Computational Analysis of a Multiple-Nozzle Supersonic Retropropulsion Configuration

Justin A. Shafner
University of Maryland

Dr. Ashley M. Korzun
NASA Langley Research Center

AIAA Aviation Forum, August 2-6 2021

Computational Analysis of a Multiple-Nozzle Supersonic Retropropulsion Configuration

Outline:

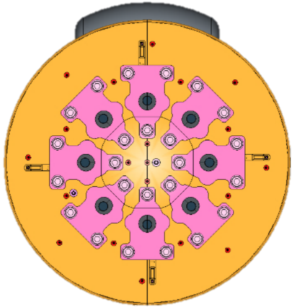
- **Introduction**
- **CFD Setup**
- **Turbulence Model**
- **Time Accurate Flow Solutions**
- **Time History Vehicle Loads**
- **Conclusions and Future Work**

Computational Analysis of a Multiple-Nozzle Supersonic Retropropulsion Configuration

Introduction:

- Supersonic Retropropulsion (SRP) will take high-mass payloads and humans to Mars
- 2021 Propulsive Descent in Test Section 2 of NASA Langley Unitary Plan Wind Tunnel
- This Paper Previews the CFD Validation Campaign

Test Model 1a (Forebody View)



Test Model 1a (Side View)

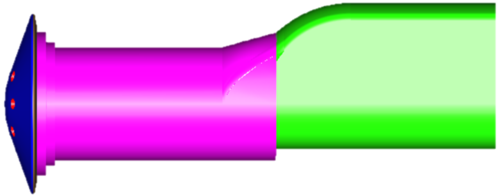
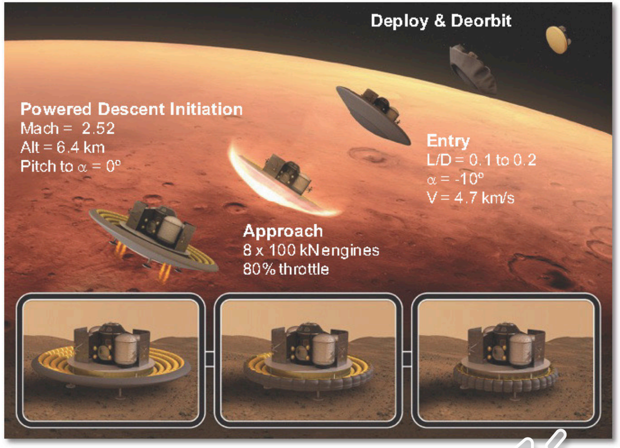


Table 1 Run Conditions

Freestream Conditions				
M_∞	V_∞ (m/s)	P_∞ (Pa)	$T_{0,\infty}$ (K)	q_∞ (Pa)
2.386	589.5	2527.1	324.8	10069.2

Nozzle Conditions				
C_T	$P_{0,j}$ (kPa)	$T_{0,j}$ (K)	M_e	$P_e/P_{0,2}$
2.5	2130.7	394.3	2.94	3.215
1.0	852.3	394.3	2.94	1.286
0.5	426.1	394.3	2.94	0.643

