IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 15, Issue 4 Ver. II (Jul. - Aug. 2018), PP 05-17
www.iosrjournals.org

Structural And Thermal Analysis of Aircraft Combustion Chamber Outer Case

Raghuram Pradhan[1], Sukumar Puhan[2], M.Sreenivasan[3]
[1, 2&3]*(Professor, Mechanical Engineering Department, PACE Institute of Technology and Sciences, India)*
Corresponding Author:RaghuramPradhan

Abstract : *The objective of this paper is to make a 3D model of the Combustion chamber outer case and study the structural and thermal behavior of the Combustion chamber outer case by performing the finite element analysis. SOLIDWORKS and 3D modeling software (UNIGRAPHICS NX) was used for designing and analysis software (ANSYS) was used for thermal and structural analysis.*

Keywords:*Combustion chamber, Finite Element Method (FEM) or Boundary Element Method (BEM), SOLIDWORKS,ANSYS, VonMoises stress, Thermal flux & Thermal Gradient.*

Date of Submission: 02-07-2018 Date of acceptance: 21-07-2018

I. Introduction

The Supersonic Combustion Ramjet (SCRAMJET) engine has been recognized as the most promising air breathing propulsion system for the hypersonic flight (Mach number > 5). In recent years, the research and development of scramjet engine has promoted the study of combustion in supersonic flows. Extensive research is being carried out over the world for realizing the scramjet technology with hydrogen fuel with significant attention focused on new generations of space launchers and global fast-reaction reconnaissance missions. However, application for the scramjet concept using high heat sink and hydrogen fuels offers significantly enhanced mission potential for future military tactical missiles. Scramjet being an air-breathing engine, the performance of the missile system based on the scramjet propulsion is envisaged to enhance the payload weight and missile range. Supersonic combustion ramjet engine for an air-breathing propulsion system has been realized and demonstrated by USA on ground and in flight X-43 vehicle used hydrogen fuel. Hydrocarbon fuel scramjet engine is still under study and research.

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.

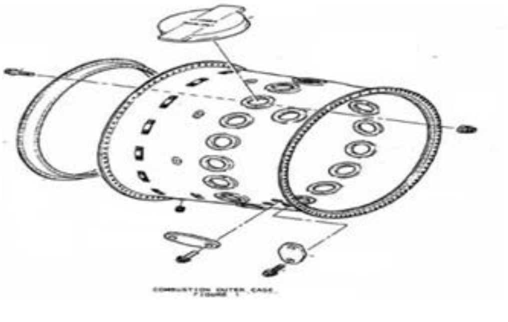


Fig.1 Aero planecombustion outer case

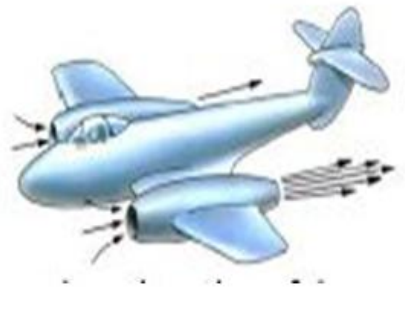


Fig.2 Thrusting aircraft by propel

1.2 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.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.

1.3 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.Combustion chambers environments present high levels of acoustic noise. Bunrley and Culick (1997) described that this can be verified when the power spectrum of the acoustic pressure levels, measured during burning tests of the chambers, is analyzed. When an oscillation is observed, i.e., combustion instability, sound pressure peaks with well-defined magnitudes summed to the background noise are present.

These peaks are correlated with the resonance frequencies of the combustion chambers cavities, where the sound pressure on each position of the acoustic fluid space represent the environment oscillation, attributed to the acoustic modes of these cavities. Such a way occurs the coupling of the acoustic natural frequencies and the burning oscillations of the combustion chamber, which can cause instabilities and consequent unexpected behaviour such as efficiency loss or even explosion of the engine. These types are also possible to occur. The tangential and radial modes are the most dangerous to high frequency instabilities (Yang, Wicker and Yoon, 1994). The three basic types of acoustic modes of a cylinder representing a LRE combustion chamber are shown in Fig. 3.

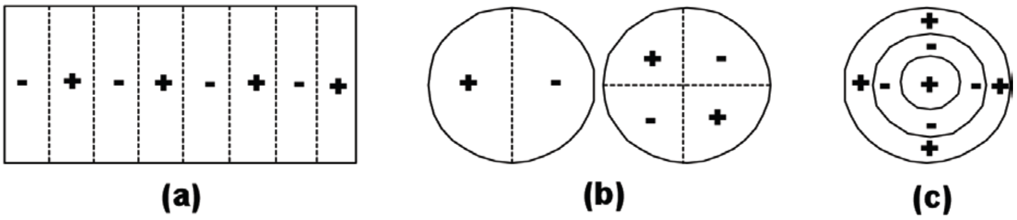


Fig. 3: Longitudinal (a), tangential (b) and radial modes (c).

Some works showed that the acoustic behavior of a combustion chamber is weakly affected by the combustion process. Comparing to room pressure and temperature conditions, the chamber cavity mode shapes remain basically the same, but its Eigen frequencies are shifted, actually multiplied by a number defined by the ratio of sound speed velocity at real operation temperature and at room temperature (Laudien et al., 1994).In the development of a liquid rocket engine of 75 KN thrust by the Institute of Aeronautics and Space (IAE), the acoustic behavior of the combustion chamber is being considered. An investigation of some different combustion chambers is proposed. These studies may be done in two steps, using theoretical calculation and experimental measurements. As such, theoretical and experimental natural frequencies of the acoustic cavity are obtained, and a comparison/validation of the mathematical model can be done.

