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# Design and Analysis of Expansion-Deflection Nozzle by Varying the Position

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**Abstract:** The altitude compensating characteristics of the Expansion-deflection (ED) nozzles is being considering in upper stage of launch vehicles. The plug nozzle has a centre body, which help to improve the performances of the nozzle. This project deals with the designing and analysis of the nozzles using CATIA V5 and ANASYS Fluent respectively. The project can be done by varying the linear position of the E-D nozzle at different percentage such as 25%, 30% and 60% after the throat of the nozzle. The flow filed obtained through the analysis of the nozzle at various conditions are evaluated and the conditions of the outflow are found out.

**Keywords:** Expansion-deflection (ED) nozzles , High Performance Ratio, Ideal Expansion, Over Expansion, Under Expansion, Isentropic Expansion.

## 1. Introduction

The nozzle that is used for altitude compensate is the advanced one for the better performance of the aircraft and economy. E-D nozzle is the altitude compensating nozzle that are commonly used in the rocket engine. That will compensate the altitude by interaction of exhaust with the atmosphere. It appears much like a standard bell nozzle, but at the throat is a 'centrebody' 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. Because of the atmospheric boundary, the atmospheric pressure affects the exit area ratio so that atmospheric compensation can be obtained up to the geometric maximum allowed by the specific nozzle.

The nozzle operates in two distinct modes: open and closed. In closed wake mode, the exhaust gas fills the entire nozzle exit area. The ambient pressure at which the wake changes from open to closed modes is called the design pressure. If the ambient pressure reduces any further, additional expansion will occur outside the nozzle much like a standard bell nozzle and no altitude compensation effect will be gained. In open wake mode, the exit area is dependent on the ambient pressure and the exhaust gas exits the nozzle as an annulus as it does not fill the entire nozzle. Because the ambient pressure controls the exit area, the area ratio should be perfectly compensating to the altitude up to the design pressure.

## 2. Problem Statement

- The nozzle is bounded by solid wall
- And It cannot adjust the intensity
- Also it cannot domain of exhaust flow with external flow.

Altitude compensating truncated nozzle can overcome all these problems mentioned above. This can help to overcome certain performance of the nozzle and can increase the performance.

## 3. Conseptual Design

The project work carried out by varying linear position of the E-D nozzle at different percentage. Position includes 25%, 30% and 60% after the throat of the nozzle. Truncated nozzle is considered for the project. Design is carried out by establishing the coordinates for the respective designs. Determine the pressure ratio and Mach number to evaluate the efficiency. Design of the aero spike nozzle mainly refers to the design of the central spike and the determination of angle of the primary nozzle. The calculation of expansion can do by **Prandtl- Meyer** function. In aerodynamics, the Prandtl–Meyer function describes the angle through which a flow can turn isentropically for the given initial and final Mach number. The default input variable is the Mach number, and by varying Mach number you can see the effect on Prandtl- Meyer angle.

$$\vartheta(M) = \sqrt{\frac{\gamma+1}{\gamma-1}}.arctan\sqrt{\frac{\gamma-1}{\gamma+1}.(M^2-1)} - \arctan\sqrt{M^2-1}$$

$$\vartheta(M) = \sqrt{\frac{\gamma+1}{\gamma-1}-1}$$

- At upstream M = 1 , **ν** = 0
- When M = 1.5 , **ν** = 18.03

**Mach Number**

| Sl. No | Mach number | N |
|---|---|---|
| 1 | 1 | 0 |
| 2 | 1.5 | 11.905 |
| 3 | 2 | 26.3797 |

At angle 20

| Sl . No | Upstream mach no. M1 | Downstream mach no. M2 | Expansion flow angle θ |
|---|---|---|---|
| 1 | 1 | 1.77497 | 20 |
| 2 | 1.5 | 2.20666 | 20 |
| 3 | 2 | 2.83060 | 20 |
| 4 | 2.5 | 3.53757 | 20 |

At angle 25

| Sl . No | Upstream mach no. M1 | Downstream mach no. M2 | Expansion deflection angle θ |
|---|---|---|---|
| 1 | 1 | 1.95030 | 25 |
| 2 | 1.5 | 2.40656 | 25 |
| 3 | 2 | 3.08550 | 25 |
| 4 | 2.5 | 3.87707 | 25 |

At angle 30

| Sl . No | Upstream mach no. M1 | Downstream mach no. M2 | Expansion Deflection angle $\theta$ |
|---|---|---|---|
| 1 | 1 | 2.13390 | 30 |
| 2 | 1.5 | 2.62190 | 30 |
| 3 | 2 | 3.36827 | 30 |
| 4 | 2.5 | 4.26506 | 30 |

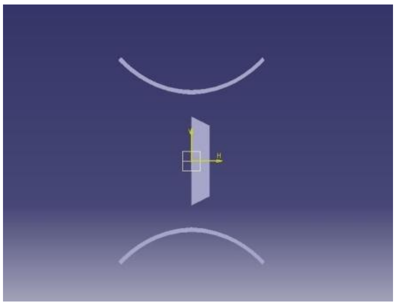
- The values can be find out using the Normal Shock Wave and Expansion Wave Table
- M1=Mach number of stream flow
- M2=Mach number of flow after passing through normal shock wave
- P2/P1=Static pressure ratio across normal shock wave
- d2/d1=Density ratio across normal shock wave
- T2/T1=Temperature ratio across normal shock wave
- Po2/Po1=Stagnation pressure

From all the above calculation, it is decided that the average value is given by the angle 25 degree, so the angle can be taken as 25 for the nozzle, which will give the intermediate performance of the both 20 and 30 degree angle.

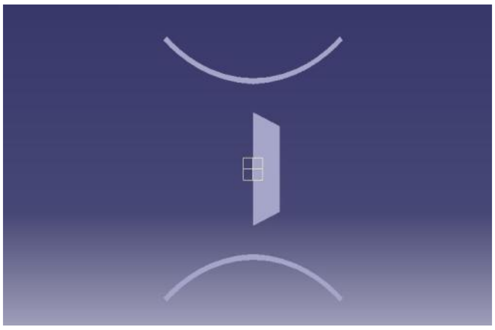
**1. CATIA V5**

CATIA software is a multi-platform software suite for computer-aided design, computer- aided manufacturing, computer-aided engineering, PLM and 3D, developed by the French company Dassault Systèmes. is the world's engineering and design leading software for product 3D CAD design excellence. It is used to design, simulate, analyze, and manufacture products in a variety of industries including aerospace, automotive, consumer goods, and industrial machinery, just to name a few. CATIA offers a solutionto 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 (blueprints).

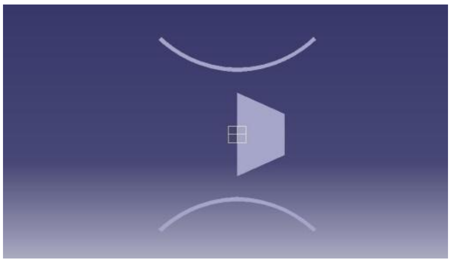
E-D nozzle at 25% of nozzle



E-D nozzle at 30% of nozzle



E-D nozzle at 60% of nozzle



The above figures are the 3D model of aerospike design inside the engine. There are different trails of the design that are added in the appendix. The design of these aero spikes is later analyzed in the Ansys fluent. Through that the different performance of the nozzle can be find out

## 4. Analysis

Analysis is the major part of the project. It will help for the detailed determination of the element or the structure of the airship. The analysis is done for the better understanding of the project by passing the flow over the airship. The application of the analytic principles and the process to revel the properties and state of the system that we are considering, here the nozzle is the system that we are considering. By using the analytic tool the understanding of variables and properties of the nozzle can be.

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## Ansys Fluent

Ansys fluent software contains the broad, physical modeling capabilities needed to model flow turbulence, heat transfer and reactions for the flow application. These range from air flow over an aircraft wing to combustion in a furnace, from the bubble column to oil platforms, from blood flow to semiconductor manufacturing and from clean room design to wastewater treatment plants. Fluent spans an expansive range, including special modes with capabilities to model in cylinder combustion, aero-acoustics, turbo machinery and multiphase system. Fluent also offers highly scalable, high performance computing (HPC) to help solve complex, large-model computational fluid dynamics (CFD) simulation quickly and cost-effectively. Fluent set a world supercomputing record by scaling to 17200 cores. The main advantages of the fluent are,

- Provides a complete, single window solution within fluent.
- Streamline the fluent workflow for generating a mesh from imported CAD.
- Removes barriers for common tasks that frustrate users.

### Cases and Respective Features

| Case | Percentage | Patm/Pdes | Condition |
|---|---|---|---|
| 1 | 25 | 0.98 | Under expansion |
| 2 | 30 | 0.98 | Under expansion |
| 3 | 60 | 0.98 | Under expansion |
| 4 | 25 | 1 | Ideal |
| 5 | 30 | 1 | Ideal |
| 6 | 60 | 1 | Ideal |
| 7 | 25 | 1.2 | Over expansion |
| 8 | 30 | 1.2 | Over expansion |
| 9 | 60 | 1.2 | Over expansion |

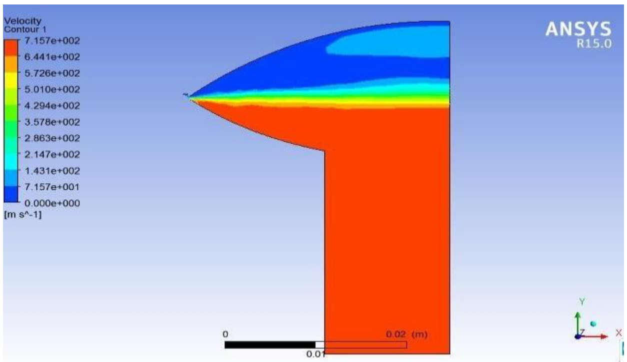
## 5. Result

In this section, flow pattern of the aero-spike nozzle with varying amount of truncation in different working conditions are compare and discussed. From those different cases we are reached the specific condition by evaluating the results of the analysis.

### I. Under expansion conditions

**Case 1:**

This case corresponds to the analysis of the 25% aero spike nozzle in under expansion conditions where the operating conditions taken accordance with the atmospheric conditions. Inthis case the expansion waves originated from the upper lip of the primary nozzle face the truncated portion.

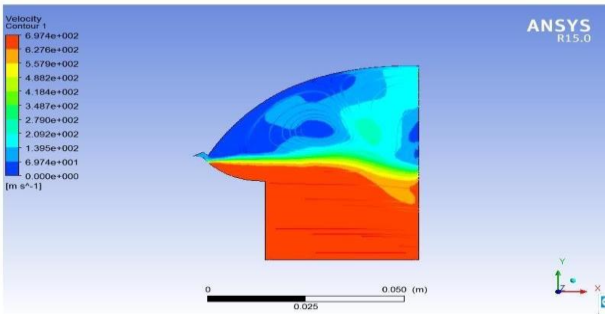



Under expansion condition at 25 %

**Case 2:**

This case corresponds to the analysis of 30% aero-spike in under expansion condition accordance with the atmospheric conditions.

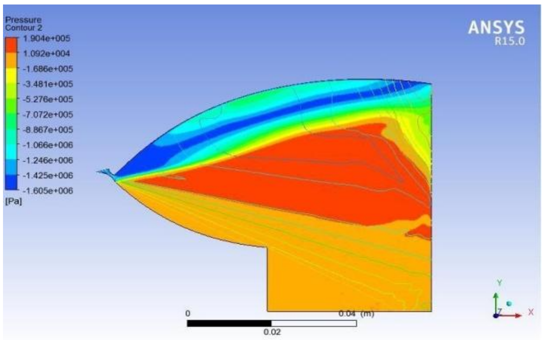
  




Under expansion condition at 30%

**Case 3:**

This case corresponds to the analysis of 60% aero-spike in under expansion condition accordance with the atmospheric conditions.

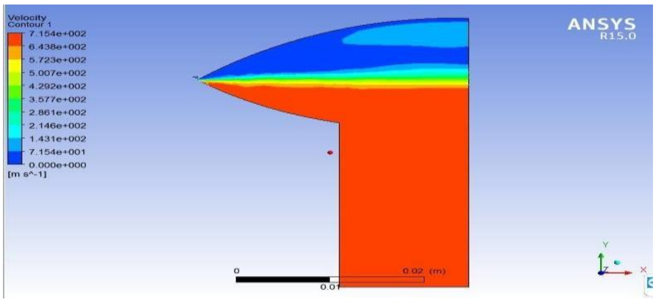



Under expansion condition at 60%

**II. Ideal condition**

**Case 4:**

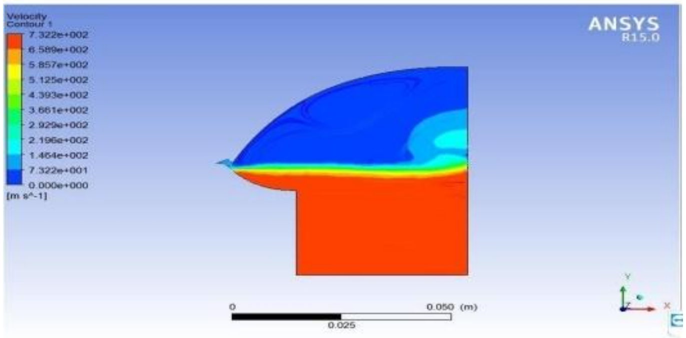
This case corresponds to the analysis of 25% aero-spike in ideal expansion condition accordance with the atmospheric conditions




Ideal condition 25%

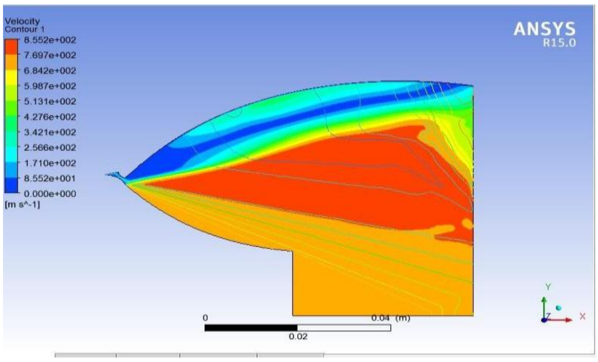
**Case 5:**

This case corresponds to the analysis of 30% aero-spike in ideal expansion condition accordance with the atmospheric conditions.

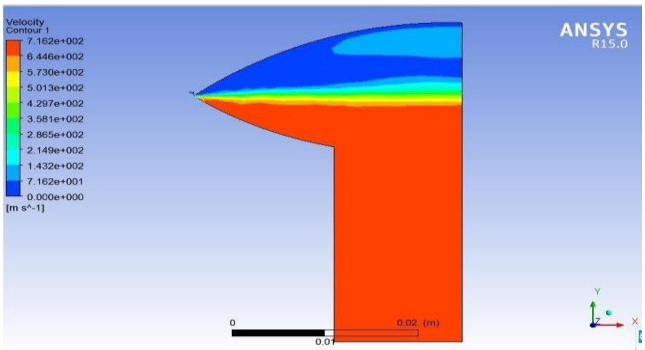



Ideal condition at 30%

Case 6




Over Expanded condition at 30%




Over Expanded condition at 25%

In under-expansion conditions, when the plug is truncated, its lateral area decreases. Therefore the pressure thrust produced by the truncation reduces. On the other hand, thrust generated by the base region increases because of the increase of the base area. These two effects compensate each other, and the total nozzle thrust becomes almost the same for different nozzle truncation.

This effect can be seen most clearly for the 25% and 30 % plug. But in over-expansion conditions, the situation is totally different. In these conditions, as the nozzle length becomes shorter, hence decreasing the truncated area, thrust produced by the truncation still decreases, while as the atmosphere pressure is higher than the exhaust pressure thrust produced by the base pressure would have a negative value. So by increasing truncation, the negative value of base thrust will increase, hence decreasing total thrust in over-expansion conditions. It can be concluded that for the 25% plug, total thrust is lowest. At low altitudes (i.e., over-expansion conditions) base pressure linearly increases as atmospheric pressure increases. Therefore, the pressure thrust which is produced by the pressure difference between the atmosphere and the base becomes small and even negative in most cases at low altitudes. On the other hand, at high altitudes, pressure at the base remains constant despite variation of altitude. As the altitude increases, atmospheric pressure decreases and the difference between base pressure and atmospheric pressure increases, hence increasing the base thrust.

## 6. Conclusion

In this thesis the design, calculation of expansion of nozzle and the analysis is done. We are considering three basic truncated nozzles that can perform in different conditions. The three basic designs are designed using CATIA V5.Total study is divided into three different cases which represent to under-expansion, ideal/ designed conditions and over-expansion conditions. Exhaust flow of the aero-spike nozzle is characterized by formation of a series of expansion waves, which originate from the upper lip of the convergent section. Since the exhaust flow is not bounded by a solid wall, these expansion waves can adjust their intensity and domain to match the exhaust flow with the external flow, which gives an advantage of the altitude compensation in contrast to the conventional nozzle.

In all the nine cases exhaust flow of the aero-spikenozzle is characterized by formation of a series of expansion waves, which originate from the upper lip of the convergent section. The flow structure and the performance of the designed nozzles at three different altitudes, which are selected hypothetically to represent under-expansion, ideal, and over-expansion conditions, are simulated using ANSYS FLUENT and the results are compared and analyzed. From the result it clearly indicate that the nozzle is capable of producing the optimum performance at different altitude, this phenomenon is called altitude compensating nozzle.

## 7. References

[1] Design and Numerical Flow Analysis of Expansion Deflection Nozzle Shaik Abdul Muwaaz1, Nazumuddin Shaik2

[2] DESIGN AND FLOW SIMULATION OF TRUNCATED AEROSPIKE NOZZLE Vinay Kumar Levaka1, Srinivasa Reddy K2

[3] Advanced Rocket Nozzles Gerald Hagemann*

[4] Angelino G., "Approximation Method for Plug Nozzle Design", AIAA Journal, Vol. 2, No. 10, Oct.1964, pp. 1834-1835.

[5] Gross, Klaus W., "Performance Analysis of Aerospike Rocket Engines," 1972.

[6] Lee, C. C., "Computation of plug nozzle contours by the Rao's optimum thrust method", NASA CR 21914 R-61, 1963.

[7] Lee, C. and Thompson D., "FORTRAN Program for Plug Nozzle Design", NASA TM X- 53019, 1964.

[8] Lee, C. C., Inman. S. J., "Numerical analysis of plug nozzles by the Method of characteristics", NASA TECHNICAL NOTE R-10, 1964.

[9] Besnard, E., H. H. Chen, T. Mueller and J. Garvey, "Design, Manufacturing and Test of a Plug Nozzle Rocket Engine", AIAA Paper 2002-4038, 2002.

[10] Naghib Lahouti, A., Nazarinia, M. and Tolouei, E., "Design and CFD Analysis of an Aerospike Nozzle to Compare Its Off Design Performance with a Conventional Nozzle", Proceedings of IMEC2004, International Mechanical Engineering Conference, IMEC2004- FM014-CP, December 5-8, 2004, Kuwait.

[11] Naghib Lahouti, A., Nazarinia, M. and Tolouei, E., "Design and numerical analysis of aerospike nozzles with different plug shapes to compare their performance with a conventional nozzle", The Eleventh Australian International Aerospace Congress, Melbourne, Australia, 13-17 March (2005).