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Modelling and Analysis of Polar Satellite Launch Vehicle C-33 with Different Cross Section of Strap on Boosters

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ABSTRACT

The knowledge of flow behavior and associated aerodynamic characteristics are important in the design and analysis of a polar satellite launch vehicle. A typical launch vehicle in flight passes through denser layers of atmosphere covering subsonic, supersonic and hypersonic Mach numbers. Aerodynamic coefficients are important inputs for trajectory simulation, performance analysis and control system design of a launch vehicle. A polar satellite launch vehicle with strapons is a complex configuration to study the flow behavior over it. Most present day launch vehicles have either solid or liquid strapons to meet the mission requirements. Generally extensive wind tunnel testing is done to understand the flow characteristics of such a configuration.

The Aim of the research work is to perform an Aerodynamic Analysis over the PSLV and investigate on the betterment of the various flow properties like Pressure, Velocity, and Temperature. For achieving efficient results, the boosters of the launch vehicle are considered and their shape is optimized to generate smoother flow around the body leading to efficient results. With the current popularity of Computation Fluid Dynamics (CFD) as a powerful design tool, it is appropriate to make use of its technology to understand the complex flow behavior over a polar satellite launch vehicle with strapons.

INTRODUCTION

In spaceflight, a launch vehicle is a rocket used to carry payloads from the Earth's surface into outer space. A launch system includes the launch vehicle, launch pad and other infrastructure. Usually the payload is a satellite placed into orbit, but some spaceflights are sub-orbital while others enable spacecraft to escape Earth orbit entirely. A launch vehicle which carries its payload on a suborbital trajectory is often called a sounding rocket.

An expendable launch system is a launch system that uses an expendable launch vehicle (ELV) to carry a payload into space. The vehicles used in expendable launch systems are designed to be used only once (i.e. they are "expended" during a single flight), and their components are not recovered for re- use after launch. The vehicle typically consists of several rocket stages, discarded one by one as the vehicle gains altitude and speed. Reusable launch vehicles, on the other hand, are designed to be recovered intact and used again for subsequent launches. For orbital spaceflights, the Space Shuttle is one of the launch vehicle with components which have been used for multiple flights.

Rocket is the ultimate high-thrust propulsive mechanism. A rocket propulsive device works on the same principle as that of a jet engine i.e. obtaining a propulsive force as reaction to the acceleration of mass of fluid, but unlike a jet engine they carry their own supply of oxidant. As a rocket does not depend on the atmosphere for supply of oxygen, it can operate at higher altitudes sand even in vacuum, where the air-breathing engines cannot. With Rockets, people have gone to the moon, and space vehicles weighing many tons have been put into orbit about the earth or sent to other planets in the solar system.

Launch vehicle is a Rocket system that boosts a spacecraft into Earth orbit or beyond Earth's gravitational pull. A wide variety of launch vehicles have been used to lift payloads ranging from satellites weighing a few kilograms to large modular components of space stations. Space launch vehicles or space boosters can be classified broadly as expendable or recoverable or reusable. Other bases of classification are the types of propellant (storable or cryogenic liquid or solid propellants), number of stages (single-stage, two-stage, etc.), size or mass of payloads or vehicles, and manned or unmanned. Each space launch vehicle has a specific space flight objective, such as an earth orbit or a moon landing. It

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uses between two and five stages, each with its own propulsion system, and each is usually fired sequentially after the lower stage is expended. The number of stages depends on the specific space trajectory, the number and types of maneuvers, the energy content of a unit mass of the propellant, and other factors.

FUTURE OF LAUNCH VEHICLE

Until recently, the future of space launch looked pretty much likes its past. For over 50 years, humanity has blasted thousands of spacecraft and satellites into space. Every launch vehicle that carried them aloft has ended up littering the planet with the broken, twisted remains of expended rocket stages. The scenario goes something like this:

1. A multi-stage rocket blasts off from its launch site.
2. After a few minutes, the largest, most expensive stage (known as the first or booster stage) shuts down and separates from the rest of the vehicle.
3. This discarded booster stage then falls back to Earth, crashing in an ocean or some bleak, uninhabited wasteland.
4. The rest of the launch vehicle continues on, throwing away stages, each one smaller and less powerful than the last.
5. The final stage deploys the payload at its targeted trajectory and velocity.

