**In the name of God**

# Report of Apprenticeship

Report

from

kamyar bakhshipour roudsary

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Supervisors:
Dr. A. Mohseni

Shahid Beheshti University

**Abstract**

This is a report of my apprenticeship in FARSKO company.

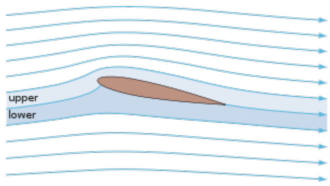


Figure 1: Relation of speed and curvature

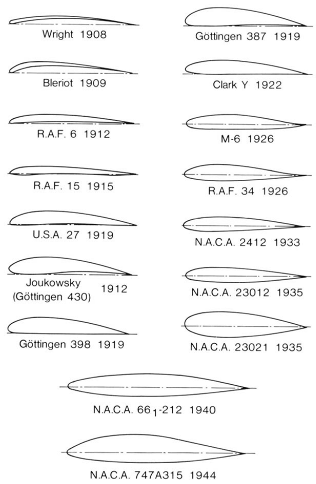


Figure 2: Airfoil profiles in different shapes

## 0.1 *General information*

It is shown in Fig.01 more speed because of curve $\rightarrow$ low pressure On the upward $\rightarrow$ lift $>$ weight

Under the wing, impact causes increasing of pressure and on it, pressure decreases with acceleration. The low pressure area on upper side of wing is more than The region of high pressure under the wing. So it has more effect on lift (both of them are effective). As the angle of attack increases, these will increase $\rightarrow$ lift force $\uparrow$

### 0.1.1 Down wash

When the air flow exits from upper side of airfoil, it has a little difference in angle called downwash. $\alpha$(angle of attack)$\uparrow$ $\rightarrow$ down wash$\uparrow$ $\rightarrow$ drag$\uparrow$ There is a resultant vector that results from lift and drag. Intersection location of this and chord is the center of pressure.

CP can go on and off on chord line (increase $\alpha \rightarrow$ on). Commonly interval is 0.3 to 0.4 times of chord length from leading edge (LE), for a lot of airfoils.

### 0.1.2 Angle of attack

An angle that chord line makes with horizon.

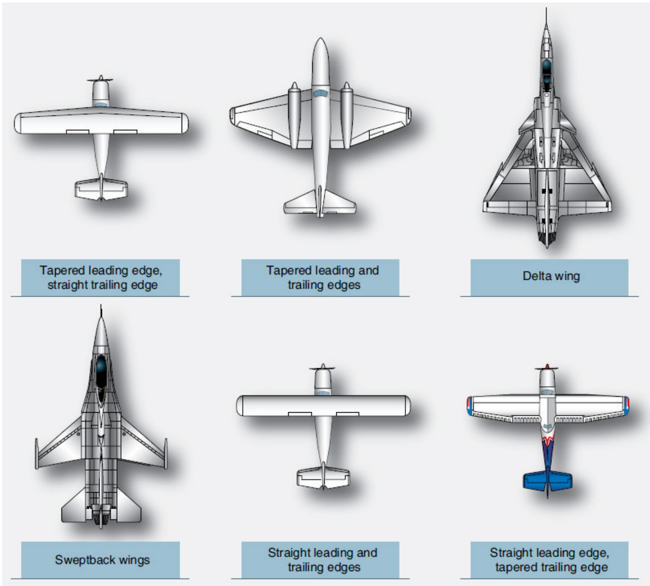


Figure 3: Different kinds of wings

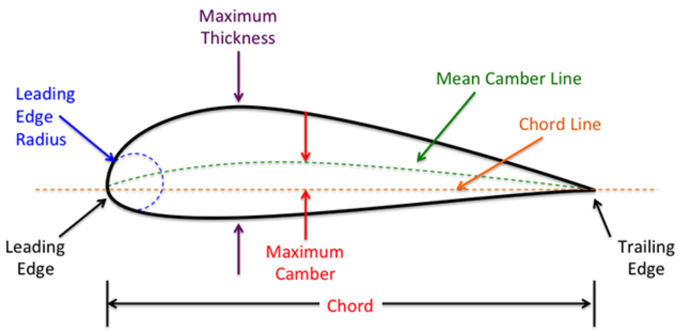


Figure 4: Airfoil characteristics

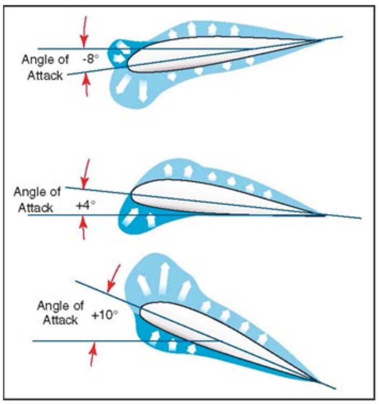


Figure 5: Down wash

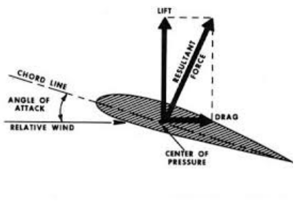


Figure 6: Forces on airfoil

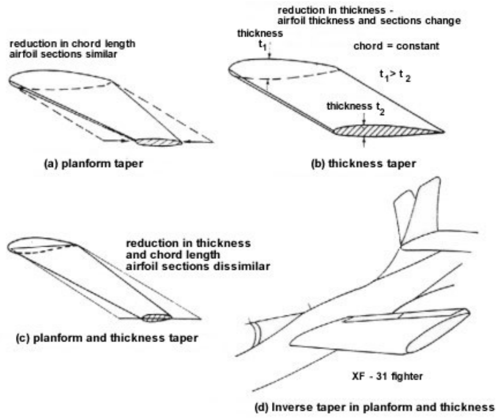


Figure 7: Aspect ratio

$\alpha \uparrow \rightarrow v \downarrow \rightarrow$ In planes, we have stall warning devices based on critical speed (minimum speed before creating turbulent airflow)

### 0.1.3 Aspect ratio

It is ratio of span to chord and is wing appearance characteristic. As wing becomes thinner and longer, this ratio will increase. Long narrow wings give a plane or a bird more stability and also have less induced drag than shorter wider wings. Induced drag is created at the tips of the wings where the high pressure air from beneath the wing leaks into low pressure zone and makes vortex that is called wing tip vortices. So it causes induced drag and lift decreasing. Thus as chord declines, aspect ratio increase, drag decrease, thrust increase and in result fuel consumption decrease. Aspect ratio interval is approximately between 4:1, 11:1. Gliders have the biggest A.R. because of having no motion. In spite of above advantage, increasing in A.R. makes more stress on wing especially on root. Hence, the most suitable design is gradually chord decreasing from root to tip.

### 0.1.4 Angle of incidence

It is chosen to L/D become maximum. For usual wings, L/D is maximum at angle of attack between 2-4degree by experience.

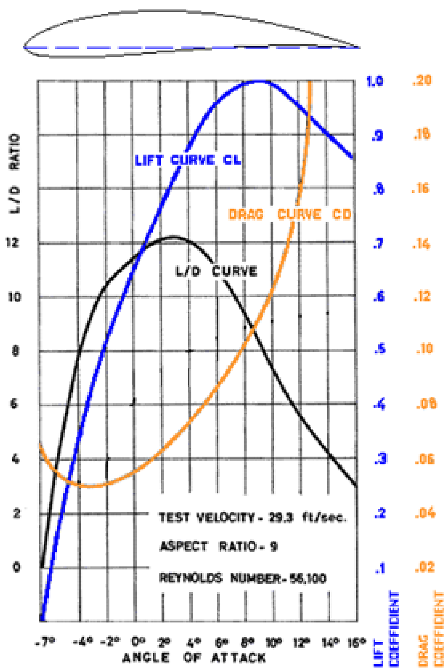


Figure 8: Angle of incidence

The wings are designed to reduce stall probability. They are made from two part. One part has smaller angle against another. When one is in stall, another one is before and against with first part. So it permits to access to more angles. One of examples, is cornerstone.

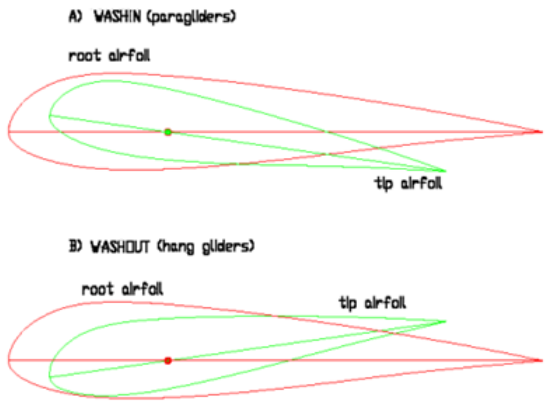


Figure 9: Wash in/out

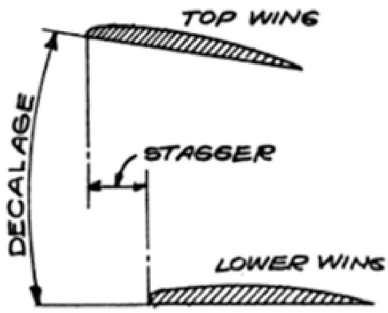


Figure 10: Decalage

### 0.1.5 Propeller torque

According to third Newton's law, plane body will rotate reversal with propeller (our discussion is around American air crafts and propeller rotates clockwise in them). left wing will be gone down by propeller reaction (or it can imagine left wing lift is less than right). So they decrease angle of right attached wing a little (wash out) or increase angle of left (wash in). locating engines which rotate reversal is a way in two-engine air crafts like, piper chieftain. According to P-factor[1], both engines rotate toward the body to not have critical engine.[2] this tactic uses rarely because of needing to two kind of engine and propeller.

