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Modelling and Thermal Effects Analysis on Toroidal Aero Spike Nozzle in Hybrid Rocket Engine

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ABSTRACT:

In toroidal aero spike nozzle combustion gases flow through a constriction (throat) and then the expansion away from the centreline is contained by the diverging walls of the nozzle up to the exit plane. Nozzles are a point design with optimum performance at one specific ambient pressure the combustion occurs in an enclosed chamber, like in a conventional nozzle engine. The hot gasses are accelerated to low supersonic speed in an internal expansion section. In this part of the engine, the flow is still totally enclosed. A way to visualize it is to imagine the gasses moving between two opposite walls which are coming closer to each other and then beginning to separate. At the point where the gasses have reached some low supersonic speed, one of the walls ends. This is the point where the external expansion ends. The other wall continues down and forms the spike contour. At the point where the other wall ends, the gasses expand around the edge of the wall. So in this project high explosive gases flow through the nozzle with high amount of temperature, due increasing of temperature high means thermal stress are devolved in the chamber that stresses are effecting the nozzles due this effects failure are accruing in the nozzles so we have to find out that temperature where nozzles are failure using thermal analysis with the help of ansys software. And modelling is done using mechanical design commercial software catia v5. And ground data acquisition system is described in detail.

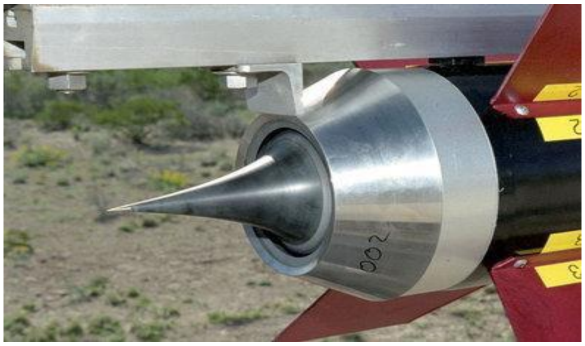
Key words: toroidal aero spike nozzle design, temperature flow rate, temperature of steam nozzle, thermal analysis, catia v5, ansys.

1. INTRODUCTION

The aero spike engine is a type of rocket engine that maintains its aerodynamic efficiency across a wide range of altitudes. It belongs to the class of altitude compensating nozzle engines. A vehicle with an aero spike engine uses 25–30% less fuel at low altitudes, where most missions have the greatest need for thrust. Aero spike engines have been studied for a number of years and are the baseline engines for many single-stage-to-orbit (SSTO) designs and were also a strong contender for the Space Shuttle Main Engine. However, no such engine is in commercial production, although some large-scale aero spikes are in testing phases. The terminology in the literature surrounding this subject is somewhat confused—the term aero spike was originally used for a truncated plug nozzle with a very rough conical taper and some gas injection, forming an "air spike" to help make up for the absence of the plug tail. However, frequently, a full-length plug nozzle is now called an aero spike.

1.2 Toroidal Aero spike:

The Toroidal "Aero spike" Rocket is a liquid fuel engine with the unique feature of being almost the most efficient at any atmospheric pressure. The aero spike rocket is an unusual rocket engine with good thrust-to-weight ratio, and relatively high fuel efficiency. Thanks to its unique nozzle, it is almost equally effective at all altitudes, unlike other engines. It does not have any thrust vectoring. Despite this drawback, it is still usually one of the best choices for an engine when building space planes. An added advantage in this application is that aero spikes are also quite short, which can help reduce the risk of collision with the runway during take-off when the engine is mounted at the rear of a space plane. Another advantage is that the short length makes it a good alternative for the LV-909 Liquid Fuel Engine on lenders, when more thrust is required or the landing takes place in an atmosphere, though it is heavier than the LV-909.The development of future launch systems and space vehicles has turned to increased efficiency and sustainability. These trends have shifted the focus of rocket propulsion research to increasing performance while maintaining if not improving safety and reliability.



