Design and Analysis of Gas Turbine Combustion Chamber

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***Abstract*—A combustor is a component or area of a gas turbine, ramjet, or scramjet engine where combustion takes place. It is also known as a burner, combustion chamber or flame holder. In a gas turbine engine, the combustor or combustion chamber is fed high-pressure air by the compression system. The combustor then heats this air at constant pressure as the fuel/air mix burns. As it burns the fuel/air mix heats and rapidly expands. The burned mix is exhausted from the combustor through the nozzle guide vanes to the turbine. In the case of a ramjet or scramjet engines, the exhaust is directly fed out through the nozzle.**

A combustor must contain and maintain stable combustion despite very high air flow rates. To do so combustors are carefully designed to first mix and ignite the air and fuel, and then mix in more air to complete the combustion process

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.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 combustion chamber is designed according to the ic engine specifications and analysed for its heat transfer rate using Finite Element analysis software ANSYS. Modelling will be done in CREO 3.0 parametric software. CFD analysis to determine the pressure drop, velocity, heat transfer rate and mass flow rate with different fluids (ethanol, methanol, Ethelene, propyl and gasoil).

Thermal analysis is to determine the heat transfer rate per unit area i.e., heat flux and temperature distribution for two materials steel and cast iron.

***Indexed Terms*—combustor, ramjet, three dimensional simulations, velocity profile, ANSYS etc.**

I. INTRODUCTION

A combustor is a component or area of a gas turbine, ramjet, or scramjet engine where combustion takes place. It is also known as a burner, combustion chamber or flame holder. In a gas turbine engine, the combustor or combustion chamber is fed high pressure air by the compression system. The combustor then heats this air at constant pressure. After heating, air passes from the combustor through the nozzle guide vanes to the turbine. In the case of a ramjet or scramjet engines, the air is directly fed to the nozzle.

A combustor must contain and maintain stable combustion despite very high air flow rates. To do so combustors are carefully designed to first mix and ignite the air and fuel, and then mix in more air to complete the combustion process. Early gas turbine engines used a single chamber known as a can type combustor. Today three main configurations exist: can, annular and cannular (also referred to as can-annular tubo- annular). Afterburners are often considered another type of combustor.

Combustors play a crucial role in determining many of an engine's operating characteristics, such as fuel efficiency, levels of emissions and transient response (the response to changing conditions such as fuel flow and air speed).

The objective of the combustor in a gas turbine is to add energy to the system to power the turbines, and produce a high velocity gas to exhaust through the nozzle in aircraft applications. As with any engineering challenge, accomplishing this requires balancing many design considerations, such as the following:

Completely combust the fuel. Otherwise, the engine wastes the unburnt fuel and creates unwanted emissions of unburnt hydrocarbons, carbon monoxide (CO) and soot.

Low pressure loss across the combustor. The turbine which the combustor feeds needs high pressure flow to operate efficiently.

The flame (combustion) must be held (contained) inside of the combustor. If combustion happens further back in the engine, the turbine stages can easily be overheated and damaged. Additionally, as turbine blades continue to grow more advanced and are able to withstand higher temperatures, the combustors are being designed to burn at higher temperatures and the parts of the combustor need to be designed to withstand those higher temperatures.

It should be capable of relighting at high altitude in an event of engine flame-out.\
Uniform exit temperature profile. If there are hot spots in the exit flow, the turbine may be subjected to thermal stress or other types of damage. Similarly, the temperature profile within the combustor should avoid hot spots, as those can damage or destroy a combustor from the inside.

Small physical size and weight. Space and weight is at a premium in aircraft applications, so a well designed combustor strives to be compact. Non-aircraft applications, like power generating gas turbines, are not as constrained by this factor.

Wide range of operation. Most combustors must be able to operate with a variety of inlet pressures, temperatures, and mass flows. These factors change with both engine settings and environmental conditions (I.e., full throttle at low altitude can be very different from idle throttle at high altitude).

Environmental emissions. There are strict regulations on aircraft emissions of pollutants like carbon dioxide and nitrogen oxides, so combustors need to be designed to minimize those emissions. (See Emissions section below)

II. COMPONENTS

- Case

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

- Diffuser

The purpose of the diffuser is to slow the high speed, highly compressed, air from the 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, the 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, the diffuser is designed to be as short and light as possible.

- Liner

The liner contains the combustion process and introduces the various airflows (intermediate, dilution, and cooling, see Air flow paths below) into the combustion zone. The liner must be designed and built to withstand extended high temperature cycles. For that reason liners tend to be made from superalloys like Hastelloy X. Furthermore, even though high performance alloys are used, the liners must be cooled with air flow.

- Snout

The snout is an extension of the dome (see below) that acts as an air splitter, separating the primary air from the secondary air flows (intermediate, dilution, and cooling air; see Air flow paths section below).