In double wings aircraft, wings create in different angles and one of them is less than another to prevent from stall.

### 0.1.6 Decalage

is difference in angle of installed wings. If angle of upper installed wing be more, is positive and if be less, is negative.

### 0.1.7 Controls

**Freedom degrees of aircraft:** Ailerons rotate vice versa to make rolling. Main and usual controls are rudder, elevator, and aileron.

### 0.1.8 Other unusual controls

#### Elevon

some air crafts, like Concorde or Mirage, have lake of stabilizer and so elevator. In this cases, aileron can play role of itself (vice versa with each other) and role of elevator (working both in a same orientation). This part is called elevon.

[1] **P-factor**: When a propeller plane wants to reach to high angle of attack, propeller's center of thrust is moved unbalanced. This pushes plane to right or left a little that causes yawing.

[2] **Critical engine**: in two engine air crafts, called to an engine which fall in more yawing moment if plane turns off. In American plans that engines are right turn, left engine is critical.

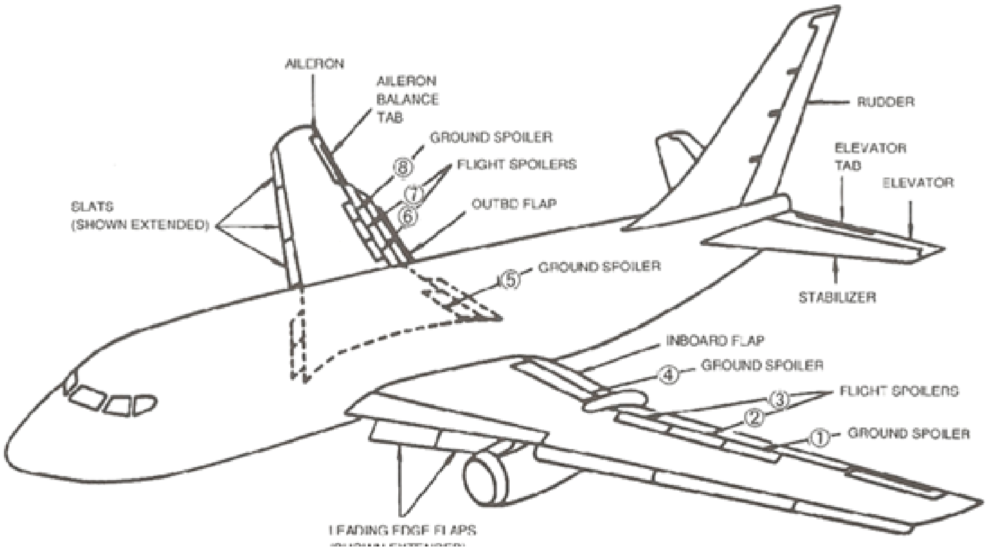


Figure 11: Freedom degrees of aircraft

### 0.1.9 Other unusual controls

Some planes have no fin and they have v-shaped tail and this shape is called butterfly tail. In this cases if parts move together, play role of elevator and move vice versa, is rudder; so it's called Ruddervator.

#### Flaps

Its clear during landing, velocity of plane must be minimum to firstly decrease shock on body and wheels, secondly decline length of landing runaway.

$$lift = \frac{\rho v^2}{2} \rightarrow lift \downarrow\downarrow \tag{1}$$

Lift violent decreasing should improve → flap locates on trailing edge of wing. It means using flap increase wing effective area → drag↑ → velocity↓ → flaps are not used in high speed. Hence, a white bow is on airspeed indicator which show interval of flap to pilot. Also, it is called triple slotted flower.

### 0.1.10 slats

In fighters, slat is used for more $\alpha$ angle and faster maneuver. In this, leading part of the airfoil opens and makes a gap, air goes through this and causes deleting separation and turbulence in angles which are more than angle of stall.

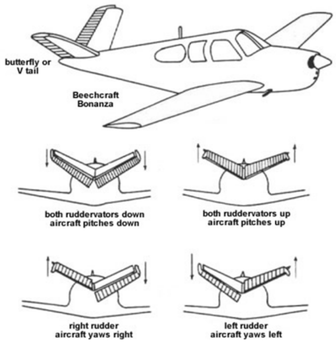


Figure 12: Ruddervators

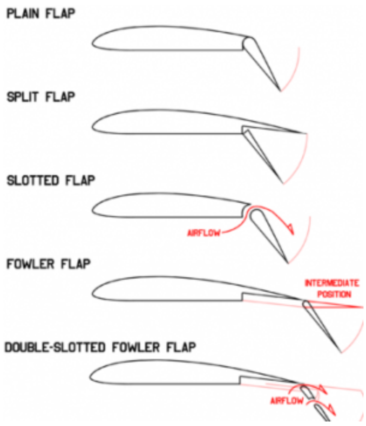


Figure 13: Flaps

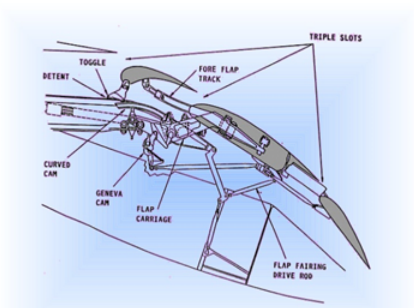


Figure 14: three staged slotted flap-Triple slotted flower-B737

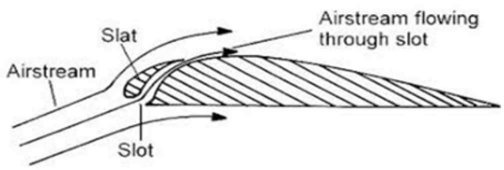


Figure 15: Slat and airflow

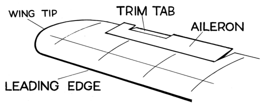


Figure 16: Trim-Tab


Figure 17: Balance-Tab

### 0.1.11 Tabs

**Trim-Tab**

Is controlled by pulleys in cockpit and rotates opposite of elevator; it means, if elevator goes up, it goes down.

**Balance-Tab**

is uncontrollable by cockpit. when pilot turns right or left, it rotates vice-versa.

**Servo-Tab**

In first productions, controls were automatically performing because of small size and low speed. But as got bigger and high speed, it was problem to directly control by pedal. So servo-tab is used and linked to controls from one side, and to pedals and stick from other side. In real, it is an internal construction.

### 0.1.12 Vortex generator

The goal is to take positive work from vortices and main goal is to prevent from separation because , in reality, stall occur in violent separations. Little objects are used to prevent from this event called small wing. These are located in direction of airflow on wings. Since curve of one side is more and A.R. is very little, violent vortices are made on tip of them ; so it inspires energy to separated air and transfer it back to airfoil surface. furthermore they, decline losses, are called vortex generator or dead air movers. Small wings are practically in pair in order to create more energy by mixing two vortices. Also, angle of that locating is very important.

### 0.1.13 Coordinate turn

According to rotation of a car in fines that observes centrifugal acceleration, so make fines with slop. Like this, in addition to rudder that makes yawing,

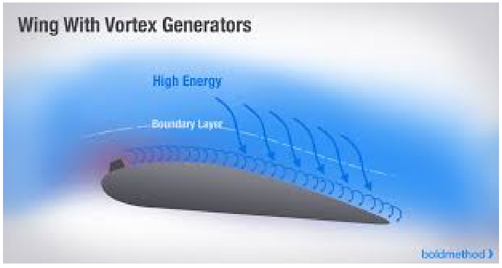


Figure 18: airflow on vortex generator

Figure 19: way of vortex generator resident

plane uses aileron to rotate and posit at a properly rotation angle and provides suitable slop. Because of rotation of engine and rotation during orientation, **Gyroscopic Acceleration** is made and it causes to nose of plane moves in vertical direction. So elevator comes into play. Hence for a single rotation, each three controls are needed.

