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Design and Configuration of Small Rocket Motor

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ABSTRACT

A Small rocket motor assembly consists of the following components 1. Mounting flange head end (head end closure made with steel) 2. Composite casing and 3. Propellant. The Small rocket motor is a secondary solid propulsion system for initiating the combustion in main motor. Burn duration for the Small rocket motor is about 800 milli seconds. The maximum temperature to which the Small rocket motor will be subjected to is about 3000 K. The maximum expected operating pressure for the Small rocket motor is 11 MPa. The Small rocket motor will also be subjected to an external pressure of 6.0 MPa, which comes from the main motor ignition.

Present project is assigned us to design and perform structural analysis of the Small rocket motor Mounting Flange along with its components which are subjected to the above pressure. Selection of the aerospace material and weight optimization are carried out. Weight optimization is carried out using the FE packages.

Configuration of the components is carried out to suit the service condition and environmental condition through providing suitable factor of safety in design and verified through finite analysis. Material selection is made based on the aerospace design criteria i.e. high power to weight ratios and where ever applicable composite material is selected.

Structural optimization of the Head End flange has been carried out and ensured that design stress is within the safe limit.

Introduction

A rocket is a missile, spacecraft, aircraft or other vehicle that obtains thrust from a rocket engine. Rocket engine exhaust is formed entirely from propellants carried within the rocket before use. Rocket engines work by action and reaction i.e., Newton’s third law of motion. Rocket engines push rockets forward simply by throwing their exhaust backwards extremely fast. [1]

While comparatively inefficient for low speed use, rockets are relatively lightweight and powerful, capable of generating large accelerations and of attaining extremely high speeds with reasonable efficiency. Rockets are not reliant on the atmosphere and work very well in space. [1]

Literature review and development

Rockets for military and recreational uses date back to at least 13th century China. Significant scientific, interplanetary and industrial use did not occur until the 20th century, when rocketry was the enabling technology of the Space Age, including setting foot on the moon. Rockets are now used for fireworks, weaponry, ejection seats, and launch vehicles for artificial satellites, human spaceflight, and space exploration. [2]

Components of solid rocket motor

A simple solid rocket motor consists of a casing, nozzle, grain (propellant charge), and igniter.The grain behaves like a solid mass, burning in a predictable fashion and producing exhaust gases. The nozzle dimensions are calculated to maintain a design chamber pressure, while producing thrust from the exhaust gases. [2]

Once ignited, a simple solid rocket motor cannot be shut off, because it contains all the ingredients necessary for combustion within the chamber in which they are burned. More advanced solid rocket motors can not only be throttled but also be extinguished and then re-ignited by controlling the nozzle geometry or through the use of vent ports. Also, pulsed rocket motors that burn in segments and that can be ignited upon command are available. [2]

Modern designs may also include a steerable nozzle for guidance, avionics, recovery hardware (parachutes), self-destruct mechanisms, APUs, controllable tactical motors, controllable divert and attitude control motors, and thermal management materials. [2]

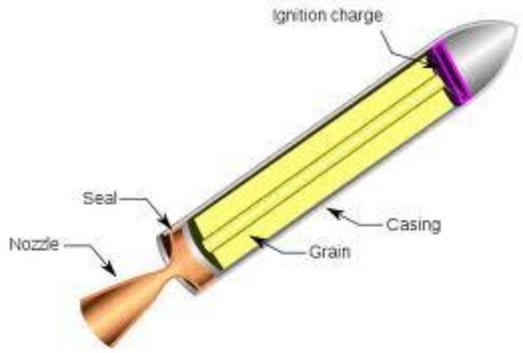

Fig.1. Solid rocket motor components

Igniter

Motors are electrically ignited with an electric match consisting of a short length of pyrogen-coated nichrome, copper, or aluminum bridge wire pushed into the nozzle and held in place with flameproof wadding, a rubber band, a plastic plug or masking tape. On top of the propellant is a tracking delay charge, which produces smoke but in essence no thrust, as the rocket slows down and arcs over. When the delay charge has burned through, it ignites an ejection charge, which is used to deploy the recovery system. [2]

The energetic material used, often called pyrogen, is usually a pyrotechnic composition made of a fuel and oxidizer, where the fuel produces a significant amount of hot particles that cause/promote the ignition of the desired material. [2]