- Dome / swirler

The dome and swirler are the part of the combustor that the primary air (see Air flow paths below) flows through as it enters the combustion zone. Their role is to generate turbulence in the flow to rapidly mix the air with fuel. Early combustors tended to use bluff body domes (rather than swirlers), which used a simple plate to create wake turbulence to mix the fuel and air. Most modern designs, however, are swirl stabilized (use swirlers).

- Fuel injector

The fuel injector is responsible for introducing fuel to the combustion zone and, along with the swirler (above), is responsible for mixing the fuel and air.

There are four primary types of fuel injectors; pressure-atomizing, air blast, vaporizing, and premix/prevaporizing injectors.[8] Pressure atomizing fuel injectors rely on high fuel pressures (as much as 3,400 kilopascals (500 psi)) to atomize the fuel. This type of fuel injector has the advantage of being very simple, but it has several disadvantages. The fuel system must be robust enough to withstand such high pressures, and the fuel tends to be heterogeneously atomized, resulting in incomplete or uneven combustion which has more pollutants and smoke.

- Igniter

Most igniters in gas turbine applications are electrical spark igniters, similar to automotive spark plugs. The igniter needs to be in the combustion zone where the fuel and air are already mixed, but it needs to be far enough upstream so that it is not damaged by the combustion itself

III. MODELING AND ANALYSIS

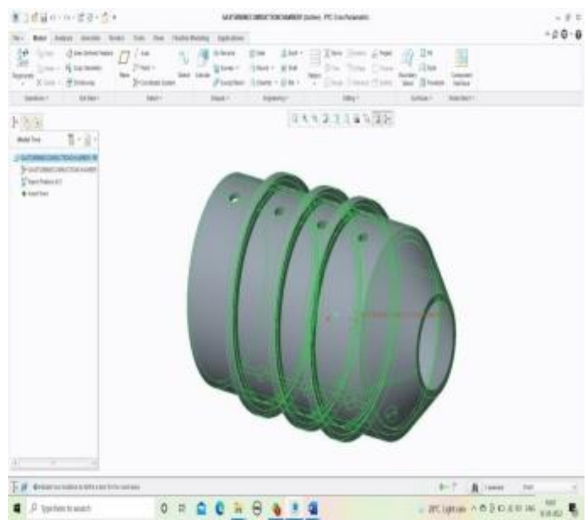
Computer-aided design (CAD) is the use of computer systems (or workstations) to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations. The term CADD (for Computer Aided Design and Drafting) is also used.

- CAD/CAM Software

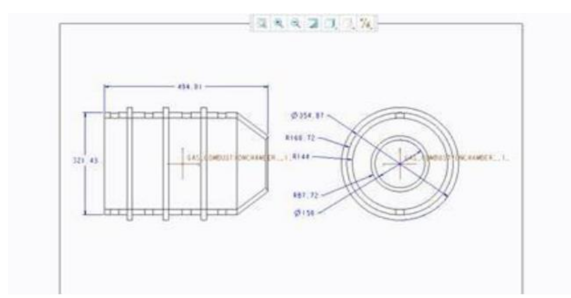
Software allows the human user to turn a hardware configuration into a powerful design and manufacturing system. CAD/CAM software falls into two broad categories,2-D and 3-D, based on the number of dimensions are called 2-D representations of 3-D objects is inherently confusing. Equally problem has been the inability of manufacturing personnel to properly read and interpret complicated 2-D representations of objects. 3-D software permits the parts to be viewed with the 3-D planes-height, width, and depth-visible. The trend in CAD/CAM is toward 3-D representation of graphic images. Such representation approximates the actual shape and appearance of the object to be produced; therefore, they are easier to read and understand.

- CREO

PTC CREO, formerly known as Pro/ENGINEER, is 3D modeling software used in mechanical engineering, design, manufacturing, and in CAD drafting service firms. It was one of the first 3D CAD modeling applications that used a rule-based parametric system. Using parameters, dimensions and features to capture the behavior of the product, it can optimize the development product as well as the design itself.



3D model of gas turbine combustion chamber



model of gas turbine combustion chamber

FEA

Finite element analysis is a method of solving, usually approximately, certain problems in engineering and science. It is used mainly for problems for which no exact solution, expressible in some mathematical form, is available. As such, it is a numerical rather than an analytical method. Methods of this type are needed because analytical methods cannot cope with the real, complicated problems that are met with in engineering. For example, engineering strength of materials or the mathematical theory of elasticity can be used to calculate analytically the stresses and strains in a bent beam, but neither will be very successful in finding out what is happening in part of a car suspension system during cornering.

ANSYS

- Structural Analysis

ANSYS Autodyn is computer simulation tool for simulating the response of materials to short duration severe loadings from impact, high pressure or explosions.