If we pay attention to resultant vector during rotation, we can see it is bigger than weight force. It can be assumed that the acceleration has actually increased along the perpendicular plane. And this artificial g has relation with $\phi$

$$\eta = \frac{g}{sin\phi}; \qquad \text{when} \qquad \phi = 80\,\text{deg} \rightarrow \eta \approx 6g \tag{2}$$

In military aircraft, g-meter is located to not occur over-g for planes by pilot

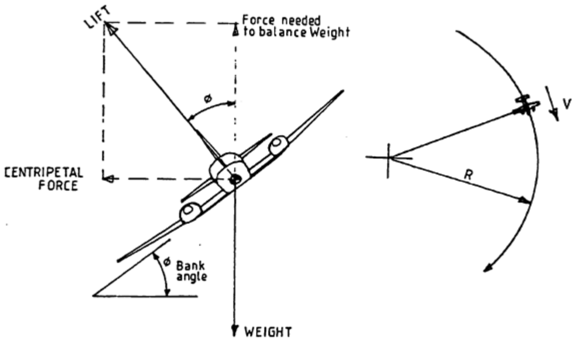


Figure 20: coordinate turn

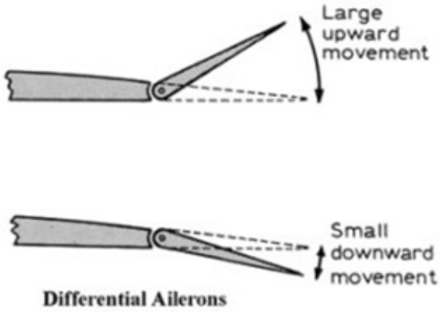


Figure 21: Differential ailerons

because every plane can bears maximum certain g that is called safe load factor. If angle is less than specific, during rotation maneuver, plane slides out of era square that is called skid and if slides into era square, is called slip. For this, pilot uses turn and bank indicator. In lower part, shot must save in middle (bank indicator ). Upper part is turn indicator and has gyroscopic mechanism. This shows angular velocity during rotational maneuver and if thick hand moves as long as a thick, it means 3 deg/sec or 180 deg/min in rotation that is called standard turn. It's very important in Blind Fly.

### 0.1.14 Differential Ailerons

New ailerons are used now which don't have equal movements (this name is for that). Also you should notice, the aileron which goes up has more movement than the one which goes down because of neutralization of adverse yaw. It should be noticed in big planes, like Al Boeing, which has high aspect ratio, uses two ailerons instead of one in each wing (outer and inner) that both are used in low speed and inner is used in high; because outer aileron is in distance from wing root; so use of that make high stress for root and it's possible for wing to twist and even cause aileron reversal. In this case, flight spoiler is used too, in high speed.

### 0.1.15 Spoiler

decreasing the lift is the main goal of spoilers.

#### Ground spoiler

it is perpendicularly located on wing and reduces speed with making turbulence.

#### Flight spoiler

in planes with high aspect ratio, like Al Boeing, there are two aileron parts; the inner one is used in high speed to prevent aileron reversal. We use flight spoiler for helping the aileron which work in same direction with that. but in other side that aileron goes down, spoiler doesn't move.

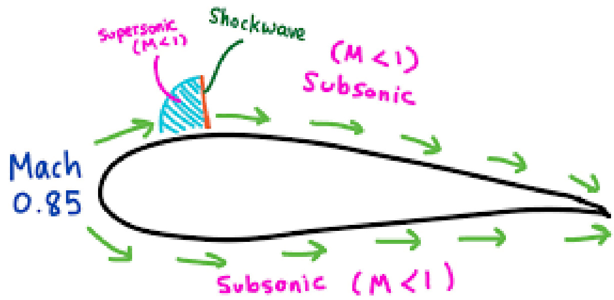


Figure 22: Local speed

### 0.1.16 Local speed

speed is different in different points of wing. speed on wing has different with under, too. Also it varies in one side, and point which is called venture throat, has max-speed. So it's clear now, somewhere have more speed than plane. As you know, shock wave is made by crossing from M=1. According to what we see later, this speed makes violent problems. So planes which can reach this speed have Mach-meter and M≈0.7 is $M_{critical}$ for wings. So with above explanations:
Subsonic-flight: whole of local speeds must be under M=1.
Supersonic-flight: whole of local speeds must be upper M=1.
Transonic-flight: some regions are lower and some are upper than M=1. Hypersonic: M>5; in these speeds in addition to aerodynamic dimension, thermodynamic dimensions affect on plane. because velocity is high, friction appears extremely between air and surface. Hence, material range is limited and passengers safety is significantly important.

When a plane moves, a lot of acoustics will be made by collision of body to air and everywhere speed reaches to sound of speed, shock wave will be naturally produced. It's clear that first place is upper surface of wing and then, lower area. Shock wave of up and down goes to Trailing Edge(T.E.). when speed increases and when speed of plane reaches to M=1, another shock wave will occur in Leading Edge. It should be said, the shock wave is normal at the first and makes a lots of drag; but will gradually fall in diagonal and drag decreases extremely with speed increasing.

Shock wave is strong wall and addition to making high stress, it causes a lot of drag. Secondly, since airflow will be transformed to turbulent by crossing from wing, it causes uncontrolled and instability.

Drag increase in first shock to 80percent (So it uses more fuel); hence, for instance when fighters are going to cross from sound wall, turn on their "after burner". This is secondary engine Ramjet). That is resides in end of supersonic planes and improves thrust to 50percent more.

**How to improve $M_c$**

**Thin wings:** speed on upper side is more as curve of airfoil is more violent; because this causes air acceleration.

$$fineness\ ratio = \frac{wing\ chord}{wing\ thickness} \quad (3)$$

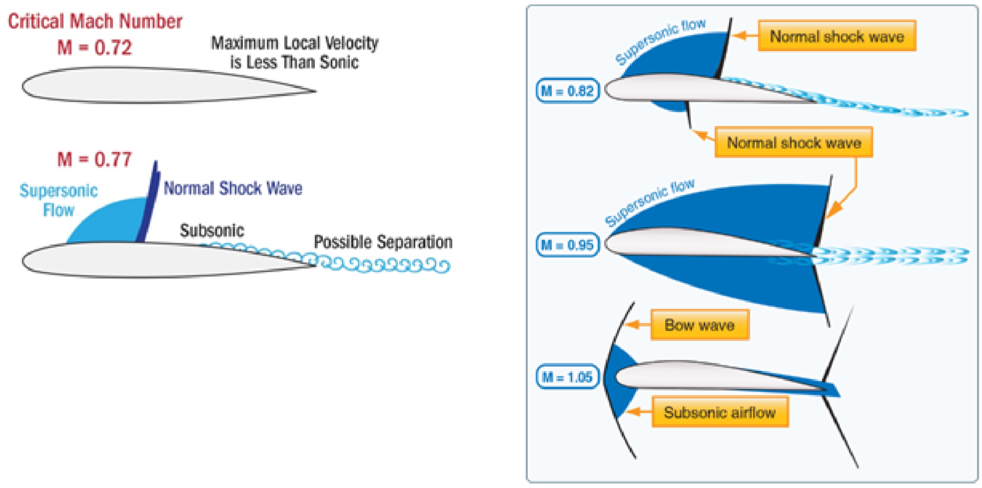


Figure 23: airflow on airfoil around M=1

But being too thin causes structural weakness and less fuel resources. If the wings are straight, all speeds on the upper side of wings reach to Mc because of parallelism of chord and airflow. For preventing from this event, wings are swept backward. Hence, air flow decreases on wings.

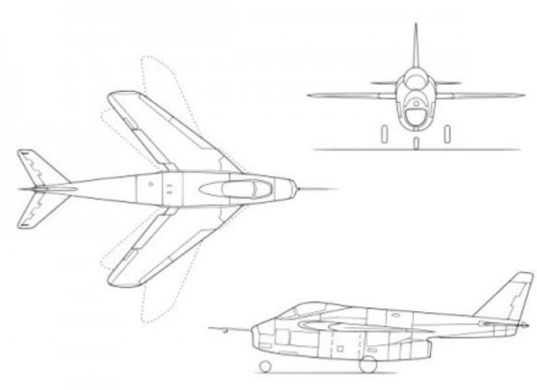

Figure 24:

## 0.2 *Engine*

Jet engine like cylindrical engine, needs to intake, compression, combustion, exhaust. The main reason that causes more power of jet than cylindrical, is continuous cycle of jet engine and discontinuous (intermittent) cycle of cylindrical. Since igniting in jet occurs in open path, produced energy affects on speed (not pressure); so jet cycle occurs in constant pressure. ⇒ Brayton's cycle

