Shock Wave-Boundary Layer Interactions on Slender Bodies

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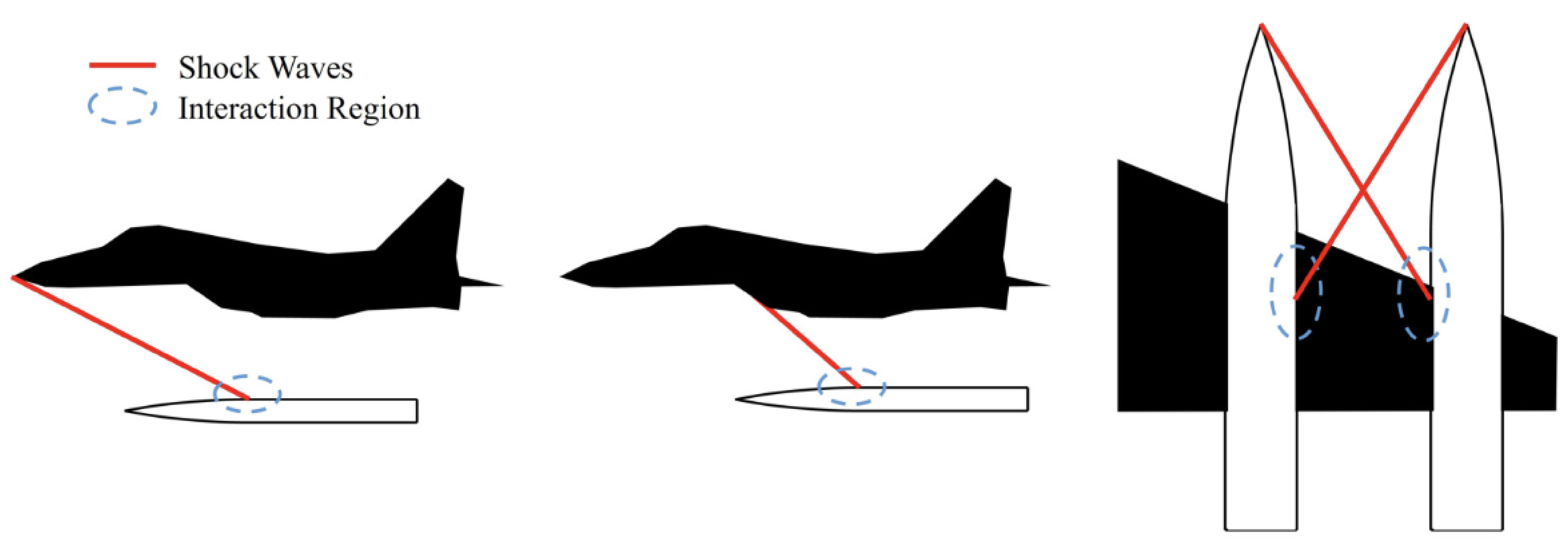
Motivation

- When a shock impinges on a boundary layer, it imposes a strong adverse pressure gradient that causes the boundary layer to thicken and potentially separate from the surface
- Shock wave-boundary layer interactions (SWBLIs) result in increased drag, unsteady aerodynamic loading, and intense localized heating
- The prevalence of shocks in supersonic flows makes understanding the effects of SWBLIs critical for the design and performance of high-speed aircraft and munitions
- Building upon existing research on flat plates, slender bodies offer a more realistic representation of real-world systems like airplane fuselages, rockets, and missiles



