OVERFLOW Analysis of Supersonic Retropropulsion Testing on the CobraMRV Mars Entry Vehicle Concept

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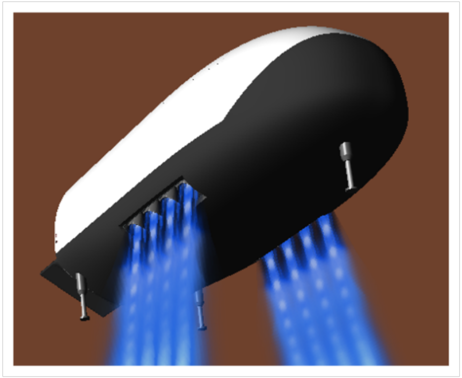
2022 AIAA SciTech Forum

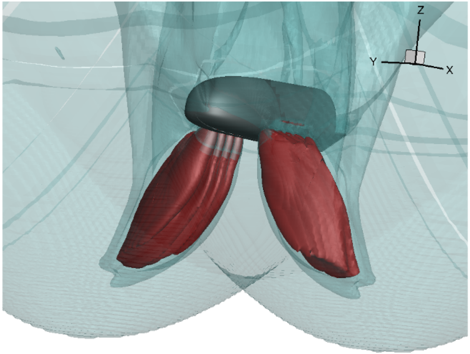
Background: CobraMRV

The CobraMRV considered for landing large payloads:

Artistic render

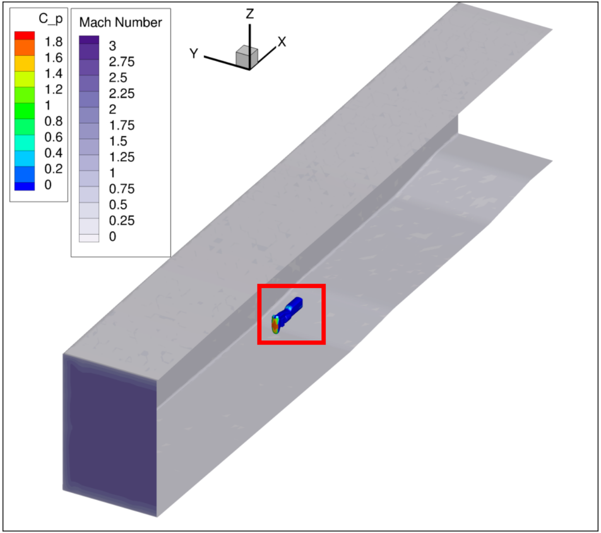


Mach number isosurfaces



Background: Tunnel & Model Geometry

$M = 2.4, \alpha = 90°, CT = 2.5$



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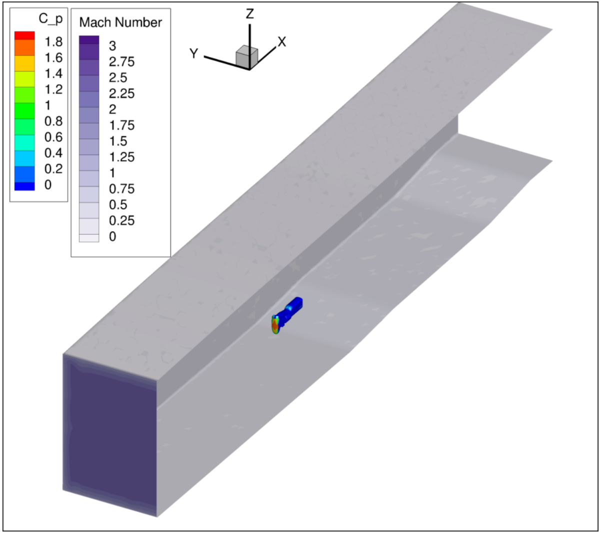
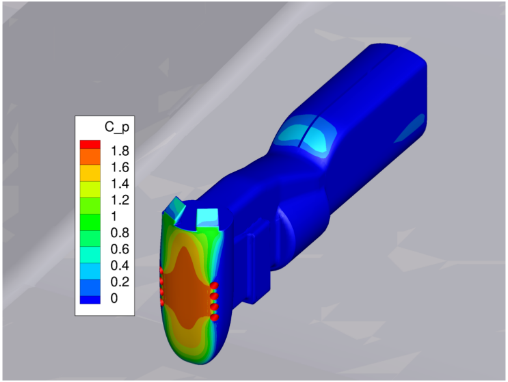
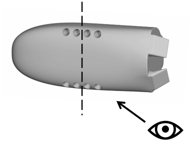


