Jet Transport Performance

Edition 2010

INTRODUCTION

This brochure is intended to give insight into the flight performance of jet transport aircraft as well as to refresh essential basic skills, which are required for safe and economic flight operations.

The brochure has been deliberately created without resorting to theoretical derivations.

To achieve this purposes the brochure covers the following subjects:

- Theory of Flight
- Jet Engine Basics
- Takeoff Performance
- Cruise Performance
- Landing Performance
- Weight and Balance

1 THEORY OF FLIGHT

1.1 Introduction

The clean, sleek appearance and the splendid performance characteristics of modern airplanes reflect the demands of modern travel, business, and industry. The present-day airplane is clean and sleek because aerodynamic cleanness of line, and efficiency of design, result in greater range, speed, and payload at the least operating cost. This is especially important in the functions of large jet transports.

"Performance" is a term used to describe the ability of an airplane to accomplish certain things which make it useful for certain purposes. For example, the ability of the airplane to land and take off in a very short distance is an important factor to the pilot who operates in and out of confined fields. The ability to carry heavy loads, fly at high altitudes at fast speeds, or travel long distances is essential performance for operators of airline type airplanes.
The chief elements of performance are the takeoff and landing distance, rate of climb, ceiling, payload, range, speed, maneuverability, stability, and fuel economy. Some of these factors are often directly opposed: for example, high speed versus shortness of landing distance; long range versus great payload; and high rate of climb versus fuel economy. It is the preeminence of one or more of these factors which dictates differences between airplanes and which explains the high degree of specialization found in modern airplanes.

The various items of airplane performance result from the combination of airplane and powerplant characteristics. The aerodynamic characteristics of the airplane generally define the power and thrust requirements at various conditions of flight while powerplant characteristics generally define the power and thrust available at various conditions of flight. The matching of the aerodynamic configuration with the powerplant is accomplished by the manufacturer to provide maximum performance at the specific design condition, e.g., range, endurance, climb, etc.

1.2 Properties of the Atmosphere

The composition of the earth's atmosphere is a vitally important factor in aerodynamics and the flight of aircraft. The forces and moments acting on a surface that is moved through the air are attributable, to a great extent, to the properties of the air mass in which the surface is operating.

The composition of the earth's atmosphere by volume is approximately 78% nitrogen, 21% oxygen, and 1% water vapor, argon, carbon dioxide, etc. In the majority of all aerodynamic considerations, air is assumed to be a uniform mixture of these gases.

Static pressure. The absolute static pressure of the air is a property of primary importance. The static pressure of the air at any altitude results from the mass of the air supported above that level. At standard sea level conditions the static pressure of the air is 14.7 pounds per square inch (psi), 29.92 inches of mercury (29.92 in.Hg.), or 1013.2 millibars. At 18,000 feet altitude this static pressure decreases to about 50% of the sea level value, and at 40,000 feet to about 10% of the sea level value. Pressure decreases with altitude (pressure lapse rate) is approximately 40 psi, 1 in. Hg, or 33 millibars per 1,000 feet.

Temperature. Many aspects of compressibility and engine performance involve considerations of atmospheric temperature. Normally with an increase in altitude there is an overall decrease of temperature in the troposphere (the lower layer of the atmosphere). This is apparent because the air nearest the earth receives the largest amount of heat. The variation of temperature with altitude is called the temperature lapse rate, and is expressed in degrees per thousand feet. On one day the temperature of the air may cool 3°C per thousand feet and on another day the air may show a decrease of only 1°C. On still another day, the temperature may increase for a distance of 2,000 or 3,000 feet above the ground (an example of an inverted lapse rate or inversion), and thereafter cool at the rate of 3°C per thousand feet. Temperature observations taken day after day over thousands of locations on the earth show the average lapse rate to be about 2°C per thousand feet. Standard sea level temperatures are 15°C with a lapse rate of 2°/1,000 feet, or 59°F., with a lapse rate of 3.5°/ 1,000 feet.

Moisture. In general, most weather hazards that interfere with the operation of aircraft are associated with water in one of its three states-vapor, liquid, or solid. Water vapor is water in the gaseous state and is not visible. When water vapor changes into liquid droplets, it becomes visible as clouds, fog, dew, rain, or drizzle. Some water droplets, remaining in the liquid state at temperatures well be low freezing, change into ice only when disturbed by an outside force, such as an aircraft in flight. These water droplets are supercooled and cause structural icing on aircraft. Water in the solid state appears either as frozen water droplets or as ice crystals such as snow.

ALTITUDE (Feet)	TEMP. (°C)	PRESSURE			PRESSURE RATIO δ = P/Po	DENSITY $\sigma = \rho/\rho o$	SPEED of SOUND (kt)	ALTITUDE (metres)
		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 1 – International Standard Atmosphere

1.3 The Airfoil or Wing

An airfoil (wing, control surface, etc.) is a surface designed to obtain a desirable reaction from the air through which it moves. Thus, we can say that any part of the aircraft which converts air resistance into a useful force for flight is an airfoil. The profile of a wing is an excellent example of an airfoil. The top surface of the wing profile has greater curvature than the lower surface. The difference in curvature of the upper and lower surfaces of the wing builds up the lift force. Air flowing over the top surface of the wing must reach the trailing edge of the wing in the same amount of time as the air flowing under the wing. To do this, the air passing over the top surface moves at a greater velocity than the air passing below the wing because of the greater distance it must travel along the top surface. This increased velocity means a corresponding decrease in pressure on the top surface. Thus a pressure differential is created between the upper and lower surfaces of the wing, forcing the wing upward in the direction of the lower pressure.

Bernoulli's principle and lift. Airflow and the useful reaction obtained in the wing configuration is an application of Bernoulli's principle which states that an increase in the velocity of a fluid over a surface gives a resultant decrease in pressure on the surface. It is relatively easy to visualize the decrease in pressure along the top surface of a wing due to the greater curvature, or camber, as it is also referred to. This lifting force is known as induced lift. Within limits, lift can be increased by increasing the angle of attack, the wing area, the freestrearn velocity, or the density of air, or by changing the shape of the airfoil.
Creating induced lift on a wing also creates induced drag, a force that acts rearward and at 90° from the upward force of lift. Within limits, drag can be increased by the same factors that increase lift, namely, by increasing the angle of attack, the wing area, the freestream velocity, or the density of air, or by changing the shape of the airfoil.

Chord, Angle of Attack, Center of Pressure
The chord of a wing section is an imaginary straight line which passes through the section from the leading edge to the trailing edge. The chord line provides one side of an angle which ultimately forms the angle of attack. The other side of the angle is formed by a line indicating the direction of the relative wind or airstream. Thus, angle of attack is defined as the angle between the chord line of the wing and the direction of the relative wind.
The lift force acts upward while the drag force acts rearward. The sum of these two forces is called a resultant force. The point of intersection of the resultant force line with the chord line is the center of pressure.
For small angles of attack, the resultant force is comparatively small. Its direction is upward and back from the vertical, and its center of pressure is well back from the leading edge of the wing. At positive angles of attack of three or four degrees, the resultant force attains its most nearly vertical direction. Either increasing or decreasing the angle of attack causes the direction of the resultant force to be farther from the vertical.

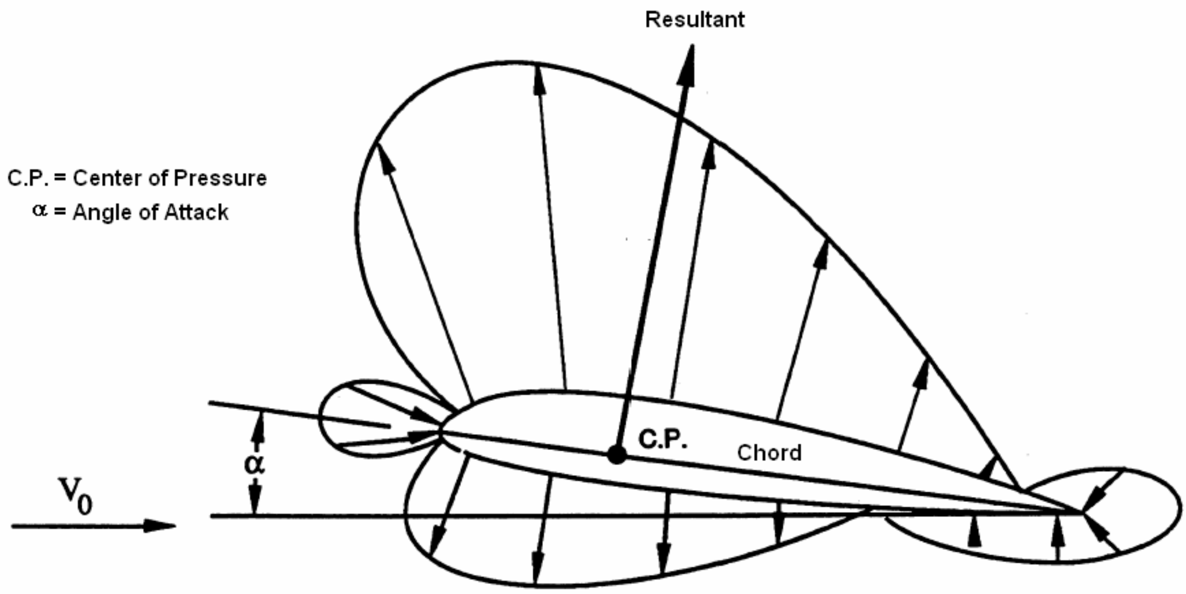


Figure 1 – Chord, Angle of Attack and Center of Pressure

Angle of Zero Lift. The zero angle of attack is normally a negative angle of attack, that is, one which places the chord line of the airfoil below the line which represents the direction of relative airstream. The angle of zero lift is obtained when the resultant force line is exactly parallel to the relative wind line. At this angle, the force acting on the airfoil is entirely drag. This principle could be demonstrated in a wind tunnel test by holding a wing section at the angle of zero lift and suddenly releasing it. Upon release of the wing section it would neither lift nor fall, but would move straight rearward in the direction of the relative wind.

Positive Angle of Attack and Stall. During flight, when the angle of attack is gradually increased toward a positive angle, the lift component increases rapidly up to a certain point and then suddenly begins to drop off. During this action the drag component increases slowly at first and then rapidly as lift begins to drop off. Finally, when the angle of attack increases to approximately 18° to 20° (on most airfoils) the air can no longer flow smoothly over the top wing surface because of the excessive change of direction required. This is the stalling angle of attack, sometimes called the burble point. At this point, turbulent airflow, which appears in small amounts near the trailing edge of the wing at lower angles of attack, suddenly spreads forward over the entire upper wing surface. The result is a sudden increase in pressure above the wing accompanied by a sharp loss of lift and a sudden increase in resistance or drag. The events that take place at the stalling angle of attack or burble point definitely show that Bernoulli's principle applies only in a smooth or streamlined airflow and not in turbulent air. The center of pressure at the point of stall is at its maximum forward position, and, as the wing stalls, the resultant vector is inclined to the rear.

Angle of Incidence. The angle of incidence of a wing is the angle between the longitudinal axis and the chord of the wing. This is a permanent angle and is sometimes referred to as the angle of wing setting. The wing is set at a proper angle with the longitudinal axis of the airplane so that the wing will provide the lift required at the speed at which the plane will normally operate and with the least amount of drag. Don't confuse the angle of incidence with the angle of attack explained earlier. The angle of attack is the angle between the wing chord and the relative wind, and changes to a positive or negative value during flight.

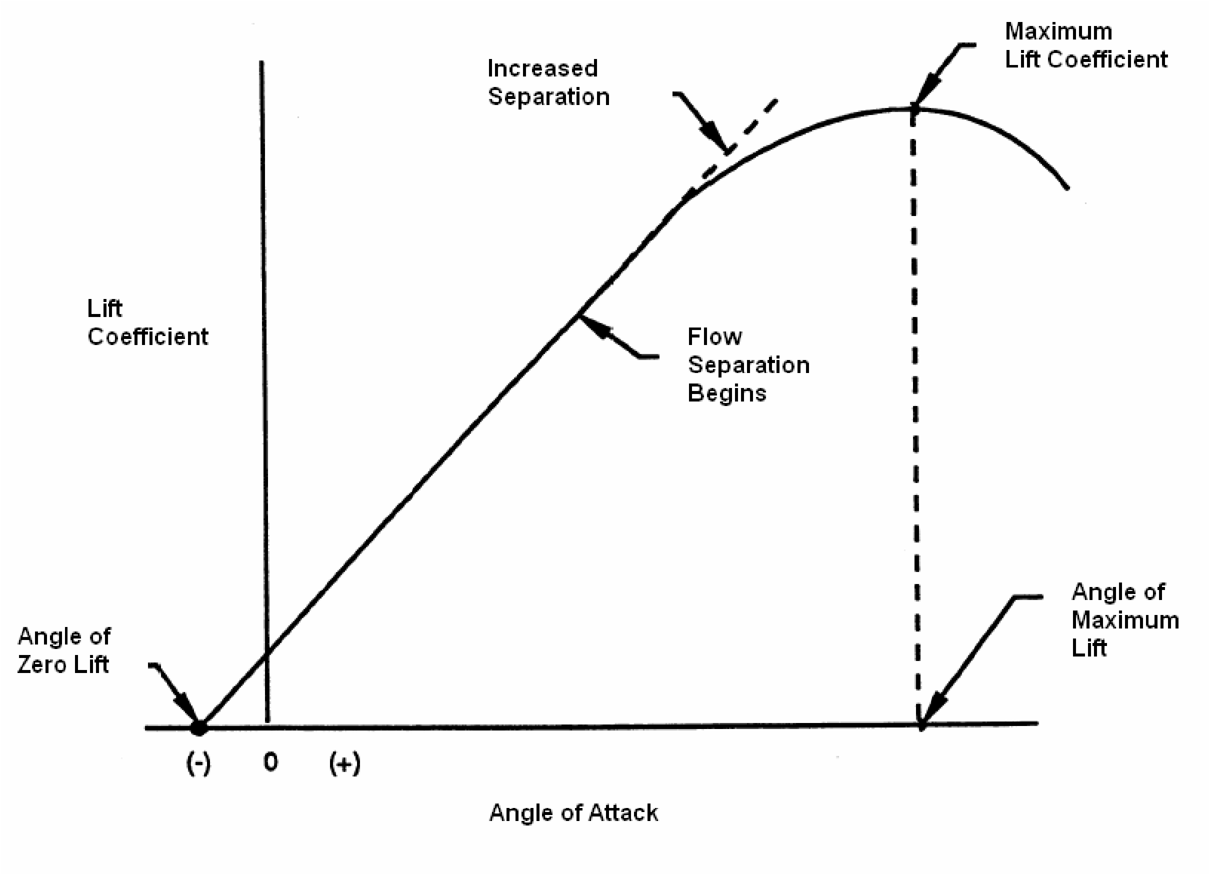


Figure 2 – Angle of Zero Lift and Angle of Maximum Lift

Wing Area and Its Efect on lift. The wing area is measured in square feet and includes the part of the wing blanked out by the fuselage. Wing area is adequately described as the area of the shadow cast by the wing at high noon. Lift and drag forces acting on a wing are roughly proportional to the wing area. This means that if the wing area is doubled, with all other variables remaining the same, the lift and drag created by the wing are doubled. If the area is tripled, lift and drag are tripled.

The Airfoil, Turbulence, and Skin Friction. The shape of an airfoil determines the amount of turbulence or skin friction that it will produce. The shape of a wing consequently affects the efficiency of the wing. Turbulence and skin friction are controlled mainly by the fineness ratio. This is defined as the ratio of the chord of the airfoil to the maximum thickness. If the wing has a high fineness ratio, it is very thin wing. A thick wing has a low fineness ratio. A wing with high fineness ratio produces a large amount of skin friction and a wing with a low fineness ratio produces a large amount of turbulence. The best airfoil or wing is a compromise between these two extremes which holds both turbulence and skin friction to a minimum.

1.4 Lift and Drag Ratio

The efficiency of a wing is measured in terms of the lift over drag (L/D) ratio. This ratio varies with the angle of attack but reaches a definite maximum value for some particular angle of attack. At this peak the wing has reached its maximum efficiency. The shape of the airfoil is the factor that determines the angle of attack at which the wing is most efficient; it also determines the amount or degree of efficiency. The most efficient airfoils for general use have the maximum thickness about one-third of the way back from the leading edge of the wing.

High-lift wings and High-Lift Devices. These have been developed by shaping the airfoils to produce the desired effect. The amount of lift produced by an airfoil will increase with an increase in camber. Camber refers to the curvature of an airfoil above and below the chord line surface. Upper camber refers to the upper surface, lower camber to the lower surface, and mean camber to the mean line of the section. Camber is positive when departure from the chord line is outward and negative when the chord line is inward. High-lift wings have a large positive camber on the upper surface and a slight negative camber on the lower surface. Wing flaps cause an ordinary wing to approximate this same condition by increasing the upper camber and by creating a negative lower camber.

Aircraft Velocity effect on Lift and Drag. The wing or airfoil shape cannot be effective unless it is continually attacking new air. Lift and drag of a wing is proportional to the square of the velocity. An aircraft traveling 400 mph has four times as much lift as one traveling 200 mph when the angle of attack and other factors remain the same. It is impossible to travel in level flight and maintain the same angle of attack when the speed is increased. Lift also increases at the same time, and the aircraft climbs, or else it will carry a greater load without climbing. For each angle of attack, an aircraft has a definite speed at which it will fly straight and level.

Lift, Drag, and Air Density. Lift and drag vary directly with the density of the air. When the density is doubled, lift and drag are also doubled, and vice versa. At an altitude of 18,000 feet (MSL), the air density is only one-half its sea-level value. In order to maintain sea-level lift and drag conditions at 18,000 feet (MSL), the aircraft must be flown at a greater true airspeed for any given angle of attack.

Aircraft operation and Lift/Drag Ratio. Aircraft will operate most efficiently at the angle of attack at which the maximum L/D value occurs.

The angle of attack at which an aircraft flies in level flight depends upon its airspeed and gross weight. That is, for a given gross weight there is one, and only one, airspeed which will cause the aircraft to fly at a given angle of attack. When the airspeed is controlled in such a way as to maintain the most efficient angle of attack, the aircraft is able to fly its maximum range.

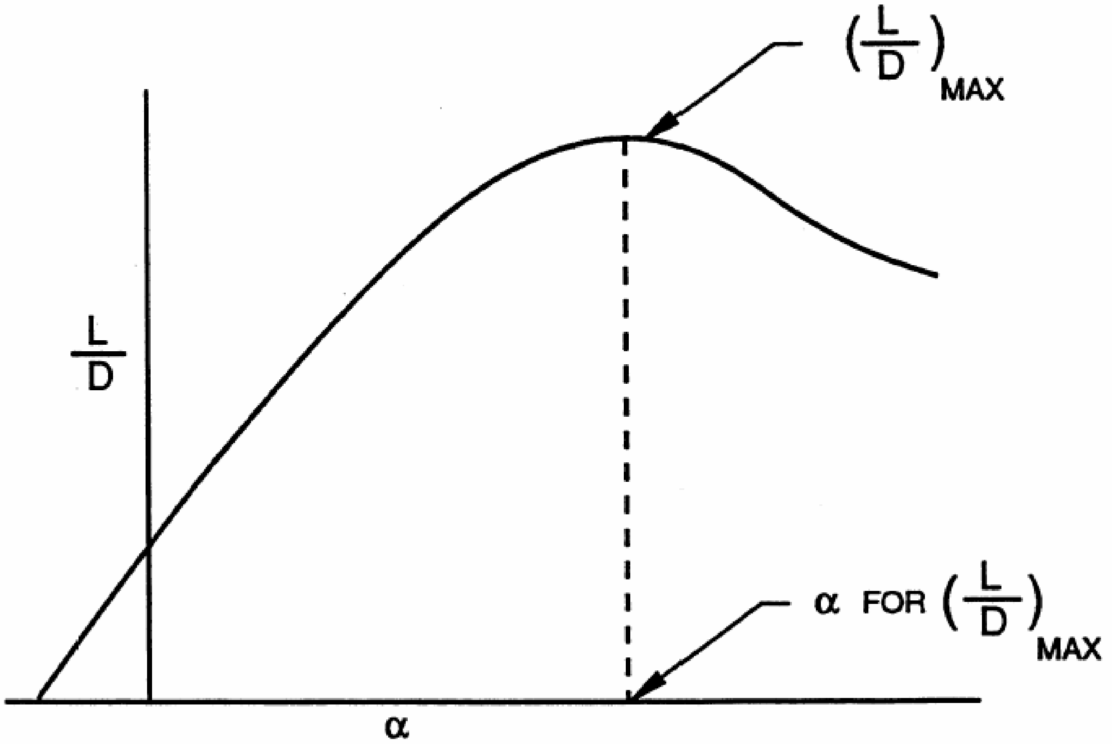


Figure 3 – Lift and Drag Ratio

Configuration and drag items. The shape or contour of an object is referred to as its configuration. When an aircraft is equipped with some items that extend into the airstream or affects the slipstream, this item affects the drag configuration of the aircraft and these items are referred to as drag items. Drag items include cowl flaps, oil cooler, intercooler flaps, deicer boots, etc. All of them affect the drag of the aircraft in flight.

Wing Loading. An important function of airplane aerodynamics is the wing loading value under various configurations of flight. Wing loading is the weight of the airplane in pounds divided by the wing area in square feet. It is the average weight each square foot of the wing must support. Wing loading varies with the weight and area of the wing in various airplanes, and is an important consideration in the airplane design. Wing loading progressively increases on a given airplane as the load is increased. Increasing speed and maneuvers increases the load factors or g's. A certain limitation must be established in order not to overstress the structure during high aircraft loading and high speed. Maneuvers must be kept within limitations.

Mean aerodynamic chord (MAC). Aerodynamically, the MAC is the mean line between the upper and lower surface of the airfoil. It is also described as the average length of the wing chord. The MAC is found by dividing the wing area by the aerodynamic span. The mean air chord of the wing is used as a reference line for the location of the relative positions of the wing center of lift and the airplane center of gravity. For weight and balance purposes the MAC is generally described as the straightline distance from leading edge of the wing (LEMAC) to the trailing edge of the wing (TEMAC) as measured along the longitudinal axis.

The mean aerodynamic chord is used in loading procedures to determine the static balance and stability of the airplane.

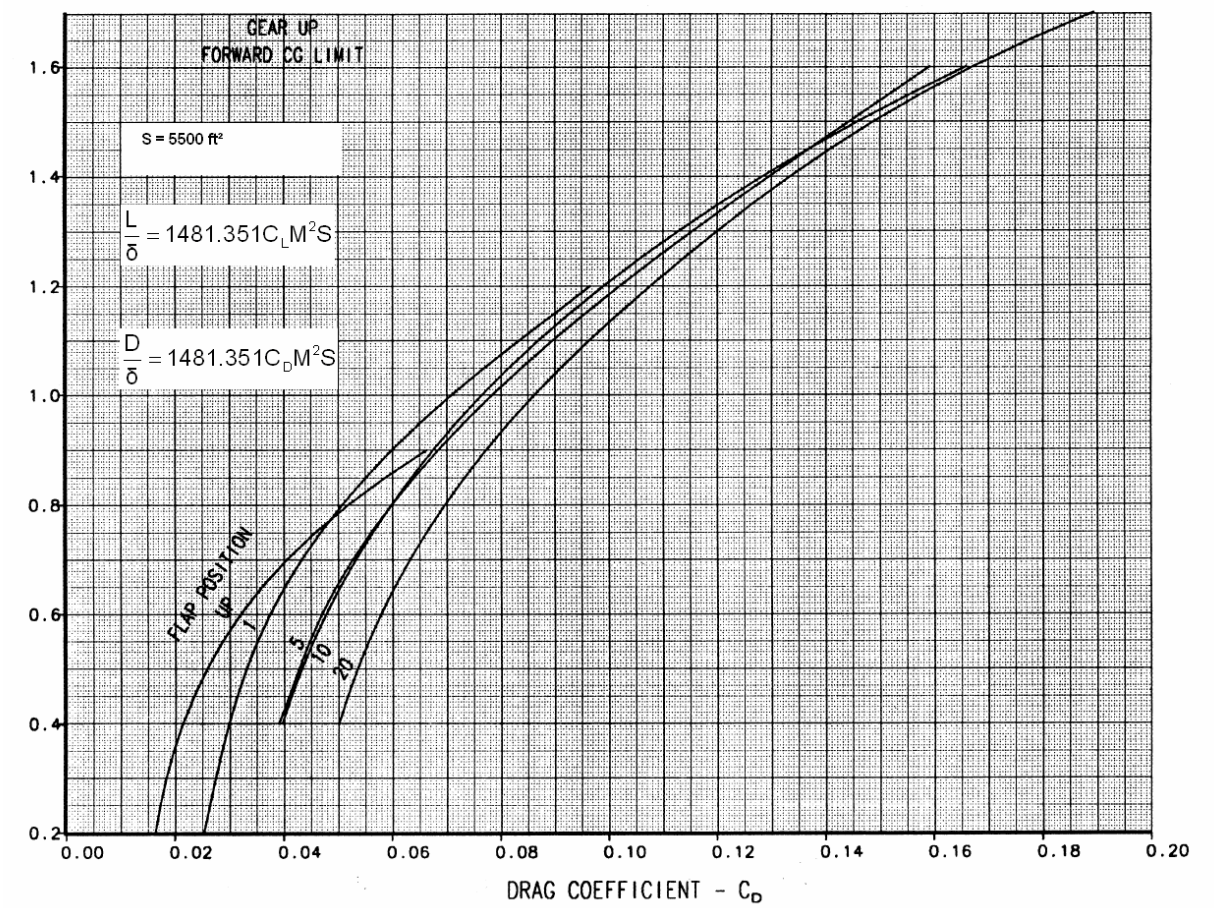


Figure 4 – Low Speed Drag Polar for a 4-Engine Jet Transport

1.5 Axes of the Airplane in Flight

Whenever the attitude of the airplane changes in flight (with respect to the ground or other fixed object) it will rotate about one or more of three axes. These axes can be thought of as imaginary axles around which the airplane turns like a wheel. The three axes intersect at the center of gravity, and each is perpendicular to the other two.

Longitudinal Axis: an imaginary line that extends lengthwise through the fuselage from nose to tail. Motion about the longitudinal axis is called roll, and is produced by movement of the ailerons at the trailing edge of the wing outboard.

Lateral Axis: the imaginary line which extends crosswise from wing tip to wing tip. Motion about the lateral axis is pitch, and is produced by movement of the elevator at the rear of the horizontal tail assembly.

Vertical Axis: an imaginary line which passes vertically through the center of gravity. Motion about the vertical axis is yaw, and is produced by movement of the rudder at the rear of the vertical tail assembly.

1.6 Airplane Control Surfaces

Ailerons. There are two ailerons, one at the outer trailing edge of each wing, raised or lowered by the pilot as he moves the wheel in the cockpit to the right or left. The ailerons control movement of the airplane about the longitudinal axis. This movement is roll, and can be described as rolling or banking about the longitudinal axis. The aileron controls are so arranged that when the aileron of one wing is lowered the aileron of the other wing is raised. The wing with the lowered aileron goes up because of its increased lift, and the wing with the raised aileron goes down because of its decreased lift. Thus movement of the ailerons induces a bank or roll attitude about the longitudinal axis. When pressure is applied to the right on the control wheel, the left aileron goes down and the right aileron goes up, rolling the airplane to the right. This occurs because the down movement of the left aileron increases the wing camber (curvature) and thus increases the angle of attack. The right aileron moves upward and decreases the camber, resulting in a decreased angle of attack. It can be seen that decreased lift on the right wing and increased lift on the left wing will cause a roll or bank attitude to the right or clockwise around the longitudinal axis. When pressure is applied to the left on the control wheel, the right aileron goes down and the left aileron goes up, rolling the airplane to the left. The lift is now greater on the right wing and less on the left wing, inducing a roll or bank to the left, or counterclockwise around the longitudinal axis.

Elevators. The elevators control the movement of the airplane about its lateral axis. This motion, pitch, causes the nose to move up or down as in a climb or glide. The elevators, which form the rear part of the horizontal tail assembly, are free to swing up or down and are hinged to a fixed surface, the horizontal stabilizer. Together, the horizontal stabilizer and the elevators form a single airfoil. A change in position of the elevators modifies the camber of the airfoil, which increases or decreases lift.
Like the ailerons, the elevators are connected to the control wheel. When forward pressure is applied on the wheel, the elevators move downward. This increases the lift produced by the horizontal tail surfaces. This in turn increases lift forces on the tail section and moves it upward, causing the nose to move downward. Conversely, when back pressure is applied on the wheel, the elevators move upward, decreasing the lift produced by the horizontal tail surfaces (or producing a downward force). The tail is forced downward and the nose moves upward.
The elevators control the angle of attack of the wings. When back pressure is applied on the control wheel, the tail lowers and the nose raises, increasing the angle of attack. This in turn increases wing lift and the airplane assumes a climb attitude. When forward pressure is applied on the control wheel, the tail raises and the nose lowers, decreasing the angle of attack. This in turn decreases the wing lift and the airplane assumes a glide or dive attitude.

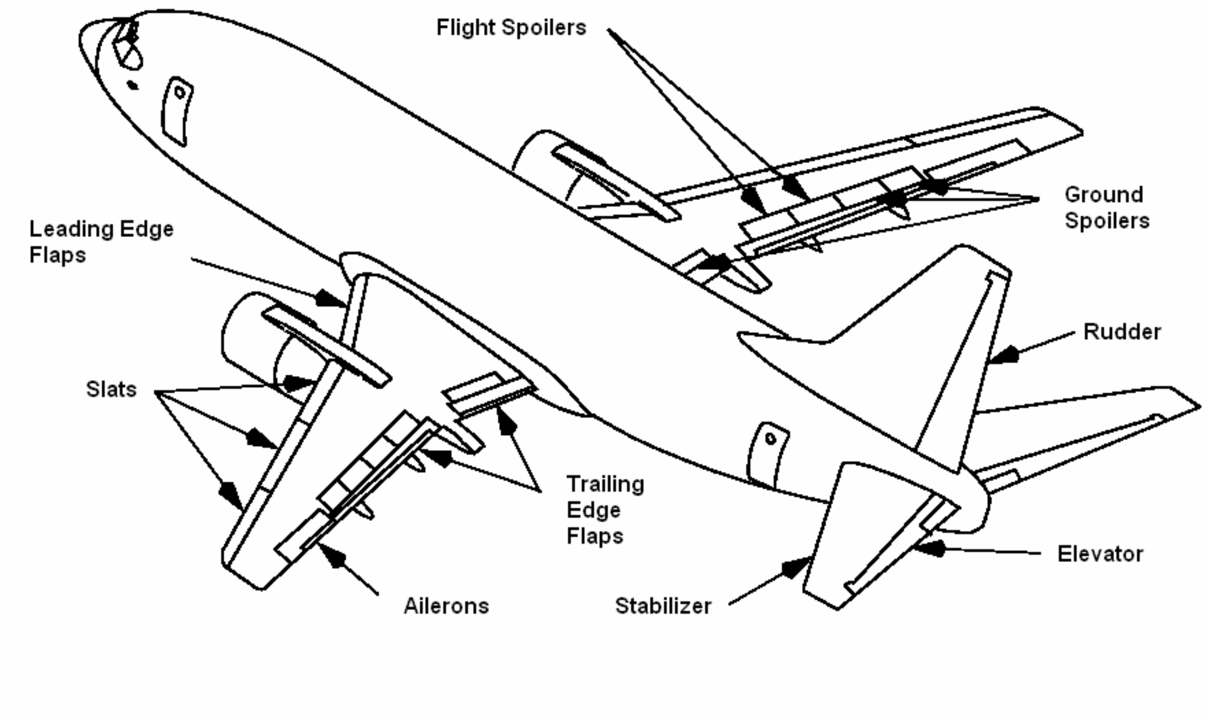


Figure 5 – Flight Control Surfaces

Rudder. The rudder controls movement of the airplane about its vertical axis. This motion, yaw, is the action of the airplane nose moving from right to left. The rudder is a movable control surface hinged to the vertical stabilizer or fin. Its action is much like the elevators except that it swings in a different plane-from side to side instead of up and down.

Trim Tabs. Trim tabs are used to keep the aircraft in the desired trim. They are relatively small, adjustable hinged surfaces located on the trailing edge of the aileron, rudder, or elevator control surfaces. Airplanes may have trim tabs on the trailing edge of all three control surfaces or, as in the case of some light airplanes, trim tabs may be installed on only one or two of the control surfaces. Trim tabs may also be of the fixed type that can be adjusted on the ground only.

The trim tab is moved in the direction opposite that of the primary control surface to relieve pressure on the control wheel or rudder pedals. Consider the situation, for example, in which the pilot wishes to adjust the elevator trim for level flight (i.e., that attitude of the airplane that will maintain a constant altitude). Assume that backpressure is required on the control wheel to maintain level flight and that the pilot wants to adjust the elevator trim tab to relieve this pressure. Since he is holding back-pressure, the elevator will be in the up position. The trim tab must then be adjusted downward so that the airflow striking the tab will hold the elevators in the desired position. Conversely, if forward pressure is being held the elevators will be in the down position, so the trim tab must be moved upward to relieve this pressure. In this example the pilot is concerned with the tab itself and not the cockpit control. Should the pilot wish to trim for a noseheavy condition, as in the first example, he would move the cockpit control toward nose-up. This movement of the cockpit control moves the elevator trim tabs down, which in turn moves the elevator up. The change in airflow on the horizontal elevator results in a high pressure above and a low pressure below, which moves the tail section downward. This in turn causes the nose of the plane to move upward for the desired trim attitude. Because the center of gravity of the airplane is located at approximately the intersection of the longitudinal, vertical, and lateral axes, the nose of the airplane moves in the direction opposite to any induced movement of the tail section.

When the pilot moves the cockpit control toward nose-down, the trim tab moves up and the elevator down, creating an upward force on the tail and a downward motion of the nose of the plane.

Rudder and aileron trim tabs operate in the same manner as the elevator trim tabs-to relieve pressure on the rudder pedals and sideward pressure on the control wheel, respectively.

Wing Flaps. Sometimes referred to as high-lift devices, wing flaps are an airfoil or a portion of an airfoil attached to the trailing edge of the wing for the purpose of changing the wing camber. In down position, wing flaps increase the wing camber (in some cases the wing area also) thus creating an increase in the effective lift of the wing. During the landing maneuver, with the flaps down, the angle of glide is steepened and the length of the flight path is decreased, while at the same time the airspeed is reduced for a slower landing speed. On takeoff, with flaps down, the wing lift is increased at a slower takeoff speed and the angle of climb is increased, effecting a safe takeoff in a shorter distance along the runway.
On landing, when the wing has lost its lift, the flaps act effectively as an air brake to decrease the length of the roll on the ground. When the flap is placed in down position, lift is increased but also the wing drag. In flight the flap constitutes an effective airbrake which affords a steeper descent for landing without an increase in airspeed. This is of great importance when approaching small fields (short runways), and especially so when there are obstructions to be cleared.

