Experimental Investigation of a Boundary Layer Ingesting Tailcone Thruster Configuration at the National Transonic Facility

David Chan, Gregory Jones, Sarah Langston, Andy Kwok

NASA Langley Research Center – Hampton, VA

2024 AIAA AVIATION Forum – Las Vegas, NV

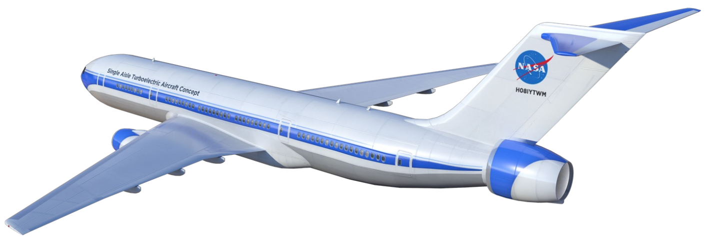
July 29, 2024

Outline

- Introduction
- Wind Tunnel Facility and Test Article Description
- Experiment Setup
- Test Results
- Summary

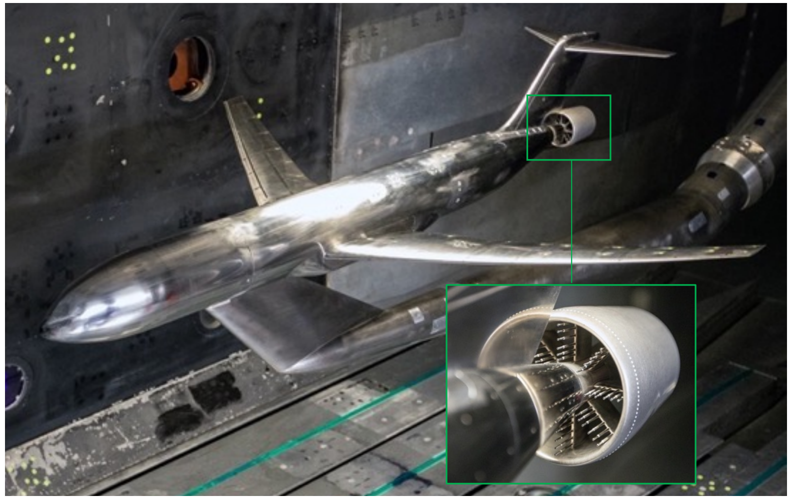
Introduction

- **NASA research on potential benefits of Boundary Layer Ingesting (BLI) propulsion systems**
  - Investigate Type-II BLI systems such as the STARC-ABL concept
  - Ingestion of lower momentum flow ➔ higher propulsive efficiency
  - Propulsion Airframe Integration (PAI) effects may overwhelm benefit
  - Develop integrated airframe-turbomachinery computational simulation capability
    - Conduct ground experiments to provide comparison data for the computational tools



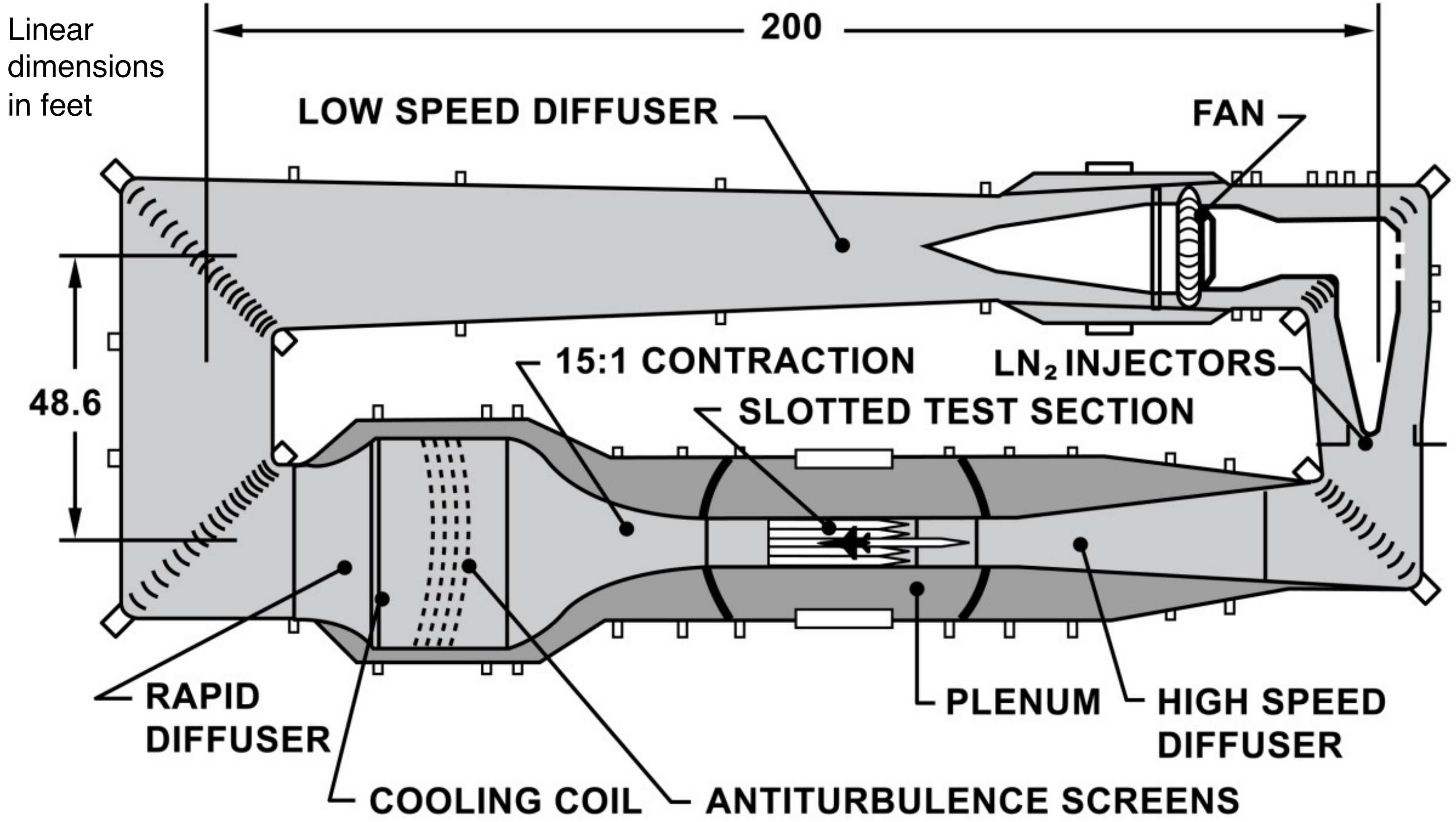
Single Aisle Turboelectric Aircraft Concept with Aft Boundary Layer Ingestion (STARC-ABL)

- **CRM-TCT high Reynolds number experiment in National Transonic Facility**
  - Characterize and measure:
    - Tailcone nacelle inlet pressure and flow angle profile
    - Aftbody boundary layer and surface pressures
    - Overall airframe cruise performance
  - Evaluate sensitivity of measured quantities to:
    - Mach number, Reynolds number, angle of attack
    - Mass flow rates through the nacelle
  - Provide comparison dataset for computational tools



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

National Transonic Facility (NTF)