1.1 Aero spike Nozzle Operation:

The aero spike nozzle's altitude compensation feature occurs by utilization of the natural expansion process that develops between the exhaust gas and the ambient atmosphere. A schematic of this process can be seen in at a specific design nozzle pressure ratio (NPR), which corresponds to the ratio between the combustion chamber gas pressure and ambient pressure, the aero spike should theoretically perfectly expand the exhaust gas with zero flow losses, as seen in the center diagram of Fig. 1. The shear layer separating the exhaust gas and the ambient atmosphere at this pressure ratio should theoretically be parallel to the axis of the nozzle. If the chamber pressure is kept constant and the ambient pressure is increased, thereby decreasing the NPR, a series of expansion and shock waves form between the central body and the shear layer.

This is represented in the top diagram in Fig. 1. This would correspond to a low altitude situation for the nozzle. This expansion and recompression process allows the combustion gas to be perfectly expanded to the ambient conditions. As the ambient pressure is decreased the NPR increases, the plume then widens and the expansion and shock waves move farther down the central spike. The adapting plume adjusts the effective expansion ratio of the aero spike nozzle as the NPR varies. As the ambient pressure is reduced further the effective expansion ratio optimally increases. 3 As the nozzle approaches the design NPR the expansion and recompression waves form along the entire length of the spike because the effective expansion ratio is fairly large. Once the design NPR is reached the expansion and shock waves dissipate forming a perfect expansion with theoretically zero flow losses due to compressibility. It should be noted that for all practical purposes this is an instantaneous condition.

$F = \mathrm{mue} + Psin\theta \mathrm{d}$

Objective of the problem

The main purpose of this research project was to design an aero spike nozzle that could withstand the heat transferred from the combustion gas within acceptable levels, and then integrate that design with a hybrid rocket motor utilizing N2O and HTPB as the oxidizer and fuel respectively. Through design analysis development and confidence testing the design could be deemed viable. Performance comparisons could then be made to bell nozzles utilized by the same system. An aero spike nozzle design that can mitigate nozzle degradation and prevent failure while being subjected to hot combustion gases allows further progression into the field of hot fire testing of such nozzles. Furthermore, direct performance comparisons of this nature have never before been conducted with this type of system, and give great insight into aero spike nozzle operation in hot fire systems. The tests carried out in this research lay down the steps for future aero spike nozzle designs and further performance testing in amass. It is hoped that information presented in this report will open a window for future nozzle designs and testing

ADVANTAGES:

- Shortened nozzle length for the same performance, or increased performance (higher expansion area rations) for a given length.
- Improved performance at sea level or low altitudes. (Annular nozzles with high expansion area ratios can be used for a single-stage sea level to vacuum vehicle mission.)
- The relatively stagnant region in the center of the nozzle can possibly be used for installation of gas generators, turbo pumps, tanks, auxiliary equipment, and turbine gas discharges.
- A segmented combustion chamber design approach can be used, easing development effort (individual segments can be built and tested during the early phases) and improving combustion stability.

DISADVANTAGES:

- Relatively high cooling requirements, because of higher heat fluxes and greater surface areas to be cooled.
- Heavier structural construction in some applications.
- Manufacturing difficulties.

CHAPTER – 2
LITERATURE REVIEW:

- Nguyen T. V. carried out different design approaches include plug nozzles with a toroidal chamber and throat (with and without truncation) and plug nozzles with a cluster of circular bell nozzle modules or with clustered quasi rectangular nozzle modules. The latter approach seems to be advantageous because further losses induced by the gaps between individual modules and the flow field interactions downstream of the module exits can be minimized. It has been shown that transition from a round to a square nozzle results in a very small performance loss.

- In principle, the flow field development of a clustered plug nozzle with rectangular nozzle modules is similar to that of a toroidal plug nozzle, but avoids the inherent disadvantages of the toroidal plug design regarding

1. The control of a constant throat gap during manufacturing and thermal expansion (side-loads and thrust vector deviations);
2. The cooling of toroidal throat with tiny throat gaps;

The control of combustion instabilities in the toroidal combustion chamber. Another plug nozzle configuration is the linear plug nozzle, which is foreseen for the propulsion system of the RLV X-33 concept.