Interaction Between Munition and Parent Aircraft

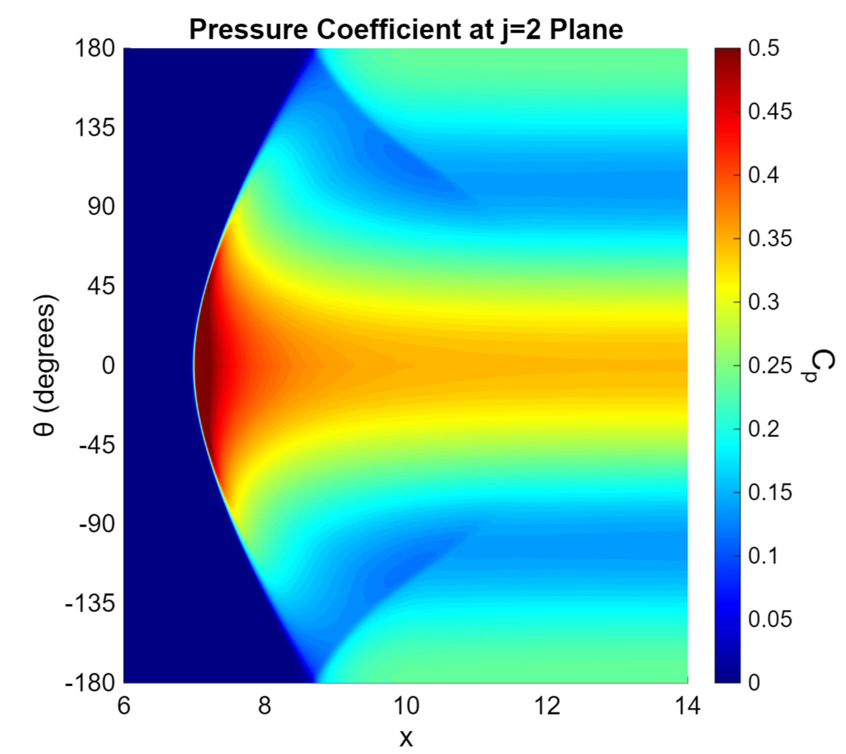
Adapted from Mason, F., Natarajan, K. and Kumar, R., 2021. **Shock-wave/boundary-layer interactions on an axisymmetric body at Mach 2.** AIAA Journal, 59(11), pp.4530-4543.

Approach

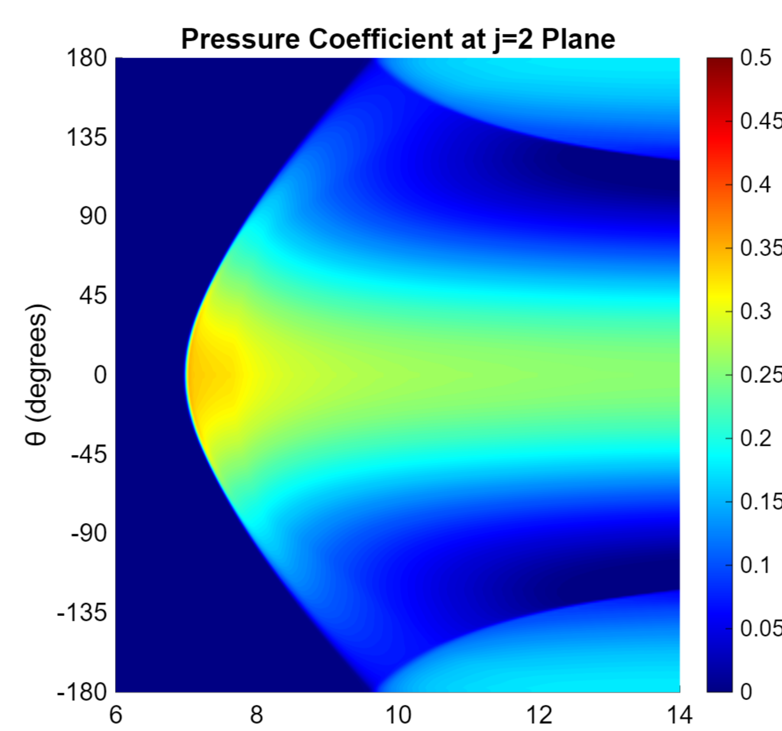
- Computational methods offer great flexibility, speed, and cost-efficiency in modifying simulation conditions while also providing detailed data across the entire flow field
- Analyze five inviscid simulations with parametric variation and one viscous simulation
- Computational Details:
  - Solve the 3D Navier Stokes equation in a curvilinear coordinate system
  - 3rd order MUSCL scheme for convective fluxes
  - 2nd order central differencing for viscous fluxes (for viscous simulations only)
  - 2nd order diagonalized Beam-Warming scheme for time integration

