Gas Turbine Technology
Lecture 05

Engine Parts: Compressor assembly, types of burners: advantages and disadvantages. Influence of design factors on burner performance. Effect of operating variables on burner performance. Performance requirements of combustion chambers. Construction of nozzles. Impulse turbine and reaction turbine. Exhaust system, sound suppression. Thrust reversal: types, design & systems. Methods of thrust augmentation, afterburner system.

Types of burners
Advantages and disadvantages.
Influence of design factors on burner performance.
Effect of operating variables on burner performance.
Performance requirements of combustion chambers.

Combustion Chamber – An Overview

- A **combustion chamber** is the part of an engine in which fuel is burned.
- Combustion chamber in gas turbines is also called as the combustor.
- Combustor is fed with high pressure and high temperature air by the compression system, and further temperature rise across combustion chamber is required since thrust or shaft power produced by engine is a function of turbine entry temperature.
- Combustor therefore adds the fuel and burns the fuel-air mix. It increases the internal energy of resulting gas, which translates into a significant increase in its temperature.
- Combustor then feeds the hot, high pressure exhaust into the turbine components of the engine.
- For the given air mass flow at the entry to the combustor (supplied by compressor), amount of fuel added in combustion chamber depends on temperature rise required across combustion chamber.
- However maximum temperature is limited by the materials of turbine rotor and nozzle guide vanes (typically 850 to 1600^{0}C)

Combustion Chamber – An Overview

- Has the difficult task of burning large quantities of fuel, supplied through the fuel spray nozzles, with extensive volumes of air supplied by compressor.
- Release heat in a manner that the air is expanded and accelerated to give smooth stream of uniformly heated gas at all conditions required by the turbine.
- This task should be accomplished with the minimum pressure loss and with the maximum heat release for the limited space available
- Combustion chamber should also be capable of maintaining stable and efficient combustion over a wide range of engine operating conditions.

Combustion Chamber – An Overview

- Although gas turbine combustion systems operate at extremely high efficiencies, they produce pollutants such as oxides of nitrogen , carbon monoxide (CO) and unburned hydrocarbons (UHC) and these must be controlled to very low levels.
- Over the years, performance of gas turbine has been improved mainly by increasing the compressor pressure ratio and turbine inlet temperature (TIT).
- Unfortunately this results in increased production of emissions.
- Ever more stringent emissions legislation has led to significant changes in combustor design to cope with the problem.

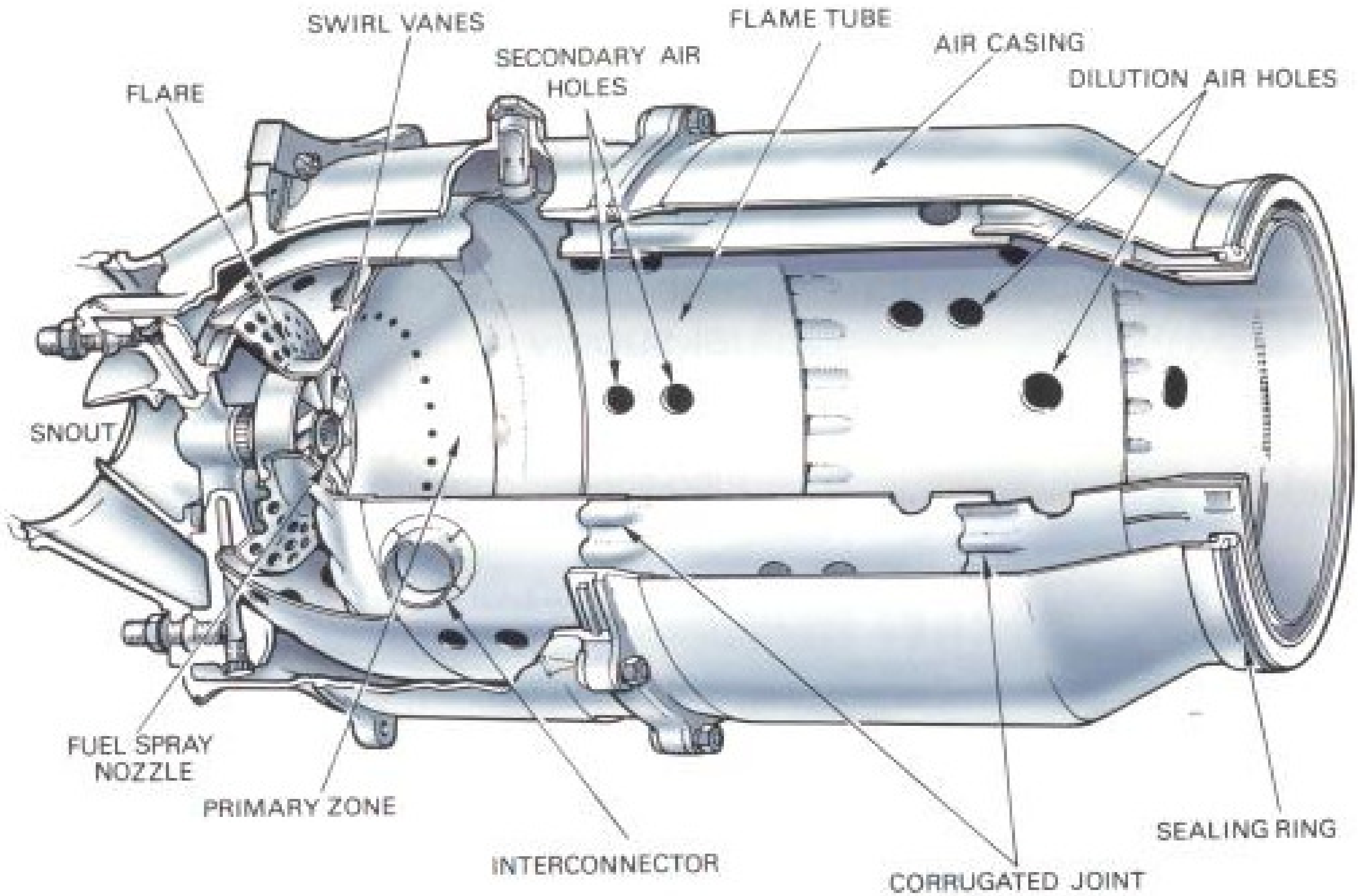
Combustion (region of low velocity)

- Air from engine compressor enters combustion chamber at a velocity of about 150 meters/sec.
- Since this velocity [or Mach number] is too high for combustion, there is a necessity to diffuse the air, i.e. to decelerate it and raise its static pressure.
- If the velocity is not reduced, any fuel lit will be blown away.
- Hence a region of low velocity has to be created in the combustion chamber, so that the flame will remain alight throughout the range of engine operating conditions.