Close up view of the model & sting (heatshield highlighted by C_p contours)



Background: Flow field visualization



- $M = 2.386, \alpha = 90°$ and $CT = 2.5$
- T_0 isosurfaces showing plume structures

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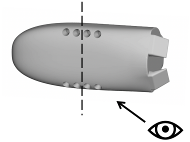

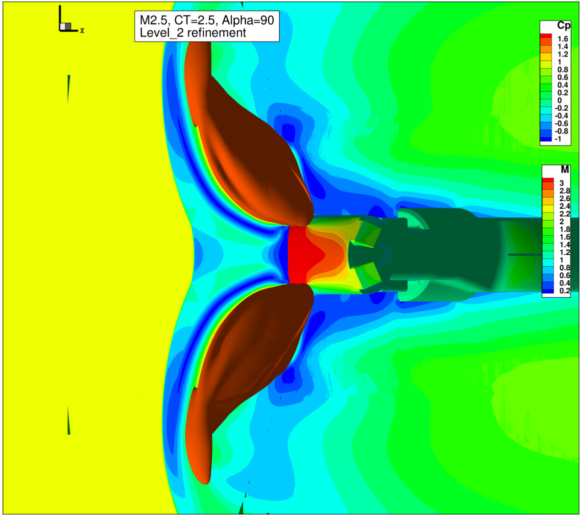

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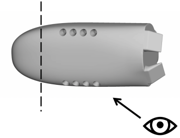

- $M = 2.386, \alpha = 90^\circ$ and $CT = 2.5$:
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- Black lines indicating the 'saddle' shock
- Bow shock changes load dynamics

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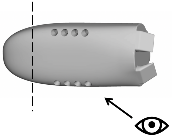

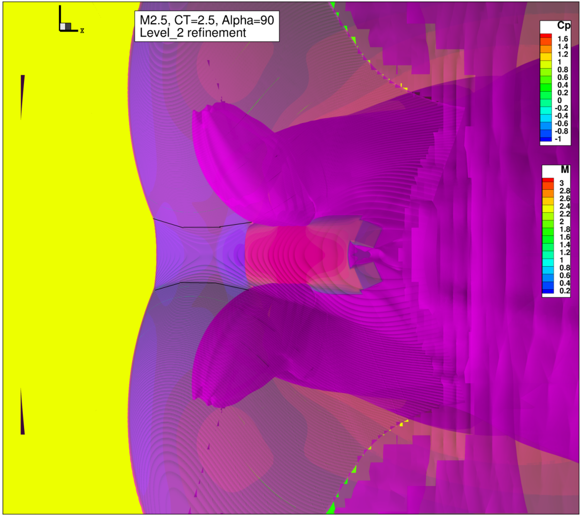

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Background: Heatshield

Steady C_p distributions on the heatshield at $\alpha = 90^\circ$ and $CT = 2.5$:

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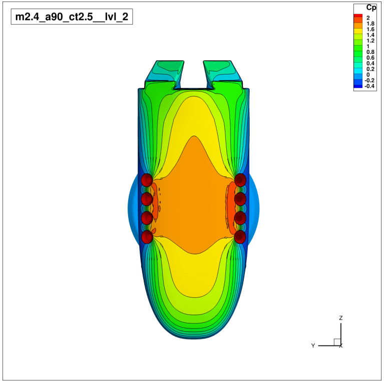