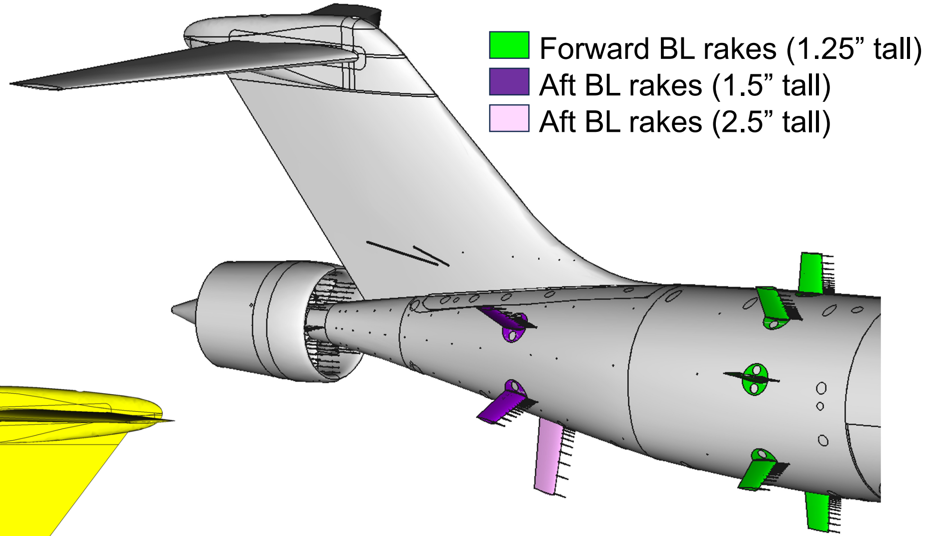
Photos : NASA

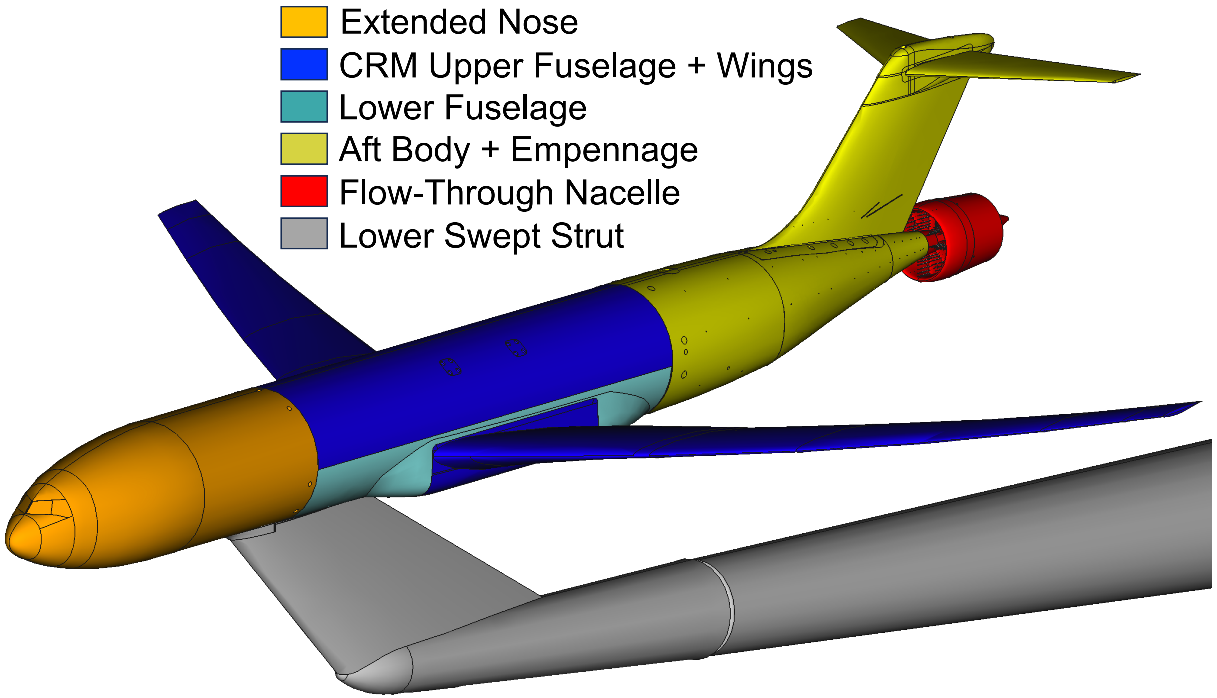
- Located at the NASA Langley Research Center
- Pressurized, cryogenic wind tunnel
- Operate in dry air or gaseous nitrogen
- Achieve very high Reynolds numbers
  - Flight or near-flight for many vehicles

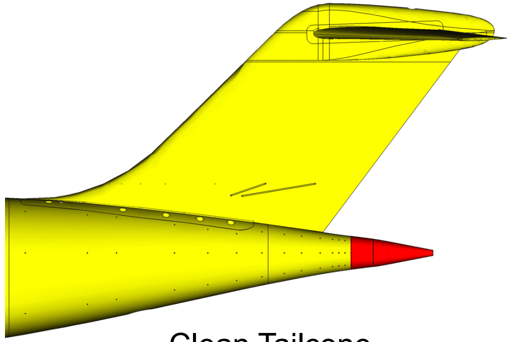
Test Gas	Air	Nitrogen
Mach Number	0.1 – 1.10	0.1 – 1.20
Max Unit Reynolds Number	20×10^6 / ft	145×10^6 / ft
Total Pressure	1 – 8.3 atm	1 – 8.3 atm
Total Temperature	80°F to 130°F	-250°F to 80°F

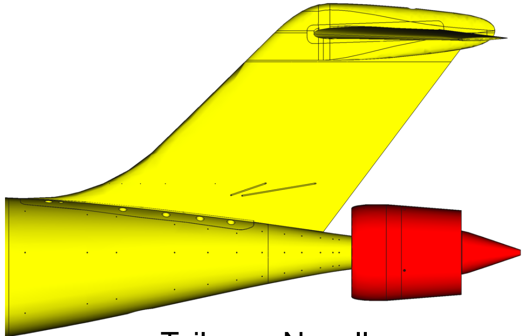
Test Article

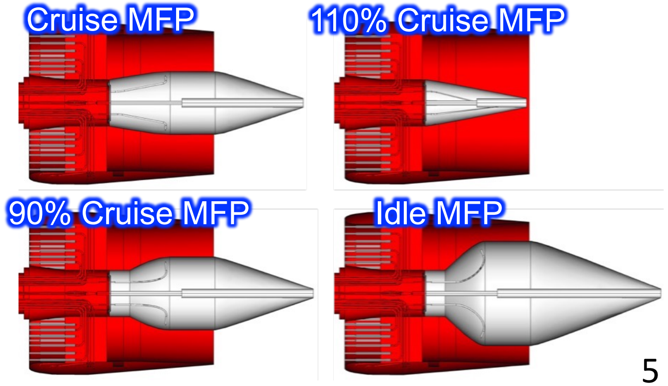
- **Common Research Model with Tail Cone Thruster (CRM-TCT)**
  - 2.7%-scale CRM model with new aftbody and empennage
  - Underchin blade support system
  - Clean tailcone or rotating tailcone nacelles (2)
  - 4 mass flow plugs (MFP) to vary mass flow through nacelle
  - Miniature boundary layer (BL) rakes on aftbody
  - Surface static pressure orifices (>200)