- Hagemann G et.al. studied performance analysis on different type of plug nozzle such as linear plug and circular, clustered plug nozzle design. The comparison of experimental results with numerical computations is also carried out. The flow field of the toroidal plug nozzle was calculated with a numerical method and reported the Mach number distribution in the combustion chamber and nozzle. Principal physical processes like expansion waves, shocks, and the recirculating base-flow region are in good agreement. Both the experiment and the numerical simulation show that the flow separates from the conical plug body before reaching its truncated end

- Tomita, T et. al., conducted an experimental evaluation of plug nozzle flow field and reported the parameter distribution and performance parameters with emphasizing the separation of the flow from the central plug body for conical contours. The principal flow field developments predicted by these numerical simulations are again in a good agreement with experimental data Within the frame of this ESA ARPT Program performance and flow behaviour of clustered plug nozzles at different truncations are being examined by European industries and research institutes (ONERA, DLR) with subscale cold-flow plug models

Chapter3

3.1 DESIGN:

CATIA offers a solution to shape design, styling, surfacing workflow and visualization to create, modify, and validate complex innovative shapes from industrial design to Class-A surfacing with the ICEM surfacing technologies. CATIA supports multiple stages of product design whether started from scratch or from 2D sketches. CATIA is able to read and produce STEP format files for reverse engineering and surface reuse

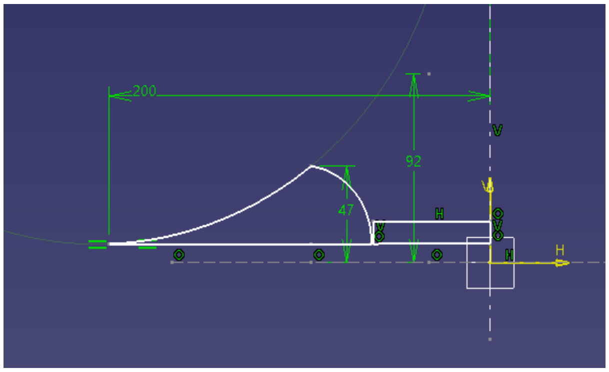


Fig2: sketch of torodial spike nozzle

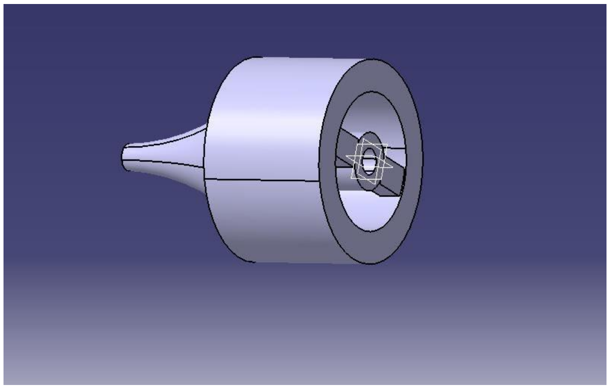


Fig3: torodial spike nozzle solid model

4 Ansys:

ANSYS is general-purpose finite element analysis software, which enables engineers to perform the following tasks:

1. Build computer models or transfer CAD model of structures, products, components or systems
2. Apply operating loads or other design performance conditions.
3. Study the physical responses such as stress levels, temperatures distributions or the impact of electromagnetic fields.
4. Optimize a design early in the development process to reduce production costs.