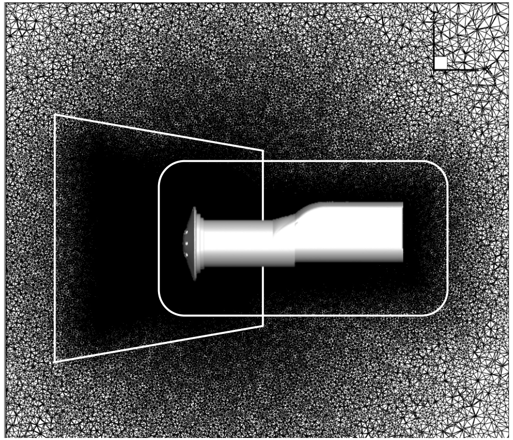


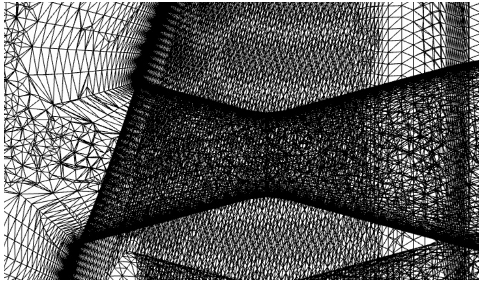
Conceptual Low-*L/D* Vehicle

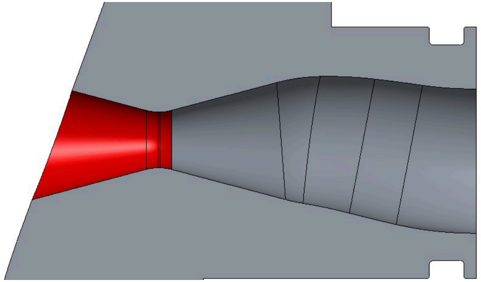
Computational Analysis of a Multiple-Nozzle Supersonic Retropropulsion Configuration

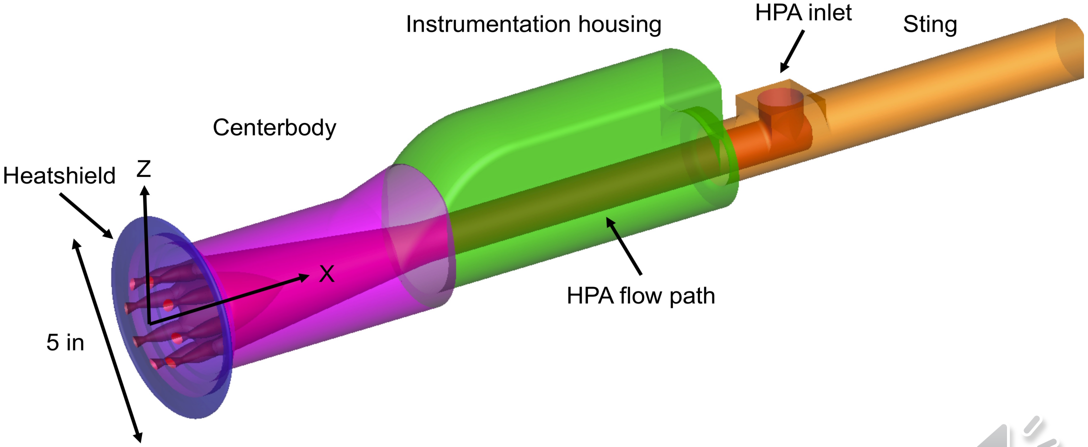
CFD Setup:

- **Fully Unstructured, 3D, unsteady, time-accurate FUN3D**
- **Fixed grid w/ heatshield, centerbody, and housing**





