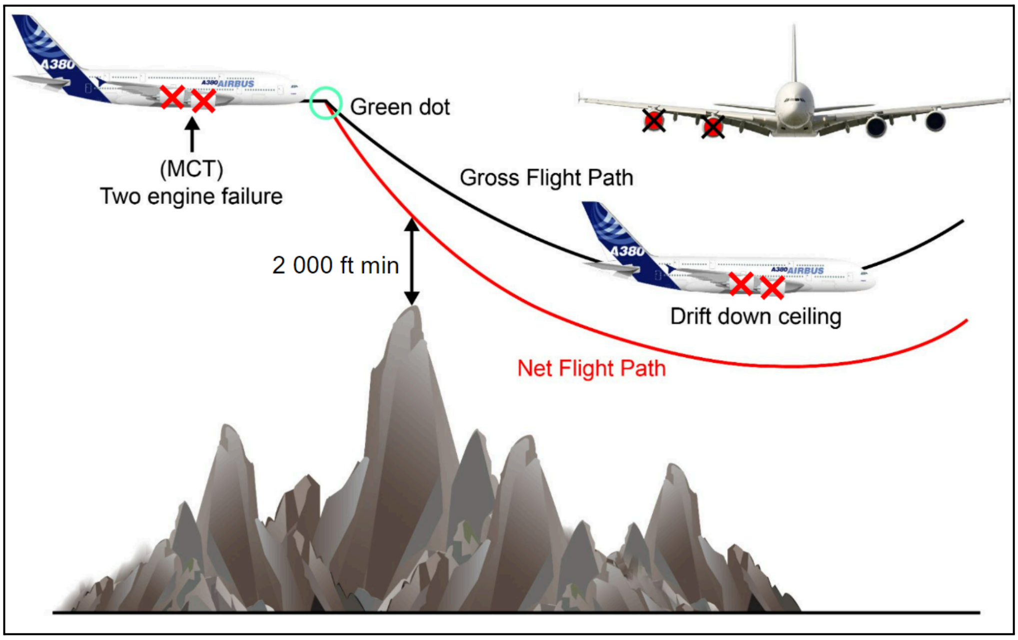


Illustration E-7: Obstacle Clearance 2,000 feet – Two Engines Inoperative

[14] FAA: 5 statute miles
[15] EASA rule not valid for FAA

1.4.3. Diversion Airfield – Two Engines Inoperative

Air OPS CAT.POL.A.220

FAR 121.193 Subpart I

"(d) The net flight path shall have a positive gradient at 1,500 ft above the aerodrome where the landing is assumed to be made after the failure of two engines." (Illustration E-8).

The route study must indicate the different possible diversion airfields for en route flight, associated with the various diversion scenarios. The gradient for the net flight path with two-engines inoperative should be positive at 1 500 ft above the airport where the landing is expected. For that purpose, fuel jettisoning can be considered, when the system is available.

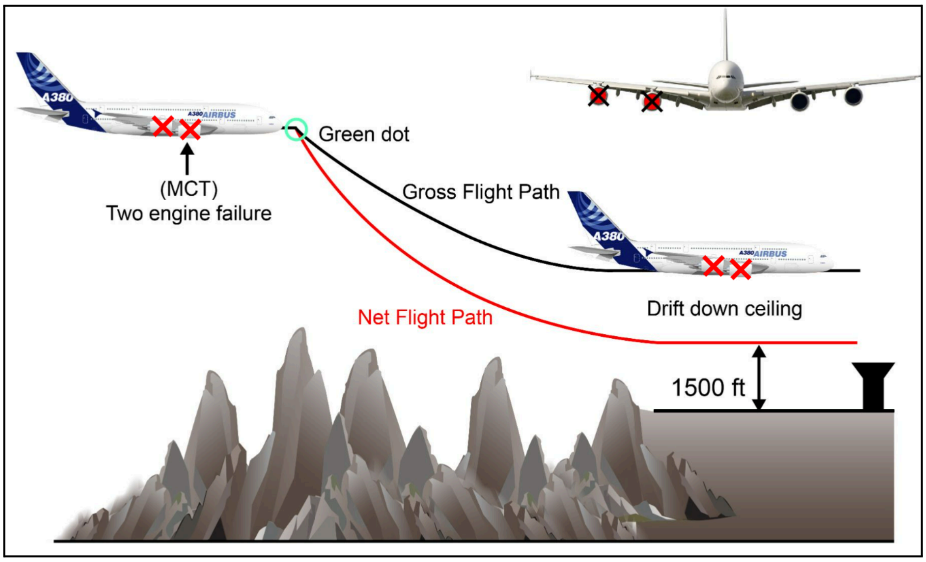


Illustration E-8: Performance Requirement above Diversion Airport

1.5. Airbus Policy

When an engine failure occurs during cruise, there are three possible strategies considered by Airbus:

- The standard strategy
- The obstacle / drift down strategy
- The fixed speed strategy (applicable for ETOPS operations).

1.5.1. Standard Strategy

Unless a specific procedure was established before dispatch (with ETOPS or mountainous areas considered), the standard strategy is used.

The standard strategy consists of the following:

- Select Maximum Continuous Thrust (MCT) on the remaining engine(s).
- Target speed of:
  - M0.78/300 kt for A320 Family
  - M0.82/300 kt for A330/A340
  - M0.85/300 kt for A350 and A380
- Climb or descend at the above speeds until EO LRC Ceiling is reached.

1.5.2. Obstacle/Drift Down Strategy

In case of an engine failure over a mountainous area during the climb or cruise phase, the Obstacle Strategy or Drift Down Strategy (Illustration E-9) should be applied. This procedure consists of:

- The selection of Maximum Continuous Thrust (MCT) on the remaining engine(s).
- Deceleration to Green Dot speed.
- Climb or descent at Green Dot speed until the drift down ceiling[16] is reached.
- Continue with the standard strategy when the EO LRC ceiling clears the obstacles with sufficient margins.

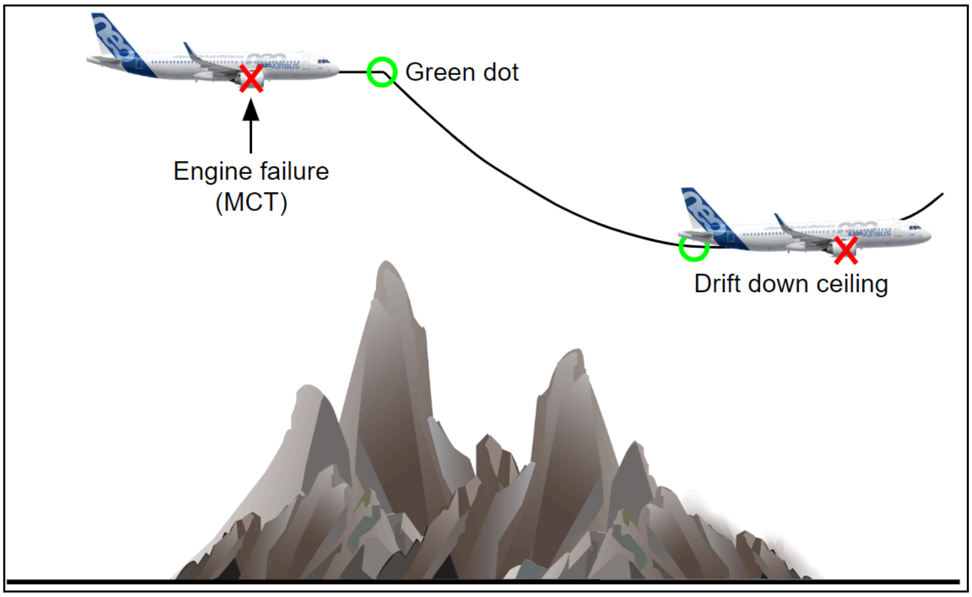


Illustration E-9: Drift Down Procedure (Climb and Descent)

Green Dot speed, indicated by a green circle on the primary flight display (PFD), corresponds to the best lift-to-drag ratio speed, where aerodynamic efficiency is at a maximum. As a result, the drift down strategy is the procedure that enables the highest possible altitude to be achieved.

1.5.3. Fixed Speed Strategy

Refer to the chapter ETOPS Speed Strategy.

[16] Drift down ceiling = maximum altitude that the aircraft can be fly at Green Dot speed (level off)

2. Pressurization Failure

In case of an in-flight cabin pressurization loss, descent to a safe altitude is necessary to comply with the oxygen system constraint. At the initial cruise altitude, the proportion of oxygen in the air is not sufficient to permit crewmembers and passengers to breathe normally. An oxygen system is required to supply oxygen to passengers and crew. Since the necessary oxygen quantity must be sufficient to supply the entire cabin, the oxygen flow rate is limited to a maximum duration. A new flight altitude, where oxygen is no longer required, must be reached before the oxygen supply is exhausted.

2.1. Passenger Oxygen Requirement

To determine passenger and flight crew supplementary oxygen requirements, regulations provide the minimum oxygen quantity depending on flight altitude. Oxygen reserves for crewmembers are always much larger than for passengers and as a result, the descent profile is always more limited by the passenger oxygen system than by the crew oxygen system.

Air OPS CAT.IDE.A.230

FAR 121.329
FAR 121.333

"GM1 CAT.IDE.A.230
(b) When calculating the amount of first-aid oxygen, the operator should take into account the fact that, following a cabin depressurisation, supplemental oxygen as calculated in accordance with Table 1 of CAT.IDE.A.235 and Table 1 of CAT.IDE.A.240 should be sufficient to cope with potential effects of hypoxia for:

(1) all passengers when the cabin altitude is above 15 000 ft;

(2) at least 30 % of the passengers, for any period when, in the event of loss of pressurisation and taking into account the circumstances of the flight, the pressure altitude in the passenger compartment will be between 14 000 ft and 15 000 ft; and

(3) at least 10 % of the passengers for any period in excess of 30 minutes when the pressure altitude in the passenger compartment will be between 10 000 ft and 14 000 ft.

CAT.IDE.A.230
(b) The oxygen supply referred to in (a) shall be sufficient for the remainder of the flight after cabin depressurisation when the cabin altitude exceeds 8 000 ft but does not exceed 15 000 ft, for at least 2 % of the passengers carried, but in no case for less than one person."

The condition (b) is usually achieved by portable oxygen. The following table (E-2) provides a summary of the passenger oxygen requirements.

Flight Altitude	> 15 000 ft	Supply to 100% of passengers
	> 14 000 ft ≤ 15 000 ft	Supply to 30% of passengers
	> 10 000 ft ≤ 14 000 ft	Supply to 10% of passengers (not required during the first 30 minutes)
	> 8 000 ft ≤ 10 000 ft	Supply to 2% of passengers after cabin depressurization (achieved by portable oxygen).
With a minimum of 10 minute supply for 100% of passengers		

Table E-2: Oxygen Supply Requirement for Passengers

2.2. Oxygen Systems

Air OPS CAT.IDE.A.235

FAR 121.329
FAR 121.333

"CAT.IDE.A.235
(a) Pressurised aeroplanes operated at pressure altitudes above 10 000 ft shall be equipped with supplemental oxygen equipment that is capable of storing and dispensing the oxygen supplies[...]"

Following a cabin pressurization failure, oxygen is automatically supplied to passengers through individual oxygen masks, deployed to seated areas and to galley and lavatory areas. These units are automatically deployed in case of a cabin pressurization loss, but they only supply oxygen for a limited period of time.

The duration of the passenger oxygen supply is different, depending on the type of system. As of today, there are two main categories of oxygen systems: chemical systems and gaseous systems.

2.2.1. Chemical Systems

A chemical system has the following characteristics:
- There is an independent chemical generator that is activated when the mask is pulled. When the mask is pulled, it is not possible to stop the oxygen flow.
- The oxygen flow and supply pressure are independent of the cabin altitude.
- The oxygen is supplied to passengers for a specific period of time, that is usually 15 or 22 minutes, depending on the system.
- The system is designed to deliver a flow of oxygen for a pre-defined time.
- A maximum flight profile is provided for these systems. Above this profile the system does not supply enough oxygen to enable the passenger to breathe.

2.2.2. Gaseous Systems

2.2.2.1. Centralised Gaseous System

A gaseous system has specific advantages over the chemical system:

- It can be customized, because the Operator can select the number of high pressure bottles of oxygen (up to 18 cylinders on the A340-600).
- The oxygen flow and supply pressure depend on the altitude. The flow rate is controlled by a device that regulates altimetric flow in each mask container. It enables passenger oxygen consumption to be optimized: The lower the altitude, the lower the oxygen flow.
- The oxygen supply time depends on the flight profile, and on the number of cylinders installed.
- There is no oxygen flow below a cabin pressure altitude of 10 000 ft.

2.2.2.2. Decentralized Gaseous Oxygen System

On some aircraft, there are options to use a decentralized gaseous oxygen system:

- Provides the same or better operational flexibility as the centralized gaseous oxygen
- Oxygen consumption varies depending on the descent profile.
- When a passenger pulls on a mask, the oxygen cylinder is mechanically activated.
- The Oxygen Control Board, located on each container, will control the oxygen flow to the masks in accordance with the cabin altitude.
- The Operator ensures that the descent procedure to be flown is compatible with the usable volume of oxygen defined for the system.

2.3. Flight Profile

2.3.1. Oxygen System Limitation

The route study for the case of a cabin pressurization failure must consider the cabin pressure to be the same as the pressure altitude of the aircraft.

An oxygen system profile is defined, based on the system design characteristics and within which the aircraft must always remain. The oxygen system profile depends on the installed oxygen system:

- Chemical system: Profile is fixed based on O2 system time constraint (published in In-Service Information articles).
- Gaseous systems: Customized profile (depends on the number of oxygen bottles and obstacle location).

This flight profile is the maximum level that the aircraft can fly considering the capability of the oxygen system. As an example, the following illustration E-10 displays the descent profile of a 22 minute oxygen system.

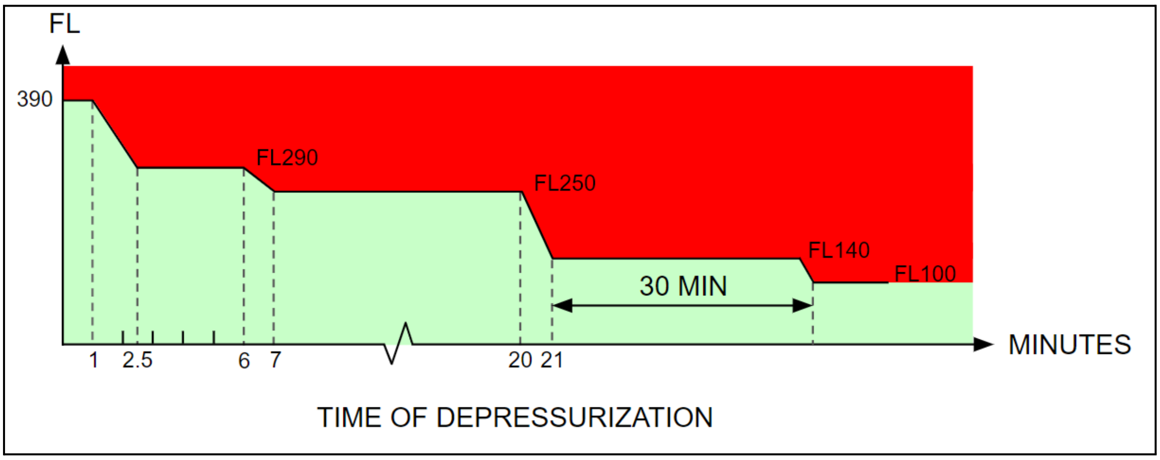


Illustration E-10: A319 Descent Profile - 22 Minute Oxygen System

For example, the above profile indicates that 7 minutes after the cabin depressurization, the aircraft must be at or below FL250. Above FL250, the oxygen flow provided by the chemical system is not sufficient to supply the passengers.

2.3.2. Performance Limitation

The descent profile displayed in Illustration E-10 only depends on the capability of the oxygen system, and not on the performance capability of the aircraft.

However, this does not mean that the aircraft is always able to follow the oxygen profile, particularly in descent. As a result, the performance profile must be determined, and this profile must always remain below the oxygen profile. The calculation is based on the following assumptions:

- Descent phase: Emergency descent at MMO/VMO. Airbrakes can be extended to increase the rate of descent if necessary.
- Cruise phase: Cruise at maximum speed (limited to VMO).

As a result, for a specific initial weight and flight level, the oxygen profile, based on time, is transformed into a performance profile, based on distance (Illustration E-11).

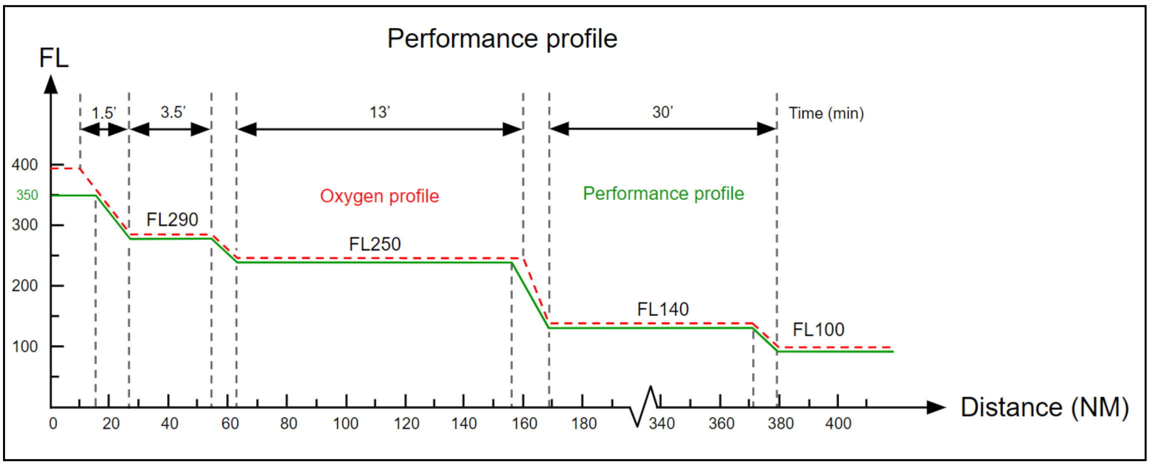


Illustration E-11: A319 Performance Profile – Oxygen System that lasts for 22 Minutes

Note: When this performance profile is established, it is always considered that the aircraft is able to fly at MMO/VMO. Cases where the speed should be decreased (structural damage, turbulence…) should not to be taken into account.

2.4. Minimum Flight Altitudes

Air OPS CAT.OP.MPA.145 ***FAR 121.657***

FAA guidance for selection of minimum flight altitudes is available in FAR 121.657. It indicates that no person may operate an aircraft under IFR, in designated mountainous areas at an altitude less than 2 000 ft above the highest obstacle within a horizontal distance of 5 miles from the center of the intended course.

EASA guidance material is provided in GM1 CAT.OP.MPA.145(a), where the standard definitions of minimum flight altitudes that are published are described:

- MOCA (Minimum Obstacle Clearance Altitude) and MORA (Minimum Off-Route Altitude) and MGA (Minimum Grid Altitude). They correspond to the maximum terrain or obstacle elevation, plus:
  - 1 000 ft for elevation up to 5 000 ft included (or 6 000 ft)[17].
  - 2 000 ft for elevation that exceeds 5 000 ft (or 6 000 ft) rounded off to the next 100 ft.
- MEA (Minimum safe En route Altitude). It corresponds to the maximum terrain or obstacle elevation, plus:
  - 1 500 ft for elevation up to 5 000 ft included.
  - 2 000 ft for elevation above 5 000 ft and below 10 000 ft.
  - 10% of the elevation plus 1 000 ft above 10 000 ft.

As a result, the minimum flight altitude above 10 000 ft is considered acceptable to carry out studies, and is equal to the highest obstacle elevation plus 2 000 ft.

3. ETOPS Flight

3.1. Twin Engine Aircraft - 60 Minute Rule

Air OPS CAT.OP.MPA.140 ***FAR 121.161 Subpart H***
AC 120-42B

"CAT.OP.MPA.140
(a) Unless approved by the competent Authority […], the operator shall not operate a two-engined aeroplane over a route which contains a point further from an adequate aerodrome, [...], than the appropriate distance [...]:
(1) flown in 60 minutes at the [approved] one-engine-inoperative cruising speed".

[17] Depends on the method: Jeppesen (5,000 feet) or KSS (6,000 feet)

ETOPS (Extended Twin Operations) criteria was initially established in 1984 by the International Civil Aviation Organization (ICAO). Under this criteria an airline must obtain an ETOPS operational approval, in order to perform commercial operations with an ETOPS certified twin-engine aircraft, on routes beyond 60 min diversion time from an adequate airport.

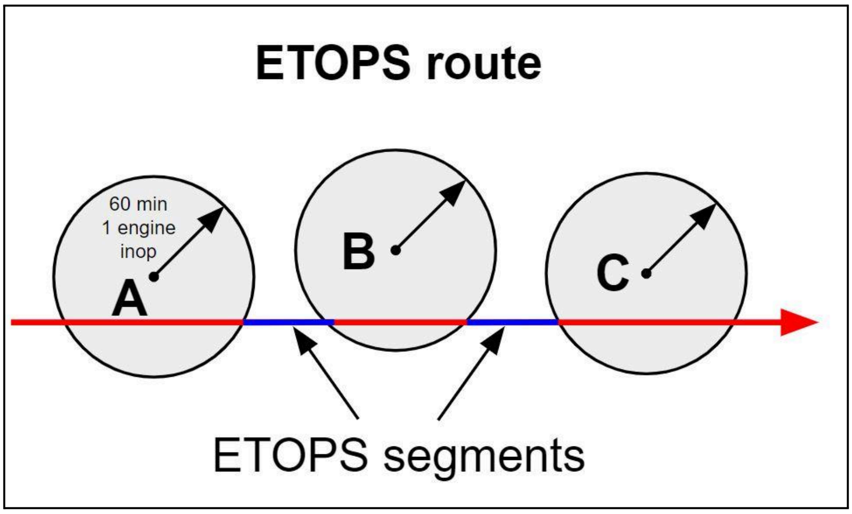


Illustration E-12: 60 Minute Rule

Authorities such as the FAA or EASA translated these ETOPS regulations into national regulations. These ETOPS regulations have evolved over the years, particularly since 2007 to gradually enable operations of twin-engined aircraft beyond the diversion time of 180 min.

In 2012, ICAO replaced its ETOPS standards with a new set of standards referred to as EDTO (Extended Diversion Time Operations). These standards are applicable to international commercial operations of both twin-engined aircraft and aircraft with more than two engines.

For more information and guidance on ETOPS/EDTO, please refer to the set of "Getting to Grips with ETOPS" brochures.

3.2. ETOPS Speed Strategy

As described in the Airbus policy chapter for One Engine Inoperative cases, the recommended strategy for ETOPS operations is the Fixed Speed Strategy.

The Fixed Speed Strategy consists of the following:

1. Select Maximum Continuous Thrust (MCT) on the remaining engine(s)
2. Decelerate to the speed established at dispatch
3. Cruise at the selected speed and altitude (established at dispatch).

4. Guidance to Route Studies

In flight, engine or pressurization failures are cases that must be carefully evaluated before operating a new route. The occurrence of engine or pressurization failures can have a significant impact on flight altitudes, and therefore, increases constraints over mountainous areas.

For flights over mountainous areas, a route study is necessary to evaluate if an acceptable escape procedure is possible or not, when a failure occurs at the worst moment during flight. If it is possible, it must be clearly defined and indicated to the pilots. If it is not possible, a new route must be found.

A route study must be performed in accordance with airworthiness requirements, detailed in the following sections.

As a general rule, engine or pressurization failures must be considered to occur at the most critical points along the intended route. However, because depressurization profiles and engine failure profiles are different, the critical points may be different between the two failure cases. It is important to note that regulations do not require to consider performance to cope with the simultaneous failure of both engine and cabin pressurization.

When both failure cases are managed separately, the number of critical points and the number of escape routes increase, resulting in more complexity, increased crew workload and higher risk of error.

In order to limit crew workload and reduce the risk of error, the Operator should, if possible, define the same critical points for both failure cases. The route study should then be based on the most penalizing descent profile. (Illustration E-13).

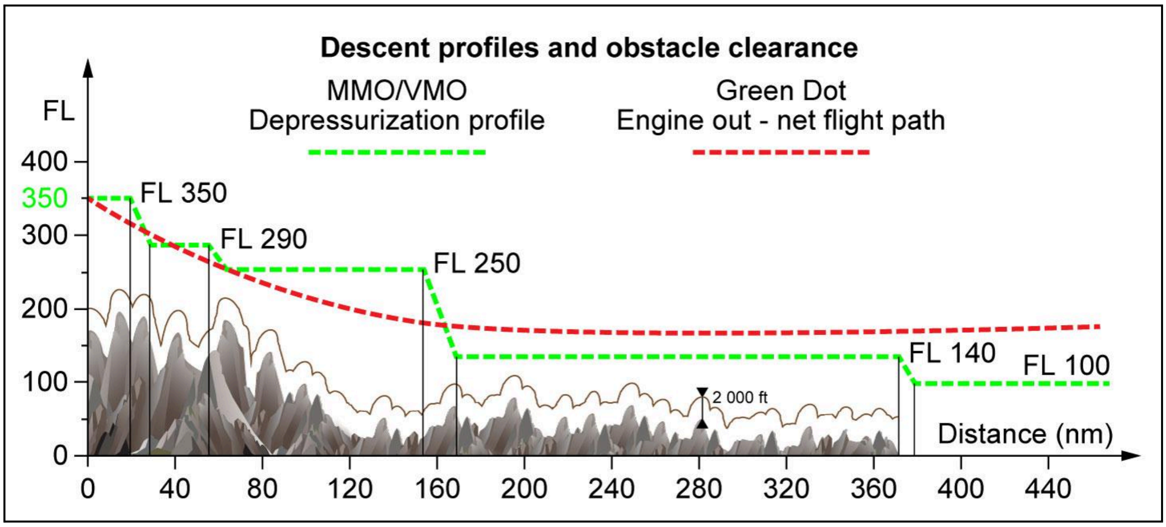


Illustration E-13: A319 Descent Profiles - Engine + Cabin Pressurization Failures

4.1. Obstacle Clearance – Engine Failure

In case of engine failure, the net flight path needs to clear obstacles by 1 000 ft if the failure occurs during climb and 2 000 ft if the failure occurs in cruise.

The Operator must check that the net flight path clears all terrain and obstacles by the regulatory margins.
The net flight path must be determined based on certified (AFM) performance and conservative assumptions:

- Takeoff weight at departure airport equal to the maximum certified takeoff weight
- Conservative environmental conditions with respect to wind and temperature.

The net flight path is then compared to the terrain and obstacles considered for the study.

This comparison enables the identification of the points (A) and (B) along the critical segment of the route. If an engine failure occurs and if the aircraft initiates a drift down:

- A no-return point (A): The point after which it is not possible to turn back, because the obstacle clearance margin of 2 000 ft on the net flight path is not ensured.
- A continuing point (B): The point after which it is possible to continue on the route because the obstacle clearance margin of 2 000 ft on the net flight path is ensured.

If the no-return point (A) is after the continuing point (B) (Illustration E-14), the procedure should consider several possibilities. If the engine failure occurs:

- Before B: Return
- After A: Continue
- Between A and B: Either return or continue

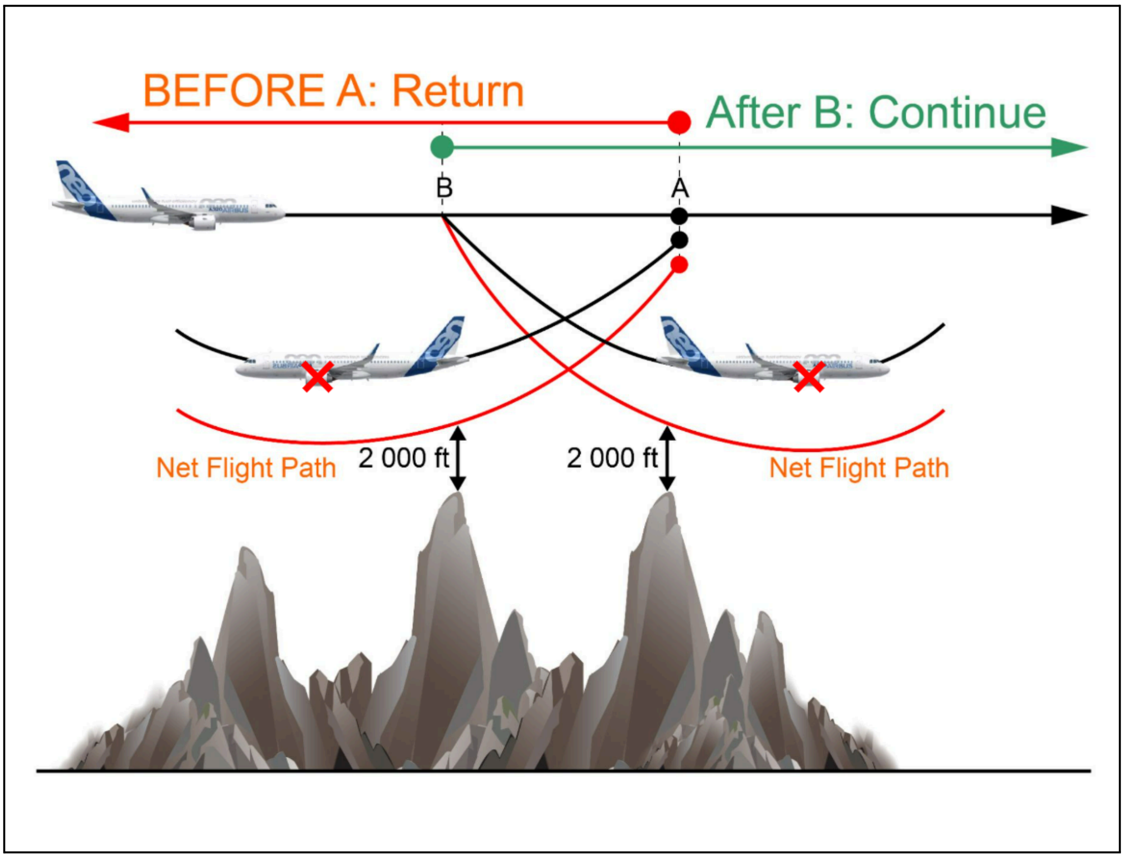


Illustration E-14: No Return Point after the continuing point

If the no-return point (A) is before the continuing point (B) (Illustration E-15), the procedure should consider the aircraft possibility as follows. If the engine failure occurs:

- Before A: Return
- After B: Continue
- Between A and B:
- Establish an escape procedure that ensures the applicable margin for obstacle clearance.
- If it is not possible, consider a weight reduction at takeoff.
- If the weight reduction is not acceptable, consider another route.