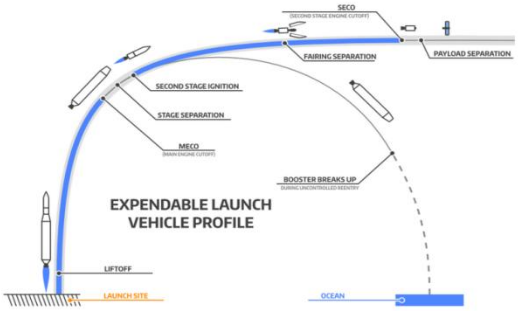

Fig 1.1:- Expendable launch vehicle profile

Only a tiny fraction of the entire rocket escapes Earth's deep gravity well to reach space as useful payload. With one notable exception, the Space Shuttle, it seemed like a virtual impossibility to recover any part of the launch vehicle. Because of this assumption, expendable launch vehicles were deemed to be just 'the cost of doing business'… until now.

A new way of doing business

This wasteful and costly method of getting payloads to space could be about to change in the near future. The California-based company Space Exploration Technologies, or SpaceX, has finally revealed how and when they will attempt to recover the booster stage of its Falcon 9 launch vehicle.

First, there was the Grasshopper test vehicle constructed from Falcon 9 booster stage tanks, a single Merlin rocket engine, and fixed steel legs. It made a number of increasingly complex vertical takeoff and landing flights over SpaceX's test facility in central Texas. Those short hops proved that the Grasshopper's rocket engine could be controlled with enough precision to make a safe, on-target landing.

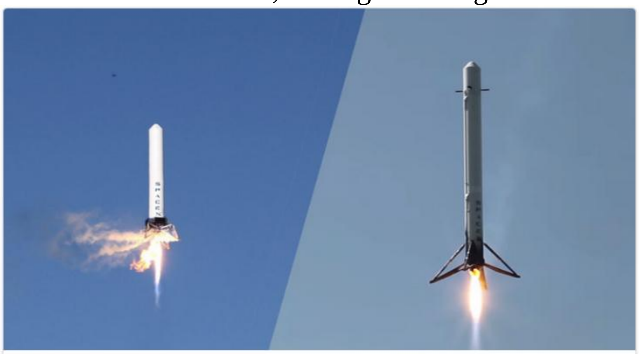

Fig 1.2:- Grasshopper, left, and the F9R-Dev1, right. The diameter of the two is identical.

Next came a follow-up test vehicle called the Falcon 9R-Dev1, the 'R' in the name standing for 'reusable'. Like the Grasshopper before it, this new vehicle was constructed with the same tanks and rocket engines used on the Falcon 9 booster stages. Instead of the Grasshopper's steel legs, its carbon composite landing legs would be folded against the side of the booster stage for launch and deployed before landing. After only a few successful flights, the vehicle self-destructed when an engine failure sent it off-course; thus showing, yet again, just how hard rocket science can be.

POLAR SATELLITE LAUNCH VEHICLE

The Polar Satellite Launch Vehicle, commonly known by its abbreviation PSLV, is an expendable launch system developed and operated by the Indian Space Research Organization (ISRO). It was developed to allow India to launch its Indian Remote Sensing (IRS) satellites into Sun-synchronous orbits, a service that was, until the advent of the PSLV, commercially available only from Russia. PSLV can also launch small size satellites into geostationary transfer orbit (GTO).

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In the year 2015 alone India successfully launched 17 foreign satellites belonging to Canada, Indonesia, Singapore, the United Kingdom and the United States. Some notable payloads launched by PSLV include India's first lunar probe Chandrayaan-1, India's first interplanetary mission Mangalyaan (Mars orbiter) and India's first space observatory, Astronaut. [20]

Development

PSLV was designed and developed in the early 1990s at Vikram Sarabhai Space Centre near Thiruvananthapuram, Kerala. The inertial systems are developed by ISRO Inertial Systems Unit (IISU) at Thiruvananthapuram. The liquid propulsion stages for the second and fourth stages of PSLV as well as the reaction control systems are developed by the Liquid Propulsion Systems Centre (LPSC) at Mahendragiri near Tirunelveli, Tamil Nadu. The solid propellant are processed at Satish Dhawan Space Centre (SHAR) at Sriharikota, Andhra Pradesh which also carries out launch operations.

The PSLV was first launched on 20 September 1993. The first and second stages performed as expected, but an attitude control problem led to the collision of the second and third stages at separation, and the payload failed to reach orbit. After this initial setback, the PSLV successfully completed its second mission in 1994. The fourth launch of PSLV suffered a partial failure in 1997, leaving its payload in a lower than planned orbit. Since then, the PSLV has launched 24 times with no further failures.