Objectives

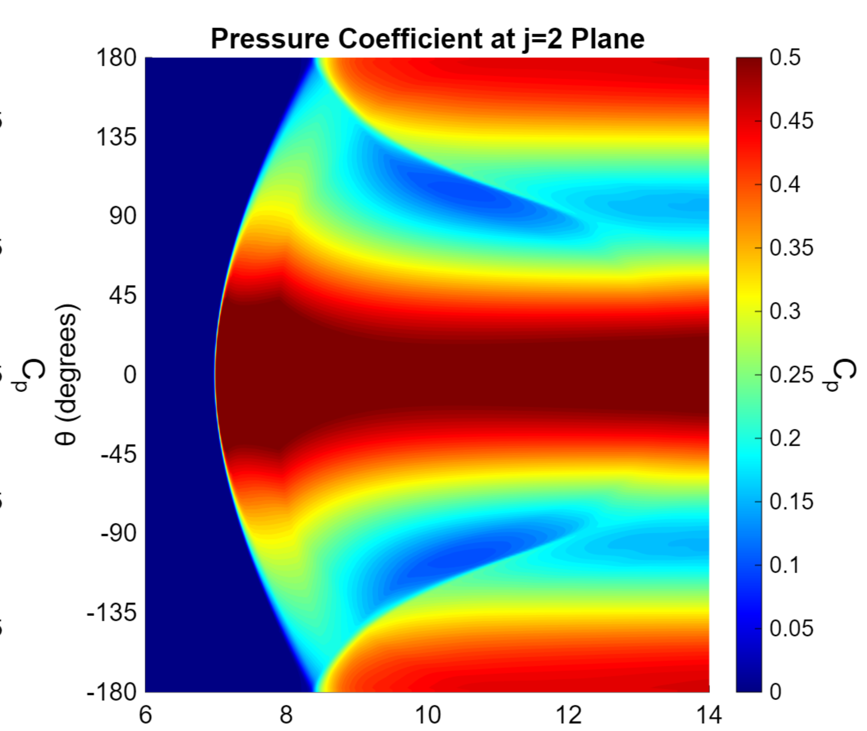
- Investigate how variations in Mach number and wedge angle influence SWBLI structures, including trends in pressure distribution, shock angles, and Mach stem formation
- Compare shock structures for inviscid and viscous simulations
- Apply findings to inform the design and aerodynamic loading considerations of high-speed aircraft and slender bodies