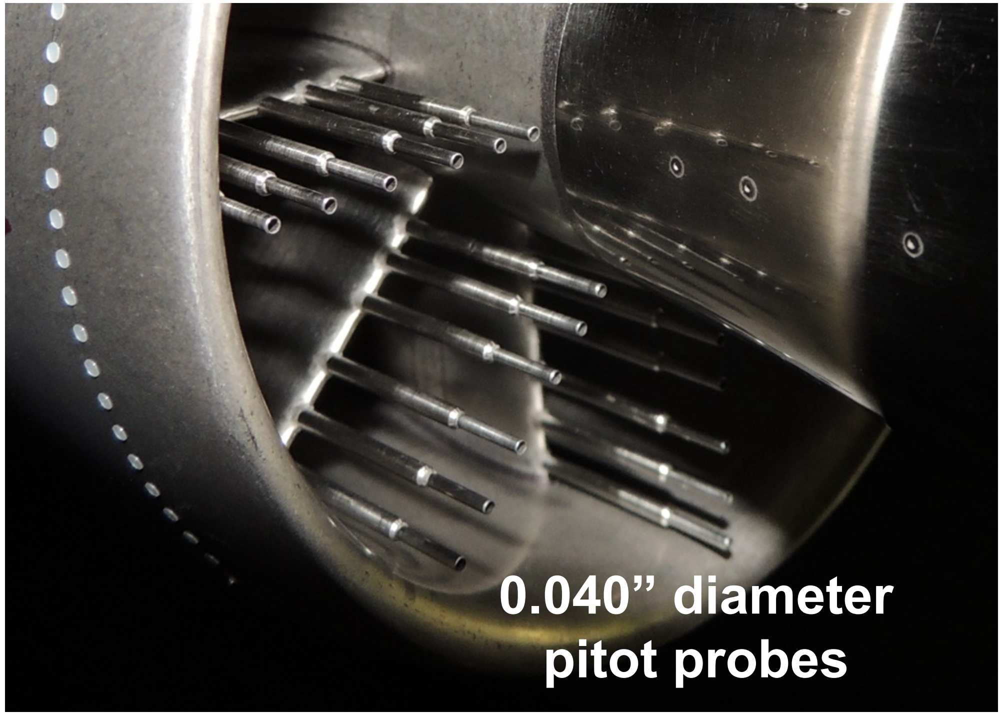

Clean Tailcone


Tailcone Nacelle

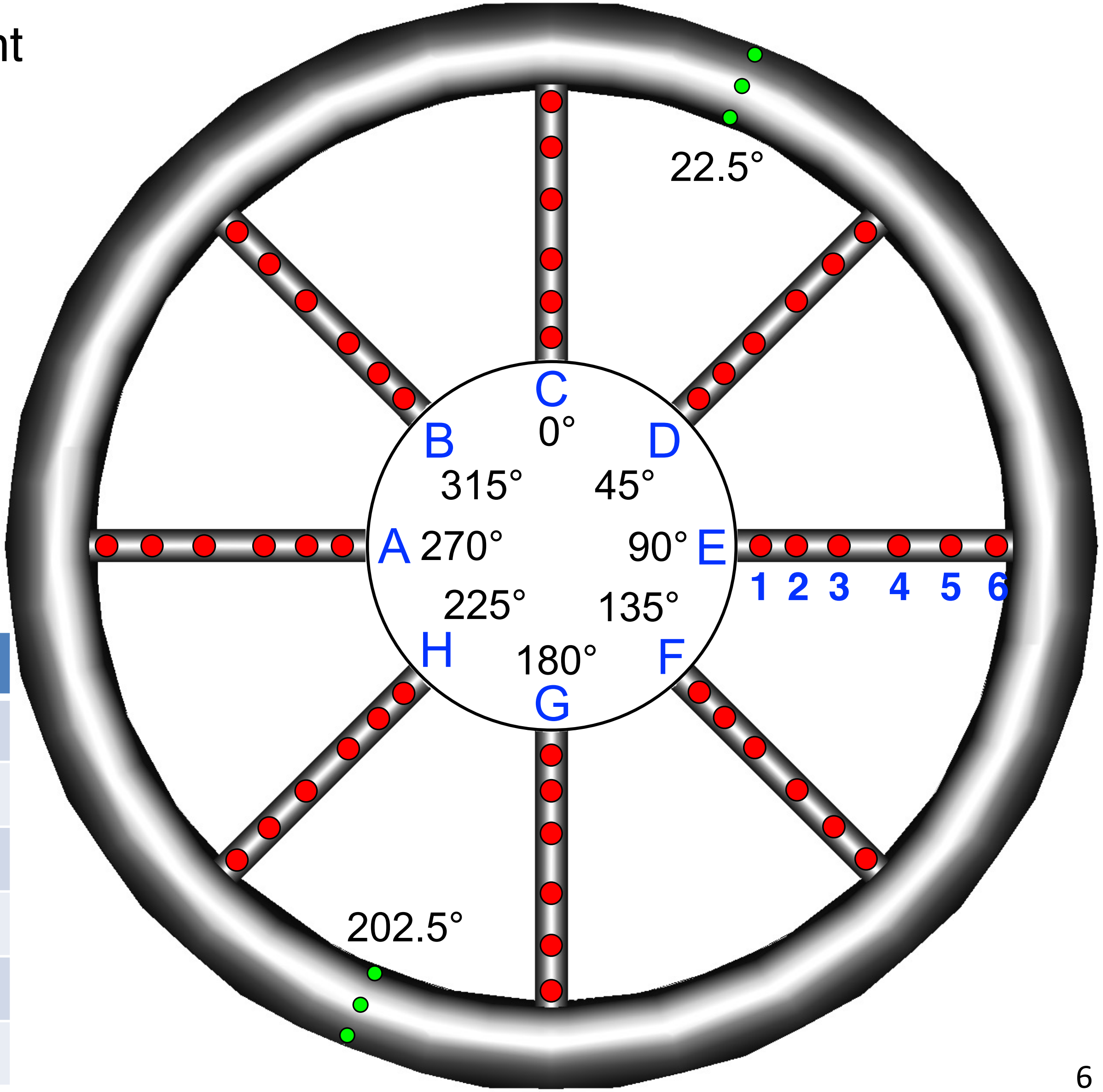


Flow-Through Nacelles

- **ARP1420 nacelle**
  - Measure total pressure profile at nacelle highlight
  - 3.3” nacelle inlet diameter
  - 8-strut rake with measurement strut every 45°
  - 6 pitot probes per measurement strut (48 total)
  - 2 rows of static pressure taps

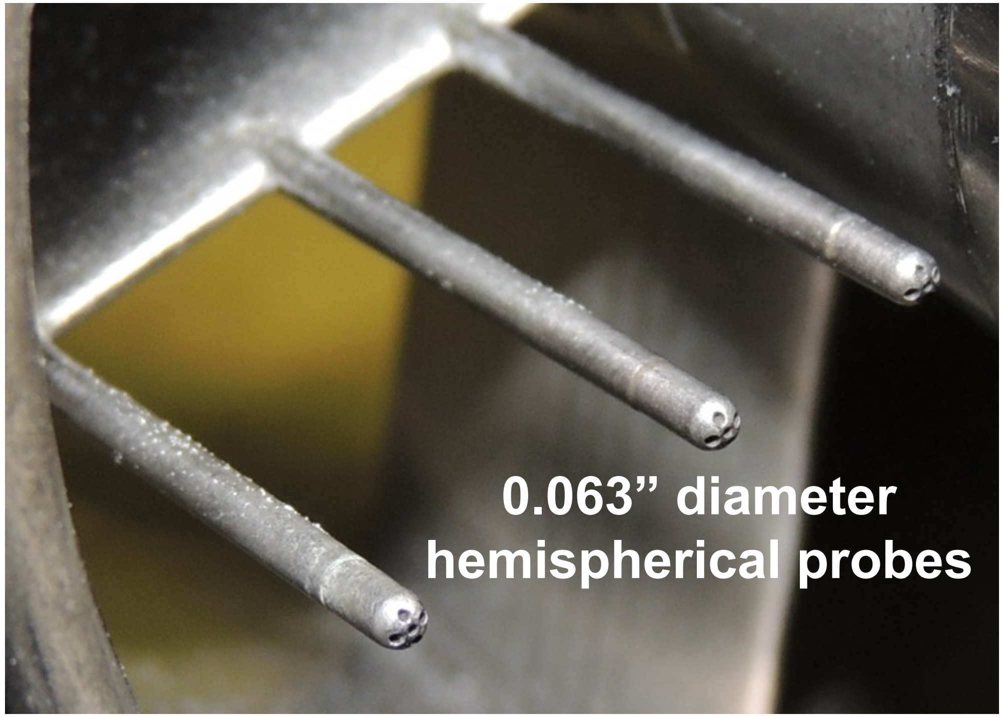


Ring	r / R
1	0.453
2	0.529
3	0.621
4	0.752
5	0.864
6	0.962

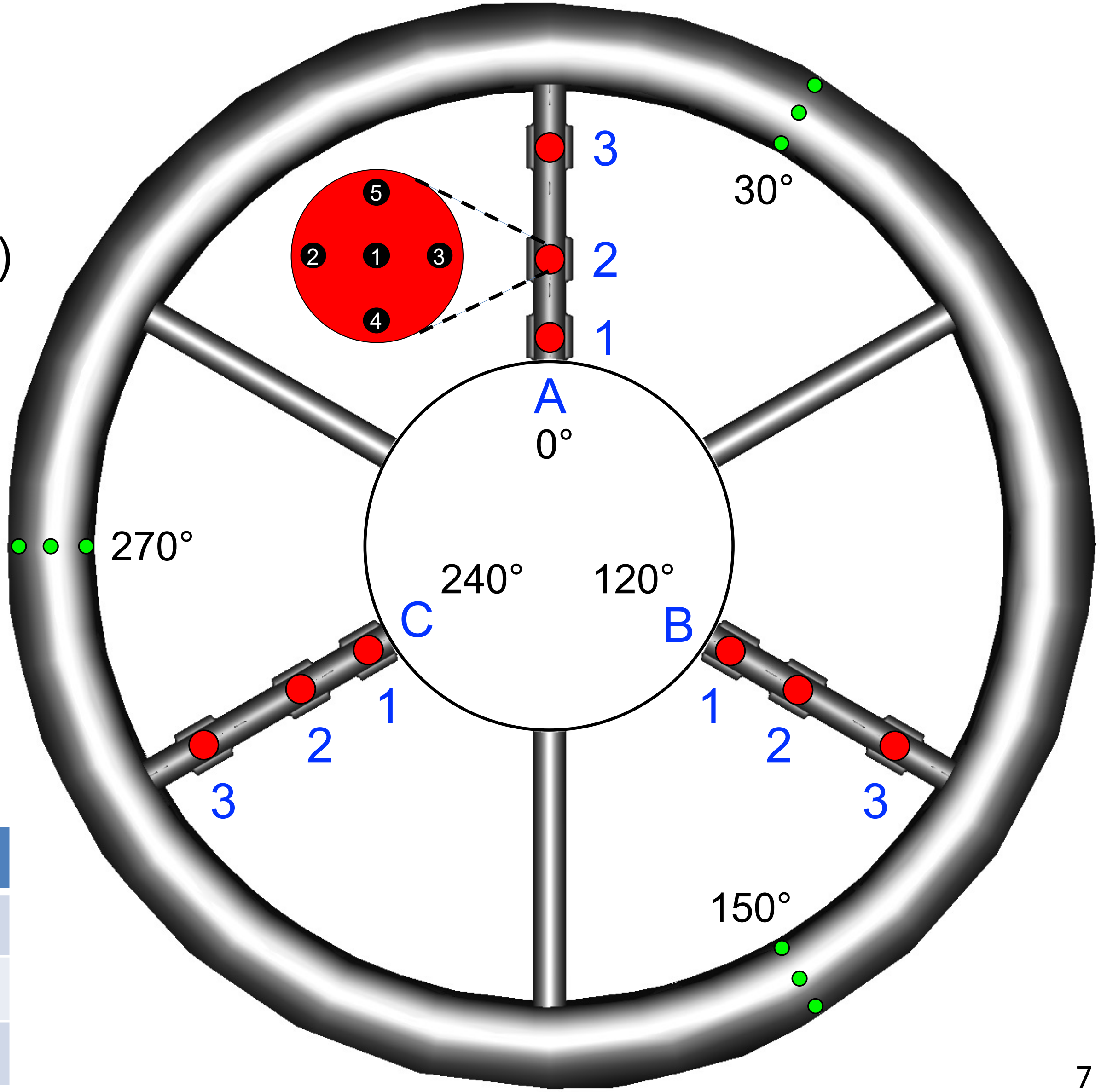


Flow-Through Nacelles

- **5-hole probe nacelle**
  - Measure flow angle profile at nacelle highlight
  - 3.3” nacelle inlet diameter
  - 6-strut rake with measurement strut every 120º
  - 5-hole probes (3) per measurement strut (9 total)
  - 3 rows of static pressure taps