When flaps are up or in the retracted position, they have no effect upon the lift characteristics of the wing.

Stated briefly, the advantages of flaps are:

- Higher lift coefficient, which permits a lower speed in landing, a steeper glide angle over obstructions, and a shorter landing roll.
- Higher drag coefficient, which permits their use as an airbrake in flight and on the ground.
- Steeper climbs and glides at reduced airspeed.
- More accurate landings, especially into small fields where obstructions may be a hazard to flight.
- Increased angle of attack before burble point and the resultant stall are reached.

Wing Slots. An additional way to increase lift and consequently reduce landing speeds is by preventing the wing from burbling until a greater angle of attack is reached. The automatic slot accomplishes this advantage. It consists of an auxiliary airfoil housed in the leading edge of the wing at low angles of attack but free to move forward a definite distance therefrom at high angles to form a flat nozzle or slot through which a portion of the airstream flows to be deflected along the upper surface of the wing. The airstream that is deflected along the upper surface maintains a streamline flow of air to a higher angle of attack and delays the burble point occurrence. The burble point, in fact, will not be reached until the angle of attack is nearly double that of a normal stall. It is obvious that lift is improved at angles where the slot is open and the maximum Coefficient of Lift (CL) is not only larger but occurs at a much higher angle of attack. Consequently, the airplane with slotted wings will have a much lower stalling speed than one that is not so equipped. The slotted wing is also an effective agent for securing lateral stability and avoiding unintentional spins.

Slots in the leading edge of the wing may not be of the automatic type. In this case the slot is simply an opening in the leading edge of the wing that has no means of being closed. At normal angles of attack the air flows over the wing as usual, but at higher angles of attack the air flows through the fixed slot or opening and has the same effect on airflow over the upper surface of the wing as does the automatic slot.

Airplanes may, in some instances, be equipped with a combination of slots and flaps. This type of installation has many advantages. It permits a much lower landing speed and better control of the flight path, and it helps to eliminate nose heaviness caused by the use of flaps alone.

1.7 Loads and Loadfactor

A load factor of one (or one G) occurs in straight and level flight when the wings support a weight equal to the airplane and all of its contents. The load on the wings will remain constant so long as the airplane is moving at a constant airspeed in a straight line. When the airplane assumes a curved flight path (all types of turns and pullout from dives) the actual load on the wings will be much greater be cause of the centrifugal force produced by the curved flight. This additional load results in the development of much greater stresses in the wing structure. The lift of the wing must offset centrifugal force on an aircraft in a coordinated turn.

Airplane strength is measured basically by the total load the wings are capable of carrying without permanent damage. The load imposed on the wings depends very largely upon the type of flight being conducted. Additional loads on the wings during flight increase the wing loading (the weight supported by each square foot of the wing). Wing loading can be determined by dividing the total square-foot area of the wing by the total weight of the airplane. Obviously, wing loading will be less in straight and level flight than it will be in maneuvers where centrifugal force is literally increasing the weight of the airplane.

The load factor is the actual load on the wings at any time, divided by the normal or basic load (weight of the airplane). A turn is produced by lift of the wing pulling the airplane from its straight course while overcoming gravity. In this case the wings must produce lift equal to the weight of the airplane plus the centrifugal force caused by the turn. The increased lift is normally obtained by increasing the angle of attack (increasing the back pressure on the control wheel). When the airplane bank steepens, this back pressure on the wheel increases, and centrifugal force builds up. Any time the airplane flies in a curved flight path, the load supported by the wings is greater than the weight of the airplane. Thus the load factor increases. In level flight the load factor is 1.00; in a 20° bank it is 1.06; in a 40° bank it is 1.31; in a 60° bank it is 2.00; and at 80° it increases to 5.76.
For each airplane there is a maximum load factor that should not be exceeded in flight. The pilot should have the basic information necessary to fly the airplane safely within its structural limitations. Pilots should be familiar with the situations in which the load factor may approach maximum, and avoid them in flight. It is important to know the right recovery technique for the airplane you are flying so that if you inadvertently exceed the permissible load factor in such maneuvers as dives and steep descending spirals you can minimize the hazards.

The feeling of increased body weight is one indication of a load factor increase. When the load on the wing increases, the effective weight of the pilot increases. This added weight can easily be sensed and is a fairly reliable guide to indicate increases in load up to twice the normal (load factor of 2). When the load approaches three times normal, the pilot notices a sensation of blood draining from his head and a tendency of his cheeks to sag. Even greater increases in load may cause the pilot to "dim out" or "black out," with a temporary loss of vision.

<u>Effect of turbulence on load factors.</u> An additional cause of large load factors is severe vertical gusts. Severe or strong vertical gusts can cause a sudden increase in the angle of attack. This results in large wing loads which are resisted by the inertia of the airplane. If severe turbulence is encountered in flight, the airplane should be immediately slowed down to the maneuvering speed (found in the airplane operating manual), or less, since the airplane is designed and constructed to withstand such disturbance at this (the maneuvering) speed. As a general requirement, all airplanes must be capable of withstanding a gust of

about plus or minus 30 feet per second at maximum level flight speed for normal rated power. A gust of such intensity occurs infrequently in ordinary flight operations.

The pilot and load factors. During flight the pilot recognizes the degree of a maneuver from the inertia forces produced by various load factors; the airplane structure senses the degree of a maneuver principally by the airloads involved. In other words, the pilot recognizes load factor while the structure recognizes only load.

Speed and load factors. In general, the amount of excess load that can be imposed on the wing depends on how fast the airplane is flying. At slow speeds the available lifting force of the wing is only slightly more than the amount necessary to support the weight of the airplane. Consequently the load cannot become excessive even if the controls are moved abruptly or the airplane encounters severe gusts. At high speeds, however, the lifting capacity of the wing (lift increases as the square of the velocity increases) is so great that a sudden movement of the controls or a strong gust may increase the load beyond safe limits. Due to this relationship between speed and safety, certain "maximum" speeds have been established for various airplanes. Every airplane is restricted in the speeds at which it can safely execute maneuvers and fly in rough air.

Clear Air Turbulence (CAT). Load factors and excessive stresses on the aircraft may occur in areas of CAT. Extreme wind shear areas (8 knots per 1,000 feet) may cause clear air turbulence, which is the bumpiness sometimes experienced while flying in cloudless skies at high altitudes. This bumpiness may be of sufficient intensity to cause serious stresses on the aircraft and physical discomfort to the crew and passengers. CAT is generally associated with changing wind velocities with height (vertical wind shear) in and near the maximum wind speed core of a jet stream. When a pilot encounters significant CAT, he should change altitude to avoid the strong wind shear and follow procedures established in the specific operating manual for flight in turbulent air.

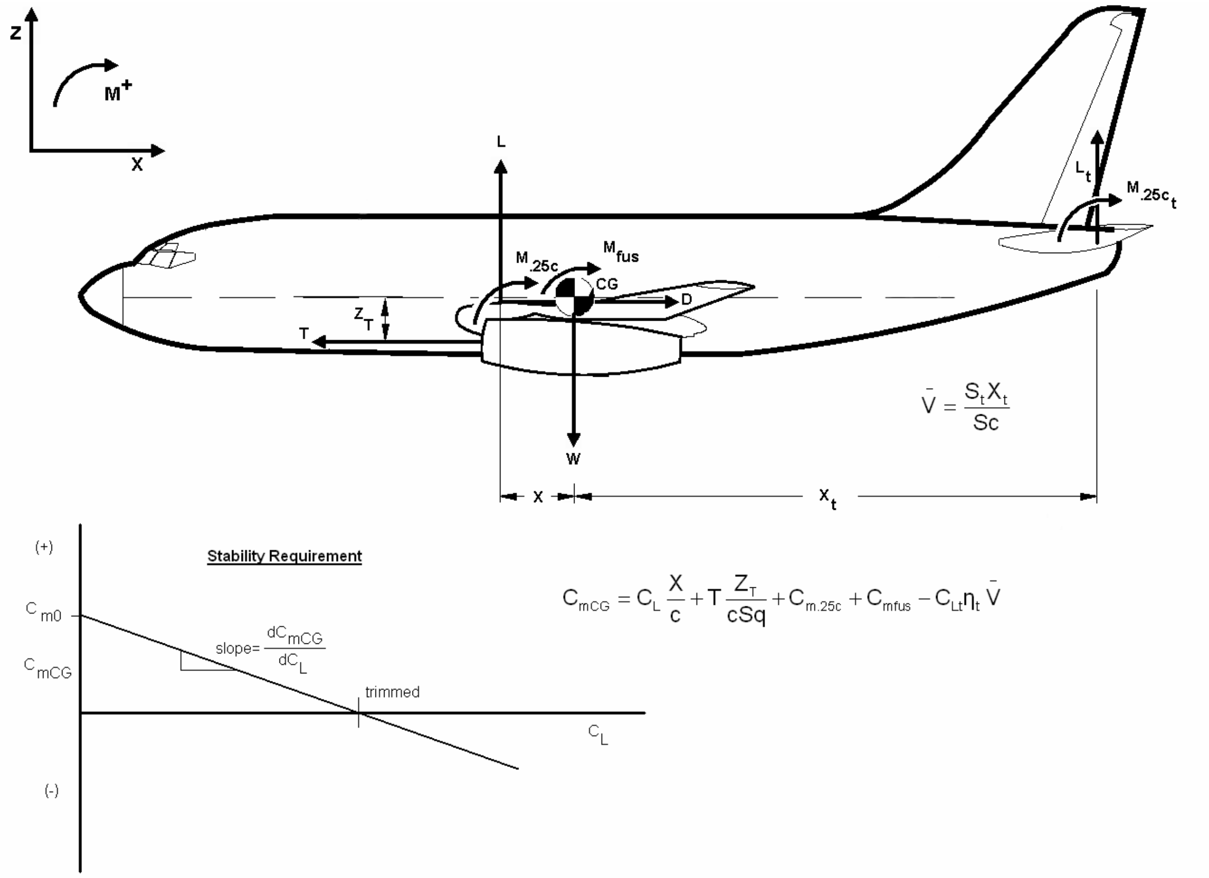
1.8 Stability

An aircraft must have satisfactory handling qualities in addition to adequate performance. It must be stable enough to maintain straight and level flight, and recover from the various disturbing influences.

It is necessary to provide sufficient stability to minimize the work of the pilot. The aircraft must have proper response to the controls so that it can achieve its inherent performance. There are certain conditions of flight which provide the most critical requirements of stability and control, and these conditions must be understood and respected to accomplish safe, efficient operation.

Static Stability. An aircraft is in a state of equilibrium when the sum of all forces and all moments is equal to zero. When an aircraft is in equilibrium there are no accelerations and the aircraft continues in steady flight. If the equilibrium is disturbed by a gust or deflection of the controls, the aircraft will experience acceleration due to the imbalance of moment force. The static stability of an aircraft system is defined by the initial tendency of the aircraft to return to equilibrium following some disturbance from that equilibrium. If an aircraft is disturbed from equilibrium and has the tendency to return to it, positive static stability exists. If the aircraft has a tendency to continue in the direction of the disturbance, negative static stability, or static instability, exists. An intermediate condition could occur where an aircraft displaced from equilibrium remains in equilibrium in the displaced position. If an aircraft subject to a disturbance has neither the tendency to return nor the tendency to continue in the displaced direction, neutral static stability exists.
The term "static" is applied to this form of stability since the resulting motion is not considered-only the tendency to return to equilibrium. The static longitudinal stability of an aircraft can be recognized by displacing the aircraft from some trimmed angle of attack. If the

aerodynamic pitching moments created by this displacement tend to return the aircraft to the equilibrium angle of attack, the aircraft has positive static longitudinal stability.



$$C_{mCG} = C_L \frac{X}{c} + T\frac{Z_T}{cSq} + C_{m.25c} + C_{mfus} - C_{Lt}\eta_t \bar{V}$$

Figure 6 – Static Stability

Dynamic Stability. Static stability is concerned with the tendency of a displaced aircraft to return to equilibrium. Dynamic stability, on the other hand, is defined by the resulting motion with time. If an aircraft is disturbed from equilibrium, the time history of the resulting motion indicates the dynamic stability of the system. In general, the aircraft will demonstrate positive dynamic stability if the amplitude of motion decreases with time.
When an aircraft is disturbed, the reduction of amplitude with time indicates that there is resistance to motion and that energy is being dissipated. The dissipation or "damping effect" is necessary to provide positive dynamic stability.

All aircraft must demonstrate the required degree of static and dynamic stability. If an aircraft were allowed to have static instability with a rapid rate of divergence, the aircraft would be very difficult, if not impossible, to fly. In addition positive dynamic stability is mandatory in certain areas to preclude objectionable continued oscillations of the aircraft.

1.8.1 Motions of the Airplane

Pitching: motion about the lateral axis. Stability in pitching is called longitudinal stability because it involves changes in inclination of the longitudinal axis in a vertical plane with no motion about the longitudinal or vertical axis.

Rolling or Banking: motion about the longitudinal axis. Stability in rolling or banking is called lateral stability because it involves changes in direction of the lateral axis with no motion about the lateral or vertical axis.

Yawing: motion about the vertical axis. Stability in yaw gives directional stability because it involves changes in direction of the longitudinal axis in a horizontal plane with no motion about the longitudinal or lateral axes.

A given airplane may be stable about one axis and unstable about the other two axes, or stable about two axes and unstable about the third. When a statement is made that an airplane is stable or unstable, the statement should be qualified by stating whether the stability or instability is longitudinal, lateral, or directional.

Aspect Ratio of the Wing. The aspect ratio of a wing is the ratio of the span to the mean chord; that is, the ratio of the square of the span to the total area of the wing. For practical purposes, the span of a wing is the maximum transverse distance normal to the relative wind or the distance between the wing tips. The span, therefore, determines the amount of air acted upon, and hence is an important factor in the production of lift by a given wing area. For an airfoil of rectangular plan form the ratio of span to chord is the aspect ratio. Thus an airfoil having a wing span of 40 feet and a chord of 8 feet would have an aspect ratio of 5 (40 - 8). Very seldom, however, is an airfoil actually rectangular in plan form, owing to the use of tapered wings, various tip shapes, etc. Consequently, the aspect ratio is defined as the span squared, divided by the wing area.

If the airfoil were of infinite span the airflow would be direct from leading edge to trailing edge because there could be no way for the streamlines below the wing surface to flow from this area of relatively high pressure to that of reduced pressure above the wing. Since the airfoil is of finite area and span, air on the underside seeks the low pressure region above by spilling over the wing tips. Vortices or eddies are thus formed at the tips, and they tend to create a trailing whirlpool of air that may be hazardous to other aircraft that fly into its area of turbulence. The larger and faster the airplane, the greater the turbulence and area effected by these wing-tip vortices. This tip vortex increases the drag because of the turbulence which absorbs energy. In addition, the vortices reduce lift by destroying the section forces of the airstream above the airfoil and close to the tips. Since these eddies are unavoidable in the standard wing configuration, the only recourse is to reduce their effect as much as possible. This is accomplished by increasing the aspect ratio of the wing, creating a wing that is as long and narrow as possible within structural considerations.

Dihedral of the wing. The principal surface contributing to the lateral stability of an airplane is the wing. The effect of dihedral of a wing is a powerful contribution to lateral stability, and it permits stable rolling or banking moments. Visually, dihedral is the apparent upward angle of the wing from the root source to the wing tips when compared to the horizontal plane. Dihedral is especially valuable during sideslip maneuvers. If the relative wind comes from the side, the wing into the wind is subject to an increase in lift. The wing away from the wind is subject to a decrease in angle of attack and develops a decrease in lift. The changes in lift effect a rolling moment tending to raise the windward wing. Dihedral thus contributes a stable roll owing to sideslip.

Since wing dihedral is so powerful in producing lateral stability it is taken as a common denominator of the lateral stability contributions of all other components. Generally, the contribution of wing position, flaps, power, etc., is expressed as an equivalent amount of "effective dihedral" or "dihedral effect."

Sweepback of the wing. Sweepback contributes to the directional stability or weathercock stability of an aircraft. The wing into the wind has less sweep and a slight increase in drag; the wing away from the wind has more sweep and less drag. The net effect of these force changes is to produce a yawing moment tending to return the nose of the aircraft into the relative wind. This directional stability is usually small but is of some importance to the overall stability of the aircraft.

Sweepback contributes to lateral stability in the same sense as dihedral. When the swept wing is placed in a sideslip, the wing into the wind experiences an increase in lift since the sweep is less and the wing away from the wind produces less lift since the sweep is greater. The swept wing in a slideslip thus experiences lift changes and a subsequent rolling moment which tends to right the aircraft. This lateral stability contribution depends on the sweepback and the lift coefficient of the wing.

1.9 High-Speed Aerodynamics

The study of aerodynamics at low flight speeds is greatly simplified by the fact that air may experience relatively small changes in pressure with only negligible changes in density. This airflow is termed incompressible since the air may undergo changes in pressure without apparent changes in density. Such a condition of airflow is similar to the flow of water, hydraulic fluid, or any other incompressible fluid. At high speeds in flight the pressure changes that take place are quite large, and significant changes in air density occur. The study of airflow at high speeds must account for these changes in air density and must consider that the air is compressible and that there will be "compressibility effects."

A factor of great importance in the study of high speed airflow is the speed of sound. The speed of sound may be given in units of feet per second (fps), knots, or miles per hour (mph). The speed of sound is the rate at which small pressure disturbances win be propagated through the air; this propagation speed is a function solely of temperature.
The speed of sound in knots can be obtained from the following equation, where θ is the temperature ratio T/T_0:

$$a = 661.4786\sqrt{\theta}$$

The ratio of the true airspeed to the speed of sound is called Mach Number:

$$M = \frac{V_{TAS}}{a}$$

When an object moves through the air mass, velocity and pressure changes occur which create pressure disturbances in the airflow surrounding the object. Of course, these pressure disturbances are propagated through the air at the speed of sound. If the object is travelling at low speed the pressure disturbances are propagated ahead of the object, and the airflow immediately ahead of the object is influenced by the pressure field on the object. Actually these pressure disturbances are transmitted in all directions and extend indefinitely in all directions. Evidence of this "pressure warning" is seen in the typical subsonic flow pattern illustration, Figure 7, which shows upwash and flow direction change well ahead of the leading edge.

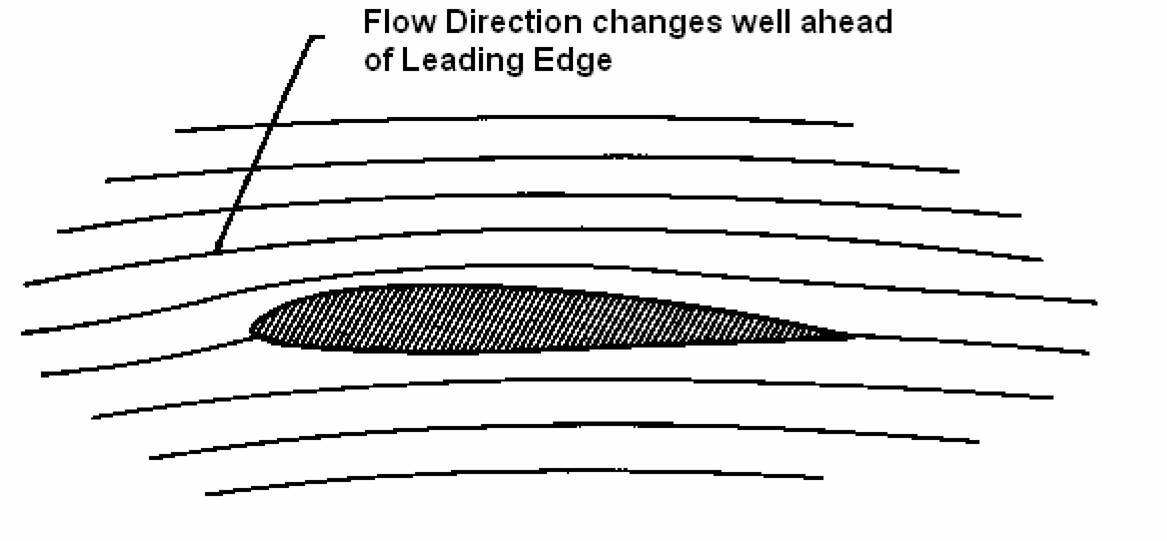


Figure 7 – Subsonic Flow Pattern

If the object is travelling at some speed above the speed of sound, the airflow ahead of the object will not be influenced by the pressure field on the object since pressure disturbances cannot be propagated ahead of the object. Thus as the flight speed nears the speed of sound a compression wave will form at the leading edge and all changes in velocity and pressure will take place quite sharply and suddenly. The airflow ahead of the object is not influenced until the air particles are suddenly forced out of the way by the concentrated pressure wave set up by the object. Evidence of this phenomenon is seen in the typical supersonic flow pattern illustration, Figure 8.

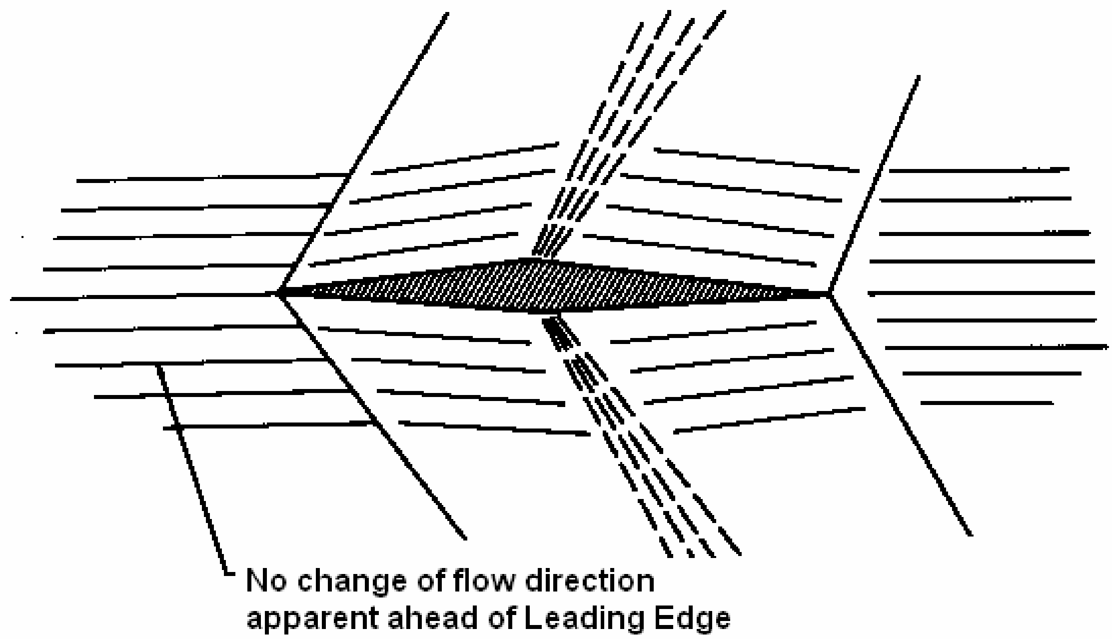


Figure 8 – Supersonic Flow Pattern

It is to be noted that compressibility effects are not limited to flight speeds at and above the speed of sound. Since any aircraft will have some aerodynamic shape and will be developing lift, there will be local flow velocities on the surfaces which are greater than the flight speed. Thus an aircraft can experience compressibility effects at flight speeds well below the speed of sound. Since there is the possibility of having both subsonic and supersonic flows existing on the aircraft it is convenient to define certain regimes of flight, approximately, as follows:

- Subsonic-Mach numbers below 0.75
- Transonic-Mach numbers from 0.75 to 1.20
- Supersonic-Mach numbers from 1.20 to 5.00
- Hypersonic-Mach numbers above 5.00

The principal differences between subsonic and supersonic flow are owing to the compressibility of the supersonic flow.

Transonic and Supersonic flight. Any object in subsonic flight which has some definite thickness or is producing lift will have local velocities on the surface which are greater than the free-stream velocity. Hence, compressibility effects can be expected to occur at flight speeds less than the speed of sound. The transonic realm of flight provides the opportunity for mixed subsonic and supersonic flow, and accounts for the first significant effects of compressibility.

In the illustration, a conventional airfoil shape is shown. If this airfoil is in flight at Mach 0.50 and at a slight positive angle of attack, the maximum local velocity on the surface will be greater than the flight speed but most likely less than sonic speed. Assume that an increase in Mach number to 0.72 would produce first evidence of local sonic flow. This would be the highest flight speed possible without supersonic flow, and would be termed the critical Mach number. Thus, critical Mach number is the boundary between subsonic and transonic flight and is an important point of reference for all compressibility effects encountered in transonic flight. By definition, critical Mach number is the free-stream Mach number which produces first evidence of local sonic flow. Therefore, shock waves, buffet, airflow separation, etc., all take place above critical Mach number.

<u>Phenomena of Transonic flight.</u> The Mach number which produces a sharp change in the drag coefficient is termed the force divergence Mach number and for most airfoils usually exceeds the critical Mach number at least 5%. This condition is also referred to as "drag divergence" or "drag rise."

Associated with the "drag rise" are buffet, trim, and stability changes, and a decrease in control surface effectiveness. Conventional aileron, rudder, and elevator surfaces subjected to this high frequency buffet may "buzz," and changes in hinge moments may produce undesirable control forces. When the buffet is quite severe and prolonged, structural damage could occur if the operation were in violation of operating limitations. When airflow separation occurs on the wing as a result of shock wave formation, there will be a loss of lift and subsequent loss of downwash aft of the affected area. If the wings shock unevenly because of physical-shape differences or sideslip, a rolling moment will be created in the direction of the initial loss of lift and will contribute to control difficulty ("wing drop").

If the shock-induced separation occurs symetrically near the wing root, a decrease in downwash behind this area is a corollary of the loss of lift. A decrease in downwassh on the horizontal tail will create a diving moment and the aircraft will "tuck under." When these conditions occur on a swept-wing planform, the wing center of pressure shift contributes to tile trim change-root shock first moves the wing center of pressure aft and adds to the diving moment; shock formation at the wing tips moves the center of pressure forward, and the resulting climbing moment and the tail-downwash--change can contribute to "pitch up."

Since most of the difficulties of transonic flight are associated with shock wave induced flow separation, any means of delaying or alleviating the shock induced separation will improve the aerodynamic characteristics. An aircraft configuration may utilize thin surfaces of low aspect ratio with sweepback to delay and reduce the magnitude of transonic force divergence. In addition, various methods of boundary layer control, high lift devices, vortex generators, etc., may be applied to improve transonic characteristics. For example, the application of vortex generators to a surface can produce higher local surface velocities and increase the kinetic energy of the boundary layer. Thus a more severe pressure gradient (stronger shock wave) will be necessary to produce airflow separation.

<u>Phenomena of Supersonic flight.</u> The airplane configuration must have aerodynamic shapes which will have low drag in compressible flow. Generally, this will require airfoil sections of low thickness ratio and sharp leading edges and body shapes of high fineness ratio to wave drag. Because of the aft movement of with supersonic flow, the increase in static will demand effective, powerful control surfaces controllability for supersonic maneuvering.

The aircraft powerplants for supersonic flight must be of relatively high-thrust output. Also, it is necessary to provide the air-breathing powerplant with special inlet configurations which will slow the airflow to subsonic speed prior to reaching the compressor face or combustion chamber. Aerodynamic heating of supersonic flight can provide critical inlet temperatures for the gas turbine engine as well as critical structural temperatures.

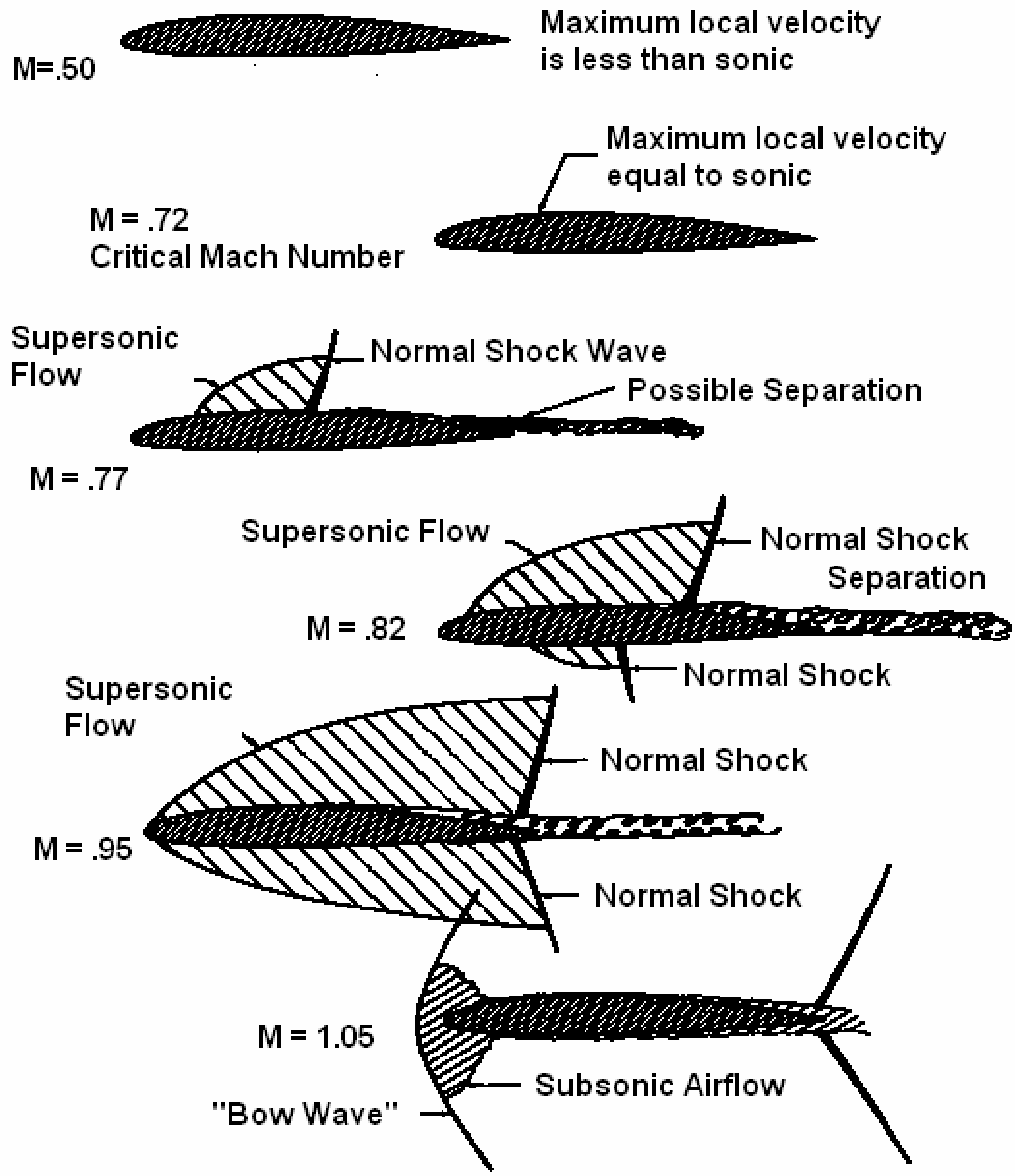


Figure 9 – Transsonic Flow Pattern

Control surfaces for transonic and supersonic flight. Trailing-edge control surfaces can be affected adversely by the shock waves formed in flight above critical Mach number. If the airflow is separated by the shock wave, the resulting buffet of the control surface can be quite objectionable. In addition to the buffet of the surface, the change in the pressure distribution traceable to separation and the shock wave location can create very large changes in control surface hinge moments. Such large changes in hinge moments create very undesirable control forces and present the need for an "irreversible" control system. An irreversible control system employs powerful hydraulic or electric actuators to move the surfaces upon control by the pilot, and the airloads developed on the surface can not feed back to the pilot. Of course, suitable control forces would be synthesized by bungees, "q" springs, bobweights, etc.

Trailing edge control surface. The reduction in effectiveness of the trailing edge control surface at transonic and supersonic speeds necessitates the use of an all-movable surface.

Application of the all-movable control surface to the horizontal tail is most usual since the increase in longitudinal stability in supersonic flight requires a high degree of control effectiveness to achieve required controllability for supersonic maneuvering.

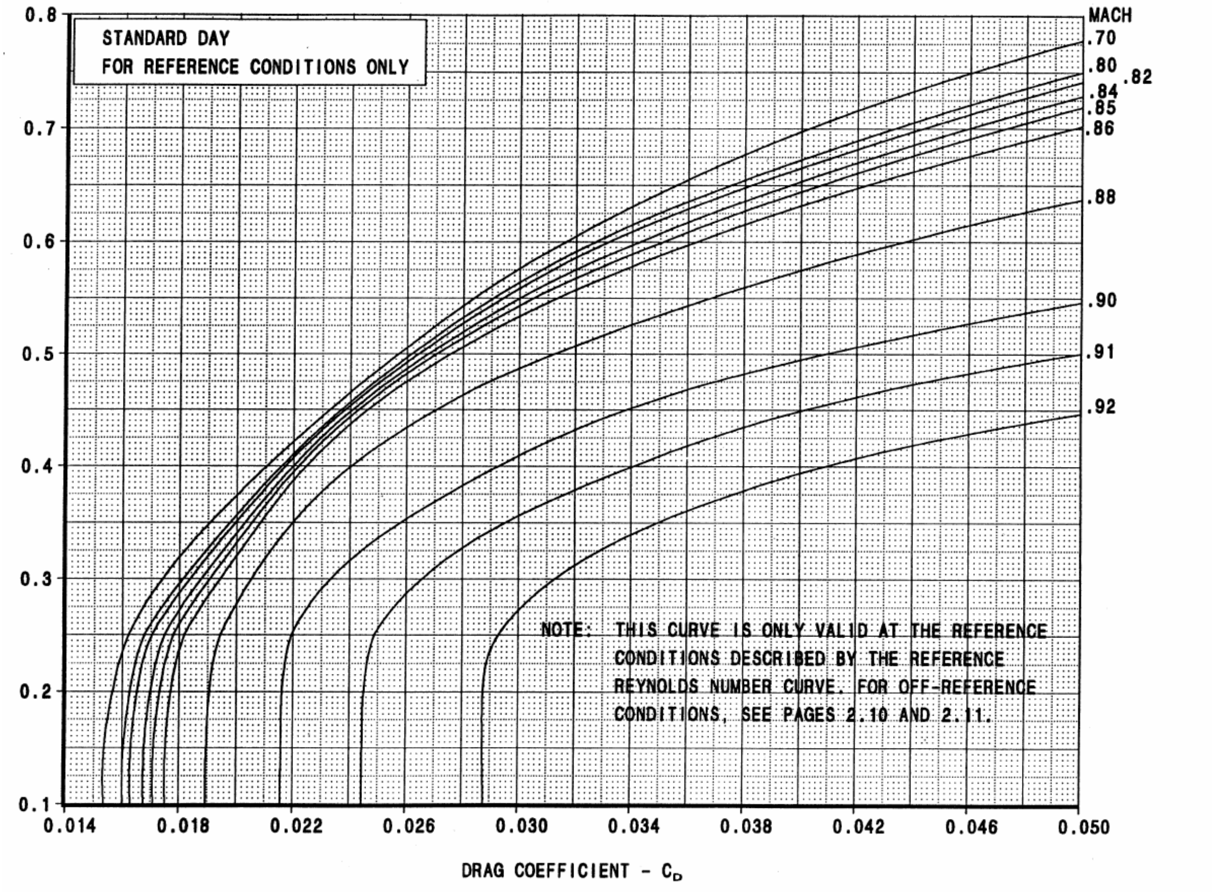


Figure 10 – High Speed Drag Polar of the same airplane as in Figure 4

1.9.1 Aerodynamic Heating

When air flows over any aerodynamic surface, certain reductions in velocity occur with corresponding increases in temperature. The greatest reduction in velocity and increase in temperature will occur at the various stagnation points on the aircraft. Similar changes occur at other points on the aircraft, of course, but these temperatures can be related to the ram temperature rise at the stagnation point. While subsonic flight does not produce temperatures of any real concern, supersonic flight can produce temperatures high enough to be of major importance to the airframe and powerplant structure.