5. A typical ANSYS analysis has three distinct steps.

6. Pre Processor (Build the Model).

Mash:

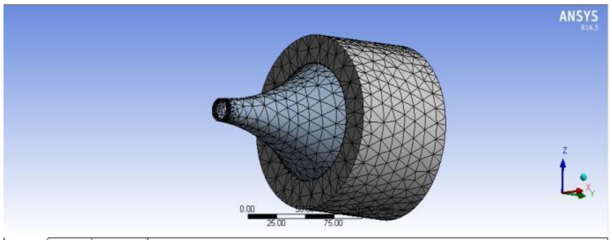


Fig4: meshing

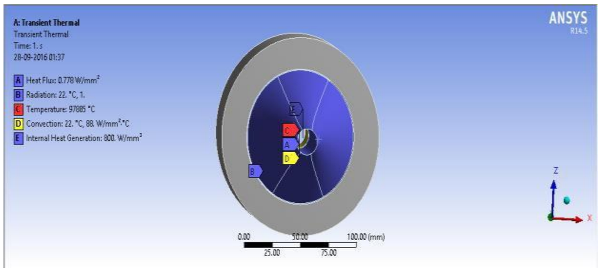
Transient Thermal:

The ANSYS/Mechanical, ANSYS/FLOTRAN, and ANSYS/Thermal products support steady-state thermal analysis. A steady-state thermal analysis calculates the effects of steady thermal loads on a system or component. Engineer/analysts often perform a steady-state analysis before doing a transient thermal analysis, to help establish initial conditions. A transient analysis also can be the last step of a transient thermal analysis, performed after all transient effects have diminished. You can use steady-state thermal analysis to determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time. Such loads include the following:

- Convections
- Radiation
- Heat flow rates
- Heat fluxes (heat flow per unit area)
- Heat generation rates (heat flow per unit volume)
- Constant temperature boundaries.

A steady-state thermal analysis may be either linear, with constant material properties; or nonlinear, with material properties that depend on temperature. The thermal properties of most material do vary with temperature, so the analysis usually is nonlinear. Including radiation effects also makes the analysis nonlinear.

Loads:



A: Transient Thermal
Transient Thermal
Time: 1. s
28-09-2016 01:37

A Heat Flux: 0.778 W/mm²
B Radiation: 22. °C, 1.
C Temperature: 97885 °C
D Convection: 22. °C, 88. W/mm²·°C
E Internal Heat Generation: 800. W/mm³

Fig5: applying loads

Type	Temperature	Heat Flux	Radiation	Convection
Magnitude	97885 °C (step applied)	0.778 W/mm² (step applied)		
Suppressed	No			
Correlation			To Ambient	
Emissivity			1. (step applied)	
Ambient Temperature			22. °C (step applied)	
Film Coefficient				88. W/mm²·°C (step

Material data:

Steel 1008

Thermal Conductivity	4.5e-002 W mm^-1 C^-1
Density	7.872e-006 kg mm^-3
Specific Heat	4.81e+005 mJ kg^-1 C^-1

Solid thermo plastic

Density	1.4e-009 kg mm^-3
Thermal Conductivity	82.245 W mm^-1 C^-1
Specific Heat	1.0467e+006 mJ kg^-1 C^-1