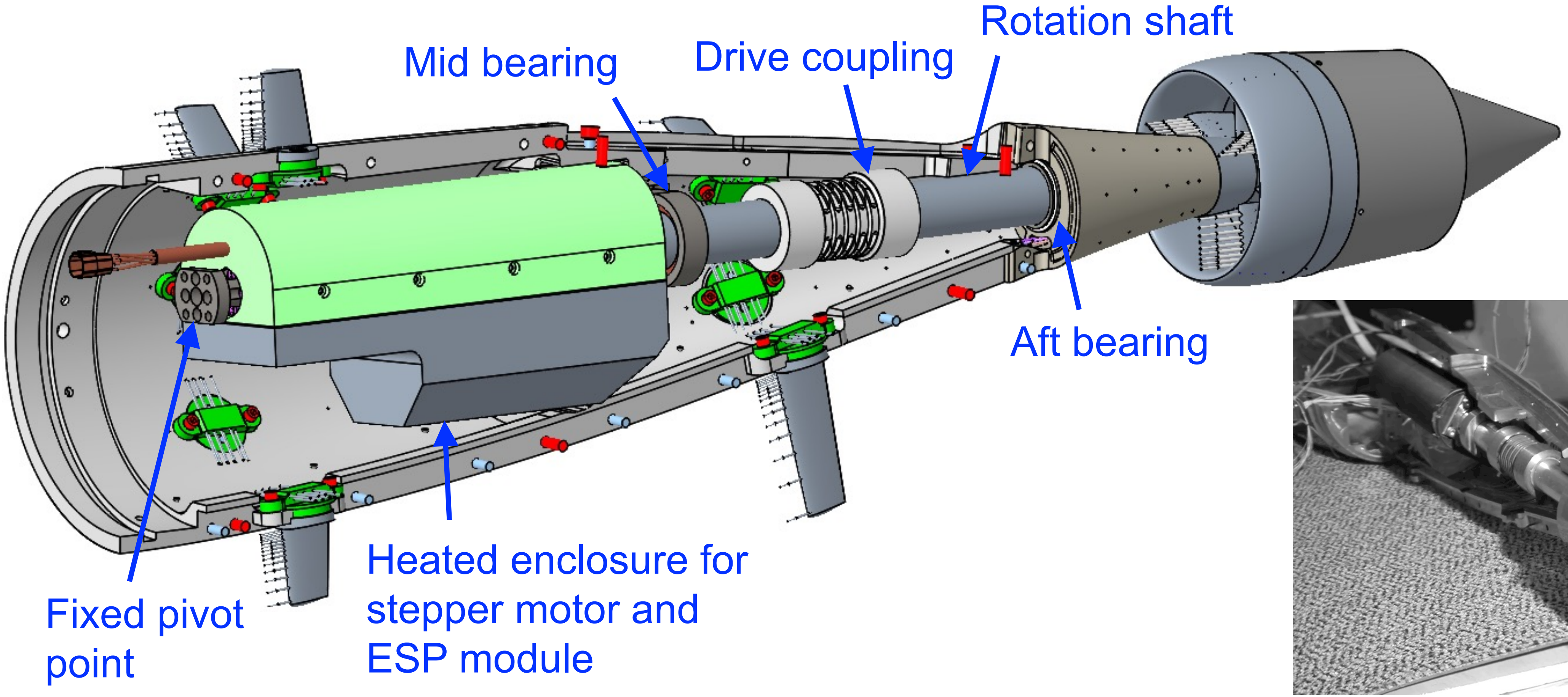


Ring	r / R
1	0.452
2	0.620
3	0.863



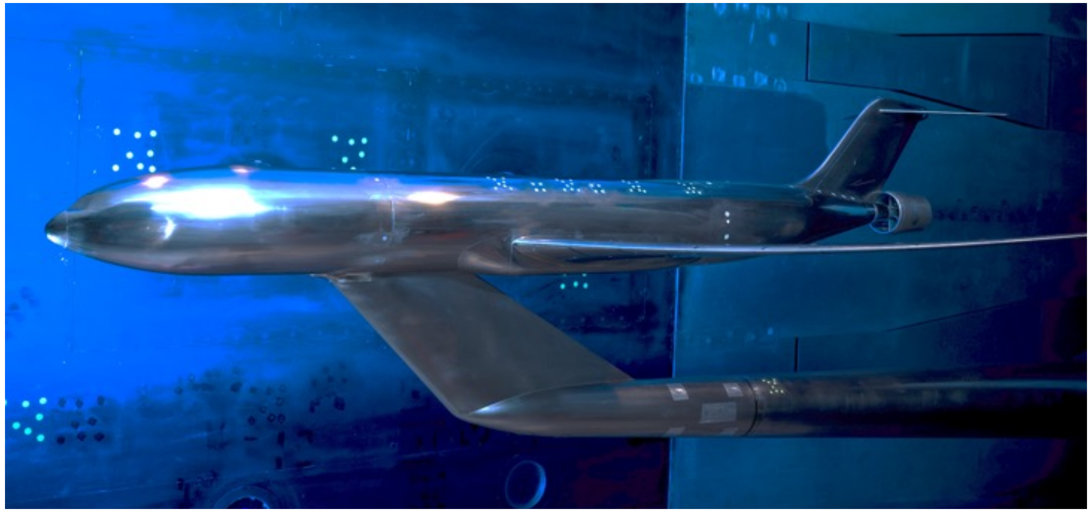
Nacelle Rotation Assembly

- **Separate assembly for each nacelle**
  - Controlled remotely with rotation range between –60º and 60º
  - Demonstrated operation at tunnel temperatures between –120ºF and 120ºF
  - Greatly reduced model change time to switch out nacelles



Experiment Setup

- **Test Conditions**
  - M_∞ = 0.75, 0.80, 0.85
  - Re_{mac} = 5M, 10M, 15M
  - T_0 = –120°F (N_2), –50°F (N_2), 120°F (Air)
  - α = -3° to 3°, β = 0°
- **Test Matrix**
  - Model configurations
    - Clean tailcone, ARP1420 nacelle, or 5-hole probe nacelle
    - 4 mass flow plugs
    - Horizontal stabilizer on or off
    - Forward or aft BL rakes
  - Data runs
    - Angle-of-attack traverses at fixed nacelle roll angle
    - Nacelle roll angle rotation at fixed angle of attack
  - Evaluation of configuration differences mostly performed at Re_{mac} = 5M
  - Evaluation of Re_{mac} effects performed on clean tailcone and ARP1420 nacelle with cruise MFP