Initiator compositions are similar to flash powders, but they differ in burning speed, as explosion is not intended, and have intentionally high production of hot particles. They also tend to be easier to ignite than thermites, with which they also share similarities. [2]

Common oxidizers used are potassium perchlorate and potassium nitrate. Common fuels used are titanium, titanium hydride, zirconium, zirconium hydride, and boron. The size of the fuel particles is determined to produce hot particles with the required burning time. More exotic materials can be used, e.g. carboranes. For special applications, pyrophoric igniters can be used which burst into flame in contact with air. Triethylborane was used as an igniter for the Lockheed SR-71 jet engines. [2]

Casing

The casing may be constructed from a range of materials. Cardboard is used for small black powder model motors, whereas aluminum is used for larger composite-fuel hobby motors. Steel is used for the space shuttle boosters. Filament wound graphite epoxy casings are used for high-performance motors. [1, 2]

The casing must be designed to withstand the pressure and resulting stresses of the rocket motor, possibly at elevated temperature. For design, the casing is considered a pressure vessel. To protect the casing from corrosive hot gases, a sacrificial thermal liner on the inside of the casing is often implemented, which ablates to prolong the life of the motor casing. [1, 2]

Nozzle

A convergent-divergent design accelerates the exhaust gas out of the nozzle to produce thrust. The nozzle must be constructed from a material that can withstand the heat of the combustion gas flow. Often, heat-resistant carbon-based materials are used, such as amorphous graphite or carbon-carbon. [2, 3]

Some designs include directional control of the exhaust. This can be accomplished by gimballing the nozzle, as in the Space Shuttle SRBs, by the use of jet vanes in the exhaust similar to those used in the V-2 rocket, or by liquid injection thrust vectoring (LITV). [2, 3]

An early Minuteman first stage used a single motor with four gimbaled nozzles to provide pitch, yaw, and roll control. [2, 3]

Types of Rocket Motors

There are essentially two different types of commercial model rocket engines, black powder and composite. One new type of engine uses a combination of liquid nitro (racing car stuff) and cellulose as the rocket fuel. This combination engine is being designed to overcome the problems with shipping larger engines containing flammable fuel. [1, 2]

RESULTS AND DISCUSSION

After the extensive study of materials that are mostly used in aerospace application, it can be concluded from the properties they exhibit that 15cdv6 steel is more economical, readily available in open market and heat treatable to required strength. While Ti-6Al-4V is also equally capable to withstand the stresses applied and pressure exerted on the mounting flange head end in comparison to 15cvd6 steel. But, it is difficult to fabricate and expensive hence, 15cdv6 steel is considered for the flange material.

For fasteners, the best material available would be En-24 steel .the material available readily in annealed condition.

Comparing the four fibers available, we can see that though the strength and stiffness of Boron and SiC fibers are comparably good, the availability of these fibers is a major drawback. In the case of Organic fibers, they have low compressive strength and are sensitive to UV light. Though the Carbon fibers are very costly, they have very good mechanical properties. But, these fibers are not consumable during operation. In the case of Glass fibers, E-glass and S-glass fibers have good mechanical properties. Though S-glass has greater strength, it is difficult to show an economical advantage when compared to E-glass fibers. Due to the combination of mechanical performance, corrosion resistance and low cost, E-glass fibers are preferred in composites.

As the corrosion resistance of polyester resins reduces with the chemical attack and dissolves the glass fiber, polyester resins cannot be used in Glass fibers. With good mechanical properties and high corrosion resistance, Epoxies are widely used in various applications. Longer gel time and better mechanical properties are the two important characteristics to be considered in the resin system. Hence Epoxy resin LY556 is used.

Therefore, the minimum thickness required as per the above calculations is 2.4 mm. as per above calculation and thickness arrived.

The Structural Optimization process has been divided into the following steps:

1. Structural Analysis with the parent material and original configuration
2. Structural Analysis with Titanium alloy and original configuration
3. Topological Optimization of the component
4. Structural Analysis with the parent material and 40 % reduction in thickness of the base plate
5. Structural analysis with the parent material and material removal at the neck in addition to the above.

The structural analysis of the closure has been carried out. 3-D modeling of a sector of the closure has been done to take advantage of the symmetry.