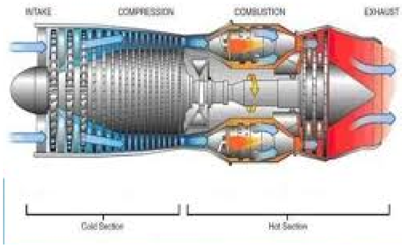


Figure 25: Turbofan

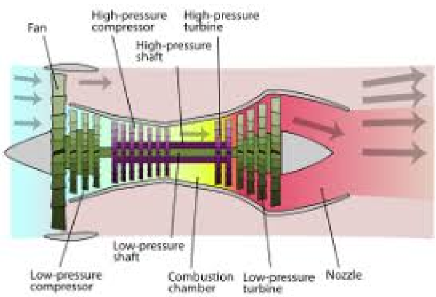


Figure 26: Triple spool turbofan jet engine

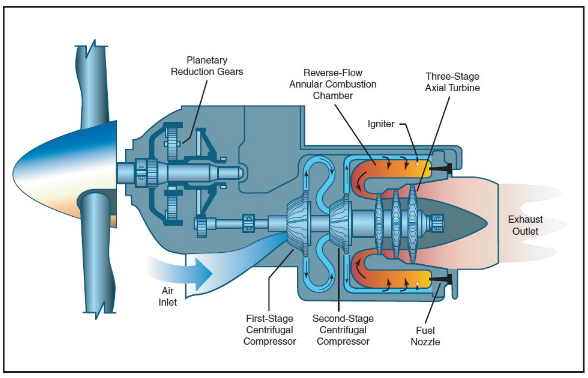


Figure 27: Turboprop

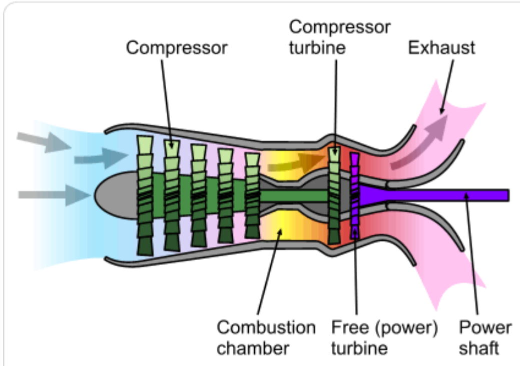


Figure 28: Turbo shaft

### 0.2.1 Effective factors on thrust

- $v_j$
- $v_a$
- *ram effect*
- *rpm*
- *pressure ratio*
- *atmospheric conditions*
- *altitude*
- *humidity*

The impact altitude is a kind of density effect. So h↑ → p↓ → ?↓; but as the temperature drops to a height of 36000ft, this decrease partially offsets the decreasing density. After this altitude, slop of thrust decreasing will increase. For instance, although JT9D on 747 produces 485000lb thrust in standard condition, makes 10500lb in 40000ft (of course declining fuel usage is its property).

### 0.2.2 Engine efficiency

1. **thermal efficiency (internal efficiency):** ratio of kinetic energy of gasses per total fuel heat energy. This is almost 35 percent in jet engines and depends on compression coefficient.

$$\text{(Thermal efficiency) TE} = \frac{\text{gas kinetic energy}}{\text{fuel heat energy}} \tag{4}$$

2. **propulsive efficiency (external efficiency):**

$$\text{PE} = \frac{\text{done work}}{\text{kinetic energy}} = \frac{2v_a}{v_a + v_j} \tag{5}$$

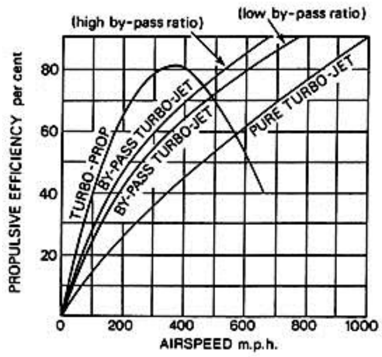


Figure 29: Comparison between jet engines

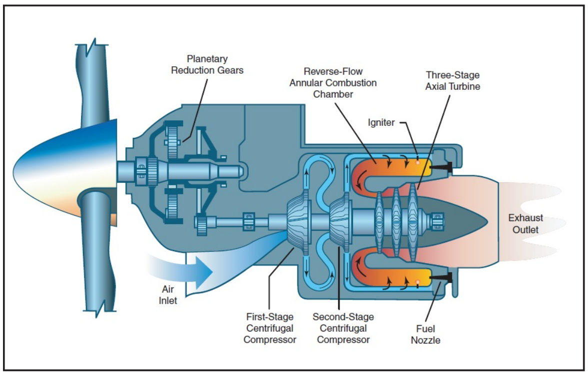


Figure 30: Turboprop

For example, P.E. of propeller jet engines reaches to maximum and declines after. P.E. of pure jet engine is less than propeller jet engine in low speed; but over takes in high speed. Also, between jet engines, efficiency of by-pass is more than turbojet and efficiency of turbofan is more than by-pass.

3. **Overall efficiency**

$$\mathrm{OE} = \mathrm{PE} \times \mathrm{TE} \tag{6}$$

### 0.2.3 kinds of jet engines

**turbo prop**

**By-pass jet**

Part of air of LP compressor goes to channels that surround all-around of the engine without passing through HP compressor, mix with hot out-let and high speed gasses in jet pipe and since out-let gasses speed decreases, propulsive efficiency will increase (according to decrease of $v_j$ in Eq. 5). MD has turbojet and 747 has turbofan

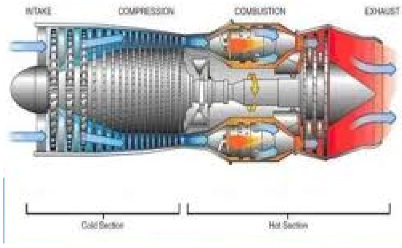


Figure 31: Turbofan

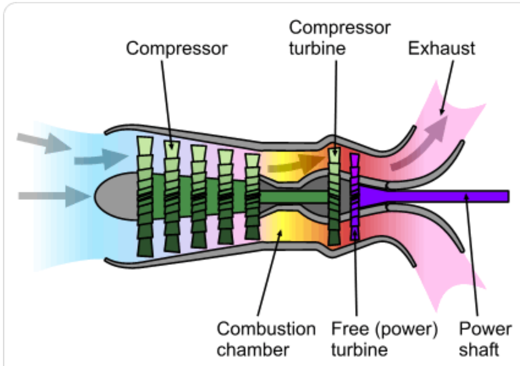


Figure 32: Turbo shaft

#### Turbofan

it is turbojet developed and its difference is bigger by-pass is called high by-pass ratio engines. For example, it is 1:5 in JT9D for 747. In these engines most of thrust is made by fan. Sound, dust and SFC (specific fuel consumption) [3] are less than turbojet. In last version of this kind of engines, e.g. GE90 or Rolls Royce Trent, using for 777, they have 1:9 by-pass ratio. It is 3m in diameter and can reaches to 125000lb in thrust.

#### Turbo shaft

### 0.2.4 Compressor

- **Centrifugal:** has not a lot usage and is limited to low power engines, especially turboprop.

  Impeller: it's a disk which blades are settled on and channels between them is divergent is called RGV (Rotating Guide Vans). When air crosses through these channel, its velocity and pressure rises up because of transferred energy of compressor. After these, air enters to diffuser (pressure increases and velocity decreases) and then is transferred to combustion via elbow (air out-let casing). In some engines impeller has shroud to prevent

[3] amount of fuel consumption (lb) for each thrust pound per hour

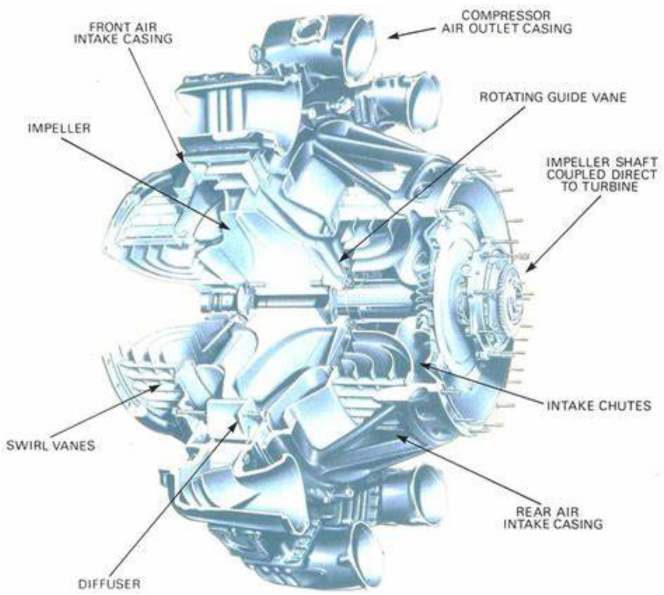


Figure 33: Centrifugal compressor-Turboprop

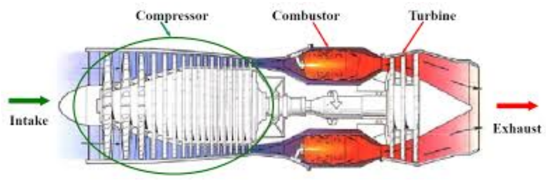


Figure 34: Axial compressor-Turboprop

air escaping from tip of blades to channels. impeller's disk is made of aluminum but its blades are made of steel to prevent from corrosion.

- **Axial:** the airfoil cross through almost linearly in compressor. It consists of rotors and stators, and a couple of stator and rotor are called a stage. In start of compressor is a static blades row that is called inlet guide vans. In some case this is rotary. So firstly controlling inlet air; secondary causes the air enters to first row of rotor in proper attack angle. Thirdly preventing rotor to stall (comp.). The channel between two blades is divergent. So air's speed decreases by crossing via this way and pressure increases with Bernoulli's law. Blades of propeller is twisted and blade angle in tip is less than root. This concept uses in compressor too, for uniform airflow that is called stagger angle instead of blade angle which is angle between chord and shaft axis (complement of blade angle. So it increases in tip). Aluminum uses In first stages, titanium in middle and according to kind of engine with special compression efficiency, steel alloy in last stages because of extreme temperature.