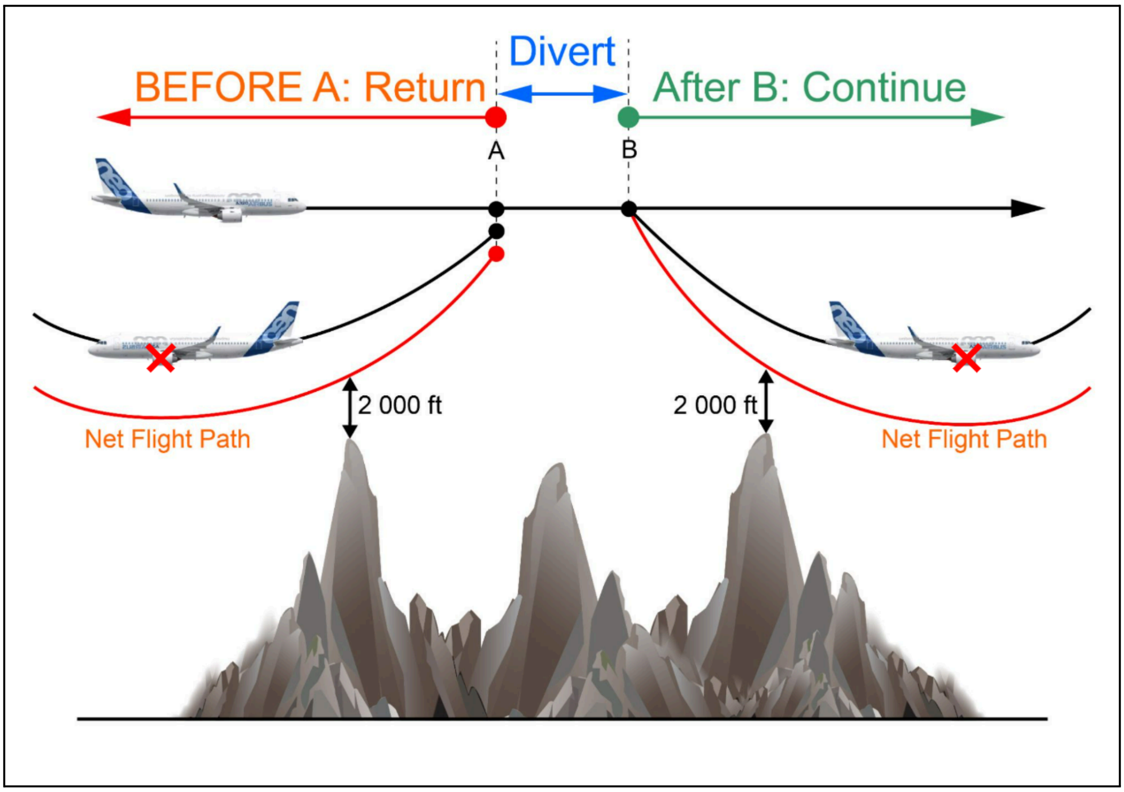


Illustration E-15: No Return Point is before continuing point

4.2. Obstacle Clearance – Cabin Pressurization Failure

A net flight path is not required in the case of cabin pressurization failure. The net flight path is a safety margin when there is a risk that the aircraft cannot maintain the expected descent performance (engine failure case).

In case of cabin depressurization, the aircraft can fly without any altitude constraint below the initial flight level, because all engines are operative. Therefore, the standard minimum flight altitudes apply and the descent profile must clear any terrain and obstacle by 2 000 ft (Illustration E-16).

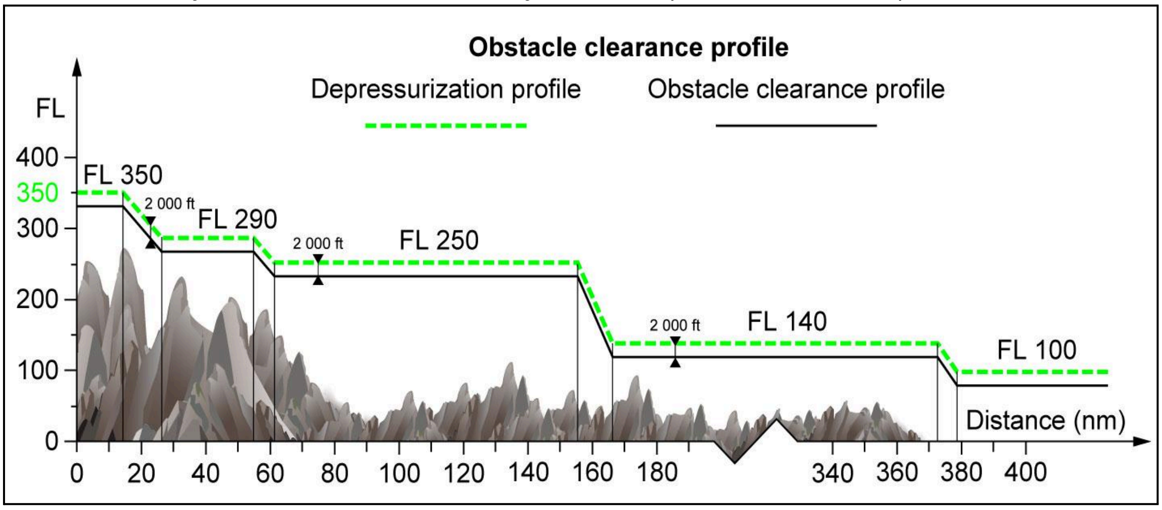


Illustration E-16: A319 Obstacle clearance profile

To check this, the Operator needs to consider all of the constraints of the terrain and obstacles that must be cleared with a 2 000 ft margin. Then, the Operator needs to calculate the "performance" profile (in distance) based on the chemical/gaseous oxygen profile (in time) with the assumption of an emergency descent and cruise speeds. The maximum speed is usually considered.

Comparing the terrain profile and performance profile enables the Operator to determine the critical sector on the route, that includes the following points: if a pressurization failure occurs and if the aircraft initiates an emergency descent, the flight path clears the most penalizing obstacle by the minimum margin of 2 000 ft. A critical point can be:

- A no-return point (A): The point after which it is not possible to turn back, because the obstacle clearance margin of 2 000 ft is not ensured, or the Oxygen system limit is exceeded.
- A continuing point (B): The point after which it is possible to continue on the route because the obstacle clearance margin of 2 000 ft is ensured and the Oxygen system limit is not exceeded.

If the no-return point (A) is after the continuing point (B),the procedure should consider the possibilities as follows, unless another procedure is found to be more appropriate (closer diversion airport, safer escape procedure…). If the pressurization failure occurs:

- Before B: Return
- After A: Continue
- Between A and B: Either return or continue

If the no-return point (A) is before the continuing point (B) (Illustration E-15), the procedure should consider the possibilities as follows, unless another procedure is found to be more appropriate. If the pressurization failure occurs:

- Before A: Return
- After B: Continue
- Between A and B: Establish an escape procedure that ensures the relevant obstacle clearance margin. If it is not possible, consider another route.

F. LANDING

1. INTRODUCTION

To operate an aircraft, an Operator must check landing requirements based on airplane certification (CS 25 / FAR 25), and on operational constraints defined in Air OPS and FAR 121. In normal operations, landing distances are not usually limiting, with landing distances at Maximum Landing Weight achievable in most cases. This results in a reduction in the level of importance associated with landing checks during dispatch. However, landing performance can be significantly limited in the case of inoperative items, adverse external conditions, or go-around constraints. Therefore, a performance assessment is of the highest importance to ensure safe operations.

The following sections describe dispatch and in-flight landing distance definitions, for dry, wet and contaminated runways.
For contaminant definition, refer to the takeoff chapter Definitions of Contaminants.
For operation on grooved or PFC runways, refer to the takeoff chapter Operation on grooved or PFC runways.

2. LANDING LIMITATIONS

2.1. RUNWAY LENGTH: LANDING DISTANCE AVAILABLE (LDA)

2.1.1. LDA with no Obstacle under Landing Path

Air OPS Annex 1 Definitions *FAR 1.1 General definitions*

When there is no obstacle under the landing path, the LDA is the runway length (TORA). The stopway cannot be used for landing distance calculation.

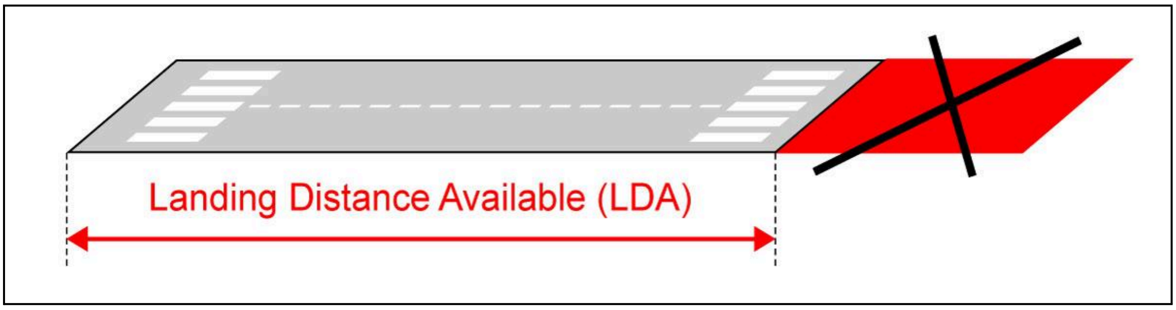


Illustration F-1: Landing Distance Available

2.1.2. LDA with Obstacles under Landing Path

The LDA may be reduced due to obstacles under the landing path.

Annex 8 of ICAO recommendations specifies the dimension of the protection surfaces for landing and approach (i.e. approach funnel).

When there is no obstacle in the approach funnel, as shown in Illustration F-2, the LDA is the full runway length.

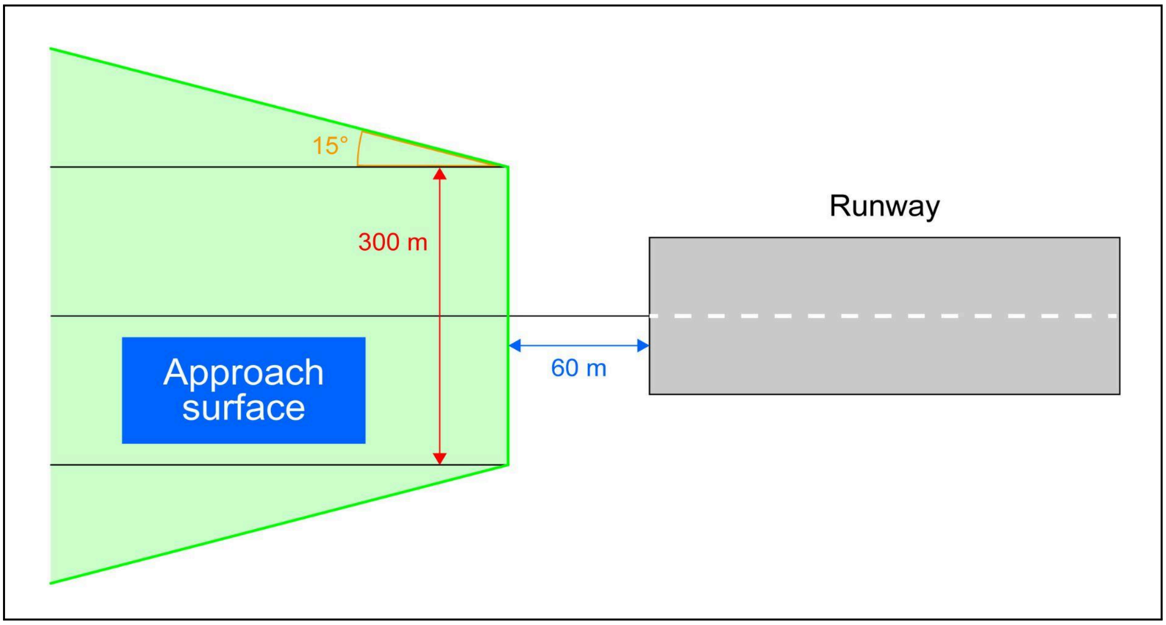


Illustration F-2 : Approach Surface

If there is an obstacle in the approach funnel, a displaced threshold is defined. The displaced threshold considers a 2 % plane from the top of the most penalizing obstacle, plus a 60 m distance margin.

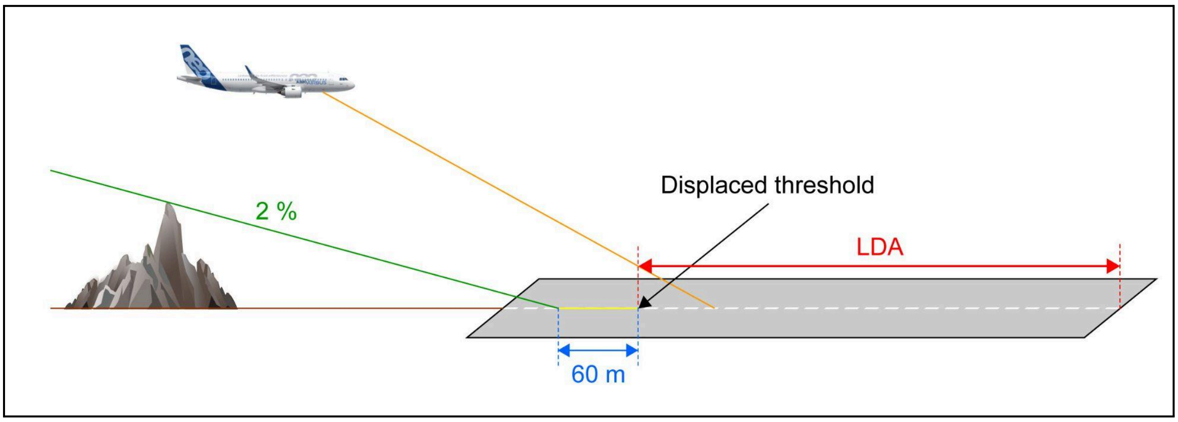


Illustration F-3: Displaced Threshold

In the case of an obstacle, the LDA should be reduced by the displaced threshold length.

2.2. Dispatch Landing Requirements

2.2.1. Actual Landing Distance (ALD)

2.2.1.1. ALD with manual landing

CS 25.125 Subpart B ***FAR 25.125 Subpart B***

"(a)The horizontal distance necessary to land and to come to a complete stop from a point 50 ft above the landing surface must be determined (for standard temperatures, at each weight, altitude and wind within the operational limits established by the applicant for the aeroplane) as follows:

- *The aeroplane must be in the landing configuration*
- *A stabilized approach, with a calibrated airspeed of VLS must be maintained down to the 50 ft."*

In addition to the above extract, several additional regulatory conditions are considered:

- Not excessive vertical acceleration
- Landing on a level, smooth, dry, runway with hard surface
- Acceptable pressure on the wheel braking systems
- Deceleration means other than wheel brakes: spoilers, reversers (except on dry runway), can be used if they are safe and reliable.

Note: For dispatch under MEL, ALD is also certified with degraded deceleration means (spoiler inoperative, one brake inoperative…).

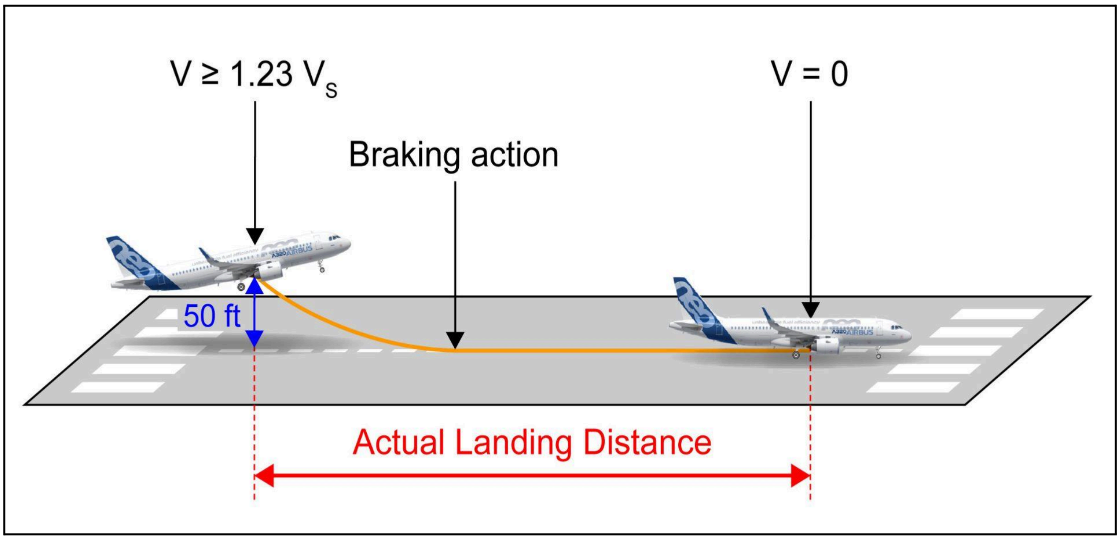


Illustration F-4: Actual Landing Distance

CS 25.1592

"(a) At the discretion of the applicant, supplementary landing performance information may be furnished for aeroplanes landing on slippery wet runways and on runways contaminated with standing water, slush, snow, or ice to be used by operators to support the dispatch of a flight."

AMC 25.1592

"6.4 Landing-distance data for dispatch:
For dispatch computation, performance data for landing on a contaminated runway surface may include credit for reverse thrust [...]; CS 25.125(g) requires to consider the one engine inoperative configuration. The applicant should assume that the engine fails during the landing flare. If this adversely affects the availability of a deceleration device, then the applicant, in compliance with CS 25.125(g), must compare:

> *(a) the normal landing distance without engine failure, using the available deceleration means factored by 1.15; and*
> *(b) the unfactored landing distance, assuming an engine failure in the landing flare and loss of availability of any related deceleration means.*

The scheduled landing distance is the longer between (a) and (b) above. Such distance is the minimum landing distance that already includes an operational factor of 1.15."

<u>Note</u>:
For aircraft certified before AMC 25-1592, only AMC 25-1592 6.4(a) is considered.
For Airbus aircraft certified after AMC 25-1592, case (a) is the longest distance.

On dry runways, landing distances are demonstrated with standard temperatures, in accordance with CS/FAR 25. However, on contaminated runways Airbus decided to take into account the influence of temperature on landing distance demonstration. This ensures additional safety because it provides a conservative ALD.

2.2.1.2. ALD with Automatic Landing

CS AWO

The ALD must be established and published in the aircraft Flight Manual, if it exceeds the manual landing distance that is expected.

On a dry runway, the ALD in autoland is defined as follows:

$$\boxed{ALD = (Da + Dg)}$$

Where: Da is the airborne phase distance.
Dg is the ground phase distance.

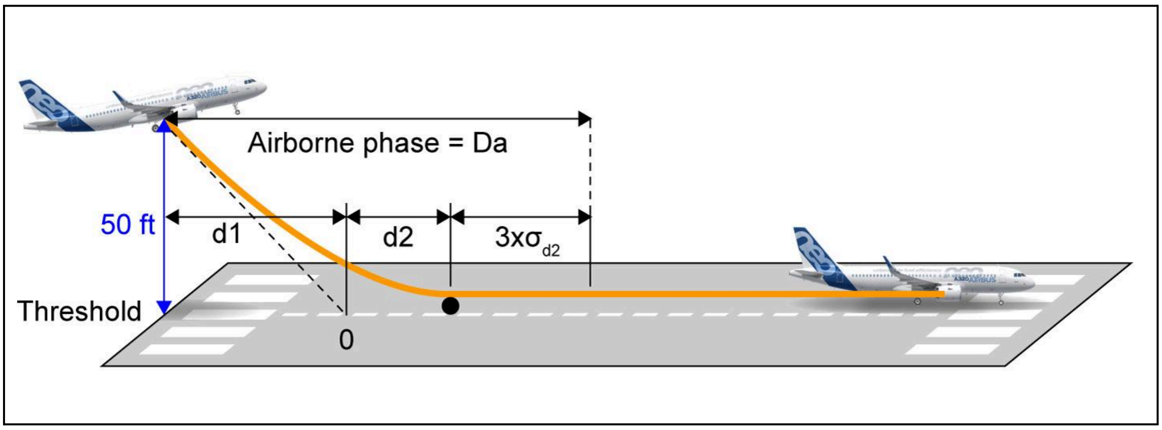


Illustration F-5 : Airborne Phase

The airborne phase Da is the distance from the runway threshold up to the beginning of the glidescope (d1), plus the distance from the beginning of the glidescope up to the mean touchdown point (d2), plus three times the standard deviation of d2 (σd2).
The distance from the beginning of the glidescope to the mean touchdown point (d2), as well as its corresponding standard deviation (σd2), were established from the results of more than a thousand automatic landings that were simulated.

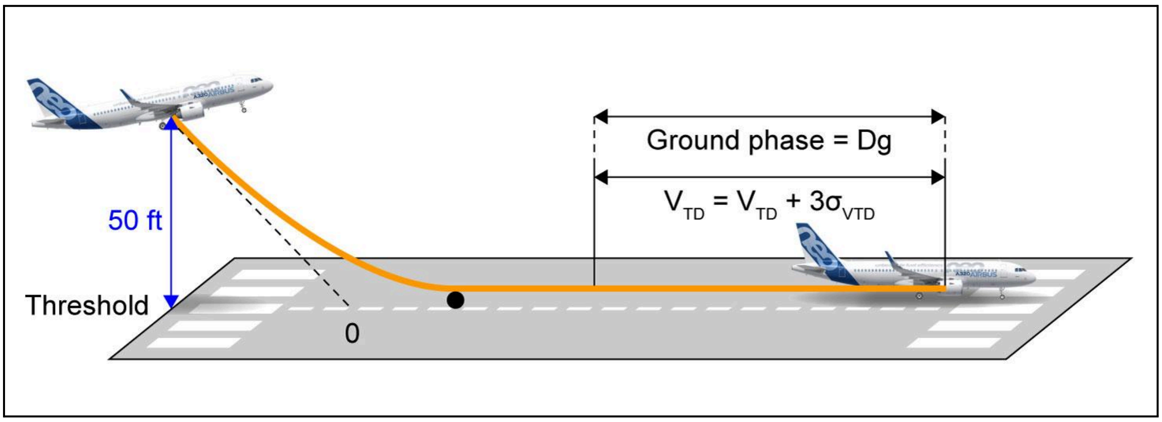


Illustration F-6 : Ground Phase

The Ground Phase Dg for an automatic landing is established as with a manual landing, under the assumption that the touchdown speed is equal to the mean touchdown speed (Vtd), plus three times the standard deviation of this speed (σVTD).

2.2.2. Required Landing Distance (RLD)

Air OPS CAT.POL.A.230 & 235 ***FAR 121.195 (b) Subpart I***

The assumption is "*that the aeroplane will land on the most favorable runway, in still air*". In addition, "*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*".

Before departure, operators must check that the LDA at the destination is at least equal to the RLD for the predicted Landing Weight and forecasted conditions.
The RLD, based on certified landing performance (ALD), was established to assist operators to define the minimum distance required at destination, and permit flight dispatch.

In all cases, the requirement is: **RLD ≤ LDA**

Operators must take into account the runway slope when its value is more than ± 2%. If not, it is considered to be zero.

In the event of an aircraft system failure that is known before dispatch, and that affects the landing distance, the available runway length must be at least equal to the RLD with failure.

2.2.2.1. RLD Dry Runways

Air OPS CAT.POL.A.230 *FAR 121.195 (b)*

The Landing Weight of the aircraft must permit landing within 60 % of the Landing Distance Available at both the destination and any alternate airport.

$$RLD_{dry} = ALD / 0.6 \leq LDA$$

2.2.2.2. RLD Wet Runways

Air OPS CAT.POL.A.235 *FAR 121.195 (d)*

For a runway surface smooth and wet, the RLD must be at least 115 % that of a dry surface.

$$RLD_{wet} = 1.15\ RLD_{dry} \leq LDA$$

A landing distance on a wet runway, shorter than 1.15 RLD_{dry}, but no less than that required on a dry runway, may be used if the Airplane Flight Manual includes specific additional information about landing distances on wet runways. In general, this is not the case for Airbus aircraft.

2.2.2.3. RLD Contaminated Runways

Air OPS CAT.POL.A.235

If the surface is contaminated, the RLD must be at least the longer of either:
- The RLD on a wet runway, or
- 115% of the landing distance determined in accordance with approved contaminated landing distance data.

For

	$ALD_{contaminated} \times 1.15$
$RLD_{contaminated}$ = the highest value of	or
	RLD_{wet}

contaminated runways, the manufacturer must provide landing performance for speed, V, at 50 ft above the airport so that:

$$1.23\ V_{S1g} \leq V \leq 1.23\ V_{S1g} + 10\ kt$$

In specific contaminated runway cases, the manufacturer can provide detailed instructions that include antiskid, reverse, airbrakes, or spoiler. In the most critical cases, landing can be prohibited.

2.2.2.4. RLD with Automatic Landing

Regulations define the RLD for an automatic landing on a dry runway as 1.15 times the ALD in automatic landing.

This distance must be used for automatic landing, when it is longer than the RLD in manual mode.

	$ALD_{automatic} \times 1.15$
$RLD_{automatic}$ = the highest value of	or
	RLD_{manual}

2.2.3. Conclusion

- Landing Weight must satisfy the structural constraints. Therefore, the first limitation is:

  LW ≤ maximum structural landing weight

- Landing Weight is limited by aircraft performance (runway limitations and go-around limitations). Therefore, the second condition is:

  LW ≤ maximum performance landing weight

- Therefore, from these two conditions, it is possible to define the *maximum permitted landing weight called maximum regulatory landing weight (MLW):*

	Maximum Structural Landing weight
MLW = the minimum of	or
	Maximum landing Weight limited by performance

2.3. In-Flight requirements – Landing Distance At the Time of Arrival (LDTA)

2.3.1. Introduction

CS 25.1592 Subpart G
AMC 25.1592

FAR 25.1592 Subpart G
AC 25-32

"CS/FAR 25.1592
(b) Landing-distance information must be furnished for assessing the landing performance at the time of arrival on dry, wet, slippery wet runways, and runways contaminated with standing water, slush, snow, or ice."

ALD and RLD may not provide sufficient accuracy for operations. CS25.1592 defines a landing distance calculation that is more operational: Landing Distance At the Time of Arrival.

As part of the approach preparation, the flight crew should always make an in-flight performance calculation, each time conditions change from the assumptions made at dispatch, particularly in the following cases:
- Runway change,
- Degradation of the runway conditions since dispatch,
- In-flight failure that affects the landing performance.

The LDTA model is designed to be consistent with an operational landing in terms of speed loss between threshold and touchdown (flare technique), and in terms of braking technique, use of reversers and runway surface condition.

The operational model takes into account:
- Approach speed
- Pressure altitude
- Outside temperature and wind
- Runway slope

<u>Note</u>: In Airbus documentation, the following terms are also used to refer to LDTA: In Flight Landing Distance (IFLD), Landing Distance (LD), Operational Landing Distance (OLD).

2.3.2. Air Distance

AMC 25.1592
chapter 6.1

"[...] 'air distance' is defined as the distance from an aeroplane height of 15 m (50 ft) above the landing surface to the point of the main-gear touchdown."
"[...] The [...] air distance represents a flare time of 7 sec and a touchdown speed (VTD) of 96 % of the VAPP."

2.3.3. Ground Distance

The ground distance is the distance from the point of the main gear touchdown to the point where the aircraft comes to a stop.
It depends on the touchdown speed and the runway surface condition.

2.3.4. Touchdown Speed

As detailed in the section 2.3.2 Air Distance, the touchdown speed depends on the approach speed (VAPP).

AMC 25.1592
chapter 6.1

"[...] The VAPP should be consistent with the procedures recommended by the applicant, including any speed additives, e.g. those that may be used due to winds or icing conditions. The applicant should also provide the effects of higher speeds, to account for variations that occur in operations or are caused by the operating procedures of individual operators."

The approach speed is equal to VLS, plus additional corrections for the following:

- A/THR
- Ice Accretion
- Headwind
- Pilot speed increment.

2.3.5. Runway Surface Condition

The airport reports the runway condition, based on six codes, called Runway Condition Codes (RWYCC). The RWYCC are defined from 6 for a dry runway down to 1 for an icy runway.

AMC 25.1592 *chapter 4*

"RWYCC is a number that is used in the runway condition report and describes the effect of the runway surface condition(s) on the deceleration performance and lateral control of the aeroplane."

Airport operators make an assessment of the runway state, report the type, depth and coverage of the contaminant, and then use the RCAM (cf. Illustration F-7) to report a RWYCC. Airport operators can upgrade or downgrade based on their experience or the current conditions, or reports (automatic or from flight crew) from aircraft that just landed. Aerodrome operators report this information in a format known as SNOWTAM, or through communication with ATC.
Flight crew also use the RCAM to evaluate the deceleration, and directional control. They need to report a PIREP if the conditions are worse than the published RWYCC.

RUNWAY CONDITION ASSESSMENT MATRIX FOR LANDING

Runway Surface Conditions		Observations on Deceleration and Directional Control	Related Landing Performance	
Runway State or / and Runway Contaminant	**AIREP**		**RWYCC**	**Level**
Dry	-	-	6	DRY
Damp **Wet:** Up to 3 mm (1/8 in) of water **Slush:** Up to 3 mm (1/8 in) **Dry Snow:** Up to 3 mm (1/8 in) **Wet Snow:** Up to 3 mm (1/8 in) **Frost**	Good	Braking deceleration is normal for the wheel braking effort applied. Directional control is normal.	5	GOOD
Compacted Snow: OAT at or below -15 °C	Good to Medium	Braking deceleration and controllability is between Good and Medium.	4	GOOD TO MEDIUM
Dry Snow: More than 3 mm (1/8 in), up to 100 mm (4 in) **Wet Snow:** More than 3 mm (1/8 in), up to 30 mm (6/5 in) **Dry Snow over Compacted Snow** **Wet Snow over Compacted Snow** **Compacted Snow:** OAT above -15 °C **Slippery Wet**	Medium	Braking deceleration is noticeably reduced for the wheel braking effort applied. Directional control may be reduced.	3	MEDIUM
Standing Water: More than 3 mm (1/8 in), up to 15 mm (3/5 in) **Slush:** (3) More than 3 mm (1/8 in), up to 15 mm (3/5 in)	Medium to Poor	Braking deceleration and controllability is between Medium and Poor. Potential for Hydroplaning exists.	2	MEDIUM TO POOR
Ice (cold and dry)	Poor	Braking deceleration is significantly reduced for the wheel braking effort applied. Directional control may be significantly reduced.	1	POOR
Wet Ice **Water on top of Compacted Snow** **Dry Snow or Wet Snow over Ice**	Less than Poor	Braking deceleration is minimal to non-existent for the wheel braking effort applied. Directional control may be uncertain.	0	-

Illustration F-7: Runway Condition Assessment Matrix (RCAM)

2.3.6. Safety Margins

Air OPS CAT.OP.MPA.303

"(a) No approach to land shall be continued unless the landing distance available (LDA) on the intended runway is at least 115 % of the landing distance at the estimated time of landing [...]."

EASA requires a minimum of a 15 % margin to be applied on the LDTA.
In Airbus documentation, the LDTA with the margin is often referred to as Factored Landing Distance (FLD).
This 15 % increment serves to provide a margin to take into account variations in operational parameters that are included in the LDTA calculation.

2.3.7. In-Flight Failure

Currently, the regulations do not provide specific guidance for LDTA calculation in the case of a failure.

Airbus provides methods to compute landing distance in the case of a failure. A failure may affect the airborne phase, the VAPP and/or the ground distance.

For a failure that does not affect the airborne phase: the air distance is the same as without failure.
In the case of a failure that affects the airborne phase (e.g. "slats fault"): the air distance is based on 7 seconds with a touchdown speed of 99 % of VAPP.

For the purpose of a performance computation with a failure, Airbus defines the Vref as the VLS in CONF FULL, plus a speed increment due to the failure (ΔVref).

The regulations do not provide specific guidance on the safety margin to apply in the case of system(s) failure(s).
Airbus position is that the 15 % margin may be disregarded in case of emergency.

