

Computational Aerodynamic Analysis of Polar Satellite Launch Vehicle C-33 with Different 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. The research work is focused 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 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 strap-ons.

Keywords - PSLV, Boosters, CFD.

INTRODUCTION

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).

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. [1] The Polar Satellite Launch Vehicle, in its thirty fifth flight (PSLV-C33), will launch IRNSS-IG, the seventh satellite of the Indian Regional Navigation Satellite System (IRNSS) into a Sub-Geosynchronous Transfer Orbit (Sub-GTO).

The launch will take place from the First Launch Pad (FLP) of Satish Dhawan Space Centre (SDSC) SHAR, Sriharikota. As in the previous six launches of IRNSS satellites, PSLV-C33 will use 'XL' version of PSLV equipped with six strap-on, each carrying 12 tons of propellant. This is the thirteenth time 'XL' configuration is being flown. Besides launching six IRNSS satellites, PSLV-XL has also launched any other spacecraft including India's Mars Orbiter spacecraft, the multi-wavelength observatory ASTROSAT, Radar Imaging satellite RISAT-1 and the Communication satellite GSAT-12. [6] This apart, PSLV-XL has successfully placed five satellites from United Kingdom into orbit in a single commercial mission. Through these launches, PSLV has repeatedly proved its reliability and versatility. [2]

MODELLING THE GEOMETRY

In our research work, for the modelling of the PSLV C-33 we have used PTC Creo Parametric 2.0. It is a CAD software that supports Product Design for various manufacturers. Creo runs on Microsoft Windows and provides apps for 3D CAD parametric feature solid modeling, 3D direct modeling, 2D orthographic views, Finite Element Analysis and simulation, schematic design, technical illustrations, and viewing and visualization. Creo Elements/Pro and **Creo Parametric** compete directly with CATIA, Siemens NX/Solid edge, and Solid works. The Creo suite of apps replaces and supersedes PTC's products formerly known as Pro/ENGINEER, Co-Create, and Product View. [3]. As the precise dimensions of the PSLV C-33 are easily not available, therefore in-order to model the geometry, we will be using the scaled geometry, wherein will take the Scaled Image of the PSLV C-33 as shown in Fig 1 from the ISRO website and import it into the Creo 2.0.



Fig 1 PSLV C-33 Scaled Image

The Scaled Image of the PSLV C-33 [4] is imported into the User Interface of the Creo 2.0 Parametric as seen in Fig 2, and then using the sketch option we need to trace the scaled image and then we revolve the sketch to generate a 3-d model of the main body of the Launch Vehicle as seen in Fig 3.

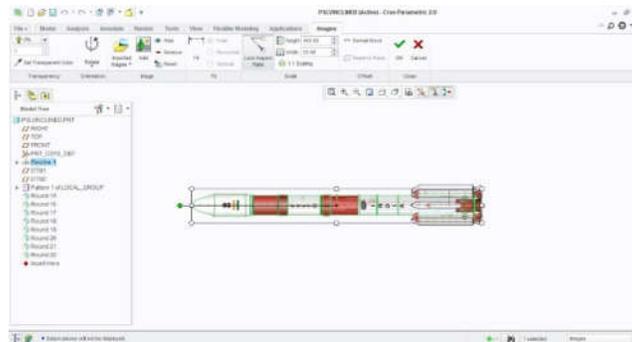


Fig. 2 Importing scaled image of the PSLV C-33 into Creo

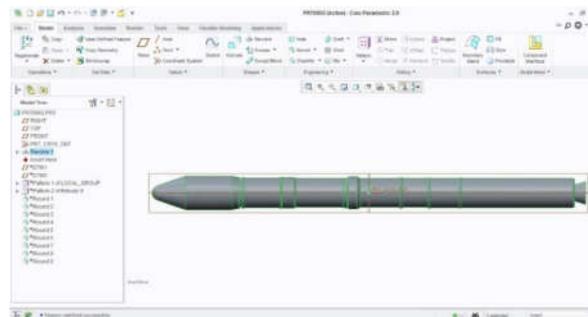


Fig. 3 CAD model of the Launch Vehicle Main Body

The research work is focused on the Aerodynamic properties of the Launch Vehicle having different Strap-on boosters, hence we need to continue the modelling by modelling the booster, in the first case we need to model the Booster having normal cone-profile, and in the second case we would need to model the booster having a cone profile which is inclined towards the main body.

Hence, our next step towards modelling is to create the Boosters assembled to the main body of the Launch Vehicle for which we sketch the booster using the Scaled Image and revolve. Therefore generating the booster with a normal cone profile, the PSLV C-33 contains six boosters, so we need to pattern the first booster and get six boosters on the whole, pattern is a command in the CAD software, which helps to attain similar shapes. After performing the round operations, wherein we remove the sharp edges, the Final 3-D CAD model of the PSLV C-33 Launch vehicle is shown in the Fig 4. This CAD model is saved in IGES format and sent to the Analysis software for flow analysis.

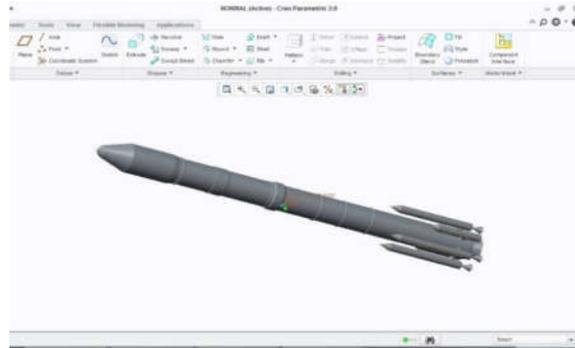


Fig 4 Final CAD Model of the PSLV C-33 with Normal Boosters

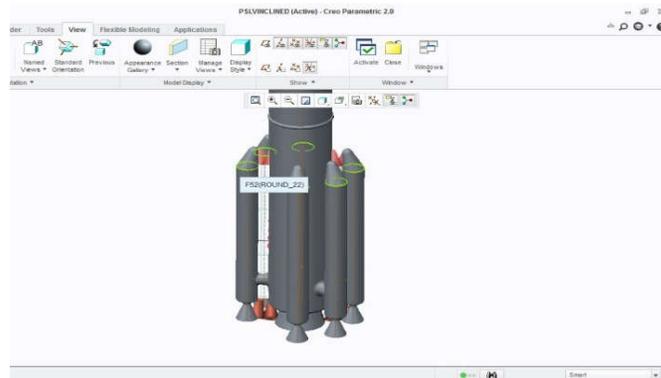


Fig 5 Generation of Inclined Boosters

The Research work is also aimed to model a PSLV Launch Vehicle with the Inclined Boosters, for which we need to use the blend tool in the software and generate inclination. The inclined booster on the Launch vehicle is seen in the Fig 5, where we have generated a single inclined booster and patterned it to get six boosters, the fig 6 shows us the Final 3-D CAD model of the PSLV C-33 with inclined boosters. This model will be saved in IGES format and sent for Analysis.

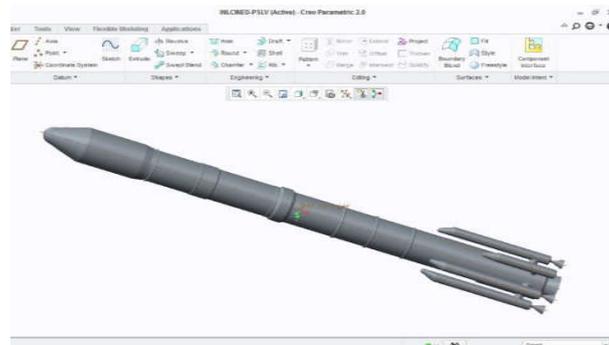


Fig 6 Final CAD Model of the PSLV C-33 with Inclined Boosters

COMPUTATIONAL FLOW ANALYSIS

The next step in our research work is to perform flow analysis over the Launch Vehicle, as the research work is aimed to investigate the aerodynamic properties over the launch vehicle with two different types of Nose cone of the booster, we need to perform two separate analysis. The first case would be the flow analysis of the Launch Vehicle having Normal Booster at three different flow regimes i.e., Sub-Sonic, Super-Sonic & Super-Sonic. The second case would be the flow analysis of the Launch Vehicle having Inclined Booster at the same three flow regimes of the first case. In order to compare both the boosters, we will be performing the flow analysis on the same boundary conditions. For the performing of the analysis, we are using the CAE tool; ANSYS [5], under which ANSYS-Workbench-Fluid Flow (Fluent) will be used to perform the flow analysis

Case 1-Flow Analysis of the Launch Vehicle with Normal Booster

The CAD file of the Launch Vehicle which was saved in IGES format will be imported in the ANSYS Workbench, after importing the IGES File, we will now need to generate an enclosure as seen in Figure 7, the enclosure will act as a domain on which we will need to apply the Boundary Conditions in future.

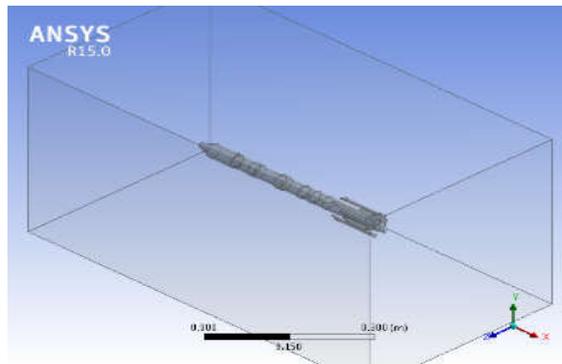


Fig 7 Generating an Enclosure for the Normal Booster

After the enclosure is formed the next step towards the analysis is to mesh the Geometry and Enclosure. The Meshing is one of the vital step towards the analysis, without which we cannot get the desired results. The finer the mesh the accurate the results are.

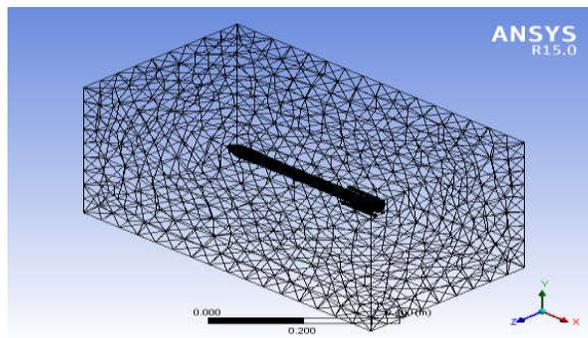


Fig 8. Mesh Generation on the Launch Vehicle with Normal Booster

After the mesh is generated we would now need to send the mesh file into the setup module where we will need to set various parameters like Boundary conditions, Solution methods etc.,

The following are the parameters chosen for the Flow Setup, and the velocity at the inlet is taken as follows:

Table 1. Boundary Condition of the Velocity at Inlet

| | |
|-------------|------------|
| Sub Sonic | : 274 m/s |
| Super Sonic | : 800 m/s |
| Hyper Sonic | : 2000 m/s |

These Magnitudes of the Velocity are again used for performing the Flow Analysis over the Inclined Boosters, keeping the same boundary conditions, we aim to investigate the suitable booster for the Launch vehicle mission. The Flow is solved keeping the Solution Methods as Coupled Second Order. After which the calculation activity is initiated and the flow is solved till its converged. On convergence the flow properties over the body are noted to compare with the Inclined Boosters parameters.

We need to perform flow analysis over the Normal Booster Launch Vehicle for three Mach Regimes individually as written above using the same solution methods. The Pressure Velocity and Temperature are the three considerations in our research work, as better aerodynamics depend on these parameters.

The next pages of the paper will show us the images of the contours obtained after the performing of the Analysis in the ANSYS-Workbench- Fluent. The contours obtained indicate the variation of its parameter over the body of the PSLV C-33. Our aim is to compare the magnitudes of the maximum and minimal values of Pressures, Temperatures, and Velocities of the Normal and Inclined Boosters. Thus we will make a tabular column as shown below and note the values of the Pressure, Velocity and Temperature, which will be latter compared to the values of the Inclined Booster.

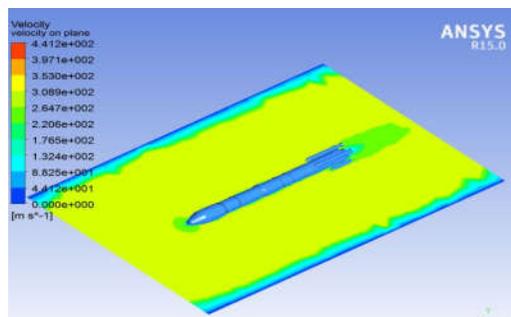


Fig 9: Velocity Contour over the Launch Vehicle with Normal Booster for Subsonic Flow

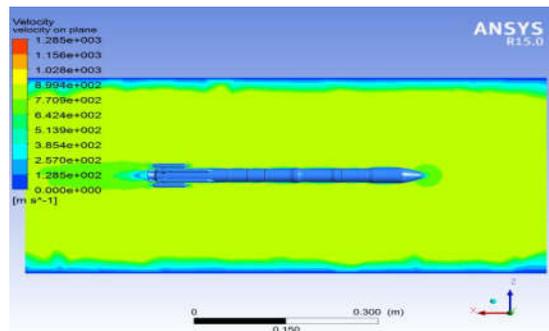


Fig 10: Velocity Contour over the Launch Vehicle with Normal Booster for Supersonic Flow

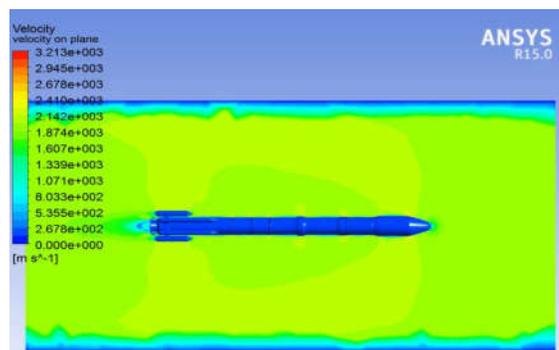


Fig 11: Velocity Contour over the Launch Vehicle with Normal Booster for Hypersonic Flow

The above figures represent the Velocity contours over the Launch Vehicle with Normal Booster, tabulating the values as follows:

Table 2. Magnitudes of the Velocity over Launch Vehicle with Normal Boosters

| | 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 |

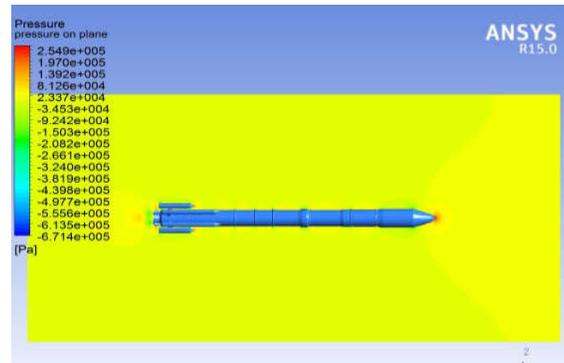


Fig 12: Pressure Contour over the Launch Vehicle with Normal Booster for Sub-sonic Flow

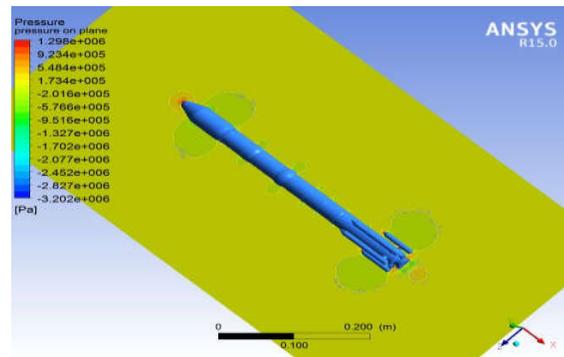


Fig 13: Pressure Contour over the Launch Vehicle with Normal Booster for Super-sonic Flow

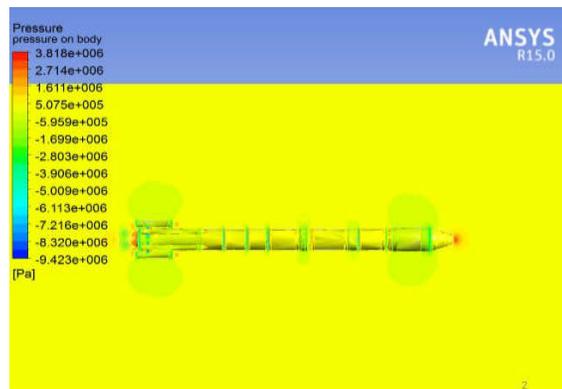


Fig 14: Pressure Contour over the Launch Vehicle with Normal Booster for Hyper-sonic Flow

Table 3. Magnitudes of the Pressure over Launch Vehicle with Normal Boosters

| | 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 |

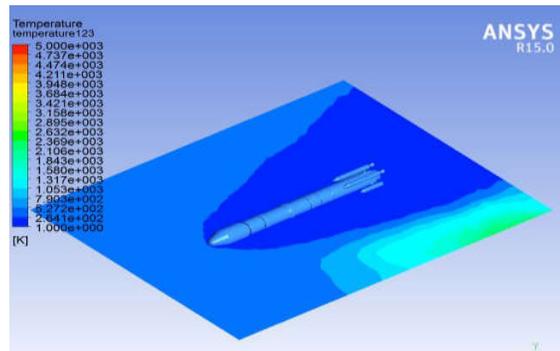


Fig 15: Temperature Contour over the Launch Vehicle with Normal Booster for Sub Sonic-sonic Flow

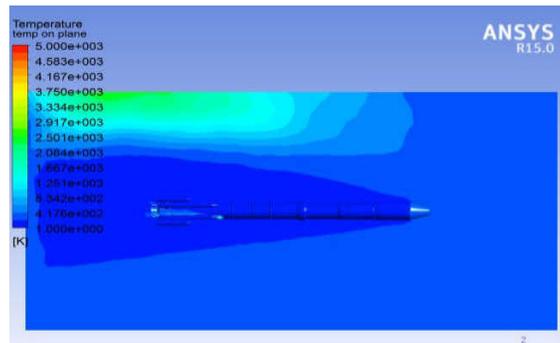


Fig 16: Temperature Contour over the Launch Vehicle with Normal Booster for Super-Sonic-sonic Flow

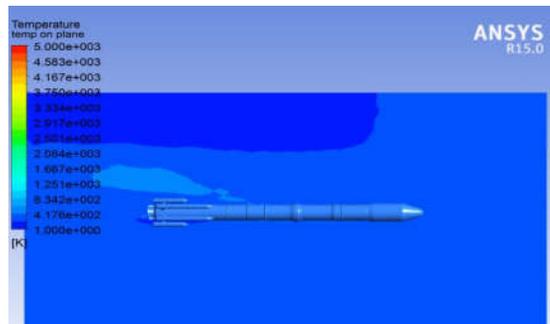


Fig 17: Temperature Contour over the Launch Vehicle with Normal Booster for Hyper-Sonic-sonic Flow

Table 4. Magnitudes of the Temperature over Launch Vehicle with Normal Boosters

| | 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 |

Case 2: Flow Analysis of the Launch Vehicle with Inclined Booster

The Second part of the research work is aimed at the flow analysis of the Launch Vehicle with Inclined Booster for which we would follow the same procedure as we have followed for the Case 1, and also with the same boundary conditions and Solution Methods. We need to import the IGES CAD file into the Workbench Geometry module and generate an enclosure which will be considered as a domain. After the closure is generated, we will generate a mesh and send the mesh file into the setup module of the Fluent and enter the same boundary conditions as we have entered in the Case 1. The same boundary conditions will help us to understand the aerodynamics over the inclined booster Launch Vehicle. On solving, we may extract the Pressure, Velocity & Temperature Contours over the body sight in a table and compare with the Values of the Normal Booster.

The below tables represent the Pressure, Velocity & Temperature Contours.

Table 5. Magnitudes of the Velocity over Launch Vehicle with Inclined Boosters

| | 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 6. Magnitudes of the Pressure over Launch Vehicle with Inclined Boosters

| | 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 7. Magnitudes of the Temperature over Launch Vehicle with Inclined Boosters

| | 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 |

CONCLUSION

The research work was initiated with the modelling 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 Modelling 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.

References

- [1] https://en.wikipedia.org/wiki/Polar_Satellite_Launch_Vehicle
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