First, considering the geometry of the combustion chamber and the physical parameters of air, natural frequencies of this cavity are calculated theoretically. The acoustic frequencies can also be obtained by using a test setup to measure the sound pressure levels of this acoustic domain. A third possible method to obtain the acoustic behavior of combustion chambers is by modeling the cavity using numerical methods such as the Finite Element Method (FEM) or the Boundary Element Method (BEM). As such, by applying virtual prototypes' techniques, besides calculating the resonance, the associated acoustic mode shapes are obtained. With these three methods, theoretical versus experimental comparisons can be carried out for the validation of the existing models.

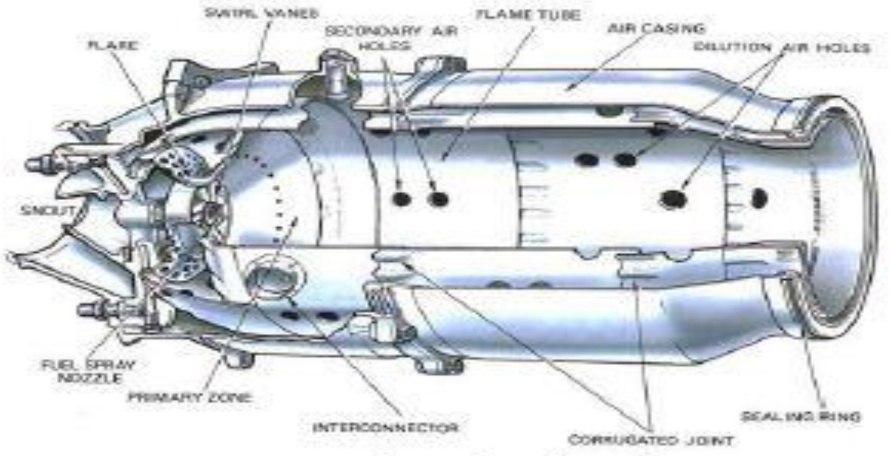


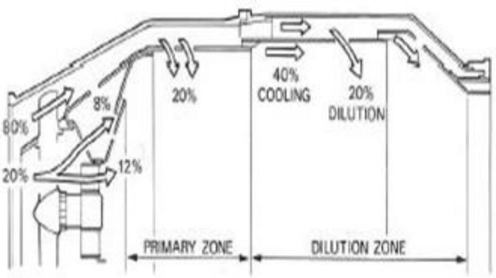
Fig.4 Combustion chamber

Since a combustion acoustic instability (and the acoustic mode to which it is related) is identified, some measures can be taken to avoid or minimize it. Some design parameters in the combustion chamber and injector play an important role in high frequency combustion instabilities. By changing these parameters, one can obtain a design less susceptible to this kind of instabilities (Huzel and Huang, 1992). Also, passive acoustic devices for the attenuation of acoustic noise, as Helmholtz resonators, liners, baffles and ¼ wave filters can be introduced in the combustion chamber (Santana Junior et al., 2009).It is important to mention that, in the latter stages of this survey, numerical methods for modelling acoustics of chambers as well as insulation treatments for attenuating acoustic noises will be presented. Currently, only comparisons between theoretical *versus* experimental results, using simple mathematical models and measured frequency response functions, respectively, are carried out for different configurations of a combustion chamber.

1.4 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.5).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.



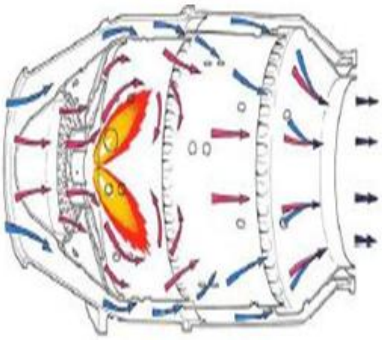


Fig.5 Airflow distribution along the chamberFig.6 Smoke ring

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.6).The re-circulating gases hasten the burning of freshly injected fuel droplets by rapidly bringing them to ignition temperature.

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.

II. Methodology

2.1. SOFTWAREUSED (SOLID WORKS & IT'BENEFITS)

The SOLIDWORKSCAD software is a mechanical design automation application that lets designers quickly sketch out ideas, experiment with features and dimensions, and produce models and detailed drawings. This document discusses concepts and terminology used throughout the SOLIDWORKS application. It familiarizes you with the commonly used functions of SOLIDWORKS.

a. Unsurpassed geometry creation capabilities allow superior product differentiation and manufacturability, b. Fully integrated applications allow you to develop everything from concept to manufacturing within one application,c. Automatic propagation of design changes to all downstream deliverables allows you to design with confidence,d. Complete virtual simulation capabilities enable you to improve product performance and exceed product quality goals, e. Automated generation of associative tooling design, assembly instructions, and machine code allow for maximum production efficiency.

SOLID WORKS can be packaged in different versions to suit your needs, from SOLID WORKS 1995 to 2018 Package. From robust part modeling to advanced surfacing, powerful assembly modeling and simulation, your needs will be met with this scalable solution. Flex3C and Flex Advantage Build on this base offering extended functionality. The main modules are Part Design, Assembly and Drawing.

III. Problem Definition And Methodology

- ✓ Create a 3D model of the Combustion chamber outer case using SOLID WORKS software and it is converted into parasolid file and import into ANSYS to do finite element analysis.
- ✓ Perform thermal analysis on the Combustion chamber outer case for thermal loads.
- ✓ Perform static analysis on the existing model of the Combustion chamber outer case for pressure loads and thermal loads to find deflections and stress, optimized if enquired.
- ✓ Based on the above results, design changes are implemented to reduce the stresses and deflections.
- ✓ Develop modified model of the Combustion chamber outer case using SOLID WORKS software, and import it to ANSYS software.

- ✓ Perform thermal analysis on the modified Combustion chamber outer case for thermal loads.
- ✓ Perform static analysis on the modified Combustion chamber outer case for pressure loads and thermal loads to find deflections and stress.
- ✓ Perform Modal analysis to find natural frequencies on the existing model of the Combustion chamber.
- ✓ From the Modal analysis results, the natural frequencies, mode shapes and their mass participations of the Combustion chamber outer case are plotted and checked if any natural frequencies are present in the operating range of the Combustion chamber router case and critical frequencies are identified.
- ✓ From the Harmonic analysis results, the operating frequencies are cheeked with the critical frequencies and documented the deflections and stresses values of critical frequencies.