Higher temperatures produce definite reductions in the strength of aluminum alloy and require the use of titanium alloys, stainless steels, etc., at very high temperatures. Continued exposure at elevated temperatures effects further reduction of strength and magnifies the problems of "creep" failure and structural stiffness.

In high-speed aerodynamics, high flight speeds and compressible flow dictate airplane configurations which are much different from those of the ordinary subsonic airplane. To achieve safe and efficient flight operations, the pilot of modem high-speed aircraft must understand and appreciate the advantages and disadvantages of the configuration. A knowledge of such fundamentals of high-speed aerodynamics as the foregoing will contribute much to that understanding.

1.9.2 RAT-SAT-TAT

Air temperature is one of the basic parameters used to establish airplane performance data. In a static condition, air temperature is relatively easy to measure using a common mercury thermometer. However, air temperature in flight is affected by adiabatic compression of the boundary layer air slowing down or stopping in relationship to the airplane. This compression results in a temperature increase which is commonly referred to as "Ram Rise". The ram rise, due to full adiabatic compression, may be calculated mathematically as a function of Mach number.

Static Air Temperature (SAT) is the ambient air temperature. This temperature is often called Outside Air Temperature (OAT) and is the temperature of the undisturbed or free air (no ram rise).

It is the temperature most difficult to measure accurately in flight because all temperature sensors are affected to some degrees by ram rise. Therefore, either the ram rise is obtained from a chart and subtracted from the instrument reading, or some mechanical means is used in the temperature measuring system to cancel the ram rise and give a corrected signal to the instrument. RAT is the commonly used abbreviation of Ram Air Temperature. RAT is equal to the ambient air temperature plus some ram rise. The proportion of ram rise is dependent on the ability of the equipment to sense or recover the adiabatic temperature increase. The sensitivity of the equipment to ram rise is expressed as a percentage which is called the "recovery factor". If a particular temperature sensor has a recovery factor of 0.80, the sensor will measure the ambient air temperature plus 80 percent of the ram rise.

RAT will equal SAT when the airplane is stationary. For all practical purposes, the ram rise may be considered negligible until speeds above 0.30 Mach are reached.

TAT is Total Air Temperature. This temperature is equal to ambient air temperature plus all of the ram rise. In other words, total air temperature is equal to ram air temperature when the recovery factor of the temperature sensor is equal to 1.00.
TAT can be obtained by the following equation:

$$TAT = SAT\left(1 + 0.2KM^2\right)$$

where:

TAT	=	Total Air Temperature in Kelvin
SAT	=	Static Air Temperature in Kelvin
M	=	Mach Number
K	=	Probe Recovery Factor

1.10 Airspeeds

1.10.1 Definitions

Indicated Airspeed, VI, IAS - Airspeed indicator reading, as installed in the airplane, uncorrected for static source position error (assumes zero instrument error).

Calibrated Airspeed, Vc, CAS - Indicated airspeed corrected for static source position error ($Vc = VI + \Delta Vp$).

Equivalent Airspeed, Ve, EAS - Calibrated airspeed corrected for compressibility ($Ve = Vc - \Delta Vc$),

True Airspeed, VT , TAS - Equivalent airspeed corrected for atmospheric density effects ($VT = Ve/\sqrt{\rho}$).

True Mach Number, M - Machmeter reading, as installed in the airplane, corrected for static source position error.

1.11 Forces Acting on the Airplane

Force is defined as any action that tends to produce, retard, or modify motion. The sea or ocean of air through which aircraft fly has mass and inertia and is capable of exerting forces on any object moving through it. There are four forces which act on an aircraft as the result of air resistance, gravity, friction, and other factors. These forces are:

- thrust-the force the aircraft exerts on the air when moving forward;
- drag-the force that acts in opposition to thrust;
- lift-the force that exerts an upward sustentation on the aircraft; and
- gravity (or weight) - the force that tends to pull the aircraft toward the earth; in effect, a force opposite to lift.

If all four forces were equal, the aircraft would be in a state of equilibrium. This is, of course, a theoretical conclusion, but in level, unaccelerated flight thrust will equal drag and lift will equal gravity.

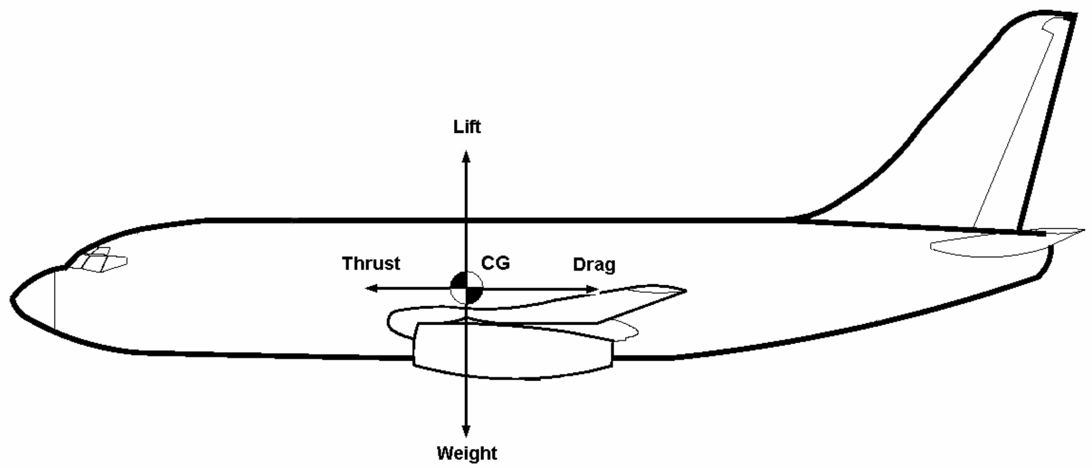


Figure 11 – Forces Acting on the Airplane

1.12 Straight and Level Flight

All of the principal items of flight performance involve steady-state flight conditions and equilibrium of the airplane. For the airplane to remain in steady level flight, equilibrium must be obtained by a lift equal to the airplane weight and a powerplant thrust equal to the airplane drag. Thus, the airplane drag defines the thrust required to maintain steady level flight.

All parts of the airplane that are exposed to the air contribute to the drag, though only the wings provide lift of any significance. For this reason, and certain others related to it, the total drag may be divided into two parts, the wing drag (induced) and the drag of everything but the wings (parasite).

The total power required for flight then can be considered as the sum of induced and parasite effects; that is, the total drag of the airplane. Parasite drag is the sum of pressure and friction drag which is due to the airplane's, basic configuration and, as defined, is independent of lift. Induced drag is the undesirable but unavoidable consequence of the development of lift.

While the parasite drag predominates at high speed, induced drag predominates at low speed. For example, if an airplane in a steady flight condition at 100 knots is then accelerated to 200 knots, the parasite drag becomes four times as great but the power required to overcome that drag is eight times the original value.

Conversely, when the airplane is operated in steady level flight at twice as great a speed, the induced drag is one-fourth the original value and the power required to overcome that drag is only onehalf the original value.
The wing or induced drag changes with speed in a very different way, because of the changes in the angle of attack. Near the stalling speed the wing is inclined to the relative wind at nearly the stalling angle, and its drag is very strong. But at ordinary flying speeds, with the angle of attack nearly zero, the wing cuts through the air almost like a knife, and the drag is minimal. After attaining a certain high speed, the angle of attack changes very little with any further increase in speed and the drag of the wing increase in direct proportion to any further increase in speed. This does not consider the factor of compressibility drag.
To sum up these changes, for a typical, airplane: As the speed increases from stalling speed to top speed, the induced drag decreases and parasite drag increases. As a result the total drag decreases for the first part of the range and then increases again.

When the airplane is in steady, level flight, the condition of equilibrium must prevail. The unaccelerated condition of flight is achieved with the airplane trimmed for lift equal to weight and the powerplant set for a thrust to equal the airplane drag.

The maximum level flight speed for the airplane will be obtained when the power or thrust required equals the maximum thrust available from the powerplant. The minimum level flight airspeed is not usually defined by thrust requirement since conditions of stall or stability and control problems generally predominate.

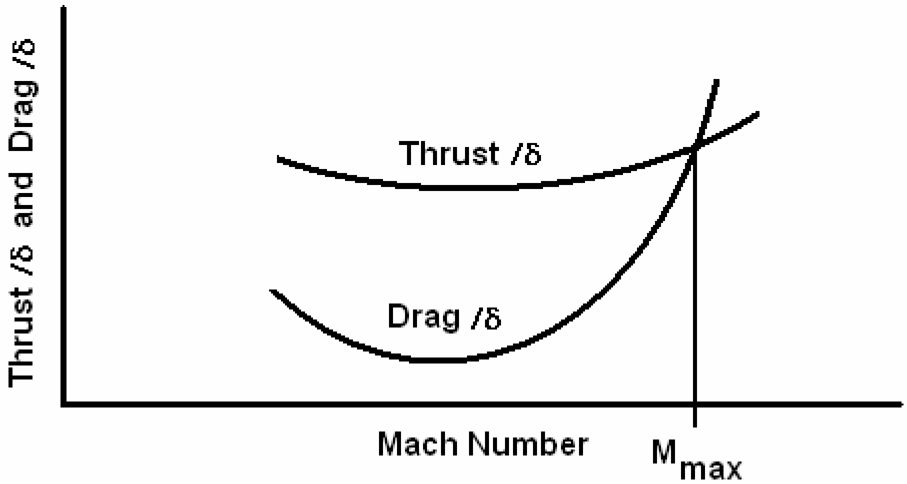


Figure 12 – Thrust and Drag

1.13 Climb Performance

Increasing the power by advancing the throttle produces a marked difference in the rate of climb. Climb depends upon the reserve thrust. Reserve thrust is the available thrust over and above that required to maintain horizontal flight at a given speed. Thus, if an airplane is equipped with an engine which produces 20000 pounds total available thrust and the airplane requires only 13000 lbs thrust at a certain level flight speed, the power available for climb is 7000 lbs thrust.

Although we sometimes use the terms "power" and "thrust" interchangeably, erroneously implying that they are synonymous, it is well to distinguish between the two when discussing climb performance. Work is the product of a force moving through a distance and is usually independent of time. Work is measured by several standards, the most com mon unit is called a "foot-pound." If a 1- pound mass is raised 1 foot, a work unit of I foot-pound has been performed. The common unit of mechanical power is horsepower; one horsepower is work equivalent to lifting 330,000 pounds a vertical distance of 1 foot in 1 minute. The term, "power," implies work rate or units of work per unit of time, and as such is a function of the speed at which the force is developed. "Thrust," also a function of work, means the force which imparts a change in the velocity of a mass. This force is measured in pounds but has no element of time or rate. It can be said then, that during a steady climb, the rate of climb is a function of excess thrust.

When the airplane is in steady level flight or with a slight angle of climb, the vertical component of lift is very nearly the same as the actual total lift. Such climbing flight would exist with the lift very nearly equal to the weight. The net thrust of the powerplant may be inclined relative, to the flightpath but this effect will be neglected here for the sake of simplicity. Although the weight of the airplane acts vertically, a component of weight will act rearward along the flight path (see Figure 13 below).

If it is assumed that the airplane is in a steady climb with essentially a small inclination of the flightpath, the summation of forces along the flightpath resolves to the following:

Forces forward = Forces aft

The basic relationship neglects some of the factors which may be of importance for airplanes of very high climb performance. (For example, a more detailed consideration would account for the inclination of thrust from the flightpath, lift not being equal to weight, a subsequent change of induced drag, etc.) However, this basic relationship will define the principal factors affecting climb performance.

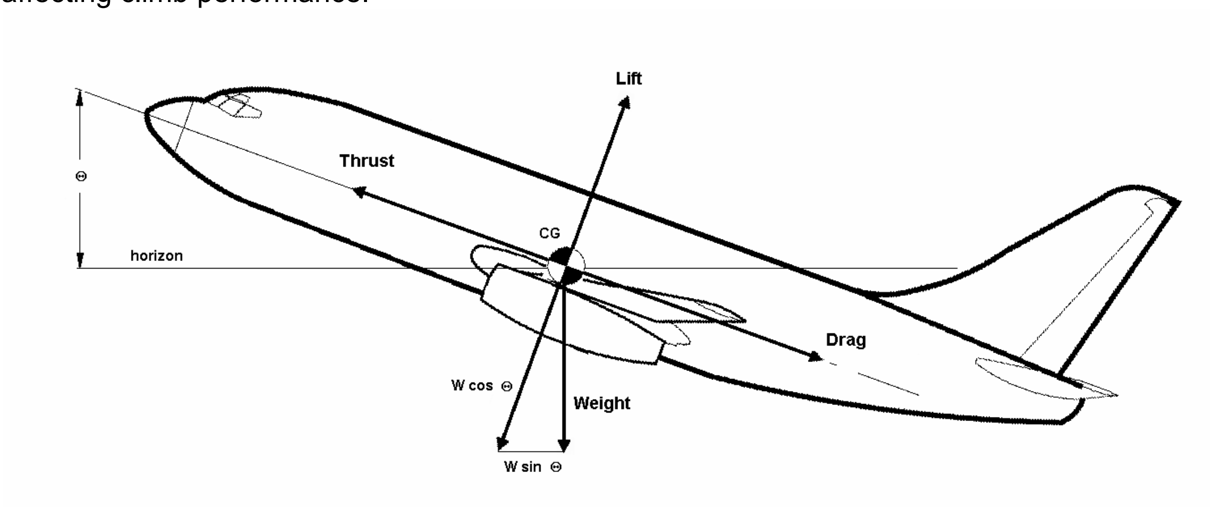


Figure 13 - Climb

This relationship means that, for a given weight of the airplane, the angle of climb depends on the difference between thrust and drag, or the excess thrust. Of course, when the excess thrust is zero, the inclination of the flightpath is zero and the airplane will be in steady, level flight. When the thrust is greater than the drag, the excess thrust will allow a climb angle depending on the value of excess thrust. On the other hand, when the thrust is less than the drag, the deficiency of thrust will allow an angle of descent.

The most immediate interest in the climb angle performance involves obstacle clearance. The most obvious purpose for which it might be used is to clear obstacles when climbing out of short or confined airports.

The maximum angle of climb would occur where there exists the greatest difference between thrust available and thrust required; i.e., for the propeller powered airplane, the maximum excess thrust and angle of climb will occur at some speed just above the stall speed.

Of greater general interest in climb performance are the factors which affect the rate of climb. The vertical velocity of an airplane depends on the flight speed and the inclination of the flightpath. In fact, the rate of climb is the vertical component of the flightpath velocity.

For rate of climb, the maximum rate would occur where there exists the greatest difference between power available and power required (see Figure 14). The above relationship mean, that, for a given weight of the airplane. the rate of climb depends on the difference between the power available and the power required, or the excess power. Of course, when the excess power is zero, the rate of climb is zero and the airplane is in steady level flight. When power available is greater than the power required, the excess power will allow a rate of climb specific to the magnitude of excess power.

It can be said, then, that during a steady climb, the rate of climb will depend on excess power while the angle of climb is a function of excess thrust.

The climb performance of an airplane is affected by certain variables. The conditlion of the airplane's maximum climb angle or maximum climb rate occur at specific speeds and variations in speed will produce variation, in climb performance. Generally, there is sufficient latitude in most airplanes that small variations in speed from the optimum do not produce large changes in climb performance, and certain operational considerations may require speeds slightly different from the optimum. Of course, climb performance would be most critical with high gross weight, at high altitude, in obstructed takeoff areas, or during malfunction of a powerplant. Then, optimum climb speeds are necessary.

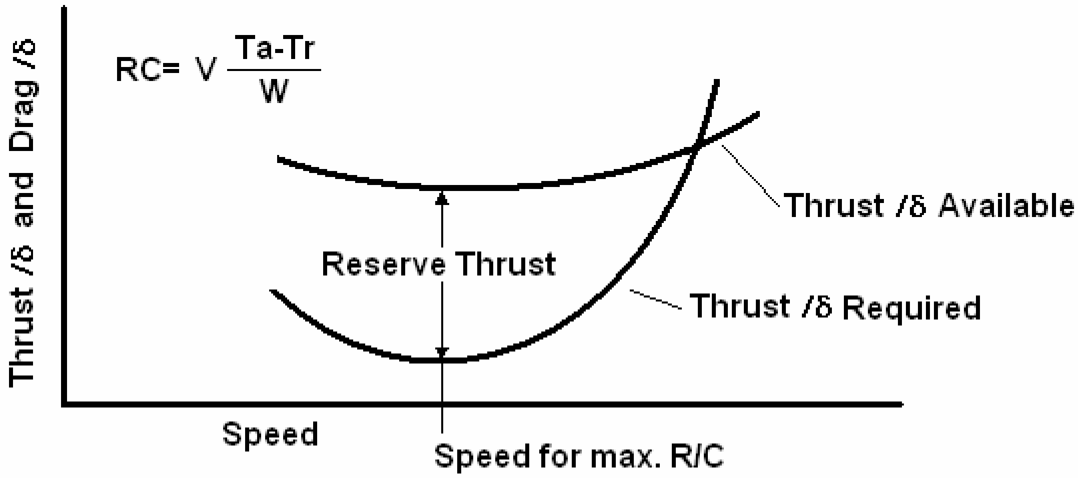


Figure 14 – Power Available and Power Required

Weight has a very pronounced effect on airplane performance. If weight is added to the airplane, it must fly at a higher angle of attack to maintain a given altitude and speed. This increases the induced drag of the wings, as well as the parasite drag of the airplane. Increased drag means that additional power is needed to overcome it, which in turn means that less reserve power is available for climbing. Airplane designers go to great effort to minimize the weight since it has such a marked effect on the factors pertaining to performance.

A change in the airplane's weight produces a twofold effect on climb performance. First, the weight affects both the climb angle and the climb rate. In addition, a change in weight will change the drag and the power required. This alters the reserve power available. Generally, an increase in weight will reduce the maximum rate of climb but the airplane must be operated at some increase of climb speed to achieve the smaller peak climb rate.

An increase in altitude also will increase the power required and decrease the power available. Hence, the climb performance of an airplane is affected greatly by altitude. The speeds for maximum rate of climb, maximum angle of climb, and maximum and minimum level flight airspeeds vary with altitude. As altitude is increased, these various speeds finally converge at the absolute ceiling of the airplane. At the absolute ceiling, there is no excess of power and only one speed will allow steady level flight. Consequently, the absolute ceiling of the airplane produces zero rate of climb. The service ceiling is the altitude at which the airplane is unable to climb at a rate greater than 100 feet per minute. Usually, these specific performance reference points are provided for the airplane at a specific design configuration.

1.14 Range Performance

The ability of an airplane to convert fuel energy into flying distance is one of the most important items of airplane performance. In flying operations, the problem of efficient range operation of an airplane appears in two general forms:

- to extract the maximum flying distance from a given fuel load or
- to fly a specified distance with a minimum expenditure of fuel.

A common denominator for each of these operating problems is the specific range; that is, nautical miles of flying distance per pound of fuel. Cruise flight operations for maximum range should be conducted so that the airplane obtains maximum Specific Range throughout the flight.

The specific range can be defined by the following relationship:

$$S.R. = \frac{\text{nautical miles}}{\text{lbs. Fuel}}$$

or

$$S.R. = \frac{\text{nautical miles/hr}}{\text{lbs. of Fuel/hr}}$$

If maximum specific range is desired, the flight condition must provide a maximum of speed versus fuel flow.

The general item of range must be, clearly distinguished from the item of endurance. The item of range involves consideration of flying distance, while endurance involves consideration of flying time. Thus, it is appropriate to define a separate term, "Specific Endurance."

$$S.E. = \frac{\text{flight hours}}{\text{lb. of Fuel}}$$

If maximum endurance is desired, the flight condition must provide a minimum of fuel flow.

While the peak value of specific range would provide maximum range operation, long range cruise operation is generally recommended at some slightly higher airspeed. Most long range cruise operations are conducted at the flight condition which provides 99 percent of the absolute maximum specific range. The advantage of such operation is that 1 percent of range is traded for 3 to 5 percent higher cruise speed. Since the higher cruise speed has a great number of advantages, the small sacrifice of range is a fair bargain. The values of specific range versus speed are affected by three principal variables:

- airplane gross weight,
- altitude, and
- the external aerodynamic configuration of the airplane.

"Cruise Control" of an airplane implies that the airplane is operated to maintain the recommended long range cruise condition throughout the flight. Since fuel is consumed during cruise, the gross weight of the airplane will vary and optimum airspeed, altitude, and power setting can also vary. Generally, "cruise control" means the control of the optimum airspeed, altitude, and power setting to maintain the 99 percent maximum specific range condition. At the beginning of cruise flight, the relatively high initial weight of the airplane will require specific values of airspeed, altitude, and power setting to produce the recommended cruise condition (see Figure 15). As fuel is consumed and the airplane's gross weight decreases, the optimum airspeed and power setting may decrease, or, the optimum altitude may increase. In addition, the optimum specific range will increase. Therefore, the pilot must provide the proper cruise control technique to ensure that optimum conditions are maintained.

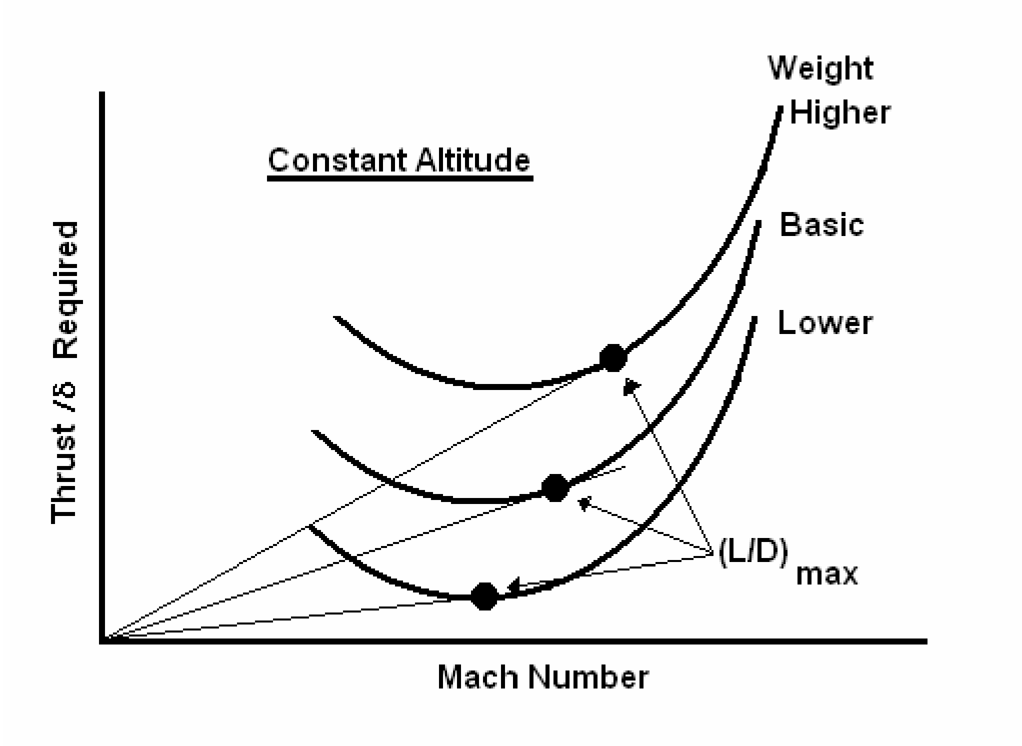


Figure 15 – Effect of Gross Weight

Total range is dependent on both fuel available and specific range. When range and economy of operation are the principal goals, the pilot must ensure that the airplane will be operated at the recommended long range cruise condition. By this procedure, the airplane will be capable of its maximum design operating radius, or can achieve flight distances less than the maximum with a maximum of fuel reserve at the destination.

The maximum endurance condition would be obtained at the point of minimum power required since this would require the lowest fuel flow to keep the airplane in steady, level flight. Maximum range condition would occur where the proportion between speed and power required is greatest. The maximum range condition is obtained at maximum lift-drag ratio (L/D max) and it is important to note that for a given airplane configuration, the maximum L/D occurs at a particular angle of attack and lift coefficient, and is unaffected by weight or altitude.

2 JET ENGINE

2.1 Development of Thrust

In discussing the ways thrust is developed, it is possible to go into all kinds of minute details. We could, for example, discuss the compressor component detail, showing how it is responsible for a certain percentage of thrust. However, it matters little just what details are necessary if we consider the overall picture of how thrust is developed.

Basically we accelerate a mass of air toward the rear of the engine. This gives us a reaction in the opposite direction called thrust. Mass can be described as the amount of matter in anything. The mass of a body is the number of molecules contained in it. Obviously, we cannot count the number of molecules passing through the engine. We can't even stop the air as it flows through the engine to weigh it.

2.1.1 Weight of Air Flow

The engine inlet is constructed with a fixed area of so many square feet. If the engine inlet has 10 square feet and the air is moving at a speed of 130 feet per second, the air flow would then amount to 1300 cubic feet per second.

One pound of standard air (air on a standard day of 59.0 °F and 29.92 in. of mercury) occupies about 13 cubic feet. Dividing 1300 cubic feet of volume by 13 cubic feet per pound gives us about 100 pounds of air per second. This is known as the weight of air flow (w_a).

2.1.2 Mass Flow From Weight of Flow

When we step on the scales we are measuring the force of gravitational attracion between the earth and ourselves. The weight of any body is the force of attraction between the earth and the body. We call this particular force of attraction "gravity".

We know that when a body is subjected to a force it will accelerate as long as there is no opposing force. If a body is allowed to fall toward the center of the earth with nothing in the way - no air, no water, no ground - it will go faster and faster until it reaches the center. Each second that it falls it will be going 32.2 feet per second faster than it was going the second before. This is often expressed as 32.2 feet per second per second, or 32.2 feet per second squared. For practical purposes this acceleration due to gravity is a constant and is designated as "g".

From Newton we know that a force to be generated is proportional to the mass times its acceleration:

$$F = ma$$

The weight of a body is the force of exerted on the body. Thus we can substitute weight for force, or W for F.

Also, "g" is the acceleration due to gravity, so we can substitute "g" for "a". Now the Newton formula reads:

$$W = mg$$

In other words, the weight of a body equals its mass times the acceleration due to gravity.

If W = mg, then $m = \frac{W}{g}$. In the jet engine we are dealing with weight of air flow, so the new look on the formular is w_a/g for mass flow.

2.1.3 Change in Velocity

If we designate the initial velocity of the air available to the engine as V_i and the velocity at the jet nozzle as V_J, $V_J – V_i$ will be the amount of the change in velocity. Wa/g = mass flow of air through the engine. So

$$\frac{W_A}{g}\left(V_j - V_a\right)$$

will give us the force or thrust resulting from accelerating the mass flow of air.

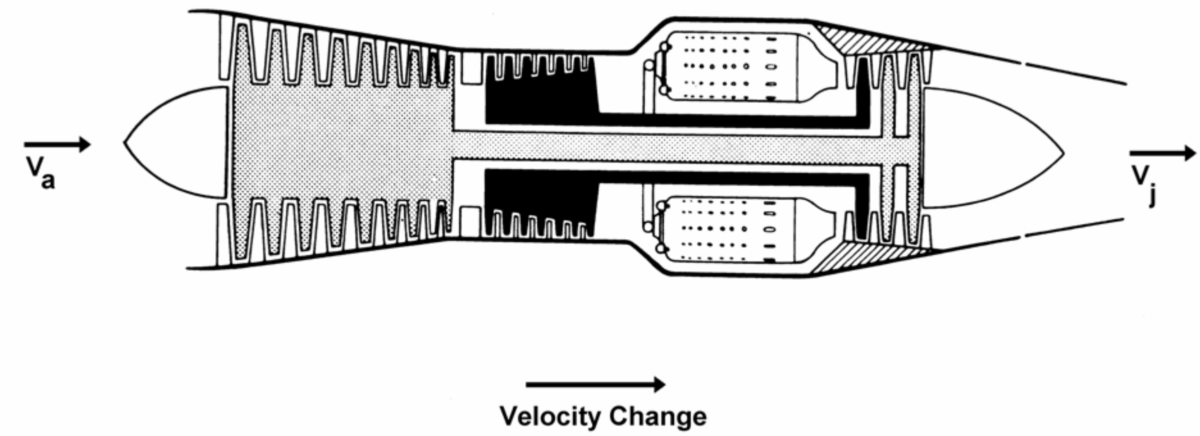


Figure 16 – Change in Velocity

2.1.4 Fuel Flow

One thing else enters into the determining of thrust. We use a considerable amount of fuel in order to obtain the heat energy to speed up the air mass. Note that the fuel always goes along with the engine and so has no initial velocity. Because there is a considerable amount of mass involved in the weight of fuel flow we must add it to the formular to make it really complete. Our complete formular would now read:

$$F_N = \frac{W_A}{g}\left(V_j - V_a\right) + \frac{W_F}{g} V_j$$

2.1.5 Static Pressure in the Jet Nozzle

When high compression ratio engines operate at high airplane speeds the overall compression ratio is quite high. The pressure in the tailpipe may not all be used in accelerating the gases through the nozzle with the result that the !static pressure in the nozzle is higher than ambient air pressure. In this case there is additional thrust due to the difference in static pressure in the nozzle(P_j), and ambient pressure (P_{am}) multiplied by the area of the jet nozzle, (A_j). The complete formula for thrust thus becomes:

$$F_N = \frac{W_A}{g}\left(V_j - V_a\right) + \frac{W_F}{g} V_j + A_j\left(p_j - p_{amb}\right)$$

The last part becomes effective only under certain conditions and is often omitted in general discussions.

2.2 Factors Affecting Thrust

If we operated the jet engine in an air-conditioned room we would never have any change in the quantities in the jet formula. However, the engine must operate efficiently from sea level to extreme altitudes, from a stand-still to extreme speeds, and under all changes of atmospheric conditions. Although we can compensate for some of these problems, there are bound to be some changes in the quantities of the thrust relationship.

2.2.1 Change in Jet Nozzle Velocity as a Variable

In a modern jet engine the jet nozzle is choked; i.e., the gases are passing through it at the speed of sound. At present, jet nozzles are limited to developing gas velocities up to the speed of sound, and the speed of sound is controlled by the square root of the absolute temperature.

The only variation in the speed of ejection at the jet nozzle will be due to a change in exhaust gas temperature. Of course, if the jet nozzle is not choked there will be considerable change in jet nozzle velocities due to changes in air speed and atmos- pheric conditions. However, when the jet nozzle is already operating at sonic velocity there will be less variation in the speed with which the gases are ejected.

2.2.2 Initial Air Velocity as a Variable

In the test stand or when the aircraft is standing still the engine V_a must pick up the air mass and accelerate it from zero speed up to the jet nozzle velocity. However, as soon as the aircraft begins to move, the initial air velocity begins to in crease along with the air speed of the airplane. This means that the greater the speed, the less difference there will be between the initial velocity and the jet nozzle velocity. In the jet formula we are multiplying the mass flow of air by the difference in velocity developed across the engine. If that difference decreases, the thrust output will decrease. Thus we see that the increasing V_a would tend to have a decreasing effect upon thrust.

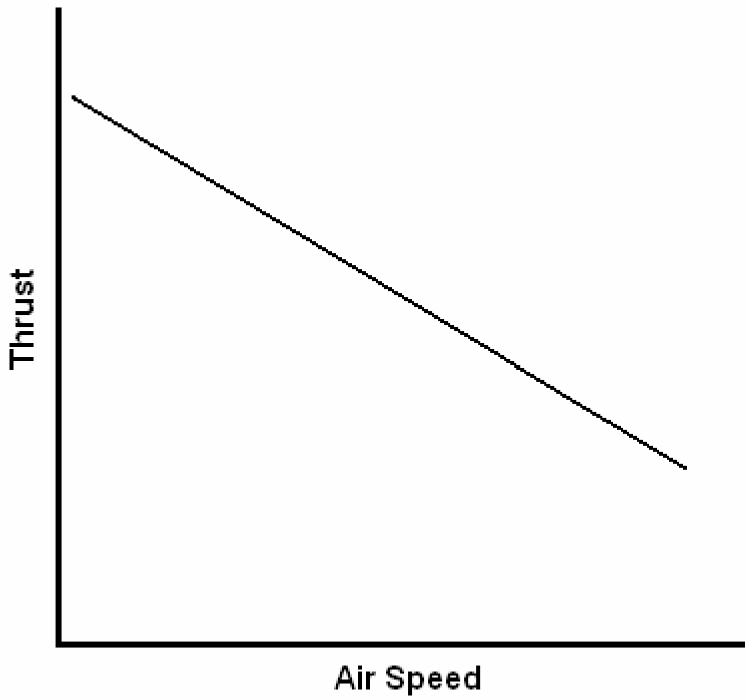


Figure 17 – Effect of Air Speed on Thrust

2.2.3 Density Effect

Density is the mass per unit of volume or the number of molecules per cubic foot. When density increases there are more molecules per cubic foot. When density decreases there are fewer molecules per cubic foot. The number of cubic feet per second we can direct into the engine is controlled by the fixed engine inlet area, assuming constant RPM. Thus the mass flow is determined by the density.