Case A: Structural Analysis with the parent material and original configuration

The parent material used is 15CDV6 in this case. The deformations in the component have been shown in Fig.16 and the Stress levels to which the component is subjected to be shown in Fig.17.

Case B: Structural Analysis with Titanium alloy and original configuration
Titanium Alloy Ti6AL4V is a high strength material with a low density as compared to 15CDV6 steel. Weight saving is evident with this material. The deformations in the component have been shown in Fig 18 and the Stress levels to which the component is subjected to be shown in Fig 19.

Case C: Topological Optimization of the component
To assess the material usage for the parent material in the component, topological optimization has been carried out. This analysis provides the required information to the places where material can be removed. The analysis shows that the portion above the bolts is not loaded appropriately and the neck region also is scantly loaded. So material can be removed from those places. Fig 20 shows the plot for the averaged material density for the given load. The blue patch shows that the material is scantly loaded and the red shows the fully loaded zone.

Case D: Structural Analysis with the parent material and 40 % reduction in thickness of the base range

Based on the results of the analysis from the topological optimization, material has been removed from the base portion of the closure. The thickness at the base of the closure has been reduced to the order of 40%. The modified geometry has been shown in Fig.25. Structural analysis with the modified configuration has been carried out to asses the integrity of the component. The deformations in the component have been shown in Fig.21 and the Stress levels to

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which the component is subjected to be shown in Fig.22.

Case E: Structural analysis with the parent material and material removal at the neck in addition to the above

The stress levels were observed to be low and still some material could be removed. Based on the previous analysis, material has been removed at the neck portion of the closure. The muddied geometry has been shown in Fig.25. Structural analysis with the muddied conjuration has been carried out to asses the integrity of the component. The deformation in the component has been shown in Fig.23 and the Stress levels to which the component is subjected to be shown in Fig.24. The weight of the component was found to be 5.52 Kg for this case.

Geometrical Changes incorporated in the model

Geometrical changes carried out in the component during the optimization process have been shown in Fig.25. The hatched portion in the drawing is the regions which have been removed from the material in course of the optimization process. The figure shows a step by step removal of material from the component.