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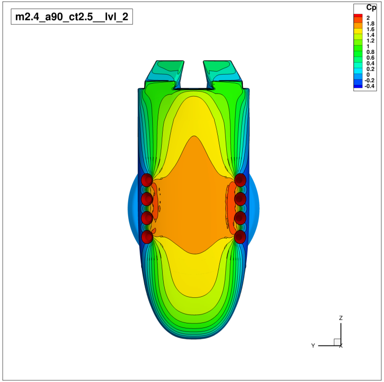

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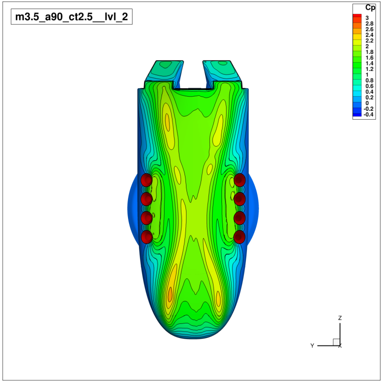

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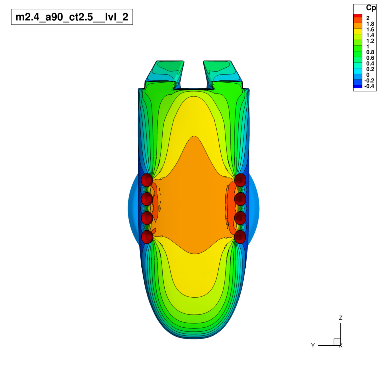

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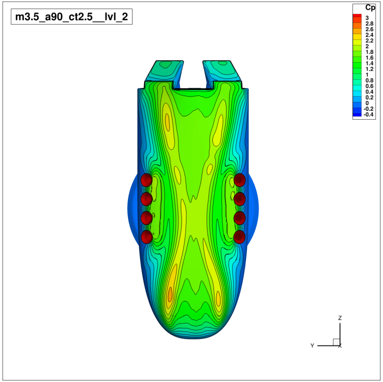
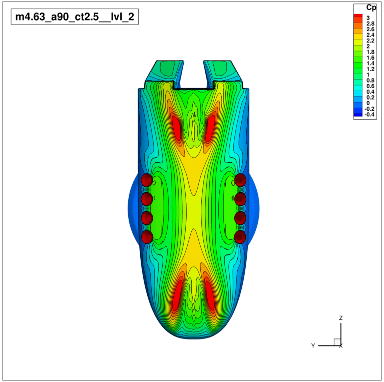
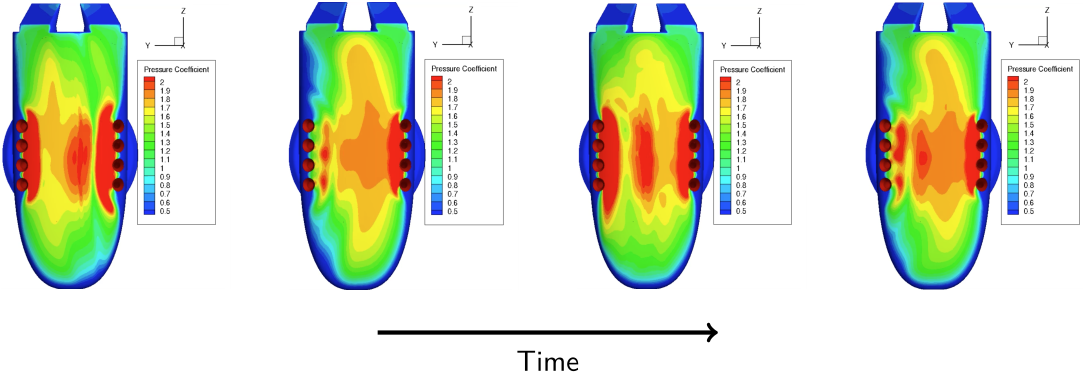


$M = 4.6$



Background: Heatshield

$M = 4.6, \alpha = 90°$ and $CT = 1.0$:
An example of flow unsteadiness in heatshield C_p



