

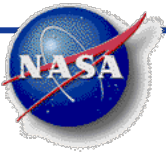
USM3D-ME Analyses Performed in Support of a Wind Tunnel Test of a Boundary-Layer Ingestion Configuration

Michael D. Bozeman Jr.

NASA Langley Research Center, Hampton, VA

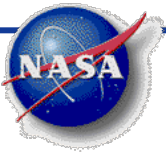
2024 AIAA Aviation Conference

July 31, 2024

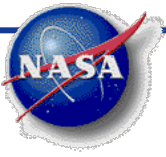


Outline

- **Introduction**
- **National Transonic Facility (NTF) Wind Tunnel Test**
 - Experimental Setup
- **Methods**
 - USM3D-ME Flow Solver
 - Grid Generation
- **Results**
 - Grid Refinement Study
 - NTF Condition Sweeps
- **Summary and Conclusions**



INTRODUCTION



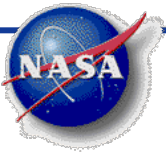
Introduction

- **Boundary Layer Ingestion (BLI) technology offers potential fuel burn reduction resulting from lower momentum flow ingested by the propulsor**
- **NASA is currently investigating the BLI technology with the goal of quantifying the potential benefit offered by this technology**
- **As a first step, a wind tunnel test was performed in the National Transonic Facility (NTF) to:**
 - Investigate the flow ingested by an aft-mounted propulsor configuration
 - Provide a database to enable validation of our computational tools
- **This work focuses on comparisons of USM3D-ME solutions to the experimental data obtained from the NTF wind tunnel test of an aft-mounted propulsor configuration**

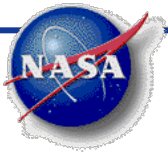
Single Aisle Turboelectric Aircraft Concept
with Aft Boundary-Layer Ingestion
(STARC-ABL)*



*Welstead, J. R. and Felder, J. L., “Conceptual Design of a Single-Aisle Turboelectric Commercial Transport with Fuselage Boundary Layer Ingestion,” 54th AIAA Aerospace Sciences Meeting, AIAA 2016-1027, 2016. doi:10.2514/6.2016-1027.



NTF WIND TUNNEL TEST



CRM-TCT Model

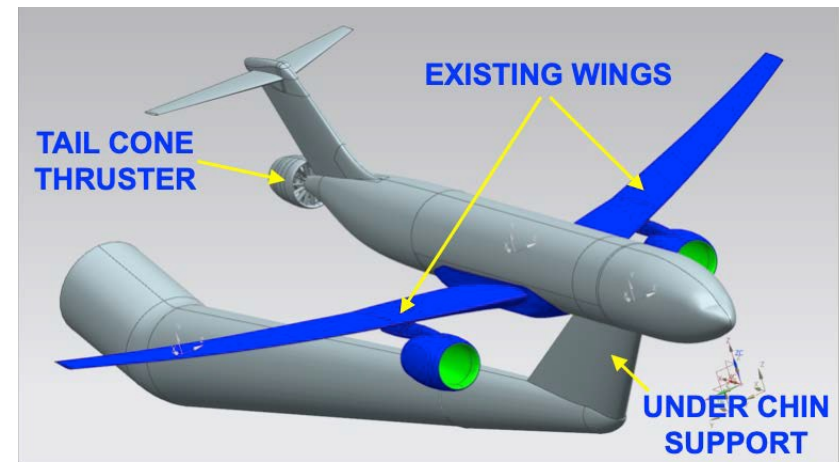
- **Common Research Model with Tail Cone Thruster (CRM-TCT)**

- Variant of CRM with an aft-mounted nacelle
- Representative of the STARC-ABL concept

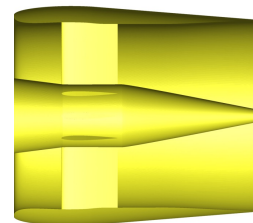
- **CRM modifications include:**

- Flow-through nacelle with mass flow plugs (MFPs) to vary mass flow rate
- 4" extension added to CRM fuselage to accommodate under chin support
- Empennage from Transonic Truss-Braced Wing (TTBW) concept utilized to accommodate tail cone thruster
- Clean configuration (no tail cone thruster) also investigated

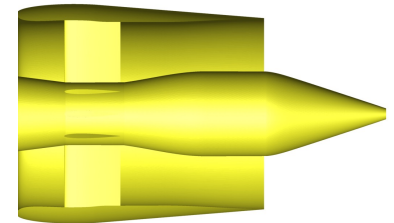
- **Modular nacelle assembly including four MFP variations**