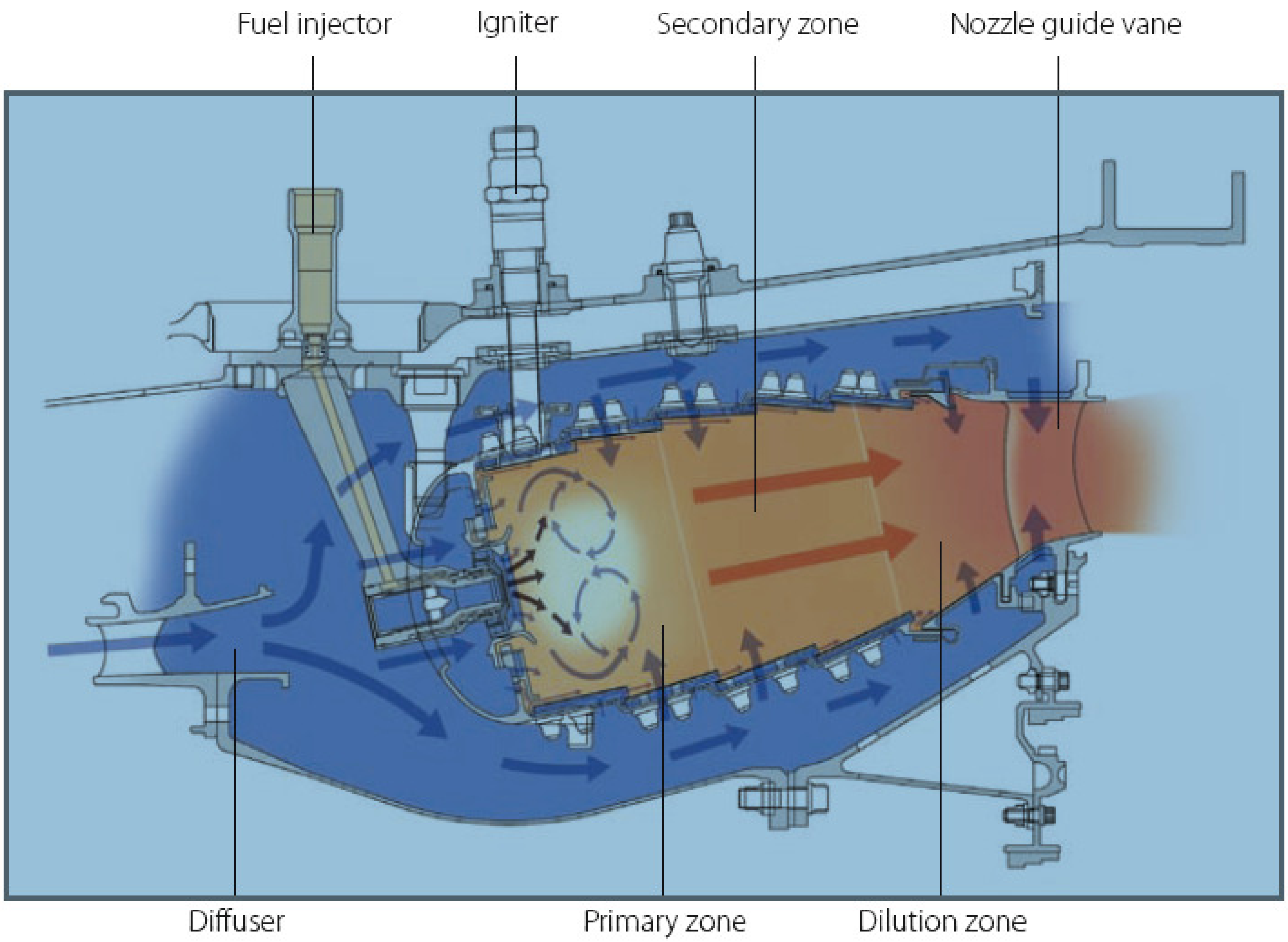
Combustion (fuel/air ratio & air flow staging)

- In normal operation, the over all fuel/air ratio of a combustion chamber varies from 0.01 to 0.025.
- However the aviation turbine fuel (a form of kerosene) burns effectively at fuel /air ratio of about 0.067 (Stoichiometric ratio).
- So the fuel must be burned with only part of the air entering the chamber, in what is called a primary combustion zone.
- This is achieved by means of a flame tube (combustion liner) that meters the airflow distribution along the chamber (hence the air is introduced in combustion chamber in stages to ensure effective combustion).

A Typical Combustion Chamber



Another Typical Combustion Chamber



Combustion Process (continued…)

- Approximately 20 per cent of the air mass flow is taken in by the snout or entry section.
- Immediately downstream of the snout are swirl vanes and a perforated flare, through which air passes into the primary combustion zone.
- The swirling air induces a flow upstream of the centre of flame tube and promotes the desired recirculation.
- Air not picked up by the snout flows into the annular space between the flame tube and the air casing.

Combustion Process (continued…)

- Through the wall of flame tube body, adjacent to combustion zone, are a selected number of secondary holes through which a further 20 per cent of the main flow of air passes into the primary zone.
- Air from swirl vanes and that from secondary air holes interacts and creates a region of low velocity recirculation.
- Fuel spray from the fuel nozzle intersects the recirculation gases.
- This action, together with general turbulence in primary zone, greatly assists in breaking up fuel & mixing it with incoming air and rapidly bringing them to ignition temperature.
- An electric spark from an igniter plug initiates combustion and the flame is then self sustained.

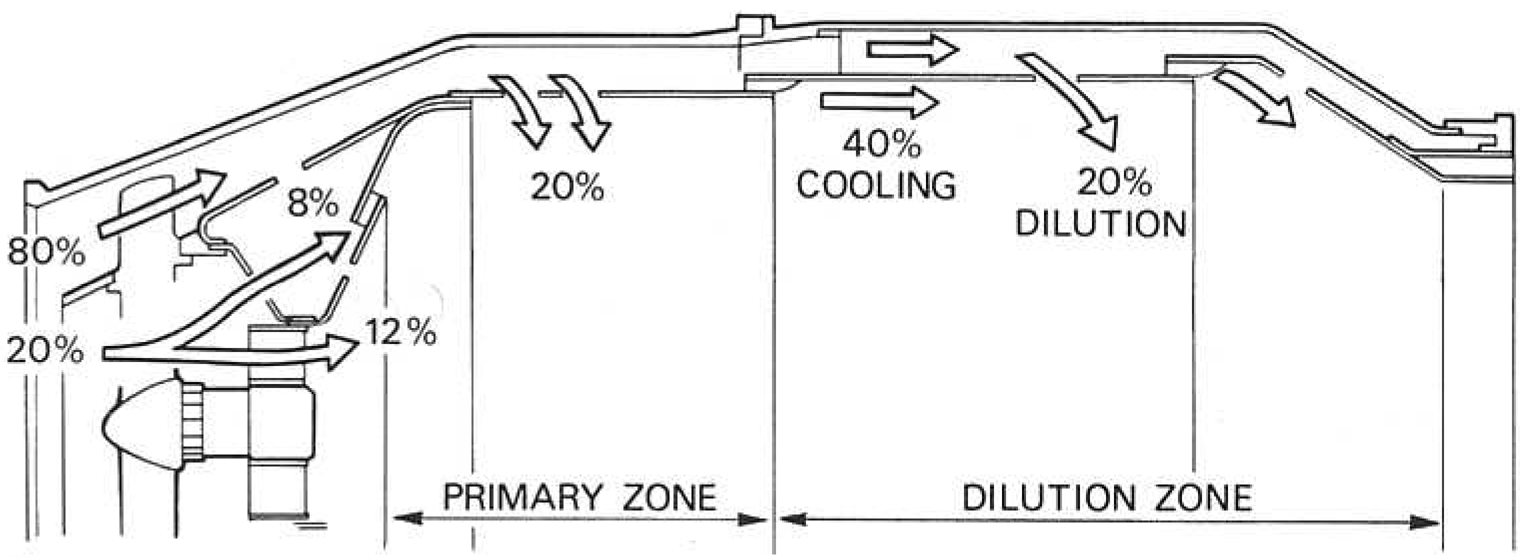
Combustion Process (continued…)

- Temperature of the gases released by combustion is about 1,800 to 2,000 deg. C., which is far too hot for entry to the nozzle guide vanes of the turbine.
- The air not used for combustion, which amounts to about 60 per cent of the total airflow, is therefore introduced progressively into the flame tube.
- Approximately a third of this is used to lower gas temperature in the dilution zone before it enters the turbine and the remainder is used for cooling the walls of the flame tube.
- This is achieved by a film of cooling air flowing along the inside surface of the flame tube wall, insulating it from the hot combustion gases.
- Combustion should be completed before dilution air enters the flame tube, otherwise incoming air will cool the flame and incomplete combustion will result.