In free air a rise of temperature will cause the speed of the molecules to increase so that they run into each other harder. When they run into each other harder, they move farther apart. When they are farther apart a given number of molecules will occupy more space. When a given number of molecules occupy more space we can get fewer through the engine inlet area. Thus, as temperature increases, thrust decrease.

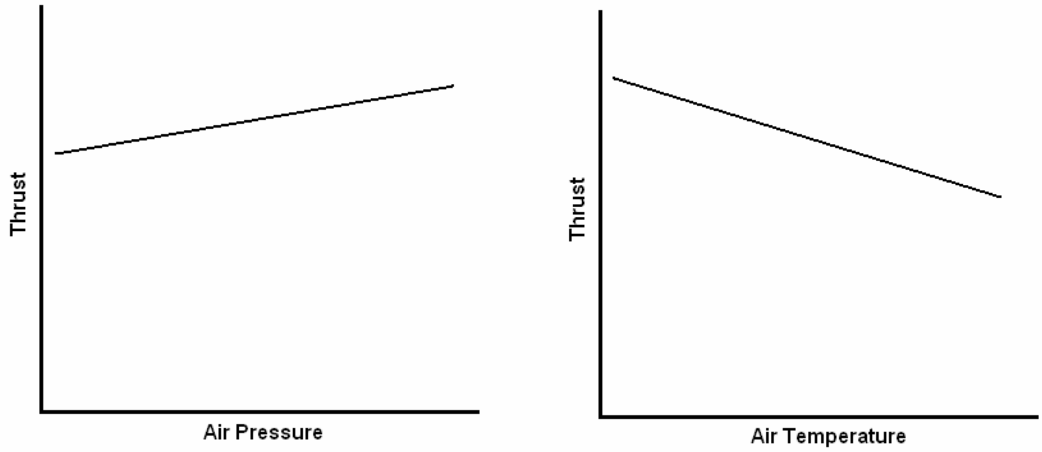


Figure 18 – Effect of Air Pressure and Air Temperature on Thrust

Again in free air when pressure increases it is because there are more molecules per cubic foot. When there are more molecules per cubic foot we can direct more of them through the fixed inlet area. More molecules going through the inlet area per second means a greater wa. As pressure goes up, density goes up. As density goes up, wa goes up and consequently the thrust goes up.

Density affects thrust proportionately. A 10,000 pound thrust engine on a hot day might generate only about 8,000 pounds of thrust, while on a cold day the engine might produce as much as 12,000 pounds of thrust.

2.2.4 Altitude Aspect

The effect of altitude on thrust output is really a function of density. The higher we go the less air pressure there is and the colder it gets. As pressure decreases thrust decreases, but as temperature decreases thrust increases. However, the pressure drops off faster than the temperature so that there is actually a drop off in thrust with altitude.
At about 36,000 feet the temperature stops falling and remains constant while the pressure continues to fall. As a result, the thrust will drop off more rapidly. This makes 36,000 feet the optimum altitude for long range cruising, just before the rate of thrust fall off increases.

2.2.5 Ram Effect

Ram is a descriptive word. We must be careful not to draw conclusions from the descriptive quality of the word that will give us wrong impressions of the effect of ram on engine perfromance.

As the aircraft picks up speed going down the runway, the air is moving by it at an increasing speed. It makes no difference whether the aircraft is stationary in a wind tunnel and the air is blown by it or the aircraft is moving through stationary air.

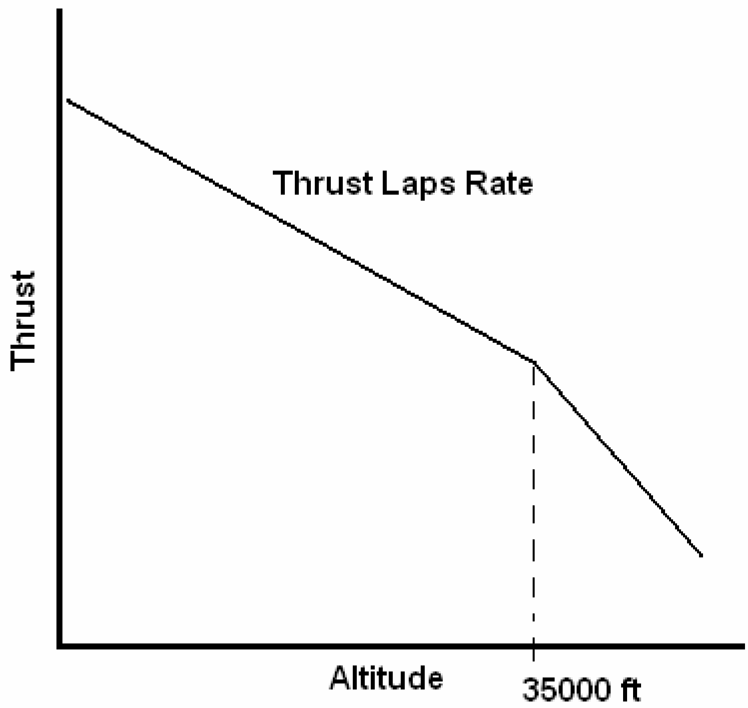


Figure 19 – Effect of Altitude on Thrust

The effect is the same. In front of the engine there is a divergent inlet duct. As the air enters the duct it will fill up the added space. When this occurs we get a drop in velocity and an increase in pressure. This is a function of the Bernoulli Theorem.

With the relative velocity of the air turned into pressure, the air molecules have developed their impact force. The restricted area of the engine inlet causes a pile-up of molecules, thus increasing the density. When the density increases, we get a corresponding increase in thrust.

Obviously, any frictional losses in the duct will cause fewer molecules to reach the engine inlet. Any friction occurring in the duct is a loss to the engine so far as ram is concerned.

A quick summary of ram can be seen from Figure 20.
"A" curve represents the tendency for thrust to drop off with air speed due to an increase in V_a.

"B" curve represents the thrust generated by ram effect on or increased w_a.

"C" curve is the result of combining "A" and "B" curves.

Notice that, due to ram, eventually the air speed is such that any losses due to increase in Vi are made up. Ram will compensate some for loss of thrust due to altitude also. Ram is important to the jet type of aircraft engine in that it will eventually at high air speeds produce an increase in thrust by increasing w_a.

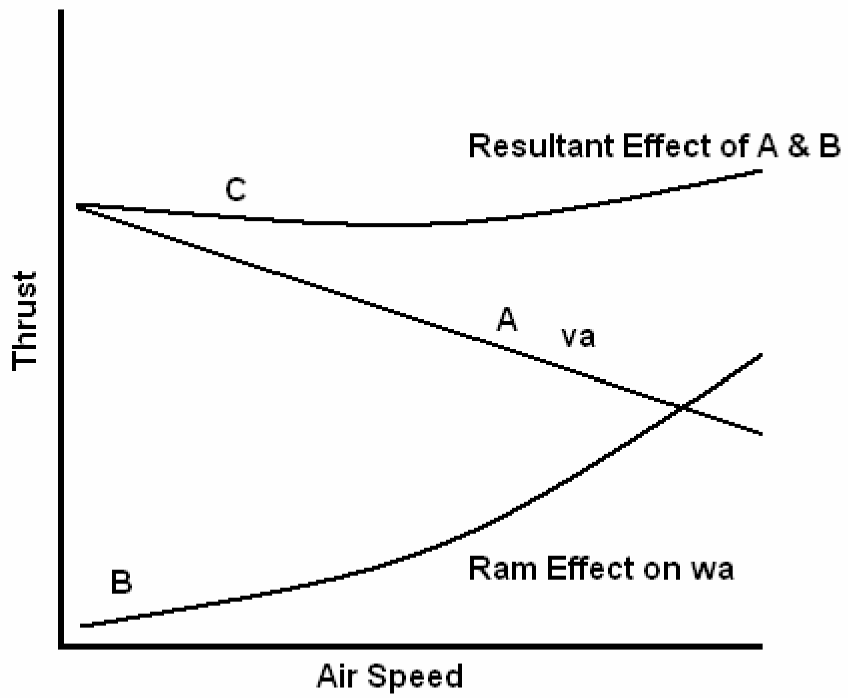


Figure 20 – Effect of Ram on Thrust

2.2.6 Water Injection

At first glance it would appear that once the wa is inside the engine there is nothing we can do to change it. However, by using water injection we can add the mass of water molecules to the mass flow of air. Even though a water molecule weighs less than an air molecule we add whatever they weigh to the air already in the engine.

Water has the effect of cooling the air mass inside the engine. However, we maintain the same pressure because we are adding water molecules to the air. We can expect that water molecules can be added as long as the constant pressure can be maintained.

Water injection does two things directly. It cools the air mass and maintains the same pressure by adding molecules to the mass flow. Obviously, if there is little cooling effect, only a few molecules can be added to the mass flow. Thus on a cold day we can obtain only a small thrust increase by utilizing water injection, but on hot days a sizeable thrust increase may be realized.

This effect will also vary considerably with the position of the injection. Water injected at the inlet will be affected more by outside temperature than if it is injected somewhere farther back in the engine where the heat generated by compression will counteract a cold outside temperature.

Not all the increase in thrust with water injection is due to the increase in mass flow. There is a cycle effect. The increase in wa causes a tendency to slow down the compressor. The fuel control adds fuel to keep the compressor going at the same speed. The resulting increase in heat energy hits the turbines and the compressor is speeded up. When the compressor speeds up it gives a greater weight of air flow. The end result is a realizing of a greater thrust increase by increased wa than is obtained by the addition of the water molecules.

2.3 Efficiencies

Just how well an engine functions involves us in a discussion of efficiencies. The efficiency of any engine can be described as the output divided by the input. If we add to the air flowing through the engine a certain amount of energy, we have given it a potential for doing work. The amount of work actually done is the output of the engine. This output divided by input is always less than 100% because a certain amount of inefficiency will always be present.

In a jet engine we are not so much interested in the amount of work actually done by the engine as in the amount of thrust or force we generate. Force times distance is work. We are satisfied to worry about how much force is generated regardless of whether it moves anything or not. For instance, in the test stand we can't allow the engine to go any distance no matter how much thrust it develops so under these conditions accomplishing work is impossible.

So we reduce our efficiency to the amount of thrust generated compared to the amount of energy we use, which in this case is fuel flow.

This brings us to one of the main measures of jet engine efficiency: the amount of thrust generated divided by the fuel consumption. This is called "Thrust Specific Fuel Consumption" or TSFC:

$$TSFC = \frac{W_F}{F_N}$$

It is obvious that the more thrust we obtain per pound of fuel the more efficient the engine is. Specific fuel consumption is made up of a number of other efficiencies. The two major factors affecting TSFC are propulsive efficiency and cycle efficiency.

2.3.1 Propulsive Efficiency

Propulsive efficiency is the amount of thrust developed by the jet nozzle compared to the energy supplied to it in a useable form. We should think of the main engine as a machine that not only gets the energy into the air but tries to get that energy into a form that can be turned into thrust. The jet nozzle does the best it can with what it has to work with.

2.3.2 Cycle Efficiency

On a much grander scale is the cycle efficiency. Briefly, cycle efficiency is the amount of energy put into a useable form as compared to the total amount of energy available in the fuel. It involves combustion efficiency, thermal efficiency, mechanical efficiency, compressor efficiency, etc. It is, in effect, a measure of the overall efficiency of the engine components starting with the compressor and going through the combustion chamber and turbine. The job of these components is to get the energy in the fuel into a form the jet nozzle can turn into thrust.

3 TAKEOFF PERFORMANCE

3.1 General

The takeoff is a portion of a flight that takes a lot of mental effort. There are many variables that a pilot has to absorb in very short time: keeping the aircraft straight down the runway, monitoring engine and flight instruments, take the proper action should a malfunction occur, rotate at the proper rate and establish a stabilized flight path after liftoff. By the end of a takeoff roll the aircraft attains a very high level of kinetic energy, so that an abort in this phase would result in an overrun.

A good understanding of both the operational and the theoretical side (certification, obstacle clearance requirements) is required.

3.2 The Takeoff Requirements

In the daily operation the maximum takeoff weight is not only a question of performance of the aircraft alone but also a question of whether the aircraft will be able to meet the regulatory requirements once it looses the critical engine.

Regulations ask for either a stop or go decision and in both cases the situation must be survivable. As far as certification is concerned, the regulatory material can be found in FAR Part 1 and 25.

3.2.1 Introduction

There are six areas that have takeoff performance requirements. They are:

- Field length
- Climb
- Obstacle clearance
- Tire speed
- Brake energy
- Other

3.2.2 Field Length

Three cases are examined to determine the required field length. They are:

- With the failure of one engine at the most critical point, the distance required to accelerate to reach 35 feet (10.7 m) above the runway at the end of the available takeoff distance
- The distance required to accelerate to V_1, have an event occur, and stop with the available stop distance
- With all engines operative throughout the takeoff, 115% of the distance to reach 35 feet (10.7m) above the runway at the end of the runway.

3.2.3 Climb

The climb limit weight is the maximum weight that still meets the minimum gradient established by the FARs. The second segment is usually the segment that determines the climb limit weight. The other two segments are the first and the final segment. For a two engine jet, the minimum climb gradient for the second segment of flight is 2.4%, The second segment occurs when the gear is up and the flaps are at the takeoff setting and the power is at takeoff power.

3.2.4 Obstacle

The airplane's net flight path must clear an obstacle by 35 feet (110.7 m). The net flight path is the gross (actual) flight path minus 0.8% of gradient for a two engine jet.

3.2.5 Tire Speed

The ground speed at the lift-off speed (V_{LOF}) must not exceed the maximum speed of the tires.

3.2.6 Brake Energy

The energy capability of the brakes may not be exceeded by a stop from V_{MBE} with both engines operating. This assumes maximum manual braking. V_1 must be less than or equal to V_{MBE}.

3.2.7 Other Requirements

Besides these several other requirements exist, such as:

- TOW limited by landing weight
- Approach and landing performance
- Enroute limitations
- Minimum Control Speed
- Runway bearing capacity

Takeoff weight limited by structure or zero fuel weight are specific to the aircraft structural design rather than regulatory performance requirements.
In order to meet the take off requirements the pilot has several tools:

- weight reduction
- flap setting
- thrust setting (e.g. packs off)
- selection of takeoff speeds (e.g. improved climb)
- runway change

Weight reduction is often the only tool left that will allow to meet the requirements under given ambient conditions, however, it should be considered last.

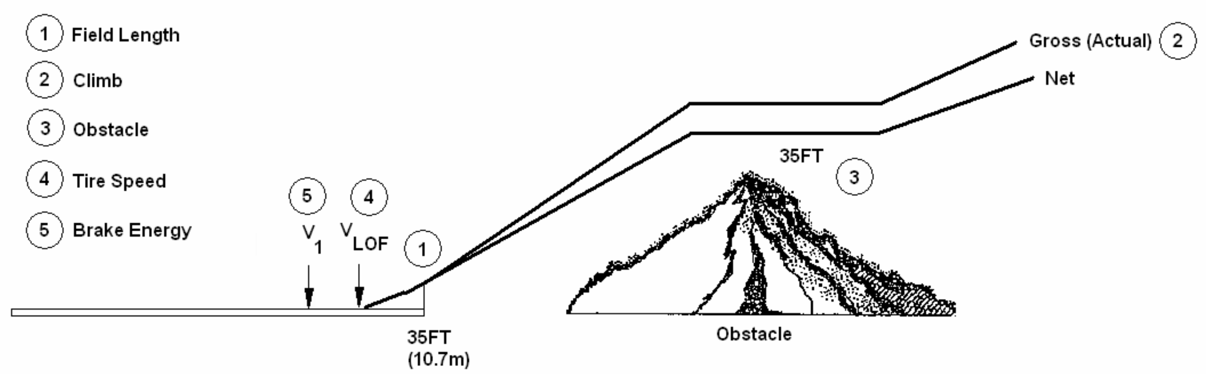


Figure 21 – Takeoff Requirements

3.3 FAR Takeoff Definition

3.3.1 Introduction

The FAR define takeoff field length as the longest distance required by these three conditions:

- Engine-out accelerate-go distance, this is the distance required to:
  - Accelerate with all engines operating
  - Have one engine fail at V_{EF}
  - This failure occures at least one second before V_1
  - Continue the takeoff
  - Lift-off
  - Reach a point 35 feet above the runway surface at V_2.
- Accelerate-stop distance, this is the distance required to:

  - Accelerate with all engines operating
  - Have one engine fail at V_{EF}
  - This failure occures at least one second before V_1
  - Recognize the failure
  - Put the airplane in a configuration for stopping
  - Stop the airplane with the use of maximum wheel brakes with the speedbrakes extended. NOTE: reverse thrust is not used determine the FAR accelerate-stop distance.
- Alle-engine do distance, this is 115% of the distance required to:
  - Accelerate with all engines operating
  - Lift-off
  - Reach a point 35 feet above the runway surface at the all engine climb out speed.

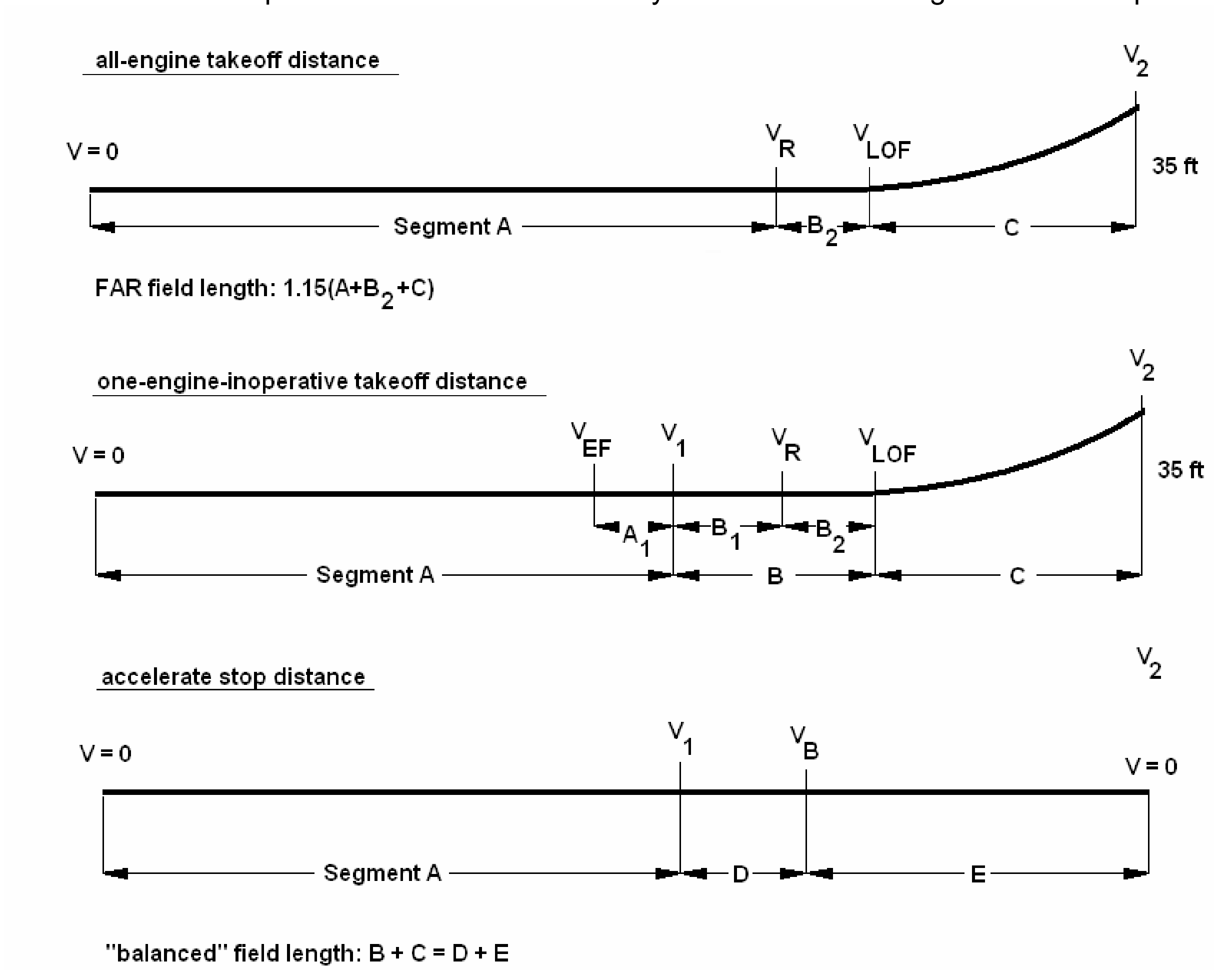


Figure 22 – Takeoff Definition

3.4 Takeoff Distances Available

3.4.1 Takeoff Run Available (TORA)

The part of the takeoff surface consisting of full strength paved surface capable of carrying the airplane under all normal operating conditions.

3.4.2 Clearway Length Available

The length of an area beyond the runway, not less than 500ft wide, centrally located about the extended centerline of the runway and under control of the airport authorities. The Clearway is expressed in terms of a clearway plane, extending from the end of the runway with an upward slope not exceeding 1.25% above which no object nor any portion of the terrain protruders, except that the threshold lights may protrude above the plane, if their height above the end of the runway is not greater than 26 inches and if they are located to either side of the runway. (FAR Part 1.1)

3.4.3 Stopway Length Available

The length of an area beyond the runway, not less in width than the runway, centrally located about the extended center line of the runway and designated by the airport authorities for use in decelerating the airplane during a refused takeoff. A stopway must be capable of supporting the airplane during a refused takeoff without inducing structural damage to the airplane. (FAR Part 1.1)

3.4.4 Takeoff Distance Available (TODA)

The sum of runway length available and clearway length available. If no clearway exists the takeoff distance available equals the runway length available. **(TODA=TORA for no Clearway)**

3.4.5 Accelerate-Stop Distance Available (ASDA)

The sum of runway length available and stopway length available. If no stopway exists the accelerate-stop distance available equals the runway length available. **(ASDA=TORA for no Stopway)**

3.4.6 Balanced Takeoff

The condition, where V_1 is selected to make the required distance to 35ft, assuming a failure of the critical engine is recognized at V_1, equal to the accelerate-stop distance required. In this case the V_1-speed is called balanced V_1.

3.4.7 Unbalanced Takeoff

The condition, where V_1 is selected to make the required distance to 35ft, assuming a failure of the critical engine at V_1, unequal to the accelerate-stop distance required. Such a V_1 selection allows to take advantage of clearway and stopway with unequal lengths available.

3.5 Takeoff Speeds

3.5.1 Definitions

<u>VEF</u>
Critical engine failure speed. V_{EF} is the speed at which the critical engine is assumed to fail. It shall not be less than the V_{MCG} determined under FAR Part 25.149 (e).
(FAR Part 25.107 (a)(1))

<u>V1</u>
Takeoff decision speed. It cannot be less than V_{EF} plus the speed gained with the critical engine inoperative during the time interval between the instant the critical engine has failed and the instant the pilot has recognized and reacted to the engine failure by application of the first retarding means. (FAR Part 25.107 (a)(2))

<u>VMCG</u>
Ground minimum control speed, is the minimum control speed on the ground, at which, when the critical engine suddenly becomes inoperative, it is possible to recover control of the airplane with the use of primary aerodynamic controls alone (without the use of nose wheel steering) to enable the takeoff to be safely continued using normal piloting skill and rudder control forces not exceeding 150 pounds.
(FAR Part 25.149 (e))

<u>V1(MCG)</u>
The minimum takeoff decision speed, at which, when the critical engine suddenly becomes inoperative at V_{EF} with the remaining engines at takeoff thrust, it is possible to control the

airplane with primary aerodynamic controls alone and continue the takeoff. This is the V_1 speed which results when V_{EF} is set equal to V_{MCG}.

VMCA
Air minimum control speed, is the airspeed, at which, when the critical engine is suddenly made inoperative, it is possible to recover control of the airplane with that engine still inoperative, and maintain straight flight either with zero yaw or with an angel of bank of not more than 5 degrees. V_{MCA} may not exceed 1.2 V_S (V_S determined at the maximum sea level takeoff weight) with maximum available takeoff thrust. Rudder forces required to maintain control my not exceed 150 pounds. (FAR Part 25.149 (b)(c)(d))

VR
Takeoff rotation speed. V_R is the speed at which rotation is initated to attain tha takeoff safety or climbout speed, V_2, at 35 feet above the takeoff surface. V_R must not be less than 1.05 times the minimum control speed (air), nor less than V_1. (FAR Part 25.107(e))

VMU
Minimum unstick speed. V_{MU} shall be the speed at which the airplane can be made to lift off the ground and to continue the takeoff without displaying any hazardous characteristics. V_{MU} speeds shall be selected by the applicant for the all engines operating and the one engine inoperative condition. (FAR Part 25.107(d))

VLOF
Airplane lift off speed. The lift off speed is closely associated to the V_R speed and is dictated by that speed. The all engines operating lift off speed must not be less than 110% of V_{MU} assuming maximum practicable rotation rate. The one engine inoperative lift off speed must not be less than 105% of V_{MU}. (FAR Part 25.107(f) and FAR Part 25.107(e)(1)(iv))

V2
Takeoff safety speed. V_2 is equal to the actual speed at the 35 foot height as demonstrated in flight and must be equal to or greater than 120% of the stall speed in the takeoff configuration or 110% of the minimum control speed (air). (FAR Part 25.107(b)(c))

3.5.2 Certification Requirements

Accelerate-Stop
During the tests for the certification of the airplane, the speed of the airplane is increased to a given point and an event occurs. This event used to be an engine failure. For determining an accelerate-stop distance it is more conservative to consider an event rather than an engine failure. V_1 occurs one second after the event. Many of these test are done. Average times are calculated for the times taken to do these things:

- Apply the brakes
- Quickly move the throttles to idle
- Apply the speedbrakes.

Next, the increase in velocity from two seconds of additional acceleration is added to the V_1 speed. This is the speed from which the airplane must stop. The increased time is not to be used for increased time to make the “no go" decision after V_1. It is added to permit the "average" pilot to change from the takeoff mode to the stopping mode.

Engine Inoperative Accelerate-Go
Also during the tests for the certification of the airplane, the speed of the airplane is increased to a given point and an engine is 'failed'. The speed one second later is V_1. The accelerate go distance is the distance required to accelerate the airplane after the engine failure, takeoff, and reach a height of 35 feet (10.7 m).

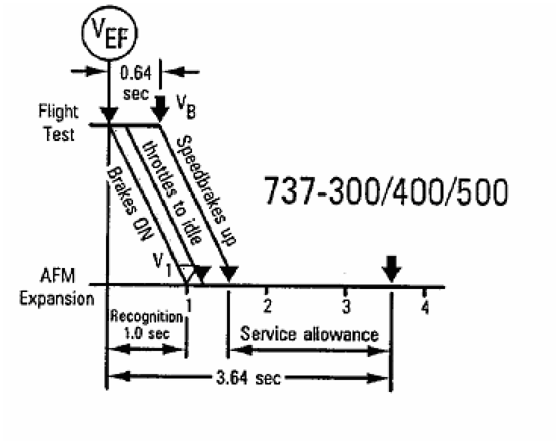


Figure 23 – Transition Time

3.5.3 V1 Variations

Standard
For a standard (balanced V_1) takeoff, the horizontal distance that the airplane goes to climb to 35 feet (10.7m) is equal to the distance required to stop the airplane from V_1.

Clearway
If clearway is available, the point where the airplane climbs to 35 feet (10.7m) can be over that clearway. This permits you to use a higher weight because you have more distance to use to climb to 35 feet (10.7m). The higher weight requires a lower V_1 to still be able to stop on the available runway.

Stopway
If stopway is available, you have more distance to stop the airplane from V_1. This permits you to use a higher takeoff weight, but requires a higher V_1 to ensure that you can still climb to 35 ft by the end of the runway.

3.5.4 Rejected Takeoff After V1

V_1 is the maximum speed at which you can start the rejected takeoff (RTO) procedure and still stop the airplane within the remaining field length. This is true under the conditons and procedures given in the AFM. It is the latest point in the takeoff roll where you can start the stop procedure.

If an RTO is started at V_1 And the airplane is at the runway limit weight, the airplane's speed will be zero at the end of the runway. If the RTO is started after V_1, the airplane will not stop on the runway. It is not recommended to do an RTO after V_1 unless the pilot finds that the airplane is unsafe or unable to fly. The spped at which the airplane goes of the runway changes with the weight of the airplane. A heavier airplane will have a higher speed than that of a lighter airplane.

3.5.6 Continued Takeoff Before V1

The FARs give minimum performance standards for the "Go" decision. The FAR "Go" condition examines the airplane with one engine failed at the most critical part of the takeoff. In this condition, the airplane must:

- Continue to accelerate
- Rotate
- Lift-off
- Be at V_2 at 35 feet above the end of the takeoff distance

The airplane must be able to be controlled throughout this time. In almost 75% of the RTO accidents, full takeoff power was available on both engines.

3.6 Effect of Flap Position on Takeoff

3.6.1 Takeoff Field Length

The position of the flaps has an effect on the length of runway that is necessary to takeoff. A higher number flap setting gives the wing more chamber. This creates more lift than a lower number flap setting. Because of this, it takes less runway to takeoff at a higher number flap setting than a lower number flap setting.

3.6.2 Climb Gradient

The position of the flaps also has an effect on the clim gradient. The climb gradient (γ) is in proportion to (Thrust/Weight)-(Drag/Lift). At a higher flap setting, both the lift and the drag increase. However the drag increases faster than the lift. This gives a lower climb gradient than a lower falp setting. Because of this, a lower number flap setting causes a higher climb angle than a higher number flap setting.

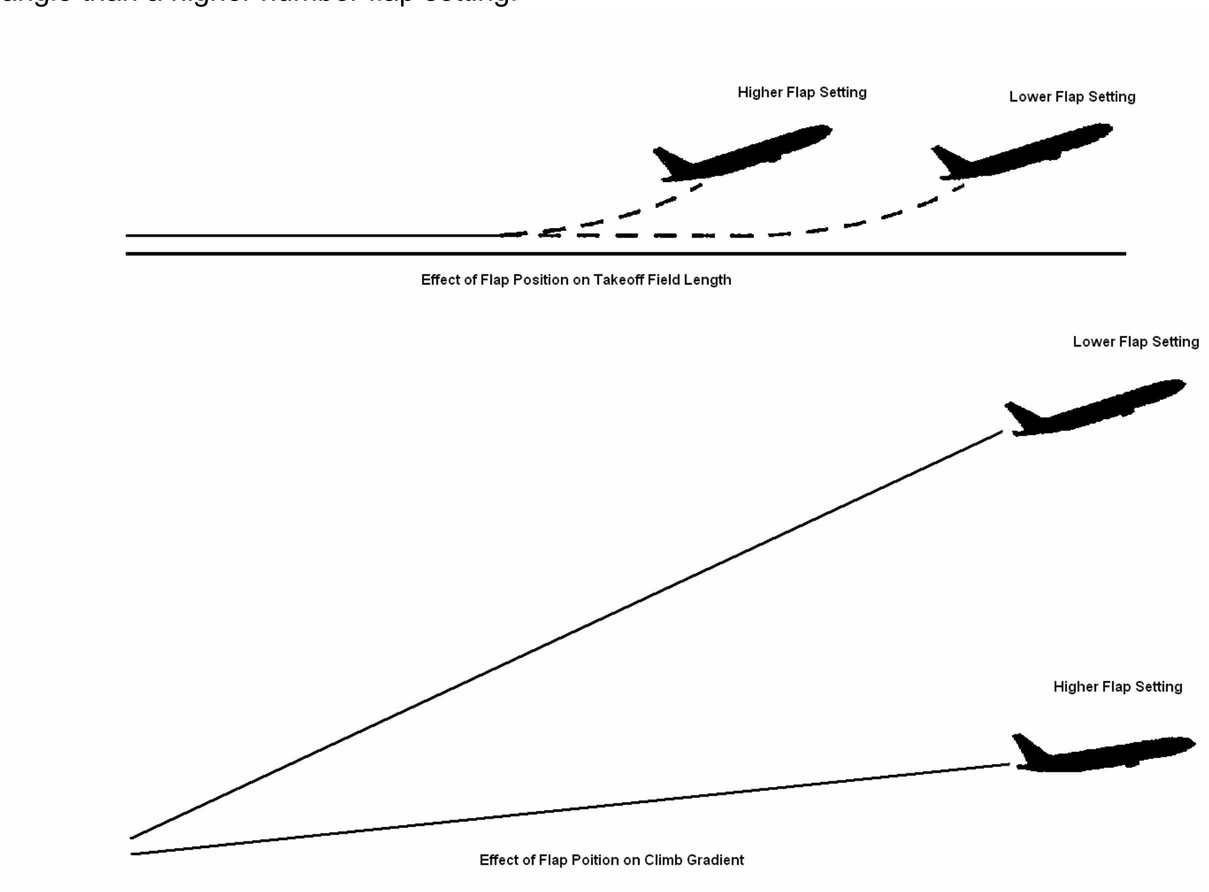


Figure 24 – Effect of Flap Position on Takeoff

3.7 Takeoff Flight Path

The takeoff flight path begins 35 ft above the takeoff surface at the end of the takeoff distance and continues to a point of the takeoff where the final segment climb speed and a height of 1500 ft for 10 min. T/O Thrust (800 ft for 5 min T/O Thrust) is reached, or, after all takeoff flight path obstacles are cleared.

3.7.1 Net Takeoff Flight Path

The net takeoff flight path is the gross takeoff flight path reduced by 0.8% climb gradient capability.
The prescribed reduction in climb gradient is applied as an equivalent reduction in acceleration along level-off part of the takeoff flight path.
The net takeoff flight path must clear all obstacles in the takeoff area by a height of at least 35 ft. However, when making a turn, one wing is below the fuselage, therefore, part of the

airplane is lower than the indicated level. To allow for a turn during takeoff the flight path must clear any obstacles by a height of at least 50 ft. As the lift component decreases in a turn, there is an additional decrement of gradient loss taken into account. Mind, that a net gradient of 1.6% only provides an altitude improvement of 16ft/1000ft or 97ft/NM ground distance.

3.7.2 Climb Gradient Requirements

A minimum climb gradient is required in each segment of the takeoff flight path as Shown below. Each segment is defined by changes in airplane configuration, speed or power setting.

First Segment
This segment extends from the 35 ft height to the point where the landing gear is fully retracted at a constant V_2 speed.

Second Segment
This segment starts at the point at which the landing gear is fully retracted and continues until the airplane reaches an altitude of at least 1500 feet above the runway. It is flown at V_2 speed, flaps .in the takeoff position and takeoff power.