Fig 5.1: temperature

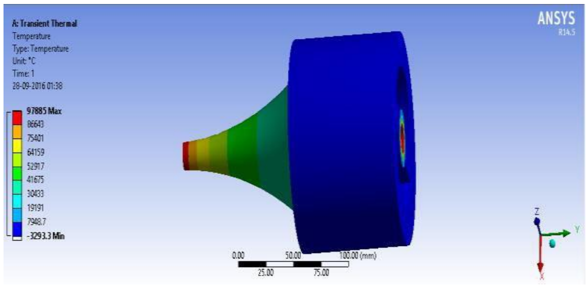


Fig5.2: total heat flux

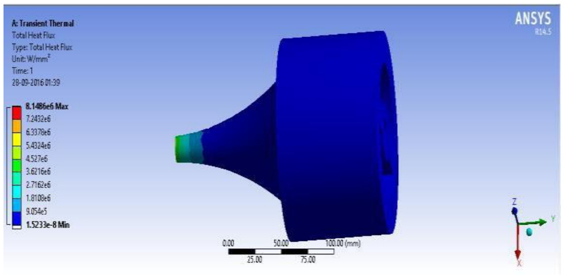


Fig 5.3: transient thermal solution global maximum

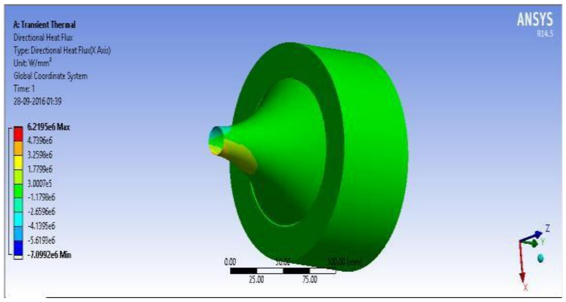


Fig 5.4:transient thermal solution

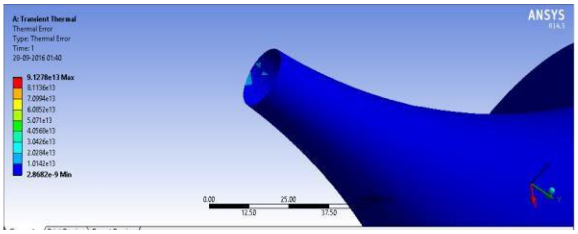


Fig 5.5: Aero spike nozzle Result

Type	Temperature	Total Heat Flux	Directional Heat Flux	Thermal Error
Minimum	-3293.3 °C	1.5233e-008 W/mm^2	-7.0992e+006 W/mm^2	2.8682e-009
Maximum	97885 °C	8.1486e+006 W/mm^2	6.2195e+006 W/mm^2	9.1278e+013

Fig 5.6: temperature probe

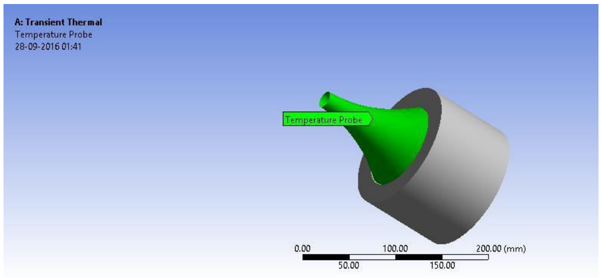
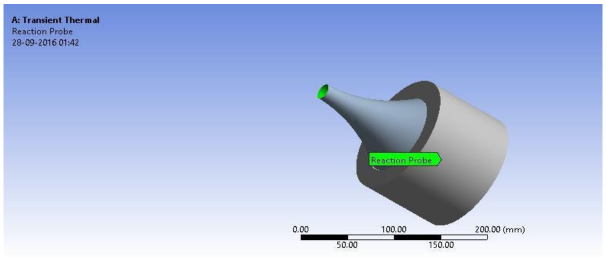


Fig 5.7: reaction probe



Object Name	*Temperature Probe*	*Reaction Probe*
Temperature	*97885 °C*	
Heat		*1.4788e+011 W*

CONCLUSION:

Research of an aero spike rocket nozzle was conducted using high power solid rockets. The lower aero spike chamber pressures and thrusts were likely to be caused by a larger actual aero spike nozzle throat area than the designed throat area. The design work on an aero spike nozzle design and associated testing hardware has been completed in preparation for a series of cold-flow tests on a truncated aero spike nozzle. The system will allow the evaluation of aerodynamic thrust vectoring and thrust augmentation through truncated aero spike base bleed. This series of tests will facilitate calibration of analytical prediction tools which include computational fluid dynamics results. Completion of cold gas testing should provide an adequate knowledge base before the project advances to hot flow testing. Mass flow rate, which relates directly to the motor's IV. Conclusion The analytical analysis of a hybrid rocket engine with a toroidal aero spike nozzle has been completed with a high level of confidence. The design is currently under construction with the help of the ASU student machine shop and will be tested in accordance with the information presented in this paper. Performance evaluation will be performed based on an the aero spike to CD nozzle comparison and future work will be decided upon based on the results.

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