Design and Analysis of Gas Turbine Combustion Chamber

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Abstract
The design and analysis of gas turbine combustion chamber is based on combined theoretical and empirical approach and the design of combustion chamber is a less than exact science. This paper presents the design of combustion chamber followed by three dimensional simulations to investigate the velocity profiles, species concentration and temperature distribution within the chamber and the fuel considered as Methane (CH4). The computational approach attempts to strike a reasonable balance to handle the competing aspects of complicated physical and chemical interactions of the flow. The modeling employs non-orthogonal curvilinear coordinates, second order accurate discretization, tetra grid iterative solution procedure and SST turbulence model. Accordingly, in present study an attempt has been made through CFD approach using ANSYS CFX 12 to analyze the flow pattern with in combustion and through air admission holes and from these the temperature distribution in the chamber walls as well as the temperature quality at the exit of combustion chamber is obtained.

Keywords: *Ansys, CATIA, CFD, Combustion Chamber, Empirical approach.*

I. INTRODUCTION

The development of the gas turbine engine as an aircraft power plant has been so rapid that it is difficult to appreciate that prior to the 1950s very few people had heard of this method of aircraft propulsion. The possibility of using a reaction jet had interested aircraft designers for a long time, but initially the low speeds of early aircraft and the unsuitably of a piston engine for producing the large high velocity airflow necessary for the 'jet' presented many obstacles.

II. PRINCIPLES OF JET PROPULSION

Jet propulsion is a practical application of Sir Isaac Newton's third law of motion which states that, 'for every force acting on a body there is an opposite and equal reaction'. For aircraft propulsion, the 'body' is atmospheric air that is caused to accelerate as it passes through the engine. The force required to give this acceleration has an equal effect in the opposite direction acting on the apparatus producing the acceleration. A jet engine produces thrust in a similar way to the engine/propeller combination. Both propel the aircraft by thrusting a large weight of air backwards (fig. 1), one in the form of a large air slipstream at comparatively low speed and the other in the form of a jet of gas at very high speed.

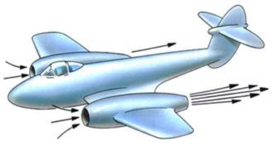


Fig.1 Thrusting aircraft by propel

This same principle of reaction occurs in all forms of movement and has been use fully applied in many ways. The earliest known example of jet reaction is that of Hero's engine (fig.2) produced as a toy in120 B.C. This toy showed how the momentum of seam issuing from a number of jets could impart an equal and opposite reaction to the jets themselves, thus causing the engine to revolve.

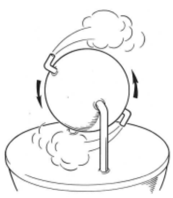


Fig.2 Toy propulsion

The familiar whirling garden sprinkler is a more practical example of this principle, for the mechanism rotates by virtue of the reaction to the water jets. The high pressure jets of modern firefighting equipment are an example of 'jet reaction', for often, due to the reaction of the water jet, the hose cannot be held or controlled by one fireman. Perhaps the simplest illustration of this principle is afforded by the carnival balloon which, when the air or gas is released, rushes rapidly away in the direction opposite to the jet.

Jet reaction is definitely an internal phenomenon and does not, as is frequently assumed, result from the pressure of the jet on the atmosphere. In fact, the jet propulsion engine, whether rocket, athodyd, or turbo-jet, is a piece of apparatus designed to accelerate a stream of air or gas and to expel it at high velocity. The engine is proportional to the mass or weight of air expelled by the engine and to the velocity change imparted to it. In other words, the same thrust can be provided either by giving a large mass of air a little extra velocity or a small mass of air a large exit velocity. In practice the former is preferred, since by lowering the jet velocity relative to the atmosphere a higher propulsive efficiency is obtained.