2.4. Factors of Influence

2.4.1. Pressure Altitude and Temperature

For Airbus Fly-by-Wire aircraft, the approach speed, VAPP, is equal to 1.23 V_{S1g}. However, the corresponding TAS increases with the pressure altitude and temperature.

$$Z_p \text{ or } OAT \nearrow \Rightarrow \rho \searrow \Rightarrow TAS \nearrow$$

Therefore, the landing distance will also increase.

$$Z_p \text{ or } OAT \nearrow \Rightarrow \text{Landing Distance} \nearrow$$

The landing distances calculation at dispatch on a dry runway considers ISA conditions. The dispatch landing distance does not depend on OAT variations, however an additional safety margin is applied to account for the influence of temperature variation.

2.4.2. Wind

CS 25.125 Subpart B ***FAR 25.125 Subpart B***

"(f) The landing distance data must include correction factors for not more than 50% of the nominal wind components along the landing path opposite to the direction of landing, and not less than 150% of the nominal wind components along the landing path in the direction of landing.

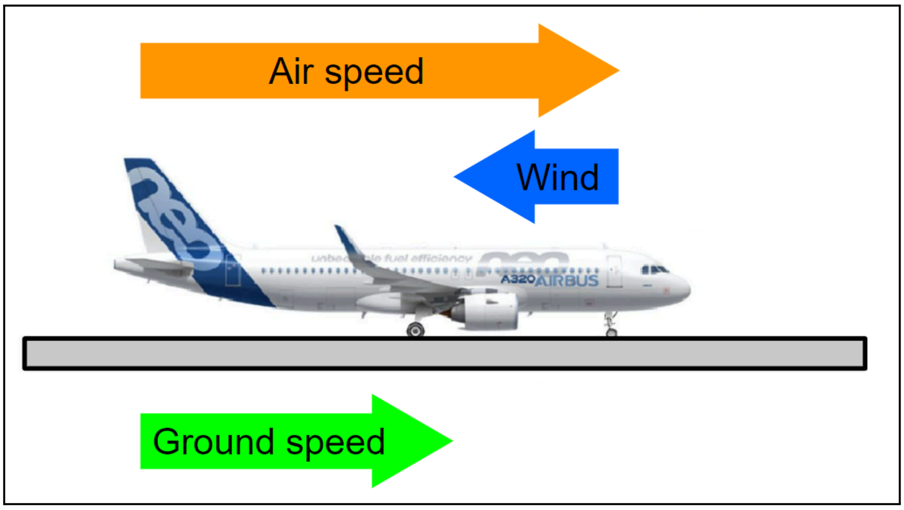


Illustration F8: Headwind ⇒ Landing distance □

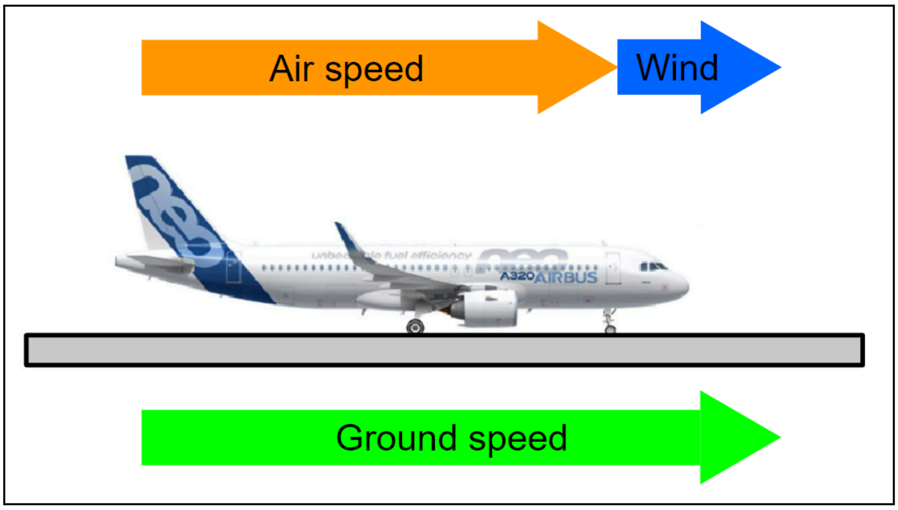


Illustration F9: Tailwind ⇒ Landing distance □

2.4.3. Runway Slope

An upward slope increases the stopping capability of the aircraft, and therefore, decreases landing distance.

Upward slope ⇒ Landing distance ↘
Downward slope ⇒ Landing distance ↗

The landing distances calculation at dispatch on a dry or wet surface only consider the runway slope when the value of the slope is more than ± 2 %. If not, it is considered to be zero.

2.4.4. Runway Conditions

The definition of runway conditions is the same as for takeoff. When the runway is contaminated, landing performance is affected by the friction coefficient of the runway and the precipitation drag due to contaminants.

Friction coefficient ↘ ⇒ Landing distance ↗
Precipitation drag ↗ ⇒ Landing distance ↘

2.4.5. Aircraft Configuration: Flap Setting

Several landing configurations are possible for landing: for example CONF 3 or CONF FULL.

A higher flap deflection results in an increase in the lift coefficient (C_L), and in the wing surface. With a higher flap deflection, it is therefore possible to reduce speed so that the aircraft will need a shorter distance to land (V_{S1G} CONF FULL < V_{S1G} CONF 3).

When wing flap deflection increases, landing distance decreases.

Wing Flap Deflection ↗ ⇒ Landing distance ↘

2.4.6. Aircraft Speeds: Approach

For an Airbus fly-by-wire aircraft the approach speed (V_{APP}) is equal to 1.23 V_{S1g}. However, this speed can be increased due to corrections related to wind, A/THR use and ice accretion. The pilot can also apply a discretionary speed increment (DVpilot) in case of turbulence.

A higher V_{APP} results in an increase in the landing distance.

V_{APP} ↗ ⇒ Landing distance ↗

2.5. Dispatch VS. In-Flight - Landing Distances Performance Checks

As seen in the chapter Dispatch Landing Requirements:

RLD ≤ LDA

In addition:

Air OPS CAT.POL.A.235 Landing - wet and contaminated runways

"The LDTA required by CAT.OP.MPA.303 may, in some cases, and in particular on wet or contaminated runways, exceed the landing distance considered at the time of dispatch."

CAT.POL.A.235 states that the FLD computation at descent preparation may exceed the LDA, even without significant changes in computation assumptions, when compared to dispatch.
Therefore, particularly for wet and contaminated runways, to anticipate a risk of diversion, both RLD and FLD should be checked at dispatch:

RLD ≤ LDA
and
FLD ≤ LDA

2.6. Overweight Landing Requirements

For overweight landing, refer to the chapter Return to Land in the Takeoff section.

3. Go-Around limitations

Flight crew may have to stop an approach and perform a go-around.
In this case, minimum climb gradients are defined in certification and operational regulations.

3.1. Certified Go-Around Gradients

In terms of certification, the aircraft manufacturer must demonstrate a minimum climb capability of the aircraft with one engine inoperative. The gradient is calculated at a specific altitude, and it does not consider a flight path. The minimum gradients to be checked are defined in the regulation.

The minimum gradient does not consider obstacle clearance since the certification requirement is not specific to an airport or runway.

3.1.1. Approach Climb

CS 25.121 Subpart B ***FAR 25.121 Subpart B***

"(d) Approach. In a configuration corresponding to the normal all-engines-operating procedure in which VSR for this configuration does not exceed 110% of the VSR for the related all-engines-operating landing configuration:

(1) steady gradient of climb may not be less than 2·1% for two-engined aeroplanes, 2·4% for three-engined aeroplanes and 2·7% for four-engined aeroplanes, with –

(i) The critical engine inoperative, the remaining engines at the go-around power or thrust setting;

(ii) The maximum landing weight;

(iii) A climb speed established in connection with normal landing procedures, but not more than 1.4 VSR; and

(iv) Landing gear retracted.

(2) The requirements of sub-paragraph (d)(1) of this paragraph must be met:

(i) In non-icing conditions; and

(ii) In icing conditions with the most critical of the Approach Ice accretion(s) [...]. The climb speed selected for non-icing conditions may be used if the climb speed for icing conditions, computed in accordance with sub-paragraph (d)(1)(iii) of this paragraph, does not exceed that for non-icing conditions by more than the greater of 5.6 km/h (3 knots) CAS or 3%."

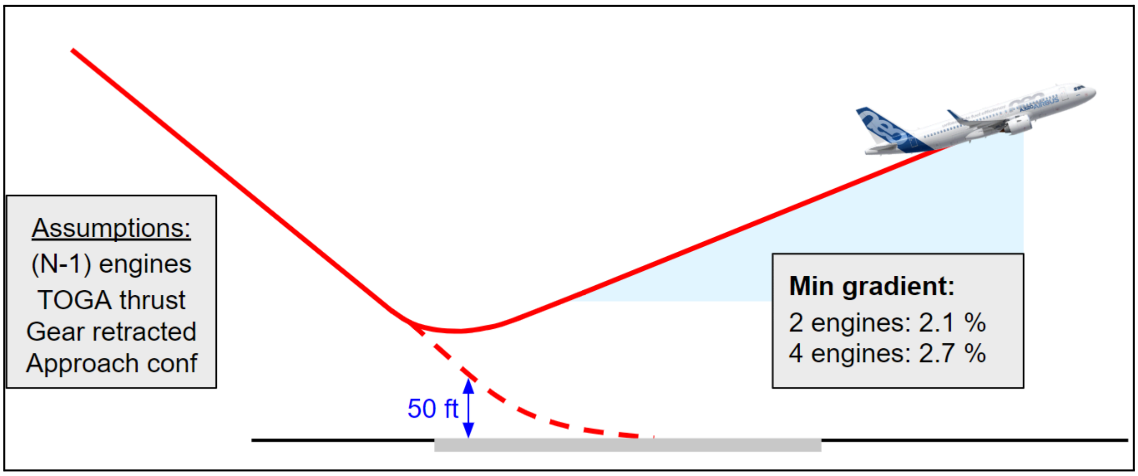


Illustration F10: Regulatory minimum approach climb gradient requirements

CS/FAR 25.121 defines the missed approach climb capability requirements of an aircraft, with one engine inoperative. The reason for the "Approach Climb" wording is that go-around performance is not based on landing configuration.

For example, for landing in configuration Full, the approach climb gradient is computed in configuration 3.

3.1.1.1. Computation Assumptions

- One engine inoperative
- TOGA thrust
- Landing gear UP
- Slats and flaps in approach configuration (CONF 2 or 3 in most cases)
- $V \geq 1.23\ V_{S1g}$
- $V \geq V_{MCL}$

(the maximum value depends on each aircraft type certification).

3.1.1.2. Requirements

The minimum gradients to be demonstrated:

		Approach Climb Gradient (%)
Minimum climb gradient one engine out	Twin	2.1 %
	Quad	2.7 %

Illustration F-11: Minimum Approach Climb Gradient Requirement

3.1.2. Landing Climb

CS 25.119 Subpart B ***FAR 25.119 Subpart B***

"CS/FAR 25.119 Landing climb: all engines operating
In the landing configuration, the steady gradient of climb may not be less than 3·2% [...]; and

(a) In non-icing conditions, with a climb speed of VREF determined in accordance with CS 25.125(b)(2)(i); and
(b) In icing conditions with the most critical of the "Landing Ice" accretion(s) [...], and with a climb speed of VREF determined in accordance with CS 25.125(b)(2)(i)."

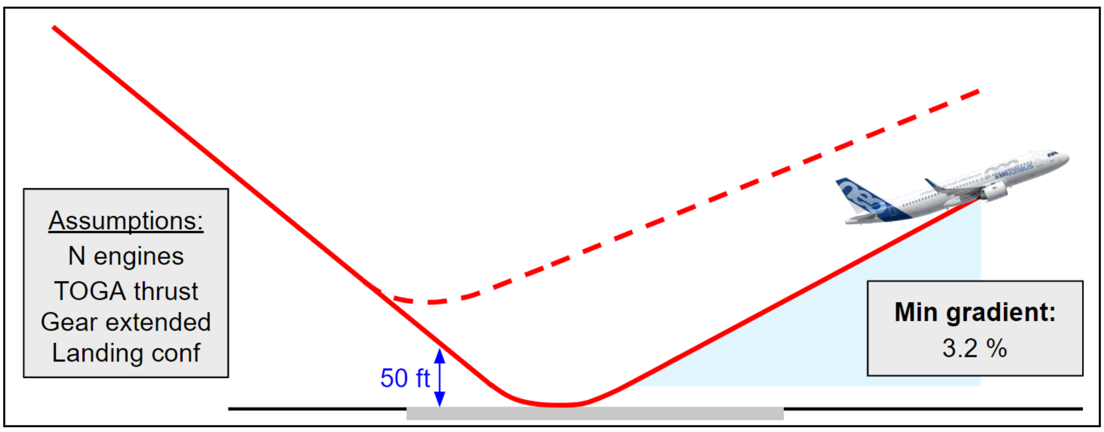


Illustration F-12: Minimum Landing Climb Gradient Requirement

The objective of the landing climb requirement is to ensure aircraft climb capability in the case of a Missed Approach with all engines operating. The reason for the "Landing Climb" wording is that go-around performance is based on landing configuration.

3.1.2.1. Computation Assumptions

- All engines operative
- Thrust available 8 seconds after start of thrust control movement from minimum flight idle to TOGA thrust
- Landing gear DOWN
- Slats and flaps in landing configuration (e.g. CONF 3 or FULL)
- $1.13\ V_{S1g} \leq V \leq 1.23\ V_{S1g}$
- $V \geq V_{MCL}$.

3.1.2.2. Requirements

The minimum landing climb gradient to be demonstrated is 3.2 % for all aircraft types.

For all Airbus aircraft, the approach climb requirement is more limiting than the landing climb requirement.

3.2. Operational Requirements

Certification standards do not define a regulatory net flight path for obstacle clearance in the go-around phase. However, airports publish Missed Approach Procedures that take into account lateral and vertical obstacle clearance margins.

3.2.1. Published Gradient for Missed Approach

For a specific approach, a Missed Approach procedure provides lateral and vertical guidance in the case of a go-around down to minimum decision altitude (DA) or minimum decision height (DH).

The PANS-OPS Vol II (Doc 8168) provides standards and recommendations to write Missed Approach Procedures.

Based on PANS-OPS, the Missed Approach procedure design criteria are outlined as follows:

- Established for each instrument approach
- Defines a start of procedure (start of climb (SOC) and an end of procedure, Missed Approach Altitude (MAA).
- MAA must be sufficient to permit:
  - The start of another approach, or
  - Return to a dedicated holding pattern, or
  - Continuation of en-route flight.
- Ensure acceptable obstacle clearance during the go-around phase
- Takes into account ATC and airspace constraints

For a specific runway, the published procedures may have Missed Approach gradients and/or Missed Approach altitudes that are different depending on the approach type, to ensure compliance with obstacle clearance.

The PANS-OPS considers an obstacle protection surface from the Start of Climb (SOC) to the Missed Approach altitude. If a 2.5 % plan ensures that all obstacles are cleared, no gradient is published on the chart and the 2.5 % gradient is applicable.

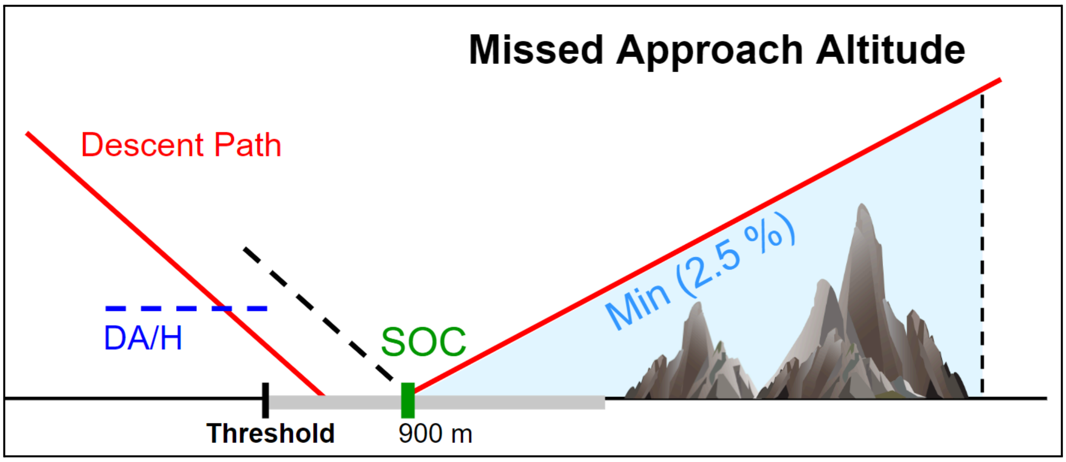


Illustration F-13: Minimum Published Gradient for Missed Approach

However, a go-around climb gradient of 2.5 % may not be sufficient to satisfy the obstacle constraints. If the minimum gradient required to clear the obstacle exceeds 2.5%, the minimum gradient value is published in the charts.

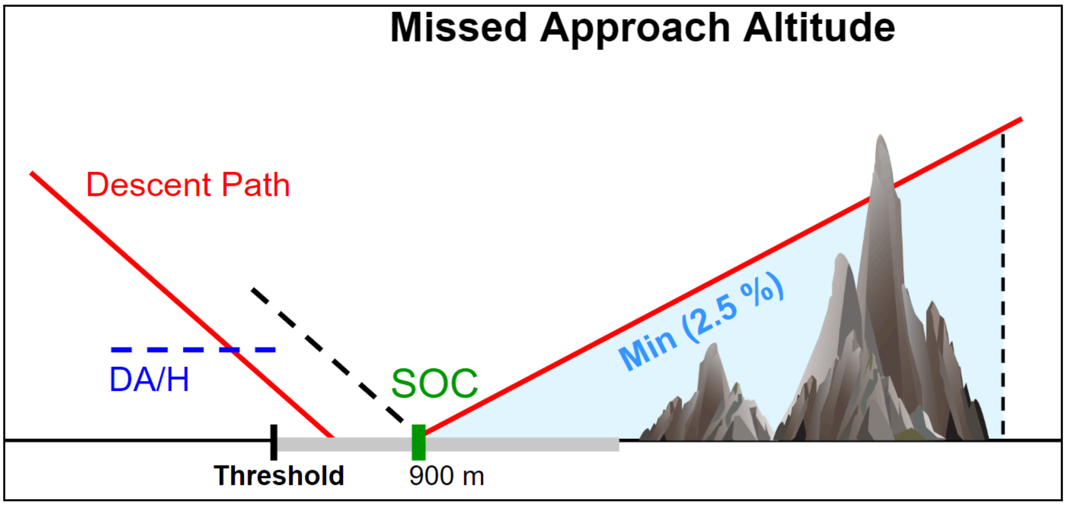


Illustration F-14: Minimum Approach Climb Gradient not Satisfied Due to Obstacle

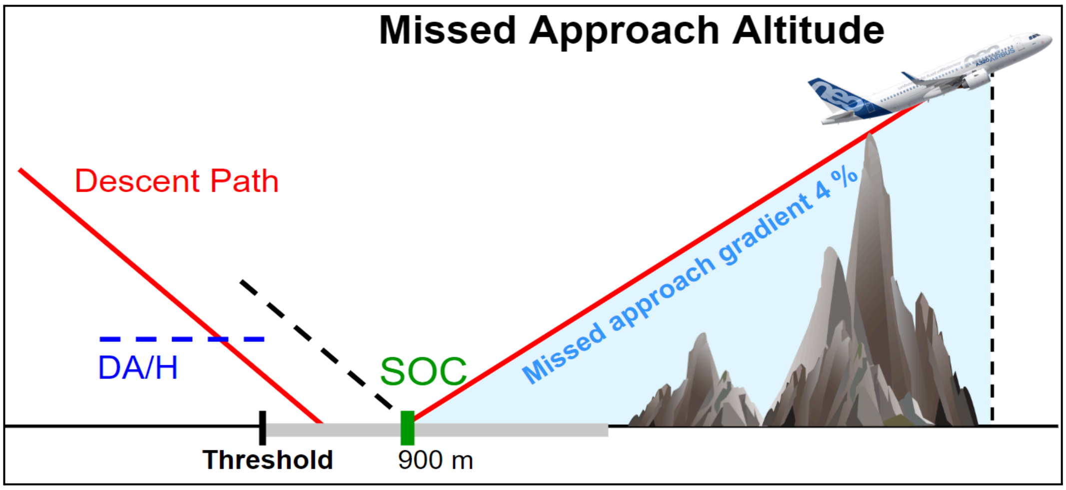


Illustration F-15: Published Missed Approach Gradient Increased to Satisfy Obstacle Constraint

The go-around gradient value is also associated with the decision height (DA/H) of the procedure. When the decision height of the procedure is increased, it is possible to define a lower minimum go-around climb gradient, and that still ensures the obstacle clearance.

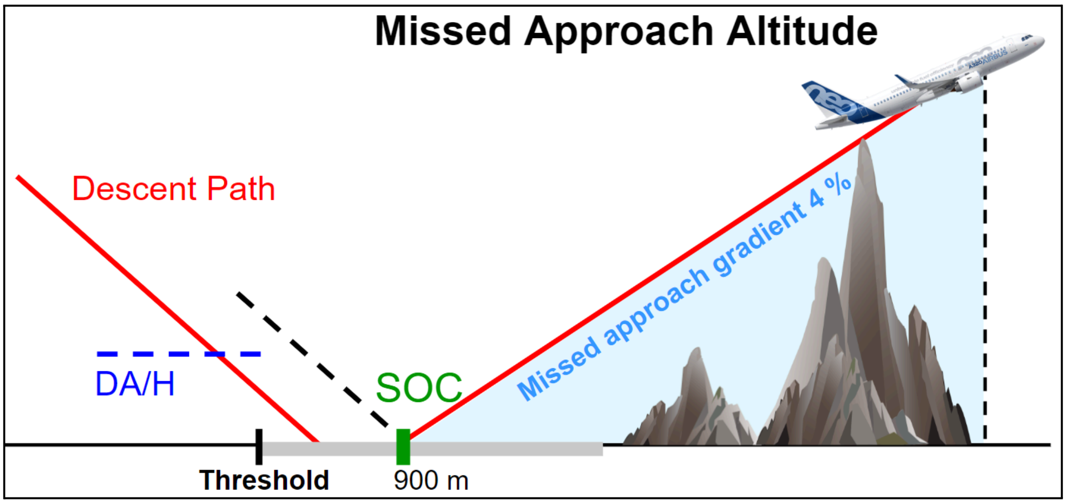


Illustration F-16: Decision Height at Threshold Elevation

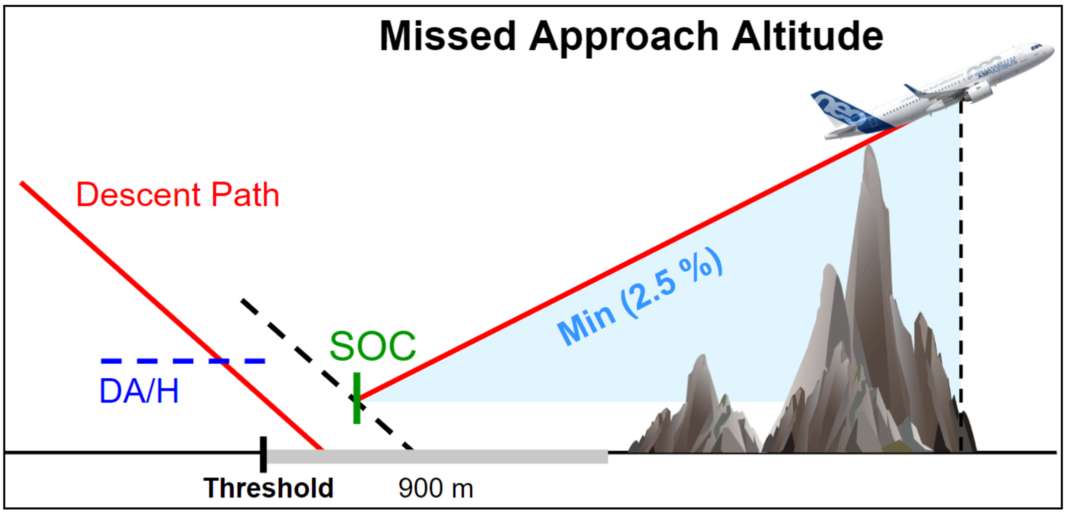


Illustration F-17: Decision height increased to meet the minimum missed approach gradient

Therefore, the published go-around gradient defines an obstacle protection surface that ensures obstacle clearance.

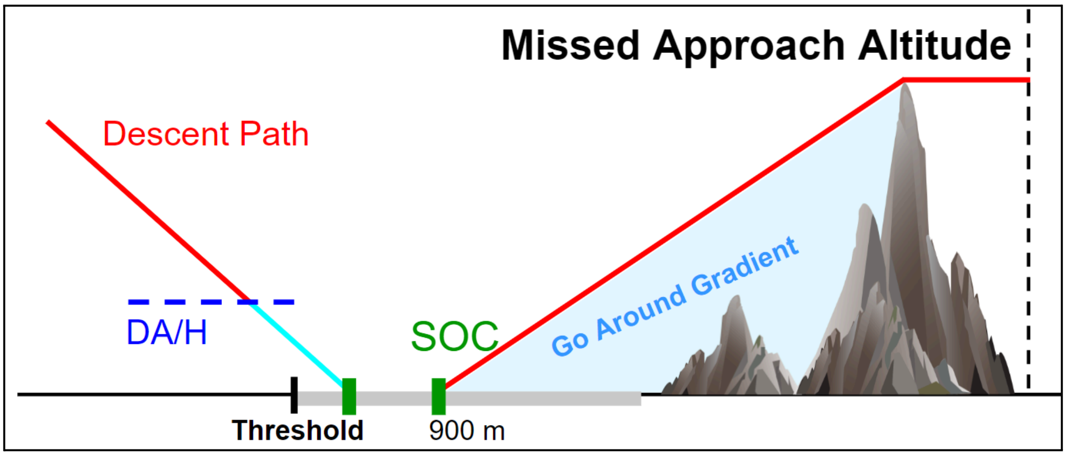


Illustration F-18: Obstacle Protection Surface

During the go around procedure, the flight path from the Start of Climb to the Missed Approach Altitude must be above the obstacle protection surface that ensures obstacle clearance. The obstacle protection surface defines a minimum average gradient.

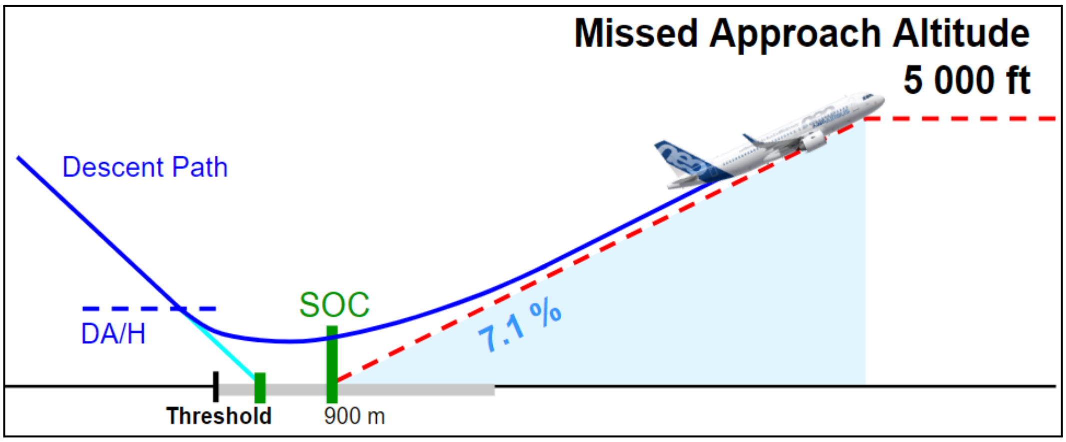


Illustration F-19: Flight path from Start of Climb to Missed Approach Altitude

The average go-around gradient must be checked from the SOC. However, the SOC is a PANS OPS procedure design parameter and is not published on the approach chart.

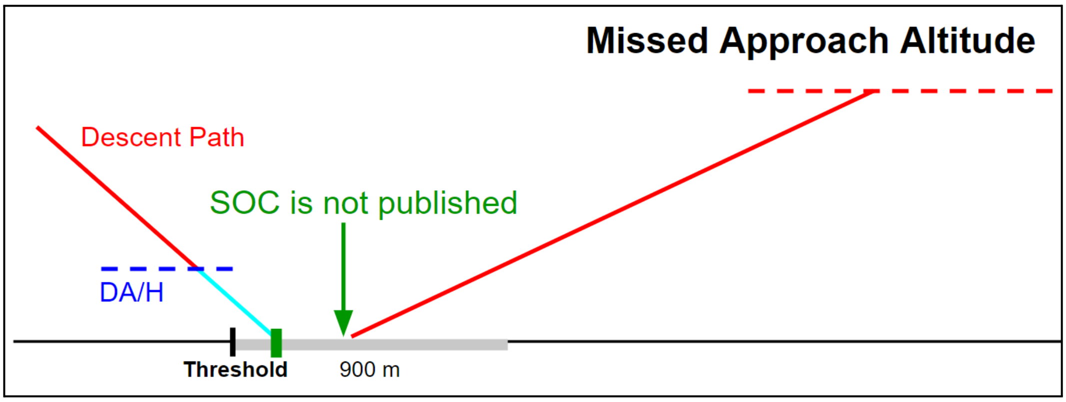


Illustration F-20: Published Descent Path (SOC is not published)

Therefore, one option to demonstrate published gradient compliance is to consider the gradient from the point when the aircraft has a positive climb gradient up to the Missed Approach Altitude. This option is more conservative than if the gradient from the SOC is considered.

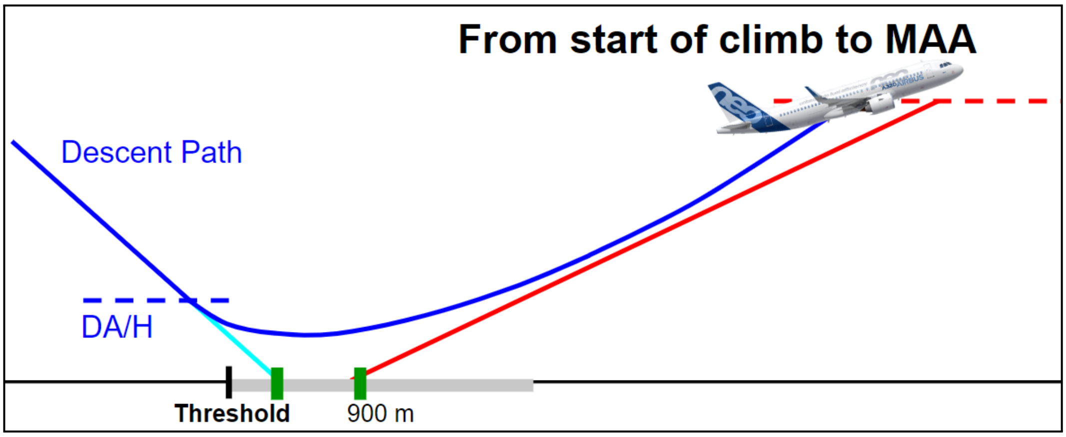


Illustration F-21: Flight Path from Start of Climb to Missed Approach Altitude

The PANS-OPS provides recommendations to design Missed Approach procedures that consider normal operations (all engine operative).

However, the regulation requires that compliance with a go-around procedure constraint must be checked one engine inoperative.

CAT.POL.A.200 General
Regulation (EU) No 965/2012

"(a) The approved performance data in the AFM shall be supplemented as necessary with other data if the approved performance data in the AFM is insufficient in respect of items such as:

(1) accounting for reasonably expected adverse operating conditions such as take-off and landing on contaminated runways; and

(2) consideration of engine failure in all flight phases."