3.1 3D MODELING OF COMBUSTION CHAMBER OUTER CASE

3D modeling software (SOLID WORKS) was used for designing of Oil pan model. Oil pan has been designed for internal pressures loading. SOLID WORKS is used in a vast range of industries from manufacturing of rockets to computer peripherals. With more than one lakh seats installed in worldwide many CAD users are exposed to NX and enjoy using NX for its power and capability.

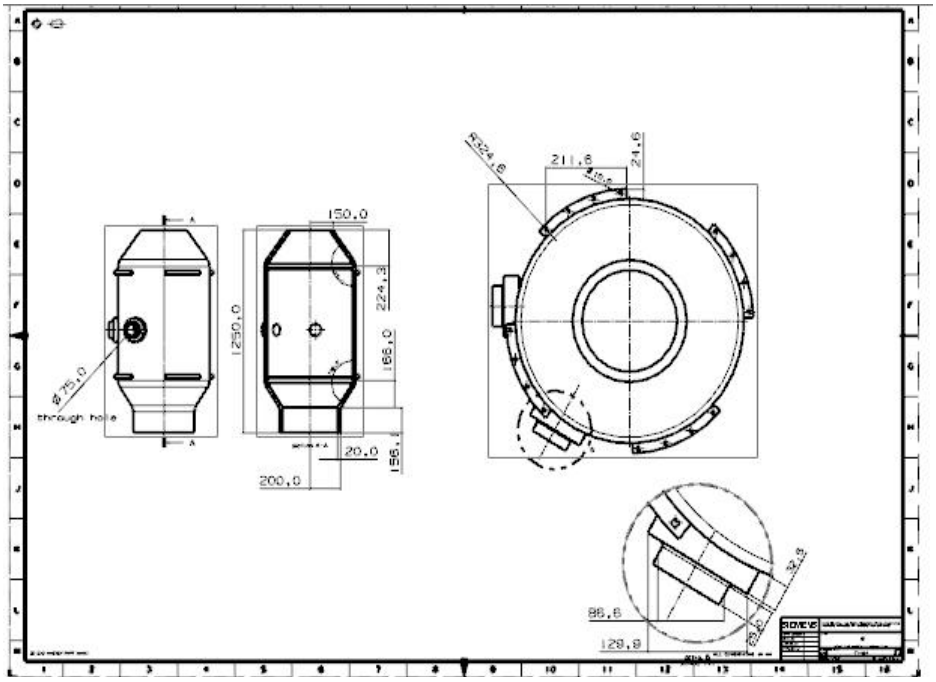


Fig.7shows the **2D drawing** of Combustion chamber (C.C) Outer Case

3.2 3D MODELLING STEPS FOLLOWED FOR COMBUSTION CHAMBER(OUTER CASE:

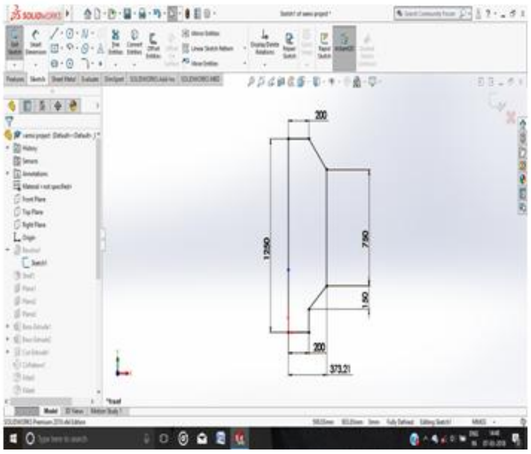


Fig.8 Shows sketch for C.C Outer case

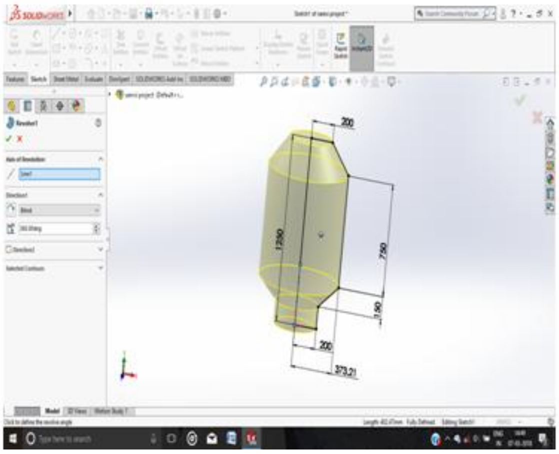


Fig.9 shows revolve option for C.C Outer case

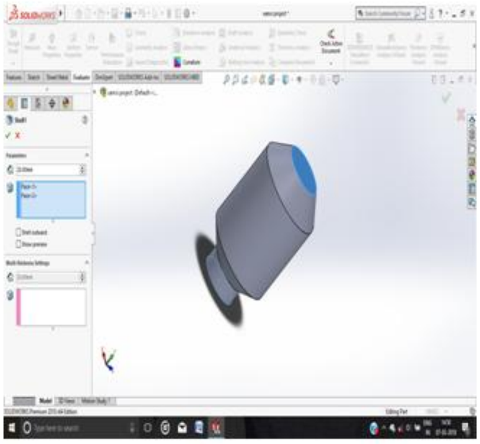


Fig.10 shows shell option for C.C Outer case inlets

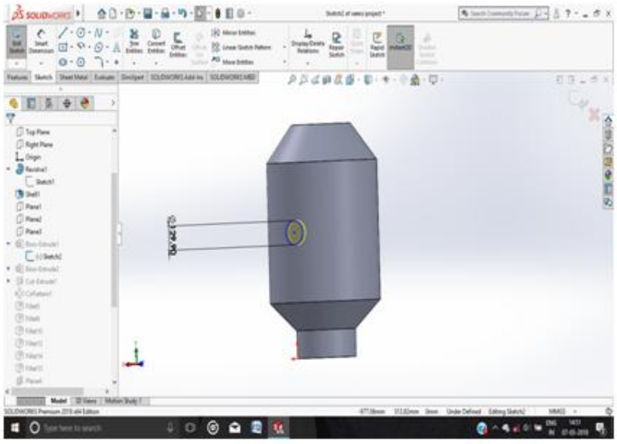


Fig.11 shows sketch for C.C Outer case supports

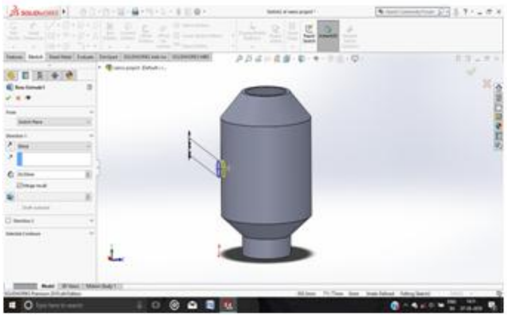


Fig.12 shows extrusion of C.C Outer case supports sketch

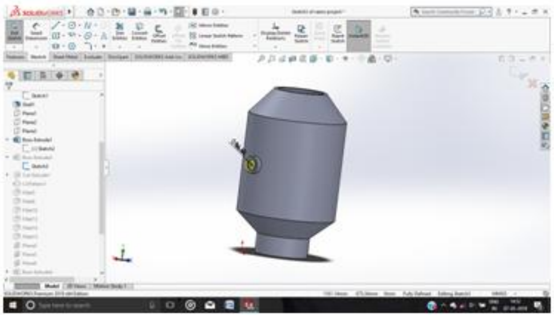


Fig.13 shows extrude option for C.C Outer case supports

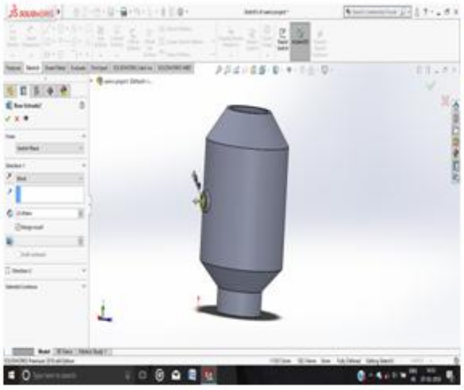


Fig.14 shows extrude cut of C.C Outer case supports body

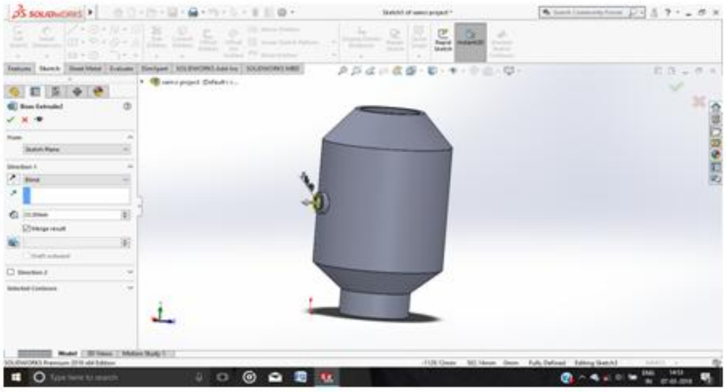


Fig.15 shows circular pattern for C.C Outer case support

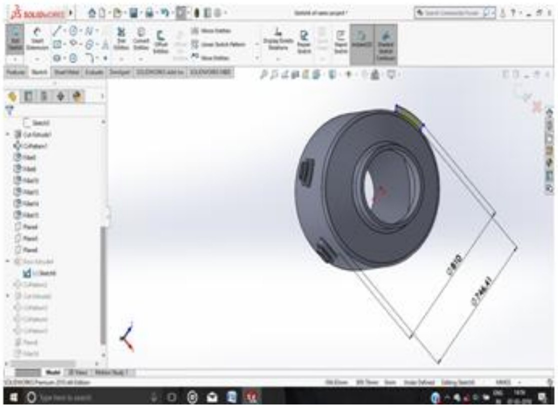


Fig.16 shows sketch for C.C Outer case support locations

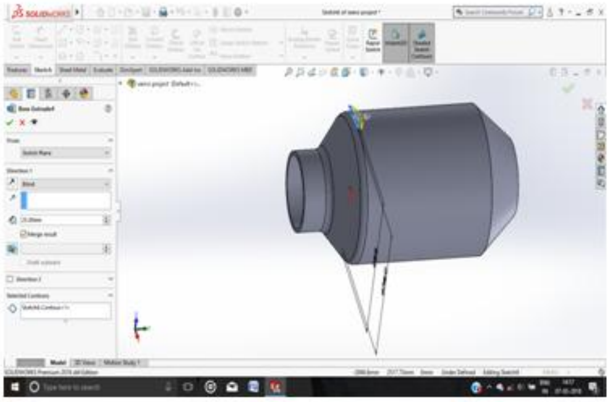


