SHA-SHIB GROUP OF INSTITUTIONS

Training Notes

Module 11- Turbine Aeroplane Aerodynamics, Structures & Systems

FOREWORD

- The information in this book is for study/ training purposes only and no revision service will be provided to the holder.

- While carrying out a procedure/ work on aircraft/ aircraft equipment you must always refer to the relevant Aircraft Maintenance Manual or Equipment Manufacturer's Handbook.

- For health and safety in the workplace you should follow the regulations/ Guidelines as specified by the Equipment Manufacturer, your company, National Safety Authorities and National Governments.

nowledge Levels – Category A, B1, B2, B3 and C Aircraft Maintenance Licence

Basic knowledge for categories A, B1, B2 and B3 are indicated by the allocation of knowledge levels indicators (1, 2 or 3) against each application subject. Category C applicants must meet either the category B1 or the category B2 basic knowledge levels.

The knowledge level indicators are defined as follows:

LEVEL 1

- A familiarization with the principal elements of the subject.

Objectives: The applicant should be familiar with the basic elements of the subject.

- The applicant should be able to give a simple description of the whole subject, using common words and examples.
- The applicant should be able to use typical terms.

LEVEL 2

- A general knowledge of the theoretical and practical aspects of the subject.
- An ability to apply that knowledge.

Objectives: The applicant should be able to understand the theoretical fundamentals of the subject.

- The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
- The applicant should be able to use mathematical formulae in conjunction with physical laws describing the subject.
- The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
- The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

LEVEL 3

- A detailed knowledge of the theoretical and practical aspects of the subject.
- A capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives: The applicant should know the theory of the subject and interrelationships with other subjects.

- The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.
- The applicant should understand and be able to use mathematical formulae related to the subject.
- The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.
- The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.
- The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.

: DGCA MODULARISATION :-

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CAR – 66 ISSUE II R 2

(LICENSING OF AIRCRAFT MAINTENANCE ENGINEERS)

DIRECTORATE GENERAL OF CIVIL AVIATION

TECHNICAL CENTRE, OPP SAFDURJUNG AIRPORT, NEW DELHI

Modules	Subject	A or B1 Aero plane with		A or B1 Helicopter with		B2
		Turbine Engine (s)	Piston Engine (s)	Turbine Engine (s)	Piston Engine (s)	Avionics
1	Not Applicable					
2	Not Applicable					
3	ELECTRICAL FUNDAMENTALS	X	X	X	X	X
4	ELECTRONIC FUNDAMENTALS	X	X	X	X	X
5	DIGITAL TECHNIQUES ELECTRONIC INSTRUMENT SYSTEMS	X	X	X	X	X
6	MATERIALS AND HARDWARE	X	X	X	X	X
7A	MAINTENANCE PRACTICES	X	X	X	X	X
7B	MAINTENANCE PRACTICES					
8	BASIC AERODYNAMICS	X	X	X	X	X
9A	HUMAN FACTORS	X	X	X	X	X
9B	HUMAN FACTORS					
10	AVIATION LEGISLATION	X	X	X	X	X
11A	TURBINE AEROPLANE AERODYNAMICS, STRUCTURES AND SYSTEMS	X				
11B	PISTON AEROPLANE AERODYNAMICS, STRUCTURES AND SYSTEMS		X			
11C	PISTON AEROPLANE AERODYNAMICS, STRUCTURES AND SYSTEMS					
12	HELICOPTER AERODYNAMICS, STRUCTURES AND SYSTEMS			X	X	
13	AIRCRAFT AERODYNAMICS, STRUCTURES AND SYSTEMS					X
14	PROPULSION					X
15	GAS TURBINE ENGINE	X		X		
16	PISTON ENGINE		X		X	
17A	PROPELLER	X	X			
17B	PROPELLER					

MODULE 11A.Turbine Aeroplane Aerodynamics, Structures & Systems		LEVEL	
		B1.1	B2
11.1	**11.1 Theory of Flight** **11.1.1 Aeroplane Aerodynamics and Flight Controls** Operation and effect of: — roll control: ailerons and spoilers; — pitch control: elevators, stabilators, variable incidence stabilisers and canards; — yaw control, rudder limiters; Control using elevons, ruddervators; High lift devices, slots, slats, flaps, flaperons; Drag inducing devices, spoilers, lift dumpers, speed brakes; Effects of wing fences, saw tooth leading edges; Boundary layer control using, vortex generators, stall wedges or leading edge devices; Operation and effect of trim tabs, balance and antibalance (leading) tabs, servo tabs, spring tabs, mass balance, control surface bias, aerodynamic balance panels; **11.1.2 High Speed Flight** Speed of sound, subsonic flight, transonic flight, supersonic flight, Mach number, critical Mach number, compressibility buffet, shock wave, aerodynamic heating, area rule; Factors affecting airflow in engine intakes of high speed aircraft; Effects of sweepback on critical Mach number.	2	-
11.2	**11.2 Airframe Structures — General Concepts** (a) Airworthiness requirements for structural strength; Structural classification, primary, secondary and tertiary; Fail safe, safe life, damage tolerance concepts; Zonal and station identification systems; Stress, strain, bending, compression, shear, torsion, tension, hoop stress, fatigue; Drains and ventilation provisions; System installation provisions; Lightning strike protection provision. Aircraft bonding (b) Construction methods of: stressed skin fuselage, formers, stringers, longerons, bulkheads, frames, doublers, struts, ties, beams, floor structures, reinforcement, methods of skinning, anti-corrosive protection, wing, empennage and engine attachments; Structure assembly techniques: riveting, bolting, bonding Methods of surface protection, such as chromating, anodising, painting; Surface cleaning. Airframe symmetry: methods of alignment and symmetry checks.	2	-
11.3	**11.3 Airframe Structures — Aeroplanes** **11.3.1 Fuselage (ATA 52/53/56)** Construction and pressurisation sealing; Wing, stabiliser, pylon and undercarriage attachments; Seat installation and cargo loading system; Doors and emergency exits: construction, mechanisms, operation and safety devices; Windows and windscreen construction and mechanisms. **11.3.2 Wings (ATA 57)** Construction; Fuel storage; Landing gear, pylon, control surface and high lift/drag attachments. **11.3.3 Stabilisers (ATA 55)** Construction;	2	-

	Control surface attachment. **11.3.4 Flight Control Surfaces (ATA 55/57)** Construction and attachment; Balancing — mass and aerodynamic. **11.3.5 Nacelles/Pylons (ATA 54)** Construction; Firewalls; Engine mounts.		
11.4	**11.4 Air Conditioning and Cabin Pressurisation (ATA 21)** **11.4.1 Air supply** Sources of air supply including engine bleed, APU and ground cart; **11.4.2 Air Conditioning** Air conditioning systems; Air cycle and vapour cycle machines Distribution systems; Flow, temperature and humidity control system. **11.4.3 Pressurisation** Pressurisation systems; Control and indication including control and safety valves; Cabin pressure controllers. **11.4.4 Safety and warning devices** Protection and warning devices.	2	-
11.5	**11.5 Instruments/Avionic Systems** **11.5.1 Instrument Systems (ATA 31)** Pitot static: altimeter, air speed indicator, vertical speed indicator; Gyroscopic: artificial horizon, attitude director, direction indicator, horizontal situation indicator, turn and slip indicator, turn coordinator; Compasses: direct reading, remote reading; Angle of attack indication, stall warning systems; Glass Cockpit Other aircraft system indication. **11.5.2 Avionic Systems** Fundamentals of system lay-outs and operation of; Auto Flight (ATA 22); Communications (ATA 23); Navigation Systems (ATA 34).	2	-
11.6	**11.6 Electrical Power (ATA 24)** Batteries Installation and Operation; DC power generation; AC power generation; Emergency power generation; Voltage regulation; Power distribution; Inverters, transformers, rectifiers; Circuit protection. External/Ground power;	3	-
11.7	**11.7 Equipment and Furnishings (ATA 25)** (a) Emergency equipment requirements; Seats, harnesses and belts. (b) Cabin lay-out; Equipment lay-out; Cabin Furnishing Installation; Cabin entertainment equipment; Galley installation; Cargo handling and retention equipment; Airstairs.	2	-
11.8	**11.8 Fire Protection (ATA 26)** **(a)** Fire and smoke detection and warning systems; Fire extinguishing systems;	3	-

	System tests. **(b)** 1 Portable fire extinguisher		
11.9	**11.9 Flight Controls (ATA 27)** Primary controls: aileron, elevator, rudder, spoiler; Trim control; Active load control; High lift devices; Lift dump, speed brakes; System operation: manual, hydraulic, pneumatic, electrical, fly-by-wire; Artificial feel, Yaw damper, Mach trim, rudder limiter, gust locks systems; Balancing and rigging; Stall protection/warning system.	3	-
11.10	**11.10 Fuel Systems (ATA 28)** System lay-out; Fuel tanks; Supply systems; Dumping, venting and draining; Cross-feed and transfer; Indications and warnings; Refuelling and defuelling; Longitudinal balance fuel systems.	3	-
11.11	**11.11 Hydraulic Power (ATA 29)** System lay-out; Hydraulic fluids; Hydraulic reservoirs and accumulators; Pressure generation: electric, mechanical, pneumatic; Emergency pressure generation; Filters Pressure Control; Power distribution; Indication and warning systems; Interface with other systems.	3	-
11.12	**11.12 Ice and Rain Protection (ATA 30)** Ice formation, classification and detection; Anti-icing systems: electrical, hot air and chemical; De-icing systems: electrical, hot air, pneumatic and chemical; Rain repellant;Probe and drain heating. Wiper systems	3	-
11.13	**11.13 Landing Gear (ATA 32)** Construction, shock absorbing; Extension and retraction systems: normal and emergency; Indications and warning; Wheels, brakes, antiskid and autobraking; Tyres; Steering. Air-ground sensing	3	-
11.14	**11.14 Lights (ATA 33)** External: navigation, anti-collision, landing, taxiing, ice; Internal: cabin, cockpit, cargo; Emergency.	3	-
11.15	**11.15 Oxygen (ATA 35)** System lay-out: cockpit, cabin; Sources, storage, charging and distribution; Supply regulation; Indications and warnings;	3	
11.16	**11.16 Pneumatic/Vacuum (ATA 36)** System lay-out; Sources: engine/APU, compressors, reservoirs, ground supply; Pressure control; Distribution;	3	-

	Indications and warnings; Interfaces with other systems.		
11.17	**11.17 Water/Waste (ATA 38)** Water system lay-out, supply, distribution, servicing and draining; Toilet system lay-out, flushing and servicing; Corrosion aspects.	3	-
11.18	**11.18 On Board Maintenance Systems (ATA 45)** Central maintenance computers; Data loading system; Electronic library system; Printing; Structure monitoring (damage tolerance monitoring).	2	-
11.19	**11.19 Integrated Modular Avionics (ATA42)** Functions that may be typically integrated in the Integrated Modular Avionic (IMA) modules are, among others: Bleed Management, Air Pressure Control, Air Ventilation and Control, Avionics and Cockpit Ventilation Control, Temperature Control, Air Traffic Communication, Avionics Communication Router, Electrical Load Management, Circuit Breaker Monitoring, Electrical System BITE, Fuel Management, Braking Control, Steering Control, Landing Gear Extension and Retraction, Tyre Pressure Indication, Oleo Pressure Indication, Brake Temperature Monitoring, etc.	3	-
11.20	**11.20 Cabin Systems (ATA44)** The units and components which furnish a means of entertaining the passengers and providing communication within the aircraft (Cabin Intercommunication Data System) and between the aircraft cabin and ground stations (Cabin Network Service). Includes voice, data, music and video transmissions. The Cabin Intercommunication Data System provides an interface between cockpit/cabin crew and cabin systems. These systems support data exchange of the different related LRU's and they are typically operated via Flight Attendant Panels. The Cabin Network Service typically consists on a server, typically interfacing with, among others, the following systems: — Data/Radio Communication, In-Flight Entertainment System. The Cabin Network Service may host functions such as: — Access to pre-departure/departure reports, — E-mail/intranet/Internet access, — Passenger database; Cabin Core System; In-flight Entertainment System; External Communication System; Cabin Mass Memory System; Cabin Monitoring System; Miscellaneous Cabin System.	3	-
11.21	**11.21 Information Systems (ATA46)** The units and components which furnish a means of storing, updating and retrieving digital information traditionally provided on paper, microfilm or microfiche. Includes units that are dedicated to the information storage and retrieval function such as the electronic library mass storage and controller. Does not include units or components installed for other uses and shared with other systems, such as flight deck printer or general use display. Typical examples include Air Traffic and Information Management Systems and Network Server Systems	3	-

	Aircraft General Information System; Flight Deck Information System; Maintenance Information System; Passenger Cabin Information System; Miscellaneous Information System.		

Module 11A: Enabling Objectives and Certification Statement

Certification Statement

These Study Notes comply with the syllabus of DGCA, CAR – 66 (Appendix I) and the associated Knowledge Levels as specified.

REVISION LOG

TABLE OF CONTENTS

11.1 THEORY OF FLIGHT

11.1.1.AEROPLANE AERODYNAMICS AND FLIGHT CONTROLS

THE ATMOSPHERE

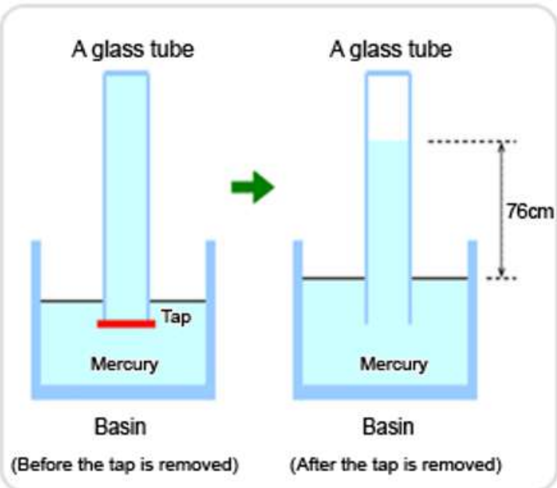
The earth‘s atmosphere is composed of about 78 percent nitrogen and 21 percent oxygen. The remaining 1 percent is made up of several other gases, primarily argon and carbon dioxide. The percentage of these gases remains constant regardless of their altitude. The atmosphere also contains some water vapour, but the amount varies from almost zero to about five percent by volume.

In order to have a reference for all aerodynamic computations, the International Civil Aviation Organization (ICAO) has agreed upon a standard atmosphere. The pressures, temperatures, and densities in a standard atmosphere serve as a reference only. When all aerodynamic computations are related to this standard, a meaningful comparison of flight test data between aircraft can be made.

Standard atmospheric conditions are based on a sea level temperature of 15C or 59^, and a barometric pressure of 29.92 inches of mercury or 1013.2 Millibars. Pressure and temperature normally decrease with increases in altitude. The standard pressure lapse rate for each 1,000 feet of altitude change is approximately 1.00 inch of mercury, whereas the standard temperature lapse rate per 1,000 -foot changeinaltitudeis2—Cor3.51=.

STATIC PRESSURE

The atmosphere is the whole mass of air extending upward hundreds of miles. It may be compared to a pile of blankets. The air in the higher altitudes, like the top blanket of the pile, is under much less pressure than the air at the lower altitude. The air at the earth‘s surface may be compared to the bottom blanket because it supports the weight of all the layers above it. The static pressure of the air at any altitude results from the mass of air supported above that level.



The term pressure may be defined as force acting upon a unit area. for example is pressure of 5 lb is acting against an area of 1 in, there is a pressure of 5 psi(pounds per square inch); if a force of 20 is lb is acting against an area of 2 in the pressure is 10 psi . Air is always pressed down by the weight of the air above it. The atmospheric pressure at any place is equal to the weight of the column of air above is and may be represented by a column of water of mercury of equal weight. If the cube shape box has dimensions of 1 in2 on all sides and is filled with mercury, the weight of the mercury, the weight of the mercury will be 0.491 lb222.72 gl, and a force of 0.49lb will be acting on the square inch at the bottom of the box. This means that there will be a pressure of 0.491 psi on the bottom of the box. If the height of the box were extended to 4 in with the cross sectional area remaining at 1 in2, the pressure at the bottom would be 4 X 0.491 psi, or 1.964 psi. the pressure as measured per square inch exerted by a column of mercury does not change with the area of the cross sectional area of 10 in2 , the pressure will be 0.491 psi even though the total volume of mercury weights 4.91 lb. likewise , if the pressure will still be 0.491psi.

A —standard atmosphere was adopted by the National Advisory Committee for aeronautics (now the national aeronautics and space Administration, or NASA). This standard atmosphere is entirely arbitrary, but it provides a reference and standard of comparison and should be known by all persons engaged in work involving atmospheric conditions.

Atmospheric pressure at sea level under standard condition is
29.92 inches of mercury (in Hg), or 14.69 psi. Remember that 1 in mercury produces a pressure of 0.491 psi; therefore 29.92 in Hg will produce a pressure of 14.69 psi (0.491 X 29.92=14.69).

Atmospheric pressure may be designated by a number of different units. Those more likely to be encountered are inches of mercury, millibars (mbr), pounds per square inch, kilopascals and millimeters of mercury (mmHg). Standard atmospheric pressure at 590F (150C) is approximately as follows in the units just described.

29.92 in Hg
1013 mbar(00C)
14.69 psi
101.04 kPa(600F)(15.560C)
760 mm Hg.

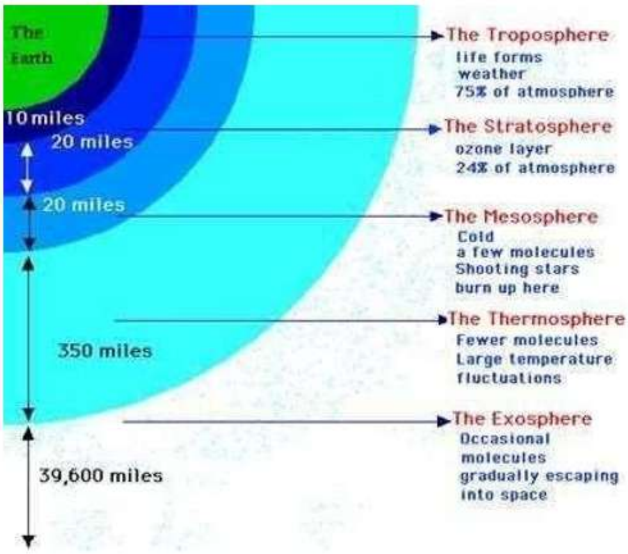
The effect of atmospheric pressure was demonstrated early in the seventeen the century by the Italian mathematician and scientist Evangelista Torricelli (1608-1647). Torricelli has worked with Galileo andhadnotedthese theories regarding the —law that nature abhors a vacuum. To explore the idea, Torricelli filled a long glass tube, having one end closed with mercury. He then placed his thumb over the open end of the tube. Holding the tube in a vertical position with the closed end up, he placed the open end of the tube in container of mercury and removed his finger from the end of the tube. Some of the mercury immediately flowed out of the tube into the container, leaving a vacuum in the upper end of the tube as indicated. The height of the column of mercury remaining in the tube was measured and found to be approximately 30 in (762mm). At sea level under standard conditions the height of such a column of mercury is 29.92 in [76mm]. Therefore we say that standard atmospheric we say that standard atmospheric pressure at sea level is 29.92 in high. Barometers and sensitive altimeters are scaled to provide pressure information in inches of mercury.

As just mentioned the space above the mercury in the tube is a vacuum this means that the pressure at this point is 0 psia. Psia indicates —pounds per square inch absolute‖. Any gauge marked for psia measures pressure form ambient pressure zero.

Atmospheric pressure passing down in the surface of any liquid will cause the liquid to rise in an evacuated tube in the same manner as mercury; however, the height to which a liquid will rise depends upon the density or specific gravity of the liquid. For example water will rise to approximately 33.9 ft (10.34m) in a completely evacuated tube. Sometimes pressure gauges are scaled for inches of water (inH20) rather than for inches of mercury because such a gauge is more sensitive and will measure lower pressure differences.

A mercury barometer is essentially a mercury- - filled glass tube scaled to show the height of a mercury column. The upper end of the tube is sealed and the lower end is exposed to the pressure being measured. The barometer can be scaled for pounds per square inch, inches of mercury, or other unit of pressure. On weather maps, approximately one thousandth of a bar. For standard purposes, the sea level is therefore the approximate atmospheric pressure at sea level. 1 inHg equals 33.86mbar

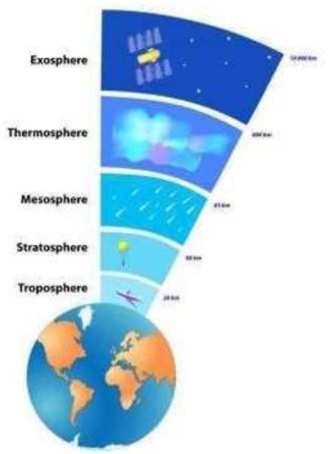
Since air has weight it is easy to recognize that the pressure of the atmosphere will vary with altitude. This is illustrated. Notice that at 20 000 ft (6097.56m) the pressure is less than half the sea level pressure. This means that more than half the atmosphere lies below the altitude of 20 000 ft even though the —outer half extends hundreds of miles above the earth.



AIR TEMPERATURE

Under standard conditions, temperature decreases at approximately 1.980C for each increase of 1000 ft (304.88m) of altitude until an altitude of 38 000 ft(11 585.44m) is reached. Above this available the temperature remains at approximately- 560C.

Textbooks on meteorology often state that the temperature normally decreases with altitude at a rate of approximately 0.50C per 100 m, or about 10F per 300ft. This amounts to a decease of about 1.520C for each increase of 100 ft, which is different form the decrease under standard conditions. Remember that the textbooks using the foregoing values are discussing average rather than standard condition.



ADIABATIC LAPS RATE

The temperature of the air decreases as pressure decreases with an increase in altitude. This decrease of temperature with altitude is flow up over mountains or from higher elevations down into valleys. As air flows to higher altitudes, it becomes cooler and as it flows to lower altitudes, it becomes warmer. This is accordance with Charles law. The adiabatic lap's rate is the increases or decrease in the temperature of the air for a given change in altitude. The adiabatic laps rate varies from 30F (1.670C per) 1000ft (304.88) for very dry air. The standard rate shown in the ICAO chart is approximately 3.50F per1000ft.

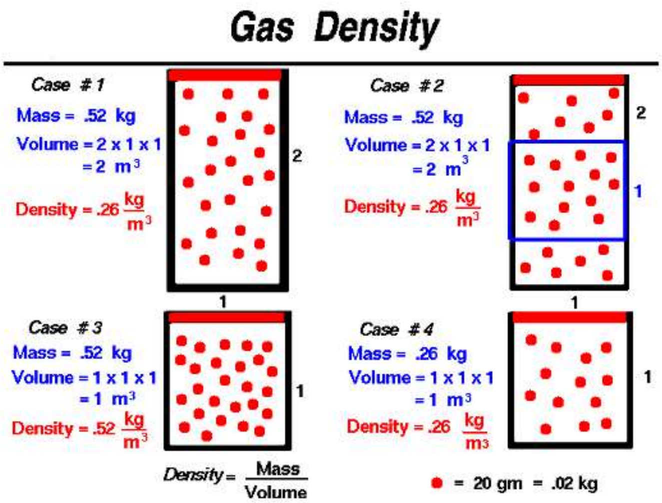
Keep in minimum the temperature of the air often does not conform to standards, for example sometimes the air temperate 1000 ft or more above the surface of the earth is higher than it is at the surface. This condition is called an inversion. Mountains clouds surface winds bodies of water and sunshine all affect the temperature of their.

DENSITY

The density of the air is a property of great importance in the study of aerodynamics. Density has defined previously however additional discussion is given here to relate density to the study of aerodynamics. Air is compressible as illustrated. As the air is compressed it be comes more dense because the same quantity of air occupies less space. Density varies directly with pressure with the temperature remaining constant. The air in cylinder B has twicethedensityoftheairincylinderA.

defined as the laps rate. An adiabatic temperature change means that the temperature of the air has changed, but the air has neither gained nor lost heat energy. The temperature change in such a case is due to a change in pressure.

Atmospheric pressure difference cause the air to flow from an areaofhigherpressuretoanareaoflowerpressure.



For the purpose of aerodynamic computations, air density is represented by the Greek letter p(rho), indicating mass density in slugs per cubic foot. The slug is a unit of mass with a value of approximately 32.175lb (14.59 kg) under standard conditions of gravity .the word mass designates the pull in standard gravitational units exerted by the earth upon a piece of matter. The difference between mass and weights is explained. Since the slug is used to indicate the density of air, it is sufficient for the technician to know that the value of p can be found in standard at atmospheric tables.

Air at standard sea level conditions weight 0.0765 lb/ft3and has a density of 0.002375 slug/ft3. At an altitude of 40 000 ft (12 192 m), the air density is approximately 25 % of the sea level value.

The general gas law defines the relationship of pressure temperature and density when there is no change of state or hear transfer. Simply stated this law says that density varies directly with pressure and inversely with temperature. On a hot day air expands becoming —thinner or less dense conversely on a cold day the air contracts becoming more dense.

Changes in air density affect the flight of an airplane. With the same thrust an airplane can fly faster at a high altitude where the density is low than at a low altitude where the density is greater. This is because the air offers less re particles of air per unit volume. This concept is illustrated. However an often encountered problem is an inability to hold the thrust constant as altitude increase. Generally engine performance will decrease with altitude.

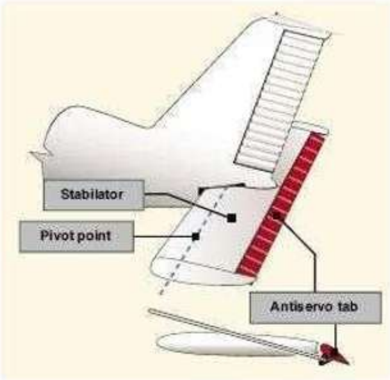
HUMIDITY

The condition of moisture of dampness in the air is called humidity. The maximum amount of water vapor that the air can hold depends on the temperature of the air the higher the temperature of the air the more water vapor it can absorb. By itself water vapor weight approximately five eights as much as an equal volume of perfectly dry air.

Therefore when air contains 5 parts of water vapor and 95 parts of perfectly dry air, it in not as heavy as air containing no moisture. This is because water is composed of hydrogen an extremely light gas and oxygen . Air is composed principally of nitrogen which is almost as heavy as oxygen .Assuming that the temperature and pressure remain the same the density of the air varies with the humidity. On damp days the density of air is less than it is on dry days.

THE EMPENNAGE

The empennage consists of the vertical stabilizer, or fin, and the horizontal stabilizer. These two surfaces are stationary and act like the feathers on an arrow to steady the Aeroplane and help you maintain a straight path through the air.

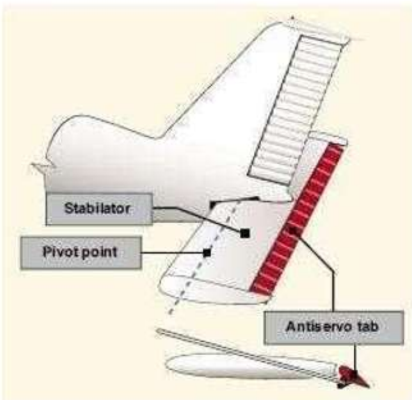


The rudder is attached to the back of the vertical stabilizer to move the aeroplane‘snose left and right. Actually, the rudder is used in combination with the ailerons during flight to initiate a turn.

The rudder has the greatest control authority of all the control surfaces. Aggressive use of the rudder by the pilot has been known to cause catastrophic failure of the aircraft structure. For this reason, large transport category aircraft incorporate Rudder Limiters, which reduce the range of movement of the rudder as the aircraft speed increases. The elevator is attached to the back of the horizontal stabilizer. During flight, the elevator is used to move the nose up and down to direct the Aeroplane to the desired altitude, or height above the ground.

STABILATOR

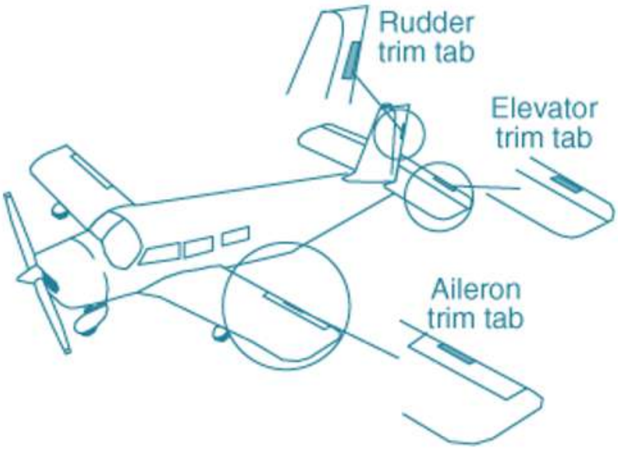
Some empennage designs vary from the type of horizontal stabilizer just discussed. They have a one-piece horizontal stabilizer that pivots up and down from a central hinge point. This type of design, called a stabilator, requires no elevator. The stabilator is moved using the control wheel, Justas you would the elevator. An anti-servo tab is mounted at the back of the stabilator, to provide a control —feel similar to what you experience with an elevator. Without the anti-servo tab, control forces from the stabilator would be very light and apolitical —over control‖theaeroplane.

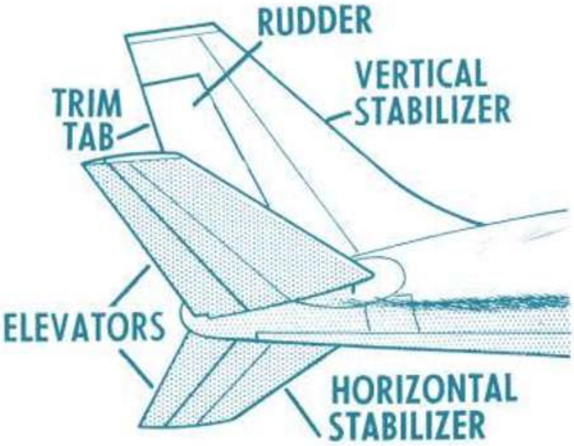


Some aircraft merge two flight controls into one system. For example, some Beechcraft Bonanza models have ruddervatorsthat combine rudders and elevators into one control surface. Depending on control inputs, the ruddervatorsmove in the same direction for pitch control, and in opposite directions for yaw control. Still other aircraft combine spoilers and aileronsintospoilerstoprovideroll.Furthermore,somedelta -wing aircraft merge elevator and aileron functions through control surfaces called elevons.

TRIM CONTROLS

Trim tabs are small movable portions of the trailing edge of the control surface. These movable trim tabs are controlled from the cockpit and alter the control surface camber to create an aerodynamic force that deflects the control surface. Trim tabs can be installed on any of the primary control surfaces. If only one tab is used, it is normally on the elevator. This is used to adjust the tail load so the Aeroplane can be flown hands-off at any given airspeed.





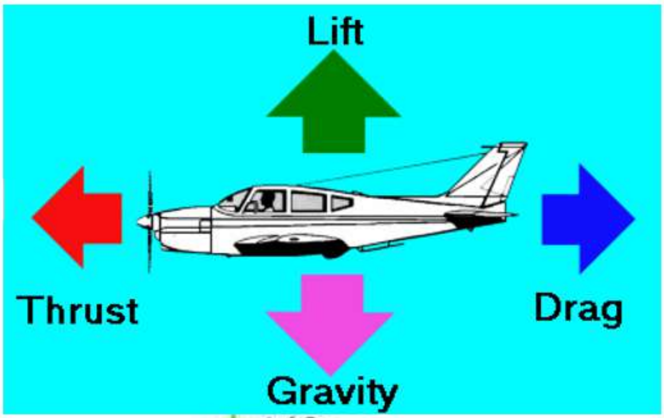
A fixed trim tab is normally a piece of sheet metal attached to the trailing edge of a control surface. This fixed tab is adjusted on the ground by bending it in the appropriate direction to eliminate flight control forces for a specific flight condition. The fixed tab is normally adjusted for zero-control forces in cruise flight. Adjustment of the tab is a trial-and-error process where the aircraft must be flownand the trim tab adjusted based on the pilot's report. The aircraft must then be flown again to see if further adjustment is necessary. Fixed tabs, normally found on light aircraft, are used to adjust rudders and ailerons.

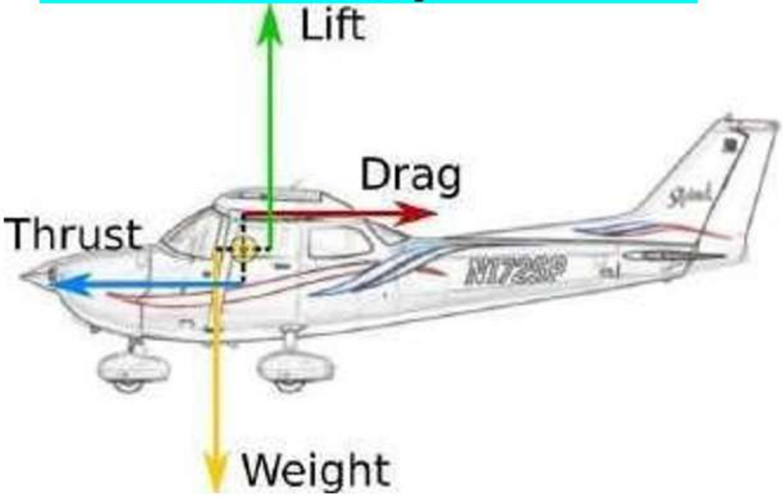
Large aircraft obviously require larger control surfaces, and more force is required to move them. To assist in moving these larger surfaces, control tabs are mounted on the trailing edges of the control surfaces. For example, a servo tab is connected directly to an aircraft's flight controls and moves in a direction opposite the desired control surfacemovement.

As thetab deflects into the air stream,it forces the control surface in the opposite direction. Balance tabs receive no control inputs, but are connected to a main structure. When a control is activated, the balance tab deflects into the airstream and helps move the controlsurface.

FOUR FORCES OF FLIGHT

During flight, there are four forces acting on an Aeroplane. They are lift, weight, thrust, and drag. Lift is the upward force created by the effect of airflow as it passes over and under the wings. It supports the Aeroplane in flight. Wei gateposts lift. It is caused by the downward pull of gravity. Thrust is the forwardforcewhichpropelstheaeroplanethroughtheair.



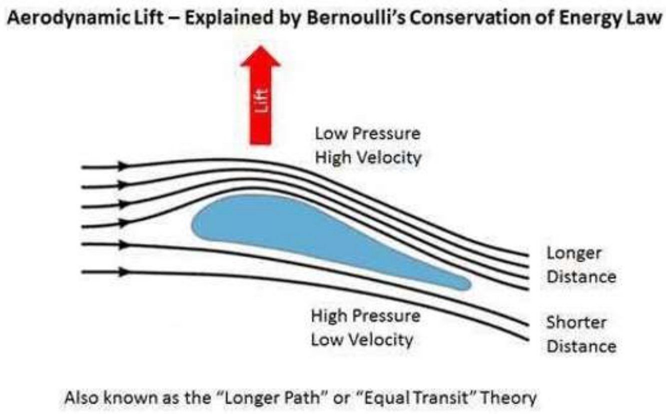


It varies with the amount of engine power being used. Opposing thrust is drag, which is a backward or retarding force that limits the speed of theaeroplane.

The arrows which show the forces acting on an Aeroplane are often called vectors. The magnitude of a vector is indicated by the arrow‘s length, while the direction is shown by the arrow‘s orientation. When two or more forces act on an object at the same time, they combine to create resultant.

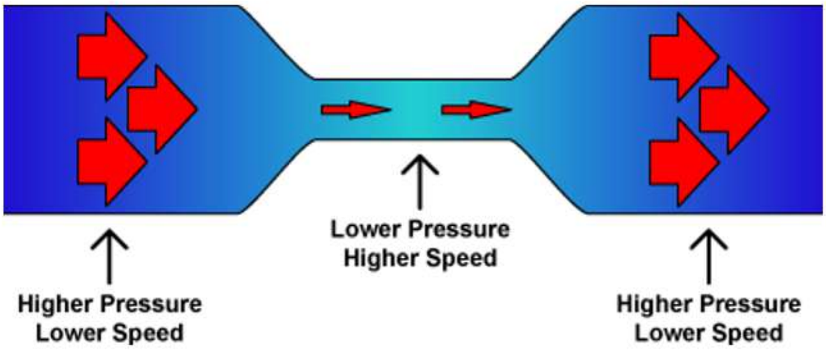
LIFT

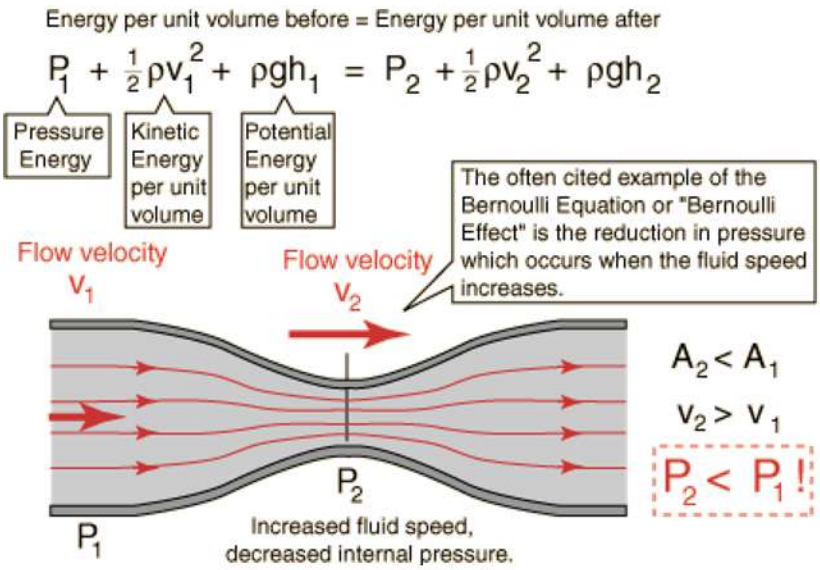
Lift is the key aerodynamic force. It is the force that opposes weight. In straight-and-level, unaccelerated flight, when weight and lift are equal, an aeroplane is in a state of equilibrium. If the other aerodynamic factors remain constant, the aeroplane neither gains nor losesaltitude.

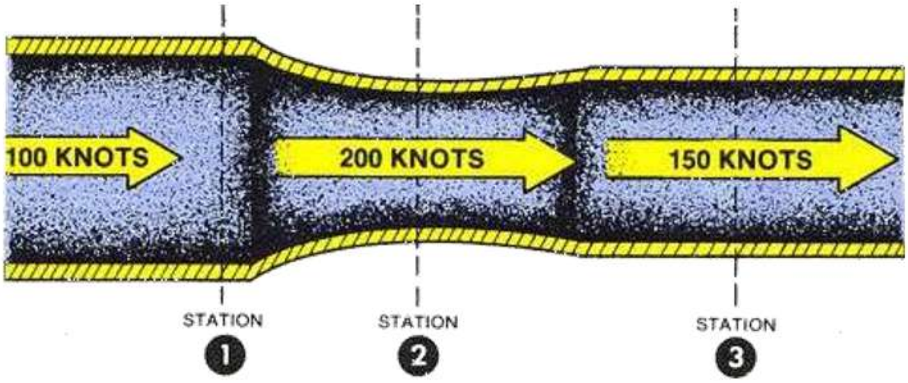


During flight, the pressures on the upper and lower surfaces of the wing are not the same. Although several factors contribute to this difference, the shape of the wing is the principle one. The wing is designed to divide the airflow into areas of high pressure below the wing and areas of comparatively lower pressure above the wing. This pressure differential, which is created by movement of air about the wing, is the primary source oflift.

BERNOULLI'S PRINCIPLE







Venturi effect.

The basic principle of pressure differential of subsonic airflow was discovered by Daniel Bernoulli, a Swiss physicist. Bernoulli's Principle, simply stated, says, —As the velocity of a fluid (air) increases, its internal pressure decreases.‖

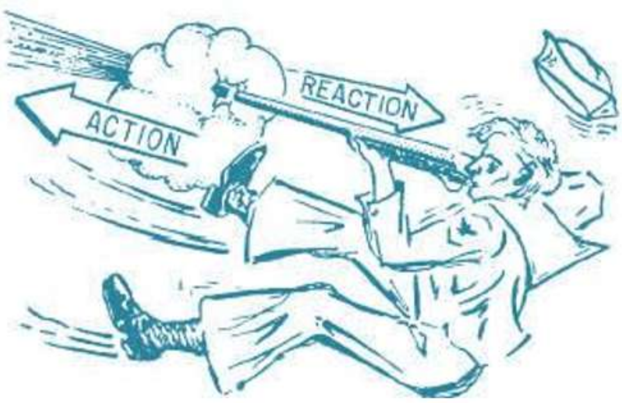
One way you can visualize this principle is to imagine air flowing through a tube that is narrower in the middle than at the ends. This type of device is usually called aventuri.

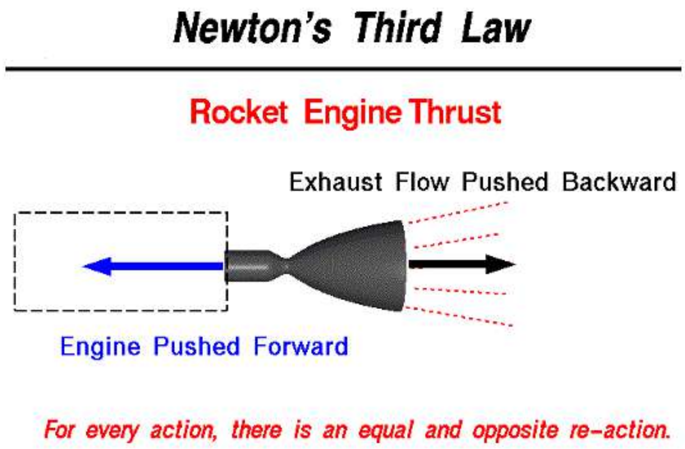
It is not necessary for air to pass through an enclosed tube for Bernoulli's Principle to apply. Any surface that alters airflow causes a venturi effect. For example, if the upper portion of the tube is removed, the venturi effect applies to air flowing along the lower section of the tube. Velocity above the curvature is increased and pressure is decreased. You can begin to see how the venturi effect works on a wing, or aerofoil, if you picturean aerofoilinset in the curved part of thetube.

Air flowing over the top of an aerofoil reaches the trailing edge in the same amount of time as air flowing along the relatively flat bottom. Since both the upper and lowersurfaces
pass through a block of air at the same speed, the air flowing over the curved upper surface travels further. This means it must go faster, resulting in lower pressure above the aerofoiland a greater pressure below. An aerofoilis specially designed to produce a reaction with the air that passes over it. This difference in pressure is the main source oflift.

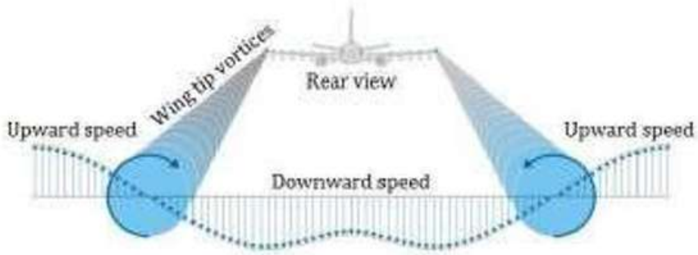
NEWTON'S THIRD LAW OF MOTION

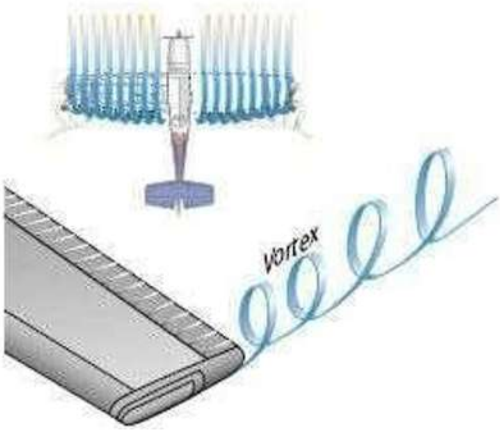
The remaining lift is provided by the wing's lower surface as air striking the underside is deflected downward. According to Newton's Third Law of Motion, —for every action there is an equal am opposite reaction.‖ Therefore, the air that is deflected downward by the wing also produces an upward (lifting) reaction.Sinceair is much like water, the explanation for this source of lift may be compared to the planingeffect of skis on water. The lift which supports the water skis (and the skier) is the force caused by the impact pressure and the deflection of water from the lower surfaces of theskis. most flying conditions, the impact pressure and the deflection of air from the lower surface of the wing provide a comparatively small percentage of the total lift. The majority of lift is the result of the decreased pressure above the wing rather than the increased pressure belowit.





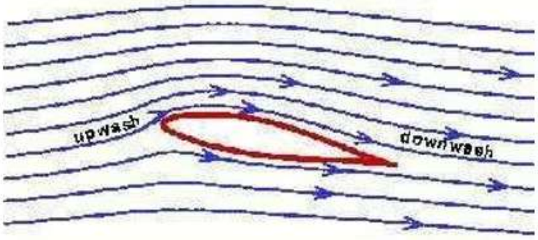
WINGTIP VORTICES
Wingtip vortices are caused by the air beneath the wing rolling up and around the wingtip. This causes a spiral or vortex that trails behind each wingtip whenever lift if being produced.

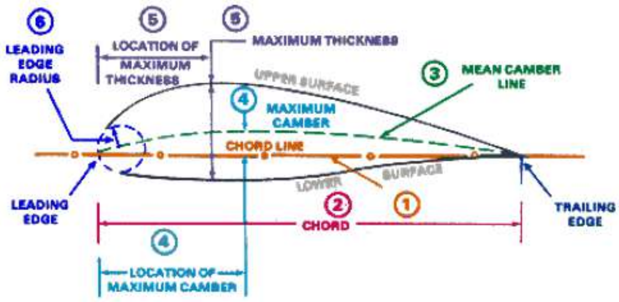




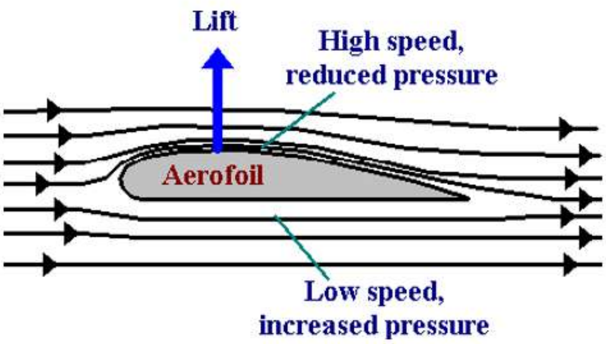
It results in a type of drag which is associated with, and proportional to, the amount of lift, called induced drag (or _lift dependant drag‘ or _vortex drag‘). The effect is greatest at low speed with high lift devices deployed, and a high wing loading. It is discussed later in thissection. and down-wash refer to

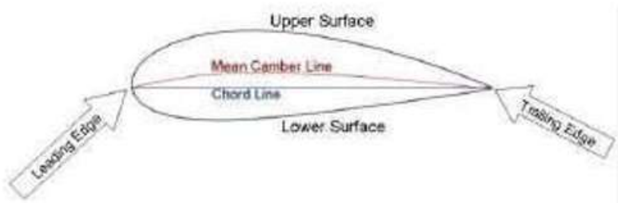
the effect an aerofoil exerts on the free airstream. Upwash is the deflectionoftheoncoming airstream upward and over the wing. Downwash is the downward deflection of the airstream as it passes over the wing and past the trailingedge.





AIRFOIL TERMINOLOGY





AEROFOIL

An aerofoilis any surface, such as a wing or propeller that provides aerodynamic force when it interacts with a moving stream of air. Remember, an aeroplane'swing generates a lifting force only when it is in motion about it. Some of the terms used to describe the wing, and the interaction of the airflow about it, are listed here.

LEADINGEDGE

This part of the aerofoil meets the airflowfirst.

TRAILINGEDGE

This is the portion of the aerofoil where the airflow over the upper surface rejoins the lower surfaceairflow.

CHORDLINE

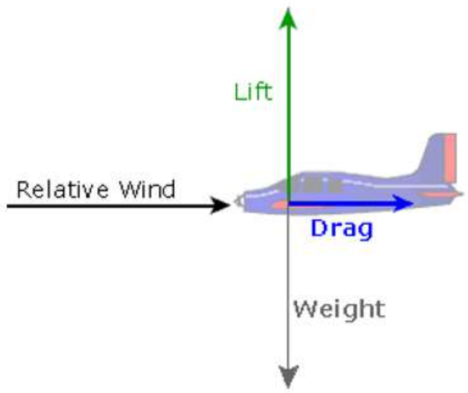
The chord line is an imaginary straight line drawn through an aerofoilfrom the leading edge to the trailingedge.

CAMBER

The camber of an aerofoilis the characteristic curve of its upper and lower surfaces. The upper camberis more pronounced, while the lower camberis comparatively flat. This causes the velocity of the airflow immediately above the wing to be much higher than that below thewing.

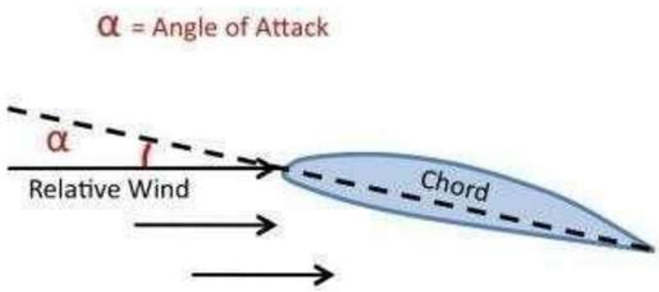
RELATIVEWIND

This is the direction of the airflow with respect to the wing. If a wing moves for- ward horizontally, the relative wind moves backward horizontally. Relative wind is parallel to and opposite the flight path of theaeroplane.



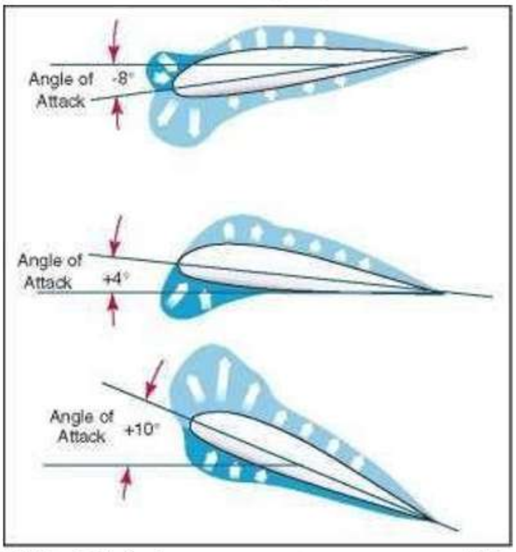
ANGLE OFATTACK

This is the angle between the chord line of the aerofoiland the direction of the relative wind, Itis important in the production of lift. The angle formed by the wing chord line and relative wind is called the angle ofattack.



CHANGING OF ANGLE OF ATTACK

Pilots have direct control over angle of attack. During flight at normal operating speeds, if a pilot increasestheangleof attack, lift increases. The angle of attack is changed anytimethecontrolcolumnismovedforeoraftduringflight. Atthe same time, the coefficient of lift is



changed. The coefficient of lift (CL) is a way to measure lift as it relates to angle of attack. CLis determined by wind tunnel tests and is based on aerofoil shape and angle of attack. Every aero plane has an angle of attack where maximum liftoccurs.

A stall is caused by the separation of airflow from the wing's upper surface. This results in a rapid decrease in lift. For a given aeroplane, a stall always occurs at the same angle of attack (known as the ‗critical angle'), regardless of airspeed, flight attitude, or weight. This is the stalling or critical angle of attack. It is important to remember that an aero plane can stall at any airspeed, in any flight attitude, or at any weight.

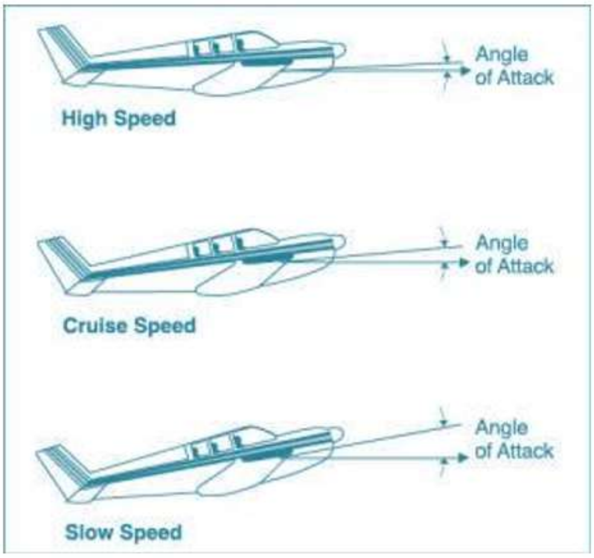
To recover from a stall, smooth airflow must be restored. The only way to do this is to decrease the angle of attack to a point below the stalling or critical angle of attack.

CHANGING AIRSPEED

The faster the wing moves through the air, the greater the lift. Actually, lift is proportional to the square of the aeroplane's speed. For example, at 200 knots, an aeroplane has four times the lift of the same aeroplane travelling at 100 knots if the angle of attack and other factors are constant. On theother hand, if the speed is reduced by one-half, lift is decreased to one-quarter of the previousvalue.

ANGLE OF ATTACK AND AIRSPEED

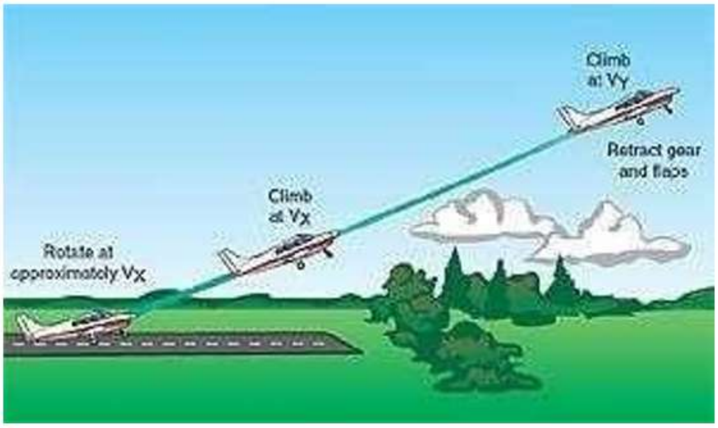
The relationship between angle of attack and airspeed in the production of lift is not as complex as it may seem. Angle of attack establishes the coefficient of lift for the aerofoil. At the same time, lift is proportional to the square of the aeroplane'sspeed. Therefore, total lift depends on the combined effects if airspeed and angle of attack. In other words, when speed decreases, the angle of attack must increase to maintain thesame amount of lift. Conversely, if the same amount of lift is maintained at a higher speed, the angleofattackmust decrease.

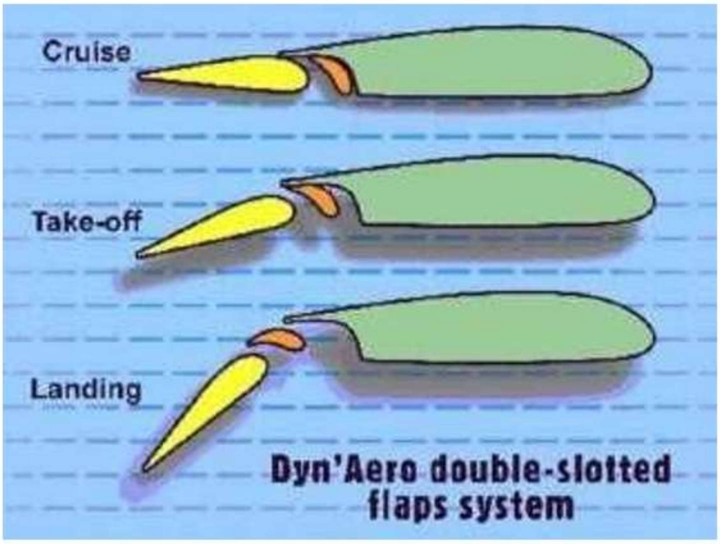


USING FLAPS

When properly used, flaps increase the lifting efficiency of the wing and decrease stall speed. This allows the aircraft to fly at a reduced speed while maintaining sufficient control and lift for sustained flight. The ability to fly slowly is particularly important during the approach and landing phases. For example, an approach with full flaps allows the aircraft to fly slowly and at a fairly steep descent angle without gaining airspeed. This allows for touch down at slower speed.

In aeroplanes, ―configuration‖normally refers to the position of the landing gear and flaps. When the gear and flaps are up, an aeroplane is in a clean configuration. If the gear is fixed rather than retractable, the aeroplane is considered to be in a clean configuration when the flaps are in the up position. Flap position affects the chord line and angle of attack for that section of the wing where the flaps are attached. Thiscauses an increase in camber for that section of the, wing and greater production of lift and drag. There are several common types of flaps. The plain flap is attached to the wing by a hinge. When deflected downward, it increases the effective camber and changes the wing‘s chord line.

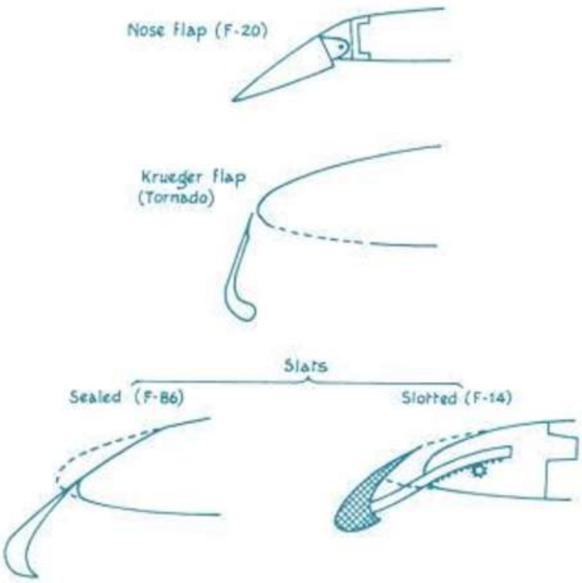




Both of these factors increase the lifting capacity of the wing. The split flap is hinged only to the lower portion of the wing. This type of flap also increases lift, but it produces greater drag than the plain flap because of the turbulence it causes. Theslotted flap is similar to the plain flap. In addition to changing the wing's camber and chord line, it also allows a portion of the higher pressureair beneath the wing to travel through a slot. This increases the velocity of the airflow over the flap and provides additional lift. Another type of flap is the Fowler flap. It is attached to the wing by a track and roller system. When extended, it moves rearward as well as down. This rearward motion increases the total wing area, as well as the camber and chord line. The Fowler flap is the most efficient of these systems. As you might expect, it also is the most expensive.

USING LEADING EDGE DEVICES

A stall occurs when the angle of attack becomes so great thatthe energy in the air flowing over the wing can no longer pullair down to the surface. The boundary layer thickens and becomes turbulent, and airflow separates from the surface.This separation can be delayed until a higher angle of attack by increasing the energy of air flowing over the surface. One way to do this is by installing a slot in the leading edge of the wing. This slot is simply a duct for air to flow from below the wing to the top. Once there, it is directed over the surface in a high- velocity stream. Slots are typically placed ahead of the aileron to keep the outer portion of the wing flying after the root has stalled. This maintains aileron effectivenessandprovides lateral control during most of thestall. high-performance aircraft utilize slats which are mounted on the leading edge on tracks. These extend outward and create a duct to direct high-energy air down over the surface. This delays separation until a very high angle of attack.



In many aircraft these slats are actuated by aerodynamic forces and are entirely automatic in their operation. As the angle of attack increases, the low pressure just behind the leading edge on top of the wing increases. This pulls the slat out of the wing. When the slat moves out, it ducts the air from the high-pressure area below the wing to the uppersurfaceandincreases the velocity of air in the boundary layer. When the angle of attack is lowered, air pressure on the slat moves it back into the wing where it has no effect onairflow.

Some aircraft have slats operated by eitherhydraulicorelectric actuators. They are lowered when the trailing edge flaps are lowered to prevent airflow from breaking away from the upper surface. Flaps used with slats are slotted and they duct high-energy air over the deflected flap sections so the air will not break away over theirsurface.

On some aircraft, the leading edge of the wing deflects downward to increase camber. These leading edge flaps are electrically or hydraulically actuated and are usedin conjunction with the trailing edge flaps. The swept wings of large turbine-engine transports develop little lift atlow

speeds. To remedy this problem, leading edge devices called Krueger flaps are usedtoeffectively increase a wing's camber and hence its lift. A Krueger flap is hinged to a wing's leading edge and lays flush to its lower surface when stowed. When the flap is deployed, it extends down and forward to alter the wingprofile.

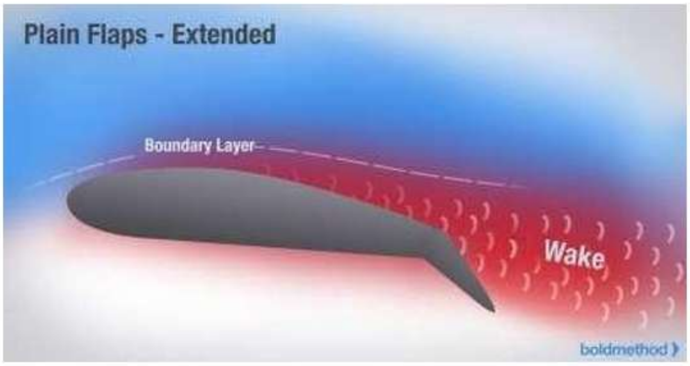
WING FLAPS

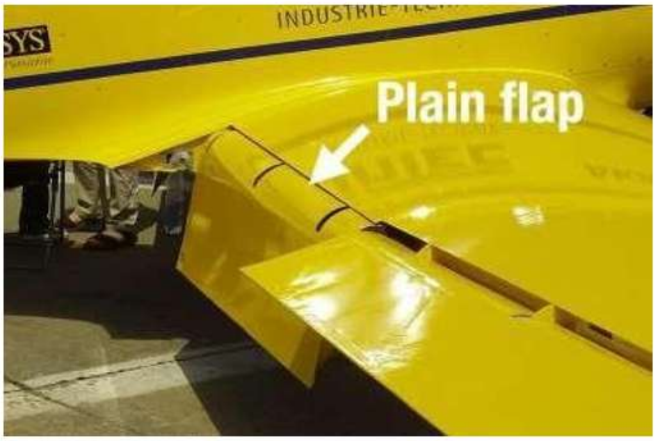
A wing flap is defined by NASA as a hinged, pivoted or sliding airfoil usually near the trailing edge of the wing. It is designed to increase the lift, drag, or both when deflected and is used principally for landing, although large airplanes use partial flap deflection for takeoff. Most flaps are usually 15 to 25 % of the airfoil's chord. The deflection of a flap produces the effect of adding a large amount of camber well aft on the chord. The more camber that the airfoil has results in a greater pressure differential and the creation of more lift. This makes it possible for the airplane to have a steeper angle of descent for the landing without increasing the air speed. Flaps are normally installed on the inboard section of the wing trailingedge.

Some of the basic types of flap are

1. PLAIN FLAP

The plain flap in effect acts as if the trailing edge of the wing were deflected downward to change the camber of the wing, thus causing a significant increase in both the coefficients of lift and dag. If the flap is moved down sufficiently it becomes an effective air brake.



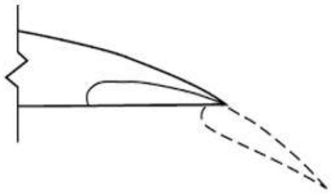


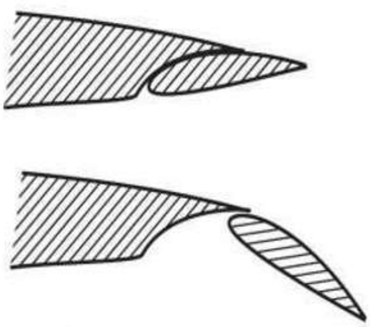
2. SPLIT – EDGEFLAP

Is usually housed flush with the lower surface of the wing immediately forward of the trailing edge. This flap is illustrated. The split edge flap is usually nothing more than a flat metal plate hinged along is forward edge. The split edge flap produces a slightly greater change in lift than the plain flap. However a much larger change in drag results from the great turbulent wake produced by this types of flap.

3. FOWLER FLAP

The flower flap which is constructed so that the lower part of the trailing edge of the wing rolls back on a track, thus increasing the effective area of the wing and at the same time lowering the trailing edge. The flap itself is a small air foil that fits neatly into the trailing edge of the main wing when closed. When the flap opens, the small airfoil slides downward and backward on tracks until it reaches the position desired, thus providing a wing with a variable coefficient of lift and a variable area with the



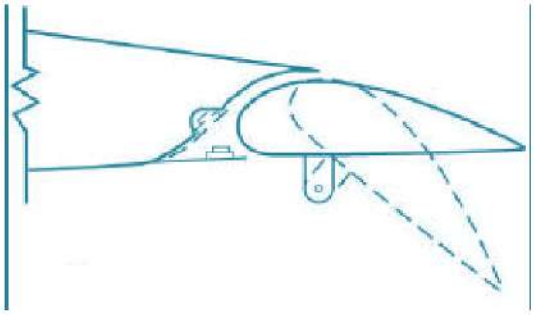


Fowler flap.

fowler flap the wing area can be increases in drag, the exact amount of increase of each depending upon the angle to which the flap is lowered. The flower flap is one of the designs which are particularlywelladaptedforusedattakeoffaswellaslanding.

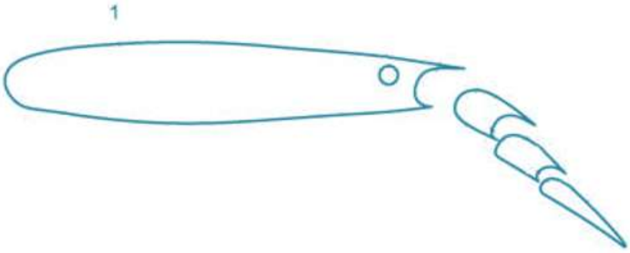
4. SLOTTEDFLAP

Is similar to Plain flap except that as the flap is extended, a gap develops between the wing and the flap. The slots allow air from the bottom of the wing to flow the upper portion of the flap and downward at the trailing edge of the wing. This aids in delaying airflow separation and creates a downward flow of air, which produces an up thrust to the wing.



5. SLOTTED FOWLERFLAP

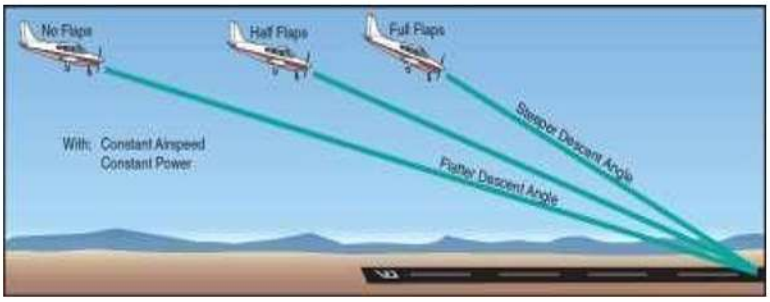
A variation and improvement, to the basic flower and slotted flaps is the slotted fowler flap. When such flaps are initially extended, they move aft movement is accompanied point on the track, further aft movement is accompanied by a downward deflection,. Which opens up one or more slots. The slotted flap can provide much greater increases in loft than the plain or split flap, and corresponding drag changes are much lower. This type of flap requires the installation of a rather complicated structure. The slotted flower flap is usually used on the trailing edge of mist turbine transport category aircraft.



