Research Article

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Designing And Simulation Analysis of A Rocket In Ansys

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Abstract

Background: *In this era of science, man is not limited to the earth, instead, is touching the soil of other planets too. Science has made it possible for humans to reach anywhere anytime by any means. One of the greatest inventions is Transportation. This transportation is not only limited to earth but is possible in the Space also. There are Space Vehicles or space crafts indulged in these operations. Energy is needed to operate them. The amount of this energy can be varied depending upon the structure of the vehicle and the forces opposing its movement.*

Result: *So, analysis is important to justify its structure and to calculate the forces exerted on it. Thus, this research includes analysis of a Rocket in Ansys software and determination of drag force acting on it and average pressure acting on it due to the environmental factors.*

Conclusion: *Subjected to these factors we will design and manufactured the required Rocket for our mission.*

Keywords: Environmental Factors; Space Vehicles; Transportation; Drag Force

Background

Humans have always dreamt of flying up to which there is no limit. It was around 1799 when Sir George Cayley identified the forces acting: weight, lift, Drag and Thrust and then bring the concept of flying fixed-wing machine, with separate systems for propulsions, lift, controls, designing a successful glider to carry a human aloft. To sustain aerodynamics flight, we require continuous working propulsion, unlike other transportations such as land and water, as they can survive without propulsion. By taking advantage of moving in a fluid, propulsion is achieved by the engines that through air backwards at a very high speed and get the same amount of force according to Newton's Third Law of Motion, which pushes their machine forward. This force is known as Thrust and the other force which opposed it is the Drag force. For a Space vehicle to run, its propulsion, i.e., Thrust force, must be more than Drag force and vehicle's weight. If the propulsion thrust is not enough to overcome drag force and the vehicle's weight, then the space vehicle will not fly.

What Is Aerospace Propulsion

A rocket is an aircraft or a projectile in space which helps in sending or launching guided missiles into space. A large amount to hot exhaust is expelled by its bottom. When we see gas molecules in the exhaust, they do not weigh much individually but the velocity with which they exit the rocket's nozzle is very high, thus by exiting they provide a lot of momentum, helps in giving further movement to the Aircraft in opposite direction. Satellites are launched into space with the help of Rocket. Its weight is about 165000 pounds, when empty. For proper launching of satellites into space, it is required to develop a very high momentum such that it gave an approximate speed about Eight Kilometers per Second to the Rocket. A Propulsion section is shown in Figure 1.

Figure 1: Propulsion section

What is a Rocket?

A rocket is an aircraft or a projectile in space which helps in sending or launching guided missiles into space. A large amount to hot exhaust is expelled by its bottom. When we see gas molecules in the exhaust, they do not weigh much individually but the velocity with which they exit the rocket's nozzle is very high, thus by exiting they provide a lot of momentum, helps in giving further movement to the Aircraft in opposite direction. Satellites are launched into space with the help of Rocket. Its weight is about 165000 pounds, when empty. For proper launching of satellites into space, it is required to develop a very high momentum such that it gave an approximate speed about Eight Kilometers per Second to the Rocket.

What Kind of Materials Are Used To Make a Rocket?

A material which has a very high strength and have less weight at the same time is the current requirement of the scenario. It is so because Rocket must withstand or overcome a high amount of force at its launch. Therefore, for the mainframe, rockets use Grade Titanium or Aluminum since both are very strong as well as have light weight. One material is also an appropriate option other than these two, which have the same property and that material is Carbon in the form of composites. Because of this, the value or cost of Carbon composite materials are very high. However, Aluminum has a low melting point. So, for mitigating this factor Silica fibers are used as Heat Shields as they have great heat insulation properties. Moreover, a layer of glass is also employed to coat these fibers for increasing its effectiveness.

Features of A Rocket

Certainly, there are three main features of a Rocket:

i. High Thrust in Mega Newton units.
ii. High Exhaust speed (ten times the speed of sound in atmosphere).
iii. High Thrust-to-Weight Ratio (>100).