Fig.17 shows extrude for C.C outer case support locations

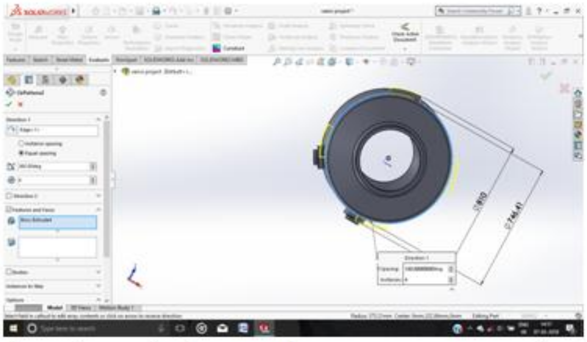


Fig.18 shows circular pattern for C.C Outer case support locations

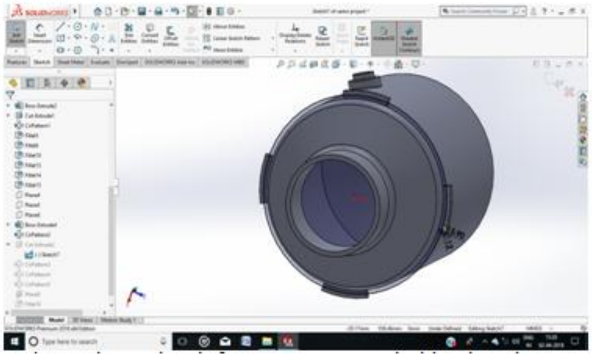


Fig.19 shows sketch for C.C Outer case bolting locations

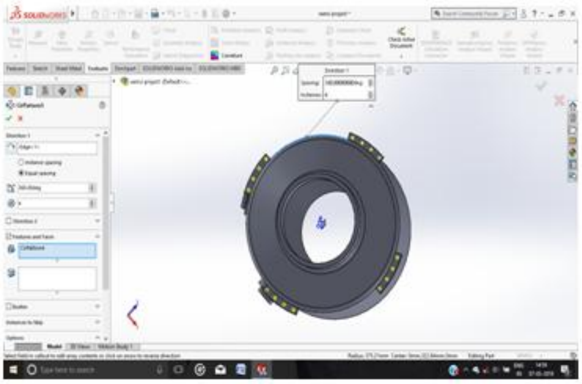


Fig.20 shows extrude cut for combustion chamber outer case bolting locations

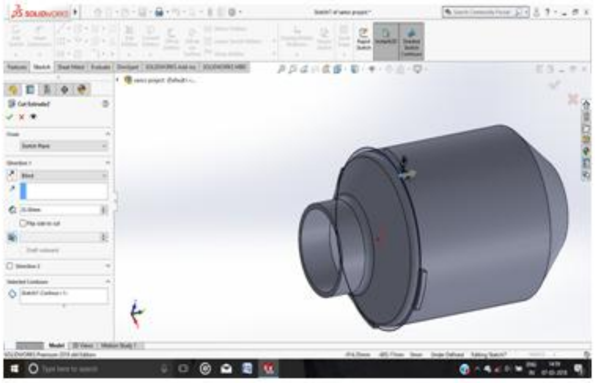
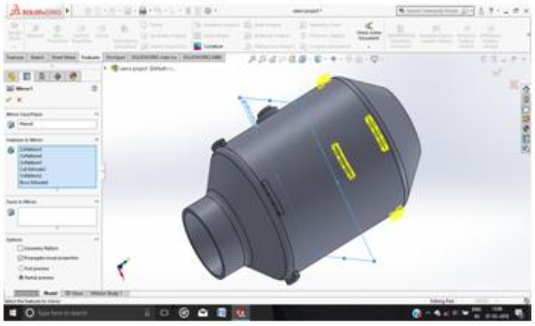


Fig.21 shows circular pattern for C.C Outer case bolting locations



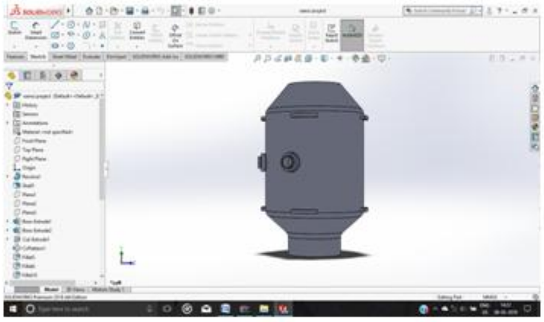
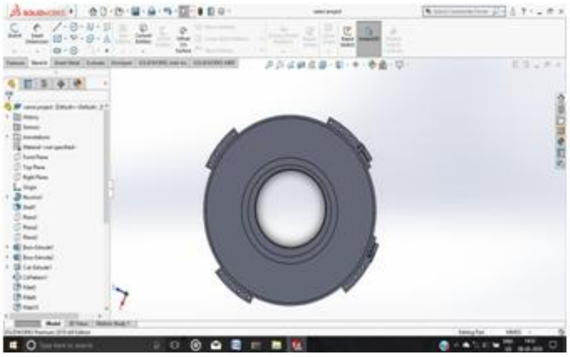


Fig.22 shows mirror option for combustion chamber outer**Fig.23** shows the 3D model of combustion chamber outer case (front view) case bolting locations



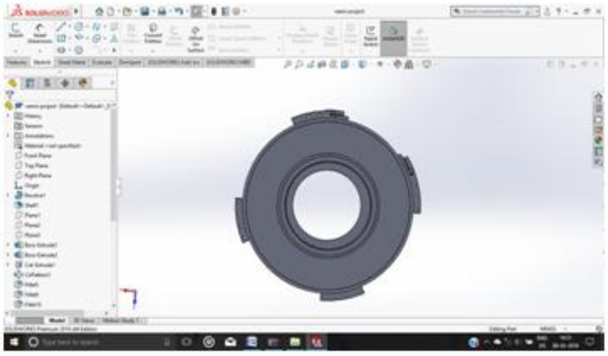
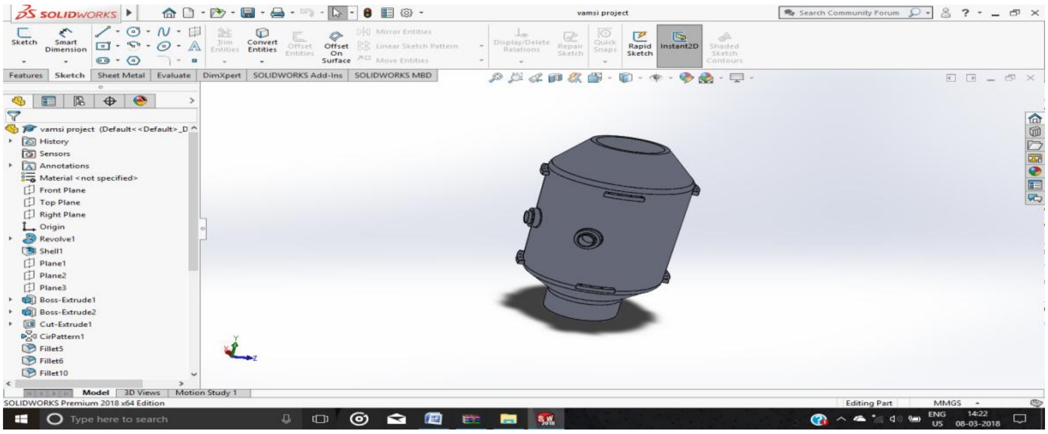