EFFECTS OF FLAPS

At normal flying speeds, when flaps are fully retracted, that is, when they are all the way up , they have no effect on the lift characteristics of the wing. On the other hand when they are lowered for landing, there is increases lift for similar angles of attack of the basic airfoil, and the maximum lift co efficient is greatly increased often as much as 70 %, with the exact amount of increase depending upon the type of flap installed.

The effectiveness of flap on a wing configuration depends on many different factors. One important factor is the amount of the wing area affected by the flaps. Since a certain amount of the span is reserved for ailerons, the actual wing maximum lift properties will be less than that of the flapped two – dimensional section. If the basic wing has a low thickness, any types of flap will be less effective than on a wing of greater thickness. With the increase of lift comes a decrease in landing speed; there is also an increase of drag when the flap is down however and this requires a steeper glide to maintain the approach speed. The increase of drag also acts as a brake when the airplane is rolling to a stop on the landing strip.



LEADING – EDGE FLAPS

While flaps are generally located on the trailing edge of a wing, they can also be placed on the leading edge. Leading edge flaps are normally used only on large transport- category aircraft that need large amounts of additional lift for landing. A leading – edge flap is a high lift device which reduces the severity of the pressure peak above the wing at high angles of attack. This enables the wing to operate at higher angles of attack than would be possible without theflap.

One method for providing a wing flap is to design the wing with a leading edge that can be drooped. Another method for providing a leading – edge flap is to design an extendable surface known as the Krueger flap that ordinarily fits smoothly into the lower part of the leading edge. When the flap is required, the surface extends forward anddownward.

SLOTS AND SLATS

Another device that is used on the leading edge of a wing is a slot. A slot is also a high- lift device because it improves lift. It is nozzle shaped passage through a wing designed to improve the airflow conditions at high angles of attack and slow speeds. As the angle of attack of the wing increases air from the high pressure region below the wing flows bottom. This flow of air postpones the breakdown of streamline flow that accompanies an increase in the angle of attack. A slot is normally placed very near the leading edge.

There are two general types of slots; the fixed and the automatic. When the fixed type is used, the airflow depends on the angle of attack. The disadvantage of a fixed slot is that it adds excessive drag at low angle of attack. The automatic slot so formed by having a leading edge airfoil that will separate from the main leading edge to form a slot. This auxiliary airfoil iscommonly referred to as a slat. A slat is a movable auxiliary airfoil attached to the leading edge of the wing which, when closed, fails within the original contour of the wing and which , opened, forms aslot.

The automatic slot is nested into the leading edge of the wing while the wing is at low angles of attack but is free to move forward a definite distance from the leading edge at high angle of attack. This forms a slot through which a portion of the airstream flows and is deflected along the upper surface of the wing. The effect of the airstream diverted by a slot the airfoil with its slot closed at a high angle of attack. The airfoil is shown in a stalling position because the burbling of the air reaches almost the leading edge of thewing.
The automatic slot has disadvantage as well as advantage. The number of moving parts and the weight of the wing are increases. The slots must be the weight of the wing are increased. The slots must be installed properly and operate equally well on both wings or they are useless. If a slot on one, wing opens before the slot on the opposite wing does so, disastrous results could occur. The usual location of slots is such that they are subjected to ice formation, and in spite of any anti-icing or deicing equipment they may fail to function. If any of these factors causes a lack of balance, lateral control may be impaired. For these reasons a device is usually provided for locking slots in a closed position if they do not functionproperly.

The effect of slot on the lift coefficient. Notice that at angles where the slot is opened, the lift is greater and the maximum CLoccurs at a much higher angle of attack. This indicates that an airplane with a slotted wing has a lower stalling speed than one without slots, other things beingequal.

With this arrangement, it is possible to have much lower landing speed, better control of the flight path, and a least a partial elimination of the nose heaviness that may result from the use of flaps alone. It should be understood .is based upon a particular set of conditions and does not illustrate the effect produced by various airfoils and combinations of different flaps and slots. Other types of flaps and combinations with slots will produce valuediffering.

WING PLANFORMS

Wing design is based on the anticipated use of the aeroplane, cost, and other factors. The main design considerations are wing planform, camber, aspect ratio, and total wing area. Planform refers to the shape of the aeroplane‘s wing when viewed from above or below. Each planform design has advantages and disadvantages. The rectangular wing (straight wing) is used on most light aircraft because it has a tendency to stall first at the root, providing adequate warning and aileron effectiveness.

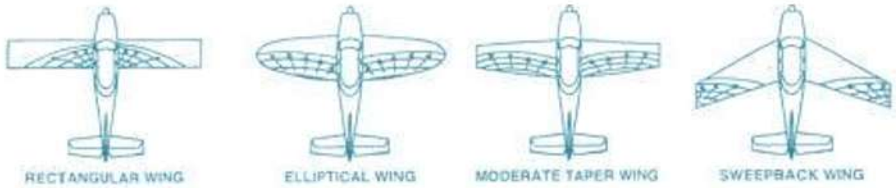


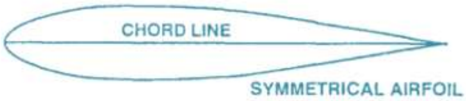
Figure 1.20: The rectangular wing has excellent slow-flight characteristics in that a stall begins at the wing root providing adequate stall warning and aileron effectiveness throughout the stall. The elliptical and tapered wings, on the other hand, typically stall along the entire trailing edge providing little stall warning. The sweptback and delta wings used on higher performance aircraftareefficientathighspeeds,butnotatlowspeeds.

It is important that a wing begins to stall at the root firstso the ailerons are able to provide lateral control throughout a stall. If a wing does not have this characteristic naturally, it can be obtained by installing small triangular stall strips at the root of the wing‘s leading edge. When the angle of attack is increased and a stall occurs, the strips disturb the air enough to hasten the stall on the section of wing behind them. This loss of lift causes the nose of the aeroplane to drop while the outer portion of the wing is still flyingand the ailerons are still effective. If a stall strip is missing from a wing‘s leading edge, the aircraft will consequently have asymmetrical aileron control at or near stall angles of attack. In other words, as the aircraft approachesa stall, the wing lacking its stall strip loses its aileron effectiveness first. As a result, the aircraft will have uneven aileroncontrol.

Camber, as noted earlier, affects the difference in the velocity of the airflow between the upper and lower surfaces of the wing. If the upper camber increases and the lower camber remains the same, the wing is said to be asymmetrical and the velocity differential increases. Symmetrical wings, on the other hand, have the same curve on the top and bottom of the wing. This type of wing relies on a positive angle of attack to generate lift and is generally used on high performance, aerobaticaircraft.

Fineness Ratio is the ratio of the wing chord to the wing thickness at its thickest point, for any given wing section. Thusa thin wing has a large fineness ratio. A wing with a large fineness ratio has a much lower amount of trailing turbulence and boundary layer (skin friction), and therefore has a reduced drag. Fineness ratio is the greatest controlling factor of turbulence and skinfriction.

Aspect ratio is the ratio of the wing spanto the average chord, or mean chord. It is one of the primary factors in determining the three dimensional characteristics of a wing and its lift/drag characteristics. An increase in aspect ratio at a given velocity results in a decrease in drag, especially at high angles of attack. It does however result in a lower stall angle and a higher stallspeed.



The asymmetrical wing has a greater camber across the wing‘s upper surface than the lower surface. This type of wing is primarily used on low speed aircraft. This symmetrical wing, on the other hand, is typically used on high performanceaircraftandhasidenticalupperandlowercambers.

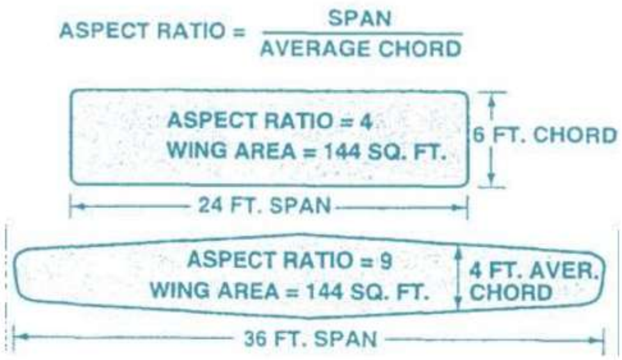


Figure 1.22: Aspect ratio is the span of the wing, wingtip to wingtip, divided by its average chord. In general, the higher the aspect ratio the higher the lifting efficiency of the wing. For example, gliders may have an aspect ratio of 20 to 30, while typical light aircraft have an aspect ratio of about seven tonine.

Aspect ratio is sometimes calculated by span2 / wing area. This formula is derived by multiplying the top and bottom of the span/average chord, by span. This negates the requirement to calculate the average chord (which may be difficult on a wing which has many changes in chord or of tapering planform)

Angle of incidence refers to the angle between the wing chord line and a line parallel to the longitudinal axis of the aeroplane. A slight positive angle of incidence provides a positive angle of attack while the aeroplane is in level flight at normal cruising speed.

Wing area is the total surface area of the wings. Most wings do not produce a great amount of lift per square foot, so wing area must be sufficient to support the weight of the aeroplane. For example, in a light aircraft at normal operating speed, the wings produce about 10.5 pounds of lift for each square foot of wing area. This means a wing area of 200 square feetis required to support an aeroplane weight of 2,100 pounds during straight-and-levelflight.

Once the design of the wing is determined, the wing is mounted on the aeroplane. Usually it is attached to the fuselage with the chord line inclined upward at a slight angle, which is called the angle ofincidence.

WEIGHT

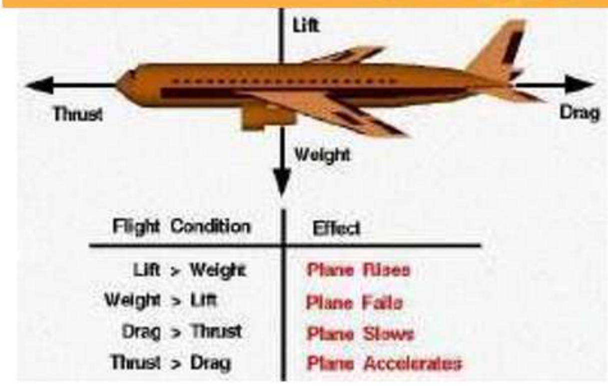
The weight of the aero plane is not a constant. It varies withthe equipment installed, passengers, cargo, and fuelload. During the course of a flight, the total weight of the aero plane decreases as fuel is consumed. Additional weight reduction may also occur during some specialized flight activities, such as crop dusting, fire fighting, or sky divingflights.

In contrast, the direction in which the force of weight acts is constant. It always acts straight down toward the centre of the earth.

THRUST

Thrust is the forward-acting force which opposes drag and propels the aeroplane. In some aeroplanes, thisforceis provided when the engine turns the propeller. Each propeller blade is cambered like the aerofoilshape of a wing. This shape, plus the angle of attack of the blades, produces reduced pressure in front of the propellerand increased pressure behind it. As is the case with the wing, this produces a reaction force in the direction of the lesser pressure. This is how the propeller produces thrust, the force which moves the aeroplaneforward.

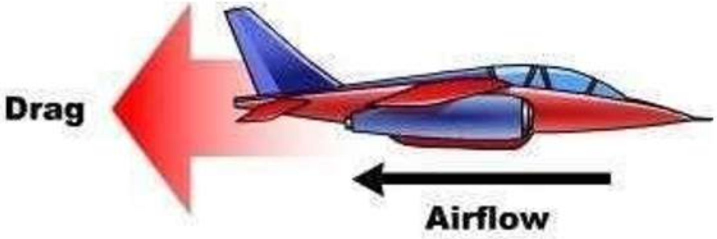
Jet engines produce thrust by accelerating a relatively small mass of air to a high velocity. A jet engine draws air into its intake, compresses it, and then mixes it with fuel. When this mixture burns, the resulting heat expands the gas, which is expelled at high velocity from the engine‘s exhaust, producing thrust.



DRAG

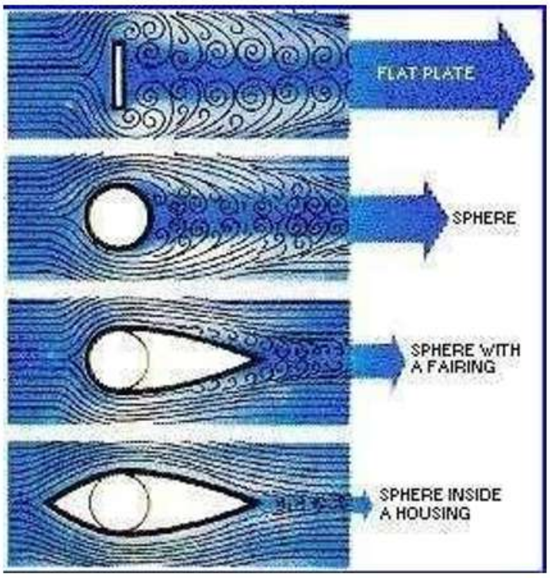
Drag is caused by any aircraft surface that deflects or interferes with the smooth airflow around the aeroplane. A highly cambered, large surface area wing creates more drag (and lift) than a small, moderately cambered wing. If you increase airspeed, or angle of attack, you increase drag (and lift).

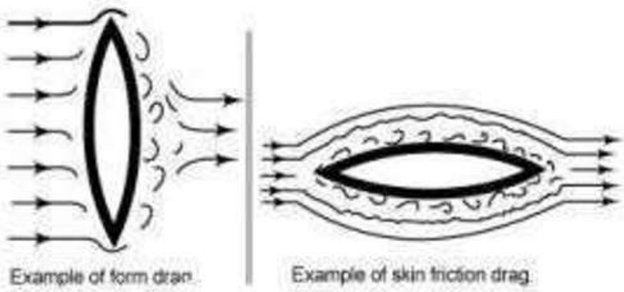
Drag acts in opposition to the direction of flight, opposes the forward-acting force of thrust, and limits the forward speed of the aeroplane. Drag is broadly classified as either profile or induced.



PROFILE DRAG

Profile drag includes all drag created by the aeroplane, except that drag directly associated with the production of lift. It is created by the disruption of the flow of air around the aeroplane‘ssurfaces. Profile drag normally is divided intothree types:





- FormDrag,
- Skin Friction Drag,and
- InterferenceDrag.

Form drag is created by any structure which protrudes into the relative wind. The amount of drag created is related to both the size and shape of the structure. For example, a square strut creates substantially more drag than a smooth or rounded strut. Streamlining reduces formdrag.

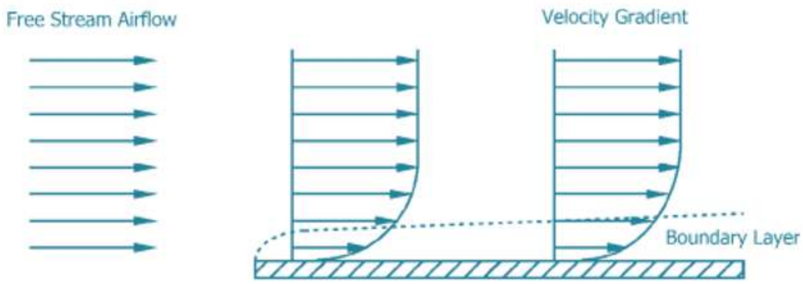
Skin friction drag is caused bythe roughness oftheaeroplane‘ssurfaces. Even though these surfaces may appear smooth, under a microscope they may be quite rough. A thin layer of air clings to these rough surfaces and creates small eddies which contribute todrag.

Interference drag occurs when varied currents of air over an aeroplane meet and interact. This interaction creates additional

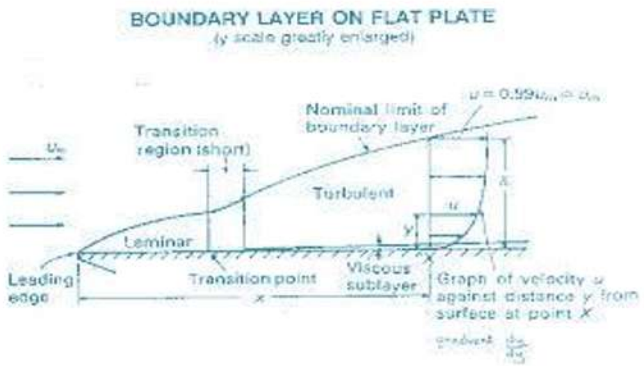
drag. One example of this type of drag is the mixing of the air where the wing and fuselage join.

Each type of profile drag varies with the speed ofthe aeroplane. The combined effect of all profile drag varies proportionately to the square of the air speed. In other words,if airspeed is doubled, profile drag increases by a factor of four.

BOUNDARY LAYER



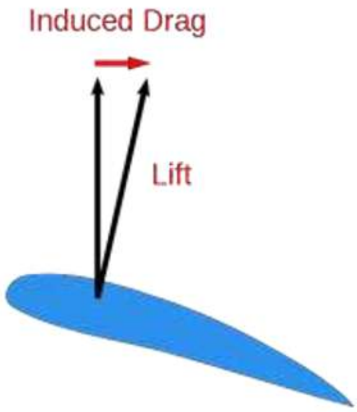
The boundary layer is a very thin layer of air flowing over the surface of an aircraft wing, or aerofoil, (as well as other surfaces of the aircraft). The molecules directly touching the surface of the wing are virtually motionless due to friction with the aerofoil surface. Each layer of molecules within the boundary layer moves faster than the layer that is closer to the surface of the wing. At the top of the boundary layer, the molecules move at the same speed as the molecules outside the boundary layer. This speed is called the free-stream velocity. The actual speed at which the molecules move depends upon the shape of the wing, the viscosity, or stickiness, of the air, and its compressibility (how much it can be compacted).

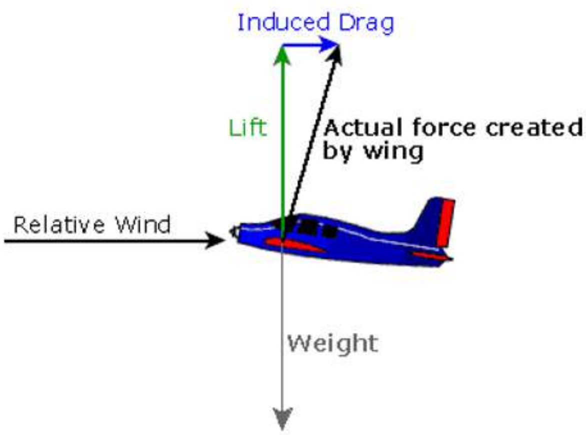


Further, boundary layers may be either laminar (layered), or turbulent (disordered). As the boundary layer moves toward the centre of the wing, it begins to lose speed due to skin friction drag. At its _transition region‘ (or transition _point‘), the boundary layer changes from laminar, where the velocity changes uniformly with distance from the object's surface increases, to turbulent, where the velocity is characterized by unsteady (changing with time) swirling flows inside the boundarylayer.

A turbulent boundary layer contains an increased airflow speed (although not all airflow is in the rearwards direction) and contains a greater amount of energy as a consequence of this. For this reason, a turbulent boundary layer produces more skin friction drag. The positive effect of a turbulent boundary layer‘s increased energy content is that it will stick to a cambered surface for longer before it breaks away (i.e. delays the stall). For this reason, flow tripping devices such as vortex generators are strategically placed on the wing ahead of flaps to trip the laminar boundary layer into a turbulent boundary layer and thus maintain theboundarylayeradhesionastheflapdeploymentincreasesthe camber. This will be at the expense of some skin friction drag, but is often outweighed by a reduced form drag.
Thedimplesonagolfballperformthis—flow-tripping"function. The dimples advance the transition point (i.e. move it forward), thus creating a turbulent boundary layer which allows the airflow to adhere further around the back of golf ball, which much reduces the form drag, at the expense of a small amount of skin friction drag. This allows the golf ball to travel further for any given strike from theclub.

The flow outside of the boundary layer reacts to the shape of the edge of the boundary layer just as it would to the physical surface of an object. Sothe boundary layer gives any object an "effective" shape that is usually slightly different from the physical shape. The boundary layer may alsoliftoffor separate from the body, creating an effective shape much different from the physical shape of the object and causing a dramatic decrease in lift and increase in drag. When this happens, the aerofoil has stalled.



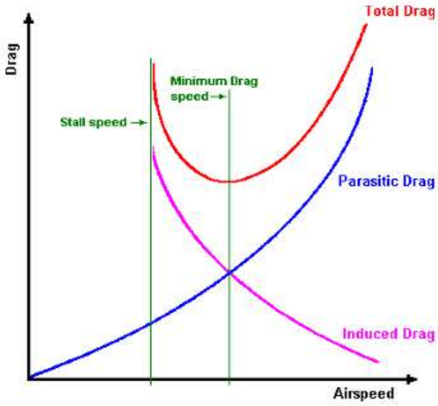


Induced drag is the main by-product of the production of lift. It is directly related to the angle of attack of the wing. The greater the angle, the greater the induced drag. Since the wing usually is at a low angle, of attack at high speed, and a high angle of attack at low speed, the relationship of induced drag to speed also can be plotted. An increase in aircraft weight will result in an increase in induced drag because the aircraft has to fly at an increased angle of attack (for any given speed) in order to support the weight.

Over the past several years the winglet has been developed and used to reduce induced drag. As discussed earlier in this section, the high pressureair beneath the wing tends to spill over to the low pressure area above the wing, producing a strong secondary flow. If a winglet of the correct orientation and design is fitted to a wing tip, a rise in both total lift and drag is produced. However, with a properly designed winglet theamountof liftproduced is greater than the additional drag, resulting in a net reduction in totaldrag.

TOTAL DRAG

Total drag for an aeroplane is the sum of profile and induced drag. The total drag curve represents these combined forces and is plotted againstairspeed.



THREE AXES OF FLIGHT

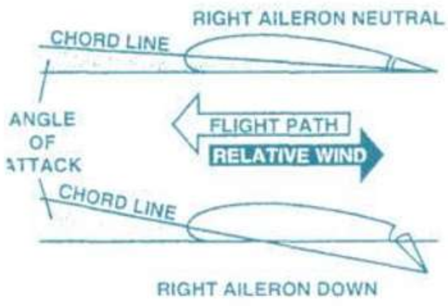
All manoeuvringflight takes place around one or more of three axes of rotation. They are called the longitudinal, lateral, and vertical axes of flight. The common reference point for the three axes is the aircraft‘s centreof gravity (CG), which is the theoretical point where the entire weight of the aeroplane is considered to be concentrated. Since all three axes pass through this point, you can say that theaeroplanealwaysmoves about its CG, regardless of which axis is involved. The ailerons, elevator, and rudder create aerodynamic forces which cause the aeroplane to rotate about the threeaxes.

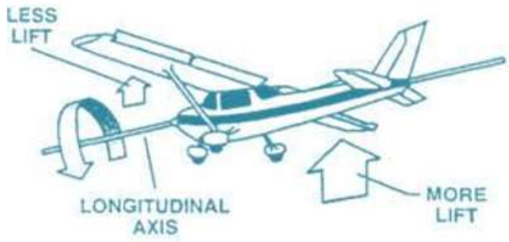
LONGITUDINAL AXIS

When the ailerons are deflected, they create an immediate rolling movement about the longitudinal axis.Sincethe ailerons always move in opposite directions, the aerodynamic shape of each wing and its production of lift are affected differently.

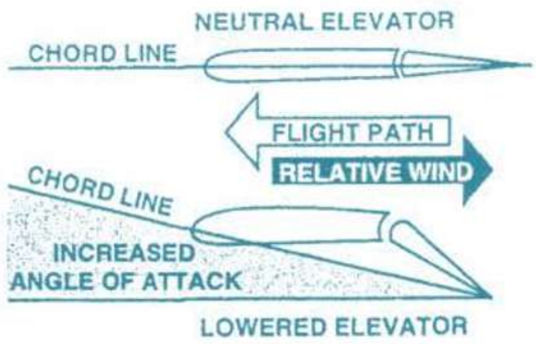
LATERAL AXIS

Pitch movement about the lateral axis is produced by the elevator or stabilator. Since the horizontal stabilizer is an aerofoil, the action of the elevator (or stabilator) is quite similar to that of an aileron. Essentially, the chord line and effectivecamberofthestabilizer arechangedby deflection of the elevator. In other words, as the elevator is deflected in one direction, the chord line changes and increases the angle ofattack. This increased angle of attack produces more lift on one side of the tail causing it tomove.





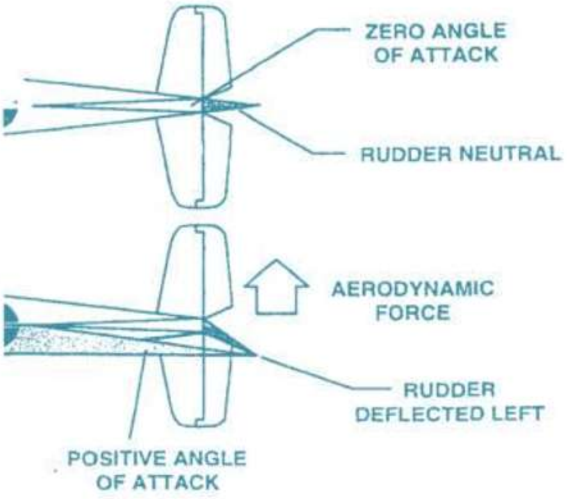
Deflected ailerons alter the chord line and change the effective camber of the outboard section of each wing. In this example, the angle of attack increases for the right wing, causing a corresponding increase in lift because of a decrease in its angle of attack. The aeroplane rolls to the left, because the right wing is producing more lift than the left wing.



When the elevator is lowered the angle of attack of the stabilizer increases, and produces more lift. The lifting force created by the stabilizer causes the aeroplane to pivot forward about its lateral axis. The net result is a decrease in the angle of attack of the wings, and an overall decrease in the pitch attitude.

VERTICAL (OR NORMAL) AXIS

When pressure is applied to the rudder pedals, the rudder deflects into the airstream. This producesanaerodynamicforce that rotates the aeroplane about its vertical axis. This is referred to as "yawing" the aeroplane. The rudder may be displaced either to the left or right of centre, depending on which rudder pedal is depressed.

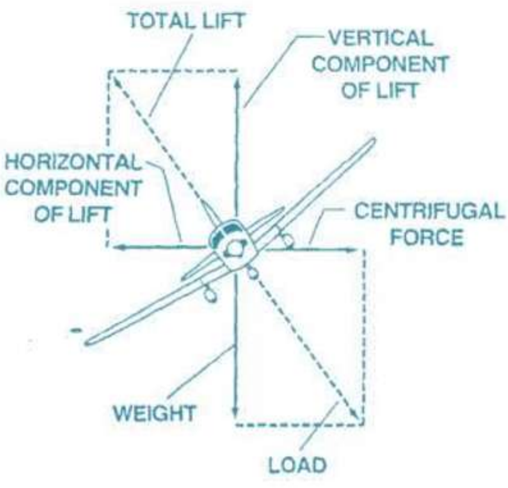


Since the vertical stabilizer also is an aerofoil, deflection of the rudder alters the stabilizer's effective camber and chord line. Inthis case, leftrudderpressure causestherudderto move to the left. With a change in the chord line, the angle of attack is altered, generating an aerodynamic force toward the right side of the vertical fin. This causes the tail section to move to the right, and the nose of the aeroplane to yaw to theleft.

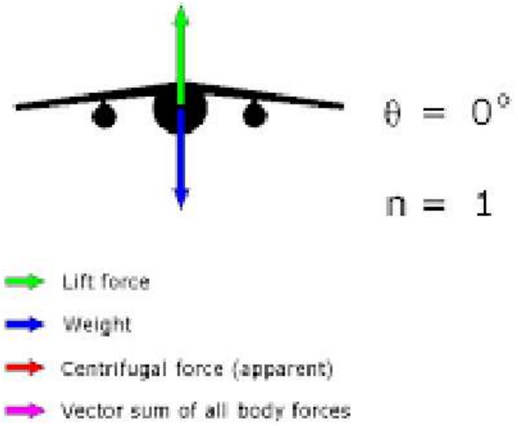
TURNING FLIGHT

Before an aeroplane turns, however, it must overcome inertia, or its tendency to continue in a straightline.

The necessary turning force is created by banking the aeroplane so that the direction of lift is inclined. Now, one component of lift still acts vertically to oppose weight, justas it did in straight- and-level flight, while another acts horizontally. To maintain altitude, lift must be increased by increasing back pressure and, therefore, the angle of attack until the vertical component of lift equals weight. Thehorizontal component of lift, called centripetal force,isdirected inward, toward the centreof rotation. It is this centre- seekingforcewhichcausestheaeroplaneto turn. Centripetal force is opposed by centrifugal force, which acts outward from the centreof rotation. When the opposing forces are balanced, the aeroplane maintains a constant rate of turn, without gaining or losingaltitude.



If a turn is rolled into without the use of rudder to help establish the turn, the aeroplane will yaw about its Vertical axis opposite to the direction of the turn. Adverse yaw is caused by higher induced drag on the outside wing, which is producing more lift.



Another way to compensate for adverse yaw is by the use of Frise ailerons. A Frise aileron has its hinge point located behind its leading edge. When the aileron is raised, its leading edge sticks out into the airstream below the wing. This produces enough profile drag to counter the aileron's induceddrag.

LOAD FACTOR

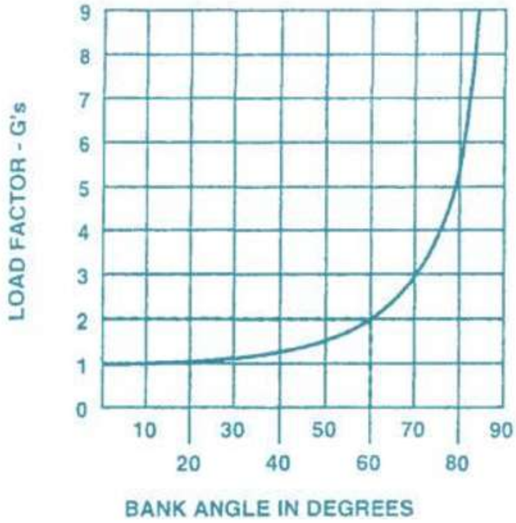
So far in this discussion, you have looked at the combinationof opposing forces acting on a turning aeroplane. Now it's time to examine load factors induced during turning flight. To better understand these forces, picture yourself on a roller coaster. As you enter a banked turn during the ride, the forces you experience are very similar to the forces which act on a turning aeroplane. On a roller coaster, the resultant force created bythe combination of weight and centrifugal force presses you down into your seat. This pressure is an increased load factor that causes you to feel heavier in the turn than when you are on a flat portion of thetrack. The increased weight you feel during a turn in a roller coaster is also experienced in an aeroplane. In a turning aeroplane, however, the increase in weight and loss of vertical lift must be compensated for or the aircraft loses altitude. This is done by increasing the angle of attack with back pressure on the control wheel. The increase in the angle of attack increases the total lift of the aeroplane. Keep in mind that when lift increases, drag also increases. This means thrust must be increased to maintain the original airspeed andaltitude.

During turning manoeuvres, weight and centrifugal force combine into a resultant which is greater than weight alone. Additional loads are imposed on the aeroplane, and the wings

must support the additional load factor. In other words, when flying in a curved flight path, the wings must support not only the weight of the aeroplane and its contents, but they also must support the load imposed by centrifugal force.

Load factor is the ratio of the loadsupported by the aeroplane's wings to the actual weight of the aircraft and its contents. If the wings are supporting twice as much weight as the weight of the aeroplane and its contents, the load factor is two.Youareprobablymorefamiliarwiththe term—G-forces‖ as a way to describe flight loads caused byaircraft manoeuvring.

Load factor is the ratio of the load supported by the aeroplane's wings to the actual weight of the aircraft and its contents. If the wings are supporting twice as much weight as the weight of the aeroplane and its contents, the load factor is two. You are probably more familiar with the term —G-forces‖ as a way to describe flight loads caused by aircraft manoeuvring.



During constant altitude turns, the relationship between load factor, or G‘s, and bank angle is the same for all aeroplanes. For example, with a 60°bank, two G‘s are required to m aintain level flight. This means the aeroplane‘s wings must support twice the weight of the aeroplane and its contents, although the actual weight of the aeroplanedoes notincrease.

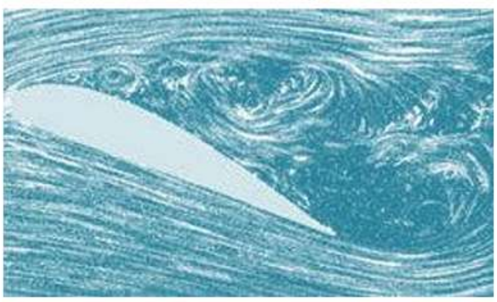
―Pulling G‘s‖is common terminology for higher performance aeroplanes. For example, an acrobatic category aeroplane may pull three or four G‘s during a manoeuvre. An aeroplane in cruising flight, while not accelerating in any direction, has a load factor of one. This one-G condition means the wings are supporting only the actual weight of the aeroplane and its contents.

LIMIT LOAD FACTOR

When the FAA or EASA certifies an aeroplane, one of the criteria they look at is how much stress the aeroplane can withstand. The limit load factor is the number of G‘s an aeroplane can sustain, on a continuing basis, without causing permanent deformation or structural damage. In other words, the limit load factor is the amount of positive or negative G‘s an airframe is capable of supporting.

Most small general aviation aeroplanes with a gross weight of 12,500 pounds or less, and nine passenger seats or less, are certified in either the normal, utility, or acrobatic categories. A normal category aeroplane is certified for non-acrobatic manoeuvres. The maximum limit load factor in the normal category is 3.8 positive G‘s, and 1.52 negative G‘s. In other words, the aeroplane‘s wings are designed to withstand 3.8 times the actual weight of the aeroplane and contents during manoeuvringflight.

In addition to those manoeuvres permitted in the normal category, an aeroplane certified in the utility category may be used for several manoeuvres requiring additional stress on the airframe. A limit of 4.4 positive G‘s and 1.76 negative G‘s is permitted in the utility category. An acrobatic category aeroplane may be flown in any flight attitude as long as its limit load factor does not exceed 6 positive G‘s or 3 negative G‘s.



THE STALL

An aeroplane can be made to stall in any pitch attitude or bank angle or at any airspeed but is commonly practiced by reducing the speed to the unaccelerated stall speed, at a safe altitude. Unaccelerated (1G) stall speed varies on different aeroplanes and is represented by colour codes on the air speed indicator. As the aeroplane flies at this speed the angle of attack must be increased to prevent any loss of altitude or gain in airspeed (which corresponds to the stall angle). The pilot will notice the flight controls have become lessresponsive and may also notice some buffeting, a result of the turbulent air separated from the wing hitting the tail of theairplane.

In most light aircraft, as the stall is reached the aircraft willstart to descend (because the wing is no longer producing enough lift to support the aeroplane's weight) and the nose will pitch down. Recovery from this stalled state usually involves the pilot decreasing the angle of attack and increasing the air speed, until smooth air flow over the wing is resumed. Normal flight can be resumed once recovery from the stall is complete. The manoeuvreis normally quite safe and if correctlyhandled

leads to only a small loss in altitude (50'-100'). It is taught and practiced in order for pilots to recognize, avoid, and recover from stalling the airplane. A pilot is required to demonstrate competency in controlling an aircraft during and after a stall for certification, and it is a routine manoeuvrefor pilots when getting to know the handling of a new aircraft type. The only dangerous aspect of a stall is a lack ofaltitude for recovery.

Stalls do not derive from airspeed and can occur at any speed, but only if the wings have too high an angle of attack. Attempting to increase the angle of attack at 1G by moving the control column back normally causes the aircraft to rise. Howeveraircraft often experience higher G, for example when turning steeply or pulling out of a dive. In these cases, the wings are already operating at a higher angle of attack to create the necessary force (derived from lift) to accelerate in the desired direction. Increasing the g loading still further, by pulling back on the controls, can cause the stalling angle to be exceeded, even though the aircraft is flying at a high speed. These "accelerated stalls" produce the same buffeting characteristics as 1G stalls and can also initiate a spin if there is also anyyawing.

SYMPTOMS OF AN APPROACHING STALL

One symptom of an approaching stall is slow and sloppy controls. As the speed of the aeroplane decreases approaching the stall, there is less air moving over the wing and therefore less air will be deflected by the control surfaces (ailerons, elevator and rudder) at this slower speed. Some buffeting mayalso be felt from the turbulent flow above the wings as the stall is reached. However during a turn this buffeting will not be felt andimmediateactionmustbetakentorecoverfromthestall.

The stall warning will sound, if fitted, in most aircraft 5 to 10 knots above the stall speed.

STALLING CHARACTERISTICS

Different aircraft types have different stalling characteristics. A benign stall is one where the nose drops gentlyand the wings remain level throughout. Slightly more demanding is a stall where one wing stalls slightly before the other, causing that wing to drop sharply, with the possibility of entering a spin. A dangerous stall is one where the nose rises, pushing the wing deeper into the stalled state and potentially leading to an unrecoverable deep stall. This can occur in some T-tailed aircraft where the turbulent airflow from the stalled wing can blanket the control surfaces at thetail.

Stalls depend only on angle of attack, not airspeed. Because a correlation with airspeed exists, however, a "stall speed" is usually used in practice. It is the speed below which the airplane cannot create enough lift to sustain the weight in 1 g flight. In steady, level flight (1G), the faster an airplane goes, the less angle of attack it needs to hold the airplane up (i.e. to produce lift equal to weight). As the airplane slows down, it needs to increase angle of attack to create the same lift (equaltoweight).

A typical Airspeed Indicator showing the speed ranges. The lower end of the green arc is the _no-flaps‘ stall speed. The lower end of the white arc is the _with-flaps‘ stall speed.

As the speed slows further, at some point the angle of attackwill be equal to the critical (stall) angle of attack. This speed is called the "stall speed". The angle ofattackcannotbe increased to get more lift at this point and so slowing belowthe stall speed will result in a descent. And so, airspeed is often used as an indirect indicator of approaching stall conditions. The stall speed will vary dependingonthe airplane's weight and configuration (flap setting,etc.).
There are multiple V speeds which are used to indicate when a stall will occur:

Vs: The computed stalling speed with flaps retracted at design speed. Often has the same value asVSi.

VSo: The stalling speed or the minimum steady flight speed in landing configuration (full flaps, landing gear down, spoiler retracted).

VSi: The stalling speed or the minimum steady flight speed in a specific configuration (usually a "clean" configuration with flaps, landing gear and spoilers allretracted).

VSR: Reference stall speed.

VSRO: Reference stall speed in the landingconfiguration.

VSri: Reference stall speed in a specificconfiguration.

VSw: Speed at which onset of natural or artificial stall warning occurs.

On an airspeed indicator, the bottom of the white arc indicates VSoat maximum weight, while the bottom of the green arc indicates VS1at maximum weight. While an aircraft's Vsspeed iscomputedbydesign, itsVSoand VSi speeds must be demonstrated empirically by flight testing

ACCELERATED STALL

One effect of an increased load factor is the increased stall speed. Although the stall angle is a constant regardless of aircraft weight and/or load factor, an increase in either of those factors means that the aircraft has to fly faster to maintain the aircraft‘s altitude. Consequently, the stall speed increases. In a turn, the stall speed increases at a rate proportional to the square root of the load factor. For example, a bank angle of 50° results in a load factor of 1.5 and an increase of 22% in stall speed (a/1.5 = 1.22). This is known as —acceleratedstall‖.

An accelerated stall is a stall that occurs while the aircraft is experiencing a load factor higher than 1 (1G), for example

while turning or pulling up from a dive. In these conditions, the aircraft stalls at higher speeds than the normal stall speed (which always refers to straight and levelflight).

Considering for example a banked turn, the lift required is equal to the weight of the aircraft plus extra lift to provide the centripetal force necessary to perform the turn, thatis:

L =nW

Where:
L = Lift
n = Load factor (greater than 1 in a turn) W = Weight of the aircraft

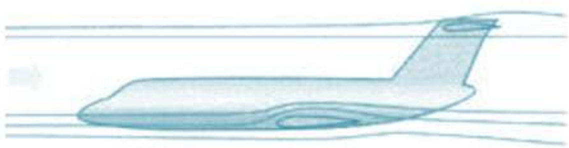
In order to achieve the extra lift, the lift coefficient, and so the angle of attack, will have to be higher than it would be in straight and level flight at the same speed. Therefore, given that the stall always occurs at the same critical angle of attack, by increasing the load factor (e.g. by tightening the turn) such critical angle - and the stall - will be reached with the airspeed remaining well above the normal stall speed, thatis:

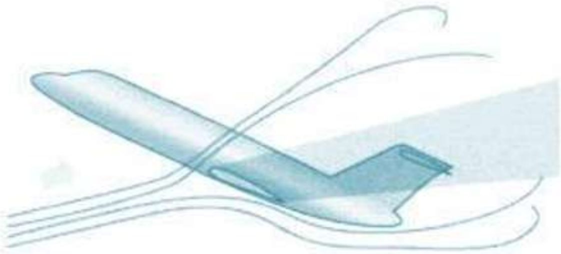
Vst�Vs
Where:
Vst = Stall Speed
Vs = Stall speed of the aircraft in straight, level flight
η = LoadFactor

DEEPSTALL

A deep stall (or super-stall) is a dangerous type of stall that affects certain aircraft designs, notably those with a T-tail configuration. In these designs, the turbulent wake of a stalled main wing "blankets" the horizontal stabilizer, rendering the elevators ineffective and preventing the aircraft from recovering from thestall.

Although effects similar to deep stall had long been known to occur on many aircraft designs, the name first came into widespread use after a deep stall caused the prototype BAC 1- 11 to crash, killing its crew. This led to changes to the aircraft, including the installation of a stick shaker in order to clearly warn the pilot of the problem before it occurred. Stick shakers are now a part of all commercialairliners.





Deep stall condition - T-tail in "shadow" of wing Stall warning and safety devices

Aeroplanes can be equipped with devices topreventor postpone a stall or to make it less (or in some cases more) severe, or to make recovery easier. An aerodynamic twist can be introduced to the wing with the leading edge near the wing tip twisted downward. This is called washout and causes the wing root to stall before the wing tip. This makes the stall gentle and progressive. Since the stall is delayed at the wing tips, where the ailerons are, roll control is maintained when the stallbegins.

A stall strip is a small sharp-edged device which, whenattached to the leading edge of a wing, encourages the stall to start there in preference to any other location on the wing. If attached close to the wing root it makes the stall gentle and progressive; if attached near the wing tip it encourages the aircraft to drop a wing whenstalling.

A stall fence is a flat plate in the direction of the chord to stop separated flow progressing out along the wing.

VORTEX GENERATORS

Even though most turbine transport category aircraft do not fly atthespeedofsound(Mach1),therearecertainareasonthe airplane where the airflow velocity will be greater than Mach

1. This is particularly true at the upper surface of parts of the wing where because of hecurvature of the wing, the air velocity must increases substantially above the airspeed of the airplane. This is illustrate, which shows an airfoilprofile moving through the air at high subsonicspeed.A short distance back from the leading edge of the wing and above the top surface. The air reaches supersonic speed. At the rear part of the supersonic area where the airflow returns to subsonic speed, a shock wave is formed as was discussed. To the near of this shock wave the air is very turbulent and this area of the wing is, effect partially stalled,.This of course causes a substantial increase in drag. Which increases as airspeed increases.

It orderto reduce the drag caused by supersonic flow over position of the wing, small airfoil called vortex generators are installed vertically into the airstream. Althoughcommonlyused on the upper inboard surface of a cambered wing, vortex generators may be installed anywhere that airflow separation creates a problem, including on tail surface and in engine ducts. Because of the low aspect ratio of the vortex generators, they develop strong tip vortices. The tip vortices cause air to flow upward and inward in circular paths around the ends ofthe airflow. The vortices generated have the effect of drawing high energy air from outside the boundary layer into the slower moving air close to the skin. The strength of the vortices in proportional to the lift developed by the generators. To operate effectively the generators are mounted forward of the point where separationbeings.

Drag reduction achieved by the addition of vortex generators can be seen in the drag rise curve. Since thegenerators effectively reduce the shock induced drag associated with the sharp rise in theright.

The addition of the vortex generators actually increases overall drag very slightly at lower speeds. However the gains at cruise speeds more than balance out the losses at lower speeds. Since the airplane spends most of its flight time at cruise speeds. The net gain issignificant.

A stick pusher is a mechanical device which prevents the pilot from stalling an

aeroplane. It pushes the elevator control forwards as the stall is approached, causing a reduction in the angle of attack. Generically, a stick pusher is known as a stall identification device or stall identification system.

A stick shaker is a mechanical device which shakes the pilot's controls to warn of thenonset of stall.

A stall warning is an electronic or mechanical device which sounds an audible warning as the

stall speed is approached. The majority of aircraft contain someformofthisdevicethatwarnsthepilotofanimpending

stall. The simplest such device is a stall warning horn, which consists of either a pressure sensor or a movable metal tab that actuates a switch, andproduces an audiblewarning in response.

An Angle-of-Attack (AoA) Indicator or also known as a Lift Reserve Indicator is a pressure differential instrument that integrates airspeed and angle of attack into one instantaneous and continuous readout. An AoAindicator provides a visual display of the amount of available lift throughout its slow speed envelope regardless of the many variables which act upon an aircraft. This indicator is immediately responsive to changes in speed, angle of attack and wind conditions and automatically compensates for aircraft weight, altitude, and temperature.

An angle of attack limiter or an "alpha" limiter is a flight computer that automatically prevents pilot input from causing the plane to rise over the stall angle. Some alpha limiters can be disabled by thepilot.

Stall warning systems often involve inputs from a broad range of sensors and systems to include a dedicated angle of attack sensor.

Blockage, damage, or in operation of stall and angle of attack (AOA) probes can lead to the stallwarningbecoming unreliable and cause the stick pusher, over speed warning, autopilot and yaw damper tomalfunction.

If a forward canard is used for pitch control, rather than an aft tail, the canard is designed to meet the airflow at a slightly greater angle of attack than the wing. Therefore, when the aircraft pitch increases abnormally,the canard will usually stall first, causing the nose to drop and so preventing the wing from reaching its critical angle of attack. Thus the risk of main wing stalling is greatly reduced. Unfortunately if the main wing stalls, recovery becomes difficult as the canard is more deeply stalled and angle of attack increases rapidly.

If an aft tail is used, the wing is designed tostall before the tail. In this case, the wing can be flownathigherlift coefficient (closer to stall) to produce more overalllift.

Modern airliner instrumentation may measure angle of attack although this information may not be directly displayed on the pilot's display, instead driving a stall warning indicator or giving performance information to the flight computer (for fly by wire systems).

AFFECT OF ALTITUDE

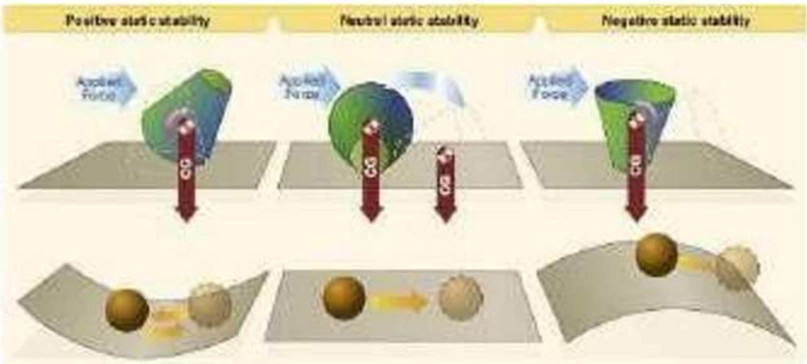
As already stated, the stall angle (the ‗critical angle of attack') for any given wing geometry is constant, regardless of weight, load factor and air density. However, the stall speed will increase with an increase in weight and load factor, and a decrease in airdensity.

Indicated Airspeed is the True Airspeed without density taken into account. Thus, as an aircraft climbs at a constant Indicated Airspeed, the True Airspeed is increasing due to the reductionin air density. The stall speed will be the same as at sea level if speed is indicated as Indicated Airspeed, butwill increase if speed is indicated as TrueAirspeed.

AIRCRAFT STABILITY DEFINITION

All airplane must possess stability in varying degrees for safety and ease of operation. Stability is the inherent ability of a body, after its equilibrium is disturbed to develop forces or moments that tend to return the body to its original position. In other words a stable airplane will tend to return to the original condition of flight if disturbed by a force. Such as turbulent air. Airplanes have varying degrees of stability. Aircraft that are inherently unstable require some type of computerized artificial stability system to be flown.

STATIC STABILITY



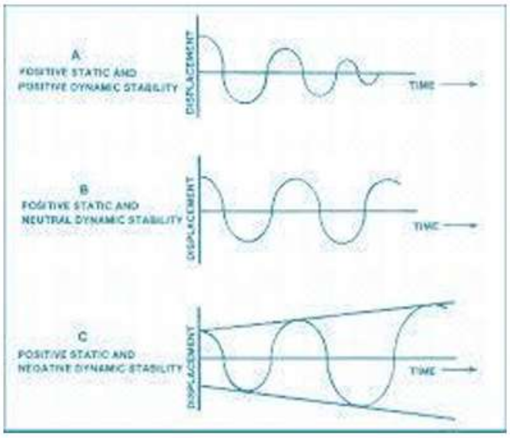
An aircraft is in a state of equilibrium when the sum of all forces and all moments is equal to zero. When an aircraft is in equilibrium,. There are no accelerations and the aircraft continues in a steady condition of flight. If the equilibrium is disturbed by a gust or a deflection of the controls, the aircraft will experience acceleration because of an unbalance of moment or force.

The static stability of an aircraft is defined by the initial tendency to return to equilibrium condition following some disturbance from equilibrium. If an object is disturbed form equilibrium and has the tendency to return to equilibrium, positive static stability exists. If the object has tendency to continue in the direction of disturbance negative static stability or static instability, exists. If the object subject to a disturbance has either the tendency to return nor the tendency to continue in the displacement direction, neutral static stability exists. This is an intermediate condition which could when an object displacedposition.

These three categories of static stability are illustrated. In ball in a trough illustrates the condition of positive static stability. If the ball is displaced form equilibrium at the bottom of the trough, the initial tendency of the ball is to return to the trough equilibrium condition. The ball may roll back and fourth through the point of equilibrium, but displacement to either side creates the initial tendency to return. The ball on a hill illustrates the condition of static instability. Displacement from equilibrium at the hilltop brings about the tendency for greater displacement. The ball on a flat, level surface illustrates the condition of neutral static stability. The ball encounters a new equilibrium at any point of displacement and has neither stable for unstabletendencies.

The term static is applied to this form of stability since the resulting motion is not considered. Only the tendency to return to equilibrium conditions is considered in staticstability.

DYNAMIC STABILITY



While static stability is concerned with the tendency of a displaced body to return to equilibrium, dynamic stability is defined by the resulting motion with time. If an object is disturbed from equilibrium, the time history of the resulting motion indicates the dynamic stability of thesystem.

Positive dynamic stability is the property which dampens the oscillations set up by a statically stable airplane, enabling the oscillations to become smaller and smaller in magnitude until the air place eventually settles down to its original condition of flight.

The existence of static stability does not necessarily guarantee the existence of dynamic stability implies the existence of static stability. An aircraft must demonstrate the required degree of static and dynamic stability if it is to be operated safely. Illustrates the relationship of dynamic and staticstability.

AXES OFAIRCRAFT

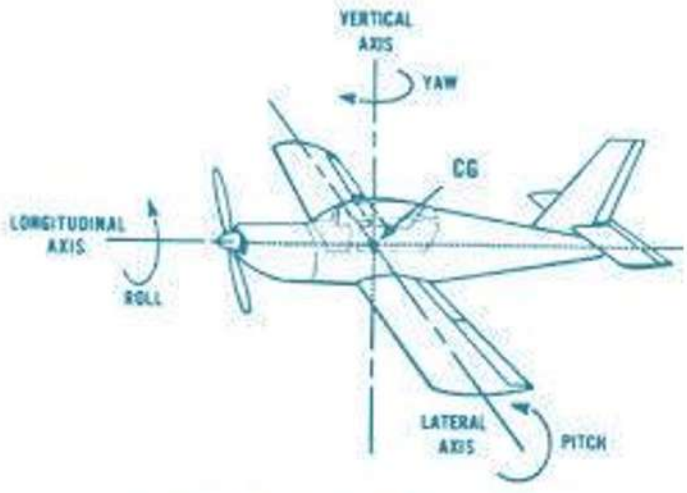


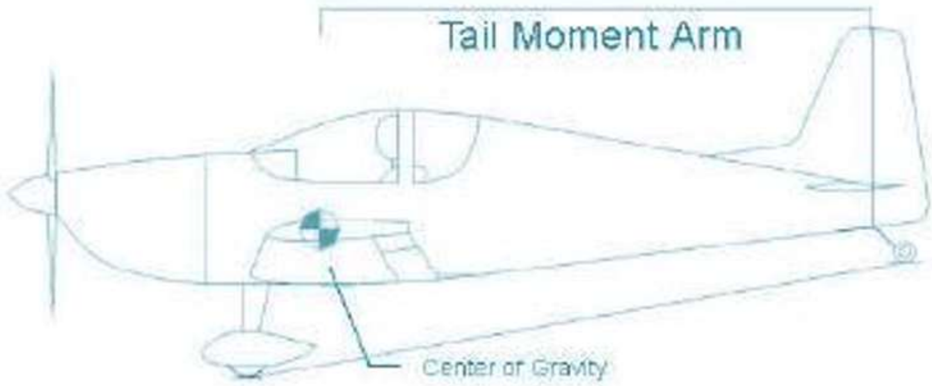
Figure 3–8 Axes of the Airplane

Discussing stability and relating it to the axis of the aircraft is somewhat confusing because stability is referenced to movement along an axis instead of rotation about an axis. For example stability about the lateral axis is referred to as longitudinal stability since it involves rotation of the airplane along the longitudinal axis. Stability around the longitudinal axis is called lateral stability, and stability around the

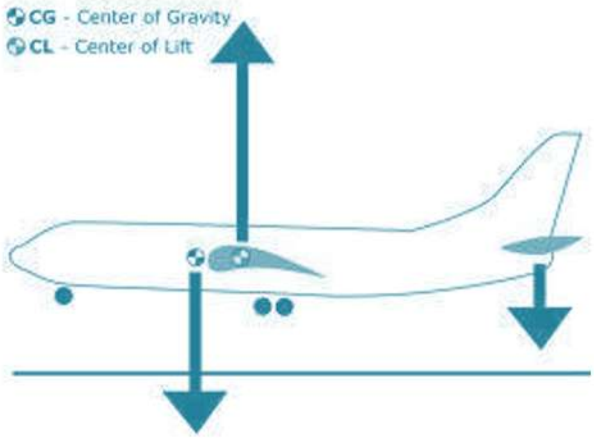
vertical axis is called directional stability.
While being supported in flight by lift and propelled though the air by thrust an airplane is free to revolve or move around three exes namely the longitudinal axis, the lateral axis and the vertical axis.

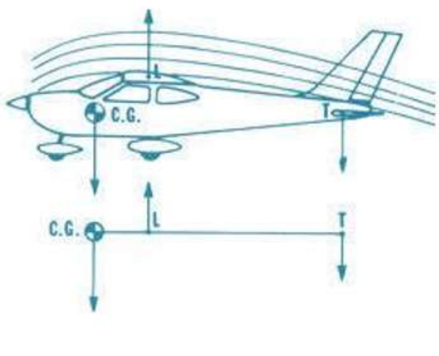
The axis which extends lengthwise through the fuselage form the nose to the tail is the longitudinal axis. The axis extending through the fuselage form wing tip wing tip is the lateral axis. The axis which passes vertically though the fuselage at the center of gravity is the vertical axis.

During flight, an airplane is rotated about the three axes by means of the three primary flight controls. The ailerons control roll about the longitudinal axis, the elevators control pitch about the lateral axis, and the rudder controls yaw about the vertical axis.



LONGITUDINAL STABILITY





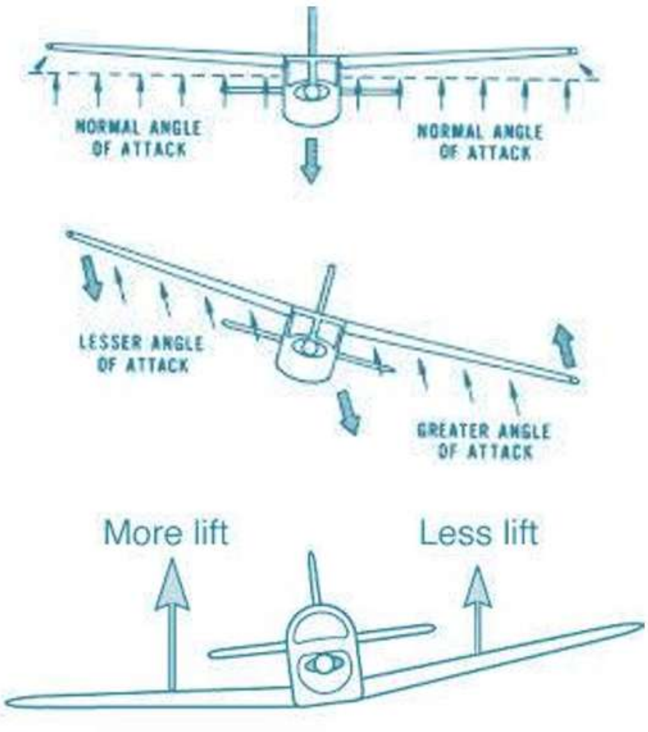
The stability of an airplane about the lateral axis is longitudinal stability. If the airplane is put into a dive or climb and then the control is released, the airplane should return to level flight automatically. If the airplane does not have longitudinal stability, it may increase the angle of dive after being placed in drive, or it may —porpoise‖that is oscillated through a series of dives and climbs unless controlled by thepilot.

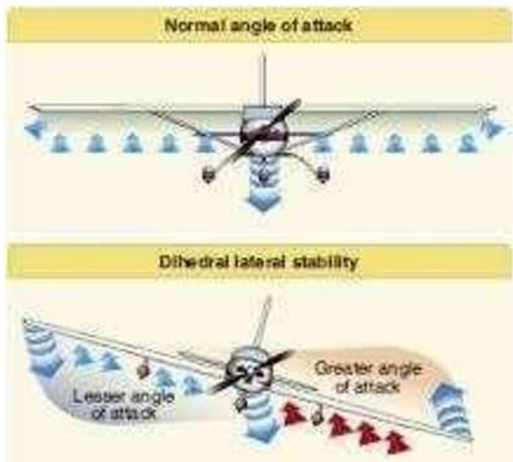
The location of the center of gravity with respect to the venter of lift determines to great extent the longitudinal stability of the airplane. Note that the center of lift is directly over the center of gravity of weight. An airplane with neutral stability will produce no inherent pitch moments around the center ofgravity.

Illustrates the center sof lift in front of the center of gravity. This airplane would display negative stability and an undesirable pitch
– up moment during flight. If disturbed the up and down pitching moment will tend to increase in magnitude. This condition can occur especially if the airplane is loaded so that the center of gravity is rearward of the airplane aft loading limits.

An airplane with the center of lift behind the center of gravity. Again this produces negative stability. Some force must balance the down force of the weight. This is accomplished by designing the airplane in such a manner that the air flowing downward behind the trailing edge of the wing strikes the upper surface of the horizontal stabilizer. This creates a downwards tail force to counteract the tendency to pitch down and provides positive stability.

LATERAL STABILITY





lateral stability

The stability of an airplane about the longitudinal or roll axis is the lateral stability. An airplane that tends to return to a wings level attitude after being displaced from a level attitude by some force such as turbulent air, is considered laterallystable.

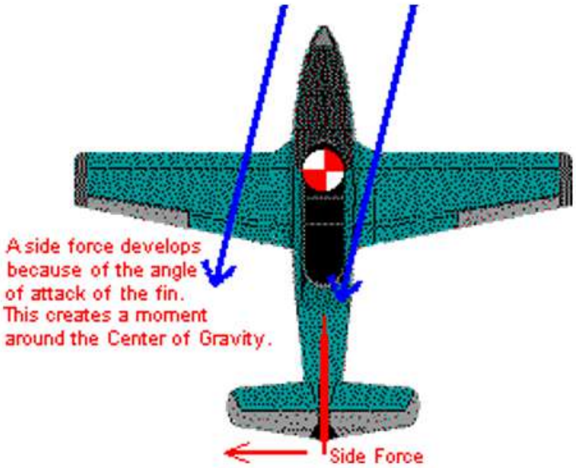
The factors that primarily affect lateral stability are dihedral and sweepback. In aircraft terminology, dihedral means the lateral angle of wing with respect to a horizontal plane. Positive dihedral exists when the tip of a wing a is above the horizontal plane passing through the root of the wing. Negative dihedral exits its when the tip of the wing is below the horizontal plane passing through the roots of the wing.

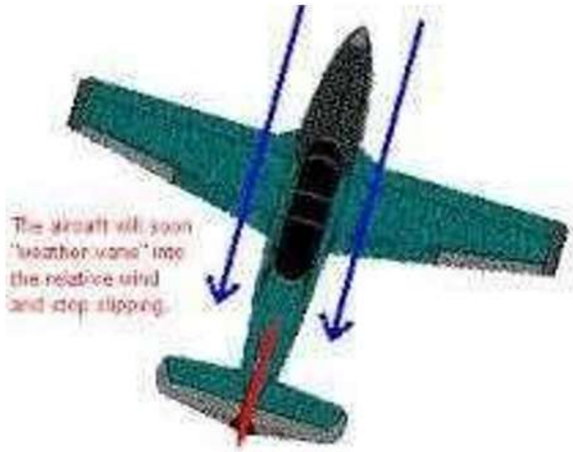
The purpose of positive dihedral is to provide lateral stability for the aircraft. The stabilizing effect of dihedral occurs when the airplane sideslips slightly as one wing is forced down in turbulent air. Usually a wing will provide the greatest amount of lift it is a perfectly horizontal position laterally. When an airplaneis designed with dihedral the both wings will from angles with the horizontal plane. If the aircraft rolls slightly to the right, the tip of the right wing moves downward and the lift to the wing increase. At the same time the left- wing lift is decreased because the angle with the horizontal plane is increasing . The airplane therefore, is subjected to more lift from the right wing and less lift form the left wing. This causes the airplane to roll back to the left to resume a level position. These effects are illustrated.

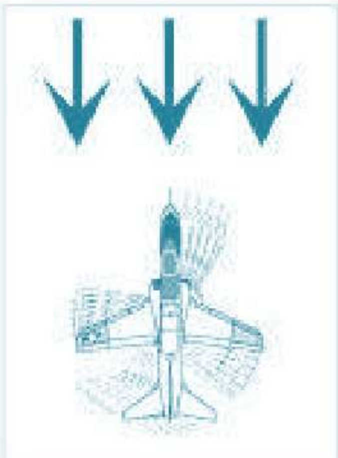
The term sweepback refers to the angle at which the wings are slanted reward form the root to the tip. The effect of seep back in producing lateral stability is similar to that of dihedral but is not as pronounced. If one wing lowers in a slip, the angle of attack on the low wing lowers increase producing greater lift. This results in a tendency for the lower wing to raise and return the airplane to level flight. Sweepback augments dihedral to achieve lateral stability.

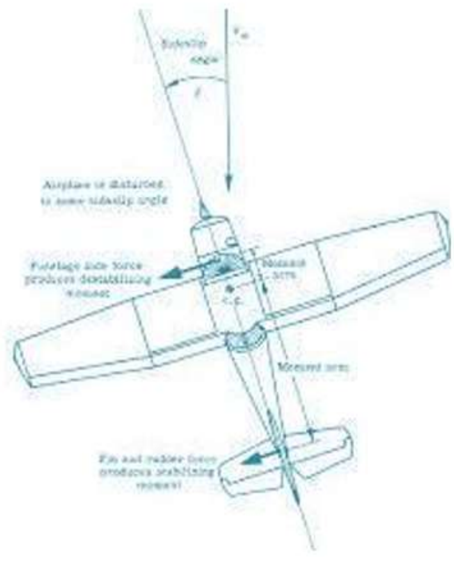
Some lateral stability is also provided by vertical fin. A sideslip of the aircraft result in an air force being applied against the vertical fin and tends to rotate the aircraft back against the rolling direction.

DIRECTIONAL STABILITY









The stability of an airplane about the vertical axis is called directional stability. This means that the airplane will return to a straight flight path after having been turned on way or the other.

Directional stability is accomplished by placing a vertical stabilizer,. Or fin to the rear to the center of gravity on the upper portion of the tail section. The surface of this fin acts similar to a weathervane and causes the airplane to pivot into the relative wind. If the airplane is yawed out of its flight path, either by force on one side of the vertical stabilizer and return the airplane to its original direction of flight. The amount of direction stability provided by the vertical fin is proportional to both the size of the fin and the distance it is located aft of the CG. The larger the surface area and the farther aft it is located, the greater the stability. Since the vertical fin is the primary directional stabilizing force, it must be located aft of the CG for a stable aircraftconfiguration.

Sweepback wings aid in directional stability. If the aircraft yaws from its direction of flight, the wing which is farther ahead offers more drag than the wing which is aft. The effect of this drag is to hold back the wing which is farther ahead and to let the other wing catchup.

EXCESSIVE STABILITY

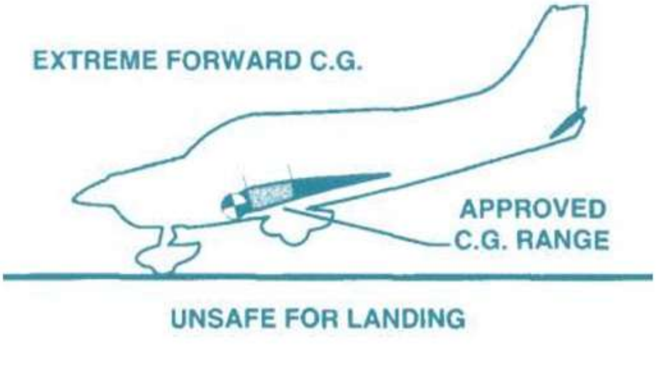
It is possible to build into an airplane a degree of stability that reduces or makes difficult control of the aircraft. Stability helps keep the aircraft in a desired to deviate from that path. Maneuverability is also an important characteristic of an airplane. This is the ability of an airplane to be directed along a selected flight path. The smooth and easy response of the airplane to its controls is important. If the airplane does not have the proper degree of this quality, it will be difficult and tiring to fly, particularly though maneuvers. A goof balance between stability and maneuverability is important in any aircraft design.

BALANCE

To achieve longitudinal stability, most aeroplanes are designed so they are slightly nose heavy. This is accomplished during the engineering and development phase by placing the centreof gravity slightly forward of the centreofpressure.

The centre of pressure is a point along the wing chord linewhere lift is considered to be concentrated. For this reason, the centreof pressure is often referred to as the centreof lift. During flight, this point along the chord line changes position with different flight attitudes. It moves forward as the angle of attack increases and aft as the angle of attack decreases. As a result, pitching tendencies created by the position of the centreof lift in relation to the CG vary. For example, with a high angle of attack and the centreof lift in a forward position (closer to the CG) the nose-down pitching tendency is decreased. The position of the centre of gravity in relation to the centre of lift is a critical factorin longitudinal stability.

If an aeroplane is loaded so the CG is forward of the forward CG limit, it becomes too nose heavy. Although this tends to make the aeroplane seem stable, adverse side effects include longer takeoff distance and higher stalling speeds. The condition gets progressively worse asthe CG moves to an extreme forward position. Eventually, stabilator (elevator) effectiveness becomes insufficient to lift thenose.