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    - Tunnel inflow conditions
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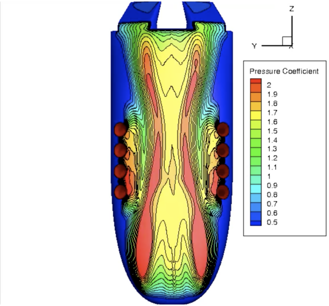
Operating conditions of particular interest:

$$M = 3.5, \alpha = 85^\circ, CT = 2.5$$



Shown: transition from 1 to 2 levels of AMR

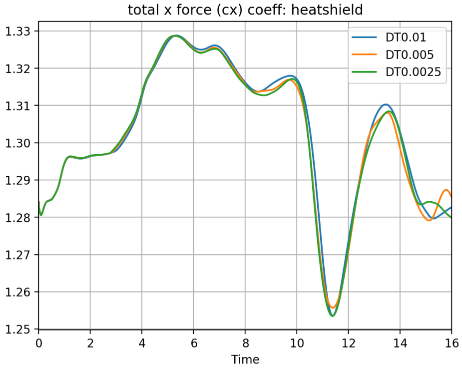
Temporal Accuracy

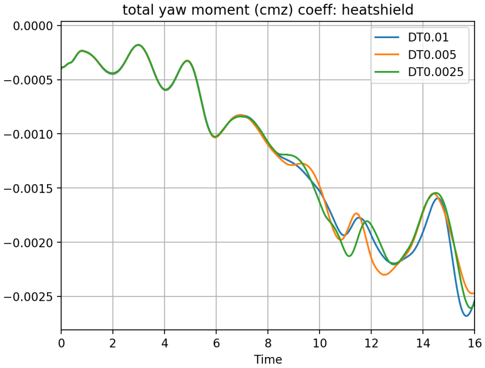
- $M = 3.5, \alpha = 85^\circ, CT = 2.5$
- What contributes to load unsteadiness, if it exists?

Temporal Accuracy: Δt

$$M = 3.5, \alpha = 85^\circ, CT = 2.5$$

Time-step size was not a factor in observed unsteadiness.





Temporal Accuracy: AMR

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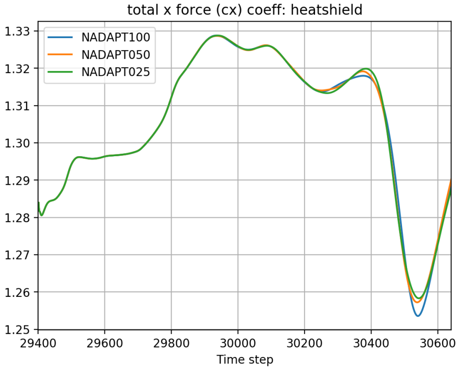
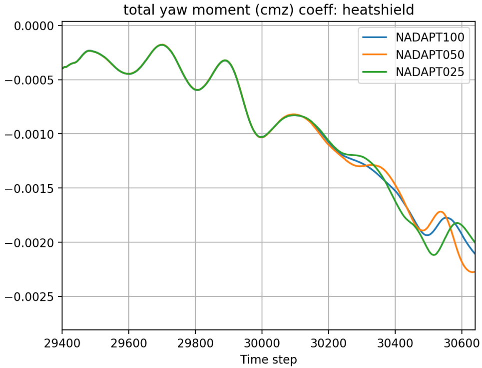
Mesh adaption frequency was not a factor in observed unsteadiness.





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Effect of mesh adaption frequency on heatshield loads: Dynamic vs. 'frozen' grid adaption

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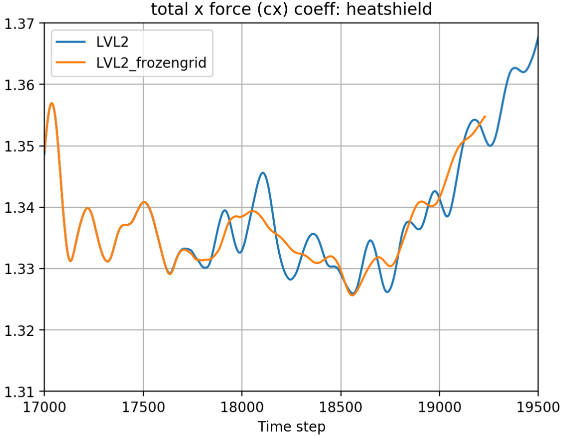