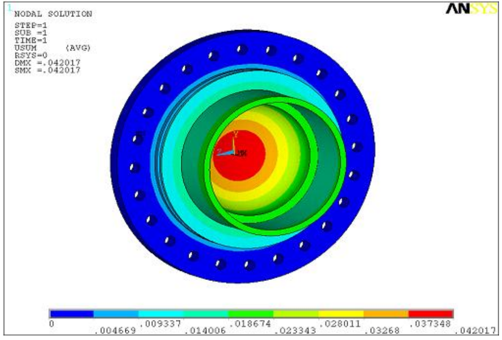

Fig.22. Deformations in the component for the Original Configuration

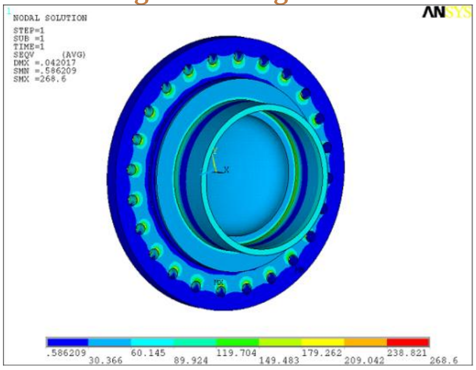

Fig.23. Von-Misses plot of the stresses in the Original Component

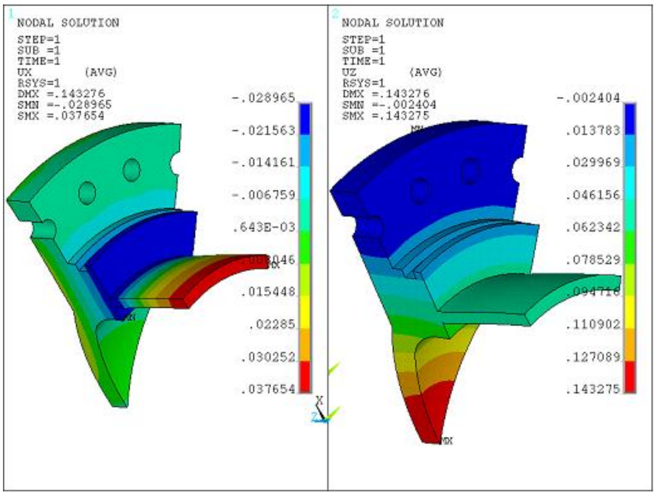

Fig.24. Radial and axial deformations for Configuration- Case B

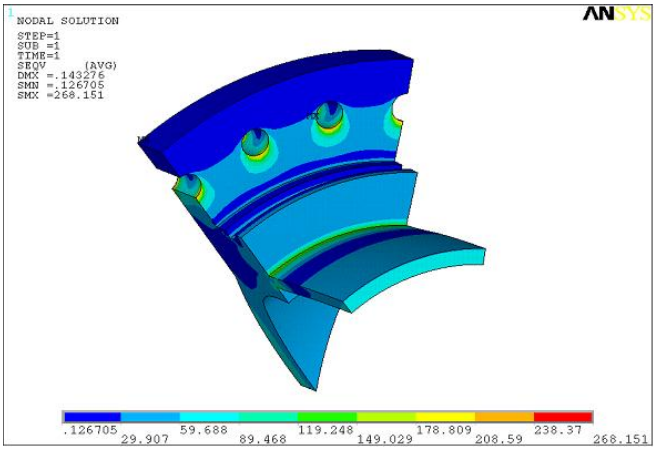

Fig.25. Von-Misses plot of the stresses in the Configuration- Case B

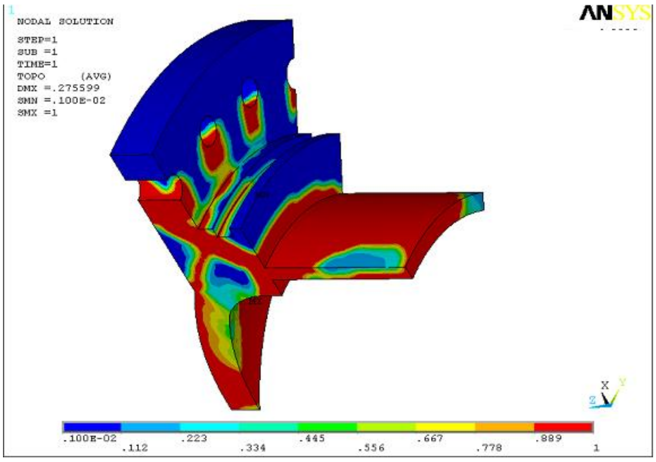

Fig.26. Pseudo Average Density plot from the Topological Optimization

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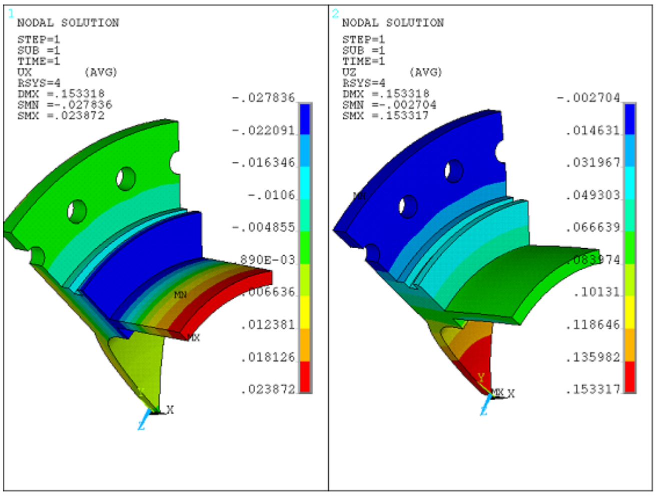