Third Segment
The third segment is that portion of the flight path during which the flaps are retracted while accelerating in level flight to the "Final Segment” climb speed. The acceleration capability must correspond to gross climb gradient shown in Table 2.
The takeoff flight path profile will vary during this segment depending upon obstacle location and height, The height to be used during level flight acceleration is determined during the obstacle clearance analysis and will be provided on runway weight charts.
Flap retraction speeds have been selected to provide adequate margins above the stall speed. The acceleration in level flight with one engine inoperative will be such that the speed will not be less than 20% above the stall speed during retraction.

Final Segment
This segment extends from the leveoff height to the end of the takeoff flight path. The minimum gross height is at least 1500 ft. It is flown at the "Final Segment" climb speed, flaps up and using maximum continuous thrust. The Final Segment is sometimes called 4^{th} segment.

Number of engines	Segment			
	1	2	3	Final
	Minimum Gross Gradient [%]			
2	positive	2.4	1.2	
3	0.3	2.7	1.5	
4	0.5	3.0	1.7	

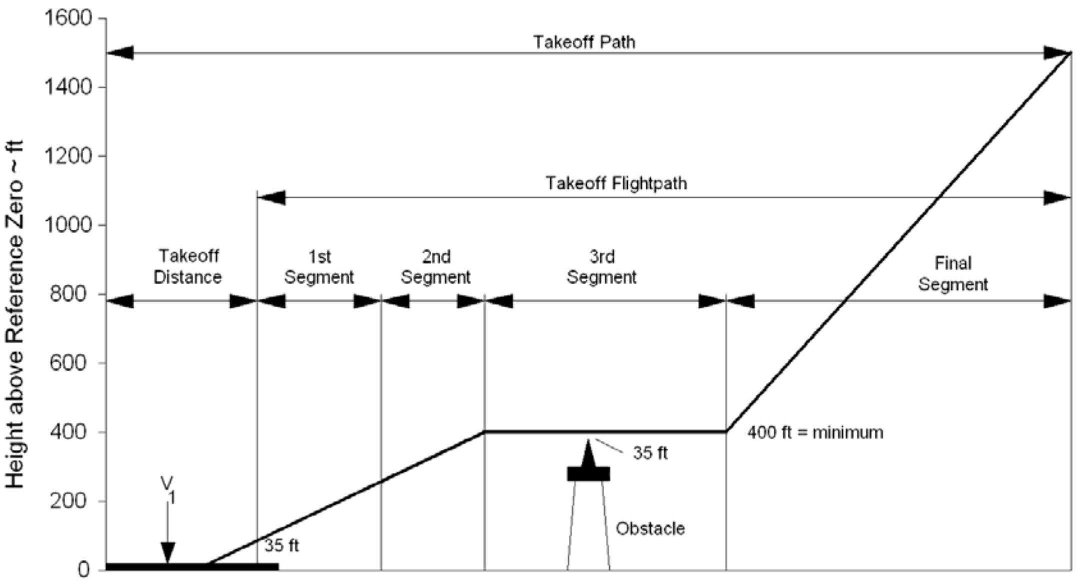
Table 2 – FAR Minimum Climb Gradients

3.8 Improved Climb

3.8.1 Introduction

Improved climb is used to make airplane performance better. It may increase the maximum allowable takeoff weight when a plane is limited by the climb limitation. To use improved climb, there must be excess field length, tire speed, brake energy, and obstacle performance.

The improved climb procedure increases the normal V_2 and, because of that, increases the climb capability to the airplane. V_1 and V_R must also be increased if V_2 is increased. Because of the use of higher speeds, there must be sufficient runway available to use improved climb.



Engines	All	One Engine Inoperative					
Thrust	Takeoff Thrust						Maximum Continuous Thrust
Gear	Down		Retraction		Retracted		
Flaps	Takeoff Flaps					Flaps Retraction	Retracted
Speed	Acceleration			V_2		Acceleration	Final Climb Speed
Gradient				positive	2.4%	1.2%	

Figure 25 – Takeoff Flight Path

3.8.2 Explanation

The FARs require a second segment climb gradient of 2.4%. The second segment of flight starts when the gear goes up and the flaps and thrust are at takeoff settings. The climb gradient (γ) is in proportion to (thrust/weight)/(drag/lift). If the weight is increased then the ratio of (thrust/weight) decreases. To maintain the same gradient, the (drag/lift) ratio must also decrease. The higher V_2 produces the decrease in the ratio of (drag/lift).

3.8.3 Technical Considerations

When using improved climb, remember these things:

- Tire speed and brake energy V_1 restrictions must be met
- Obstacle clearance requirements must be met.
- Field length requirements must be met at the higher speeds.

3.9 Reduced Thrust

3.9.1 Introduction

Many times it is not necessary to takeoff at the maximum takeoff weight. It is not necessary to use the maximum takeoff thrust when you are not at the maximum takeoff weight. The most wear on the engine occurs during takeoff. When you operate at reduced thrust you use less than the full thrust rating of the engine for takeoff. This lowers the temperature of the turbine inlet and increases the engine's life. The results of reduce thrust operation are:

- Increased engine reliability
- Increased airplane dispatch reliability
- Decreased engine operating costs
- Decreased maintenance costs.

There are two ways to get reduced thrust, derate and the assumed temperature method.

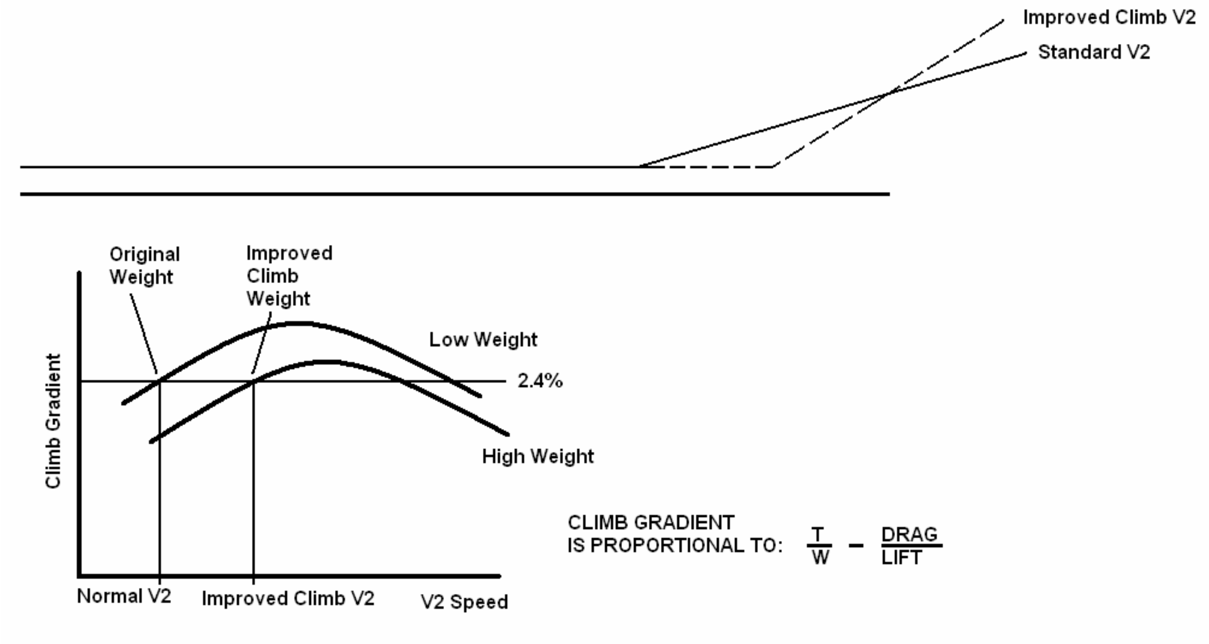


Figure 26 – Improved Climb

3.9.2 Derate

Derate is one way to operate an engine at less than full thrust. When you operate at a derate it is like having a less powerful engine. Because derate is a separate thrust rating, each derate thrust level will have its own set of performance charts in the airplane flight manual. If you operate at a derate the reduced thrust is a new maximum and may not be exceeded.

Derates may be used under any circumstances only if the expected takeoff weight is low enough to permit the use of reduced thrust. When you use derate, all of the performance information is calculated at the lower takeoff thrust. Because of this the V_{mcg} is lower. Derate can be used to increase the performance limited weight if the runway is short or is contaminated with standing water, slush, or ice.

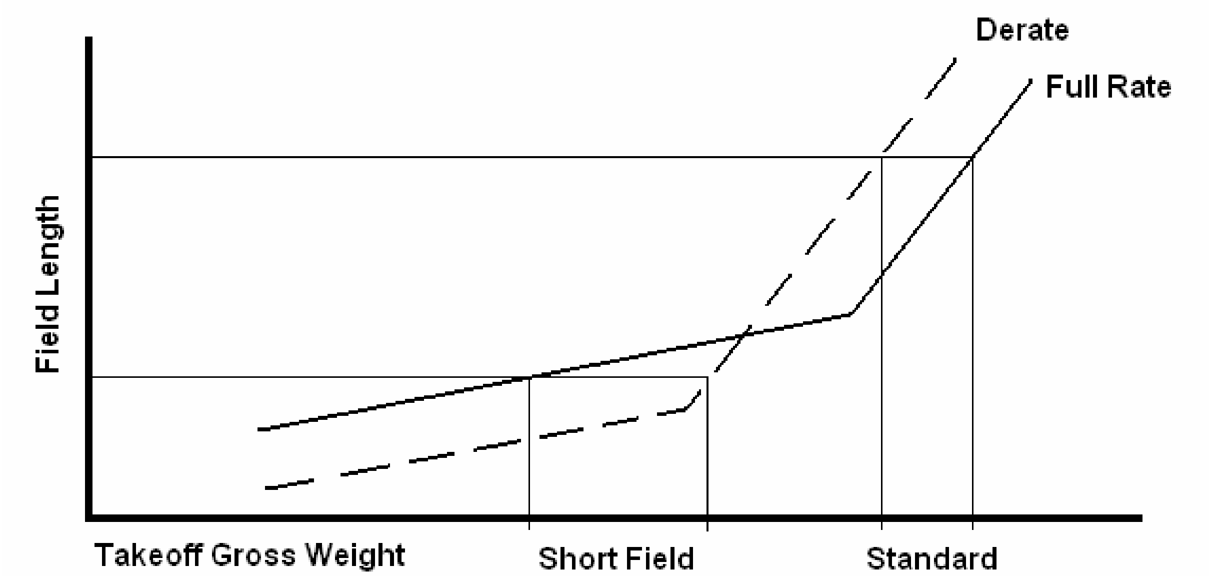


Figure 27 – Derate

3.9.3 Assumed Temperature

As the ambient takeoff temperature increases, the allowable takeoff weight decreases. If the takeoff weight is less than the maximum allowable takeoff weight, you may be able to use the assumed temperature method to reduce the thrust. The assumed temperature method uses the maximum temperature that meets all the takeoff performance requirements at the expected takeoff weight for the planned takeoff runway. These requirements include takeoff distance, climb gradient, and obstacle clearance.

The assumed temperature method is conservative. This is because of the effect of temperature on true airspeed and on engine thrust. The true airspeed will be less than the indicated airspeed because the actual temperature is less than the temperature that is assumed.

Restrictions

There are FAA restrictions on the use of the assumed temperature method. The maximum thrust reduction permitted is 25% from the chosen thrust rating. The minimum control speeds must be calculated at the normal thrust for the actual outside air temperature. This is because the pilot may advance the throttles to the rated takeoff setting. This method is not permitted when the runway is contaminated by water, ice, slush, or snow. Its use is permitted on a wet runway it the airline accounts for the reduced braking performance.
The assumed temperature method may be used with a derate. There are times when you can use assumed temperature and not derate. If the scheduled takeoff weight is less than the performance limited weight at the full thrust rating but higher than the performance limited weight at T01 derate could not be used. However, assumed temperature could be used.

Important Note

The maximum assumed temperature is dependent on:

- Airport
- Runway
- Flap position
- Wind

For example, an assumed temperature that is used for one runway may not be usable for the reciprocal runway because of obstacles or runway slope.

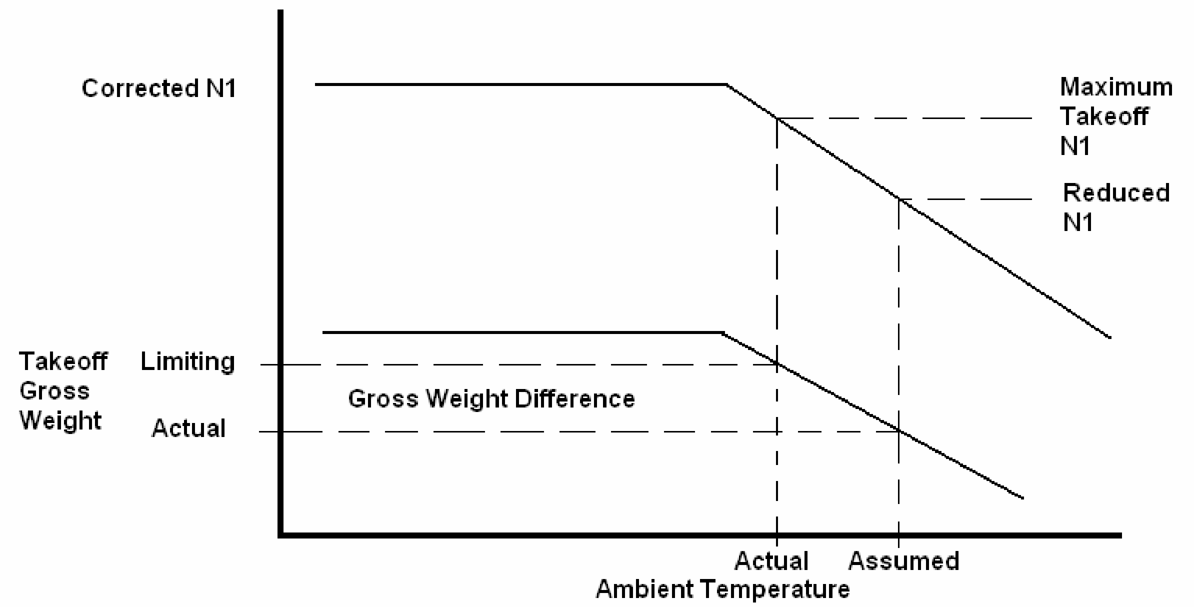


Figure 28 – Assumed Temperature

4 CRUISE PERFORMANCE

4.1 Fuel Requirements

4.1.1 FAA Fuel Requirements

Domestic

FAR 121.639 covers fuel requirements for domestic air carriers for all operations. It states that no person may dispatch or takeoff an airplane unless it has enough fuel:

- To fly to the airport to which it is dispatched
- Thereafter, to fly to and land at the most distant alternate airport (where required) for the airport to which dispatched; and
- Thereafter, to fly for 45 minutes at normal cruising fuel consumption.

International

FAR 121.645 covers turbine powered airplanes, other than turbo propeller, flag and supplemental air carriers and commercial operators. It states for any flag air carrier, supplemental air carrier, or commercial operator, operation outside of the 48 contiguous United States and the District of Columbia, unless authorized by the administrator in the operations specifications, no person may release for flight or takeoff a turbine engine powered airplane, other than a turbo propeller powered airplane, unless, considering wind and other weather conditions expected, it has enough fuel:

- To fly to and land at the airport to which it is released
- 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
- After that, to fly to and land at the most distant alternate airport specified in the flight release, if an alternate is required, and
- After that, to fly for 30 minutes at holding speed at 1500 feet above the alternate airport (or the destination airporl, if no alternate is required) under standard conditions.

4.1.2 ICAO Fuel Requirements

The Internation Civil Aviation Organization (ICAO) gives fuel requirements in annex 6 to the convnetion on international civil aviation, part 1 - international commercial air transport. Section 4, Flight Operations, Subsection 3, Flight Preperation, Paragraph 6, Fuel and Oil Supply contains the following:

4.3.6.1 All aeroplanes. A flight shall not be commenced unless, taking into account both the meteorological conditions and any delays that are expected in flight, the aeroplane carries sufficient fuel and oil to ensure that it can safely complete the flight. In addition, a reserve shall be carried to provide for contingencies.

4.3.6.3 Aeroplanes equiped with turbo-jet engines.

4.3.6.3.2 A) When an alternate aerodrome is required:

To fly to and execute an approach, and a missed approach, at the aerodrome to which the flight is palnned, and thereafter:

- To fly to the alternate aerodrome specified in the flight plan, and then
- To fly for 30 minutes at holding speed at 1500 ft above the alternate aerodrome under standard temperature conditions, and approach and land; and
- To have an additional amount of fuel sufficient to provide for the increased consumption on the occurrence of any of the potential contingencies specified by the operator to the satisfaction of the state of the operator (typically a percentage of the trip fuel – 3% to 6%).

4.2 Altitude Capability and Maneuver Capability

The maximum altitude which an airplane can fly is limited by either the thrust of the engines (Altitude Capability) or by the ability of the wing to generate enough buffet-free lift (Maneuver Capability).

Since the thrust which the engine can generate depends on the temperature, Altitude Capability is also dependent on temperature. Altitude Capability is given for various weights and three different temperatures.

The Maneuver Capability represents the ability of the wing to generate enough lift for the weight of the airplane. To ensure that there is a sufficient safety margin, a "g" limit is normally specified. For a given weight and "g" margin, the Maneuver Capability table shows the maximum altitude at which the airplane can fly.

The "g" margin is also expressed in terms of the level flight bank angle which corresponds to the given "g" loading. For example, an airplane flying in a 39 degree bank while maintaining a level flight altitude will generate a loading of 1.3 g.

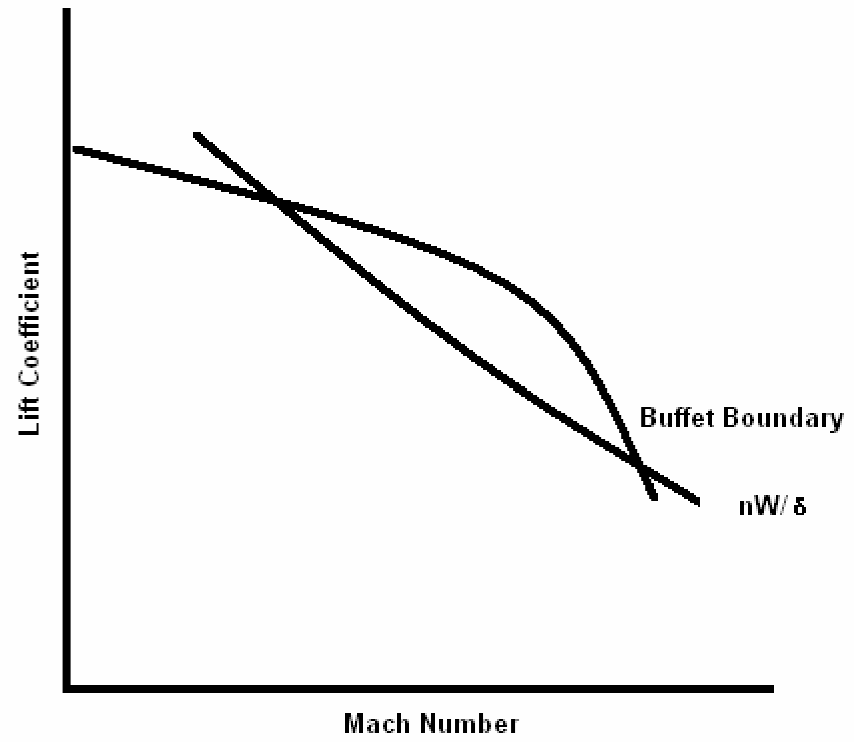


Figure 29 – Buffet Boundary

4.3 Step Climb

There is an optimum altitude to fly a plane at based on its weight. As the weight of a plane changes, so does its optimum altitude. Therefore, as fuel burns during cruise, the optimum altitude changes. In addition, as fuel burns off, the airplane's tendency is to climb.

Typically airlines are not allowed to do a climbing cruise, i.e. allow the airplane to climb as fuel burns off. Rather they must fly at specified altitudes. For this reason a step climb is used.

A step climb starts at an altitude that is above optimum altitude (typically 2000 feet above optimum altitude) and stays at that altitude until it is a given amount under the optimum altitude (again, typically 2000 feet). At this point, the airplane will climb and be above optimum altitude again. The typical climb is 4000 feet to again be 2000 feet above optimum.

This method keeps planes at specified altitudes yet lets planes climb in increments to save fuel.

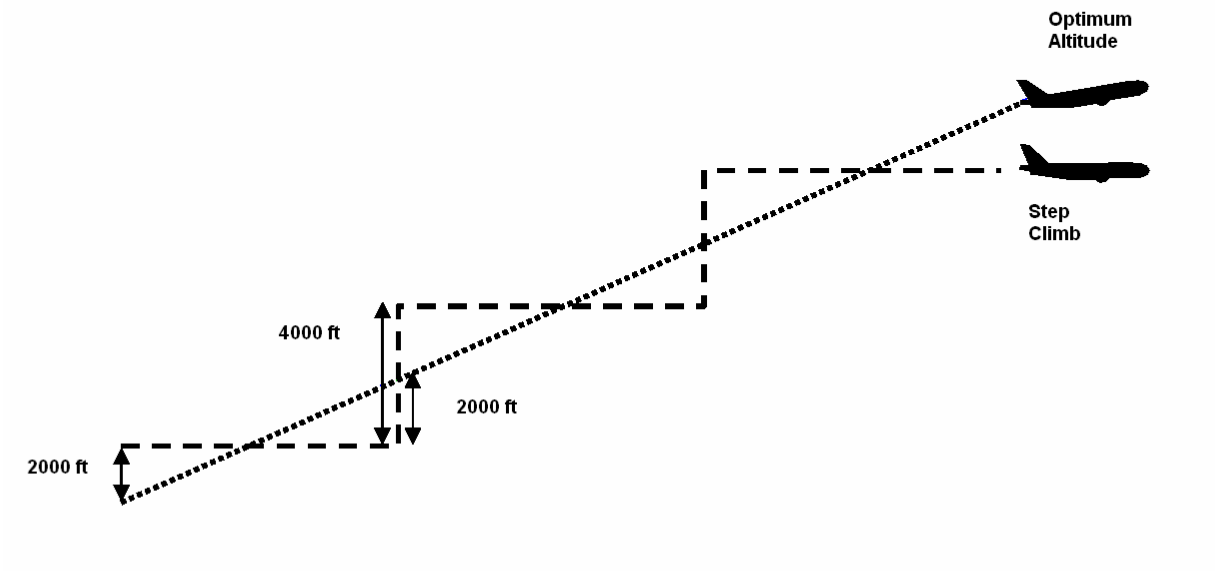


Figure 30 – Step Climb

4.4 Driftdown and Net Level Off Weight

4.4.1 General

If an engine fails in flight, the maximum altitude at which the airplane can fly will be reduced. Regulations require that the airplane be able to clear all terrain by a given amount when an engine falls. The amount of clearance required depends upon whether the terrain can be cleared in level flight with one engine inoperative or while the airplane is descending (drifting down) following an engine failure.

4.4.2 Net Flight Path

For most normal cruise weights and altitudes, an airplane will not be able to maintain its cruise altitude following an engine failure. It will begin to descend. To remain as high a possible, the pilot will use maximum continuous thrust on the remaining engine and slow down to the optimum driftdown speed. The airplane will then descend along what is called the optimum driftdown profile. The optimum driftdown profile will keep the airplane as high as possible during the descent.

Regulations require that the actual airplane performance be calculated in the most conservative airplane configuration and then further decreased by a 1.1 percent climb gradient for two engine airplanes, 1.4 percent for three engine airplanes, and 1.6 percent for four engine airplanes. This reduced gradient is called the enroute net flight path and is used to ensure enroute obstacle clearance.

4.4.3 Driftdown

During the driftdown phase of flight following an engine failure, the airplane must have a net flight path capable of clearing all obstacles within 5 statue miles of the intended flight track by at least 2000 feet vertically.

4.4.4 Level-Off

Following a driftdown, an airplane will level off when it reaches some altitude. This altitude is called the Net Level-Off altitude and depends on the atmospheric temperature and the weight of the airplane. The Net Level-Off altitude must clear all obstacles within 5 statue miles of the intended flight track by at least 1000 feet.

4.4.5 Landing

The net flight path of the airplane must have a positive gradient at 1500 feet above the airport where the airplane intends to land following an engine failure.

4.4.6 Practical

The net flight path is greatly influenced by the weight of the airplane. A maximum enroute weight based on the net flight path is usually determined for the obstacles and temperatures on each route. To ensure enroute obstacle clearance in level flight:

- Determine the maximum enroute weight which will give a net flight path which will clear all obstacles by 1000 feet,
- Compare this weight to the predicted actual weight of the airplane at that point in the flight to ensure obstacle clearance.

For most routes, the Net Level-Off altitude will clear all enroute obstacles and the driftdown profile is not calculated.

For flights over very high terrain, the Net Level-Off weight may be insufficient for the flight. In this case the driftdown profile is calculated for each limiting obstacle, and critical points along the flight track are determined. If an engine failure occurs prior to a critical point, then the flight will have to divert along another route with lower terrain. Flights over these types of high terrain require careful analysis of the various tracks and alternate airports available.

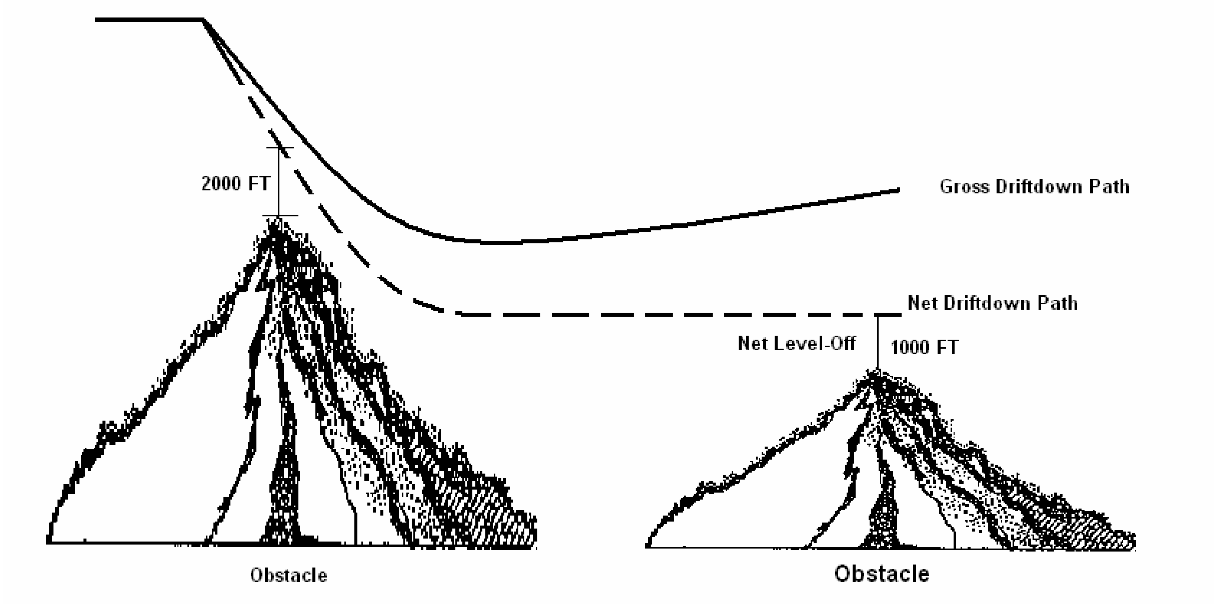


Figure 31 – Driftdown

5 LANDING PERFORMANCE

5.1 Introduction

Landing weights limited by field length and the climb gradient. The maximum landing weight is the lower of these two limiting weights.

5.1.1 Climb Limit

The climb limit weight is the maximum weight that still meets the minimum gradient established by the FARs. For a two engine aircraft the gradient is 2.1% for approach and 3.2% for landing. The conditions for the approach climb gradient are:

- one engine inoperative
- go-around thrust
- approach flaps
- landing gear up.

The conditions for the landing gradient are:

- all engines operative
- go-around thrust
- landing flaps
- landing gear down.

5.1.2 Field Length Limit

The field length limit weight is determined during flight test. For a dry runway the required distance is 167% of the demonstrated stopping distance. For a wet runway the distance required is 115% the dry runway, no reverse thrust, maximum manual braking, from 50 feet above the runway distance.

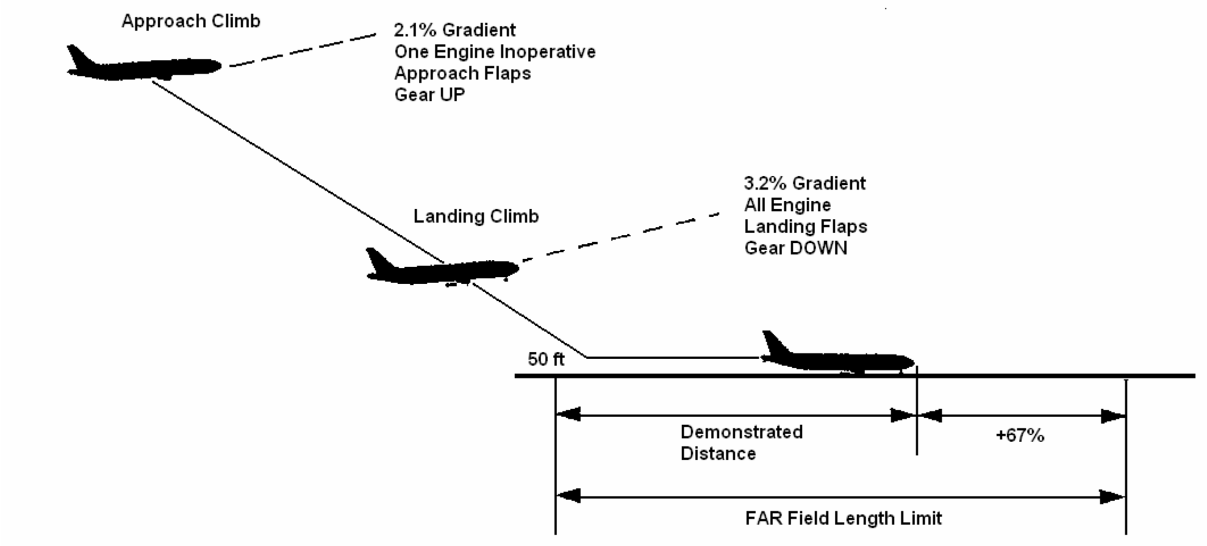


Figure 32 – Approach and Landing Requirements

Number of engines	Segment	
	Approach	Landing
	Minimum Gross Gradient [%]	
2	2.1	3.2
3	2.4	3.2
4	2.7	3.2

Table 3 – FAR Minimum Approach and Landing Climb Requirements

6. PERFORMANCE INFORMATION

The following chapter contains a description of the Performance Information which will be used by the Flight Crew during daily normal operations.

6.1 Performance Data Sources

There are a number of manuals from which the Flight Crew can get information about the airplane performance. These manuals are:

- Airplane Flight Manual (AFM)
- Flight Crew Operations Manual (FCOM)
- Quick Reference Handbook (QRH)
- Flight Planning and Performance Manual (FPPM)
- Operations Manual Part B (OM-B)
- Route Performance Manual (RPM)

AFM

The AFM is the Official Source for Regulatory Performance. It contains the following sections:

- Section 1: Certificate Limitations
- Section 2: Emergency Procedures
- Section 3: Normal and Non-normal Procedures
- Section 4: Performance

FCOM

The primary audience is Flight Crew.

- Volumes 1 and 2 + Quick Reference Handbook (QRH)
- May cover multiple airframes
- May include multiple airframe/engine combinations
- All performance data is in tabular format

Volume 1 contains:

- Revision Record
- List of Effective Pages
- Bulletin Record
- Service Bulletins
- Limitations
- Normal & Supplementary Procedures
- PERFORMANCE DISPATCH (Chapter PD)

Volume 2 contains:

- Systems Information

QRH

Primary crew reference on flight deck

- Quick Action Index (front cover)
- Annunciated Index (EICAS Messages)
- Normal Checklist
- Checklist Introduction
- Non-normal Checklist (by system)
- Maneuvers
- PERFORMANCE INFLIGHT (Chapter PI)
- Index
- Evacuation checklist (back cover)

FPPM
Source of performance information primarily for dispatchers and flight operations engineers. The FPPM is in 8.5 x 11 inch format, and much of the performance is presented in graphs. It contains:

- Takeoff and Landing
- Flight Planning:
  - Simplified flight planning
  - Driftdown
- Enroute:
  - All Engines
  - Engine Inoperative
- Non-standard Configuration:
  - Gear Down

OM-B
The OM-B is the airline produced company flight manual for the Boeing 737-300. It contains in chapter 4 the Performance data and in chapter 5 the Flight Planning data.

RPM
The Route Performance Manual contains the Runway Weight Charts (RWCs) for the regular airports.

6.2 Takeoff Performance

This chapter contains the description of the charts and tables necessary for takeoff performance calculation.
Only those charts and tables which are required during daily operation will be discussed.

6.2.1 Determination of Performance Limited Takeoff Weight

There are four ways for the flight crew to determine the Performance Limited Takeoff Weight:

- With the Airplane Flight Manual (AFM)
- With the Flight Planning and Performance Manual (FPPM)
- With the Route Performance Manual (RPM)
- With chapter PD of FCOM Volume 1

Of those four methods only the last two shall be discussed here. For an explanation of the AFM method refer to appendix 2 of the AFM and for the FPPM method refer to the FPPM.

Route Performance Manual
The RPM contains the Runway Weight Charts (RWC) for the regular airports. RWCs present Performance limited Take-off Weight (PTOW) calculations for the Boeing 737-300 with CFM56-3_22K engines. It is allowed to interpolate in the wind and the temperature as long as all data is for the same flaps setting.