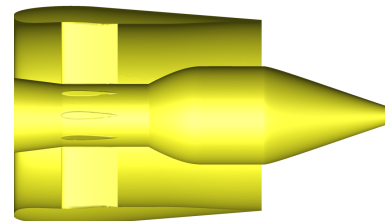
90% Cruise MFP



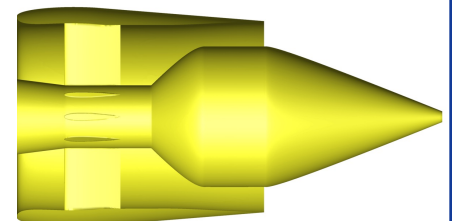
Cruise MFP

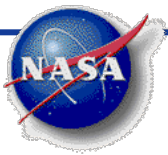


110% Cruise MFP



Idle MFP

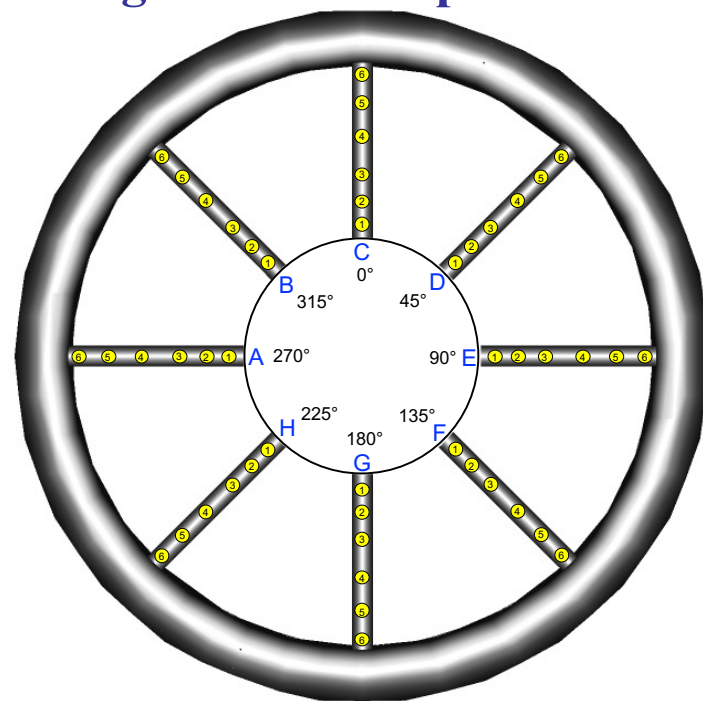




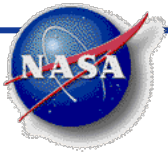
48-probe AIP Rake

- **Aerodynamic Interface Plane (AIP), located at the nacelle highlight, instrumented with total pressure probes**
- **Primary AIP rake included eight struts and 48 probes**
 - Other rakes investigated include a six-strut rake with 27 probes, and a 5-hole probe rake
- **AIP rakes rotated in experiment to provide high-resolution pressure data**
 - Rakes rotated by 45 degrees in 2.5 increments
- **More details found in Chan***

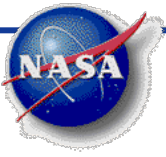
Probe	Radius (in.)	Normalized Radius (r/R)
1	0.747	0.4527
2	0.872	0.5285
3	1.024	0.6206
4	1.241	0.7521
5	1.425	0.8636
6	1.588	0.9624



*Chan, D. T., Jones, G. S., Langston, S. L., and Kwok, A. K., “Experimental Investigation of a Boundary Layer Ingesting Tailcone Thruster Configuration at the National Transonic Facility,” AIAA Aviation 2024 Forum, 2024.



METHODS



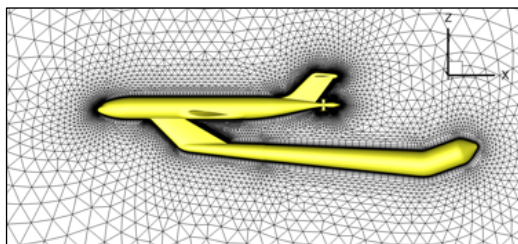
USM3D-ME Flow Solver

- **Mixed-element USM3D (USM3D-ME) is a 3D, unstructured flow solver developed at the NASA Langley Research Center**
 - Cell-centered, finite volume Reynolds-averaged Navier-Stokes (RANS) solver
 - Allows for variety of element types including tetrahedral, prismatic, hexahedral, and pyramidal elements
- **Variety of inviscid flux schemes and flux limiters available**
 - Roe scheme with no limiting employed for this work
- **Turbulence closure options include variations of Spalart-Allmaras model**
 - One equation Spalart-Allmaras model with negative provisions, rotation correction, and Quadratic Constitutive Relation (SA-neg-R-QCR) selected as baseline model for this work
 - Turbulence model study additionally considered the SA model with negative provisions without correction (SA-neg) and with the rotation correction (SA-neg-R)
- **Hierarchical Nonlinear Iteration Method (HANIM) employed for improved robustness**
- **Simulations performed steady-state**

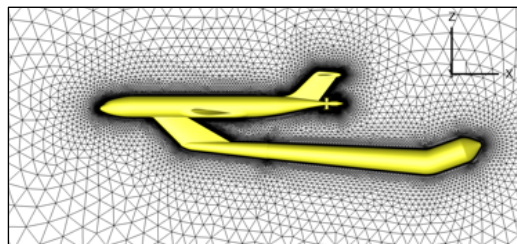
Grid Generation

- Mixed-element grids generated using HeldenMesh™
- HeldenMesh™ refinement factor, h , varied to provide $\sim 3\times$ increase in cells between grid levels

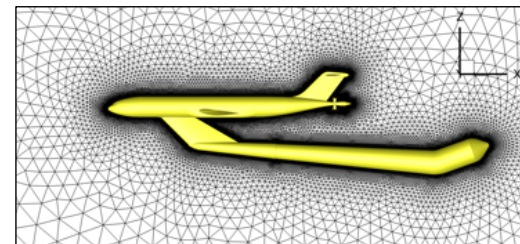
	h	y^+	Cells (million)
Coarse	1.00	1.00	35.3
Medium	0.44	0.44	94.1
Fine	0.20	0.20	281.7