AMC2 CAT.POL.A.225
Landing – destination and alternate aerodromes
ED Decision 2014/015/R

"MISSED APPROACH
(a) For instrument approaches with a missed approach climb gradient greater than 2.5 %, the operator should verify that the expected landing mass of the aeroplane allows for a missed approach with a climb gradient equal to or greater than the applicable missed approach gradient in the OEI missed approach configuration and at the associated speed.
(b) For instrument approaches with DH below 200 ft, the operator should verify that the expected landing mass of the aeroplane allows a missed approach gradient of climb, with the critical engine failed and with the speed and configuration used for a missed approach of at least 2.5 %, or the published gradient, whichever is greater."

The Maximum Landing Weight, limited by go-around performance, must satisfy the CS 25.121 requirements (defined in the chapter Approach Climb), CS 25.119 (defined in the chapter Landing Climb), and also CAT.POL.A.200 and AMC2 CAT.POL.A.225.

Therefore, operators need to ensure the aircraft is safe to fly a go-around with one engine inoperative.

Airbus position is that in order to ensure obstacle clearance in case of Missed Approach, the aircraft flight path must remain above the procedure protection surface, with one engine inoperative.

As part of the Operational Performance data, Airbus provides computation tools for the Operator to compute the average climb gradient for a Missed Approach with one engine inoperative. In some cases, this average gradient may penalize the Maximum Landing Weight.

The go-around speed (V_{GA}) can be optimized to improve the climb gradient in the go-around at a fixed weight, or to increase the missed approach limited weight at a fixed gradient. The optimization of the V_{GA} consists of an increase in speed, in the following the range:

$$1.23\ V_{S1g} \leq V_{GA} \leq 1.41\ V_{S1g}$$

The V_{GA} optimization requires the introduction of an acceleration segment before climb in the go-around (from the VAPP to the V_{GA}) in the Missed Approach procedure. Also, it must consider the impact on obstacle clearance in the Missed Approach path, due to the acceleration of the aircraft.

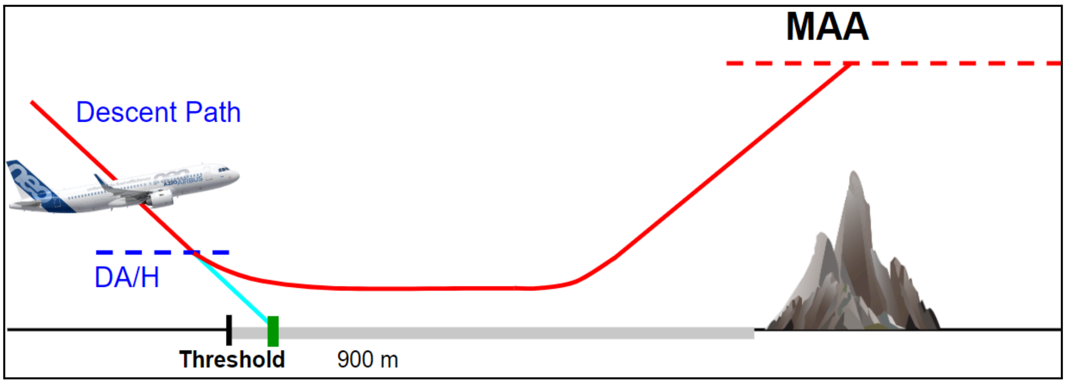


Illustration F-22: Go around speed optimization

Therefore, the go-around speed optimization must only be used if an obstacle check is performed.

The go-around performance can also be increased by increasing the approach speed. However, this is not recommended because a higher VAPP results in longer landing distance.

If it is not possible to comply with the minimum published gradient, the regulation permits the application of alternative means of compliance.

3.2.2. Alternative Means of Compliance

GM1 CAT.POL.A.225
Landing – destination and alternate aerodromes
ED Decision 2014/015/R

"MISSED APPROACH GRADIENT
(a) Where an aeroplane cannot achieve the missed approach gradient specified in AMC2 CAT.POL.A.225, when operating at or near maximum certificated landing mass and in engine-out conditions, the operator has the opportunity to propose an alternative means of compliance to the competent authority demonstrating that a missed approach can be executed safely taking into account appropriate mitigating measures.
(b) The proposal for an alternative means of compliance may involve the following:
(1) considerations to mass, altitude and temperature limitations and wind for the missed approach;
(2) a proposal to increase the DA/H or MDA/H; and
(3) a contingency procedure ensuring a safe route and avoiding obstacles."

FAA - AC 120-91A

"20.b.3.h: Operators may make obstacle clearance assumptions similar to those applied to corresponding takeoff flight paths in the determination of net vertical flightpath clearance or lateral track obstacle clearance."

The Alternative Means of Compliance provides the Operator with a number of options to ensure compliance with the Missed Approach procedure. One option is to retain the published Missed Approach procedure, however, the Operator must check obstacle clearance for each aircraft type in their fleet. The Missed Approach procedure is designed to ensure obstacle clearance for various types of aircraft, and as a result it may be conservative for some aircraft. To validate the obstacle clearance, the Operator can use the takeoff obstacle requirements to ensure sufficient lateral and vertical obstacles margins.

Another option for the Operator is to develop their own contingency procedure for a Missed Approach with One Engine Inoperative. It is possible to design an entirely new procedure that considers a new flight path, or for the Operator to use their own Takeoff procedure with One Engine Inoperative. For both cases, the Operator must ensure appropriate obstacle clearance in the go-around configuration.

The Operator must submit the procedure to the competent authority, in order to obtain the approval of the Alternative Means of Compliance.

3.3. Factors of Influence

3.3.1. Pressure Altitude

TOGA thrust, used for go-around, decreases when pressure altitude increases.

ZP ↗ ⇒ engine thrust ↘

Therefore, in the case of a go-around, a decrease in engine thrust results in a decrease in the air climb gradients.

ZP ↗ ⇒ air climb gradients ↘

3.3.2. Temperature

Engine thrust decreases when the temperature exceeds the reference temperature. Therefore, in case of a go-around, the air climb gradients will decrease.

Temperature ↗ ⇒ air climb gradients ↘

3.3.3. Aircraft Configuration

3.3.3.1. Engine Air bleed

Engine air bleed, for de-icing or air conditioning, results in a decrease in engine thrust.
As a result, air climb gradients for the go-around will decrease.

Engine air bleed ON ⇒ air climb gradients ↘

3.3.3.2. Flap setting

When flap deflection increases, drag increases, and therefore air climb performance decreases.

Wing Flap Deflection ↗	⇒	air climb gradients ↘

For landing at high elevation airports, a lower landing flap may be preferable to increase the go-around performance, if the landing distance is not limiting.

3.3.3.3. Aircraft Speed: Go-Around

When go-around speed (V_{GA}) increases, it increases the lift-drag ratio, and therefore has a positive effect on the climb performance of the aircraft.

V_{GA} ↗	⇒	air climb gradients ↗

Therefore, an increase in the go-around (V_{GA}) speed results in an increase in the air climb gradients in the event of a go-around.

G. FUEL PLANNING AND MANAGEMENT

1. EASA – FUEL/ ENERGY PLANNING AND MANAGEMENT

1.1. INTRODUCTION

The minimum fuel quantity required for the planned route must be calculated for each flight. Currently, Airbus aircraft use fuel as energy, but the regulation anticipates the use of future sources of energy.

Operational documentation must include procedures that permit the flight crew to manage fuel. Procedures must be provided for normal operations and unplanned situations that can occur in flight.

These two features are part of the EASA Fuel Scheme Rules. Since October 2022, three different schemes for fuel planning and in flight fuel management are proposed to the operators:

Air OPS Subpart B
CAT.OP.MPA.180(a)

"Each operator shall establish, implement, and maintain a fuel/energy scheme that is either:

(i) a basic fuel/energy scheme, which shall form the basis for a basic fuel/energy scheme with variations and an individual fuel/energy scheme; the basic fuel/energy scheme derives from a large-scale analysis of safety and operational data from previous performance and experience of the industry, applying scientific principles; the basic fuel/energy scheme shall ensure, in this order, a safe, effective, and efficient operation of the aircraft; or

(ii) a basic fuel/energy scheme with variations, which is a basic fuel/energy scheme where the analysis referred to in point (i) is used to establish a variation to the basic fuel/energy scheme that ensures, in this order, a safe, effective, and efficient operation of the aircraft; or

(iii) an individual fuel/energy scheme, which derives from a comparative analysis of the operator's safety and operational data, applying scientific principles; the analysis is used to establish a fuel/energy scheme with a higher or equivalent level of safety to that of the basic fuel/energy scheme that ensures, in this order, a safe, effective, and efficient operation of the aircraft."

An Operator can select from three different fuel schemes options as follows:

- The basic fuel scheme (e.g. 5 % contingency fuel)
- The basic fuel scheme with variations (e.g 3 % contingency fuel or a statistical contingency fuel and statistical taxi fuel)
- The individual fuel scheme with fuel reduction based on specific criteria and on a statistical database of more than two years.

Each fuel/energy scheme has three policies:

Air OPS Subpart B
CAT.OP.MPA.180(b)

"All fuel/energy schemes shall comprise:
(1) a fuel/energy planning and in-flight re-planning policy;
(2) an aerodrome selection policy; and
(3) an in-flight fuel/energy management policy."

The three fuel policies are connected. For example, the selection of alternate airports has an impact on the fuel reserves. In addition, inaccuracies on planned fuel quantities will have an impact on fuel management during the flight.

These three different fuel schemes were established to make fuel planning and fuel management more flexible for operators, and to enable them, in some cases, to carry less fuel, based on:

- The appropriate selection of alternate airport
- The appropriate in-flight fuel management procedures
- Historical and statistical data.

Since fuel schemes are the responsibility of the Operator and are specific to each airline's operation, no specific guidelines for individual fuel schemes are provided in this document.

1.1. Policy for Fuel/Energy Planning and In-Flight re-planning

1.1.1. Regulatory Fuel/Energy Quantities (Basic and Variations)

1.1.1.1. Introduction

Air OPS Subpart B
CAT.OP.MPA.181(c)

Irrespective of the fuel scheme chosen by the Operator, the minimum fuel quantity (Q) calculated for fuel/energy planning is defined as:

$$Q = taxi\,fuel + TF + CF + AF + FR + Add + XF + DF$$

Where

- **TF** = Trip Fuel
- **CF** = Contingency Fuel
- **AF** = Alternate Fuel
- **FR** = Final Reserve Fuel
- **Add** = Additional Fuel
- **XF** = Extra Fuel
- **DF** = Discretionary Fuel

Illustration G-1 identifies the fuel quantities for the different flight phases of a standard flight plan.

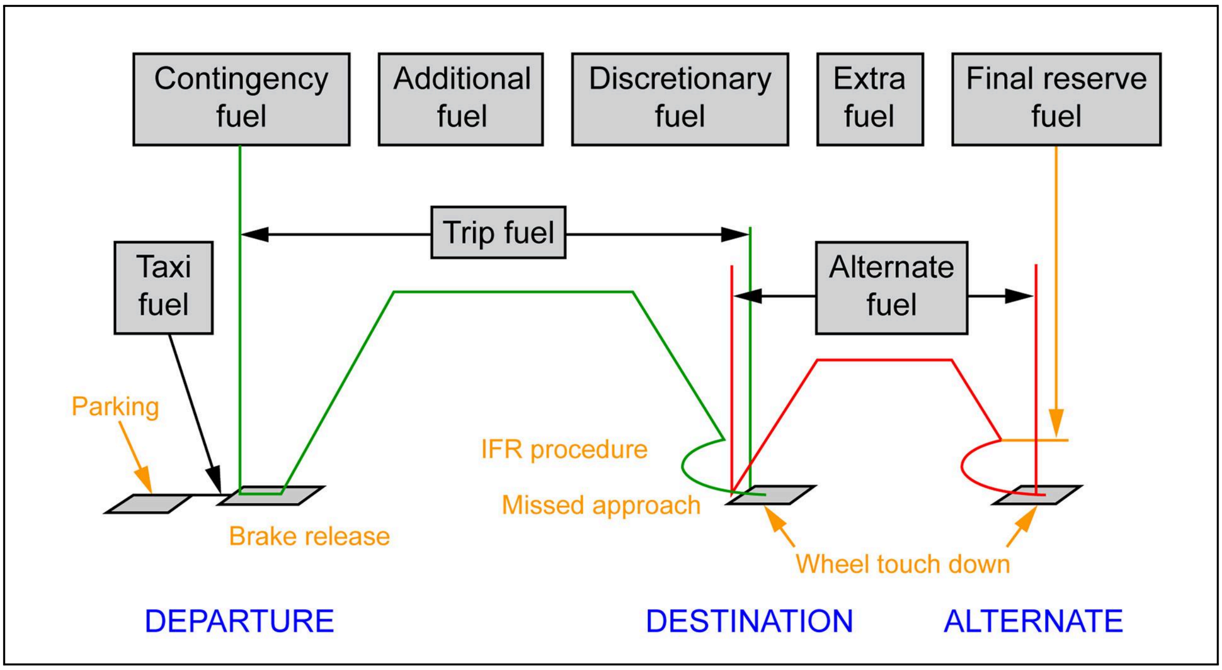


Illustration G-1: Fuel quantities for different phases of flight of a Standard Flight Plan

The regulation defines the conditions that must be considered for each flight in order to correctly adjust the fuel quantities:

Air OPS Subpart B
CAT.OP.MPA.181(b)

"(1) aircraft fuel/energy consumption data;
(2) anticipated masses;
(3) anticipated meteorological conditions;
(4) the effects of deferred maintenance items and/or of configuration deviations;
(5) the expected departure and arrival routing and runways; and
(6) anticipated delays".

Suppliers of flight planning software use the fuel consumption data provided by the manufacturer for each aircraft model. In addition, fuel consumption data that results from fuel consumption monitoring should be used when available:

Air OPS Subpart B
GM1 CAT.OP.MPA.181(b) *Basic Fuel Scheme*

"PLANNING OF FLIGHTS
(b) A flight should be planned by using the most accurate information available. If aircraft-specific data that is derived from a fuel consumption monitoring system is available, this data is used in preference to data that is provided by the aircraft manufacturer. Data that is provided by the aircraft manufacturer should be used only in specific cases, e.g. when introducing a new aircraft type into service."

The operators can find more information on Aircraft Performance Monitoring in the *Getting to Grips with Aircraft Performance Monitoring* brochure.

In addition, the Airbus MMEL and MCDL provide the effects on the fuel consumption of deferred maintenance items and configuration deviations. MMEL and MCDL items can result in an increase in fuel consumption. The effects are taken into account if the MMEL/MCDL items and the associated fuel penalties are defined in the flight planning software, or by manual adjustment of the fuel quantity by the flight dispatcher.

The following chapter outlines the different fuel quantities defined by CAT.OP.MPA.181 (c), and their associated requirements as part of a Basic Fuel Scheme, and of a Basic Fuel Scheme with variations, when applicable.

1.1.1.2. Taxi Fuel/Energy

Air OPS Subpart B
CAT.OP.MPA.181(c)(1)

Quantity "that shall not be less than the amount expected to be used prior to take-off."

1.1.1.2.1. Basic Fuel Scheme

Air OPS Subpart B
AMC1.CAT.OP.MPA.181(a) *Basic Fuel Scheme*

"*The operator should take into account the local conditions at the departure aerodrome and the APU consumption".*

The Operator can estimate the taxi time before takeoff, in terms of operational constraints (e.g. traffic or weather conditions).
In the "Minimum Fuel Requirements" section of the Aircraft Performance Data (APD) manual, Airbus provides the average fuel consumption per minute of the aircraft during taxi. It also includes the APU consumption per hour.
The Operator is, then, able to calculate the taxi fuel quantity with this value and taxi time.

1.1.1.2.2. Basic Fuel Scheme with Variations

Air OPS Subpart B
AMC5.CAT.OP.MPA.181 *Basic Fuel Scheme with variations*

"To calculate taxi fuel for a basic fuel scheme with variations, the operator may use statistical taxi fuel".

The Operator can use historical data on taxi fuel available in their system (e.g. ACARS messages), and define a taxi fuel quantity that is adapted to the departure airport.

1.1.1.3. Trip Fuel/Energy

Air OPS Subpart B
CAT.OP.MPA.181(c)(2)

Quantity "that shall be the amount of fuel/energy that is required to enable the aeroplane to fly from take-off, or from the point of in-flight re-planning, to landing at the destination aerodrome."

Air OPS Subpart B
AMC1 CAT.OP.MPA.181(b) *Basic Fuel Scheme*

"The operator should for trip fuel, include:

- *Fuel for take-off and climb from the aerodrome elevation to the initial cruising level/altitude, taking into account the expected departure routing*
- *Fuel from the top of climb to the top of descent, including any step climb/descent*
- *Fuel from the top of descent to the point where the approach procedure is initiated, taking into account the expected arrival routing*
- *Fuel for making an approach and landing at the destination aerodrome."*

The supplier of the flight planning software may be able to confirm that the calculated trip fuel is compliant with the EASA rules, particularly that the expected SID and STAR are considered.
It may also display the variation in fuel consumption depending on the SID or the STAR that the aircraft flies, in the case of any change in the departure or arrival routes.

1.1.1.4. Contingency Fuel/Energy

Air OPS Subpart B
CAT.OP.MPA.181(c)(3)

Quantity "that shall be the amount of fuel/energy required to compensate for unforeseen factors".

1.1.1.4.1. Basic Fuel Scheme

Air OPS Subpart B
AMC1.CAT.OP.MPA.181(c) *Basic Fuel Scheme*

"Contingency fuel is the greatest of two quantities:

- *5 % of the planned trip fuel or, in the event of in-flight re-planning, 5 % of the trip fuel for the remainder of the flight.*
- *An amount to fly for 5 minutes at holding speed at 1 500 ft (450 m) above the destination aerodrome in standard conditions."*

Flight planning software may be able to determine for each flight the highest quantity in order to comply with the basic fuel/energy scheme for contingency fuel/energy.

In order to provide a minimum reference value for contingency fuel, the Operator can calculate, for a given aircraft type, the fixed value of fuel quantity that corresponds to 5 minutes of flight, in the following conditions:

- At holding speed
- At 1 500 ft
- At MLW
- In standard conditions.

The fuel quantity corresponding to the above conditions can be determined using engineering performance software.

1.1.1.4.2. Basic Fuel Scheme with Variations

Air OPS Subpart B
AMC6.CAT.OP.MPA.181(c) *Basic Fuel Scheme with variations*

"*The contingency fuel should be the fuel described in points (1) or (2), whichever is higher:*

(1) An amount of fuel that should be either:

- *Not less than 3 % of the planned trip fuel, or in the event of in-flight re-planning, 3 % of the trip fuel for the remainder of the flight provided that a fuel en route alternate (fuel ERA) aerodrome is available*
- *An amount of fuel sufficient for 20-minute flying time based upon the planned trip fuel consumption*

- *An amount of fuel based on a statistical fuel method that ensures an appropriate statistical coverage of the deviation from the planned to the actual trip fuel; prior to implementing a statistical fuel method, a continuous 2-year operation is required during which statistical contingency fuel (SCF) data is recorded*

(2) an amount of fuel to fly for 5 minutes at holding speed at 1 500 ft (450 m) above the destination aerodrome in standard conditions."

GM2.CAT.OP.MPA.181 provides an example of statistical contingency fuel.

Air OPS Subpart B
AMC7.CAT.OP.MPA.181 *Basic Fuel Scheme with variations*

AMC7 CAT.OP.MPA.181 provides the location criteria for fuel en route alternate (ERA) in order to reduce the contingency fuel from 5% to 3%:

"The fuel en route alternate (fuel ERA) aerodrome should be located within a circle with a radius equal to 20 % of the total flight plan distance; the centre of this circle lies on the planned route at a distance from the destination aerodrome equal to 25 % of the total flight plan distance, or at least 20 % of the total flight plan distance plus 50 NM, whichever is greater. All distances should be calculated in still-air conditions. The fuel ERA aerodrome should be nominated in the operational flight plan."

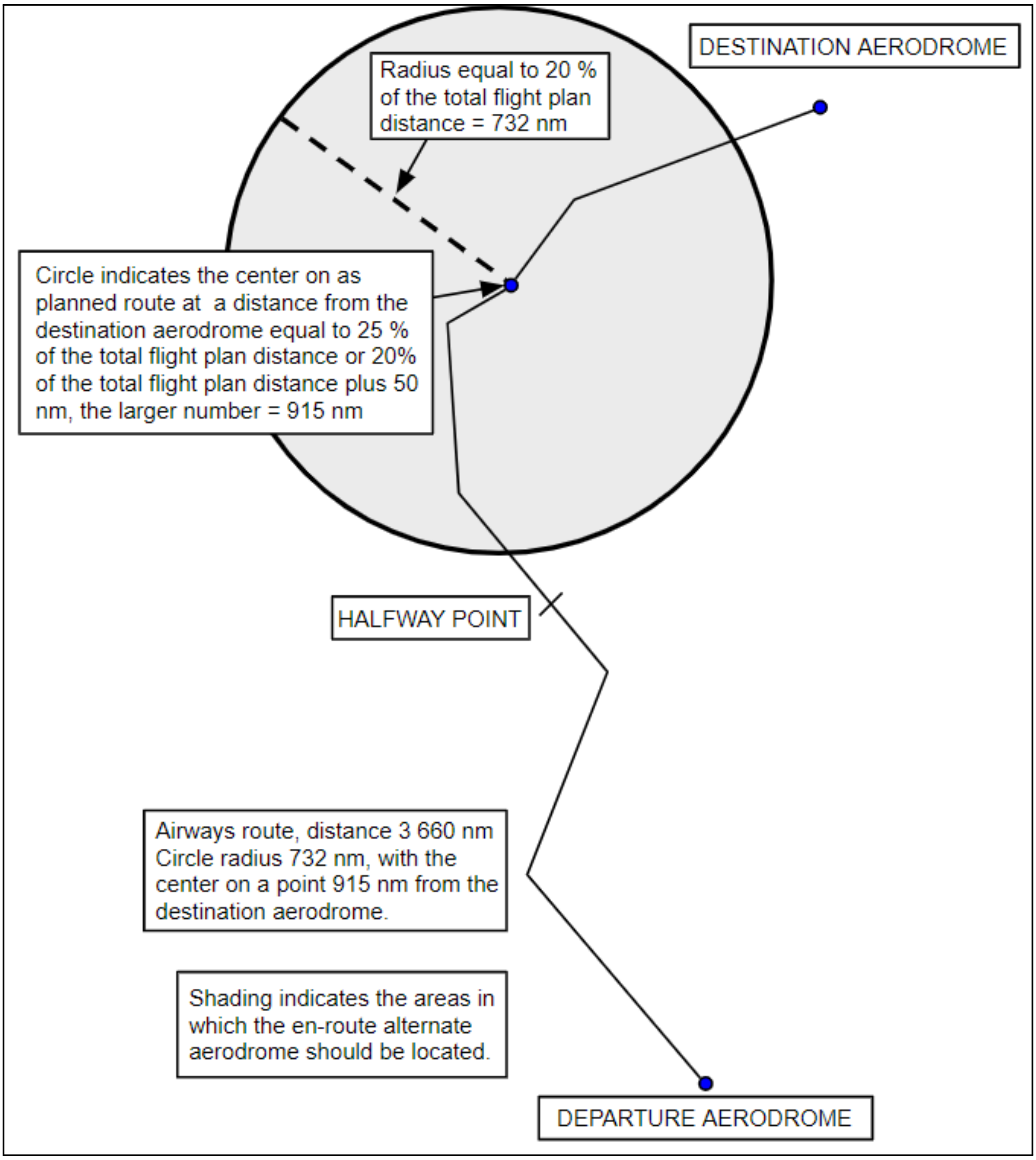


Illustration G-2 Contingency Fuel

If the Operator plans to apply the contingency fuel variation, they must check if their flight planning provider can handle it. Flight planning providers may offer for example:

1. An ERA functionality (i.e. automatic ERA airport suggestion)
2. A comparison between the “3 % of the planned trip fuel” and the “20-minute flying time”.

In addition, the ERA airport must be available and the MLW for this airport must be determined at the time of dispatch as required by GM1 CAT.POL.A.330(a).

1.1.1.5. Destination Alternate Fuel/Energy

Air OPS Subpart B
CAT.OP.MPA.181(c)(4)

"When a flight is operated with at least one destination alternate aerodrome, it shall be the amount of fuel/energy required to fly from the destination aerodrome to the destination alternate aerodrome; or
when a flight is operated with no destination alternate aerodrome, it shall be the amount of fuel/energy required to hold at the destination aerodrome, while enabling the aeroplane to perform a safe landing, and to allow for deviations from the planned operation; as a minimum, this amount shall be 15-minute fuel/energy at holding speed at 1 500ft (450 m) above the aerodrome elevation in standard conditions, calculated according to the estimated aeroplane mass on arrival at the destination aerodrome."

1.1.1.5.1. Basic Fuel Scheme

Air OPS Subpart B
AMC1.CAT.OP.MPA.181(d) *Basic Fuel Scheme*

"(1) When the aircraft is operated with one destination alternate aerodrome:

- *Fuel for a missed approach from the applicable DA/H or MDA/H at the destination aerodrome to the missed-approach altitude, taking into account the complete missed-approach procedure*
- *Fuel for climb from the missed-approach altitude to the cruising level/altitude, taking into account the expected departure routing*
- *Fuel for cruising from the top of climb to the top of descent, taking into account the expected routing*
- *Fuel for descent from the top of descent to the point where the approach is initiated, taking into account the expected arrival routing*
- *Fuel for making an approach and landing at the destination alternate aerodrome*

(2) When the aircraft is operated with two destination alternate aerodromes, the amount of fuel that is calculated in accordance with point (1), based on the destination alternate aerodrome that requires the greater amount of fuel;"

Flight planning software, depending on the provider, can check that, in the case of one or two destination alternate aerodromes, the alternate fuel is compliant with the EASA regulations, particularly the consideration of the complete procedure for missed approach at the destination airport.

1.1.1.5.2. Basic Fuel Scheme with Variations

Air OPS Subpart B
AMC1.CAT.OP.MPA.181(d)

Basic Fuel Scheme with variations - No destination Alternate aerodrome

"The operator may operate with no destination alternate aerodrome when the destination aerodrome is an isolated aerodrome or when the following two conditions are met:

- *The duration of the planned flight from take-off to landing does not exceed 6 hours or, in the event of in-flight re-planning, in accordance with point CAT.OP.MPA.181(d), the remaining flying time to destination does not exceed 4 hours; and*
- *Two separate runways are usable at the destination aerodrome and the appropriate weather reports and/or weather forecasts indicate that for the period from 1 hour before to 1 hour after the expected time of arrival, the ceiling is at least 2 000 ft (600 m) or the circling height 500 ft (150 m), whichever is greater, and ground visibility is at least 5 km.*

In the case of operations without alternate airports, the Operator may calculate, for a given aircraft type, the fixed value of fuel quantity that corresponds to 15 minutes of flight in the following conditions:

- At holding speed
- At 1 500 ft
- At MLW
- In standard conditions.

The fuel quantity corresponding to the above conditions can be computed using engineering performance software.

1.1.1.6. Final Reserve Fuel/Energy

Air OPS Subpart B
CAT.OP.MPA.181(c)(5)

The final reserve fuel quantity is "the amount of fuel/energy that is calculated at holding speed at 1 500ft (450 m) above the aerodrome elevation in standard conditions according to the aeroplane estimated mass on arrival at the destination alternate aerodrome, or destination aerodrome when no destination alternate aerodrome is required, and shall not be less than the fuel/energy to fly for 30 minutes".

In order to provide a minimum reference value for the fuel final reserve, the Operator may calculate, for a given aircraft, the fixed value of fuel quantity that corresponds to 30 minutes of flight in the following conditions:

- At holding speed
- At 1 500 ft
- At MLW
- In standard conditions.

The fuel quantity corresponding to the above conditions can be computed using engineering performance software.

1.1.1.7. Additional Fuel/Energy

Air OPS Subpart B
CAT.OP.MPA.181(c)(6)

The additional fuel quantity is "the amount of fuel/energy to enable the aeroplane to land at a fuel/energy en route alternate aerodrome in the event of an aircraft failure that significantly increases the fuel/energy consumption at the most critical point along the route. This additional fuel/energy is required only if the minimum amount of fuel/energy that is calculated according to points (c)(2) to (c)(5) is not sufficient for such an event."

If it is determined that the fuel required for aircraft failure scenarios exceeds the fuel on board at the most critical point (based on the applicable operational requirements), additional fuel should be included. The additional fuel quantity is that necessary to safely manage the failure scenarios.

Air OPS Subpart B
AMC1.CAT.OP.MPA.181(f) *Basic Fuel Scheme*

The additional fuel quantity is the "Amount of fuel that allows the aeroplane to proceed, in the event of an engine failure or loss of pressurization, from the most critical point along the route to a fuel en route alternate (fuel ERA) aerodrome in the relevant aircraft configuration, hold there for 15 minutes at 1 500 ft (450 m) above the aerodrome elevation in standard conditions, make an approach, and land."

This additional fuel/energy is required only if the minimum amount of fuel/energy that is calculated according to chapter Trip Fuel/Energy to Final Reserve Fuel/Energy is not sufficient for such an event.

The flight planning software must include functionalities to determine the following:

- Identify the most critical point on the route
- The fuel required, in the case of engine failure or loss of pressurization, between the critical point and the ERA airport.

Flight planning softwares should calculate the fuel consumption for these scenarios at a specific speed and flight level, in accordance with the settings defined by the administrator of the flight planning software.

Airbus recommends the following strategies for speed and Flight Level (FL), in case of diversion:
Diversion Speed:

- For an engine failure scenario: standard, obstacle or fixed speed strategy (refer to the FCTM).
- For a loss of pressurization scenario: VMO/MMO above 10 000 ft, and LRC speed at or below 10 000 ft.

Diversion FL:

- For an engine failure scenario: the flight planning software may, depending on the provider, be able to calculate the OEI optimum FL for diversion at specific aircraft weights and specific external conditions.
- For a loss of pressurization scenario: FL100.

Note: If the descent is not managed by the flight planning software, and if possible, cruise may be considered at diversion FL, starting from the critical point. This proposal is more conservative in terms of fuel planning than a descent from the critical point followed by cruise at diversion FL.

Additional Requirements for ETOPS Flights:

To comply with *AMC1 CAT.OP.MPA.181 (f)* and *AMC 20-6 APPENDIX 4 4.c,* three critical scenarios must be considered:

- A rapid decompression at the most critical point followed by descent to 10 000 ft or MSA.
- A rapid decompression and a simultaneous engine failure at the most critical point followed by descent to 10 000 ft or MSA.
- An engine failure at the most critical point, followed by descent to the cruise altitude with One Engine Inoperative (OEI).

The scenario that requires the largest fuel/energy quantity must be selected.

As for non-ETOPS flights, flight planning softwares may, depending on the provider, be able to find the most critical point on the route and to calculate the fuel required to satisfy these three scenarios.

The *Getting to Grips with ETOPS* vol I & II provide guidelines on the different ETOPS scenarios, for the correct setup of the flight planning software.

1.1.1.8. Extra Fuel/Energy

Air OPS Subpart B
AMC1.CAT.OP.MPA.181(g) *Basic Fuel Scheme*

Quantity of fuel/energy that "include anticipated delays or specific operational constraints that can be predicted."

1.1.1.9. Discretionary Fuel/Energy

Air OPS Subpart B
AMC1.CAT.OP.MPA.181(h) *Basic Fuel Scheme*

"Quantity of fuel/energy at the sole discretion of the commander."