Fig.27. Radial and axial deformations in the Configuration- Case D

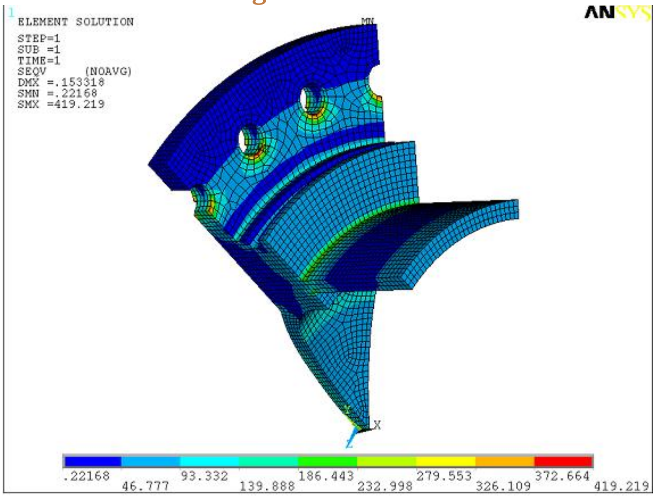

Fig.28. Von-Misses plot of the stresses in the Configuration- Case D

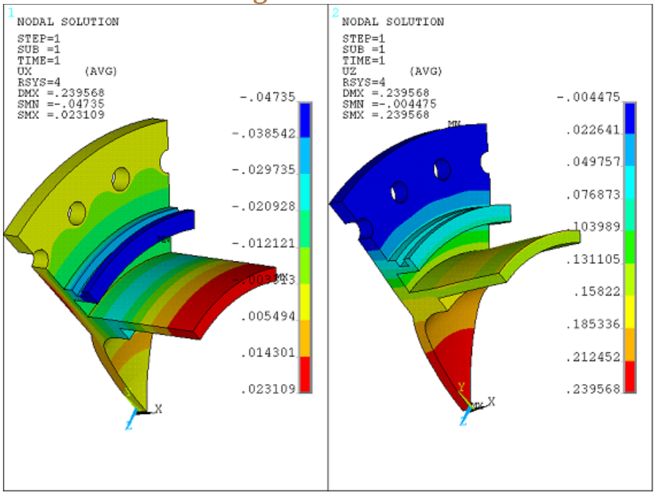

Fig.29. Radial and axial deformations in the Configuration- Case E

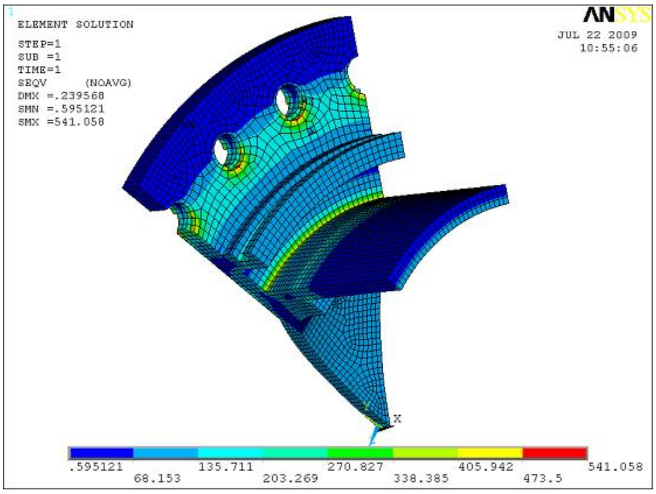

Fig.30. Von-Misses plot of the stresses in the Configuration- Case E

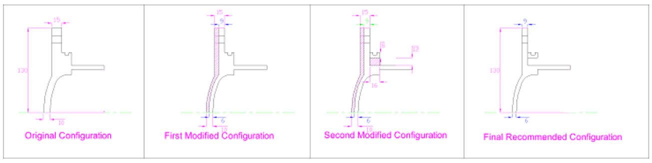

Fig.26. Geometrical changes incorporated in the component during the optimization process

Table.28. Summary of the Results & Conclusion

Configurations	Material	Weight (Kg)	Stress (MPa)	F.O.S (Yield)
C1	15CDV6	8.5	268.60	3.16
C2	Titanium	4.6	268.20	3.17
C3	15CDV6	6.2	419.20	2.02
C4	15CDV6	5.52	541.05	1.57

The above all materials were investigated for the mounting flange. Titanium alloy- Ti6Al4V-It is observed that titanium alloy has a lower density and strength comparable with steel. Aluminum alloy is not chosen as a candidate material because aluminum alloy cannot withstand high temperatures as being subjected to the component.

Conclusion

Design is carried out for flange and casing based on theoretical calculations which led to the optimization of thickness and material that is to be used.

15cdv6 steel is considered for flange and casing and then ti-6al-4v has replaced due to its properties.

Thickness for flange is estimated as 3.9 mm on factor of safety of 1.5 and for the casing it is evaluated to be 2.4 mm and fastener diameter to be 10.6 mm.

FE analysis proves that the design stress is within the material stress hence, the design is considered to be safe.

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