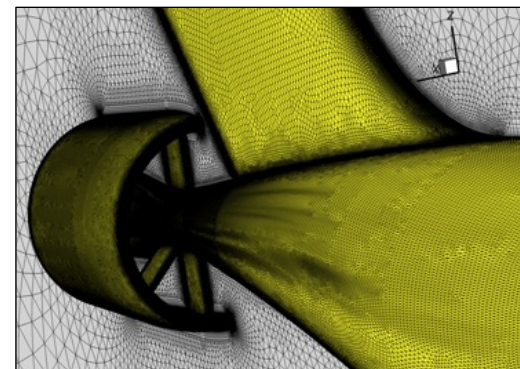
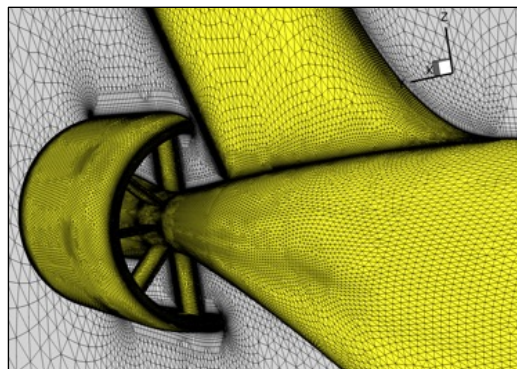
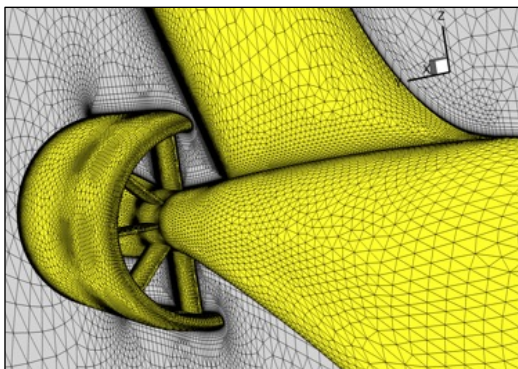
Coarse

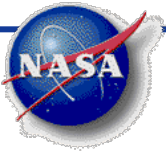


Medium

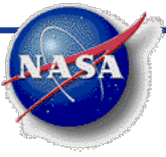


Fine



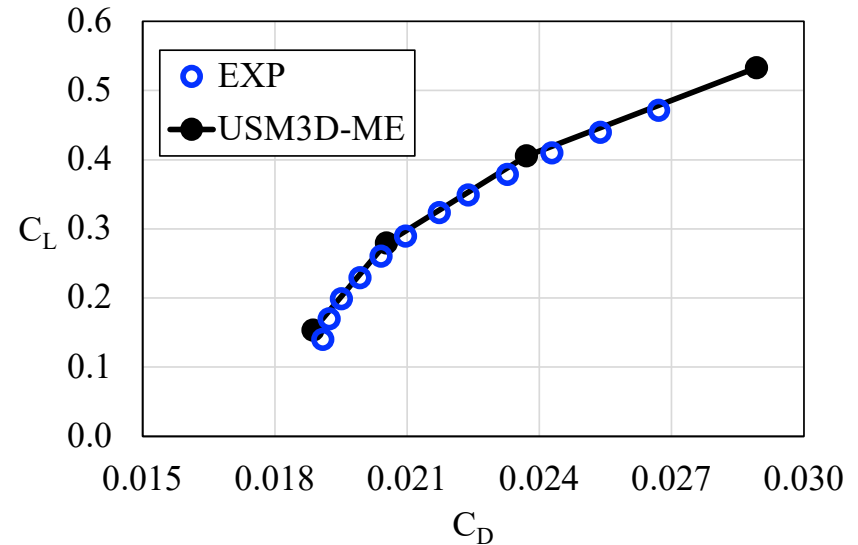
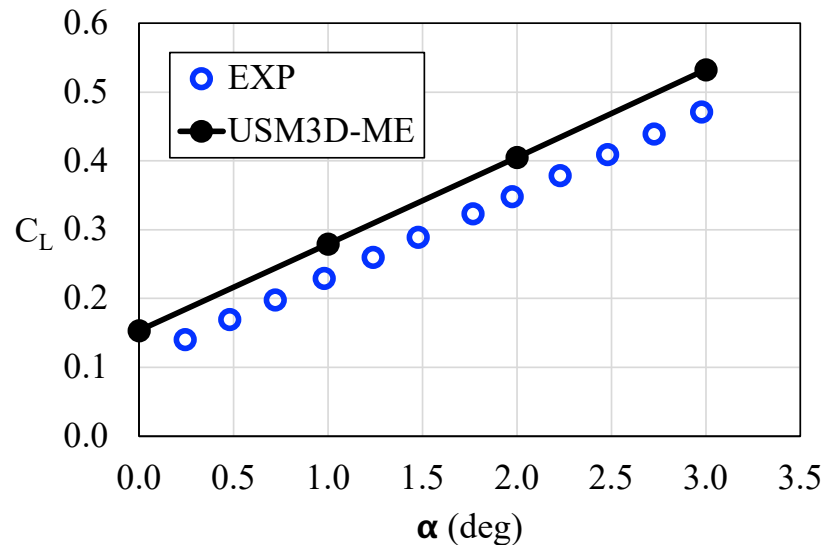


RESULTS

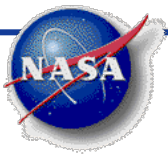


Grid Refinement Study

- Grid refinement study performed for Cruise MFP and Clean configurations at $Re_{MAC} = 5$ million, $Mach = 0.8$, and $\alpha = 2^\circ$
- Preliminary force and moment comparisons illustrated a shift in α between the experiment and CFD
- CFD solutions lift-matched to experimental data point to provide consistent comparison

