BOEING

Engineering, Operations & Technology

International Conference on Flow Physics and its Simulation
In memory of Prof. Jaw-Yen Yang

CFD Simulation of Serpentine S-Duct With Flow Control

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National Taiwan University

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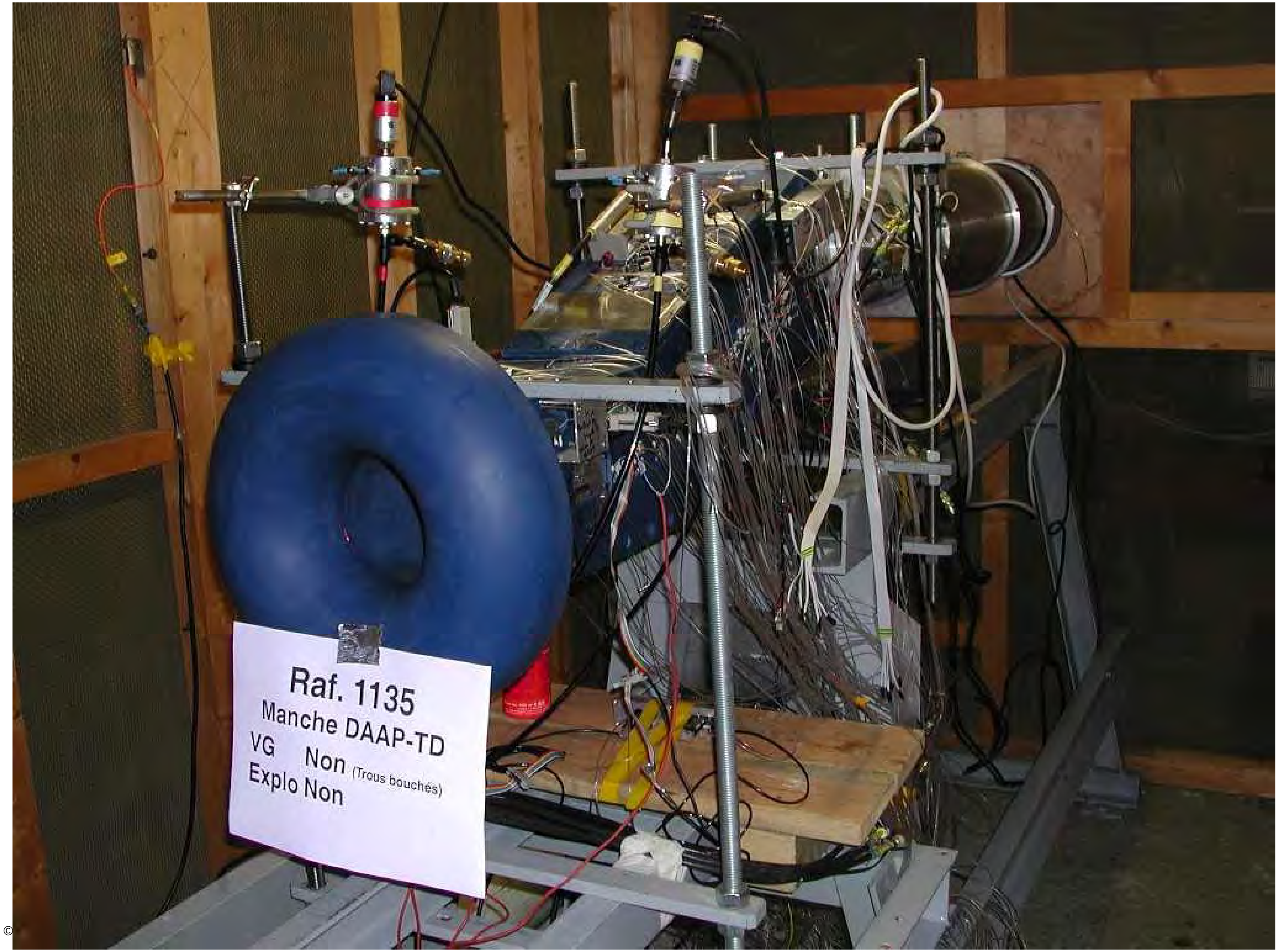
Huntington Beach, CA

