

Comparison of OVERFLOW Computational and Experimental Results for a Blunt Mars Entry Vehicle Concept during Supersonic Retropropulsion

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Overview

SRP is essential for enabling human missions to Mars

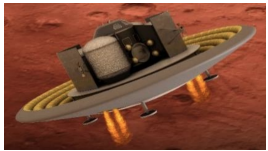
- Payloads are too heavy for traditional supersonic parachutes
- NASA has conducted an extensive campaign of wind tunnel testing and companion CFD for multiple Mars SRP concepts

Langley Unitary Plan Wind Tunnel SRP test

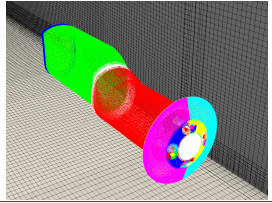
- 6 models (blunt and mid-L/D, multiple nozzle configurations)
- $M = \{2.4, 3.5\}$, $C_T \in [0.5, 2]$, $\alpha \in [-10°, 10°]$ (Model 1F)

Test-analogous, OVERFLOW CFD comparisons

- Nozzle configuration 1F, $M = 3.5$, $C_T = 1.89$, $\alpha = \{0°, -10°\}$
- Selected challenging-to-model conditions (strong unsteadiness)
- Data measurements for comparison:
  - Schlieren flow visualization (instantaneous and averaged)
  - Discrete surface pressure measurements (unsteady and static)







Manuscript Outline

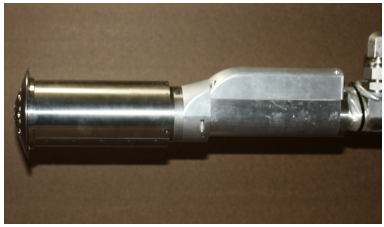
Comparison of OVERFLOW Computational and Experimental Results for a Blunt Mars Entry Vehicle Concept during Supersonic Retropropulsion

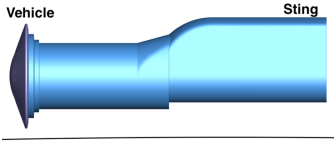
- Introduction
  - Experiment Overview
  - Simulation Overview
- Computational Methodology
  - Numerical Methods
  - Overset Grid System
- Results and Comparisons
  - Mean Supersonic Retropropulsion Flowfield
  - Unsteady Supersonic Retropropulsion Flowfield
- Conclusion

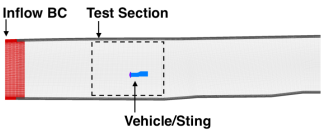
Computational Methods

Test-analogous computational domain

- All CFD mesh geometries designed from CAD
  - Vehicle is mounted to truncated wind tunnel sting
  - Some differences between CAD-based and as-built sting
  - Minimal influence expected from downstream features
- Simulations bounded by the tunnel test section geometry
- Inflow BC derived from full-tunnel simulations







Numerical methods best practices from pre-test CFD

- High-frequency AMR in SRP region to refine shock, plumes
- DES turbulence modeling
  - Significant difference compared to URANS observed for some conditions in pre-test CFD
  - Resolves finer scales and highly dynamic unsteadiness

CFD SRP Flow Unsteadiness

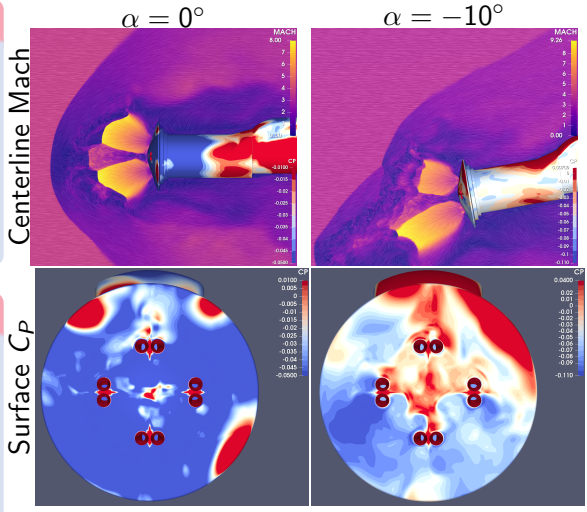
Model 1F, $M = 3.5$, $C_T = 1.89$

Supersonic retropropulsion flow region

- Bow shock offset+augmented by plumes
  - High-freq., local fluctuations
  - Periodic oscillation of standoff distance
- General bow shock shape
  - $\alpha = 0°$: convex, continuous
  - $\alpha = -10°$: discontinuous inflection point

Heatshield surface pressure distribution

- Baseline distributions augmented by high-frequency, local fluctuations
- $\alpha = 0°$: relatively constant baseline C_P, with high-C_P fluctuations on the edges
- $\alpha = -10°$: high-pressure on windward side (expected)