III. COMBUSTION CHAMBER

The combustion chamber (fig.3) has the difficult task of burning large quantities of fuel, supplied through the fuel spray nozzles, with extensive volumes of air, supplied by the compressor and releasing the heat in such a manner that the air is expanded and accelerated to give a smooth stream of uniformly heated gas at all conditions required by the turbine. This task must be accomplished with the minimum loss in pressure and with the maximum heat release for the limited space available. The amount of fuel added to the air will depend upon the temperature rise required. However, the maximum temperature is limited to within the range of 850 to 1700 deg. C. by the materials from which the turbine blades and nozzles are made. The air has already been heated to between 200 and550 deg. C. by the work done during compression, giving a temperature rise requirement of 650 to 1150 deg. C. from the combustion process. Since the gas temperature required at the turbine varies with engine thrust, and in the case of the turbo-propeller engine upon the power required, the combustion chamber must also be capable of maintaining stable and efficient combustion over a wide range of engine operating conditions. Efficient combustion has become increasingly important because of the rapid rise in commercial aircraft traffic and the consequent increase in atmospheric pollution, which is seen by the general public as exhaust smoke.

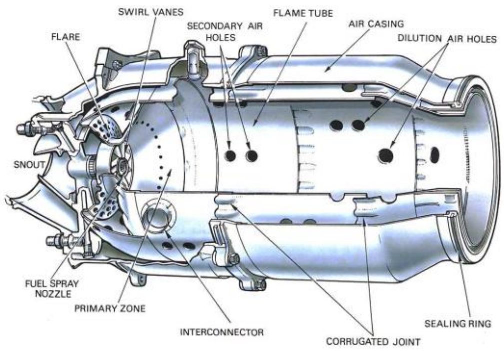


Fig.3 Combustion chamber

IV. COMBUSTION PROCESS

Air from the engine compressor enters the combustion chamber at a velocity up to 500 feet per second, but because at this velocity the air speed is far too high for combustion, the first thing that the chamber must do is to diffuse it, i.e. decelerate it and raise its static pressure. Since the speed of burning kerosene at normal mixture ratios is only a few feet per second, any fuel lit even in the diffused air stream, which now has a velocity of about 80 feet per second, would be blown away. A region of low axial velocity has therefore to be created in the chamber, so that the flame will remain alight throughout the of a combustion chamber can vary between 45:1 and130:1, However, kerosene will only burn efficiently at, or close to, a ratio of 15:1, 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 has various devices for metering the airflow distribution along the chamber.

Approximately 20 per cent of the air mass flow is taken in by the snout or entry section (fig.4).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 the flame tube and promotes the desired recirculation. The air not picked up by the snout flows into the annular
Space between the flame tube and the air casing.

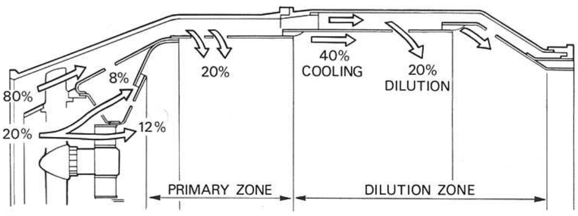


Fig.4 Airflow distribution along the chamber

Through the wall of the flame tube body, adjacent to the 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. The air from the swirl vanes and that from the secondary air holes interacts and creates a region of low velocity recirculation. This takes the form of a toroidal vortex, similar to a smoke ring, which has the effect of stabilizing and anchoring the flame (fig,5).The re-circulating gases hasten the burning of freshly injected fuel droplets by rapidly bringing them to ignition temperature.

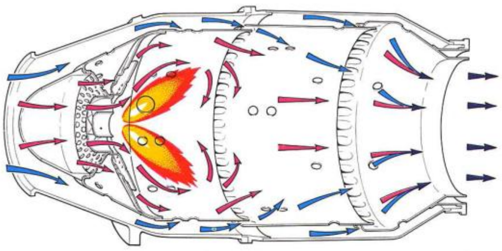


Fig.5 Smoke ring

It is arranged that the conical fuel spray from the nozzle intersects the recirculation vortex at its centre. This action, together with the general turbulence in the primary zone, greatly assists in breaking up the fuel and mixing it with the incoming air. The 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 the 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. A recent development allows cooling air to enter a network of passages within the flame tube wall before exiting to form an insulating film of air, this can reduce the required wall cooling airflow by up to 50 per cent. Combustion should be completed before the dilution air enters the flame tube, otherwise the incoming air will cool the flame and incomplete combustion will result.