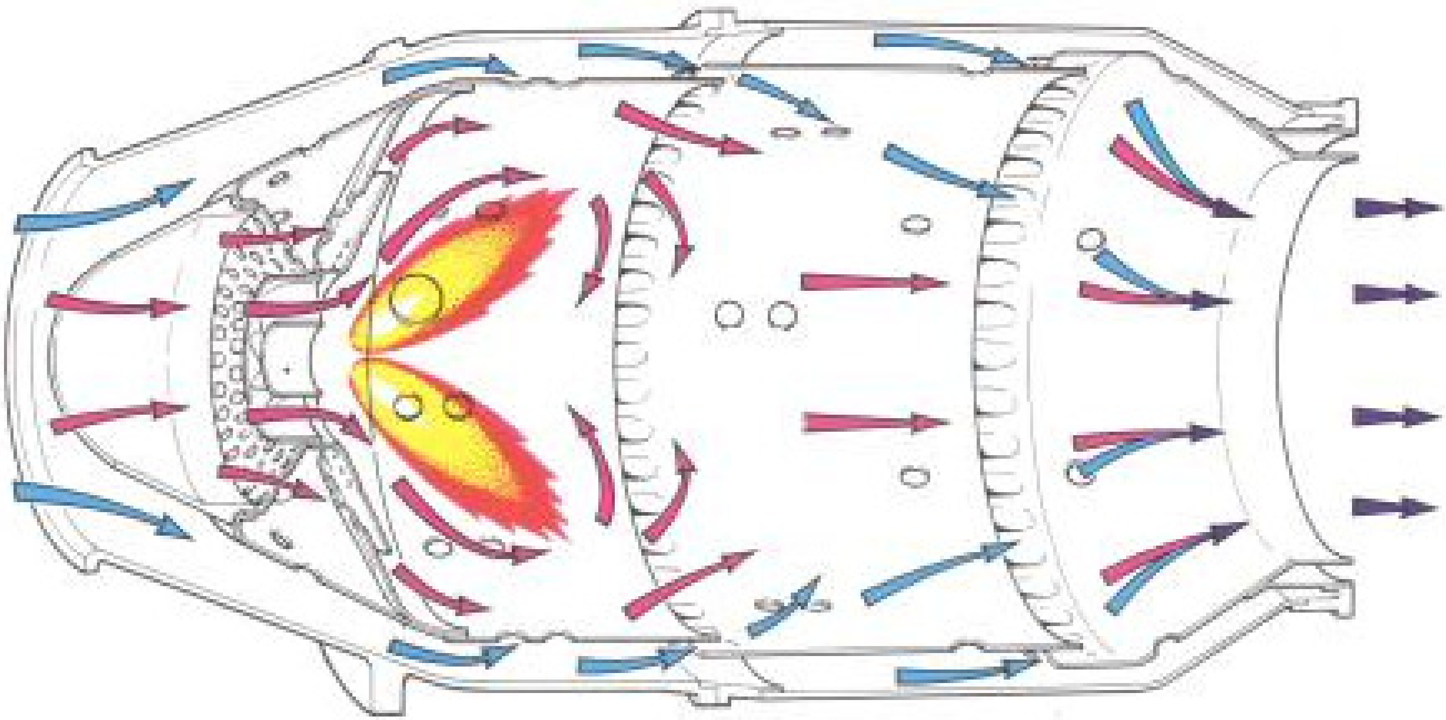
Combustion Process (continued…)

- Combustion occurs practically at constant pressure (except for a pressure loss of about 5%- 6 %).
  - Cold loss: frictional loss
  - Hot loss: due to fuel addition and associated temperature rise
- Efficiency of modern combustion chamber is almost 100%.
- The design of combustion chamber may vary, but the airflow distribution used to effect and maintain combustion is always similar to what is described above

Combustion Chamber - Apportioning Airflow



Flame Stabilizing and General Air Flow Pattern



Combustion Summary

- A compressor exit diffuser to reduce the Mach number of the air before it reaches the combustor.
- Primary, secondary and tertiary injector holes through the combustor wall.
- Mach number through the holes to be of the order of 0.3, to provide sufficient penetration of the jets into the combustor.
- A slow moving recirculating ‘primary zone’ to enable fuel injected to mix sufficiently with the air to facilitate combustion and flame stabilisation.
- A secondary zone where further air is injected and combustion is completed.
- A tertiary zone where the remaining air is injected to quench the mean exit temperature to that required for entry to the turbine, and to control the radial and circumferential temperature traverse.
- Wall cooling systems.
- Fuel injectors or burners.
- Ignition system

Combustor Operation - Summary

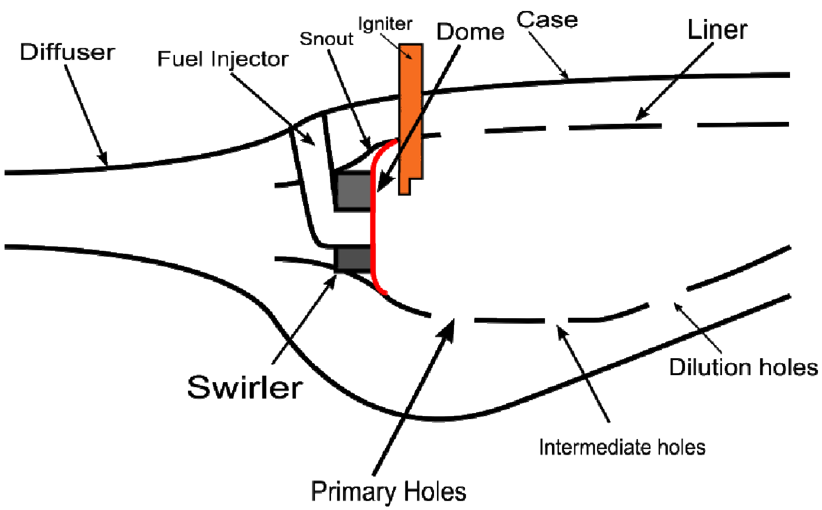
- Combustor receives high pressure and high temperature air from compressor at reduced Mach number (using diffuser at comp exit).
- Since overall air/fuel ratio is ~100: 1, while stoichiometric ratio is ~15: I, first essential is that the air should be introduced in stages.
- About 15-20% of air is introduced around the jet of fuel in *primary zone* to provide necessary high temperature for rapid combustion.
- Some 20 % of the total air is then introduced through holes in the flame-tube in the *secondary zone to complete the combustion.*
- *For high combustion efficiency, this* air must be injected carefully at the right points to avoid chilling the flame locally and drastically reducing the reaction rate in that neighbourhood.
- Part of the air is also used to cool liner walls (about 40%).
- Finally, in *tertiary or dilution zone,* remaining air is mixed with products of combustion to cool them down to the temperature required at inlet to the turbine.

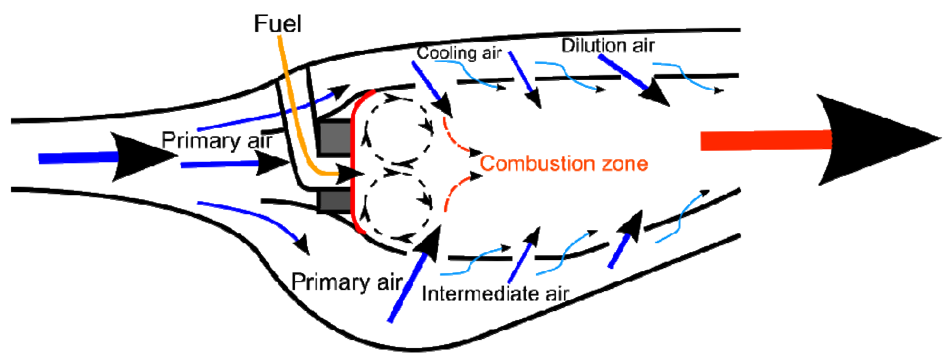
Combustor Operation - Summary

- Air flows in around the fuel nozzle and through the first row of combustion air holes in the liner.
- Fuel is introduced in the front of the combustor by fuel nozzles.
- Air entering the forward section of the liner tends to re-circulate and move upstream against the fuel spray.
- This re-circulating action permits rapid mixing between fuel and air and prevents flame blowout by forming a low-velocity stabilization zone that acts as a continuous pilot for rest of burner.
- After ignition, flame quickly spreads to the primary zone where there is approximately the correct proportion of air to completely burn the fuel.
- Air entering the downstream part of liner provides intense turbulence that is necessary for transferring energy from burned gases to unburned gases.
- It also controls the radial and circumferential temperature traverse and provides a mean exit temperature as required for entry to the turbine.
- Liner walls must also be protected from the high temperatures.