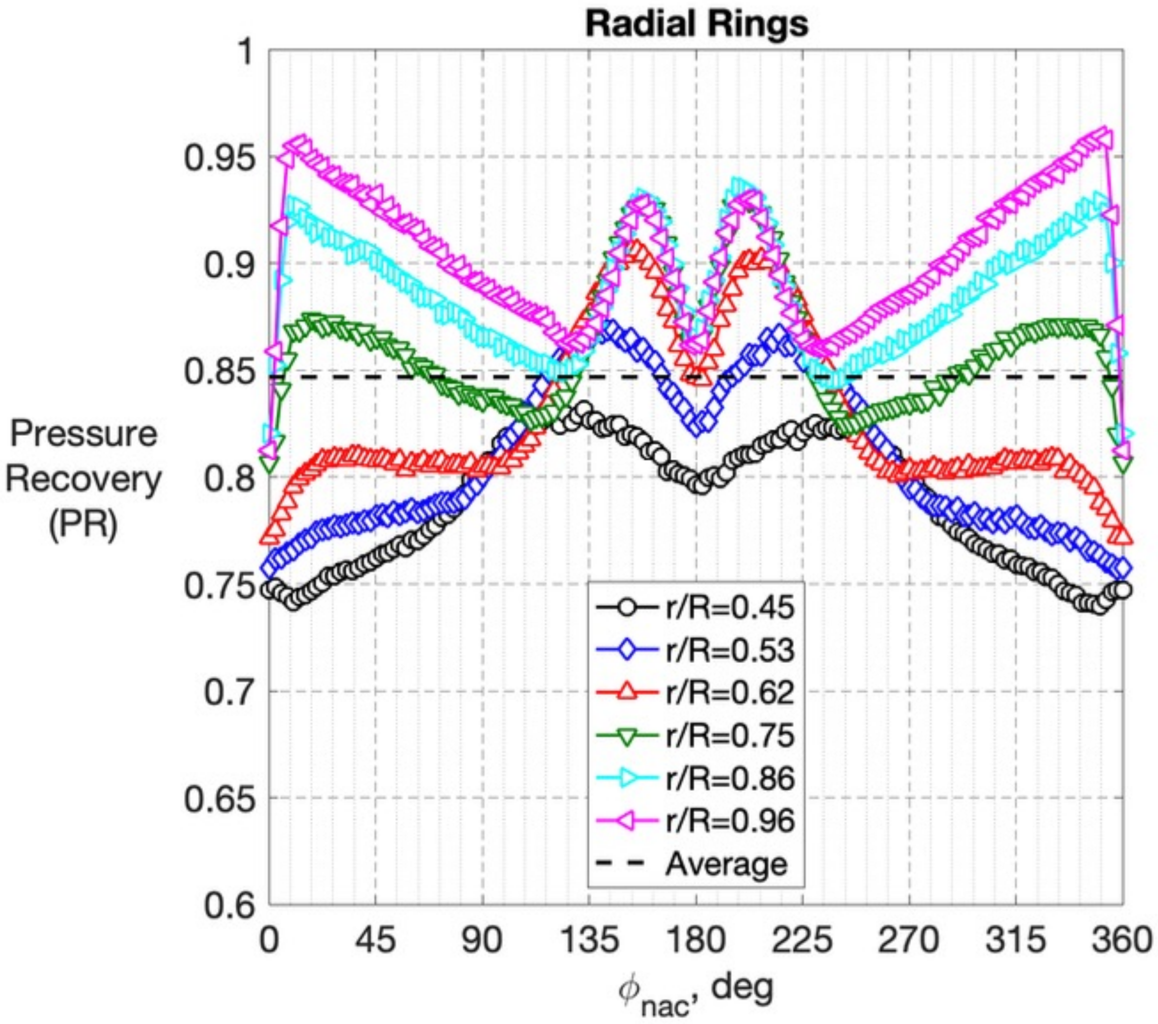


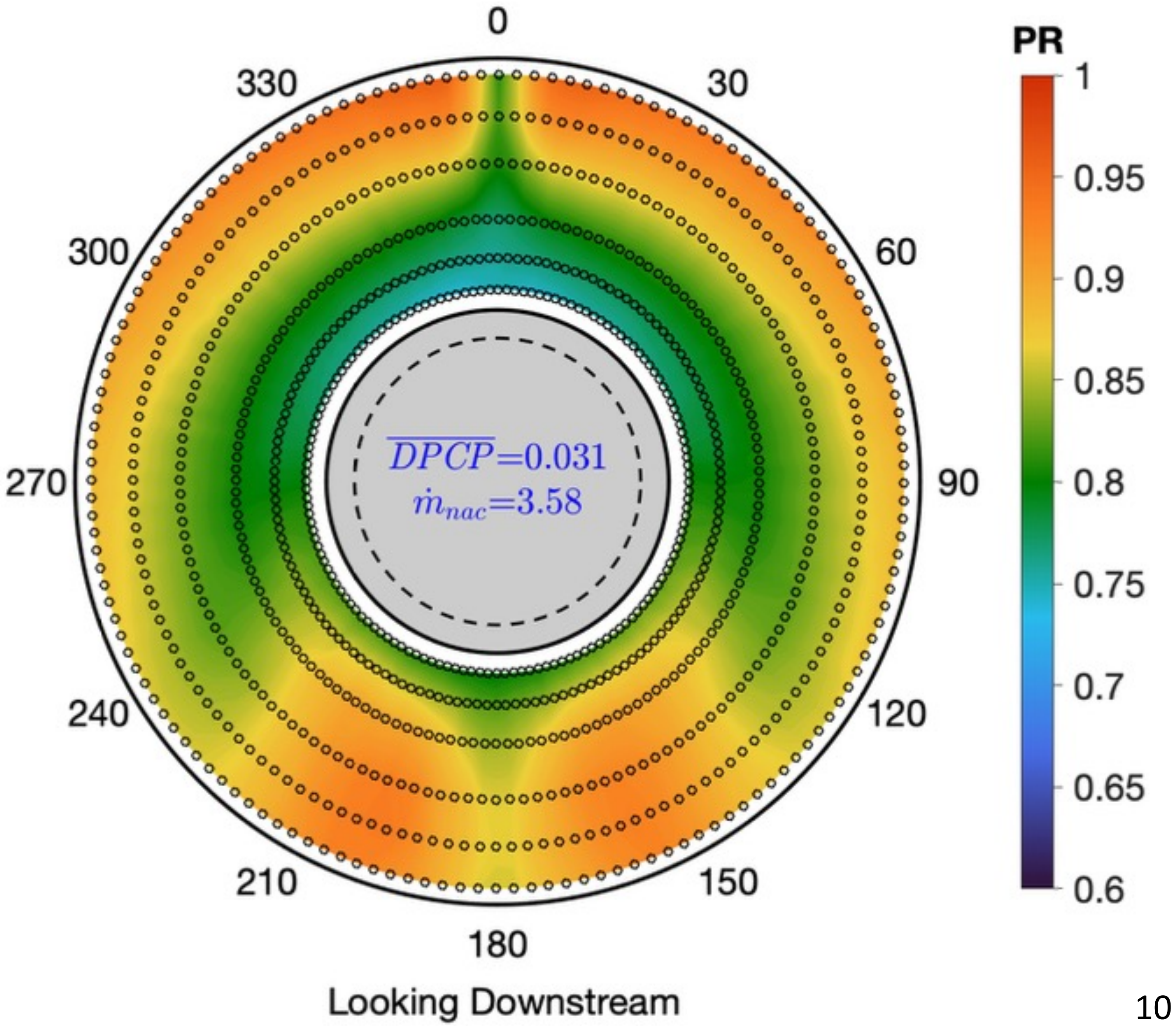
Inlet Flow Distortion (Total Pressure Recovery)

- **Data acquired with nacelle rotation in 2.5° increments over 45° range**

ARP1420 nacelle with 110% cruise MFP ($M_\infty = 0.8$, $Re_{mac} = 10M$, $\alpha = 2°$)

$$PR = \frac{(P_T)_{probe}}{P_0}$$

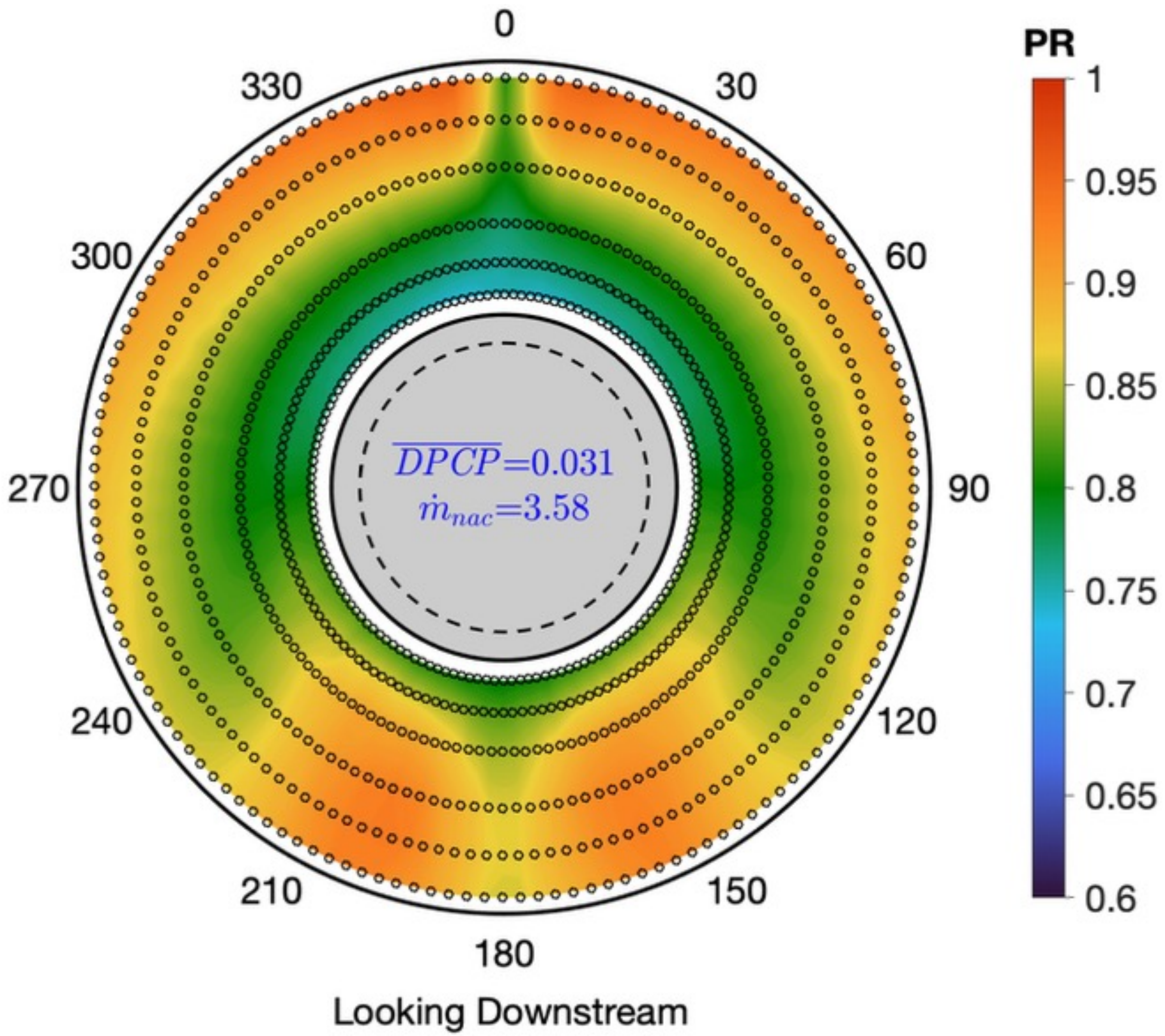




Inlet Flow Distortion (Total Pressure Recovery)

- **Several features in measured pressure profile at nacelle highlight**

ARP1420 nacelle with 110% cruise MFP (M_∞ = 0.8, Re_{mac} = 10M, α = 2°)



Prominent features in PR contour

1. Lower momentum core flow
   - BL ingestion
2. Two lobes at bottom of nacelle
   - Vortices from bottom of aft fuselage and downwash from wing/body fairing
3. Regions at 0° and 180°
   - Influence of vertical tail and blade support strut