1.1.2. Procedures with an Impact on Fuel Quantities

1.1.2.1. Procedure for Reduced Contingency Fuel (RCF)

The RCF procedure is a variation proposed to the Operator. It has an impact on the contingency fuel, because it permits to carry less contingency fuel than the quantity required by the Basic Fuel Scheme.

The Operator selects a point (B), referred to as the decision point, along the planned route (Illustration G-3). At this point, there are two possibilities:

- To reach a suitable diversion airport, compliant with the Maximum Landing Weight (MLW) limitations.
- To continue the flight to the destination airport C, when the remaining fuel is sufficient.

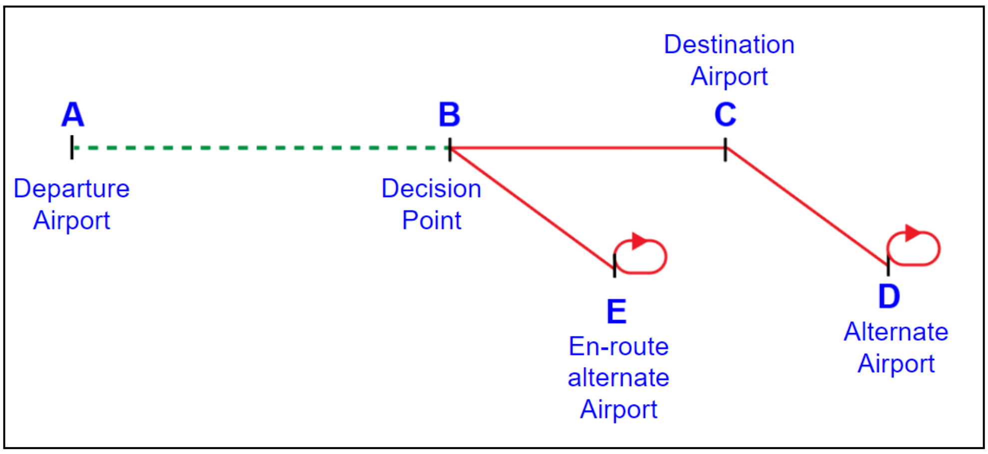


Illustration G-3: Reduced Contingency Fuel - Decision Point

Air OPS Subpart B
AMC6.CAT.OP.MPA.181(d) Basic Fuel Scheme with variations

“If the operator’s fuel policy includes pre-flight planning to a destination 1 aerodrome (commercial destination with an RCF procedure using a decision point along the route) and a destination 2 aerodrome (optional refueling destination), the amount in the pre-flight calculation of the required usable fuel should be greater than the sum in points (1) or (2):

(1) The sum of (Q1):

- Taxi fuel;
- Trip fuel to the destination 1 aerodrome via the decision point;
- Contingency fuel equal to not less than 5 % of the fuel that is estimated to be consumed from the decision point to the destination 1 aerodrome;
- Destination 1 alternate fuel or no alternate fuel if the remaining flying time from the decision point to destination 1 aerodrome is less than 6 hours and destination 1 fulfill the other criteria for operations with no alternate airport;
- FRF;
- Additional fuel;
- Extra fuel if there are anticipated delays or specific operational constraints;
- Discretionary fuel, if required by the commander.

(2) The sum of (Q2):

- Taxi fuel;
- Trip fuel to the destination 2 aerodrome via the decision point;
- contingency fuel equal to not less than the amount that is calculated in accordance with point (c) of this AMC, from the departure aerodrome to the destination 2 aerodrome;
- Alternate fuel if a destination 2 alternate aerodrome is required
- FRF;
- Additional fuel;
- Extra fuel if there are anticipated delays or specific operational constraints;
- Discretionary fuel, if required by the commander;”

The fuel scenarios are summarized as follows:

$$F1 = taxi_A + trip_{AC} + 5\%\ trip_{BC} + alternate_{CD} + holding_D + additional + extra + discretionary$$

$$F2 = taxi_A + trip_{AE} + fuel_{1.2.1.4.2} + alternate + holding_E + additional + extra + discretionary$$

The destination 2 airport is usually selected close to the decision point (B) and Q1 is equal to the highest fuel quantity. As a result, the contingency fuel is only a percentage of the trip fuel between the decision point (B) and the destination airport C and not a percentage of the fuel required for the entire trip, as it is the case for a standard flight.

Flight planning software may, depending on the provider, be able to manage the application of the RCF procedure.

To be allowed by the authority to apply RCF procedure, the Operator must demonstrate to the authority that their operations are based on a reliable APM process.

1.1.2.2. Isolated Airport

The use of an isolated destination airport is a variation proposed to the Operator. This variation has an impact on different fuel reserves and enables a reduction of the amount of fuel on board when the destination alternate airport is far from the destination airport.

Air OPS Subpart B
AMC7 CAT.OP.MPA.182

"(a) The operator should use a destination aerodrome as an isolated aerodrome if the alternate fuel plus the Final Reserve Fuel (FRF) that is required to reach the nearest adequate destination alternate aerodrome is more than the amount of fuel required to fly for 2 hours with normal cruise consumption above the destination aerodrome, including the FRF.

(b) If the operator's fuel planning policy includes an isolated aerodrome, a Point of No Return (PNR) should be determined by a computerized flight-planning system and specified in the operational flight plan. The required usable fuel for pre-flight calculation should be as indicated in points (b)(1) or (b)(2), whichever is greater:

(1) the sum of (Q1):

- Taxi fuel;
- Trip fuel from the departure aerodrome to the isolated aerodrome via the PNR;
- Contingency fuel that is calculated in accordance with the operator's current fuel scheme
- Additional fuel, if required, but not less than the fuel to fly for 2 hours with normal cruise consumption above the destination aerodrome, including the FRF;
- Extra fuel if there are anticipated delays or specific operational constraints;
- Discretionary fuel, if required by the commander.

(2) The sum of (Q2):

- Taxi fuel;
- Trip fuel from the departure aerodrome to the fuel ERA PNR aerodrome via the PNR;
- Contingency fuel that is calculated in accordance with the operator's current fuel scheme;

- Additional fuel, if required, but not less than the fuel to fly for 30 minutes at holding speed at 1 500 ft (450 m) above the fuel ERA aerodrome elevation in standard conditions, which should not be less than the FRF;
- Extra fuel if there are anticipated delays or specific operational constraints;
- Discretionary fuel, if required by the commander."

The fuel ERA PNR aerodrome is usually selected close to the PNR, and the Q1 is the highest fuel quantity. As a result, with the use of a PNR, the fuel quantity required for a normal cruise of 2 hours replaces the alternate and final reserve fuel quantities.

A conservative value may be defined for the fuel quantity, based on the normal consumption for a cruise of 2 hours above the destination aerodrome. This value can be determined with engineering performance software.

1.2. Fuel Management

1.2.1. Introduction

The CAT.OP.MPA.185 provides information on in-flight fuel management and fuel reserves.

Air OPS Subpart B
AMC1 CAT.OP.MPA.185(b) *Basic Fuel Scheme*

"The flight should be conducted to ensure that the usable fuel expected to remain upon landing at the destination aerodrome is not less than:

- The required alternate fuel plus the Final Reserve Fuel (FRF); or
- the FRF if no alternate aerodrome is required."

The CAT.OP.MPA.185 defines the announcements for "Minimum Fuel" and "Mayday Fuel" that the flight crew must use to advise Air Traffic Control when the above requirements cannot be met.

1.2.2. Procedure for Reduced Contingency Fuel (RCF)

Air OPS Subpart B
AMC2 CAT.OP.MPA.185(a) *Basic Fuel Scheme with variations*

"If the RCF procedure is used on a flight to proceed to destination 1 aerodrome, the commander should ensure that the remaining usable fuel at the decision point is at least the total of the following:

- Trip fuel from the decision point to destination 1 aerodrome
- Contingency fuel that is equal to 5 % of the trip fuel from the decision point to destination 1 aerodrome
- Additional fuel, if required
- FRF."

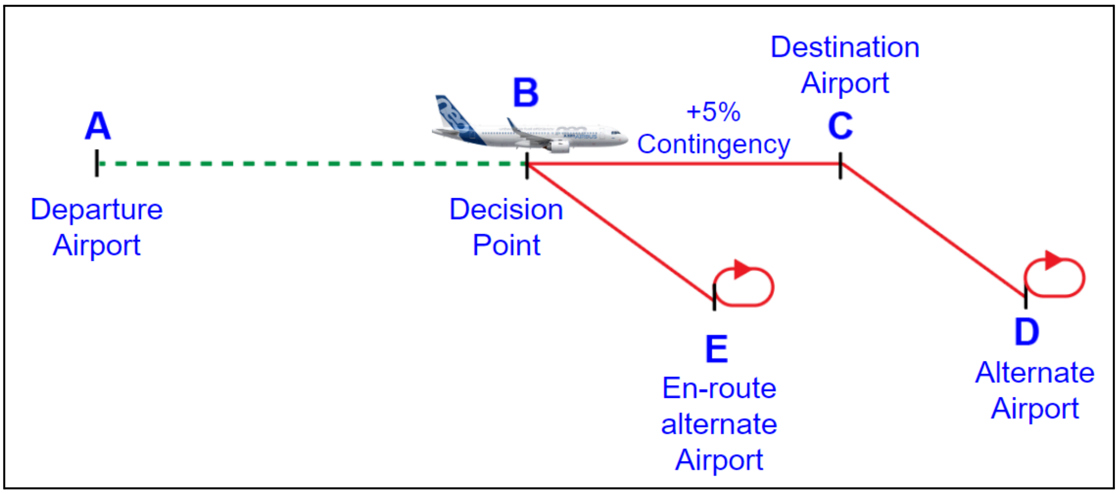


Illustration G-4: Reduced Contingency Fuel : Fuel Management

Minimum Remaining Usable Fuel = $trip_{BC}$ + 5% $trip_{BC}$ + additional + FRF

If at the decision point the remaining usable fuel is below this minimum amount, the flight crew must proceed to the refueling aerodrome (E).

1.2.3. Isolated Aerodrome Procedure

Air OPS Subpart B
AMC2 CAT.OP.MPA.185(b) *Basic Fuel Scheme with variations*

"On a flight to an isolated aerodrome, the commander should ensure that the remaining usable fuel at the actual PNR is at least the total of the following:

- Trip fuel from the PNR to the destination isolated aerodrome
- Contingency fuel from the PNR to the destination isolated aerodrome
- The additional fuel required for isolated aerodromes, as described in AMC7 CAT.OP.MPA.182."

If the remaining usable fuel at the actual PNR is below this amount, the flight crew must proceed to the fuel ERA PNR aerodrome referred to in the chapter Isolated Airport.

2. FAA – Fuel/Energy Planning and Management

2.1. Different Types of Operations

The FAA does not establish different fuel schemes, but instead different types of operations that have an impact on the minimum quantity of required fuel.

Three cases must be considered:

- **Domestic Operations**
  - Between any points in the 48 contiguous States of the USA or the District of Columbia, or
  - Operations only in the 48 contiguous States of the USA or the District of Columbia, or
  - Operations in any State, territory, or possession of the USA, or
  - When specifically authorized by the Administrator, operations between any point in the 48 contiguous States of the USA or the District of Columbia and any specifically authorized point outside the 48 contiguous States of the USA or the District of Columbia.
- **Flag Operations**
  - Between any point in the State of Alaska or the State of Hawaii or any territory or possession of the USA and any point outside the State of Alaska or the State of Hawaii or any territory or possession of the USA, respectively, or
  - Between any point in the 48 contiguous States of the USA or the District of Columbia and any point outside the 48 contiguous States of the USA and the District of Columbia, or
  - Between any point outside the USA and another point outside the USA.
- **Supplemental Operations**
  - Operations for which the departure time, the departure location, and the arrival location are specifically negotiated with the customer or with the customer's representative.
  - Operations with only cargo.

2.2. Fuel Policy

The required fuel quantity for a safe trip along the planned route is calculated for each flight. Each Operator has their own fuel policy. This policy is based on the loading of the minimum fuel required by the regulation (FAR 121).

2.2.1. Minimum Fuel Quantity

2.2.1.1. Minimum Fuel Quantity for Domestic Operations

For domestic operations, the minimum fuel quantity is:

FAR 121.639 Subpart U

"No person may dispatch or take off an airplane unless it has enough fuel--
(a) To fly to the airport to which it is dispatched
(b) Thereafter, to fly to and land at the most distant alternate airport (where required) for the airport to which dispatched; and
(c) Thereafter, to fly for 45 minutes at normal cruising fuel consumption."

The minimum fuel quantity (Q) calculated for domestic operations is defined as:

$$Q = taxi\,fuel + TF + AF + FR$$

Where:

- TF = Trip Fuel
- AF = Alternate Fuel
- FR = Final Reserve fuel

Illustration G-5 indicates the fuel quantities for the different flight phases of a standard flight plan.

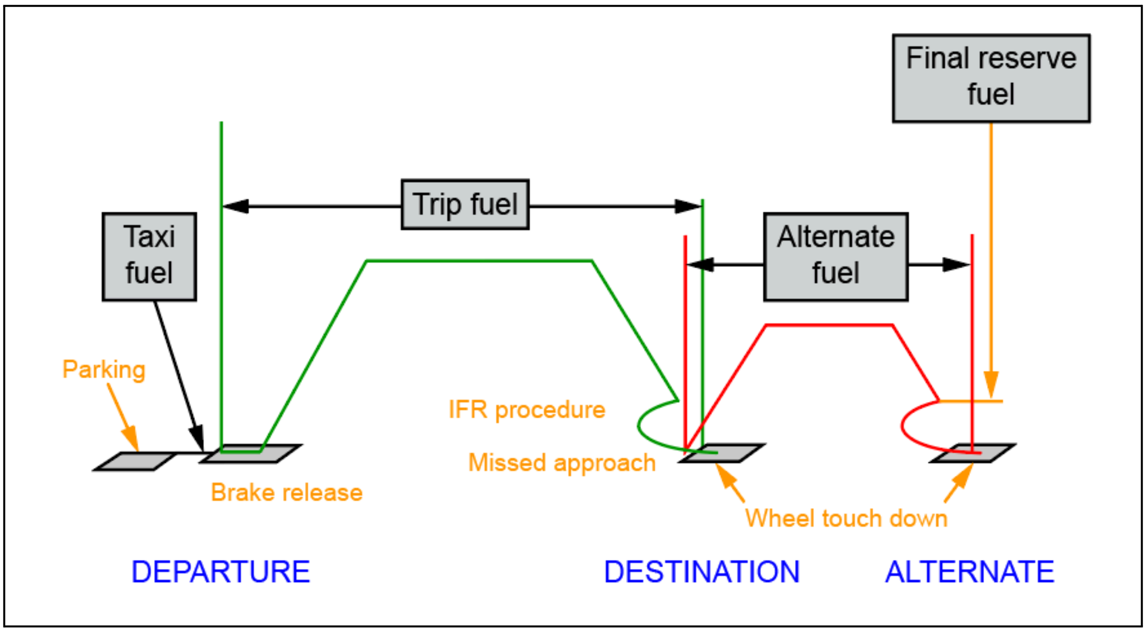


Illustration G-5: Fuel Quantities for Domestic Operation

2.2.1.2. Minimum Fuel for Flag and Supplemental Operations

For flag and supplemental operations, the minimum fuel quantity is defined as:

FAR 121.645 Subpart U

"(b) Any certificate holder conducting flag or supplemental operations, […] considering wind and other weather conditions expected, must have enough fuel–

> *(1) To fly to and land at the airport to which it is released;*
> *(2) After that, to fly for a period of 10 percent of the total time required to fly from the airport of departure to, and land at, the airport to which it was released;*
> *(3) After that, to fly to and land at the most distant alternate airport specified in the flight release, if an alternate is required; and*
> *(4) After that, to fly for 30 minutes at holding speed at 1,500 feet above the alternate airport (or the destination airport if no alternate is required) under standard temperature conditions."*

The minimum fuel quantity (Q) calculated for flag and supplemental operations is defined as:

$$Q = taxi\,fuel + TF + AF + FR + Add$$

Where:
- TF = Trip Fuel
- CF = Contingency Fuel
- AF = Alternate Fuel
- FR = Final Reserve fuel
- Add = Additional fuel

Illustration G-6 indicates the fuel quantities for the different flight phases of a standard flight plan.

The following operating conditions should be considered for each flight:

- Realistic data for aircraft fuel consumption
- Anticipated weight
- Expected weather conditions
- Procedures and restrictions related to air traffic services.

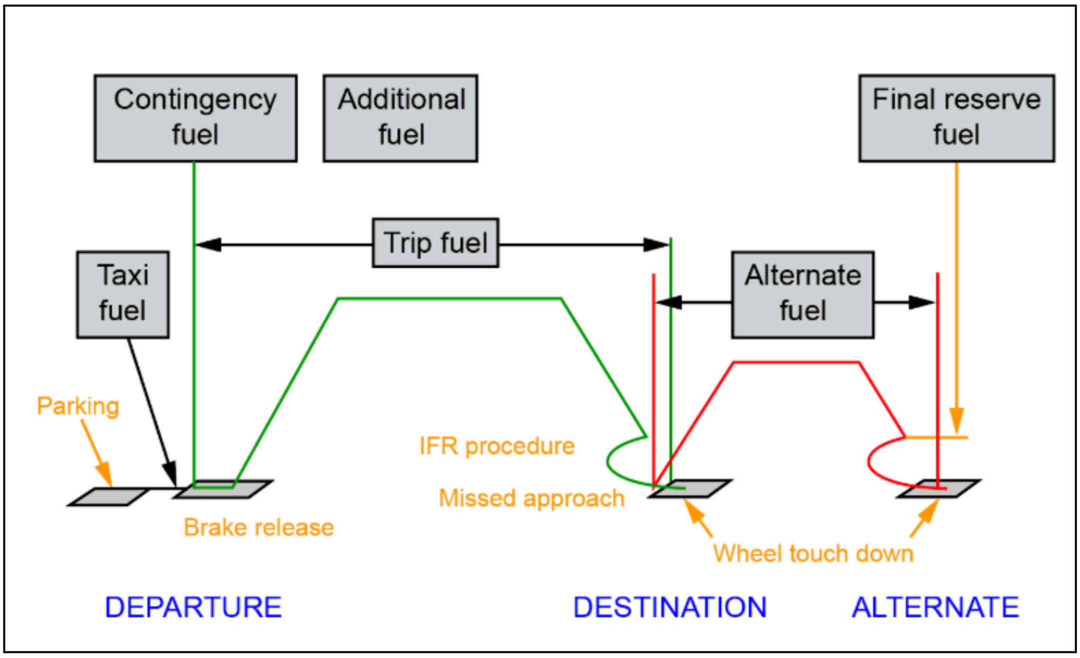


Illustration G-6: Fuel Quantities for Flag and Supplemental Operations

2.2.2. Taxi Fuel

The required taxi fuel is the same for all types of operations. In order to determine this quantity, the local conditions at departure and the APU consumption should be considered. Therefore this quantity is the same as per the EASA Basic Fuel Scheme, refer to chapter Taxi Fuel/Energy.

2.2.3. Trip Fuel

The required trip fuel is the same for all types of operations. The required fuel quantity from brake release at the departure airport to landing at the destination airport. This quantity takes into account the fuel required for the following:

- Takeoff
- Climb to cruise level
- Flight from the end of climb to the beginning of descent
- Flight from the beginning of descent to the beginning of approach
- Approach
- Landing at the destination airport
- Anticipated traffic delays.

Latest forecast weather conditions must also be considered.

2.2.4. Contingency Fuel

Contingency fuel is only required for flag and supplemental operations. For these operations, the contingency fuel is the amount of fuel that is necessary to fly for 10 % of the total required time from brake release at the departure airport to landing at the destination airport.

2.2.5. Alternate Fuel

The alternate fuel required is the same for all types of operations. The alternate fuel is the amount of fuel that is necessary to fly to the most distant alternate airport, and takes into account:

- Missed approach at the destination airport
- Climb from the missed approach altitude to the cruise level
- Flight from the end of climb to the beginning of descent
- Flight from the beginning of descent to the beginning of approach
- Approach
- Landing at the alternate airport.

When two alternate airports are required (see below), the alternate fuel should be sufficient to proceed to the alternate airport that requires the greater fuel quantity.

2.2.5.1. Two Alternate Airports Required

Two alternate airports are required, when:

FAR 121.619 Subpart U

"When the weather conditions forecast for the destination and first alternate airport are marginal at least one additional alternate must be designated."

2.2.5.2. Destination Alternate Airport Not required

A destination alternate airport is not required, if the following conditions are satisfied:

2.2.5.2.1. Domestic Operations

FAR 121.619 Subpart U

*"(a) […] However, no alternate airport is required if for at least **1 hour before and 1 hour after the estimated time of arrival** at the destination airport the appropriate weather reports or forecasts, or any combination of them, indicate--*
*(1) The **ceiling will be at least 2,000 feet above the airport elevation**; and*
*(2) **Visibility will be at least 3 miles.**"*

2.2.5.2.2. Flag Operations

FAR 121.621 Subpart U

*"(1) The flight is scheduled for **not more than 6 hours** and, for at least **1 hour before and 1 hour after the estimated time of arrival** at the destination airport, the appropriate weather reports or forecasts, or any combination of them, indicate the ceiling will be:*

*(i) At least **1,500 feet above the lowest circling MDA**, if a circling approach is required and authorized for that airport; or*

*(ii) At least **1,500 feet above the lowest published instrument approach minimum or 2,000 feet above the airport elevation**, whichever is greater; and*

*(iii) The **visibility at that airport will be at least 3 miles, or 2 miles more than the lowest applicable visibility minimums**, whichever is greater, for the instrument approach procedures to be used at the destination airport."*

2.2.6. Final Reserve Fuel

2.2.6.1. Domestic Operations

The final reserve fuel is the minimum fuel required to fly for 45 minutes at normal cruise consumption.

2.2.6.2. Flag and Supplemental Operations

The final reserve fuel is the minimum fuel required to fly for 30 minutes, in the following conditions:

- At 1 500 ft above the alternate airport, or destination airport (if an alternate is not required)
- At holding speed
- In ISA conditions

2.2.7. Additional Fuel

Additional fuel may be required for flag and supplemental operations, if requested by the FAA administrator for safety reasons (e.g: engine failure, pressurization failure, ETOPS, etc.).

2.3. Procedures with an Impact on Fuel Quantities

2.3.1. Isolated Airport Procedure

FAR 121.645(c) Subpart U

"No person may release a turbine-engine powered airplane (other than a turbo-propeller airplane) to an airport for which an alternate is not specified under § 121.621(a)(2) or § 121.623(b) unless it has enough fuel, considering wind and other weather conditions expected, to fly to that airport and thereafter to fly for at least two hours at normal cruising fuel consumption."

FAR 121.621 (a)(2) Subpart U

"The flight is over a route approved without an available alternate airport for a particular destination airport and the airplane has enough fuel to meet the requirements of § 121.641(b) or § 121.645(c)."

For this type of airport, there is no alternate airport. The regulatory quantity of takeoff fuel must include:

- Taxi fuel
- Trip fuel
- Additional fuel: This quantity must be above the quantity necessary for a 2 hour flight at normal cruise fuel consumption.

2.3.2. Redispatch Procedure

This procedure permits the Operator to carry less than the standard contingency fuel. This procedure may be advantageous in the case of fuel capacity limitations, or takeoff limitations.
Operators select a point, referred to as the decision point along the planned route (Illustration I9). At this point, there are two possibilities:

- To reach a suitable diversion airport, where the maximum landing weight limitation is complied with.
- To continue the flight to the destination airport, if the remaining fuel is sufficient.

This procedure is advantageous for flag and supplemental operations, for which the contingency fuel depends on the flight time. The FAR 121 regulation defines the following:

FAR 121.631

"(a) ***A certificate holder may specify any regular, provisional, or refueling airport, authorized for the type of aircraft, as a destination for the purpose of original dispatch or release***

(b) No person may allow a flight to continue to an airport to which it has been dispatched or released unless the weather conditions at an alternate airport that was specified in the dispatch or flight release are forecast to be at or above the alternate minimums specified in the operations specifications for that airport at the time the aircraft would arrive at the alternate airport. ***However, the dispatch or flight release may be amended en route to include any alternate airport that is within the fuel range of the aircraft*** *[…]*
(c) ***No person may change an original destination or alternate airport*** *that is specified in the original dispatch or flight release to another airport* ***while the aircraft is en route unless the other airport is authorized for that type of aircraft and the appropriate requirements […] are met at the time of redispatch or amendment of the flight release.”***

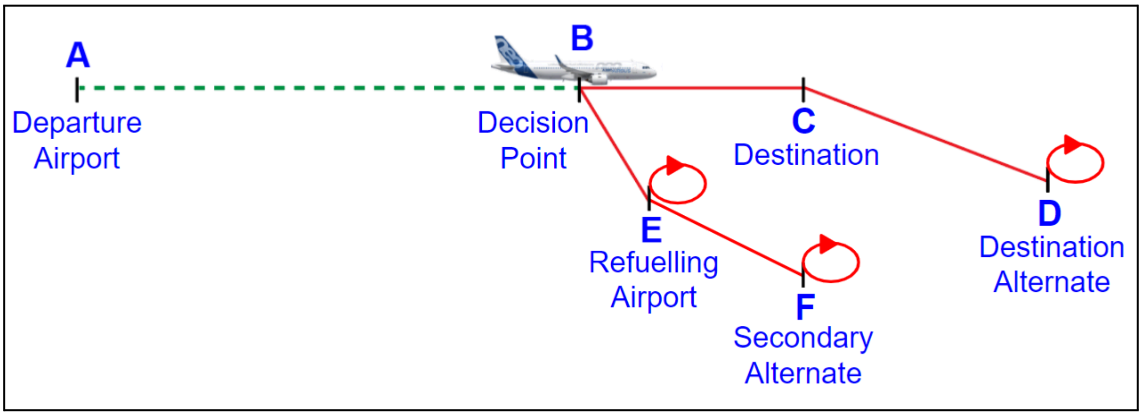


Illustration G-7: Redispatch Procedure

With this procedure, the required fuel is the greatest of:

$$F1 = taxi_A + trip_{AC} + 10\%\ trip\ time_{BC} + alternate_{CD} + holding_D + additional$$

$$F2 = taxi_A + trip_{AE} + 10\%\ trip\ time_{BE} + alternate_{EF} + holding_F + additional$$

If we compare the standard fuel planning to the fuel planning provided in the Redispatch Procedure, the maximum contingency fuel reduction is 10% of the trip time between A and B.

2.3.3. ETOPS Procedure

FAR 121.621 Subpart H

AC 120-42A

The procedure is similar to Air OPS ETOPS Procedure (chapter Additional Fuel Energy).

2.4. Fuel Management

FAR 121 does not provide fuel management rules, but the Operating Manual must address the appropriate procedures. For example, operators may consider the following:

The remaining fuel in flight must be sufficient to fly to an airport where a safe landing is possible.

The *minimum quantity of remaining fuel at landing is defined in the Operating Manual of the Airline,* and is usually equal to the *final reserve fuel*. The final reserve fuel is defined as the fuel quantity that is necessary to fly for a period of 30 to 45 minutes at 1 500 ft above the airport, in ISA conditions, at holding speed.

This applies to the destination airport, the destination alternate airport, and/or any en route alternate airport.

APPENDIX

APPENDIX 1: INTERNATIONAL STANDARD ATMOSPHERE (ISA)

1.1. OBJECTIVE

It is essential to know the density, pressure and temperature at any point of the atmosphere, in order to determine other parameters that include the aircraft speed or altitude.

To provide a common reference based on a relationship between these variables, ICAO defined a standard mathematical model of the atmosphere to be as realistic as possible.

This standard atmospheric model, referred to as the International Standard Atmosphere, ISA, is used as a reference to compare real atmospheric conditions and the corresponding engine/aircraft performance.

For example, a standard computable atmosphere enables:

- The calibration of measurement instruments so that all instruments provide the same information in the same atmospheric conditions.
- Aircraft and engine performance comparison. Atmospheric inputs in performance software are based on ISA values.

ICAO publishes a Manual of the ICAO Standard Atmosphere (extended to 80 km (262 500 ft)), Doc 7488, Third Edition, 1993, ISBN 92-9194-004-6.

1.2. TEMPERATURE MODELING

The following diagram (Illustration A1-1) illustrates the temperature variations in the standard atmosphere:

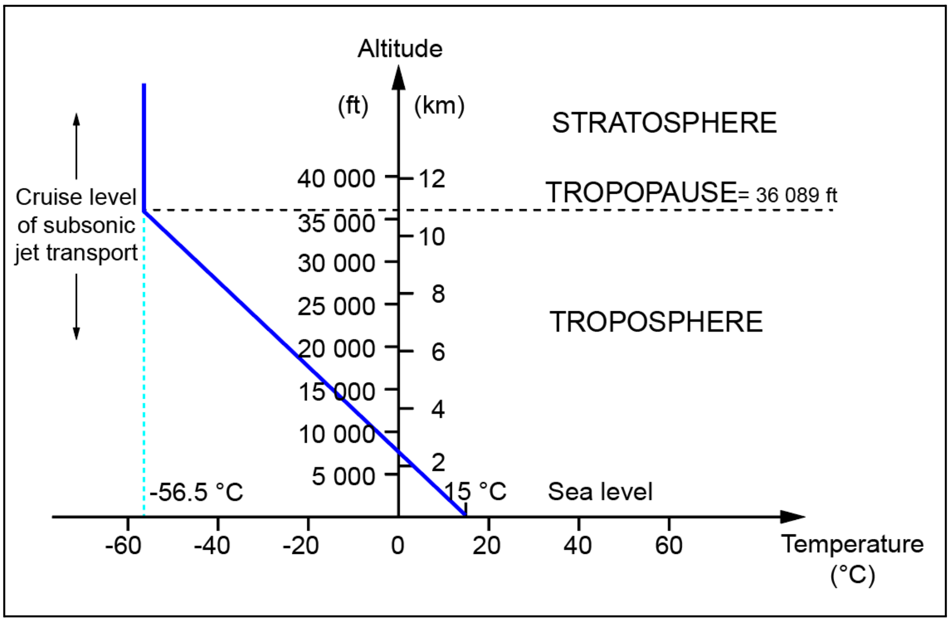


Illustration A1-1: ISA Temperature

The international reference is based on a sea level temperature of 15 °C at a standard pressure of 1013.25 hPa. The standard density of the air at sea level is 1.225 kg/m3.

Temperature decreases with altitude at a constant rate of -6.5 °C / 1 000 m or -1.98 °C / 1 000 ft up to the tropopause. The standard tropopause altitude is 11 000 m or 36 089 ft.
From the tropopause upward, the temperature remains at a constant value of -56.5 °C.
Therefore, the air, that is considered as a perfect gas in the ISA model, has the following characteristics:

- At Mean Sea Level (MSL):
  ISA temperature = T0 = +15 °C = 288.15 K

- Above MSL and below the tropopause (36 089 ft):
  ISA temperature (ºC) = T0 - 1.98 x [Alt(ft)/1000]

For a rapid determination of the standard temperature at a specific altitude, the following approximate formula can be used:
ISA temperature (ºC) = 15 - 2 x [Alt(ft)/1000]

- Above the tropopause (36 089 ft):
  ISA temperature = -56.5 ºC = 216.65 K

The ISA model is used as a reference to compare real atmospheric conditions and the corresponding engine/aircraft performance. The atmospheric conditions will therefore be defined as ISA +/- ΔISA at a given flight level.