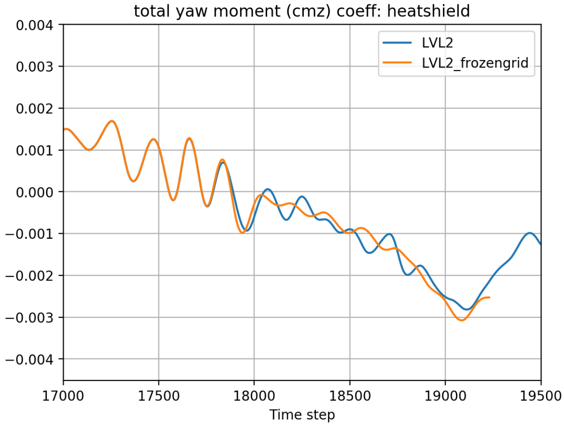

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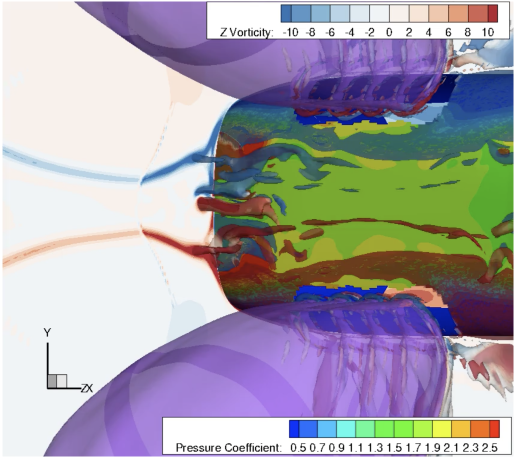

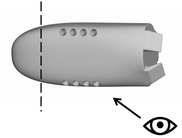

Dynamic grid adaption captures near-surface vortical structures as they travel.

Temporal Accuracy: AMR

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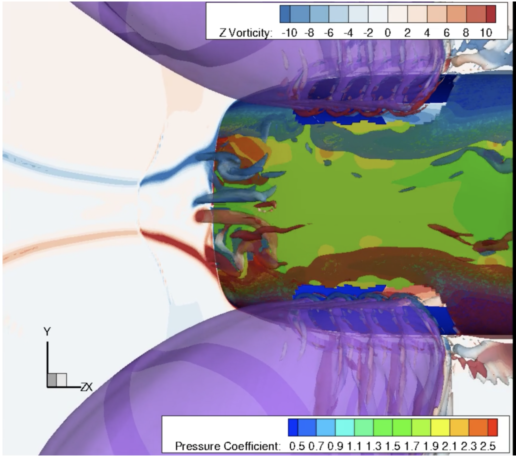
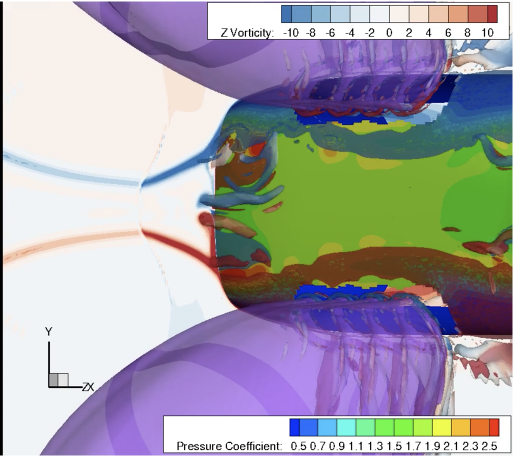
Dynamic AMR



Frozen AMR



Inflow BC

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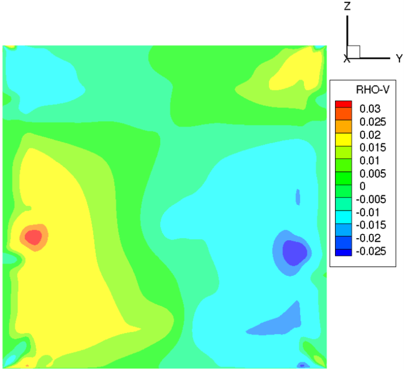