PSLV continues to support Indian and foreign satellite launches especially for low (LEO) satellites. It has undergone several improvements with each subsequent version, especially those involving thrust, efficiency as well as weight. In November 2013, it was used to launch the Mars Orbiter Mission, India's first interplanetary probe. [21]

Vehicle description

The PSLV has four stages using solid and liquid propulsion systems alternately. The first stage, one of the largest solid rocket motors in the world, carries 138 tons of hydroxyl-terminated polybutadiene urethane-bound (HTPB) propellant and develops a maximum thrust of about 4,800 kN. The 2.8-m diameter motor case is made of managing steel and has an empty mass of 30,200 kg. Pitch and yaw control during first stage flight is provided by the Secondary Injection Thrust Vector Control System (SITVC), which injects an aqueous solution of strontium perchlorate into the nozzle to produce asymmetric thrust. The solution is stored in two cylindrical aluminum tanks strapped to the solid rocket motor and pressurized with nitrogen. Roll control is provided by two small liquid engines on opposite sides of the stage, the Roll Control Thrusters (RCT).

On the PSLV and PSLV-XL, first stage thrust is augmented by six strap-on solid boosters. Four boosters are ground-lit and the remaining two ignite 25 seconds after launch. In the standard PSLV, each booster carries nine tonnes of propellant and produces 510 kN thrust. The PSLV-XL uses larger boosters which carry 12 tonnes of propellant and produce 719 kN thrust. Two strap-on boosters are equipped with SITVC for additional attitude control. The PSLV-CA uses no strap-on boosters.

The second stage employs the Vikas engine and carries 41.5 tonnes (40 tonnes till C-5 mission) of liquid propellant – unsymmetrical dimethylhydrazine(UDMH) as fuel and nitrogen tetroxide (N_2O_4) as oxidizer. It generates a maximum thrust of 800 kN (724 till C-5 mission). The engine is hydraulically gimbaled (±4°) to provide pitch and yaw control, while roll control is provided by two hot gas reaction control motors.

Table1.1PSLV is developed with a group of wide-range control units.

	Stage 1	Stage 2	Stage 3	Stage 4
Pitch	SITVC	Engine Gimbal	Flex Nozzle	Engine Gimbal
Yaw	SITVC	Engine Gimbal	Flex Nozzle	Engine Gimbal
Roll	RCT and SITVC in 2 PSOMs	HRCM Hot Gas Reaction Control Motor	PS4 RCS	PS4 RCS

Variants

ISRO has envisaged a number of variants of PSLV to cater to different mission requirements. There are currently three operational versions of the PSLV — the standard (PSLV), the core-alone (PSLV-CA) without the six strap-on booster motors, and the (PSLV-XL) version, which carries more solid fuel in its strap-on motors than the standard version.[10] These configurations provide wide variations in

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payload capabilities ranging from 3800 kg in LEO to 1800 kg in Sun-synchronous orbit.

PSLV-G (Operational)

The standard version of the PSLV (PSLV-G) has four stages using solid and liquid propulsion systems alternately and six strap-on boosters. It currently has capability to launch 1,678 kg to 622 km into Sun-synchronous orbit.

PSLV-CA (Operational)

The PSLV-CA, CA meaning "Core alone", model premiered on 23 April 2007. The CA model does not include the six strap-on boosters used by the PSLV standard variant. Two small roll control modules and two first-stage motor control injection tanks were still attached to the side of the first stage.The fourth stage of the CA variant has 400 kg less propellant when compared to its standard version. It currently has capability to launch 1,100 kg to 622 km Sun synchronous orbit.

PSLV-XL(Operational)

PSLV-XL is the updated version of Polar Satellite Launch Vehicle in its standard configuration boosted by more powerful, stretched strap-on boosters. Weighing 320 tons at lift-off, the vehicle uses larger strap-on motors (PSOM-XL) to achieve higher payload capability. PSOM-XL uses larger 1-metre diameter, 13.5m length motors, and carries 12 tons of solid propellants instead of 9 tonnes used in the earlier configuration of PSLV. On 29 December 2005, ISRO successfully tested the improved version of strap-on booster for the PSLV. The first version of PSLV-XL was the launch of Chandrayaan-1 by PSLV C11. The payload capability for this variant is 1800 kg compared to 1600 kg for the other variants. Other launches include the RISAT Radar Imaging Satellite and GSAT-12. [8]

Table -1.2: Variants of PSLV

Variant	Launches	Successes	Failures	Partial failures	Remarks
PSLV (Standard)	11	9	1	1	
PSLV-CA (Core Alone)	11	11	0	0	
PSLV-XL (Extended)[2]	13	13	0	0	

Table 1.3:- Dimensions of GSLV MK3

SIZE	
MAIN BODY HEIGHT	44m
DIAMETER	2.8m
MASS	290299 kg
STAGES	4
BOOSTER	15 m
DIAMETER	2.8 m

Table 1.4 IRNSS-1G Salient features

ORBIT	Geostationary, at 129.5 deg East longitude
LIFT-OFF MASS	1425 kg
DRY MASS	598kg
PHYSICAL DIMENSIONS	1.58 meter x 1.50 meter x 1.50 meter
POWER	Two solar panels generating 1660 W, one Lithium-ion battery of 90 Ampere-Hour capacity
PROPULSION	440 Newton Liquid Apogee Motor, twelve 22 Newton Thrusters
CONTROL SYSTEM	Zero momentum system, orientation input from Sun and Star Sensors and Gyroscopes; Reaction Wheels, Magnetic Torques and 22 Newton thrusters as actuators
MISSION LIFE	12 years

Modeling Steps of PSLV C-33

- We need a Scaled geometry image for tracing out the PSLV's CAD model.
- Hence , I've taken the scaled image form the Indian Space Research Organizations' official website[17]
- The scaled image is used for modeling the CAD model of the PSLV as we cannot find the precise dimensions of the PSLV.
- The following image represents the scaled image from ISRO's official website.

Fig 3.1 –Scaled image of the PSLV

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Import the Scaled image in Creo 2.0.

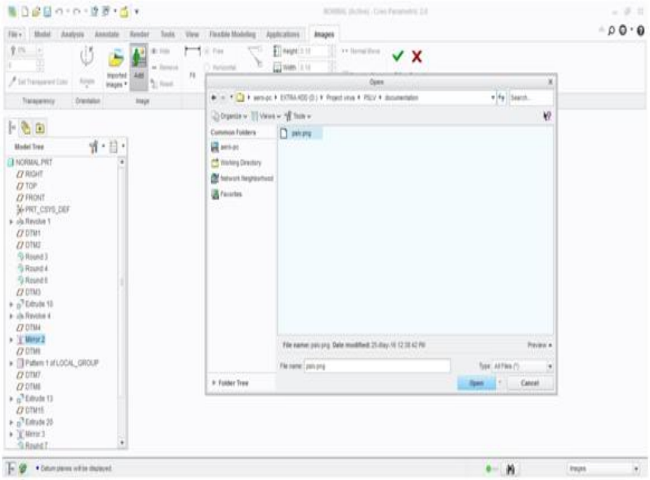

Fig 3.2 importing the scaled image

Align the image as per the required view.

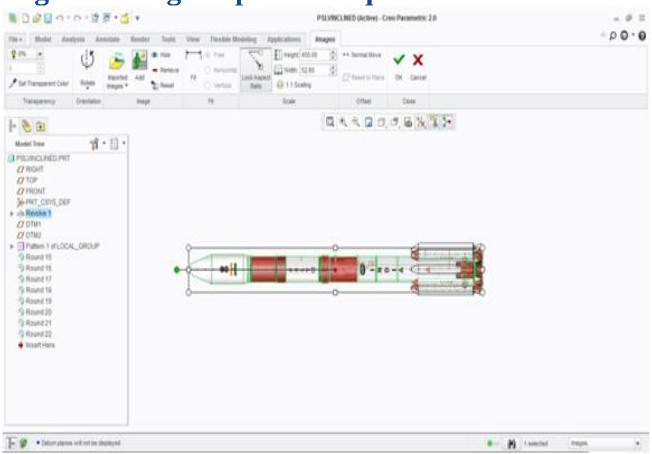

Fig 3.3 imported image (PSLV)

Sketch the geometry of the PSLV using revolve option

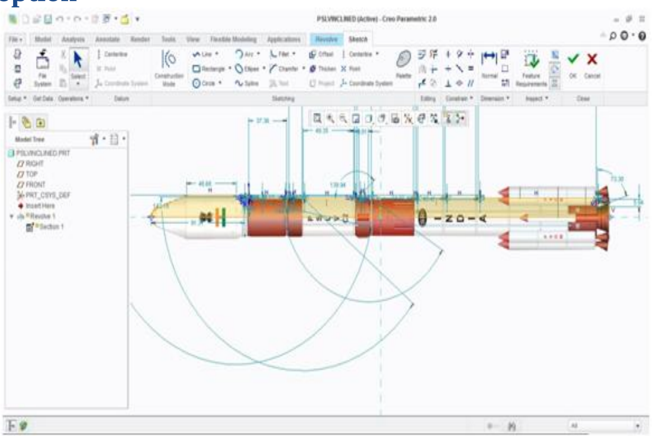

Fig 3.4: Sketching the image for revolving

Perform the revolve option, i.e., about an axis of revolution

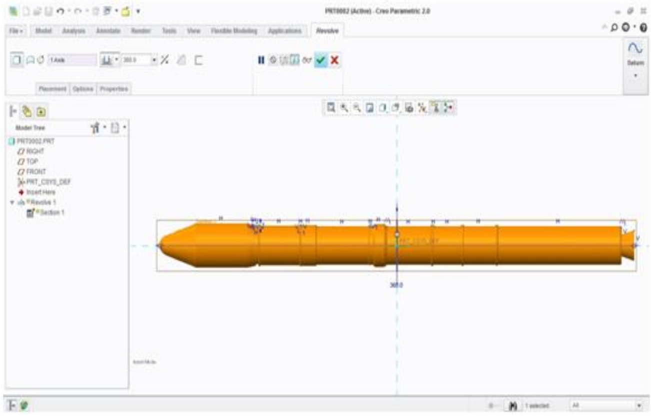

Fig 3.5: Revolved Geometry

The PSLV's cylindrical shell appears to be modeled as shown in below figure.

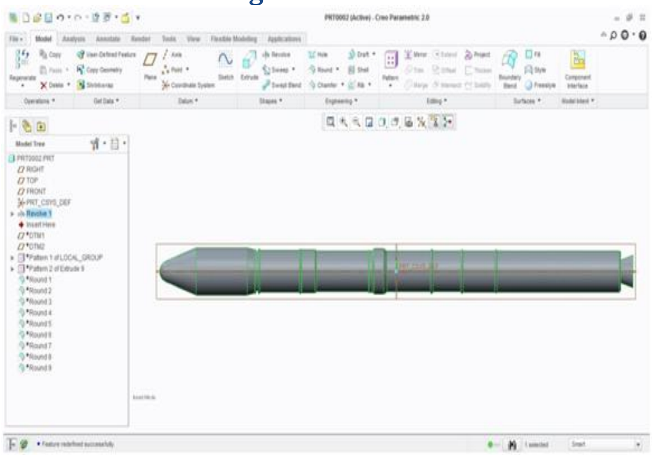

Fig 3.6 Solid Cylindrical Rocket

Create a plane DATUM 1 at a distance of 20mm above the horizontal plane.

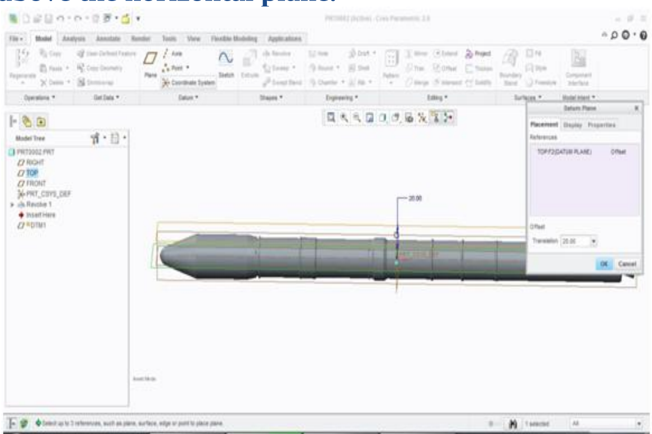

Fig 3.7 Creating Datum plane-I

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Create a plane DATUM 2 at a distance of 128 mm from the vertical plane

