DESIGN AND ANALYSIS OF A RE-ENTRY VEHICLE WITH DOCKING SYSTEM TAILORED TO INDIAN SPACE STANDARDS

Project Reference No.: *48S_BE_0384*

College : SJC Institute Of Technology, Chikkaballapura
Branch : Department Of Aerospace Engineering
Guide(s) : Dr. Madhusudhana S V
Student(S): Mr. Prithviraj M Talwar
Ms. Maitreyi R Mudri
Ms. Deeksha R
Mr. Prakash B Gedageri

Keywords:

Re-entry capsule, docking system, scaling laws, Buckingham Pi Theorem, finite element analysis, ISS standards.

Introduction:

The integration of docking systems with re-entry vehicles is pivotal for advancing crewed space missions, orbital servicing, and space station logistics. This study presents a conceptual design of a re-entry capsule equipped with an International Space Station (ISS)-compliant docking mechanism, optimized for compatibility with India's GSLV Mk-III launch vehicle. A scaled-down (1:10) prototype was modeled using Solid Edge ST10, and its structural, thermal, and aerodynamic performance was evaluated via finite element analysis (ANSYS 2024 R1). The docking system adheres to NASA's International Docking System Standard (IDSS), featuring a petal-and-capture-ring design for androgynous mating. Structural analysis under 200 MPa pressure revealed a maximum deformation of 19.123 mm and von Mises stress of 24,074 MPa, safety and dynamic similarity validated through **Buckingham Pi Theorem** and **Rayleigh's Method** to ensure dimensional consistency between the scaled model and full-scale system. **Theory of Models** and **Scaling Laws** governed the thermo-structural and aerodynamic simulations, ensuring accurate extrapolation of results. Steady-state thermal analysis confirmed resilience at 2,700°C, simulating re-entry conditions. Hypersonic flow analysis at 11 km/s (Earth's escape velocity) demonstrated stable shockwave formation and minimal drag. The design addresses a critical gap in India's space infrastructure, offering a cost-effective solution for future crewed missions and orbital rendezvous.

Objectives:

1. Design of a Docking System for ISS Standards: Develop a docking model that meets the International Space Station (ISS) standards to ensure compatibility with existing space infrastructure.
2. Conceptual Design of a Re-Entry Capsule: Create a re-entry capsule design that integrates seamlessly with the GSLV Mark III rocket, emphasizing aerodynamic efficiency, structural integrity and heat resistance.
3. CAD Model Analysis: Simulate the docking system and re-entry capsule design in a CAD environment, using analytical tools like Ansys to evaluate performance under space and atmospheric conditions.
4. Prototype Development: Construct a scaled-down model of the docking system to visually demonstrate its design, functionality and compatibility with re-entry scenarios (only for understanding not how actual model going to work).

9. Methodology :

The methodology for re-entry and docking system, here's a detailed step-by-step methodology used for the construction of our conceptual model.

1. **Literature Review:** Conducted a thorough review of existing literature to understand the current state of knowledge, previous studies and best practices of the environment of both earth and space, considerations for its orbital dynamics and relative velocity calculations along with studying of GSLV MK III last stage as a reference model for its proven reliability is utilized to integrate with the designed re-entry capsule system.

2. **Own theoretical re-entry capsule and design:** Designed Re-entry capsule concept for embodying the actual designed docking system model placed in the GSLV MK III last stage ensuring its compatibility along with its aerodynamic efficient design and its structural integrity.

I. The re-entry capsule is placed in the GSLV MK III

II. the re-entry capsule it mainly consists of

a. Docking system

b. Astronauts cabin (pressurized chamber)

c. Fuel and oxidizer

d. Booster and thrusters

III. Developing of the actual focused concept of the docking system with define objectives and scope their design and mechanism standards for constructing a safe and reliable docking model.

3. **Analysis:** subjecting the docking system, re-entry capsule assembly into various analysis condition with the specified boundary conditions including structural, vibrations, modal, thermal and fluid flow analysis in Ansys Workbench (18.1 and 24R1).