Working Of A Rocket

Imagine a person standing on a skateboard, throwing a ball in a forwarding direction. The skateboard will move in a forward direction, but the person will move backwards. The person moves backwards because when he applied force on the ball, the equal and opposite force applied to him by the virtue he moves backwards. Newton's 3rd Law of Motion is the reason behind this. A thrust is produced in a rocket by the high-speed fluid exhaust. This exhaust is produced by the combustion of propellant and oxidized in a chamber at very high pressure (40-210 bar). The exhaust is then passed through a converging-diverging supersonic nozzle in which the internal energy is converted into kinetic energy, which results in the propagation of a high velocity which pushes the rocket body in the opposite (upward direction). For the efficient performance of a rocket, high temperature and high pressure are mandatory requirements. Due to this, a more extended nozzle is then fitted in the rocket, resulting in high exhaust velocity. Thus, a high amount of speed and thrust is provided to the missile, which also increases its thermodynamic efficiency. An approximate equation for calculating the net thrust of a rocket engine is given below.

$$F_n = m\dot{v}_e = mv_{e\text{-}act} + A_e\,(p_e - p_{amb})$$

Where:

$\dot{m}$ =Exhaust gas mass flow

v_e =Effective exhaust velocity

$v_{e\text{-}act}$ =Actual jet velocity

A_e =Flow Area at nozzle exit plane

p_e =Static pressure at nozzle exit

p_{amb} =Ambient pressure

The $mv_{e\text{-}act}$ term represents the momentum thrust, which remains constant at a given throttle setting, whereas the pressure thrust term is represented by the term $A_e\,(p_e - p_{amb})$.

We know that with increasing altitude, the atmospheric pressure decreases, thus the pressure thrust term increases. Therefore, at full throttle, the net thrust of a rocket motor improves. At the surface of the Earth the pressure thrust may be reduced by up to 30%, depending on the engine design. This reduction drops roughly exponentially to zero with increasing altitude. An interior structure of a conventional Rocket is shown in Figure 2.

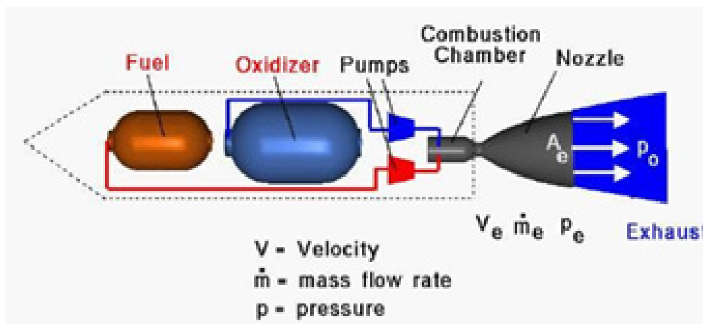


Figure 2: Rocket Interior

How is Rocket Designed?

There are certain factors on which designing of a Rocket depends such as amount of Thrust it should produce, its velocity range, and these factors depends on the type of environment from which it will be launched, viscosity of the fluid in which it will travel etc. Previously there were no software, so practical experimental methods are used which were so expensive, resulting in wastage of time as well as money. But now a days, there are various simulation software in which we can design and experiment analytically and can change its design according to our requirements.

Software Used

We use ANSYS Fluent 2021 R1 for the designing and testing of Rocket in viscous condition. It majorly consists of five parts. It majorly consists of five parts as shown in Figure 3.

Geometry; Mesh; Setup; Solution; and Result.