1. Modeling using Catia

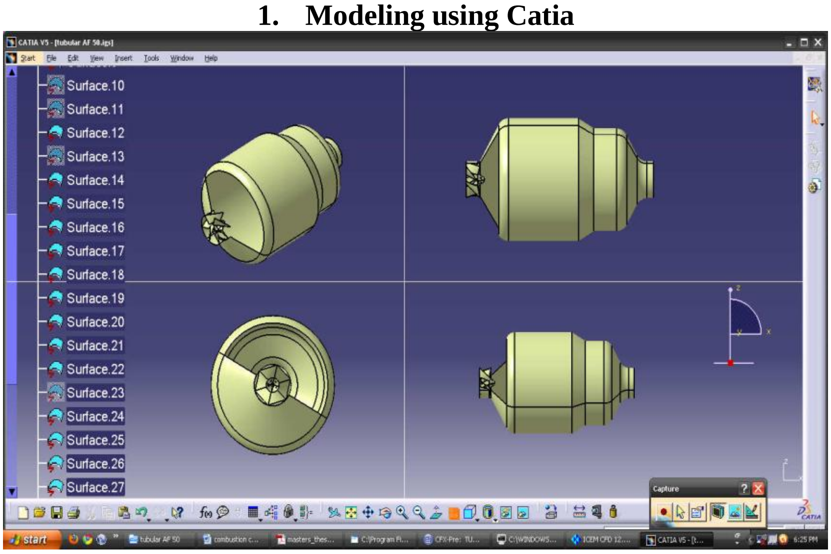


Fig.6 Combustion chamber model in Catia

2. Analysis by using Ansys

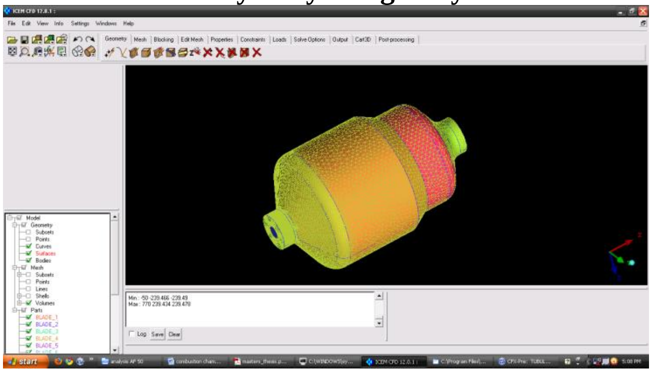
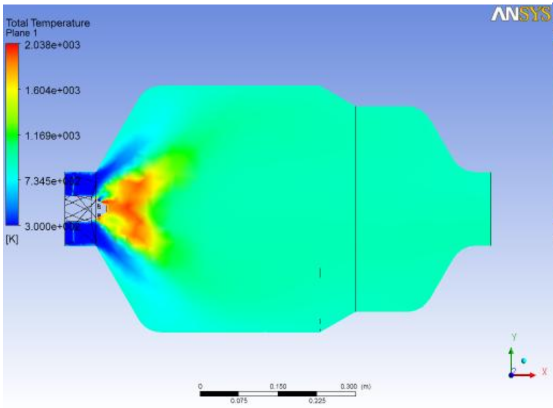


Fig.7 Mesh model of a can-annular combustion chamber

3. Results & Discussion



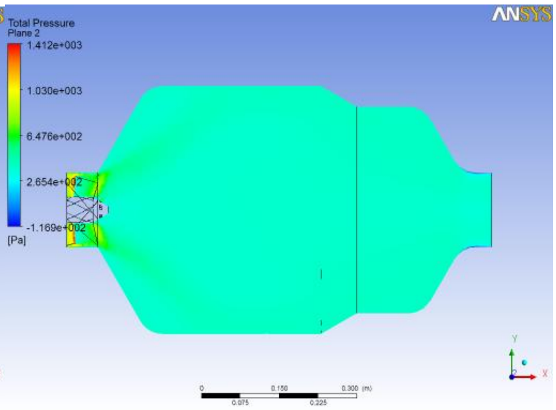
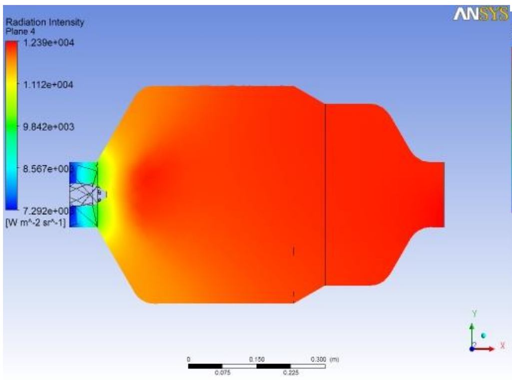


Fig.8 Total temperature   **Fig.9** Total pressure

Fig 8 indicates the pressure variations in the combustion chamber. The temperature within the combustion chamber is about 2500k .in the Fig 1 the blue colored region area indicates the air. The red colored region area indicates the reaction of air with fuel particles. This air is reacted with the fuel particles and produce large amount of heat. This heat is occupies the total combustor and comes out at outlet.