4. **Results:** conducting all the analysis and retrieving the results provides a complete picturization of the compatibility of the designed re-entry capsule along with docking system.

5. **Modelling:** additive manufacturing (3d printing) of scaled down model with PLA

6. **Reporting:** Prepared a comprehensive report that includes the objectives, methodology, analysis results, conclusions and recommendations. Ensuring that the report is clear, concise and well-organized.

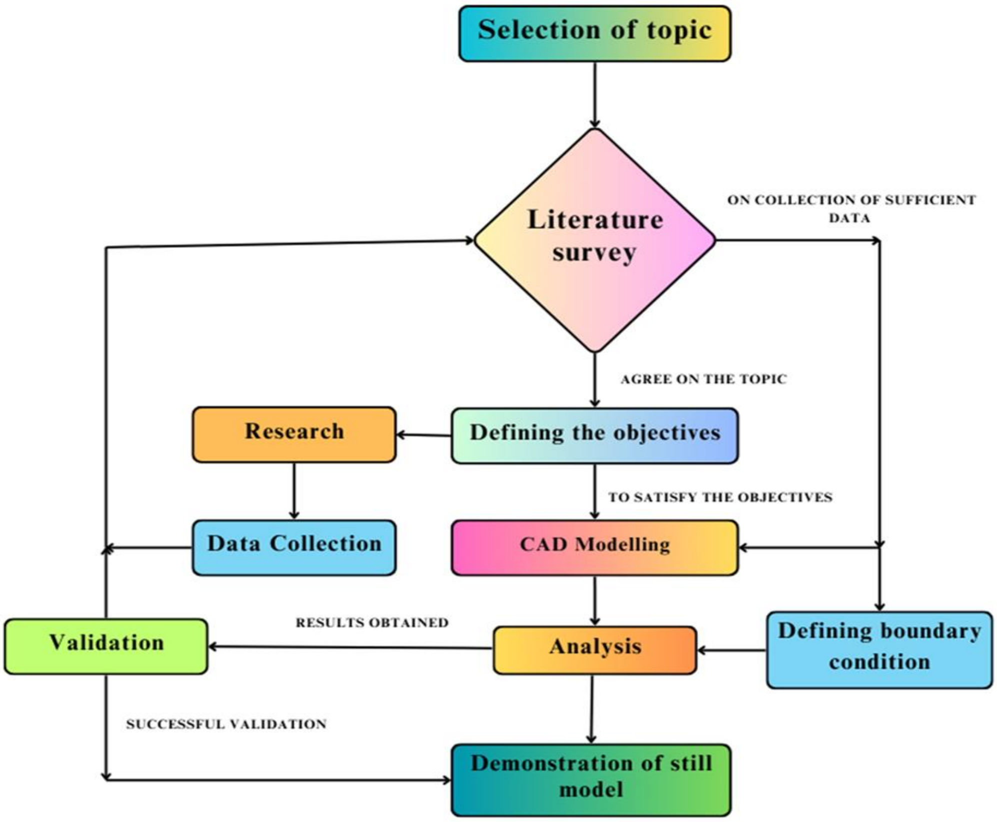

Figure 1: Flowchart of Methodology

Results & Conclusions:

Analysis conforms that the total **Deformation** of the design exhibits deformation under safe limits, indicating excellent structural integrity and resilience with **negligible Strain** suggesting that the material's elasticity and strength are well-utilized without nearing failure limits. **The Stress** analysis over the structure is high due to test model being too small compared to boundary conditions given.

Smooth analysis shows the formation of the shock wave over a body that defines the flow of air over body as streamline at supersonic in nature. This indicates the smooth flow over the body at maximum velocity and formation of drag and vortexes at lower velocity with **sustainable temperature distributions.**

Novel design, showcasing advanced engineering and creative problem-solving skills and **Improved Design Validation** through rigorous testing and simulation, ensuring it meets all required specifications and performance standards.

