OVERFLOW Analysis of Supersonic Retropropulsion Testing on a Blunt Mars Entry Vehicle Concept

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Background

Human missions to Mars will benefit from SRP

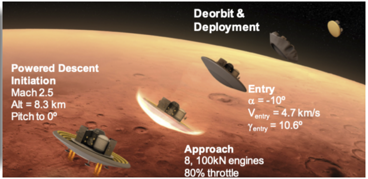
- Payloads are too heavy for traditional parachutes
- NASA is conducting an extensive test of multiple Mars SRP concept vehicles in Langley Unitary Plan Wind Tunnel

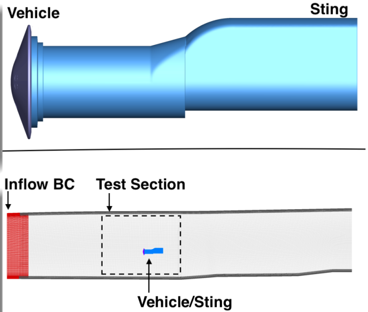
Comparison CFD simulations will be conducted

- Will improve SRP CFD uncertainty quantification
- Multiple CFD solvers will be utilized
- **Focus: Pre-test OVERFLOW CFD results for HIAD**

Test-analogous computational domain

- Vehicle is mounted to truncated wind tunnel sting
- Simulations are bounded by the tunnel test section geometry
- Inflow BC derived from full-tunnel simulations





HIAD low-L/D concept vehicle [1] and OVERFLOW CFD model

Manuscript Outline

OVERFLOW Analysis of Supersonic Retropropulsion Testing on a Blunt Mars Entry Vehicle Concept

- Background
- Computational Methodologies
- Overset Grid System Best Practices for SRP
  - → Grid Refinement Studies
  - → Mesh Adaptive Shock/Plume Capturing
- Pre-test CFD Results
  - Conditional Variations
  - → Unsteady Flow Cases
  - → Turbulence Modeling Uncertainty
  - Vehicle Aerodynamic Performance
- Conclusion

Mesh Refinement Studies

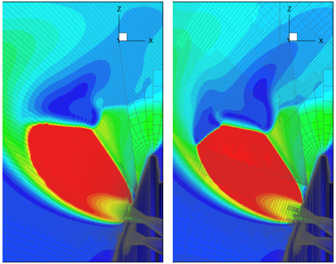
$M = 2.4, C_T = 2.5, \alpha = 0°$

Grids for SRP flow phenomena have many requirements

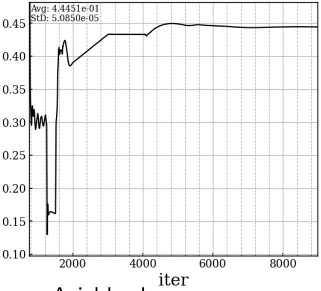
- Complex shock/plume interaction behavior is dependent on mesh resolution (e.g. plume Mach disk)
- Grid cells must align with bow shock
- Unsteadiness introduces spatial variation of SRP flow features

Apply Adaptive Mesh Refinement (AMR) in SRP region

- Refine grid incrementally to successively finer levels
- Solution is mesh-independent when mean loads convergence
- Grid convergence test can be performed on every CFD case



Mach disk resolved on finer mesh



Axial load convergence

Adaptive Mesh Shock/Plume Capturing

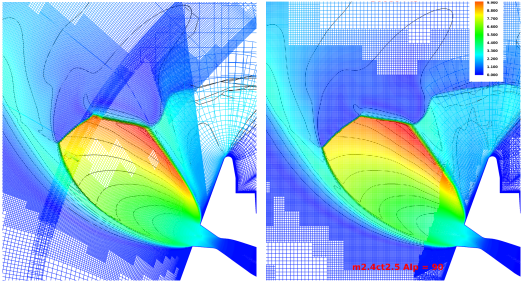
$M = 2.4, C_T = 2.5, \alpha = 0^\circ$

Original methodology: custom-made overset shock and plume "capturing" grids

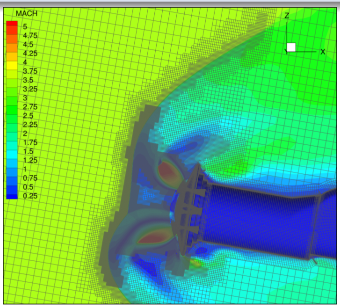
- Fine-resolution meshes manually shaped to fit SRP flow features for each condition
- Tedious, iterative grid design process. Compromised optimality between conditions

New methodology: Overlay vehicle with coarse box mesh, apply AMR

- Produces flow solutions of similar or greater accuracy
- General AMR grid is more optimal to condition <u>and</u> computationally efficient