Outline

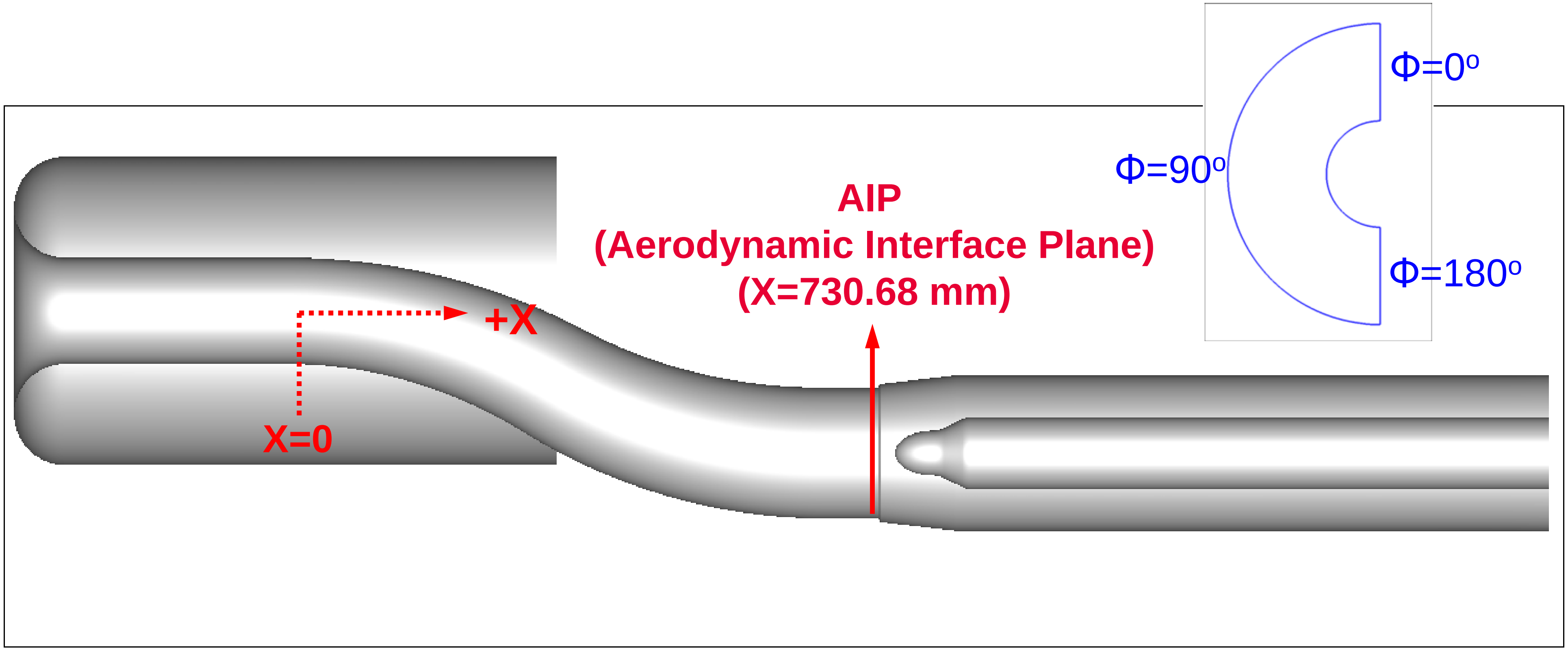
- **Experimental & CFD Models**
  - ONERA test model
  - Overset Grids for Half Model
  - OVERFLOW RANS/URANS
- **Validation**
  - Surface Pressures
  - Pressure contours at PAI
- **Passive Flow Control**
  - Effects of VG number, height, and orientation angle
  - Recovery and Distortion
- **Active Flow Control**
  - Blowing jets model
- **Time Accurate Run (URANS)**
- **Conclusions**

S-duct Test Case (serpentine diffuser)



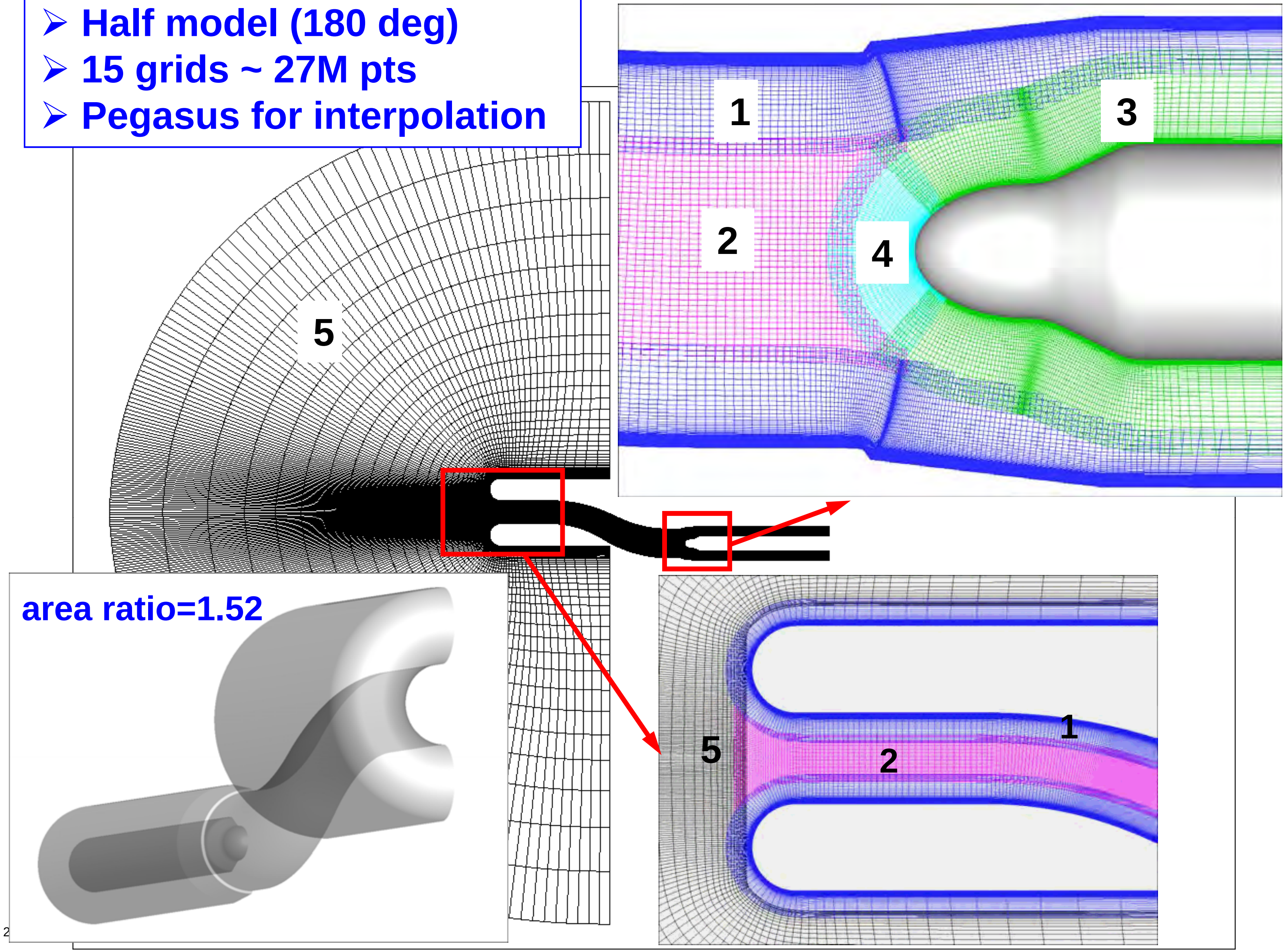
Nomenclature

- **Flow in +X direction**
- **Aerodynamic Interface Plane (AIP)**
- **Polar angle in circumferential direction (Φ)**