This project explores the design and analysis of a re-entry vehicle featuring a docking system. The re-entry capsule is integrated into the GSLV Mark-III which includes a fuel tank with a propellant and oxidizer. The 3D modelling was carried out using Solid Edge, and the analysis was performed using Ansys work bench 2024. The capsule design is based on proprietary specifications, while the docking system adheres to ISS standards. The scaled down still (static) model of the re-entry vehicle with docking system is manufactured with 3D printing. Which briefs the idea of the assemble of the real capsule with demonstrative modelling (not how actual model is going to work). A viewer can have a brief idea what is being trying to connived.

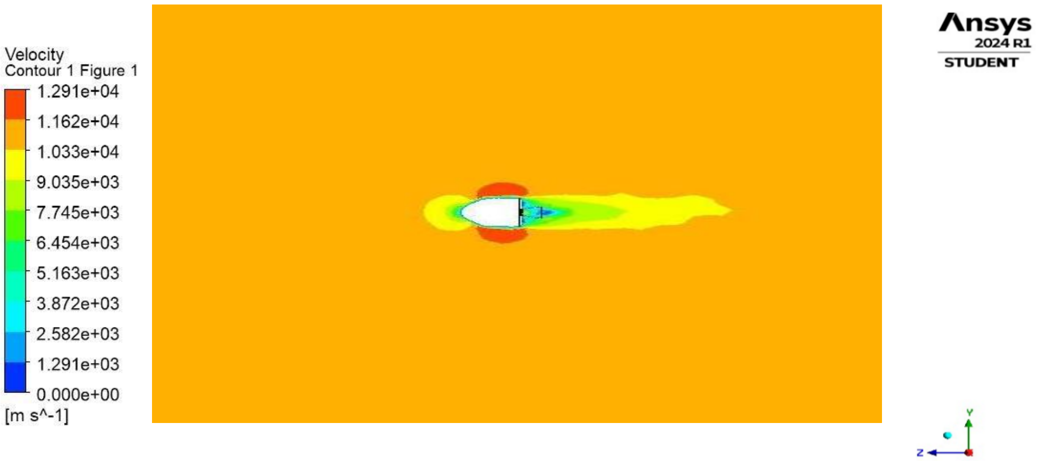

Figure 2: Velocity distribution on the designed model for flow analysis of velocity 11000 m/s

