Flow Simulation over a Multi-Stage Launch Vehicle with Strapons Using CFD Techniques

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

I. 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.

A. Types of launch vehicles

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

B. Rockets and their Applications

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.

C. Space Launch Vehicle

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 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.

D. Spacecraft

Depending on their missions, spacecraft can be categorized as earth satellites, lunar, interplanetary, and trans-solar types, and as manned and unmanned spacecraft. Rocket propulsion is used for both primary propulsion along the flight path and secondary propulsion functions in these vehicles. Some of the secondary propulsion functions are attitude control, spin control, stage separation systems etc.

E. Missiles and Other applications

Most of the missiles right now in production are almost exclusively using rocket motors. Other applications of rockets include primary engines for research airplanes, assist take off rockets for airplanes, ejection of crew escape capsules, signal rockets, weather sounding rockets etc.

As the performance of rocket is unequalled by its prime movers, it has its own fields of applications. Space launch vehicle is rocket system that boosts a payload in to earth orbit or beyond. A wide variety of vehicles like multi-stage rockets, single-stage to orbit vehicles and reusable launch vehicles are used to carry the payload. Rockets are used for both primary and secondary propulsion for spacecrafts. There are other applications like Missiles, Sounding rockets, ejection systems etc. Rockets are defined by many variables and constraints, and ultimately deliver payload.

Fig: 1 Launching of GSLV

II. COMPUTATIONAL SETUP

- *Grid Generation*

The grid for the typical SLV model was generated using the GAMBIT software.

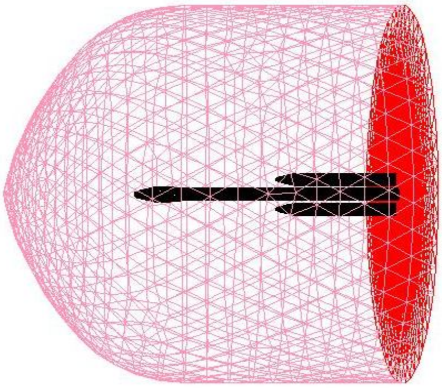


Fig: 2 3D Unstructured Grid gaps of 200mm

Unstructured grid was used for the analysis of the flow field around the model. The details of the grids are discussed in the following sections.

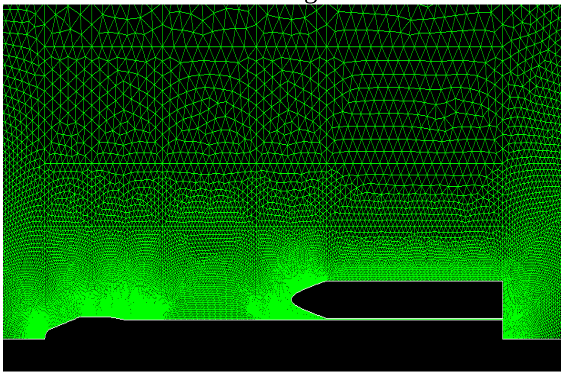


Fig: 3 Grid cell distributions in the vicinity of body

III. SOLUTION METHADOLOGY USING FLUENT

The solution method in FLUENT can be broadly divided into three parts namely: Pre – processing, Solver and Post processing. Pre – processing of the problem was done in GAMBIT as discussed in detail in the preceding sections. Once the problem is meshed and the boundary conditions are specified the meshed geometry is then imported as a 'mesh file' into FLUENT.

FLUENT uses a control-volume-based technique to convert the following governing equations as conservation of mass, conservation of momentum and conservation of energy to algebraic equations that can be solved numerically. This control volume technique consists of integrating the governing equations about each control volume, yielding discrete equations that conserve each quantity on a control volume basis

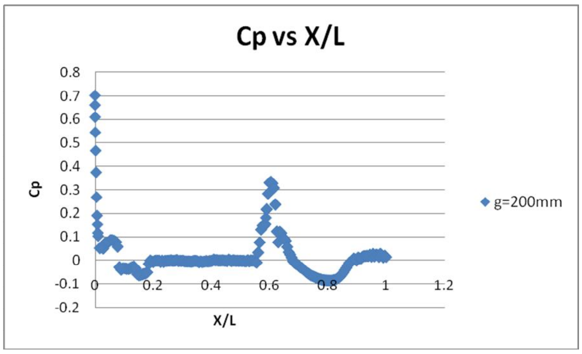
Fig:2 3D unstructured grid for a gap of 200mm

IV. RESULTS AND DISCUSSION

Computations were performed to understand the flow field around a scaled down model of a typical space launch vehicle with strapons. Computations using the commercially available software FLUENT 6.3.26 were carried out for two dimensional and three dimensional fully developed flows. A validation test was performed by referring to the same type of model at a same mach number. The details of the computations are discussed in this chapter.

V. COMPUTATIONAL RESULTS

Two dimensional and three dimensional computational simulations were carried out for studying the flow field around a typical space launch vehicle geometry at supersonic Mach number. The results of computations performed are discussed in detail in the following sections. The computations were performed on a work station Core 2 Duo processor with a bus speed of 2.0GHz and a RAM of 2GB. Typical time taken for inviscid problem was 250 iterations per hour and for viscous three dimensional problems were 150 iterations per hour. For all the cases, an average 3000 iterations were performed until desired convergence is obtained. The inviscid analysis was performed for comparing the results obtained for viscous flows. The standard S-A turbulence model was adopted for the viscous computation after checking with the other turbulence models like k-ω and standard k-ε. The viscous computations performed are discussed in detail in the following sections.



Graph: 1 Cp Vs X/L for 3D grid for a gap of 200mm

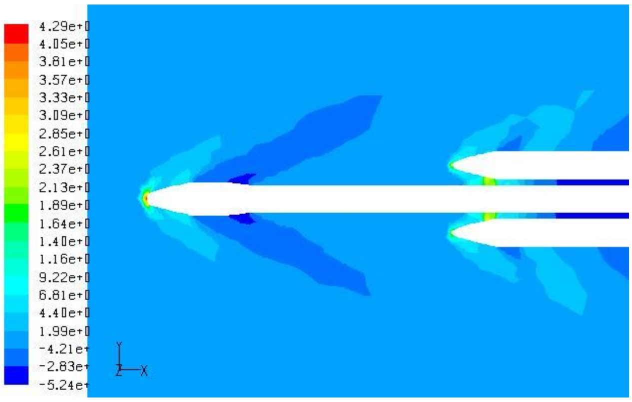


Figure: 4 Pressure contours for 3D grid for a gap of 200mm

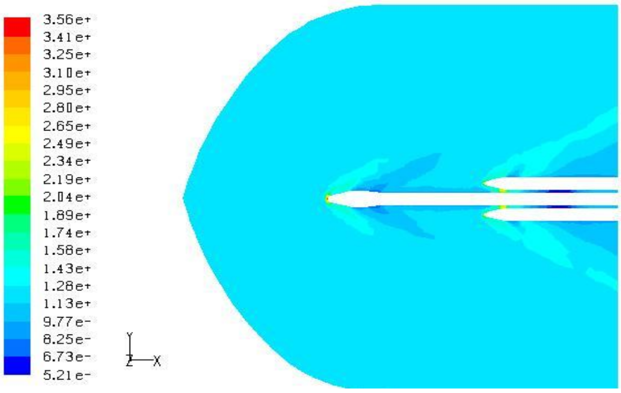


Figure: 5 Density contours for 3D grid for a gap of 200mm

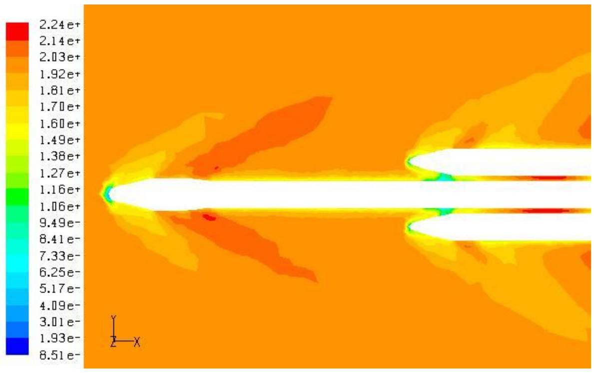


Figure: 6 Mach contours for 3D grid for a gap of 200mm

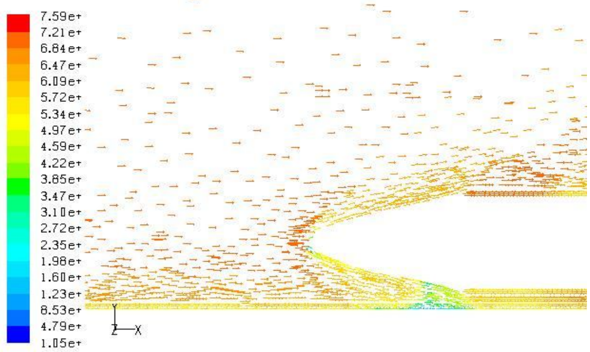


Figure: 7 Velocity vector for 3D grid for a gap of 200mm

VI. CONCLUSION

Computational studies were carried out to get an understanding of the flow field around typical space launch vehicle with strap ons at Mach 2. Three dimensional simulations of the flow field using FLUENT 6.3.26 were performed. SA turbulent model was adopted to capture the flow field. Computations were validated through a simulation of flow field around the similar geometry at a Mach number 2 by earlier investigators. After a good agreement with reported results, simulation of the present case was carried out and compared with available experiments. Results obtained through the series of tests are discussed in the previous chapter.

The following important observations were made from the results obtained through computations and experiments:

- The basic flow structure around a typical launch vehicle with strap ons was captured through 2D and 3D computations.
- Mach and density contours showed the bow shock wave structure, near the nose cone of the main body and near the booster nose. Shock and boundary layer interferences were observed near the booster nose.
- Comparison of SA, k-ε and k-ω turbulence modeled viscous simulations around the typical space launch vehicle showed that the SA model predicts well for the flow field features of wall bounded shear flows.
- A good comparison of computations and available experimental results were achieved.

- Path lines captured shows the circulation of air around the complete body.
- As the gap is increased in between the booster and the main body, Cp value is decreased. Gap beyond 250 mm shall have minimum effect on the main body.

VII. SCOPE OF FUTURE WORK

2D and 3D Computations were carried out to get an understanding of the flow field around a typical launch vehicle at a free stream Mach 2, at zero angle of attack. After obtaining the results it was observed that further studies related to the topic can be carried out for getting a better understanding of the flow phenomenon. Some of the suggested work is outlined below:

- Finer 3D grid can be generated for better capturing of the shock waves near the nose cone and the booster nose.
- Study of flow field by keeping the model at various angles of attack.
- Base flows were not considered in the present work. It can be studied further.
- For the present case only computations were performed. Experimental work can be carried out.
- Experiments and computations can be carried out by considering the protrusions for a complete space launch vehicle.

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