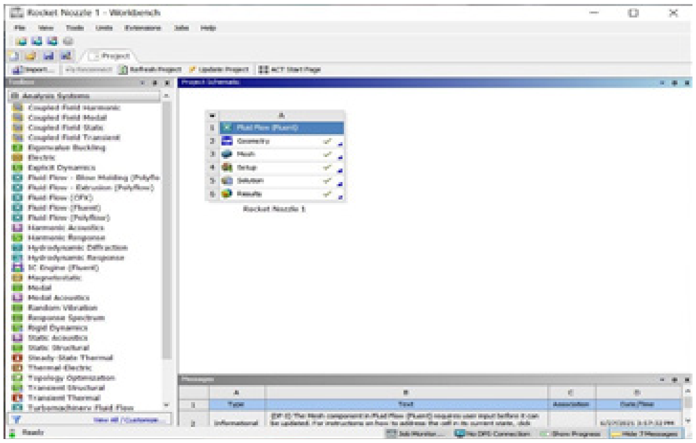


Figure 3: Ansys Fluent

i. In the Geometry section, 2D cross-section figure of Rocket is designed and it will be then converted to 3D figure. Special care should be taken because if there is any problem in Geometry section then we will not get the required solutions and all the four parts are linked to this part.
ii. In Meshing the 3D figure formed is divided into 1000 or more Hexagonal parts to define its shape properly for getting the realistic forces on its body.
iii. In Setup and Solutions part, type of material which Rocket is made up of is defined and boundary conditions are also defined such as Temperature, Pressure, Viscosity. After that, iterations are made, and calculations occur.
iv. In the results section, drag force acting on the Rocket Airframe will be calculated.

Solution Settings And Boundary Conditions

All the Boundary conditions decided along with Free stream conditions and Nozzle inlet conditions are shown in Table 1,2,3 respectively

Table 1: Solution Methods settings

Solver type	Pressure based
Energy Equations	ON
Viscous Model	k-omega (2 equation) SST
Viscosity Determination	Sutherland Method
Scheme	Coupled
Gradient	Green-Gauss Node based

Table 2: Free stream conditions

Operating Pressure	0 Pa
Mach Number	2
Static Pressure	70 kPa
Temperature	284 K

Table 3: Nozzle Inlet conditions

Gauge Total Pressure	4 MPa
Gauge Initial Pressure	3.8 MPa
Mach Number	0.15
Inlet Temperature	3300K

Methods

i). Plotting the key points
First, we will create the correct dimensions of the Rocket according to the coordinate points given.
ii). Making edges
Join these points to make edges, we must be sure that right key points are joined with each other as it is very critical portion of the process.
iii). Making faces
The 2D figure which is formed is converted to 3D figure by using Extrusion Revolve command. The results along with the measurements are shown in Figure 4.

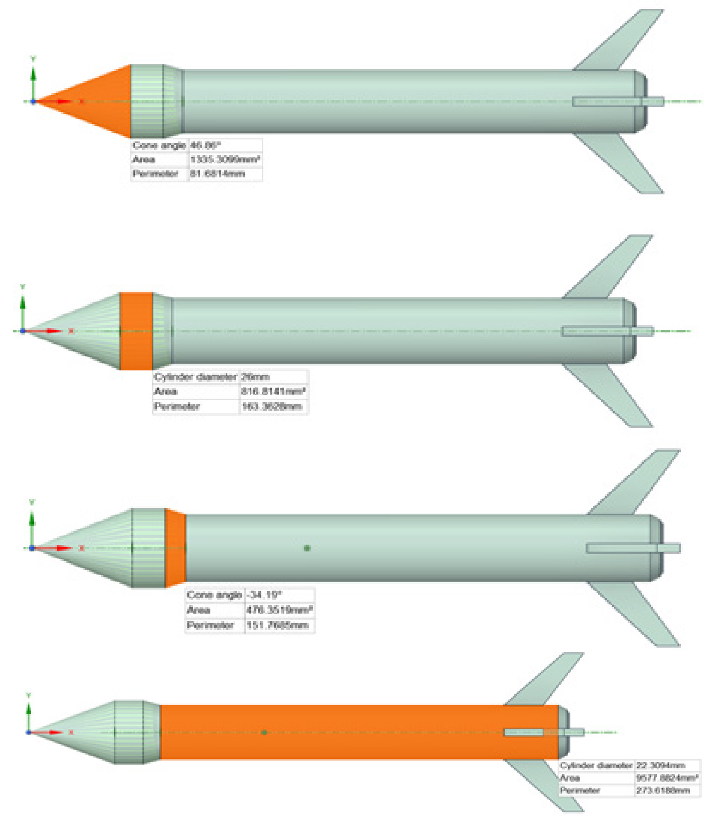


Figure. 4 Rocket Measurements

iv). Creating Enclosures
Rocket is divided into separate parts and enclosures are created around each part in which forces on that part will be measured as shown in Figure 5 given below.