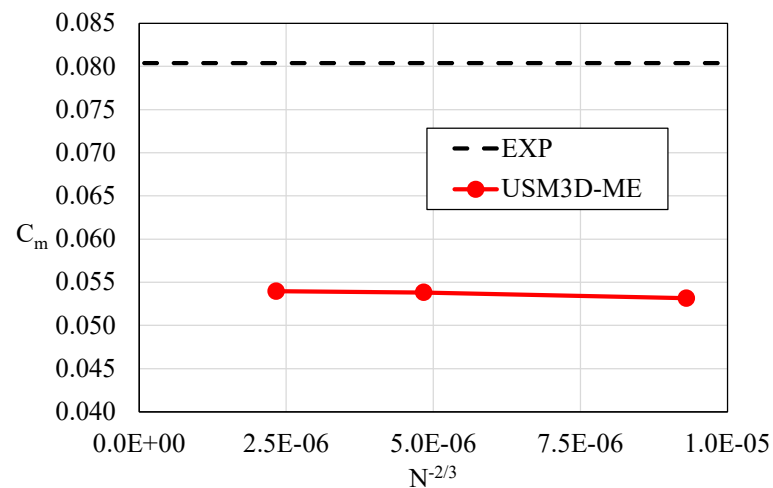
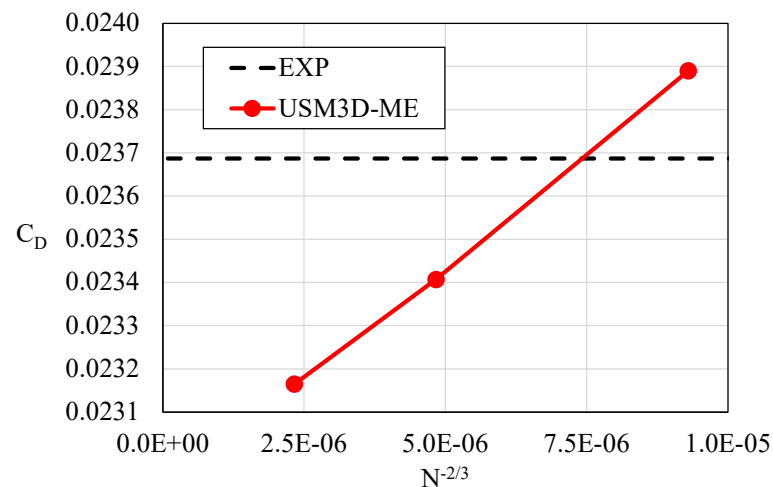
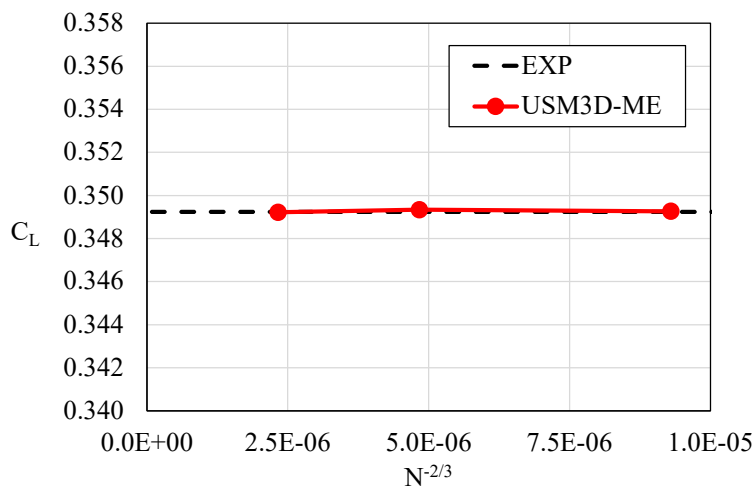


Clean Configuration, $Re_{MAC} = 5$ million, $Mach = 0.8$, Medium Grid

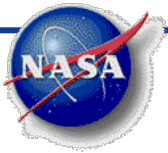


Force and Moment Coefficients

- All remaining results provided for Cruise MFP configuration
- C_L results illustrate successful lift-matching with experiment
- Largest differences observed for C_m comparisons
- Only 2 counts difference in C_D for medium and fine grids