Unsteady Schlieren Comparisons

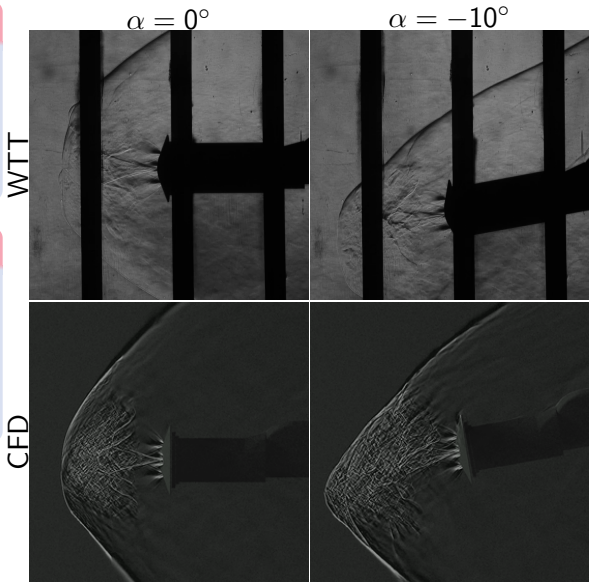
SRP flow region comparisons

- Qualitative similarity in general shock shape, oscillations
- Differences in timescale of shock oscillation and local fluctuations

Variations in shock standoff distance

	$\alpha = 0°$	$\alpha = -10°$
WTT	$1.25 - 1.4D$	$1.1 - 2.9D$
CFD	$1.2 - 1.8D$	$1.2 - 2.1D$

*D = Heatshield diameter



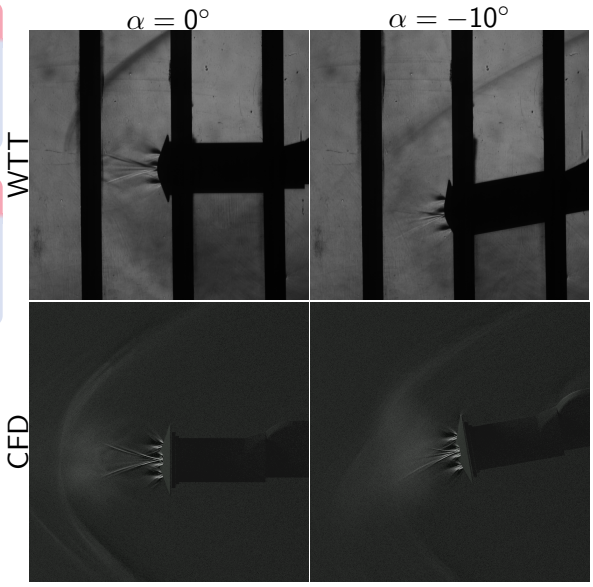
Averaged Schlieren Comparisons

$\alpha = 0°$

- Bow shock standoff distance
  - WTT$\sim 1.25D$
  - CFD$\sim 1.33D$

$\alpha = -10°$

- Bow shock point of inflection
  - WTT $\sim 1D$
  - CFD $\sim 1D$



Pressure Unsteadiness Comparisons (kulites®)

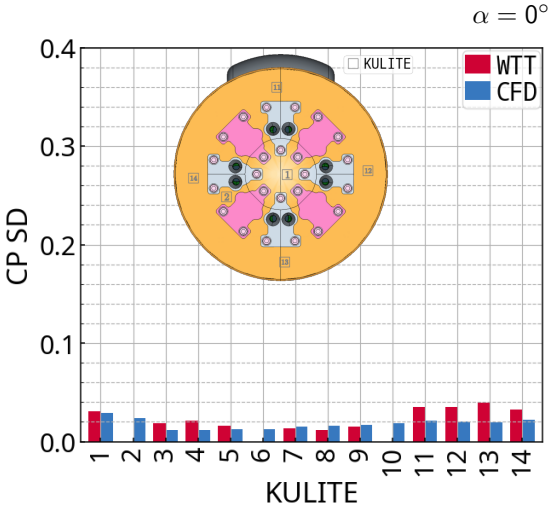
Model 1F, $M = 3.5$, $C_T = 1.89$

kulites®

- Locations:
  - 1: Heatshield center (Stagnation)
  - 2: Nozzle-radius (no test data)
  - 11-14: Heatshield edge
  - Others: backshell and sting
- Compare C_P standard deviation (SD_{C_P})

Comparison at $\alpha = 0°$

- Relatively low unsteadiness magnitude
- stag: $|\Delta SD_{C_P}| < 10\,\%$
- edge: CFD significantly less unsteady than WTT ($|\Delta SD_{C_P}| \approx 40\,\%$)