Example:
Let us consider an aircraft in flight in the following conditions:
Altitude = 33 000 ft
Current Temperature = -41 ºC

The standard temperature at 33 000 ft is: ISA = 15 - 2 x 33 = -51 ºC, and the current temperature is -41 ºC, i.e. 10 ºC above the standard.

Result: The atmospheric flight condition corresponds to ISA+10.

1.3. Pressure Modeling

To calculate the standard pressure P at a specific altitude, the following assumptions are used:

- Temperature is standard.
- Air is a perfect gas.

The altitude obtained from the measurement of the static pressure is referred to as pressure altitude (Zp), and a standard (ISA) table can be set up (table A1-1).

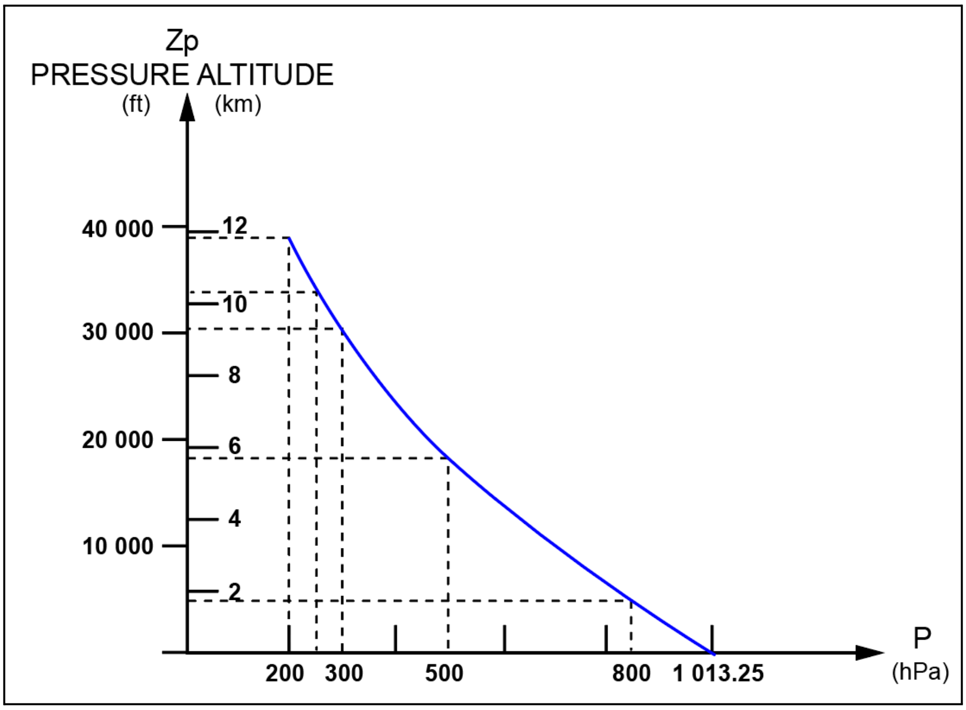


Illustration A1-2: Pressure Altitude variation with Pressure

Pressure (hPA)	Pressure Altitude (ZP)		FL = ZP/100
	(ft)	(m)	
200	38 661	11 784	390
250	34 000	10 363	340
300	30 066	9 164	300
500	18 287	5 574	180
850	4 813	1 467	50
1 013	0	0	0

Table A1-1: Example of Tabulated Pressure Altitude Values

With the assumption of a volume of air in static equilibrium, the aerostatic equation relates a change in height to a change in pressure as follows:

$$dP = -\rho g dh$$

With ρ = air density at an altitude h
g = gravity acceleration (9.80665 m/s^2)
dh = height of the volume unit
dP = pressure variation on dh

The temperature, pressure and density are related by the equation for a perfect gas:

$$\frac{P}{\rho} = RT$$

With R = universal gas constant (287.053 J/kg/K)

Therefore:

- At Mean Sea Level (MSL):
  P0 = 1013.25 hPa

- Above MSL and below the tropopause (36 089 ft):

$$P = P_0 \left(1 - \frac{\alpha}{T_0} h\right)^{\frac{g_0}{\alpha R}}$$

With P_0 = 1 013.25 hPa (standard pressure at sea level)
T_0 = 288.15 K (standard temperature at sea level)
α = 0.0065 °C/m
g_0 = 9.80665 m/s^2
R = 287.053 J/kg/K
h = Altitude (m)

Note: For low altitudes, a reduction of 1 hPa in the pressure approximately corresponds to a pressure altitude increase of 28 ft.

- Above the tropopause (36 089 ft):

$$P = P_1 e^{\frac{-g_0(h-h_1)}{RT_1}}$$

With P_1 = 226.32 hPa (standard pressure at 11 000 m)
T_1 = 216.65 K (standard temperature at 11 000 m)
h_1 = 11 000 m
g_0 = 9.80665 m/s^2
R = 287.053 J/kg/K
h = Altitude (m)

1.4. Density Modeling

To calculate the standard density ρ at a specific altitude, the air is considered to be a perfect gas. Therefore, at a specific altitude, the standard density ρ (kg/m^3) can be obtained as follows:

$$\rho = \frac{P}{RT}$$

with R = Universal gas constant (287.053 J/kg/K)
P in Pascal
T in Kelvin

At Mean Sea Level (MSL):
ρ_0 = 1.225 kg/m^3

1.5. ISA TABLE

The ISA parameters (temperature, pressure, density) can be provided as a function of the altitude in a table, as shown in Table A1-2:

ALTITUDE (ft)	TEMPE-RATURE. (°C)	PRESSURE			PRESSURE RATIO δ = P/Po	DENSITY σ = ρ/ρo	Speed of sound (kt)	ALTITUDE (meters)
		hPa	PSI	In.Hg				
40 000	- 56.5	188	2.72	5.54	0.1851	0.2462	573	12 192
39 000	- 56.5	197	2.58	5.81	0.1942	0.2583	573	11 887
38 000	- 56.5	206	2.99	6.10	0.2038	0.2710	573	11 582
37 000	- 56.5	217	3.14	6.40	0.2138	0.2844	573	11 278
36 000	- 56.3	227	3.30	6.71	0.2243	0.2981	573	10 973
35 000	- 54.3	238	3.46	7.04	0.2353	0.3099	576	10 668
34 000	- 52.4	250	3.63	7.38	0.2467	0.3220	579	10 363
33 000	- 50.4	262	3.80	7.74	0.2586	0.3345	581	10 058
32 000	- 48.4	274	3.98	8.11	0.2709	0.3473	584	9 754
31 000	- 46.4	287	4.17	8.49	0.2837	0.3605	586	9 449
30 000	- 44.4	301	4.36	8.89	0.2970	0.3741	589	9 144
29 000	- 42.5	315	4.57	9.30	0.3107	0.3881	591	8 839
28 000	- 40.5	329	4.78	9.73	0.3250	0.4025	594	8 534
27 000	- 38.5	344	4.99	10.17	0.3398	0.4173	597	8 230
26 000	- 36.5	360	5.22	10.63	0.3552	0.4325	599	7 925
25 000	- 34.5	376	5.45	11.10	0.3711	0.4481	602	7 620
24 000	- 32.5	393	5.70	11.60	0.3876	0.4642	604	7 315
23 000	- 30.6	410	5.95	12.11	0.4046	0.4806	607	7 010
22 000	- 28.6	428	6.21	12.64	0.4223	0.4976	609	6 706
21 000	- 26.6	446	6.47	13.18	0.4406	0.5150	611	6 401
20 000	- 24.6	466	6.75	13.75	0.4595	0.5328	614	6 096
19 000	- 22.6	485	7.04	14.34	0.4791	0.5511	616	5 791
18 000	- 20.7	506	7.34	14.94	0.4994	0.5699	619	5 406
17 000	- 18.7	527	7.65	15.57	0.5203	0.5892	621	5 182
16 000	- 16.7	549	7.97	16.22	0.5420	0.6090	624	4 877
15 000	- 14.7	572	8.29	16.89	0.5643	0.6292	626	4 572
14 000	- 12.7	595	8.63	17.58	0.5875	0.6500	628	4 267
13 000	- 10.8	619	8.99	18.29	0.6113	0.6713	631	3 962
12 000	- 8.8	644	9.35	19.03	0.6360	0.6932	633	3 658
11 000	- 6.8	670	9.72	19.79	0.6614	0.7156	636	3 353
10 000	- 4.8	697	10.10	20.58	0.6877	0.7385	638	3 048
9 000	- 2.8	724	10.51	21.39	0.7148	0.7620	640	2 743
8 000	- 0.8	753	10.92	22.22	0.7428	0.7860	643	2 438
7 000	+ 1.1	782	11.34	23.09	0.7716	0.8106	645	2 134
6 000	+ 3.1	812	11.78	23.98	0.8014	0.8359	647	1 829
5 000	+ 5.1	843	12.23	24.90	0.8320	0.8617	650	1 524
4 000	+ 7.1	875	12.69	25.84	0.8637	0.8881	652	1 219
3 000	+ 9.1	908	13.17	26.82	0.8962	0.9151	654	914
2 000	+ 11.0	942	13.67	27.82	0.9298	0.9428	656	610
1 000	+ 13.0	977	14.17	28.86	0.9644	0.9711	659	305
0	+ 15.0	1013	14.70	29.92	1.0000	1.0000	661	0
- 1 000	+ 17.0	1050	15.23	31.02	1.0366	1.0295	664	- 305

Table A1-2: International Standard Atmosphere (ISA)

APPENDIX 2: Temperatures for Aircraft Operations

1.1. Definitions

1.1.1. Total Air Temperature (TAT)

The TAT or Impact Temperature takes into account the temperature of the still air (static air temperature, refer to the chapter Factors of Influence) and the heat energy of the air stream due to its motion (dynamic aspect).
The TAT is measured by a probe.

1.1.2. Static Air Temperature (SAT)

The SAT or Outside Air Temperature (OAT) is the temperature of the ambient air. It enables the computation of the:

- True Air Speed (TAS) from the Calibrated Air Speed (CAS)
- True altitude from the pressure altitude
- Thrust parameters (EPR or N1) for the takeoff power.

In flight, the SAT is computed from the measured TAT and Mach number as follows:

$$SAT = \frac{TAT}{1+\frac{\gamma-1}{2}M^2} \text{ with } \gamma = \frac{C_P}{C_v} = 1.4 \text{ when } M < 2$$

$$TAT = SAT(1 + 0.2M^2) \text{ with TAT and SAT in K}$$

1.2. How is it measured?

The temperature is measured by three different TAT probes.
The OAT is provided by the weather services of the airports.
Some aircraft (e.g. A350) have OAT probes for OAT measurement when on ground.

The TAT probes are on the lower side of the fuselage, below the cockpit windows, near the nose. When the aircraft is fitted with OAT probes, these are found in the nose landing gear bay.

Illustration A2-1 Example of TAT and OAT probes location on aircraft

1.3. WHERE IS IT DISPLAYED IN THE COCKPIT?

The TAT and the SAT are permanently displayed in the cockpit.

Illustration A2-2: Example of TAT and SAT location on the system display page of the ECAM

APPENDIX 3: ALTIMETRY

1.1. PRESSURE ALTITUDE

1.1.1. Definition

Pressure altitude is a barometric measurement changed into an altitude via the ISA model.

1.1.2. How is it measured?

On Airbus aircraft, the static pressure measurement is achieved through dedicated probes.

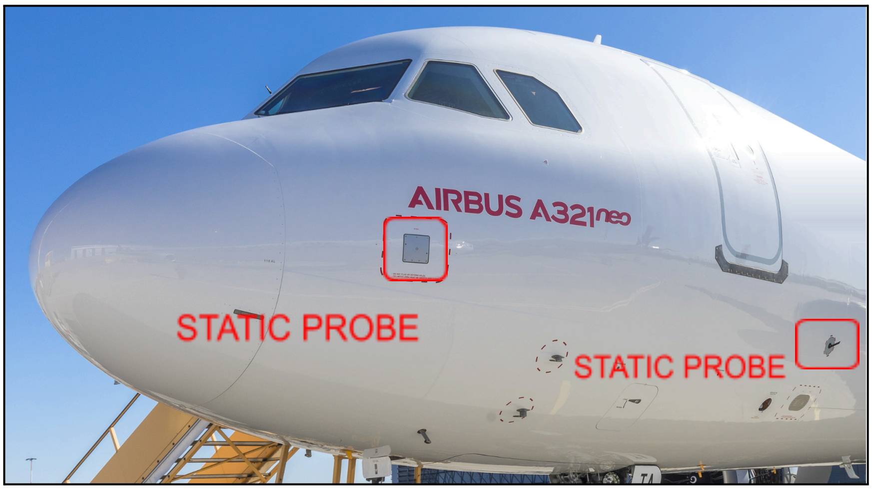


Illustration A3-1: Example of pressure probes location on aircraft

1.1.3. Where is it displayed?

The pressure altitude is displayed by the altimeter. All the indications associated with altitude are permanently displayed on the right hand side of the PFDs.

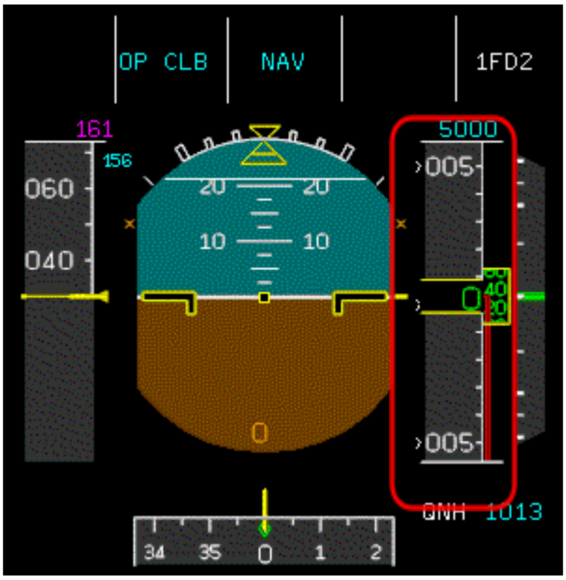


Illustration A3-2: Altitude scale location

1.1.4. Altimetry setting

The objective of altimetry is to ensure vertical margins, above ground and between aircraft.
In the cockpit, the altimeter displays a vertical distance between the static pressure measured and a reference pressure.

Under the assumption of ISA temperature, the Indicated Altitude (IA) is the vertical distance between the following two pressures (Illustration A3-3):

- The ambient pressure (current location of the aircraft)
- A reference pressure, corresponding to a pressure selected by the pilot through the pressure setting knob of the altimeter.

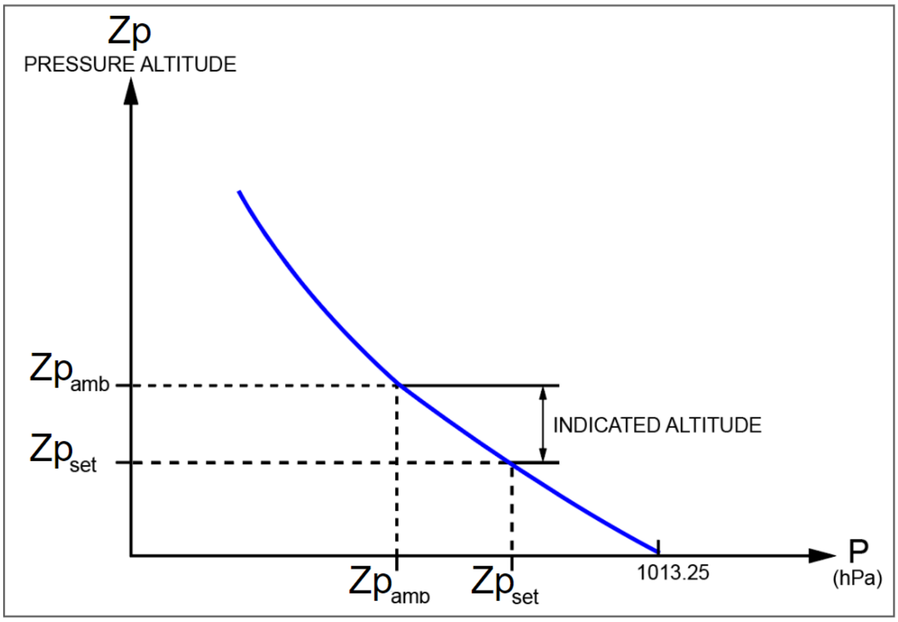


Illustration A3-3: Indicated altitude (IA)

The altimetry setting defines the reference pressure that will define the reference altitude (Zp = 0 ft). The use of an identical reference by all aircraft enables to ensure their vertical separation. The pressure setting and the indicated altitude move in the same direction: Any increase in the pressure setting results in an increase in the corresponding Indicated Altitude.

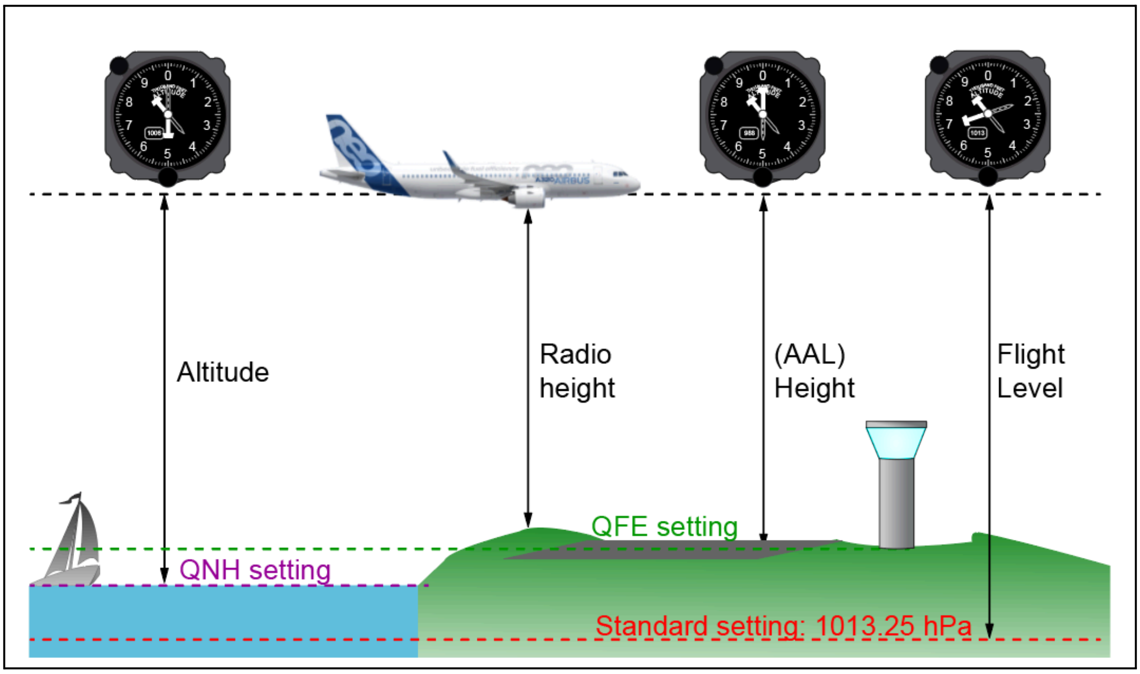


Illustration A3-4: QNH and Pressure Altitude

Several operational settings for pressure can be selected through the pressure setting knob of the altimeter (Illustration A3-4):

- The QFE is the pressure measured at the airport reference point. With the QFE setting, the altimeter indicates the height above the airport or Above Airport Level (AAL), provided the temperature is standard.
  - On ground, at the related airport, the Indicated Altitude is 0 ft.

Note: The QFE setting is only relevant next to the airport. It is less and less used in commercial aviation and is often just an option on Airbus aircraft.

- The QNH is the pressure measured at the official airport elevation, set at sea level by the ISA Model. With the QNH setting, the altimeter indicates the Altitude, or height Above the Mean Sea Level (AMSL), provided the temperature is standard.
  - At the airport level in ISA conditions, the Indicated altitude is the topographic altitude of the terrain.
  - At sea level, the Indicated Altitude is 0 ft.

Note: The QNH setting is obtained by the correction of a measured QFE to the sea level pressure. It is the reference for low altitude, takeoff and landing operations.

- The Standard setting is the pressure measured when the altimeter is set at 1013 hPa. With the standard setting, the altimeter indicates the pressure altitude of the aircraft. As a reminder, the pressure altitude is the altitude above the 1 013 hPa isobaric surface (provided temperature is standard).

Note: The objective of the standard setting is to have the same reference for all aircraft regardless of where they come from. With the same reference, all aircraft have the same indicated altitude when they cross the same point. It provides a vertical separation between aircraft and also removes the local pressure variations throughout the flight.

After takeoff (usually performed with QNH setting), the flight crew selects the standard setting when a specific altitude is exceeded, referred to as Transition Altitude.
Before landing, the flight crew selects QNH (or QFE) setting when below the Transition Level.

The layer between the transition altitude and the transition level is called the transition layer (Illustration A3-5).

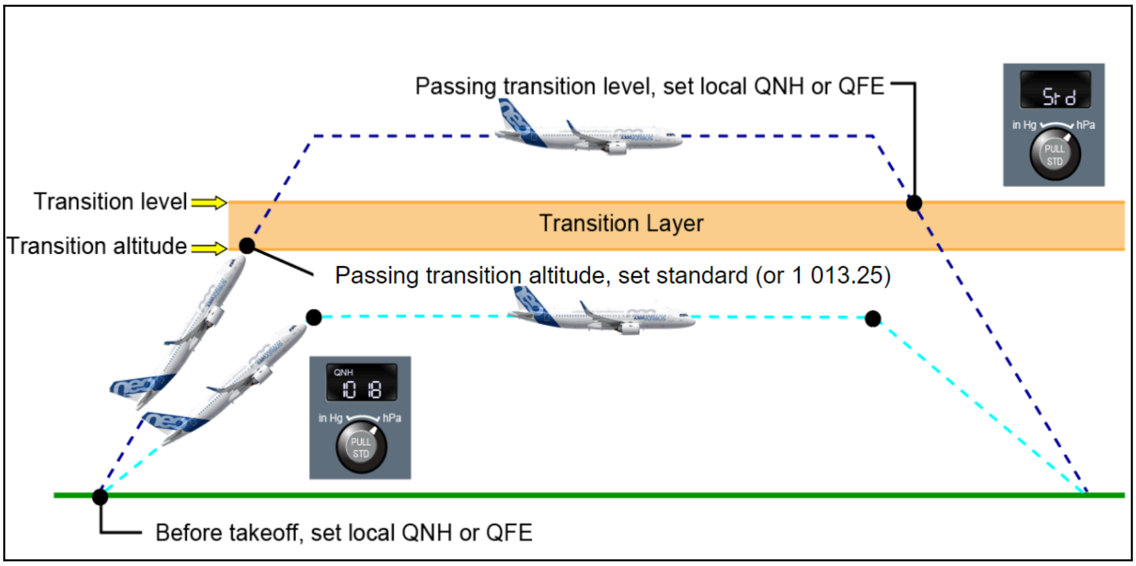


Illustration A3-5: Transition Altitude and Transition Level

The transition altitude is usually provided on the Standard Instrument Departure (SID) charts, however, the transition level is usually given by the Air Traffic Control (ATC).

1.1.5. Where is it set/checked?

The altimeter setting (also referred to as baro reference) is controlled via a knob and its outer ring. They are on the external part of the EFIS control panel.

Illustration A3-6: Baro reference knob and window location

The baro reference is displayed on the corresponding window and on the PFD, below the altitude scale.

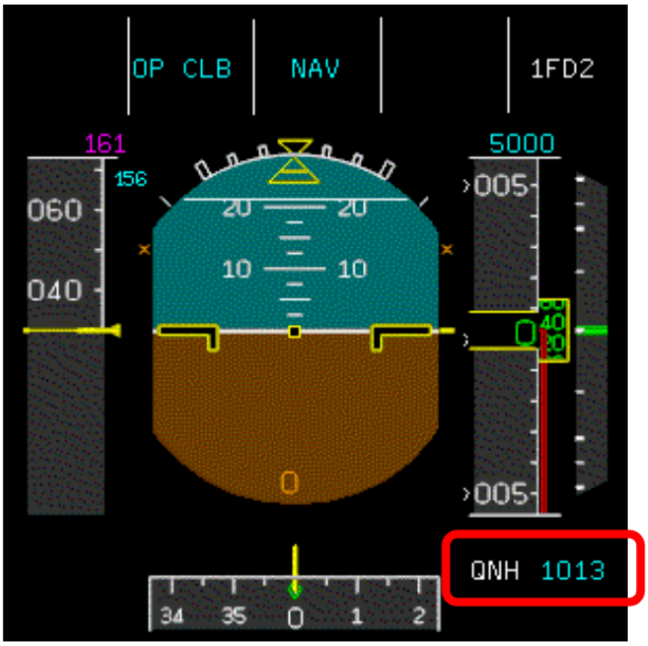


Illustration A3-7: Baro reference location on PFD

1.1.6. Flight Levels

The Flight Level is the aircraft altitude when in standard setting. It corresponds to the Indicated Altitude in ft divided by 100, provided the standard setting is selected.

$$FL = \frac{Zp}{100}$$

As an example, at 30 000 ft with standard setting selected, the Flight Level is FL300.

The Transition Level is the lowest flight level above the transition altitude.

1.1.7. True altitude

The True Altitude is the geometric height above the Mean Sea Level (MSL). The true altitude of an aircraft is not usually the same as the Indicated Altitude. This is mainly because the temperature is different from ISA.

1.1.8. Temperature Correction

Temperature has a significant influence on separation between isobaric surfaces: altimetric ISA indications can be affected. In addition, the ISA law considers that T = 15 °C at sea level, but this is not usually the case. As a result, a correction of the ISA table is necessary, to fit with the conditions of the day.

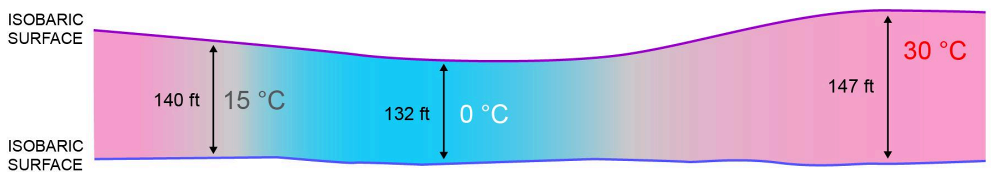


Illustration A3-8: Example of variation of separation between Isobaric surfaces with temperature

Based on the conditions of the day, the temperature can be corrected by ΔT, for all ISA values. ΔT is the difference between OAT and ISA. This ISA + ΔT modelization prevents the aircraft from flying too low in a cold atmosphere.

The correction between True Altitude and Indicated Altitude can be defined as follows:

$$\Delta TA = \Delta IA \left(\frac{T_{ISA+\Delta T}}{T_{ISA}}\right)$$

With *ΔTA = True altitude correction*
IA = Indicated altitude
$T_{ISA+\Delta T}$ *= Current temperature (in Kelvin)*
T_{ISA} *= Standard temperature (in Kelvin)*
ΔT = Temperature correction (OAT - ISA)

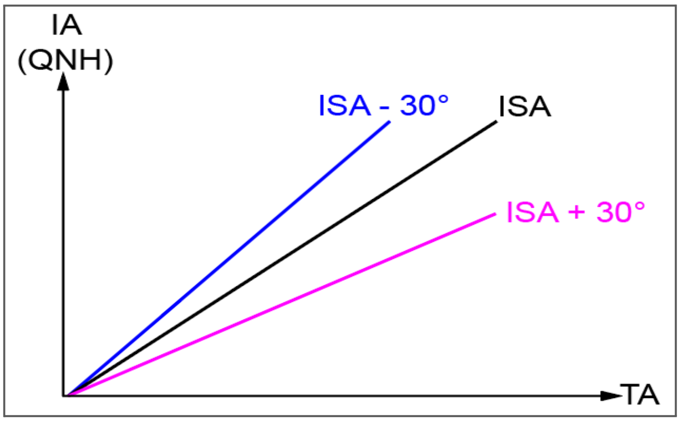


Illustration A3-9: IA VS.TA as a function of temperature

- When it is hot (OAT>ISA), True Altitude is higher than Indicated Altitude.
- When it is cold (OAT<ISA), True Altitude is lower than Indicated Altitude.
- The effect of temperature on Indicated Altitude increases with altitude.

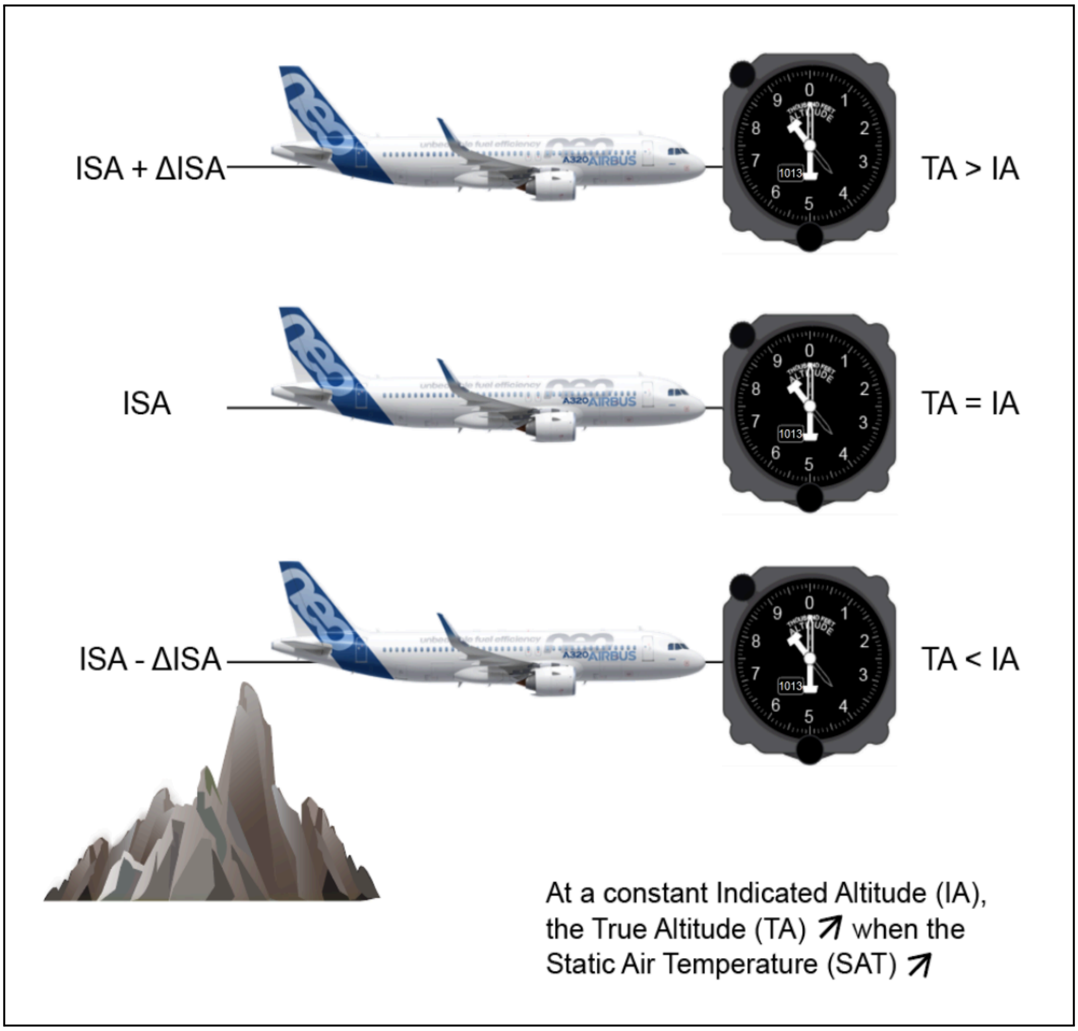


Illustration A3-10: Temperature effect on True Altitude, for a constant Indicated Altitude

Study case: Sion airport in Switzerland.