  When air pass through rotor's blades, speed and pressure rise up. But when is passing through stator's blades, speed decreases and pressure increases. It means speed is almost constant during transferring. But pressure increasing has to be low in each stage for stall preventing. But stage No. can't be more than special because back rows performance declines. So manufacturers use twin spool or even triple spool that is way to prevent from stall.

In new engines, e.g. Rolls Royce Trent, this efficiency increase to 1:1.35 And engine's compression efficiency incredibly reaches to 1:45. Also bypass efficiency is 1:9 that declines violent sound and propulsive efficiency improving.

**Axial**

**Advantages**

1. High peak efficiency, created by its straight through design
2. Higher peak efficiency, attainable by addition of compression stage if desired.
3. small frontal area.→ low drag

**Disadvantages**

1. Difficulty and high cost
2. Relatively high weight
3. High starting power

**Centrifugal**

**Advantages**

1. High pressure rise per stage (1:10)
2. Good efficiency, over a wide rotational speed ranges, idle, to full power (almost 1.3 much tip speed).
3. low cost
4. low weight
5. low starting power

**Advantages**

1. Large frontal area
2. More than two stage isn't practical because of the energy loses between stages

**Reasons of comp. stall**

- Intake icing in threat of engine entrance.
- Ordinary airflow is destroyed by extreme plane maneuver
- If with each reason, attack angle of blade through out of standard range, like wing, compressor will stall

  Hint: The spinning blades in the compressor stage of a jet engine or turbo fan are themselves airfoils, like the aircraft's wings. The operation of the engine depends on the smooth flow of air over the blades.

  Just like a wing, an individual blade, or a small component of one, can experience an airfoil "stall", where the air flow over the blade separates into a cell of "stuck", highly turbulent air behind the blade, and the air flows around the cell instead of smoothly around the blade.

  When a flow separation occurs, the airfoil's ability to push the air in proper direction at the right flow rateand thereby contribute to the compression of air behind the fan assemblyis inhibited.

  Since these blades are rotating, the blade quickly moves away from the packet of stagnant air. Of course the stalled air packet has some momentum from the intake air, and it will experience a drift along with the rotating blade, but it is not moving with the average flow of the air through the engine anymore.

  Thus the next blade spinning round tends to encounter the stalled air packet. If the stalled air cell is not particularly large, it may be absorbed by the air flow at this stage and dissipated. Alternatively, it might be large enough to stall the subsequent blade as well. At this point, it is called a "rotational stall".

  If the stall continues to propagate, the ability of the fan stage to deliver air to the subsequent compression stage is impeded, and it will lead to an abrupt drop in pressure inside the combustion chamber. This causes a reduction in available oxygen for combustion. The engine's performance, measured by the thrust delivered, is strongly impaired, and there is likely to be a lot of unburnt fuel remaining after the oxygen in the compressor is exhausted. That unburnt fuel may ignite in a bright exterior flame as it escapes out the back of the combustion chamber and mixes with the oxygen-rich bypass flow, or in the case of a jet engine, after it exits the engine altogether.

  The drop in back pressure in the compressor will, under normal conditions, enable the compressor fan blades to begin operating as proper air foils again.

  An alternative type of stall is a compressor surge. In this case, the problem is caused by unexpectedly high pressure in the combustion chamber (or in the compressor), which forces its way forward as well as backwards, against the incoming flow rate. Again, this disrupts the operation of the compressor blades as airfoils.

We have transient stall which isn't visible on indicators and will disappear after 1 or 2 impact.

Figure 35: Variable inlet guide vans

Figure 36: Bleed valve

**Ways of stall preventing**

- **Structural changes**
  1. Variable inlet guide vans: in low speed (low air sucking), these are almost close and in high speed, they'll automatically open (ideal angle of inlet air 2-4 degree).
  2. Variable stator blades
  3. Twin spool compressor: they have two separated compressors; LP, HP (they'll consider on JT8D soon)
- **Air bleed valves:** These reside on shield of compressor in middle, near back stages and are open in low speed. So extra air on back part of compressor is exited and in by-pass engines, it'll guide to by-pass duct. Since air can't be compressed enough, volume of air is high for this path in low speed, it has to bleed. In this situation, air flow will be declined in back stages and increased in front stages and prevent from stall. When the plane has reached to full speed, valves are closed.
- **Supersonic intake:** air speed is subsonic in axial compressors; but speed is dramatically higher than sonic in supersonic and must be more less than M=1 because of choking. Air intakes of supersonic planes usually is kind of variable throat. According to below, behavior of air flow of supersonic is unlike subsonic. Hence intake has convergent shape in beginning and divergent at end in order to speed reaches to M=1 in throat and as plane speed differing, intake section is variable throat too, for matching with different speeds and speed become always M=1 in throat.

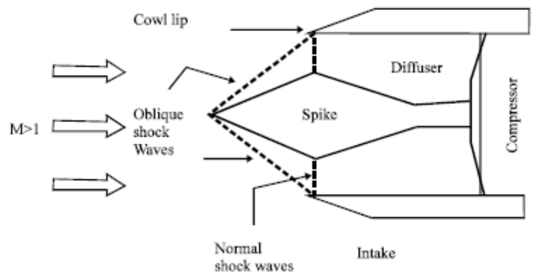


Figure 37: Supersonic throat

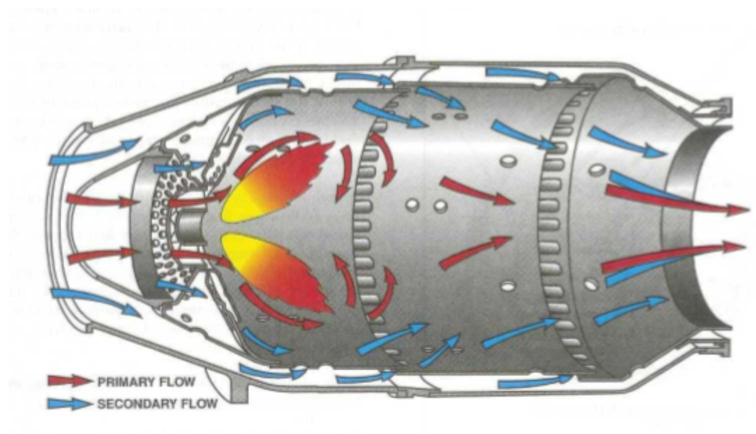


Figure 38: Can Combustion

### 0.2.5 Combustion

Combustion speed of kerosene is approximately 5 ft/sec whereas speed of compressed air is 500 ft/sec from diffuser to combustion and since inlet is divergent, speed declines to 80 ft/sec which is high for burning.

Almost 25 percent of compressor out-take pour into flame zone via **swirl vanes**, **primary holes** and uses to burn. These flows interference and in flame tube inlet make toroidal and this will get opportunity to fuel to burn. Flame temperature is almost 2000C. 75 percent of compressor output flows in distance between flame tube and air case and gradually leaks into flame tube from dilution holes to cause temperature decreases to 1000C that is suitable for turbine (highlighted words and fuel nozzle, are main parts of combustion chamber).

18 percent enters from snout, entrance of flame tube, which 10 percent from primary air holes for combustion and 8 percent crosses through flare. So 28 percent air for burning and residual uses for cooling.

#### Kinds of combustion

1. Multiple or individual or can type: Combustions are separated from each other and flame tube just are linked to each other by inner connectors. So, when engine is turning on, just two cans have spark, flame go into flame tube via inter connectors; hence, all flame tubes work in same pressure

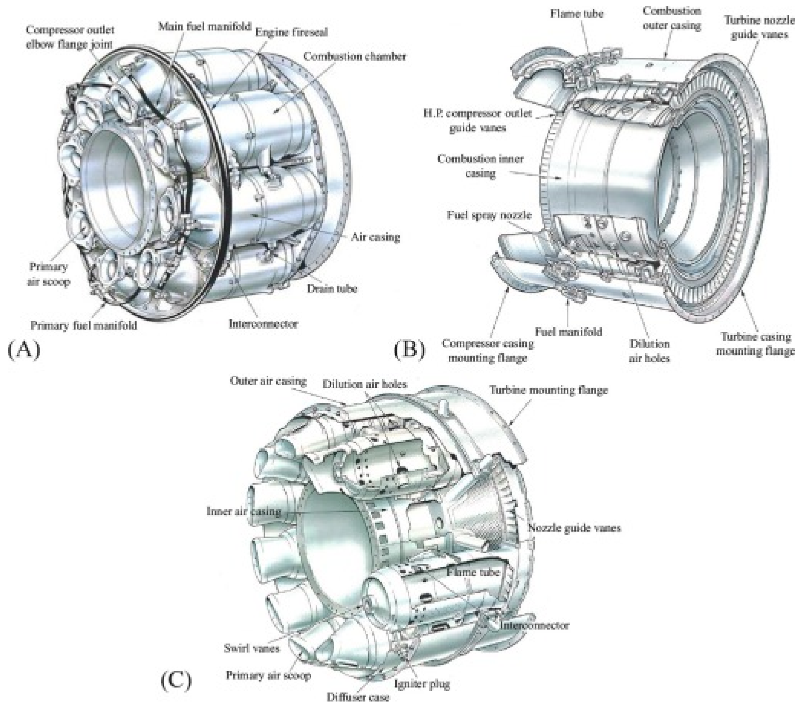


Figure 39: Combustion types

and conditions. The advantage is low production cost, easy maintenance. But it's so heavy and has more loss pressure. Furthermore, efficiency decreases. Used in centrifugal and low-power axial.