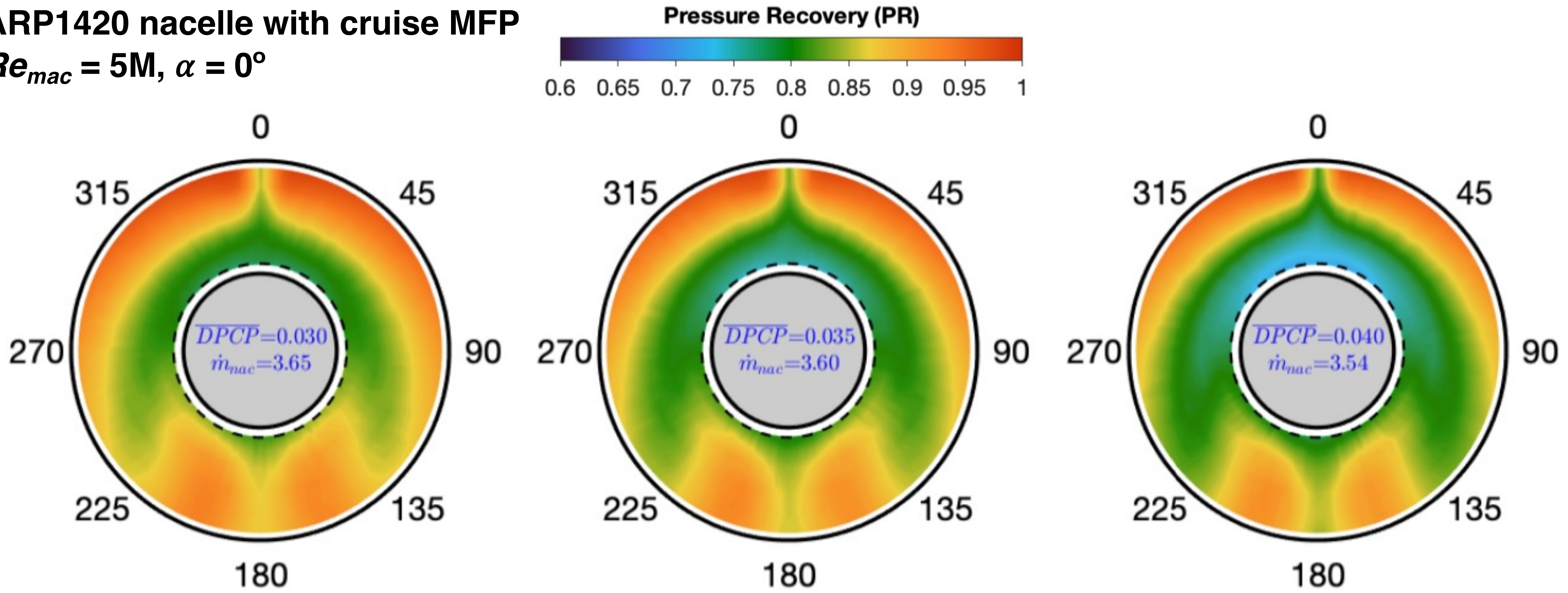
Information in center

- Gray shaded region is tailcone hub
- Dashed line circle is maximum diameter of installed MFP
- $\overline{DPCP}$ = Avg. circumferential pressure distortion intensity
- $\dot{m}_{nac}$ = Mass flow rate through nacelle

Inlet Flow Distortion (Total Pressure Recovery)

- **Effect of Mach number**
  - Increasing M_∞ : Lower PR and higher distortion intensity

ARP1420 nacelle with cruise MFP
Re_{mac} = 5M, α = 0°

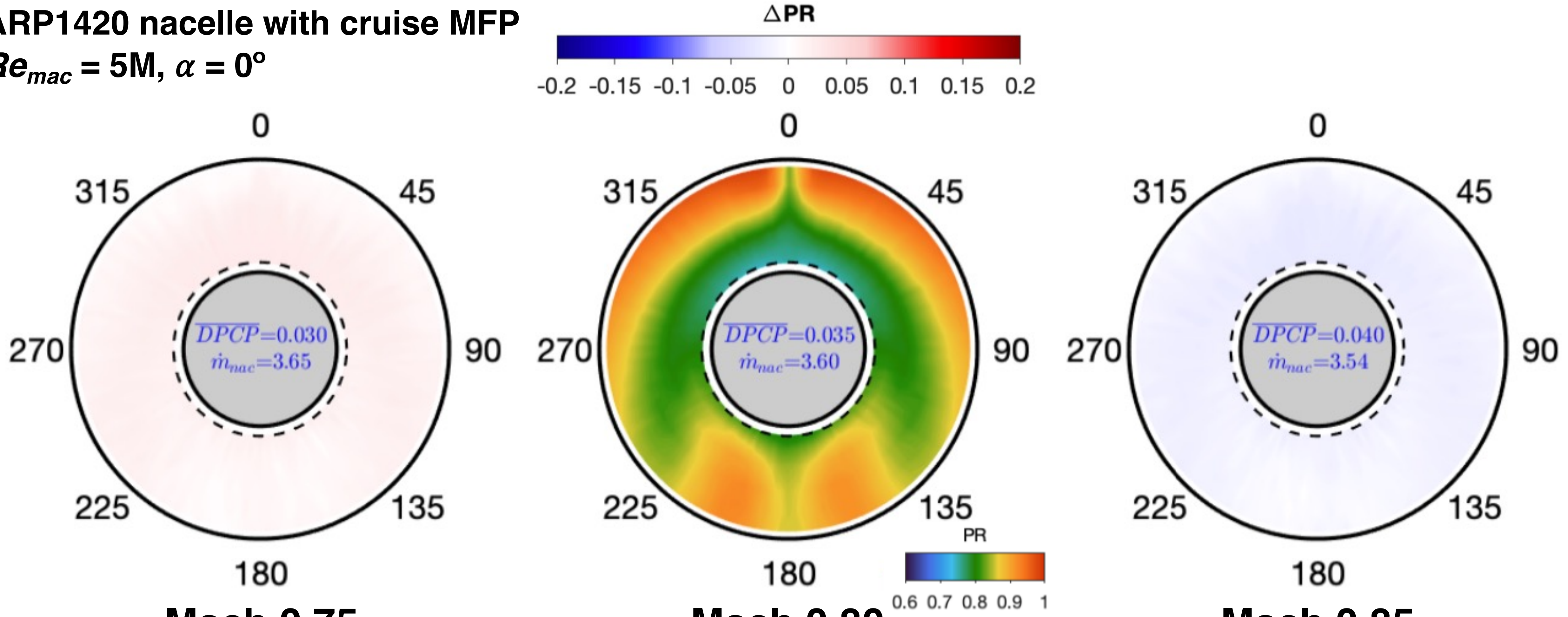


Mach 0.75 **Mach 0.80** **Mach 0.85**

Inlet Flow Distortion (Total Pressure Recovery)

- **Effect of Mach number**
  - Increasing M_∞ : Lower PR and higher distortion intensity

ARP1420 nacelle with cruise MFP
Re_{mac} = 5M, α = 0°

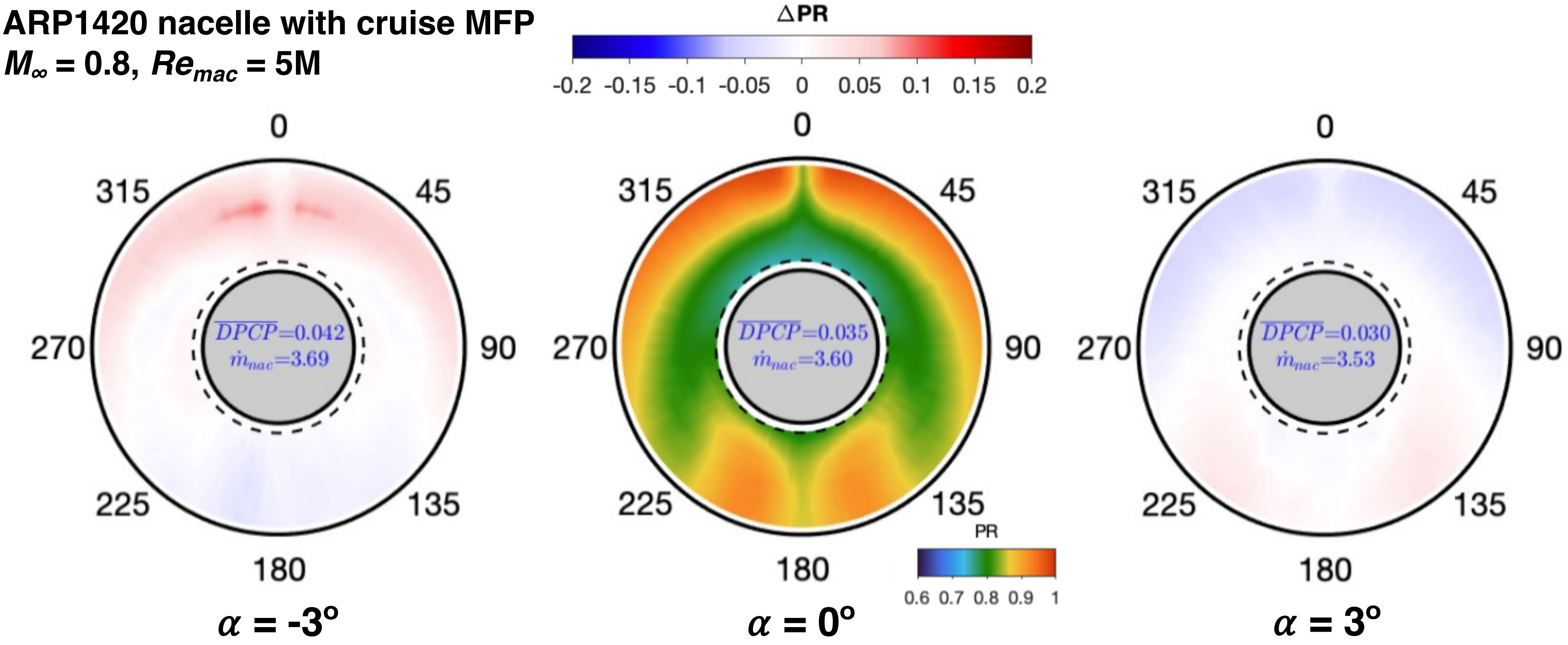


Mach 0.75 **Mach 0.80** **Mach 0.85**

Inlet Flow Distortion (Total Pressure Recovery)

- **Effect of angle of attack (AOA)**
  - Increasing AOA : Lower PR at top and higher PR at bottom, and lower distortion intensity

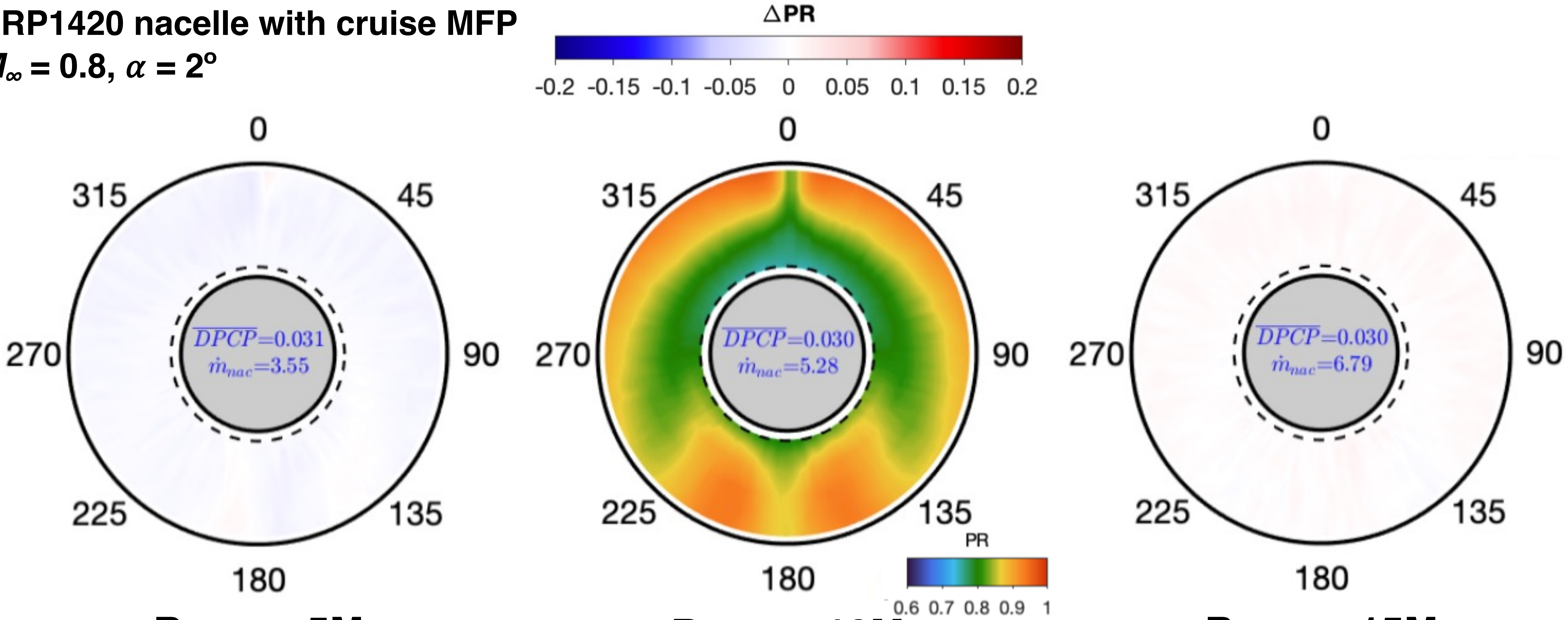
ARP1420 nacelle with cruise MFP
$M_\infty = 0.8$, $Re_{mac} = 5M$



Inlet Flow Distortion (Total Pressure Recovery)

- **Effect of Reynolds number**
  - Increasing Re_{mac} : Higher PR and similar distortion intensity

ARP1420 nacelle with cruise MFP
$M_\infty = 0.8$, $\alpha = 2^o$

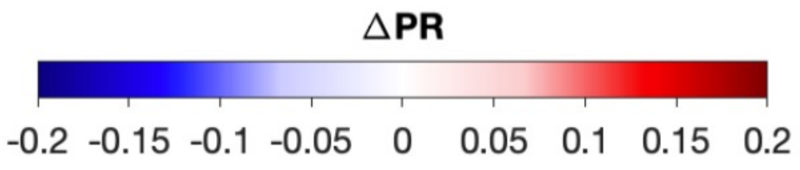


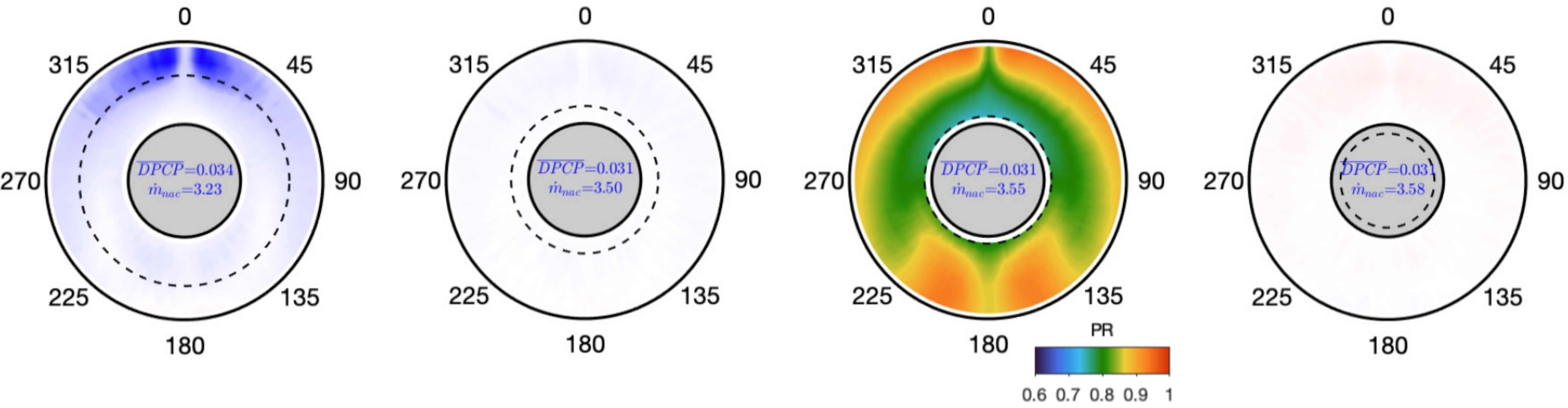
Re_{mac} = 5M **Re_{mac} = 10M** **Re_{mac} = 15M**

Inlet Flow Distortion (Total Pressure Recovery)

- **Effect of mass flow**
  - Increasing $\dot{m}_{nac}$: Higher PR and similar distortion intensity (except for idle MFP)

ARP1420 nacelle
$M_\infty = 0.8$, $Re_{mac} = 5M$, $\alpha = 2^o$



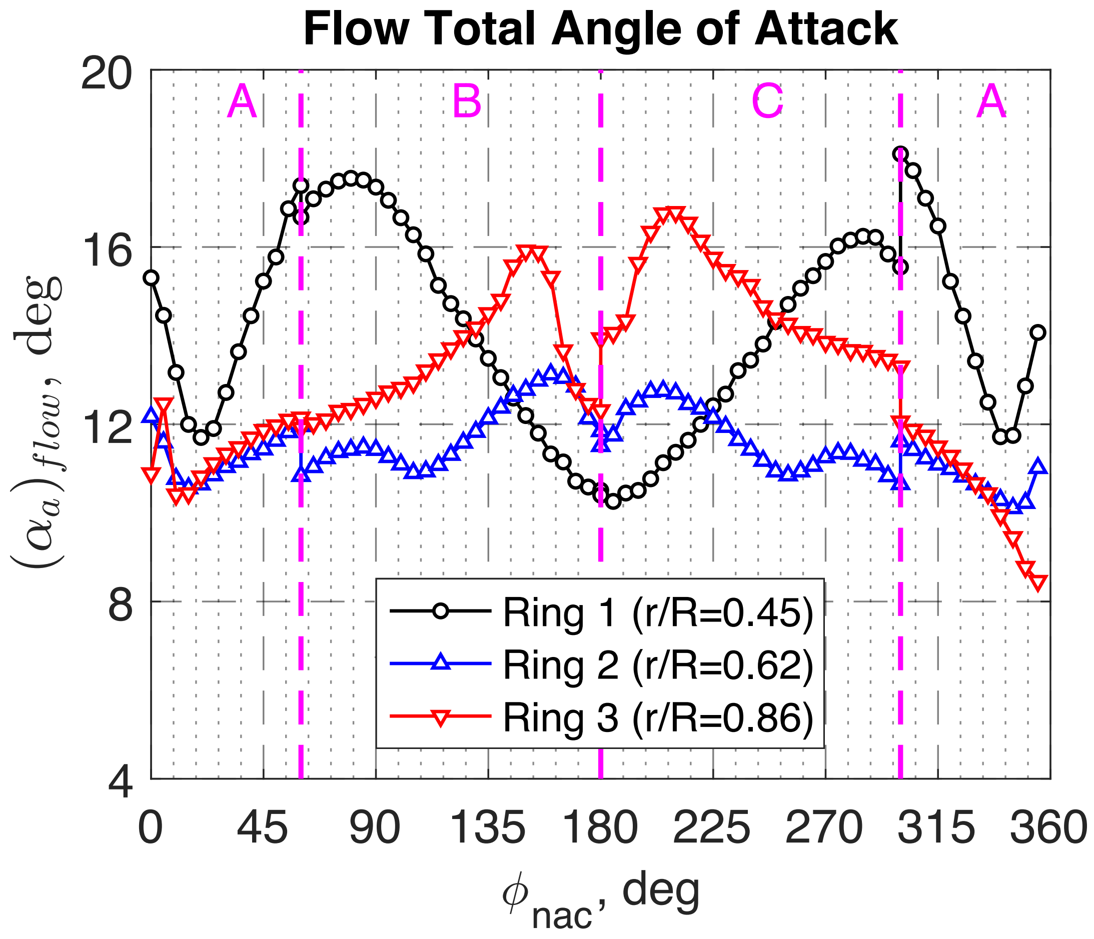


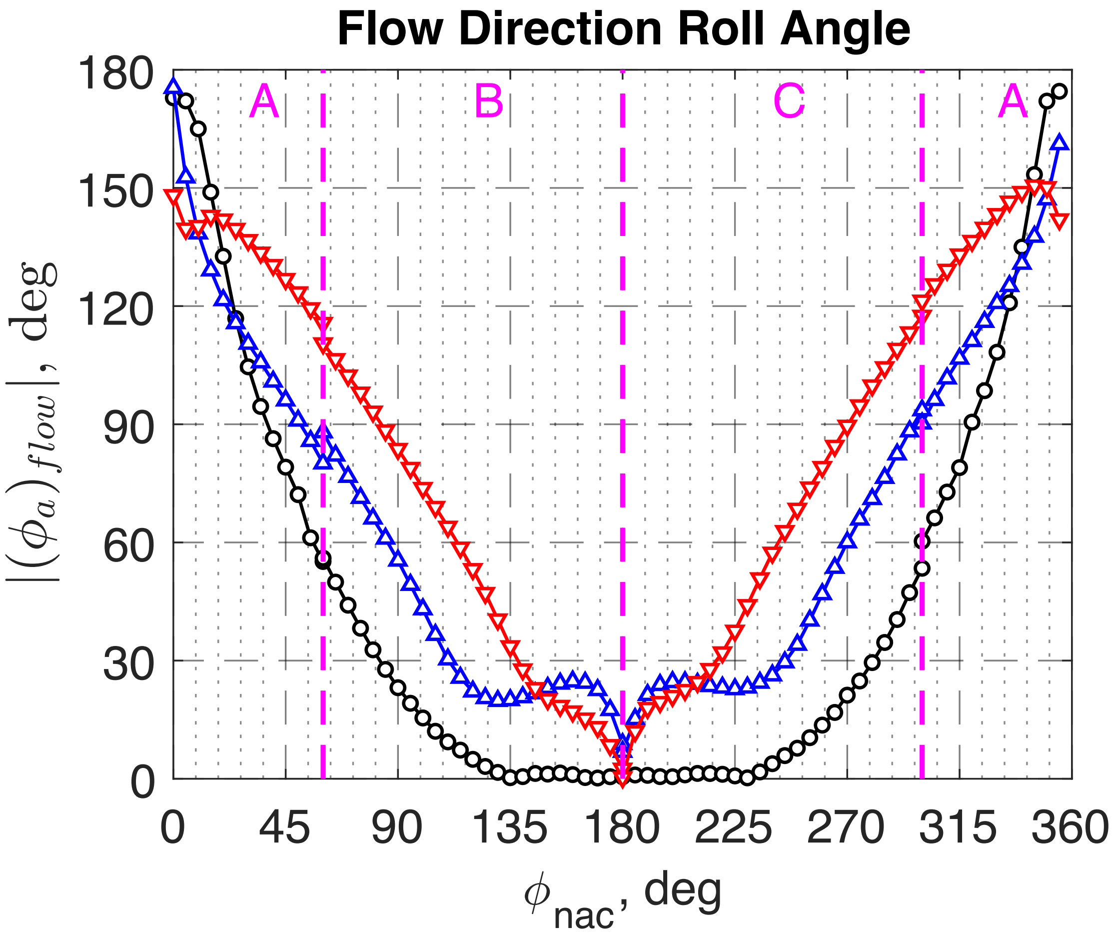
Idle MFP | **90% Cruise MFP** | **Cruise MFP** | **110% Cruise MFP**

Inlet Flow Distortion (Flow Angle)

- **Data acquired with nacelle rotation in 5° increments over 120° range**
  - Data mostly smooth and symmetric, but some discontinuities at overlap points

5-hole probe nacelle with cruise MFP (*M_∞* = 0.8, *Re_{mac}* = 5M, *α* = 2°)

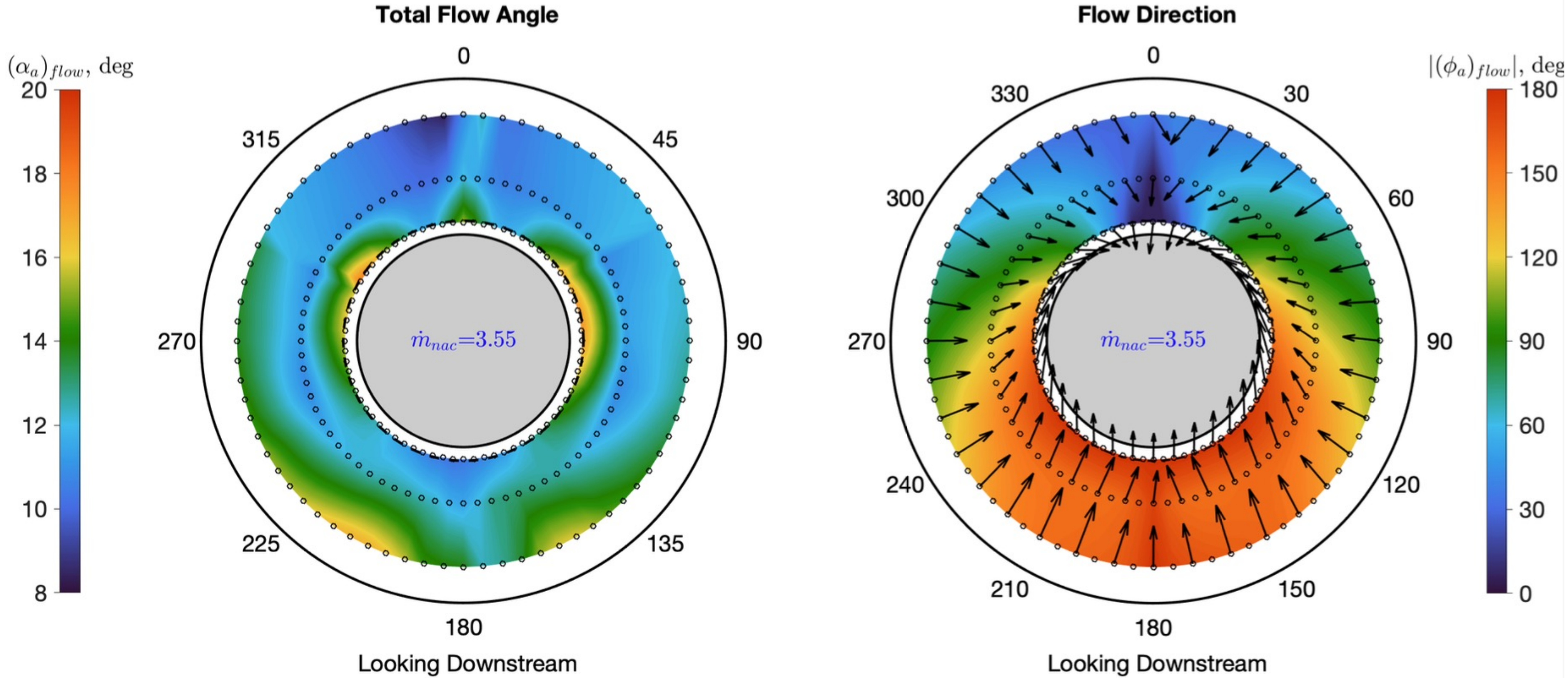




Inlet Flow Distortion (Flow Angle)

- **Flow angle and flow direction contours**
  - Similar features to pressure profile, but also shows rollup around and onto top of hub
  - Trends with Mach number and angle of attack were minimal

5-hole probe nacelle with cruise MFP (M_∞ = 0.8, Re_{mac} = 5M, α = 2°)



Other Test Results

- **Aerodynamic force and moment coefficients**
  - Trends with Mach number, Reynolds number, and angle of attack within expectations
  - C_D results with 110% cruise MFP were out of family with other MFPs
    - Discovered shock likely developed inside nacelle near inlet

- **Aftbody BL heights**
  - Smooth BL profiles with a few exceptions (one rake affected by wing/body junction downwash)
  - Trends with Mach number, Reynolds number, and angle of attack within expectations
  - Presence of nacelle did not affect BL height at aft rake location
    - Aft location is about 3 nacelle diameters upstream of nacelle highlight

- **Aftbody surface pressures**
  - Pressures exhibited good left-right symmetry
  - Influence of nacelle on aftbody pressures reach up to 1.5 nacelle diameters upstream of nacelle highlight

Summary

- **CRM-TCT high Reynolds number experiment in National Transonic Facility**
  - Focused on characterization of tailcone nacelle inlet pressure and flow angle profile
  - Provided comparison dataset for computational tools
- **CRM-TCT cryogenic wind tunnel model with rotating tailcone nacelle**
  - 2.7% CRM model with new aftbody, empennage, and tailcone nacelle
  - ARP1420 nacelle used for pressure profile and 5-hole probe nacelle used for flow angle profile
  - Remote control nacelle rotation successful down to –120°F
- **Inlet flow distortion**
  - High resolution measurements acquired for nacelle highlight pressure and flow angle profile
  - Evaluated sensitivities to Mach number, Reynolds number, angle of attack, and mass flow rates
- **Other test results detailed in paper**
- **Comparisons of CFD (LAVA and USM3D-ME) to experiment**
  - Luis Fernandes, et al., "*Computational Analysis of a Boundary-Layer Ingesting Tailcone Thruster Configuration within the National Transonic Facility using the LAVA Solver*", <u>Tues. 9:30AM</u>
  - Michael Bozeman, "*USM3D-ME Analyses Performed in Support of a Wind Tunnel Test of a Boundary-Layer Ingestion Configuration*", <u>Weds 9:30AM</u>

Questions?