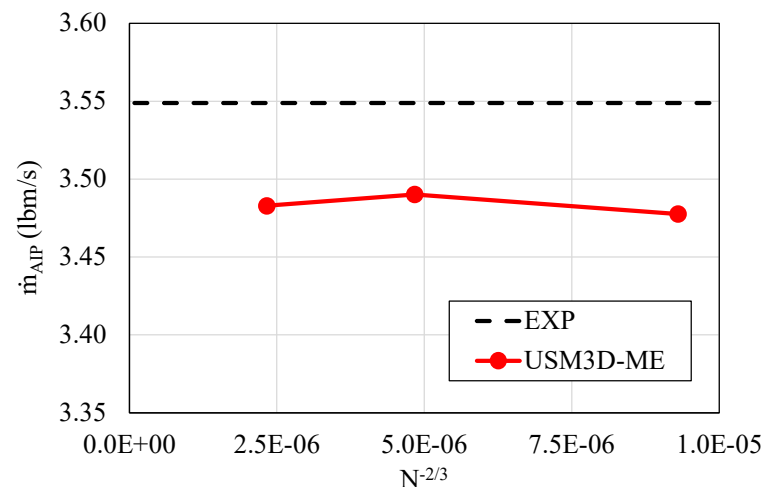
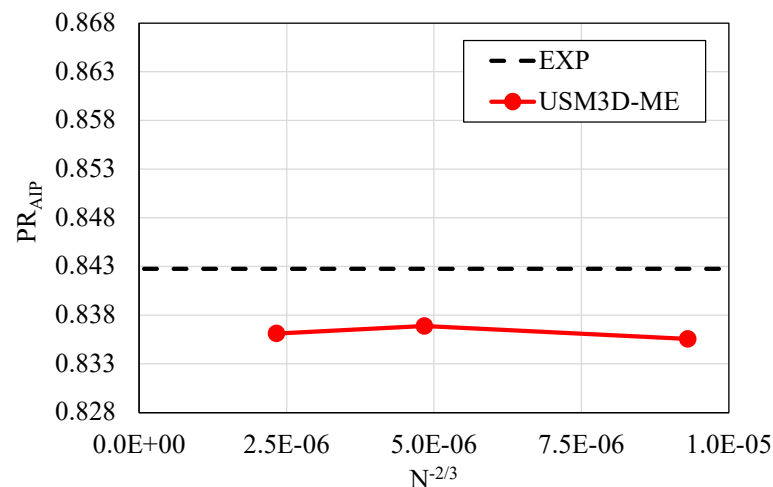
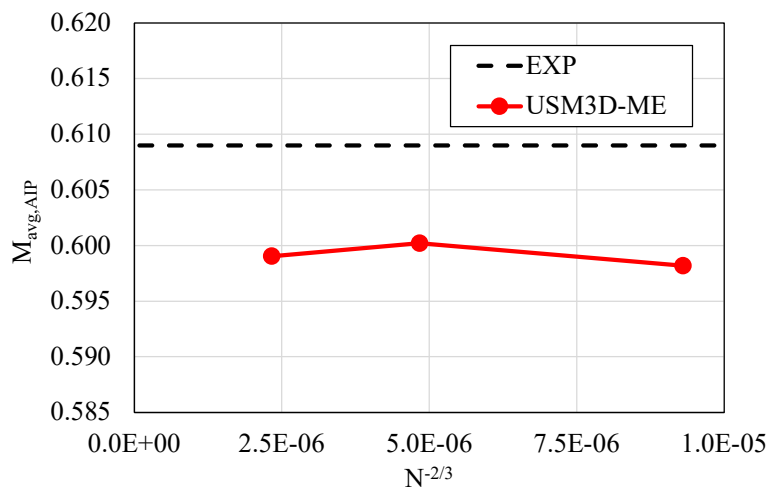


Cruise MFP Configuration, $Re_{MAC} = 5$ million, Mach = 0.8, $C_L = 0.349$

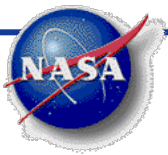


AIP Quantities

- Comparisons at AIP illustrate non-monotonic trends with increasing grid refinement
- USM3D-ME predictions within 2% of experimental data
- Small differences observed between medium and fine grids

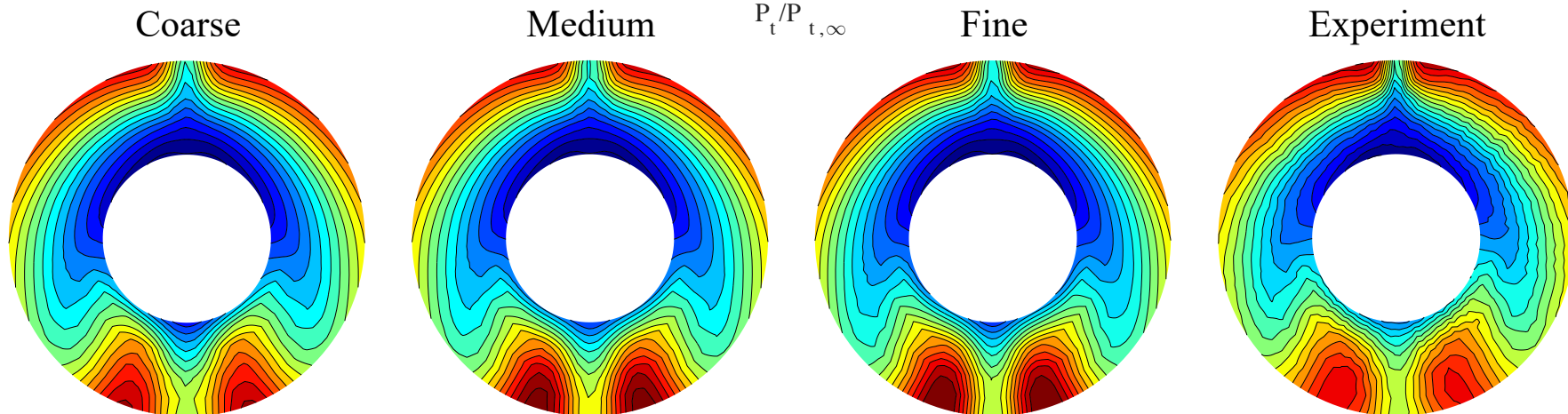
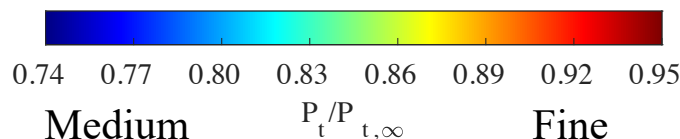
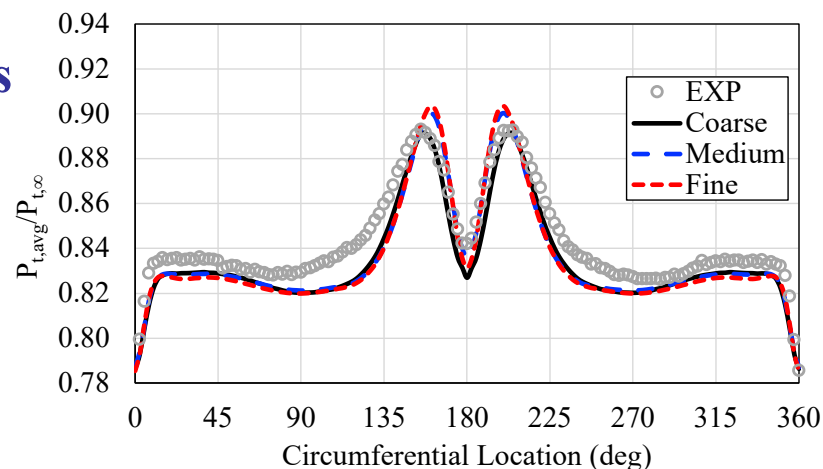