Components and Air Flow Paths of a Combustor

- **Components**
  - Case
  - Diffuser
  - Liner
  - Snout
  - Dome / Swirler
  - Fuel Injector
  - Fuel Ignitor
- **Air Flow Paths**
  - Primary air
  - Secondary or Intermediate air
  - Dilution air
  - Cooling air





Combustion Components

Case

- Case is the outer shell of the combustor, and is a fairly simple structure. The casing generally requires little maintenance.
- It is protected from thermal loads by the air flowing in it, so thermal performance is of limited concern.
- However, casing is like a pressure vessel that must withstand difference between high pressures inside the combustor and lower pressure outside. Therefore mechanical (rather than thermal) load is a driving design factor.

Diffuser

- It slows the high speed, highly compressed air from compressor to a velocity optimal for the combustor.
- Reducing the velocity results in an unavoidable loss in total pressure, so one of the design challenges is to limit the loss of pressure as much as possible. Furthermore, diffuser must be designed to limit the flow distortion as much as possible by avoiding flow effects like boundary layer separation.
- Like most other gas turbine engine components, diffuser is designed to be as short and light as possible.

Combustion Components (continued…)

Liner

- Liner contains the combustion process and introduces the various airflows (intermediate, dilution, and cooling) into the combustion zone.
- Liner must be designed and built to withstand extended high temperature cycles.
- Therefore, liners tend to be made from superalloys, but still, liners must be cooled with air flow.
- Some combustors use of thermal barrier coatings, but still need air cooling.

Dome / swirler

- Primary air flows through the dome and swirler. Their role is to generate turbulence in the flow to rapidly mix the air with fuel.
- Most modern designs are *swirl stabilized* (use swirlers).
- Swirlers establish a local low pressure zone that forces some of combustion products to recirculate, creating the high turbulence.
- However, higher the turbulence, higher the pressure loss, so dome and swirler must be carefully designed to generate only the required turbulence, that is needed to sufficiently mix the fuel and air.

Combustion Components (continued…)

Snout

It is an extension of the dome that acts as an air splitter, separating the primary air from the secondary air flows.

Fuel injector

Fuel injector is responsible for introducing fuel into the combustion zone.

Igniter

Most igniters in gas turbine applications are electrical spark igniters.

Igniter needs to be in the combustion zone where fuel and air are already mixed, but it needs to be far enough upstream so that it is not damaged by the combustion itself.

Once the combustion is initially started by the igniter, it is self-sustaining and the igniter is no longer used.

Air Flow Types

Primary air

- This is the main combustion air.
- It is highly compressed air from high pressure compressor (often decelerated via diffuser) that is fed through main channels in the dome of the combustor and the first set of liner holes.
- This air is mixed with fuel, and then combusted.

Intermediate air

- Air injected into the combustion zone through the second set of liner holes (primary air goes through the first set).
- This air completes the reaction processes, cooling the air down and diluting the high concentrations of carbon monoxide (CO) and hydrogen (H_2).

Air Flow Types (continued…)

Dilution air

- It is the airflow injected through holes in the liner at the end of the combustion chamber to help cool the air to before it reaches the turbine stages.
- The air is carefully used to produce the uniform temperature profile desired in the combustor.

Cooling air

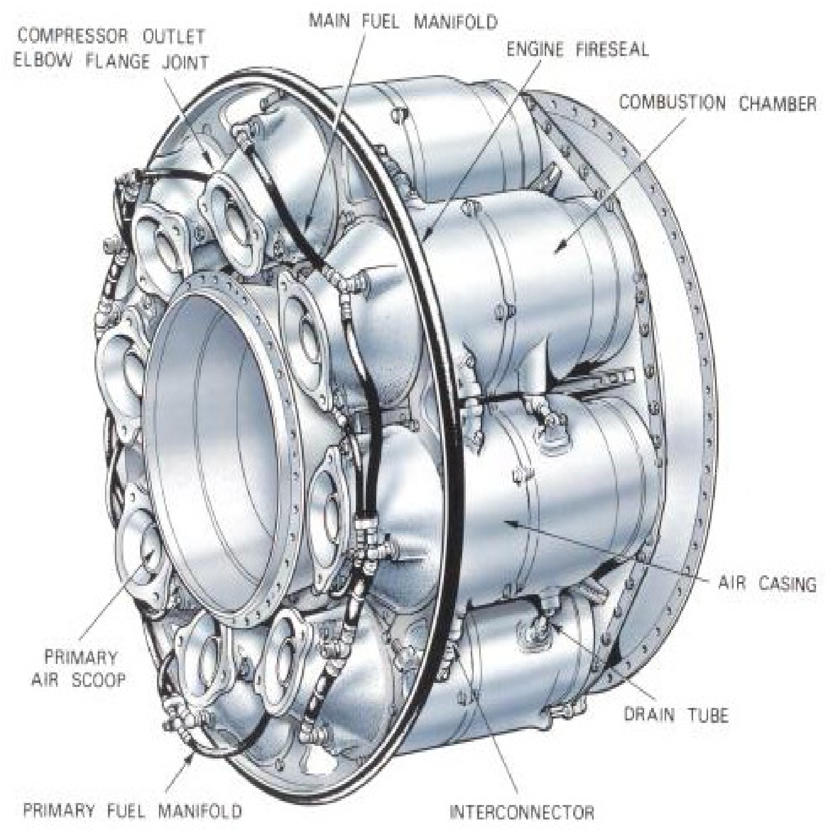
- Cooling air is airflow that is injected through small holes in the liner to generate a layer (film) of cool air to protect the liner from the combustion temperatures.
- Implementation of cooling air has to be carefully designed so it does not directly interact with the combustion air and process.
- In some cases, as much as 50% of inlet air is used as cooling air.
- There are several different methods of injecting this cooling air, and the method can influence the temperature profile that the liner is exposed to (see Liner, above).

Types Of Combustion Chambers

There are three basic types of burners:

1. CAN (or Tubular) Type Combustor
2. CANNULAR (can-annular or tubo - annular) Type Combustor.
3. ANNULAR Combustor

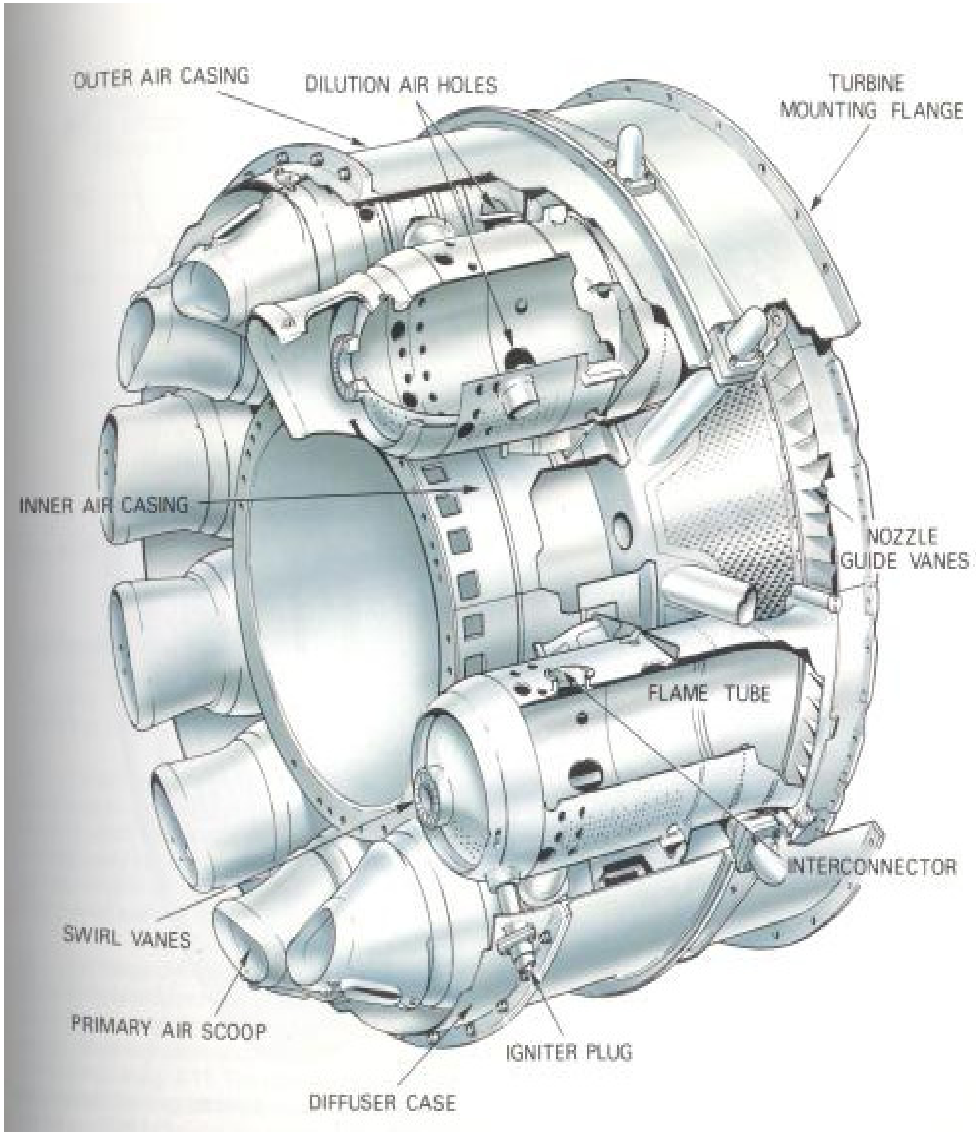
Can Type Combustion Chamber



- Early aircraft engines made use of *can (or tubular) type combustors,* in which air leaving the compressor is split into a number of separate streams, and each stream is directed by ducts to pass into individual chambers.
- These chambers are spaced around the shaft connecting the compressor and turbine, each chamber having its own fuel jet fed from a common supply line.
- This arrangement was well suited to engines with centrifugal compressors, where flow was divided into separate streams in the diffuser.

Can combustors are self-contained cylindrical combustion chambers.
Each "can" has its own fuel injector, igniter, liner, and casing.
Primary air from compressor is guided into each individual can, where it is decelerated, mixed with fuel, and then ignited.
Secondary air also comes from compressor, where it is fed outside of the liner (inside of which is where combustion is taking place). Secondary air is then fed, usually through slits in liner, into the combustion zone to cool liner via thin film cooling.

Cannular Combustion Chamber



A number of individual flame tubes are fitted (uniformly spaced) around a common annular casing.

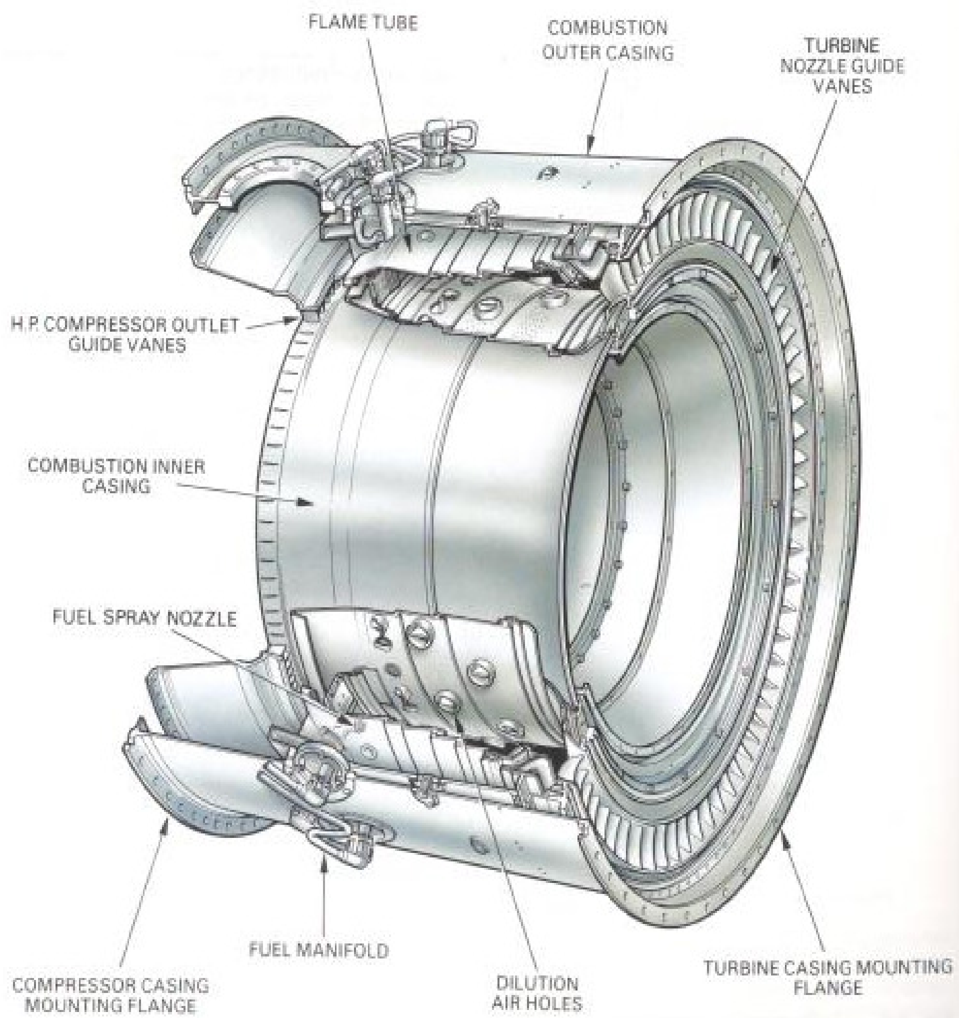
Bridges the gap between can and annular combustion chamber (can-annular).

Like the can type combustor, can-annular combustors have discrete combustion zones contained in separate liners with their own fuel injectors.

However, unlike the can combustor, all the combustion zones share a common ring (annulus) casing.

Each combustion zone no longer has to serve as a pressure vessel.

Annular Combustion Chamber



Consist of a single flame tube completely annular in form which is contained in an inner and outer casing.

Widely used combustion chamber .

Main advantage is that for the same power out put, the length is short (only 75% of can-annular).

Very good heat release rate with compact size.

Minimum pressure loss.

Elimination of combustion propagation problems from chamber to chamber.

Results in considerable saving of weight and production cost.

Advantages & Disadvantages of Different Combustor Types

Can Type Combustor

- In the can type combustor, individual burners or cans are mounted in a circle around the engine axis, with each one receiving air through its own cylindrical shroud.
- One of the main disadvantages of can type of combustor is that they do not make the best use of the available space and this results in a large diameter engine.
- On the other hand, the burners are individually removable for inspection, and it is easier to control fuel-to-air ratios than an annular combustor.
- Also, development could be carried out on a single can using only a fraction of the overall airflow and fuel flow.
- In aircraft application, however, can type combustor is undesirable in terms of weight, volume and frontal area – hence no longer used in current designs.

Advantages & Disadvantages of Different Combustor Types

Annular Combustor (Advantages)

- Annular combustor is essentially a single chamber made up of concentric cylinders mounted coaxially about the engine axis.
- This arrangement makes more complete use of available space within the specified diameter, has low pressure loss, fits well with axial compressor and turbine, and from a technical view point has the highest efficiency.
- Annular combustors have less surface-to-volume ratio than comparable can or can-annular combustors, hence less cooling air (by almost 15%) is required, which also helps to improve combustion efficiency.
- Burner weight is less, while at the same time, there is an improvement in combustor performance

Advantages & Disadvantages of Different Combustor Types

Annular Combustor (Disadvantages)

- Structural problems may arise due to the large diameter, thin-wall cylinder required with this type of combustor
- The problem is more severe for larger engines
- There is also some disadvantage in that the entire combustor must be removed from the engine for inspection and repair

Cannular (Can-Annular) Combustor

- Cannular design employs a number of individually replaceable cylindrical inner liners that receive air through a common annular housing for good control of fuel and airflow patterns.
- Makes good use of available space
- Has the added advantage of greater structural stability and lower pressure loss than that of can type.
- This arrangement combines the ease of overhaul and testing of can type with the compactness of the annular system.