Fig.23 **Top view of combustion chamber outer case chamber** Fig.23 **Bottom view of combustion outer case**



Isometric view of combustion chamber outer cas

IV. Finite Element Analysis Modified Combustion Chamber

ANSYS is a Finite Element Analysis (FEA) code widely used in the Computer Aided Engineering (CAE) field. ANSYS software allow to construct computer models of structures, machine components or systems, apply operating loads and other design criteria and study physical responses, such as stress levels, temperature distributions, pressure, etc. The ANSYS program has a variety of design analysis applications, ranging from automobiles to such highly sophisticated systems as aircraft, nuclear reactor containment buildings and bridges. There are 250+ elements derived for various applications in ANSYS. In the present application shell, beam and mass elements that have structural static and dynamic analysis capabilities were considered.

4.1 STRUCTURAL ANALYSIS

Structural analysis comprises the set of physical laws and mathematics required to study and predict the behavior of structures. The subjects of structural analysis are Engineeringartefacts whose integrity is judged largely based upon their ability to withstand loads; they commonly include buildings, bridges, aircraft, and ships. Structural analysis incorporates the fields of mechanics and dynamics as well as the many failure theories. From a theoretical perspective the primary goal of structural analysis is the computation of deformations, internal forces, and stresses. In practice, structural analysis can be viewed more abstractly as a method to drive the engineering design process or prove the soundness of a design without a dependence on directly testing it.`

4.2 THERMAL ANALYSIS:

A thermal analysis calculates the temperature distribution and related thermal quantities in a system or component. Typical thermal quantities of interest are:

- The temperature distributions
- The amount of heat lost or gained
- Thermal gradients
- Thermal fluxes.

Thermal simulations play an important role in the design of many engineering applications, including internal combustion engines, turbines, heat exchangers, piping systems, and electronic components. In many cases, engineers follow a thermal analysis with a stress analysis to calculate thermal stresses (that is, stresses caused by thermal expansions or contractions).

4.3 COUPLED-FIELD ANALYSES

Some types of coupled-field analyses, such as thermal-structural and magnetic-thermal analyses, can represent thermal effects coupled with other phenomena. A coupled-field analysis can use matrix-coupled ANSYS elements, or sequential load-vector coupling between separate simulations of each phenomenon.

4.4 FINITE ELEMENT MODELING:

3D model of the rocket engine nozzle was developed in UNIGRAPHICS. The model was then converted into a para-solid to import into ANSYS. A Finite Element model was developed with solid elements. The elements that are used for idealizing the rocket engine nozzle were described below. A detailed Finite Element model was built with solid elements to idealize all the components of the rocket engine nozzle. The elements that are used for idealizing the exhaust manifold are solid87. The description of each element is given below.

4.5 CREATING A FINITE ELEMENT MESH

According to given specifications the element type chosen is Shell 57.Shell 57is higher order version of the 3D ten node thermal element (Shell 57). The element has 4 nodes with single degree of freedom, temperature, at each node. The 4-node elements have compatible temperature shape and are well suited to model curved boundaries. The 4-node thermal element is applicable to a 3D, steady state or transient thermal analysis. If the model containing this element is also to be analyzed structurally, the element should be replaced by the equivalent structural element (Shell 63).The para-solid file is imported into ANSYS and is meshed with 4node thermal Shell 57element type. The structure, number of nodes and input summary of the element is given below.