Cruise MFP Configuration, $Re_{MAC} = 5$ million, Mach = 0.8, $C_L = 0.349$

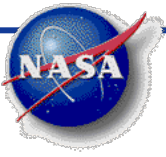


Total Pressure at the AIP

- Predicted total pressure distributions at AIP in good agreement with experiment
- Minor differences observed between medium and fine grids
- Medium grid selected for NTF condition sweeps



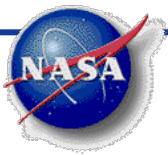
Cruise MFP Configuration, $Re_{MAC} = 5$ million, $Mach = 0.8$, $C_L = 0.349$



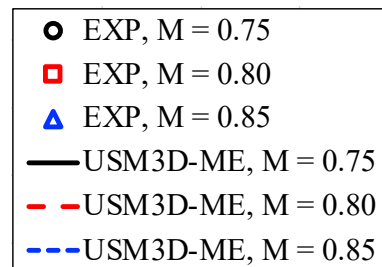
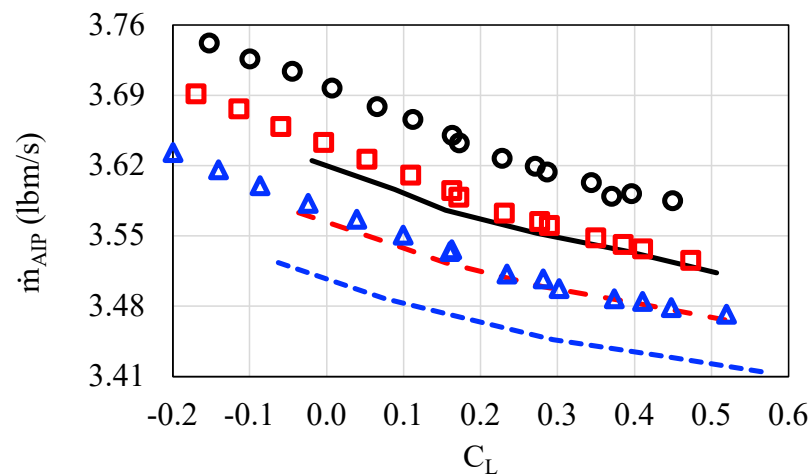
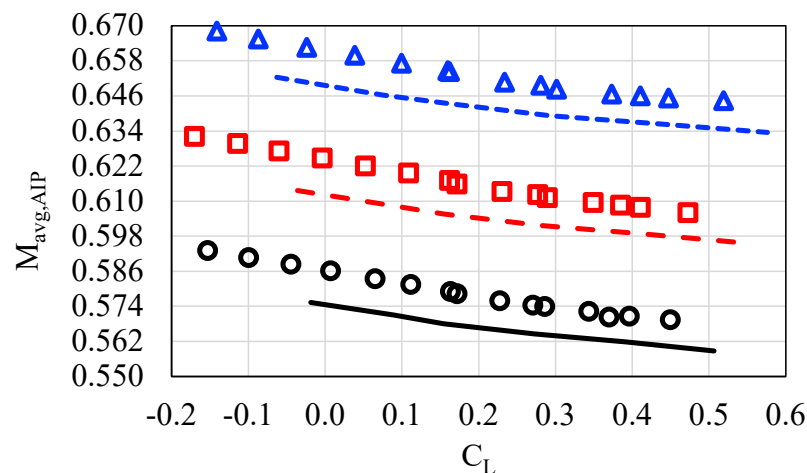
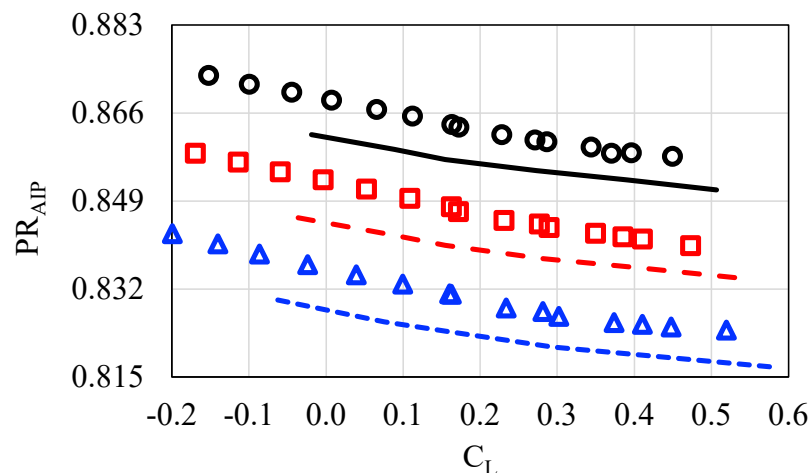
NTF Condition Sweeps