2. Tube annular or can annular type: Air shield joint uses instead of air casing; so cooling will improve. It has inner and outer air casing and flame tube is separated by. they are linked by interconnection.

3. Annular type: it has Flame tube which is uniform, two air casing, less weight and lower loss pressure. → efficiency↑; but design, product and maintenance are more complex and expensive than early types.

**Burner**

In engines, a component uses to inject fuel in combustion chamber. Fuel nozzle connect to **pressurize and dump valve** to get fuel and after atomizing injects it. In plane which has less power, fuel nozzle has only one orifice whereas fuel nozzle has two orifices called primary and secondary, in more powerful planes. In idle, start, or low speeds, fuel is sprayed to combustion chamber only by primary orifice. But in high speeds, P&D valves guides fuel to spray via secondary orifice as sends to primary.

### 0.2.6 Turbine

- Nozzle guide vanes (NGVs): static blades are settled in front of rotors. The channel between two blades are convergent → speed↑. These blades

Figure 40: fuel nozzle

are uniform annulus in some engines called Nozzle diaphragm. NVGs is gash. In high power engines and warm air of HPC passes from root and tip of blades to trailing edge. This air flows all the time so cools the blades and prevent from destroying.

- Blades are settled after each NGVs and link to disk in shape of fir tree. These have airfoil shape, too and are twisted. Hence velocity is constant and uniform along blades. In some engines blades are shrouded to prevent from gas escaping caused loss efficiency. In these cases, blades are thinner for less weight. Blades material is Nimonic alloy [4] linked in forge way.

In strong engines, first row of blades of turbine are hollow and air of HPC crosses from root to tip.→ cooling
A row of NGVs and a row of turbine blades are a stage. Pressure and heat loss in turbine stage is very more than a compressor stage. So the number of turbine stage is lower than the number of compressor stage. Material of turbine disk is **special steel alloy** made by forged way.

### 0.2.7 Kinds of engines

***Turbo prop***

90 percent of thrust is result of the propeller's increased air speed and10 percent exhaust gasses (residual thrust). Efficiency is more than other engines in low speed (400mph).

Compressor has two kinds of axial and centrifugal in this kind; but engines are newly axial and:

1. Single spool: compressor and propeller are rotated by a turbine
2. Twin spool: propeller and LP compressor Are rotated by LP turbine and HP turbine rotates HP compressor.
3. Free spool: propeller doesn't connect to compressor and has a separated turbine.

(Russians are the most turboprop production)

[4]Nimonic alloy refers to a family of nickel-based high-temperature low creep super alloys. Nimonic alloys typically consist of more than 50 percent nickel and 20 percent chromium with additives such as titanium and aluminum.

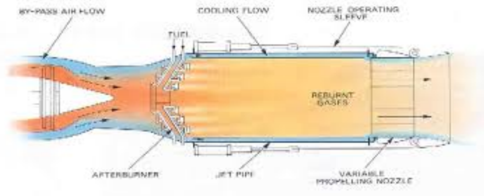


Figure 41: After burner

***Turbofan***

It's shortcut between prop and pure jet. So propulsion efficiency is more than turbojet and has good performance in low speed. In this case, like turboprop, a part of thrust is made by fan and a part with exhaust and thrust is more as by-pass ratio rises up. Modern and big engines, e.g. JT8D, CF6, GE90, etc. have big fan. Furthermore, by-pass efficiency is 5:1. Hence, is called high by-pass ratio.

1. **Twin spool:** (CF6, JT9D), fan and LP compressor rotate mutually with LP turbine.
2. **Twin spool geared fan:** LP compressor and fan have relation with reduction gear. So interval of fan's velocity is more.
3. **Triple spool:** (RB-211, Rolls Royce Trent), fan has separated turbine. Fan plays role of LP compressor, first compressor is called IP (Intermediate pressure), and second compressor is HP.

***Turbo shaft***

All of the energy of outlet gas is taken by turbine and transforms to mechanical work, like helicopter or generators and oil pump stations (Russians are producer of the most powerful turbo-shaft engines-the biggest helicopter (Mil-26) has 11500hp thrust).

***Afterburner***

Is practically ramjet that settles at the end of supersonic military air crafts and other like Concord, causes noticeable thrust in special and short part. This increasing is more than 50 percent and even is 100 percent. As is said, just 25 percent of intake air uses for burning and remaining uses for cooling. So exhaust gas has enough oxygen for burning again. An amount of fuel spray to hot gasses from fuel nozzle when afterburner is turned on. Afterburner is in shape of ramjet ? it has lack of compressor. $\rightarrow$ SFC$\uparrow$ $\rightarrow$ fuel consumption increases to 2.5 time; but its work interval is short (take off or special maneuver). Jet nozzle of engines which has afterburner, is variable. So when it's turned on, jet nozzle opens automatically and increase area to adjust outlet and inlet.

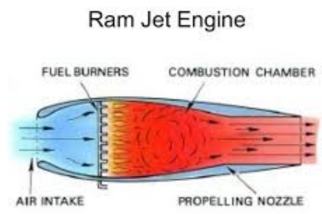


Figure 42: Ramjet

Figure 43: APU

## 0.3 *components*

### 0.3.1 Differences between spark and ignition:

spark plug needs to $20kv$ for sparking; however, plane has tow batteries which they can't prepare this power. Hence, exciter uses to. This takes radial energy of generator which is behind gearbox which get its energy from APU. There is 3 ways for aeration:

1. APU
2. GPU
3. engine 2 engine

APU does two works: Electrification, airing, using for motor and air condition.two starters are in a plane. one of them for APU to give air and electricity

Figure 44: GPU

and one other for motor.

### 0.3.2 Gearbox

It is linked to N2. when APU turns on, its rotation causes rotation of gearbox and HPC will proceed to rotate and when its velocity arrives to certain rpm (20 percent of its efficiency), APU will separate. as work of HPC, HPT will work with. by this, air comes into engine and since the HPC velocity is sufficient, outlet gas makes LPC rotation. so fan will start to work. One of ways for seeing the engine works healthily, is a person stand forward that and considers the fan will work or not.

### 0.3.3 engine cooling

The air has already been heated to between 200 to 550 deg. C. from the compression (for JT8D is almost 250)and rises between 650 to 1150 deg. C. from the combustion (for JT8D is almost 800). Hence, compressor is colder than combustion. Also, this high temperature may melt its body. So air must come and cool it; but if it take this from out air, temp. changes suddenly so that it is possible for combustion shell to corrode.

Hence, this cold air extracts from stages of compressor and link to it so that for inner layers of combustion, air comes from $13^{th}$ and for outer comes from $8^{th}$

### 0.3.4 Pt sensor

$Pt_s$ use in before and after each turbine and compressor (in JT8D, Pt4 is in the back of HPC, Pt3 is in the back of LPC, Pt7 is in the back of HPT). In engines, a valve is that considers and control them which is binary and has only two modes of open and close. When Pt4 is more Pt2+Pt3, like time which plane takes off that rpm is high. So, Pt4$\succ$Pt2+Pt3 $\rightarrow$ PRBC close (vice-versa)

### 0.3.5 materials

In inlet, there is 2 kinds of material. At the beginning of the engine, before fan blades is a cover of titanium. after that and exactly on fan and a little after that, titanium is covered by two aluminum plate. On one aluminum plate is a lot of small holes arranged tidily and is staggered with another plate. Under these two, there is honeycomb structure. This set of structure is made to absorb acoustics. Also, honeycomb structure proceeds along engine to the end.