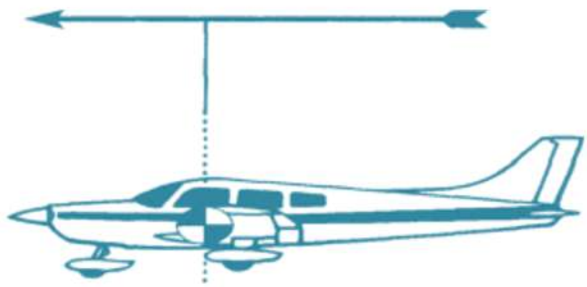


If the CG is well forwardoftheapprovedCGrange, stabilator effectiveness becomes insufficient to exert the required tail- down force needed for a nose-high landing attitude. This may cause the nose wheel to strike the runway before the maingear.

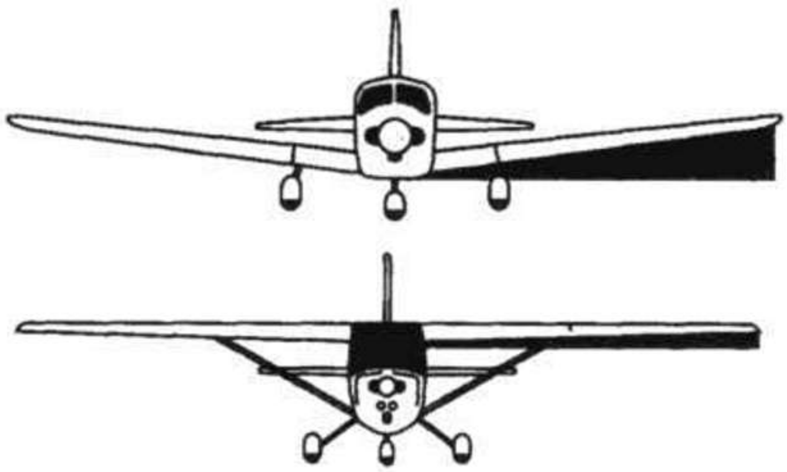
DIRECTIONAL STABILITY

Stability about the vertical axis is called directional stability. Essentially, an aeroplane in flight is much like a weather vane. You can compare the pivot point on the weather vaneto the centreofgravity pivot point of the aeroplane. The nose of the aeroplane corresponds to the weather vane's arrowhead, and the vertical fin on the aeroplane acts like the tail of the weather vane.

High-speed jet aircraft are subject to a form of dynamic instability called Dutch roll, which is characterized by a coupling of directional and lateral oscillation. In other words, an aircraft experiencing Dutch roll tends to wander about theroll and yaw axes. Dutch roll generally occurs when an aircraft's dihedral effect is larger than its staticdirectional stability. To prevent Dutch roll, many aircraft employ yaw dampers that sense uncommanded roll and yaw motion and activate appropriate flight controls to overcome them.



An aeroplane must have more surface area behind the CG than it has in front of it. The same is true for a weather vane; more surface area aft of the pivot point is a basic design feature. This arrangement helps keep the aero plane aligned with the relative wind, just as the weather vane points into thewind.

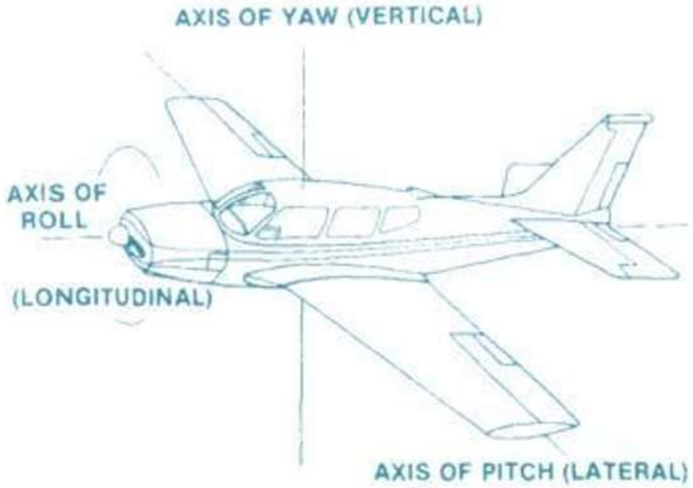


Wing Dihedral

Wing dihedral contributes to lateral stability. Low- wing aeroplanes commonly have more dihedral than high-wing aeroplanes. The centre of gravity is well below the wing in a high- wing aeroplane. Because this CG position has a stabilizing effect, very little dihedral isnecessary.

AIRCRAFT CONTROL PITCH CONTROL

The lateral axis of an aeroplane is an imaginary line that parallels the span of the wing and passes through the centreof gravity. The elevators, which are thehorizontal movable control surfaces mounted on the tail of the aeroplane, cause the aeroplane to rotate about its lateralaxis.



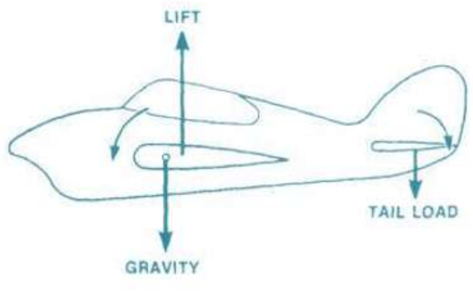
When the control wheel is pulled back, the trailing edge of the elevator moves upward and deflects the airstream upward. This increases the down load on the tail and rotates the nose of the aeroplane upward.

Pushing the control wheel in deflects the trailing edge of the elevators downward and deflects the airdownward. This pushes the tail up, lowering the nose.

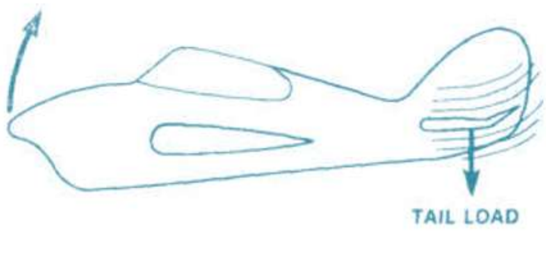
ROLL CONTROL

The longitudinal axis of an aeroplane extends lengthwise through the fuselage, and rotation about this axis, or banking, is controlled by theailerons.

Hinged surfaces on the trailing edge of the wing near the tips are connected to the control wheel, usually by steel cables, in such a way that the rotation of the wheel to the left will raise the left aileron and lower the aileron on the right wing. The action deflects the air upward that passes over the left aileron, lowering the left wing, while the air passing over the right aileron is deflected downward, which raises the rightwing.



The elevators vary the tail load to rotate the aero plane about its lateral axis.



When the control wheel is pulled back, the elevators deflect air upward, increasing the downward tail load. This rotates the nose upward.

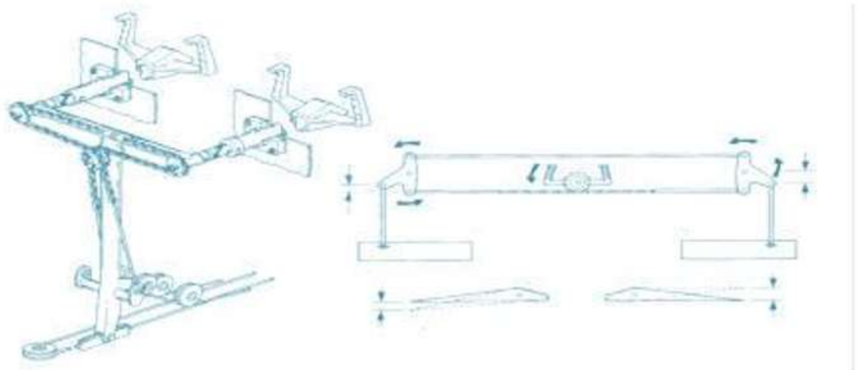
Deflecting the aileron downwards increases the lift, but it also increases the induced drag. And this drag is so far out on the wing that it yaws, or pulls the nose of the aeroplane around, toward the raised wing. This direction is exactly opposite the way the nose should move when the aeroplane is banked. This movement is called adverse yaw, and it can cause an aeroplane to enter an inadvertentspin.

To minimize adverse yaw, the ailerons are rigged so the one moving upward will travel farther than the one moving downward. Thus the upward moving aileron, while decreasing both the lift and the induced drag on the wing moving down will have more profile drag because of its largerdeflection.

To further increase the profile drag, most ailerons are of the Frise type, in which the hinge line is back quite a way from the leading edge. When the aileron is moved upward, the portionahead of the hinge-line sticks out below the wing and produces additional profile drag. The profile drag on the lowering wing will balance the induced drag on the wing that is moving up and so there will be a minimum of yaw accompanying the rolling or banking.

YAW CONTROL

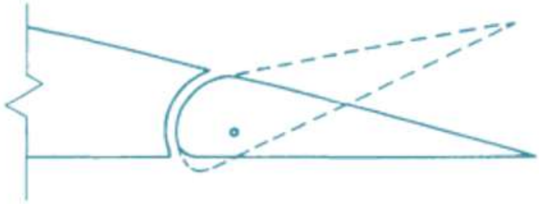
Contrary to common belief, an aeroplane is not turned by theuse of its rudder as a boat is turned in the water. But for an aeroplane to turn, it must be banked by moving the control wheel in the direction it is desired to turn. When the aeroplane banks, the lift produced by the wings no longer acts vertically but tilts, since it always acts in line with the vertical axis of the aeroplane. This inclined, or tilted, lift force not only supports the aeroplane against the force of gravity, but it also pulls the nose around in curved flight in much the same way a weight suspended from a string and slung around your headwillfollow a curvedpath.



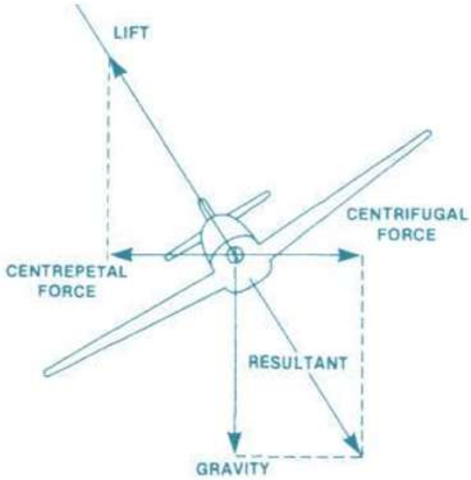
Turning the control wheel moves the ailerons to rotate the aero plane about its longitudinal axis.

If an aeroplane could be designed in such a way that there was no adverse yaw when it was banked, turns could be made by simply rolling the wheel in the direction the turn was wanted and the aeroplane would turn. But this is not quite the case in actual flight. When the control wheel is rolled to the right, for example, there is slightly more drag, on the left wingthan

there is on the right, and as the left wing moves upward to establish the bank, the nose of the aeroplane will start to move to the left. Just as soon as the bank is established and the wing stops rising, this adverse yaw will disappear and the nose will then move to the right, as itshould.



The leading edge of a Frise aileron protrudes below the lower wing surface when the aileron is up. This produces profile drag to minimize adverse yaw. To overcome the effect of adverse yaw, aeroplanes have rudders that are used to start the nose moving in the direction the wheel is turned.



An aeroplane is actually turned by tilting its lift by rolling the aeroplane about its longitudinal axis. This tilted lift pulls the nose around in curvedflight.

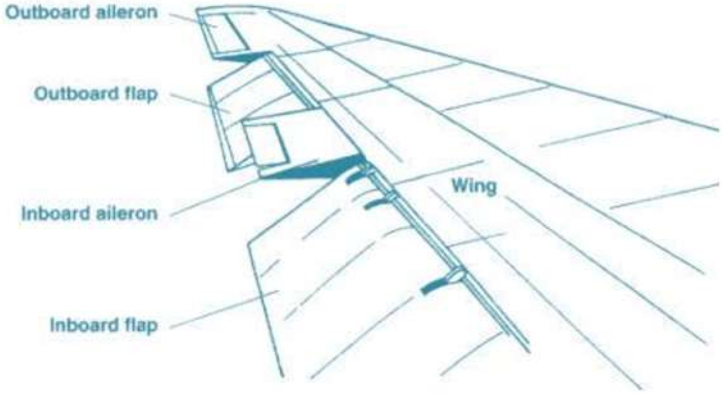
The rudder is the hinged surface on the rear of the vertical fin, connected to the two pedals controlled by the pilot's feet. Depressing the right pedal moves the trailing edgeof the rudder to the right. This deflects the air to the right, creating a force that moves the tail to the left and the nose oftheaeroplane to the right. Depressing the left pedal has the exact oppositeeffect.

A turn is started by the coordinated use of wheel and rudder,and once the nose starts to move in the right direction, the rudderpressureisrelaxed;whenthebankangleiscorrect,the

control wheel is centred. The turn will continue with the control surfacesstreamlined.

CONTROL CONFIGURATION AILERONS

The ailerons on almost all aeroplanes are located near the wing tips and hinge to the aileron spar to become part of the trailing edge of the wing.



Because of the extreme range of control forces needed by the large jet transport aircraft, many of them have two sets of ailerons—one in the conventional location, and one inboard. For slow-speed flight all four of the ailerons and the spoilers operate to provide the needed lateral control, but for high- speed flight, only the inboard, or high-speed, ailerons areactive in the controlsystem.

SPOILERS

A spoiler is a control device that destroys lift by disrupting the airflow over a part of the wing.

The most common spoilers are used on sailplanes. They are —popped up‖to —kill off‖lift on a portion on the wing, allowing a rapid rate of descent, while still retaining fullcontrol. They can be retracted to regain full lift when the desired altitude isreached.

Transport category aircraft use a little different application for spoilers. They are part of the secondary flight control system and are used as an aid for the ailerons, to relieve control pressures, to increase and decrease lift, and as speed brakes, to allow the aircraft to kill off some lift and increase its rate of descent without pitching the nose down. On the ground, both spoilers can be raised to help increase braking efficiencyby

increasing contact pressure of the tires with the ground and providing additional drag, thus becoming aerodynamic speed brakes.

For aileron assistance, theyact on the —down‖wingthrough a mixer system and move in proportion to the aileron. The spoiler system can also act as a backup aileron system, should the primary system everfail.

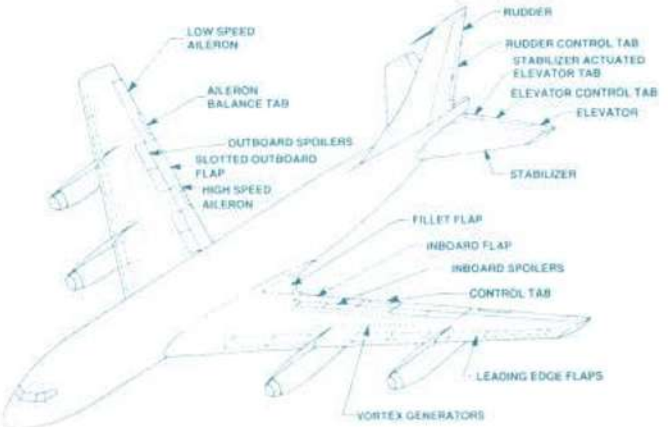
EMPENNAGE

The empennage of an aero plane is the assembly of tail surfaces that are used both for control and for stability. Regardless of their location or configuration, they serve the samefunctions.

Longitudinal stability and control are provided by thehorizontal surfaces, while directional stability and control are provided by verticalsurfaces.

The location of the horizontal tail surfaces must take into consideration both the effect of the propeller slipstream and the turbulence produced by the airflow over the wings. Some aeroplanes have these surfaces located quite low on thefuselage. The vertical fin on the aeroplane in Figure 1.51 is quite large and is swept back to provide not only an attractive appearance, but to increase its effective aerodynamic arm by moving the centreof its area as far back from the vertical axis of the aeroplane as practical. The extension of the vertical finup nearly to the back window is called a dorsal fin. Large vertical fins are often needed to counteract the surface area ahead of the vertical axis caused by the nose wheel fairing (if fitted).

Typical empennage configuration



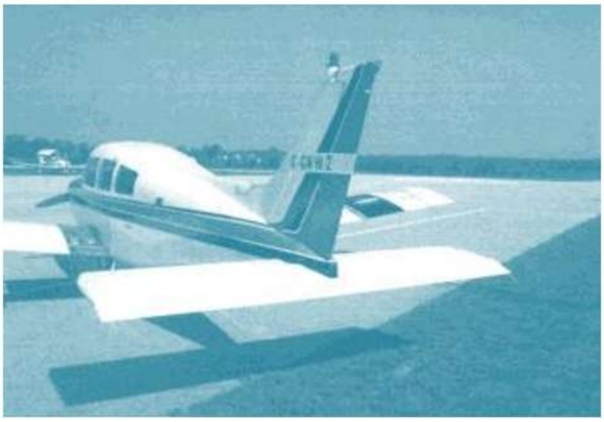
Control surfaces of a jet airliner.

A number of modern aero planes use the T-tail configuration. The horizontal tail surfaces are mounted on top of the vertical

surfaces. This keeps them out of the turbulence caused by the wing and prevents the rudder being blanketed by the horizontal surfaces and losing its effectiveness in a spin.

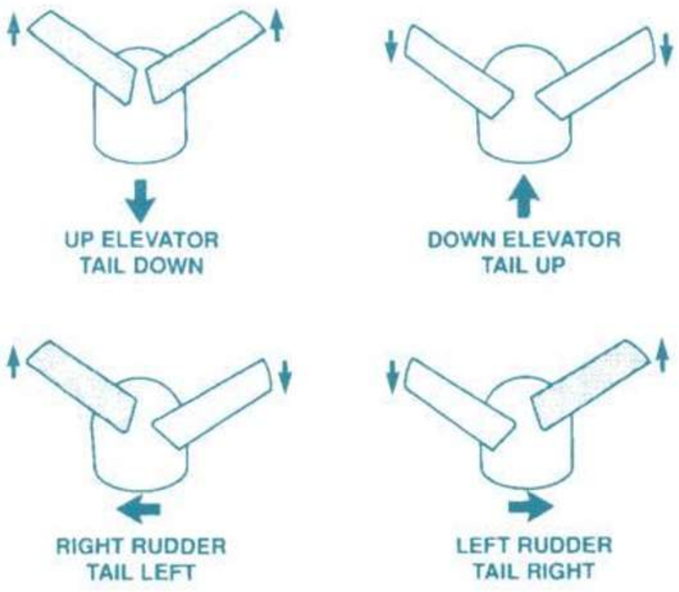
The T-tail configuration places the horizontal tail surface at the top of the verticalsurface.

The stabilator, or all-movable tail, is one form of horizontal tail surface that is finding a good deal of popularity. This type of horizontal tail surface has no fixed stabilizer, but rather there is an almost full-length anti-servo tab on its trailing edge. This tab cannot only be adjusted from the cockpit to change the longitudinal trim for hands-off flight at various airspeeds, but the adjustment jack screw is attached to the fixed structure in such a way that when the leading edge of the stabilator moves down to increase the downward tail load, the anti-servo tabmovesup.Thistabactiontendstorestorethestabilatortoa normal streamlined position. In the same way,when the noseof the stabilator moves up, the tab moves down and the resultant air load tends to streamline thestabilator.



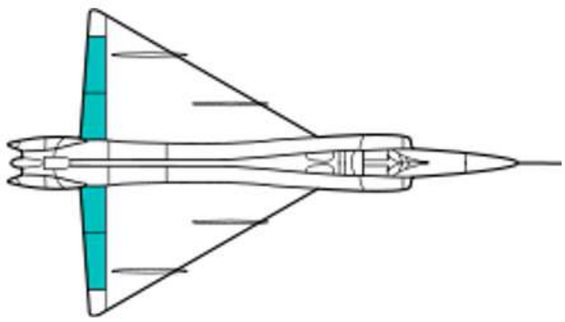
This all-movable horizontal tall surface is mounted far back on the fuselage to increase its effectivearm. A stabilator requires a rather heavy weight on a long arm inside the fuselage to give it staticbalance.

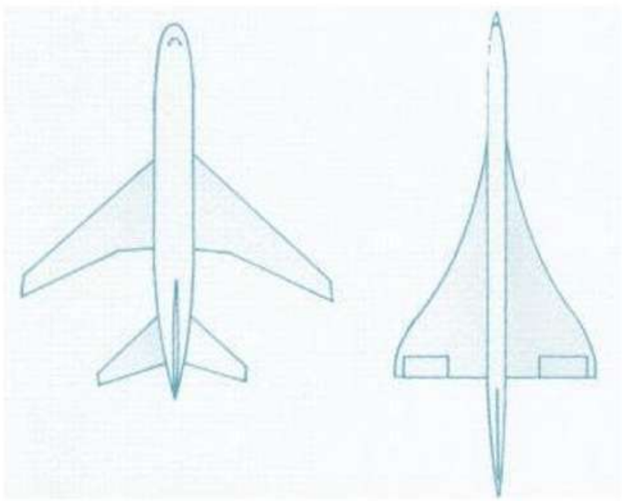
The horizontal tail surface on this turboprop aeroplane is mounted up on the vertical surface to get it away from the engine exhaust and turbulence from thewing.



Operation of ruddervators

FLAPERONS AND ELEVONS





Two additional control devices not normally seen on civilian aeroplanes are flaperons and elevons.

Flaperons consist of a mixer device that combines trailing edge flaps with aileron action. Generally, the entire trailing edge is lowered to increase lift by increasing the camber, as is normal. Aileron control is provided by outer sections of theflaps.

These sections act just like a normal aileron, except instead of starting from a streamlined position, they start from the flap angle.

Elevonsareused as the primary control system for all wing, or flying wing, designs. A mixer assembly similar to the ruddervator system is used. Only it combines the actions of both ailerons and elevators at the same time. Several designs of variable geometry military aircraft use elevons when the wings are swept back for high-speedflight.

HIGH LIFT DEVICES

The lift on a wing is dependent upon creating a difference in pressure between the upper and lower surfaces. For example, a difference of just 2PSI, when calculated over a large wing area of say 5,000 square inches, will produce a lift force of 2PSI x 5,000 in2= 10,000lbs.

Increasing the camber of the wing is the easiest way to provide a greater pressure difference between upper and lower wing surfaces, when increasing speed and/or angle of attack is not a viable option (such as during landing andtake-off).

Flaps and leading edge slats are designed primarily to increase the camber of a wing. On some types however, the flap/slat deployment will also increase the wing surface area. Other features such as slots and vortex generators are to help to control the airflow over the flaps/slats and to counter some of the disadvantages associated with theiruse.

FLAPS

The lift that is produced by an aerofoilsection is determined by the shape of the section, the amount of surface area, the speeditmovesthroughtheair,andtheangleofattackaswell as the density of the air. Changing any one of these variables changes the amount of lift the aerofoil produces.

We have already seen the way deflecting an aileron or an elevator changes the lift produced by the surface to which it is attached, and lowering the flaps changes the shape of the wing in such a way that it deflects more air for any given air density and airspeed. This greater air deflection is actually the production of a greater amount of lift. Along withthe production of a large amount of lift, deflected flaps alsoproduce a great amount of drag so the pilot can steepen his approach path without increasing his approachspeed.

TRAILING EDGE FLAPS

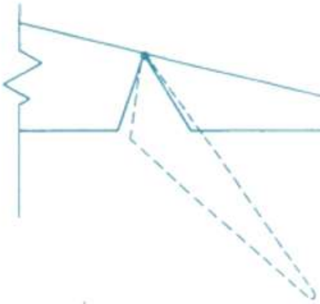
Flaps are usually mounted on the trailing edge of the wing between the inboard end of the ailerons and the fuselage. Depending upon the aeroplane, they may be lowered manually, electrically or hydraulically, and usually have preset stops to allow them to be lowered in increments. Normal flap settingsare 10, 20, 30, and in some instances, 40 degrees. Usually a deflection of up to about 20 degrees increases the lift more than the drag, and flap deflection in this range is often used for takeoff. Deflection beyond 20 degrees normally produces more drag than lift, and these deflections are used primarily for landing to provide the steepest descent path for a givenspeed.

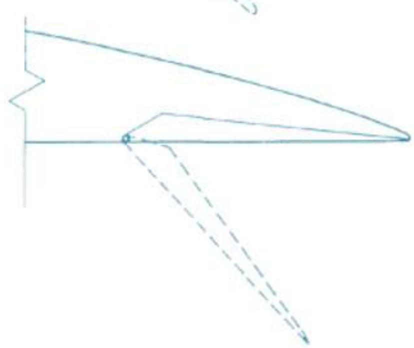
There are a number of configurations of trailing edge flaps. The simplest is the plain flap. When these flaps are lowered, the trailing edge of the wing moves down and the camber, or curvature, of the wing is increased. This increases thedownwash from the wing and increases both the lift and the drag.

The split trailing-edge flap lowers a hinged section of the under surface of the trailing edge. The very popular Douglas DC-3 transport aeroplane used this type of flap. Lowering a split trailing- edge flap increases the drag enough to allow the aeroplane to have a much steeper descent path for a given airspeed than it could have with the flapsup.

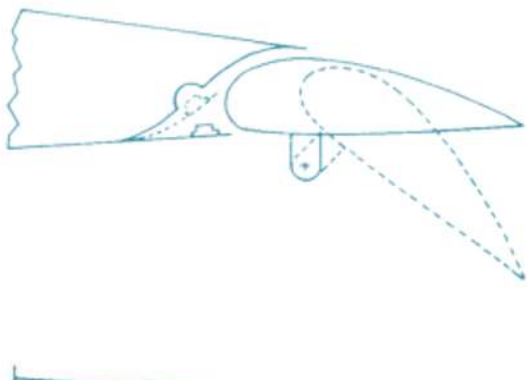
When most types of flaps are lowered to their full deflection, the airflow will break away from the upper surface, or will burble. When this happens, the increased lift produced by the flap is lost and only a great deal of drag results. In order to deflect the flaps the maximum amount without this airflow breakaway, slotted flaps are oftenused.

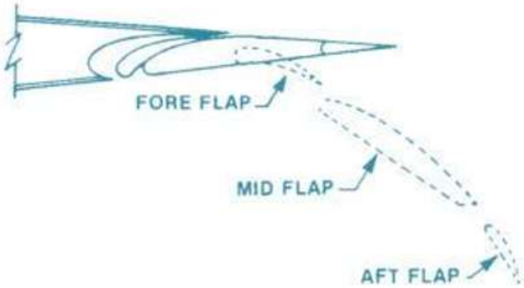
The simplest type of slotted flap has its hinge located below its lower surface, so when the flap is lowered a slot is formed between the high-pressure area below the wing and the low- pressure area above the wing. High-energy air flows through this slot and over the deflected flap with such a high velocity that it does not separate from the surface even at full flap deflection.

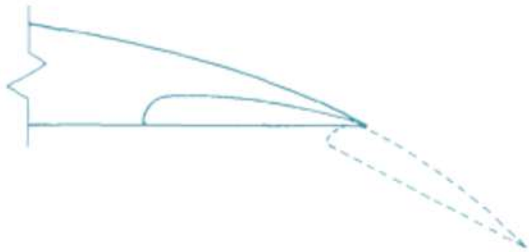


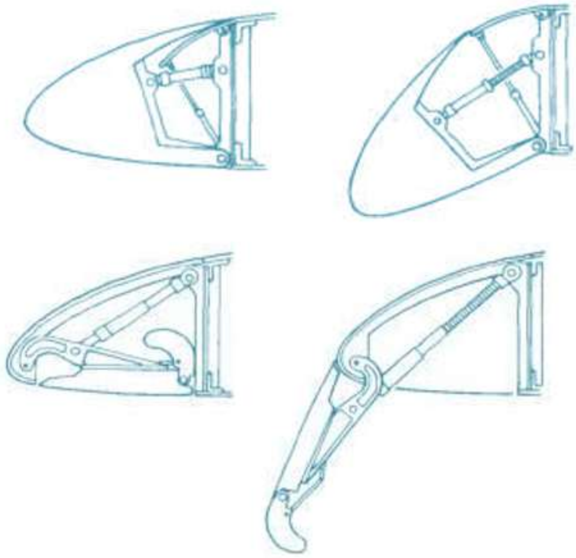


The extremely large and heavy jet transport aeroplanes use double and even triple-slotted flaps. When these flaps are lowered from the wing, there are either two or three sections that fold down. Between each section, there is a slot that allows high-energy air to flow over the deflected surface. By using this type of flap, these large and heavy aeroplanes are able to lift off and touch down at speeds that are notprohibitive.









The Fowler flap that was used quite a bit on Lockheed aeroplanes during and soon after World War II not only increased the camber of the wing, but actually added a considerable amount of wingsurface.

Fowler flaps ride out of the trailing edge of the wing on tracks, and when they are lowered, they stick out quite a way behind the wing. Because of the complexity of the Fowler flap operating mechanism, they have been largely replaced by slottedflaps.

LEADING EDGE FLAPS

To augment the action of trailing edge flaps, many of the large jet transport aeroplanes also have flaps on the leading edge as well.

The drooped leading edgeflap uses a jackscrew arrangement to push the leading edge of the wing against a hinge on its lower surface. This causes the leading edge to droop and increase the camber of the wing so it will deflect moreair.

The Krueger flap is similar to the drooped leading edge flap, except that a hinged linkageextendsout ahead of the leading edge arid produces a special high-lift leading edgeshape.

SLOTS AND SLATS

A wing stalls when the smooth airflow over its upper surface breaks away, or burbles. The slot is one expedient that has been used for many years to allow the wing to reach a high angleofattackbeforethisburbleoccurs.

Some aeroplanes have a fixed slot in the leading edge of the wing ahead of the aileron. At high angles of attack, air flows through this slot from the high-pressure area below the wing to the low-pressure area above. This air has enough energy that it will remain on the surface of the wing and not break away, or burble, until an exceptionally high angle of attack is reached. Since this slot is directly ahead of the aileron, it will maintain aileron effectiveness and therefore lateral control throughout thestall.

A later development that has increased the performance of Short Takeoff and Landing (STOL) aeroplanes is the full-span retractable slat. Under normal flight conditions, the slat forms a part of the leading edge of the wing, but when the angle of attack is increased enough, the low pressure over the leading edge causes the slat to automatically move out of the wing on itstracks, increase the wing camber, and form a full-length duct through which high-energy air from below thewingblows back across the upper surface. This type of slat allows the aeroplane to fly at an exceptionally high angle of attack withoutstalling.

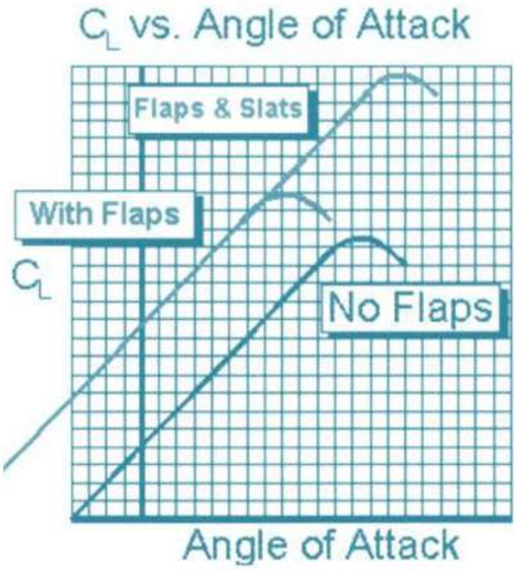
Some large airliners use jackscrew-operated slats which are mechanically driven out of the leading edge rather than being pulled out by aerodynamic forces.

EFFECT OF FLAPS AND SLATS ON STALL ANGLE

The effect of slats and flaps on the stall angle. Notice that the stall angle reduces with flaps only (however, the associated increase in CLwill permit a lower stall speed). The reason for the decrease in stall angle is the local increase in angle of attack at the location of the flap, and the increased camber at the flap location moves the separation pointforward.

Deploying the slats with the flaps restores the stall angle and actually increases it beyond the no-flap position. This is due to the associated slot, and its effect of increasing the energy of the airflow over the wing at that critical angle of attack and the approach to it, and also the associated drooping of the leading edge on some slat designs, decreases the local angle of attackslightly. This is why (on larger airliners) slats are always deployed with flaps, often automatically, and usually begin deployment only after the first stage of flapdeployment.

An associated increase in camber with the slat deployment also increases the camber significantly, resulting in a large increase in lift coefficient. Thus the deployment of slats with flaps is by far the preferred design configuration on largetransport categoryaircraft.



EFFECT OF FLAP DEPLOYMENT OF PITCH

When a flap is deployed, the bulk of the lift moves to the trailing edge on the wing, at the location of the flap. This is itself produces a nose down moment of the wing. However the overall effect on the aircraft pitching moment is a little more complicated than that.

For example there is an associated increase in drag at the wing position, and if the wing is mounted significally higher than the thrust line of the aircraft, there will be a nose- up moment which may be stronger than the previously mentioned nose down moment.

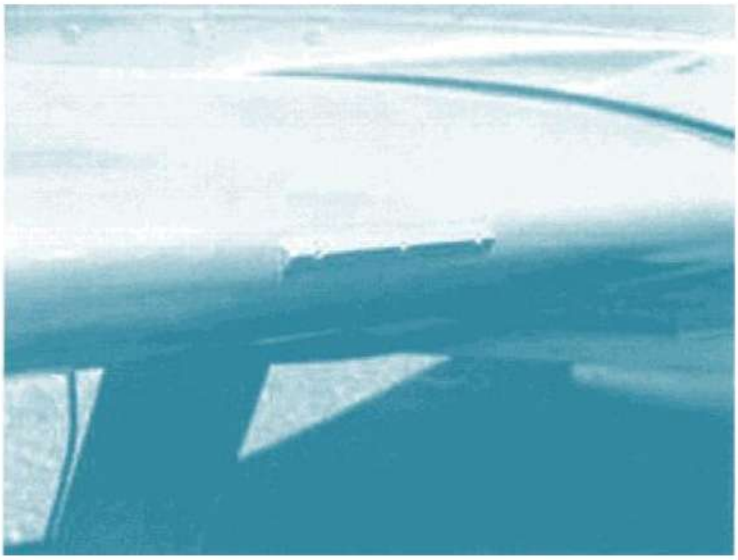
Secondly, when there is a flap deployment, there isasignificant increase in the angle of downwash of the airflow leaving the trailing edge of the wing. If the tailplaneis positioned low and close enough to the wing, there will be an increased negative angle of attack on the tailplaneas a result of the wind downwash, and thus an increase in the tail download and a further nose-up moment. Mounting the tailplanehigh on the vertical fin will help to preventthis.

Consequently, the actual pitching effect of deployment of the flaps cannot be determined without close analysis of theaircraft configuration, i.e. its relative wing positionand tailplane position.

High-lift devices	Increase of maximum lift	Angle of basic aerofoil at max. lift	Remarks
 Basic aerofoil	–	15°	Effects of all high-lift devices depend on shape of basic aerofoil.
 Plain or camber flap	50%	12°	Increase camber. Much drag when fully lowered. Nose-down pitching moment.
 Split flap	60%	14°	Increase camber. Even more drag than plain flap. Nose-down pitching moment.
 Zap flap	90%	13°	Increase camber and wing area. Much drag. Nose-down pitching moment.
 Slotted flap	65%	16°	Control of boundary layer. Increase camber. Stalling delayed. Not so much drag.
 Double-slotted flap	70%	18°	Same as single-slotted flap only more so. Treble slots sometimes used.
 Fowler flap	90%	15°	Increase camber and wing area. Best flaps for lift. Complicated mechanism. Nose-down pitching moment.

STALL STRIPS

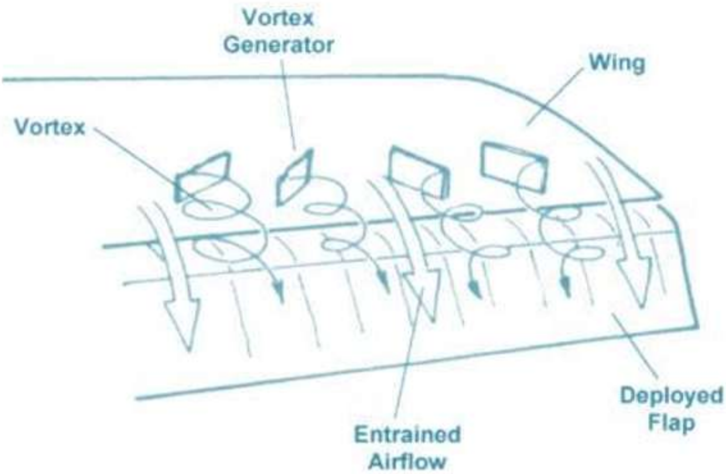
It is extremely important that an aeroplane wing stall progressively from the root out to the tip, so the ailerons will be effective throughout the stall. If a wing does not naturally have this stall progression characteristic, it is possible for the manufacturer to place a small triangular strip of metal on the leading edge of the wing in the rootarea.



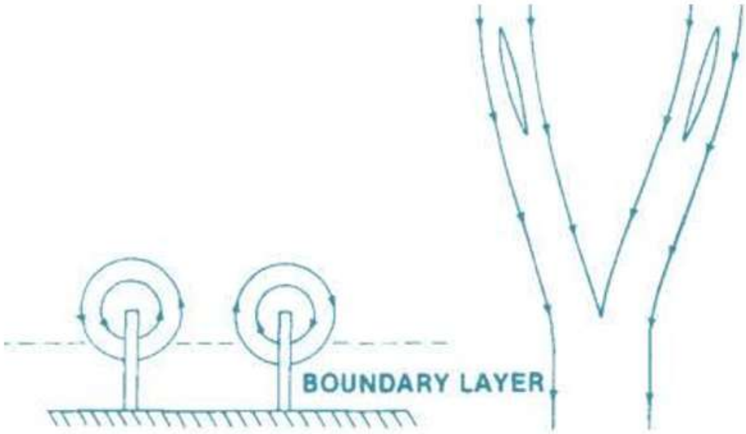
When a high angle of attack is reached, this triangular stall strip will break the airflow over the root section, and it willstall while the airflow is still smooth over the aileron. The loss of lift caused by the turbulence over the root section will cause the nose of the aeroplane to drop and restore the smooth flow of air over the entire wing.

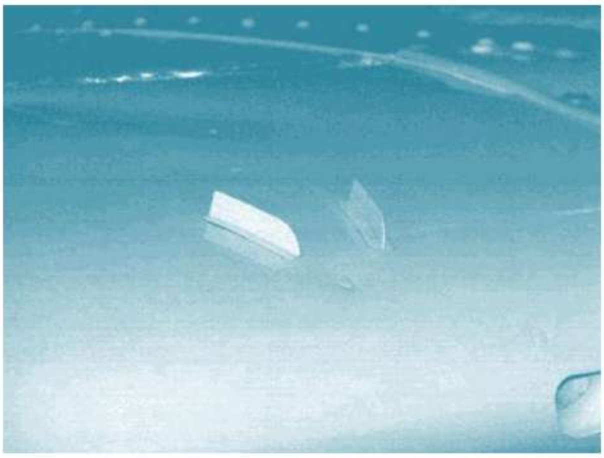
VORTEX GENERATORS

A wing stalls whenever the smooth airflow over its surface breaks away and becomes turbulent. And we generally associate stalls with high angle of attack flight conditions, but a special type of stall called shock-induced separation can occur on the wing of a high-speed aeroplane when it approaches its critical Mach number; that is, when it flies at a speed at which the airflow at any portion of the surface reaches the speed ofsound.



When an aerofoilapproaches its critical Mach number, a shock wave begins to form just behind the point at which the air is moving the fastest. This shock wave does not immediately attach to the trailing edge of the wing, but it moves back and forth and causes the air to separate from the upper surface of the wing. This separation causes a buffeting of the controls. To prevent this separation, vortex generators may be installed onto the top of the wing at the point where this separation is most likely to occur. Vortex generators are short, low-aspect-ratio aerofoil arranged in pairs. The tip vortices of these aerofoil pull high-energy air down into the boundary layer and prevent the separation.





SPOILERS, LIFT DUMPS AND SPEED BRAKES SPOILERS AND LIFT DUMPS

Spoilers are used to disrupt airflow over the wing and greatly reduce the amount of lift. This allows a pilot to lose altitude without gaining excessive airspeed. Spoilers are sometimes called "lift dumps". Spoiler deployment causes a large increase in drag and a large decrease in lift.

On most airliners, spoiler panels mixed with aileron inputs to enhance roll control. For example, a left bank will engage the ailerons as well as deploy certain spoiler panels on the down- going wing.

Ground spoilers are essentially similar to flight spoilers, except that they deploy upon touchdown on the runway, and include all spoiler panels for maximum "lift dump.‖ After touchdown, the ground spoilers deploy, and "dump" the lift generated by the wings, thus placing the aircraft's weight on the wheels, which accomplish the vast majority of braking after touchdown.

SPEED BRAKES (AIR BRAKES)

Air brakes are a type of flight control used to reduce speed during landing.

Speed brakes differ from spoilers in that speed brakes are designed to increase drag while making little change to lift, whereas spoilers greatly reduce the lift-to-drag ratio and a higher angle of attack required to maintain lift, resulting in a higher stall speed.

Often, characteristics of both spoilers and speed brakes are desirable and are combined – most modern airliners feature combined spoiler and speed brake controls. On landing, the deployment of these spoilers causes a dramatic loss of lift and hence the weight of the aircraft is transferred from the wings to the undercarriage, allowing the wheels to be mechanically braked with much less chance of skidding. In addition, the form drag created by the spoilers directly assists the braking effect. Reverse thrust is also used to help slow the aircraft after landing.

Note: Sometimes, spoilers, as described above, are referred to as ―air brakes‖ when used in flight for the purpose of slowing down the aircraft.

TRIM TABS

The term trim tab describes small secondary flight control surface set into the trailing edge of the primary control surface. Tabs are used to reduce the work load required to hold the aircraft in some constant attitude by ―loading ―the control surface to a neutral or trimmed center position.

Tabs can be fixed or the average flight condition.

Variable and the variable tabs can be designed to operate in several different manners.

FIXED TRIM TABS

A fixed trim tab, such as is normally a piece of sheet metal attached to the trailing edge of a control surface. This fixed tab is adjusted on the ground by bending it in the appropriate direction to eliminate flight control forces for a specific flight condition. The fixed tab is normally adjusted for zero control forces in cruise flight. Adjustment of the tab is trial and error process where the aircraft must be flown and the trim tab adjusted based on the pilot‘s report. The aircraft must then be flown again to see of further adjustment is necessary. Fixed tabs normally found on light aircraft, are used to adjust rudders andailerons.

CONTROLLABLE TRIM TABS

A controllable trim tab is illustrated. Controllable tab are adjusted by means of control wheels knobs or cranks in the cockpit and an indicator is supplied to dente the position of the tab.

Controllable trim tabs are found on most aircraft with at least the elevator tab being controlled. These tabs may be operated mechanically, electrically, or hydraulically. When the trim control system is activated the trim tab is deflected in the directionoppositetothedesiredmovementofthecontrolsurface.

When the trim tab i s deflected into the airstream, the air tries to push the tab back flush with the control surface. Since the control mechanism prevents the tab from being pushed back flush the control surface will be moved.

BALANCE TABS

A balance tabs like some servo tabs are usually found on large aircraft that require considerable force to move a control surface. The purpose of the spring tab is to provide a boost, thereby aiding in the movement of a control surface. On the spring tab illustrated in the control horn is connected to the control surface by springs. Spring tabs

Spring tabs are similar in appearance to trim tabs, but serve an entirely different purpose. Spring tabs are used for the same purpose as hydraulic actuators; tat is to aid in moving a primary control surface. There are various spring arrangements used in the linkage of the spring tab.

On a some aircraft a spring tab is hinged to the trailing edge of each aileron and is actuated by a spring loaded push pull rod assembly which is the linked to the aileron control linkage. The linkage is connected in such a way that movement of the aileron in one direction caused the spring tab to be deflected in the direction cause the spring tab to be de deflected in the opposite direction. This provides a balanced condition, thus reducing the amount of force required to move the ailerons.

The deflection of the spring tabs is directly proportional to the aerodynamic load imposed upon the aileron; therefore, at low speed the spring tab remains in a neutral position and the aileron isadirectmanuallycontrolledsurface.Athighspeedshowever,
where the aerodynamic load is great the tab functions as an aid in moving the primary control surface.

To lessen the force required to operate the control surface they are usually balanced statically and aerodynamically. Aerodynamic balance is usually achieved by extending a portion of the control surface ahead of the hinge line. This utilizes the airflow about the aircraft to aid in moving the surface. The various method of achieving aerodynamic balance.

Static balance is accomplished by adding weight to the section forward of the hinge line until it weights the same as the section aft of it. When repairing a control surface use care to prevent up setting or disturbing the static balance. An unbalanced surface has a tendency to flutter as air passes overit.

ANTI-SERVO TAB

Rather than requiring help to move a stabilator against the air loads, the area ahead of the hinge line makes the stabilator overly sensitive, and to decrease this sensitivity, most stabilator shave an anti-servo tab extending across their entire trailing edge. These tabs move in the same direction as the surface.

When the control wheel is pulled back, the trailing edge of the stabilator moves up, increasing the tail load and bringing the nose of the aeroplane up. As the trailing edge of the stabilator moves up, the anti-servo tab also moves up, producing an aerodynamic force in the direction needed to move the trailing edge of the stabilator down. In other words, the anti-servo tab counteracts the extreme sensitivity caused by the location of the hinge line of thestabilator.

OTHER CONTROL SURFACE FEATURES BALANCED CONTROL SURFACE

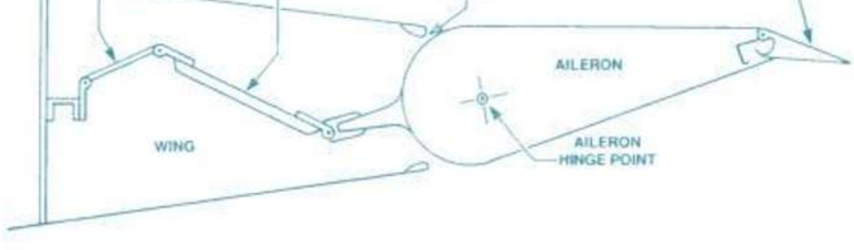
Even on small, light aeroplanes, aerodynamic assistance in the movement of the controls has been used. The simplest form of this assistance is the balanced control surface. In the case of the rudder, the balance portion, or overhang, deflects to the opposite side of the fuselage from the main rudder surface to produce an aerodynamic force that aids the pilot in moving the surface.

AERODYNAMIC BALANCE PANEL

The aerodynamic boost provided by the overhanging balance surface does not provide an increasing amount of assistance as the need increases. But an aerodynamic balance panelconnected to the leading edge of the control surface may be built in such a way that it will provide very little help when the surface is deflected a small amount, but will increase theamount of assistance that it gives as the surface deflection is increased.

The compartment ahead of the aileron is divided by a hinged lightweight, rigid balance panel which has a relatively large area. The panel divides this space into two smaller compartments, with one connected through a vent to the gap in the upper surface between the wing and the aileron, and the other through a vent to the samegap in the lower surface.

When the aileron is deflected upward, the high velocity air over the lower vent gap decreases the air pressure under the balance panel and pulls itdown.



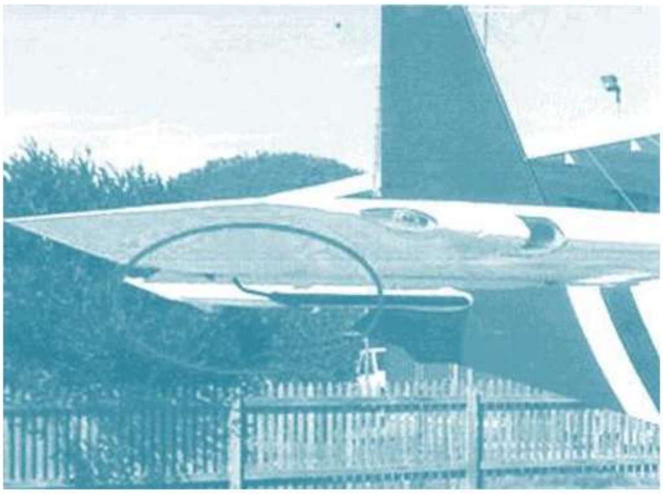
This downward force on the leading edge of the aileron causes the trailing edge to move up.
The greater the deflection, the lower the pressure, and the more assistance will be provided by the balance panel. When the aileron is moved downward, the high-velocity air over the topof the aileron will

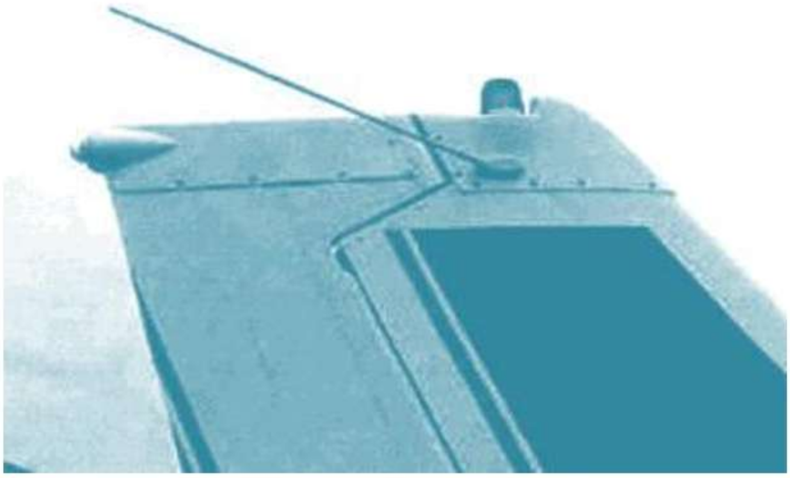
produce a pressure drop that will cause the balance panel to assist in moving the ailerondown.

CONTROL SURFACE MASS BALANCE

A phenomenon known as control surface flutter occurs at specific speeds (usually high speeds) and can cause vibration of the airframe and in severe conditions can lead to structural divergence and catastrophic failure of the structure.

The remedy for this is to set a specific mass some distance ahead of the control surface hinge- line, such that its moment about the control surface hinge is equal and opposite to the mass- moment of the control surface itself.





V SPEEDS

In aviation, V-speeds or Velocity-speeds are standard terms used to define airspeeds important or useful to the operation of aircraft These speeds are derived from data obtained by aircraft designers and manufacturers during flight testing and verified in most countries by government flight inspectors during aircraft type- certification testing. Using them is considered a best practice to maximize aviation safety, aircraft performance orboth.

The actual speeds represented by these designators are true airspeeds specific to a particular model of aircraft, and are expressed in terms of the aircraft's indicated airspeed, so that pilots may use them directly, without having to apply correction factors.

In general aviation aircraft, the most commonly-used and most safety-critical airspeeds are displayed as colour-coded arcs and lines located on the face of an aircraft's airspeed indicator.

The lower ends of the green arc and the white arc are the stalling speed with wing flaps retracted, and stalling speed with wing flaps fully extended, respectively. These are the stalling speeds for the aircraft at its maximum weight.

Having V speeds properly displayed is an airworthiness requirement for type-certificated aircraft in most parts of the world.

V – Speed Designator	Description
V_1	Critical engine failure recognition speed. (See V-i definitions below)

V – Speed Designator	Description
V_2	Takeoff safety speed. The speed at which the aircraft may safely become airbornewith one engineinoperative.
V_{2min}	Minimum takeoff safety speed.
V_3	Flap retraction speed.
V_4	Design manoeuvring speed, also known as the "Speed for maximum control deflection." This is the speed above which it is unwise to make full application of anysingleflightcontrol(or"pulltothestops")asit may generate a force greater than the aircraft's structural limitations. The heavier an aircraft is loaded the faster thisspeed.
V_A	Design speed for maximum gust intensity.
V_B	Design cruising speed, also known as the optimum cruise speed, is the most efficient speed in terms of distance, speed and fuel usage.
V_C	Demonstrated flight diving speed.
V_D	Design diving speed.
V_{DF}	Demonstrated flight diving speed.
V_{EF}	The speed at which the Critical engine is assumed to fail duringtakeoff.
V_F	Designed flap speed.
V_{FC}	Maximum speed for stability characteristics
V_{EF}	Maximum flap extended speed.
V_{FTO}	Final takeoff speed.
V_H	Maximum speed in level flight at maximum continuous power.

V – Speed Designator	Description
V_{LE}	Maximum landing gear extended speed. This is the maximum speed at which it is safe to fly a retractable gear aircraft with the landing gearextended.
V_{LO}	Maximum landing gear operating speed. This is the maximum speed at which it is safe to extend or retract the landing gear on a retractable gearaircraft.
V_{OF}	Lift-off speed.

V_{MC}	Minimum control speed with Critical engine inoperative.
V_{CG}	Minimum control speed in the take-off configuration-theminimum calibrated airspeed at which the aircraft is directionally controllable in flight with a sudden Critical engine failure and takeoff power onthe operative engine(s).
V_{MO}	Maximum operating limit speed.
V_{MU}	Minimum unstick speed.
V_{NE}	Never exceed speed.
V_{NO}	Maximum structural cruising speed or maximum speed for normal operations.
V_R	Rotation speed. The speed at which the aircraft's nosewheel leaves the ground. Landing reference speed or threshold crossing speed.
V_{REF}	Landing reference speed or threshold crossing
V – Speed Designator	Description
	speed.
VS	Stall speed or minimum steady flight speed for which the aircraft is still controllable.
VSO	Stall speed or minimum flight speed in landing configuration.
VS1	Stall speed or minimum steady flight speed for which the aircraft is still controllablein a specificconfiguration.
VSR	Reference stall speed.
VSR0	Reference stall speed in landing configuration.
VSR1	Reference stall speed in a specific configuration .
VSW	Speed at which the stall warning will occur.
VTOSS	Category A rotorcraft takeoff safety speed
VX	Speed that will allow for best angle ofclimb.
VY	Speed that will allow for the best rate of climb.

COMPRESSIBILITY

At low flight speeds, the study of aerodynamics is greatly simplified by the fact that air may experience relatively small 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 air flow is similar to the flow of water, hydraulic fluid or any other incompressible fluid. However at high flight speed, the pressure changes that take place are quite large, and significant changes in air density occur, as is also illustrated. The study of airflow at high speeds must account for these changes in air density and consider the fact the air is compressible.

SPEED OF SOUND

A factor of great importance in the study of high speed air flow is the speed of sound. The speed of sound is the rate at which small pressure disturbance will be spread through the air. Theaerodynamic effects of pressure are carried through the air at the same rate as that of sound disturbances.

The speed at which sound travels in air under standard se- level conditions is 1116ft/s or 761 mph, or 661 kn. The speed of sound is not affected by a change in atmospheric pressure because the density also changes. However a change in the temperature of the atmosphere changes the density without appreciably affecting the pressure; therefore the speed of sound changes with a change in temperature. The speed of sound can be calculated with the equation.

$a = 49.022 \sqrt{T}$

Where,

a = Speed of sound, ft/s
T – Absolute temperature, R0

The temperature of the air decrease in altitude up to an altitude of about 37000 ft and it is taken constant to an altitude of more than 100 000 ft. therefore under standard atmospheric conditions, the speed of sound decreases with altitude to about 37,000 ft and then remains constant to more than 100 000 ft. for example at 30,000 ft the temperature of standard air is -480F, and the speed of sound is 995 ft/s or 589 kn.

MACH NUMBER

Because of the relationship between the effect of high speed air forces and the speed of sound and because the speed of sound varies with temperature it is the ratio of the speed of the aircraft to the speed of sound that is important, rather than the speed of the aircraft with respect to the air. This ratio called the Mach number (M), is the true airspeed of the aircraft divided by the speed of sound in the air through which the aircraft is flying at the time.

M ? True Airspeed

- Subsonic : Mach numbers below0.75
- Transonic : Mach numbers from 0.75 to1.20
- Supersonic : Mach numbers from 1.20 to5.00
- Hypersonic : Mach numbers above5.00

The flight mach numbers used to define these areas of flight are approximate. A more accurate way to define these ranges for a particular aircraft is

Speedof Sound SUBSONIC
Thus Mach 0.5 at sea level under standard conditions ()0558 ft/s

[170 m/s]) is faster than Mach 0.5 at 30 000 ft (497 ft/s [151.52m/s]).

TYPES OF HIGH SPEED FLIGHT

Airflow speeds under Mach 1 termed subsonic, airflow at Mach 1 is considered sonic, and airflow speeds in excess of Mach 1 are called supersonic. Itis important to note that compressibility effects are not limited to flight speed at and above the speed of sound.

The speed of the air flowing over a particular part of the aircraft is called the local speed. The local speed of the airflow may be higher than the speed of the aircraft. For example, the speed of the air across the upper portion of the wing is accelerated to produce lift. Thus, an aircraft flying in the vicinity of Mach 1 will have local airflows over various parts of the aircraft at speeds both above and below Mach 1. 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. These regimes are defined asfollows:

The aircraft maximum Mach number that all local speeds will be less than mach 1.

TRANSONIC

The regime where local speeds are greater and less than mach 1.

SUPERSONIC

The aircraft minimum mach number when all local speeds are greater than 1.

The airspeed when local flows start to reach mach 1 is very critical to aircraft performance. For this reason, the free stream Mach number that produces the first evidence of local sonic flow is called the critical mach number. The 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.

SHOCK WAVE FORMATION

At speed less than 300mph , the airflow around an aircraft behaves as though the air were incompressible. Pressure disturbance, or pressure pluses are formed ahead of the parts of the aircraft, such as the leading edge if the wing. Theses pressure pluses travel through the air at the speed of sound and in effect serve as warning the air begins to move ot of the way. As a result of this warning, the air begins to more out of the way. Evidence of this―pressurewarning‖issimilartowavespreadingacrosswater. If pebbles were drooped into a smooth pond at the rate of one per second, at the same point, waves would spread out. Instead of drooping the pebbles in the water at the very same location, the point of dropping is slowly moved to the left each time. Each pebble still produces a circular wave, but the spacing between the rings is no longer uniform and is more closely spaced in the direction of movement. As already described, these wave disturbances provide a warning of the approaching aircraft. Notice that the warning tine, however will decreases as speed increases. If the speed of movement continues to increases between dropping the pebbles, a wavepattern.

Notice that no advance warning is being sent out by the wave pattern. This is speed of movement continuous to increase between dropping the pebbles, the smaller wave circle are no longer completely inside the next larger ones. The circles are now within a wedge- shaped pattern. This is similar to an aircraft flying at speeds above Mach 1 and illustrates how a shock wave is formed.

TRANSONIC FLIGHT

As has been previously discussed an aircraft in the transonic flight area can be expected to have local velocities which are greater than the free-stream airspeed. Therefore the effects of compressibility can be expected to occur at flight speeds less than the speed ofsound.

Using a conventional airfoil shape and assuming the aircraft is flying at Mach 4, the maximum local velocity will be greater than the free stream speed but most likely will be less than Mach 1. Notice that there is up wash and flow direction change well ahead of the edge.
Assume that a speed increaser to Mach. 72 will produce the first evidence of sonic for this aircraft. This means that M = 072 is the critical Mach number for this aircraft. As the critical Mach number is exceeded, an area of supersonic airflow is created and a normal shock wave forms as the boundary between the supersonic airflow and the subsonic airflow and the subsonic airflow on the aft portion of the airfoil surface. The acceleration of the airflow from subsonic to supersonic is smooth and the transition gradual. However transition of airflow from supersonic to subsonic is always accompanied by a shock wave and when there is no change in direction of the airflow the wave formed will be a normal shockwave.

Once of the principle effects of the normal shock wave is to produce a large increase in the static pressure of the airstream behind the wave. If the shock wave is strong the boundary layer may nit have sufficient energy to withstand the adverse pressure gradient of the wave and airflow separation will occur. At speeds that are only slightly beyond the critical Mach number the shock wave formed is not strong enough to cause separation or any noticeable change in the aerodynamic handling characteristics of the aircraft. The normal shock wave being formed at mach 77. As the number continues to increase to mach .28, the supersonic flow area gets larger on the upper surface and additional area od supersonic flow and normal shock wave forms on the lower surface.

As the flight speed approaches the sped of sound the areas of supersonic flow enlarge and the shock wave move nearer the trailing edge. The boundary layer may remain separated or may reattach depending primarily upon the airfoil shape.

The magnitude the location of these shock wave are constantly changing. Airflow separation will occur with the formation of

shock waves, resulting in the loss of lift. Other phenomena that may be associated with transonic with transonic flight are aircraft buffeting, trim and stability changes, and a decrease in control surface effectiveness. These forces and the turbulence that accompanies transonic flight may cause the pilot to lose control, especially if the airplane is not designed to operate under transonicconditions.

When the flight speed exceeds the speed of sound the bow wave forms at the leading edge. The typical flow pattern. If the speed is increased to some higher mach number, the oblique portions of the waves incline more greatly and the detached normal shock wave moves closer to the leading edge. At supersonic speeds the aerodynamic control conditions become predictable and orderly again. 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 object. Therefore the airflow does not change direction ahead of the air foil as occurred in the subsonicflow.

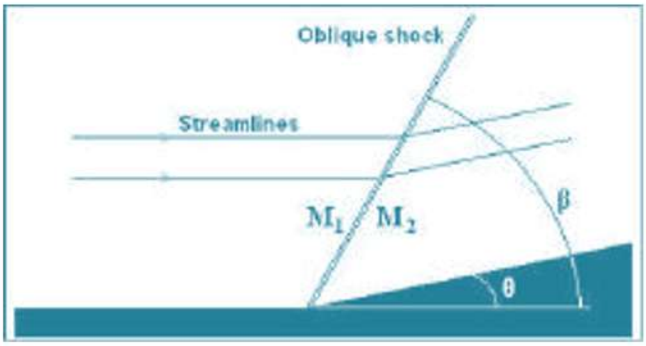
When supersonic flow is clearly established, all changes in velocity pressure density and flow direction take place quite suddenly and in relatively confined areas. The areas of flow change are very distinct and these areas are referred to as wave formations.

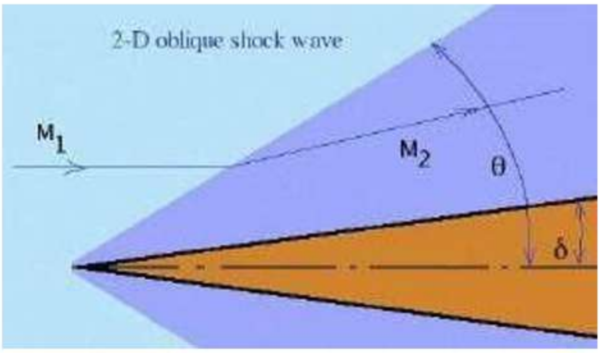
The wave formations formed at supersonic speeds are not imaginary or theoretical and in a suitable arranged high speed wind tunnel they can be photographed. Wave formed on a wind tunnel model at low supersonicspeed.

Various types of wave can occur in supersonic flow and the nature of the wave formed depends upon the airstream and the shape of
the object causing the flow change. Essentially there are three fundamental types of waves formed in supersonic flow:

1. the oblique shockwave
2. the normal shockwave
3. the expansion wave

OBLIQUE SHOCK WAVE

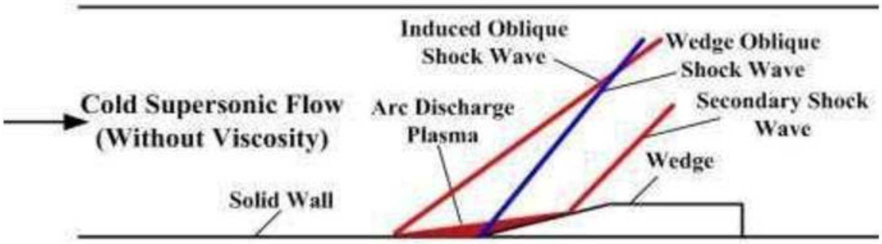


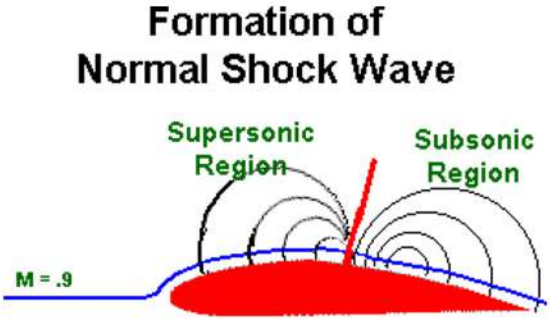


A typical case of oblique shock wave formation is that of a wedge pointed into a supersonic airstream. An oblique shock wave will from on each surface of the wedge. A supersonic airstream passing through the oblique shock wave will experience these changes:

1. The airstream is slowed down; the velocity and mach number behind the wave are reduced, but the flow is stillsupersonic.
2. The flow direction is changed to flow along the surface of the airfoil.
3. The static pressure of the airstream behind the wave is increased.
4. The density of the available energy of the airstream is dissipated and turned into unavailable hear energy. Therefore the oblique shock wave is wasteful ofenergy.

NORMAL SHOCK WAVE





If a blunt nosed object is placed in supersonic air stream, the shock wave which is formed will be detached form the leading edge. Whenever the shock wave forms perpendicular to the upstream flow, the wave is termed a normal shock wave, and the flow immediately behind the wave is subsonic. Placed in supersonic airstream will form a normal shock wave immediately ahead of the leading edge, showing the airstream to supersonic so that the airstream may fee the presence of the blunt nose and flow around it. Once past the blunt nose, the air steam may remain subsonic or accelerate back to supersonic, depending on the shape of the nose and the Mach number of the free stream. This type of normal shock wave which is formed ahead of an object in a supersonic airstream is called a bowwave.

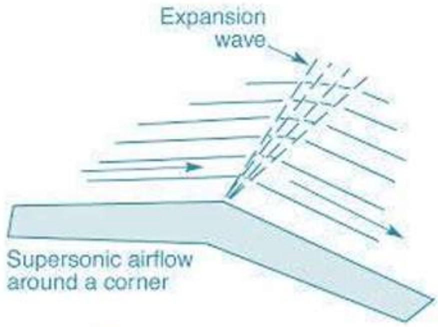
In addition to the formation of normal shock waves just described, this same type of wave may be formed in an entirely different manner. Illustrates the way in which an airfoil at high subsonic speeds has local flow velocities which are supersonic. As the local supersonic flow moves aft, a normal shock wave forms, slowing the flow to subsonic. The transition of flow form subsonic to

supersonic is smooth and is not accompanied by shock waves if the transition is made gradually with a smooth surface. The transition change always forms a normal shockwave.

A supersonic airstream passing through a normal through a normal shock wave will experience these changes:

1. The air steam is slowed tosubsonic.
2. The airflow direction immediately behind the wave is uncharged.
3. The static pressure of the air stream behind the wave is increasedgreatly.
4. The density of the air stream behind the wave is increased greatly.
5. The energy of the air steam is greatly reduced. The normal shock wave is very wasteful of energy.

EXPANSION WAVE



expansion wave

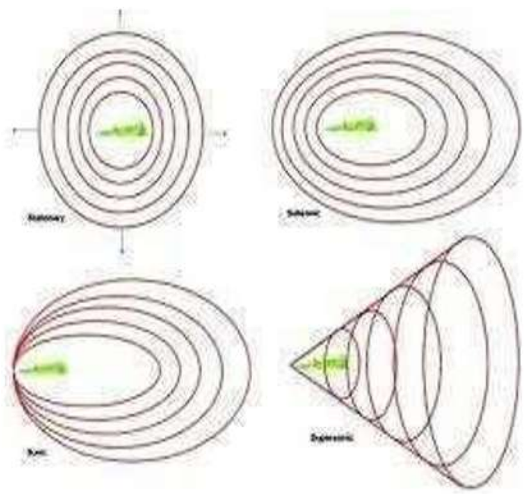
If a supersonic air steam were to flow —around a corner‖ an expansion wave would form. An expansion wav does not cause sharp, sudden changes in the airflow except at the corner itself and thus is not actually shock wave. A supersonic air stream passing through an expansion wave will experience these changes:

1. The airstream is accelerated; the velocity and Mach number behind the wave aregreater.
2. The flow direction is changed to flow along the surface, provided separation does notoccur.
3. The static pressure of the air stream behind the wave is decreased.
4. The density of the air stream behind the wave isdecreased.
5. Since the flow changes in a rather gradual manner, there is no shock and no loss of energy in the airstream. The expansion wave does not dissipate airstreamenergy.

DRAG DIVERGENCE

As previously described, the operation of aircraft can be both unpredictable and unstable in the transonic flight area. The formation of shock waves can create significant problems with airflow separations and the resulting rapid rise in drag. At speed only slightly above the critical Mach number, the shock wave information is formation is usually not strong enough to cause flow separation, and therefore drag changes only slightly. However as the speed continues to increase and the shock wave grows in strength, airflow separation will occur. This separation will result in a rapid increase in the airfoil drag coefficient. This point is called the drag divergence Mach number. Itis also sometimes referred to as the critical drag mach number. Inreferring to notes that form the drag divergence mach number to Mach 1 the drag rises sharply and operation within this range is not desirable. Also notice that at speeds higher that mach 1 the drag drops offsharply.

SONIC BOOMS



When an airplane is in level supersonic flight, a pattern of shock waves is developed. Although there are many shock waves coming form an aircraft flying supersonically, these waves tend to combine into two main shocks, one originating from the nose of the aircraft and one from the tail.
If these waves extend to the ground or water surface. They will be reflected, causing a sonic boom. An observer would actually hear two booms. The time between the two booms and their intensity is primarily a function of the distance the airplane is form the ground. The lower the aircraft is, the closer together and louder the two booms will be.

HYPERSONIC FLIGHT

When the speed of an aircraft or spacecraft if five times the speed of sound or greater, the speed is said to be hypersonic. Practical experience with such speeds has been gained by engineers working in a the space program under the direction of the National Aeronautics and Space Administration with the result that certain hypersonic vehicles are now practical, with other to be developed. The principle hindrance to hypersonic flight is the extreme temperature generated by air friction at hypersonic speeds. New materials and cooling methods are being developed to overcome thisproblem.

The high velocity test of a space shuttle model. The shuttle enters the earth‘s atmosphere at hypersonic speed. The model was tested in a Mach 20 helium tunnel at NASA‘s langely research center. The configuration developed by the NASA manned spacecraft
center is being tested at a 200angle of attck at simulated Mach 20 reentry speed. Row shock patterns from the nose and fixed straight wing are made visible by exciting the helium flow with a high energy electron beam.

11.1.2 HIGH SPEED FLIGHT

INTRODUCTION

Low speed aerodynamics is based on the assumption that air is incompressible; the attendant errors are negligible since at low speeds the amount of compression is negligible. At speeds approaching that of sound, however, compression and expansion in the vicinity of the aircraft are sufficiently marked to affect the streamline pattern about the aircraft. At low subsonic speeds a flow pattern is established about the aircraft, but at high subsonic andsupersonicspeedstheflowaroundagivenwingcanbe
controlled, and its behavior predicted. In the transonic range where a mixture of subsonic and supersonic flow exists, marked problems of control and stability arise, necessitating special design features to minimize the effects ofcompressibility.

TERMINOLOGY

a. SPEED OFSOUND

The speed at which a very small pressure disturbance is propagated in a fluid under certain conditions. Speed of sound is proportional to the absolute temperature (K) and can be calculated from theformula:

Therefore the higher the temperature, the higher the LSS. In fact, at MSL at ISA LSS= 661 kts, and at 30,000 ft LSS = 589kts.
Derivation of the formula for ISA conditions is as follows : LSS = C X √288K= 661
Therefore,

C = 661
288 K □ 38.95□
For practical purpose, the figure of 39 may be used.

b. MACH NUMBER(M)

The ratio of true airspeed (TAS) to the local speed of sound applicable to air temperature. Thus
Mach No (M) □TAS
LSS
therefore, at sea level temperature 15°C TAS = 529 kt.
LSS = 661 kt, M □529□ 0.80
661

c.	FREE STREAM MACH NO(Mfs)

The Mach number of the flow at a point unaffected by the presence of the aircraft.

d.	LOCAL MACH NUMBER(ML)

When an aerofoilis placed in a subsonic airflow, the flow is accelerated in some places, and slowed down in others. The local Mach number is the speed at some specified region of flow, and may be greater than, the same as, or lower thanMfs.

e.	CRITICAL MACH NUMBER(MCnt)

This is the lowest MFs which for a given aerofoiland angle of attack, gives rise to a MLof 1.0 on the aerofoil. As will be seen, Mcritfor a wing varies with angle ofattack.

f.	COMPRESSIBILITY MACHNUMBER

The Mach number at which, because of compressibility effects, control of an aircraft becomes difficult, and beyond which loss of control isprobable.

g.	CRITICAL DRAG RISE MACHNUMBER

This relates the Mach number to an appreciable increase of drag associated with compressibility effects, usually 10 -15% higherthan

h.	SUBSONICREGION

Aircraft speeds where flow everywhere around the aircraft is subsonic. Aircraft speeds up to Mach 0.75.

i.	TRANSONICREGION

Aircraft speeds where flow around the aircraft is mixed; somesubsonic, some supersonic. Aircraft speeds from Mach
0.75 to Mach 1.2.

j.	SUPERSONICREGION

Aircraft speeds where flow everywhere around the aircraft is supersonic. Aircraft speeds Mach 1.2.

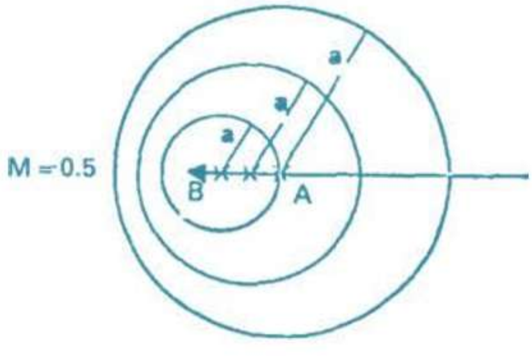
k.	HYPERSONICFLOW

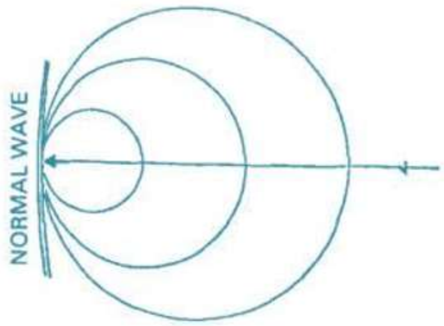
Aircraft speeds greater than Mach 5.0.

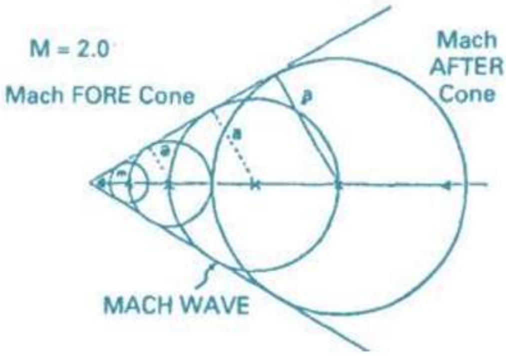
SPEED OF SOUND

Anything which moves through the air creates pressure waves and, what may not be generally realized, these waves not only travel out in all directions from the object but they radiate at the speed of sound. If the object is moving at a speed less than the speed of sound these pressure waves will be able to move away from the object. When considering aircraft moving at very high speed it is possible that the sound wave cannot get away from it, because the aircraft‘s speed is close to the radiation speed of the waves. It is this which gives rise to the problems of high speed flight.

Illustrates the situation of an aircraft flying at less than the speed of sound. If its starting point is A, then the pressure waves set out in all directions from the aircraft are moving steadily away and by the time point B is reached they will be well clear of the aircraft. This should be contrasted with the situation illustrated in where the aircraft is traveling just at the speed of sound. The pressure waves are also traveling at the speed of sound with the result that they pile up ahead of the aircraft and form into a pressure wave, also called a shock wave.







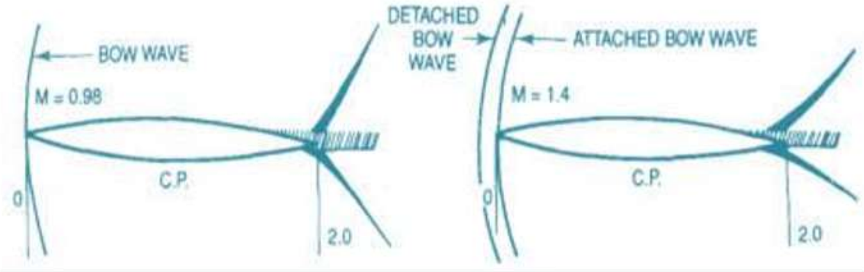
An aircraft traveling substantially faster than the speedof sound will leave its own pressure waves behind and form a cone of pressure waves asillustrated

SHOCK WAVES

When a shock wave is formed the pressure distribution over the wings is materially altered, causing considerable alterations in the values of lift and drag and also affecting control operation. It could be argued that few civil passenger transport aircraft are capable of reaching the speed of sound,however,

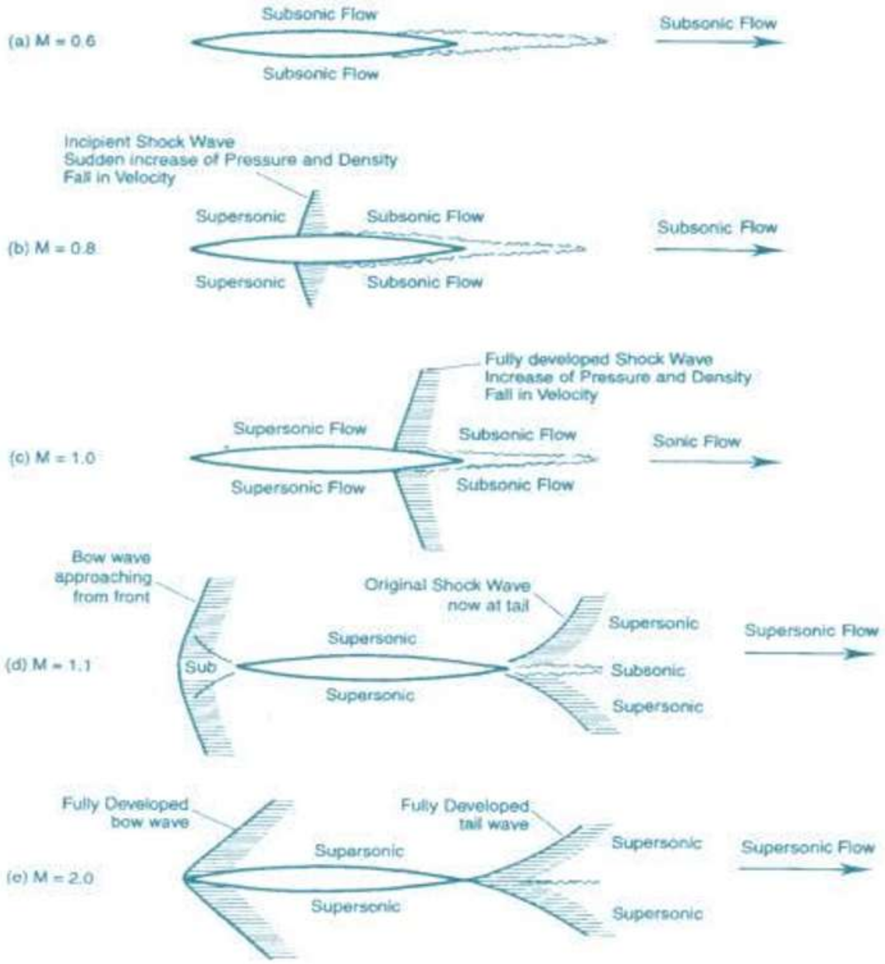
the air over the upper surface of the wing is deliberately accelerated in order to produce lift and even though the aircraft itself may be flying below the speed of sound, some of the air flowing over the wings may be accelerated to Mach 1.0. When the airflow over the upper surfaces of the wing reaches Mach 1.0, the actual speed of the aircraft is called the critical Mach Number or Mcrit. When this point is reached a shock wave forms over the upper surface of the wing because the pressure waves from the rear of the wing that aretryingtomoveforward are meeting air traveling at exactly the same speed flowing backward. This is similar to trying to move along a moving walkway in the wrong direction at the same speed as the walkway is traveling. The point at which this shock wave usually forms isjustaft of the point of maximum camber of the wing where the acceleration of the air is greatest. In front ofthe shock wave the flow is at or higher than Mach 1 whilstbehind the flow it is stillsubsonic.

At the shock wave, the normal laws of physics seem to break down and as the air pass through the shock wave the pressure increases and the temperature increases. If the speed of the aircraft is increased still further the region of supersonic flowon top of the wing also increases and the shock wave will startto move back towards the trailing edge. On the undersurface the curvature of the wing is usually less than on the upper surface and the shock wave will form later. However, once having formed, if the actual speed of the aircraft is further increased, this shock wave will also move rearward and when the actual speed of the aircraft reaches Mach 1 both shock waves will have migrated to the trailing edge of the wing. At the same time another shock wave will form close to the leading edge of the wing, this is called the bow wave. If speedis further increased this bow wave will actually touch the leading edge of the wing and is then termed an ‗attachedbow wave'.Thisis illustrated and further speed increases will not change the relative positions of these two shock waves, but will just bend thembackwards.



Shock waves can be:

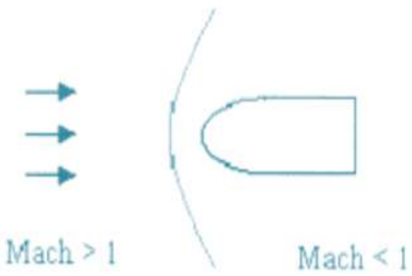
- NORMAL : at 90°(perpendicular) to the shock medium's flow direction.
- OBLIQUE : at an angle to the direction of flow.



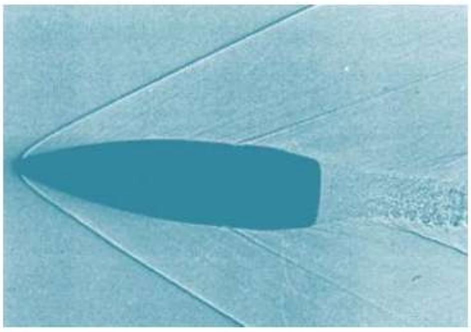
- BOW: Occurs upstream of the front (bow) of a blunt object when the upstream velocity exceeds Mach1.

NORMAL SHOCK

A Normal Shock is created by a blunt body in supersonic flow. The same body in a subsonic flow produces waves of sound that propagateaheadofthebody, basically—warning‖theapproaching air stream of the approaching body. These sound waves cause the molecules in the air stream to begin to diverge around the body well in advance of the actual body. When the object is traveling supersonically, however, these sound waves cannot outrun the object, and they pile up a short distance in front of the object. This stacking of sound waves is a Normal shock wave, and it serves to instantaneously force the air to change direction around the body. This effect is also referred to as a Bow Shock.



As a unit of air passes through the Normal shock wave, its temperature, pressure, and density dramatically rise as its velocity falls. In the case of the Normal Shock, the air flow downstream of the shock (and therefore seen by the bullet) is always subsonic.



OBLIQUE SHOCK

An Oblique Shock is a sharp edged shock wave that is formed when supersonic flow is turned on itself. These shocks are weaker than Normal Shocks, and although the temperature, pressure, density, and air stream velocity are reduced across the shock similar to the Normal Shock, the air stream behindthe shock is not necessarily subsonic. The Mach numberbehind the Oblique shock is calculated from the upstream Mach number, defined by the angle at which the flow is turned.

RAISING THE CRITICAL MACH NUMBER – SLIMNESS

When increase in engine thrust – due to the development of jet engines- first made transonic flight possible, research was concentrated on the problem of raising the critical Mach number, of postponing the shock stall, of getting as near to the barrier as possible without getting into it- in short, of keeping out of trouble rather than facing it.

There are two main ways of raising the critical Mach number. The first is slimness. The need for slimness will be abundantly clear from all that has been said about shock waves and their effects- and the slimness applies to all parts, the aero foil section, the body the engine nacelles the fin, tail plane and control surface and perhaps most of all to small excrescences on the aircraft. The aero foil section must be of the low drag laminar flow type already referred to, and must have a very low ratio of thickness to chord. The spilt fire of the second world war has already been mentioned as an sample of slimness, and of a high critical Mach number all the more remarkable in that it was not designed for transonic speeds.

The full line very clearly the effect of thickness/chord ratio on the critical Mach number for a straight wing (the dotted line will be referred to in the next paragraph); at a t/c ratio of 10 per cent this wing has a critical Mach number of only just over 0.8 at t/c ratio of 8 per cent it is raised to 0.85, and at 4 per cent it is over 0.9. not long ago the t/c ratios of wings for fighter aircraft were from 9 to 12 per cent, but they have now been reduced to 7 or 8 per cent, and may yet be still further reduced to a figure as low as 3 per cent, though there are course very great design and manufacturing difficulties in producing such thin wings. In thus speaking of thin wings it is important to keep in mind that what really matters is not the actual thickness, but the ratio of thickness tochord.

RAISING THE CRITICAL MACH NUMBER –
SWEEPBACK

The second main way of raising the critical Mach number is sweepback not just the few degrees of sweepback that was sometimes used, rather apologetically and for various and

sometimes rather doubtful reasons, on subsonic aircraft, but 400, 500, 700 or more.

Sweep back of this magnitude not only delays the shock stall, but reduces its severity when it does occur. The theory behind this is that it is only the component of the velocity across the chord of the wing which is responsible for the pressure distribution and so for causing the shock wave, the component V sin α along the span of the wing causes only frictional drag. This theory is borne out by the fact that when it does appear the shock wave lies parallel to the span of the wing, and only that part of the velocity perpendicular to the shock wave, i.e. across the chord, is reduced by the shock wave to subsonic speeds as the figure clearly shows, the greater the sweepback the smaller will be the component of the velocity which is affected, and so the higher will be the critical Mach number and the less will be the drag at all transonic speeds of a wing of the same t/c ratio and at the same angle of attack.

Experiment confirms the theoretical advantages of sweepback, though the improvement is not quite so great as the theory suggests. The dotted line in how a wing swept back at 450has a higher critical Mach number than a straight wing at allvalues of
t/c ratio, the advantage being greater for the wings with the higher values of t/c. tells us even more; it sweepback not only increases the critical Mach number but it reduces the rate at which the drag coefficient rises, and it lowers the peal of the drag coefficient – and 450of sweepback does all this better then 300. Incidentally this figure also that above M2, sweepback has very little advantage- but that is another story and, in any case aero planes cannot fly at M2 without first going through the transonic range.

Of course, as always there are snags, and the heavily swept- back wing is no exception. There is tip stalling – an old problem but a very important one; in the crescent shaped wing an attempt has
been made with some success to alleviate thisbygradually flow behind the shock wave, and so may itself be very ineffective reducing the sweepback from root totip. C⁄L max is low, and in producing the control forcesrequired.

therefore the stalling speed is high and C⁄L max is obtained at too large an angle to be suitable for landing- another old problem and one that can generally be overcome by special slots flaps or suction devices. There are also control problem of various kinds, and the designer doesn‘t like the extra bending and twisting stresses that are inherent in the heavily swept-back wing design. But whatever the problem sweepback seems to have come to stay- at least for aircraft which are designed to fly for any length of time at transonic or low supersonicspeeds.

CONTROL PROBLEMS

Reference has already been made to the unpleasant things that may happen to aircraft as they go through the speed of sound- violent changes of trim, up or down oscillations, buffeting and so on. In such circumstances the first essential from the pilot‘s point of view is that he should have complete control; and so be master of the aircraft and its movements.

Unfortunately this is by means easy to provide- and for several reasons.

Consider for instance an ordinary tail plane and elevator. At subsonic speeds and elevator depends for its effectiveness on the complete change of flow which occurs over both tail plane and elevator when the elevator is raised or depressed the actual forces which control the aircraft are in fact much grater on the tail plane than they are no the elevator itself. Now as soon as a shock were is formed on the tail plane- and the most likely place for its formation is at the hinge between tail plane and elevator a movementoftheelevatorcannot affectwillbeintheturbulent

At higher speeds, when the shock wave moves back over the elevator the opposite trouble may occur, and the forces on the elevator may be so great that it becomes almost immovable.

The answer to these troubles has been found in the all – moving slab type of tail plane sometimes given the rather curious name of a flying tail – and in making this power operated. In this way we have that what at the same time is an adjustable tail plane and an elevator.

The same principle can be applied to the ailerons by having all moving wing tips and more rarely, to the rudder by having a combined fin and rudder.

But this is not the only high speed control problem. Another is the possibility of reversal of the controls, owing to the distortion of the structure by the great forces on the control surfaces. This is most likely to happen on the ailerons. Suppose for instance, that the starboard aileron is lowered in order to raise the starboard wing – if the force on the aileron is very great it will tend to twist the wing in such a way as to reduce its angle of attack, and so reduce the lift instead of increasing the lift on that wing and the net result is that the wing will fall instead of rise. The aileron is acting on the wing just as a control tab is intended to act on a control surface, but that is the little consolation to the pilot and it doesn‘t take much imagination to realize his horror when a movement of the control column has exactly the opposite effect to that intended! Nor is it an easy problem for the designer to solve since the extra weight involved in providing sufficient stuffiness, especially on him and heavily swept back wings may be prohibitive. So as well as requiring power generatedcontrols

special high speed ailerons may be needed these are situated well inboard where the structure is stiffer instead of at the tips. Another solutions is to us _spoilers‘.

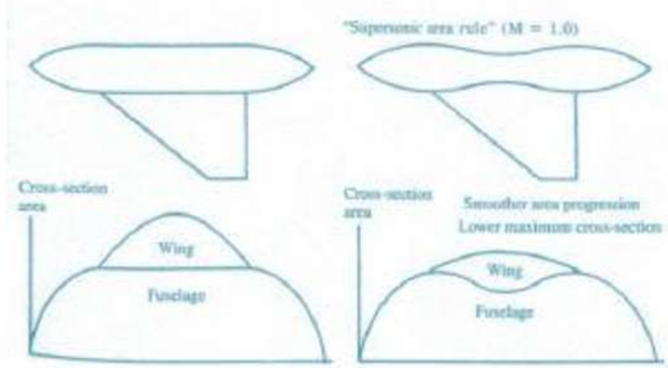
INSTEAD OF AILERONS

These are small flaps which come out of the top surface of the wing and disrupt the local flow, thus reducing lift on that wind and giving rollingcontrol.

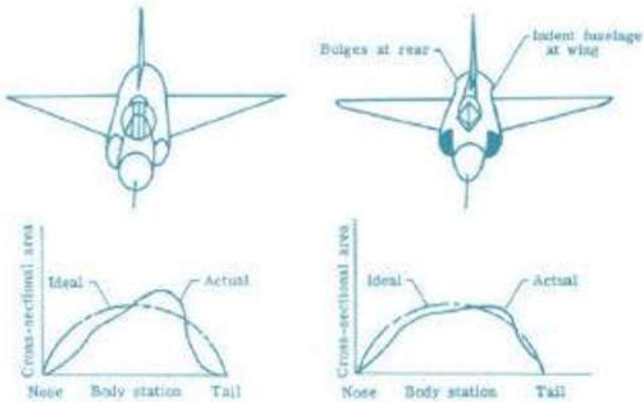
The introduction of power operated controls has in itself caused a new problem in that the pilot no longer _feels‘ the pressure resisting the movement of the controls; this feel was always a safety factor in that it made the pilot conscious of the forces he was a limit to what he could do to the airplane owing to the sheer limitation of his strength. So important is this matter of feel that when power operated controls are used it has been and necessary to incorporate artificial or synthetic feel and this is made even more easy by grading it so that it varies not only with the movement of the control surface but with the density of the air and the air speed, in other words with the dynamic or stagnation pressure, ½ pI2or q- it is sometimes called _q feel‘. Quite apart form the safety aspect this synthetic feel gives the pilot a sense of control over the aero plane which restores some things of the art offlying.

But his is not only problem resulting from the use of powered controls. If the power fails, and if there is no means of reverting to manual operation, the control may lock solid and the pilot be denied the use of rudder, elevators or ailerons. The answer to this is to introduce a safety factor by having more than one control surface, each having a separate power control thus the concord has two rudders, one above the other and six elevons. The Russian counterpart even has eightelevons.

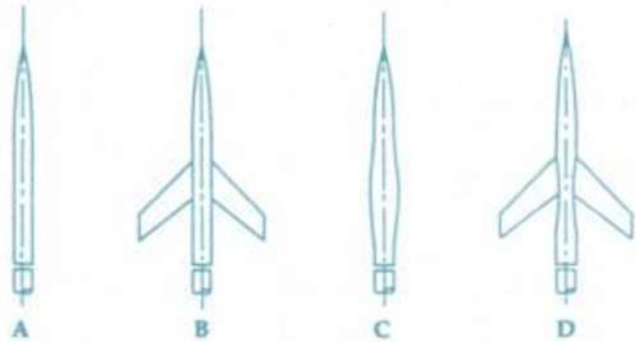
Again on delta and highly swept wings there is sometimes an interesting use of spoilers, this time as an aid to longitudinal control. Large aircraft flying at high speed, with their considerable inertia, are slow to respond to the elevatots, just as they are to the ailerons. If one set of spoilers is fitted inboard set of spoolers is fitted inboard , on each wing and so forward of the aerodynamics centre; and another set is fitted well outboard and so owing to the sweepback behind the aerodynamics centre and these are then linked to the elevator control in such a way that the fore and aft sets can be operated differentially, they will cause a movement of the centre of pressure which will aid the elevator control, just as when they are operated differentially on the port and starboard wings they assist the ailerons in providing lateral control as describedabove.



AREA RULE



(a) YF-102A before area ruling. (b) F-102A after area ruling.



We should by now realize that if the drag is to be kept to minimum at transonic speeds, bodies must be slim and smooth and have clean lines. What is the significance of clean lines? Well it is often said to be in the eye of the beholder, what looks right is right – yes but it depends on who looks at it; and a little calculation, a little rural, formula or whatever it may be will often aidoureyesindesigningthebestshapesfordefinitepurposes.

The area rule is simply one of these rules, and put in its simplest form it means that the area of cross section should increase gradually to a maximum, then decrease gradually; in this sense a streamline shape obey the are rule, though for transonic speeds, and indeed for high subsonic speeds the maximum cross sectional area should be about half way rather than one third of the way back, this giving a more gradual increase of cross sectional area with an equally gradual decreases. The body obey the area the transonic british aerospace Buccaneer which finally saw action of the Gulf war shortly before retirement. The bulge in the rear fuselage is for purposes of arearule.

Rule but is hasn‘t got any wings. If we add a projection to a body such as the wings to a fuselage, we shall get a sudden jump in the cross sectional area and that means that the area rule is not being obeyed.

What then can we do ?the answer is that we must decrease the cross sectional area of the fuselage as we add the cross sectional area of the wings in such a way that the total cross sectional area of the aero plane I creases gradually. Similarly behind the point of maximum cross sectional area it is the total cross sectional area that must be graduallydecreased.

It will be realized that the application of this rule gives a waist to the fuselage where wings or other parts such as the tail plane are attached. It will be realized too that sweepback in addition to its other advantages is to some extent an area rule in itself so far as the wings ware concerned, the cross sectional area being added gradually, and so the waisting to the fuselage will be less marked with swept back wings than with straightwings.

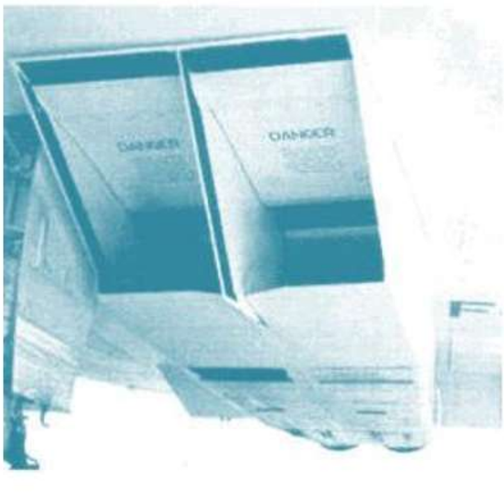
SUPERSONIC INTAKES

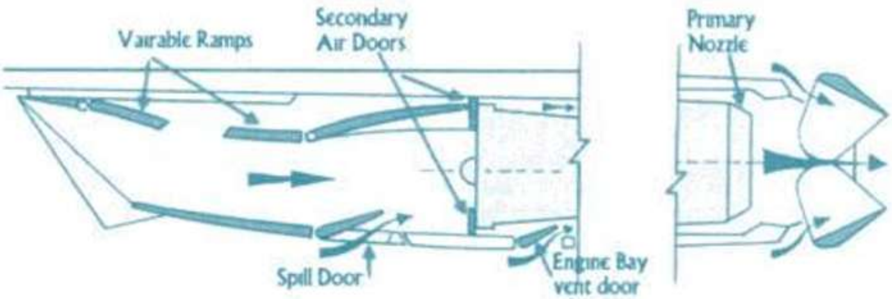
It is required that the airflow onto the compressor face is subsonic regardless of the aircraft speed, (Normally mach 0.4) if the rotating aerofoils are to remain free of shock wave accumulation which would be detrimental to the compression process.

Additional to this, it is often necessary to restrict the amount of airflow entering the compressor at supersonic speeds since the amount of airflow at this speed is simply not required.
At supersonic speeds, a Convergent-Divergent intake is found to be most effective, but at subsonic speeds this type of intake is inefficient. The usual method of overcoming this is to use a variable geometry inlet.

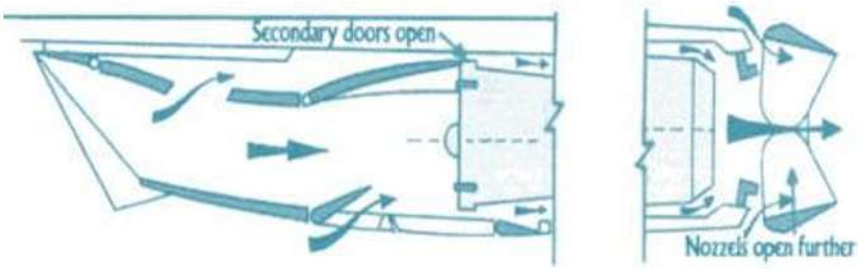
VARIABLE THROAT AREA INLET

The diagram of the concord inlet firstly an inlet at subsonic speeds. The throat is a maximum size for maximum air inlet. The last (the same inlet at supersonic speeds with the throat area reduced. The convergent part breaks the airflow in to a series of weak shocks which slow down the air progressively. Any unwanted air thereafter can be dumped by the spillvalve.





At take off the engines need maximum airflow, therefore the ramps are fully retracted and the auxiliary inlet vane is wide open. This vane is held open aerodynamically. The auxiliary inlet begins to close as the Mach number builds and it completelyclosedbythetimetheaircraftreachesMach0.93.



Shortly after take-off the aircraft enters the noise abatement procedure where the re-heats are turned off and the power is reduced. The secondary nozzles are opened further to allow more air to enter, therefore quietening down the exhaust. The Secondary air doors also open at this stage to allow air to bypass theengine.

At slow speeds all the air into the engine is primary airflowand the secondary air doors are kept closed. Keeping them closed also prevents the engine ingesting any ofitsown exhaust gas. At around Mach 0.55 the Secondary exhaust bucketsbegin to open as a function of Mach number to be fully open when the aircraft is atM1.1.

The ramps begin move into position at Mach 1.3 which shock wave start to form on the intakes.

At take off and during subsonic flight, 82% of the thrust is developed by the engine alone with 6% from the nozzles and 21% from the intakes.

At the supersonic cruse speed of mach2.0 the ramps have moved over half their amount of available travel, slowing down the air by producing a supersonic Shockwave (yellow lines) at the engine intakelip.

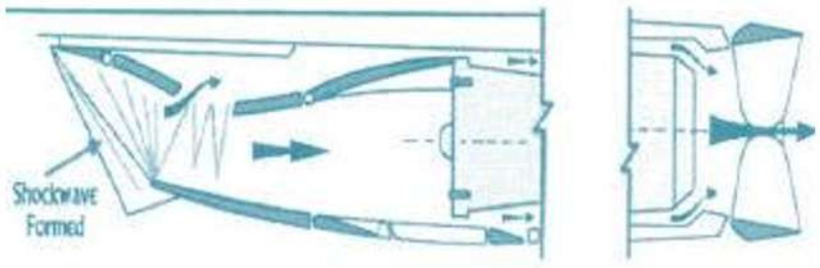
When the throttles are brought back to start the decent the spill door is opened to dump out excess air that is no longer needed by the engine, this allows the ramp to go down to their maximum level of travel. As the speed is lowered the spill doors are closed and the ramps begin to move back so by M1.3 are again fullyretracted.

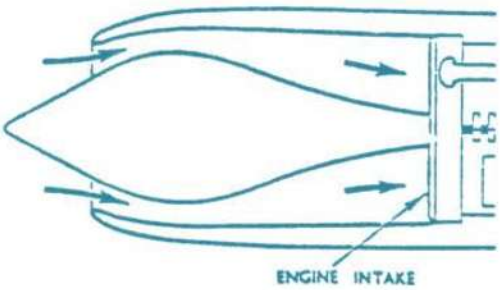
The ramps can continue in operation till Mach 0.7, should an engine have had to have been shut down.

During the Supersonic cruse only 8% of the power is derived by the engine with the other 29% being from Nozzles and an impressive 63% from the intakes.

EXTERNAL I INTERNAL INTAKE

At higher supersonic speeds, a more suitable type of intake is the one shown below. This type of intake produces a series of mild shock waves without excessively reducing the intake efficiency.





This intake is sometimes known as a plug intake. In some applications the plug position is variable dependent upon Mach number.

EFFECTS OF INCREASING MACH NUMBER ON STABILITY

TRANSONIC LONGITUDINAL STABILITY

Most aircraft operating in the transonic range experience a nose down pitch with speed increase, mainly due to two causes:

a. Rearward movement of CPwhich increases longitudinal stability.

b. Modification of airflow over the tailplane. The effect of main plane shock waves is to modify the flow over the tailplane which will tend to pitch the aircraft nosedown.

The effects on an aircraft's handling characteristics of nose down pitch are two-fold:

i. At some MachNo an aircraftwillbecomeunstable with respect to speed, necessitating a rearward movement of the control column. This particular problem is dealt with more fully in MachTrim.

ii. The requirement for a large up deflection of elevator/tailplanereduces the amount of available control deflection formanoeuvres.

SUPERSONIC LONGITUDINAL STABILITY

The rearward movement of the Cp in the transonic range continues as the aircraft accelerates into full supersonic flight. Thus all aircraft experience a marked increase in longitudinal stability.

TRANSONIC LATERAL STABILITY

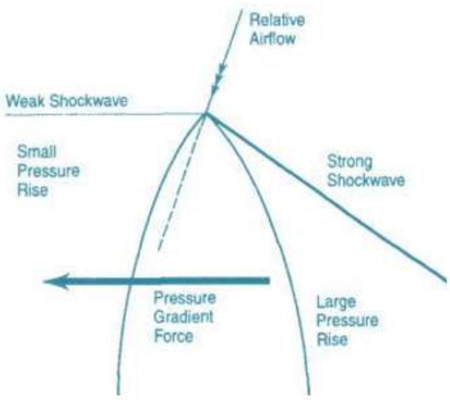
Disturbances in the rolling plane are often experienced in transonic flight, on some aircraft one wing starts to drop when Mcritis exceeded, due mainly to the difference in lift on the two wings because shock waves do not form at identical Mach numbers and positions on each wing.

SUPERSONIC LATERAL STABILITY

Lateral stability depends, after sideslip, on the lower wing developing lift. Since Cldecreasesin supersonic flight the correcting force is thus reduced and dihedral and sweepback are consequently less effective. Another adverse effect is the lift/drag ratio decreasing due tosurface friction drag, the decrease in lift/drag ratio being due to pressure differences between upper and lower surfaces combined with the pressures at the wing tips and their associated Machcones.

DIRECTIONAL STABILITY

The trend towards rear mounted engines, and consequently an aft CG, has meant a decreased arm about which the fin can act. Also, the supersonic decrease in CLfora given angle of attack caused by sideslip means a reduction in fin effectiveness. Subsonically, the fuselage side force in a sideslip acts in front of the CG and the vertical fin surfaces are able to overcome the destabilizing condition. In supersonic flight the fuselage side- force moves forward. As long as the aircraft is in balanced flight no problem arises, but if the relative airflow is off the longitudinal axis a destabilizing force at the nose results. This is caused by asymmetry in the strength of the two shock waves producing a pressure gradient across thenose.



The nose force illustrated in is tending to prevent the nose beingturnedintotherelativeairflowandisthereforedestabilizing. The force increases with speed and has a longer arm than the fin and rudder. The point of application of the force is difficult to define, but is located at that part of the fuselage where the cross-sectional area isincreasing.

One answer to this problem is to fit longer fins and increasetheir numbers, but there is a limit if only for wave drag considerations. A better method is the fitting of yaw dampers, which have already been dealtwith.

MACH TRIM

The device which corrects or compensates for longitudinal instability at high Mach numbers is the Mach Trimmer. As stated previously, at some Mach number an aircraftwillbecome unstable with respect to speed; this is potentially dangeroussinceany inattention on the part of the pilot in allowing a small increase in Mach No will produce a nose down pitch, which will give further increase in Mach No, in turn leading to even greater nose down pitch. However, the Mach Trimmer will in fact correct or compensate for the initial increase inspeed.

The Mach Trimmer is sensitive to Mach number and is programmed to feed into the elevator/stabilizer a signal whichis proportional to Mach number so that stability remains positive. The signal fed into the elevator/stabilizer simply causes their deflection in a direction to compensate for the trim change.

Mach trim operation in normal conditions will not be shown up by the behaviour of the aircraft, butwill usually be indicated by activation of the trim wheel and/or illuminationofa monitor light.

Mach trim operation should be checked against Mach number for any significant change in flightcondition.

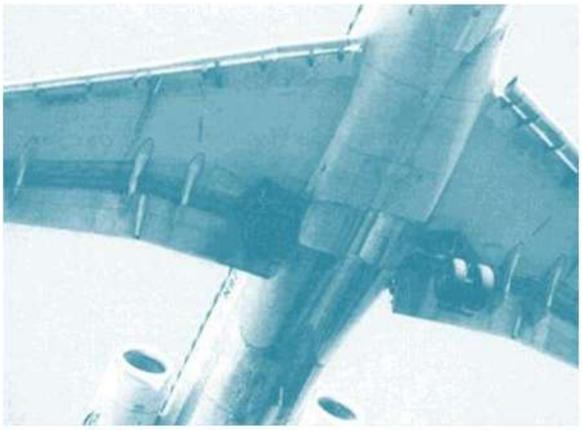
SWEEPBACK

A swept wing is a wing planform with a wing root to wingtip direction angled beyond (usually aftward) the spanwise axis, generally used to delay the drag rise caused by fluid compressibility.

Unusual variants of this design feature are forward sweep, variable sweep wings, and pivoting wings.

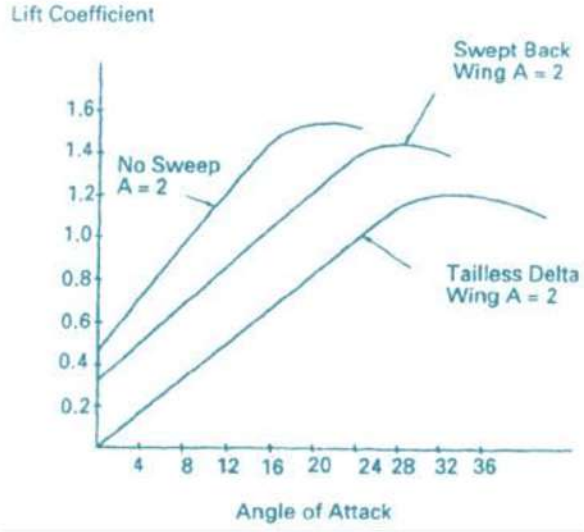
Swept wings as a means of reducing wave drag were first used on jet fighter aircraft. Today, they have becomealmost universal on all but the slowest jets, and most faster airliners and businessjets.

The angle of sweep which characterizes a swept wing is conventionally measured along the 25% chord line. If the 25% chord line varies in sweep angle, the leading edge is used; if that varies, the sweep is expressed in sections (e.g., 25 degrees from 0 to 50% span, 15degrees from 50% to wingtip).



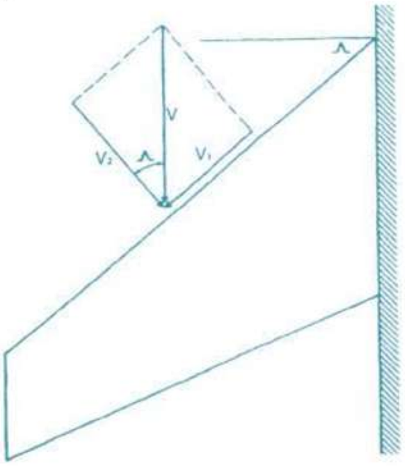
EFFECT OF SWEEPBACK ON LIFT

If a straight wing is changed to a swept planform, with similar parameters of area, aspect ratio, taper, section and washout, the CLmax is reduced. This is due to premature flow separation from the upper surface at the Wing tips. For a sweep angle of 45° the approximate reduction in CLmaxisaround30%. Typical Clcurvesfor a straight wing, a simple swept back wing and a tailless delta wing of the same low aspectratio.

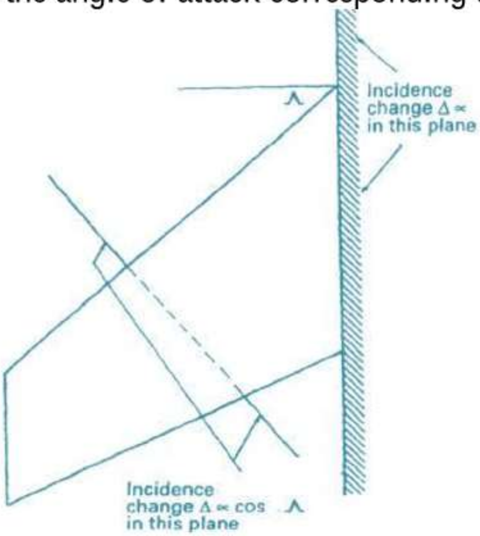


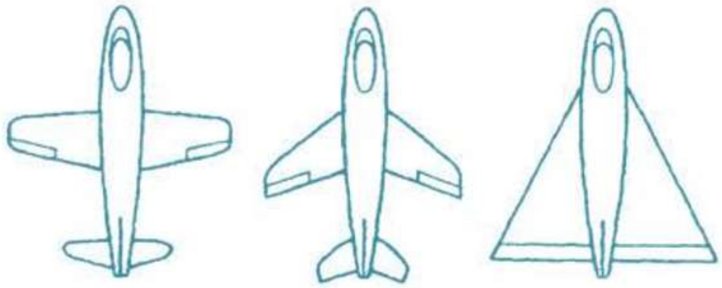
The main reason for the lowering of the CLslopeis best explained by examination .From the first it can be seen that the velocity V can be divided into wo components \A| parallel to the leading edge which has no effect on the lift, and V2normal to the leading edge which does affect the lift and is equal to V cosA. Therefore, all other factors being equal, the Clofa swept wing is reduced in the ratio of the cosine of the sweep angle.

That an increase in fuselage geometric incidence A will only produce an increase in the angle of attack AcosA in the plane perpendicular to the wing quarter chord line. Since it has already been said that it is airflow in the latter planewhich effects CL, the full increment of lift expected from the A change is reduced to that of aAcosAchange.



Considering the graphthe stall occurs on all three wings at angles of attack considerably greater than those of wings of medium and high aspect ratios. On all aircraft it is desirable that the landing speed should be close to the lowest possible speed at which the aircraft can fly; to achieve this desirable minimum the wing must be at the angle of attack corresponding to theCLmax.



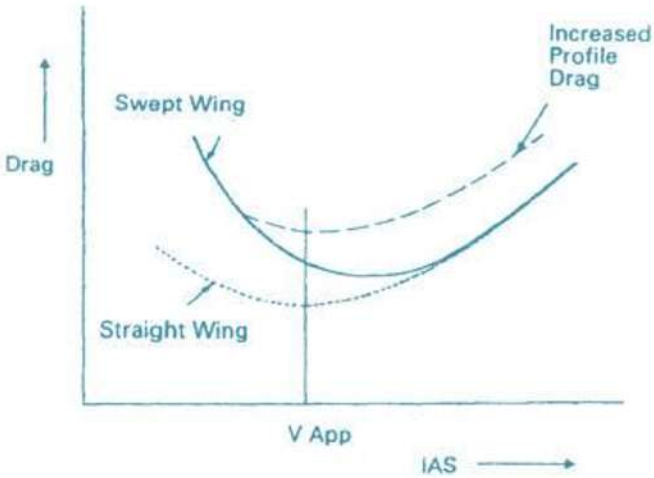


On all wings of very low aspect ratio, and particularly on those with a swept-back plan form, the angles of attack giving the highest lift coefficients cannot be used for landing. This is because swept-back plan form have some undesirable

characteristics near the stall and because the exaggerated nose- up attitude of the aircraft necessitates, among other things, excessively long and heavy undercarriages. The maximum angle at which an aircraft can touch down without recourse to such measures is about 15° and the angle of attack at touch-down will therefore have to be something of this order. The Cl corresponding to this angle of attack is lower than the CLmax for each wing. Compared with the maximum usable lift coefficient available for landing aircraft with un swept wings, those of the swept and delta wings are muchlower, necessitating higher landing speeds for a given wing loading. It is now apparent that, to obtain a common minimum landing speed at a stated weight, an unsweptwing needs a smaller area than either of the swept planforms. The simple swept wing needs a greater area, and so a lower wing loading, in order that the reduced CLcan support the weight at the required speed. The tailless delta wing needs still more area, and so a still lower wing loading, to land at the require speed. Typical planforms for the three types of wing under consideration, with areas adjusted to give the same stalling speed. The much larger area of the delta wing isevident.

EFFECT OF SWEEPBACK ON DRAG

The main reason for employing sweepback as a wing planform is to improve the high speed characteristics of the wing. Unfortunately this has adverse effects on the amount of drag produced at the higher range of angles of attack. The induced drag increases approximately in 1proportion to This is because, as already explained, Clisreduced by sweeping thecos Awing, and therefore to maintain the same lift the angle of attack has to be increased. This increases the induced downwash and hence the



induced drag.

The practical significance of this high increase in drag is the handling problems it imposes during an approach to landing. Because of the greater induced drag, the minimum drag speed is higher than that for a comparable straight wing, and the approach speed is usually less than the minimum drag speed. Therefore, if a pilot makes a small adjustment to the aircraft's attitude by, for example raising the nose slightly, the lift will be increased slightly, but there will be a large increase in drag, which will result in a rapid fall off in speed, with a large increase in power needed to restore equilibrium. In fact, the stage may be reached where even the use of full power is insufficient to prevent the aircraft from descendingrapidly.

On some aircraft this problem is overcome by employing high drag devices, such as airbrakes or drag-chutes, to increase the profile drag. This results in a flatter drag curve with the minimum dragspeedclosertotheapproachspeed.Afurtheradvantageis

that more power is required on the approach, which on turbojet aircraft means better engine response.

SUBSONIC AND TRANSONIC BEHAVIOUR

As an aircraft enters the transonic speeds just below the speed of sound, an effect known as wave drag starts to appear. Using conservation of momentum principles in the directionnormal to surface curvature, airflow accelerates aroundcurvedsurfaces, and near the speed of sound theacceleration can cause the airflow to reach supersonic speeds. When this occurs, an oblique shock wave is generated at the point where the flow slows down to supersonic. Since this occurs on curved areas, they are normally associated with the upper surfaces of the wing, the cockpit canopy, and the nose cone of the aircraft, areas with the highest localcurvature.

Shock waves require energy to form. This energy is taken out of the aircraft, which has to supply extra thrust to make up for this energy loss. Thus the shocks are seen as a form of drag. Since the shocks form when the local air velocity reaches supersonic speeds over various features of the aircraft, there is a certain "critical mach" speed (or drag divergence mach number) where this effect becomes noticeable. This is normally when the shocks start generatingover the wing, which on most aircraft is the largest continually curved surface, and therefore the largest contributor to thiseffect.

Since these shock waves are generated at areas of curvature, the obvious way to reduce their effect is to reduce the curvature. In the case of the fuselage, this suggests long, thin designs that are pointed at the ends. Such designs are common on high speed aircraft, the Concorde being one example, and are referred to as having a high "finenessratio".
This applies to the wing as well, which suggests that wings should have as little curvature as possible, be as thin as possible, and have a long chord. Examples of this sort of wing plan form can be found on the F-104 Star fighter for instance, which is highly optimized for high-speed performance. However, these same characteristics make a wing have a very low lift coefficient, and poor performance at slow speeds. The Star fighter has had a large number of landing accidents caused by its very high landing speed that was needed to keep the wing generating enough lift tofly.

SUPERSONIC BEHAVIOUR

Airflow at supersonic speeds generates lift through the formation of shock waves, as opposed to the patterns of airflow over and under the wing. These shock waves, as in the transonic case, generate large amounts of drag. One of these shock waves is created by the leading edge of the wing, butcontributes little to the lift. In order to minimize the strength of this shock it needs to remain "attached" to the front of the wing, which demands a very sharp leading edge. To better shape the shocks that will contribute to lift, the rest of an ideal supersonic aerofoilis roughly diamond-shaped in cross-section. For low-speedlift these same aerofoilsare very inefficient, leading to poor handling and very high landingspeeds.

One way to avoid the need for a dedicated supersonic wing is to use a highly swept subsonic design. Airflow behind the shock waves of a moving body are reduced to subsonic speeds. This effect is used within the intakes of engines meant to operate in the supersonic range, as jet engines are generally incapable of ingesting supersonic air directly. This can alsobe

used to reduce the speed of the air as seen by the wing, using the shocks generated by the nose of the aircraft. As long as the wing lies behind the cone-shaped shock wave, it will "see" subsonic airflow and work as normal. The angle needed to lie behind the cone increases with increasing speed, at Mach 1.3 the angle is about 45 degrees, at Mach 2.0 it is 60 degrees. For instance, at Mach 1.3 the angle of the Mach cone formed off the body of the aircraft will be at about sinp= 1/M (p is the sweep angle of the Machcone).

Generallyit is not possible to arrange the wing so it will lie entirely outside the supersonic airflow and still have good subsonic performance. Some aircraft, like the English Electric Lightning or F-106 Delta Dart are tuned entirely for high- speed flight and feature highly-sweptplan form without regard to the low-speed problems this creates. In other casesthe useof variable geometry wings, as on the F-14 Tomcat, allows an aircraft to move the wing to keep it at the most efficient angle regardless of speed, although the costincomplexityand weight makes this a rarefeature.

Most high-speed aircraft have a wing that spends at least some of its time in the supersonic airflow. But since the shock cone moves towards the fuselage with increased speed (that is, the cone becomes narrower), the portion of the wing in the supersonic flow also changes with speed. Since these wings are swept, as the shock cone moves inward, the lift vector moves forward as the outer, rearward portions of the wing are generating less lift. This results in powerful pitching moments and their associated required trimchanges.

DISADVANTAGES OF SWEEPBACK

When a swept wing travels at high speed, the airflow has little time to react and simply flows over the wing almost straight from front to back. At lower speeds the air does have time to react, and is pushed span wise by the angled leading edge, towards the wing tip. At the wing root, by the fuselage, this has little noticeable effect, but as one moves towards the wingtip the airflow is pushed span wise not only by the leading edge, but the span wise moving air beside it. At the tip the airflow is moving along the wing instead of over it, a problem known as span wiseflow.

The lift from a wing is generated by the airflow over it from front to rear. As an increasing amount travels span wise, the relative amount flowing front to rear is reduced, leading to a loss of lift. Since the span wise flow increases towards the wing tips, the lift at the tips drops off before the lift from the root. Normally this is not much of a problem, but as the plane slows for landing the tips can actually drop below the stall point even at aircraft speeds where stalls should notoccur.

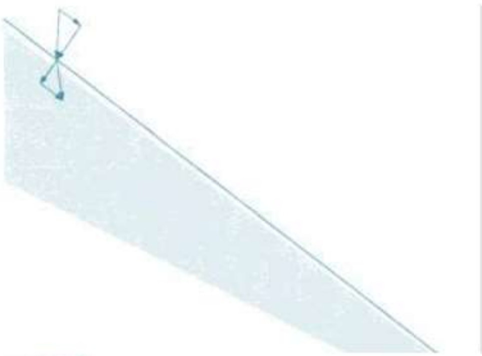
Since the tip is swept to the rear of the center of lift, the net lift of the wing as a whole moves forward. This creates a nose-up pressure on the aircraft. If this is not corrected by the pilot it causes the plane to pitch up, leading to more of the wing stalling, leading to more pitch up, and so on. This problem came to be known as the Sabre dance in reference to thenumber of North American F-86 Sabresthatcrashedonlanding as aresult.

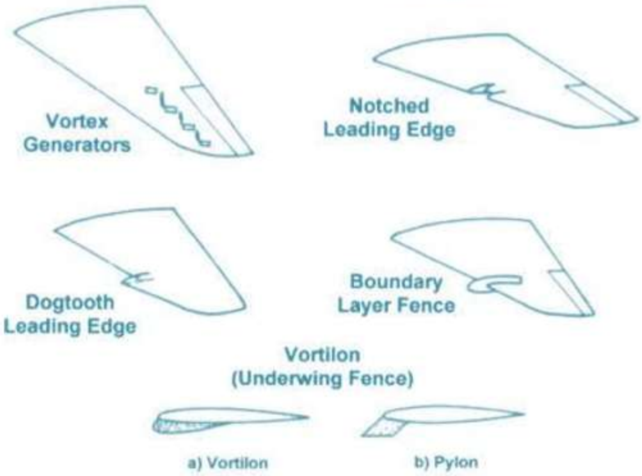
The solution to this problem took on many forms. One was the addition of a fin known as a wing fence on the upper surface of the wing to redirect the flow to the rear (see the MiG-15 as an example). Another closely-related design was addition of a dogtooth notch to the leading edge (Avro Arrow). Other

designs took a more radical approach, including the XF-91 Thunderceptor' swing that grew wider towards the tipto provide more lift at the tip. The Handley Page Victor had a plan form based on a crescent compound sweep or scimitar wing that had substantial sweep-back near the wing root where the wing was thickest, and progressively reducing sweep along the span as the wing thickness reduced towards the tip. Some other methods of reducing span wise flow at lowspeed.

Modern solutions to the problem no longer require "custom" designs such as these. The addition of leading edgeslats and large compound flaps to the wings has largely resolved the issue. On fighter designs, the addition of leading edgeextensions, included for high maneuverability, also serve to add lift during landing and reduce theproblem.

The swept wing also has several more problems. One is that for any given length of wing, the actual span from tip-to-tip is shorter than the same wing that is not swept. Low speed drag is strongly correlated with the aspect ratio, the span compared to chord, so a swept wing always has more drag at lower speeds. Another concern is the torque applied by the wing to the fuselage, as much of the wing's lift lies behind the point where the wing root connects to the plane. Finally, while it is fairly easy to run the main spars of the wing right through thefuselage in a straight wing design to use a single continuous piece of metal, this is not possible on the swept wing because the spars will meet at anangle.





SHOCK STALL

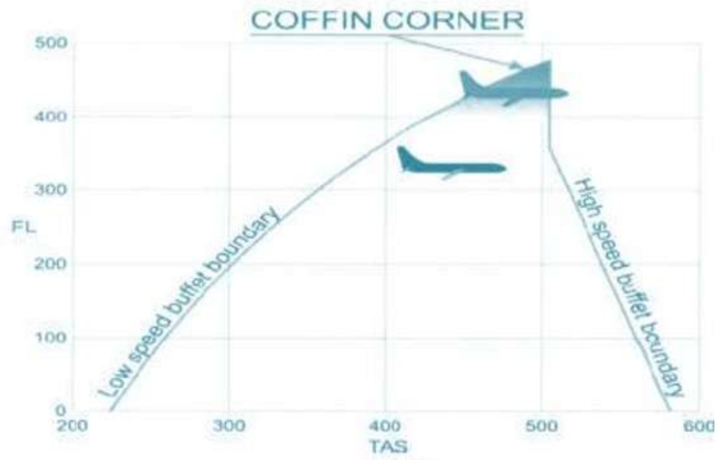
Shock stall this occurs when the airflow over the wings start to approach the speed of sound. When this happens the shockwaves/compression produced by the airflow makes the air separate from the aircraft earlier and therefore produce less lift. The aircraft goes into 'Mach Tuck' which is a nose down pitching movement (as opposed to a slow speed stall where the nose pitches up) and eventually the loss of lift is so great that the aircraftstalls.

COFFIN CORNER

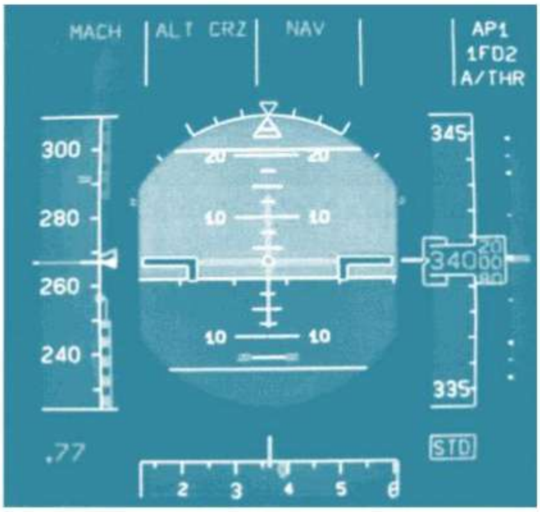
As an aircraft climbs at constant true airspeed, the local speed of sound decreases (up to the tropopause at 36,000 ft) as this depends only on the air temperature. Therefore the aircraft, although climbing at a constant true airspeed, will be approaching the shock stall (critical mach speed) the higher it gets.

At the same time, the aircraft‘s low speed stall is increasing with increasing altitude, since the reducing density effect reduces the lift and therefore increases the stall speed (in TrueAirspeed).
As the aircraft climbs therefore, the speed range between the shock stall and low speed stall decreases

to such a point, at a critically high altitude, the aircraft can neither increase speed nor decrease speed without encountering one or other of the stall types. The aircraft is in ―coffin corner‖.



Coffin corner



The amber ―barber pole‖is the low speed stall margin. The red ―barber pole‖is the shock stall margin. As the displayindicates Indicated Airspeed (IAS), the low speed stall margin will remain constant as the aircraft climbs, but the high speed stall margin will reduce as the aircraft climbs, thus reducing the speed range in which the aircraft can fly at highaltitude.

11.2 Airframe Structures - General Concepts

Airworthiness Requirements for Structural Strength

Safety means more than only that the aircraft must be capable to withstand the most severe loadings it will encounter during its service life. It should not be difficult for the flight crew to control it under all circumstances. This means the aircraft should also show sufficient positive stability during all flight phases and attitudes throughout the flight envelope.

EASA Certification Specification (CS) -25 is based on Part 25 of the Federal Aviation Administration.

These requirements are applicable for all large aircraft. This means aircraft with a maximum mass not less than 5700 kg. Excluded are reciprocating-engine aircraft, seaplanes and ski planes.

Safe-Life

The discovery of fatigue cracks, and failures of major structural elements on aero planes in the late 1930s and early 1940s, forced the development of the safe-life design principle. The safe- life design principle requires that major structural elements be replaced after a fixed number of flight cycles. These parts cannot be repaired or refurbished to extend the component's life. The basis for safe-life design is fatigue analysis.

Fatigue

Soon after the first jet transport aircraft started flying in the early 1950s, three of them broke apart in the air under mysterious circumstances, two of them in relatively non- turbulent air. An extremely thorough investigation disclosed that the cause of the break-ups was metal fatigue brought about by the flexing of the structure during the pressurization and depressurization cycles.

When the first jet transports, the British Comets, were put into service with their pressurization of 8 PSI, real problems did arise. The continued flexing of the structure caused by the pressurization and depressurization cycles fatigued the metal to such an extent that a crack developed at a square come of a cut-out in the structure and the large amount of pressure differential caused the structure to virtually explode. When the cause of the structural failure was determined, new emphasis was placed on fail-safe design of aircraft structures. Stress risers, or portions of the structure where eliminated. Joints and connections are carefully pre- stressed to minimize the cyclic stresses from the flight loads.

The life of a structure may depend more on how it is loaded than on the total number of times it is loaded, or on the maximum amount of the loads themselves. This is best shown by loading a 5 cm2 bar of aluminium alloy that breaks at 370kN when loaded once (see Figure2.1).
However, if loads of from 0 to 111 kNwere applied, it would last about 25,000 cycles. Loadings from 111 kNtensionto111kNcompression(commonlycalledplusto minus 111 kN) it would fail at about 4,000 cycles.

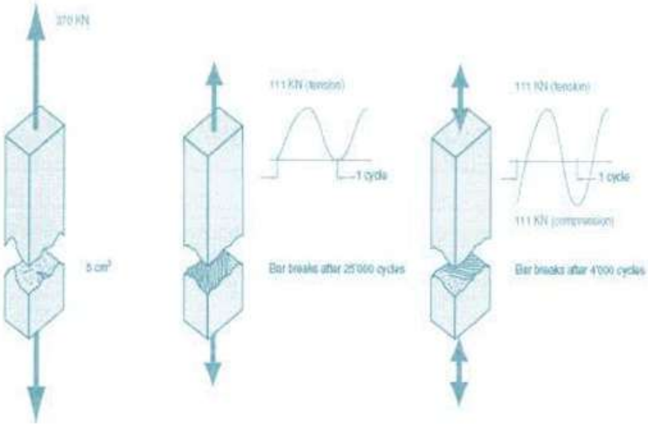


Figure 2.1 Fatigue Demonstration

Fail-Safe Design

The fail-safe design principle uses multiple load paths to ensure structural integrity. If one load path cracks completely through, or sustains accidental damage; the remaining load paths carry the additional load. This type of design is common on modern jetaeroplanes.

Examples include:

- Multiple stringers and ribs in wings.
- Multiple wing panels.
- Multiple stringers and frames in fuselage

construction. This construction also breaks the fuselage skin into redundant panels.

- Bonded and bolted fittings (often called back-to- back fittings), and bonded and bolted landing gear beams.

The fail-safe principle also requires that any damage will be detected during an inspection, and then repaired. Some types of damage produce effects that are obvious, such as flapping fuselage skin panels, or wing tank leaks. This obvious damage is considered part of the fail-safe inspections.

Fail-safe design is a good philosophy, and worked well for many decades. In fact, fail-safe design still provides the basis for most new aeroplane designs. However,operational experience shows that some of the assumptions of fail-safety do not holdtrue.

Cracks usually develop in several elements at the same time, making the alternate load paths weaker. This is called "multiple site cracking". Corrosion weakens alternate load paths, and accelerates crackgrowth.

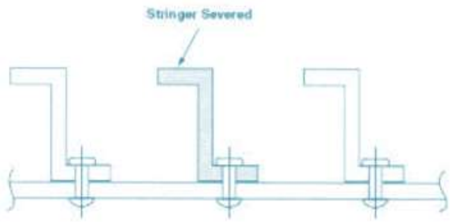


Figure 2.2: Fail Safe Design

To compensate for these deficiencies in fail-safe design, the damage tolerance philosophy was developed.

Damage Tolerance

The damage tolerance principle requires that any aeroplane damage is detected, and repaired before the strength is below a minimum level.

Damage Tolerant Design

Fail-safe structure forms the basis for damage tolerant design. Damage tolerance improves on fail-safety by considering multiple site cracking, and the residual strength of partially failed structural elements. Damage tolerance also considers the effects of environmental damage (corrosion), and discrete damage(accidental).

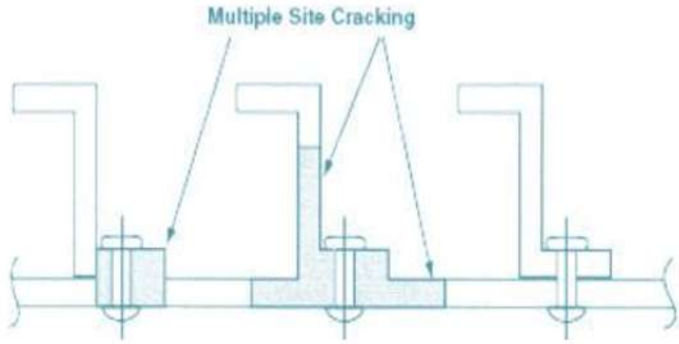


Figure 2.3: Damage Tolerant Design

Damage Tolerance Concept

Maximum structural strength capability occurs at the beginning of an aeroplanes life.

The operating loads are much smaller than the ultimate strength. As the aeroplane ages, the strength slowly reduces, due to crack growth and/or corrosion damage. Before the strength becomes less than the residual requirement, the damage is detected and repaired back to original capability. This process continues throughout the life of theaeroplane.

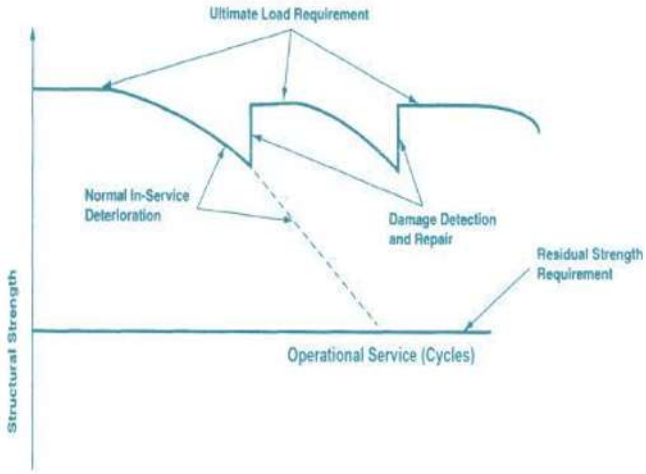


Figure 2.4: Damage Tolerance Concept

Structural Classification

When designing aeroplanes, loads to which the various parts are exposed must be taken into consideration. These loads are different for each part of the construction. A difference is made between primary, secondary and tertiary constructions. When choosing materials for maintenance work, this must be taken intoaccount. The primary construction consists of those parts of the aeroplane construction that bear the loads.

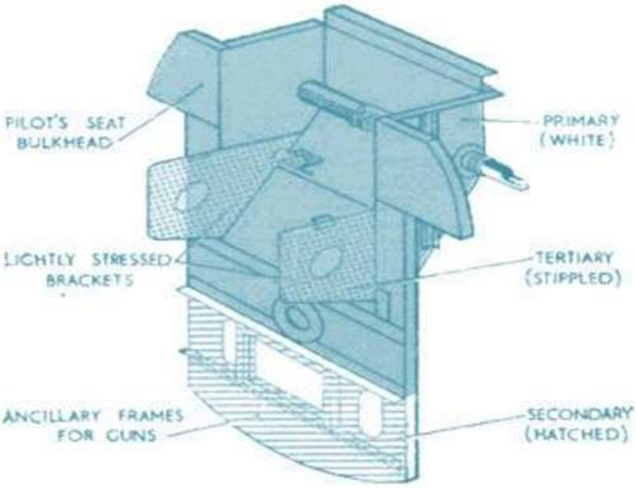


Figure 2.5: Primary, secondary and tertiary structure identifications

- PrimaryStructure.

These parts of the airframe are highly stressed and, if damaged, may cause failure of the aircraft and loss of life of the aircrew, e.g. spars, Longerons, engine mounting, stressed skin, etc. They are sometimes shown in RED (or white) in repair manuals anddrawings.

- SecondaryStructure.

These parts of the airframe are highly stressed but, if damaged, will not cause failure of the aircraft or loss of life of the aircrew, e.g. flooring, which is normally stronger than is necessary and if damaged locally would not collapse. This classification also includes ancillary frames designed to support components such as oxygen bottles, cameras, etc. They are sometimes shown as YELLOW (or hatched) in repair manuals and drawings. The secondary structure often gives the aerodynamic shape to the aeroplane construction. On the basis of the main sections, the difference between primary and secondary can be clearly illustrated. For example, a wing section consists of a primary part and asecondary part.

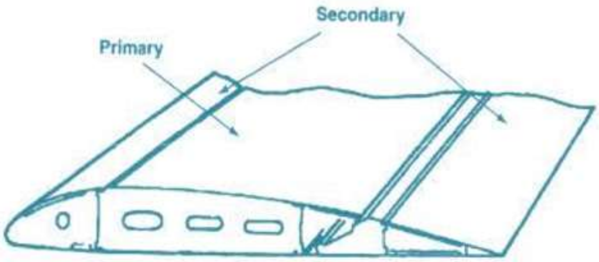


Figure 2.6: Wing Structure Classification

- TertiaryStructure.

These are lightly stressed parts such as fairing, wheel shields, minor component brackets, etc. They are often shown in GREEN (or stippled) in repair manuals or drawings.

Identification of Structure

The structure diagrams are colouredor specially shaded to represent the various classifications. Primary structures are coloured red or shown white. Secondary structures are colouredyellow or shown hatched. Tertiary structures are colouredgreenor shownstippled.If there is any doubt whatsoever, as to whether a piece of structure is primary or secondary, itis safest to assume it is primary.

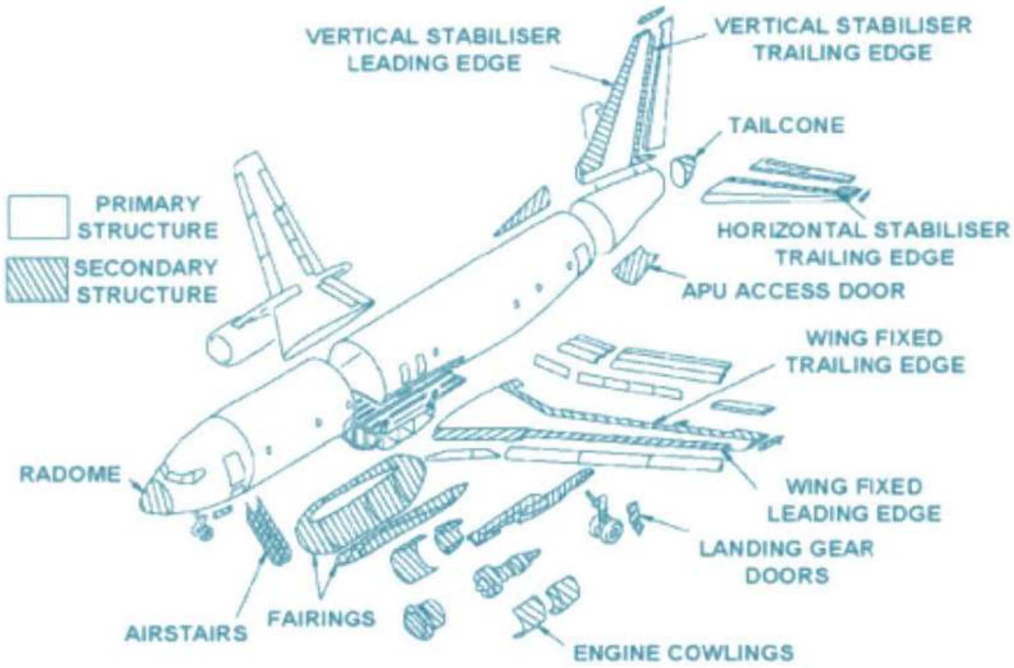


Figure 2.7: Structural Classifications

Dimensions and Locations

Station identification Systems in order to determine a particular location in an aeroplane, it is divided into three (imaginary) planes that are at an angle of 90°to each other, (see Figure 2.8).

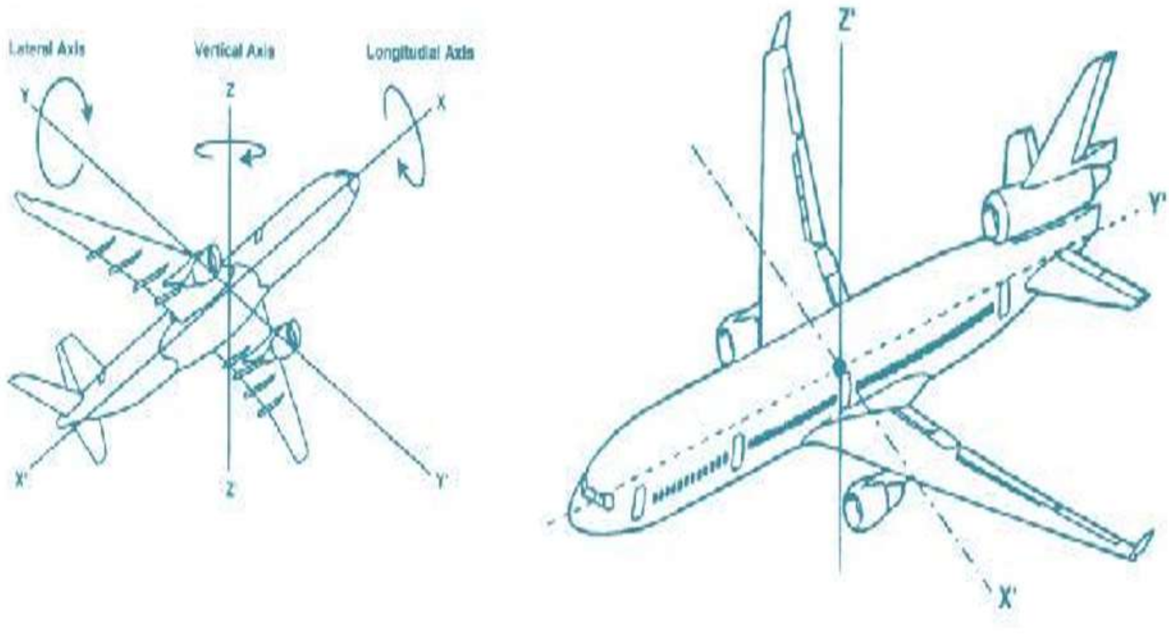


Fig. 2.8 Axle Systems

The first plane cuts the aeroplane horizontally (based on a cross section). These planes are called water lines or Z stations. The second plane cuts the aeroplane vertically (based on a cross section). These planes are called buttock lines or Y stations. The third plane cuts the aeroplane vertically (based on a side view). These are called body stations or X stations. By means of these three planes, any and every point in the aeroplane can be given an X, a Y and a Z coordinate. Some aeroplane manufacturers use abbreviations for these coordinates asfollows:

- Sta. (body stations) - the Xcoordinate;
- B.L. (buttock lines) - the Y coordinate;
- W.L. (water lines) - the Zcoordinate.
- Other manufacturers use the followingabbreviations:
- X Sta. (X Stations) - the Xcoordinate;
- Y Sta. (Y Stations) - the Y coordinate
- Z Sta. (Z Stations) - the Z coordinate.

There is a number behind these abbreviations which indicates the distance of the part from the zero point. For aeroplanes built by Boeing, these distances are given in inches. For aeroplanes built by Airbus, in cm. The zero point of the Sta. (Y Sta.) is in front of, behind or on the point of the fuselage nose (Figure 2.9). In cases where the station number 0 is behind the point of the nose, the station numbers that are in front of the zero point have a minus sign, for instance: Sta. -60.4.

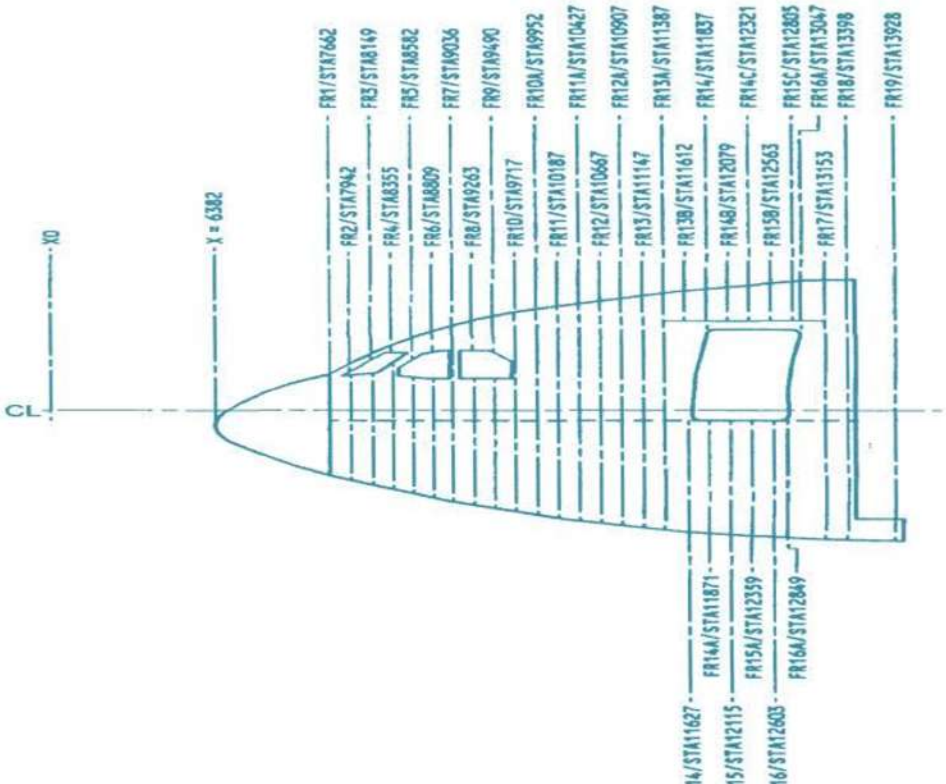


Fig. 2.10 Body Buttock Lines And Stringer Numbers

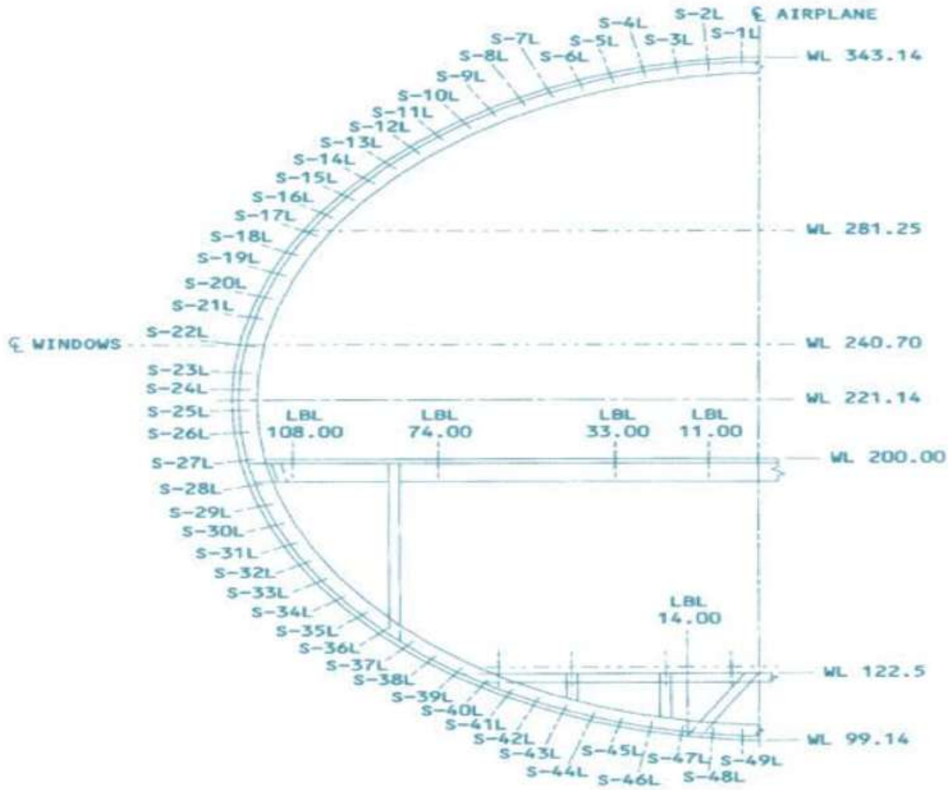


Figure 2.10: Body Buttock Lines and Stringer Numbers

The zero point of the W.L. (Z Sta.) depends on the type of aeroplane. The zero point of the W.L. in a B-747 is 91 inches below the lowest point. The zero point of the B.L. (Y Sta.) is the centre line of the aeroplane (see Figure 2.10). Looking in the direction of flight, there are left-hand and right-hand buttock lines. The left-hand buttock lines areindicated by a minus sign and the right-hand ones with a plus sign. The wings, horizontal and vertical stabilizers, and power plants of most aeroplane types have their own location identificationsystem.

Zonal Identification Systems

The location identification system is used to pinpoint the various locations in an aeroplane. The station numbers make it possible to indicate the location of the centreof gravity, the distribution of the load, the location of the compartments and of parts. To localize parts more easily and to localize where work must be done, the aeroplane is dividedinto:

- Majorzones
- Majorsub-zones
- Unitzones

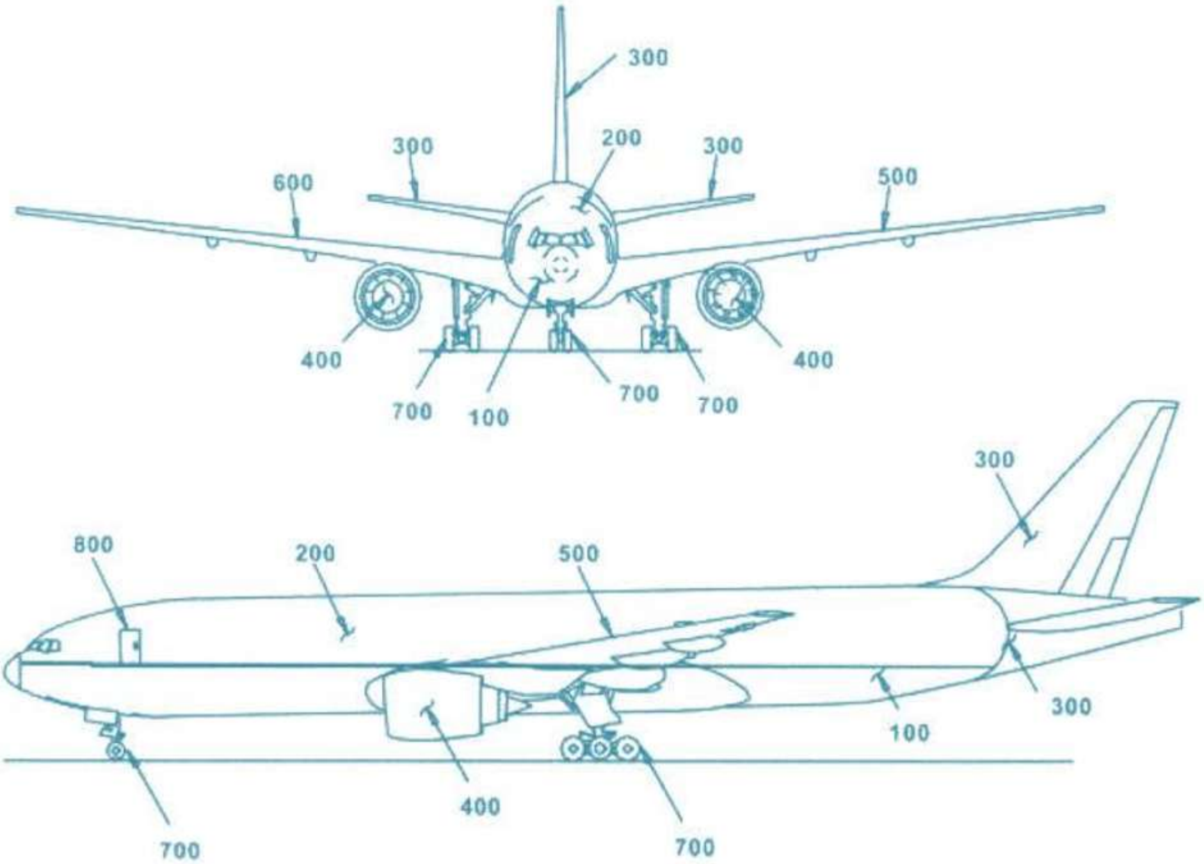


Fig. 2.11: Major Sub Zones (Example)

Major zones are identified by hundred asfollows:

- 100 FUSELAGE LOWERSECTION
- 200 FUSELAGE TOPSECTION
- 300STABILIZERS
- 400NACELLES
- 500 LEFTWING
- 600 RIGHTWING
- 700 LANDINGGEAR
- 800DOORS

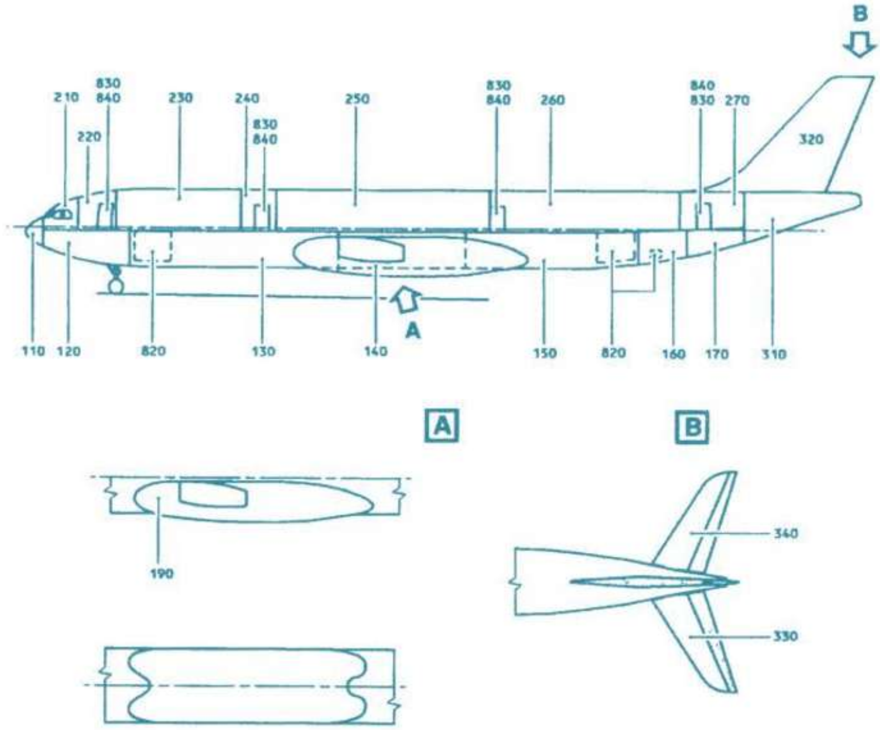


Figure 2.12: Major Sub Zones (Example)

Unit zones are identified by a three digit number. An example of a location identification system is 212:

- 200: upper half of body (majorzone)
- 10: Cockpit (majorsub-zone)
- 2: zone number on the right-hand side (unitzone)

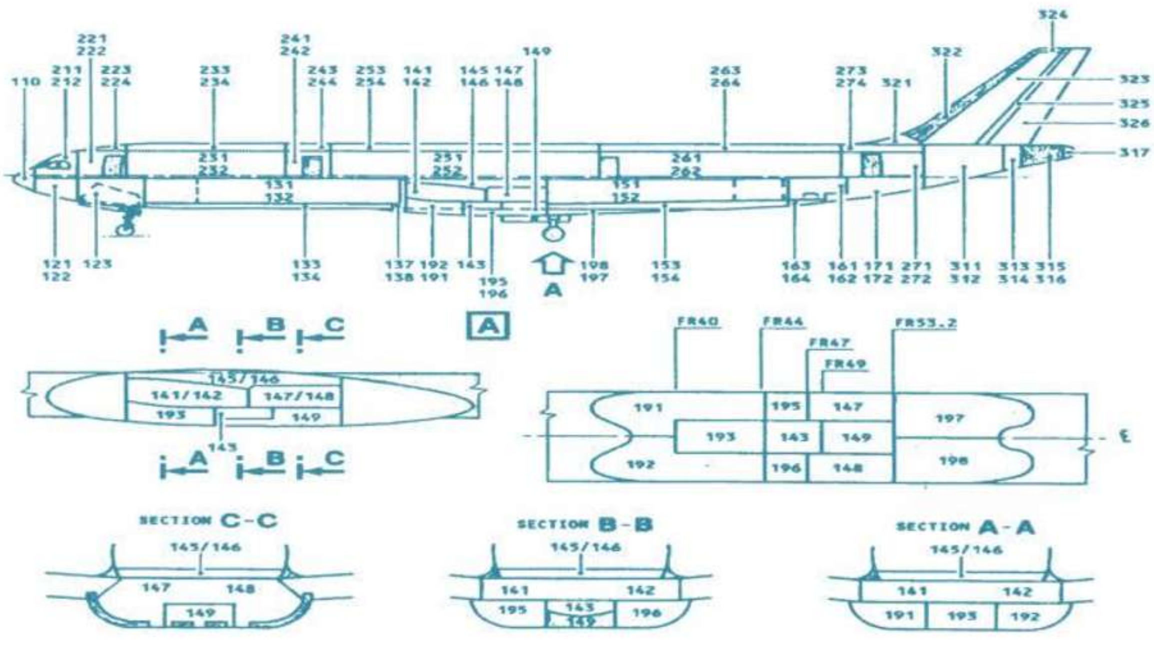


Figure 2.13: Unit Zones (Example)

Where necessary, the uneven zone number refers to the left-hand zone, and an even number indicates a right-hand zone. Large construction sections, including doors and control surfaces,
have their own zone numbers.

Although the major focus of structural design in the early development of aircraft was on strength, now structural designers also deal with fail-safety, fatigue, corrosion, maintenance and inspectability, and producability.

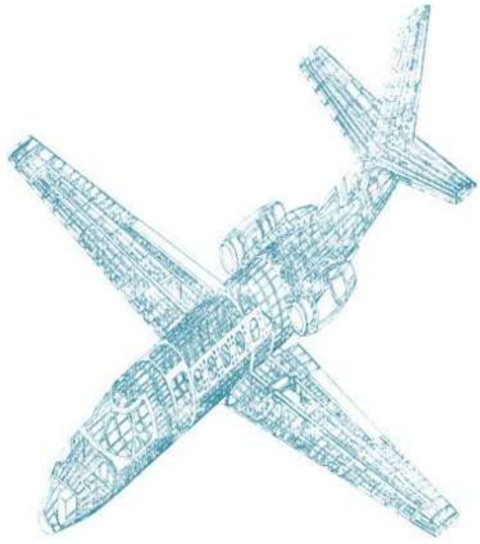


Fig. 2.14 A typical aluminium alloy fabricated aircraft structure

Structural Concepts

Modern aircraft structures are designed using a semi-monocoque concept- a basic load- carrying shell reinforced by frames and longerons in the bodies, and a skin-stringer construction supported by spars and ribs in thesurfaces.

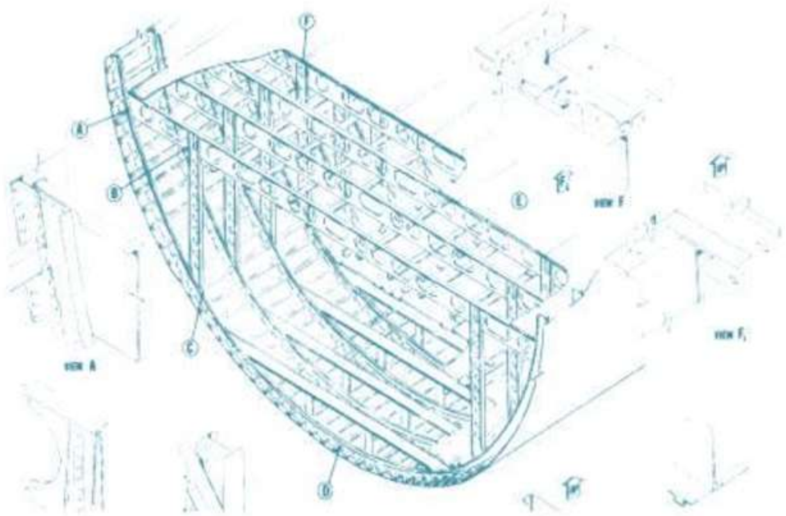


Figure 2.15: Aircraft Structural details

Proper stress levels, a very complex problem in highly redundant structures, are calculated using versatile computer matrix methods to solve for detailed internal loads. Modern finite element models of aircraft components include tens-of-thousands of degrees-of- freedom and are used to determine the required skin thicknesses to avoid excessive stress levels, deflections, strains, or buckling. The goals of detailed design are to reduce or eliminate stress concentrations, residual stresses, fretting corrosion, hidden undetectable cracks, or single failure causing component failure.

Open sections, such as Z or J sections, are used to permit inspection of stringers and avoid moisture accumulation.

Fail-safe design is achieved through material selection, proper stress levels, and multiple load path structural arrangements which maintain high strength in the presence of a crack or damage.

Examples of the latter are:
- Use oftear-stoppers
- Spanwise wing and stabilizer skinsplices

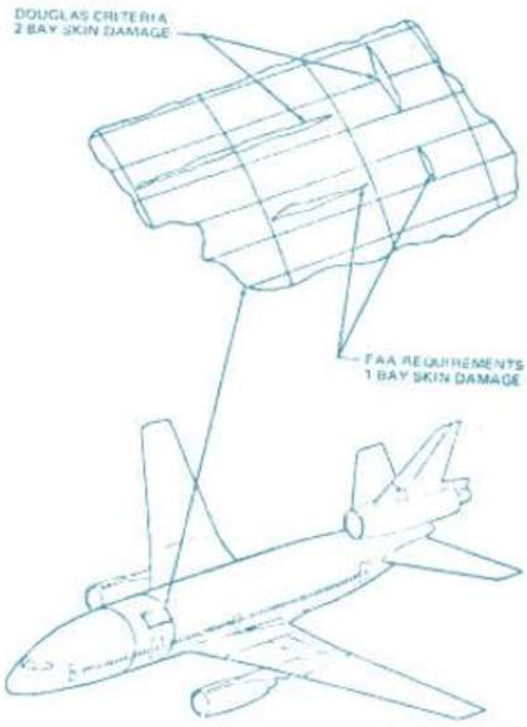


Fig. 2.16 Fail Safe Criteria

Analyses introduce cyclic loads from ground-air-ground cycle and from power spectral density descriptions of continuous turbulence. Component fatigue test results are fed into the program and the cumulative fatigue damage is calculated. Stress levels are adjusted to achieve required structural fatigue designlife.

Design Life Criteria - Philosophy

Fatigue failure life of a structural member is usually defined as the time to initiate a crack which would tend to reduce the ultimate strength of the member. Fatigue design life impliesthe average life to be expected under averageaircraftutilization and loads environment. To this design life, application of a fatigue life scatter factor accounts for the typical variations from the average utilization, loading environments, and basic fatigue strength allowables. This leads to a safe-life period during which the probability of a structural crack occurring is very low. With fail-safe, inspectable design, the actual structural life is muchgreater.

The overall fatigue life of the aircraft is the time at which the repair of the structure is no longer economically feasible.
Scatter factors of 2 to 4 have been used to account for statistical variation in component fatigue tests and unknowns in loads. Load unknowns involve both methods of calculation and type of service actually experienced. Primary structure for present transport aircraft is designed based on average expected operational conditions and average fatigue test results, for 120,000 hrs. For the best current methods of design, a scatter factor of 2 is typically used, so that the expected crack-free structural life is 60,000 hrs, and the probability of attaining a crack-free structural life of 60,000 hrs is 94 percent as shown in the following figure andtable.

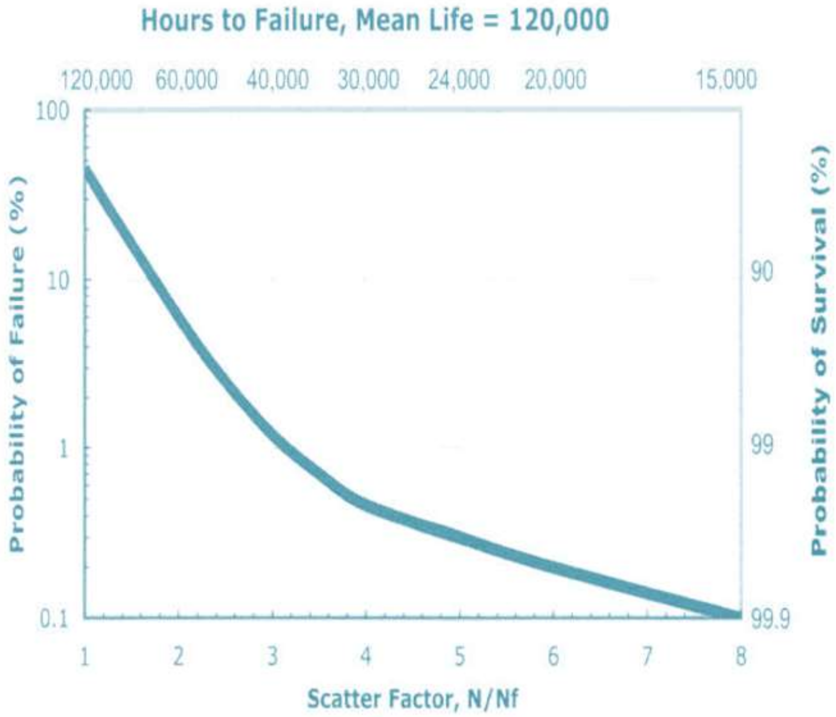


Fig. 2.17: Hours to failure

With fail-safe design concepts, the usable structural life would be much greater, but in practice, each manufacturer has different goals regarding aircraft structural life.

Materials

Choice of materials emphasizes not only strength/weight ratio but also:

- Fracturetoughness
- Crack propagationrate
- Notchsensitivity
- Stress corrosionresistance
- Exfoliation corrosionresistance

Acoustic fatigue testing is important in affected portions of structure. Doublers are used to reduce stress concentrations around splices, cut-outs, doors, windows, access panels, etc., and to serve as tear-stoppers at frames and longerons. GenerallyDC-10 uses 2024-T3 aluminiumfor tension structure such as lower wing skins, pressure critical fuselage skins and minimum gage applications. This material has excellent fatigue strength, fracture toughness and notch sensitivity. 7075-T6 aluminiumhas the highest strength with acceptable toughness. It is used for strength critical structures such as fuselage floor beams, stabilizers and spar caps in control surfaces. It is also used for upper wing skins.For those parts in which residual stresses could possibly be present, 7075-T73 material isused.

7075-T73 material has superior stress corrosion resistance and exfoliation corrosion resistance, and good fracture toughness. Typical applications are fittings that can have detrimental preloads induced during assembly or that are subjected to sustained operational loads. Thick- section forgings are 7075- T73, due to the possible residual stresses induced during heat

treatment. The integral ends of 7075-T6 stringers and spar caps are over-aged to T73 locally. This unique use of the T73 temper virtually eliminates possibility of stress corrosion cracking in critical joint areas. Although the yield stress of 7075 or 2024 Aluminiumis higher, a typical value for design stressatlimitloadis54,000psi.Thedensityofaluminiumis

101 lb/in3.Minimum usable material thickness is about 0.06 inches for high speed transport wings. This is set by lightning strike requirements. (Minimum skin gauge on other portions of the aircraft, such as the fuselage, isabout
0.05 inches to permit countersinking for flush rivets.
On the Cessna Citation, a small high speed airplane, 0.04 inches is the minimum gauge on the inner portion of the wing, but 0.05 inches is preferred. Ribs may be as thin as 0.025 inches. Spar webs are about 0.06 inches at the tip.
For low speed aircraft where flush rivets are not a requirement and loads are low, minimum skin gauge is as low as 0.016 inches where little handling is likely, such as on outer wings and tail cones. Around fuel tanks (inboard wings) 0.03 inches is minimum. On light aircraft, the spar or spars carry almost all of the bending and shear loads. Wing skins are generally stiffened. Skins contribute to compression load only near the spars (which serveas stiffeners in a limited area).Lower skins do contribute to tension capability but the main function of the skin in these cases is to carry torsion loads and define the section shape. In transport wings, skin thicknesses usually are large enough, when designed for bending, to handle torsion loads.

System Installation Provision

Consideration needs to be given to the construction of the fuselage where it may be necessary to increase its structural integrity.
For example:

- The installation of brackets for the attachment of system components such as hydraulic system reservoirs, fuel filter modules and system shut off valvesetc.
- Increasing structural strength will be required in areas of high load; landing gear and engine attachments would be a good example ofthis.
- The installation of firewalls to prevent the spread of fire from hot sections of the aircraft such as engine nacelles and APU housing.
- Some system fluid lines, ducting and controls will have to be routed through the aircraft structure. This will weaken the structure; the manufacture will keep this in mind during the design stage and keep this to aminimum.
- Control cables are used extensively throughout the aircraft to operate different aircraft systems, these control cables will be routed through the aircraft structure, and special consideration will need to be given to the routing of these cables to protect the aircraft structure from the cables. This is accomplished by the use of grommets, fairleads and pressureseals.

Not only is the routing of control cable important, the routing of hydraulic system fluid lines, electrical cables, fuel lines, pneumatic system ducting and air-conditioning distribution must be considered and provisions made for the attachment and correct routing of these systemcomponents.

Drains and Ventilation Provision

At places in aeroplane structures where collection of fluids may be expected, drainage points are provided. To prevent unintended pressure differentials and the accumulation of hazardous gases, structures are supplied with means ofventilation.

Drainage

External and internal holes and drain paths are provided in aircraft structures to prevent water and other fluids collecting within the structure. These fluids could cause a fire or corrosion.

External drain ports are located on exterior surfaces of the fuselage, wing and tail unit to drain any fluids overboard. These drains are always open.

Drain valves are fitted along the lowest points of the pressure cabin. These drain valves are open when the aircraft cabin is unpressurised, but closed when the cabin is pressurized to prevent loss of cabin pressure. In the simplest type, a rubber diaphragm forms the seal. Other types of drain valve are illustrated in Figure2.18.

Sometimes a leveling compound is used to prevent fluid collecting in cavities. The compound directs fluid to the drains. The internal structure of an aircraft is provided with tubes, channels, dams and drain holes to direct the flow of fluid towards external drain points. An example of this is the holes drilled in stringers to allow fluids to drain down to the bilgearea.

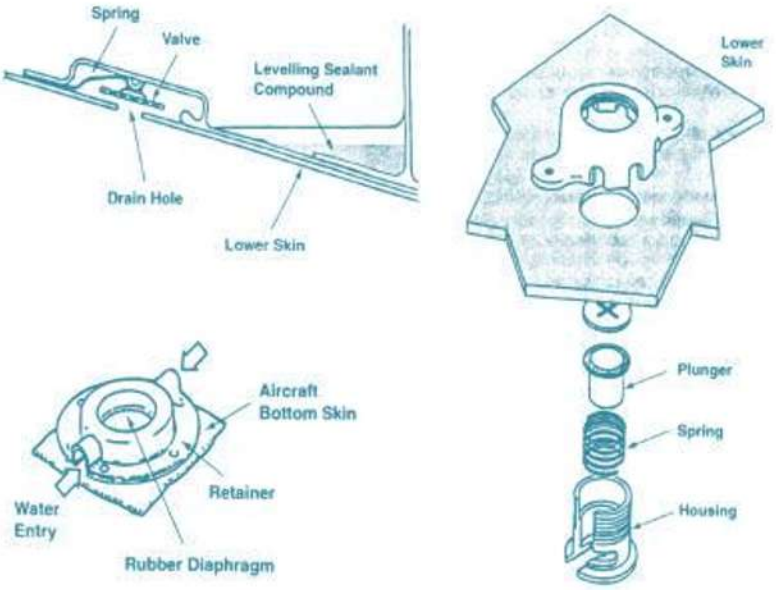


Fig. 2.18: Pressure Zone Drain Valves Stresses Acting on an Aeroplan Structure

Aircraft are unique in their structural requirements. They must be lightweight and at the same time withstand flight loads, landing loads, and a wide range of vibration. In this study of all-metal structure, we will consider the five basic stresses that act on all physical objects: tension, compression, torsion, bending, and shear. Tension and compression are the basic stresses and the other three are combinations of these two. A stress is a force that is set up within an object that tries to prevent an outside force changing its shape. A strain is a deformationor a physical change caused by astress.A material that is strained within its elastic limit will return to its original size and shape after the stress is removed, but if ithas been strained beyond this limit, it will be permanently deformed.

Torsion

Torsion is a combination of tension and compression acting in the same object. The shaft in Figure 2.19 has a tensile stressand a compressive stress acting at 90°to each other, and they are both acting at 45° to the shaft. Propeller shafts and helicopter rotor shafts are both subjected to torsionalstresses.

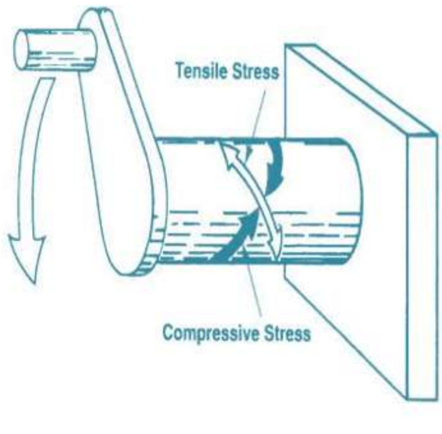


Fig. 2.19: Torsion Bending

Bending is also made up of tension and compression. The wing of the aeroplane in Figure 2.20 is under a bending stress. When the aeroplane is on the ground, the top skin of the wing is under a tensile stress and the bottom skin is under a compressive stress. In flight these forces are the opposite. The top skin is under a compressive stress and the bottom skin is under a tensilestress.

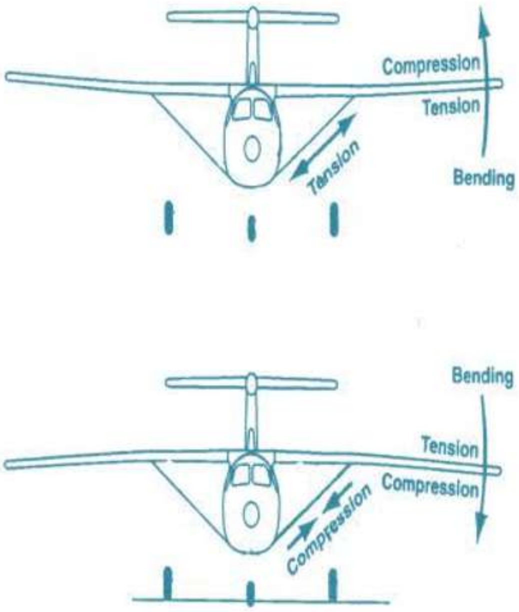


Fig. 2.20: Bending Tension

Tension tries to pull an object apart. Consider the hoist in Figure 2.21. The chain is under tension, or more properly stated, it has a tensile stress in it.

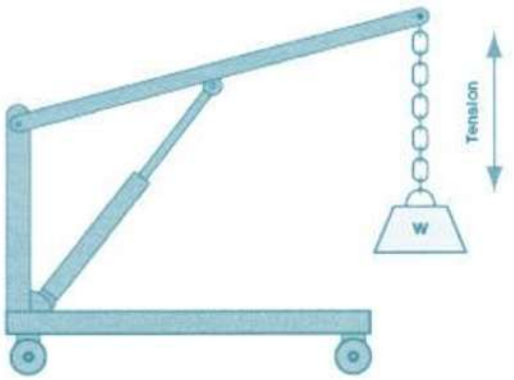


Figure 2.21: Tension Compression

Compression tries to squeeze the ends of an object together. The rivet in Figure 2.22 is distorted or strained by a compressive stress between the rivet gun and the bucking bar.

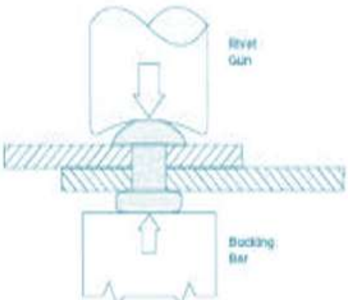


Fig. 2.22: Compression

Shear

A shear stress tries to slide an object apart. The rivet bolt in Figure 2.23 is subject to a shear stress. The force on one sheet puts a tensile stress in the rivet toward the right while the fixed other sheet puts a tensile stress into the bolt toward the left. These two tensile stresses act beside each other rather than opposite each other, and the result is a force that tries to shear the rivet, or to slide itapart.

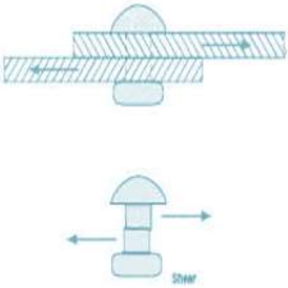


Figure 2.23: Shear

Stress, Strain and Hooke's Law

Introduction

Structural integrity is a major factor in aircraft design and construction. No production aeroplane leavestheground before undergoing extensive analysis of how it will fly, the stresses it will tolerate and its maximum safecapability.
Every aircraft is subject to structural stress. Stress acts on an aeroplane whether on the ground or in flight. Stress is defined as a load applied to a unit area of material. Stress produces a deflectionordeformationinthematerialcalledstrain.Stressis always accompanied by strain.Currentproduction general aviation aircraft are constructed of various materials, the primary being aluminum alloys. Rivets, bolts, screws and special bonding adhesives are used to hold the sheet metal in place. Regardless of the method of attachment of the material, every part of the fuselage must carry a load, or resist a stress placed on it. Design of interior supporting and forming pieces, and the outside metal skin all have a role to play in assuring an overall safe structure capable of withstanding expected loads andstresses.
The stress a particular part must withstand is carefully calculated by engineers. Also, the material a part is made from is extremely important and is selected by designers based on its known properties. Aluminiumalloy is the primary material for the exterior skin on modern aircraft. Thismaterialpossesses a good strength to weight ratio, is easy to form, resists corrosion, and is relativelyinexpensive.

Stress, Strain and Young's Modulus

What is known as Axial (or Normal) Stress, is defined as the force perpendicular to the cross sectional area of the member divided by the cross sectional area. Or

In Figure 2.24, a solid rod of length L, is under simple tension due to force F, as shown. If we divide that axial force, F, by the cross sectional area of the rod (A), this would be the axial stress in the member. Axial stress is the equivalent of pressure in a gas or liquid. As you remember, pressure is the force/unit area. Axial stress is really the 'pressure' in a solidmember.
Now the question becomes, how much 'pressure' can a material bear before it fails.

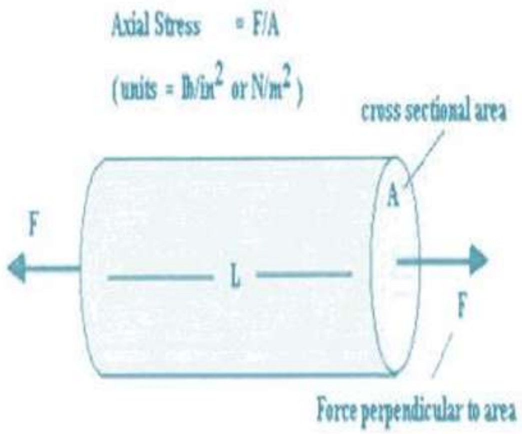


Fig.2.24Tensile Stress

In fact, if we look at a metal rod in simple tension as shown in Figure 2.24, we see that there will be an elongation (or deformation) due to the tension. If we then graph the tension (force) versus the deformation we obtain a result as shown in Figure 2.25.

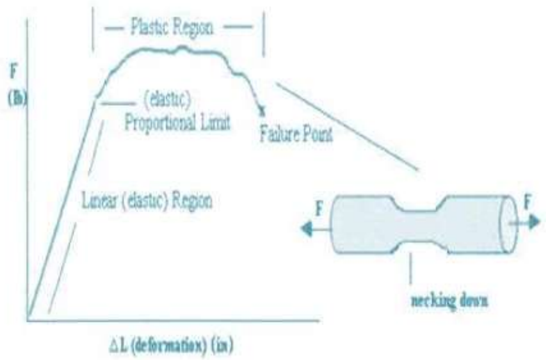


Fig. 2.25 Force-Extension diagram

In Figure 2.25, we see that, if our metal rod is tested by increasing the tension in the rod, the deformation increases. In the first region the deformation increases in proportion to the force. That is, if the amount of force is doubled, the amount of deformation is doubled. This is a form of Hooke's Law and could be written this way: F °o k (deformation), where k is a constant depending on the material (and is sometimes calledthe spring constant). After enough force has been applied the material enters the plastic region - where the force and the deformation are not proportional, but rather a small amount of increase in force produces a large amount of deformation. In this region, the rod often begins to 'neck down', that is, the diameter becomes smaller as the rod is about to fail. Finallythe rod actuallybreaks.
The point at which the Elastic Region ends is called the elastic limit, or the proportional limit. In actuality, these two pointsare not quite the same. The Elastic Limit is the pointat which permanent deformation occurs, that is, after the elastic limit, if the force is taken off the sample, Itwill not return to its original size and shape, permanent deformation has occurred. The Proportional Limit is the point at which the deformation is no longer directly proportional to the applied force (Hooke's Law no longer holds). Although these two points are slightly different, we will treat them as the same in thiscourse.

Next, rather than examining the applied force andresulting deformation, we will instead graph theaxial stress verses the axial strain (Figure 2.27). We have defined the axial stressearlier.

The axial strain is defined as the fractional change in length or

Strain = (deformation of member) divided by the (original length of member)

$$\text{Strain} = \frac{\Delta L}{L_o}$$

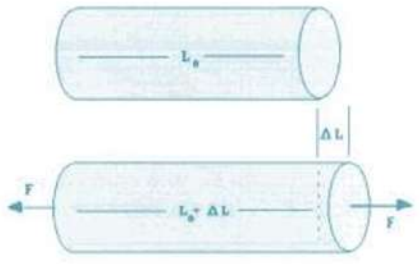


Figure 2.26: Axial force in a member of length L_o causing deformation (extension) of ΔL

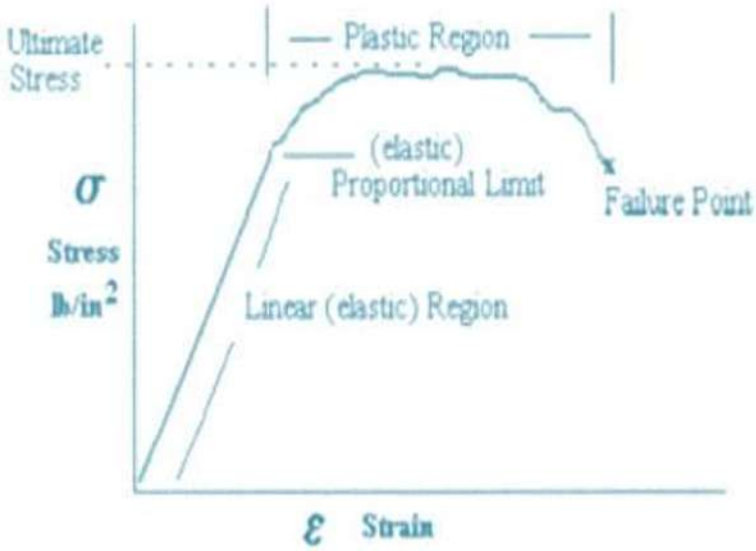
We may write:

$$\text{Strain} = \frac{\text{Deformation}}{\text{Original Length}}$$

where L_o is the original length of the member.

train has no units - since its length divided bylength,however it is sometimes expressed as 'in/in (or inchesper inch)' in some texts. As we see from Figure 2.27, the Stress verses Strain graph has the same shape and regions as the force verses deformation graph in Figure 2.25. In the elastic (linear) region, since stress is directly proportional to strain, the ratioof stress/strain will be a constant (and actually equal to the slope of the linear portion of thegraph).

This constant is known as Young's Modulus, and is usually symbolized by an E or Y. We will use E for



Young's modulus.

Figure 2.27 Stress-Strain graph

The value of Young's modulus - which is a measure of the amount of force needed to produce a unit deformation - depends on the material.

Young's Modulus for **Steel is 30 x 10^6 lb/in^2**, for **Aluminium E = 10 x 10^6 lb/in^2**, and for **Brass E = 15 x 10^6 lb/in^2**.

To summarize our stress/strain/Hooke's Law relationships up to this point, we have:

$$\textbf{Stress} = \frac{\textbf{Force}}{\textbf{Area}} \left(\textbf{units lb/in}^2 \textbf{ or N/m}^2\right)$$

$$\textbf{Strain} = \frac{\textbf{Deformation}}{\textbf{Original Length}}$$

$$\textbf{Young's Modulus} = \frac{\textbf{Stress}}{\textbf{Strain}}$$

Structure Definitions

Bulk Modulus - The bulk modulus gives the change in volume of a solid substance as the pressure on it is changed. The formula for bulk modulus is very similar to that for Young"s Modulus: Some examples of Bulk Modulus for different materials are given on the next page.

Poisson's Ratio - As a member is stressed in tension, its length increases (axial strain) and its width decreases (transverse strain).
Poisson"s Ratio is the ratio of transverse strain to the axial strain in a stressed member.

Cantilever – Figure 2.28 illustrates a cantilever structure. The beam is under bending stress (which is greatest at the root end) and shear stress (which is constant along the beam).

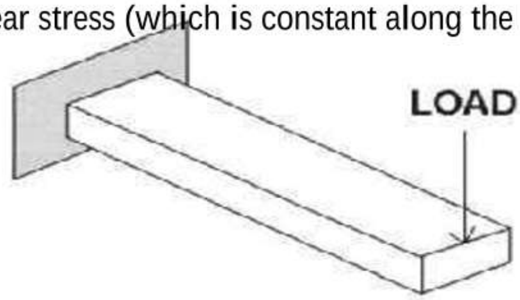


Figure 2.28 A Cantilever Structure Hoop Stress and Longitudinal Stress–

A pressure vessel (such as a pressurised fuselage) has to retain pressure. In doing this the pressure applies two types ofstresses. They are circumferential andlongitudinal.

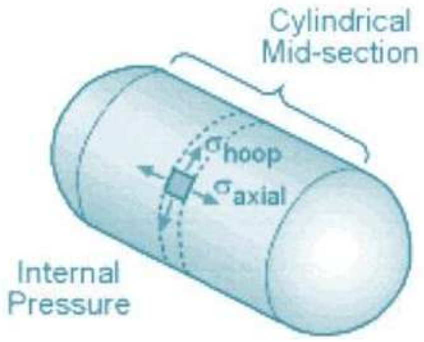


Figure 2.29 Hoop stress and longitudinal stress

Longitudinal stresses are half as much as the circumferential (hoop) stresses for any given pressure contained within the vessel.

Hogging and Sagging – Hogging and sagging describe the shape of a beam or similar long object when loading is applied. Hogging describes a beam which curves upwards in the middle (like a hogs back), and sagging describes a beam which curves downwards in themiddle.
When applied to an aircraft wing, the wing is sagging if the wingtips are bending upwards, as would be the case when the aircraft is in normal straight and level flight.
The wing is hogging if the wingtips are bending downwards, as would be the case when the aircraft has just landed and the inertial forces cause the wings to benddownwards.

Fig. 2.30: Bending ElectricalBonding
Bonding is the electrical interconnection of all metal parts of an aircraft, provided for the following reasons:

- Gives a low resistance path for earth return circuits.
- Reduces radiointerference.
- Reduces danger from lightningstrikes.
- Prevents the accumulation of local staticcharge.
- Ensures that all metal is connected to the ground earth point and to static dischargers iffitted.

Normally the structure of an aircraft consists of metallic assemblies which ensure an excellent electric conductibility; however certain insulating intermediate partsstop the continuity in large zones. The continuity is restored by means of strips, screws or grounding lugs fitted between metallic assemblies. Hinged parts (control surfaces, doors, hatches, etc.), removable parts (unhinged inspection doors, etc.), are provided with one or several bonding means shunting each part where conductibility may be interrupted. For particular zones such as fuel tanks, engines and APU,the bondings provide an efficient circulation ofstatic potential; bonding strips and screws are connected to the mainstructure.

External protruding parts, metallic or not, are provided with electrical leads connected to the main structure. Antennas and other equipment are not bonded due to the fact that a flash of lightning could damage only the element struck without endangering the other parts of the aircraft.
Different manufacturers use different methods to dissipate the electrical charge on composite structures. These are a few differentmethods:

• Aluminiumwires may be woven into the top layer of composite fabric. This is usually done with fibreglassor Kevlar and not withcarbon/graphite.
• A fine aluminium screen may be laminated under the top layer of fabric. If this method is used on a carbon/ graphite component; it is usuallysandwiched
between two layers of fibre glass to prevent a galvanic potential.
• A thin aluminium foil sheet may be bonded to the outer layer of composite during the manufacturing process.
• Aluminiummay be flame sprayed onto the omponent. This is molten aluminiumwhich is sprayed on like paint. Some companies will just paint the component with an aluminizedpaint.
• In some structures, a piece of metal is bonded to the composite to allow thedissipation
of the electrical charge out to another metal component or static wick.

Bond Testing

Using the Bonding Test Meter

The bond test meter consists of a single nickel alkaline cell and a low reading ohmmeter. Aset
of leads are provided.

• One lead is 60 foot long with a single spike.
• One lead is 6 foot long with a double spike.

It is NOT permissible to shorten either lead in the event of damage.

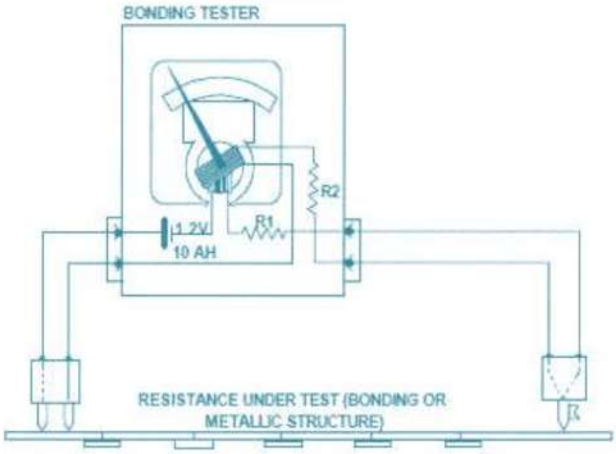


Figure 2.31 Bonding Test Meter

Preliminary Check of the Bond tester

• Connect the two leads to the meter by their plugs, it does not matter which socket they are pluggedinto.

- Short all three spikes together and check for a ZERO reading. Momentarily short the two spikes of the 6 foot lead together and check for full scaledeflection.

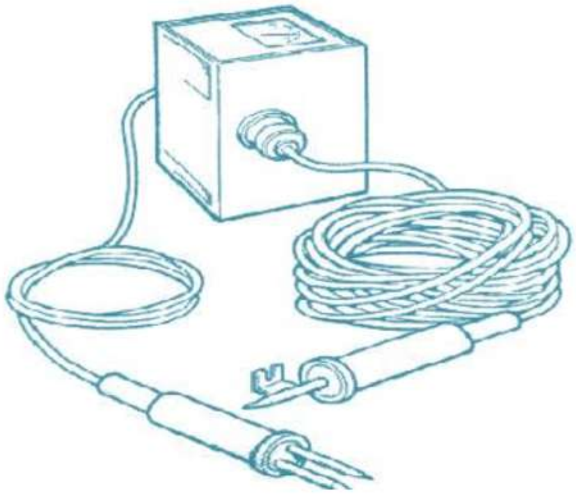


Figure 2.32 Bonding Test Meter

- Remove or pierce non-conductive protectivetreatments,

i.e. primer or paint, varnishes, chromate, anodic and phosphate coatings.

Note: Do NOT remove cadmium or tin plate.

- Connect the single spike 60 foot lead to an airframe main earthpoint.
- Using the 6 foot twin spike check that items being tested are within the limits laid down by the aircraft manufacturers.
- On all metal aircraft the resistance should not exceed 0.05 ohms.
- Replace or repair the protectivefinish.

Bonding Test Results

The CAA's requirements with regard to the maximum resistance values for the various conditions of bonding are summarised in the table below

Bonding Classification	Test Condition	Maximum Resistance
Primary	Between extremities of the fixed portions of aircraft of non-metallic or composite construction.	Estimated and declared by manufacturer
	Between extremities of the fixed portions of metallic aircraft	0.05 ohm
	Between bonded components and portions of main earth systems to which they are connected.	
Secondary	Between metallic parts normally in contact flammable	1 ohm (See Note 1)

	fluids and main earth system and also between the parts themselves.	
	Between all isolated conducting parts which may be subject to appreciable electrostatic charging and ohms per sq ft of surface	0.5 megohm or 1,000,000 ohms per sq ft of surface area whichever is less
	Between equipment supplied from an unearthed system, of any voltage and the main earth system. (See Note 2)	1 ohm (See Note 1)
	Between equipment containing circuits carrying 50 volts (RMS or DC) or more and the main earth system.	

Note 1 :

The value of 1 ohm is chosen to allow for the inclusion of the resistance of any cable that may be employed for this bonding case, but no one contact resistance should exceed 0.05 ohm.

Note 2:

The parts concerned are those situated inside and outside an aircraft and having an area greater than 3 sq in and a linear dimension greater than 3 inch.

Lightning Strike Protection (LSP) and Static Dissipation

If a lightning bolt strikes an unprotected structure, up to 200,000 amps of electricity seeks the path of least resistance. In the process, it may vaporize metal control cables, weld hinges on control surfaces and explode fuel vapours within fuel tanks if current arcs through gaps around fasteners. These direct effects also typically include vaporization of resin in the immediate strike area, with possible burn-through of the laminate. Indirect effects occur when magnetic fields and electrical potential differences in the structure induce transient voltages, which can damage and even destroy onboard electronics that have not been EMF (electromagnetic field) shielded or lightningprotected.

No matter whether an aircraft is aluminium or composite, when lightning hits an aircraft it needs a path for the electricity to flow through. On an aluminium skin, the electricity will flow through the skin and discharge out the static wicks.LSP strategies have three goals: provide adequate conductive paths so that lightning current remains on the structure's exterior; eliminate gaps in this conductive path to prevent arcing at attachment points and ignition of fuel vapours; and protect wiring, cables and sensitive equipment from damaging surges or transients through careful grounding, EMF shielding and application of surge suppression devices wherenecessary.

Normally the structure of anaircraft consists of metallic assemblies which ensure an excellent electric conductibility; however certain insulating intermediate parts stop the continuity in largezones. The continuity is restored by means of strips, screws or grounding lugs fitted between metallic assemblies. Hinged parts (control surfaces, doors, hatches, etc.), removable parts (unhinged inspection doors, etc.), are provided with one or several bonding means shunting each part where conductibility may be interrupted. For particular zones such as fuel tanks, engines and APU, the bondings provide an efficient circulation of static potential; bonding strips and screws are connected to the mainstructure.

Figure 2.33 Lightning Attachment Zone

External protruding parts, metallic or not, is provided with electrical leads connected to the main structure. Antennas and other equipment are not bonded due to the fact that a flash of lightning could damage only the element struck without endangering the other parts of the aircraft.
Composite Structure

Since composites do not conduct electricity, lightning and static protection has to be built into the structure.

Traditionally, conductive paths in composite structures have been established in one of the followingways:

Bonding aluminium foil to the structure as the outside ply Bonding aluminiumor copper mesh to the structure either as the outside ply or embedded one ply down Incorporatingstrands of conductive material into the laminate. All require connecting the conductive pathways to the rest of the aircraftin order to give the current an ample number of routes to safely exit the aircraft. This is typically achieved by using metal bonding strips (i.e., electrical bonding) to connect the conductive surface layer to an internal "ground plane," which includes metal components such as engines, conduit, etc.A fine aluminium screen may be laminated under the top layer of fabric. If this method is used on a carbon/graphite component;it is usually sandwiched between two layers of fibre glass to prevent a galvanic potential.Athin aluminium foil sheet may be bonded to the outer layer of composite during the manufacturing process. Aluminium may be flame sprayed onto the component. This is molten aluminium that is sprayed on like paint. Some companies will just paint the component with an aluminized paint (often a primerpaint).

In some structures, a piece of metal is bonded to the composite to allow the dissipation of the electrical charge out to another metal component or static wick. In some cases, all metallic components are connected via strips of aluminium or copper, effectively forming an internal "cage" throughout the airframe.

Because lightning strikes can attach to metal fasteners in composite structures, it may be desirable to prevent arcing or sparking between them by encapsulating fastener nuts orsleeves with plastic caps or polysulfidecoatings.

For external surface protection, a number of metal and metalized fibre products have been developed, typically woven and nonwoven screens and expanded foils. These mesh-like products enable the lightning's current to quickly transmit across the structure's surface, reducing itsfocus.

b) Construction Methods of Aeroplanes Evolution of AeroplaneStructures

Aircraft structures have evolved fully as much as have their power plants. The very first airframes were made of open trusses of either wood strips or bamboo. The aerodynamic surfaces were made of lightweight wood covered with cotton or linen fabric, shrunk and made airtight with a syrup-like collodion product that dried to a hardfilm.

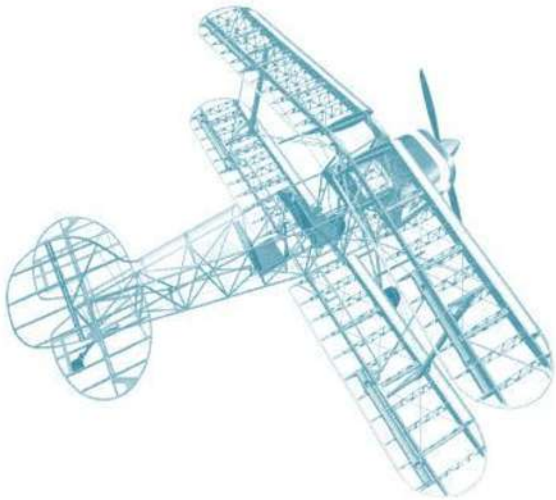


Fig. 2.34: Truss Type Structure

The next major development came with the welded steel tube fuselage structure that replaced the woodentruss.This structure is strong, but it has the disadvantage that to give it a streamlined shape, a superstructure must be built around the load-bearing truss. This adds weight but is needed for aerodynamic smoothness and aesthetics. In the late 1920s the Lockheed Company developed a streamlined wooden monocoque structure that carried virtually all of the stresses in its outer skin. This light-weight streamlined structure was used on some of the most efficient aircraft of the time. It, however, had the disadvantage of being extremely labourintensive in its construction.

Figure 2.35: Plywood Monocoque Aeroplane (Lockheed Orion)

The next logical step in the evolution of aircraft structure was to replace the wooden monocoque with a thin aluminiumalloy monocoque. This decreased the dependence upon skilled craftsmen for its construction and made mass production of interchangeable parts practical and costeffective.

Pure aluminiumis weak, but during World War I, the Germans discovered that by alloying baluminiumwith copper, manganese, and magnesium, they could increase its strength without increasing its weight. This new alloy was called Duralumin, and it was the forerunner of the high-strength and lightweight alloys (7017 aluminium alloy) that we use in aircraft constructiontoday.

Metal stressed-skin aircraft structure has been the standard since the 1930s, but a new era is dawning, that of composites. Composite structure can be made stronger, lighter in weight, more rigid, and less costly than metal. We have experienced what may be termed a plastics revolution. Early plastic materials such as celluloid and Beetlewaregave promise of a low-cost, easy-to-manufacture material, but they did not have the strength needed for structural applications. One of the first plastic materials used in aviation was a thermosetting phenol- formaldehyde resin that was reinforced with paper or linen cloth. This phenolic material, trade named Micarta or Tufnol, pioneered in the early 1930s, is still used for control cable pulleys and fairleads and for electricalinsulators.

Glass fibres, both woven into cloth and packed into loose mat and roving, have been reinforced with polyester resins and used for radomes, wing tips, and wheel pants since the early 1950s. This material is truly a composite, andmay be thought of as being the ancestor of modern composite structuralmaterials.

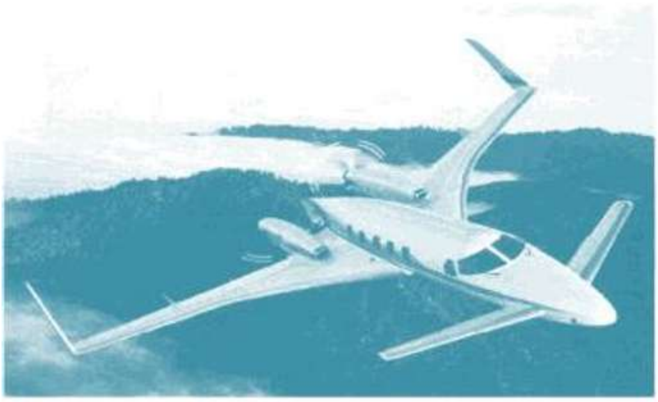


Figure 2.36: First All-Composite Commercial Aircraft (Beech Starship)

Modern composite materials use fibres of graphite and Kevlar as well as glass for most applications, with boron and ceramic used in some special applications. These fibres are primarily bonded into an epoxy resin matrix. Composite structural components have the advantage over metal of being lighter in weight, stronger, more rigid, and better able to withstand the sonic vibrations that are commonly encountered in aircraft structure.

The military forces have been responsible for much of the development in advanced composite structure because performance and the successful accomplishment of military goals have always been more important than cost. The airlines have also contributed to its development because every pound of weight saved by replacing metal with composite materials adds a pound of payload capability for each flight and reduces the fuelburn.

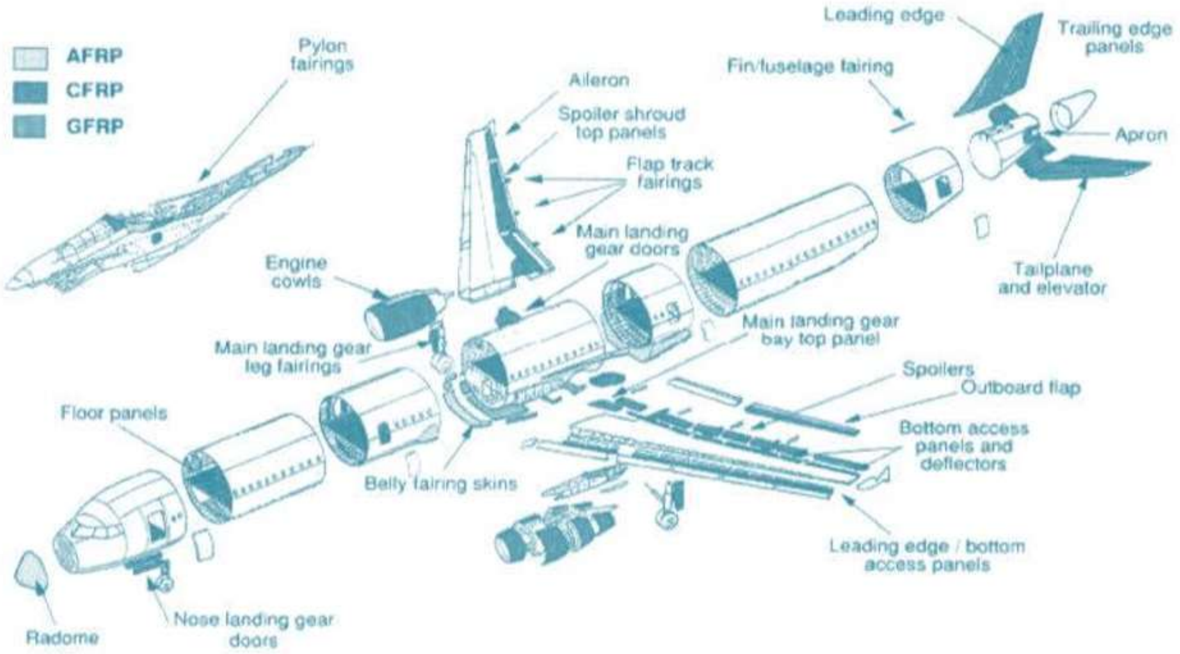


Figure 2.37 Use of Composites on Jet Airliner (Airbus A321)

Maintenance and repairs to aeroplanes must be done well, fast and at the right location. That is why the aeroplane maintenance mechanic must know where the part to be repaired or replaced. When constructing an aeroplane, a distinction is made between the main sections and the subsections. The main sections are connected to each other in a particular order in various ways. The main sections of the aeroplane construction as shown in Figure 2.38are:

- thefuselage
- thewings
- the landinggears
- the empennage (consisting of the vertical and horizontal stabilizers, rudder andelevator)
- the propulsion systems (powerplants, also referred to as engines).

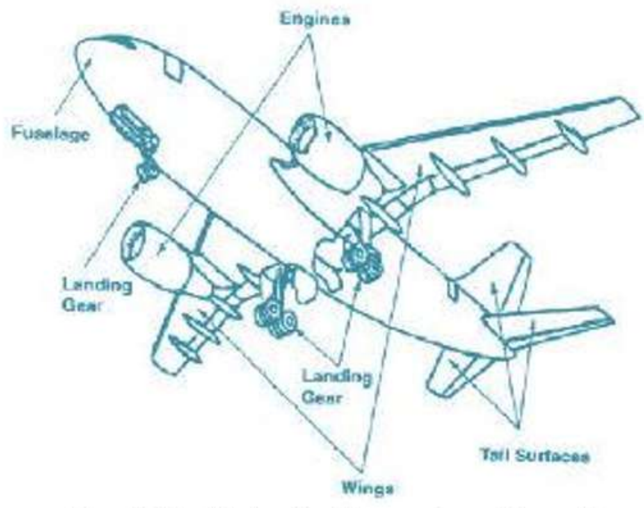


Fig. 2.38: Main Sections of an Aircraft

Stressed Skin Construction Method

To take the maximum advantage of metal, most aircraft structure is of the stressed skin. A type of aircraft structure in which all or most of the stresses are carried in the outside skin. A stressed skin structure has a minimum of internal structure. There are two types of metal stressed skin: monocoque and semimonocoque.

Monocoque Structure

The name monocoque means single shell, and in a true monocoque structure, all the strength of the structure is carried in the outside skin. Figure 2.36 shows a view of a monocoque structure. The formers give the structure its shape, but the thin metal skin riveted to them carries all the flightloads.
A monocoque fuselage is similar to a tube; its cross section is of high bending and torsion strength. There is no need for cross-struts, which would demand too much space from the cabin and cargocompartments.
The formers are directly attached to the skin.

Fig. 2.39: Metal semi-monocoque structure

Semi-monocoque Structure

Pure monocoque structure has the serious drawback that any dent or deformation will decrease its ability to carry the flight loads. To overcome this limitation, semi monocoque structure as seen in Figure 2.40 is widely used. In this type of structure, formers not only provide the shape, they carry the majority of the flight loads.

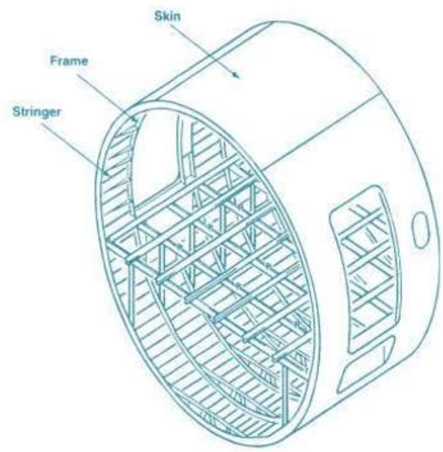


Fig. 2.40: Semi-Monocoque Structure

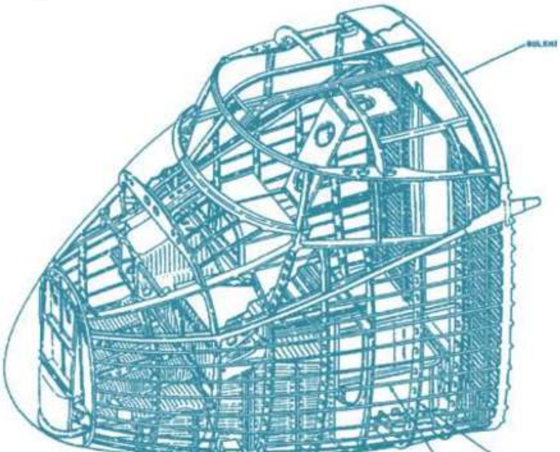


Figure 2.41 Semi-Monocoque Structure Structure Assembly Techniques

There are many different assembly methods used by the manufacture, it should be remembered that it is far easier to remove a nut and bolt than it is to de-rivet a component. Those items that are removed on a regular basis are normally secured by the nut and bolt method.

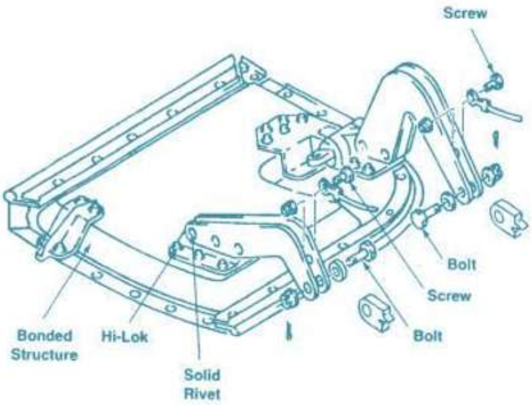


Figure 2.42 Different Assembly Techniques on a Panel Riveting

Sheets of metal must be fastened together to form the aircraft structure, and this is usually done with solid aluminium alloy rivets. There are many locations on an aircraft where it is not possible to reach both sides of the structure, and special blind rivets must be installed. Rivets and other permanent types of fastener used in aircraft construction may be divided into four classes asfollows:

- Solid
- Tubular
- Blind
- Cherrylock
- TuckerPop
- SpecialPurpose
- Hi-Lok
- Taper-Lock

Solid Riveting Introduction

Only the solid-shank rivet increases, when it is properly installed, in size and strength. A steel bolt, for example, will actually decrease in diameter when it is installed and torqued. Some manufacturers of special fasteners attempt to duplicatethe natural action of solid-shank rivets by putting expanding sections on the fasteners pulling stems. Most of these special fasteners only approximate the natural shank expansion of a driven solid-shank rivet.Since pure aluminiumweighs one- third as much as steel, aluminiumalloy solid-shank rivets are lighter than many other fasteners. Their lightness is an advantage, but it limits theirusefulness:

Solid-shank rivets greater than 1/2-inch in diameter are not used. However, the allowable range, 3/32 to 1/2-inch in diameter, is broad enough for the needs of most typical aircraft construction and repairs. Rivets are always supplied to the operator with one head already formed and the shank plain to permit insertion into the rivet hole, the opposite end being formed into a head by manual or mechanicalmeans.
Solid rivets have the greatest strength and are therefore preferable to any other type of rivet, but they can only be used where there is access to both sides of the structure.

Solid Rivet Dimensions and Head Types

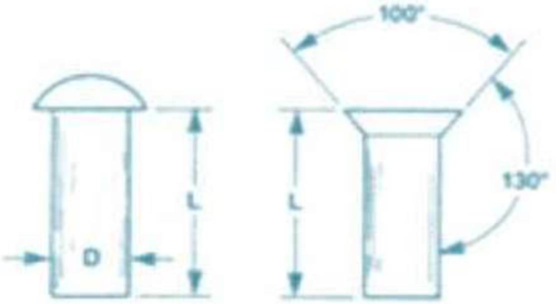


Fig. 2.43: Snap head and countersunk rivetdimensions

Types of Head

The most common forms of solid rivets are as follows:

a) Snap head: for general purposes where strength is required but not a streamlined finish
b) Mushroom head: for skin coverings to give maximumstrength
c) Flat head: for internal work where heads are not easilyaccessible
d) Countersunk: for flush finish (90°, 100°, 120° head)
e) Pan head: for heavystructures

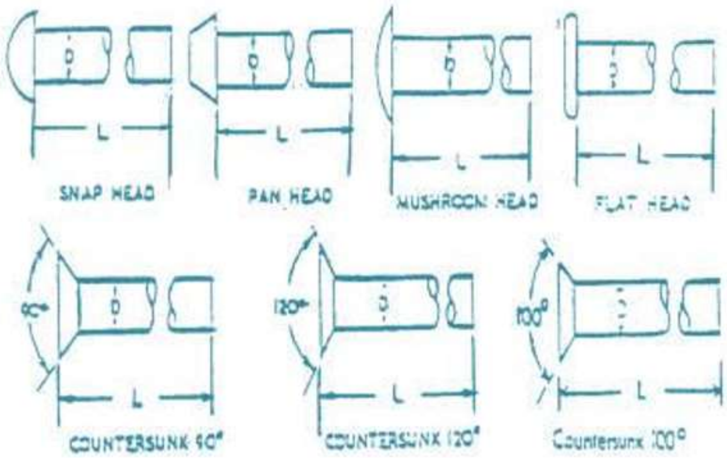


Fig. 2.44: Rivet head type Rivet Clearance

The clearance is the difference between the size of the hole and the rivet diameter; rivet holes are normally drilled 0.003 in oversize. Clearance is necessary, particularly with light alloys to prevent puckering of the sheet owing to the metal spreading when the rivet head isformed.

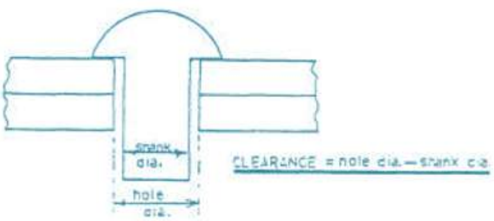


Fig. 2.45: Rivet clearance

Allowances for Riveting

When fitting a rivet, sufficient shank must beleft protruding above the plate to take up the clearance and form the head. Failure to observe this precaution leads to many riveting faults. The allowance for rivet heads is expressed in terms of the diameter of the rivet shank and are dependent on the material specification of the rivet and gauge of sheet beingriveted.

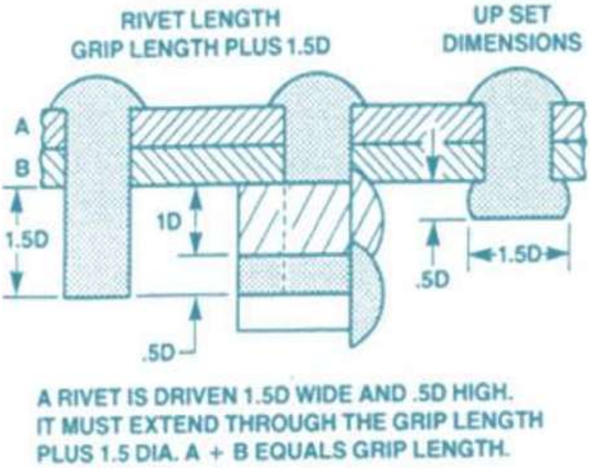


Fig. 2.46: Rivet allowance Typical values of allowanceare:

- SnapHead 1.5D
- Countersunk 0.75D
- Reaction 1.5D

Rivet Grip Length

This is the length of rivet shank taken up by the combined thickness of the sheets being joined.

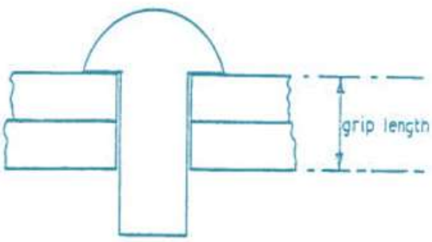


Fig. 2.47: Grip length

To determine the length of rivet to be used add the rivet allowance to the rivet grip length. Have a trial on scrap metal of the same thickness and specification.

Solid Riveting Tools

Solid rivets can be fitted manually using appropriate snaps, sets and dollies or mechanically, using the special power operated riveting tools. It is essential to have access to both sides of the joint since the rivet must be supported on one side as the head is formed.

Set - this is a hollow punch tool used to draw the metal sheets together and bring the pre-formed rivet head hard against the metal surface.

Snap - a punch tool with a shaped hollow at one end, the same shape as the manufactured head.
The set and snap may be separate tools or combined into one tool.

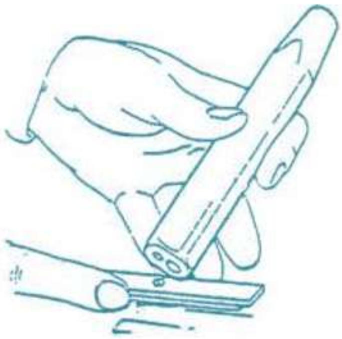


Fig. 2.48: Combined Set and Snap tool

Dolly - This is a metal block with a recess to the same shape as the pre-formed head. It is used to support the pre formed head whilst forming the rivet. The pre-formed head should fit squarely into the dolly. For reaction rivet the dolly is a smooth flatblock.

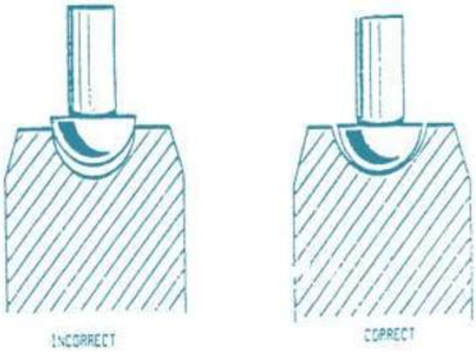


Fig. 2.49: Dolly sizing

The riveting tools are available in different sizes depending on diameter or rivet being used and the shape of head.

Cleco Clamps and Pliers

Cleco clamps are used to align parts prior to being re- riveted to an aircraft. The clamps are in- stalled with Cleco pliers (Figure 2.50). The color of the Cleco clamp indicates the diameter of the rivet it is to be used with. Four commonly used sizes are 3/32 of an inch (silver), 1/8 of an inch (copper), 5/32 of an inch(black), and 3/16 of an inch (brass, gold).inch (copper), 5/32 of inch (copper), 5/32 of an inch (black), and 3/16 of an inch (brass,gold).

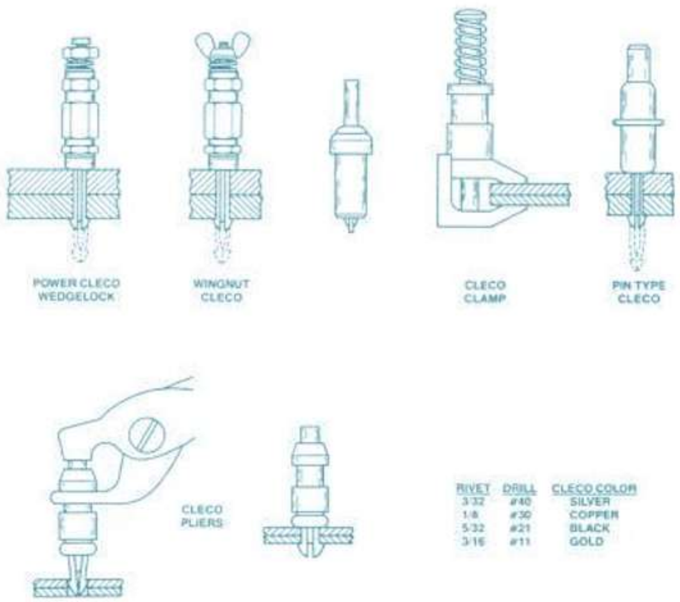


Figure 2.50 Metal Cleico Clamps

Rivet Guns

The hand tool commonly used to drive rivets is a rivet gun (Figure 2.51). Rivet guns are powered by compressed air and are classified as light, medium-, or heavy-hitting. A light-hitting gun is used to install 1/32-inch and 1/8-inch diameter rivets. Medium-hitting guns are used to install 5/32-inch and 3/16-inch diameter rivets. Heavy-hitting guns are used to install larger diameter rivets and some specialfasteners.

Rivet Sets or Gun Sets

There are two types of gun sets: The universal and the countersink. The universal gun set is sized to fit on the driven end of the various shapes of rivet heads. The opposite end ofthe universal gun set fits into the rivet gun barrel and is held in place by a beehive retainerspring.

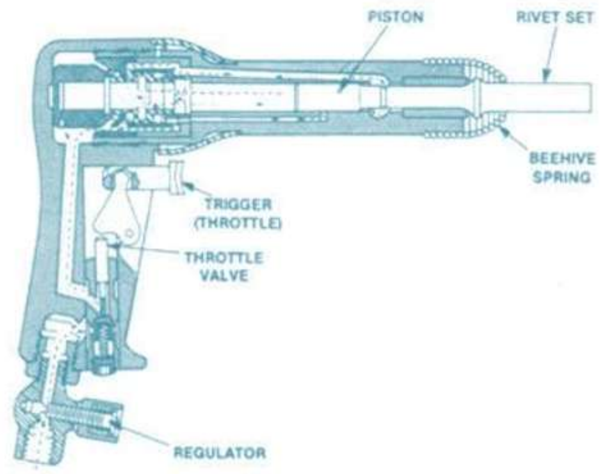


Fig. 2.51. Rivet gun

Countersink Gun Set

The countersink gun set is made to fit on the driven end of any size flush head rivet. A beehive retainer spring will not fit over the gun set retainer ring of the countersink gun set. It uses a specially constructed retainer spring. Figure 2.52 pictures both types of retainer springs. The retainer ring, located in the middle of the gun set, holds the retainer spring as it is threaded onto the gun barrel and prevents the gun set from accidentally flying off. The rivet gun should never be fired if the gun set is not held in place by the retainingspring.

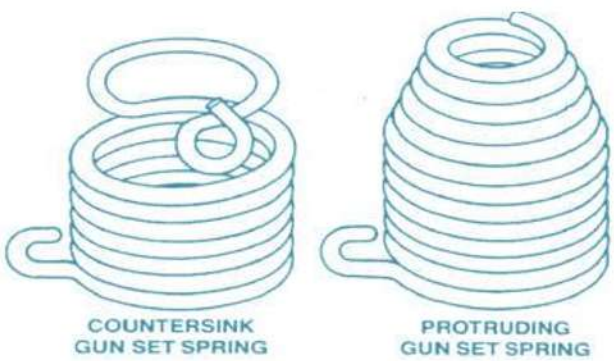


Fig. 2.52: Gun set retaining springs Rivet Cutters

Rivet cutters are used to cut rivets to size prior to driving. The rivet cutter has a stack of thickness gauges which are used to determine the correct rivet length by measuring the space between the rivet head and the cutting edge (Figure 2.53). When rivet cutters are not available, the rivets can be cut to size using a pair of diagonal cutting pliers. Therivet is cut by squeezing together the two rotating plates connected to the cutterhandles.

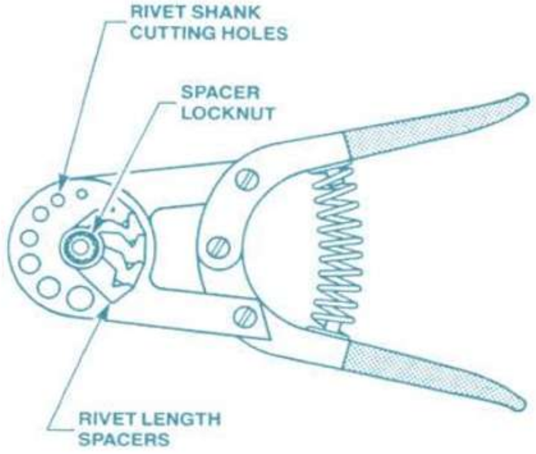


Fig. 2.53: Rivet cutters Bucking Bars

Bucking bars are tools used to form shop heads on solid- shank rivets during installation. Bucking bars are available in many sizes, shapes and weights. An assortment of bucking bars is illustrated in Figure 2.54. When installing rivets, it is important to remember that the bucking bar weight should correspond to the diameter of the rivet being driven (Figure 2.55).

The face of the bucking bar is smooth and must be protected from any nicks or scars which can affect the proper shaping of the driven head. Damaged bucking bar faces can be filed and then smoothed using oil and crocus cloth.

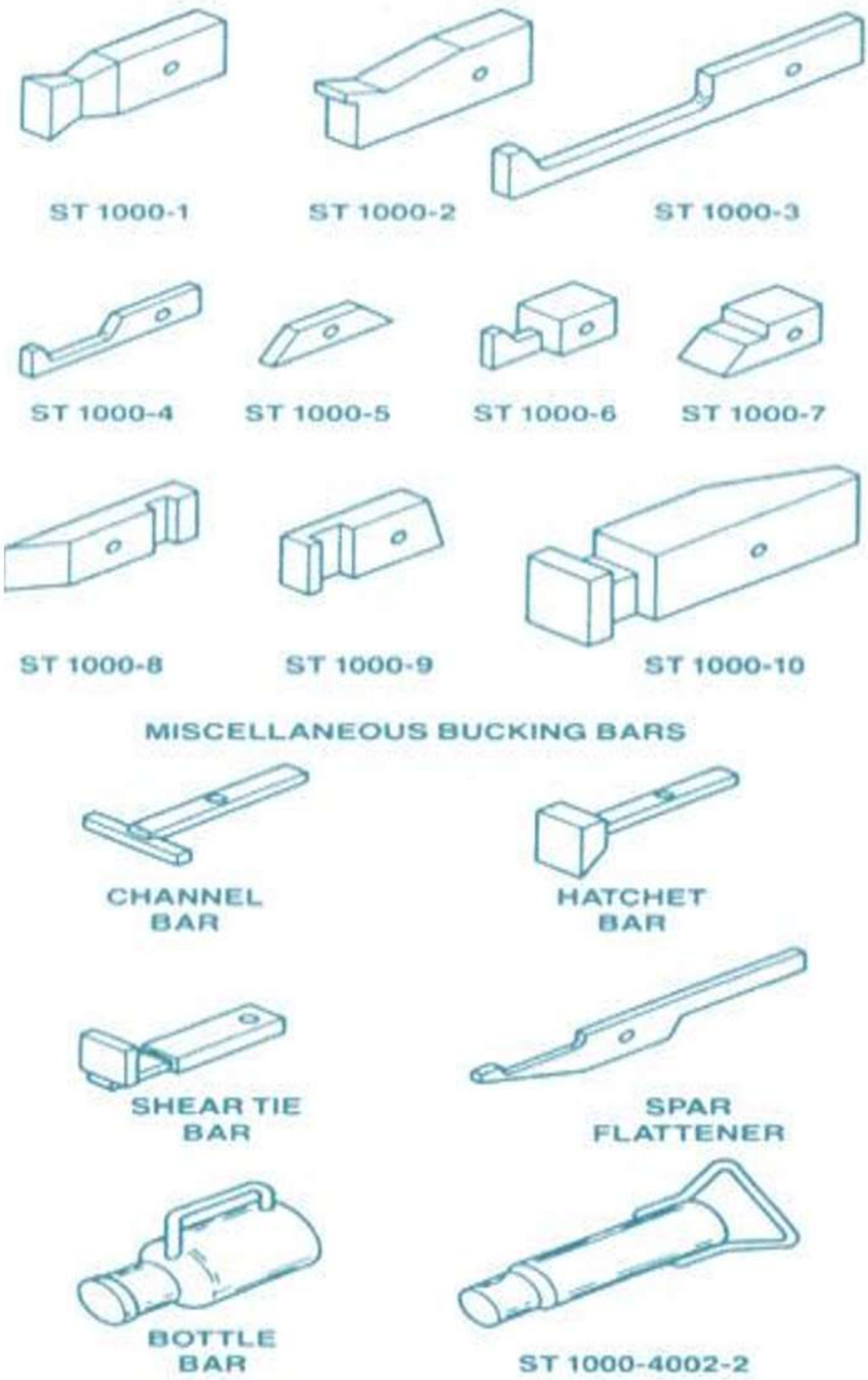


Figure 2.54: Various bucking bars

RIVET – DRILL – CLECO – BUCKING BARS – MINIMUMS								
DIAMETER OF RIVET	RIVET DIAMETER DECIMAL	DRILL DECIMAL	OVERSIZE OF DRILL	DRILL NUMBER	CLECO COLOR	BUCKING BAR WEIGHT	MINIMUM RIVET PITCH	MINIMUM EDGE DIST.
3/32	.0937	.0980	.0043	40	SILVER	2-3 lbs.	9/32	6/32
1/8	.125	.1285	.0035	30	COPPER	3-4 lbs.	3/8	2/8
5/32	.15625	.1590	.0028	21	BLACK	3-4.5 lbs.	15/32	10/32
3/16	.1875	.1910	.0035	11	GOLD	4-5 lbs.	9/16	6/16
1/4	.250	.2570	.007	F	GREEN	5-6.5 lbs.	3/4	2/4

Fig. 2.55: Rivet information chart

NOTE: Alcoa claims that a rivet should fit as tight as possible before driving, especially those rivets of harder alloy. the hole clearances listed above are the recommended sizes used in the field.

Solid Riveting Procedure (Snap Head)

a) Mark out rivet positions using pencil onlight alloys and centrepop centreof rivet position, drill the holes to the correct clearancesize.

b) Clean the joining surfaces removing all burrs from the drilled holes. It may be a requirement to put a jointing compound between the surfaces to reduce the possibilityof corrosion.

c) To prevent movement during riveting join the surfaces together temporarily using skin or sheet grip pins at regular intervals along thejoint.

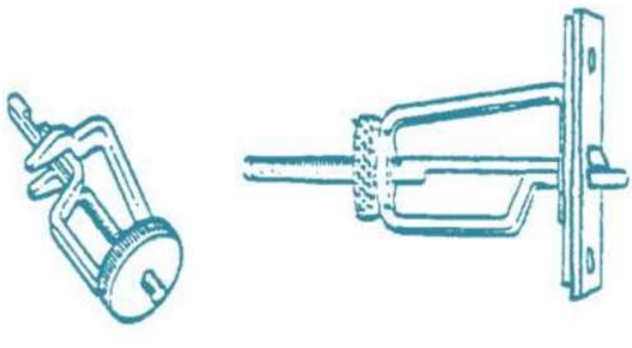


Fig. 2.56: Sheet grip pins

d) Insert the correct length of rivet, support the head in the dolly and place the set over the rivet shank. Lightly tap the set to draw the sheets of metal close together and bring the pre-formed head hard against the metalsheet.

e) Remove the set and strike the rivet centrally to spread the rivet shank in thehole.

f) Using the snap, form the second head of the rivet to the correctshape.

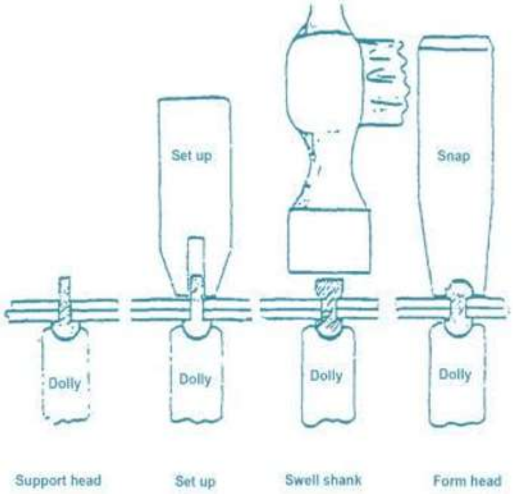


Fig. 2.57: Rivet procedure using snap

Solid Riveting Procedure (Reaction)

This is a rapid method of solid riveting used in setting rivets in light metal structures. In this process, the pre-formed head of the rivet receives theblowsviaa snap. The other end of the rivet being supported by a flat and smooth block (dolly). The impact of the hammer drives the head of the rivet againthe metal sheets and at the same time the rivet shank is spread into a "cheese-head" by the reaction of the metalblock.

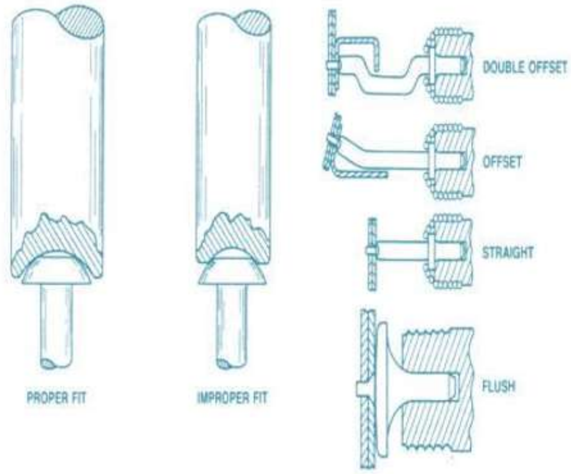


Fig. 2.58: The radius of the cup of the rivet must be slightly larger than the radius of the rivet head. Also shown is a selection of rivet sets.

Heat Treatment Duralumin Rivets

Owing to their age-hardening properties, duralumin rivets must be heat treated. They must be used within two hours of this treatment unless they have been kept in cold storage. Immediate cold storage after solution heat treatment retards duralumin"s age hardening property. On removal from cold storage, the rivets must be used within the two hour period previously specified.

Formed Rivet Dimensions

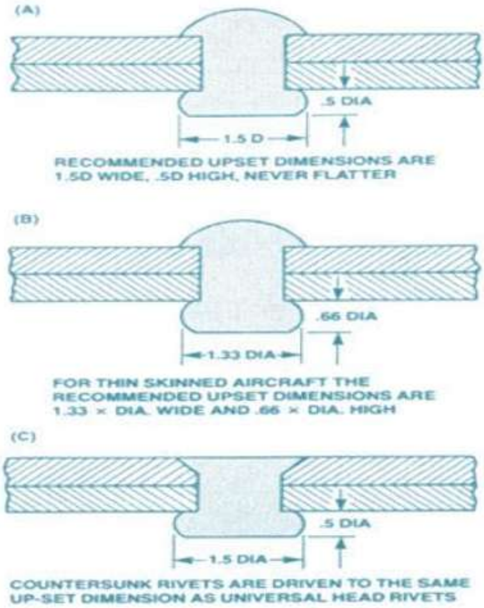


Figure 2.59 shows the ideal formed rivet dimensions.

Rivet Faults

Before commencing any type of riveting job, the operator should whenever possible, make a "dummy run" by forming rivets in some spare piece of metal of corresponding thickness.

The main causes of faulty riveting are asfollows:

a) Excessive or insufficient shankallowance.
b) Rivet holes not drilled straight or drilled to wrong size.
c) Rivet holes out of line on separateplates.
d) Surface of metal not drawn up together, possibly due to burrs around the drillholes.
e) Wrong size of dolly or snap used,thus
f) Damaging the metal surface or forming a bad rivethead.
g) Rives not filling rivet holes correctly because initial hammer blows on the tail of the rivet have not swollen the shank.

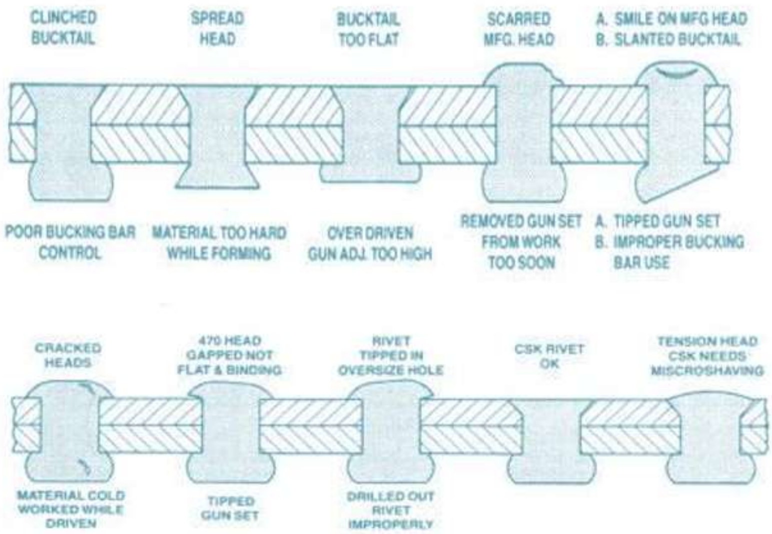


Fig. 2.60: Rivet faults

Removal of Rivets Procedure

a) File a flat on the pre-formed (markers) head of the rivet. The pre-formed head is more symmetrical about the shank than the formedhead.

b) Mark the centre with a centrepunch

c) Drill through the head with a drill of the same diameter of the rivet shank and to a depth slightly less than the thickness of the rivet head, and then carefully chip off the head with small flatchisel.

d) Support the work locally to prevent buckling of the plate on fitting and drive out the rivet with a parallel pin punchslightly smaller than the rivetshank.

If any rivet hole is found to be enlarged as indicated by a loose rivet, or shows signs of cracks around the edges, or a hole is enlarged during the drilling out operations for rivet removal prior to repairs, the repair information in the relevant aircraft repair manual usually contains authorisation for the hole to be enlarged up to 1/32" more than the existing rivet holes, they must be carefully reamed to required size, ensuring that all cracks are removed for edges of holes.

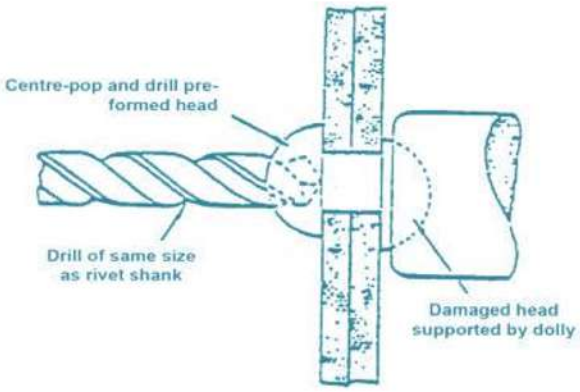


Fig. 2.61: Removal of snap-head rivet Riveted Joints

Introduction

In considering a typical joint it should be understood that the plate resists shear, bearing andtensile loads while the rivet resists shear and bearing loads only.Atno timeshouldthe rivets be in tension as this tends to burst them apart with a load they arenot designed towithstand.

Strength of Joints

The factors that govern the strength of a joint are:

a) Plate specification. This will be of such a material and gauge as to successfully withstand tensile and bearingloads.

b) Rivet specification. This will be selected to withstand shear loads. In cases where the specification of the rivet is not given, use a rivet of the same material as the plate, with a diameter of 3 xTwhereTisthethicknessofoneofthesheets.

Rivet pitch. This is important as too great a pitch will result in insufficient rivets to take the shear loads and too small pitch will result in lowering the resistance of the plate to tensile loads.

Types of Rivet Spacing

a) Single Chain - used chiefly on attachment and lightly stressedjoints.

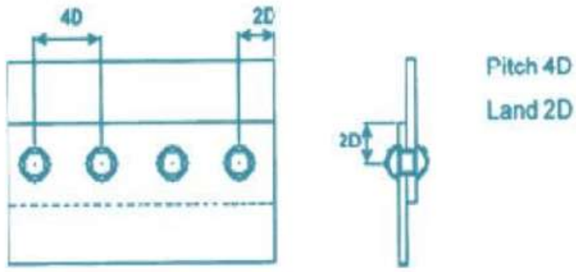


Fig. 2.52 single row rivet spacing and land

b) Multiple Chain - used on watertight joints and in places of high stress, where thick gauge plate is used.

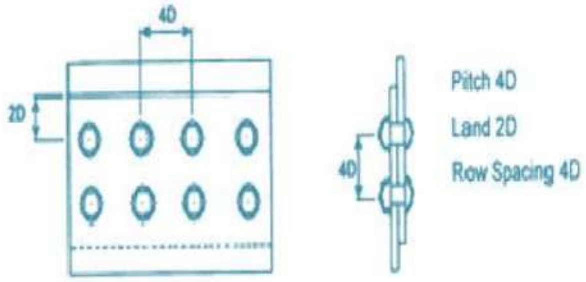


Fig. 2.63: Multiple chain rivet spacings

c) Staggered Riveting- used as an alternative to Multiple Chain in watertight joints, circular patches,etc.

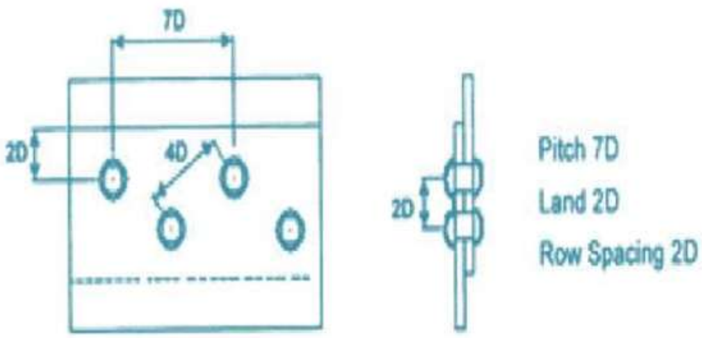


Fig. 2.64: Staggered riveting spacings

Types of Joints

a. Lap Joint - used in places where stress is not particularly high and where flush surfaces are not required. A disadvantage is that the loads are not directly opposite one another and therefore not truly axial.

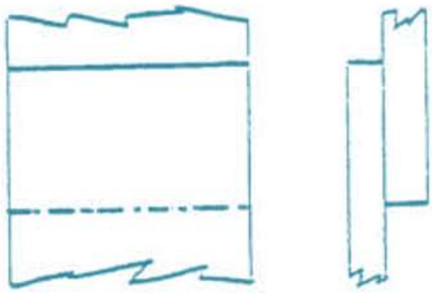


Fig. 2.65: Lap joint

b. The Joggled Lap Joint - the under plate is joggled to preserve the continuity of the upper surface. This provides a flush surface but as in the previous joint, the load is not trulyaxial.

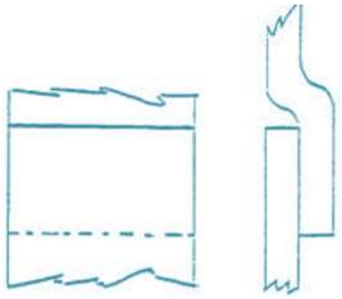


Fig 2.66 The Joggled Lap Joint

c. The Butt Joint - single strap, used on flush surfaces where stress is encountered, requiring the use of heavy gauge plate.

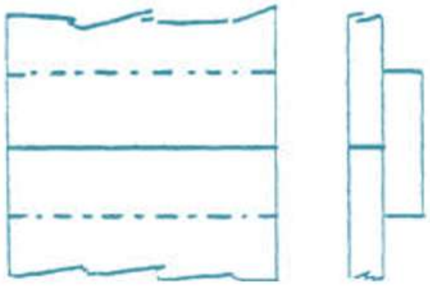


Fig 2.67 Single Strap Butt Joint

The butt joint - double strap, used in places of very high stress, where strength is more important than streamlining.

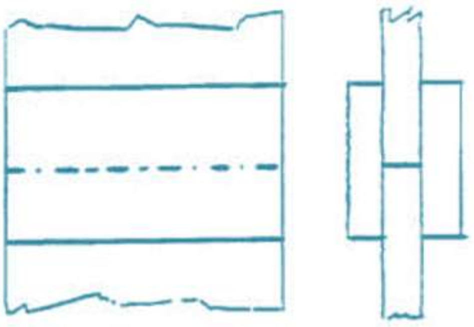


Fig 2.67 Double Strap Butt Joint Faying Surfaces

The faying surfaces are those surfaces of the plate that lie in contact with each other. All joints have faying surfaces and theses must be treated as laid down in current instructions. On normal joints where only structural considerations are involved the surfaces are insulated with suitable jointing compound, such as pigmented varnish or by zinc shims. This is absolutely essential if dissimilar metals are in contact, otherwise rapid corrosion of the parts will result. On watertight or airtight joints the faying surfaces must be separated by a cotton strip impregnated with jointing compound, to ensure the joint is water tight. To make a good joint care must be taken when preparingthe plates to ensure that there are no gaps in the faying surfaces.

Guide to Rivet Pitch and Position

It should be understood that when working to a repair scheme as laid down in the particular aircraft repair manual, the rivet pitches and positions given there must be strictly adhered to even if they conflict with one or more of the following statements:

The rivet pitch of a joint will depend on the function to be performed by that joint. The rivet pitch is the distance between each rivet.

a) If it is merely an attachment joint, then the pitch will be 8 -10D.

b) Joints subjected to high stress, the pitch should not be more than 4D and under no circumstances less than3D.
c) Rivets should never be placed nearer than 2D from the edge of a plate. Theland.
d) The distance between adjacent rows of rivets should be 3 - 4D. The spacing

Bolting

Maintenance accesses, replaceable and movable structural parts are normally attached by bolts.Boltings are non permanent fasteners. This is necessary in order to perform periodic inspections and maintenance work. The replacement of parts and system components also require the use of non permanent fasteners. Some examplesare:
- Bolts andNuts
- Screws
- Studs andInserts
- Pins
- Clamps
- BayonetFittings

Bolted joints are one of the most common elements in aircraft construction design. They consist of cap screws or studs that capture and join other parts, and are secured with the mating of screw threads.
There are two main types of bolted joint designs.In one method the bolt is tightened to a calculated clamp load, usually by applying a measured torque load. The joint will be designed such that the clamp load is never overcome by the forces acting on the joint (and therefore the joined parts seenorelativemotion).
The other type of bolted joint does not have a designed clampload but relies on the shear strength of the bolt shaft. This may include clevis linkages, joints that can move, and joints thatrely on locking mechanism (like lock washers, threadadhesives, and locknuts).

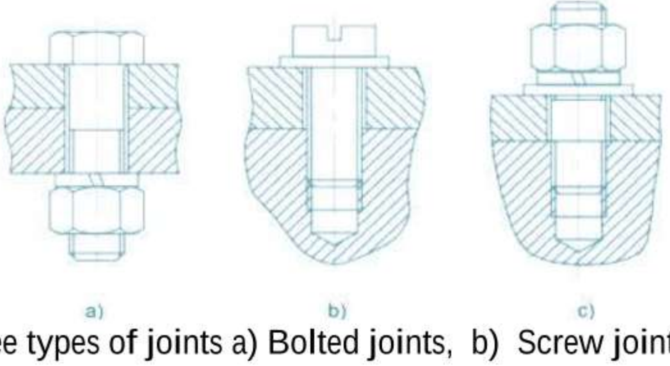


Figure 2.69 Three types of joints a) Bolted joints, b) Screw joints, c) Studjoints.

The clamp load, also called preload, of a cap screw is created when a torque is applied, and is generally a percentage of the cap screw's proof strength. Cap screws are manufactured to various standards that define, among other things, their strength and clamp load. Torque charts are available that identify the required torque for cap screws based on their property class or grade.Whena cap screw is tightened it is stretched, and the parts that are captured arecompressed.

The result is a spring-like assembly. External forces are designed to act on the parts that have been compressed, and not on the cap screw.Theresult is a non-intuitive distribution of strain; in this engineering model, as long as the forces acting on the compressed parts do not exceed the clamp load, the cap screw does not see any increased load. This model is only valid when the members under compression are much stiffer than the capscrew.Thisis a simplified model. In reality the bolt will see a small fraction of the external load prior to it exceeding the clamp load, depending on the compressed parts' stiffness with respect tothe hardware's stiffness.
The results of this type of joint design are:

- Greater preloads in bolted joints reduce the fatigue loading of thehardware.
- For cyclic loads, the bolt does not see the full amplitude of the load. As a result, fatigue life can be increased or, if the material exhibits an endurance limit, extendedindefinitely.
- As long as the external loads on a joint don't exceed the clamp load, the hardware doesn't see any motion and will not come loose (no locking mechanisms arerequired)

In the case of the compressed member being less stiff than the hardware (soft, compressed gaskets for example) this analogy doesn't hold true. The load seen by the hardware is the preload plus the externalload.

In some applications joints are designed so that the screw or bolt will intentionally fail beforemore expensive components. In this case replacing an existing fastener with a higher strength fastener can result in equipment damage. Thusit is generally good practice to replace fasteners with the same grade originallyinstalled.

Torque Setting of Bolted Joints

Engineered joints require the torque to be accurately set. Setting the torque for cap screws is commonly achieved usinga torque wrench. The required torque value for a particular screw application may be quoted in the AircraftMaintenance

Manual or defined by the manufacturer.

The clamp load produced during tightening is higher than 75% of the fastener's proof load. To achieve the benefits of the pre- loading, the clamping force in the screw must be higher than the joint separation load. For some joints a number of screwsare required to secure the joint, these are all hand tightened before the final torque is applied to ensure an even jointseating.

The torque value is dependent on the friction between the threads and beneath the bolt or nut head, this friction can be affected by the application of a lubricant or any plating (e.g. cadmium or zinc) applied to the screw threads. The screw standard will define whether the torque value is for a dry or lubricated screw thread. If a screw is torqued rather than thenutthen the torque value should be increased to compensatefor the additionalfriction- screws should only be torqued if they are fitted in clearanceholes.

Lubrication can reduce the torque value by 15 - 25%, so lubricating a screw designed to be torqued dry could over tighten it. Over tightening may cause the bolt to fail, it could damage the screw thread or stretch the bolt. A bolt stretched beyond its elastic limit may no longer adequately clamp the joint.Torquewrenches do not give a direct measurement of the clamping force in the screw - much of the force applied is lost in overcoming friction. Factors affecting the tightening friction: dirt, surface finish, lubrication, etc. can result in a deviation in the clamping force.

More accurate methods for setting the screw clamping force rely on defining or measuring the bolt extension. Thescrew

extension can be defined by measuring the angular rotation of the screw (turn of the nut method) which gives a screw extension based on thread pitch. Measuring thescrewextension directly allows the clamping force to be very accurately calculated. This can be achieved using a dial test indicator, reading deflection at the bolt tail, using a strain gauge or ultrasonic lengthmeasurement.

There is no simple method to measure the tension of a bolt already in place other than to tighten it and identify at which point the bolt starts moving. This is known as re-torqueing. An electronic torque wrench is used on the bolt under test, and the torque applied is constantly measured. When the bolt starts moving (tightening) the torque briefly drops sharply - this drop- off point is considered the measure oftension.

Failure Modes of Bolted Joints

The most common mode of failure is overloading. Operating forces of the application produce loads that exceed the clamp load, and the joint then works itself loose, or fails catastrophically. Over torquingwill cause failure by damaging the threads and deforming the hardware, the failure might not occur until long afterward. Under torquingcan cause failuresby allowing a joint to come loose. It may also allow the joint to flex and thus fail under fatigue.Brinelling may occur with poor quality washers, leading to a loss of clamp load and failure of thejoint.
Corrosion, embedment and exceeding the shear stress limit are other modes of failure.Bolted joints may be used intentionally as sacrificial parts, intending to fail before other parts, as in a shear pin.

Bonding

On more and more aircraft, bonding is also used to attach stringers, stiffener, etc. to structure skin. Lightweight materials can often be used with adhesive bonding rather than withconventional fastening, simply because the uniform stress distribution in the joint permits full utilization of the strength and rigidity of the adherents. Payloads in aircraft can beincreased.

The following are possible advantages of properly designed adhesive bonded joints:

- Adhesive bonds provide airtight joints.
- Electrochemical corrosion is reduced orlaminated.

In a bonded joint adhesives are electrically insulated from each other; there are no holes to expose base metal, and cladding, anodize and other corrosion protection surfaces are not destroyed.

- Higher fatigue life of joints may possibly allow reduced sheetgauges.
- Residual strength of damaged structure, which is adhesively bonded, can be large. In a laminated panel, cracks may grow for some time in only one layer; in stiffened panels, cracks may grow more slowly across a bonded area than across a rivetline.
- Aerodynamic surface smoothness of adhesively bonded structure isexcellent.

Adhesively bonded joint may suffer from the following limitations:

- Assembly may be more expensive than for conventionaljoints.

- Very extensive process control over the entire bonding procedure isrequired.
- Curing temperatures of some adhesives may degrade othercomponents.
- Service degradation of bonds is difficult to check. Bonded joints shall not be used in any application in which a complete bond failure or obvious partial failure could cause loss of the aircraft. Bonded joints shall be classified for structural application as follows as a means for designating levels and types of inspection and peel strengthrequirements.

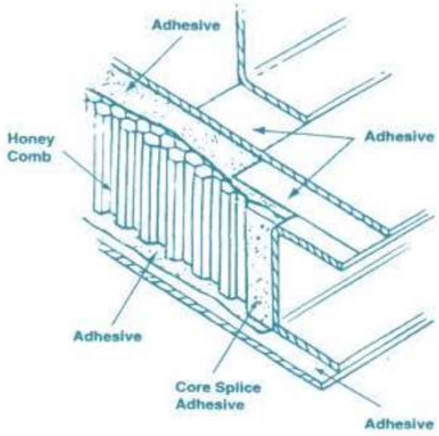


Fig. 2.70: Bonded Structure Bonded Joint Design

In practice, bonded structures must sustain a combination of forces. For maximum strength, loading stresses should be directed along the lines of the adhesive's greatest strength. Cleavage and peel stresses should be avoided. Moreover, the type of substrate, its thickness, and the adhesive must be analyzed for the optimum area of overlap.

Joints can compensate for a variety of mechanical stresses, minimize stress concentrations on the bondline, and optimize the characteristics of the substrates being bonded. Lap joints, a simple layer on layer, are generally strongest. The length of an overlap increases strength but by decreasing amounts. Increasing the width of the overlap produces a proportional increase instrength.

Most data on adhesive lap shear and peel strengths is based on simple lap joints made on aluminium-alloy substrates. But many other joint designs are successful. For example, metals such as mild steel are oftenbent or folded to form durable joints. Sheets that cannot be bent or folded can be bonded together using profiles (a connection method) designed for the application. For instance, tapering the edges of a stiffener reduces high-stress concentrations caused by abrupt sectionalchanges.

Large, thin sheets of metal and plastic are reinforcedby bonding on stiffeners made of the same material in a similar gauge. For instance, a "top-hat" stiffener (the cross section resembles a top hat) can be tapered at the edge of the sheet to perform like a scarf joint for maximumstrength.

(A scarf joint is made by tapering substrate surfaces to produce a longer or larger bonding area that adds strength to the assembly.) The long-term performance of bonded assemblies also depends on the adhesive and substrate, bondline thickness, and service conditions. The most widelyused adhesives in bonded structuresinclude:

Types of Bonding Agent

Epoxies. These form extremely strong, durable bonds on most substrates including metals, rigid plastics, composites, ceramics, and glass. Epoxies are available with different physical characteristics. These low-shrinkage materials stand up to challenging conditions with good solvent and chemical resistance.

Polyurethanes

produce strong, resilient joints that resist impact and abrasion. They are room- temperature curable and maintain good flexibility even at temperatures to O0F.
Polyurethane adhesives are well suited for bonding thermoplastics and assembling dissimilar materials. They typically require little or no surface preparation, resist sagging, and apply easily from dual cartridge dispensingsystems.
Polyurethanes are well suited for projects such as multi- component ABS housing for a personal vehicle and the assembly of aircraft tray tables.
On the downside, polyurethanes cannot handle temperatures above 2500. And a few polyurethanes weather poorly. Uncured materials have some toxicity, crystallize when wet, and can be attacked bysolvents.

Methacrylate adhesives are fast curing and tough. They have epoxy- like strength and produce long-lasting bonds on thermoplastics including ABS, polycarbonate, thermoset composites, as well as metals, ceramics, and glass. And methacrylates can withstand environmental extremes.

Design considerations

After selecting an adhesive and identifying service conditions, there are few decisions to make regarding the bond line and surface prep. The adhesive, how it's applied, and bondline thickness affect bond performance. Making the bondline thicker reduces stress by absorbing more load when the adhesive is more flexible than the substrate. Toughened adhesives like polyurethanes, for example, maintain more strength in thicker bondlines than rigid adhesives such as epoxies. An optimum bondline thickness generally falls between 0.004 and 0.01 in. Between 0.02 and 0.04 in., adhesive strength drops. Shear strength is relatively constant in thicknesses greater than 0.04 in. The tensile tests of simple epoxy-adhesive lap joints show a maximum load of about 1,885 psi.
For thicker bondlines, adding fillers to an adhesive lets it fill gaps better. Propeller blades, for example, require a specially formulated epoxy for high-strength joints on blade shells.

Surface Preparation of Bonded Joints

Surface preparation is critical to the bond. The four levels of pre-treatment (from least to most effective) include a dry wipe, degreasing, degreasing followed by abrasion (sanding or sand blasting) and removal of loose particles, and finally degreasing with a chemical treatment.

Dry wiping with clean, lint-free cloth removes loose particles and dust. A few polyurethanes and methacrylates have been formulated for this minimal pre-treatment on specific substrates.

Degreasing removes all traces of oil and grease. Methods include suspending the surfaces in solvent in a vapour- degreasing unit. Washing and rinsing in separate tanks of the same solvent also works. Technicians can brush or wipe the material with a clean brush or lint-free cloth soaked in a clean commercial degreasing solvent. An additional degreasing process scrubs the surface in a solution of liquid detergent and rinses with clean, hot water, although steam drying is preferable. The best degreasing method uses an alkaline agent following manufacturer's instructions, or with ultrasonic equipment.

Abrading surfaces lightly produces stronger bonds than joining polished surfaces. Sandpaper, a wire brush, or for maximum effectiveness, grit blasting works well. When abrading, the substrate must then be degreased or cleaned using dry and filtered compressed air.
Chemical pre-treatment improves adhesion. Specific treatments are selected based on substrates. Metals can be acid etched to remove scale. Typical pre-treatments include chromic acid for aluminium,

sulphuric acid for stainless steel, and nitric acid for copper. Metals arealsocleanedby anodizing orpriming.
Chemical pre-treatment for thermosetting plastics include using a solvent such as acetone or methyl ethyl ketone. Thermoplastics are the most difficult substrates to join and pre-treatment is determined by the grade of plastic and moulding process that formed thesubstrates.
Bonding should proceed as soon as possible after surfaces are cleaned and pre-treated. To ensurereliableadhesion, accurately weigh the resin and hardener, mix them for 3 min, and apply in a controlled thickness. Once applied, jigs or other fixtures prevent bonded surfaces from moving during curing. Fixing requires only light pressure, but it should be applied as evenly as possible over the bonded area. Finally, follow curing temperatures and times recommended bymanufacturers.

Bonded Joint Strength and Testing

Adhesives are strongest when exposed to shear, compression, and tension stresses. They perform less effectively under peel and cleavage loading.
In shear stress, force is applied parallel to the plane of the substrates and distributed over the bonded area to minimize its affecton joint strength. Compression stress applies force perpendicular to the substrate surfaces and toward the bond line. This type of stress is limited and calls for use of a resilient adhesive. Tension stress applies force perpendicular to the substrate surface and away from the bond line. Peel stress produces a loading at either 90 or 180°to the plane of the bondline, andrepresents the most severe challenge that can be placed on an adhesive. Cleavage stress is also hard on adhesive joints. Its prying forces are exerted perpendicular and away from the plane of the bond line. Cleavage stress typically is concentrated on oneedge.

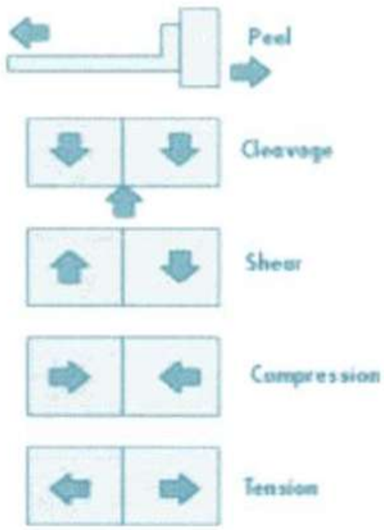


Fig. 2.71: Bonded joint stress types

Surface Protection

Many different surface protection methods are applied on aircraft structures, because of the variety of materials used.

The processes of surface treatments, more formally surface engineering, tailor the surfaces of engineering materials to:

- Control friction andwear
- Improve corrosionresistance
- Change physical property, e.g., conductivity, resistivity, andreflection
- Alterdimension

- Vary appearance, e.g., colour androughness
- Ultimately, the functions and/or service lives of the materials can beimproved

Common surface treatments can be divided into two major categories: treatments that cover the surfaces and treatments that alter thesurfaces.

- Inorganic Coatings: The inorganic coatings perform electroplating, autocatalytic platings(electrolessplatings), conversion coatings, thermal sprayings, hot dippings, hardfacings, furnace fusings, or coat thin films, glass, ceramics on the surfaces of thematerials.

- Organic Coatings: The organic coatings apply paints, cements, laminates, fused powders, lubricants, or floor toppings on the surfaces of materials.

- Water Displacing Fluids: this are wax based Super penetrating, water displacing, heavy duty, corrosion inhibiting compound. Forms a tack-free, more or less firm film which depends on the type. Some examples are Dinitrol AV8, AV15, AV30, etc.

- Surface Cleaning: the most fundamental and important rule for corrosion control is to keep the aircraft clean. When it is clean and free of grease and dirt, there is nothing to hold the corrosion-forming moisture incontact with the aluminium alloy surface. Also, a clean aircraft is easy to inspect for the first indication ofcorrosion.

Inorganic Coatings Electroplating
Electroplating is an electrochemical process by which
metal is deposited on a substrate by passing a current through the bath.

Usually there is an anode (positively charged electrode), which is the source of the material to be deposited; the electrochemistry which is the medium through which metal ions are exchanged and transferred to the substrate tobecoated; and a cathode which is the substrate (the negatively charged electrode) to becoated.

Plating is done in a plating bath which is usually a non- metallic tank (usually plastic). The tank is filled with electrolyte which has the metal, to be plated, in ionic form.

Electrolysis
The anode is connected to the positive terminal of the power supply. The anode is usually the metal tobeplated (assuming that the metal will corrode in the electrolyte). For ease of operation, the metal is in the form of nuggets and placedin an inert metalbasketmade out non- corroding metal (such as titanium or stainlesssteel).

The cathode is the workpiece, the substrate to be plated. This is connected to the negative terminal of the power supply. The power supply is well regulated to minimize ripples as well to deliver a steady predictable current, under varying loads such as those found in platingtanks.
As the current is applied, positive metal ions from the solution are attracted to the negatively charged cathode and deposit on the cathode. As replenishment for these deposited ions, the metal from the anode is dissolved and goes into the solution and balances the ionicpotential.

In the case of materials such as gold, the anode is not sacrificial (gold does not dissolve easily!), but it is made out of material that does not dissolve in the electrolyte, such as titanium. The deposited gold comes out of the solution. Plating is an oxidation-reduction reaction, where one material gives up electrons (gets oxidized) and the other material gains electrons (gets reduced). The anode is the electrode at which oxidation occurs, and the cathode is the electrode at which reductionoccurs.

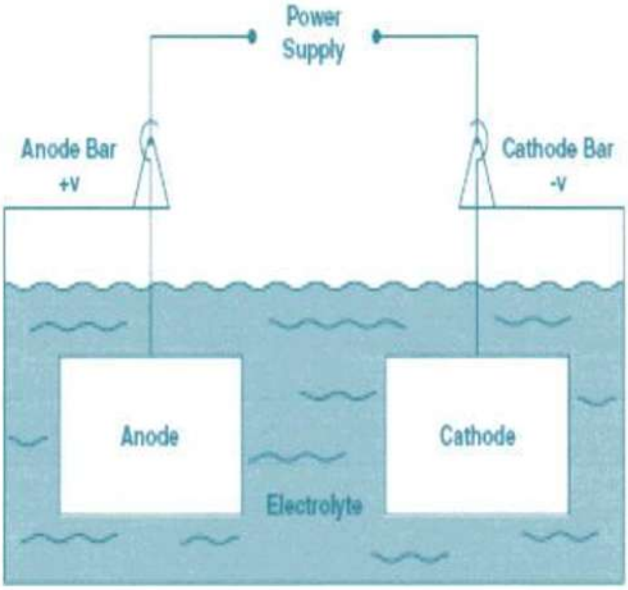


Fig. 2.72: Electrolysis Bath Hydrogen Embrittlement

Hydrogen is released at the cathode in any electrolysis process, and the cathode is the job being plated.Thiscan lead to a problem called hydrogen embrittlementdueto some of the hydrogen being absorbed into the surface of the metal. This is particularly the case with the very high tensile steels, used in undercarriage parts. As a resultthe metal becomes very brittle after a period in service resulting in the risk of cracking. Special plating processes andstress relieving heat treatments are required for these steels - or better still processes not involving electrolysis.

Electroless Plating

Autocatalytic plating, also known as electroless plating, is a plating process which involves deposition without any current applied. The process is a chemical reaction and is autocatalytic. The deposition rate is normally 12.5 - 25 (0.0005 - 0.001 in). Although, it has been done up to 650 |im (0.026 in) in thickness, the coating is usually less than 50 (am (0.002 in) in practice due to the slow deposition rate. The plating thickness tends to be uniform compared to electroplating due to the absence of electric fields and the associated problems in making them uniform. Typically nickel and copper are used in electroless platings. In the case of nickel, the deposits are dense, relatively hard(43-55HRC,increaseto65HRCafter2hr.at343,,C(650
T) and brittle. Electroless Nickel is not as bright as electro-plated, easy to solder and braze, but difficult to weld. For aircraft parts aluminium is extensively used. It forms a non-porous film, which affords high protection once painted.
Combustion chambers may also be spray coated with aluminium. The metal to be sprayed is fed into a special spray gun as a wire or powder, and is melted in the gun. Compressed air is fed into the gun to atomize the metal and to blow it onto the surface to be treated in the form of tiny globules. Careful control of the spraying operation ensures a thick evenplating.

Thermal Spraying Processes

Popular in the 1990s, thermal spraying processes form a continuous coating by melting the consumable material (target) into droplets and impinging these droplets on the substrate. The mechanism of bonding to surface in thermal sprayings is the same as platings, both mechanical interlocking and atomic interaction, with the shear strength around 7 MPa (10 PSI). The thickness of the coatings may range from 25 mm to 2.5 mm (0.001 - 0.1 in). In practice, the thermal sprayings are capable of competing with

platings and paintings for atmospheric corrosion resistance.
The thickness of the coating can be built up by successive operations. Old coatings can be removed and new ones applied so that worn out components can be recovered. It is used extensively on compressor and impeller blades, and on parts of pumps and hydraulic motors. Some common thermal spraying processes, including Flame Spraying (FLSP), Plasma Arc Spraying (PSP), Electric Arc Spraying (EASP), Detonation Gun (d-Gun), and High-velocity Oxy/Fuel (HVOF), are briefly discussed asfollows:

Flame Spraying (FLSP): FLSP was the first thermal spraying process. It uses a 2760^ (5000 T) oxyacetylene flame to melt the targets which may be powders, rods, or wires.

Plasma Arc Spraying (PSP): Similar to flame spraying, PSP however produces 16,650 'C (30,000 T) heat for melting powders and yet the surface temperature of the substrate rarely exceeds 150
„C (300 T). PSP is th us more suitable for spraying ceramics on metals and thermoset plastics for building up
dimensions or wearresistance. The coatings are usually denser, contain less porosity, and have better adhesion than FLSP.

Electric Arc Spraying (EASP): EASP uses electric arc to melt the motor driven target wires. The melted droplets are then injected into the substrate surface by gas.

Detonation Gun (d-Gun): D-Gun melts target powders in a gun by spark ignition of explosive gas.

High-velocity Oxy/Fuel (HVOF): Executed in a combustion chamber, HVOF uses oxygen, hydrogen, and a fuel gas, e.g., methane, to melt the target powder. Resulting in better control in working environment, the HVOF serve the same function as plasma spraying and often has better quality control.

Dipping

A suitable prepared component is immersed in a bath of molten metal and when withdrawn has a coating of that metal. Applicable mainly to plating low melting temperature metals onto components with much higher meltingtemperatures.

Cladding
Aluminium alloy sheet is commonly protected by the application of pure aluminiumto both sides of the sheet. The aluminiumis pressure rolled on and the heat generated welds the aluminiumto the sheet. Any cut edges need to be protected against corrosion either by paint or by the jointing compound squeezed out during wetassembly

Conversion Coatings

Common conversion coatings processes are briefly discussed in this section, including oxide coatings, phosphate coatings, and chromate coatings.

Oxide Coatings:
The oxide coatings are in fact corrosion products which are a thin, usually less than 2.5 jam (.0001 in) oxide with good adhesion. The oxide treatments are done by heat, chemicals, or electrochemical reactions. Gun-bluing-type oxidations are done by heating the metals, generally steel, at 3700 (700^) in a steam atmosphere. An oiled gun bluing provides some atmospheric corrosion resistance, but little protection on wear and other corrosion. Chemical baths produce coatings similarto a gun bluing coating by immersion techniques. Black oxide treatments are done by proprietary chemicals. Some pastes can be rubbed on surfaces to produce similar results. Black oxide can be applied on steel, copper, andmost

stainless steel.

Anodizing: Probably the most important treatment for aluminum alloys. It is producedby electrochemicalconversion. The anodizing process, usually performed on aluminum for protection and cosmetic purposes, builds up both on the surface as well as into the metal. Thin coatings, 2 fim to 25 |im(100 juinto 1000 jiin) can be coated on most aluminum. Thick coatings from 25 to 75 |im(1000 to 3000 |iin) are more durable and abrasion resistant than above chemical conversion oxide coatings. This oxide layer can be made in different coloursdepending on the post chemistries that are employed. The anodized parts are quite durable and do not tarnish and maintain their cosmetic appearance for a long period of time. Anodized coatings are usually dielectric in nature. There are three different anodizing processes commonly used. They are the sulphuric acid, chromic acid and hard anodizing methods.

- Sulphuric Acid Anodizing (SAA): is the most common process giving a deep, almost transparent, film of oxide and a good surfacefinish.

The tank is often lead-lined steel, the lead forming thecathode. The electrolyte, as the name implies, is a weaksolution of sulphuric acid, which is heated andagitated.

- Chromic Acid Anodizing (CAA): process uses aweak

chromic acid solution, which is less corrosive than sulphuric acid, and is only used for anodizing components, which involve folded or riveted joints or crevices in which the electrolyte could be trapped. However it produces only a very thin oxide film and is therefore not recommended very often.

- Hard Anodizing: is a sulphuricacid process in whichthe electrolyte is maintained at a low temperature. It produces a hard, abrasion resistant, as well as corrosion resistant surface, but at the expense of some fatigue resistance and an increase in dimensions. It leaves a dark grey surface. Incidentally the phenomenon of dimensional increase is sometimes used to advantage during manufacture in order to recover a component in aluminum alloy which has been machined beyond its minimum metal condition. In these cases all other surfaces are masked beforetreatment.

Phosphate Coatings: Phosphate coatings are processes of chemical conversion on a metal surface to producethin adherent phosphate compound coatings. Thephosphatecrystals formed on the surfaces of materials can be iron, zinc, or manganese phosphates. Amongthesephosphates, manganese phosphate is more suitable for wear applications. Phosphate coatings are usually applied to carbon steel, low- alloy steel, and cast iron. They can also be applied to zinc, cadmium, aluminium, and tin. Phosphate processes are hard to apply on high alloys for these alloys are likely immune to the phosphoric acid. In short, phosphating is one of the most useful non-metalliccoatings

Chromate Coatings: Chromate coatings, similar to phosphate coatings, are processes of chemical conversion. But the chromate coatings are formed by the reactionofwater solutions of chromic acid or chromium salts. The coatings can be applied to aluminium, zinc, cadmium, and magnesium. The coatingsusually havegood atmospheric corrosion resistance. Chromate coatings are widely used in protecting common household products, such as screws, hinges, and many hardware items with the yellow-brownappearance.

Chromates are used extensively as corrosion inhibitors and are generally yellow in colour. Commercial namesofsuch products are: Alodine 1200, Iridite 14E,etc.

Paint Systems for Aeroplane Structures

One painting system uses Chromatin, to protect the base metal then a two pack epoxy or polyurethane primer and then a top coat of two pack polyurethane or epoxy finish.

Another painting system uses wash primer (two pack - filiform corrosion resistant), followed by a two

pack polyurethane or epoxy primer and then a two pack polyurethane or epoxy top coat.
There are also different types of primer specifications for components that are ferrous or contain ferrous elements.
Nowadays, high-tech paints are used that are more environmentally friendly. For example, paint containing no solvents. This lowers the VOC (Volatile Organic Components) emissions. The newer trial paints are based on two pack water basedpaints. However, the latest technology does not include paint at all, rather a film of self-adhesive plastic (similar to placards) that isremovable simply with hot soapy water. It is currently on test on an F-16 fighter in theUSA.
There are several methods of applying the paint; spraying, rolling, brushing and dipping.

Spraying

Spraying would be used to cover a complete aircraft or large panels. Special equipment is required to blow the paint onto the surfaces. Spray guns are used; they have adjustable nozzles to vary the spray pattern for large or small jobs. The dust and over-spray that spraying produces necessitates specially prepared bays or hangers with adequate ventilation. Protective clothing, masks and goggles must beworn.

Rolling

Paint rolling is also used on large areas, it is less messy than spraying but as the paint is applied more thickly a weight penalty is incurred. The paint is applied using a lambs-wool roller.

Brushing and Dipping

Brushing and dipping are used to cover small or inaccessible areas. Dipping will require the components to be removed from the aircraft.

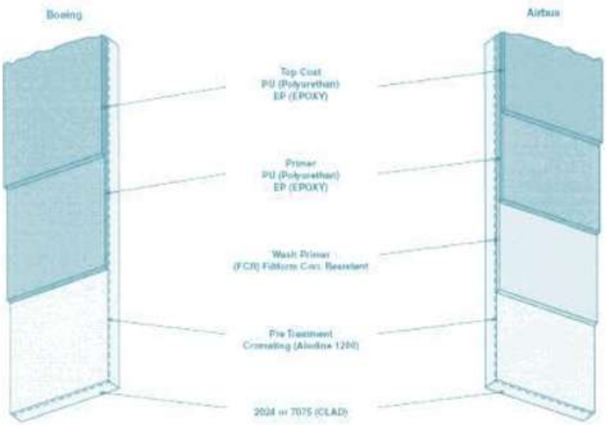


Fig. 2.73: Examples of Painting Systems

Water Displacing Fluids

These can be used in two ways:

- To provide additional protection over protected surfaces.
- To protect unprotectedsurfaces.

Although they can be readily removed by the useofsolvents some are as durable and protective as paints and are intended to have a long life. Control cables, for instance, are often protected throughout their life in this way.

This is wax based, super penetrating, water displacing, heavy-

duty, corrosion inhibiting compound. It forms a tack-free, more or less firm film which depends on the type. Some examples are LPS-3, Dinitrol, AV8, AV15, AV30, etc.Itis applied as a coating to protect metals commonly used in airframe structures and in aerospace components, from corrosion.

They can be used in all areas of the airframe on painted and unpainted surfaces. It combines good penetration properties with excellent corrosion inhibiting characteristics and a low applied film weight.

The viscosity of these products is optimized to ensure an effective protective coating and to promote penetration into otherwise inaccessible areas of the airframe.

Remember to observe these general precautions:
- None of these should be allowed to come into contact with Perspex or naturalrubber.
- Use the correct type for eachapplication.
- Keep solvents and cleaning fluids away unless it is intended to remove theprotective

Aircraft Cleaning

Before commencing cleaning operations all panels and covers should be in place and apertures sealed off. Thick mud, grease or oil should be removed by, first, hand scraping using wood or soft plastic scrapers and then lint-free cloth soaked in solvent. Care should be taken to avoid damage to paint or other anti- corrosivetreatment.
Cleaning should then be carried out using a recommended solvent. These solvents are usually used diluted in hot water. Application to the aircraft surface is best made with spraying equipment but care should be taken to ensure that the solution does not become atomised. After allowing the solution to penetrate, the dirty surface should be washed thoroughly with clean water until all traces of the solution are removed. Care should be exercised when using water hoses or pressure washers for rinsing as too high a pressure may cause damage or ingress of moisture. Undiluted solvents should never be allowed to come into contact with acrylic windows, etc., as crazing is likely to ensue. In all cases the recommended solvent manufacturer"s instructions should be adhered to. Re-lubrication of mechanical parts may be necessary after washing, and application onto sealed bearings, etc., should beavoided.

Certain areas of an aircraft may become heavily contaminated by exhaust gas deposits, the areas varying with different types of aircraft. This contamination, if not removed, could cause severe corrosion and require expensive repairs. Stronger cleaners recommended for the particular aircraft or part should be used with extreme care. Dilution may be required with either water or white spirit and application can be made with a non-atomising spray. In all cases, the solvent manufacturer"s instructions must be strictly complied with. The solution, when applied, should be allowed to soak for a given period and care taken to avoid areas becoming dried out. After soaking, further application is usually required and agitation or scrubbing with a soft brush may be advantageous. Very thorough rinsing, preferably with clean warm water, is necessary. Painted surfaces as well as acrylic windows may become damaged if these stronger solutions are allowed to come into contact withthem.

Snow and Ice

Chemical salts and other melting agents are often used on

runways during the winter months. This slush will inevitably become splashed or sprayed onto the aircraft and could be detrimental. The contaminated areas should be washed down with clean water as soon as possible after exposure. The use of a wetting agent may prove helpful.

Salt Air Operating Environments

Aircraft operated in salt air marine environments will be more susceptible to associated detrimental effects caused by salt deposits and salt contaminant corrosion. Aircraft cleaning and protection programmes should be tailored accordingly for these operating environments and may include increased frequency of aircraft washing and lubrication procedures, engine compressor washing,etc.

Acrylic Windows

After aircraft washing, the windows should be washed with soap or a mild detergent in warm water. Polishing minor scratched surfaces may be accomplished with an approved plastics polish and finally finished with an anti-static polish orcloth.

Radioactive Contamination

This is usually confined to aircraft regularly flying above the stratosphere. Regular monitoring of high flying aircraft with a Geiger counter should be made. Normal regular cleaning will in most cases keep contamination within acceptablelimits.
After cleaning of windows has been completed, the aircraft should be inspected for signs of damage, deterioration of protective treatment, cracks, corrosion, etc. A careful check should be made to ensure that all blanks and sealing fitted have been removed and that cleaning equipment such as rags,sponges, etc., are not left in the intakes, flying controls or other susceptible places. Vents and drain holes, etc., should be checked and cleared ifnecessary.

Aircraft Symmetry Checks Levelling the Aircraft

The position or angle of main components is related to a longitudinal datum line parallel to the aircraft centreline and a lateral datum line parallel to a line joining the wing tips. Before these positions or angles are checked, the aircraft should (generally) be brought totherigging position (i.e. with the lateral and longitudinal datum lines horizontal) by means of jacks or trestles, depending on the particular aircraft type, with the wheels just clear of the ground.

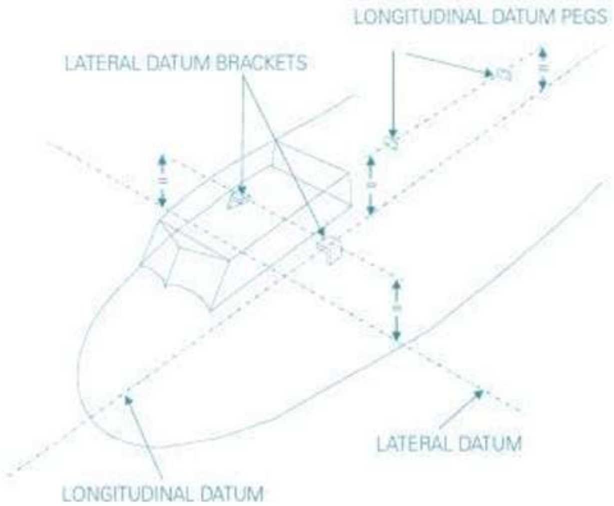


Fig. 2.74: Datum Lines and Levelling Points

For the purpose of checking the level of smaller types of aircraft, fixed or portable datum pegs or blocks, on whichcan be rested a straight-edge and spirit level and which are generally attached to the fuselage parallel to or co-incident with the datum lines, are used, although in some instances parts of the structure which run parallel with the datum lines (e.g. top longeronsor canopy rails of some aircraft) may be utilised. A typical levelling arrangement is shown in Figure2.74.

Another method of levelling the aircraft is the 'grid' method illustrated in Figure 2.75. The grid plate is a permanent fixture on the floor of the aircraft and, when the aircraftis to be levelled, a plumb bob is suspended from a predetermined position in the roof of the aircraft over the grid plate. The adjustments necessary to the lifting gear to bring the aircraft to the level position areindicatedby the grid scale, true level being obtained when the plumb bob is immediately over the centre point of thegrid.

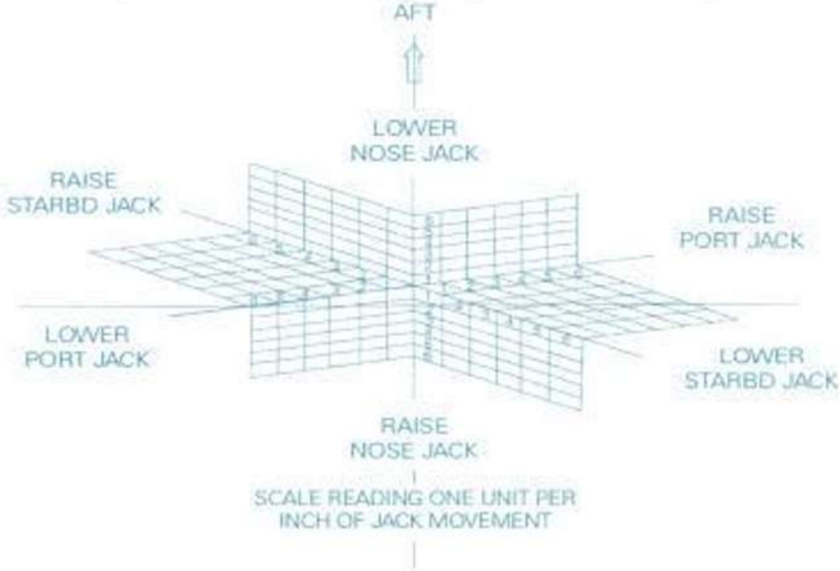


Fig. 2.75: Typical Grid Plate

The method of bringing the aircraft to the rigging position depends largely on the size and type of aircraft and whether a nose wheel or tail wheel configuration applies.

A level site capable of bearing the load to be applied should be selected for the operation otherwise, where trestles are used, it may not be possible to level the aircraft and where jacks are used, the danger of the jacks toppling and dropping the aircraft wouldexist.

Rigging checks should not normally be undertaken in the open, but if this is unavoidable the aircraft should be positioned nose into wind. In any case the aircraft should not be lifted in strong winds or gusts. The weight and loading of the aircraftfor the rigging check should be exactly as described in the manual or as quoted on the original rigging chart supplied by the manufacturer. Variations from this condition, especially in the case of larger aircraft, will prohibit a comparison with the original figures. In any case the aircraft should not be lifteduntil it is ensured that the maximum jacking weight (if any) specified by the manufacturer will not beexceeded.

All equipment which may cause damage to the aircraft during the lifting operation should be moved away before lifting is commenced and no personnel other than those directly connected with the rigging check should be permitted on or around the aircraft for the duration of the complete operation. For most aircraft the brakes should be OFF and the wheels chocked prior to lifting but for aircraft fitted with levered suspension undercarriage units the wheels should be leftunchocked.

Tail Wheel Aircraft

The tail should be raised to an approximately level position by means of the appropriate jacks or adjustable trestle accurately positioned under the rear lifting position. Where single-engine aircraft in particular are concerned, it may be necessary to weight down the tail to prevent the aircraft nosing over due to the weight of the engine. This weight must not be allowed to swing but must touch the ground and be secured by a taut rope to that part of the aircraft specified by the manufacturer. The appropriate jacks or adjustable trestles should be accurately positioned under the main lifting points and the aircraft raised evenly by operating both jacks and trestle gears together until the wheels are just clear of the ground and the aircraft is in the (approximate) rigging position.

The lateral and longitudinal levels should be checked and adjusted as necessary by means of the lifting gear. Where hydraulic jacks are used, the locking devices provided must be applied immediately the aircraft has been correctly positioned and, to ensure the safety of personnel, at any time when the jack is not actually being operated during the lifting of the aircraft.
If steady trestles are placed under the wings after the aircraft has been supported in the rigging position, it must be ensured that they are not in contact with the wings when incidence or dihedral checks are being made, that no adjustments are made to the lifting gear with the steady trestles in position and that the trestles are removed before any attempt is made to lower theaircraft.

Nose Wheel Aircraft

The appropriate trestles or jacks should be accurately positioned under the main, nose and (if applicable) tail positions. The main and nose lifting gear should be operated simultaneously and evenly until the aircraft is just clear of the ground and the operationcompleted.

RiggingChecks

Although the dihedral and incidence angles of conventional modern aircraft cannot be adjusted (with the possible exception of adjustable tailplanes) they should be checked at specified periods and after heavy landings or abnormal flight loads (see Module 7 Study Notes) to ensure that the components are not distorted and that the angles are within permitted limits. The relevant figures together with permitted tolerances are specified in the appropriate manual for the aircraft concerned, but the actual figures relevant to an individual aircraft are recorded in the aircraft logbook.

The usual method of checking rigging angles is by the use of special boards (or the equivalent) in which are incorporated or on which can be placed an instrument for determining the angle,
i.e. a spirit level or clinometer as appropriate. On a number of aircraft the rigging can be checked by means of sighting rods and atheodolite.

Sequence of Rigging Checks

A suitable sequence for checking the rigging is as follows; it is essential that the checks should be made at all the positions specified in the relevant manual.

- Wing dihedralangle(s)
- Wing incidenceangle(s)
- Enginealignment
- Tailplane lateral level ordihedral
- Tailplane incidenceangle
- Vertically offin
- Symmetrycheck

Checking Aircraft with Rigging Boards Dihedral

The dihedral angle should be checked in the specified positions with the special boards provided by the aircraft manufacturer or, if no such boards are provided, with a straight-edge and clinometer. The methods of checking with both types of board are shown in Figure2.76.

NOTE: Certain portions of the wings or tailplanes may sometimes be horizontal or, on rare occasions, anhedral angles may be present.

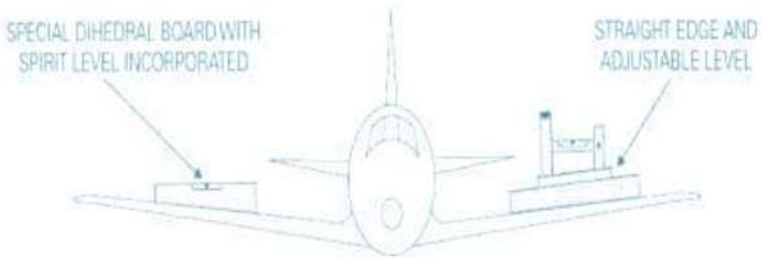


Fig. 2.76: Checking Dihedral

Incidence

The incidence is usually checked in at least two specified positions, inboard and outboard, on the component to ensure that it is free from twist.

a. There are a variety of types of incidence boards, some having stops at the forward edge which must be placed in contact with the leading edge of the wing, whilst others are provided with location pegs which fit into some specified part of the structure, but the main purpose in each case is to ensure the board is fitted in exactly the position intended and, if the rigging is correct, that a clinometer on the top of the board will register zero or within a permitted tolerance about zero. In most instances the boards are kept clear of the wing contour (so that the incidence check is not influenced by any irregularities which may occur in the contour) by means of short feet attached to the board. A typical wooden incidence board is shown in Figure 2.77 although, of course, some are manufactured ofmetal.

b. It must be borne in mind that modifications in areas where incidence boards are located may affect results. For example, if leading-edge de-icing shoes were fitted this might seriously affect the position taken up by a board having a leading edge stop as shown in Figure2.77.

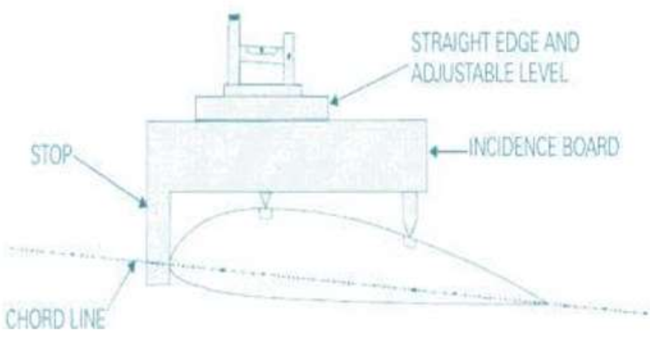


Fig. 2.77: Typical Incidence Board

c. Where possible, the vertically of theincidence board should be checked with a plumb bob. Where the checks are being taken in the open and it is difficult to steady the plumb bob due to wind, the suspension of the plumb bob in a container of oil or water will be ofassistance.

Verticality of Fin

After the rigging of the tailplaneshas been checked, the verticality of the fin relative to a lateral datum can be checked from a given point on either side of the top of the fin to a givenpoint on the port and starboard tailplanesrespectively; the measurements should be similar withinprescribedlimits. When the verticality of the fin stern post has to be checked, it may be necessary to remove the rudder and drop a plumb bob through the rudder hinge attachment holes, when the cord should pass centrally through all the holes. It should be noted that some aircraft have the fin offset to the longitudinal centre line to counteract enginetorque.

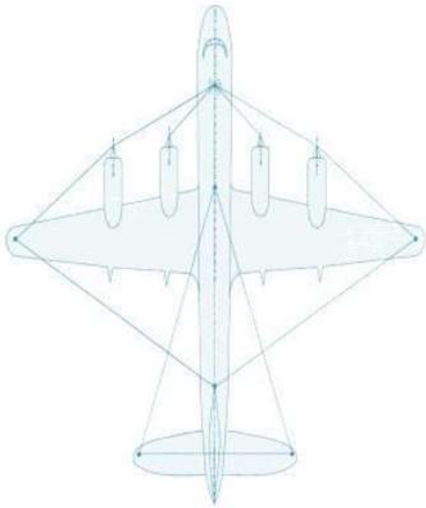


Fig. 2.78: Symmetry Check

Engine Mountings

Engines attached to the wings are usually mounted with the thrust line parallel to the horizontal longitudinal plane of symmetry but not always parallel to the vertical longitudinal plane, since, due to their disposition along the wing, the outboard engines are often offset a degree or so to enable the slipstream from the propellers to converge on the tailplane. The check to ensure that the position of the engine, including the degree of offset, is correct depends largely on the type of mounting, but usually entails a measurement from the centre line of the mounting to the longitudinal centre line of the fuselage at apoint specified

in the relevant manual. (See also Figure 2.78.

Symmetry Check

Figure 2.78 illustrates the principle of a typical symmetry check, the relevant figures and tolerances for which will be found in the appropriate manual, although the actual measurements relating to the aircraft concerned are given in the aircraft log book. For the smaller types of aircraft the measurements between points are usually taken by means of a steel tape. It is recommended that a spring balance should be used on the longer distances to obtain an equal tension, 51b usually being sufficient. Where the larger types of aircraft are concerned, it is more usual to chalk the floor locally under the positions where the dimensions are to be taken, to drop plumb bobs from the checking points, marking the floor with an 'X' immediately under the point of each plumb bob and then to measure the distance between the centre of the markings. This method has the advantages of ensuring more accurate measurement and reducing the amount of walking necessary on main planes andtailplanes.

Rigging Checks on Biplanes

In general the rigging checks applicable to single-engined biplanes during reassembly after overhaul are as follows, but specific requirements relating to a particular type of aircraft should be ascertained from the relevant approvedmanual.

The centre-section should be placed on suitable trestles and the centre-section struts and wires (complete with fork-ends) attached. NOTE: It is important that the fork-ends should be screwed the same number of turns on each end of the wire to provide for subsequent adjustment.

The centre-section should be erected onto the fuselage and the stagger and lateral symmetry checked. The stagger should be checked by dropping plumb bobs from the leading edge of the upper portion of the centre-section (or other defined position) and measuring the distance from the plumb bobs to the leading edge of the lower portion of the centre-section (or other defined position). If necessary, the stagger can be adjusted by means of the front centre-section struts on most aircraft of this type. The symmetry about the centre line should be checked by measuring from plumb bobs to the sides of the fuselage and can be adjusted, if necessary, by means of the bracing wires.

NOTE:It is essential that the centre-section rigging checks should be accurately carried out, since small errors in the centre-section bracing can result in large errors in the general rigging.

The port (or starboard) top main plane should be attached to the centre-section, care being taken to ensure that the main plane is adequately supported during the assembly.Thelanding wires should then be attached to the centre-section, the port (or starboard) lower main plane attached to the centre section, the interplane struts, flying wires and incidence wires fitted and the whole assembly lightly tensioned up. The completed side of the aircraft should be steadied with a trestle whilst the opposite side is assembled in the same order.

NOTE: Although usually of similar appearance, front and rear interplane struts are usually of slightly different lengths to compensate for wing contour, thus it is important to ensure that the correct strut has been fitted in the correctposition.

After assembly the fuselage level should be re-checked and adjusted as necessary, after which the main planes should be trued-up by adjustments to the appropriate wires, the aim being to achieve the correct dihedral first and then to work the incidence and stagger together. Caremust be taken during rigging to ensure that the main flying and landing wires are not over- tensioned to the extent of bowing the main plane spars or interplanestruts.

NOTE: The specified lengths and permitted tolerances applicable to all wires are given in theriggingdiagrams appropriate to the aircraft type, but the actual figures to which the aircraft had previously been rigged is recorded in the aircraft log book. If using the same componentsit is advisable to re-rig to the log book figures, since these may have been determined specifically to counteract a flying fault. After the rigging of the main planes has been completed, it should be ensured that all fork- ends, etc., are in safety, are not 'butting' against the ends of the fitting and have been correctly locked, that the wires are in streamline and that anti-chafing discs and spreader bars are correctly fitted to prevent vibration of thewires.

Empennage

The empennage should be attached in accordance with the instructions contained in the relevant manual and adjusted (where this is possible) to within the limits specified in the relevant rigging diagram. It should be notedthatthe tailplane struts are usually handed and, unless these are correctly positioned, the fairings will not be in line offlight.

NOTE: Tailplanes provided with an adjustment mechanism must be set to the neutral position before checking is commenced.

Twin-Engine Biplanes

The general procedure for rigging twin-enginedbiplanes is basically similar to that described above for single-enginedbiplanes but it must be ensured that the weight of theengines is taken up on the appropriate struts before completing the generalrigging.

Checking Rigging with Sighting Rods

This method of checking rigging is used mainly on the larger types of aircraft and consists basically of sighting with a theodolite the positions of datum marks on a series of rods of graduated lengths, each of which is inserted into a specified jigged position on the underside of the aircraft. For the initial check, the aircraft should be brought to the rigging position and thesightingrodsinserted at the appropriatestations.

NOTE:Since any rod can be fitted into any socket, it is important to ensure that the rods are inserted in their correct positions.

A theodolite, erected at an appropriatedistanceand position from the aircraft should be levelled up with the datum mark on the master sighting rod (usually the shortest rod fitted under the fuselage) and then readings should be taken from this sighting line at each rod station and recorded. A typical method of taking the readings is illustrated in Figure2.79.

NOTES:

1) A method which provides accurate vertical adjustment and rigidity for a theodolite is to mount it on a hydraulicjack.

2) It may not be possible in every instance to obtain a reading on every sighting rod fromonetheodolite position, in which case the theodolite should be appropriately repositioned, realigned on the master rod and the check continued in the samemanner as before.

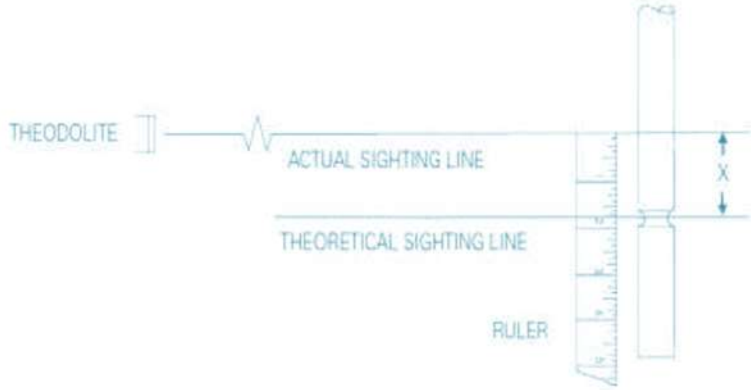


Fig. 2.79: Typical Method of Taking Readings

The readings thus obtained must be within the tolerances permitted by the manufacturer (details of which are usually included in the rigging drawing) and entered in the aircraft log book for permanent record. There are two basic methods applicable to the use of sighting rods and these are described below.

a) On some types of aircraft the sockets into which the sighting rods are inserted are adjustable in the vertical direction so that once variations from nominal figures have been recorded, the rods can be 'zeroed' and permanently locked. Thus the sighting line on all subsequent checks should in fact coincide with thedatum marks on all the rods if the rigging is correct. Rods used for this method have the single datum as illustrated in Figure2.79.

b) The second method is to use sighting rods on which are marked the datum line, on either side of which is also marked graduations indicating the permissible tolerance on the nominal figure in increments of 1/4 degrees. With this method the sockets into which the rods are inserted are not adjustable and subsequent readings should give the actual figures recorded on the initial check.

NOTE: When rods of the 'screw-in' type are used it should be ensured that they are fully screwed home before the check is commenced. When a component (e.g. wing or tailplane) is changed, it will be necessary to again carry out the initial check to ascertain actualfigures.

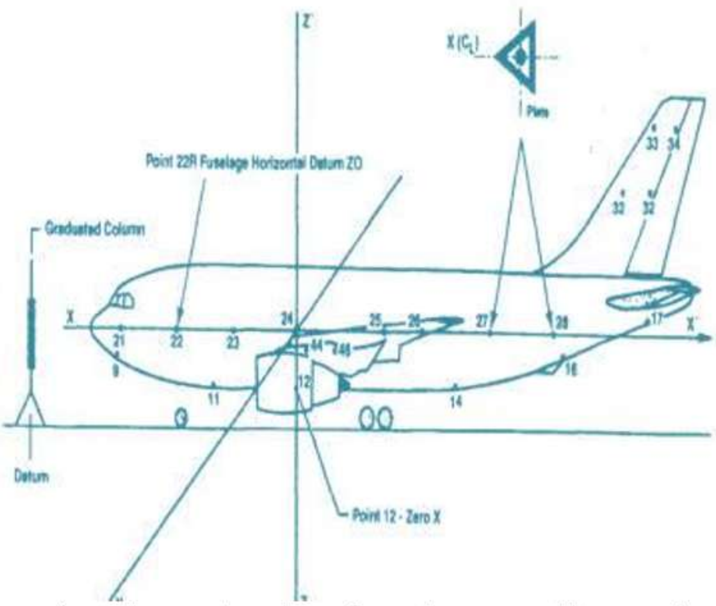
Large Aeroplane Symmetry Check Procedure To check larger types of aircraft, it is usual to chalk the floor locally under the positions where the dimensions are to be taken, to drop plumb bobs from the checking points, marking the floor with an X immediately under the point of each plumb bob and then to measure the distance between the centreofthe markings. This method has the advantages of ensuring more accurate measurement and reducing the amount of walking necessary on main planes and tail-planes.ChapterATA 05 of the AMM gives the instructions for the levelling,measurement and alignment operations of the aircraft. It gives measurement instructions to find possible structural deformations after hard landings, too much turbulence, after the replacement or major repair of a part of the structure, etc.Tables give information about the measurements recorded on the first three aircraft at zero flight hours. They can be used as a guide in appraising the structural and aerodynamic condition of an aircraft after major repairs or after an aircraft has been subjected to manoeuvres requiring analignment check.
Deviations from given values do not automatically mean that the aircraft is not serviceable. These deviations must be appraised from the structural and aerodynamic points of view in order to determine their effects on flightsafety.
In the event of important deviations, visually checkfor presence of the followingfailures: Localized structural failures such as:
Buckled or cracked skins, stiffener, machined parts. Peeled-off paint. Tore or torn fasteners.
Structural failures resulting in:

- Fuel leaks in tankareas
- After the replacement or major repair of a part of the structure
- Air leaks in pressurizedareas
- Interference of moving parts of amechanism
- Leaks in air conditioning, hydraulic or fuelsystems
- Shortcircuits
- Refusal to closure of doors and access panels due to surrounding structuredistortion
- Required excessive control surface trim limiting control range.

	Point	X	Y	Z	Angle	Variation X	Variation Y	Variation Z	Variation Angle
Wing	1	6245.9	9289.6						
	2	8861.3	15275.3						
	3	11139.5	20615.5						
	4	3902.7	9280.5						
	5	7006.6	14773.8						
	6	10468	20902.6						
Fuselage Bottom	9	14205.5	0						
	11	5880	0						
	12	0	0						
	14	8946.2	0						
	16	21053.2	0						
	17	25580.2	0						
Fuselage Lateral	21	-12816							
	22	-9386							
	23	-4896							
	24	-2776							
	25	6774							
	26	9424							
	27	12604							
	28	18854							
Vertical Stabilizer	31	22472.4							
	32	24887.5							
	33	27567.7							
	34	28683.6							

Table 2.4: Example of Aircraft Dimension Chart (A310)

Fig. 2.80: Example of Aircraft Measurement Points Lowering the Aircraft



Before any attempt is made to lower the aircraft to the ground it must be ensured that wing supports and any other equipment which might foul and damage the aircraft are moved clear. The aircraft should be lowered evenly and, when the aircraft weight is accepted on the undercarriage, the jacks should be further lowered to ensure that they can be removed without fouling the aircraftstructure.

Definitions

Anhedral- An inclination outwards and downwards relative to the lateraldatum.

Dihedral - The angle (or angles) at which the wings and tailplanes are inclined outward and upward relative to the lateral datum.

Flying Wires - Wires the principal function of which is to transfer the lift of the main planes to the main structure. These wires are sometimes termed 'liftwires'.

Landing Wires - Wires which brace the main plane against forces opposite in direction to the direction of lift, as occur, for example, in landing. These wires are sometimes termed 'anti-lift wires'.

Incidence - The angle between the chord line of the wing or tailplane and the longitudinal datum.

Incidence Wires - Wires bracing the main plane structure in the plane of a pair of front and rear struts.

Stagger - The distance between the leading edge of the lower plane and the projection of the leading edge of the upper plane on the chord of the lower plane.

11.3.1 FUSELAGE (ATA 52/53/56)

Fuselage Construction

The fuselage is the body of the aircraft, to which the wings, tail, engine and landing gear attach. Becauseofthetremendous loads that are imposed upon the fuselage structure, it must have maximum strength and, as with all of the parts of an aircraft, it must also have minimum weight. Stressed-skin-type fuselages are used in modern transport aircraft.

The main limitation of a stressed-skin structure is thatitcannot tolerate any dents or deformation in its surface. We have all seen this characteristic demonstrated with a thin aluminium beverage can. When the can is free of dents, it will withstand a great amount of force applied to its ends, but if we put only a slight dent in its side, it can be crushed very easily from top orbottom.

Most fuselages of transport aircraft are semi-monocoque structures. It is shaped by a number of frames and stringers that keep each other at the correct distance (see Figure 3.1).The skin panel is attached to these stringers by means of rivets or glue. Sheets of different thicknesses are used. The big advantage of these fuselage constructions is that an area is created that is not blocked anywhere by extra means of strengthening. Extra means of strengtheningareonly necessary at those places where large forces are transmitted. This is the case at places where wings, tail surfaces, engines and landing gears are attached to the fuselage. In addition, this occurs at those places where weak spots are created in the construction as a result of missing frames and stringers, as at doors, windows and hatches. Special strengthening is used at those places in the fuselage where the area is used for stowing the retracted landing gears.

The fuselage is made of separate assemblies which are riveted together.

The cabin floor structure divides the fuselage into two areas, the main deck and the lower deck. The main deck includes the cockpit and the cabin. The lowerdeck normally includes the avionics compartments, the landing gear bays and the fwd, aft and bulk cargo compartments. Support struts and crossbeams support the cabin floor structure.

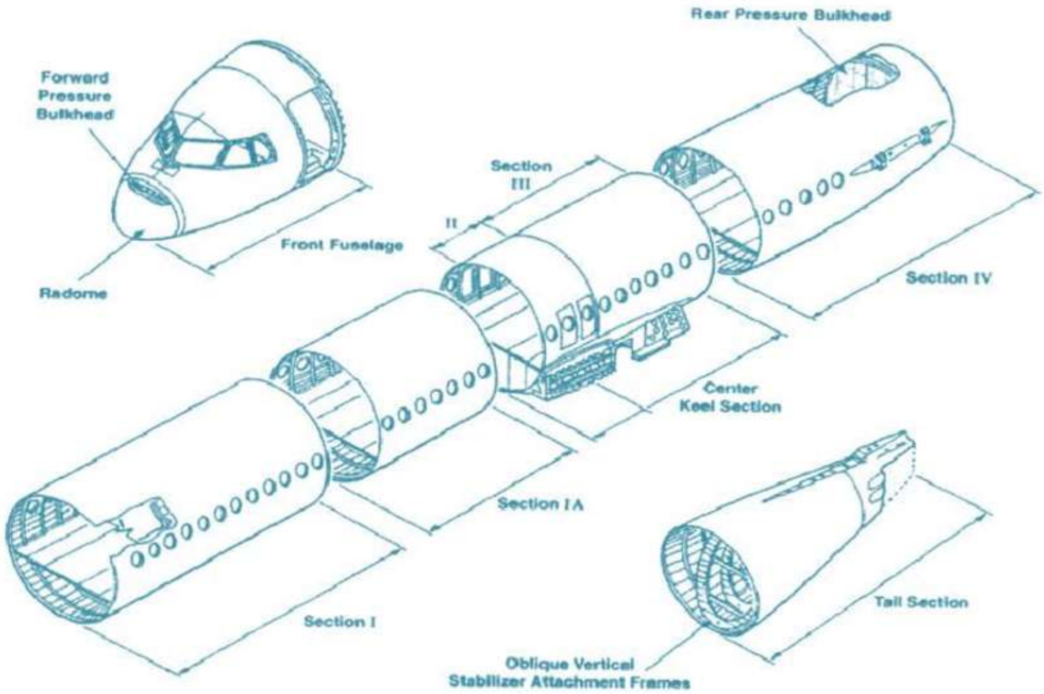


Fig. 3.1: Typical Sections of a Fuselage (Fokker 100)

Primary Structure

The frames and the forward and aft pressure bulkheads are primary structural components of the fuselage. Each frame is a „Z" or other sectioned circumferential member carrying pressure loads in hoop tension. The frames are generally spaced at approximately twenty-inch intervals along the fuselage. The bulkheads consist of webs that fit the sectional contours of the aeroplane. These bulkheads are reinforced by beams attached to thewebs. The floor beams are primary structural components of the fuselage. Each floor beam carries a tension load and is attached at its ends to a frame.The stringers are primary structural members. They are hat- or „Z"-section which extend longitudinally along the fuselage. Other longitudinal members considered primary are the crease beams and the keel beams. Skin and reinforcing structure around openingis primary. Basic structure associated with the wheel wells is primary.

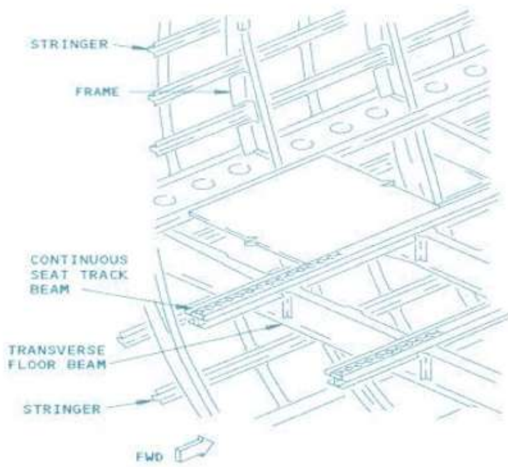


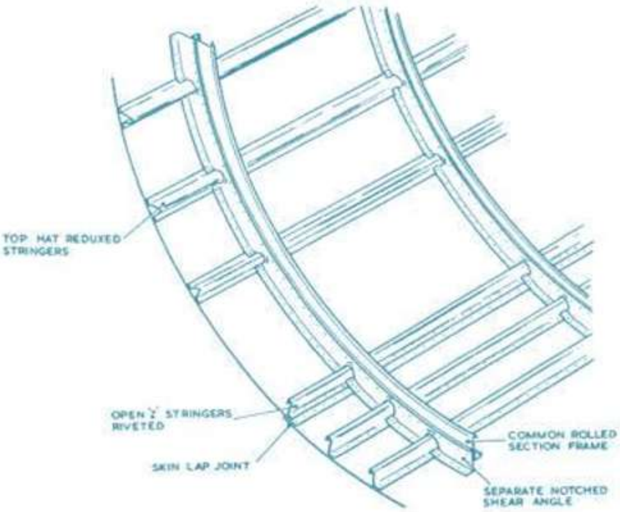
Fig. 3.2: Fuselage primary structure elements Stringers and Other Longitudinal Members

Stringers are multiple failsafe (as a resultof their multiplicity) longitudinal members designed to provide stiffness to the skin and help to provide the longitudinal strength to the fuselage.

Intercostals (or webs) are short longitudinal members which may span between only two adjacent frames, to provide some local structural reinforcement at or around windows and doors for example.
A horizontal beam extends along each side of the fuselage level with the top of the floor. These beams are known as the crease beams because they are attached to the fuselage skin at the "crease" formed by the intersection between the upper and lower lobes of the fuselagecross-section.

Fig. 3.3: Fuselage stringers, skin and frame

The keel beams comprise the beam between the mainlanding gearwheel wells and the beam which passes beneath the centre wing box. The beam between the wheel wells is a reinforced box structure which carries pressurization loads originating on the sealed floor structure across the wheel well area. Both of the beams carry the bending loads acting along the lower fuselage across the cavities for the centre wing box and the wheel well. Longerons areany longitudinal structural component of an aircraft's



fuselage which are larger than the stringers.

Fig. 3.4: Stringers, frames and skin on the BAe 146 Doublers and Waffles

Doublersand waffles are sometimes bonded to the inside of fuselage skins, or integrally machined, or the skin between the doubler/waffle is thinned by acid etching. Their purpose is to stop or retard the growth of a crack that may begintopropagate in the skin. This „tear stopper" function provides some fail safeelement to the fuselageskin.

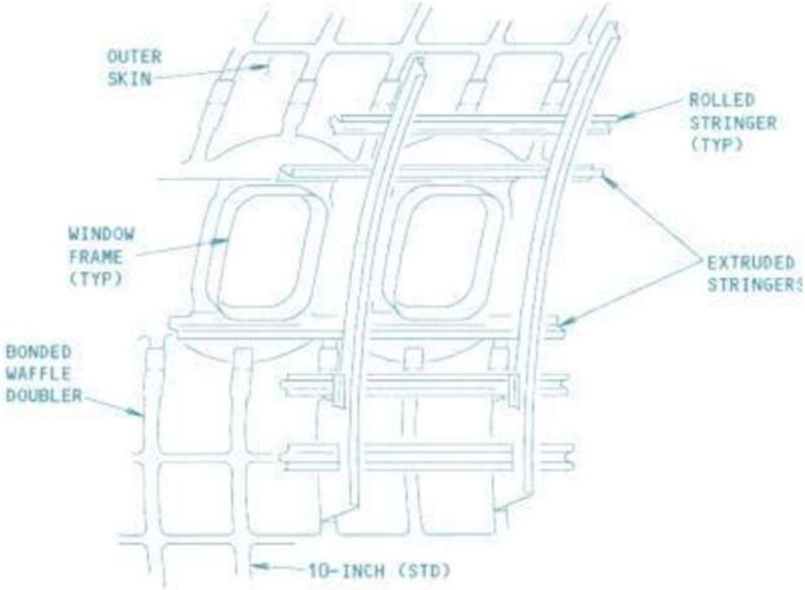


Fig. 3.5: A bonded waffle doubler on a Boeing 737 fuselage structure

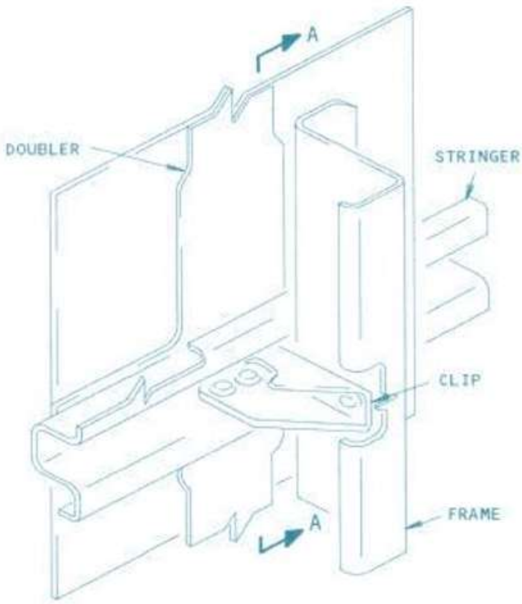


Fig. 3.6: A bonded doubler on a Boeing 737 fuselage structure Blowout panels

Blowout panels are provided wherever there is a danger of an excessive pressure differential across a structural membrane causing structural damage. They are, for example, provided in the cabin floors should there be a sudden decompression in a cargo hold (due to a cargo hold door coming open during flight for example. The blowout panels „blow out" in such a situation to release the excess pressure in the cabin and thus safeguard the structural integrity of the floor (which may also hold the flight control cables).Blowout panels can also be found on cockpit doors and other doors to prevent a differential pressure causing the door to be jammed or damaged. The fitting and maintenance of blowout panels and their seals is critical, and procedures and figures such as retaining bolt torque loading must be applied in strict accordance with the applicableAMM.

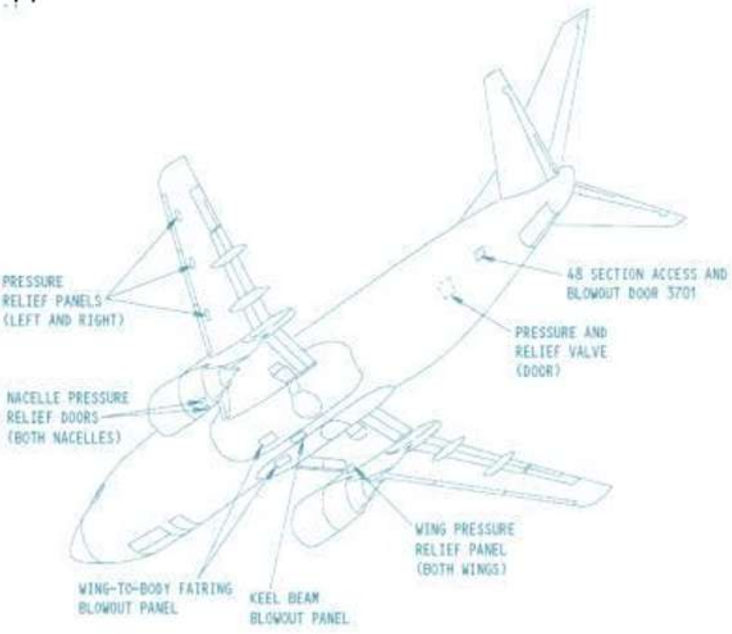


Fig. 3.7: External blowout panels on the Boeing737

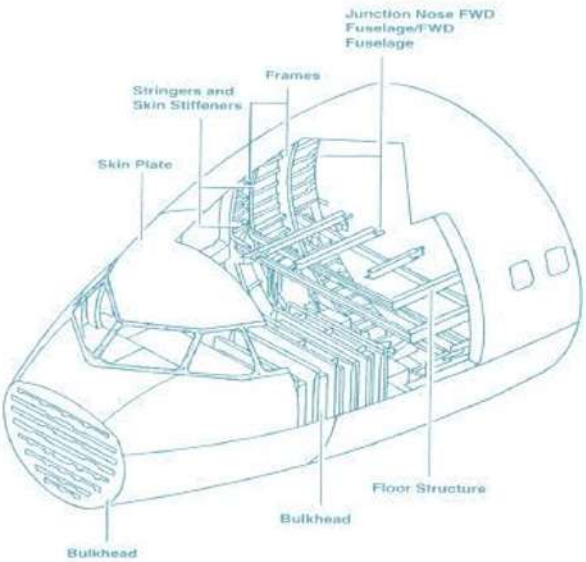


Fig. 3.8: Cockpit section

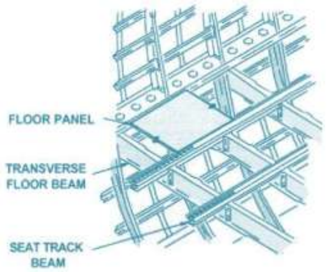


Fig. 3.9: Floor section detail

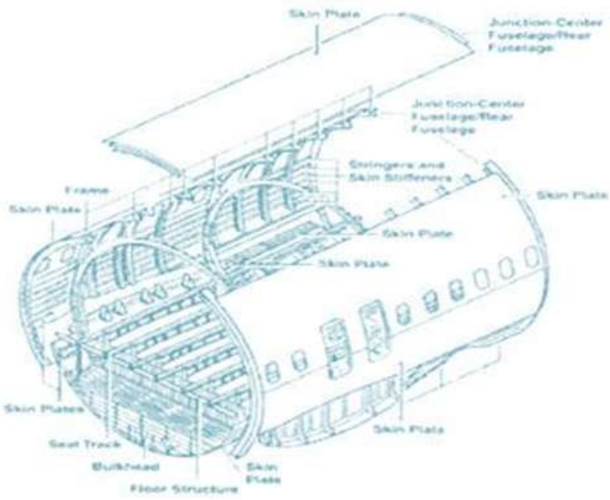


Fig. 3.10: Mid Fuselage

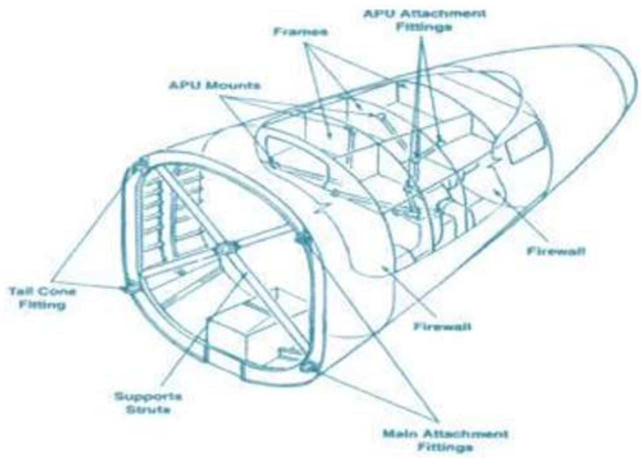
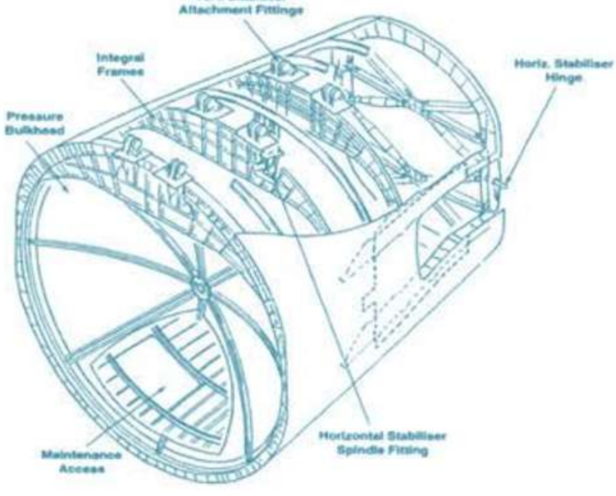


Fig. 3.11: Aft Fuselage

Fig. 3.12: Aft Fuselage Stringer and Skin Materials and Shapes

The following table provides the materials and stringer sections used by some common transport category aircraft.



Aircraft	Radius R_{max} (inches)	$T_{min.}$ (inches)	Material Skin/Str.	Str. Spacing (inches)	Str. Shape	Frame Depth/ Spacing (inches)
B707	74*	0.04	2024-T3/7075-T6	9		3.8/20
B727	74*	0.04	2024-T3/7075-T6			3.8/20
B737	74*	0.036	2024-T3/7075-T6			3.8/20
B757	74*	0.04				3.8/20
B747	128*	0.071	2024-T3/7075-T6	7.5–9.5		6.3/20
B767	99*					/22
1649	69.6	0.032				4.4/21.3
L-188	68	0.04	2024-T3/7075-T6	6		3.75/19
C-130	85	0.032	2024-T3/7075-T6	—	Longerons	
C-141	85	0.053	7079-T6/7075-T6	6		3/20
C-5	143*	0.045	7079-T6/7075-T6	7.5		8/20
L-1011	117.5	0.075	2024-T3/7075-T6	9		3–6/20
DC-8	73.5*	0.05	2024-T6/7075-T6	7.2		3.5/20
DC-9	65.8*		2014-T6/7075-T6	7		/19
DC-10	118.5	0.071	2024-T3/7075-T6	6.5–8		4.5–5.5/20
YC-15	108	0.05	2024-T3/7075-T76			6/24
CV880	69*	0.067	2024-T3/7075-T6	6–10		4/19
CV990	69*	0.067	2024-T3/7075-T6			4/19
A300	111	0.063				/20
A310	111	0.063				/20
A320	77*					/20
BAC111	77	0.060	2024-T3/			/20
Trident	72.75	0.048	2014-T/2014-T	6.5		/20
Concord	56.5*	0.055	RR58/RR58			/21.5

The following table provides some of the advantages and disadvantages of the aluminium alloys quoted in the table above.

Material	Recommended Application
2024-T3, T42, T351, T81	Use for high strength tension application; has best fracture toughness and slow crack growth rate and good fatigue life. -T42 has lower strength than -T3. Thick plate has low short transverse properties and low stress corrosion resistance. Use -T81 for high temperature applications.
2224-T3 2324-T3	8% improvement strength over 2024-T3; fatigue and toughness better than 2024-T3.
7075-T6, T651, T 7351	Has higher strength than 2024, lower fracture toughness, use for tension applications where fatigue is not critical. Thick plate has low short transverse properties and low stress corrosion resistance (-T6). -T7351 has excellent stress corrosion resistance and better fracture toughness.
7079-T6	Similar to 7075 but has better thick section (> 3 in) properties than 7075. Fracture toughness, between 7075 and 2024. Thick plate has low stress corrosion resistance.
7150-T6	11% improvement strength over 7075-T6. Fatigue and toughness better than 7075-T6.
7178-T6, T651	Use for compression application. Has higher strength than 7075, lower fracture toughness and fatigue life.
Aluminum-Lithium	Compared to conventional aluminum alloys: 10% lighter, 10% stiffer, and superior fatigue performance.
PM Aluminum	Compared to conventional aluminum alloys: Higher strength, good fatigue life, good toughness, higher temperature capability and superior corrosion resistance.

Pressure Sealing

To make it possible to use pressurized cabins, the front and rear of the fuselage construction and the landing gear areas are closed off by a pressure bulkhead.The cockpit, the cabin, the avionics compartment and the cargo compartments are normally pressurized. The radome, the wing centre box, the landing gear bays, the belly fairing and the cone/rear fuselage are normally notpressurized.
It would be impractical to build the pressure vessel of an aircraft that is airtight, as pressurization is accomplished by flowing more air into the cabin than is needed and allowing the excess air to leak out. There are two types of leakage in an aircraft pressure vessel; controlled and uncontrolled. The uncontrolled leakage is that in which air escapes around door and window seals, control cables and other openings in the sealed portion of the structure, and the controlled leakage through the outflow valve and the safety valve. This controlled leakage is far more than the uncontrolled and it determines the amount of pressure in the cabin. Pressurization control systems can be of the pneumatic or electronic type, with the electronic type incorporating electrically controlled outflowvalves.

Wing-to-Body Fairings

The wing-to-body fairings serve as aerodynamic fairings, are made of aluminium alloy or a honeycomb composite lay-up, and are secondary structure.
The wing-to-body fairings are attached to the wing surface and the fuselage skin. A cut-out in the fairing allow for the passage of the main landing gear. Othercut-outswithpanelsordoorsareprovidedasaccessto equipment within thefairing.

A blowout panel on each wing-to-body lower fairing protects the aeroplane skin in that area from excessive pressure build-up. Each panel is held by a hinge and secured by shear rivets, with an energy absorbing retaining strap to limit panel opening. An aerodynamic deflector is included to hold panel open and prevent uncontrolled buffeting, if the panelopens.

Fuselage Fire Zones

For the purposes of fire protection and extinguishing, all compartments of an aeroplane are classified A, B, C or E, asfollows:

- Class A - Visual detection of smoke and have an accessible in-flight fire extinguisheravailable.
- Class B - There is a separate approved smoke detector or fire detector system to give warning atthe pilot or flight engineer station. Thereissufficient access in flight to enable a crewmember to effectively reach any part of the compartment with the contents of a hand fire extinguisher. Whenaccess provisions are being used, no hazardous quantity of smoke, flames, or suppression agent can enter any compartment occupied by the crew or passengers. There are means to control ventilation and drafts within thecompartment

- Class C - here is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station. There is an approved built-in fire extinguishing or suppression system controllable from the flight deck. There are means toexclude hazardous quantities of smoke, flames,or suppression agent from any compartment occupied by the crew or passengers. There are means to control ventilation and drafts within the compartment so that the suppression agent used can control any fire that may start within the compartment.

- Class D - Classification removed in1998.

- Class E - Cargo-only aircraft. There is a separate approved smoke or fire detector system to give warning at the pilot or flight engineer station. There are means to shut off the ventilating airflow to, or within, the compartment, and the controls for these means are accessible to the flight crew in the crew compartment. There are means to exclude hazardous quantities of smoke, flames, or noxious gasses from the flight crew compartment. The required crew emergency exits are accessible under any cargo loadingcondition.

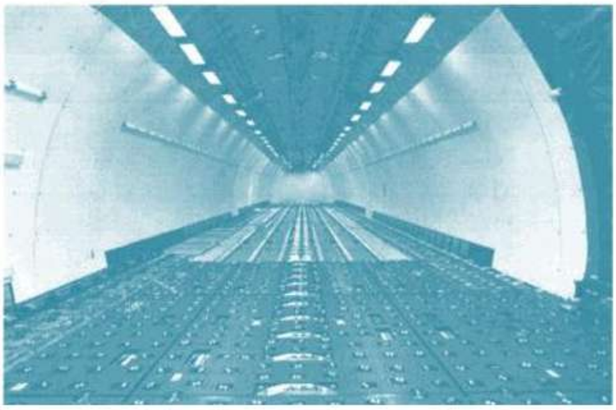
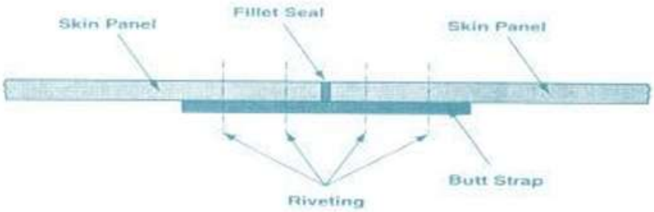


Fig. 3.13: Fire protection in a typical cargo compartment. This main deck cargo compartment illustrates two types of fire protection: liners on the sidewalls and smoke detectors running overhead.

Design Features for Pressurized Airframes Butt Joint

The construction of this type of joint is such that a forward skin panel and aft skin panel are joined together by an internal butt strap. When this joint is assembled, there is a gap between the forward skin panel and aft skin panel. This gap is filled with what is commonly referred to as a fillet seal. This type of joint allows for the expansion and contraction of the fuselage and at the same time providing adequate pressurization sealing. This kind of connection is used to join the fuselage sectionstogether.



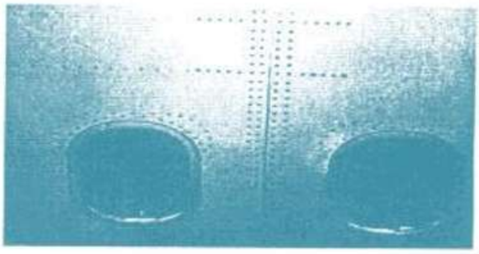
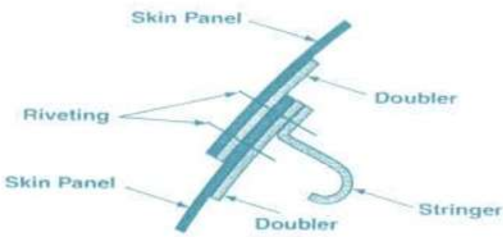


Fig. 3.14: Example of Butt Joint

Lap Joint

The construction of this type of joint is such that the upper skin panel overlaps the lower skin panel. During the assembly of the joint the upper skin and lower skin area of contact has a faying surface seal applied to it. The joint is then made while the sealant is still wet. This kind of connection is used to join the skin panels together at the longitudinaledge.



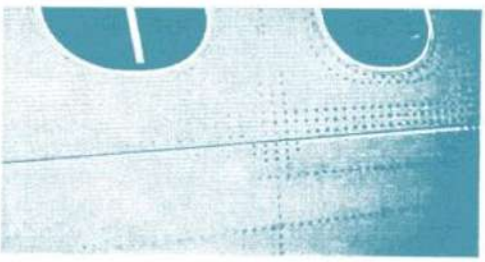


Fig. 3.15: Examples of Lap Joint

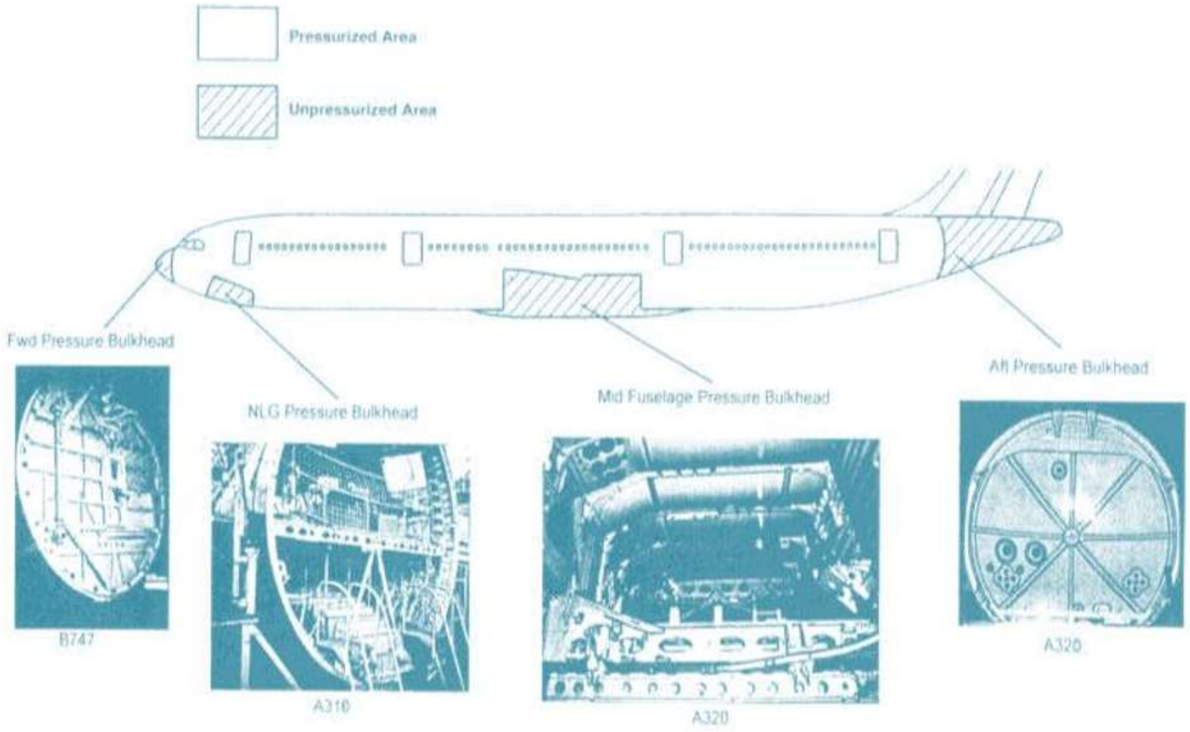


Figure 3.16: Typical pressurized bulkhead arrangement

Nose Radome

The nose radome extends forward from the forward pressure bulkhead. The two main functions of the radomeare to serve as a fairing and to house the weather radar antenna and the glide slope antenna directorbar.

The radomeis a cone-shaped structure of fibreglassand is hinged at two places, usually to the top side of the forward bulkhead. Further attachment of the radomeis by fasteners which screw into clips on the bulkhead. In theopenposition, the radomeis supported byrods.

The weather radar antenna is cantilevered from the forward bulkhead. The nose of the radomeis equipped with erosion protection and a layer of conductive spray paint provides static dissipation, but is not enough to interfere with the operation of the weather radar or any other antenna which may be mounted inside the radome. The radome is provided with lightning diverter strips on the exterior surface.

Fig. 3.17: Boeing 737 Radome showing clearly the lightning diverter strips

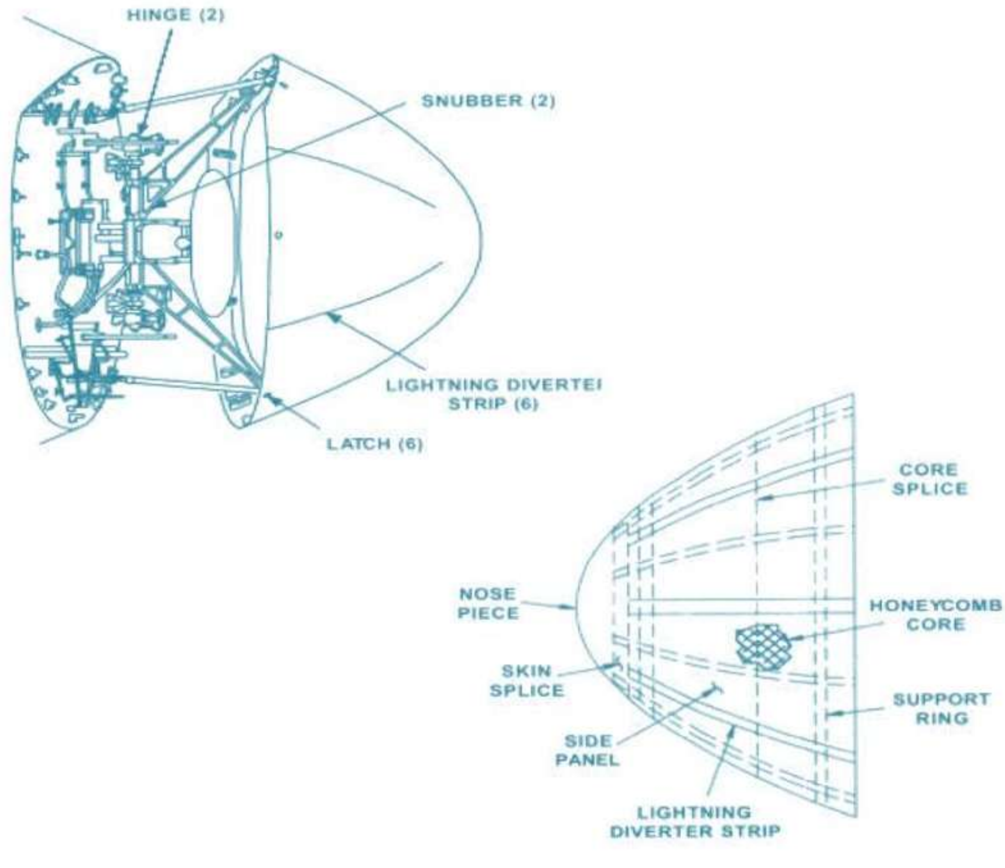
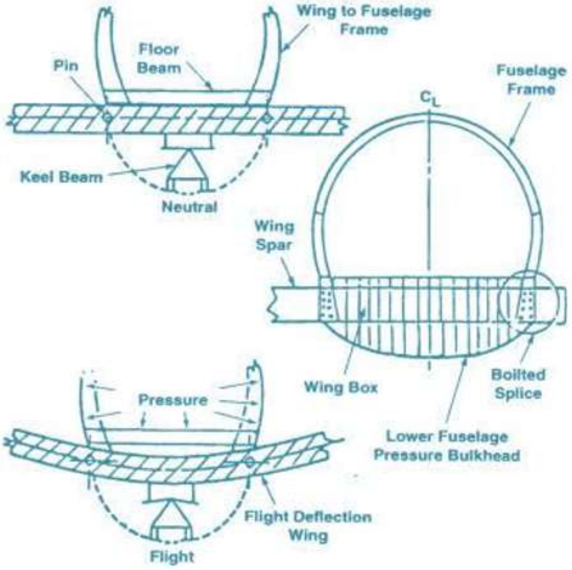


Figure: Radome details Wing to Fuselage Attachment

One method that can be used to support the wing is a simple four-pin attachment method. However, because of the thrust and drag loads (fore and aft loading) this simple four-pin design may not be sufficient for big airliners. Another way of overcoming the fore and aft loads imposed by the wing is to attach the fuselage frames to the wing spars, mainly used for bigger aircraft. This is known as integral



wing attachment.

Fig. 3.19: Wing to Fuselage Attachment

Bolted Wing Attachment

This kind of attachment is mainly used in smaller aeroplanes. The following description belongs to the Saab 2000.There are eight wing-to-fuselage attachment fittings on the mainframe. They transmit the load to the fuselage during flight for multiple load path redundancy. The aluminium attach fittings are put in position on the front and the rear spar to engage the related fuselage attach fittings.

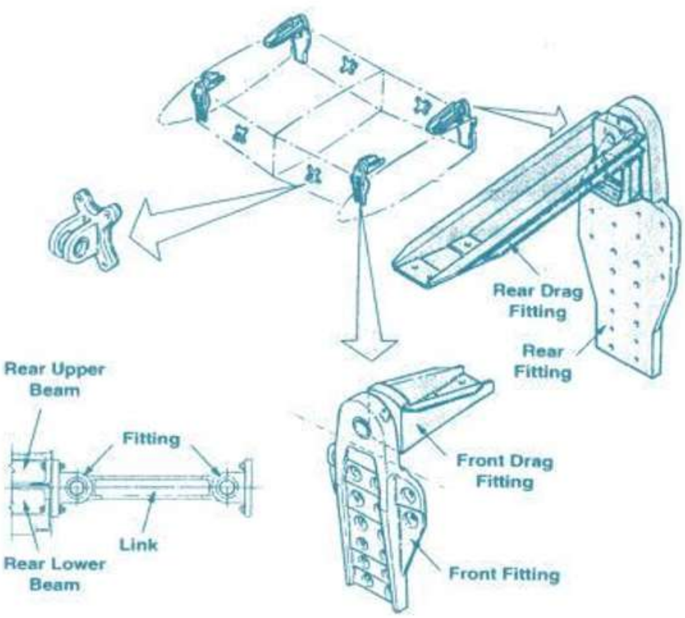


Fig. 3.20: Example of Centre Wing Box Attachment (Saab 2000)

Integral Wing Attachment

Most big aeroplanes are designed with this kind of wing attachment. There are also some smaller aeroplanes like the Embraer 145, which also use this kind ofdesign.The following description is of airbusaeroplanes.

The wing centrebox structure extends across the width of the fuselage and is a continuation of the wing cantilever box. The wing box is usually attached to two primary frames of the fuselage; they are also part of the wing centre-box structure. These frames are normally made of aluminium alloy and of integral kind (machine milled). The wing box distributes the wing loads in the fuselage and can form an optional integral fueltank.

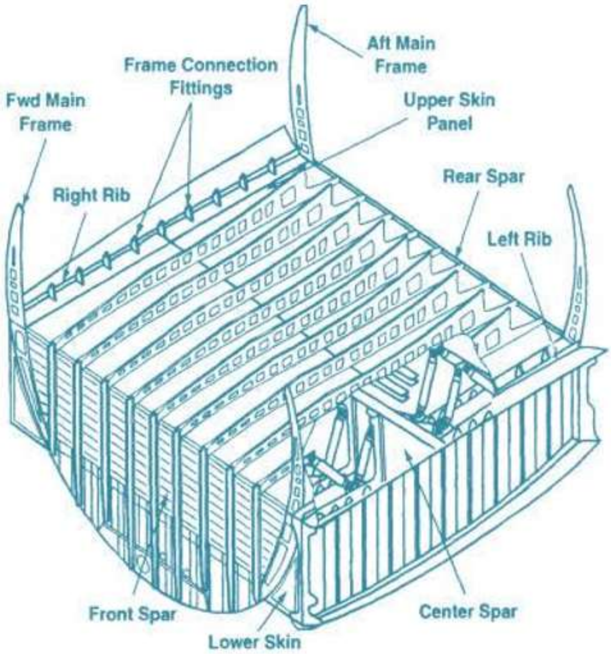


Fig. 3.21: Example of Centre Wing Box Attachment (Airbus A330)

Landing Gear Attachment to the Fuselage

The landing gear loads are the largest loads on the aircraft. For this reason, the transfer of these loads to the fuselage shell requires extensive localreinforcement.
The wing spars along with additional structural members, support and attach the main landing gear to the wings on larger transport aircraft. The retractable landing gear system is required to move, the upper shock strut is supported by trunnion fittings. These are shafts that fit to the shock strutand pass through fittings, which are bolted to thefuselage.

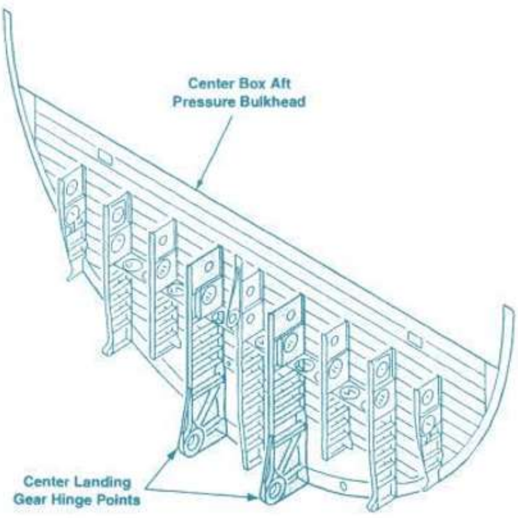


Fig. 3.22: Example of Fuselage Landing Gear Attachment (Airbus A340-200)

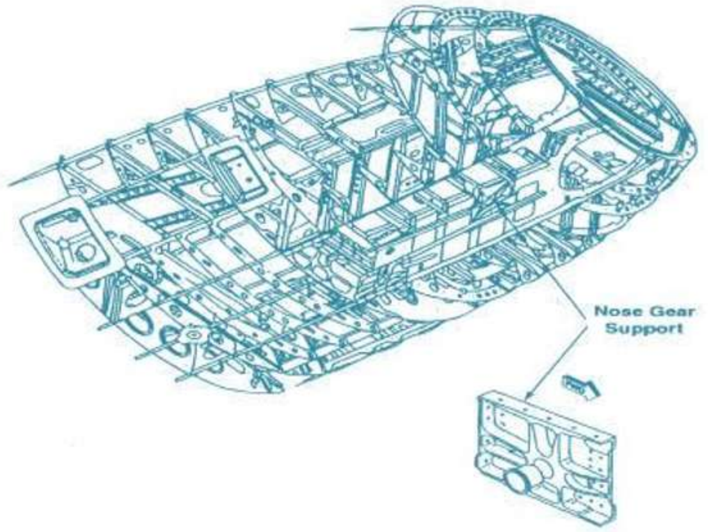


Fig. 3.23: Example of Nose Landing Gear Support (Saab 2000)

Horizontal Stabilizer to Fuselage Attachment

Modern high-speed transport category aeroplaneshave adopted the use of an adjustable stabilizer. The aft portion of the stabilizer incorporates hinge assembles that are attached to the fuselage structure. The forward section of the stabilizer has a drive mechanism, which changes the pitch of the stabilizer. Figure 3.24 shows the attachment fittings at the fuselage.

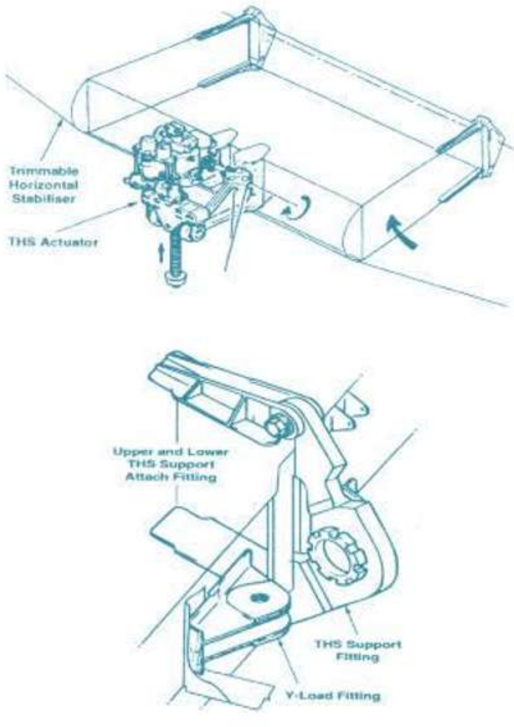


Fig. 3.24: Example of Horizontal Stabilizer Attachment Vertical Stabilizer to Fuselage Attachment
One method of construction is to attach the vertical stabilizer fore and aft spars to the fuselage using fittings. These fittings may be permanent or allow for the vertical stabilizer to beremoved.

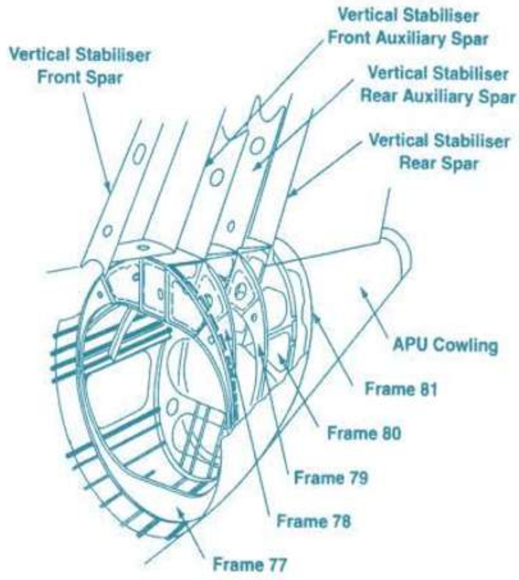


Fig. 3.25: Vertical Stabilizer Attachment

Another method used is to make the vertical stabilizer an integral part of the aft fuselage. The vertical stabilizer spars enter the fuselage and become part of the aft fuselage frames. The skin panels of the vertical stabilizer tie directly onto the skin panels of thefuselage.

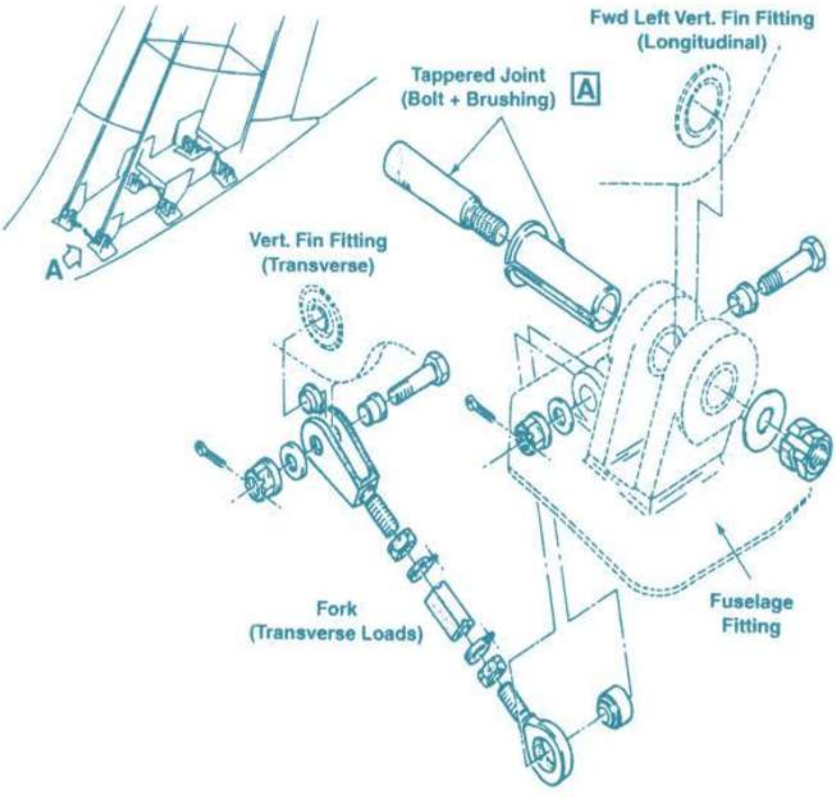


Fig. 3.26: Vertical Stabilizer Attachment

Doors

There are a number of different kinds of doors in an aeroplane. When talking about doors that are part of the pressurized cabin, the following are included:

- Cabindoors;
- Cargo compartmentdoors;
- Access doors to equipment compartments that are part of the pressurizedcabin.

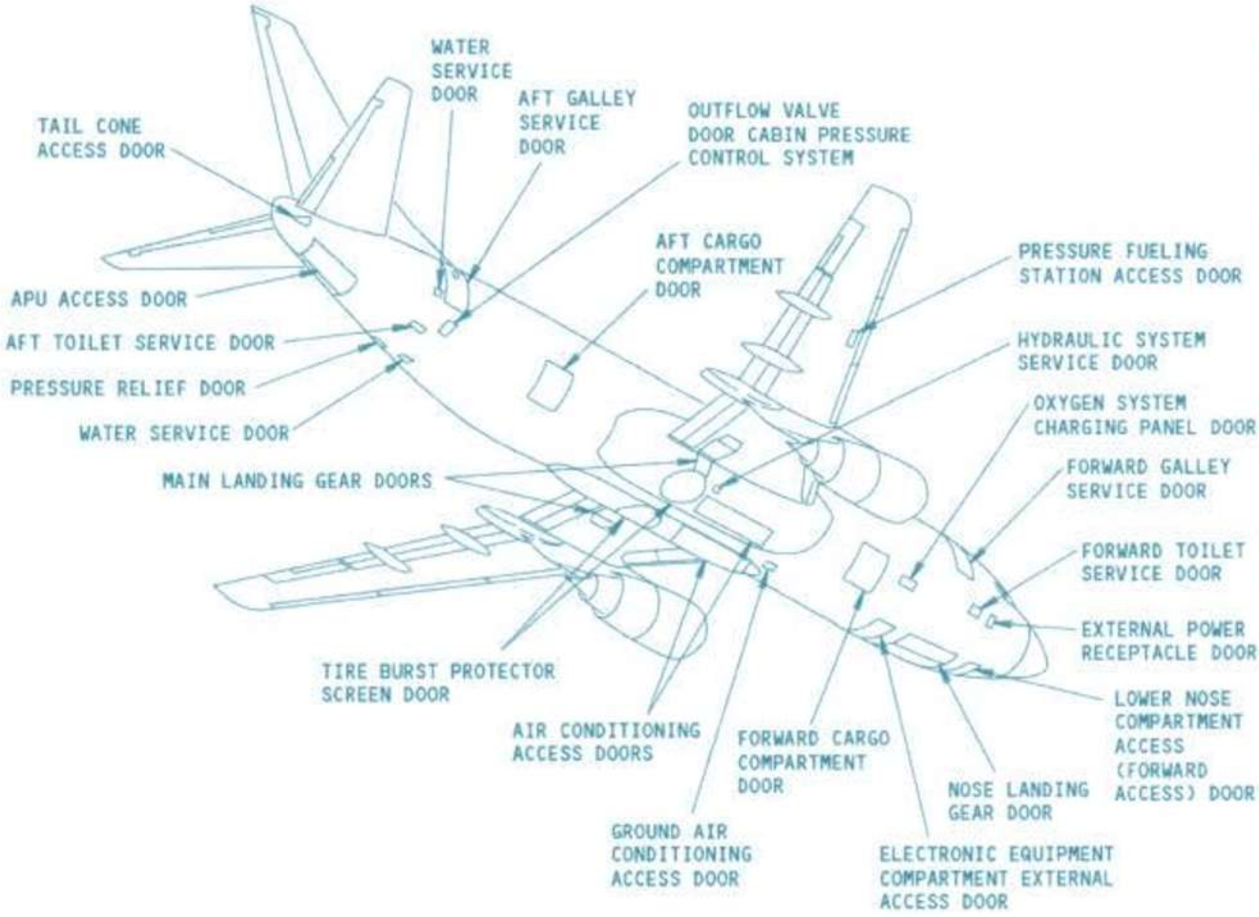


Fig. 3.27: Door locations on the Boeing 737 (fromunderside)

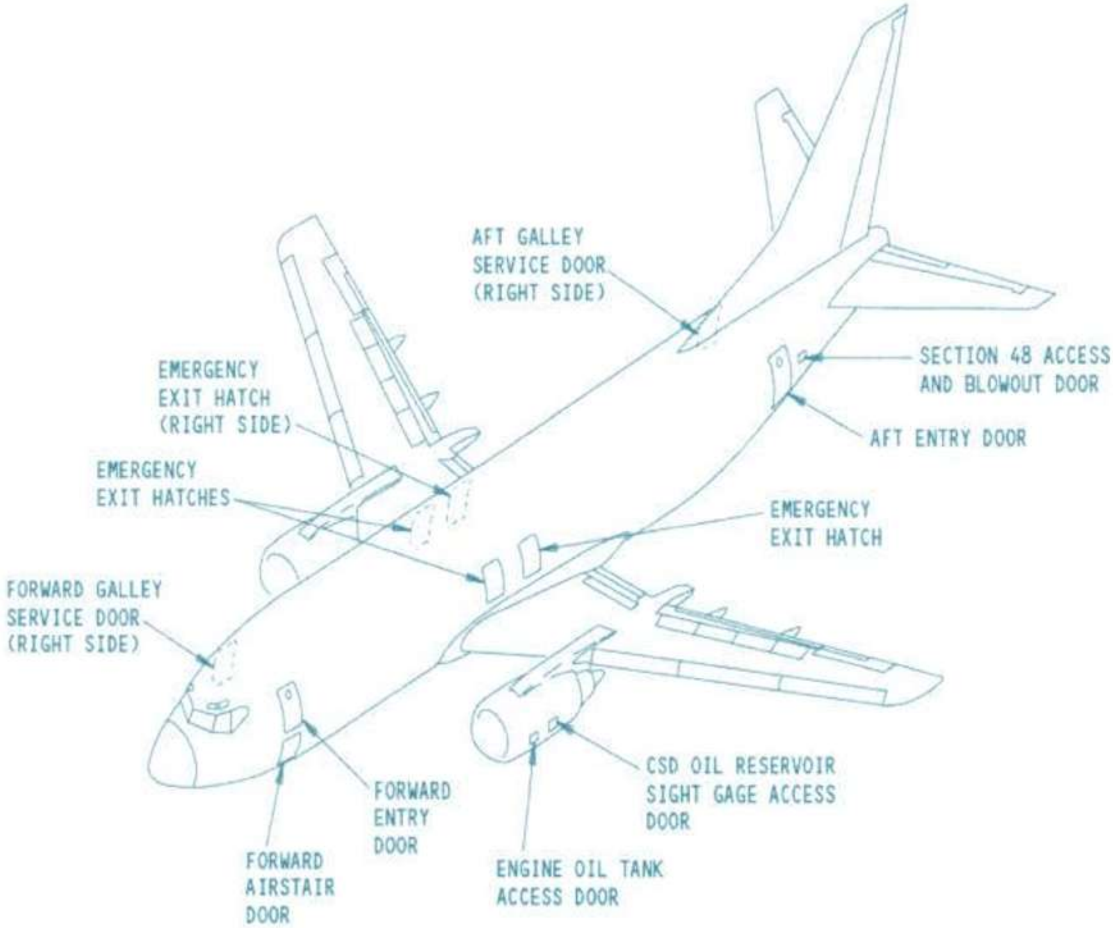


Fig. 3.28: Door locations on the Boeing 737 (fromupper)

These doors should meet the following requirements:

- The doors must be opened and closed from the inside and the outside;
- Instructionsforclosingandopeningthemmustbeeasytoreadandsimpletounderstand;
- There must be an indication on the cockpit as well as a mechanical indication near the door itself that the door is properly closed.

•Inaddition,cargodoorsmustbeconstructedinsuchawaythat,inclosedposition,theyarepartofthetotalstrengthofthe fuselage construction.

The doors in the pressurized cabin can be divided into two groups :

- Plug-type doors
- Non-plug-type doors.

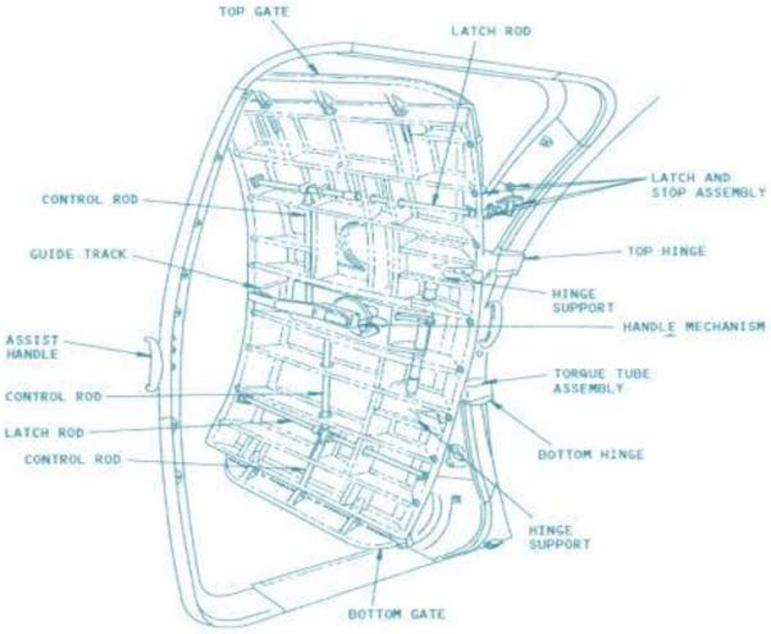


Fig. 3.29: Typical passenger door features of the Boeing737

Door Safety

Proximity sensors attached to the door for „Door Closed, 'Door Locked" and 'Girt Bar Activated" give an indication to the flight crew at time any one of these conditions is not met.

Door Seals

Usually a silicon rubber seal is installed around the door. When the door is closed, the seal is pushed against the door frame of the fuselage. The seal usually has holes at equal intervals, which let the cabin air to the seal inside and vice versa. When the door is closed and the cabin is pressurized, the door seals inflate because of the pressure difference between inside andoutside.

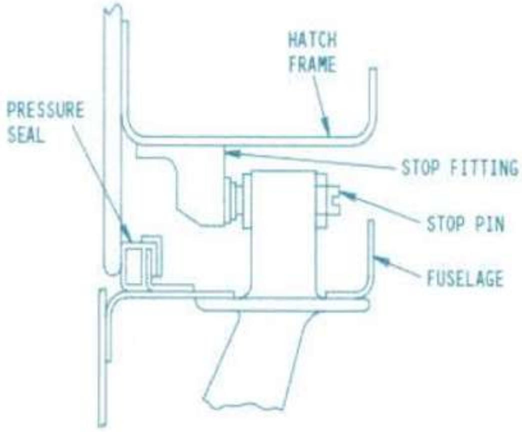
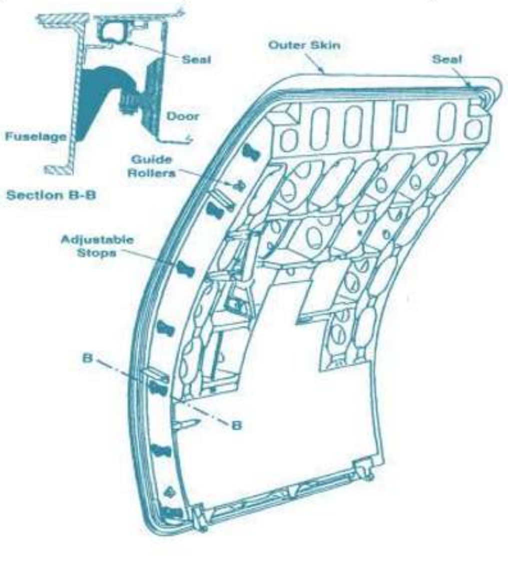


Fig. 3.30: Example of Door Seal (Boeing)



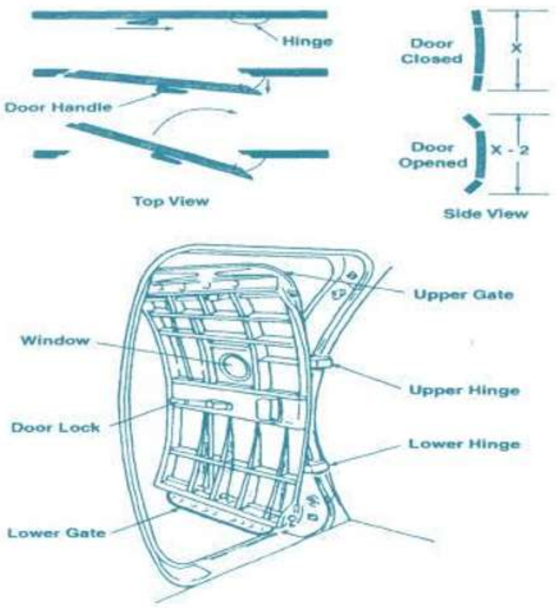


Fig. 3.31: Example of Door Seal (Airbus) Plug-type Doors

Doors that close the fuselage from the inside are called plug-type doors. Plug-type doors are a little bigger than the dimensions of the doorjamb in which they fit. For this reason, the door in open position is sometimes kept inside the pressurized cabin. Another possibility is that the door has what is known as gates. They make the door smaller while opening or closing so that it can be brought outside the pressurized cabin when it is in open position.

The advantages of a plug-type door are:

- The total load is distributed over the whole doorjamb;
- The doors close tighter as the pressure increases.

Fig. 3.32: Plug-Type Door with Gates (Boeing)

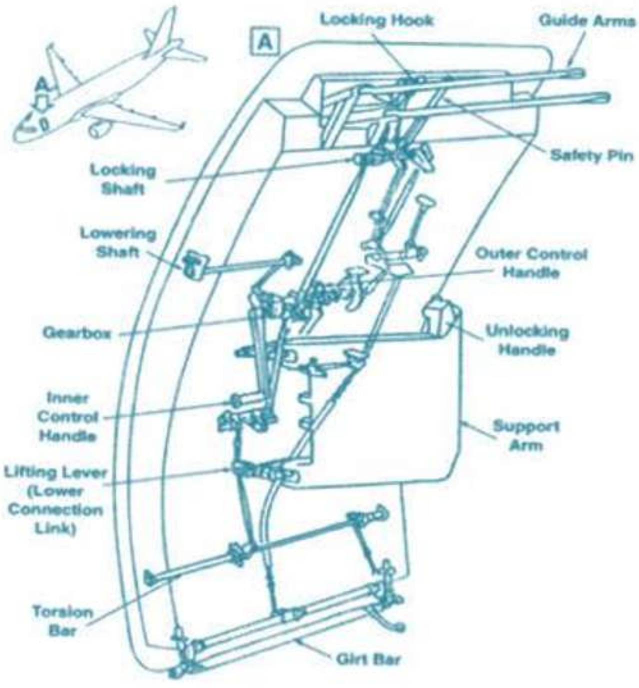


Fig. 3.33: Other plug-type door (passenger cabin)

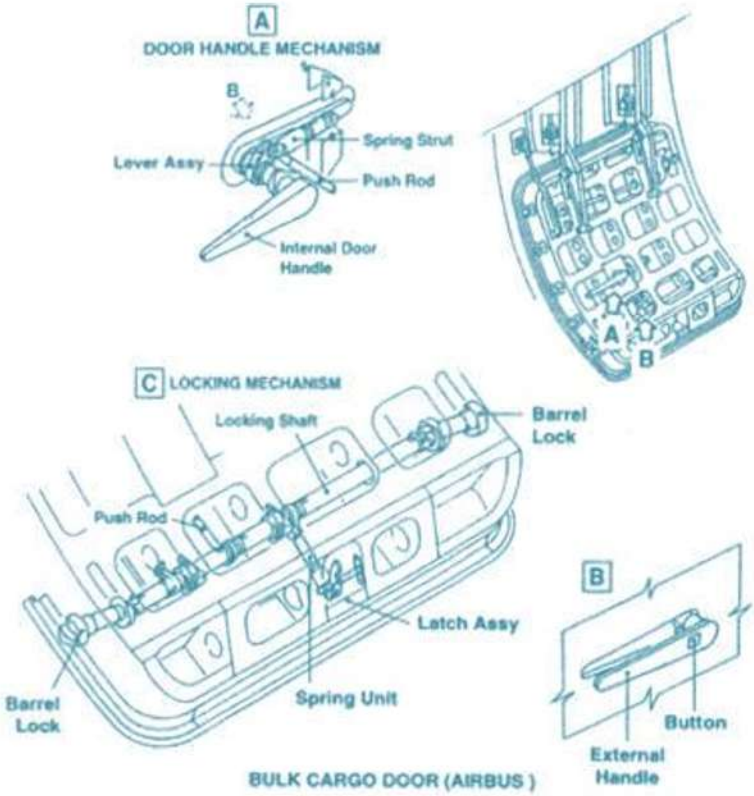


Fig. 3.34: Other plug-type door (cargo door) Non-Plug-Type Doors

Doors that close from the outside are called non-plug-type doors. The hinges and the closing mechanism of this type of door must carry all the forces that are caused by pressure differences. For the above mentioned reasons, the large cargo compartment doors have heavy locking mechanisms. These locks are at the exact locations where the frames in the fuselage and the cargo door are broken. The lock forms the

connection between these frames when the door is closed (Figure 3.34). In this way, non-plug-type doors add to the total strength of the fuselage construction.

Operation and Locking

This kind of door is mainly used for cargo compartments. Depending on the dimensions of the doors, they are equipped with counterbalance mechanism for manual operation, electrical motor actuation or hydraulic actuation.

The locking hooks keep each cargo door in theclosed position. To show this condition there are indication windows in the access panel of the cargo door. The green mark shows that the safety mechanism locks each locking unit in itslatched position. The red marks show that the locking unitsare not locked and satisfactory. When the cargo doors are locked, the door seal makes the related cargo compartment pressure-tight. To balance the difference in pressure on the ground and in the cargo compartments, there is a vent door in each cargo door. This spring-loaded vent door opens inboard and remains in this position until the cargo door is correctly locked.

Drift Pins

The drift pin mechanism is installed in the middle of the cargo door. It decreases the contour off- set between the fuselage and the door. The drift pin mechanism includes the linkage assembly and the drift pins with the related bellcranksand the connection links. The linkage assembly transmits the movement of the safety shaft to the bellcranks. They operate the connection links which retract or extent the drift pins. When the cargo door is correctly locked, the extended drift pins engage with the pockets of the fuselage frame.

Door Seals

The door seal made usually of silicone rubber integrated with fabric is a round hose-type seal with inflation holes. The door seal is installed in the retainers so that the inflation holes show to the inner side of the cargo compartment. When the cargo door is in the closed position, the door seal comes into contact with the fuselage profile. Due to the higher internal pressure of the cargo compartment during the flight, the door seal is inflated via the inflation holes so that the cargo compartment is sealedair-tight.

Door Indication and Warning

Electrical switches (micro switches or proximity switches) of the door warning system monitor the closed and locked condition of the cargo door. They send a signal to the cockpit indication system when a cargo door is not locked. Then an indication warns the pilots about the unlocked condition of thedoor.

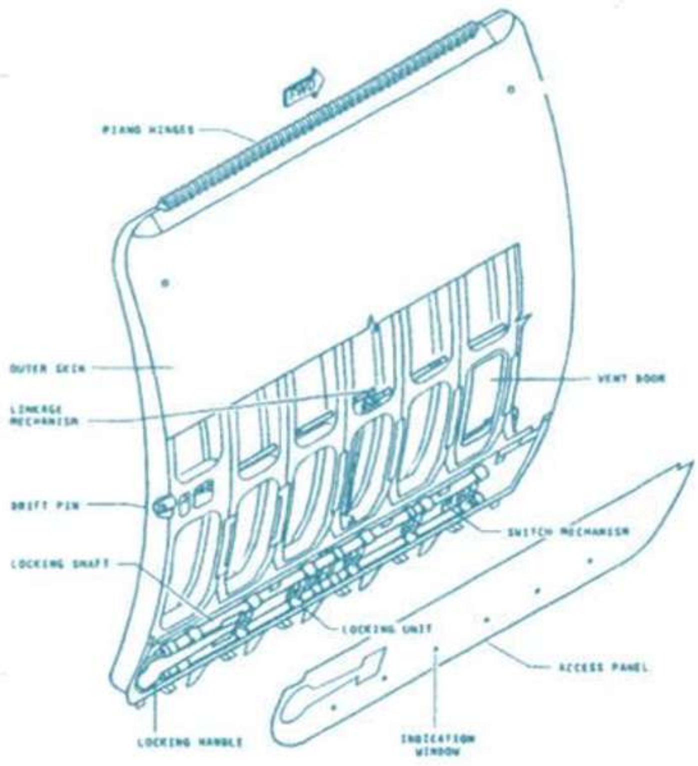


Fig. 3.35: Example of Non-plug-Type Door (Airbus A321)

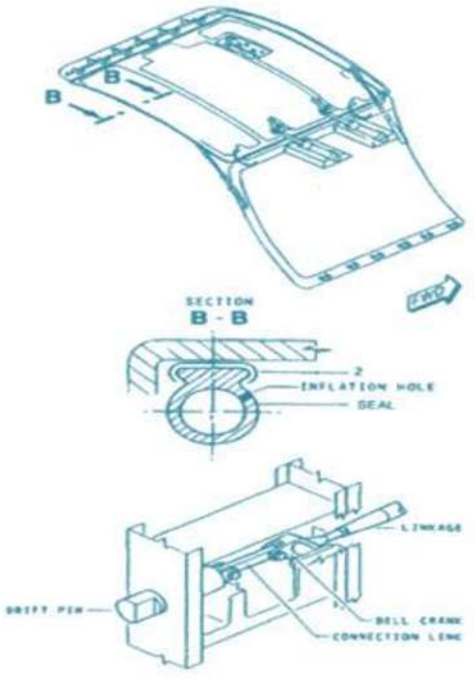


Fig. 3.36. Example of Non-plug-Type Door (Airbus A321)

Pressure Door Warning System

The door warning system is an electrical circuit which gives the crew a visual warning when a door is open or not latched.

These doors are included in the door warningsystem:

- The forward and aft entrydoors
- The forward and aft galley servicedoors
- The forward and aft cargo compartmentdoors
- The lower nose compartment access (forward access) door
- The forward airstair door (ifinstalled)
- Tire burst protector screens (ifinstalled)
- The electronic equipment compartment external access door.

The door warning system has these components:

- A door warning module on the overhead panel in the control cabin The door warning module uses lights to warn the crew that doorsare
- open orunlocked
- A miscellaneous switching module in the electronic equipmentcompartment
- Door warning sensors on thedoors.

A MASTER CAUTION light identifies a malfunction.

A door warning light identifies the applicable door. Each door warning light has two bulbs. One light continuously shows the words on the cap. One light illuminates the translucent cap as a warning. The illuminated colour is amber/opaque and the non-illuminated colour iswhite/gray.

Cockpit Windows

The flight deck windows are again divided into two kinds: windshield (front windows) and side windows. The requirements that flight deck windows must meet are significantly more severe than the requirements for cabin windows. This is understandable because the safety of the flight crew must be guaranteed under all circumstances. Windshields consist of layers of toughened glass and plastics.

There is a heating element between the outside window and the plastic layer (see Figure 3.37). The heating element is made of gold, tin oxide or indium oxide. The outside window has a stiff, hard, scratch resistant layer. The synthetic middle layer keeps splinters from being spread in the flight deck if the inside window breaks. Heating the windshields is necessarybecause:

- it increases the flexibility of thewindshields;
- it keeps the windows free ofice;
- it keeps the windows from foggingover.

The construction of the cockpit window consists of a glass pane laminated to each side of a polyvinyl butyral (vinyl) interlayer or core.

The inner glass pane is the thicker of the two and is the primary load carrying member. The vinylinterlayer,or core, acts as the "fail-safe" load carrying member and prevents the window from shattering if the inner paneshould break. The outer pane has no structural significance, but provides rigidity and a hard, scratch resistant surface. The different layers of the windows expand and contract at different rates during a change in temperature. Thiscan cause the layers to pull against each other at their interface with great force causing internal glass chipping and vinyl interlayer cracking, especially around the edges. To prevent this windows have thin layers of a slippery material around the edges, called parting material or slip planes, to allow the window layers to slide against each other during expansion and contraction. Some windows have soft material layers around the edges or across the whole window that will flex when the main structural layers pull against them. Uneven heating, expansion and shrinkage, careless installation, ultraviolet rays, pressure differences and seeping in of humidity via leaks in the window seals can all lead to delamination (the layers come loose), pealing, tearing or breaking. The side windows consist of layers of toughened glass and plastics just as the windshields. In windows that can be heated (against fogging), the heating element is between the inside window and the synthetic layer.

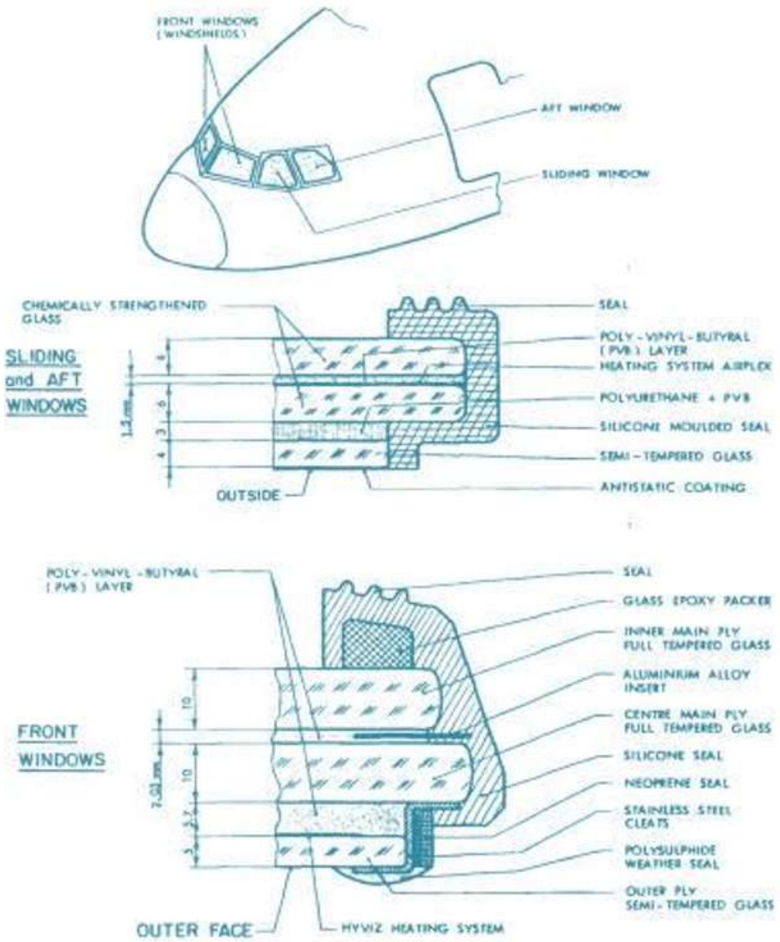


Fig. 3.37: Cockpit Windows (Airbus A310) Sliding Windows

The cockpit of most transport category aeroplanes include two sliding windows (left and right) installed at both sides. The flight crew can use these sliding windows as emergency exits.

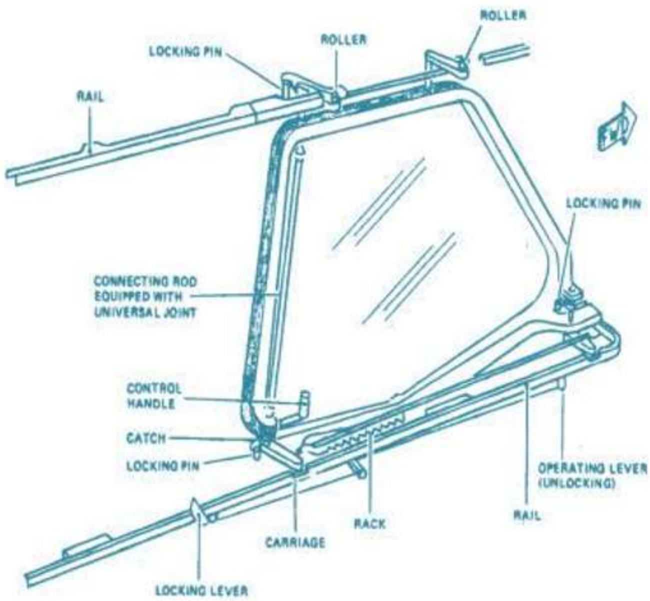


Fig. 3.38: Example of Sliding Window (Airbus)

Inspection and Maintenance of Cockpit Windows

The information given in the following paragraph is of a general nature and should be read in conjunction with the Maintenance Manuals and approved Maintenance Schedules for the aircraft concerned.

Damage

Panels should be inspected for defects and anysignsof damage such as delamination, chipping and cracking of glass layers. The following brief descriptive details are intended as a guide to this type of damage and other defects which may occur.

Delamination

This is a defect which can occur in laminated windscreens characterized by the separation of a glass layer from the vinyl interlayer. Delamination should not be confused with deliberate stress- relieving edge separation of panels which is sometimes employed. In such cases a parting medium is used, introducing a separation penetrating the edges of the panel assembly to a, distance of 6 mm to 25 mm (0-25 inch to 1 inch) and giving a yellowish or brownish appearance at theedges.

a) Defective delamination has characteristics that tend to divide it into the following main types and resulting from different types of stress at the glass/ vinyl interface.

I. Clear (or cloudy). Of the two types, delamination is apt to be clear. However cloudy delamination will result if moisture penetrates the delaminated area. In doubtful cases delamination can be confirmed by carrying out a reflection test by means of a flaw detector using a light beam. The beam is directed onto the surface of the windscreen and produces two sharply defined lines on a ground glass screen representing the top and bottom surfaces of the windscreen. Anydelamination

present will produce an additional line and its proximity to either of the other lines is helpful in deciding which of the layers has separated.

II. Rough-edge. This is characterised by its irregular, sharp or jagged boundary. It may develop long finger-like projections if, during the course of delamination the parting between vinyl and glass is notuniform.

III. Smooth-edge. Smooth-edge delamination advances with a smooth boundary. It does not have rough or jagged areas within it, nor indications of internal cracks orchips.

b) A small amount of delamination is permitted on most aircraftbut details of the permissible extentand any limits concerned with aircraft flight operations, e.g. flights under pressurised conditions, should be obtained from the relevant aircraft Maintenance Manual and FlightManual.

Scratches

Scratches are defects in the surface of a panel and every effort must be made to avoid them. They are normally more prevalent on the outer surface where windshield wipers are indirectly the primary cause. Any dust or grit trapped by a wiper blade can immediately become an extremely effective cutting device as soon as the wiper is set in motion. Wiper blades must therefore be maintained in a clean condition and should only be operated when the windscreens arewet.

a. On the basis of severity, scratches may be classifiedas hairline, light andheavy.

I. Hairline Scratches. A hairline scratch can be seen but is difficult to feel with a fingernail. It can be caused by wiping the glass with a dry cloth. To avoid hairline scratches, the glass should be cleaned with a mild detergent andwater, using a soft brush or clean, soft cotton cloth, followed by drying with a clean, soft cotton cloth.

II. Light Scratches. A light scratch is less than 0- 254 mm (0 010 inch) deep and can be felt with a fingernail. This type of scratch ordinarily has few edgechips.

III. Heavy Scratches. A heavy scratch is 0 254 mm (0 010 inch) or more in depthm and can be readily felt with a fingernail. This type of scratch is apt to show extensive edgechipping.

b. If the integrity of a panel is not suspected and provided visibility is not seriouslyaffected, scratches are permissible within limits detailed in the relevant aircraft MaintenanceManual.

c. Scratches can be removed by polishing, but due to an uneconomic time factor, possible optical distortion and problems of assessing optical standards acceptable in the ultimate operational situations, it is recommended that a panel assembly be returned to the manufacturer and replaced by a serviceable assembly.

Chipping

Chips are flakes or layers of glass broken from the surface which can occur if the exterior surfaces of a panel are struck by a sharp object. The inner surfaces of a lamination of the panel may also chip in unheated areas, as a result of high internal stresses. There are two types of chips: conchoidal and V-shaped. Conchoidal chips are usually circular or curved in shape with many fine striations that follow the outline of the outer edge. V-shaped chips are sharp and narrow, the 'V' appearing to propagate toward the interior of the glass. Visibility through chipped areas of a windscreen panel is usually poor. Chips occurring at the inner surfaces of glass panels are critical because the existing condition may result in cracking or shattering of a pane, or in the case of an electrically heated windscreen, destruction of the resistance heating film. These chips are usually associated with rough- edge delamination.

Cracks

These are serious defects which, depending on the type of glass and the formation and propagation of the cracks, may result in considerable strength reduction of the windscreen and effects on visibility varying from slightly impaired to complete obscurity. In annealed glass the damage may take the form of single cracks, or cracks forming anirregularcriss-crosspattern. The more usual result of damage to strengthened glass is the formation of cracks spreading radially from the point of damage and in these cases, vision is impaired but not completely obscured. Cracks in a toughened glass form a pattern defined as shattering, a defect resulting in considerable reduction in strength and loss of vision. A windscreen having such a defect should be removed and replaced by a serviceable

assembly. The extent to which cracks arepermitted,limitations on aircraft operation and the action to be taken in order to rectify the defects, may vary between aircraft types. Details are given in the relevant aircraft Maintenance Manual and Flight Manual and reference must therefore always be made to these documents.

Vinyl Rupture

Vinyl rupture consists of a failure across the section of vinyl at the inner edge of the metal insert and necessitates changing the panel.

Vinyl 'Bubbling'

Small bubbles occurring within the vinyl interlayer of electrically heated windscreens are not a delamination nor are they structurally dangerous. They are usually due to overheating conditions, being formed by a glass liberated by the vinyl. They need not be a cause for windscreen replacement unless vision is seriously impaired. Their presence, however, may indicate a defective window heat control system which should be rendered inoperative pending rectification.

Discoloration

Electrically heated windscreens are transparent to direct lightbut they normally have a distinctive colour when viewed by reflected light. This apparent discolourationis due to the resistance heating film and it may vary slightly between windscreens. Only black or brown discolouration, when viewed normal to the surface, should be regarded as a possible defect necessitating removal of the windscreenand

replacement by a serviceable one. The cause of such discoloration may be a burnout of the heating film or a carbon deposit between a busbarandthe heating film due to overheating.

Sealants

Weather sealants provided around the peripheryofwindscreens must be inspected for evidence of erosion, lack of adhesion, separation or holes. The obvious purpose of maintaining an effective weather sealant is to protect the windscreens against moisture entry and the delamination or electrical problems associated withmoisturepenetration. When new sealant is required, the damaged material should be removed, the area cleaned and new material applied in the manner prescribed in the relevant aircraftMaintenanceManual.

NOTE: Damaged material should always be removed with a plastic tool that will fit, without binding, in the gap between windscreen and frame. The use of a metal tool is inadvisable, as this could damage the glass or vinyl interlayer.

Cleaning of Cockpit Windscreens

Windscreens should be washed regularly with warm water and mild detergent, using a clean, soft cloth or cotton wool pad; after washing the panels should be rinsed and dried with a clean, soft cotton cloth. Scratching of the glass must be avoided.

Some aircraft manufacturers recommend the use of a proprietary detergent which is also suitable for the surrounding aircraft structure and therefore to some extent simplifies cleaning operations; it is important that only the detergent specified is used and that the prescribedproportionof detergent to water is observed.

Grit, dirt, etc., should be removed at regular intervals from recesses, for example, where the panel joins the frame, to prevent it being picked up by the cleaning cloths and causing scratching. The accumulation of cleaning and polishing materials in recesses must be avoided.

Storage of Cockpit Windows

Extreme care is necessary during transportation, storage and handling of windscreens to prevent damage. It is recommended that panels should be packed with both faces covered with adhesive polythene; they should then be wrapped in acid-free paper and cellulose wadding and put into reinforced cartons, these being covered with waxed paper and secured with adhesivetape.

The panel should be stored in their cartons on suitable racks,away from sunlight or strong artificial light, at a controlled temperature of between 1OC to 21C (50T to 700) in well ventilated conditions.

It is important to ensure that during handling or storage the thicker glass ply of a laminated panel is kept uppermost to prevent delamination and that the polythene film is notremoved until the panel is fitted to the aircraft.

Cabin windows

Cabin windows (see Figure 3.39) really consist of three windows. The outside and the middle window are installed in the construction of the fuselage, butare of no importance to the strength of the fuselage. The protective windows are installed in the wall panels. There is a small ventilation hole in the inside window to allow adjustment for pressure differences between the inside and the outsidewindow.

Cabin windows are made of a certainsynthetic.The advantages are its extreme clearness and that is weather proof. A disadvantage of this material is that it is sensitive to solvents, stripping compounds, ultraviolet rays and air pollution.

Each window is made with two panes. Each of the two panes can carry the full differential cabin pressure on their own. The panes are made of stretchedacrylic.

Near the bottom of the inner pane, at the centre, there is a small vent hole to equalisethe pressure between the panes in normal operating conditions, but is not large enough to cause significant pressure loss in the event of outer pane damage. It also helps to prevent condensation and misting between the twopanes.

In maintenance areas where fumes of solvents occur, all cabin windows within a radius of 5m from the work spot must be covered. In some types of aeroplanes (for example, the Boeing 747) the first few cabin windows are attached even more securely to lessen the effects of a possible birdstrike.

Windows are designed to preclude fogging and frosting by means of multiple pane construction with intervening cavities essentially isolated from cabin interior airconditions.

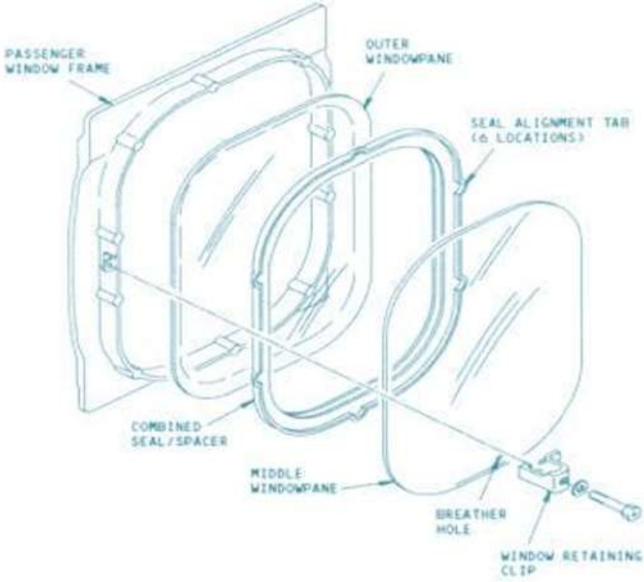


Fig. 3.39: Cabin Window components

A third pane known as the acoustic pane or scratch pane is a non-structural pane and is installed into the sidewall lining. It is made from polycarbonate.

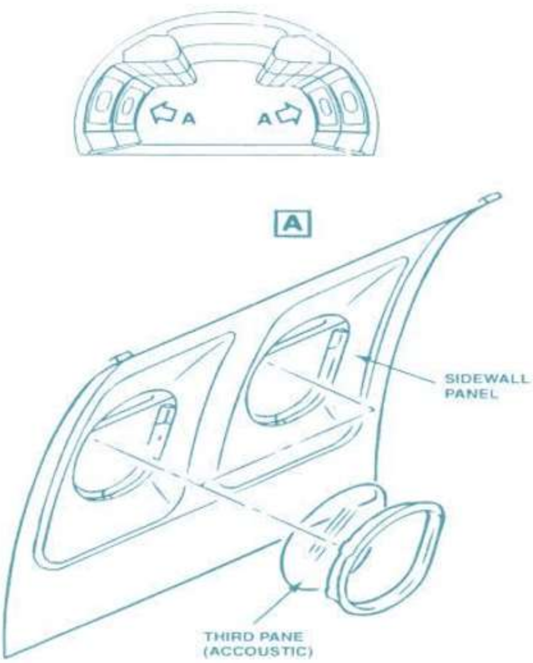


Fig. 3.40: Sidewall lining assemblies

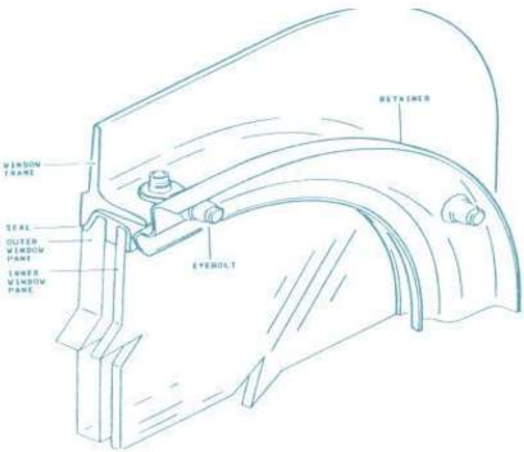


Fig. 3.41: Cabin window assemblies

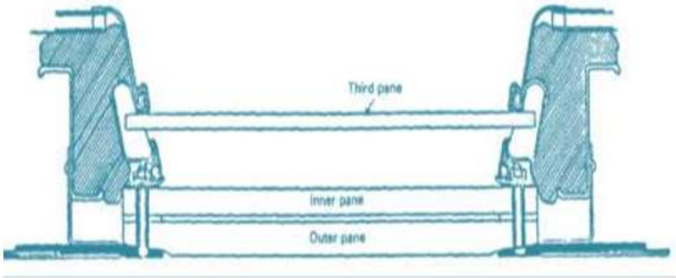


Fig. 3.42: Cabin window assemblies

Dummy Window

In areas of the cabin where equipment and furnishings (e.g. galleys and lavatories etc.) are located, cabin dummy windows are installed. This are made of one layer of aluminum alloy plate.

Window Cleaning

Transparent acrylic panels should be maintained in a dean condition and any slight scratch or slight crazing should be removed by cleaning and polishing. Panels should never be left in a dirty state, since this will affect their optical qualities.
Warm water (40°C maximum temperature) and soap is recommended for cleaning, using a soft clean cloth or cotton wool pad; after washing, the panels should be rinsed and dried with a clean chamois leather. Some aircraft manufacturers recommend a proprietary detergent which is also suitable for the surrounding aircraft structures and therefore to some extent simplifies cleaning operations; it is important to ensure that only the detergent specified is used and that the proportion of detergent to water is observed. Grit or dirt should, at regular intervals, be removed from recesses, such as where, for example, the panel joins the frame, to prevent its being picked up by the polishing doth. The accumulation of cleaning and polishing materials in recesses must beavoided.

Window Polishing

Various proprietary polishing kits are available which usually consist of a jar of cleaning compound, a jar of polishing compound, polishing cloths and application cloths.
Polishing cloths and application cloths must be kept separate. Polishing cloths may be used until soiled but application cloths should be discarded after use.
When using cloths that are not specifically obtained for cleaning or polishing transparent material, it is essential to ensure that the cloth is of soft texture andclean.
Scratches can usually be removed by polishing, the depth of the scratch being the controlling factor. The repair manual of the aircraft concerned should be consulted to ascertain the extent, depth and location of any scratches or damage that may be removed, since apart from the amount of material that may beremoved,theopticalqualitiesofthepanelmaybeaffected.

NOTE: A dry cloth should never be used to remove dust or din.

Because of the high surface and volume resistivities of acrylic sheet, a static charge is built up when it is

rubbed with a dry cloth. Treating the surface with an anti-static polish approved for use on acrylic will help to prevent this static charge and reduce the resultant accumulation ofdust.
A small quantity of the specified type polish (which may be thinned down with water if desired) should be applied to the sheet and spread evenly, using a soft cloth. Finally, the panel should be rubbed with a clean soft cloth until a bright polish is obtained This treatment helps to eliminate the static charge and so reduce dust collection for approximately two months under normal dry indoor conditions. Frequent polishing with a dry cloth does not impair the efficiency of the treatment, butwashing destroys the anti-static effects and polish must be re- applied.
NOTE: It is important to ensure that all surfaces are treated.

Inspection of AcrylicWindows

When inspecting transparent acrylic panels, the following points should be borne inmind.
The optical standard and the standard of cleanliness of cockpit panels can have a direct effect on the flying of the aircraft especially in conditions of poor visibility. A hazy-panel blurs the details, reduces black to grey and dims outlines. Dirt or slight scratching scatters the light and makes it impossible for the pilot to see against the sun.
The soft nature of acrylic panels (compared with glass) makes them very susceptible to scratching. Some of the common causes of scratches are asfollows:

- Protective paper covering, which hasslipped.
- Cloths of a rough texture used for cleaning orpolishing.
- Dirty cloths used for cleaning orpolishing.
- Dirty hands.
- Contact with any hardobject.

During maintenance, the following precautions should be taken:

- Panels should be cleaned as detailed in the aircraft Maintenance Manual, and only approved polishes and soft, clean polishing cloths should beused.

- Panels should not be covered with rough canvas covers. In frosty or changeable weather, covers especially designed for the purpose should be used. In damp weather, prolonged rain or fog. the panels should be left uncovered.
- Personnel should not touch panels with barehands.
- Fuel should never come in contact withpanels.

- Any damage to the panel should be carefully checked in accordance with the requirements of the aircraft MaintenanceManual.

Because of the adverse reaction of acrylic material to various chemical vapours, the cockpit and cabin should be well ventilated during maintenance.

Crazing - Stress crazing is caused if the surface tensile stress of a panel exceeds a critical value. Crazing consists of multiple hairline surface cracks which, being very narrow, relatively deep and sharp at the bottom, act as notches and may cause a serious drop in strength. The depth of the crack may increase with time if the formation of the surface cracks doesnotrelieve the stress, and to couldultimately penetrate through the sheet. Stress crazing is a time- dependent phenomenon and, therefore, it may occur at lower stresses after longer periods of loading.

Stress crazing is not usually dangerous because the loss of strength in the presence of such crazing is small and in any ease the window would be changed because of appearance long before it became too weak. However, crazing caused by solvents can be much more serious in that the window can suffer

appreciable loss of strength. It is impossible to distinguish between the causes of crazing, hence the necessity of keeping harmful solvents away from panels, both in storage and inservice.
Crazing usually occurs in the vicinity of a joint and. when the panel is held up to the light, the faulty area appears sparkling and iridescent. It should be noted that hot sun will further aggravate craze-prone areas.

Cracks - Cracks should be prevented from spreading by drilling (if permitted by the aircraft manufacturer), but owing to the brittle nature of the material, it should only be drilled when the hole is to be filled with a cementedpatch.

Cracks which start at the edge of a panel should be arrested (drilled) and then opened up by inserting a sharp instrument (a razor blade is often suitable) as near to the edge of the panel as possible. The surface of the panel immediately adjoining the crack should then be painted with adhesive cement, using a fine clean brush (preferably sable or camel hair), and the adhesive should be allowed to run into the crack. When the adhesive becomes tacky, the instrument should be withdrawn to allow the faces of the crack to come together; surplus adhesive should then be wiped off and the repair allowed todry.

The adhesive cements used for repair work are highly flammable and the fumes are poisonous Therefore, naked lights must be avoided and good ventilation is essential.

Storage of Acrylic Windows and Sheet

Acrylic sheets are best stored on edge, with the protective paper left in position; this will help to prevent particles of grit, etc., becoming embedded in the surfaces of the sheets. When this is not possible, the sheets should be stored on solid shelves, and soft packing, such as cotton wool, should be placed between each sheet. The pile of sheets should be kept to a minimum and should never exceed 12sheets. Curved panels should be stored singly with their edges supported by stops to prevent 'spreading'. There are several proprietary lacquers available for the protection of acrylic panels and shapings during handling and storage, including those complying with Specifications DTD 900/4051, DTD 900/4294 and DTD 900/4356. Protective paper may also be used, but to prevent deterioration of the adhesive between the protective paper and the sheet, store rooms should be wellventilated, cool and dry. The material should not be placed near steam pipes or radiators, as hot conditions will cause the adhesive to harden and make the subsequent removal of the paper difficult.

Acrylic sheets or panels in storage should not be exposed to strong sunlight, particularly when light shines through a glass window which might cause a 'lens' formation, as this may result in local overheating and bedetrimental.

Seats
Passenger seats are attached to seat tracks in the floor, and may be rearranged for different passenger configurations by moving the seats forward or aft on seat tracks. Seat tracks are beams of special cross section and are bolted to the floor structure. Tracks are provided with circular cut-outs for seat studs and lock pins, which lock the seats in position. Cut-outs in the tracks are spaced one inch apart. The seats are triple or double passengertyp Seat retention studs are mounted in the front and rear of each leg. At the rear of each leg is a pivoted double retaining stud. Seat retention and locking is by a spring loaded shear pin located at the rear of eachleg.

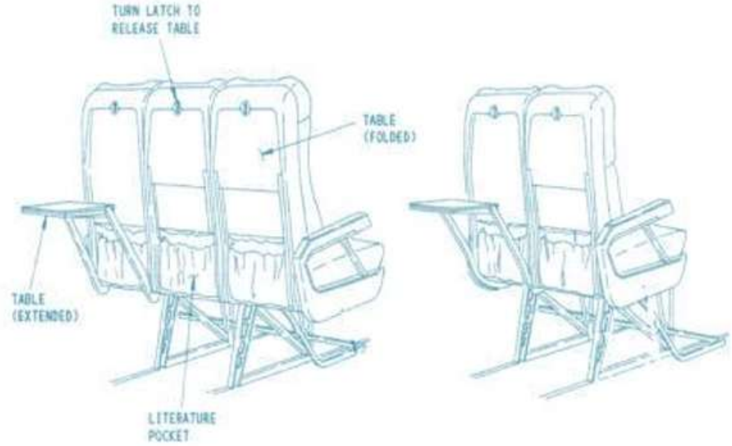


Fig. 3.43: Triple and double passenger seatassemblies

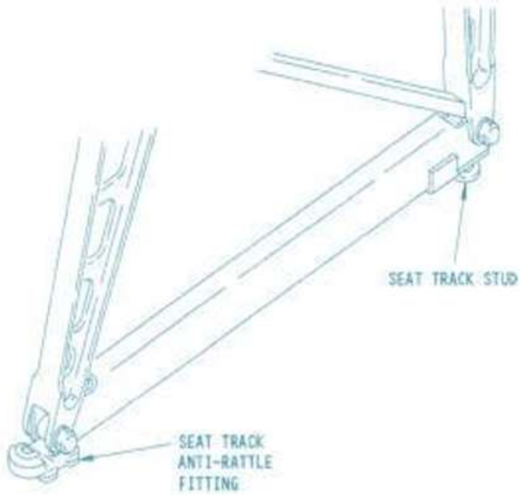


Fig. 3.44: Seat anti-rattle fitting on rear legs

Cargo Loading

Many large aircraft have a powered cargo loading system which enables the single handedloading and securing of heavy containers. This system comprises of retractable drive wheels and stops together with rollers and ball mats which allow the containers to be turned, positioned and locked in dedicated drivebays.
Freighter and Combi aircraft may have a powered cargo handling system on the main deck. This enables the movement of both containerised and palletizedfreight.
To prevent accidents, power to the drive system is only available when the cargo door is fullyopen.

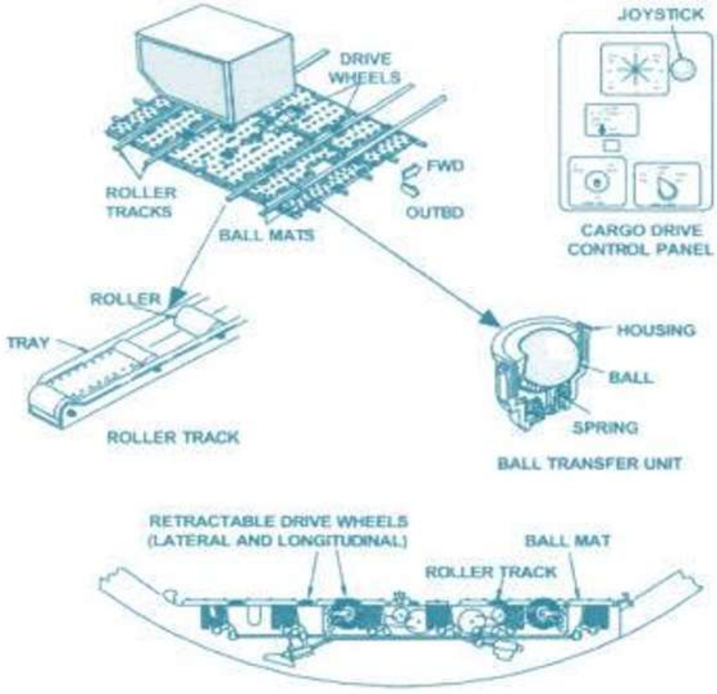


Fig. 3.45: Door area cargo handling equipment

The cargo handling system will include various fittings and locks to secure the containers and pallets andprevent movement inflight. When a containerised cargo system is not available, loads such as baggage have to be carried loose. Such load must be restrained from moving about the aircraft duringflight. Loose cargo may be carried in a cargo bay beneath the passenger floor, or in a baggage area on the main deck of a passenger carrying aircraft.

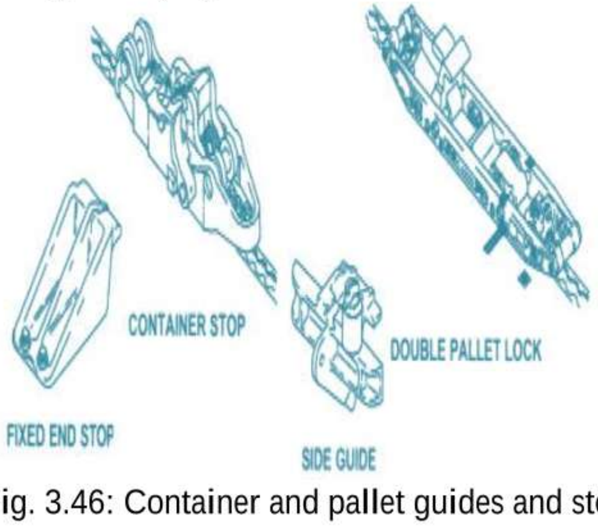


Fig. 3.46: Container and pallet guides and stops

A loose or bulk cargo area is usually provided under the passenger floor, even if the aircraft carries under floor containers. Cargo nets are provided to restrain the cargo and prevent it falling against or obstructing the door. The net is clipped to tie down fittings on the floor of the cargo area.

A typical restraint system for baggage in the main holds is illustrated. This is a form of net wall that can be removed to allow loading and unloading to take place. The net is attached to aluminium posts which are attached to floor and ceiling sockets, provided in the aircraft. A retractable spring loadedplunger is fitted to the top of each post so that it can be detached from the ceiling socket and lifted out of the floor socket. The nets are attached by quick release hooks, to shackles which are fixed to strong points on the aircraftfuselage.

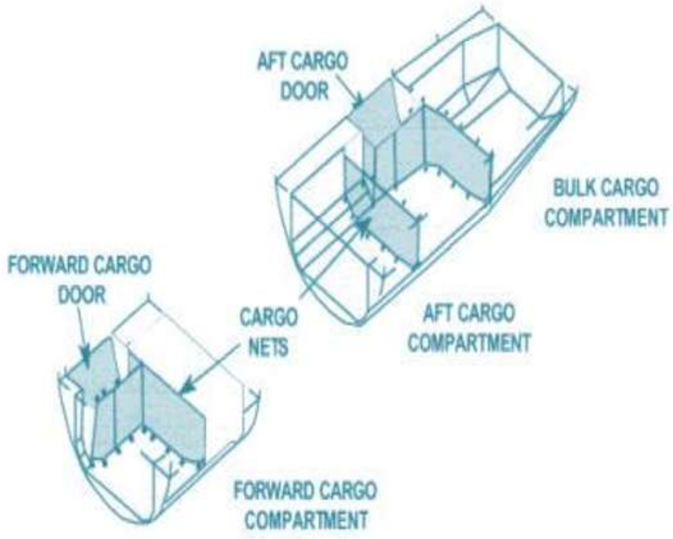


Fig. 3.47: Cargo compartments

13.3.2Wings (ATA 57) Introduction

The lift, which produced by the wing, must be transmitted into the structure in such a manner and in such a location that the aeroplane can be balanced in every condition of flight. And the structure must be built in such a way that it can support all of the loads without any damagingdeflection.

The wing is mounted on the aeroplane in a location that placesits centreof pressure just slightly behind the point at which all of the weight of the aeroplane is concentrated, the centre of gravity. Thecentreof pressure travel on the wing chord produces some rather large torsional, or twisting, loads on its structure, especially at the point where the wing attaches to the fuselage.

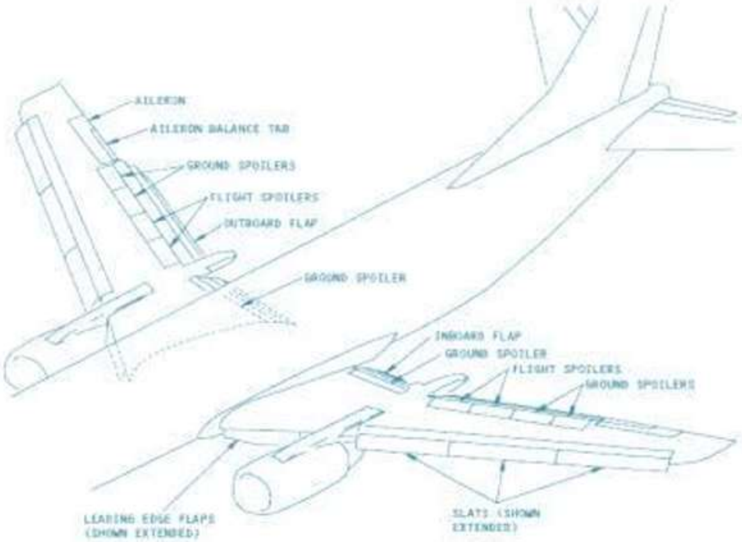


Fig. 3.48: Wing description

In addition to the twisting loads imposed on the structure in flight, the wing is also subjected to bending loads. The weightis essentially concentrated at the fuselage, but the lift is produced all along the wing. The wing spars, which are the main span-wise members of the structure, are designed to carry these bendingloads.

Cantilever and Non-Cantilever

Figure 3.49 shows a cantilever wing and a non-cantilever wing. A cantilever wing has no external supports and its structural strength is derived from its internal design. The advantage of this kind of wing is it eliminates drag caused by wing struts. Its disadvantage is the added weight required to give