Australian Journal of Basic and Applied Sciences, 9(11) May 2015, Pages: 883-892

ISSN:1991-8178

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com

Comparative study on Performance of Linear and Annular Aero-Spike Nozzles

[1]Shanmuganathan VK, [2]Gayathri N, [3]Kabilan S , [4]Umanath K

[1,3]Department of Aeronautical Engineering, Jaya Engineering College, Chennai, India
[2,4]Department of Mechanical Engineering, Veltech Hightech Dr. Rangarajan Dr. Sakunthala Engineering College, Chennai, India

ARTICLE INFO

Article history:
Received 16 March 2015
Accepted 28 May 2015
Available online 22 June 2015

Keywords:

ABSTRACT

The fully reusable SSTO's (Single Stage To Orbit) and rocket engines, light weight and high performance propulsion system from low altitude to high altitude are essential. Engines with aerospike nozzles are drawing attention as promising candidates which satisfy these requirements. A renewed interest into aerospike (plug) nozzles has surfaced for the possible replacement of standard contoured nozzles used for the propulsion systems of space vehicles .In this paper a study on linear and annular aerospike nozzles and characteristics of its flow field are carried out. Numerical analysis of a typical aerospike nozzle with result analysis and discussion on flow characteristics, comparison on annular spike and linear spike configuration for different velocities are included. The performance analysis is done by plotting maximum pressure and exit velocity produced. Based on the analysis report it is can stated that the annular aerospike nozzle proves to be a better type when compared with linear aerospike nozzle.

© 2015 AENSI Publisher All rights reserved.

To Cite This Article: Shanmuganathan VK, Gayathri N, Kabilan S , Umanath K, Comparative study on Performance of Linear and Annular Aero-Spike Nozzles. ***Aust. J. Basic & Appl. Sci.,*** *9(11): 883-892, 2015*

INTRODUCTION

Aerospike nozzle is a type of nozzle with capacity of continuous altitude compensation. The nozzle plays a vital part in the performance of a gas turbine engine. In this paper aerospike or plug nozzles are analysed. Plug nozzles are characterized by having an expansion point about which the fluid is accelerated as well as wall contour. Plug nozzles have distinct advantage of altitude adjustment during flight allowing maximum thrust throughout the entire trajectory of the rocket where the conical and bell nozzles only have a maximum thrust at a designed altitude which is at some optimized altitude during its flight. Plug nozzle's major disadvantage to conical and bell nozzles, they are typically less efficient in converting thermal energy into kinetic energy because the flow is bounded on one side by a constant pressure boundary. This constant pressure boundary creates an imaginary contour which allows the nozzles to generate the maximum thrust possible by the nozzles as the imaginary contour adjusts to the changes in pressure as the rocket gains altitude.

An advantage that the Aerospike has over the bell and conical nozzles is that can be truncated to reduce the weight and length of the nozzle while maintaining a thrust similar an Aerospike nozzle that was not truncated. Another advantage that is unique to the Aerospike nozzle is that it can be designed to incorporate altitude controls without the needs for fins or additional thrusters. This lends itself to additional weight advantages of the overall rocket design.

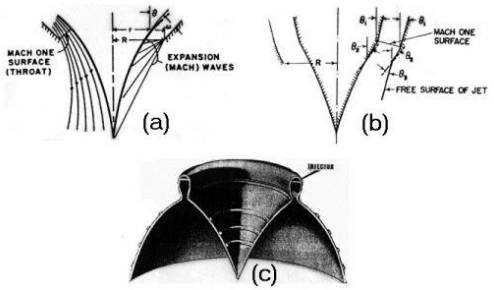

Fig. 1: Expansion-Deflection Nozzle.

Expansion-deflection nozzle appears much like a standard bell nozzle, but at the throat is a 'centre body' or 'pintle' which deflects the flow towards the walls. The exhaust gas flows past this in a more outward direction than in standard bell nozzles while expanding before being turned towards the exit. This allows for shorter nozzles than the standard design whilst maintaining nozzle expansion ratios. *TrongT.Bui, et al (2005) discussed that* flight

Corresponding Author: Shanmuganathan VK, Department of Aeronautical Engineering, Jaya Engineering College, Chennai, India.
E-mail: shankris21@gmail.com

research has been conducted on an aerospike rocket nozzle using high power solid rockets.

Aerospike aerodynamics:

A. Thrust Characteristics:

The basic thrust characteristics of the aerospike nozzle can be better understood by referring to the following figure.

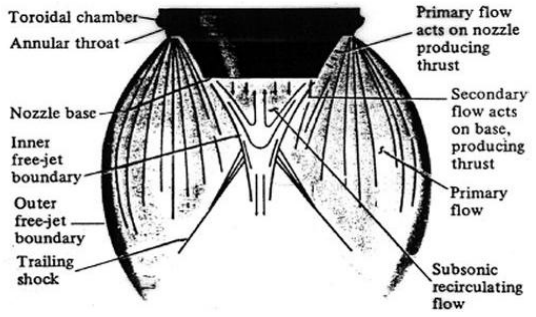

Fig. 2: Aerospike nozzle with a subsonic, recirculating flow.