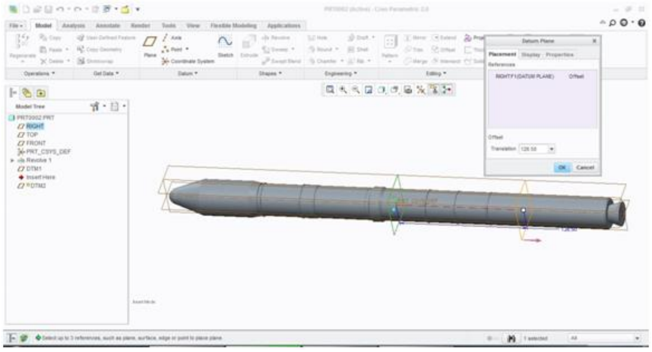

Fig 3.8 Creating Datum plane –II

Modules

ANSYS APDL

Ansys Apdl is an analysis using for study of the physical response ,stress levels temp distribution or electromagnetic field. It is a lengthy process for analysis. We have to give every value like poison ratio, young'smodulus,density, pressure , temp, etc [7]

ANSYS WORKBENCH

Workbench is user friendly. No need to mention all characteristic of material properties as APDL.

RESULTS

Table 5.1:- velocity on main body with inclined strapon

VELOCITY		
	MINIMUM	MAXIMUM
SUBSONIC	0 ms^-1	4.370e+002 ms^-1
SUPERSONIC	0 ms^-1	1.278e+003 ms^-1
HYPERSONIC	0 ms^-1	3.199e+003 ms^-1

Table 5.2:- velocity on main body with Normal strapon

VELOCITY		
	MINIMUM	MAXIMUM
SUBSONIC	0 ms^-1	4.412e+002 ms^-1
SUPERSONIC	0 ms^-1	1.285e+002 ms^-1
HYPERSONIC	0 ms^-1	3.213e+002 ms^-1

Table 5.3:- pressure on main body with inclined strapon

PRESSURE		
	MINIMUM	MAXIMUM
SUBSONIC	-6.304e+005 pa	2.100e+005 pa
SUPERSONIC	-3.053e+006 pa	1.250e+006 pa
HYPERSONIC	-9.005e+006 pa	3.118e+006 pa

Table 5.4:- Pressure on main body with Normal strapon

PRESSURE		
	MINIMUM	MAXIMUM
SUBSONIC	-6.714e+003 pa	2.549e+005 pa
SUPERSONIC	-3.202e+006 pa	1.298e+006 pa
HYPERSONIC	-9.423e+006 pa	3.818e+006 pa

Table 5.5:- Temperature on main body with inclined strapon

	MINIMUM	MAXIMUM
SUBSONIC	1.000e+000 K	4.245+003 K
SUPERSONIC	1.000e+000 K	5.000e+003 K
HYPERSONIC	1.000e+000 K	5.000e+003 K

Table 5.6:- Temperature on main body with normal strapon

	MINIMUM	MAXIMUM
SUBSONIC	1.000e+000 K	5.000e+003 K
SUPERSONIC	0 K	1.285e+003 K
HYPERSONIC	1.000e+000 K	5.000e+003 K

CONCLUSION

The research work was initiated with the modeling of the PSLV C-33 using the scaled geometry from the ISRO's website and has concluded with the flow analysis over the geometry with the normal boosters and the inclined boosters of the PSLV for various

Boundary Conditions seeking us Pressure Velocity and Temperature values.

The Modeling of the geometry was performed using the CAD tool Creo 2.0 and the Aerodynamic Analysis was performed using the ANSYS Workbench.

The research is focused on the boosters of the PSLV-C33, i.e., how to increase the performance of the boosters aerodynamically by optimizing the pressure and velocity over it. Hence we have considered two different boosters, the normal conventional one, whose shape is generally used by the PSLV, wherein the cone is perpendicular to the cylindrical booster; & the Optimized booster wherein we have created an inclination of the booster cone towards the main rocket cylinder. The results of the inclined optimized booster attained are validated with the Normal boosters.

The aerodynamic flow analysis for different speed regimes on both the boosters is concluded giving us the maximum and minimum pressure velocity and Temperature values that are stated in the tabular in the previous chapter. The analysis of those results, indicate us that the velocity of air over the boosters having inclined boosters is comparatively more than the velocity of air on the normal booster, which means the air is smoothly passing over the body of the launch vehicle. Further comparing the pressure values the pressure is reducing on the body of the inclined booster for all the speed regimes, as we know by nature the lesser amount of pressure acting on any moving body indicates more aero-dynamicity. The two parameters obtained in our analysis helps us to understand that the inclined optimized booster is efficient for the ISRO's PSLV- C33.

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