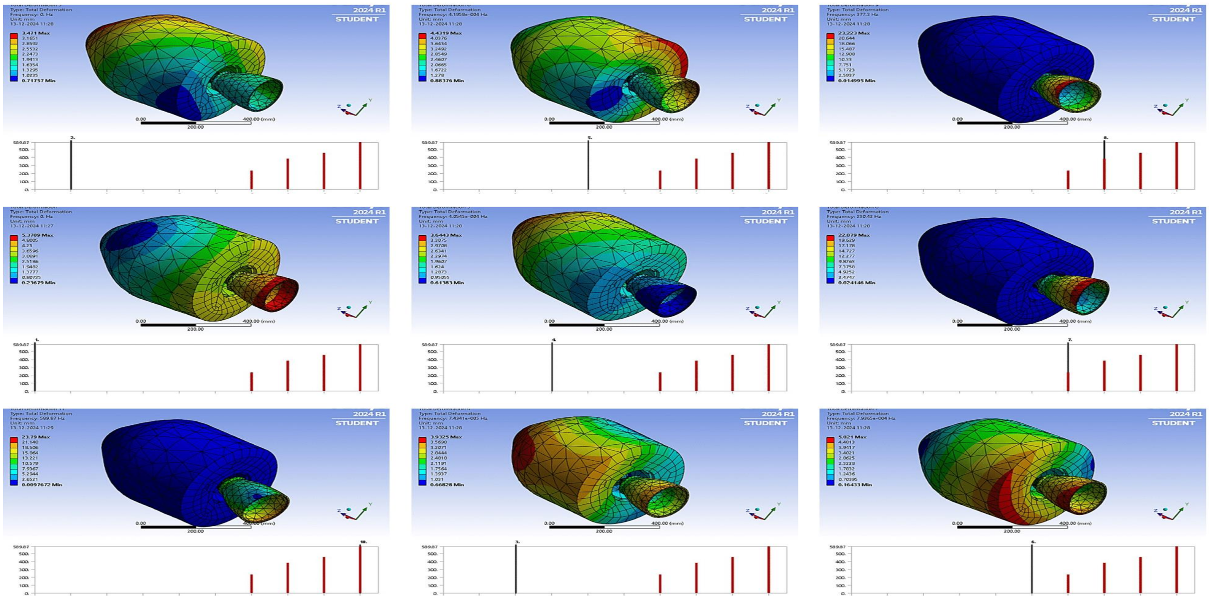

Figure 3: Total deformation for different frequency by modal analysis

Project Outcome & Industry Relevance:

The successful completion of this project will result in a scalable and efficient re-entry vehicle design equipped with an ISS-compliant docking system, optimized for integration with the GSLV Mark III. The project will deliver a functional prototype, validated through advanced simulations, serving as a foundation for future full-scale space missions.

From an industry perspective, the project directly contributes to the advancement of reusable spacecraft and precision docking technologies—key enablers for sustainable space missions. Its compatibility with international docking standards enhances collaboration opportunities and commercial viability for satellite servicing, crew transfer, and orbital station integration. Aerospace manufacturers, launch service providers, and mission planners can benefit from the project's innovations, especially in structural design, thermal protection systems, and modular docking solutions. Moreover, the initiative supports India's space ecosystem by fostering homegrown technological capabilities, encouraging public-private partnerships, and nurturing a skilled talent pool ready to drive the next wave of aerospace innovation. Additionally, the project offers valuable research opportunities for students at school, pre-university, and engineering levels. It provides hands-on exposure to cutting-edge technologies and design principles, cultivating the next generation of aerospace innovators

Working Model vs. Simulation/Study:

This project is completely simulation-based results are obtained only on the CFD and no testing is done on still model. The working still model is done just for understanding if the real scale capsule is done in future how it might work and respond. A real scale model will be having different allows at different parts and functions, but our still demonstrative module is completely 3d printed with PLA

The working model helps visualize and understand the assembly and design intent, while the simulation/study validates the performance of the design against real-world conditions such as stress, heat, and fluid flow — ensuring the concept is both feasible and safe.

Project Outcomes and Learnings:

This project successfully achieved the conceptual design and analysis of a re-entry vehicle integrated with a docking system, tailored for compatibility with the upper stage of the GSLV Mk III launch vehicle. A scaled-down prototype was fabricated using PLA through 3D printing, showcasing critical components such as the docking mechanism, crew module, cryogenic tanks, and engine layout. Alongside the prototype, comprehensive simulation studies were conducted using ANSYS Workbench 2024R, which included structural, thermal, fluid flow, and modal analyses. These simulations validated the design under extreme space and atmospheric conditions, such as re-entry temperatures reaching 2700°C and fluid velocities up to 13,000 m/s.

Through this project, we gained extensive knowledge of spacecraft design, simulation tools, and engineering analysis. We developed a strong understanding of how to integrate complex systems like docking mechanisms within the constrained space of a re-entry capsule, while maintaining structural integrity and thermal protection. Additionally, the project strengthened our skills in technical documentation, collaborative research, and critical analysis of real-world spacecraft

Future Scope:

1. Suborbital flights: Companies like SpaceX and Blue Origin are already offering suborbital space flights, and this market is expected to grow significantly in the coming years.
2. Exploration of other planets and moons: Missions to Jupiter's moons (like Europa and Ganymede), Saturn's moon Titan, and other potentially habitable worlds will continue to expand our understanding of the universe. Mission can focus on searching for signs of past or present life on other planets and moons, such as Mars and Europa if human can travel that far.
3. Interstellar travel: While still a distant goal, research into advanced propulsion systems like nuclear fusion or even warp drives will be crucial for interstellar exploration.
4. Lunar Gateway: A space station in lunar orbit will serve as a staging ground for future missions to the lunar surface and beyond.
5. Asteroid mining: Extracting valuable resources like metals and water from asteroids could be a significant economic driver for space exploration.