During an ILS approach on Runway 26, it is required to overfly specific waypoints at defined geometrical altitudes, regardless of the temperature conditions (Illustration A3-11). For example, at 17 Nm from the glide antenna, the aircraft must be at a height of 8 919 ft above the runway, or at a true altitude of 10 500 ft above mean sea level.

The glide slope intersection on Illustration A3-11 is 16 000 ft, corresponding to a height of 14 419 ft.

Illustration A3-12 provides the indicated altitude values to maintain the required true altitude for different temperature conditions:

When temperature is **ISA - 10:**

• True altitude	16 000 ft	10 500 ft
• Indicated altitude	16 600 ft	10 900 ft
• Δ altitude	600 ft	400 ft

When temperature is **ISA - 20**:

• True altitude	16 000 ft	10 500 ft
• Indicated altitude	17 300 ft	11 350 ft
• Δ altitude	1 300 ft	850 ft

Result:

- **When the temperature moves away from the standard, altimetric error increases.**
- **The altimetric error induced by temperature is proportional to altitude.**

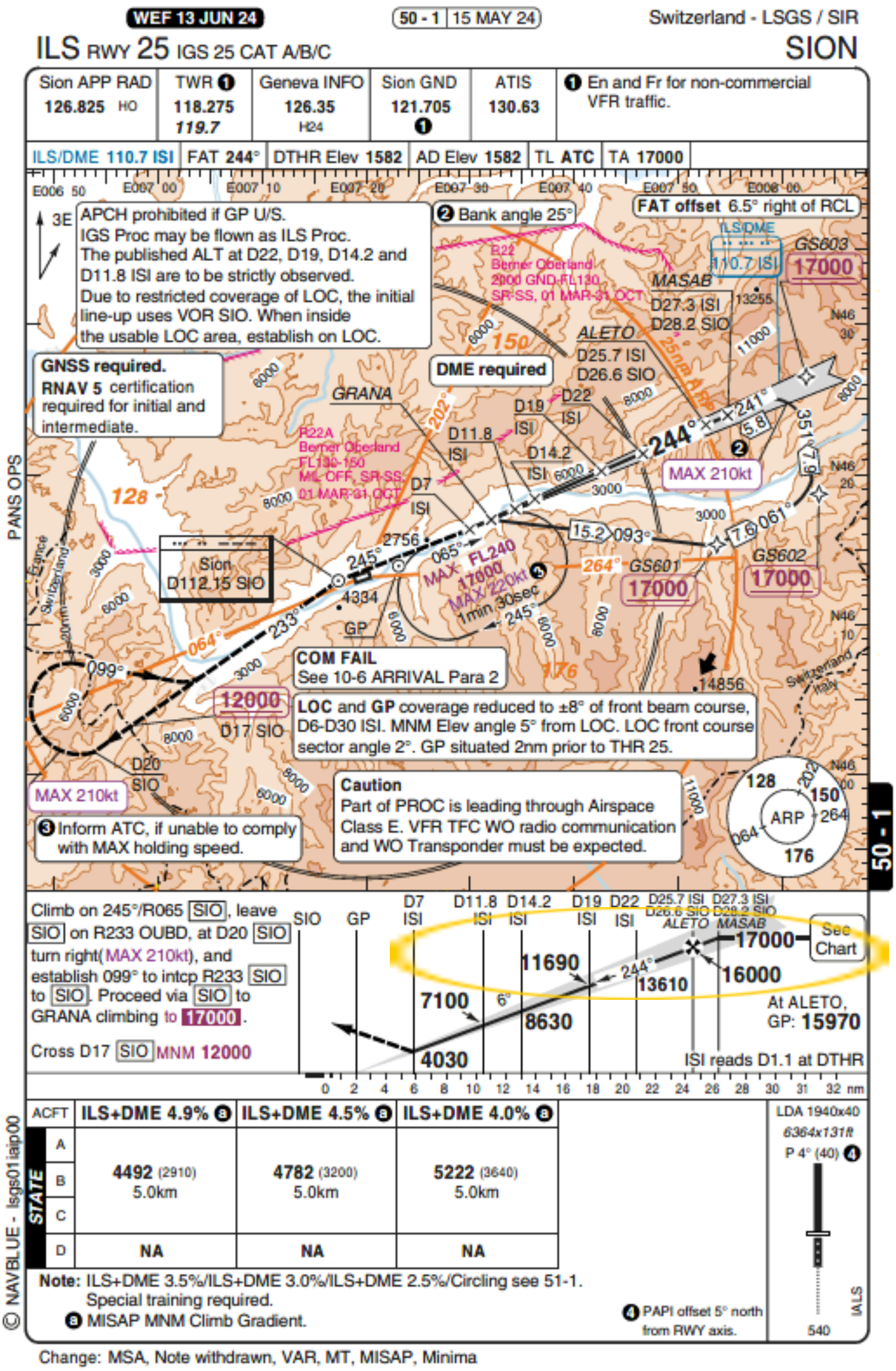


Illustration A3-11: Sion Airport Chart

Radio signals are transmitted to the ground and the time to receive the return signal provides the means to determine the height.

JEPPESEN 3 OCT 97 (11-0) Eff 9 Oct SION, SWITZERLAND
SION

DESCRIPTION OF INSTRUMENT GUIDANCE SYSTEM (IGS) RWY 26

IGS Components

- MOT VORDME as initial approach fix (IAF).
- SIO VORDME for initial line-up.
- ILS (LOC/GS/DME) for final line-up and from ALETO to MAP LOC opening angle: 2°.
- GS PSN: 3.2 NM before LOC-Antenna.

Restrictions

LOC and GS may only be used in the following area: Angle of +/- 8° of approach axis and dist of 31 - 7.5 NM DME LOC during apch. Minimum angle 5°.

Procedure

Due to the limited usable area of the LOC, the initial line-up uses SIO. When inside the usable LOC area, establish on LOC.
IGS procedure may be flown as ILS procedure.
The published altitudes at D21.0 ISI, D17.0 ISI and D12.0 ISI are strictly to be observed.

After reaching DA(H) proceed to rwy maintaining visual ground contact. At DA(H) rwy is still 7 NM ahead and may not yet be in sight. During the visual part use LOC and GS as back-up to D6.0 ISI. Then follow the highway until intercepting rwy 26 axis. Follow the PAPI for final descent segment (3.5°).

The altimeter error may be significant under conditions of extremely cold temperatures. For temperature deviation from ISA use the correction table to read the corrected altitude at the DME fixes.

Table for temperature below ISA

ALT	ISA	ISA +20° Altimeter Reading	ISA +10° Altimeter Reading	ISA -10° Altimeter Reading	ISA -20° Altimeter Reading
16000'	-17°	OAT +3° 14920'	OAT -7° 15450'	OAT -27° 16600'	OAT -37° 17300'
13100'	-12°	OAT +8° 12200'	OAT -2° 12650'	OAT -22° 13600'	OAT -32° 14170'
10500'	-6°	OAT +14° 9800'	OAT +4° 10150'	OAT -16° 10900'	OAT -26° 11350'
7400'	0°	OAT +20° 6920'	OAT +10° 7180'	OAT -10° 7670'	OAT -20° 7950'
6000'	+3°	OAT +23° 5650'	OAT +13° 5820'	OAT -7° 6210'	OAT -17° 6450'

CHANGES: New chart.

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Illustration A3-12: Temperature Effect on Indicated Altitude

1.2. Radio Height

1.2.1. Definition

The source of Radio Height is the radio altimeter, an antenna installed on the underside of the aircraft rear fuselage. The radio altimeter transmits radio signals to the ground and the time to receive the return signal provides the means to determine the height.

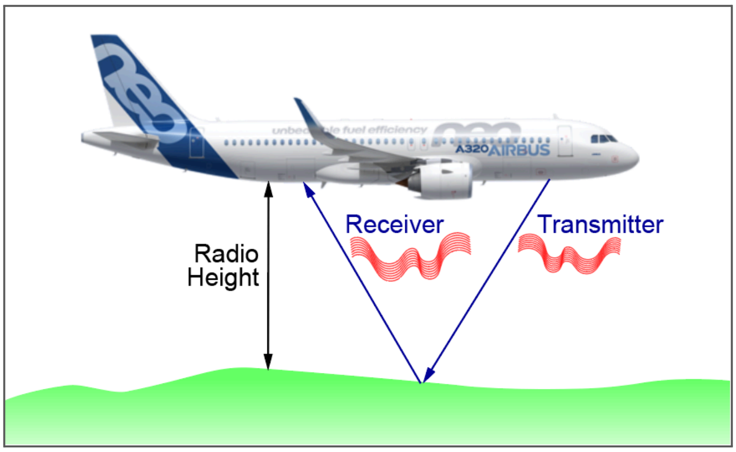

Illustration A3-13: Radio height principle

The RH indicates the geometric height between the aircraft and the ground.

1.2.2. The Use of Radio Height

The radio altitude is more accurate than the pressure altitude, but it cannot be used for vertical separation because there is no common reference. It is used for landing, particularly for precision approaches.

1.2.3. Where is it displayed?

The RH is displayed on the PFD (below the attitude scale) when the aircraft is at or below 2 500 ft above the ground.

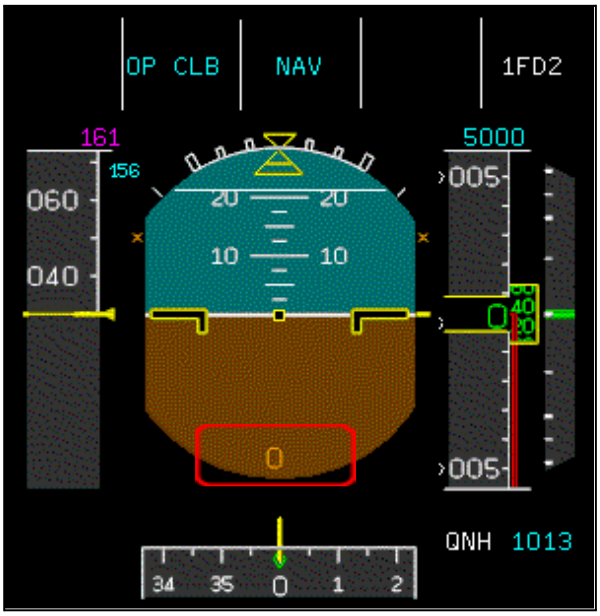

Illustration A3-14: Radio Height location on PFD

APPENDIX 4: SPEEDS

1.1. DEFINITIONS

To operate an aircraft, the flight crew use different types of speed. There are speeds to manage the flight while margins from critical areas are maintained, and there are other speeds that are mainly used for navigational and performance optimization purposes.

1.1.1. Calibrated AirSpeed (CAS)

The Calibrated AirSpeed (CAS) is obtained from the dynamic pressure q (or ΔP) that is a difference between the impact pressure P_i (measured by the pitot probes) and the static pressure P_s (measured by the static probes). The takeoff and landing performance calculations are performed in CAS.

$$CAS = f(P_i - P_s) = f(q)$$

Flight at a constant CAS during a climb phase enables the aerodynamic effect to remain the same as at sea level.

1.1.2. Indicated Air Speed (IAS)

The Indicated Air Speed (IAS) is the speed displayed by the airspeed indicator. The flight crew use it for low speed operations, that is why operational speeds (e.g. V_1, V_R, V_2, etc…), are in IAS.
If the pressure measurement were perfect, the IAS would be equal to the CAS. However, some errors need to be corrected due to various parameters that include aircraft angle of attack, slats/flaps configuration, ground effect etc.
The IAS is the CAS plus a correction called “instrument error” (K_i). CAS to IAS calibration is certified and available in the AFM.

$$IAS = CAS + K_i$$

1.1.3. True Air Speed (TAS)

The True Air Speed (TAS) is the speed of the aircraft in the airflow (general definition of a mobile speed).

$$TAS = \frac{Air\ distance}{Time}$$

The TAS can be computed from the CAS, with the use of the air density (ρ) ratio and a compressibility correction (K).

$$TAS = \sqrt{\frac{\rho_0}{\rho}}\,.K.\,CAS$$

The TAS is used for flight mechanics (e.g. lift determination) and for the computation of the Ground Speed (GS).

1.1.4. Ground Speed (GS)

The Ground Speed (GS) is the aircraft speed in a ground reference system that is fixed. It is equal to the TAS corrected for the wind component (Illustration A10). The aircraft computes the GS with the use of the inertial and GPS data.

Ground Speed = True Air Speed + Wind Component

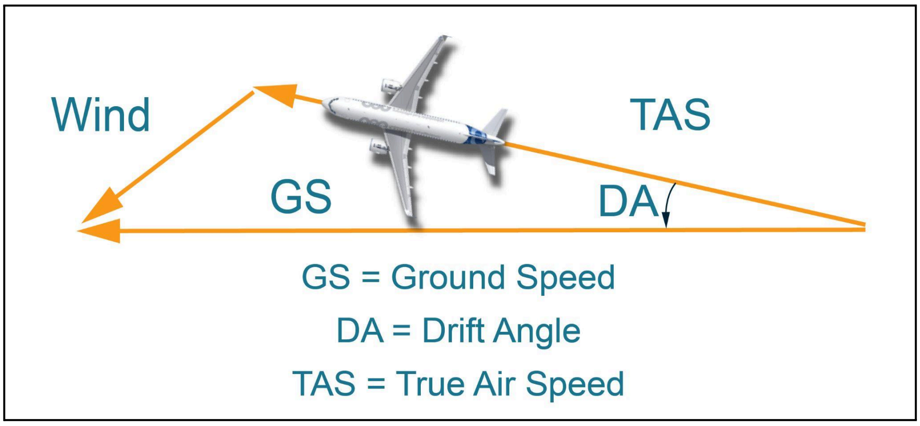

Illustration A4-1: Ground Speed and Drift Angle

The GS is used for navigation calculations because the flight routes always refer to the ground.

Ground Distance = GS x Time

1.1.5. Mach Number (M)

The Mach Number (M) is a comparison between the TAS and the sound velocity. It is used as a cruise control parameter.

$$M = \frac{TAS}{a}$$

With TAS = True Air Speed in knots
a = The sound velocity at the flight altitude in knots

The sound velocity in m/s is deduced from the following:

$$a = \sqrt{\gamma R T}$$

With γ*=1.4*
R=287J/kg/K
T= SAT = ambient temperature in Kelvin

1.2. TAS VARIATION

The following graph (Illustration A11) illustrates the TAS variation as a function of the pressure altitude for a typical climb of a subsonic aircraft:

- Initially constant CAS 250kt till FL100
- Acceleration
- Constant CAS 300 kt up to the crossover altitude
- Constant Mach (M0.78).

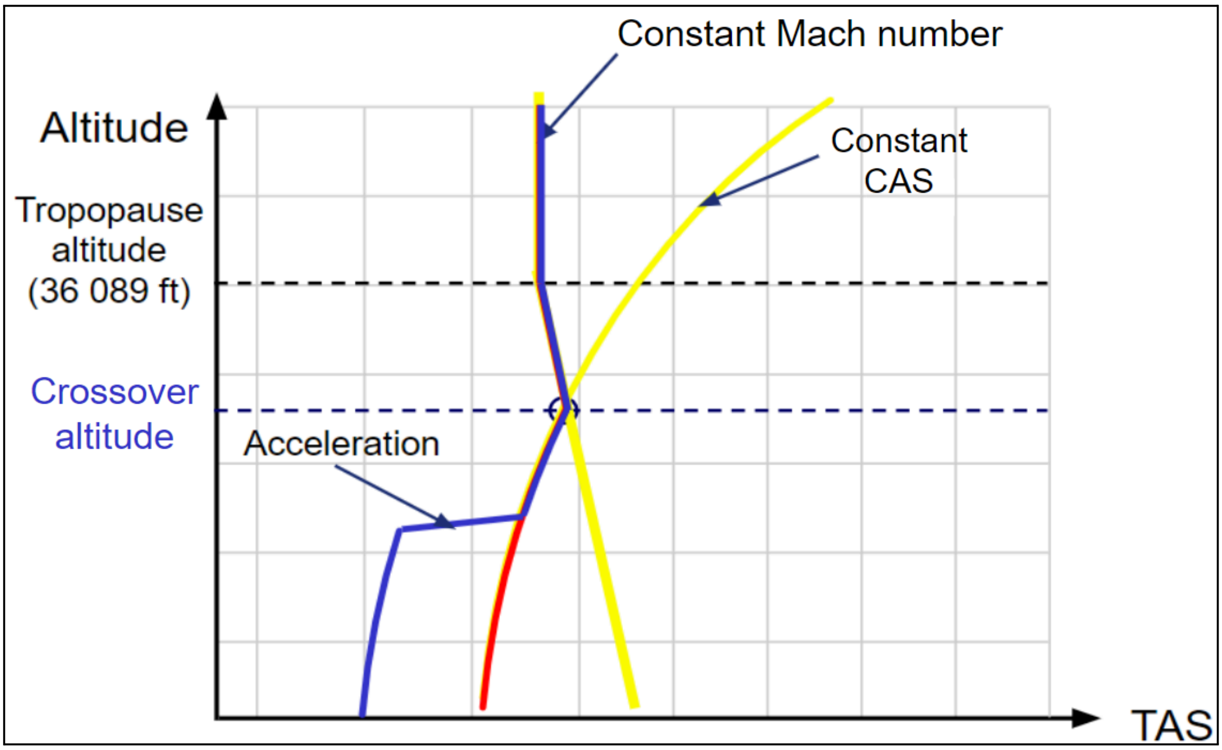

Illustration A4-2: Blue line: Variations of True Air Speed – Climb profile 300 kt / M0.78

The altitude at which the CAS and Mach correspond to the same TAS is called the crossover altitude. The curves for constant CAS and constant Mach intersect at this point. The crossover altitude value is different for each couple (CAS, Mach). Above the crossover altitude, the Mach number becomes the reference speed.

1.3. Where is it displayed?

The IAS is displayed on the speed scale of the PFD.
The Mach number is displayed below the speed scale of the PFD.
The GS and TAS are displayed on the top left of the Navigation Display (ND).

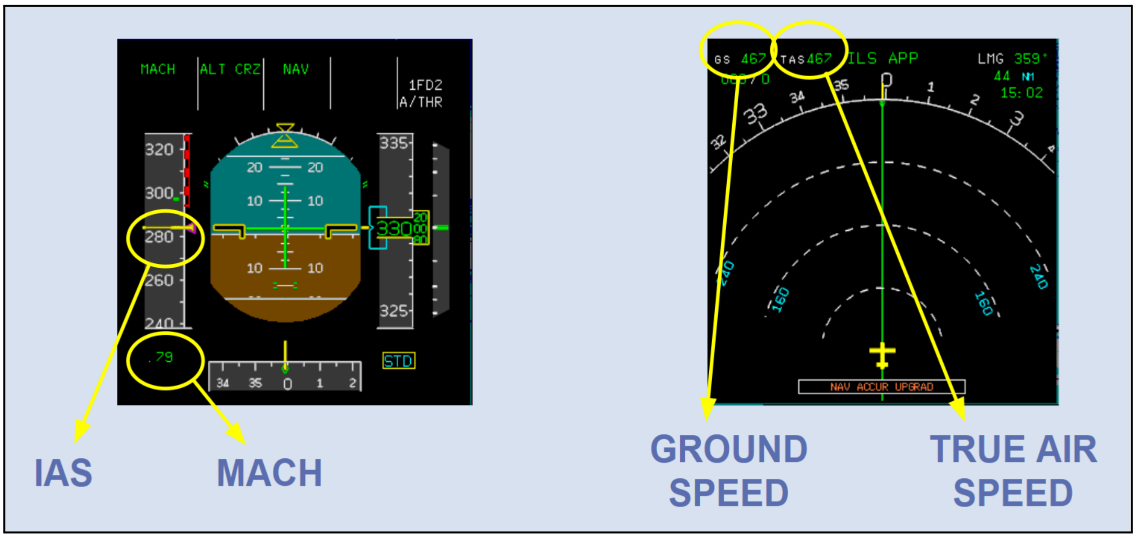

Illustration A4-3: Speeds displayed on the PFD

1.4. Summary

The TAS is the speed used for flight mechanics ($L = \frac{1}{2} S \cdot P_s / RT \cdot TAS^2 \cdot C_L$).
The GS is the speed used for navigation.
The CAS (or IAS) is the speed used for low speed flight phases and for certification (e.g. Stall speeds).
The MACH is the speed for high speed flight phases, it enables cruise speed optimization.

APPENDIX 5: FLIGHT MECHANICS

For a flight at constant speed in level flight, the engine thrust must balance the drag force.

As a general rule, when engine thrust is higher than drag, the aircraft can use this extra thrust to accelerate and/or climb. Contrary to this, when the thrust is not sufficient enough to compensate for drag, the aircraft must decelerate and/or descend.

In flight, four forces are applied to an aircraft: thrust, drag, lift and weight. If the aircraft is in steady level flight, as a first approximation, the following balance is obtained (Illustration A12):

- The thrust for steady level flight (T) is equal to drag ($D = ½ \rho S V^2 C_D$),
- Weight (mg) is equal to lift ($L = ½ \rho S V^2 C_L$).

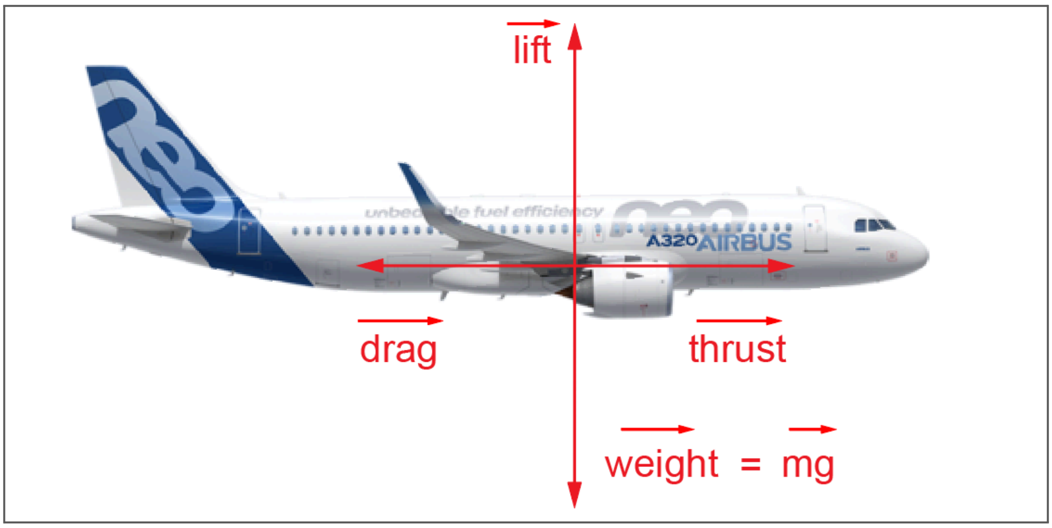

Illustration A5-1: Balance of Forces for Steady Level Flight

1.1. STANDARD LIFT EQUATION

$$\text{Weight} = mg = ½ \rho S (TAS)^2 C_L \qquad (1)$$

With *m = Aircraft mass*
g = Gravitational acceleration
ρ = Air density
S = Wing area
C_L = Lift coefficient

The lift coefficient, C_L, is a function of the angle of attack (α), the Mach number (M), and the aircraft configuration.

1.2. Standard Drag Equation

$$\text{Thrust} = \tfrac{1}{2}\,\rho\, S\,(TAS)^2\, C_D$$

With C_D = Drag coefficient

The drag coefficient, C_D, is a function of the angle of attack (α), the Mach number (M) and the aircraft configuration.

1.3. Equations as a function of the Mach number

Lift and drag equations may be expressed as a function of the Mach number M. As a result, the equations are:

$$\text{Weight} = 0.7\, P_S\, S\, M^2\, C_L$$

$$\text{Thrust} = 0.7\, P_S\, S\, M^2\, C_D$$

With P_s = Static Pressure

1.4. Equations in Climb and Descent

The following Illustration (A5-2) displays the different forces applied on an aircraft in climb and Illustration (A5-3) displays the different forces applied in descent.

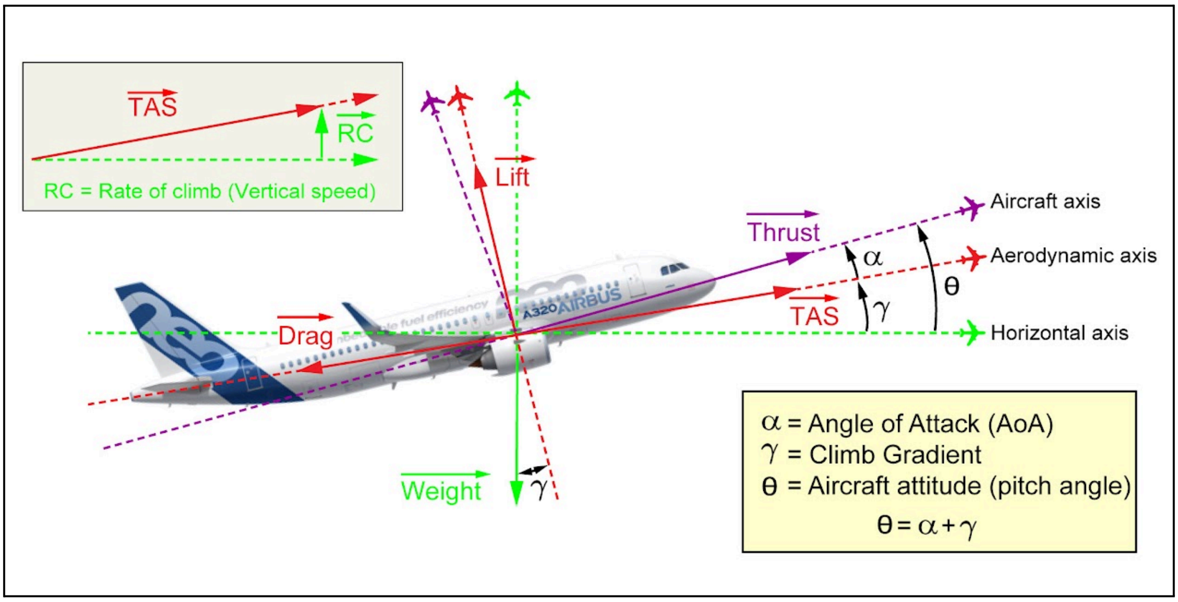

Illustration A5-2: Balance of Forces in Climb[18]

[18] In order to simplify, the thrust vector is represented parallel to the aircraft longitudinal axis.

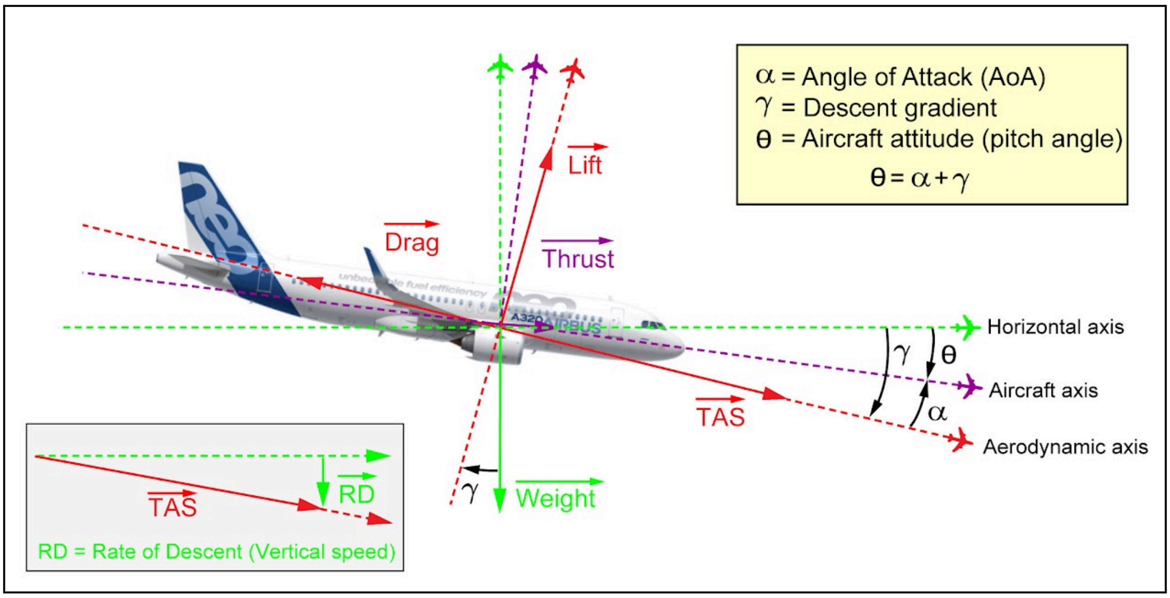

Illustration A5-3: Balance of Forces in Descent[19]

- The angle of attack (α) is the angle between the aircraft axis and the aerodynamic axis (speed vector axis tangent to the flight path).
- The climb/descent gradient (γ) is the angle between the horizontal axis and the aerodynamic axis.
- The aircraft attitude (θ) is the angle between the aircraft axis and the horizontal axis (in a ground reference system).
- The rate of climb (RC)/rate of descent (RD) is the vertical component of the speed of the aircraft. RC and RD are defined in ft per minute. RC is positive and RD is negative.

During climb or descent at constant speed, the balance of forces is reached. Along the aerodynamic axis, this balance can be defined as:

(1) $$\text{Thrust} \cos\alpha = \text{Drag} + \text{Weight} \sin\gamma$$

The balance along the vertical axis, becomes :

(2) $$\text{Lift} = \text{Weight} \cos\gamma$$

[19] In order to simplify, the thrust vector is represented parallel to the aircraft longitudinal axis.

1.4.1. Climb/Descent Gradient (γ)

The climb/descent gradient (γ) and the angle of attack (α) are usually small and can be neglected so that :

$$\sin\gamma \approx \tan\gamma \approx \gamma \text{ (in radian)}$$
$$\cos\gamma \approx 1 \text{ and } \cos\alpha \approx 1$$

As a result:

(3) $$\text{Thrust} = \text{Drag} + \text{Weight}\ \gamma$$

(4) $$\text{Lift} = \text{Weight}$$

From equation (3), Thrust - Drag = Weight γ. Then:

(5) $$\gamma_{rad} = \frac{\text{Thrust - Drag}}{\text{Weight}}$$

(4)+(5) $$\gamma_{rad} = \frac{\text{Thrust}}{\text{Weight}} - \frac{\textbf{Drag}}{\textbf{Lift}}$$

With the use of L/D (the Lift-to-Drag ratio), the climb angle becomes:

(6) $$\gamma_{rad} = \frac{\text{Thrust}}{\text{Weight}} - \frac{\mathbf{1}}{\mathbf{L/D}}$$

That gives, in percent:

(7) $$\gamma(\%) = 100 \cdot \left(\frac{\text{Thrust}}{\text{Weight}} - \frac{\mathbf{1}}{\mathbf{L/D}}\right)$$

Descent is performed at the Flight Idle thrust (i.e. at a thrust near zero). As a result, in descent:

(6 for descent) $$\gamma_{rad} = -\frac{\mathbf{1}}{\mathbf{L/D}}$$

That gives, in percent:

(7 for descent) $$\gamma(\%) = -\frac{\mathbf{100}}{\mathbf{L/D}}$$

Summary: At a fixed weight and engine rating, the climb gradient is maximum when (Thrust – Drag) is maximum (i.e. when the drag is minimum or when the lift-to-drag ratio is maximum). The best lift-to-drag ratio speed is called Green Dot (or Drift-down) speed. In case of an engine failure, flight at Green Dot speed permits the aircraft to have maximum aerodynamic efficiency and compensate for the power loss.