A Note On – Why Can-Annular Type of Combustor

- Annular combustor has compact dimensions, higher efficiency, and lower pressure loss - hence more appealing.
- However, Annular Combustors presented some disadvantages, which led to the development of cannular combustors initially.
    - Firstly, although a large number of fuel jets can be employed, it is more difficult to obtain an even fuel/air distribution and an even outlet temperature distribution.
    - Secondly, annular chamber is inevitably weaker structurally and it is difficult to avoid buckling of hot flame tube walls.
    - Thirdly, most of the development work must be carried out on complete chamber, requiring a test facility capable of supplying full engine air mass flow, compared with testing of a single can in the can type layout.
- But these problems were vigorously attacked and annular combustors are now universally used in modem aircraft engines as the ideal configuration.

Combustion Chamber Performance Requirements

- **High Combustion Intensity:**
  - Heat released by a combustor is dependent on the volume of combustion area.
  - Thus, to obtain required high power output, a comparatively small and compact gas turbine combustion chamber must release heat at exceptionally high rates.
- **Stable Operation:**
  - Must provide freedom from blow-out at airflows ranging from idle to maximum power and at pressures representing the aircraft's entire altitude range.
- **High Combustion Efficiency:**
  - Necessary for improved fuel efficiency, lower fuel burn, and longer range for given amount of fuel.
- **Low Pressure Loss:**
  - It is desirable to have as high a pressure ratio as possible across exhaust nozzle in order to maximize the thrust.
  - Higher pressure loss in the combustor will reduce thrust and increase specific fuel consumption. Must be minimized.

Combustion Chamber Performance Requirements

- **Uniform Temperature Distribution:**
  - Average temperature of gases entering the turbine should be as close to the temperature limit of the burner material as possible to obtain maximum engine performance.
  - High local temperature or hot spots in gas stream will reduce the allowable average turbine inlet temperature to protect turbine.
- **Easy Starting and Re-starting:**
  - Low pressures and high velocity in the burner make starting difficult.
  - Therefore a poorly designed burner will start within only a small range of flight speeds and altitudes, whereas a well design burner will permit easier starts over a wider range.
  - In case of flame extinction, it should be possible to relight.
- **Small Size:**
  - Small size is desirable from a lower weight perspective, lower diameter, and a lower aerodynamic drag.

Combustion Chamber Performance Requirements

- **Low Smoke Burner:**
  - Smoke is annoying.
  - Allows easy tracking aircraft – not desirable for military aircraft.
- **Low Carbon Formation:**
  - Carbon deposits can also block critical air passages and disrupt airflow along the inner walls in the combustor, causing high metal temperature and low burner life.
  - Small particles carried into the turbine in the high velocity gas stream can erode the blades and can block cooling air passages.
- **Lower Pollutant Formation**
  - Combustion produces pollutants such as oxides of nitrogen (NOx), carbon monoxide (CO) and unburned hydrocarbons (UHC) and these must be controlled to very low levels.
- **Others:**
  - Flame tube and fuel spray nozzles should be mechanically reliable and have good structural integrity.
  - Must withstand corrosion due to the products of the combustion, and creep failure due to temperature gradients.
  - All requirements must be satisfied over a wide range of operating conditions (Temperature, Pressure, Mass flow, and fuel/air ratio).

Combustor Performance Parameters

<u>Main factors in assessing combustion chamber performance:</u>

- Combustion Intensity.
- Combustion Stability (stability limits)
- Pressure loss in the combustor
- Combustion efficiency
- Outlet temperature distribution
- Pollutant formation (smoke, carbon deposits, Nox, CO, and UHC)

Combustion Stability Limits

Combustion stability means smooth burning and ability of flame to remain alight over a wide range of operation.

There are both lean and rich limits to air/fuel ratio beyond which flame is extinguished.

An extinction is more likely to occur in flight during a glide or dive with engine idling when there is a comparatively high air flow and only a small fuel flow i.e a very weak mixture strength.

Operating range defined by the stability loop must cover the air/fuel ratios and mass flow of the combustion chamber.

Ignition has weak and rich limits similar to as shown for stability. Ignition loop, however, lies within stability loop as it is more difficult to establish combustion under ’cold’ conditions than to maintain normal burning.

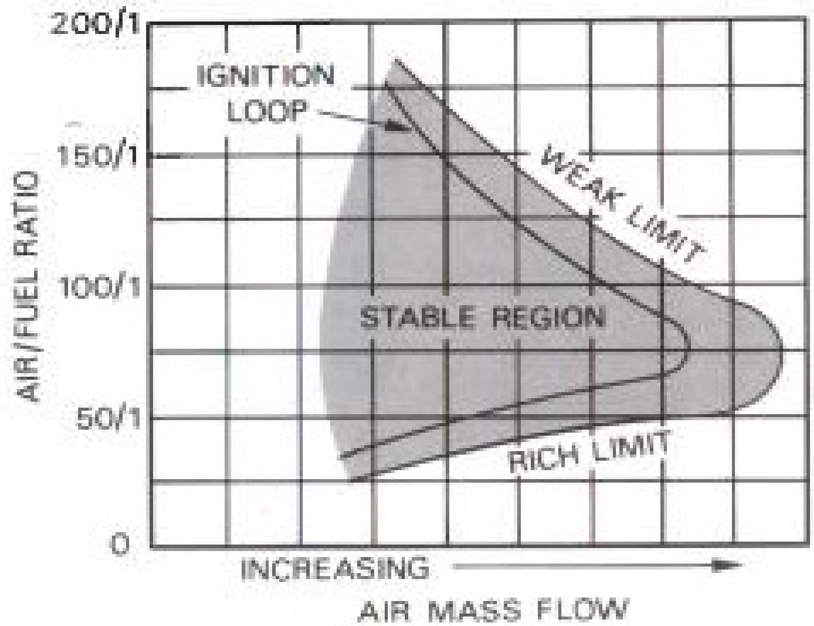
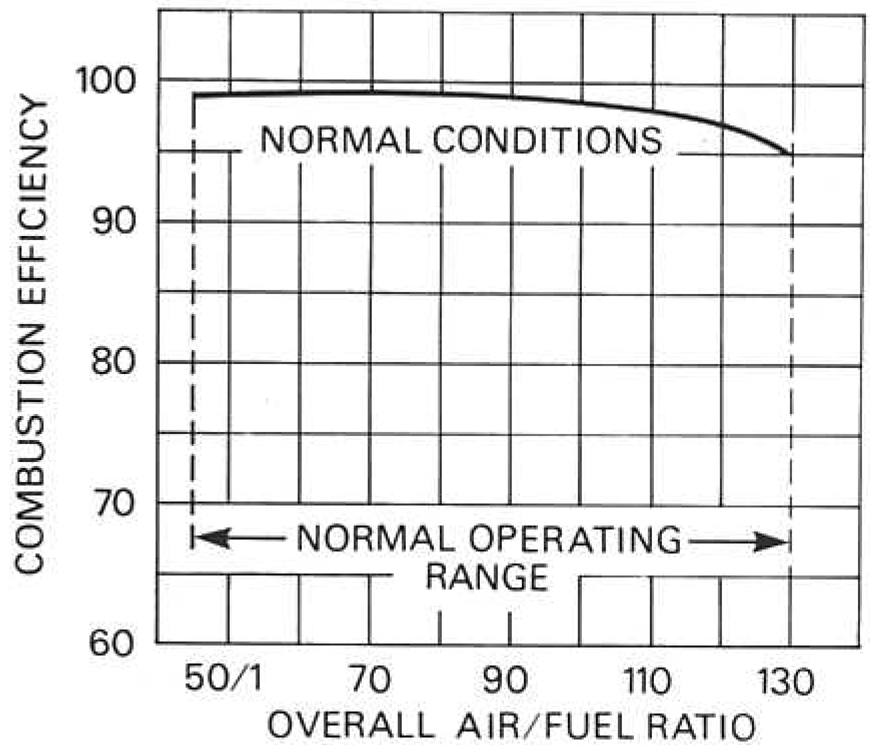


Fig. 4-11 Combustion stability limits.

Combustion Efficiency



Combustion efficiency of most gas turbine engines at sea-level take off conditions is almost 100 per cent, reducing to 98 per cent at altitude cruise conditions, as shown in adjoining figure.

Effect of Operating Variables on Burner Performance

The operating variables that affect the performance of gas turbine combustors are as follows:

- Pressure
- Inlet air temperature
- Fuel / air ratio
- Flow velocity / Mach number

Effect of Op Variables on Combustion Efficiency

- As the pressure of the air entering the combustor increases, combustion efficiency rises and levels off to a relatively constant value
- Pressure at which this leveling off occurs is usually about 1 atmosphere (atm), but this may vary somewhat with different combustor configurations
- As inlet temperature is increased, combustion efficiency rises until it reaches a value of substantially 100percent
- With increase in fuel/air ratio, combustion efficiency first increases, then levels off when the mixture in combustion zone is close to the ideal value, and then decreases as the fuel/air ratio becomes too rich

Effect of Op Variables on Combustion Efficiency

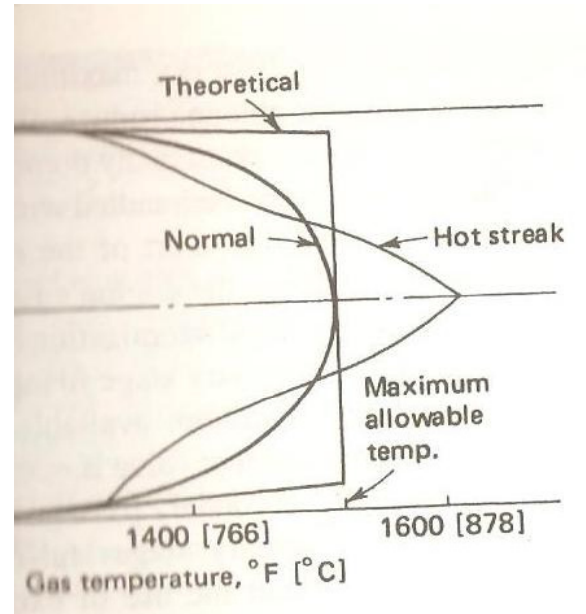
- An increase in fuel/ air ratio will result in increased pressure loss, because increasing fuel/air ratios cause higher temperatures with a corresponding decrease in gas density
- In order to maintain continuous flow, the gases must travel at higher velocities, and the energy needed to create higher velocities must come from an increase in pressure loss.
- Increasing the flow velocity beyond a certain point reduces combustion efficiency because it reduces the time available for mixing and burning.

Effect of Op Variables on Stable Operating Range

- The stable operating range of a combustor also changes with variations in pressure and flow velocity.
- As the pressure decreases, the stable operating range becomes narrower until a point is reached below which burning will not take place
- As the flow velocity increases, the stable operating range again becomes narrower until a critical velocity is reached, above which combustion will not take place
- In addition, as flow velocity is increased, the burner pressure loss will rise, mainly due to higher expansion losses, as the air flows through the restricting or metering holes in the liner.
- Increasing the temperature of the incoming charge usually increases the fuel/air ratio range for stable operation.

Effect of Op Variables on Temperature Distribution

- Temperature distribution of combustor exit is also affected by changes in the operating variables.
- Reducing the pressure below a set point tends to upset temperature uniformity
- With increase in fuel/air ratio and flow velocity, the exit temperatures tend to become less uniform because more heat is released, and there is less time for mixing.
- On the other hand, for a given size combustor, more uniform temperatures may be obtained by creating better mixing of cold and hot gases.



Effect of Op Variables on Starting

- Starting is usually easier with high temperature, high pressure, and low velocity.
- In addition, there is an optimum fuel/air ratio , above or below which ignition of fuel-air mixture is increasingly difficult
- Light up fuel/air ratio is determined based on low RPM engine test trials supplemented by analysis of starting characteristics
- Light up/Relight characteristics, Combustor stability, Temperature profile (radial and circumferential), Pressure loss, Efficiency, and Mechanical integrity are well assessed during altitude testing of the engine .

Effect of Op Variables on Carbon Deposits

- Operating variables have some effect on the accumulation of carbon deposits in the combustor, but their effect may vary with different types and configurations of the combustor.
- Generally deposits get worse with increasing temperatures and pressures, until a point is reached where they begin to burn off.
- Increase in fuel/air ratio has a tendency to increase deposits, probably because the proportion of oxygen in the combustion zone becomes too low to burn the fuel completely.
- In addition, changes in fuel/air ratios may change the location of carbon deposits within the combustor.
- Also properties of fuel have a significant effect on carbon accumulation and combustor performance and must be considered in the design of the combustor.

Effect of Op Variables on Temperature and Cooling Requirements

- Changes in operating variables have a direct effect on the temperature and cooling requirements of the liner.
- With increase in pressure and temperature of the incoming charge, more heat is transferred from the burning gases to the liner, partly by radiation through the insulating blanket of cool air and partly by forced convection, and the liner temperature goes up
- With increase in fuel/air ratio, combustion temperatures become higher, and again the liner temperature goes up, mainly due to radiation
- On the other hand, an increase in flow velocity outside the liner tends to increase external convection, thereby reducing the temperature of the liner

Effect of Design Factors on Burner Performance

The design factors that affect the performance of gas turbine combustors are as follows:

- Methods of air distribution
- Physical dimensions of burner
- Fuel-air operating range
- Fuel nozzle design

Operating variables that affect combustor performance:

- Pressure
- Inlet air temperature
- Fuel / air ratio
- Flow velocity / Mach number

Methods of Air Distribution

- Since the quantity of air required for efficient combustion is much less than total amount pumped through the engine, a correct distribution of between the combustion zone and the dilution zone is an important factor in combustor design.
- The manner in which the air is introduced into the burner also has a good effect on combustion efficiency.
- Therefore, the size, number, shape, and location of air inlet holes has a marked influence on burner performance.

Physical Dimensions of Burner

- One method of reducing pressure loss is to increase the diameter or length of the burner.
- This increase allows more time for the mixing of the hot and cold gases, leading to a reduced pressure loss.
- If the burner diameter is made too large, pressure loss may increase in order to produce adequate mixing and to provide sufficient cooling for the added liner surface area.
- If a greater proportion of air is used to cool the liner, an increased pressure loss results, since cooling air filtered in along the liner walls must be eventually mixed with the central high-temperature stream.

Fuel – Air Operating Range

- There are several ways in which the fuel/air ratio operating range or blowout limit of the burner can be increased.
  - Cut down flow velocity through the burner by increasing its diameter.
  - Increase fuel atomization and distribution by increasing the pressure drop across fuel nozzle.
  - Improve the manner in which the combustion air is introduced and distributed.
- Starting ability of a burner is related to its blowout limits. So increasing the blowout limits will also improve the starting.
- Life of burner to a large extent depends upon its operating temperature. Hence fuel/air ratio and cooling must be effectively controlled to maintain safe operation with minimum pressure loss.

Fuel Nozzle Design

- Fuel nozzle design plays a major role in burner performance.
- It must be able to atomize and distribute the fuel flow and must also be able to handle the wide range of fuel flows.
- For a given fuel system, there is a small pressure drop across the nozzle for good atomization.
- Gas turbines normally use a two stage fuel system. The primary stage functions at low fuel flows until a certain pressure is reached, at which a pressure sensitive vale opens and fuel begins to spray through the secondary passages as well.
- The total flow in the primary and secondary stages meets the engine fuel requirements without the use of excessive pressure drop and without a sacrifice in atomization qualities of fuel.

Combustor CFD

- Understanding of combustor performance parameters and design objectives
- Appreciation of design inputs from compressor(upstresam) and turbine (downstream)
- Appreciation of combustor geometry and cross section
- Knowledge of compressor and turbine interface dimensions
- Identification of combustor elements to be modelled
- Knowledge of boundary conditions and their settings
- Understanding of flight envelope as applicable to combustor design

Combustor CFD(contd)

- Knowledge of dynamic similarity parameters and scaling effects
- Understanding the CFD code
- Knowledge of input and output parameters of the code and where to obtain the input parameters
- Discretization of combustor geometry keeping the code inputs in view
- Correlation methodology of rig test results with CFD analysis
- **In the event of shortfall in performance. ability to look for corrective actions**

Rig Testing of Combustor

Rig testing of the combustor includes the following:

- Sectorial (90 degree) testing of the combustor; in this type of testing the mass flow requirements of the combustor will be less.
- Flow visualization test.
- In both of the above tests, the dynamic similarity parameters like Reynolds number and Mach number are simulated
- Full scale testing of the combustor in a specially built combustor test with detailed instrumentation and data acquisition

Rig Testing of Combustor (contd.)