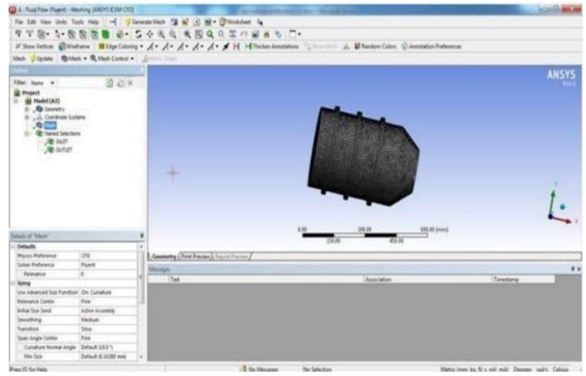
- ANSYS Mechanical

ANSYS Mechanical is a finite element analysis tool for structural analysis, including linear, nonlinear and dynamic studies. This computer simulation product provides finite elements to model behavior, and supports material models and equation solvers for a wide range of mechanical design problems. ANSYS Mechanical also includes thermal analysis and coupled-physics capabilities involving acoustics, piezoelectric, thermal–structural and thermo-electric analysis.

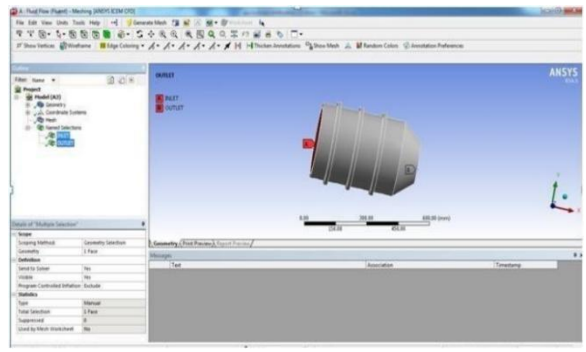
- Fluid Dynamics

ANSYS Fluent, CFD, CFX, FENSAP-ICE and related software are Computational Fluid Dynamics software tools used by engineers for design and analysis. These tools can simulate fluid flows in a virtual environment — for example, the fluid dynamics of ship hulls; gas turbine engines (including the compressors, combustion chamber, turbines and afterburners); aircraft aerodynamics; pumps, fans, HVAC systems, mixing vessels, hydro cyclones, vacuum cleaners, etc.

IV. CFD ANALYSIS OF GAS TURBINE COMBUSTION CHAMBER

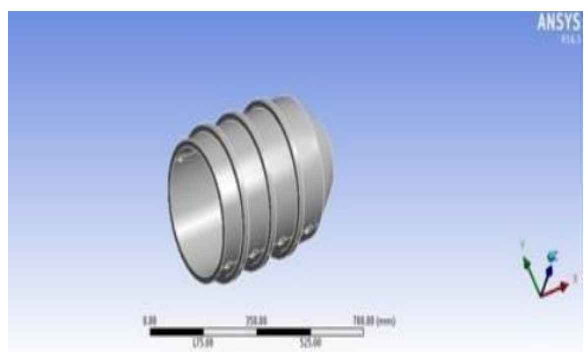


MESHED MODEL

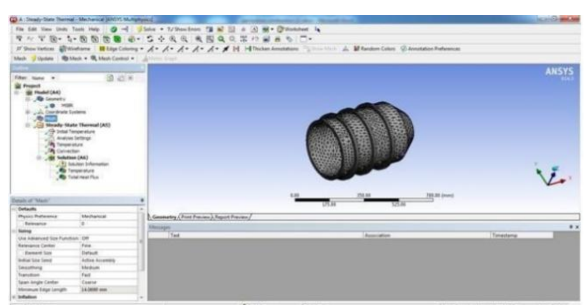


SPECIFYING THE BOUNDARIES FOR INLET & OUTLET

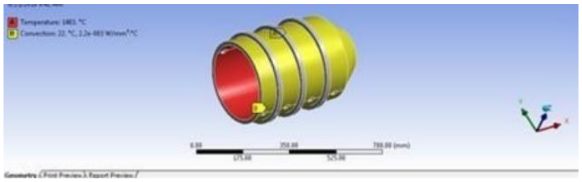
V. THERMAL ANALYSIS OF GAS TURBINE COMBUSTION CHAMBER



Imported model



Meshed model



Boundary conditions

VI. CONCLUSION

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), Ethane and gasoil.

By observing the CFD analysis the heat transfer coefficient value maximum at ethane fluid when we compare methane and gasoil.

By observing the thermal analysis the heat flux value maximum at ceramic material when we compare the cast iron and steel.

So it can be concluded the better fluid ethane and ceramic material better material for gas turbine combustion chamber

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