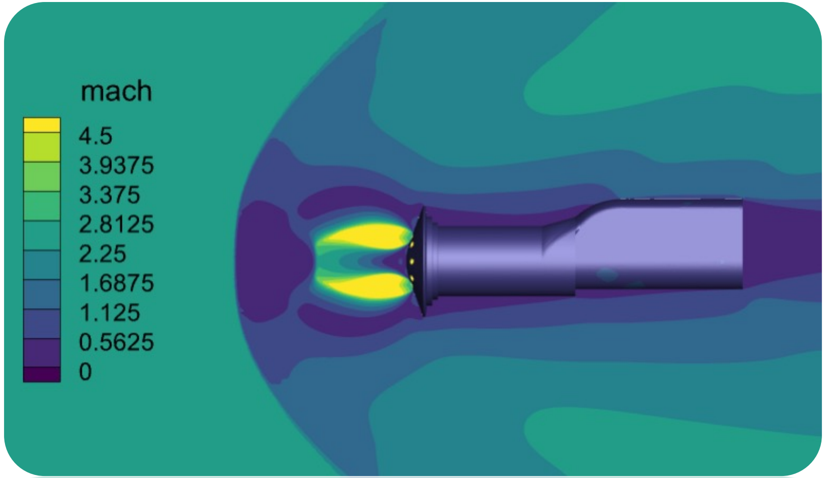




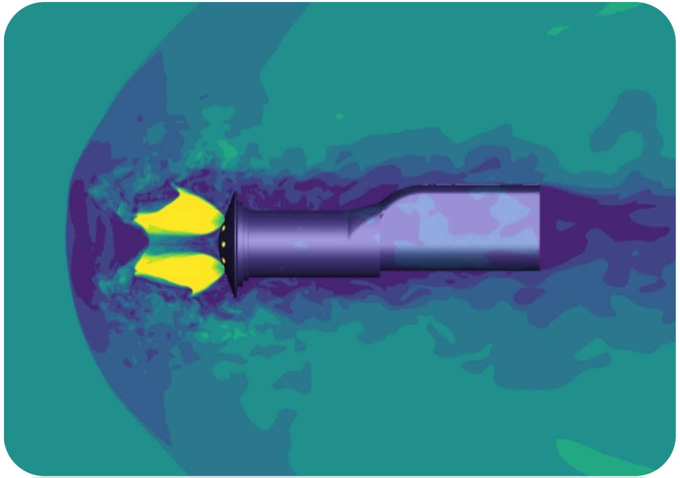
Computational Analysis of a Multiple-Nozzle Supersonic Retropropulsion Configuration

Turbulence Modeling:

- **Comparison of full-domain RANS using SA-NEG-RC-QCR2000 and DES-DDESMod1 w/ SA-NEG-RC-QCR2000**