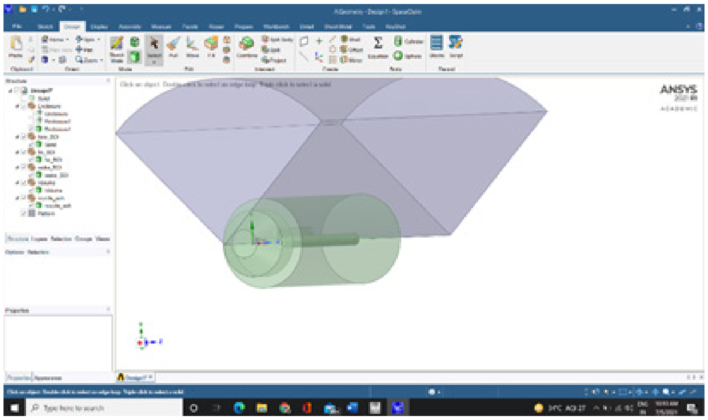
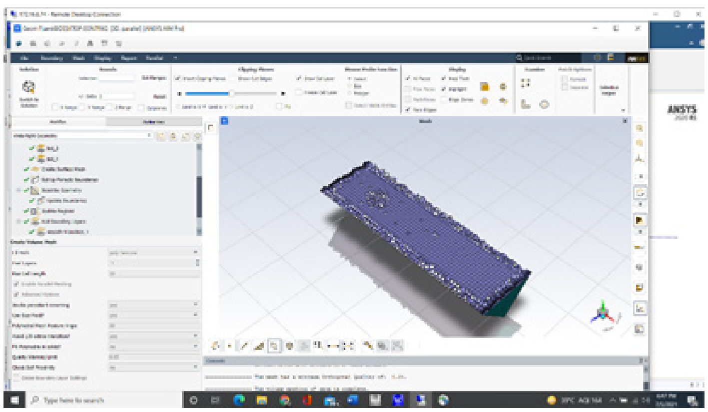


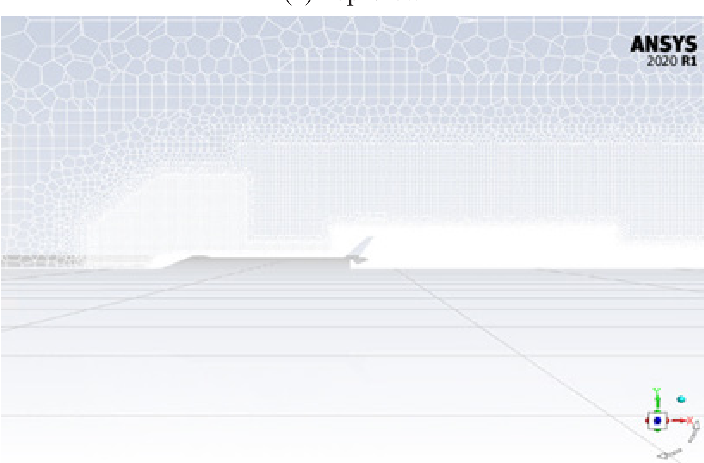
Figure 5: Enclosed final Geometry

v). Applying Mesh

In the mesh part we divide the figure into distinct elements and then apply proper sizing and then meshing to each part and then generate the required mesh. Below, Top view and Side view of Meshed part is shown in Figure 6 (a) and (b) respectively.



(a) Top View



(b) Side View

Figure 6: Meshed part (a) Top view and (b) Side view

vi). Now in Figure 7, it is shown the setup and solution part, we define boundary conditions given above such as Nozzle Inlet Temperature, Free stream Temperature, Inlet Gauge Pressure, Viscosity, Gradient, Viscous Model type. We will turn on energy equations and defined the material as air and set its density to ideal. At last, we will run iterations and calculations.

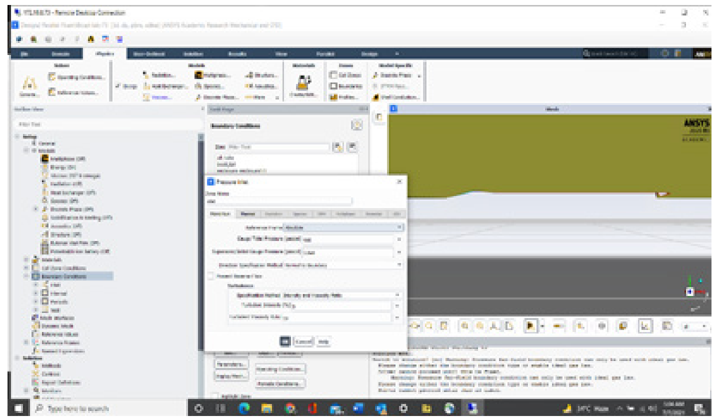


Figure 7: Settings Boundary conditions

vii). At last, we will enter the solutions part and obtain the Drag force acting on the Rocket which we have designed.