- The parameters which are studied during rig testing of the combustor are:

  *Pressure loss

  *Temperature profile (both radial and circumferential)

  *Combustion efficiency

  *Combustor stability

- After establishing these parameters on the rig these are again correlated during full scale engine testing in sealevel test bed and altitude test facility

Materials

- The containing walls and internal parts of the combustion chamber must be capable of resisting the very high gas temperature in the primary zone.
- In practice, this is achieved by using the best heat resisting material available, the use of high heat resistant coatings and by cooling the inner wall of the flame tube as an insulation from the flame
- The combustion chamber must also withstand corrosion due to the products of combustion, and creep failure due to temperature gradients.

Closure

- All of the operating and design variables must be taken into account when the combustor is designed and manufactured .
- Final configuration of the combustor is a compromise to achieve the desired operating characteristics
- **Because:**
- it is impossible to design and manufacture a given combustion chamber that will have 100% combustion efficiency, zero pressure loss, perfect outlet temperature distribution, maximum life, minimum weight, and minimum frontal area, all at the same time.

End of Lecture

Which one of the following is favorable for an airplane operation?

(A) Tail wind in cruise and head wind in landing

(B) Tail wind both in cruise and landing

(C) Head wind both in cruise and landing

(D) Head wind in cruise and tail wind in landing

The mass flow rate of air through an aircraft engine is 10 kg/s.
The compressor outlet temperature is 400 K and the turbine inlet temperature is 1800 K.
The heating value of the fuel is 42 MJ/kg and the specific heat at constant pressure is 1 kJ/kg-K.
The mass flow rate of the fuel in kg/s is approximately

____

For a given inlet condition, if the turbine inlet temperature is fixed, what value of compressor efficiency given below leads to the lowest amount of fuel added in the combustor of a gas turbine engine?

(A) 1

(B) 0.95

(C) 0.85

(D) 0.8

A gas turbine engine is mounted on an aircraft which can attain a maximum altitude of 11 km from sea level. The combustor volume of this engine is decided based on conditions at

(A) sea level

(B) 8 km altitude

(C) 5.5 km altitude

(D) 11 km altitude

Consider two engines P and Q. In P, the high pressure turbine blades are cooled with a bleed of 5% from the compressor after the compression process and in Q the turbine blades are not cooled.

Comparing engine P with engine Q, which one of the following is NOT TRUE?

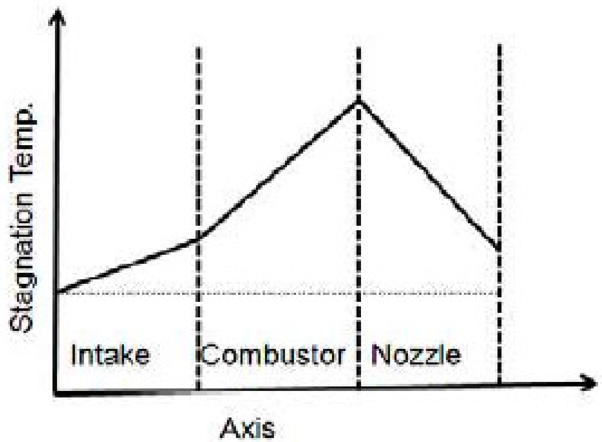
(A) Turbine inlet temperature is higher for engine P

(B) Specific thrust is higher for engine P

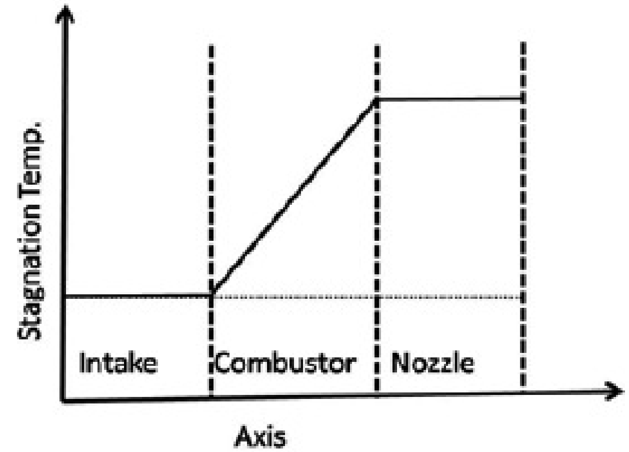
(C) Compressor work is the same for both P and Q

(D) Fuel flow rate is lower for engine P

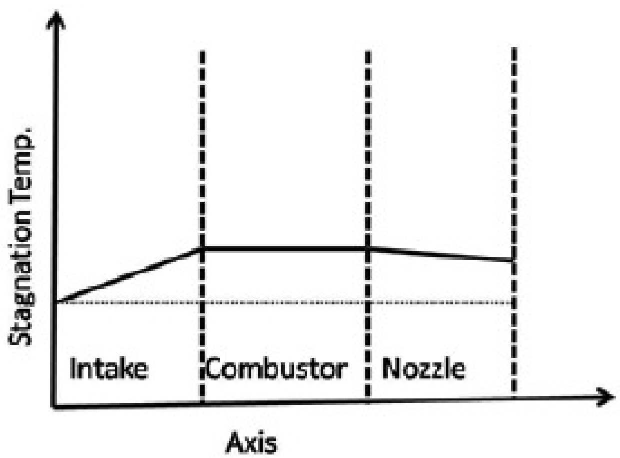
Which one of the following shows the CORRECT variation of stagnation temperature along the axis of an ideal ram jet engine?



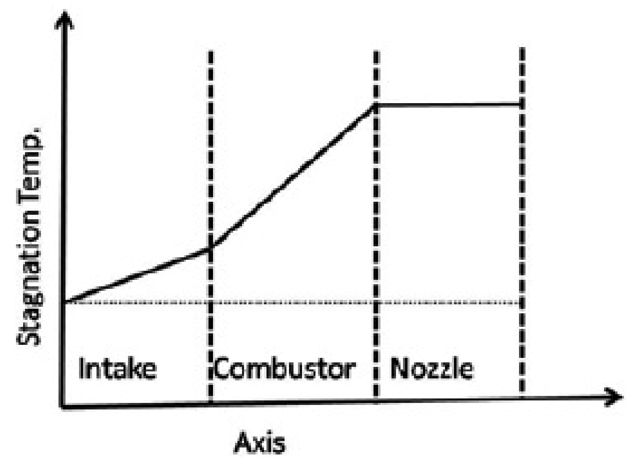
(A)



(B)



(C)



(D)

COMBUSTION PROCESS[cont.]

Around 20% of the compressed air is introduced around the jet of fuel known as the primary zone to provide the necessary high temperature for rapid combustion.

About 30 % of the compressed air is introduced through the holes in the flame tube in the secondary zone to complete the combustion process.

Finally in the tertiary or the dilution zone the remaining air is mixed with the products of combustion to cool them down to the temperature required at inlet to the turbine (turbine inlet temperature) . This temperature acceptable to the turbine Nozzle Guide Vanes (NGV) depends on the turbine material as well as the blade cooling technique.

Sufficient turbulence must be promoted so that the hot and cold streams are thoroughly mixed to give the desired outlet temperature distribution with no hot streaks which would damage the turbine blades.

IMPORTANT FACTORS AFFECTING COMBUSTOR DESIGN (Repeat Slide with Minor Variations)

Acceptable combustor outlet temperature to the turbine nozzle guide vanes.

Good temperature distribution so as to prevent local overheating of turbine blades.

Stable operation over a wide range fuel/air ratios from full load to idling conditions.

Formation of carbon deposits (coking) should be avoided.

Avoidance of smoke in the exhaust is of major importance.

Less pollution level namely production of oxides of nitrogen carbon monoxide (CO) and unburnt hydrocarbons (UHC).