Definitions Used on the RWC's

AD	Name of the airport. Presented along with City name in page header of all RWC's.
AIP	Aeronautical Information Publication.
ASDA	Accelerate-stop distance available. The length of the take-off 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 airplane under the prevailing operating conditions. Presented in page header of all RWC's.
Clearway	Obstacle free surface after the end of TORA used for extending the TODA used in case of continued takeoff.
Damp RWY	A RWY is considered damp when the surface is not dry, but when the moisture on it does not give it a shiny appearance. For performance purposes,

	a damp runway may be considered to be dry.
Dry RWY	A dry RWY is one which is neither wet nor contaminated, and includes those paved RWYs which have been specially prepared with grooves or porous pavement and maintained to retain “effectively dry” braking action even when moisture is present.
Contaminated RWY	A RWY is considered to be contaminated when more than 25% of the RWY surface area (whether in isolated areas or not) within the required length and width being used is covered by the following: Surface water more than 3mm deep, or by slush, or loose snow, equivalent to more than 3mm of water. Snow, which has been compressed into a solid mass which resists further compression and will hold together or break into lumps if picked up (compacted snow). Ice, including wet ice.
Elev	Airport Reference Point elevation. Is presented in page header of all RWC’s.
ICAO	ICAO code of the airport. Presented along with IATA code in page header of all RWC’s.
MTOW	Maximum Takeoff Weight (kg).
PTOW	Performance limited Takeoff Weight (kg).
RWY	RWY denomination or Intersection TKOF position this RWC chart is calculated. Presented in page header of all RWC’s.
Slope	RWY slope (max ±2%), negative - down, positive - up. Presented´in page header of all RMC’s.
Stopway	Extension of the runway with limited runway bearing capacity. Used to extent the ASDA in case of a rejected takeoff.
TODA	The length of the take-off run available plus the length of the clearway available. Presented in page header of all RMC’s.
TORA	Take Off Run Available. The length of a runway which is declared available by the appropriate Authority and suitable for the ground run of an aeroplane taking off. Presented in page header of all RWC’s.
WED	Water Equivalent Depth.
Weight	Weight definition have the same meaning as a Mass for the purpose of Takeoff performance
Wet RWY	A RWY is considered wet when the RWY surface is covered with water, or equivalent, less or equal than 3mm WED or when there is sufficient moisture on the RWY surface to cause it to appear reflective, but without significant areas of standing water.

Airport Data

All airport data used in the calculation is the officially declared distances and are presented as TORA, ASDA, TODA and LDA.
The slope is the difference in elevation between the line-up position and the rwy end divided by the distance. This is a mean slope used for calculations.
Aerodrome elevation is the elevation of the Airport Reference Point. This is used for deciding the general pressure altitude, and is not used for obstacle calculations.
Obstacle data is given as distance from brake release point and height above the runway end, i.e. the end of TORA. When calculating obstacle clearance with TOD shorter than the TODA, the lift-off point will have another altitude than the runway end.

Runway Aligment Penalities

Runway alignment penalties are included. There are three different line-up methods considered:

1) Line-up from behind the take-off position.
   This assumes that the nose wheel is behind the takeoff position.
2) Line-up with 90° entry – Penalty: TORA/TODA –9,2m; ASDA -20,27m.

This assumes that the aircraft arrives from a taxiway perpendicular to the runway and makes a 90-degree turn onto the runway. Note that the taxi runway markings will take the aircraft too far into the runway.

3) Line-up with 180° turn – Penalty: TORA/TODA –14,78m; ASDA -25,85m. This assumes that backtrack with a full 180 degree turn is made.

Engine Failure Procedure

The engine failure procedure / CLP is published in the note in the lower part of the Runway Weight Chart (RWC).

Acceleration Altitude

The standard acceleration altitude of 1 000' AGL ft is used. If any special considerations are in conflict with the standard acceleration height, a non-standard acceleration altitude will be printed in the note on the RWC.

Aircraft Configuration

The aircraft configuration is shown in the header of the RWC. This includes information about:

- T/O Flaps 5, 15 or OPT
- A/I OFF or ON
- Packs ON or OFF
- QNH 1013
- 5 minutes takeoff thrust limitation

Limitation Codes

The takeoff weight presented is based on the following limitations:

Limit code	Limiting factor
F	Field length
O	Obstacle limitation
C	Climb limitation
T	Tire Speed
B	Brake energy
V	V_{mcg} limiting
P	5 min of T/O thrust / Acceleration segment limitation
R	V_2 restriction
**	Improved Climb
-	SCAP Limited

Use of Corrections

The corrections are calculated for each runway.

The corrections are tabulated with a column for each flaps setting used in the Airport Analysis.

Layout

The following page shows a RWC sample.

	Boeing 737-300 / CFM-56-3B-2 Route Performance Manual	Section: 4 Sheet: LEMD Date: Sep 20,08
TORA 12000 FT ASDA 12000 FT TODA 12000 FT LDA 12000 FT	**MADRID** Slope 0% AD Elev 2000 FT **LEMD/MAD 36R**	**Flaps 5** Anti-Ice......OFF A/C..........AUTO

In case of engine failure climb straight ahead.

TAKEOFF – Dry Runway – Max Structural Weight: 63276 kg (All weight in 100 kg)

OAT °C	C	T10	0 (Calm)	H10	H20
66A	392	519F/15-16-22	553F/16-16-22	562F/16-16-22	572F/16-16-22
64A	406	530F/17-18-24	564F/18-18-24	574F/18-18-24	583F/18-18-24
62A	419	541F/19-20-26	575F/20-20-26	585F/20-20-26	595F/20-20-26
60A	432	552F/21-22-28	587F/21-22-28	597F/21-22-28	606F/21-22-28
58A	445	562F/23-24-30	598F/23-24-30	608F/23-24-30	617F/23-24-30
56A	458	572F/24-26-32	608F/25-26-32	618F/25-26-32	628F/25-26-32
54A	472	582F/26-28-34	619F/27-28-34	629F/27-28-34	638F/27-28-34
52A	485	591F/27-30-36	629F/27-30-36	639F/28-30-36	648F/28-30-36
50	497	599F/28-31-38	637F/29-31-38	647F/29-31-38	657F/30-31-38
48	505	605F/30-33-39	644F/30-33-39	653F/30-33-39	663F/31-33-39
46	514	611F/31-34-41	650F/32-34-41	660F/32-34-41	669F/32-34-41
44	522	617F/32-35-42	656F/33-35-42	666F/33-35-42	675F/33-35-42
42	531	623F/33-36-43	662F/34-36-43	672F/34-36-43	682F/34-36-43
40	539	628F/35-38-44	668F/35-38-44	678F/36-3844	688F/36-38-44
38	548	635F/35-39-46	675F/36-39-46	684F/36-39-46	694F/36-39-46
36	557	641F/36-40-47	681F/37-40-47	691F/37-40-47	700F/37-40-47
34	567	647F/37-42-49	687F/38-42-48	697F/38-42-48	707F/38-42-48
32	576	653F/39-43-50	694F/39-43-50	700F/40-43-50	713F/40-43-50
30	585	659F/40-44-51	700F/41-44-51	710F/44-44-51	720F/41-44-51
28	594	665F/41-45-52	707F/42-45-52	717F/42-45-52	727F/42-45-52
26	603	671F/42-47-54	713F/43-47-54	723F/43-47-54	733F/43-47-54
24	604	673F/42-47-54	715F/43-47-54	725F/43-47-54	735F/44-47-54
22	605	675F/42-47-54	717F/43-47-54	727F/43-47-54	737F/44-47-54
20	605	677F/42-47-54	719F/43-47-54	729F/43-47-54	739F/4447-54
18	606	679F/43-47-54	721F/43-47-54	731F/44-47-54	742F/44-47-54
16	606	68IF/43-47-54	723F/44-47-54	733F/44-47-54	744F/44-47-54
12	607	685F/43-47-54	728F/44-47-54	738F/44-47-54	748F/44-47-54
8	608	689F/43-47-54	732F/44-47-54	742F/44-47-54	752F/44-47-54
4	608	694F/43-47-54	736F/44-47-54	747F/44-47-54	757F/44-47-54
2	608	696F/43-47-54	739F/44-47-54	749F/44-47-54	759F/44-47-54
0	609	698F/43-47-54	741F/44-47-54	751F/44-47-54	760F/44-47-54

ENG A/I ON CORR	A/C OFF CORR	**KEY:**
F: -219kg C: -170kg	F: +738kg C: +1400kg	PTOW Limit /V1 VR V2

Limit code: F=Field, O=Obstacle, B=Brakes, T=Tires, V=Vmc, OZ=5 min thrust limit and C=Climb.
JAR-OPS 1 line-up with 90 degr turnaround

Obstacles included in calculation: (Height above runway end / Distance from brake release point)
No obstacles.

Instruction for the Use of the RWC's

a) Enter the RWC at the ambient head or tail wind and OAT. Use interpolation between the given values, if required.

b) Correct for the QNH, if other than 1013:
Subtract the QNH correction from the Takeoff Weight if QNH < 1013.
Add the QNH correction to the Actual Takeoff Weight if QNH > 1013

c) Correct for engine bleed/anti-ice/anti-skid inoperative, if required.

d) Obtain PTOW.

Example

Given:

Wind Component = 5 kts
OAT = 26°C
Normal Bleed Configuration

Find:

Climb Limited Weight (C) = 60300 kg

Field Length Limited Weight (F) = 71800 kg

Maximum Structural Weight (MTOW) = 63279 kg

The maximum takeoff weight is 60300 kg and it is climb limited.

Method of chapter PD of FCOM Volume 1

Chapter PD of FCOM Volume 1 contains self dispatch performance data intended primarily for use by flight crews in the event that information cannot be obtained from the airline dispatch office or from the RWC. The data provided is for a single takeoff flap at max takeoff thrust. The range of conditions covered is limited to those normally encountered in airline operation. In the event of conflict between the data presented in this chapter and that contained in the approved Airplane Flight Manual, the Flight Manual shall always take precedence.

Determination of Performance Limited Takeoff Weight

These tables provide corrections to the field length available for the effects of runway slope and wind component along the runway. Enter the Slope Correction table with the available field length and runway slope to determine the slope corrected field length. Now enter the Wind Correction table with slope corrected field length and wind component to determine the slope and wind corrected field length.

Tables are presented for selected airport pressure altitudes and runway conditions and show both Field and Climb Limit Weights. Enter the appropriate table for pressure altitude and runway condition with "Slope and Wind Corrected Field Length" determined above and airport OAT to obtain Field Limit Weight. Also read Climb Limit Weight for the same OAT. Intermediate altitudes may be interpolated or use next higher altitude.

The Reference Obstacle Limit Weight table provides obstacle limit weights for reference airport conditions based on obstacle height above the runway surface and distance from brake release. Enter the adjustment tables to adjust the reference Obstacle Limit Weight for the effects of OAT, pressure altitude and wind as indicated. In the case of multiple obstacles, enter the tables successively with each obstacle and determine the most limiting weight.

Slope Correction

Field Length Available (ft)	Slope Corrected Field Length (ft)								
	Runway Slope (%)								
	-2.0	-1.5	-1.0	-0.5	0	0.5	1.0	1.5	2.0
4200	4330	4290	4260	4230	4200	4060	3920	3780	3640
4600	4750	4710	4680	4640	4600	4430	4260	4090	3920
5000	5180	5130	5090	5040	5000	4800	4590	4390	4190
5400	5600	5550	5500	5450	5400	5170	4930	4700	4460
5800	6030	5970	5910	5860	5800	5530	5270	5000	4740
6200	6450	6390	6330	6260	6200	5900	5600	5310	5010
6600	6880	6810	6740	6670	6600	6270	5940	5610	5280
7000	7300	7220	7150	7070	7000	6640	6280	5920	5560
7400	7720	7640	7560	7480	7400	7010	6610	6220	5830
7800	8150	8060	7970	7890	7800	7380	6950	6530	6100
8200	8570	8480	8390	8290	8200	7740	7290	6830	6380
8600	9000	8900	8800	8700	8600	8110	7620	7140	6650
9000	9420	9320	9210	9110	9000	8480	7960	7440	6920
9400	9850	9740	9620	9510	9400	8850	8300	7750	7200
9800	10270	10160	10040	9920	9800	9220	8630	8050	7470
10200	10700	10570	10450	10320	10200	9590	8970	8360	7740
10600	11120	10990	10860	10730	10600	9950	9310	8660	8020
11000	11550	11410	11270	11140	11000	10320	9640	8970	8290
11400	11970	11830	11690	11540	11400	10690	9980	9270	8560
11800	12400	12250	12100	11950	11800	11060	10320	9580	8830

Wind Corrections

Slope Corrected Field Length (ft)	Slope & Wind Corrected Field Length (ft)							
	Wind Component (kts)							
	-15	-10	-5	0	10	20	30	40
4200	2280	2920	3560	4200	4400	4610	4840	5080
4600	2640	3290	3950	4600	4810	5030	5270	5510
5000	3000	3670	4330	5000	5220	5450	5690	5940
5400	3370	4050	4720	5400	5630	5870	6120	6370
5800	3730	4420	5110	5800	6040	6290	6540	6800
6200	4090	4800	5500	6200	6450	6700	6970	7230
6600	4460	5170	5890	6600	6860	7120	7390	7660
7000	4820	5550	6270	7000	7270	7540	7820	8090
7400	5190	5920	6660	7400	7680	7960	8240	8530
7800	5550	6300	7050	7800	8090	8380	8670	8960
8200	5910	6670	7440	8200	8500	8790	9090	9390
8600	6280	7050	7830	8600	8910	9210	9520	9820
9000	6640	7430	8210	9000	9320	9630	9940	10250
9400	7000	7800	8600	9400	9730	10050	10370	10680
9800	7370	8180	8990	9800	10130	10460	10790	11110
10200	7730	8550	9380	10200	10540	10880	11220	11540
10600	8090	8930	9760	10600	10950	11300	11640	11970
11000	8460	9300	10150	11000	11360	11720	12070	12400
11400	8820	9680	10540	11400	11770	12140	12490	12840
11800	9180	10060	10930	11800	12180	12550	12920	13270

Takeoff Field & Climb Limit Weights - Dry Runway
Flaps 5
Sea Level Pressure Altitude

Corr Field Length (ft)	Field Length Limited Weight (1000 kg)										
	OAT (°C)										
	-40	14	18	22	24	26	28	30	42	46	50
4600	55.1	50.1	49.8	49.5	49.3	49.2	49.0	48.8	45.8	44.8	43.9
5000	57.3	52.3	51.9	51.6	51.4	51.3	51.1	50.9	47.9	46.9	45.9
5400	59.4	54.3	53.9	53.6	53.4	53.3	53.1	52.9	49.8	48.7	47.7
5800	61.4	56.2	55.8	55.5	55.3	55.1	55.0	54.8	51.6	50.5	49.5
6200	63.3	58.0	57.6	57.3	57.1	56.9	56.7	56.6	53.3	52.2	51.2
6600	65.0	59.6	59.3	58.9	58.8	58.6	58.4	58.2	54.9	53.9	52.8
7000	66.7	61.2	60.9	60.5	60.3	60.2	60.0	59.8	56.4	55.4	54.3
7400	68.2	62.7	62.3	61.9	61.7	61.6	61.4	61.2	57.8	56.7	55.6
7800	69.8	64.1	63.8	63.4	63.2	63.0	62.8	62.6	59.1	58.0	56.9
8200	71.3	65.5	65.2	64.8	64.6	64.4	64.2	64.0	60.5	59.4	58.2
8600	72.7	66.8	66.5	66.1	65.9	65.7	65.5	65.3	61.7	60.6	59.4
9000	74.0	68.1	67.7	67.3	67.1	66.9	66.7	66.5	62.9	61.7	60.5
9400	75.2	69.2	68.8	68.4	68.2	68.0	67.8	67.6	63.9	62.8	61.6
9800	76.0	70.3	69.9	69.5	69.3	69.1	68.9	68.7	65.0	63.8	62.6
10200	76.0	71.4	71.0	70.6	70.4	70.2	70.0	69.8	66.0	64.8	63.6
10600	76.0	72.5	72.0	71.6	71.4	71.2	71.0	70.8	67.0	65.8	64.6
11000	76.0	73.5	73.1	72.7	72.5	72.2	72.0	71.8	68.0	66.7	65.5
Climb Limit	64.4	63.7	63.5	63.5	63.4	63.4	63.3	63.2	57.5	55.7	54.0

2000 FT Pressure Altitude

Corr Field Length (ft)	Field Length Limited Weight (1000 kg)										
	OAT (°C)										
	-40	14	18	22	24	26	28	30	42	46	50
4600	52.1	47.4	47.1	46.8	46.6	46.4	46.0	45.5	42.6	41.7	40.7
5000	54.3	49.5	49.1	48.8	48.7	48.5	48.0	47.5	44.6	43.6	42.7
5400	56.3	51.4	51.1	50.7	50.6	50.4	49.9	49.4	46.4	45.4	44.4
5800	58.3	53.2	52.9	52.6	52.4	52.2	51.7	51.2	48.1	47.2	46.1
6200	60.1	55.0	54.7	54.3	54.1	54.0	53.5	52.9	49.8	48.8	47.8
6600	61.8	56.6	56.3	56.0	55.8	55.6	55.1	54.5	51.4	50.4	49.4
7000	63.4	58.2	57.8	57.5	57.3	57.1	56.6	56.1	52.9	51.8	50.8
7400	64.9	59.5	59.2	58.8	58.7	58.5	57.9	57.4	54.1	53.1	52.0
7800	66.4	61.0	60.6	60.2	60.1	59.9	59.3	58.8	55.4	54.4	53.3
8200	67.8	62.3	62.0	61.6	61.4	61.2	60.7	60.1	56.7	55.6	54.5
8600	69.2	63.6	63.2	62.8	62.6	62.5	61.9	61.3	57.9	56.8	55.7
9000	70.4	64.8	64.4	64.0	63.8	63.6	63.0	62.5	59.0	57.9	56.7
9400	71.6	65.8	65.5	65.1	64.9	64.7	64.1	63.5	60.0	58.9	57.7
9800	72.7	66.9	66.5	66.1	65.9	65.8	65.2	64.6	61.0	59.9	58.7
10200	73.8	68.0	67.6	67.2	67.0	66.8	66.2	65.6	62.0	60.9	59.7
10600	74.9	69.0	68.6	68.2	68.0	67.8	67.2	66.6	62.9	61.8	60.6
11000	76.0	70.0	69.6	69.2	69.0	68.8	68.2	67.5	63.9	62.7	61.5
Climb Limit	61.2	60.6	60.5	60.4	60.4	60.3	59.4	58.5	53.0	51.3	49.7

With engine bleed for packs off, increase field limit weight by 350 kg and climb limit weight by 1000 kg.
With engine anti-ice on, decrease field limit weight by 250 kg and climb limit weight by 200 kg.
With engine and wing anti-ice on, decrease field limit weight by 250 kg and climb limit weight by 825 kg.

Takeoff Obstacle Limit Weight
Flaps 5
Sea Level 30°C & Below, Zero Wind
Based on engine bleed for packs on and anti-ice off

Obs Height (ft)	Reference Obstacle Limit Weight (1000 kg)											
	Distance from Brake Release (1000 ft)											
	8	10	12	14	16	18	20	22	24	26	28	30
10	61.1											
50	55.9	60.7	63.8									
100	52.1	56.5	59.9	62.2	64.3							
150	49.0	53.6	56.8	59.4	61.5	63.1	64.4					
200	46.7	51.2	54.5	57.1	59.2	61.0	62.4	63.5	64.4			
250	44.7	49.1	52.5	55.2	57.3	59.1	60.7	61.9	62.9	63.7	64.4	
300	41.4	47.3	50.7	53.5	55.6	57.4	59.0	60.4	61.5	62.4	63.2	63.8
350		45.8	49.1	51.9	54.1	55.9	57.5	58.9	60.2	61.2	62.0	62.7
400		44.1	47.6	50.4	52.7	54.6	56.2	57.6	58.8	60.0	60.9	61.6
450		40.4	46.3	49.0	51.4	53.4	55.0	56.4	57.6	58.8	59.8	60.6
500			45.1	47.8	50.1	52.1	53.9	55.3	56.5	57.7	58.7	59.6
550			43.9	46.7	49.0	51.0	52.8	54.3	55.5	56.6	57.7	58.6
600			39.9	45.6	47.9	50.0	51.7	53.3	54.6	55.7	56.7	57.7
650				44.6	47.0	49.0	50.8	52.3	53.7	54.8	55.8	56.8
700				43.6	46.1	48.0	49.8	51.4	52.8	54.0	55.0	55.9
750				38.8	45.2	47.2	49.0	50.5	51.9	53.2	54.2	55.2
800					44.2	46.4	48.1	49.7	51.1	52.3	53.5	54.4
850					42.6	45.6	47.3	48.9	50.3	51.6	52.7	53.7
900						44.8	46.6	48.2	49.6	50.8	52.0	53.0
950						44.0	45.9	47.5	48.9	50.1	51.3	52.3
1000						41.6	45.2	46.8	48.2	49.5	50.6	51.7

Obstacle height must be calculated from lowest point of the runway to conservatively account for runway slope.

OAT Adjustments

OAT(°C)	Reference Obstacle Limit Weight (1000 kg)							
	36	40	44	48	52	56	60	64
30&below	0	0	0	0	0	0	0	0
32	-0.5	-0.6	-0.6	-0.7	-0.8	-0.8	-0.9	-1.0
34	-1.0	-1.1	-1.3	-1.4	-1.5	-1.6	-1.8	-1.9
36	-1.5	-1.7	-1.9	-2.1	-2.3	-2.5	-2.7	-2.9
38	-2.0	-2.2	-2.5	-2.8	-3.0	-3.3	-3.5	-3.8
40	-2.5	-2.8	-3.1	-3.5	-3.8	-4.1	-4.4	-4.8
42	-3.0	-3.4	-3.8	-4.2	-4.5	-4.9	-5.3	-5.7
44	-3.5	-4.0	-4.4	-4.9	-5.3	-5.7	-6.2	-6.6
46	-4.0	-4.5	-5.0	-5.6	-6.1	-6.6	-7.1	-7.6
48	-4.5	-5.1	-5.7	-6.3	-6.8	-7.4	-8.0	-8.5
50	-5.1	-5.7	-6.3	-7.0	-7.6	-8.2	-8.8	-9.5

Pressure Altitude Adjustments

Alt	OAT Adjusted Obstacle Limit Weight (1000 kg)							
(ft)	36	40	44	48	52	56	60	64
S.L.&below	0	0	0	0	0	0	0	0
1000	-1.3	-1.5	-1.7	-1.8	-2.0	-2.1	-2.3	-2.4
2000	-2.7	-3.0	-3.3	-3.6	-3.9	-4.2	-4.5	-4.9
3000	-3.9	-4.3	-4.8	-5.2	-5.6	-6.0	-6.5	-6.9
4000	-5.2	-5.7	-6.2	-6.8	-7.3	-7.8	-8.4	-8.9
5000	-6.2	-6.8	-7.5	-8.2	-8.9	-9.6	-10.3	-11.0
6000	-7.1	-8.0	-8.9	-9.7	-10.6	-11.4	-12.3	-13.1
7000	-8.1	-9.2	-10.2	-11.2	-12.2	-13.2	-14.2	-15.2
8000	-9.1	-10.3	-11.5	-12.6	-13.8	-15.0	-16.1	-17.3

Wind Adjustments

Wind	OAT & ALT Adjusted Obstacle Limit Weight (1000 kg)								
(kts)		36	40	44	48	52	56	60	64
15	TW	-8.4	-8.1	-7.9	-7.6	-7.4	-7.1	-6.9	-6.7
10	TW	-5.6	-5.4	-5.3	-5.1	-4.9	-4.8	-4.6	-4.4
5	TW	-2.8	-2.7	-2.6	-2.5	-2.5	-2.4	-2.3	-2.2
	0	0	0	0	0	0	0	0	0
10	HW	0.8	0.7	0.7	0.6	0.5	0.5	0.4	0.3
20	HW	1.6	1.5	1.3	1.2	1.1	0.9	0.8	0.6
30	HW	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0
40	HW	3.3	3.0	2.7	2.5	2.2	1.9	1.7	1.4

With engine bleed for packs off, increase weight by 450 kg.
With engine anti-ice on, decrease weight by 1150 kg.
With engine and wing anti-ice on, decrease weight by 2650 kg.

Example
The following example will illustrate the use of the tables in Chapter PD of FCOM Volume 1:
Given:

Field Length Available (TODA) = 8600 ft
Runway Slope = -0.5%
Wind Component = 5 kts
OAT = 26°C
Pressure Altitude = 0 ft
Obstacle: 22000 ft form brake release at 200 ft height.

Find:

Slope Corrected Field Length = 8700 ft
Slope & Wind Corrected Field Length = 8856 ft
Field Length Limited Weight = 66700 kg

Climb Limted Weight = 63400 kg

Obstacle Limited Weight = 63500 kg
Wind Adjustment for Obstacle Limited Weight = +300 kg
Adjusted Obstacle Limited Weight = 63800 kg

The lowest weight is the Climb Limited Weight

6.2.2 Takeoff Speeds

Takeoff Speeds can be obtained from:

- Runway Weight Chart
- QRH Chapter PI (Performance Inflight)

The speeds presented in the Takeoff Speeds table can be used for all performance conditions provided adjustments are made to V_1 for clearway, stopway, brake deactivation, improved climb, contaminated runway situations, brake energy limits or obstacle clearance with unbalanced V_1. These speeds may be used for weights less than or equal to the performance limited weight.

Normal takeoff speeds, V_1, V_R, and V_2, with anti-skid on, are read from the table by entering with takeoff flap setting, brake release weight, and appropriate column. The appropriate column is obtained by entering the Column Reference chart with the airport pressure altitude and the actual temperature. If an Altitude Adjustment chart is provided, adjust the takeoff speeds appropriately. Slope and wind adjustments to V_1 are obtained by entering the Slope and Wind V_1 Adjustment table.

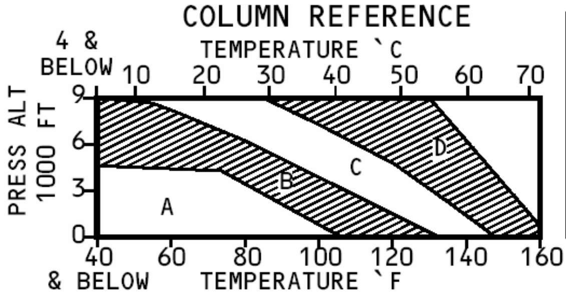
<u>V1(MCG)</u>

Regulations prohibit scheduling takeoff with a V_1 less than minimum V_1 for control on the ground, $V_{1(MCG)}$. Therefore compare the adjusted V_1 to the $V_{1(MCG)}$. To find $V_{1(MCG)}$ enter the $V_{1(MCG)}$ table with the airport pressure altitude and actual OAT. If applicable, add the adjustments shown below the table. If the adjusted V_1 is less than $V_{1(MCG)}$, set V_1 equal to $V_{1(MCG)}$. If V_R is less than $V_{1(MCG)}$, set V_R equal to $V_{1(MCG)}$, and determine a new V_2 by adding the difference between the normal V_R and $V_{1(MCG)}$ to the normal V_2.
If it is necessary to increase V_1 to $V_{1(MCG)}$, then provided the actual field length exceeds the minimum field length of 4500 ft no takeoff weight adjustment is necessary.

6.2.3 Takeoff N1

The Takeoff N1 Table can be found in the QRH section PI.10.11.
To find Max Takeoff %N1 based on normal engine bleed for air conditioning packs on (Auto), enter Takeoff %N1 Table with airport pressure altitude and airport OAT and read %N1. For packs off operation, apply the %N1 adjustment shown below the table. No takeoff %N1 adjustment is required for engine and wing anti-ice.

Takeoff Speed Table



SLOPE/WIND V_1 ADJUSTMENT*						
WEIGHT 1000 KG	SLOPE % DN		UP	WIND KTS TAIL		HEAD
	−2	0	2	−15	0	40
65	−2	0	3	−3	0	1
55	−2	0	2	−3	0	1
45	−2	0	1	−3	0	1
35	−2	0	1	−3	0	1

*V_1 NOT TO EXCEED V_R

FLAPS	WT 1000 KG	A			B			C			D		
		V_1	V_R	V_2	V_1	V_R	V_2	V_1	V_R	V_2	V_1	V_R	V_2
1	65	158	162	168	160	164	168	161	165	168			
	60	149	153	160	152	155	160	153	156	160			
	55	141	144	153	143	146	152	144	147	152	147	150	152
	50	132	134	145	134	137	145	136	138	144	139	140	144
	45	123	125	138	125	127	137	127	129	137	130	131	136
	40	114	116	131	116	118	130	118	120	129	121	122	128
	35	104	107	124	107	109	122	109	110	122	111	113	121
5	65	151	154	160	152	156	160						
	60	143	146	153	145	148	153	146	149	153			
	55	135	137	146	137	140	146	139	141	146			
	50	127	129	139	129	131	139	131	133	139	132	135	139
	45	118	120	132	120	122	132	123	124	132	125	126	131
	40	109	112	126	112	114	125	114	115	124	117	117	123
	35	100	103	119	103	105	118	105	106	117	107	108	116
15	65	144	146	152	145	148	152						
	60	136	138	145	138	140	145						
	55	129	130	139	131	132	139	133	134	138			
	50	121	122	132	123	124	132	125	126	132			
	45	113	114	126	115	116	125	117	118	125	118	119	125
	40	104	106	120	106	108	119	108	109	118	110	111	118
	35	96	98	113	97	99	112	100	101	112	102	103	111

CHECK V1(MCG).

V1(MCG) Table

ACTUAL OAT		PRESS ALT FT					
`C	`F	−1000	0	2000	4000	6000	8000
55	131	106	105	99			
50	122	108	107	103			
40	104	113	111	107	103	99	94
30	86	116	116	111	107	103	99
20	68	117	116	113	111	107	102
10	50	117	116	113	111	108	104
−50	−58	118	118	115	112	109	105

FOR A/C OFF INCREASE V_1(MCG) BY 2 KNOTS.

Takeoff %N1
Based on engine bleed to packs on (Auto) and anti-ice on or off

Airport OAT		Airport Pressure Altitude (ft)									
°C	°F	-1000	0	1000	2000	3000	4000	5000	6000	7000	8000
55	131	93.2	93.8	93.8	93.8						
50	122	93.8	94.3	94.3	94.3	93.9	93.6				
45	113	94.2	94.7	94.7	94.6	94.6	94.6	94.7	94.4	94.2	
40	104	94.6	95.2	95.2	95.1	95.0	95.1	95.1	95.2	95.1	94.9
35	95	95.2	95.6	95.6	95.6	95.5	95.7	95.7	95.7	95.6	95.5
30	86	95.2	96.1	96.1	96.0	96.0	96.3	96.2	96.1	96.0	96.0
25	77	94.4	95.3	95.8	96.2	96.5	96.7	96.6	96.6	96.5	96.4
20	68	93.6	94.5	95.0	95.4	95.9	96.6	97.1	97.1	97.0	96.9
15	59	92.8	93.7	94.2	94.6	95.1	95.8	96.3	96.8	97.2	97.5
10	50	92.0	92.9	93.4	93.8	94.2	95.0	95.4	95.9	96.4	96.8
5	41	91.2	92.1	92.5	92.9	93.4	94.1	94.6	95.1	95.5	96.0
0	32	90.3	91.2	91.7	92.1	92.6	93.3	93.7	94.2	94.7	95.1
-10	14	88.7	89.6	90.0	90.4	90.8	91.5	92.0	92.5	92.9	93.4
-20	-4	87.0	87.8	88.3	88.7	89.1	89.8	90.2	90.7	91.1	91.6
-30	-22	85.2	86.0	86.5	86.9	87.3	88.0	88.4	88.9	89.3	89.7
-40	-40	83.5	84.3	84.7	85.1	85.5	86.2	86.6	87.1	87.4	87.9
-50	-58	81.7	82.5	82.9	83.2	83.7	84.3	84.7	85.2	85.6	86.0

%N1 Adjustments for Engine Bleeds
PACKS OFF 1.0%

6.2.4 Reduced Thrust

Regulations permit the use of up to 25% takeoff thrust reduction for operation with assumed temperature reduced thrust. To find the maximum allowable assumed temperature enter table 1 with airport pressure altitude and OAT.

Compare this temperature to that at which the airplane is performance limited as determined from available takeoff performance data.

Next, enter center table 2 with airport pressure altitude and the lower of the two temperatures previously determined to obtain a maximum takeoff %N1.

Do not use an assumed temperature less than the minimum assumed temperature shown. Enter the %N1 Adjustment table with OAT and the difference between the assumed and actual OAT to obtain a %N1 adjustment. Subtract the %N1 adjustment from the maximum takeoff %N1 found previously to determine the assumed temperature reduced thrust %N1.

Takeoff with assumed temperature reduced thrust is not permitted when:

- runway is contaminated with ice, slush, snow, or standing water;
- anti-skid is inoperative; or
- PMC is off.

Use of this procedure is not recommended if potential windshear conditions exist.

Assumed Temperature Reduced Thrust

Maximum Assumed Temperature (Table 1)

Based on 25% Takeoff Thrust Reduction

OAT (°C)	PRESS ALT (1000 FT)										OAT (°F)	PRESS ALT (1000 FT)									
	-1	0	1	2	3	4	5	6	7	8		-1	0	1	2	3	4	5	6	7	8
55	74	71	71								130	165	159	159							
50	71	69	68	68	69	70					120	160	155	154	154	155	157				
45	69	67	66	66	67	67	67	68	70		110	155	151	149	149	150	151	151	152	155	
40	67	65	64	64	64	64	64	64	66	68	100	151	148	145	145	145	145	147	145	149	151
35	65	63	62	62	62	61	61	62	63	64	90	146	143	141	141	140	140	140	140	143	144
30	63	61	60	60	59	59	59	59	60	61	80	146	142	139	138	136	135	135	135	137	138
25	63	61	59	58	57	56	56	56	57	58	70	146	142	138	136	135	131	129	129	130	132
20	63	61	59	58	57	55	53	54	54	55	60	146	142	138	136	135	131	127	127	126	126
15 & BELOW	63	61	59	58	57	55	53	53	52	52	50 & BELOW	146	142	138	136	135	131	127	127	126	126

Maximum Takeoff %N1 (Table 2)

Based on engine bleed to packs on (Auto) and engine anti-ice on or off

ASSUMED TEMP		AIRPORT PRESSURE ALTITUDE (FT)									
°C	°F	-1000	0	1000	2000	3000	4000	5000	6000	7000	8000
75	167	86.0	85.4	85.4							
70	158	87.8	87.6	87.4	87.4	87.6					
65	149	89.7	89.7	89.4	89.2	89.2	89.2	89.3	89.5	89.9	90.4
60	140	91.6	91.8	91.3	91.0	90.8	90.7	90.7	90.8	91.1	91.4
55	131	93.1	93.8	93.2	92.7	92.4	92.1	92.1	92.0	92.1	92.3
50	122	93.7	94.3	94.3	94.3	93.9	93.6	93.4	93.2	93.2	93.2
45	113	94.0	94.7	94.7	94.6	94.6	94.6	94.7	94.4	94.2	94.0
40	104	94.4	95.2	95.2	95.1	95.0	95.1	95.1	95.2	95.1	94.9
35	95	95.0	95.6	95.6	95.6	95.5	95.7	95.7	95.7	95.6	95.5
30	86	95.2	96.1	96.1	96.0	96.0	96.3	96.2	96.1	96.0	96.0
25	77	94.4		96.6	96.5	96.5	96.7	96.6	96.6	96.5	96.4
20	68	93.6					97.1	97.1	97.1	97.0	96.9
15	59	92.8							97.6	97.5	97.5
MINIMUM ASSUMED TEMP °C (°F)		32(90)	30(86)	28(82)	26(79)	24(75)	22(72)	20(68)	18(64)	16(61)	15(59)

With engine bleed to packs off, increase %N1 by 1.0.