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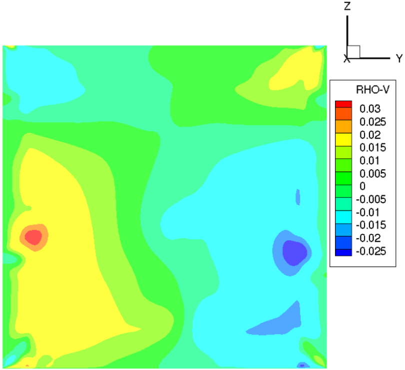
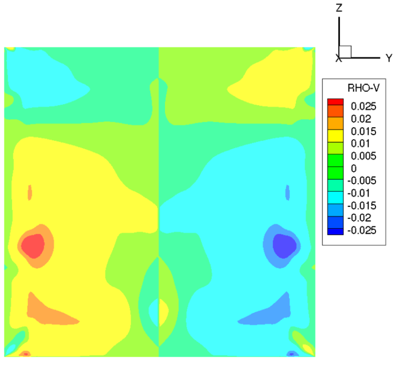


Symmetrized BCs



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Averaged heatshield C_p contours

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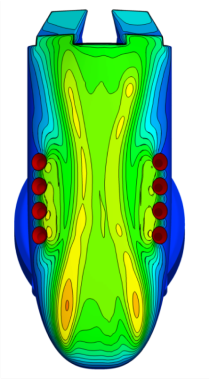

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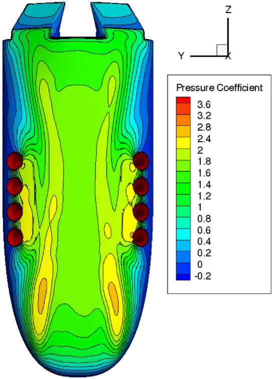

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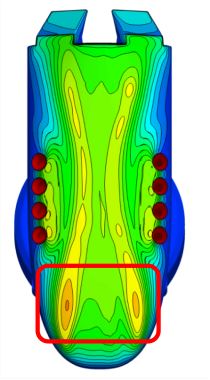

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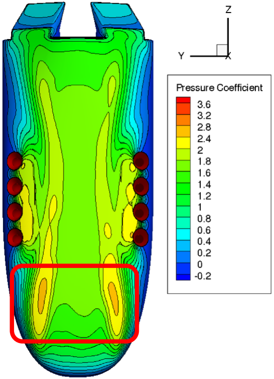

Turbulence Modeling

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Turbulence Modeling

$$M = 2.4, \alpha = 90°, CT = 2.5$$

DES raises the heatshield c_x by about 20% and greatly increases load unsteadiness compared to URANS

	c_x **mean**	c_x **std. dev.**
URANS	1.113	7.9×10^{-3}
DES	1.334	1.01×10^{-1}

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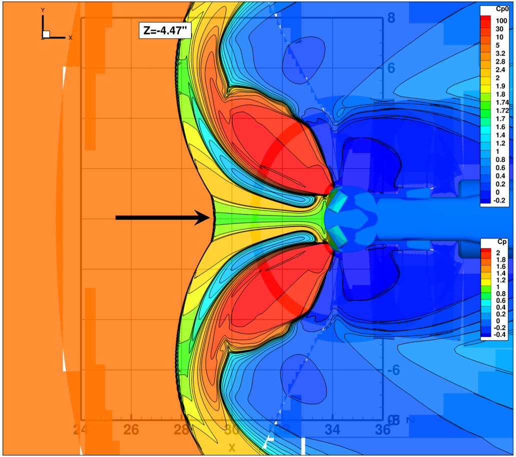
Contours of stagnation pressure coefficient C_{p0}