Re_{MAC} (million)	T_t (°F)	Mach	α (deg)
5	120	0.75, 0.80, 0.85	-3° to 3°
10	-50	0.75, 0.80, 0.85	0.5° to 3°
15	-120	0.75, 0.80, 0.85	0.5° to 3°

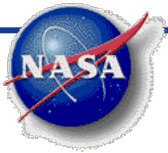
- **Horizontal stabilizer removed for negative angles of attack to prevent over-ranging balance**
- **NTF ran in cryogenic mode, utilizing Nitrogen, to achieve $Re_{MAC} = 10$ and 15 million**
 - USM3D-ME currently only allows for air mode
 - All calculated quantities from the experiment (Mach number and mass flow rate) assume air to provide consistent comparison with experiment
- **Comparisons of Pressure Recovery, Mach, and Mass Flow Rate at the AIP provided as a function of lift coefficient due to observed angle of attack shift**



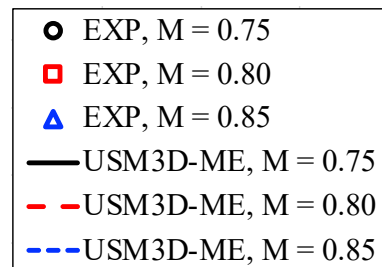
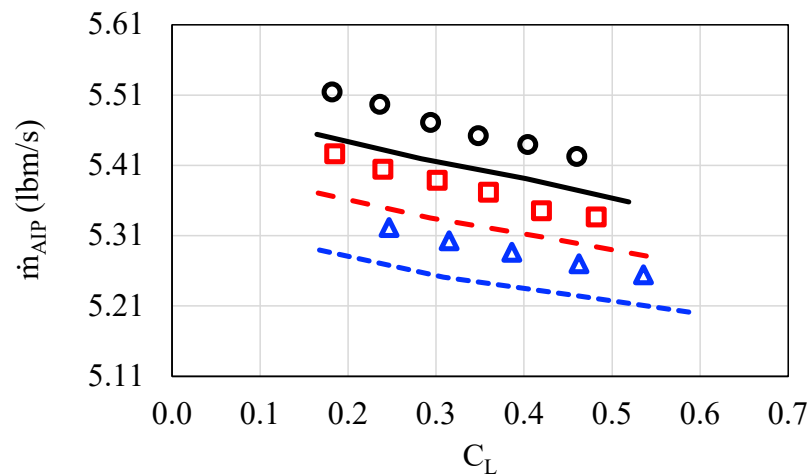
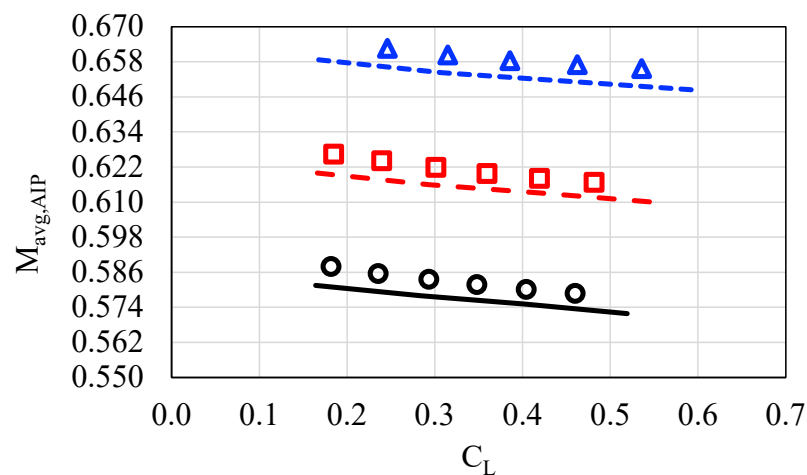
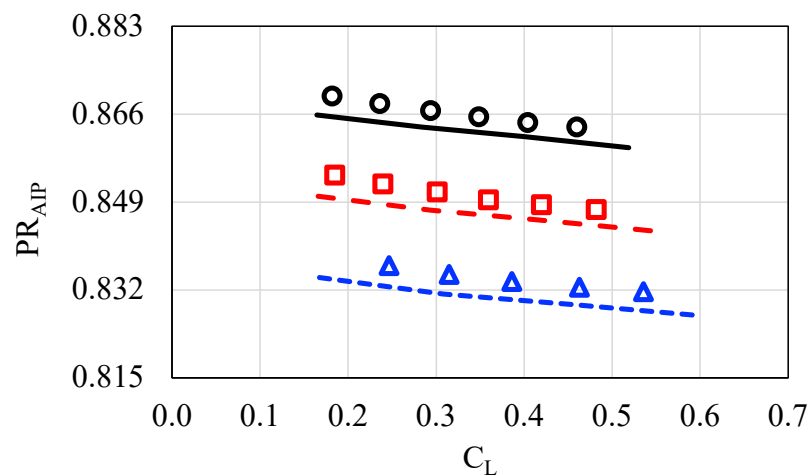
Cruise MFP, $Re_{MAC} = 5$ Million



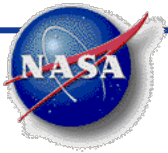
Cruise MFP Configuration, $Re_{MAC} = 5$ million



