DEPARTMENT OF AEROSPACE ENGINEERING

Faculty Name	:	**Dr.A.Arun Negemiya, ASP/ Aero**	Academic Year	:	**2024-2025 (Even)**
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Course	:	**19ASB304 - Computational Fluid Dynamics for Aerospace Application**			

UNIT V – FLOW FIELD ANALYSIS AND TURBULENCE MODELS

Case Study: Stage Separation Aerodynamics for Space Systems

Stage separation in space systems involves separating rocket stages, requiring careful aerodynamic design and analysis to ensure a safe and successful separation. This case study will explore the aerodynamic challenges and solutions during stage separation, including interstage interference, dynamic stability, and separation mechanisms.

Challenges of Stage Separation Aerodynamics:

- **Interstage Interference:**

During separation, the flow field around the separating stages can create complex and potentially destabilizing aerodynamic forces and moments.

- **Dynamic Stability:**

The dynamic stability of the vehicle during separation is crucial for ensuring a safe separation and preventing unwanted motions or collisions.

- **Uncertainty in Flight Conditions:**

Variations in flight path angle, altitude, and stage separation timing can significantly impact the aerodynamic forces experienced during separation.

Solutions and Approaches:

- **Aerodynamic Separation:**

In some cases, aerodynamic surfaces (like elevons) can be used to actively control the separation process and ensure a safe separation.

- **Separation Motors:**

  For more complex separation scenarios, separation motors can provide the necessary thrust to separate the stages.

- **Simulation and Analysis:**

  Computational Fluid Dynamics (CFD) simulations and 6-degree-of-freedom (6DOF) analyses are used to model the separation process and assess the aerodynamic forces and stability.

- **Wind Tunnel Testing:**

  Wind tunnel tests can provide valuable data on the aerodynamic characteristics of the separating stages and the effects of interstage interference.

- **Multi-body Dynamics:**

  Modeling the separation process as a multi-body dynamics problem allows for a more comprehensive analysis of the interactions between the separating stages.

- **Separation Mechanism Design:**

  The design of the separation mechanism (e.g., explosive bolts, and clamp bands) is crucial for ensuring a reliable and safe separation.

Case Studies and Examples:

- **Ares I Launch Vehicle:**

  NASA's Ares I launch vehicle involved powered stage separation, requiring time-accurate simulations of the separating stages under the influence of time-varying thrusts from separation motors.

- **Space Launch System (SLS) Booster Separation:**

  The separation of the SLS boosters is a complex multi-body problem that requires sophisticated simulation techniques to account for the interactions between the separating stages.

- **Parallel-Staged Shuttle:**

  Studies on parallel-staged shuttle separation have investigated the feasibility of separating the orbiter from the booster at various points along its ascent trajectory.

- **Hypersonic Vehicles:**

  Numerical analysis of hypersonic flow past parallel-staged vehicles during stage separation is performed to analyze the aerodynamic characteristics and dynamic stability.