SST $k - \omega$ URANS



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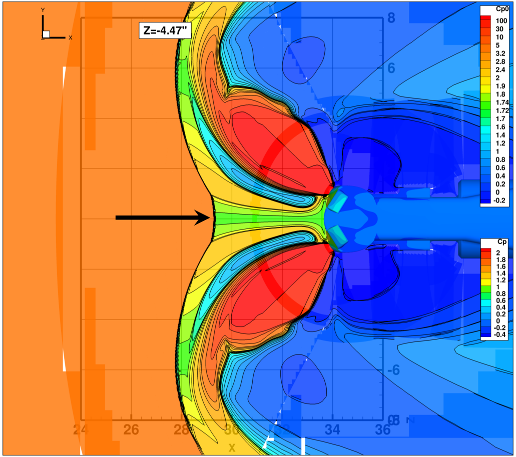
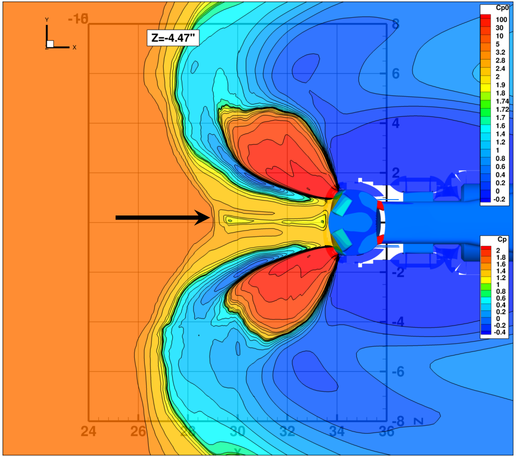
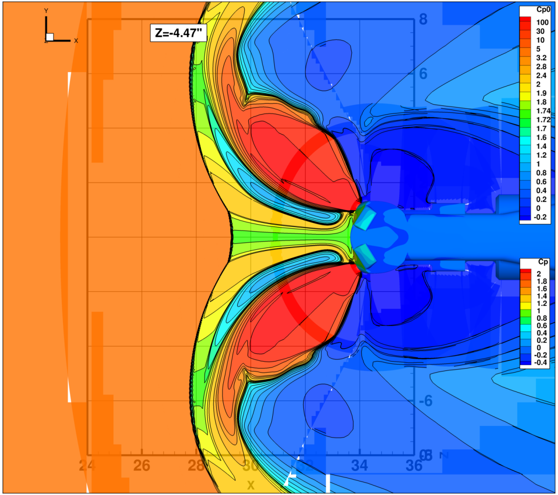


SST $k-\omega$ DES



Summary

- Present CobraMRV pre-test solutions are independent of time stepping and mesh adaption frequency
- Dynamic AMR must be used to capture the full range of vehicle dynamics
- Inflow asymmetry impacts vehicle loads
- SST $k-\omega$: DES gives 20% increase in loads compared to URANS



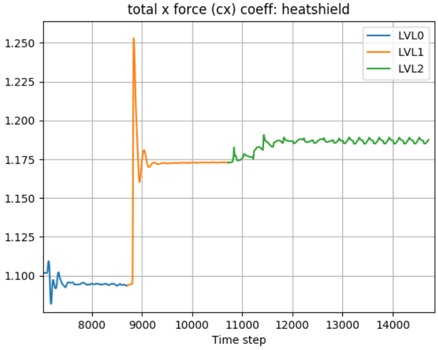
Acknowledgements: Funding provided by AETC DSS and NESC LAV projects.
Contact: kristen.v.matsuno@nasa.gov

Numerical methods

- 5^{th} order WENO
- HLLE++ in shock region, HLLC elsewhere
- 'time-accurate' mode
- Two levels of AMR in shock and plume regions
- Inflow conditions: averaged 'empty tunnel' solutions (Childs et al. AIAA Aviation (2021))
- Base turbulence model: SST $k - \omega$
  - QCR on in tunnel wall grids; disabled elsewhere
  - RC on
  - CC off

$M = 2.4, \alpha = 90°, CT = 0.5$

Heatshield loads at each AMR level



Misc. Notes

- Due to unsteadiness and scale resolution, DES is likely (at least) an order of magnitude more expensive that URANS
- Nozzle boundary conditions: P_0, T_0 specified, then run with mutigridding through transient period