At a fixed weight, the descent gradient is minimum when the drag is minimum, or when the lift-to-drag ratio is maximum. The minimum descent angle speed is, therefore, Green Dot speed.

1.4.2. Rate of Climb (RC)/ Rate of Descent (RD)

The Rate of Climb (RC)/Rate of Descent (RD) corresponds to the vertical speed of the aircraft. As a result:

(8) $RC = TAS \sin\gamma \approx TAS\ \gamma$ ($\sin\gamma \approx \gamma_{rad}$ as γ is small)

$RD = TAS \sin\gamma \approx TAS\ \gamma$ ($\sin\gamma \approx \gamma_{rad}$ as γ is small)

From equation (5), $\gamma = \dfrac{\text{Thrust - Drag}}{\text{Weight}}$

Therefore:

(9)

$$\mathbf{RC} = \mathbf{TAS} \cdot \frac{\text{Thrust - Drag}}{\text{Weight}}$$

$$\mathbf{RD} = -\mathbf{TAS} \cdot \frac{\text{Drag}}{\text{Weight}} \quad \text{or} \quad \mathbf{RD} = \frac{\text{- TAS}}{L/D} < 0$$

Summary: At a fixed aircraft weight, the rate of climb is maximum when TASx(Thrust – Drag) is maximum. In terms of power[20], the rate of climb is maximum when ($P_{thrust} - P_{drag}$) is maximum.
At a fixed aircraft weight, the rate of descent is minimum, when TASxDrag is minimum.

[20] The force power (P_{force}) is the force multiplied by the speed (TAS). The unit is watt (W).

1.5. Speed Polar

1.5.1. Required Thrust

To fly at a constant level and constant speed, the thrust must balance the drag. As a result, drag can be considered as the thrust required to maintain a constant flight level and a constant speed. The Speed Polar Curve enables to identify the variation of the required thrust, as a function of the cruise speed and angle of attack.

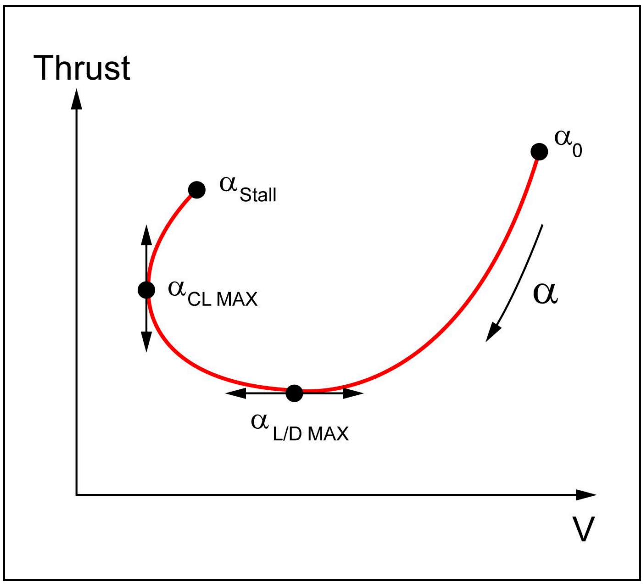

Illustration A5-4: Required Thrust

1.5.2. Required Thrust and Available Thrust

At a fixed altitude, temperature, weight and thrust setting, the engines produce a specific amount of Thrust available (Ta), as displayed in the illustration below.

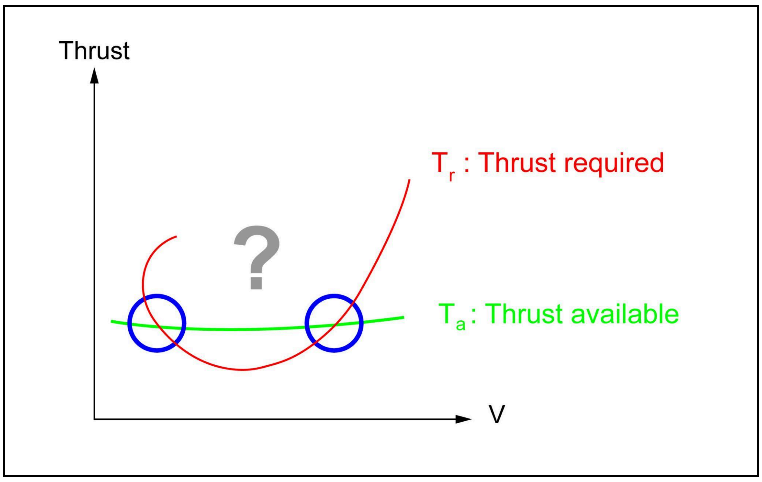

Illustration A5-5: Required Thrust and Available Thrust

To maintain level flight, the thrust available must be equal to the thrust required at a specific cruise speed.

As displayed in the Illustration A5-5, two possible speeds can be used to maintain level flight: a “stable” point (after a change, the parameters return to the initial state) and an “unstable” point (after a change, the parameters do not return to the initial point). The stable point corresponds to engine first rating, and the unstable point corresponds to engine second rating.

The following Illustration (A5-6) displays both the thrust and the drag forces variation with the True Air Speed.

To fly at a constant flight level and constant speed, the thrust must balance the drag. As a result, drag can be considered as the thrust required to maintain a constant flight level and a constant speed. Climb is only possible when the available thrust is higher than the required thrust (excess of thrust).

The following illustration indicates that, for a given weight:

- The climb angle (γ) is proportional to the difference between the available thrust and the required thrust.
- The rate of climb (RC) is proportional to the difference between the available thrust and the required thrust. In addition, as RC = TAS γ, the maximum rate of climb is obtained for a TAS higher than Green Dot (when dRC/dTAS = 0).

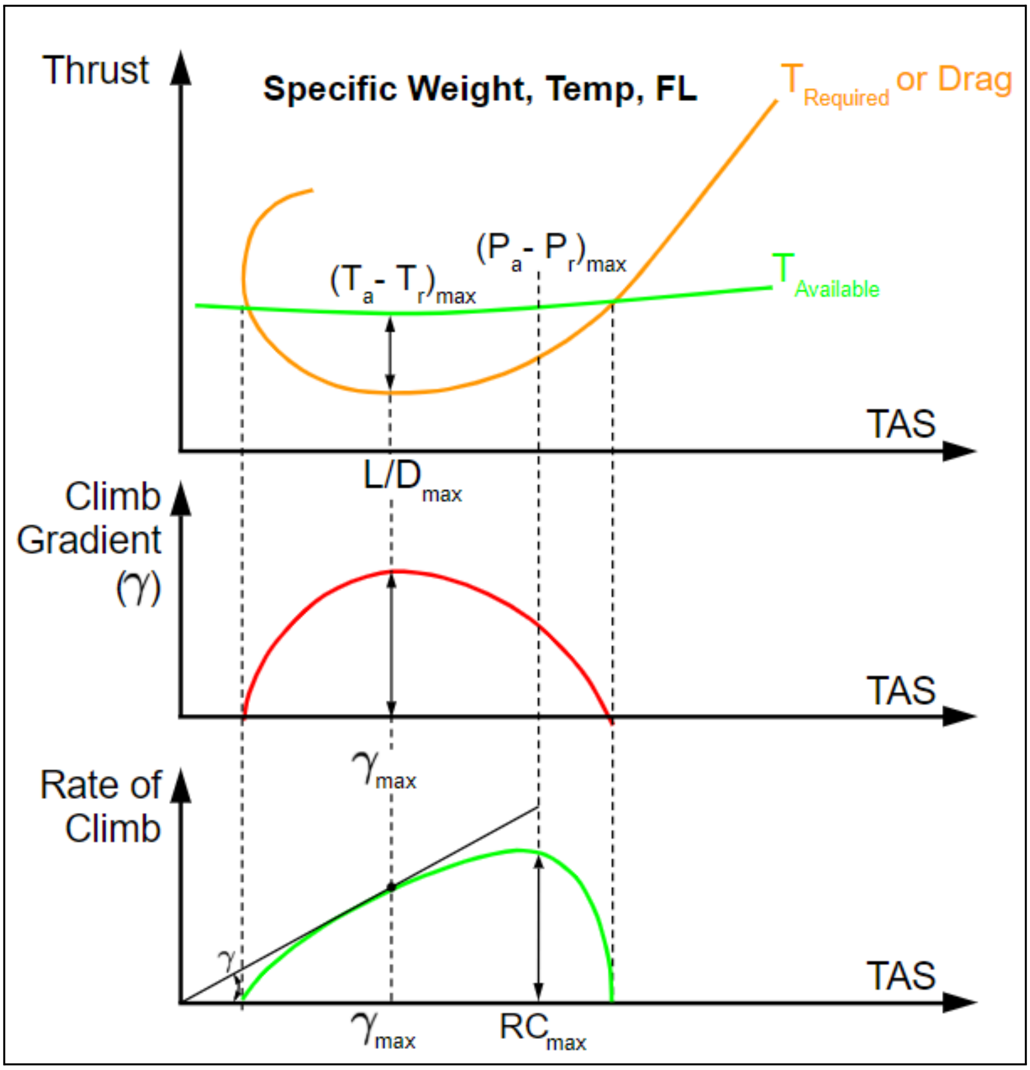

Illustration A5-6: Thrust Curves and Speed Polar for Climb

In operation, flight crews use Green Dot speed, not L/Dmax ratio. It is not advantageous to climb at a speed lower than Green Dot, as it requires a longer distance and time to reach a specific flight level.

The example below (Illustration A5-7) displays both thrust and drag forces, as a function of True Air Speed for descent.

The following illustration indicates that, for a given weight:

- The descent angle (γ) is proportional to the drag force, and is at its minimum at Green Dot speed.
- The rate of descent (RD) is proportional to the drag force. As RD = TAS.γ, the minimum rate of descent is obtained for a TAS lower than Green Dot (when dRD/dTAS = 0).

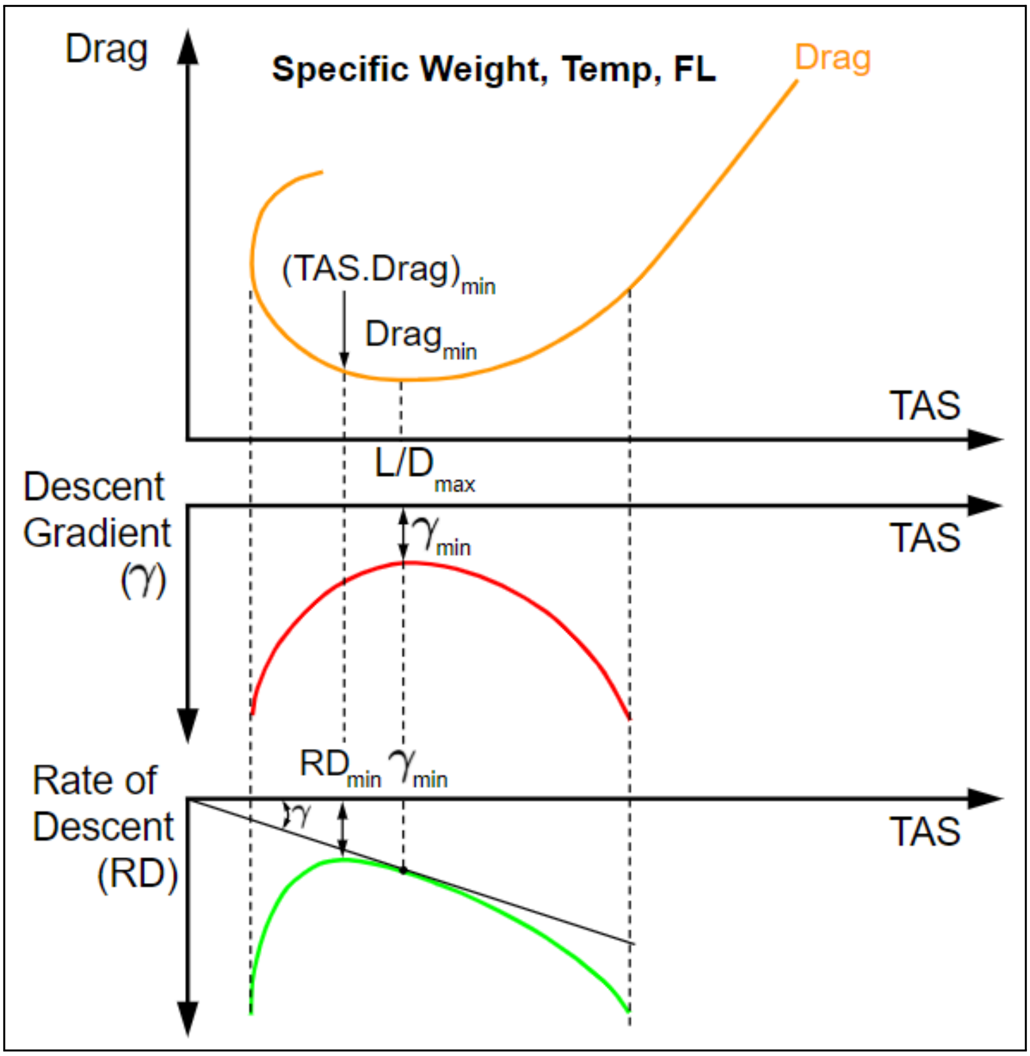

Illustration A5-7: Drag Curve and Speed Polar for Descent

APPENDIX 6: AERONAUTICAL INFORMATION PUBLICATION

The primary source of aeronautical data for a specific airport is the Aeronautical Information Publication (AIP).
The AIP is edited and revised by the National Aviation Authorities of the specific country.
Based on this information, some airport data providers put all the information available in a single publication.

The AIP usually includes (for all local commercial airports) the following information in an electronic format (eAIP):

- Aerodrome Chart:
  This chart provides precise information on the runway heading and threshold position. It also provides all declared runway lengths (TORA, TODA, ASDA) for main runways and intersections.

- Obstacle positions and elevations:
  The obstacle information is available in charts (Type A, B and C). In addition, National Aviation Authorities now usually provide information on the obstacles in the eAIP through Electronic Terrain and Obstacle Data (eTOD) surrounding the airport. The eTOD is the digital representation of terrain and obstacles provided as a database used by airborne and ground applications, for example Procedure Design etc.
  Four areas of the State territory are required in eTOD:
  - Area 1: the entire territory of a State: useful for en-route analyses.
  - Area 2: the smallest of terminal control area or a 45 km radius around the airport: useful for Engine Failure Procedure analyses.
  - Area 3: aerodrome/heliport area that extends from the edges of the runway to 90 m from the runway centreline and for all other parts of aerodrome/heliport movement areas, 50 m from the edges of the defined areas.
  - Area 4: Category II or III operations area (restricted to those runways with Category II or III precision approaches).

- Standard Instrument Departure Chart (SID):
  This chart describes the departures procedures and provides all the information required for navigation (navaids positions, flight headings, turn descriptions, altitude limitations)

- Standard Terminal Arrival Route Chart (STAR):
  Similarly to the SID chart, the STAR chart describes the arrival procedures and provides information required for navigation.

APPENDIX 7: USE OF SNOWTAM IN OPERATIONS

ICAO 10066 PROCEDURES FOR AIR NAVIGATION SERVICES AERONAUTICAL INFORMATION MANAGEMENT

EASA Aerodromes (Regulation (EU) No 139/2014) Annex I — Definitions for terms

(41b) 'SNOWTAM' means a special series NOTAM given in a standard format, which provides a surface condition report notifying the presence or cessation of hazardous conditions due to snow, ice, slush, frost, standing water or water associated with snow, slush, ice, or frost on the movement area;

The FAA defines FICON NOTAM in the AC 150/5200-30D to report the pavement surface conditions on runways, taxiways, and aprons and Runway Condition Codes (RWYCC) if more than 25 percent of the overall runway length and width coverage or cleared width of the runway is contaminated.

Appendix 2 — SNOWTAM FORMAT

Delegated Regulation (EU) 2020/2148

(COM heading)	(Priority indicator	(Addresses)		<≡
	(Date and time of filing)	(Originator's indicator)		<≡
(Abbreviated heading)	(SWAA* SERIAL NUMBER) S W * *	(LOCATION INDICATORS)	DATE-TIME OF ASSESSMENT	(OPTIONAL GROUP) <≡(

SNOWTAM →	(Serial number)	<≡

Aeroplane performance calculation section			
(AERODROME LOCATION INDICATORS)	M	A)	<≡
(DATE/TIME OF ASSESSMENT *(Time of completion of assessment in UTC)*)	M	B)	→
(LOWER RUNWAY DESIGNATION NUMBER)	M	C)	→
(RUNWAY CONDITION CODE (RWYCC) ON EACH RUNWAY THIRD) (From Runway Condition Assessment Matrix (RCAM) 0, 1, 2, 3, 4, 5 or 6)	M	D)	// →
(PER CENT COVERAGE CONTAMINANT FOR EACH RUNWAY THIRD)	C	E)	// →
DEPTH (mm) OF LOOSE CONTAMINANT FOR EACH RUNWAY THIRD)	C	F)	// →
(CONDITION DESCRIPTION OVER TOTAL RUNWAY LENGTH (Observed on each runway third, starting from threshold having the lower runway designation number) COMPACTED SNOW DRY DRY SNOW DRY SNOW ON TOP OF COMPACTED SNOW DRY SNOW ON TOP OF ICE FROST ICE SLIPPERY WET SLUSH SPECIALLY PREPARED WINTER RUNWAY STANDING WATER WATER ON TOP OF COMPACTED SNOW WET WET ICE WET SNOW WET SNOW ON TOP OF COMPACTED SNOW WET SNOW ON TOP OF ICE	M	G)	// →
(WIDTH OF RUNWAY TO WHICH THE RUNWAY CONDITIONS CODES APPLY, IF LESS THAN THE PUBLISHED WIDTH)	O	H)	<≡≡
Situational awareness section			
(REDUCED RUNWAY LENGTH, IF LESS THAN THE PUBLISHED LENGTH (m))	O	I)	→
(DRIFTING SNOW ON THE RUNWAY)	O	J)	→
(LOOSE SAND ON THE RUNWAY)	O	K)	→
(CHEMICAL TREATMENT ON RUNWAY)	O	L)	→
(SNOWBANKS ON THE RUNWAY) (If present, distance from runway centreline (m) followed by 'L', 'R' or 'LR' as applicable))	O	M)	→
(SNOWBANKS ON A TAXIWAY)	O	N)	→
(SNOWBANKS ADJACENT TO THE RUNWAY)	O	O)	→
(TAXIWAY CONDITIONS)	O	P)	→
(APRON CONDITIONS)	O	R)	→
(MEASURED FRICTION COEFFICIENT)	O	S)	→
(PLAIN-LANGUAGE REMARKS)	O	T)	) <<≡

NOTES:
1. *Enter ICAO nationality letters as given in ICAO Doc 7910, Part 2 or otherwise applicable aerodrome identifier.
2. Information on other runways, repeat from B to H.
3. Information in the situational awareness section repeated for each runway, taxiway and apron. Repeat as applicable, when reported.
4. Words in brackets () not to be transmitted.
5. For letters A) to T), refer to the *Instructions for the completion of the SNOWTAM format, paragraph 1, item b)*.

SIGNATURE OF ORIGINATOR *(not for transmission)*

SNOWTAM FORMAT

SNOWTAM example:
ESGG
02170055 03 5/3/3 100/100/100 03/08/09 SLUSH/WET SNOW/WET SNOW

1.1. Description of SNOWTAM

(AERODROME LOCATION INDICATOR)
ESGG

(LOWER RUNWAY DESIGNATION NUMBER)
03 => RUNWAY 03

(RUNWAY CONDITION CODE (RWYCC) ON EACH RUNWAY THIRD)
5 /3 /3 => RWYCC 5 on first third of the runway, RWYCC 3 on 2nd third, RWYCC 3 on last third

(PER CENT COVERAGE CONTAMINANT FOR EACH RUNWAY THIRD)
100/100/100 => 100% coverage on the first third of the runway…

(DEPTH (mm) OF LOOSE CONTAMINANT FOR EACH RUNWAY THIRD)
03/08/09 => 3mm of contaminant of the first third of the runway…

(CONDITION DESCRIPTION OVER TOTAL RUNWAY LENGTH)
(Observed on each runway third, starting from threshold having the lower runway designation number)
SLUSH/WET SNOW/WET SNOW

1.2. Primary use of SNOWTAM information

1.2.1. Takeoff

As referred to in the section Takeoff, the certification of the takeoff performance is based on contaminant type and depth.
In the example above, the takeoff performance computation is based on WET SNOW 10mm.
With the use of Contaminant type and depth, all the effects of the contaminant are considered, including:

- Effect of reduced friction coefficient
- Effect of contaminant on drag
- Aquaplaning considerations.

The effect of fluid contaminants on aircraft drag must be considered for TOR, TOD and ASD computations. The higher the drag of the contaminant, the longer the takeoff distance.

1.2.2. Landing Dispatch

As referred to in the section Landing, the certification of Required Landing Distance is based on contaminant type.

In the example above, the performance computation for Landing Dispatch is based on WET SNOW. The drag effect of the contaminant is not considered, or is considered only for the minimum depth.

1.2.3. Landing distance at time of arrival

As referred to in the section Landing, the computation of Landing Distance at time of arrival is based on RWYCC information.
In the above SNOWTAM example, the performance computation for Landing distance is based on RWYCC 3.
The use of RWYCC only considers the effect of reduced friction forces (reduced braking action). The drag of the contaminant is not considered.

1.2.4. Use of intermediate depth

Airbus aircraft are certified for specific values of contaminant depth. When the reported depth is between two certified values, assessments for both the lower and the higher depth of the contaminant must be performed to identify the most conservative depth.

1.3. Use of RWYCC at Takeoff

Although RWYCC is defined for landing performance assessment, when a SNOWTAM provides information that is not consistent between the contaminant type and RWYCC, a pilot may decide to consider all available information, including RWYCC, for the takeoff performance computation. It is important to take this information into account when the reported RWYCC is lower than the expected one.

For example: 2/2/2 100/100/100 10/10/10 DRY SNOW/DRY SNOW/DRY SNOW

Based on the RCAM matrix, DRY SNOW must be reported as RWYCC 3. In this example, the airport decided to 'downgrade' the RWYCC based on observations or reports that describe the braking action as degraded.
In this type of situation, the pilot should consider this information, and consider this 'downgrade' for the takeoff computation.

Depending on aircraft type, two options may be available for Airbus operators:
- Both the downgraded RWYCC and the runway condition (contaminant type and depth) are used to perform the takeoff computation. In this case, the lowest friction coefficient is considered. The drag and aquaplaning effect are based on the contaminant type and depth input.
- An equivalent contaminant type is used as a representation of the downgraded conditions. For example, for a runway covered by a hard contaminant, or a fluid contaminant with a depth of 3 mm (1/8 in) or less and, in the case of a downgrade to RWYCC 4, the takeoff performance computation may be performed with Compacted Snow.

APPENDIX 8 : ABBREVIATIONS AND SYMBOLS

Greek letters

α	(alpha)	Angle of attack
γ	(gamma)	Climb or descent angle
δ	(delta)	Pressure ratio = P / P_0
Δ	(DELTA)	Parameters' variation (ex : ΔISA, ΔP)
η	(eta)	Anti-skid efficiency
φ	(phi)	Bank angle
μ	(mu)	Runway friction coefficient
θ	(theta)	Aircraft pitch angle
ρ	(rho)	Air density
ρ_0	(rho zero)	Air density at Mean Sea Level
σ	(sigma)	Air density ratio = ρ / ρ_0

A

a	Sound velocity
a_0	Sound velocity at sea level
AAL	Above Aerodrome Level
AC	Advisory Circular (FAA)
ADIRS	Air Data / Inertial Reference System
AECG	All Engine Climb Gradient
AEO	All Engines Operative
AFM	Aircraft Flight Manual
AIP	Aeronautical Information Publication
ALD	Actual Landing Distance
AMC	Acceptable Means of Compliance (EASA)
AMSL	Above Mean Sea Level
AOM	Airline Operation Manual
APD	Aircraft Performance Data
APM	Aircraft Performance Monitoring (program)
APR	Automatic Power Reserve
APU	Auxiliary Power Unit
ASD	Accelerate-Stop Distance
ASDA	Accelerate-Stop Distance Available
ATC	Air Traffic Control
A/THR	Autothrust
ATTCS	Automatic Take-off Thrust Control System

C

C_D	Drag coefficient
C_L	Lift coefficient
C_{Lmax}	Maximum Lift Coefficient
CAS	Calibrated Air Speed
CDL	Configuration Deviation List
CG	Center of gravity
CI	Cost Index
CL	Climb throttle position
CS	Certification Specifications (EASA)
CWY	Clearway

D

DA	Drift Angle (for GS computation)
DA	Decision Altitude (for approach)
DA/H	Decision Altitude or Height
DGAC	Direction Générale de l'Aviation Civile
DH	Decision Height
DOC	Direct Operating Cost
DOW	Dry operating weight

E

EASA	European Aviation Safety Agency
ECON	Economic (minimum cost) speed
EFB	Electronic Flight Bag
EFP	Engine Failure Procedure
ERA	En Route Alternate
EGT	Exhaust Gas Temperature
EO	Engine Out
EOSID	Engine Out Standard Instrument Departure
EOP	Engine Out Procedure
EPR	Engine Pressure Ratio
ETOPS	Extended range with Twin engine aircraft OPerationS

F

FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Control
FAR	Federal Aviation Regulation
FCOM	Flight Crew Operating Manual
FCTM	Flight Crew Techniques Manual
FF	Fuel Flow (hourly consumption)
FG	Flight Guidance
FL	Flight Level
FLD	Factored Landing Distance
FMS	Flight Management System
FRF	Final Reserve Fuel
FMGS	Flight Management and Guidance System

G

g	Gravitational acceleration
GDS	Green Dot speed
GS	Ground Speed

H

hPa	hecto Pascal

I

in Hg	Inches of mercury
IA	Indicated Altitude
IAS	Indicated Air Speed
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFP	In Flight Performance (program)
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IOSA	IATA Operational Safety Audit
ISA	International Standard Atmosphere

J

JAA	Joint Aviation Authority
JAR	Joint Airworthiness Requirements

K

K_i	Instrumental correction (Antenna error)

L

LDA	Landing Distance Available
LDTA	Landing Distance at the time of Arrival
LRC	Long Range Cruise speed
LW	Landing Weight

M

m	Aircraft's mass
M	Mach number
M_{ECON}	Economic Mach number
M_{LRC}	Mach of Long Range Cruise
M_{MR}	Mach of Maximum Range
M_{MO}	Maximum Operating Mach number
MAA	Missed Approach Altitude
MCA	Minimum Crossing Altitude
MCDL	Master Configuration Deviation List
MCDU	Multipurpose Control and Display Unit
MCT	Maximum Continuous Thrust
MEA	Minimum safe En route Altitude

MEL	**Minimum Equipment List**
MEW	**Manufacturer Empty Weight**
MGA	**Minimum safe Grid Altitude**
MLW	**Maximum Landing Weight** Depending on the context, MLW means either: - The maximum weight limited by performance, - The maximum weight limited by structure, - The minimum between both limitations above.
MMEL	**Master Minimum Equipment List**
MOCA	**Minimum Obstacle Clearance Altitude**
MORA	**Minimum Off Route Altitude**
MSA	**Minimum Sector Altitude**
MSL	**Mean Sea Level**
MTOW	**Maximum TakeOff Weight** Depending on the context, MTOW means either: - The maximum weight limited by performance, - The maximum weight limited by structure, - The minimum between both limitations above.
MTW	**Maximum Taxi Weight**
MZFW	**Maximum Zero Fuel Weight**

N

n	**Load factor**
n_z	**Load factor on Aircraft Z-axis**
n_{zw}	**Load factor normal to flight path at V_{CLmax}**
N	**All engines operating**
N1	**Speed rotation of the fan**
N-1	**One engine inoperative**
N-2	**Two engines inoperative**
NOTAM	**NOtice To AirMen**

O

OAA	**Obstacle Accountability Area**
OAT	**Outside Air Temperature**
OCTOPUS	**Operational and Certified Takeoff and landing Universal Softw**
OEI	**One Engine Inoperative**
OEW	**Operational Empty Weight**

P

P	**Pressure**
P_0	**Standard pressure at Mean Sea Level**
P_{force}	**Force power**
P_s	**Static pressure**
P_t	**Total pressure**
PEP	**Performance Engineering Programs**
PFD	**Primary Flight Display**
PPM	**Performance Program Manual**
PNR	**Point of No Return**

Q

q	Dynamic pressure
QFE	Pressure at the airport reference point
QNH	Mean Sea Level pressure

R

R	Universal gas constant
RC	Rate of Climb
RCAM	Runway Condition Assessment Matrix
RCF	Reduced Contingency Fuel
RESA	Runway End Safety Area
RD	Rate of Descent
RLD	Required Landing Distance
RVSM	Reduced Vertical Separation Minima
RWYCC	Runway Condition Code

S

S	Wing area
SAT	Static Air Temperature
SFC	Specific Fuel Consumption
SID	Standard Instrument Departure
SOC	Start of Climb
SOP	Standard Operating Procedure
SR	Specific Range
SRS	Speed Reference System
STAR	STandard ARrival procedure
STD	Standard
SWY	Stopway

T

T	Temperature
T_0	Standard temperature at Mean Seal Level
T_{ISA}	Standard temperature
T_{REF}	Flat Rating Temperature or reference temperature
T/C	Top of Climb
T/D	Top of Descent
TA	True Altitude
TAS	True Air Speed
TAT	Total Air Temperature
THR RED	Thrust Reduction altitude
TLO	TakeOff and Landing Optimization (program)
TO	TakeOff
TOD	TakeOff Distance
TODA	TakeOff Distance Available
TOGA	TakeOff / Go-Around thrust
TOR	TakeOff Run
TORA	TakeOff Run Available
TOW	TakeOff Weight

V

V	Velocity
V_1	Takeoff decision speed
V_2	Takeoff climb speed
$V_{2\ GA}$	See V_{AC}
$V_{2\ MIN}$	Minimum takeoff climb speed
V_{AC}	Approach climb speed
V_{APP}	Final approach speed
V_{CLmax}	See V_{S1G}
V_{EF}	Engine failure speed
V_{FE}	Maximum flap extended speed
V_{GA}	Climb Speed for Go Around
V_{LE}	Landing gear extended speed
V_{LO}	Landing gear operating speed
$V_{LO\ RET}$	Landing gear operating speed : retraction
$V_{LO\ EXT}$	Landing gear operating speed : extension
V_{LOF}	Lift Off speed
V_{LS}	Lowest selectable speed
V_{MBE}	Maximum brake energy speed
V_{MCA}	Minimum control speed in the air
V_{MCG}	Minimum control speed on ground
V_{MCL}	Minimum control speed during approach and landing
V_{MCL-2}	V_{MCL} two engines inoperative
V_{MO}	Maximum Operating speed
V_{MU}	Minimum Unstick speed
V_R	Rotation speed
V_{REF}	Reference landing speed
V_S	Stalling speed
V_{S1G}	Stalling speed at one g or V_{CLmax}
V_{SR}	Reference stalling speed
V_{TIRE}	Maximum tire speed

W

W	Weight
W_a	Apparent weight

Z

Zp	Pressure Altitude
ZFW	Zero Fuel Weight