### 0.3.6 Fuel system

The fuel system supplies clean, metered fuel to the combustion chambers during all conditions of engine operation. Boost pumps send fuel from the aircraft tanks to the fuel pump inlet. The inlet fuel pressure is typically in the range of 15 - 25 psi. It must be 5 psi higher than the pressure of the fuel but no more than 50psi. The fuel flows thorough the (impeller)boost stage which increases its pressure by approximately 10 to 60 psi from start to takeoff power. If there is a boost stage failure the delta P across the impeller bypass valve

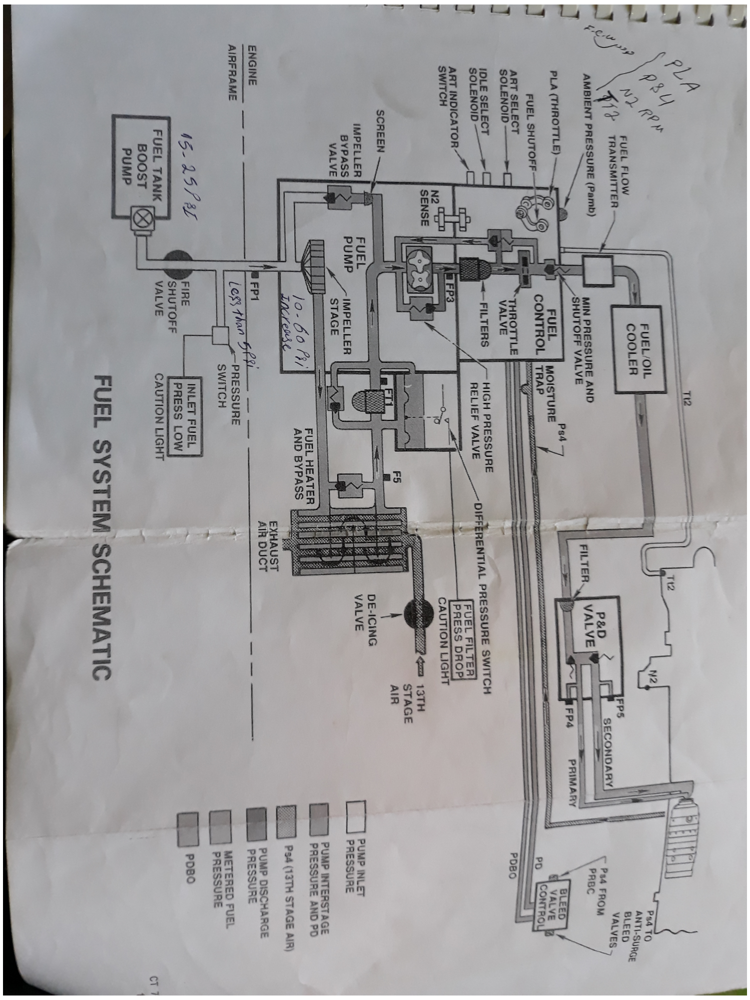


Figure 45: Fuel system

increases. The bypass valve opens permitting fuel to pass directly to the pumps gear stage (if this occurs fuel does not pass through the heater and main fuel filter). After passing through the pump it goes to the fuel heater. The fuel is heated as it passes the heater providing the fuel heat is on. If the pressure drop across the fuel heater is large the fuel can bypass the heater. From the heater the fuel flows to a fuel filter in the fuel pump. If this filter becomes clogged by dirt or ice particles the delta P across the filter increases. If delta P increases the differential pressure switch sends a signal which turns on the icing light in the flight deck. If delta P increases further the filter bypass opens. This permits the fuel from the heater to go directly to the gear stage. (Fuel that goes from the boost stage through the fuel heater and filter is called interstage fuel). Fuel goes from the filter to the pump gear stage which increases it's pressure. Approx. 150 psi when the engine is motored, approx. 900 psi at takeoff power (1,000 psi for the -17/R/AR engines). If the output pressure of the gear stage increases to more than 950 psi (1,050 psi -17) the high pressure relief valve opens. Returning some fuel back to the gear stage inlet.

From the fuel pump gear stage fuel passes to the fuel control unit. The FCU has inputs to it from some of the engine parameters and the power level requested by the flight crew. It schedules the correct fuel flow rate and pressure that is necessary for combustion. The metered fuel then passes to the fuel flow transmitter, unneeded fuel is sent back to the gear stage. (Fuel that goes from the FCU thorough the FF Transmitter, fuel/oil cooler, P&D valve to the nozzles is called metered fuel). The metered fuel goes through the fuel flow transmitter which passes flow rate information to the flight deck. After the transmitter fuel passes through the fuel/oil cooler which reduces the oil temperature. Fuel now passes to the P&D valve (Pressurizing and Dump). When it enters the P&D valve it goes through a filter. This filter has a bypass facility. The P&D valve divides fuel into primary and secondary fuel flows and send it to the fuel manifolds. Above idle (higher power settings) it also sends fuel to the secondary manifolds. Fuel from the primary and secondary manifolds passes through the nozzle supports and into nine fuel nozzles Here it is atomized and sent to the combustion chambers

### 0.3.7 Can combustion

In planes, like MD, can combustion uses which has 9 can and they have 3 holes for link. northern for fuel nozzle link, northwest and northeast for linking to other two cans. Between all of them, just 2 cans can spark settled on 4,7 o'clock position and fire inspires in other by these two. 3,9 is better; but exciter is located at 6 'clock position (easy and quick access) and also, price and loss is more as cables length, connected to flame, get bigger. In old planes, both spark together; but it has two modes, A and B, in new planes. both are used in bad atmospheric conditions and A (7 o'clock) is used in good conditions (connected cable length is shorter than 7).

It is possible for fire to leak out of can combustion chamber because of holes on shell and causes shell to scorch. Sometimes this burning reaches to crossover and scorches it, too. Hence, surface of cross-over coats with Cast iron (it sprays); but it's possible, fire becomes a lot so that causes corrosion.

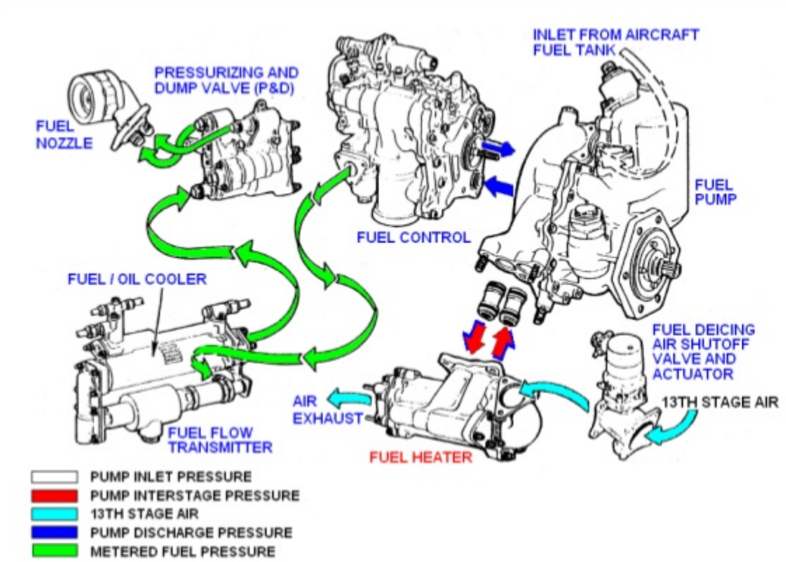


Figure 46: fuel components

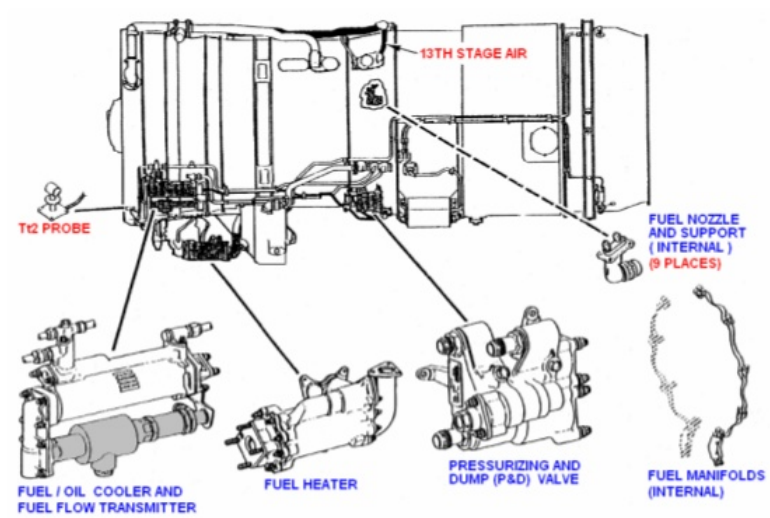


Figure 47: fuel components position

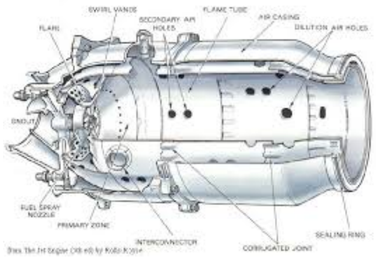


Figure 48: Can combustion chamber

### 0.3.8 oil system

Oil is sent to oil pump. This pump can be only for pressurizing and sending to next part which is called single; but in some cases, this pump can send back this from destinations which is called duel. Oil enters to a filter after pressurizing. If the oil has impurity, after a while filter become lock or the oil is very cold, the oil filter bypass is designed to oil continues this circle and go to regulator valve. pressure regulator valve can be closed in which case it doesn't bypass any oil, so all of the Filtered oil goes to Fuel/Oil cooler. If it is partially or fully open it bypasses some of the oil and sends it back to the oil pump inlet. The pressure of the non bypassed oil is reduced and passes to the Fuel/Oil cooler. In the Fuel/Oil cooler, the oil flows around the heat exchanger tubing to transfer some of it's heat to the fuel. Thus the oil is cooled before it flows to the bearing compartments. This goes to bearing for:

- preventing from rubbing
- lubrication
- cooling

After bearings, fuel send back to oil tank.