Similar solution on: manually-fit (left), general AMR-box (right) grids



General AMR-box shock capturing

HIAD SRP Flow Results

$M = 3.5, C_T = 2.5, \alpha = 10^\circ$

Two HIAD nozzle configurations

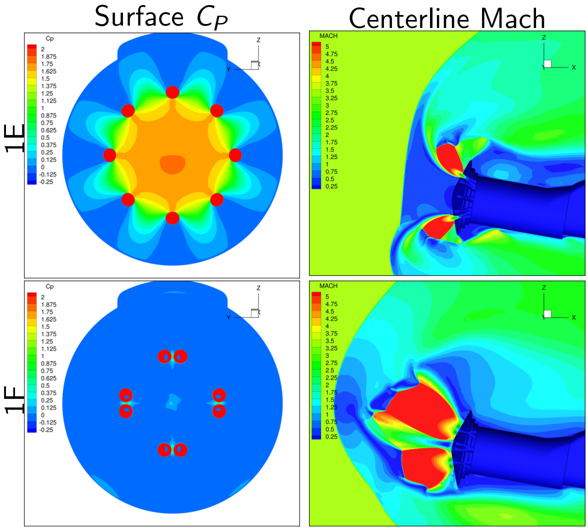
- 1E: Radially symmetric
- 1F: Paired

Primary SRP flow features

- High pressure inboard of engines
- Bow shock offset+augmented by plumes
- Triple point separates normal/oblique

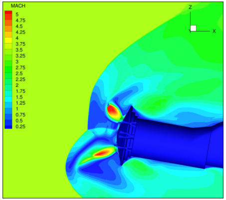
Special case: 1F at high-thrust

- Convex bow shock
- $C_P \sim 0$ (thrust-dominated)

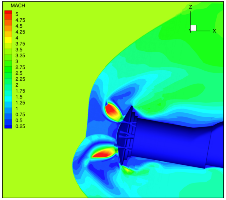


SRP Flow Unsteadiness (URANS)

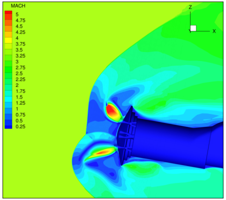
$1F, M = 3.5, C_T = 1.0, \alpha = 10°$



(a) $i = 12500$

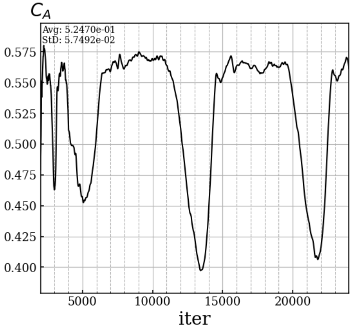


(b) $i = 16000$



(c) $i = 18000$

Time-varying, "chugging" plume oscillation



- Long-period unsteadiness occurs for a subset of 1F conditions ($f = 315Hz$)
- Quasi-steady "chugging" of plumes alters bow shock shape and heatshield pressure
- Quantification of accuracy dependent on comparison to experiment
- (Video duration: iter=8000-18000)

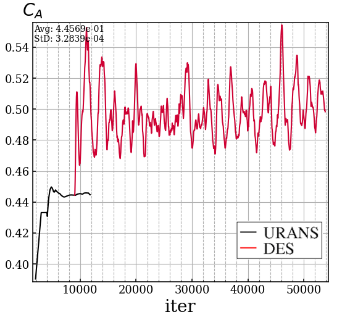
Uncertainty Due to Turbulence Modeling

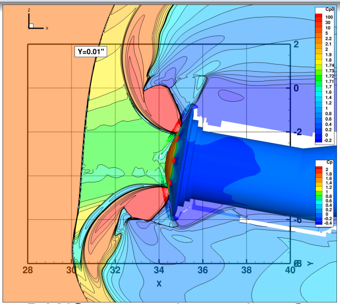
15% axial load increment observed between RANS/DES (for subset of conditions)

- DES *can* provide higher-fidelity modeling given sufficient computational resources
- **Wind tunnel data is needed to determine relative accuracy of each method**

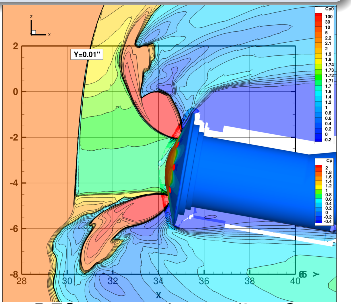
Identified flow sources of DES C_A increment

- Larger oblique area of bow shock → higher post-shock stagnation pressure
- Reduced shear layer entrainment → less mass flow radially outward from stagnation





RANS, averaged centerline C_{P_0}



DES, averaged centerline C_{P_0}

Summary and Future Work

Summary

- Conducted OVERFLOW CFD simulations of SRP flow over HIAD in wind tunnel
- Established best practices for overset grid generation for SRP flows:
  - Overlaid, coarse AMR-box to resolve SRP flow features
  - Increased AMR refinement until asymptotic loads convergence
- Identified significant uncertainty due to turbulence modeling for subset of conditions
  - $\Delta C_A \sim \pm 7.5\%$, increased flow unsteadiness
  - Identified flow sources of uncertainty in CFD solution

Future Work

- Compare to experiment/CFD uncertainty quantification
- Determine most accurate methodologies for SRP CFD (e.g. turbulence modeling)
- Post-test CFD analysis with updated best practices

Questions?

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References

[1] A. Cianciolo, A. Korzun, J. Samareh, R. Sostaric, D. Calderon, and J. Garcia, "Human mars entry, descent, and landing architecture study: Phase 3 summary," 2020.