Fig.9 indicates the total pressure variation in the combustion chamber .according to this fig the total pressure throughout the combustion chamber is equal so the combustion chamber is in stable condition. The pressure at the boundaries of a combustion chamber is constant. so there is no much effect on the combustion chamber.



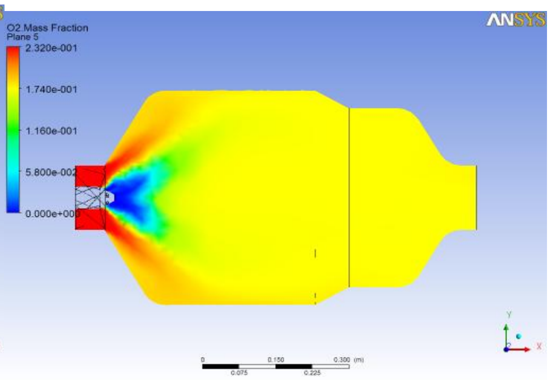


Fig.10 Radiation intensity   **Fig.11** Mass fraction

Fig.10 indicates the radiation intensity throughout the combustion chamber. The radiation intensity is constant on walls of a combustion chamber .the radiation intensity is increased from one end to another end. The intensity at collision of air and fuel particles is minimum and it will be increased to end. At the end of a chamber the intensity is maximum. The red color region area indicates the radiation intensity.

Fig.11 indicates the oxygen mass fraction. The oxygen is entered from the air inlets. In air 21% oxygen is present this oxygen is react with the fuel which is comes from the fuel inlets. The combustion process is takes places because of this oxygen. The red colored region indicates the oxygen concentration. The blue colored region is fuel .the concentration of air is decreased because of combustion process.

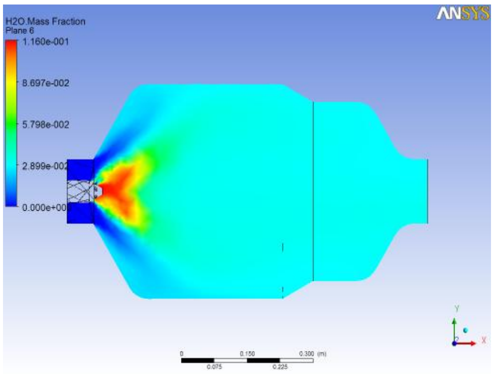


Fig.12 H_2O mass fraction

Fig.12 indicates the water mass fraction in the air. The water mass fraction is gradually decreased in the combustion chamber because of combustion process. The blue colored region area is indicates the water in air .this H2O comes from the air inlets with air. The concentration of water molecules is decreased because large amount of heat is produced during the combustion process so the water molecules are evaporated easily.

The temperature of the gas has increased to approximately 2500 K which may leads to combustion process. Pattern factor lies in between 0.025-0.3 and pressure loss should be below 8% for good combustion process.

V. CONCLUSION

The above analysis reaches to the following conclusions mentioned below:

- The static temperature is very high in the regions where combustion takes place and goes on decreasing towards the outlet. The maximum temperature reached is 2500 K which indicates that there is efficient combustion process.
- The turbulent intensity is high in the immediate vicinity of the ramp injector indicating a superior air-fuel mixing. It is of the order of 60000% with respect to the turbulent intensity at the inlet. A very high turbulent intensity indicates a superior air-fuel mixing. The high value of mass fraction of NO formed indicates an efficient combustion process.
- The sudden rise in temperature observed near the tip of the injector indicates the generation of shocks which help in superior air-fuel mixing. Superior air-fuel mixing resulting in better quality of combustion and thus better performance. As predicted, the results obtained from this study show an enhanced air-fuel mixing and a proper combustion which can be attributed to the geometry of the ramp injector considered in this study.

  However in has to be in process the outlet temperature has to maintain pattern factor below 0.3 and at the same pressure loss should be less than 8%.

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