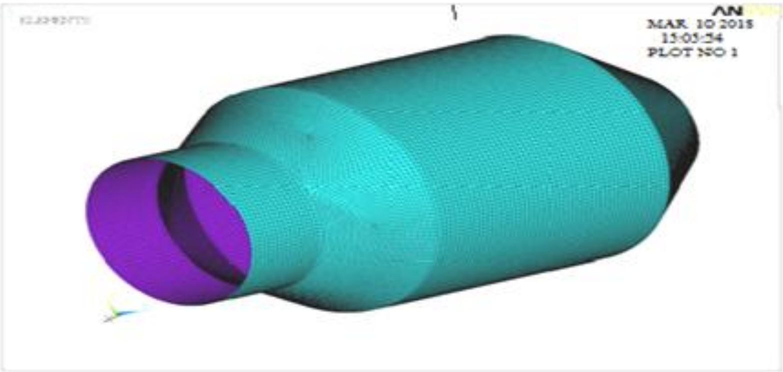


Fig.25 shows the Finite element model of the modified combustion chamber

4.6 MATERIAL PROPERTIES OF MODIFIED COMBUSTION CHAMBER:

In its raw form, tungsten is a hard steel-grey metal that is often brittle and hard to work. If made very pure, tungsten retains its hardness (which exceeds that of many steels), and becomes malleable enough that it can be worked easily. It is worked by forging, drawing, or extruding. Tungsten objects are also commonly formed by sintering. Of all metals in pure form, tungsten has the highest melting point (3,422 °C, 6,192 °F), lowest vapor pressure (at temperatures above 1,650 °C, 3,000 °F) and the highest tensile strength. Although carbon remains solid at higher temperatures than tungsten, carbon sublimes, rather than melts, so tungsten is considered to have a higher melting point. Tungsten has the lowest coefficient of thermal expansion of any pure metal. The low thermal expansion and high melting point and tensile strength of tungsten originate from strong covalent bonds formed between tungsten atoms by the 5d electrons. Alloying small quantities of tungsten with steel greatly increases its toughness.The free element is remarkable for its robustness, especially the fact that it has the highest melting point of all the elements. Also remarkable is its high density of 19.3 times that of water, comparable to that of uranium and gold, and much higher (about 1.7 times) than that of lead. Tungsten with minor amounts of impurities is often brittle and hard, making it difficult to work. However, very pure tungsten, though still hard, is more ductile, and can be cut with a hard-steel hacksaw.

4.6.1 Material Properties of tungsten:

Thermal conductivity, K (w/m k)	-	174
young’s modulus, E (GPa)	-	405
Density, (kg/m3)	-	19250
Poisson’s ratio, v	-	0.3
Thermal expansion, α (10^6 / k)	-	4.3
Coefficient of friction, µ	-	0.2

4.7.2 Element Description

SHELL57: No of Nodes: 4**,** No. of DOF: 6 (Ux, Uy, Uz, Rotx, Roty, Rotz

SHELL57 is a 3-D element having in-plane thermal conduction capability. The element has four nodes with a single degree of freedom, temperature, at each node. The conducting shell element is applicable to a 3-D, steady-state or transient thermal analysis.

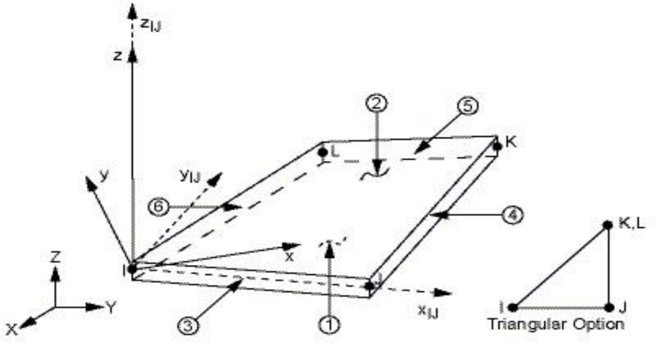


Fig.26 shows the **SHELL 57**Element Description

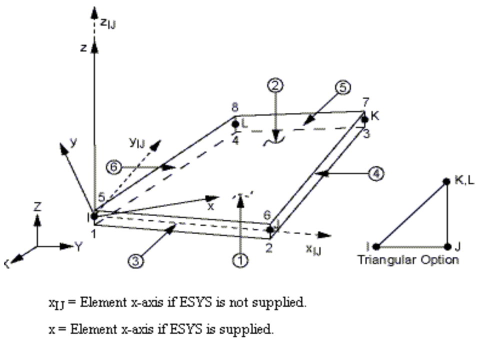
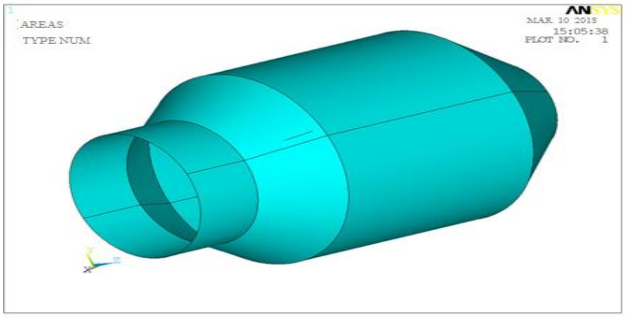


Fig.27 shows the **SHELL 63** Element Description

If the model containing the conducting shell element is to be analyzed structurally, the element should be replaced by an equivalent structural element (Such as SHELL63).

SHELL63: No of Nodes: 4, No. of DOF: 6 (Ux, Uy, Uz, Rotx, Roty, Rotz)

SHELL63 has both bending and membrane capabilities. Both in-plane and normal loads are permitted. The element has six degrees of freedom at each node: translations & rotations in the nodal x, y, and z directions. The geometry, node locations, and the coordinate system for this element are shown in the above Figure 1. The element is defined by four nodes, four thicknesses, elastic foundation stiffness, and the orthotropic material properties. The thickness is assumed to vary smoothly over the area of the element, with the thickness input at the four nodes.



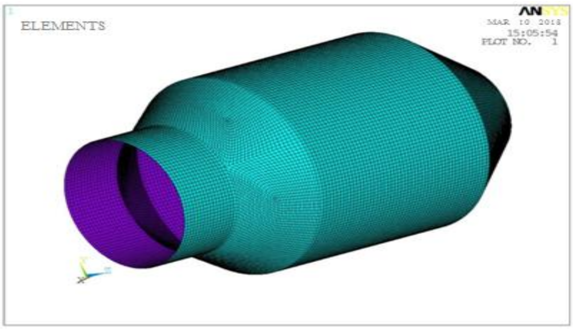


Fig.25 shows the geometric model of the modified C.CFig.26 shows the Finite element model of the modifiedC.C

V. Results

5.1 BOUNDARY CONDITIONS

In thermal analysis of modified combustion chamber, we have to apply thermal loads. Temperature 2273k is applied on the inner areas of modified combustion chamber, and convection is applied on outer areas of modified combustion chamber.