%N1 Adjustment For Temperature Difference (Table 3)

ASSUMED TEMP MINUS OAT		OUTSIDE AIR TEMPERATURE														
°C	°F	°C	-40	-20	0	5	10	15	20	25	30	35	40	45	50	55
		°F	-40	-4	32	41	50	59	68	77	86	95	104	113	122	131
10	18							1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.4	1.4
20	36				3.3	3.2	3.2	3.1	3.0	3.0	2.9	2.8	2.8	2.7	2.5	2.3
30	54				4.8	4.8	4.6	4.5	4.4	4.3	4.0	3.8	3.6	3.6	3.6	3.6
40	72			6.0	6.2	6.1	6.0	5.8	5.7	5.2	5.0	5.0				
50	90			8.2	7.5	7.3	7.2	6.6	6.5							
60	108		10.4	9.5	8.7	8.1	7.9									
70	126		11.8	10.7	9.3											
80	144		13.0	11.8	10.1											
90	162		14.0	12.4												
100	180		15.0	12.8												
110	198		15.4													

1. **Determine Maximum Assumed Temperature allowed from Table 1.**
2. **Find Maximum %N1 from Table 2 using the desired assumed temperature (no greater than temperature from Table 1).**
3. **Use the difference between assumed temperature and OAT to determine the %N1 adjustment from Table 3.**
4. **Subtract %N1 adjustment from Maximum %N1 in Table 2.**

Example
Find the Reduced Thrust for the following conditions:
Airport = Madrid Runway 36R
Zero Wind
OAT = 18°C
Actual Takeoff Gross Weight = 56500 kg

Solution
Enter Runway Weight Chart with Actual Gross Weight and find in the OAT column TASS = 34°C.

Enter table 1 and find Maximum Assumed Temperature of 58°C. Use the lower temperature (34°C) for further calculations.

From table 2 find Maximum N1 which is 95.6%.

Enter table 3 with Actual OAT (18°C) and the difference between TASS and OAT (16°C) and obtain N1 Adjustment: 3.1%

The Reduced Takeoff N1 is: 92.5%

6.3 Flight Planning and Enroute Performance

6.3.1 Trip Fuel

General
Fuel for the flight is determined as an amount to fulfil the minimum requirements set in JAR-OPS and any extra fuel requested by the Commander.

The flight shall not be started with fuel on board below Minimum Required, which is calculated as sum of Taxi Fuel, Trip Fuel, Contingency Fuel, Alternate or Minimum Additional Fuel (depended on Flight Planning Rule used) and Final Reserve Fuel.

NOTE: 1. For explanation of fuel terms see OM Part A Chapter 8.1.7
2. The crew in case of in-flight re-planning must apply the same system of minimum required fuel calculation.

Extra fuel, upon Commander's discretion, shall provide safety, punctuality and economical efficiency of the flight, taking into account weight limitations, weather, traffic situation, time available, etc.

NOTE: Economy tankage (if available) should be adhered to, but shall never be in conflict with the safety and punctuality of the flight.
Pre-flight precise fuel calculations for particular aircraft / weather conditions are presented in EFP Operational Flight Plan.

Minimum Required Fuel and Trip Time Calculation for planning/re-planning purposes.
The following information is given to make Minimum Required fuel calculation easier for pilots on the planning/re-planning stage. The same procedure can be used when EFP Flight Plan calculation is not available

1) Taxi Fuel ....200 kg

2) Trip Fuel:
The table below shows time and fuel needed for sector distances in still air.
Select actual route including longest SID and STAR for sector distance calculation. To correct an actual sector distance for wind component use following formula:

$$\text{Air Distance} = \frac{\text{Sector Distance} \times \text{TAS}}{\text{GS}}$$

Air distance tables are also available in the Performance In-flight chapter of the QRH.
For Trip fuel see "Trip Fuel and Time Required" tables shown below.

3) Contingency Fuel...................................... 5% of Trip Fuel or 5 min at holding fuel consumption, whichever gives the highest result.

4) Alternate Fuel: For rough alternate fuel calculation use the trip fuel table.

5) Final Reserve Fuel: 30 min of flight at holding fuel consumption For final reserve fuel see Holding Planning Flaps Up table shown below.

<u>Evaluation of fuel required for flight</u>
To evaluate fuel required for flight, follow the below mentioned steps:

Step 1
ZFW + Extra Fuel (if required) → Holding Planning Table → Min Reserve Fuel
(Pressure altitude = Pressure altitude of alternate + 1500 ft)

Step 2
$LW_{AT\ ALTERNATE}$ = ZFW + Min Reserve Fuel + Extra Fuel
$LW_{AT\ ALTERNATE}$ → Trip Fuel and Time Table → Alternate Fuel

Step 3
$LW_{AT\ DESTINATION}$ = $LW_{AT\ ALTERNATE}$ + Alternate Fuel + Contingency Fuel (5 minutes at holding fuel consumption)
$LW_{AT\ DESTINATION}$ → Trip and Time Table → Trip Fuel

Step 4
Contingency Fuel = 5% of Trip Fuel
If 5% of Trip Fuel is more than 5 minutes at holding fuel consumption go to Step 3 and use new Contingency Fuel to determine $LW_{AT\ DESTINATION}$.

Step 5
TO Fuel = Trip + Contingency + Alternate + Min reserve + Extra Fuel

Step 6
Block Fuel = TO Fuel + Taxi Fuel

<u>Example</u>
Calculate the Takeoff Fuel for the following conditions:
ZFW = 48000 kg
Extra Fuel = 0 kg
Alternate Elevation = 0ft
Alternate Distance = 150 NAM
Segment Distance = 1200 NAM at Flight Level 330

<u>Find</u>
Holding Fuel = 1135 kg. $LW_{AT\ ALTERNATE}$ = ZFW + Min Reserve Fuel + Extra Fuel = 49135 kg.

Alternate Fuel = 1300 kg. $LW_{AT\ DESTINATION}$ = $LW_{AT\ ALTERNATE}$ + Alternate Fuel + Contingency Fuel = 50624 kg.

Trip Fuel from table = 6400 kg, and Adjustment for LW = +400 kg. Trip Fuel = 6800 kg

<u>Summary</u>

Holding Fuel	=	1135 kg	00:30
Alternate Fuel	=	1300 kg	00:30
Trip Fuel	=	6800 kg	02:59
Contingency Fuel	=	340 kg	00:09
TAKEOFF FUEL	=	9575 kg	04:08
Taxi Fuel	=	200 kg	
BLOCK FUEL	=	9775 kg	

Trip Fuel and Time

Air Dist NM	Pressure Altitude (feet)							
	29000		31000		33000		37000	
	FUEL 1000 KG	TIME HR:MIN	FUEL 1000 KG	TIME HR:MIN	FUEL 1000 KG	TIME HR:MIN	FUEL 1000 KG	TIME HR:MIN
200	1.5	00:38	1.5	00:38	1.5	00:38	1.5	00:38
400	2.6	01:06	2.5	01:06	2.5	01:06	2.4	01:06
600	3.6	01:35	3.5	01:34	3.5	01:33	3.4	01:34
800	4.7	02:03	4.6	02:02	4.5	02:01	4.3	02:02
1000	5.8	02:31	5.7	02:30	5.5	02:29	5.3	02:30
1200	6.9	02:59	6.7	02:57	6.6	02:57	6.4	02:59
1400	8.0	03:27	7.8	03:25	7.6	03:25	7.4	03:27
1600	9.2	03:54	8.9	03:52	8.7	03:52	8.5	03:55
1800	10.3	04:22	10.0	04:20	9.8	04:20	9.5	04:23
2000	11.5	04:49	11.2	04:47	10.9	04:48	10.6	04:51
2200	12.7	05:17	12.3	05:15	12.0	05:16	11.8	05:19
2400	13.9	05:44	13.5	05:43	13.1	05:43	13.0	05:47
2600	15.1	06:11	14.7	06:10	14.3	06:11		
2800	16.3	06:39	15.9	06:38	15.5	06:39		
3000	17.6	07:06	17.0	07:05	16.6	07:07		
3200	18.8	07:33	18.3	07:33	17.9	07:35		
3400	20.1	08:01	19.5	08:00	19.1	08:02		

Fuel Required Adjustments (1000 kg)

Reference Fuel Required (1000 kg)	Landing Weight (1000 kg)				
	30	35	40	45	50
2	-0.3	-0.2	-0.1	0.0	0.1
4	-0.6	-0.4	-0.2	0.0	0.2
6	-0.9	-0.6	-0.3	0.0	0.4
8	-1.2	-0.8	-0.4	0.0	0.5
10	-1.5	-1.0	-0.5	0.0	0.7
12	-1.8	-1.2	-0.6	0.0	0.9
14	-2.1	-1.5	-0.7	0.0	1.1
16	-2.5	-1.7	-0.8	0.0	1.3
18	-2.8	-1.9	-1.0	0.0	1.6
20	-3.1	-2.1	-1.1	0.0	1.8
22	-3.4	-2.3	-1.2	0.0	2.1

Based on 280/.74 climb, Long Range Cruise speed and .74/250 descent.

Short Trip Fuel and Time Required

Air Distance (NM)		Landing Weight (1000 kg)					Time
		30	35	40	45	50	HR:MIN
50	FUEL (1000 kg)	0.5	0.6	0.6	0.6	0.7	00:14
	ALT (ft)	13000	13000	11000	11000	11000	
100	FUEL (1000 kg)	0.8	0.8	0.9	0.9	1.0	00:22
	ALT (ft)	25000	23000	23000	21000	19000	
150	FUEL (1000 kg)	1.0	1.1	1.2	1.2	1.3	00:30
	ALT (ft)	35000	33000	31000	29000	27000	
200	FUEL (1000 kg)	1.2	1.3	1.4	1.5	1.6	00:37
	ALT (ft)	37000	37000	37000	35000	33000	
250	FUEL (1000 kg)	1.4	1.5	1.6	1.7	1.8	00:45
	ALT (ft)	37000	37000	37000	37000	35000	
300	FUEL (1000 kg)	1.6	1.7	1.8	1.9	2.1	00:52
	ALT (ft)	37000	37000	37000	37000	35000	
350	FUEL (1000 kg)	1.8	1.9	2	2.2	2.3	00:58
	ALT (ft)	37000	37000	37000	37000	35000	
400	FUEL (1000 kg)	2.0	2.1	2.2	2.4	2.6	01:05
	ALT (ft)	37000	37000	37000	37000	35000	
450	FUEL (1000 kg)	2.1	2.3	2.5	2.6	2.9	01:13
	ALT (ft)	37000	37000	37000	37000	35000	
500	FUEL (1000 kg)	2.3	2.5	2.7	2.9	3.1	01:20
	ALT (ft)	37000	37000	37000	37000	35000	

Based on 280/.74 climb, Long Range Cruise speed and .74/250 descent.

Holding Planning

Flaps Up

GW	Total Fuel Flow (kg/h)								
1000	Pressure Altitude (ft)								
kg	1500	5000	10000	15000	20000	25000	30000	35000	37000
64	2870	2830	2780	2730	2700	2690	2680		
62	2800	2740	2700	2650	2610	2610	2590		
60	2720	2660	2620	2570	2530	2520	2500		
58	2640	2590	2540	2490	2450	2440	2420		
56	2570	2510	2460	2410	2370	2360	2330	2380	
54	2490	2430	2380	2330	2290	2280	2250	2270	
52	2420	2360	2310	2250	2210	2190	2170	2180	
50	2340	2280	2230	2170	2130	2110	2090	2080	2120
48	2270	2210	2150	2100	2050	2030	2000	2000	2020
46	2200	2130	2080	2020	1970	1960	1920	1920	1930
44	2130	2060	2010	1940	1900	1880	1840	1840	1850
42	2070	2010	1950	1890	1830	1800	1770	1760	1770
40	2010	1950	1900	1830	1780	1750	1700	1690	1700
38	1970	1910	1850	1780	1720	1690	1650	1630	1640
36	1920	1860	1800	1740	1680	1640	1600	1580	1590

This table includes 5% additional fuel for holding in a racetrack pattern.

6.3.2 Enroute Performance

To ensure a safe flight over the mountainous terrain, the flight must be planned in such a way, that in case of engine failure, the aircraft can clear the most critical terrain en route with acceptable safety margins.

Climb

There is no problem with all engines operative to reach and maintain the minimum safe altitude with the maximum take-off weight even in the worst ISA + 20 conditions.
For one engine inoperative climb, after flap retraction and all obstructions are cleared, on the FMC ACT ECON CLB page select ENG OUT prompt and the FMC calculates for the actual gross weight:

- N1 for maximum continuous thrust;
- Maximum altitude, and
- Climb speed.

If appropriate FMC page is not available, use V_{CLEAN} or approx 210Kts and check Long Range Cruise Altitude Capability with 100ft/min residual rate of climb (QRH PI.13.7).

Long Range Cruise Altitude Capability

100 ft/min residual rate of climb

Weight (1000 kg)	Pressure Altitude (ft)		
	ISA + 10°C & below	ISA + 15°C	ISA + 20°C
64	9500	7200	4900
60	12300	10200	7900
56	15200	13200	11000
52	18000	16200	14100
48	20900	19200	17400
44	24000	22300	20600
40	27000	25600	24000
36	30000	28800	27500
32	33200	32200	31000

With engine anti-ice on, decrease altitude capability by 1400ft.
With engine and wing anti-ice on, decrease altitude capability by 5300ft.

NOTE: Planning operations in mounting area on aerodromes/routes where the climb performance is critical, the sec. 4.11 of AFM to be consulted.

Driftdown
If an engine failure occurs during cruise/descent, on FMC CRZ page select ENG OUT prompt and the FMC calculates for the actual gross weight:

- N1 for maximum continuous thrust;
- Maximum altitude, and
- Descent speed.

If appropriate FMC page is not available, use V_{CLEAN} or approx 210Kts and check Drift–down Level off altitudes with 100 ft residual rate of climb table (QRH, PI.13.5).

Driftdown Speed/Level Off Altitude

100 ft/min residual rate of climb

Weight (1000 kg)		Optimum Driftdown Speed (KIAS)	Level Off Altitude (1000 ft)		
Start Driftdown	Level Off		ISA + 10°C & below	ISA + 15°C	ISA + 20°C
64	61	235	16200	15000	13600
60	57	228	18200	17200	15900
56	53	220	20400	19300	18200
52	49	212	22700	21700	20600
48	46	204	25100	24100	23100
44	42	196	27400	26600	25700
40	38	187	29900	29200	28400

Includes APU fuel burn

6.4 Landing Performance

6.4.1 General

Maximum Landing Weight (MLW) could be limited either by:

- Maximum certified structural landing weight;
- Aircraft performance
  - Landing weight field limit weight;
  - Climb limit weight (approach and landing climb, go-around climb for Low Visibility instrument approaches).

The most limiting of these requirements defines the maximum allowable landing weight for dispatch.

Presentation

Landing performance is presented in a way of diagrams or tables in AFM and QRH.
For planning purposes the following criteria must be fulfilled:

- Be able to land on the expected runway in expected wind and runway conditions.
- Be able to land on the longest runway in zero wind conditions;
- When gusty winds are forecasted, average wind speed plus 50% of the gust factor shall be used.

6.4.2 Landing field limit weight

General

The Landing field limit weight is the maximum weight for which the landing distance available (LDA) is equal to the landing distance required (LDR).
DRY runway LDR is the flight test demonstrated landing distance plus an additional margin of 67%.
WET runway LDR is a "dry runway LDR" increased further by an additional margin of 15%.
CONT/LOW FRICTION runway – same as wet.
The performance is based on the weather/runway conditions and the following assumptions:

- Engines Idle on all engines before touch down
- Wing flaps Landing setting
- Landing Gear Down
- Speed brake Selected After Touchdown
- Wheel Brakes Full Braking with Anti-skid ON
- Runway Paved Runway
- Airspeed VREF
- Reverse Not used

The following considerations do not directly accounted but protected by the margins used to define the LDR:

- Runway slope
- Non-standard temperature
- Approach speed.

NOTE: For more detailed information refer to FCOM, Performance Dispatch, Landing and Flight Planning and Performance Manual, Landing, Landing Field Length Limit 1.3.1.

Landing Landing Field Limit Weight - Dry Runway Flaps 30

Anti-skid Operative and Automatic Speedbrakes
Category "A" Brakes
Wind Corrected Field Length (ft)

Field Length (ft)	Wind Component (kts)							
	-15	-10	-5	0	10	20	30	40
3000			2690	3000	3210	3400	3600	3780
3400		2790	3070	3400	3620	3830	4040	4240
3800	2880	3130	3440	3800	4030	4260	4480	4700
4200	3190	3470	3810	4200	4440	4680	4920	5160
4600	3510	3820	4180	4600	4850	5110	5360	5620
5000	3830	4160	4550	5000	5270	5530	5800	6080
5400	4140	4500	4920	5400	5680	5960	6250	6540
5800	4460	4850	5290	5800	6090	6380	6690	6990
6200	4780	5190	5660	6200	6500	6810	7130	7450
6600	5090	5530	6030	6600	6910	7240	7570	7910
7000	5410	5880	6400	7000	7330	7660	8010	8370
7400	5730	6220	6780	7400	7740	8090	8450	8830
7800	6050	6560	7150	7800	8150	8510	8890	9290
8200	6360	6910	7520	8200	8560	8940	9330	9750
8600	6680	7250	7890	8600	8970	9370	9780	10210
9000	7000	7590	8260	9000	9380	9790	10220	10670
9400	7310	7940	8630	9400	9800	10220	10660	11120
9800	7630	8280	9000	9800	10210	10640	11100	
10200	7950	8620	9370	10200	10620	11070		
10600	8270	8970	9740	10600	11030			

Field Limit Weight (1000 kg)

Wind Corr Field Length (ft)	Airport Pressure Altitude (ft)				
	0	2000	4000	6000	8000
3400	36.4	34.4			
3800	41.8	39.4	37.3	35.1	
4200	47.1	44.5	42.1	39.6	37.6
4600	51.8	49.3	46.9	44.2	41.9
5000	55.3	53.4	51.2	48.7	46.2
5400	58.3	56.5	54.6	52.6	50.2
5800	61.1	59.2	57.3	55.5	53.6
6200	63.7	61.8	59.9	58.0	56.1
6600	66.2	64.2	62.1	60.2	58.3
7000		66.2	64.1	62.1	60.2
7400			65.9	63.9	61.9
7800			67.7	65.6	63.6
8200				67.3	65.2
8600					66.7

Decrease field limit weight by 7700 kg when using manual speedbrakes.

Landing Landing Field Limit Weight - Wet Runway
Flaps 40

Anti-skid Operative and Automatic Speedbrakes
Category "A" Brakes
Wind Corrected Field Length (ft)

Field Length (ft)	Wind Component (kts)							
	-15	-10	-5	0	10	20	30	40
3000				3000	3220	3440	3640	3830
3400			3050	3400	3640	3860	4080	4290
3800		3110	3420	3800	4050	4290	4520	4750
4200	3170	3450	3790	4200	4460	4710	4960	5210
4600	3490	3790	4170	4600	4870	5140	5410	5670
5000	3810	4140	4540	5000	5280	5570	5850	6130
5400	4120	4480	4910	5400	5690	5990	6290	6590
5800	4440	4820	5280	5800	6110	6420	6730	7050
6200	4760	5170	5650	6200	6520	6840	7170	7500
6600	5070	5510	6020	6600	6930	7270	7610	7960
7000	5390	5860	6390	7000	7340	7690	8050	8420
7400	5710	6200	6760	7400	7750	8120	8490	8880
7800	6030	6540	7130	7800	8170	8550	8940	9340
8200	6340	6880	7500	8200	8580	8970	9380	9800
8600	6660	7230	7880	8600	8990	9400	9820	10260
9000	6980	7570	8250	9000	9400	9820	10260	10720
9400	7290	7920	8620	9400	9810	10250	10700	11180
9800	7610	8260	8990	9800	10230	10670	11140	11630
10200	7930	8600	9360	10200	10640	11100	11580	12090
10600	8250	8940	9730	10600	11050	11530	12030	12550

Field Limit Weight (1000 kg)

Wind Corr Field Length (ft)	Airport Pressure Altitude (ft)				
	0	2000	4000	6000	8000
3800	35.2				
4200	39.8	37.6	35.5		
4600	44.4	42.0	39.7	37.4	35.4
5000	48.9	46.4	43.9	41.3	39.2
5400	52.7	50.4	48.0	45.3	42.9
5800	55.6	53.8	51.6	49.1	46.6
6200	58.2	56.4	54.6	52.5	50.2
6600	60.7	58.8	56.9	55.1	53.2
7000	63.0	61.1	59.2	57.3	55.4
7400	65.2	63.2	61.2	59.3	57.4
7800	67.3	65.1	63.1	61.1	59.1
8200		66.8	64.7	62.7	60.7
8600			66.3	64.2	62.3
9000			67.8	65.7	63.7
9400				67.2	65.1
9800					66.4
10200					67.7

Decrease field limit weight by 7700 kg when using manual speedbrakes.

6.4.3 Climb Limit Weight

Climb performance limits for landing ensure a minimum climb gradient capability in the certified approach and landing configurations in case of goaround becomes necessary at any point during the landing approach.

Approach and landing climb limit weight accounts for:

- Airport temperature
- Airport pressure altitude
- Engine bleed
- Icing conditions

Approach climb requirements:

- Minimum gradient in approach configuration shall not be less then 2.1%.
- Approach configuration is based on the approach flaps setting 15 deg.,
- landing gear up, one engine inoperative, and the operating engine at go-around thrust.
- Normally it is not a limiting factor until aerodrome temperature exceeds 45° C and field elevation 3000 ft.

Landing climb:

- Minimum gradient in landing configuration shall not be less then 3.2 %.
- Landing configuration is based on the landing flaps setting 30 or 40 deg., landing gear down, all engines operative, the engines are at go-around thrust.

Landing Climb Limit Weight

Valid for approach with Flaps 15 and landing with Flaps 40
Based on engine bleed for packs on, APU operating and anti-ice off

Airport	Landing Climb Limit Weight (1000 kg)					
OAT	Pressure Altitude (ft)					
°C	-1000	0	2000	4000	6000	8000
54	55.0	53.9				
52	56.1	54.9				
50	57.2	56.0	51.7			
48	58.0	56.8	52.5			
46	58.8	57.7	53.4	49.3		
44	59.7	58.6	54.2	50.2		
42	60.6	59.5	55.1	51.0	47.3	
40	61.5	60.4	56.0	51.7	48.2	
38	62.6	61.3	56.8	52.7	48.9	45.0
36	63.6	62.2	57.7	53.6	49.7	45.8
34	64.7	63.2	58.6	54.5	50.5	46.6
32	65.7	64.1	59.5	55.4	51.3	47.4
30	65.8	65.1	60.5	56.4	52.2	48.2
28	65.8	65.3	61.5	57.3	53.0	48.9
26	65.9	65.4	62.4	58.3	53.8	49.6
24	65.9	65.4	62.4	59.3	54.6	50.3
22	66.0	65.5	62.5	60.0	55.4	51.0
20	66.0	65.5	62.5	60.1	56.2	51.7
18	66.0	65.6	62.6	60.1	57.1	52.5
16	66.0	65.6	62.6	60.2	57.2	53.4
14	66.0	65.7	62.7	60.2	57.2	54.1
12	66.0	65.7	62.7	60.3	57.2	54.1
10	66.0	65.7	62.7	60.3	57.3	54.1
-40	66.0	66.0	63.4	61.0	57.9	54.7

With engine bleed for packs off, increase weight by 1250 kg.
With engine anti-ice on, decrease weight by 400 kg.
With engine and wing anti-ice on, decrease weight by 5500 kg.
When operating in icing conditions during any part of the flight with forecast landing temperature below 8°C, decrease weight by 5100 kg.

Go-Around Climb

The climb gradient in the go-around configuration is greater of 2.5%, or the published gradient for the specific airport, based on one engine inoperative and landing gear up.

For more detailed information refer to FCOM, Performance Dispatch and Flight Planning and Performance Manual

Go-Around Climb Gradient

Flaps 15

Based on engine bleed for packs on and anti-ice off

Reference Go-Around Gradient (%)

OAT	Reference Go-Around Gradient (%)				
	Airport Pressure Altitude (ft)				
°C	0	2000	4000	6000	8000
50	3.39	2.33	1.12	0.12	
46	3.86	2.72	1.71	0.66	
42	4.31	3.16	2.07	1.18	0.11
38	4.75	3.61	2.56	1.57	0.56
34	5.27	4.07	3.04	2.00	0.98
30	5.81	4.55	3.53	2.41	1.37
26	5.84	5.03	3.97	2.81	1.74
22	5.87	5.06	4.40	3.22	2.11
18	5.90	5.09	4.42	3.63	2.48
14	5.93	5.11	4.45	3.64	2.83
10	5.94	5.14	4.47	3.66	2.85

Gradient Adjustment for Weight (%)

Weight	Reference Go-Around Gradient (%)						
(1000 kg)	0	1	2	3	4	5	6
60	-2.00	-2.22	-2.45	-2.67	-2.89	-3.12	-3.34
55	-1.34	-1.48	-1.63	-1.77	-1.92	-2.06	-2.21
50	-0.50	-0.55	-0.60	-0.65	-0.71	-0.76	-0.81
47.5	0	0	0	0	0	0	0
45	0.61	0.67	0.74	0.8	0.87	0.94	1.01
40	2.03	2.24	2.45	2.67	2.89	3.12	3.36
35	3.97	4.37	4.78	5.21	5.66	6.13	6.62

Gradient Adjustment for Speed (%)

Speed	Weight Adjusted Go-Around Gradient (%)													
(KIAS)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
VREF	-0.55	-0.59	-0.63	-0.66	-0.69	-0.71	-0.72	-0.73	-0.73	-0.73	-0.72	-0.70	-0.67	-0.64
VREF+5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VREF+10	0.19	0.20	0.21	0.22	0.23	0.24	0.24	0.25	0.26	0.26	0.27	0.27	0.27	0.27
VREF+20	0.47	0.48	0.50	0.51	0.52	0.53	0.53	0.53	0.53	0.52	0.51	0.50	0.49	0.47
VREF+30	0.56	0.57	0.58	0.58	0.58	0.57	0.56	0.54	0.52	0.49	0.46	0.42	0.38	0.33

With engine bleed for packs off, increase gradient by 0.3%.
With engine anti-ice on, decrease gradient by 0.1%.
With engine and wing anti-ice on, decrease gradient by 1.2%.
When operating in icing conditions during any part of the flight with forecast landing temperatures below 8°C, decrease gradient by 0.8%.

6.4.4 Contaminated/Low Friction RWY

When landing on contaminated/low friction runway the following criteria shall be met:

- No tailwind;
- Landing flap setting 40O shall be used;
- Engine anti-ice on (if required by RWY contaminant);
- Speed brakes, anti-skid/wheel brakes shall be serviceable.

There are no tables for contaminated runway in QRH and Low Friction Runway landing distances having the same friction coefficient are used instead as they give more conservative result (with assumption that a contaminant layer on the contaminated runway surface creates an additional drag during landing roll in comparison with the slippery runway).
For Low Friction/Contaminated Runway actual landing distances without reversers see following tables.
To obtain LDR - actual landing distance from the graph/tables shall be multiplied by coefficient 1.67.

Malfunctions

In case of malfunctions that effect landing performance, QRH, Performance In-flight – Advisory information, Non-Normal Configuration Landing Distance Tables shall be used to determine the un-factored (actual) distance for different RWY conditions.
To obtain LDR - actual landing distance given in the tables and corrected appropriately, if required, should be multiplied by coefficient 1.67.

Landing Speeds

V_{REF} for actual landing weight shall be taken directly from FMC or AFM 4.13.
Speed VREF +10 increases landing distance by 110 m.

Normal Configuration Landing Distance
Flaps 30

DRY	Landing Distance and Adjustments (m)											
	Ref Dist	Weight Adj	Alt Adj	Wind Adj per 10kts		Slope Adj per 1%		Temp Adj per 10°C		VREF Adj	Reverse Thrust Adj	
Braking Config	48000kg Landing Weight	Per 5000kg above/below Ref Weight	Per 1000ft above Sea Level	Head Wind	Tail Wind	Down Hill	Up Hill	Above ISA	Below ISA	Per 10kts above VREF	One Rev	No Rev
Max MAN	790	95/-45	15	-25	105	10	-5	15	-15	65	15	40
Max AUTO	825	85/-50	20	-30	110	10	-5	20	-15	75	10	15
Auto 3	1000	125/-80	30	-45	170	15	-5	30	-20	110	10	20
Auto 2	1430	160/-130	45	-70	260	15	-15	45	-40	165	5	20
Auto 1	1645	185/-160	55	-85	315	50	-45	50	-45	145	130	155

Good Reported Braking Action (FC > 0.4)

Max MAN	1080	85/-80	30	-45	175	25	-20	25	-20	85	55	190
Max AUTO	1080	85/-80	30	-45	175	25	-20	25	-20	85	55	190
Auto 3	1220	105/-95	35	-55	195	15	-10	35	-30	125	15	75
Auto 2	1585	155/-140	50	-75	275	25	-20	50	-40	155	25	25
Auto 1	1750	185/-165	55	-90	325	55	-50	50	-45	145	170	205

Medium Reported Braking Action (FC = 0.30 – 0.35)

Max MAN	1430	130/-120	40	-70	280	60	-45	40	-30	110	140	595
Max AUTO	1430	130/-120	40	-70	280	60	-45	40	-30	110	140	595
Auto 3	1455	130/-120	40	-75	285	50	-30	40	-35	135	110	565
Auto 2	1695	165/-155	50	-85	320	50	-40	50	-40	150	65	370
Auto 1	1810	185/-175	60	-90	340	70	-55	55	-45	140	190	425

Poor Reported Braking Action (FC = 0.15 – 0.25)

Max MAN	1795	175/-165	55	-105	430	130	-85	50	-40	125	280	1670
Max AUTO	1795	175/-165	55	-105	430	130	-85	50	-40	125	280	1670
Auto 3	1795	175/-165	55	-105	430	130	-80	50	-40	130	280	1670
Auto 2	1900	185/-175	60	-110	445	120	-80	50	-45	140	210	1565
Auto 1	1965	205/-190	65	-115	455	135	-90	55	-50	140	280	1535

Reference distance is for sea level, standard day, no wind or slope, VREF30 approach speed and two engine detent reverse thrust.
Max manual braking data valid for auto speedbrakes. Autobrake data valid for both auto and manual speedbrakes.
For max manual braking and manual speedbrakes, increase reference landing distance by 85 m.
Actual (unfactored) distances are shown.
Includes distance from 50 ft above threshold (305 m of air distance).

Normal Configuration Landing Distance
Flaps 40

DRY	Landing Distance and Adjustments (m)											
	Ref Dist	Weight Adj	Alt Adj	Wind Adj per 10kts		Slope Adj per 1%		Temp Adj per 10°C		VREF Adj	Reverse Thrust Adj	
Braking Config	48000kg Landing Weight	Per 5000kg above/below Ref Weight	Per 1000ft above Sea Level	Head Wind	Tail Wind	Down Hill	Up Hill	Above ISA	Below ISA	Per 10kts above VREF	One Rev	No Rev
Max MAN	790	95/-45	25	-25	100	10	-5	15	-10	65	15	40
Max AUTO	810	85/-50	20	-25	110	10	-5	20	-15	75	10	15
Auto 3	970	125/-75	30	-40	165	10	-5	30	-20	110	10	20
Auto 2	1375	190/-150	40	-70	250	15	-10	40	-40	160	5	20
Auto 1	1570	190/-150	55	-85	305	50	-40	50	-40	140	120	150

Good Reported Braking Action (FC > 0.4)

Max MAN	1050	95/-75	25	-45	175	25	-15	25	-20	85	50	175
Max AUTO	1050	95/-75	25	-45	175	25	-15	25	-20	85	50	175
Auto 3	1170	110/-90	30	-50	195	15	-5	30	-25	125	15	70
Auto 2	1515	155/-135	45	-70	265	25	-20	45	-40	145	25	25
Auto 1	1665	185/-155	55	-85	315	50	-45	50	-45	135	150	195

Medium Reported Braking Action (FC = 0.30 – 0.35)

Max MAN	1375	135/-110	40	-70	275	60	-40	35	-30	105	125	540
Max AUTO	1375	135/-110	40	-70	275	60	-40	35	-30	105	125	540
Auto 3	1395	135/-110	40	-70	280	50	-30	40	-30	130	105	520
Auto 2	1615	165/-145	50	-80	310	45	-40	45	-40	135	65	335
Auto 1	1715	185/-165	55	-90	330	65	-50	50	-45	135	165	400

Poor Reported Braking Action (FC = 0.15 – 0.25)

Max MAN	1715	180/-155	55	-105	420	125	-80	45	-40	120	250	1495
Max AUTO	1715	180/-155	55	-105	420	125	-80	45	-40	120	250	1495
Auto 3	1715	180/-155	55	-105	420	125	-75	45	-40	125	250	1495
Auto 2	1815	190/-165	55	-110	435	115	-75	50	-45	135	190	1400
Auto 1	1865	205/-180	60	-110	445	125	-85	50	-45	135	245	1385

Reference distance is for sea level, standard day, no wind or slope, VREF40 approach speed and two engine detent reverse thrust.
Max manual braking data valid for auto speedbrakes. Autobrake data valid for both auto and manual speedbrakes.
For max manual braking and manual speedbrakes, increase reference landing distance by 75 m.
Actual (unfactored) distances are shown.
Includes distance from 50 ft above threshold (305 m of air distance).

7 WEIGHT AND BALANCE

7.1 Introduction

In air carrier operations, balance of the airplane is of prime importance and must be thoroughly understood by the pilot. Stability of an aircraft in flight can be easily upset by improper loading or by the placement of weights at aircraft stations not in accordance with the loading procedures for that particular aircraft.

There are several methods used in computing weight and balance of aircraft:

- by slide rule, if the slide rule is designed specifically for the particular aircraft;
- by formulas which can be applied generally to all aircraft;
- by "block and expanded" systems in which variations in anticipated loads can be corrected up to the scheduled departure time of the aircraft;
- by common weight and balance principles plus basic formulas as well as mathematical calculations with the aid of long-hand arithmetic, a slide rule, or standard circular computer; and
- by an index system.