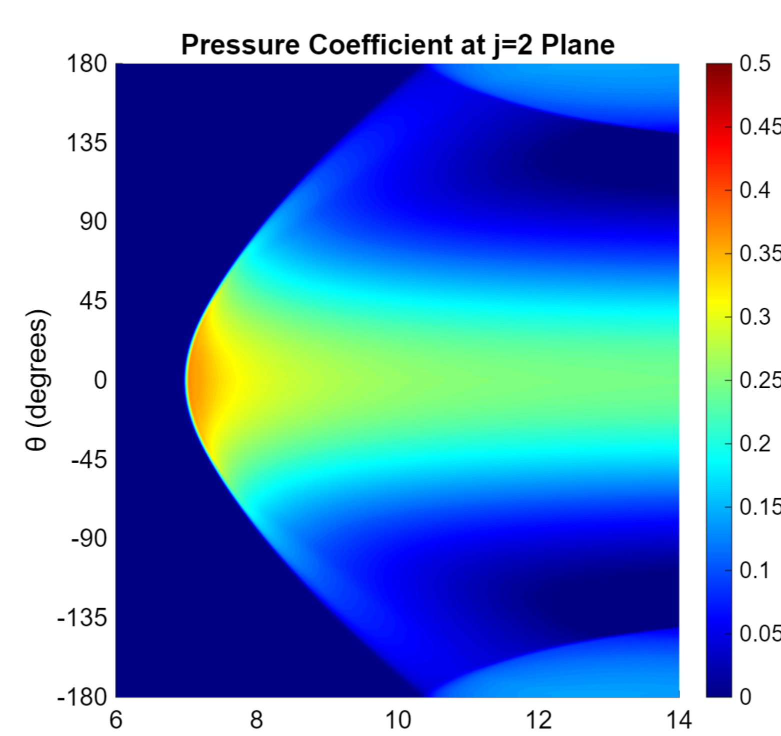
Mach 2, 10˚ Wedge



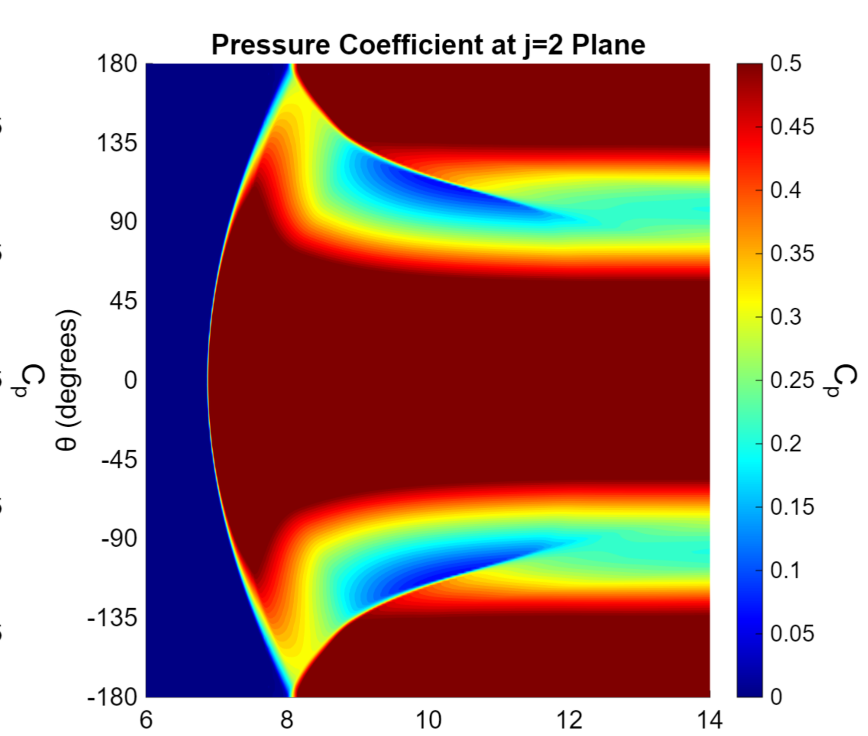
Mach 3, 10˚ Wedge



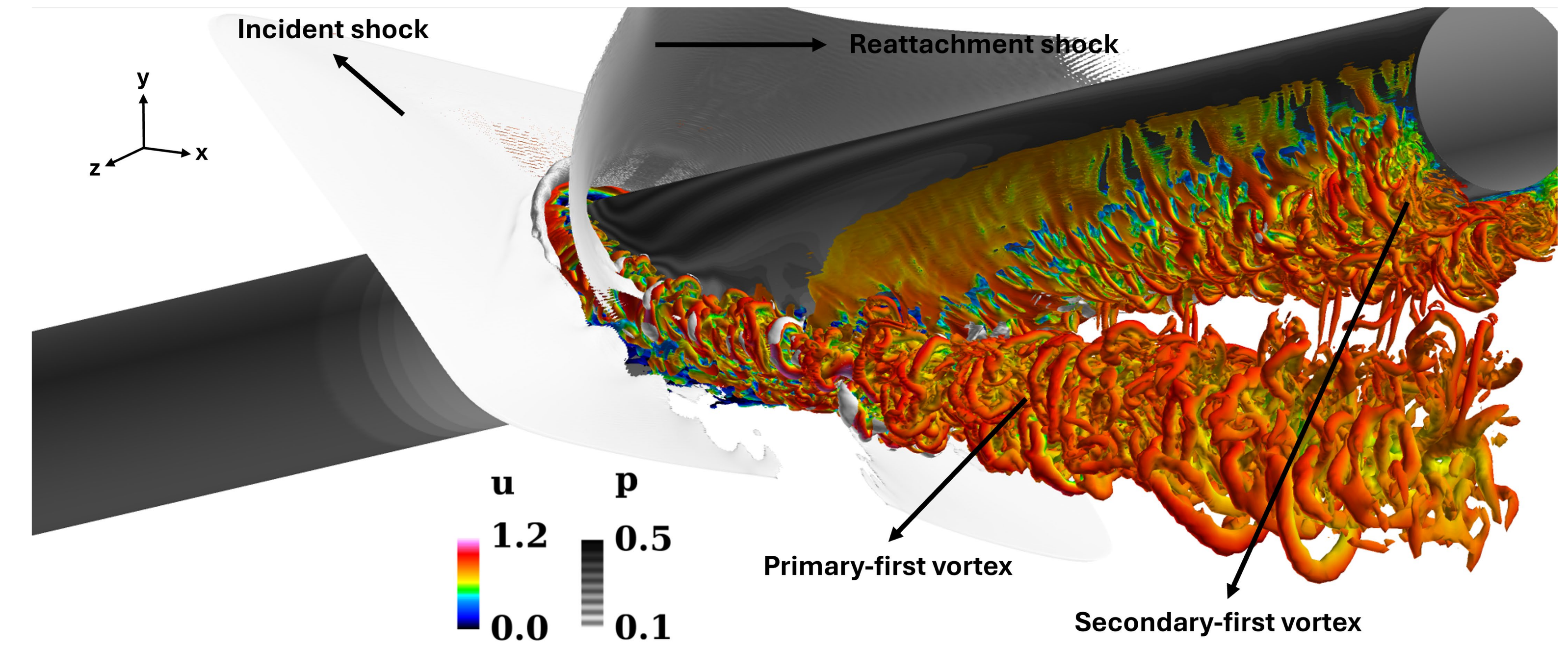
Mach 2, 15˚ Wedge



Mach 4, 10˚ Wedge



Mach 2, 20˚ Wedge



SWBLI on a Slender Body

Results

- Due to the θ-β-M relationship, increasing Mach number (with constant wedge angle) decreases shock angle while increasing wedge angle (with constant Mach number) increases shock angle
- Even with parametric variation, the overall structure of the inviscid shock-body interaction is very similar from case to case; a planar oblique shock generated by an off-body wedge impinges on the cylinder at approximately x=7, reflecting directly off the surface followed by the formation of a Mach stem on the leeward side
- In contrast, the viscous shock-boundary layer interaction exhibits an off-surface reflection caused by boundary layer separation, along with the formation of primary and secondary vortices
- Shock strength is a product of Mach number and wedge angle; higher Mach numbers and larger wedge angles result in larger pressure increases along the body, indicating a stronger shock-body interaction and Mach stem

Conclusions

- Higher Mach numbers create a narrower high-pressure cone, while larger wedge angles result in a wider cone
- A decrease in Mach number or an increase in wedge angle results in higher pressure coefficients along the body, indicating stronger pressure-induced loading
- Variations in freestream Mach number and wedge angle strongly influence the location and distribution of aerodynamic loading, which is important to consider when designing high-speed aircraft and munitions