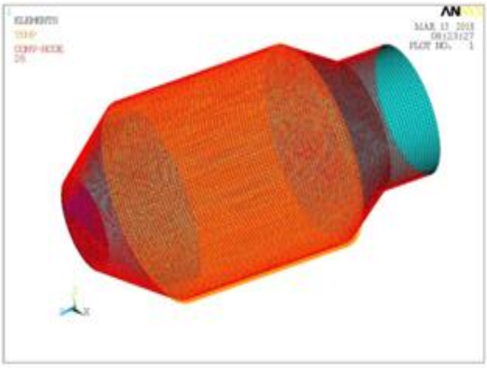


Fig.27 shows the Temperature and Convection boundary condition applied on modified C.C

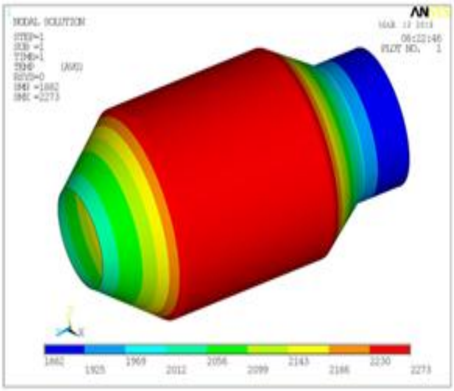


Fig.28Shows the temperature on modified C.C

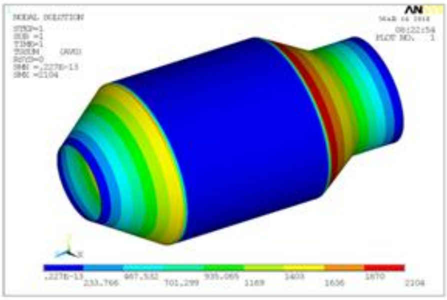


Fig.29Shows the thermal gradient on modified C.C

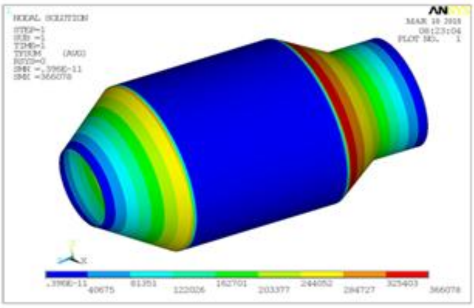


Fig.30Shows the thermal flux on modified C.C

From the above resultsthe maximum Temperature distribution on modified combustion chamber is 2273k.

VI. Coupled Feild Analysis Of Modified Combustion Chamber Results

In structural analysis of modified combustion chamber, we have to apply structural and thermal loads. The modified combustion chamber edges are arrested in all DOF and pressure load 8000000Pa is applied inside of the modified combustion chamber. Temperature distribution is applied as Thermal loads on modified combustion chamber obtained from the thermal analysis performed earlier.

6.1 BOUNDARY CONDITIONS:

- Modified Combustion chamber is arrested in all DOF at modified combustion chamber exit and inlets.
- Pressure load is applied on the inner surface of modified Combustion chamber.
- Thermal loads are applied on the inner areas of modified Combustion chamber by the thermal analysis.

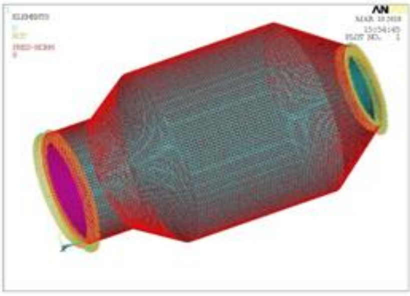


Fig.31 Shows the applied structural and thermal boundary conditions on modified Combustion chamber

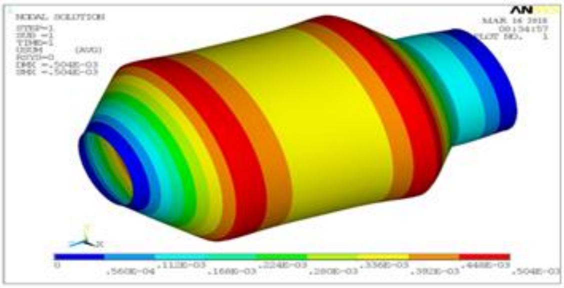


Fig.32 Shows the Total deflection vector sum of modified combustion chamber

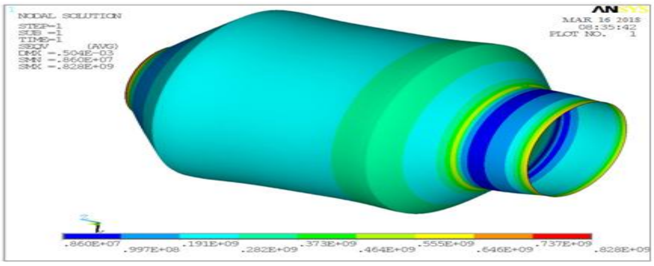


Fig.33 Shows the Von Moises stress of modified combustionchamber

VII. Conclusion

In the paper combustion chamber has been designed and analysis for structural and thermal behavior of well-designed modal with design calculations. The combustion chamber was studied for Nodal Temperature, ThermalGradient, Displacementand Von MoisesStress. From the above analysis it was concluded that the combustion chamber outer case had stresses and deflections were within the allowable limits of the material. Therefore it was concluded that the combustion chamber outer case is safe under the given operating conditions. The Max Deflection .0503m observed on the combustion chamber for pressure loading conditions and thermal loads. The Max Avg. VonMises Stress observed 828Mpa on the combustion chamber for operating loading conditions.And the Yield strength of the materials tungston is 941Mpa .Hence according to the Maximum Yield Stress Theory, the VonMoises stress is less than the yield strength of the material. Hence the design of combustion chamber is safe for the above operating loads. Perform dynamic analysis on modified combustion chamber for vibrations. For that case modal analysis carried on modified combustion chamber for natural frequencies and harmonic analysis on modified combustion chamber for operating frequencies. Objective of this dynamic analysis is to get free from resonance.

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RaghuramPradhan.’’Structural And Thermal Analysis of Aircraft Combustion Chamber Outer Case.” IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , vol. 15, no. 4, 2018, pp. 05-17