The last method is the basis for the weight and balance solutions in this chapter.

7.2 Definitions

Algebraic signs: When computing weight and balance where the datum is at the leading edge of the wing, the rudder pedals, or other position aft of the nose of the airplane, care must be taken to use the proper plus or minus signs (+ or -). Items placed ahead of the datum would be at a minus arm, and items placed aft of the datum would be at a plus arm. On large aircraft the datum is generally at the nose or forward of the nose section. Therefore, all items placed in the aircraft will be at a plus arm. Note: When working weight and balance problems, always visualize the nose of the aircraft to your left.

Aircraft weight check: This consists of checking the sum of the weights of all items of useful load against the authorized useful load (maximum weight less empty weight) of the aircraft.

Arm or moment arm: the horizontal distance (in inches) from the datum to the center of gravity of an item (occupant, baggage, etc.). A plus (+) arm indicates the item is located aft of the datum; a minus (-) arm indicates the item is forward of the datum.

Basic Index (BI): Center of gravity at basic weight (BW) expressed as an index value.

Center of gravity: generally known as the balance point of an aircraft. It is an imaginary point about which the nose-heavy and tailheavy moments are exactly equal in magnitude. Any assumed position of the center of gravity will be along the longitudinal axis, at the inter section of the lateral and vertical axes.

Datum: an imaginary vertical plane or line from which all horizontal measurements are taken for balance purposes with the aircraft in level flight attitude. The datum can be at the leading edge of the wing, or nose of the aircraft, or ahead of the nose of the aircraft, or rudder pedals, etc. If not specified, the datum can be located in any convenient position on the aircraft. Generally, the manufacturer designates the datum position, which remains fixed throughout the life of the airplane.

Dry Operating Index (DOI): Center of gravity at dry operating weight expressed as an index value. Basic index (BI) corrected for the balance influence of the loads included in Dry Operating Weight (DOW).

Dry Operating Weight (DOW): The total weight of an aircraft ready for a specific type of operation excluding all usable fuel and traffic load. Operational Empty Weight plus items specific to the type of flight, i.e. catering, newspapers, pantry equipment, extra crew etc…

Empty weight: includes all operating equipment (structure, powerplants, fuel tanks, etc.) with a fixed location and actually installed in the aircraft. Generally, fixed ballast, unusuable fuel, undrainable oil, and hydrualic fluid are included in the empty weight check of the aircraft. The condition of the aircraft should be such that the empty weight condition can be easily repeated.

Empty weight center of gravity: established by weighing the aircraft with suitable scales in a closed hangar and in level flight attitude.

Empty weight center of gravity range: determined so that when the empty weight center of gravity falls within this range the specification operating center of gravity limits will not be loading arrangements.

Equipment changes: The registered owner of an aircraft is responsible for a continuous record of each aircraft. In order that a computed weight and center of gravity location can be established at any time, all changes affecting the weight, center of gravity location, and equipment must be listed.

Equipment list: a complete list of the equipment included in the ccrtificated empty weight; found in either the approved airplane operating manual or the weight and balance data.

Full oil: the quantity of oil shown in the aircraft specifications as oil capacity.

Installation of ballast. Ballast is sometimes permanently installed for center of gravity balance purposes as a result of the installation or removal of equipment items. Ballast should not be used to correct a nose-up or nose-down tendency of the aircraft.

Landing Weight (LW): The weight at landing at the destination airport. It is equal to the Zero Fuel Weight plus the fuel reserves.

Loading schedule. This should be kept with the aircraft, and usually forms a part of the airplane flight manual.

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 essentially a "dry" weight, including only those fluids contained in closed systems (e.g. hydraulic fluid).

Maximum Landing Weight (MLW): Maximum weight for landing as limited by aircraft strength and airworthiness requirements.

Maximum Takeoff Weight (MTOW): Maximum weight at brake release as limited by aircraft strength and airworthiness requirements.

Maximum Taxi Weight (MTW): Maximum weight for ground maneuver as limited by aircraft strength and airworthiness requirements. (It includes weight of taxi and runup fuel.)

Maximum Zero Fuel Weight (MZFW): Maximum weight allowed before usable fuel must be loaded in the aircraft as limited by strength and airworthiness requirements.

Minimum Flight Weight (MFW): Minimum weight for flight as limited by aircraft strength and airworthiness requirements.

Mean Aerodynamic Chord (MAC): the mean chord of the airfoil or wing. For weight and balance purposes it is used to locate the center of gravity range of the aircraft. MAC data can be found in the aircraft specifications, flight manual, or aircraft weight and balance records.

Moment. The moment of an item about the datum is obtained by multiplying the weight of the item by its horizontal distance from the datum.

Operating center of gravity range: the distance between the forward lind rearward center of gravity limits shown in the aircraft specifications.

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

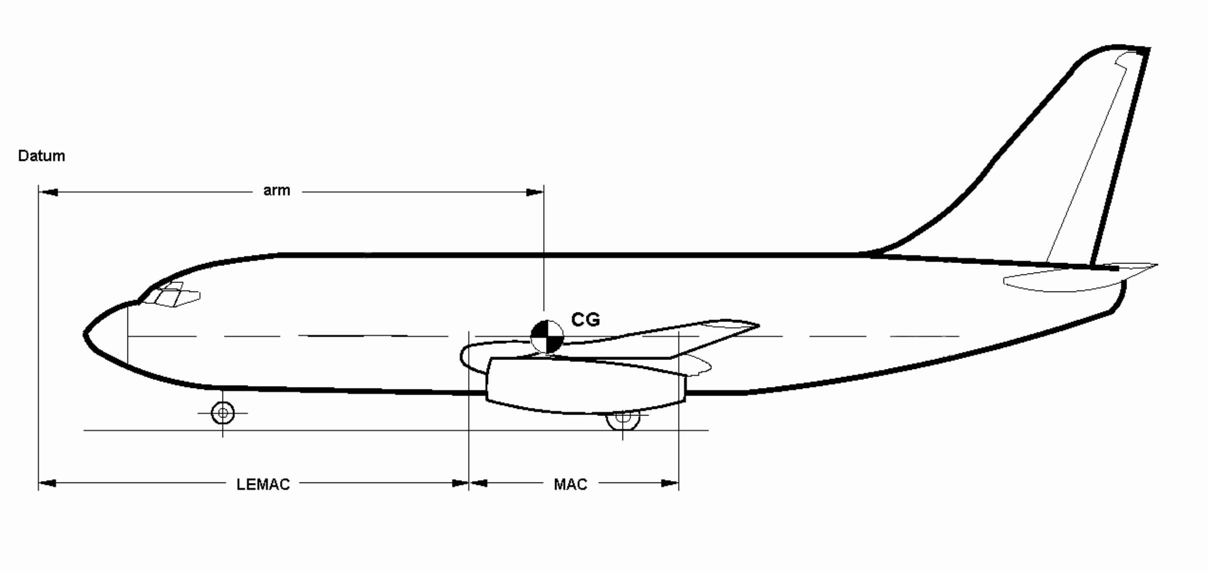


Figure 33 – MAC Definition

Tare: the weight of chocks, blocks, etc., used when weighing the aircraft and included in the scale weight readings. Tare must be deducted from the scale readings to obtain the actual or net weight of the aircraft.

Takeoff Weight (TOW): The weight at takeoff at the departure airport. It is equal to the landing weight at destination plus the trip fuel (fuel needed for the trip), or to the zero fuel weight plus the takeoff fuel (fuel needed at the brake release point including reserves).

Take-off fuel (TOF): The weight of the fuel on board at take-off.

Trip fuel: The weight of the fuel necessary to cover the normal leg without reserves.

Total Traffic Load (TTL): The total weight of the passengers, baggage and cargo, including non-revenue loads.

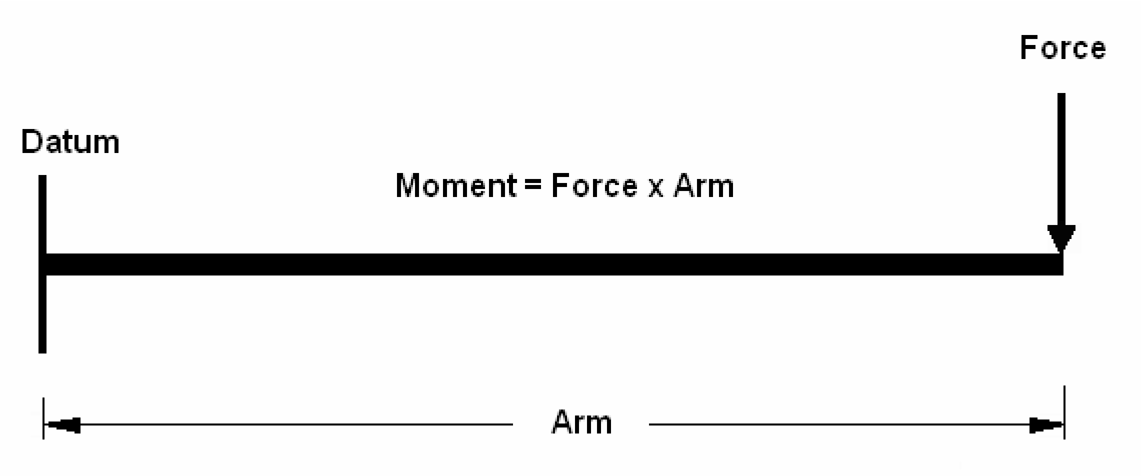


Figure 34 – Moment

Unit weights. Unless otherwise noted, unit weights used in weight and balance computations in actual practise as well as in the written exams are: fuel - 6 lbs. per U.S. gallon; oil – 7 1/2 lbs. per U.S. gallon; water - 8 lbs. per U.S. gallon; crew and passengers - 170 lbs. per person.

Useful load: found by subtracting the empty weight from the maximum permissible weight of the aircraft. Useful load consists of the flight crew, passengers, baggage, cargo, etc., unless otherwise noted.

Weight and balance extreme conditions: the forward and rearward center of gravity limits for the particular aircraft.

Weighing point. When required to locate the empty weight center of gravity by weighing the aircraft, it is first necessary to obtain horizontal measurements between the points on the scales at which the airplane's weight is concentrated. In usual weighing practice, a vertical line passing through the centerline of the wheel axles locates the point on the scales at which the weight is concentrated.

Zero Fuel Weight: the sum of Dry Operating Weight and Payload.

7.3 Calculation of Center of Gravity

Center of gravity, C.G., is the point around which no motion or rotation occurs if the object, or group of objects, is theoretically supported at that point.
The sum of the forces and moments produced by the distribution of weight of a group of objects about their combined C.G. would be equal to zero if the objects could be supported at exactly that location.
To determine the location of the C.G. for a group of objects we need to determine the point at which the group of objects would be in balance if they were supported at that location. Refer to Figure 35.

Example:
W1 = 2000 lbs
d1 = 240 inches
W2 = 1500 lbs
d2 = 400 inches

D = 309 inches

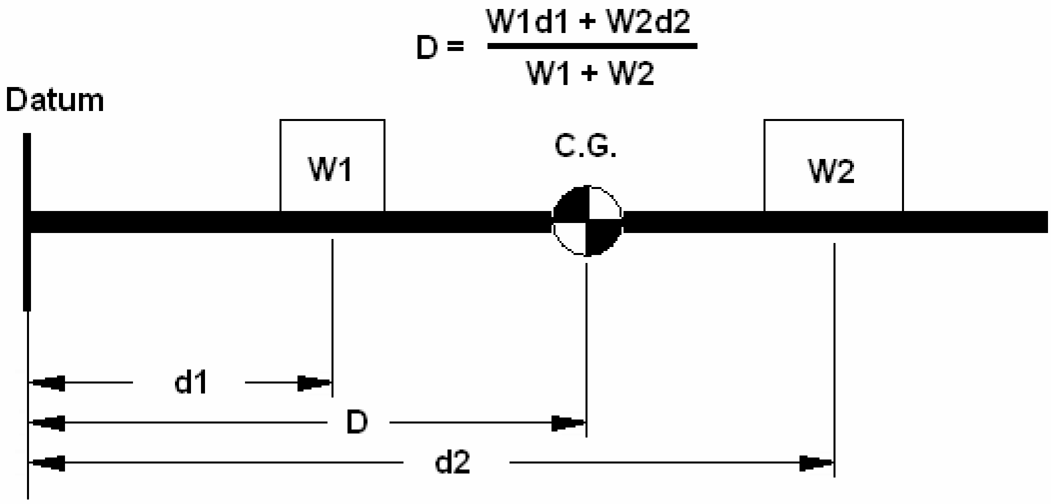


Figure 35 – Calculation of Center of Gravity

7.4 Index Equation

When loading an airplane, summation of moments is necessary to accurately determine the center of gravity for the loaded airplane:

- Moment due to airplane empty weight
- Moment of all items that are loaded:
    - Flight and cabin crew
    - Passengers, carry-on and baggage
    - Cargo
    - Fuel
    - etc.

An Index Equation is used to simplify the presentation of moment data on the loading schedule.

Index is moment scaled to a convenient magnitude that is easy to add and subtract based on a scale which is offset such that the index values are typically positive

The Index Equation has the following form:

Index: $$I = \frac{W(Sta - Ref.Sta)}{C} + K$$

% MAC: $$\%MAC = \frac{\frac{(I-K)C}{W} + Ref.Sta - LEMAC}{\frac{MAC}{100}}$$

W	=	Weight actual
Sta	=	Station horizontal distance in inches or meters from station zero to the location of the weight.
Ref. Sta	=	Reference station/axis. Selected station around which all index values are calculated.
K	=	Constant used as a plus value to avoide negative index figures.

C	=	Constant used as a denominator to convert moment values into index values.
I	=	Index value corresponding to respective weight.
MAC	=	Length of Mean Aerodynamic Chord in inches or meters.
LEMAC	=	Horizontal distance in inches or meters from station zero to location of the Leading Edge of the MAC.

Normally the following values are choosen for the Boeing 737-300 when the weights are in kilograms:

Ref Sta at	= 648.5 inches from zero
K (constant)	= 40
C (constant)	= 30000
Length of MAC	= 134.5 inches
LEMAC at	= 625.6 inches from zero

Now the equation becomes:

$$I = \frac{W(Sta - 648.5)}{30000} + 40$$

7.5 Load and Trimsheet

Two types of Load and Trimsheets are in use:

- Computer Generated
- Manually Calculated

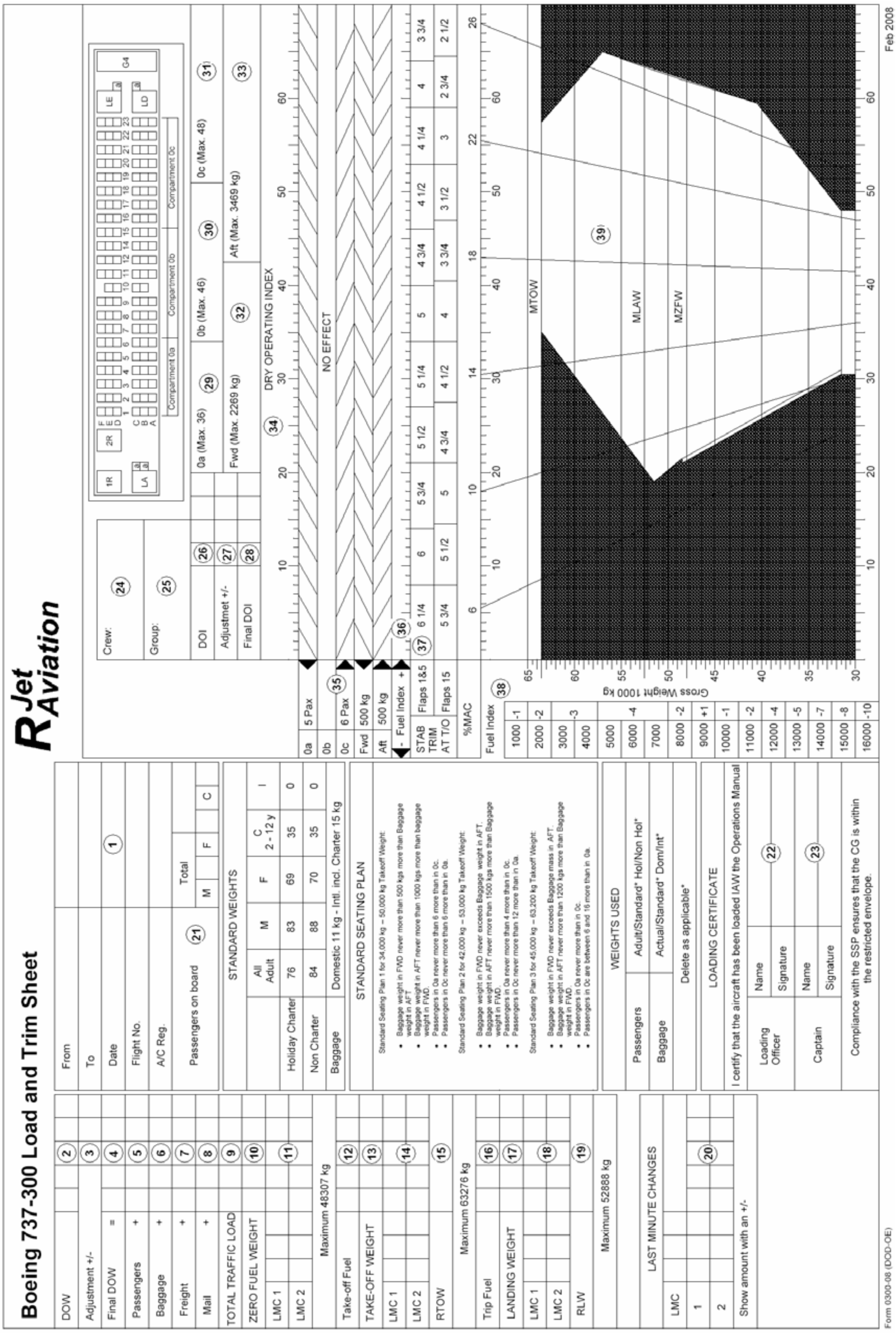
7.5.1 Computer Generated Loadsheet

```
  L O A D S H E E T          CHECKED:          DATE            EDNO
  ALL WEIGHTS IN KILOGRAM    APPROVED:         31JUL09

  FROM/TO FLIGHT     A/C REG    VERSION      CREW            TIME
  TSR_FRA RJ1234     YR-RLT     0/130        2/3             0955
                        WEIGHT DISTRIBUTION
  LOAD IN COMPARTMENTS   3500  1/1500  4/2000
  PASSENGER/CABIN BAG   10248  TTL 122
  TOTAL TRAFFIC LOAD    13748
  DRY OPERATING WEIGHT  34056
  ZERO FUEL WEIGHT      47804  MAX 48307
  TAKE OFF FUEL         12000
  TAKE OFF WEIGHT       59804  MAX 63276
  TRIP FUEL              8500
  LANDING WEIGHT        51304  MAX 52888

****************************************************************************
  BALANCE AND SEATING CONDITIONS           LAST MINUTE CHANGES
  DOI      36.82                DEST     SPEC     CL/CPT     PLUS     MINUS
  LIZFW    52.81                ....     ....     ......     ....     .....
  MACZFW   23.00                ....     ....     ......     ....     .....
  LITOW    49.68                ....     ....     ......     ....     .....
  MACTOW   20.64                ....     ....     ......     ....     .....
  LILAW    49.66                ....     ....     ......     ....     .....
  MACLW    21.23                ....     ....     ......     ....     .....
                                     LMC TOTAL +/-

  TRIM BY COMPARTMENT
  0A30.0B46.0C46

  UNDERLOAD BEFORE LMC   503

****************************************************************************
  END OF LOADSHEET
```

No.	Heading	Description	Remarks
1	LOADSHEET	Loadsheet Document identifier, weight units	Kilogram, Kilo, etc.
2	CHECKED	Loadsheet agent's signature	
3	DATE	Date	
4	ED NO	Edition number	
5	APPROVED	Approved Signature of authorized person (PIC)	
6	FROM/TO	Three-letter IATA codes of departure & landing airports	
7	FLIGHT	Flight Number	
8	A/C REG	Registration	

9	VERSION	A/C version & divider position	
10	CREW	Crew version cockpit/cabin	
11	TIME	Time of loadsheet generation	
12	LOAD IN COMPARTMENTS	Total weight in baggage compartments and distribution	
13	PASSENGER/CABIN BAG	Total weight of passengers and number of passengers divided into specified groups and categories	
14	TOTAL TRAFFIC LOAD	The total weight of passengers, baggage, cargo and mail	
15	DRY OPERATING WEIGHT	DOW	
16	ZERO FUEL WEIGHT	Sum of Dry Operating Weight and Total Traffic Load	
17	TAKEOFF FUEL	Take Off Fuel The amount of fuel on board less the fuel consumed before takeoff. Note: If after refuelling actual fuel on board minus expected taxi fuel differs from the take-off fuel presented on the loadsheet the same procedure as for traffic load LMC (OM-B 6.2.4) to be applied	
18	TAKEOFF WEIGHT	Sum of 16 and 17	
19	TRIP FUEL	The amount of fuel planned to be consumed from take-off to landing	
20	LANDING WEIGHT	18 minus 19	
21	BALANCE AND SEATING CONDITIONS	Section contains balance information for dry and loaded aircraft. Standard abbreviation are used	
22	LAST MINUTE CHANGES	Destination of LMC / Kind of LMC / Class or Compartment / on or off load indicator / weight of LMC. At the bottom of this section the Total LMC weight is presented.	
23	TRIM BY COMPARTMENT	Changes of DOI due to passengers' position. All specified cabin sections are presented. Depends on aircraft version.	
24	UNDERLOAD BEFORE LMC	Difference between maximum and actual weight	

7.5.2 Manual Loadsheet



Boeing 737-300 Load and Trim Sheet — Jet Aviation

DOW		(2)
Adjustment +/-		(3)
Final DOW	=	(4)
Passengers	+	(5)
Baggage	+	(6)
Freight	+	(7)
Mail	+	(8)
TOTAL TRAFFIC LOAD		(9)
ZERO FUEL WEIGHT		(10)
LMC 1		(11)
LMC 2		
Maximum 48307 kg		
Take-off Fuel		(12)
TAKE-OFF WEIGHT		(13)
LMC 1		(14)
LMC 2		
RTOW		(15)
Maximum 63276 kg		
Trip Fuel		(16)
LANDING WEIGHT		(17)
LMC 1		(18)
LMC 2		
RLW		(19)
Maximum 52888 kg		

LAST MINUTE CHANGES

LMC		
1		(20)
2		

Show amount with an +/-

From		
To		
Date	(1)	
Flight No.		
A/C Reg.		
Passengers on board (21)	Total	
	M F C	

STANDARD WEIGHTS

	All Adult	M	F	C 2 - 12 y	I
Holiday Charter	76	83	69	35	0
Non Charter	84	88	70	35	0
Baggage	Domestic 11 kg - Intl. incl. Charter 15 kg				

STANDARD SEATING PLAN

Standard Seating Plan 1 for 34,000 kg – 50,000 kg Takeoff Weight:

- Baggage weight in FWD never more than 500 kgs more than Baggage weight in AFT
- Baggage weight in AFT never more than 1000 kgs more than baggage weight in FWD.
- Passengers in 0a never more than 6 more than in 0c.
- Passengers in 0c never more than 6 more than in 0a.

Standard Seating Plan 2 for 42,000 kg – 53,000 kg Takeoff Weight:

- Baggage weight in FWD never exceeds Baggage weight in AFT.
- Baggage weight in AFT never more than 1500 kgs more than Baggage weight in FWD.
- Passengers in 0a never more than 4 more than in 0c.
- Passengers in 0c never more than 12 more than in 0a.

Standard Seating Plan 3 for 45,000 kg – 63,200 kg Takeoff Weight:

- Baggage weight in FWD never exceeds Baggage mass in AFT.
- Baggage weight in AFT never more than 1200 kgs more than Baggage weight in FWD.
- Passengers in 0a never more than in 0c.
- Passengers in 0c are between 6 and 16 more than in 0a.

WEIGHTS USED

Passengers	Adult/Standard* Hol/Non Hol*
Baggage	Actual/Standard* Dom/Int*

Delete as applicable*

LOADING CERTIFICATE

I certify that the aircraft has been loaded IAW the Operations Manual

Loading Officer	Name	(22)
	Signature	
Captain	Name	(23)
	Signature	

Compliance with the SSP ensures that the CG is within the restricted envelope.

Crew: (24)

Group: (25)

1R 2R F E D 1 2 3 4 5 6 7 8 9 10 11 12 14 15 16 17 18 19 20 21 22 23 LE G4 C B A LA LD Compartment 0a Compartment 0b Compartment 0c

DOI	(26)	0a (Max. 36) (29)	0b (Max. 46) (30)	0c (Max. 48) (31)
Adjustmet +/-	(27)	Fwd (Max. 2269 kg) (32)		Aft (Max. 3469 kg) (33)
Final DOI	(28)			

DRY OPERATING INDEX (34)

0a	5 Pax
0b	NO EFFECT
0c	6 Pax (35)
Fwd	500 kg
Aft	500 kg
- Fuel Index +	(36)

STAB TRIM AT T/O												
Flaps 1&5 (37)	6 1/4	6	5 3/4	5 1/2	5 1/4	5	4 3/4	4 1/2	4 1/4	4	3 3/4
Flaps 15	5 3/4	5 1/2	5	4 3/4	4 1/2	4	3 3/4	3 1/2	3	2 3/4	2 1/2

%MAC 6 10 14 18 22 26

Fuel Index (38)	
1000	-1
2000	-2
3000	-3
4000	
5000	
6000	-4
7000	
8000	-2
9000	+1
10000	-1
11000	-2
12000	-4
13000	-5
14000	-7
15000	-8
16000	-10

Form 0300-08 (DOD-OE) Feb 2008

No.	Description	Remarks
1	General Flight Data	
2	Dry Operating Weight	From OM-B 6.4
3	DOW Adjustment	From OM-B 6.4
4	Corrected DOW	2 ± 3
5	Total Passenger Weight	
6	Baggage Weight	
7	Freight	
8	Mail	
9	Total Traffic Load	5+6+7+8
10	Zero Fuel Weight	9+4
11	LMC Field	
12	Takeoff Fuel	
13	Takeoff Weight	10+12
14	LMC Field	
15	Performance Limited Takeoff Weight	From OM-B Chapter 4
16	Trip Fuel	
17	Landing Weight	13-16
18	LMC Field	
19	Performance Limited Landing Weight	From OM-B Chapter 4
20	LMC Field	
21	Passengers	M = Male F = Female C = Children
22	Load agents name and signature	
23	Commanders name and signature	
24	Crew version	From OM-B 6.4
25	Group	From OM-B 6.4
26	Dry Operating Index	From OM-B 6.4
27	DOI Correction	From OM-B 6.4
28	Corrected DOI	28 ± 27
29	Number of passengers in compartment 0a	
30	Number of passengers in compartment 0b	
31	Number of passengers in compartment 0c	
32	Weight in forward compartment	
33	Weight in aft compartment	
34	DOI scale	Enter DOI from28
35	Compartment scales	
36	Fuel index scale	From 38
37	Stabilizer trim setting scale	
38	Fuel index table	
39	Center of Gravity field	

7.6 Weight and Balance Information

Weight and Balance Information can be found in OM-B Chapter 6 (Weight and Balance) as well as in Chapter 7 (Loading).

7.6.1 Weight and Balance

Chapter 6 of the OM-B contains the following information:

- 6.1 Weight and Balance Calculation System
  - 6.1.1 System Definition
  - 6.1.2 Standard Weights
- 6.2 Instructions for Completion of Weight and Balance Documentation
  - 6.2.1 General
  - 6.2.2 Computer Generated Loadsheet
    - 6.2.2.1 Example
    - 6.2.2.2 Description
  - 6.2.3 Manual Loadsheet
    - 6.2.3.1 Example
    - 6.2.3.2 Description
  - 6.2.4 Last Minute Changes (LMC)
    - 6.2.4.1 General
    - 6.2.4.2 Limitations
    - 6.2.4.3 Electronic Loadsheet
    - 6.2.4.4 Manual Loadsheet
- 6.3 Weight and Center of Gravity Limitations
  - 6.3.1 Weight Limitations
  - 6.3.2 Center of Gravity
- 6.4 Dry Operating Weight and Index

7.6.2 Loading

Chapter 7 of OM-B contains the following topics on Loading:

- 7.1 Loading Instructions
  - 7.1.1 General
  - 7.1.2 Normal Loading Instructions
  - 7.1.3 Cargo Compartments
    - 7.1.3.1 Distribution of Cargo
    - 7.1.3.2 Designation
    - 7.1.3.3 Limitations
    - 7.1.3.4 Flight Kit
    - 7.1.3.5 Dimensions
- 7.2 Distribution of Passengers
  - 7.2.1 Standard Seating Plan
- 7.3 Transportation of Live Animals
- 7.4 Special Loading Instructions
  - 7.4.1 Transportation of Childeren and Disabled Persons
  - 7.4.2 Transportation of electrically Wheelchairs
  - 7.4.3 Transportation of Weapons
  - 7.4.4 Transportation of Radioactive Material
  - 7.4.5 Transportation of Live Human Organs (LHO)

Dry Operating Weight and Index

WEIGHTS: KG; **INDEX:** KG.INCH

A/C REG.	SEATS	DRY OPERATING WEIGHT AND INDEX					
		CREW 2/3	PANTRY A	CREW 2/4	PANTRY A	CREW 3/3	PANTRY A
		WEIGHT	INDEX	WEIGHT	INDEX	WEIGHT	INDEX
XX-RLT	130	34056	36.8	34143	38.0	34240	36.4
XX-ARR	130	34056	36.8	34143	38.0	34240	36.4
XX-TMI	130	34056	36.8	34143	38.0	34240	36.4
XX-TMS	130	34056	36.8	34143	38.0	34240	36.4
XX-ABS	130	34056	36.8	34143	38.0	34240	36.4

Dry Operating Weight includes Basic Weight, Crew, Crew Baggage and Pantry

- Adjust Dry Operating Weight and Index in above table for other Pantry Code & Weights given in adjustment table below.
- Dry Operating Weight and Index does not include nose gear & main gear spare wheel & tire, tool box ect.
- Refer to Adjustment Table below

Index Formular: [Wt(kg) x [H.arm(inch) – 648.5]] / 30000 + [40]

MAX Taxi Weight	MAX Takeoff Weight	MAX Landing Weight	MAX Zero Fuel Weight	Fuel Tank Capacity	MAX Cargo Capacity
63,502	63,276	52,888	48,307	16,140	5,738

DRY OPERATING WEIGHT & INDEX ADJUSTMENT TABLE			
Item and Location	**Weight**	**Index**	**Remarks / Notes**
Cockpit Crew	97 kg	-1.57	
Cabin Crew - FWD	87 kg	-1.19	Total 2 seats available
Cabin Crew - AFT	87 kg	1.19	Total 2 seats available
Pantry Code	FWD (1R / 2R)	AFT (G4)	Total Weight / Index
A	103 kg / 150 kg	397 kg	650 kg / 2.58
No Pantry	DOW / DOI Correction: -650 kg / -2.58		
Nose Gear Wheel and Tire		32 kg / 0.23	Dry Operating Weight and Index does NOT include the Flight Kit. Check if Flight Kit is located in AFT Compartment.
Main Gear Wheel and Tire		120 kg / 0.86	
Tool Kit Box		47 kg / 0.34	
FLIGHT KIT TOTAL		200 kg / 1.44	

7.6.3 Passenger Standard Weights

To avoid having to weigh each passenger and baggage, a standard weight is used for Load and Trim sheet calculation.

For all flights, the standard weight of passengers including hand baggage is the following:

Table 1: Mass values for passengers including hand baggage
Aeroplane with 20 passenger seats or more

Passenger seats	30 and more	20 and more	
	All adult	**Male**	**Female**
Adult - All flights except holiday charters (*)	84 kg	88 kg	70 kg
Adult - Holiday charters (*)	76 kg	83 kg	69 kg
Children - All flights	35 kg	35 kg	35 kg

(*) Holiday charter means a charter flight solely intended as an element of a holiday travel package.

Table 2: Mass values for passengers including hand baggage
Aeroplane with 19 passenger seats or less

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

Note1: The weight of infants under 2 years old carried by an adult is not considered. Infants occupying separate passenger seats must be considered as children (35 kg).

Note 2: When the total number of passenger seats available on an aeroplane is 20 or more, the standard masses of male and female in table 1 are applicable. As an alternative, when the total number of passenger seats available is 30 or more, the "All Adult" mass value are applicable.

Note 3: When the total number of passenger seats available on an aeroplane is 19 or less, on flight where no hand baggage is carried in the cabin or where hand baggage is accounted for separately, 6 kg may be deducted from male and female masses given in table 2.

Corrections have to be made if the actual weight of passengers with their hand baggage is known or if the average weight can be estimated as obviously different than the standard weight given above.

When the passenger checked baggage (loaded in the cargo compartment) are not weighed, the following standard weight per piece of checked baggage is used:

Table 3: Mass values for each piece of check baggage
Aeroplane with 20 passenger seats or more

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

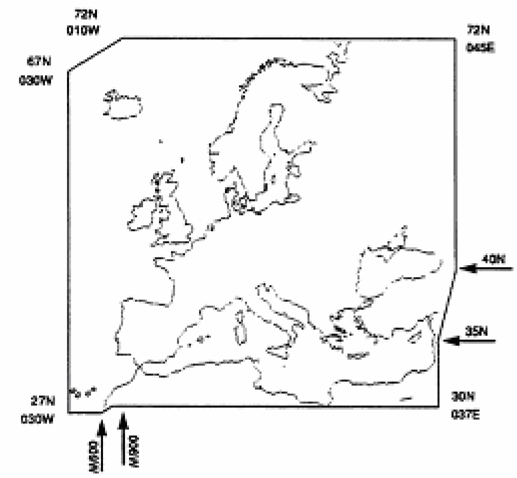
Notes:

1 - For aeroplanes with 19 passenger seats or less, the actual mass of checked baggage, determined by weighing, must be used i.e. table 3 is not applicable.

2 - Domestic flight means a flight with origin and destination within the borders of one State;

3 - Flights within the European region means flights, other than Domestic flights, whose origin and destination are within the area bounded by rhumb lines between the following points:

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



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

- “Jet Transport Performance Methods”, D6-1420, The Boeing Company
- “Introduction to Jet Engine Fundamentals, Pratt & Whitney
- “Airplane Performance”, Deutsche Lufthansa AG
- “Performance Engineers Training Manual”, The Boeing Company
- “The Flight Engineers Manual”, Zweng Company
- “Flight Crew Operations Manual (FCOM) Boeing 737-3/4/5” D6-27370,, The Boeing Company