

Computational Analysis of a Boundary-Layer Ingesting Tailcone Thruster Configuration Within the National Transonic Facility Using the LAVA Solver

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Overview of the AATT Project

Advanced Air Transport Technology (AATT) Project

Goal Bring forth NASA's vision for sustainable aviation

Focus Development of revolutionary concepts and technologies for fixed wing subsonic transports

Objectives Enable cleaner, quieter, and more efficient aircraft
Address system-level success metrics for aircraft noise, NO_x emissions and fuel consumption
Partition near-term, mid-term and far-term goals

Key Technology: Boundary Layer Ingestion (BLI)

BLI Propulsion Systems

- Key technology currently being explored by the AATT project
- Designed to ingest the boundary layer flow from the aircraft's surface
- Potential to improve fuel efficiency (3–9%)[†] and noise shielding



Type-I BLI example (Credit: NASA)



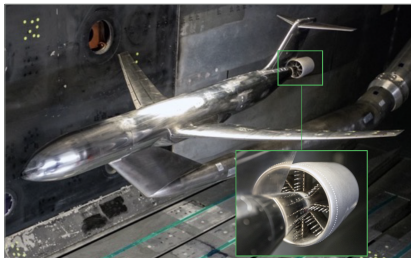
Type-II BLI example (Credit: NASA)

[†] Hardin, L. et al. (AIAA 2012-3993); Ochs, S. et al. (JPP B36114, 2017); Hall, D. et al. (JPP B36321, 2017); Machado, L. et al. (AIAA Aviation, 2024)

BLITS Test in the National Transonic Facility (NTF)

Boundary Layer Ingesting Tailcone System (BLITS) test

- Experimental campaign conducted in the NTF (NASA Langley) in 2023
- Common Research Model with Tailcone Thruster (CRM-TCT) model
- **Goal:** Produce a large dataset for validation of computational tools in the simulation of airframe integrated BLI propulsion systems
- See *Chan, D. et al. (APA-03)* for more info

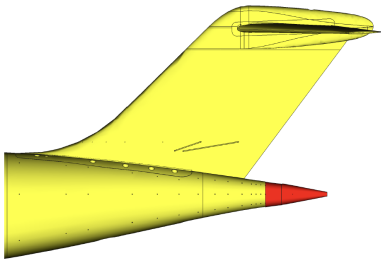


CRM-TCT model in the NTF
(Credit: Chan, D., 2024)

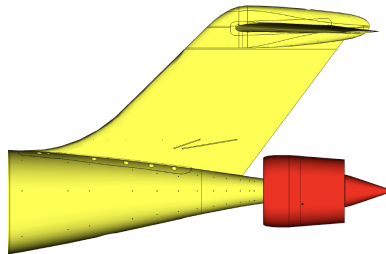
BLITS Test in the National Transonic Facility (NTF)

Variants of the CRM-TCT tested

- *Clean tailcone* and *Flow-through tailcone*



Clean tailcone (Credit: Chan, D., 2024)

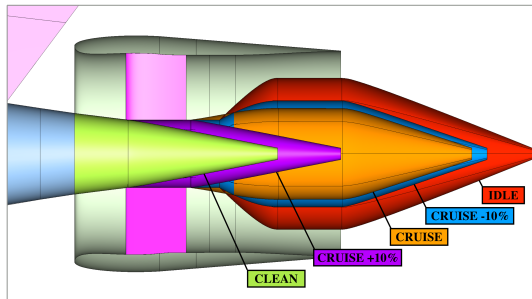


Flow-through tailcone (Credit: Chan, D., 2024)

BLITS Test in the National Transonic Facility (NTF)

Variants of the CRM-TCT tested

- *Clean* tailcone and *Flow-through* tailcone
- Four different mass flow plugs



Flow-through tailcone (Credit: Chan, D., 2024)

BLITS Test in the National Transonic Facility (NTF)

Variants of the CRM-TCT tested

- *Clean* tailcone and *Flow-through* tailcone
- Four different mass flow plugs

Multitude of conditions tested

- Reynolds numbers of 5-, 10- and 15-million
- Mach numbers of 0.75, 0.80 and 0.85
- Angles-of-attack between -3° and $+4^{\circ}$

BLITS Test in the National Transonic Facility (NTF)

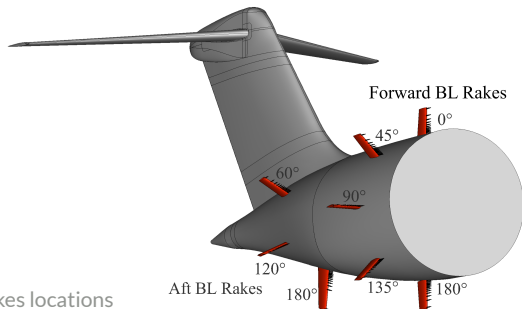
Experimental data gathered

- Model aerodynamic load coefficients

BLITS Test in the National Transonic Facility (NTF)

Experimental data gathered

- Model aerodynamic load coefficients
- Aftbody boundary layer flow characterization



Boundary layer rakes locations

BLITS Test in the National Transonic Facility (NTF)

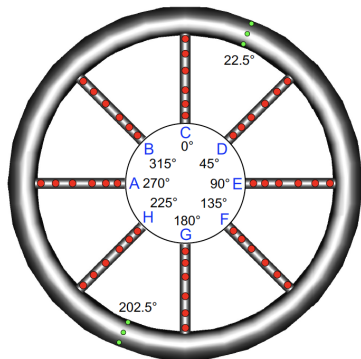
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- Model aerodynamic load coefficients
- Aftbody boundary layer flow characterization
- Nacelle highlight flow characterization

BLITS Test in the National Transonic Facility (NTF)

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- Total pressure distortion using ARP1420 probes

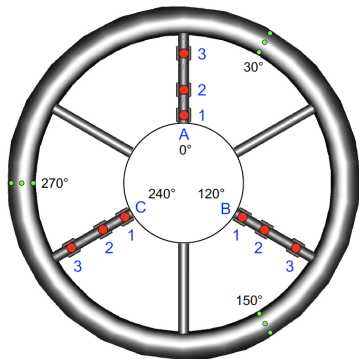


ARP1420 probe locations
(Credit: Chan, D., 2024)

BLITS Test in the National Transonic Facility (NTF)

Experimental data gathered

- Model aerodynamic load coefficients
- Aftbody boundary layer flow characterization
- Nacelle highlight flow characterization
 - ▶ Total pressure distortion using ARP1420 probes
 - ▶ Flow angles using 5-hole probes



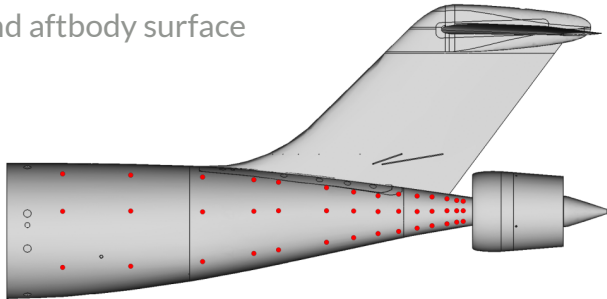
5-hole probe locations
(Credit: Chan, D., 2024)

BLITS Test in the National Transonic Facility (NTF)

Experimental data gathered

- Model aerodynamic load coefficients
- Aftbody boundary layer flow characterization
- Nacelle highlight flow characterization
- Static pressures in wing and aftbody surface

5-hole probe locations
(Credit: Chan, D., 2024)



The goals of this work are to

- Develop best-practices to simulate BLI flows within the LAVA solver framework using steady RANS
 - ▶ Grid refinement study
 - ▶ Turbulence model sensitivity study
- Assess the ability of steady RANS to predict the aftbody flow ingested by the TCT
 - ▶ Under a variety of conditions
 - ▶ Using the experimental data collected for validation

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Modeling the problem

LAVA Launch, Ascent, and Vehicle Aerodynamics

- Several grid paradigms: curvilinear overset, unstructured, cartesian
- Conservative finite-difference formulation of the RANS equations

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- Several grid paradigms: curvilinear overset, unstructured, cartesian
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- Turbulence closure: SA w/ RC and QCR corrections (SA-RC-QCR2000)

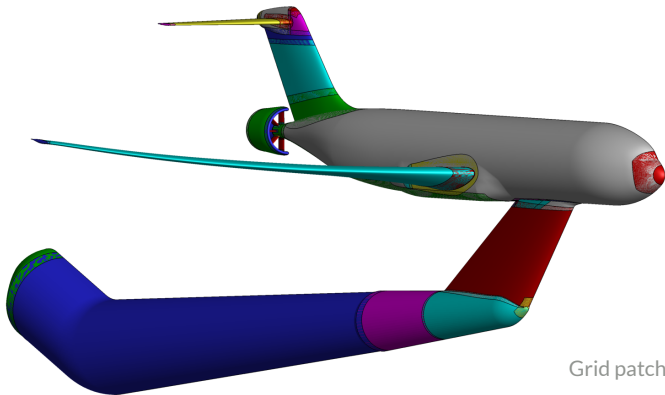
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LAVA Launch, Ascent, and Vehicle Aerodynamics

- Several grid paradigms: curvilinear overset, unstructured, cartesian
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- Convective fluxes
 - ▶ Modified Roe scheme w/ third-order left/right state reconstruction
 - ▶ Koren limiter

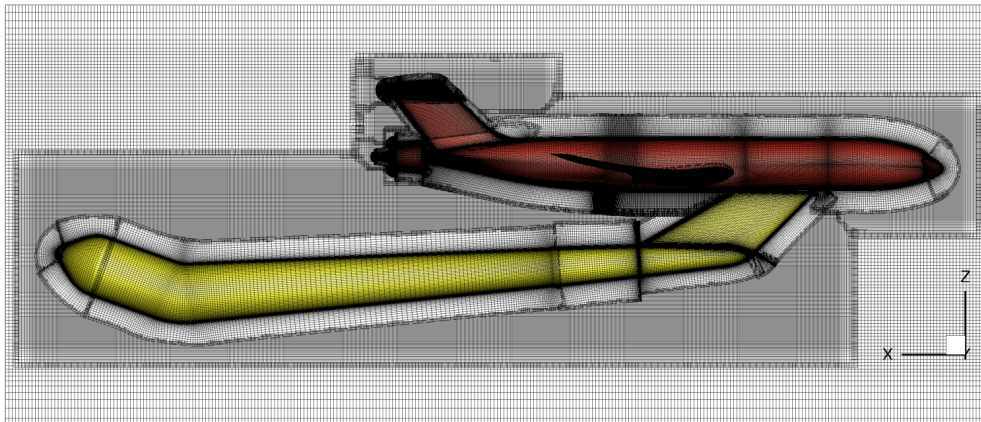
Computational setup

- Half-span model with symmetry BC at $Y = 0[\text{m}]$
- Viscous wall BC applied at model surfaces



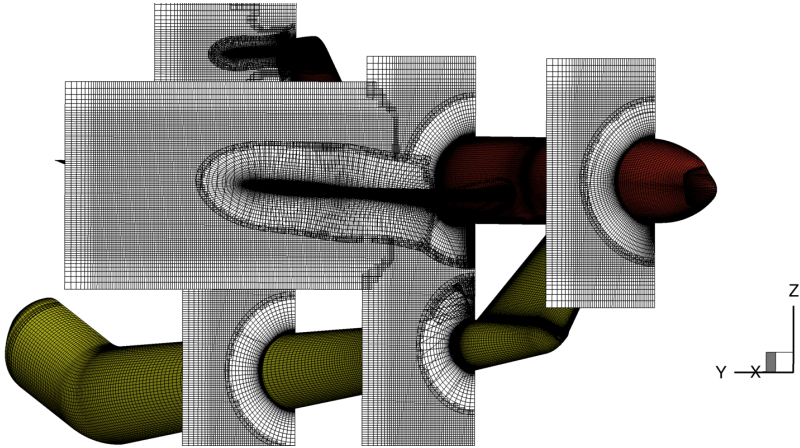
Grid patches overview

Overview of the grid system



Grid slice side view. Configuration: *Flow-through w/ Cruise MFP (w/ sting)*

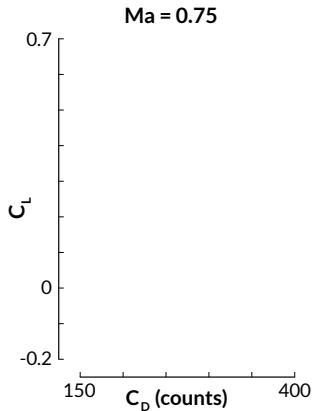
Overview of the grid system



Grid slices. Configuration: *Flow-through w/ Cruise MFP (w/ sting)*

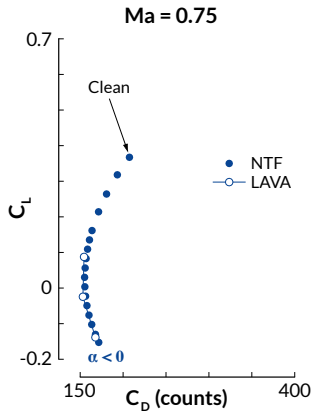
Results - Load coefficients

Re = 5-million



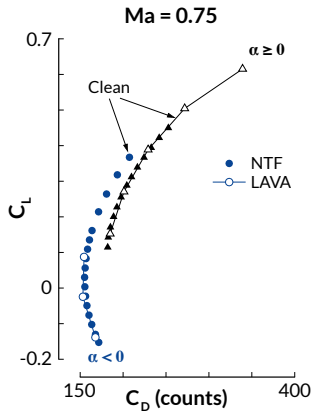
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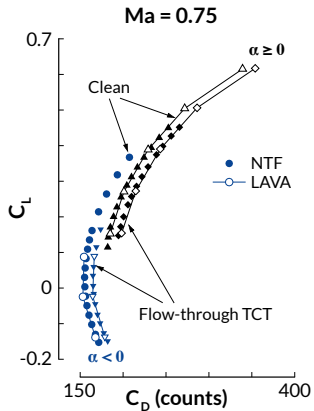
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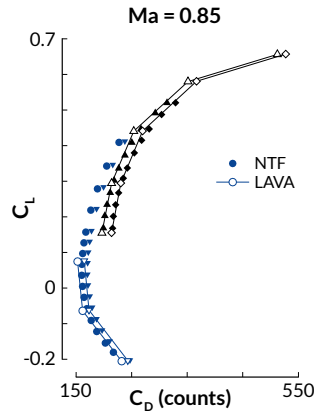
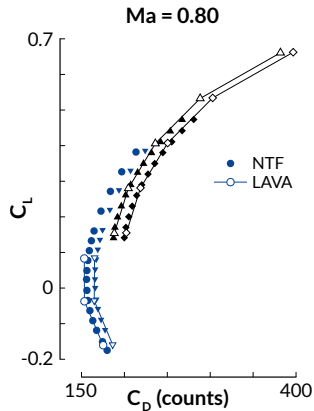
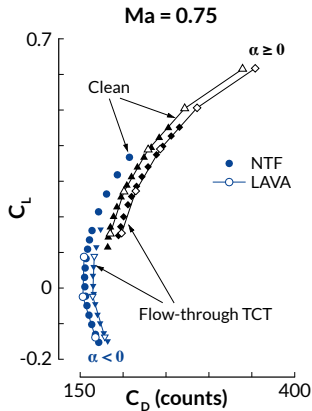
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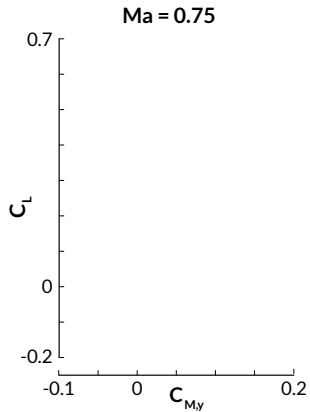
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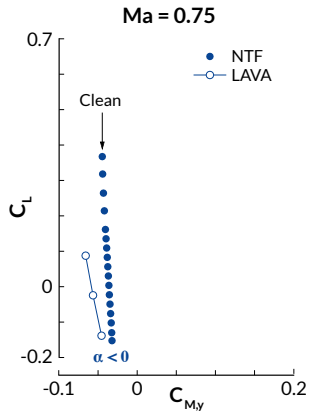
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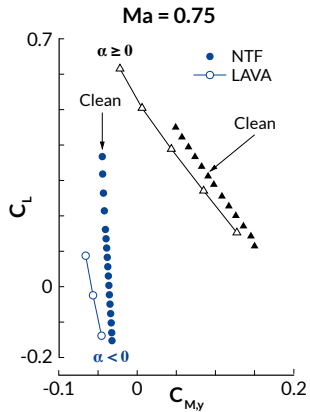
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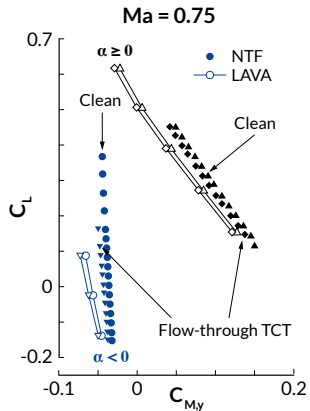
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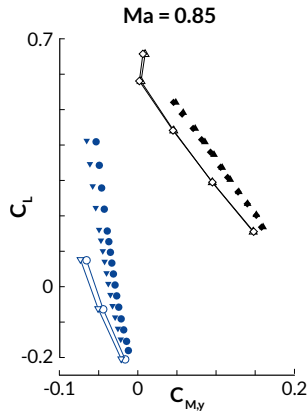
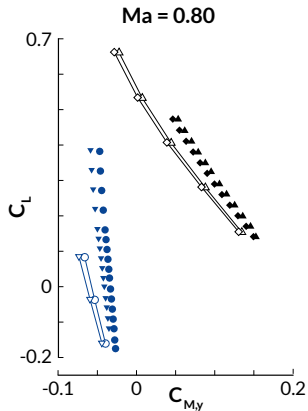
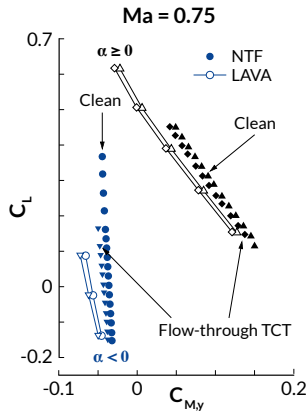
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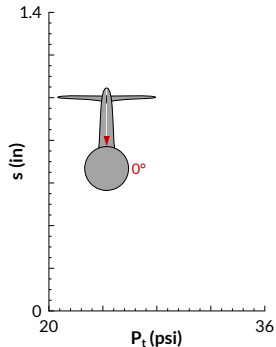
Re = 5-million



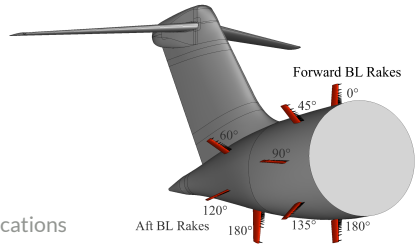
Results - Boundary layer rakes

$Re = 5\text{-million}$, $Ma = 0.85$

Front rakes



Boundary layer rakes locations

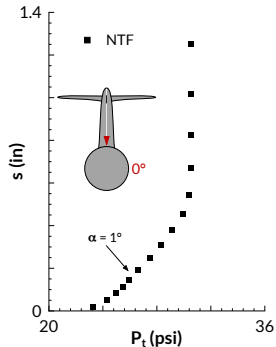
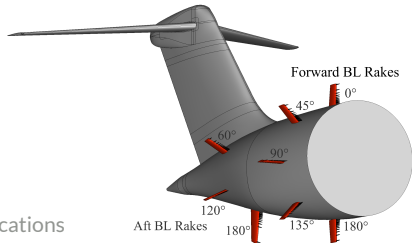


Results - Boundary layer rakes

$Re = 5\text{-million}$, $Ma = 0.85$, $\alpha = 1^\circ$

Front rakes

Boundary layer rakes locations

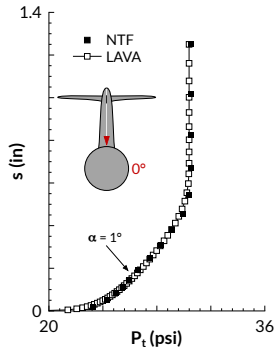
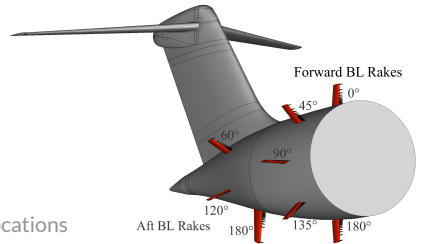


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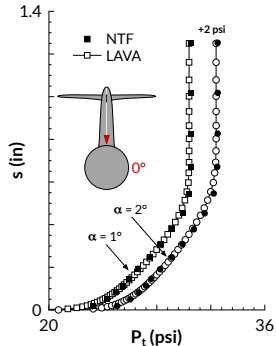
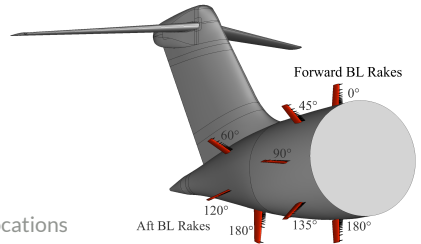


Results - Boundary layer rakes

$Re = 5\text{-million}$, $Ma = 0.85$, $\alpha = 1^\circ, 2^\circ$

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Boundary layer rakes locations

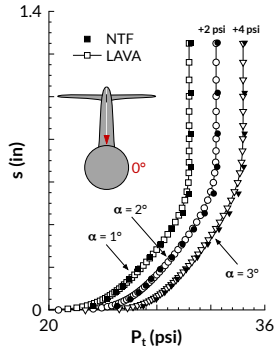
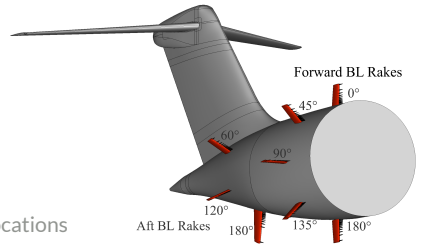


Results - Boundary layer rakes

$Re = 5\text{-million}$, $Ma = 0.85$, $\alpha = 1^\circ, 2^\circ, 3^\circ$

Front rakes

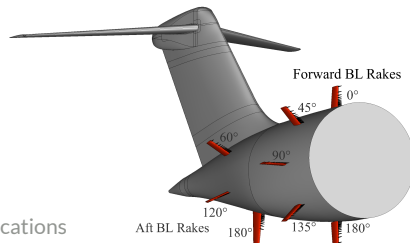
Boundary layer rakes locations



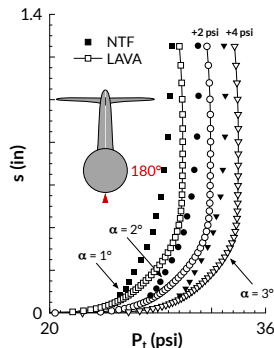
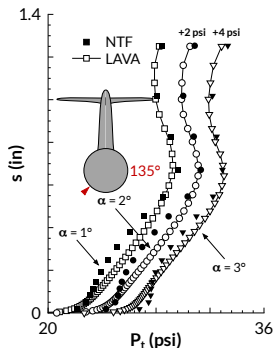
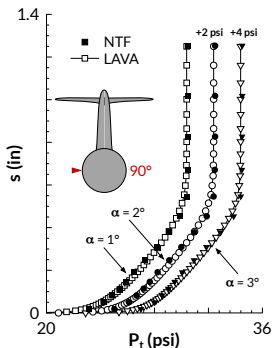
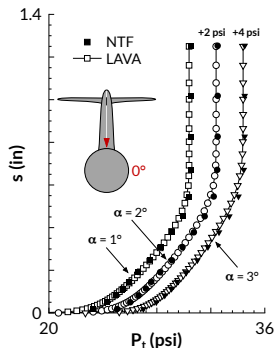
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Boundary layer rakes locations

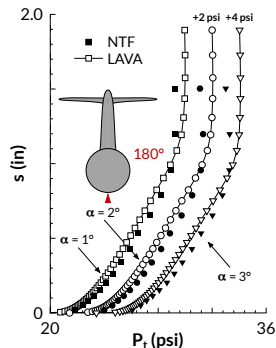
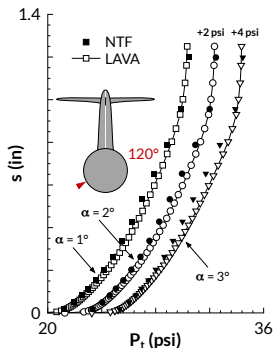
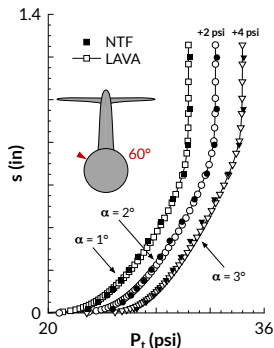
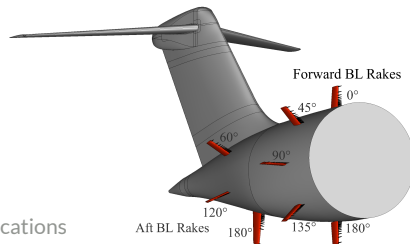


Results - Boundary layer rakes

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Aft rakes

Boundary layer rakes locations

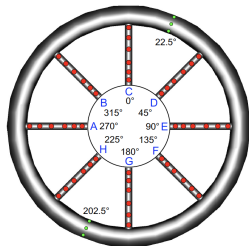


Results - Nacelle highlight total pressure distortion

$Re = 5\text{-million}, Ma = 0.75, \alpha = 2^\circ$

Pressure Recovery = $\frac{P_t}{P_{t,\infty}}$

ARP1420 probe locations
(Credit: Chan, D., 2024)

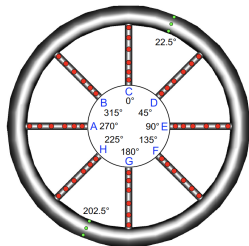
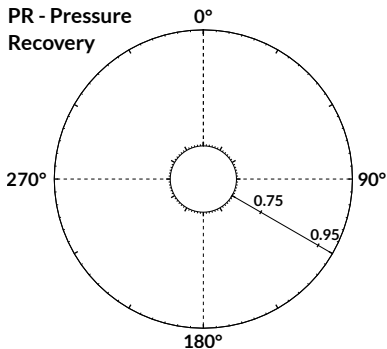


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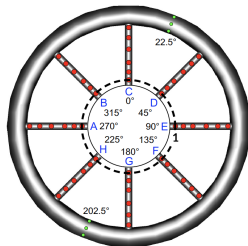
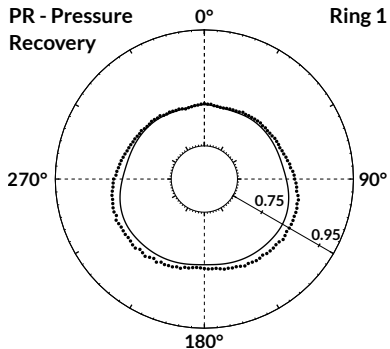


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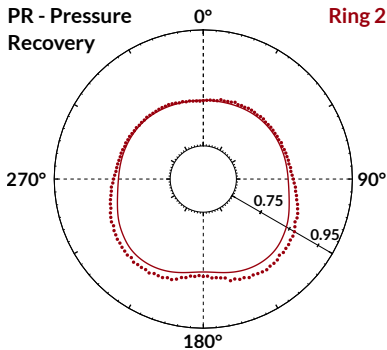
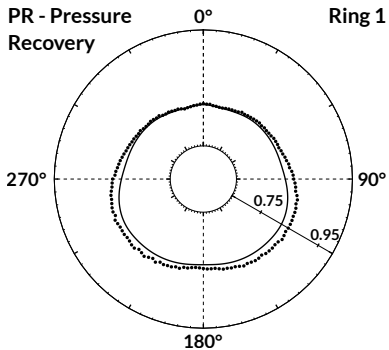
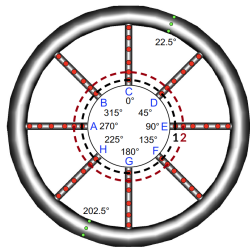


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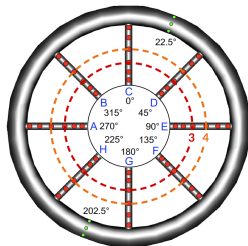


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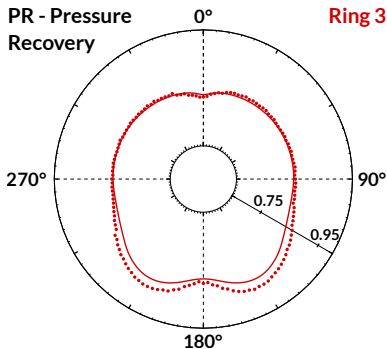
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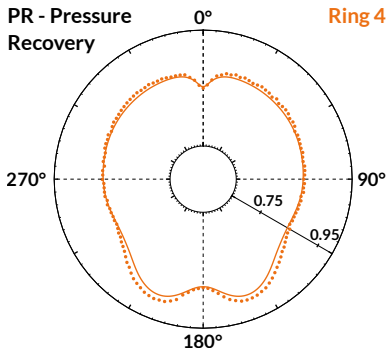
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PR - Pressure
Recovery



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Recovery

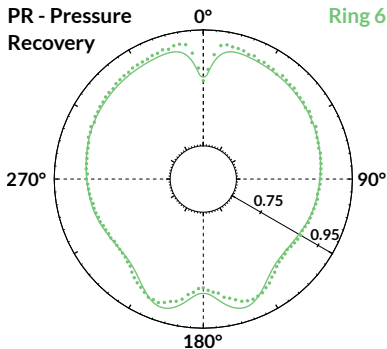
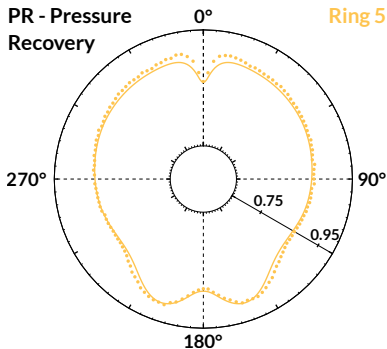
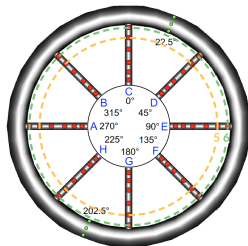


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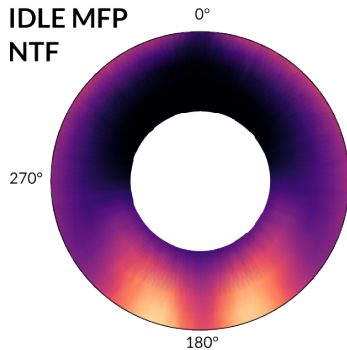
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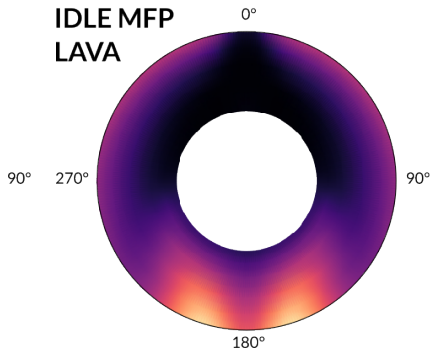
Mass flow plug (MFP) effects

ARP1420 probe locations
(Credit: Chan, D., 2024)

IDLE MFP
NTF



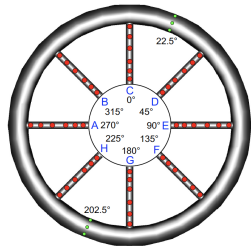
IDLE MFP
LAVA



PR

0.950

0.725



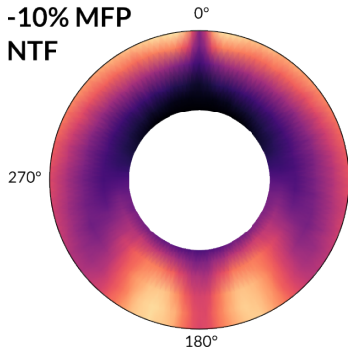
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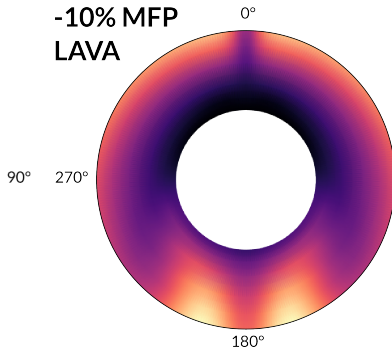
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-10% MFP
NTF



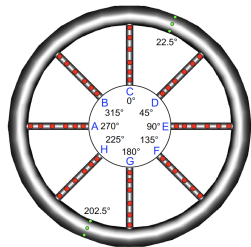
-10% MFP
LAVA



PR

0.950

0.725



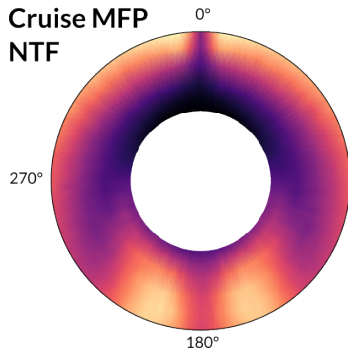
Results - Nacelle highlight total pressure distortion

$Re = 5\text{-million}$, $Ma = 0.85$, $\alpha = 2^\circ$

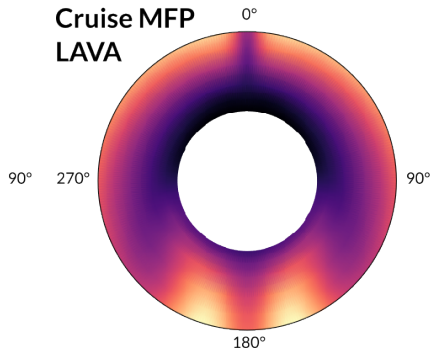
Mass flow plug (MFP) effects

ARP1420 probe locations
(Credit: Chan, D., 2024)

Cruise MFP
NTF



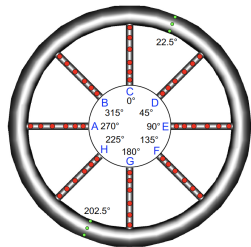
Cruise MFP
LAVA



PR

0.950

0.725



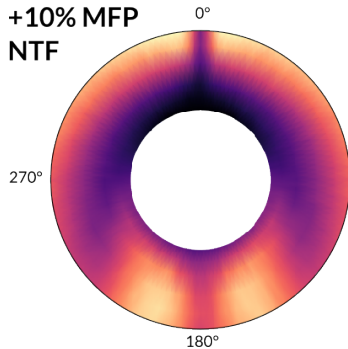
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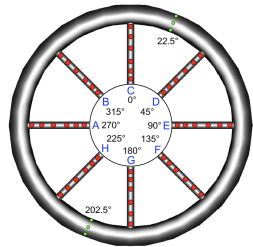
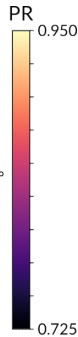
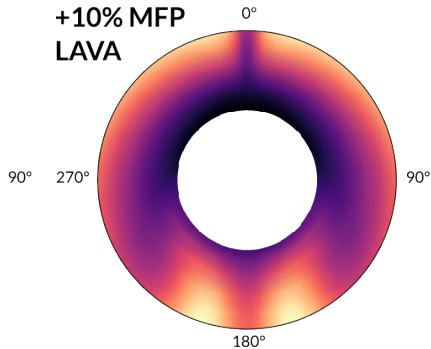
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+10% MFP
NTF



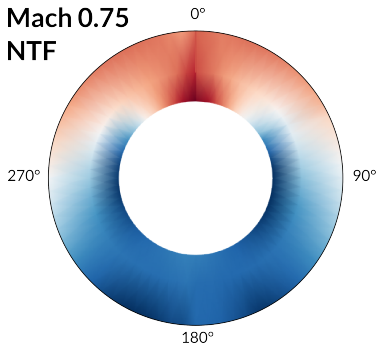
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LAVA



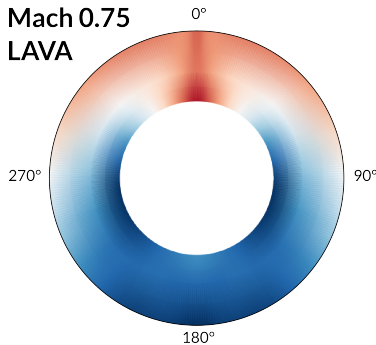
Results - Nacelle highlight flow angularity distortion

Re = 5-million, $\alpha = 2^\circ$
Mach number effects

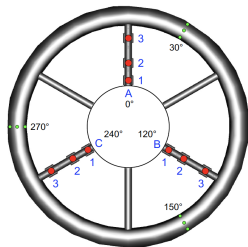
Mach 0.75
NTF



Mach 0.75
LAVA



5-hole probe locations
(Credit: Chan, D., 2024)

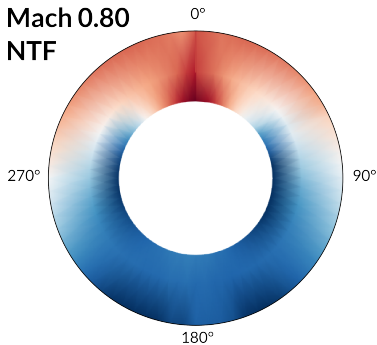


$$\alpha_{\text{flow}} = \text{atan} \frac{V_z}{V_x}$$

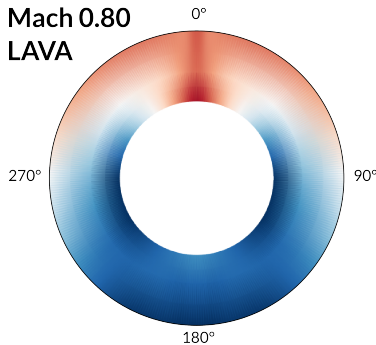
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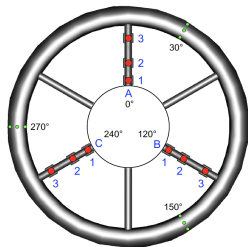
Mach 0.80
NTF



Mach 0.80
LAVA



5-hole probe locations
(Credit: Chan, D., 2024)