**In JT8D:"**

The scavenge system collects oil from the bearing compartments and accessory gearbox and returns it to the oil tank. The flow sequence is as follows:

A gear type pump scavenge pump sends the oil from the No1 bearing compartment to the accessory gearbox. Oil from the No2 and No3 bearing compartments drains by gravity through the tower shaft housing to the accessory gearbox. A gear type scavenge pump sends oil from the No6 bearing compartment through an internal tube to the sump for the No4, 4 1/2, 5 bearing compartments. Scavenge oil from the compartments is sent by a dual element gear type scavenge pump to the accessory gearbox. It then flows to the oil tank through an internal passage. There is a scavenge pump in the accessory gearbox sump that sends oil to the oil tank. When the scavenge oil enters the oil tank it goes through a tube to a deaerator that removes the air from the oil.

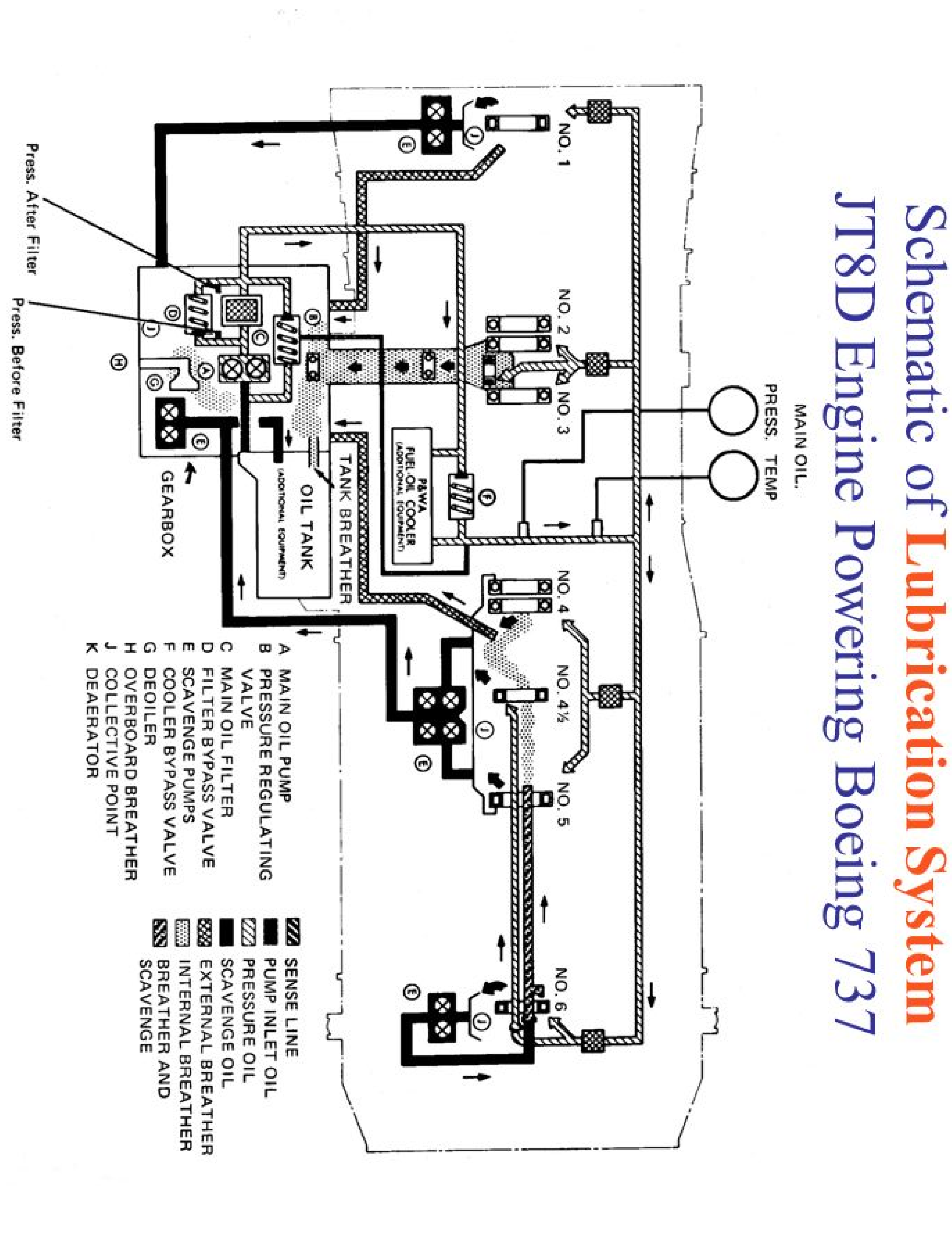
Schematic of Lubrication System
JT8D Engine Powering Boeing 737
MAIN OIL.
PRESS.
TEMP
NO. 1
NO. 2
NO. 3
NO. 4
NO. 4½
NO. 5
NO. 6
P&WA
FUEL OIL COOLER
(ADDITIONAL EQUIPMENT)
TANK BREATHER
OIL TANK
(ADDITIONAL EQUIPMENT)
GEARBOX
Press. After Filter
Press. Before Filter
A MAIN OIL PUMP
B PRESSURE REGULATING VALVE
C MAIN OIL FILTER
D FILTER BYPASS VALVE
E SCAVENGE PUMPS
F COOLER BYPASS VALVE
G DEOILER
H OVERBOARD BREATHER
J COLLECTIVE POINT
K DEAERATOR
SENSE LINE
PUMP INLET OIL
PRESSURE OIL
SCAVENGE OIL
EXTERNAL BREATHER
INTERNAL BREATHER
BREATHER AND SCAVENGE

Figure 49:

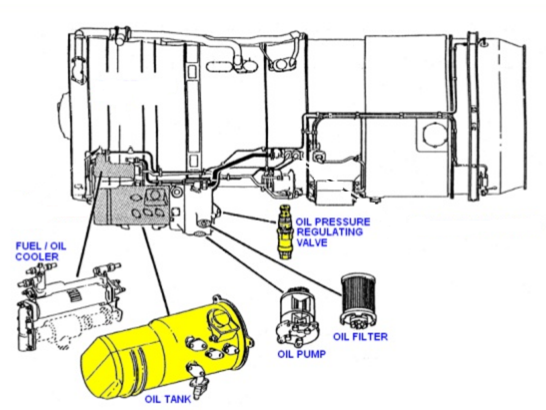


Figure 50: Oil system

## 0.4 *General components*

### 0.4.1 Electric dis-charger

Loaded electricity on plane body exits via this component because it has high resistance (Carbon), and very thin tip. It's settled on sharp and edged places, like tail and aileron.

### 0.4.2 Sheets of body surface

firstly, it cause to prevent body from cracks growth. Secondly, makes easy access to inner parts. In plane is tow kinds of **rivets**:

1. **universal:** their end is spherical to neutralize normal stresses (tension).
2. **counter sink:** to neutralize shearing stresses. It's almost invisible and flat with surface. They product and use in two material, steel and aluminum. The material of surface and rivet must be same. In other wise, they make Galvanization effects that causes corrosion.

### 0.4.3 Rear exhaust:

In some planes, in rear, is a hole. This is not rear exhaust really. This hole is for APU exhaust when turns on. This is a little air turbine and its aim is air condition like cooling. Also, it uses to run the main engines. But it usage has very expensive and waste a lot of money. Hence, it uses in emergency situations. Also if engineers want to run computers system to examine performance, they link APU to ground card and it transforms mechanical to electrical power. In some planes in front of the tail, is a hole which sucks the air and brings up to APU (in emergency). In some, like MD, it's on above of engines and in other, like Airbus, is in the back side of tail.

### 0.4.4 components on airplanes

two kinds of sensors are located on body surface (in part of cockpit); static and pi-tot. pi-tot estimate plane velocity by fluid flows which is analog. In some planes, it translates to digital by A/D. This makes pi-tot's tubes shorten from meter to centimeter in length. Behind pi-tot, is a gate, $1 \times 1$ in dimensions, which is access to computer system that it must open carefully because of sensitive components.

static sensor has square-shaped and in the center is almost 6 very small holes. near the surface boundary layer is made and it can read static pressure.

These two sensor send data to computer system and absolute velocity of plane will be calculated.

In two sides of cockpit, in the left-bottom corner, two gates are located that they are connected by ducts and use for computer system cooling contains water and during flight it is close.

after cockpit, under the plane, is a subject for preventing from water icing in plane and water exit from there. The water can include remain water of cleaning or made by inner ducts.

On the whole around of plane (on and under), antennas, in small scales, are located. These are settled in different shapes, like triangular charter, cylindrical, etc.

### 0.4.5 some extra information:

A different number is written on each blades of turbine. This is because after examination on them, they must put on their certain place for balance.

In all airplane, wings fluctuate because of air flow which; but since they are small versus span, they are invisible. But is more visible in big planes with big wings, like 747. It interesting to know that its domain of vibration is 7-meter (-3.5 to 3.5) and it looks like it wings.

Figure 51: