

Design and Optimization of Aerodynamics Nozzle for maximum thrust using Multidisciplinary Design Optimization (MDO)- An overview

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Abstract - An Aerospoke nozzle model is selected for evaluating multidisciplinary optimization procedure. A multidisciplinary analytic model of a linear aerospoke rocket nozzle has been developed; this model includes predictions of nozzle thrust, nozzle weight, and effective vehicle gross-liftoff weight. The contour of the aerospoke nozzle has been designed for maximum thrust at one design condition. The aerospoke geometry (length, base height, surface contour) and the structural (dimensions like tube radii and thickness) design parameters are computed to satisfy a structural constraints (displacement, stress and buckling). An Design optimization formulation has been implemented with a goal of minimizing gross-liftoff weight (GLOW). For this thrust and nozzle wall pressure calculations were made using CFD and were linked to structural FEA for determining nozzle weight and structural integrity. Calculations for specific impulse and engine thrust to weight ratio are executed to determine optimum vehicle liftoff weight. The Multidisciplinary analysis was integrated with an optimization procedure that allowed investigation of Multidisciplinary feasible strategy. This MDO result are compared with the separate aerodynamics & structural optimized design which shows the comparatively improvement over individual results. The Rocketdyne-developed F-1 engine is the most powerful single-nozzle liquid-fueled rocket engine ever flown. The RD-170 produces 11% more and the RD-171 produces 20% greater thrust using a cluster of four combustion chambers and four nozzles. The M-1 rocket engine was designed to have more thrust, however it was only tested at the component level. The F-1 was a liquid-fueled rocket motor, burning RP-1 (kerosene) as fuel, and using liquid oxygen (LOX) as the oxidizer. Therefore I had take F1 as the reference engine.

Key Words: Structural analysis in ANSYS, CFD, Aerodynamic Nozzle, etc..

1 INTRODUCTION:

A multidisciplinary analytic model of a aerospoke rocket nozzle has been developed, this model includes

predictions of nozzle thrust, nozzle weight, and effective vehicle gross-liftoff weight (GLOW). The linear aerospoke rocket engine is the propulsion system proposed for the X-33. The model has been developed to demonstrate multidisciplinary design optimization (MDO) capabilities for relevant engine concepts, assess performance of various MDO approaches, and provide a guide for future application development[1].

Fluid-structure interaction (FSI) is the interaction of some movable or deformable structure with an internal or surrounding fluid flow. Fluid-structure interaction problems and multiphysics problems in general are often too complex to solve analytically and so they have to be analyzed by means of experiments or numerical simulation. Research in the fields of computational fluid dynamics and computational structural dynamics is still ongoing but the maturity of these fields enables numerical simulation of fluid-structure interaction. There are Two main approaches exist for the simulation of fluid-structure interaction problems:

1) **Monolithic approach:** In monolithic approach consisting the equations, governing the flow and the displacement of the structure are solved simultaneously, with a single solver. This approach becomes complicated but requires less time.

2) **Partitioned approach:** the equations governing the flow and the displacement of the structure are solved separately, with two distinct solvers. We shall used partitioned approach where fluid dynamic equations are solved using separate solver i.e. CFD and structural equations are solved using Finite element method in ANSYS. For industrial designing purpose this methodology is more reliable than the monolithic approach as design criteria for flow design and structural design is satisfied individually but it takes more time.

There are many parameters including rocket, such as thrust chamber assemble, thrust chamber injector, oxidizer zone, Gimbal bearing, thrust chamber body, Thrust chamber nozzle extension, nozzle, hypergol cartridge, etc lots of parameters are included there. But till we will study on aerospoke nozzle, because our aim is to getting higher thrust. Therefore we had selected nozzle as the main parameter for this work. The thrust chamber nozzle extension increases the expansion ratio of the thrust chamber from 10:1 to 16:1. It is detachable unit that is bolted to the exit end ring of the thrust chamber. The interior of the nozzle extension is protected from the engine exhaust gas environmental by film cooling, using turbine exhaust gases as the coolant. The gases enter the

extension between a continues outer wall and a shingled inner wall, pass out through injection slots between the shingles, and flow over the surface of shingles forming a boundary layer between the inner wall of the nozzle extension and the hotter exhaust gases existing from the main engine combustion chamber. The nozzle extension is made of high strength stainless steel.

In recent years, concepts from optimization theory have been successfully applied to an ever growing number of engineering problems. The first applications were in the area of automatic control systems. Subsequently, optimization techniques were used in flight and orbital mechanics to determine flight profiles of minimum propellant consumption. More recently, these same techniques have been applied to gas dynamic problems. In the field of external gas dynamics, the determination of minimum wave drag bodies has been the subject of a large number of investigations. Following Fig is given from Saturn v/s-IC stage five engine.

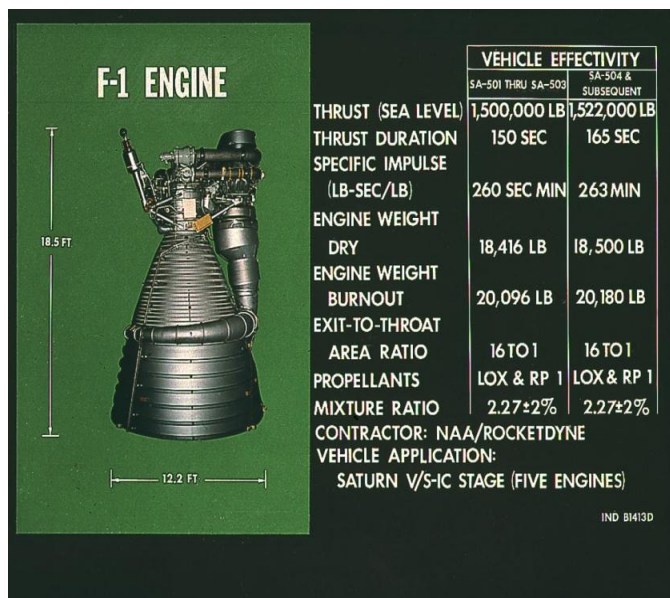


Fig 1: Nozzle description

1.1 MDO development:

First of all we shall concentrate on the development of multidisciplinary analysis. This analysis includes computational fluid dynamic(CFD) and structural analysis. In this section the discipline problems and their corresponding design parameters are presented, along with the discipline analyses related to the objective function. The aerospike nozzle geometry is treated as a two dimensional surface defined from a fixed point at the end of cowl. A MDO of an aerospike nozzle has been developed for calculating MDO optimization and new design both of two.

2 RESERCH APPROACH:

Rapid progress in aerospace technologies requires a constant interplay between analysis, ground testing, and flight testing activities. All three of these activities are equally important. Testing, both on the ground and in flight, keeps analysis well-grounded and relevant, while analysis provides the foundation and explains flight and ground test results [3]. In this project I shall draw the drawings of nozzle shape in CFD and then we will got the different results in terms of fluid analysis, but here we shall concentrate on pressure only for further work.

3 METHODOLOGY:

Input parameters for this work are basically Nozzle geometry (contours), weight, thickness of the contours, various constrains like Area ratio, Length of Nozzle. And output is nozzle profile. Generally after the study related to this topic gives the basic shape of nozzle which is parabolic. And we will do study on parabolic contour nozzle by taking the parabola is the basic shape and finding all the results related to it. After that will change the contour shape in different manner's to comparing study between it. Those different nozzle contour shapes are cubical contour profile, semi cubical parabolic profile. After that finding best results from these.

For analysis in CFD it requires some input for determining the respected results, so this input getting by following equation. For parabolic profile: $y = -0.2088x^2 + 0.46865$. in this x is the total nozzle length. If x varies automatically y will get varied, therefore getting the different wall points of parabolic profile for CFD analysis. Then by taking this wall point it gets nozzle shape profile and then analyzed it which will give the results in terms of pressure. Same procedure is followed for other two profiles i.e cubical profile and semi cubical profile.

For cubical contour profile, equation is $y = -(0.208e-4)x^3 + 0.46865$. and for semi cubical parabolic equation is $y^3 = -(0.0667) x^2 = 0.10293$. Pressure coming from this software is then validated with numerical solution. Generally pressure measurements are presented in two form:

- 1) As a pressure ratio
- 2) in terms of a pressure coefficient(Cp)

$$Cp = \frac{(P - P_{\infty})}{0.5 * \rho V^2}$$

- P - Pressure of exhaust gas coming from nozzle
- P_{∞} - Ambient Pressure
- C_p - Pressure Co-efficient
- ρ - Density of exhaust gases coming from nozzle
- V_f - Flow velocity of exhaust gases
- V_{sound} - Velocity of sound

4 COMPUTATIONAL PROCEDURE:

The finite volume solver, FLUENT 6.3, is used to obtain the numerical solution of the two-dimensional compressible Reynolds averaged Navier–Stokes (RANS) equations in connection with six turbulence models for closure of the RANS equations. The discretized equations, along with the initial condition and boundary conditions, were solved using the segregated solution method. Using the segregated solver, the conservation of mass and momentum were solved sequentially and a pressure correction equation was used to ensure the conservation of momentum and the conservation of mass (continuity equation). Several turbulence models, i.e. the standard k–e model, the extended k–e model, shear-stress transport k–x model, RSM, v2– f and the realizable v2–f model are tested. The extended k–e model differs from the standard k–e model in its constant and it has an additional source term in the e equation. This model was implemented in the code by adjusting the standard k–e model constants and by defining the additional source term using User Defined Functions (UDF). Moreover, the four equation turbulence v2–f models are implemented using User Defined Scalars (UDS) along with UDF.

The governing equation consist of the continuity equation and Reynolds-average governing equations for steady compressible turbulent flow coupled with the equation of state, $p=\rho RT$. The system of the governing equations can be described as follows:

The continuity equation:

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0.$$

RANS equations:

$$\frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left[\mu \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3} \delta_{ij} \frac{\partial u_l}{\partial x_l} \right) \right] + \frac{\partial}{\partial x_j} (-\rho \overline{u_i' u_j'})..$$

Energy equations:

$$\frac{\partial}{\partial t}(\rho E) + \frac{\partial}{\partial x_i} [u_i(\rho E + p)] = \frac{\partial}{\partial x_j} \left(\left(k + \frac{C_p \mu_t}{0.85} \right) \frac{\partial T}{\partial x_j} + u_i(-\rho \overline{u_i' u_j'}) \right).$$

5 Nomenclature:

U -	Mean quantities
u' -	Fluctuating or turbulence quantities
μ -	Viscosity
P -	Pressure of exhaust gas coming from nozzle
P_∞ -	Ambient Pressure
C_p -	Pressure Co-efficient
ρ -	Density of exhaust gases coming from nozzle
Vf -	Flow velocity of exhaust gases
Vsound -	Velocity of sound
R -	Universal gas constant
M -	Molecular weight of exhaust gas

The additional fluctuation quantities $\overline{\rho u_i' u_j'}$ are the unknown turbulent or Reynolds-stress tensors, while u_i' represents the velocity fluctuations in i-direction.

6 CONCLUSION

In this paper, the Fluid structure interaction formulation has been implemented i.e. correlation between CFD and FEM results, is implemented on the rocket nozzle for getting optimum contour design, as the profile change for maximum thrust and minimum stresses

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