Cfd Results

The CFD analysis of Rocket which we have designed is done by ANSYS R1 2021 to calculate the Drag force acting on the Rocket Airframe and Nozzle. We will plot Mach number contour also. The Energy method is turned on as well as Density based calculations are made because we consider fluid to be compressible. K-Epsilon-2 equation Model is selected. Second order upwind is selected for both Turbulent Dissipation rate and Turbulent Kinetic Energy. CFD Analysis on Ansys software is a great method of testing Rocket in realistic conditions or situations because Experimental methods are very costly and results in the loss of money as well as time. The Mach number contour and Drag plot contour are given below in Figure 8 and 9 respectively.

i). Rocket Airframe results:

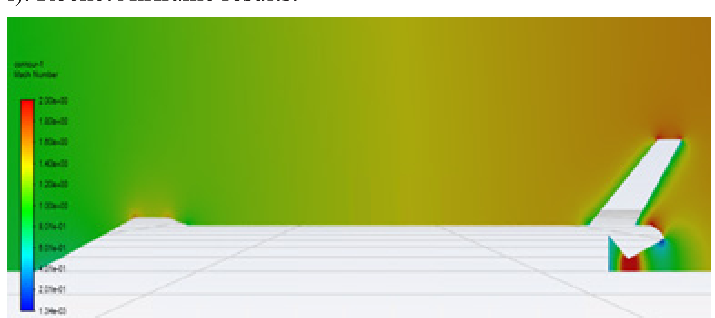


Figure 8: Mach Number Contour

ii). Drag Plot:

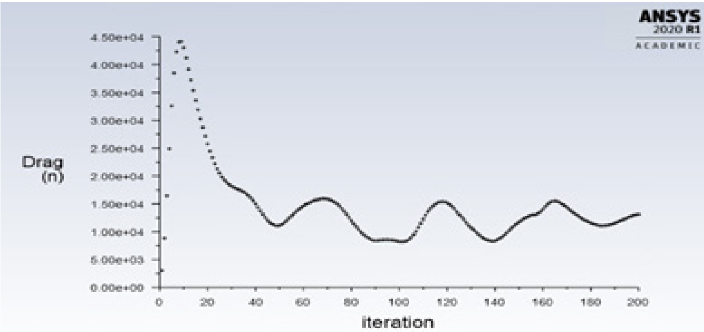


Figure 9: Drag Plot VS Iterations

Results And Discussion

The Drag force and Average pressure exerted on the Rocket is shown in Table 4 given below.

Table 4: Analysis of Drag Force and pressure on Rocket

Average pressure on Rocket Airframe	13.4 kPa
Average Drag on Rocket	1.33e+04

The implications that we can draw from these findings is that Rocket's Airframe is designed in such a way that, it can withstand high magnitude forces and for practical simulations as we are undergoing experiment in a real environment, Energy equations are turned on and Enclosure taken for testing of Rocket is triple the size of it. There are certainly no limitations as we can define everything in Boundary even Materials also. But this method is far better than Experimental methods.

Conclusions

As per our results, it is showing that Pressure acting on a Rocket is in the units of kPa which is indeed an average amount as the size of the Rocket is very large and it is also heavy. The average Drag on it is 1.33e+4. All the concepts have been subjected to the analytical work and gave much better and realistic results. It means that given coordinates of the Rocket are correct and hence it can be manufactured accordingly.

List of Abbreviations

Not applicable.

Declarations

Ethics approval and consent to participate

Not Applicable.

Consent for publication

Not Applicable.

Availability of data and material

Not Applicable.

Competing interests

The authors have no competing interests as defined by Nature Research, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

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Author Contribution Statement

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation [1-6].

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Not Applicable

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