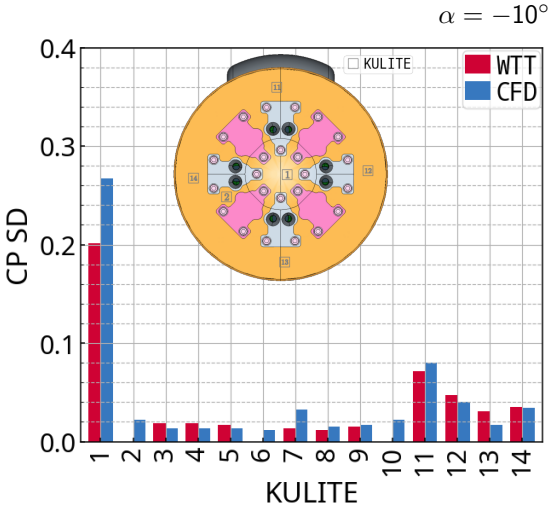
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  - Others: backshell and sting
- Compare C_P standard deviation (SD_{C_P})

Comparison at $\alpha = -10°$

- More unsteady than $\alpha = 0°$
- stag: $|\Delta SD_{C_P}| \approx 30\,\%$
- edge:
  - $|\Delta SD_{C_P}| \approx 20\,\%$
  - Similar trends: unsteadiness increases to windward (up)



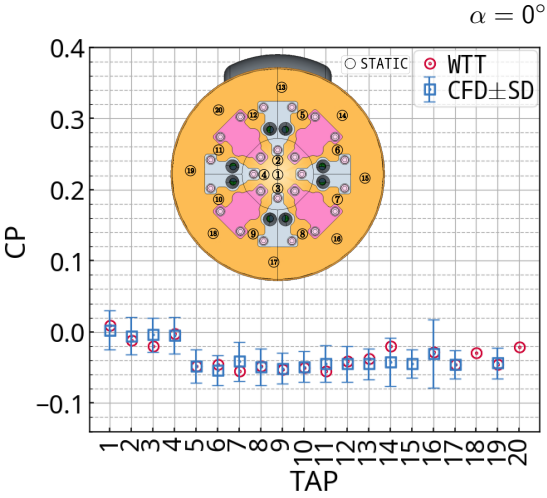
Average Pressure Comparisons (Static Taps)

Static Taps

- Locations:
  - 1-4: Heatshield center (Stagnation)
  - 5-12: Nozzle-radius
  - 13-20: Heatshield edge
- CFD variance bars: standard dev. (SD)

Comparison $\alpha = 0°$

- stag: low $|C_P|$, large relative differences
- nozz: more negative C_P, $|\Delta C_P| \approx 11\,\%$
- edge: varied accuracy
  - Generally good agreement ($|\Delta C_P| < 10\,\%$)
  - . . . except #14 (north-east of HS)



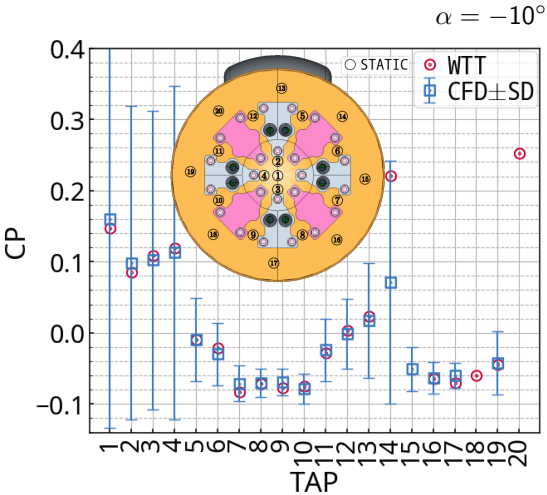
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Static Taps

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  - 13-20: Heatshield edge
- CFD variance bars: standard dev. (SD)

Comparison $\alpha = -10°$

- stag: Greater $|C_P|$, $|\Delta C_P| < 10\,\%$
- nozz: $|\Delta C_P| \approx 12\,\%$
- edge:
  - Similar accuracy to $\alpha = 0°\ldots$
  - Increased $|\Delta C_P| \approx 15\,\%$ for leeward #17
  - Similar large error for #14



Summary

- Comparisons of OVERFLOW DES CFD of SRP to wind tunnel results
- HIAD SRP flow is highly dynamic and unsteady (Model 1F, $M = 3.5, C_T = 1.89$)
- Bow shock standoff distance: Similar average shape within 10-30 %
- Similar oscillations and local fluctuations of shock, notable differences in timescales
- Surface pressure within 10 % for most of the heatshield, some significant, local differences
- Notable differences in unsteadiness (20-40 %) at some outboard heatshield locations
- Overall: properly calibrated DES CFD of SRP can produce results generally comparable to experiment, but there are notable areas where simulation accuracy can be improved

Further Work

- Simulation additional conditions for comparison to wind tunnel results
- Code-to-Code CFD comparisons
- Investigate effectiveness of TMRC turbulence modeling for HIAD SRP flow

Questions?

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