Mach contour for C_T = 2.5, α = 0º using RANS w/ Spalart-Allmaras

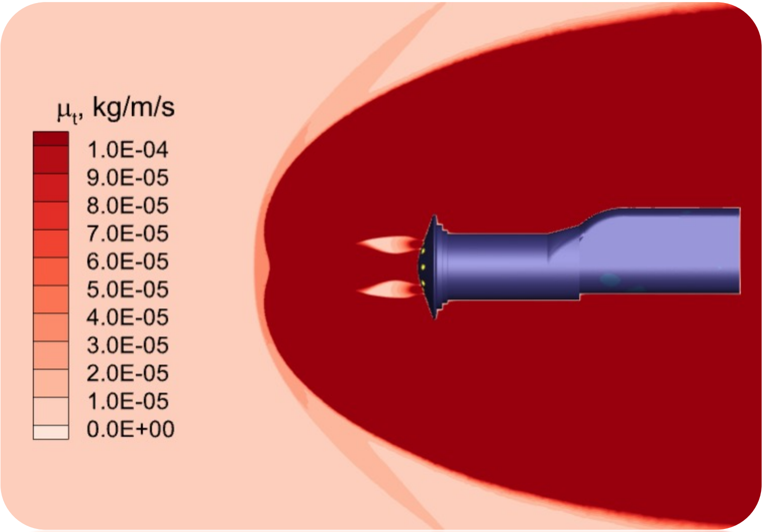


Mach contour for C_T = 2.5, α = 0º using DES w/ Spalart-Allmaras near-wall

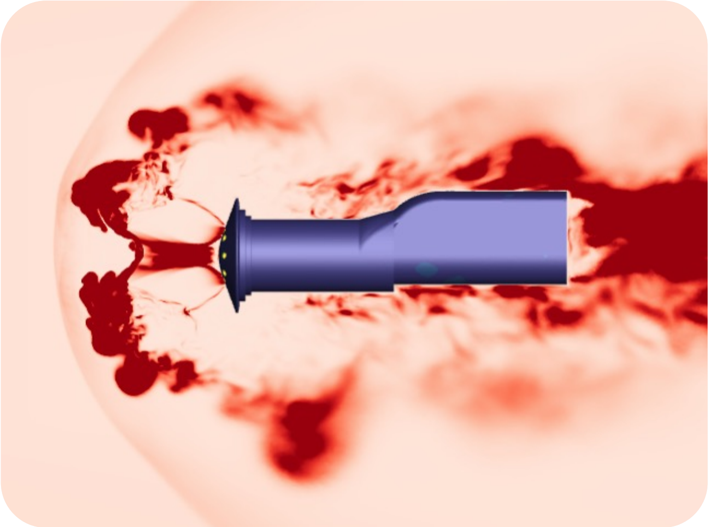
Computational Analysis of a Multiple-Nozzle Supersonic Retropropulsion Configuration

Turbulence Modeling:

- **See full paper for derivation of viscosity growth in RANS solution**



Eddy viscosity contour for C_T = 2.5, α = 0º using RANS w/ Spalart-Allmaras

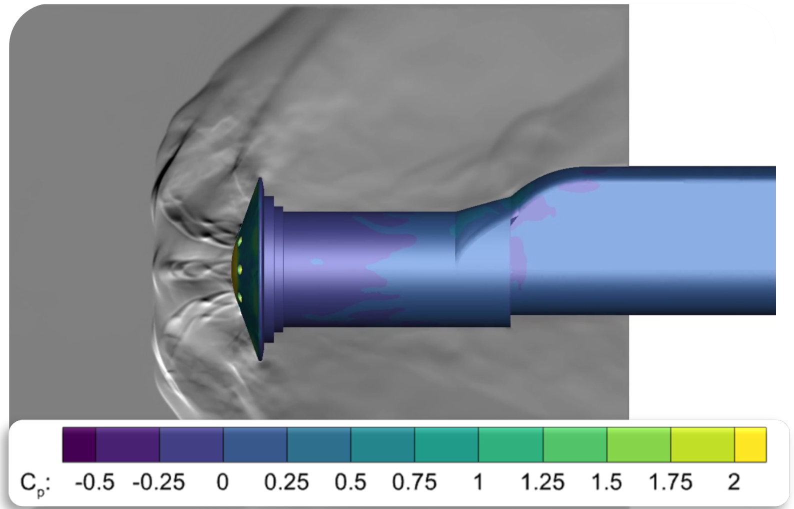


Eddy viscosity contour for C_T = 2.5, α = 0º using DES w/ Spalart-Allmaras

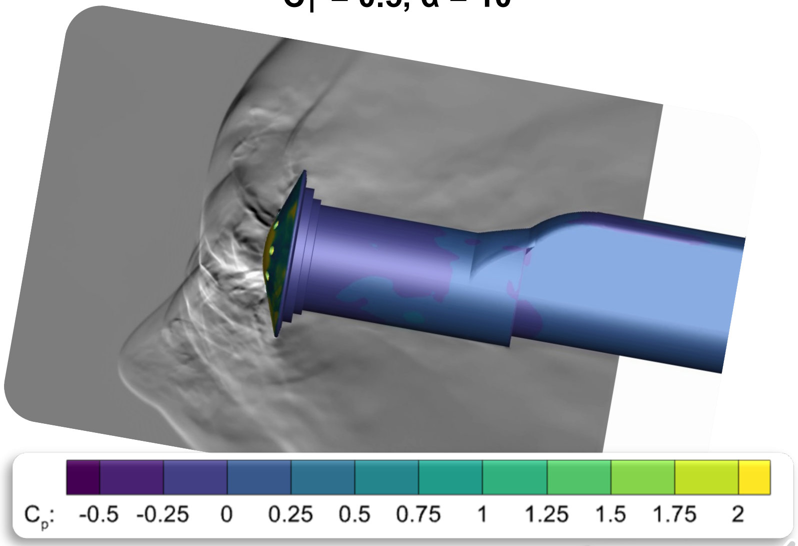
Time Accurate Flow Solutions:

- **Simulated schlieren results for low thrust configuration**

$C_T = 0.5$, $\alpha = 0^\circ$



$C_T = 0.5$, $\alpha = 10^\circ$

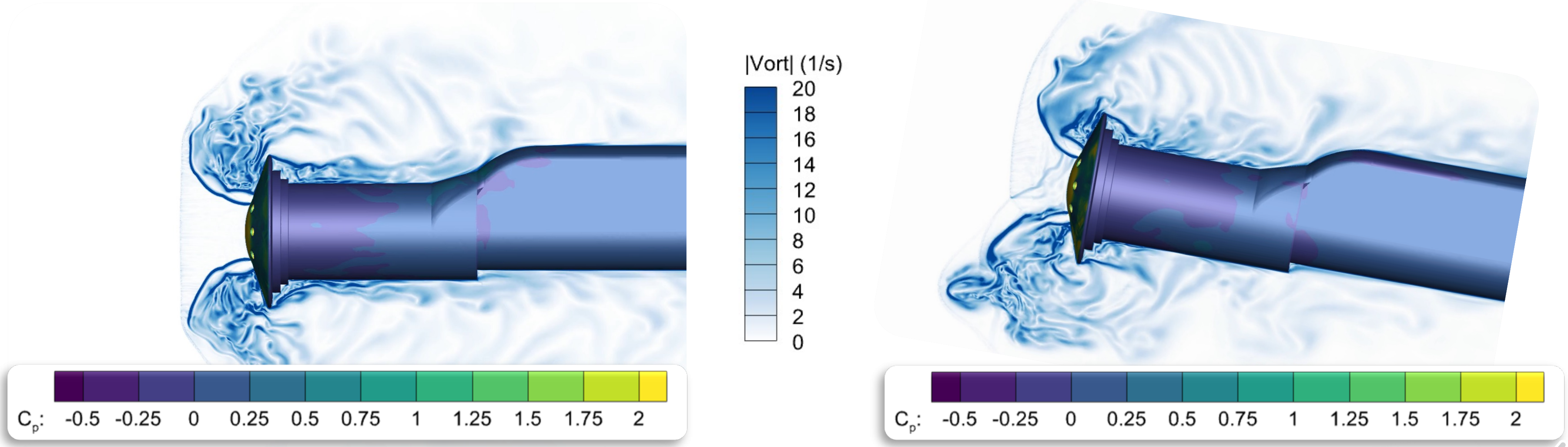


Computational Analysis of a Multiple-Nozzle Supersonic Retropropulsion Configuration

Time Accurate Flow Solutions:

- **Simulated vorticity magnitude results for low thrust configuration**

C_T = 0.5, α = 0º **C_T = 0.5, α = 10º**

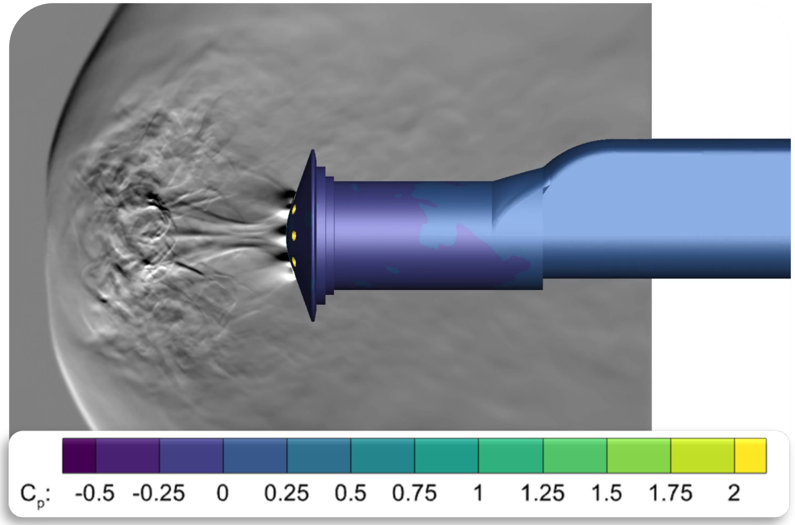


Computational Analysis of a Multiple-Nozzle Supersonic Retropropulsion Configuration