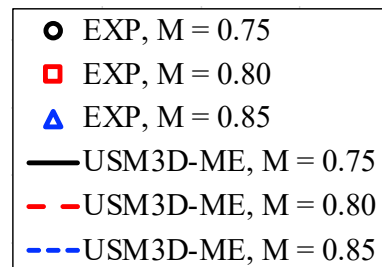
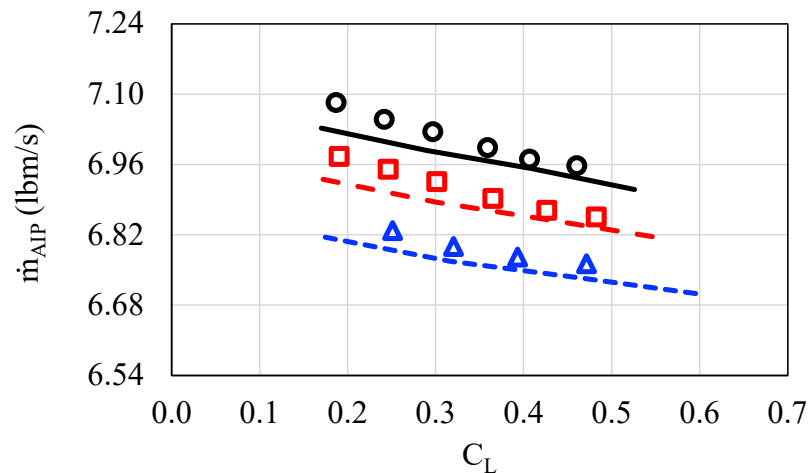
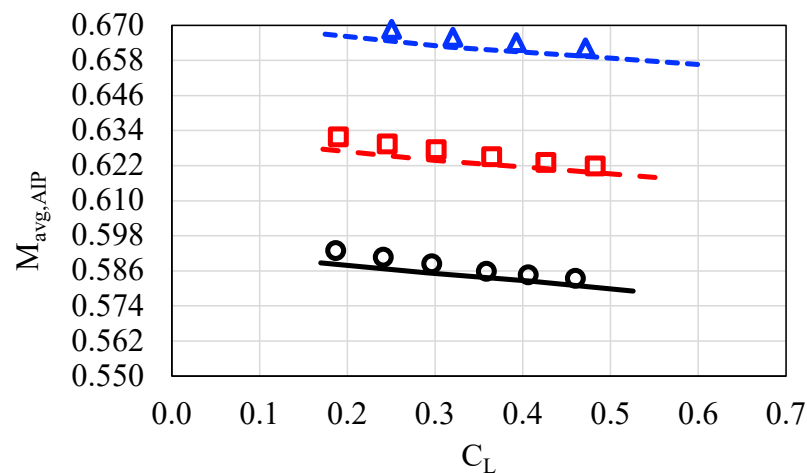
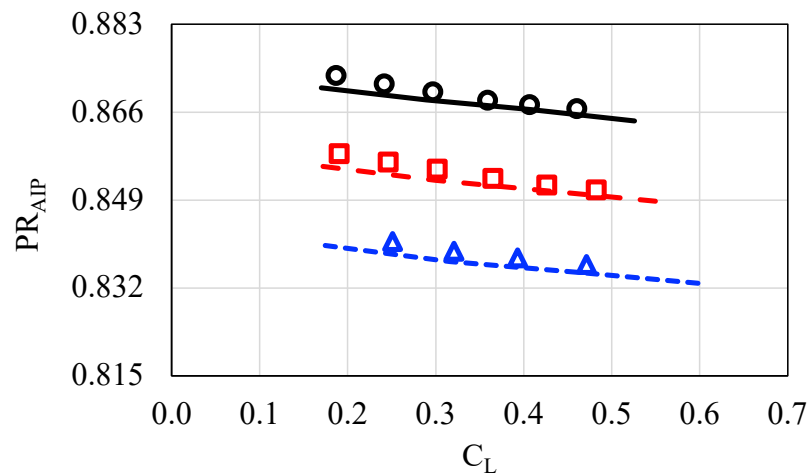
Cruise MFP, $Re_{MAC} = 10$ Million



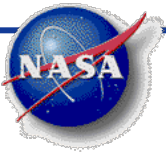
Cruise MFP Configuration, $Re_{MAC} = 10$ million



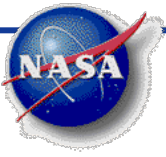
Cruise MFP, $Re_{MAC} = 15$ Million



Cruise MFP Configuration, $Re_{MAC} = 15$ million

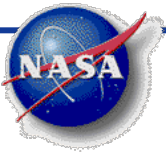


SUMMARY AND CONCLUSIONS



Summary and Conclusions

- **NTF wind tunnel test performed for CRM-TCT model to both investigate the flow ingested by aft-mounted propulsor configuration and provide a database to enable code validation**
- **Grid refinement study performed to assess impact of grid size**
 - Results show that grid convergence not achieved but only small differences observed between two finest grid levels
 - Medium grid selected as best tradeoff between accuracy and computational cost
- **Condition sweeps illustrated tendency for USM3D-ME to underpredict the pressure recovery at the AIP**
 - Pressure recovery differences propagated to Mach number and mass flow rate calculations at the AIP
 - USM3D-ME shown to be within 2% of experimental data for all quantities shown
- **Agreement between USM3D-ME and the experimental data was observed to improve as Reynolds number increased**
- **Overall, the USM3D-ME predicted trends agree favorably with the experimental data**



**Thank you.
Questions?**