The nozzle generates thrust in three ways. First, the thrusters in the toroidal chamber, located at the base of the nozzle, generate thrust as the fuel is combusted and exhausted. We shall label this thrust component $F_{thruster}$, and we can compute this thrust using the equation

$$F_{thruster} = (\dot{m}\, v_{exit} + (p_{exit} - p_{\infty})A_{exit})cos\theta$$

Already the methods in which the nozzles generate thrust while the exhaust gases expand have been discussed in detail. It is preferred to use the bell nozzle to demonstrate that discussion, because the exhaust gases in a spike nozzle expand against the spike centerbody rather than outer walls. Thus, the expansion of the exhaust gases exerts a thrust force that is called as $F_{centerbody}$.

$$F_{centerbody} = \int A_{centerbody}\ (p_{centerbody} - p_{\infty})\, dA$$

Finally, it is mentioned that the aerospike nozzles so named because an "aerodynamic spike" is created through the addition of a secondary, circulating flow aft of the flat nozzle base. As the supersonic primary flow, consisting of the high-pressure gases exhausted from the thrusters, expands downstream of the base, the primary flow interacts with the subsonic, secondary flow causing it to circulate. This low-pressure flow then re-circulates upward to exert an additional thrust force on the base.

$$F_{base} = (p_{base} - p_{\infty})\, A_{base}$$

Summing up these three thrust components yields the following relationship for the total thrust force (T) generated by an aerospike nozzle:

$$T = F_{thruster} + F_{centerbody} + F_{base}$$

Trunkated spike nozzle:

The truncated spike can be far smaller than a typical bell nozzle for the same performance, as shown below. ft.*Sanoob.S.N., et al(2013) discussed that* in this project a study on various types of aero spike nozzles and characteristics of its flow field is carried out. In truncated spike configuration, 20%,40%,60%,80% of spike length are included. In addition, a spike can give greater performance for a given length. Altitude compensation may result in greater installed performance. The Aerospike engine uses a simple gas generator cycle with a lower chamber pressure than typical rocket engines reducing the risk of a catastrophic explosion. Although, the low chamber pressures result in reduced performance, the aerospike's high expansion ratio makes up for this deficiency. The Aerospike nozzle fills the base portion of the vehicle thereby reducing a type of drag called base drag. The linear Aerospike engine is made up of these small, easier to develop, less expensive thrusters that give the engine greater versatility.

The combustion chambers can be controlled individually and the vehicle can be manoeuvred using differential thrust vectoring. This eliminates the need for the heavy gimbals and actuators used to vary the direction of traditional nozzles. Even though the Aerospike tends to be heavier than the bell nozzle, it shares many major structural elements with the vehicle reducing overall weight.

The central spike experiences far greater heat fluxes than does a bell nozzle. This problem can be addressed by truncating the spike to reduce the exposed area and by passing cold cryogenically-cooled fuel through the spike. The secondary flow also helps to cool the center body. The Aerospike is more complex and difficult to manufacture than the bell nozzle. As a result, it is more costly. No Aerospike engine has ever flown in a rocket application. As a result, little flight design experience has been gained.

Design:

The proposed design and design parameters for the numerical simulation are as follows, The schematics of the linear and annular aerospike nozzle configurations used are shown below. The axisymmetric models used for analysis along with the dimensions and coordinates of contoured spike profile used is depictured below

Table I: Design parameters for the nozzle design

S.No.	DESIGN PARAMETERS	VALUES
1.	Length of the nozzle	97.24 mm
2.	Length of the truncated spike	137.21 mm
3.	Inner diameter	115.9 mm
4.	Diameter of the annular hole	16 mm

5.	Throat Area, A_t	1195 mm^2
6.	Exit Area, A_e	6207 mm^2
7.	Exit Area ratio	5.192

The design parameters for the aerospike nozzles had been referred from the reference paper
The CATIA models made for the analysis are as follows

A. Linear Aerospike Nozzle Design:

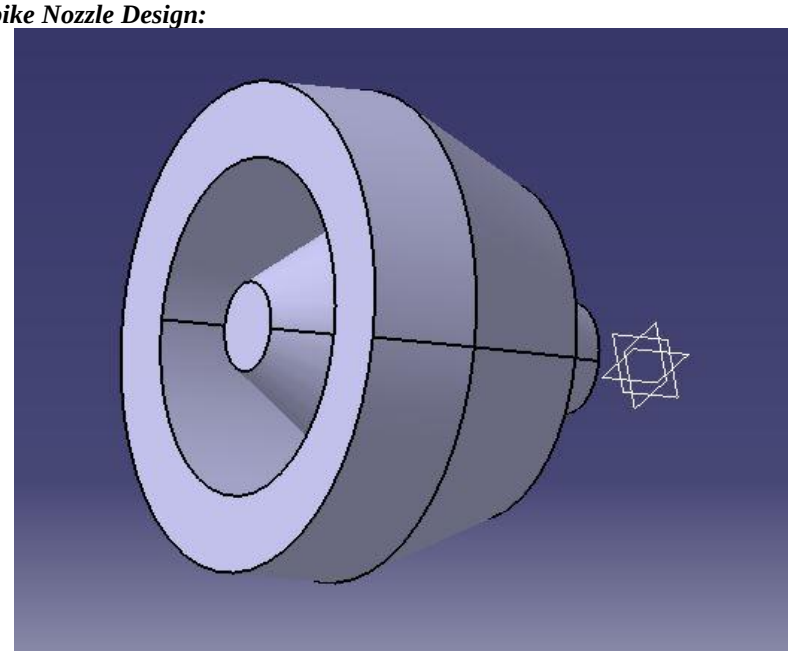

Fig. 3: Linear aerospike nozzle.

B. Annular Aerospike Nozzle Design:

The design of this nozzle differs from the previous one having annular holes that has been created where the area has been further reduced. It is a proposed design where the analysis has been done and compared with linear aerospike nozzle design.

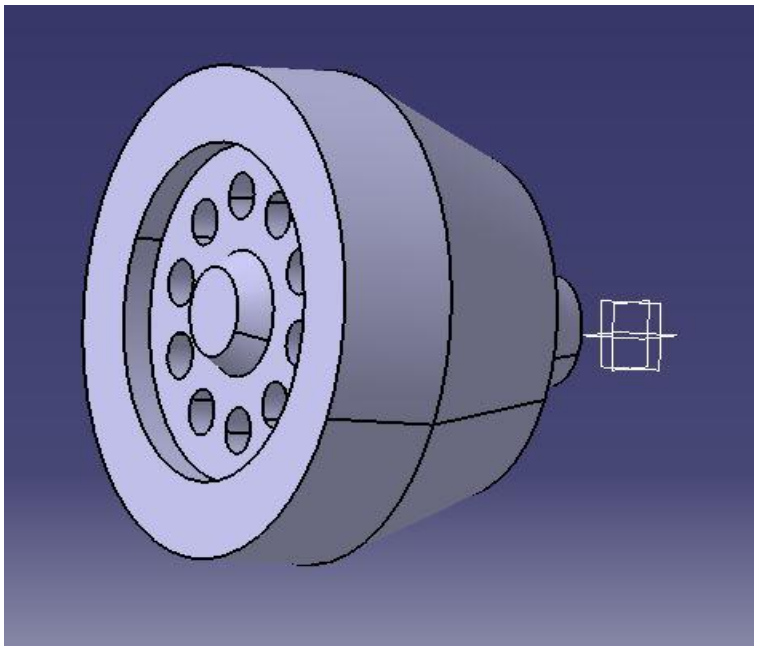

Fig. 4: Annular aerospike nozzle.

C. Linear Aerospike Nozzle Mesh:

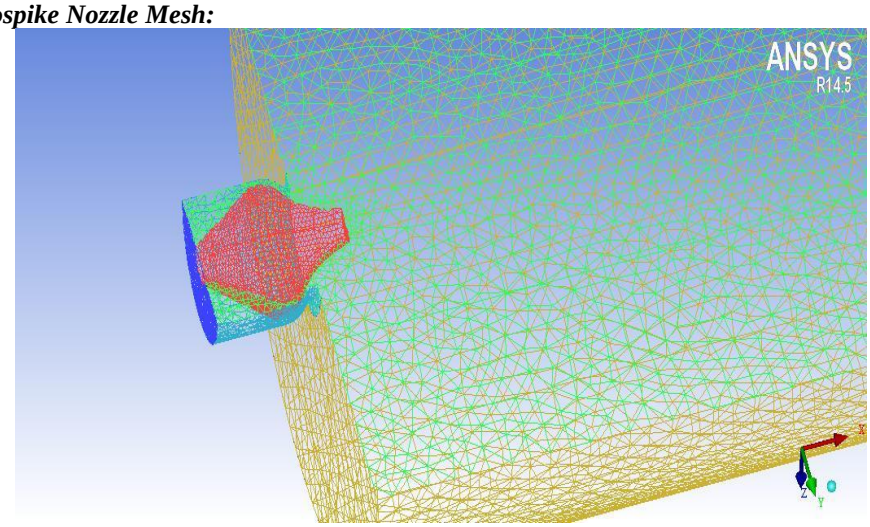

Fig. 5: Linear aerospike nozzle after meshing

RESULTS AND DISCUSSIONS

The performance of the aerospike nozzle is studied for several parameters. The flow properties such as pressure, temperature, exit velocity etc. are analysed and reported. The complex flow behaviour inside the flow domain is identified using the counters and charts. The counters for different velocity inlet are as follows. The results of the numerical analysis conducted are arranged as shown in below

***A. Flow through Linear Aerospike Nozzle*:**

In this section the results from linear aerospike nozzle configuration are discussed here. The velocity and pressure are depicted and discussed. The force exerted by nozzle exit flow is discussed.

1) Velocity counters for Linear Aerospike Nozzle:

1.1) For Linear aerospike nozzle at 20 m/s:

The figure 7 shows the velocity counter of linear aerospike nozzle at inlet velocity of 20 m/s. It gives the information about the velocity distribution in the nozzle and the domain. The maximum exit velocity is noted from the figure.

***D. Annular Aerospike Nozzle Mesh*:**

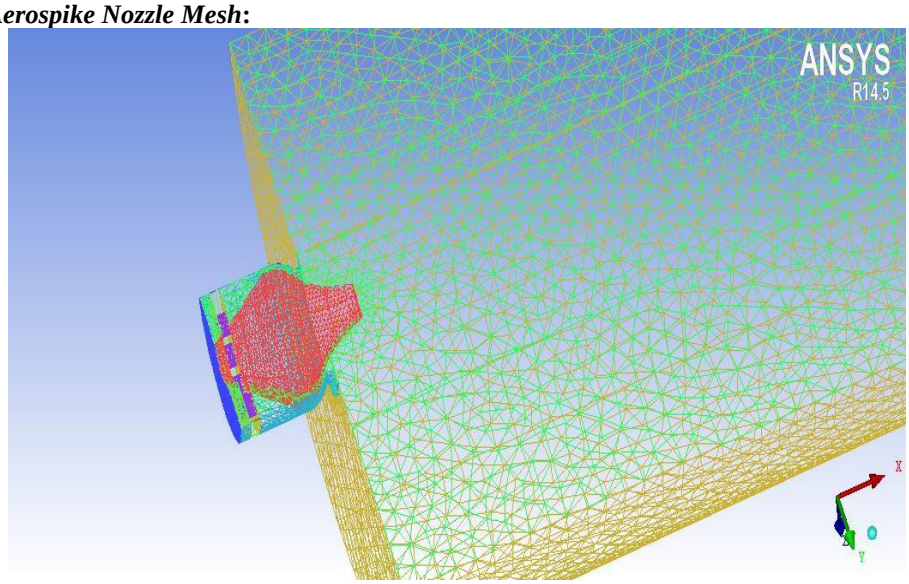

Fig. 6: Annular aerospike nozzle after meshing.

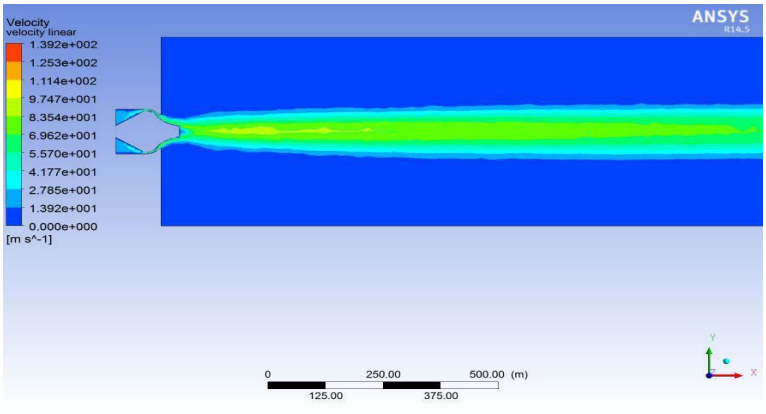

Fig. 7: Velocity counter of linear aerospike nozzle at 20 m/s

1.2) For Linear Aerospike Nozzle at 200 m/s:

The figure 8 shows the velocity counter of linear aerospike nozzle at inlet velocity of 200 m/s. It gives the information about the velocity distribution in the nozzle and the domain. The maximum exit velocity is noted from the figure.

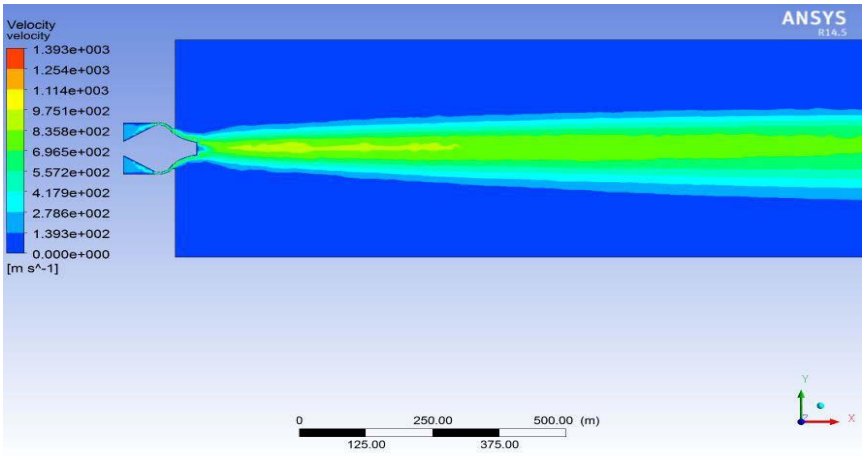

Fig. 8: Velocity counter of linear aerospike nozzle at 200 m/s.

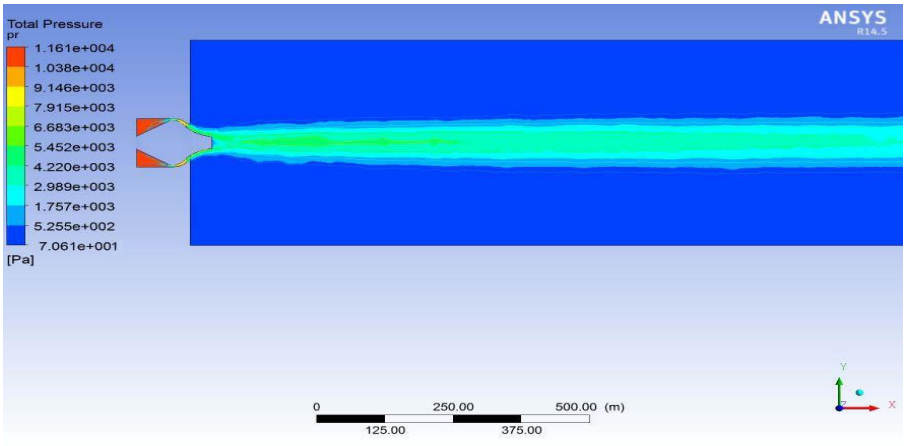

Fig. 9: Total pressure counter for linear aerospike nozzle at 20 m/s

2)Total Pressure Counter for Linear Aerospike Nozzle:

2.1) For Linear Aerospike Nozzle at 20 m/s:

The figure 9 shows the pressure counter of linear aerospike nozzle at inlet velocity of 20 m/s. It gives the information about the total pressure distribution in the nozzle and the domain. The maximum exit total pressure is noted from the figure.

2.2) For Linear Aerospike Nozzle at 200 m/s:

The figure 10 shows the pressure counter of linear aerospike nozzle at inlet velocity of 200 m/s. It gives the information about the total pressure distribution in the nozzle and the domain. The maximum exit total pressure is noted from the figure.

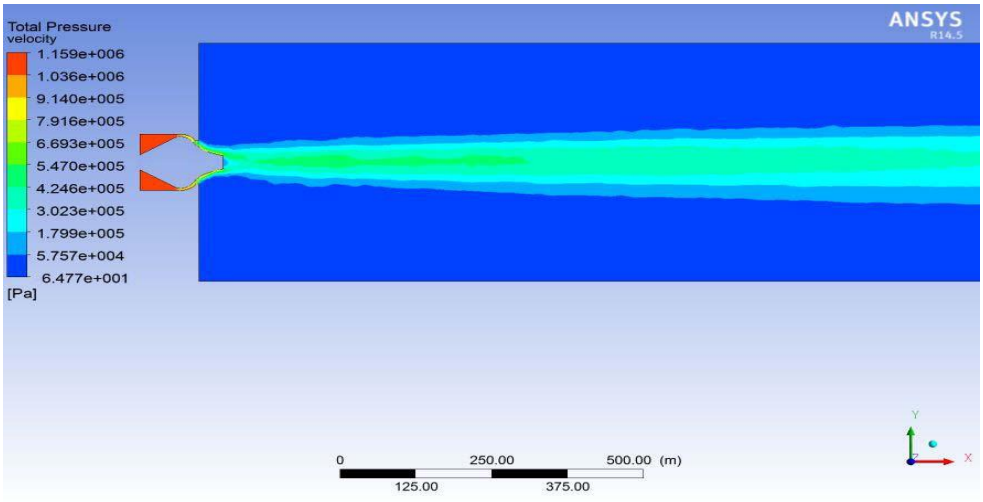

Fig. 10: Total pressure counter for linear aerospike nozzle at 100 m/s

B. Flow through Annular Aerospike Nozzle:

In this section the results from annular aerospike nozzle configuration are discussed here. The velocity and pressure are depicted and discussed. The force exerted by nozzle exit flow is discussed.

1) Velocity Counter for Annular Aerospike Nozzle:

1.1) For Annular Aerospike Nozzle at 20 m/s:

The figure 11 shows the velocity counter of annular aerospike nozzle at inlet velocity of 20 m/s. It gives the information about the velocity distribution in the nozzle and the domain. The maximum exit velocity is noted from the figure.

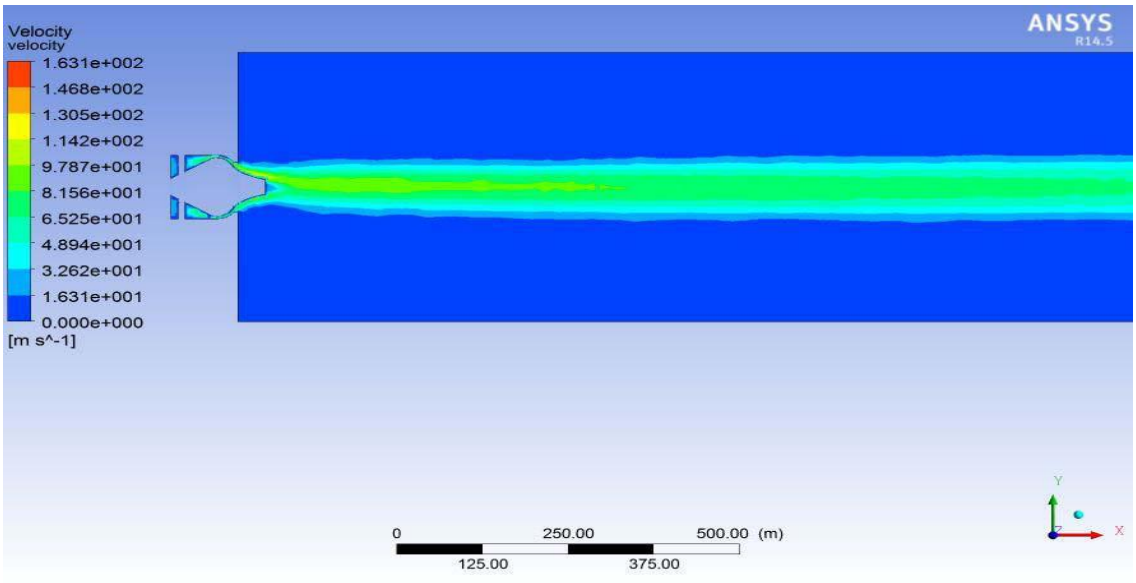

Fig. 11: Velocity counter of annular aerospike nozzle at 20 m/s

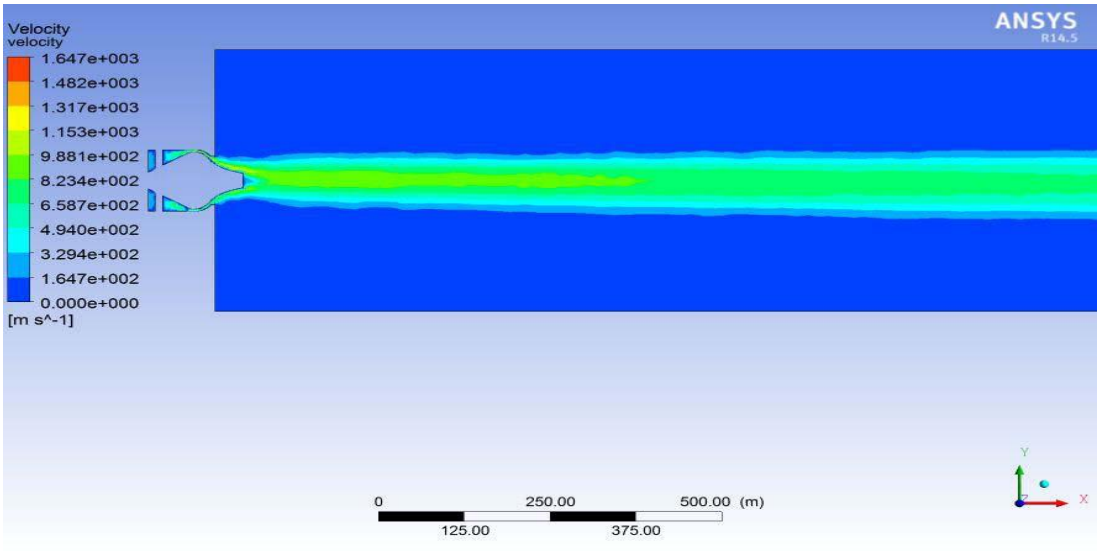

Fig. 12: Velocity counter of annular aerospike nozzle at 200 m/s.

1.2) For Annular Aerospike Nozzle at 200 m/s:

The figure 12 shows the velocity counter of annular aerospike nozzle at inlet velocity of 200 m/s. It gives the information about the velocity distribution in the nozzle and the domain. The maximum exit velocity is noted from the figure.

2) Total Pressure counter for Annular Aerospike Nozzle:

2.1) For Annular Aerospike Nozzle at 20 m/s:

The figure 13 shows the pressure counter of annular aerospike nozzle at inlet velocity of 20 m/s. It gives the information about the total pressure distribution in the nozzle and the domain. The maximum exit total pressure is noted from the figure.

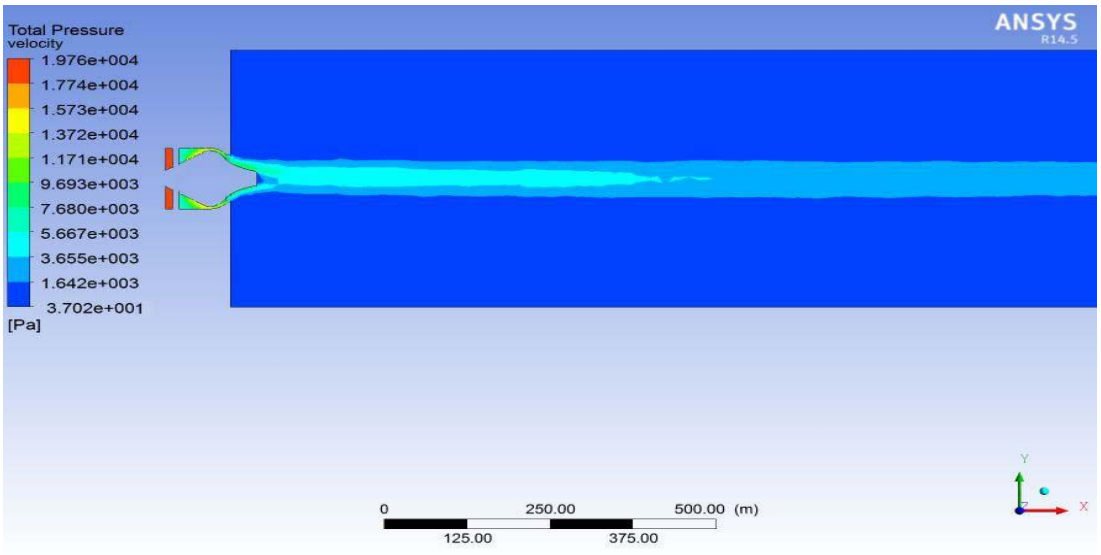

Fig. 13: Total pressure counter for annular aerospike nozzle at 20 m/s

2.2) For Annular Aerospike Nozzle at 200 m/s:

The figure 14 shows the pressure counter of annular aerospike nozzle at inlet velocity of 200 m/s. It gives the information about the total pressure distribution in the nozzle and the domain. The maximum exit total pressure is noted from the figure.

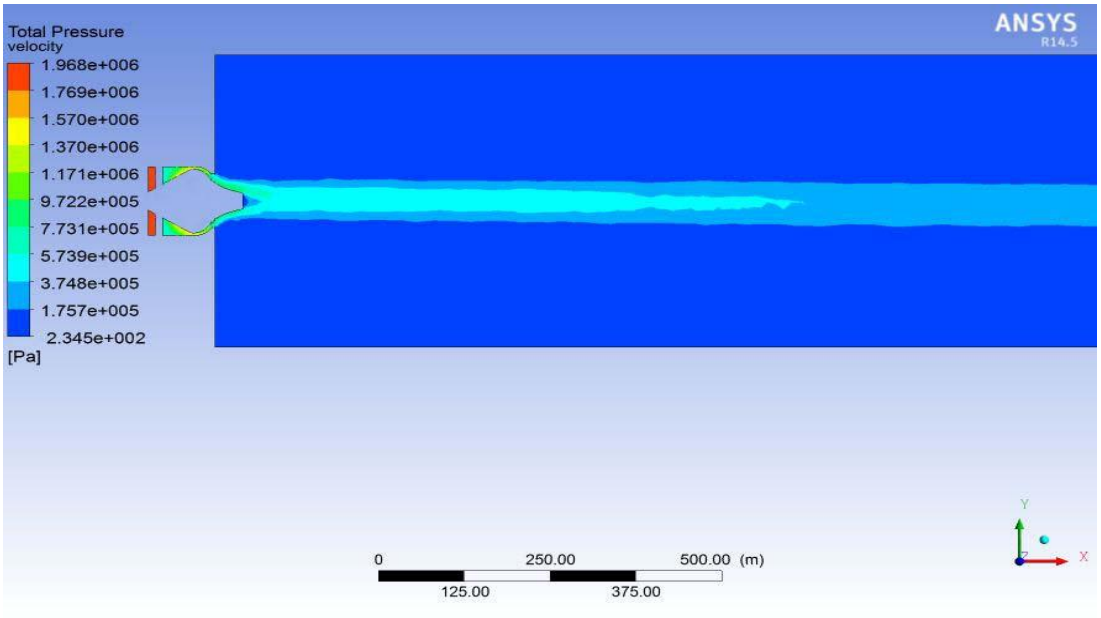

Fig. 14: Total pressure counter for annular aerospike nozzle at 200 m/s

C. Graphical Representation:

The values for maximum exit velocity and maximum exit pressure for both linear and annular type nozzles are noted down from the analysis report that has been created.

The figure 14 shows the maximum exit velocity vs inlet velocity graph. It can be seen that the exit velocity for the annular aerospike nozzle is considerably higher when compared to that of the linear type nozzle. This is occurred due to further reduction of the area at inlet of annular type as that of the linear one.

Table II: Shows the velocity values that are to be plotted down.

S.No.	Inlet Velocity m/s	Max Exit Velocity (Linear) m/s	Max Exit Velocity (Annular) m/s
1.	20	97.47	114.2
2.	30	146.2	171.1
3.	50	243.7	286.4
4.	100	487.5	574.3
5.	200	975.1	1153.4

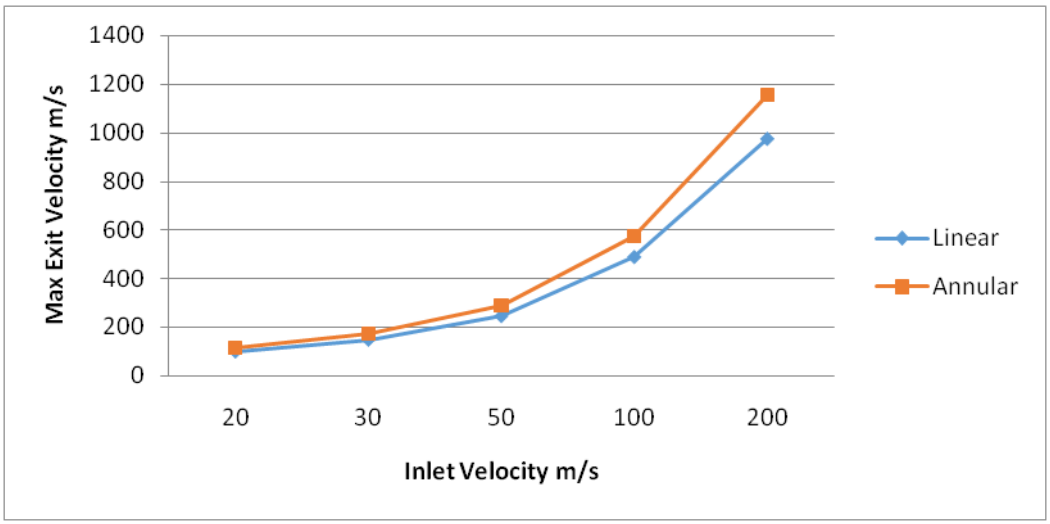

Fig. 14: Maximum Exit Velocity in the Flow Domain for Various inlet velocities.

Table III: Total pressure values that are plotted down.

S.No.	Inlet Velocity m/s	Total Pressure at Exit (Linear) N/m^2	Total Pressure at Exit (Annular) N/m^2
1.	20	$6.68*10^3$	$1.17*10^4$
2.	30	$1.50*10^4$	$2.64*10^4$
3.	50	$4.19*10^4$	$7.31*10^4$
4.	100	$1.67*10^5$	$2.92*10^5$
5.	200	$6.69*10^5$	$1.17*10^6$

The figure 15 shows the maximum exit total pressure vs inlet velocity graph. It can be seen that the pressure at exit for annular type has a steady increase over the linear type nozzle for the corresponding inlet velocities. At 200 m/s inlet velocity there is a sudden rise in the exit pressure.

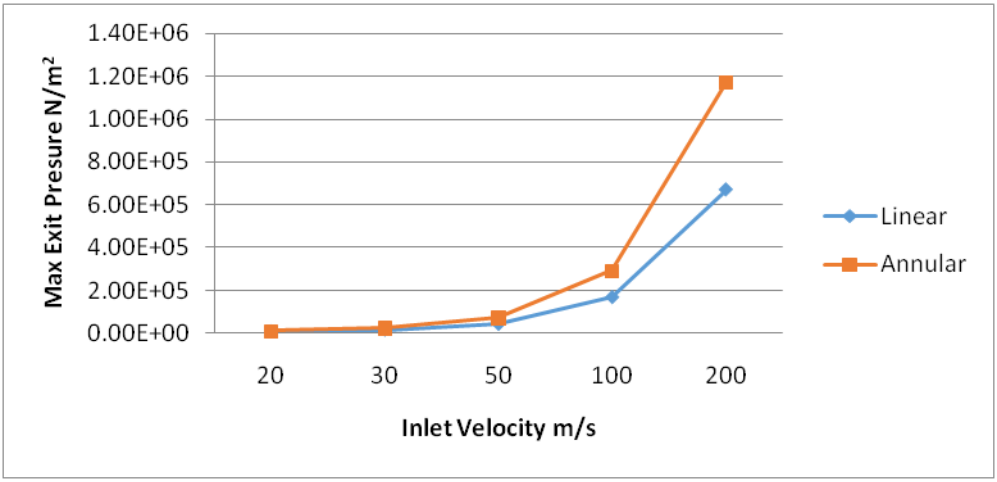

Fig. 15: Maximum Exit pressure in the flow domain for various inlet velocities

Conclusion:

The study on both linear and annular aerospike nozzles is conducted with the help of available literature. Numerical analysis is carried out to identify the aerospike characteristics. Ansys-Fluent14.0 is used for the numerical simulation. Steady, implicit formulation, mass, momentum and energy conservation is carried out. The k-e turbulence model is used. The obtained flow phenomena in the aerospike flow domain for both the nozzles are reported with the help of exit velocity, exit pressure counters.

At higher pressure inlets the performance of the annular aerospike nozzle gets into a pragmatic condition compared to that of the linear aerospike nozzle. This is due to reason that as the area at inlet for annular type is further reduced to that of the linear one, there can be a chance of flow reversal inside the nozzle itself. This can cause the flow to be reversed back to the combustion chamber. This can also affect the combustion process, therefore resulting in less performance to that of the linear aerospike nozzle. The various inlet conditions have been studied with the help of available literature. Finally at lower inlet velocities, the annular type proved to be economic when compared to that linear aerospike nozzle. Based on the fact that the nozzle inlet velocity for rocket engine could be very less than that for a jet engine, the inlet boundary conditions were chosen. As these nozzles are employed in free vacuum space, there won't be hardly any effects by the surrounding pressure and temperature.

It can be proved that the maximum performance can be delivered from annular aerospike nozzle at low inlet velocities. But when the pressure at inlet of the nozzle is high, then the linear aerospike nozzle proves to be more sufficient to that of the annular aerospike nozzle.

REFERENCES

Eric Besnard, 2012. "Design, Manufacturing and Test of a Plug Nozzle Rocket Engine" AIAA-02-4038.

Gerald Hagemann, 1998. "Advanced Rocket Nozzles", Journal of propulsion and power.

Khan, K.M. and S. Khushnood, 2013. "Numerical Simulation of Aerospike Nozzle Inviscid Isentropic Flow field", Life Science Journal.

Nathan Erni, 2011. "Attitude Control Using Aerodynamic Vectoring on an Aerospike Nozzle", Rocky Mountain NASA space grant symposium.

Sanoob, S.N., 2013. "Numerical Analysis of Aerospike Nozzle for spike length optimization", International Journal of Research in Engineering & Technology, Vol. 1.

Trong Bui, T., 2005. "Flight Research of an Aerospike Nozzle Using High Power Solid Rockets", Tucson Convention Center, Tucson, Arizona.

Zili´c, A., "Numerical Simulations of Supersonic Flow in a Linear Aerospike Micro nozzle", School of Engineering, University of Vermont, School of Aeronautics & Astronautics, Purdue University.