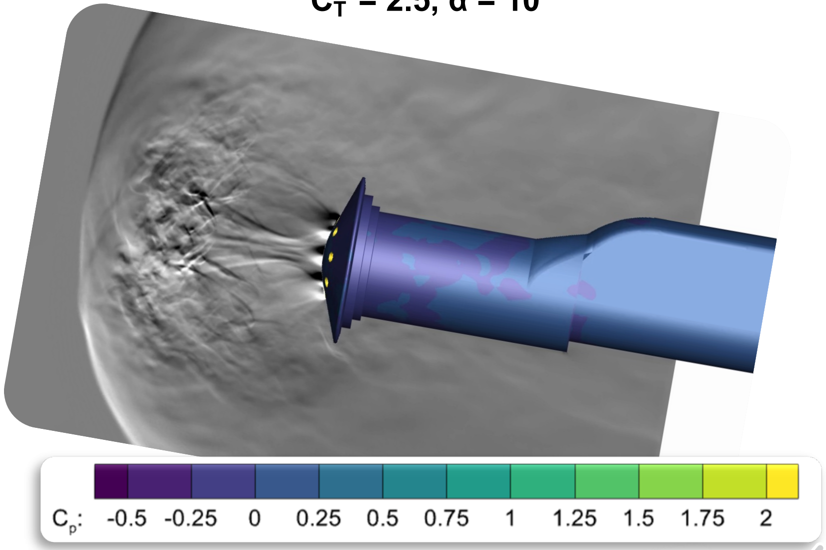
Time Accurate Flow Solutions:

- **Simulated schlieren results for high thrust configuration**

C_T = 2.5, α = 0º

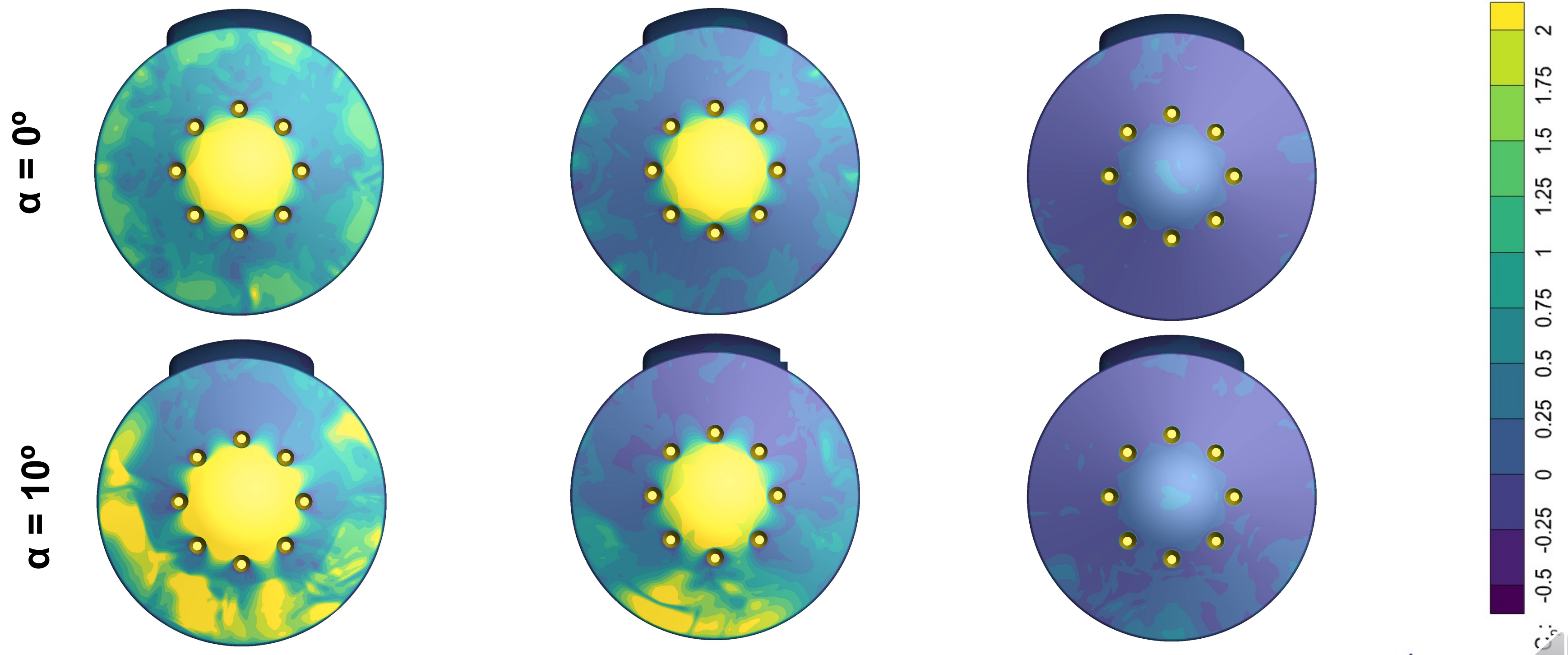


C_T = 2.5, α = 10º



Computational Analysis of a Multiple-Nozzle Supersonic Retropropulsion Configuration

Time History Forebody Forces:



$C_T = 0.5$ $C_T = 1.0$ $C_T = 2.5$

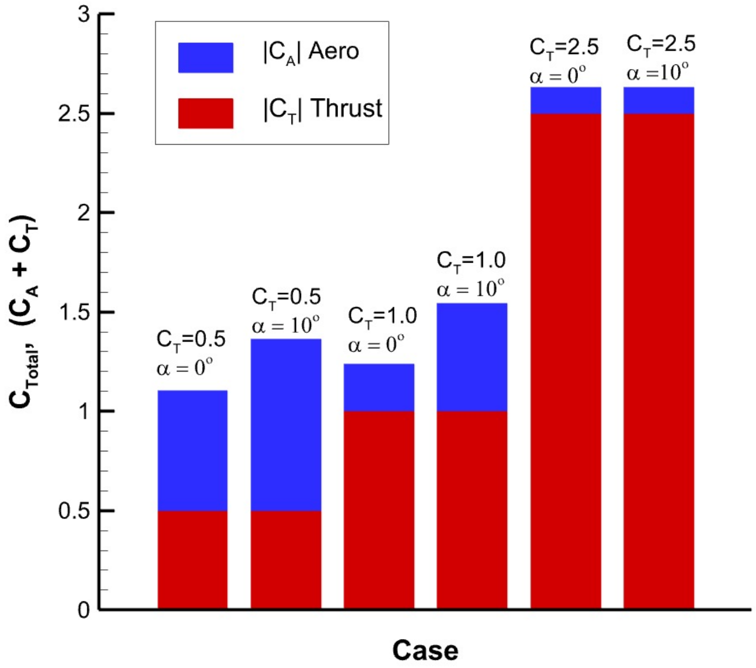
Computational Analysis of a Multiple-Nozzle Supersonic Retropropulsion Configuration

Conclusions:

- Use of hybrid DES approach necessary to capture time-accurate solutions
- Aero interference increases as C_T is reduced
- Turbulent, unsteady flow appears quasi-periodic

Future Work:

- 2021 SRP Tunnel Test to generate validation data
- Further investigation into turbulence modeling and code calibration
- Extrapolation to Mars atmospheric flight and full-combustion SRP



AMERICAN INSTITUTE OF
AERONAUTICS AND ASTRONAUTICS