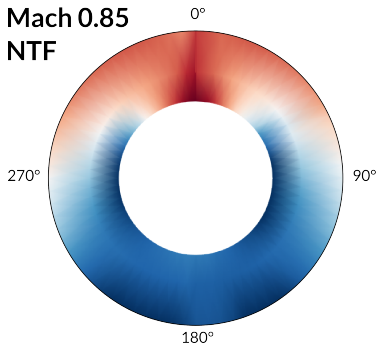
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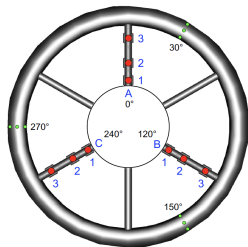
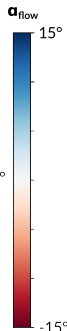
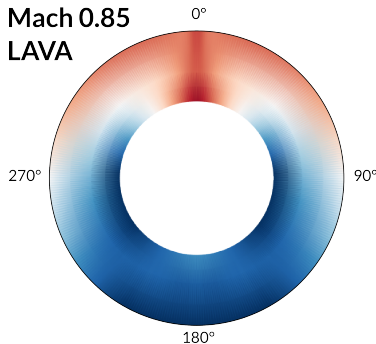
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Mach 0.85
NTF



Mach 0.85
LAVA

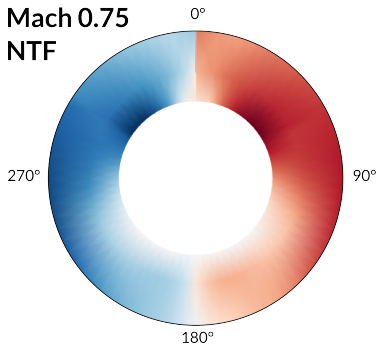


$$\alpha_{\text{flow}} = \text{atan} \frac{V_z}{V_x}$$

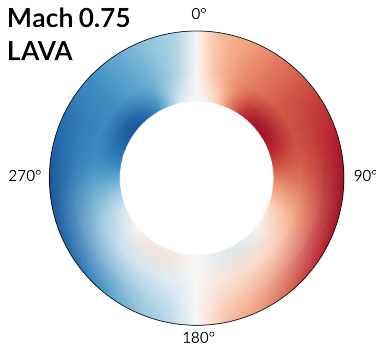
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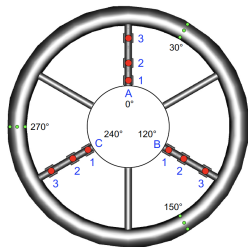
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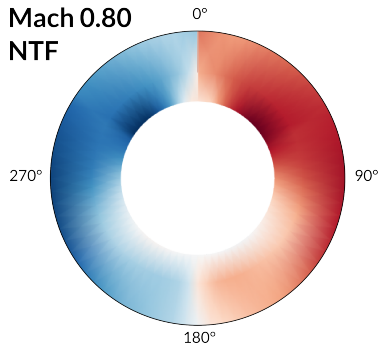


$$\beta_{\text{flow}} = \text{atan} \frac{V_y}{V_x}$$

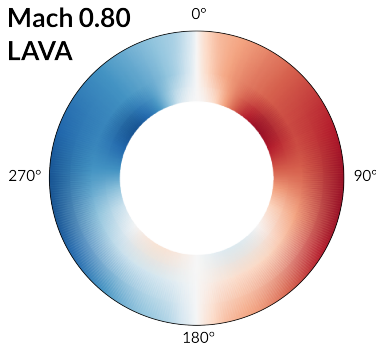
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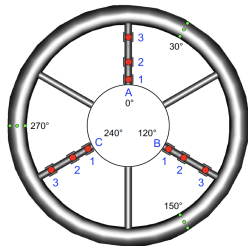
Mach 0.80
NTF



Mach 0.80
LAVA



5-hole probe locations
(Credit: Chan, D., 2024)

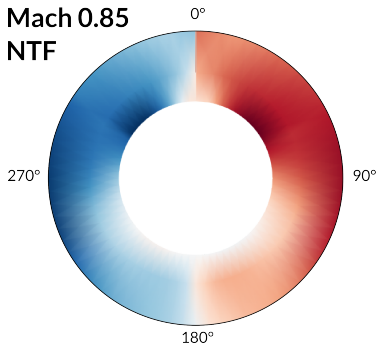


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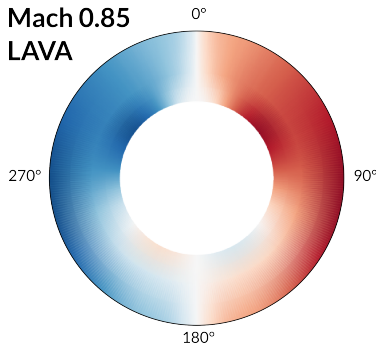
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Re = 5-million, $\alpha = 2^\circ$
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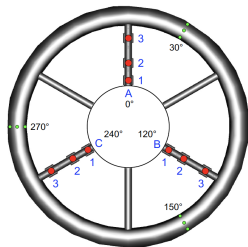
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- Demonstrated that RANS-based flow analysis can be used to accurately model TCT configurations using the LAVA curvilinear flow solver

If you are interested in hearing more about this research

Do not miss the related work:

- **David T. Chan**, Gregory S. Jones, Sarah L. Langston, Andy K. Kwok
Monday, July 29th, 10:30AM (APA-03/GT-01 Session)
Experimental Investigation of a Boundary Layer Ingesting Tailcone Thruster Configuration at the National Transonic Facility
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Acknowledgements



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- Special thanks to David Chan and the rest of the NTF team for hosting a visit to NASA Langley during the test campaign
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