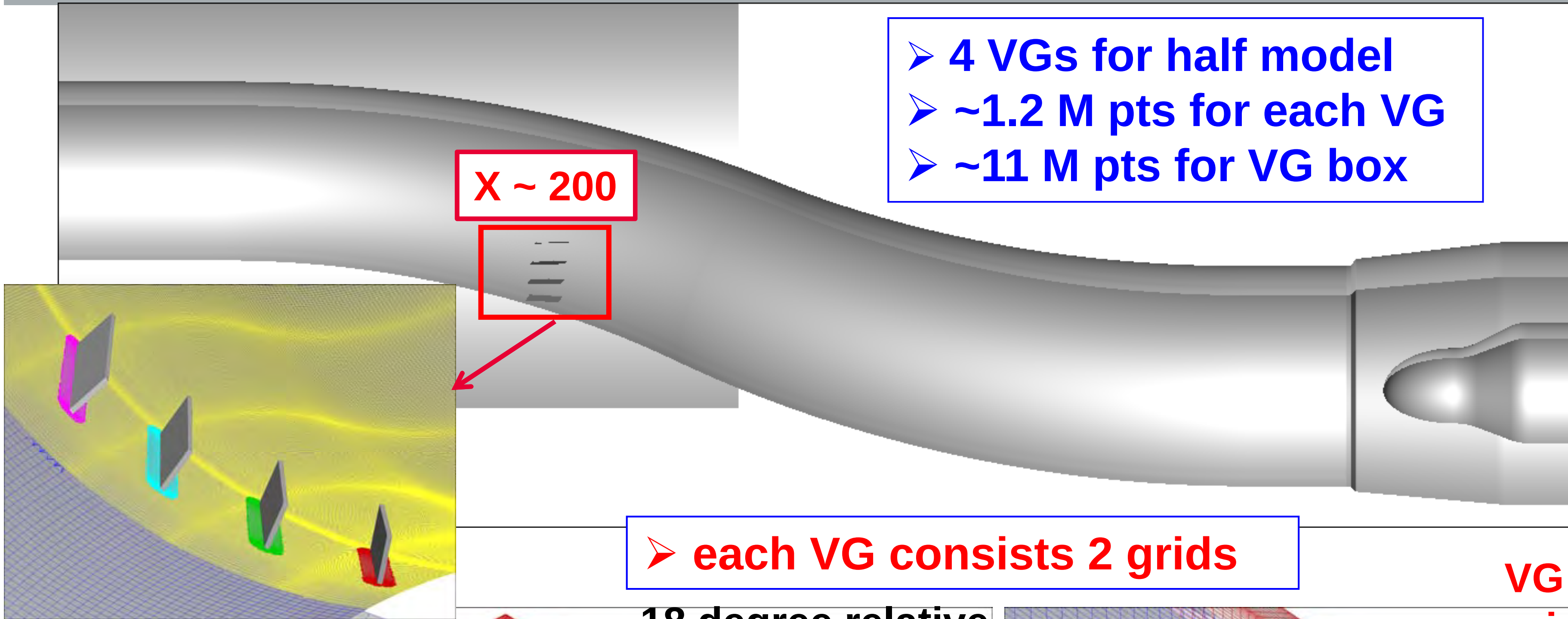


Overset Grid System

- Half model (180 deg)
- 15 grids ~ 27M pts
- Pegasus for interpolation

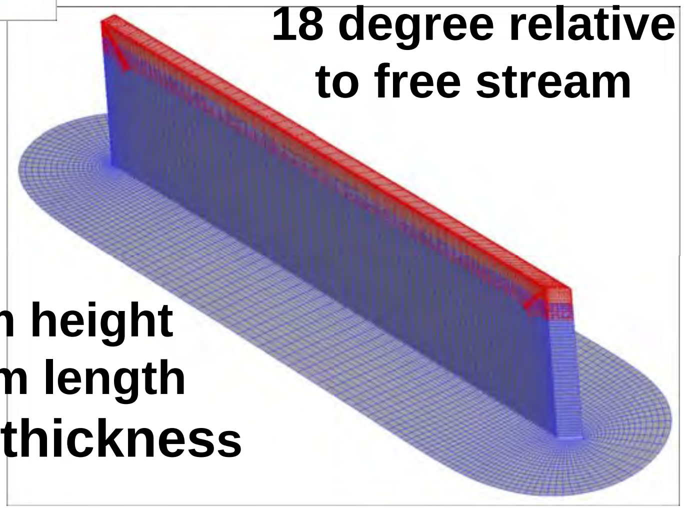


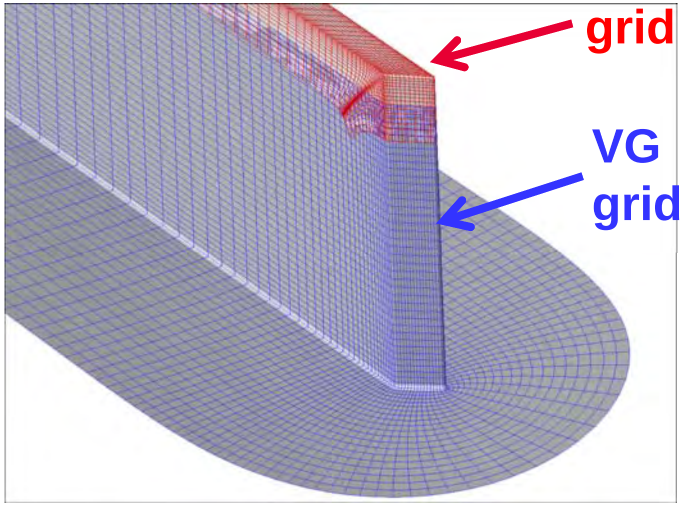
Overset Grid System



- 4 VGs for half model
- ~1.2 M pts for each VG
- ~11 M pts for VG box

- each VG consists 2 grids



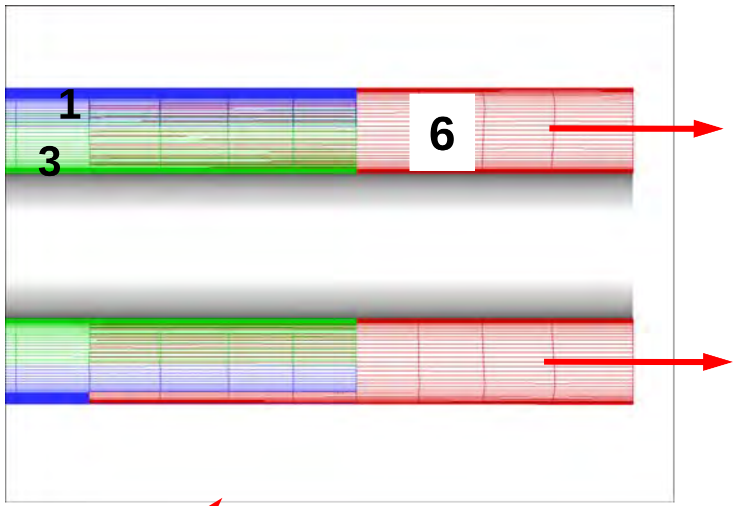


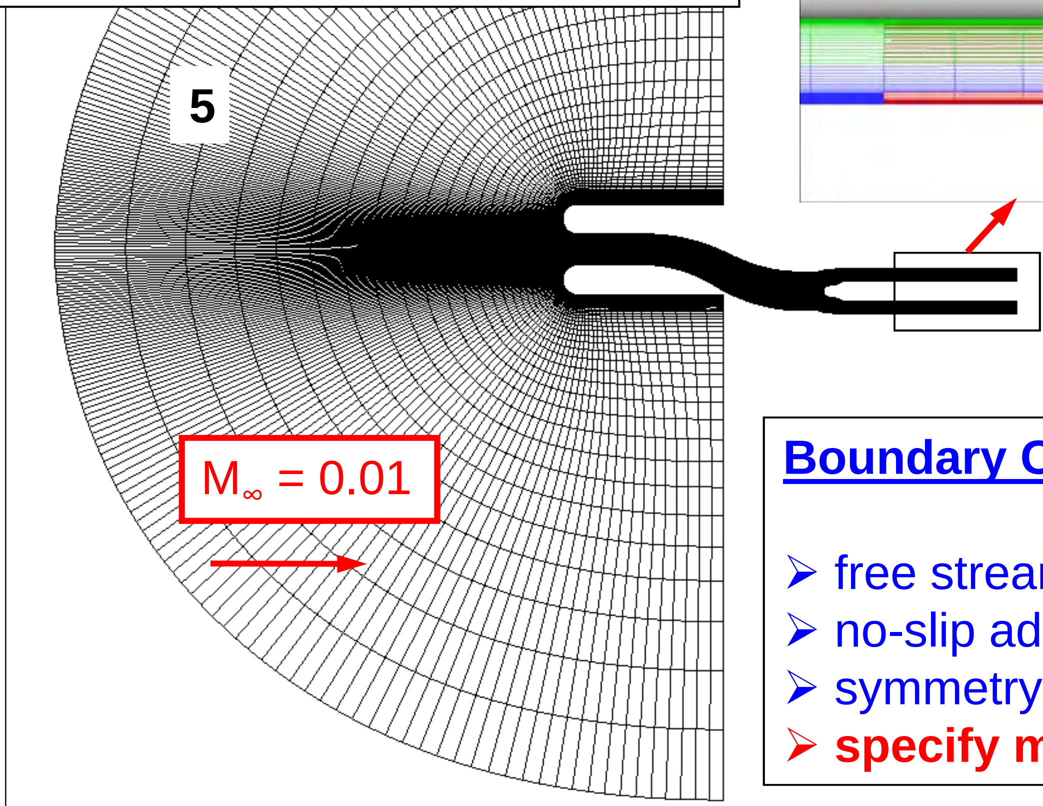
6 mm height
24 mm length
0.6 mm thickness

Flow Solver/Boundary Conditions

OVERFLOW (RANS):

- NASA developed/overset technique
- 3 level multi-grid
- central diff, matrix dissipation
- SST turbulence model





specify mass flow:
2.427 kg/s (standard case)
1.356 kg/s (optional case)

Boundary Conditions:

- free stream/characteristic condition
- no-slip adiabatic wall
- symmetry plane
- **specify mass flow**

Validation – Surface Pressures

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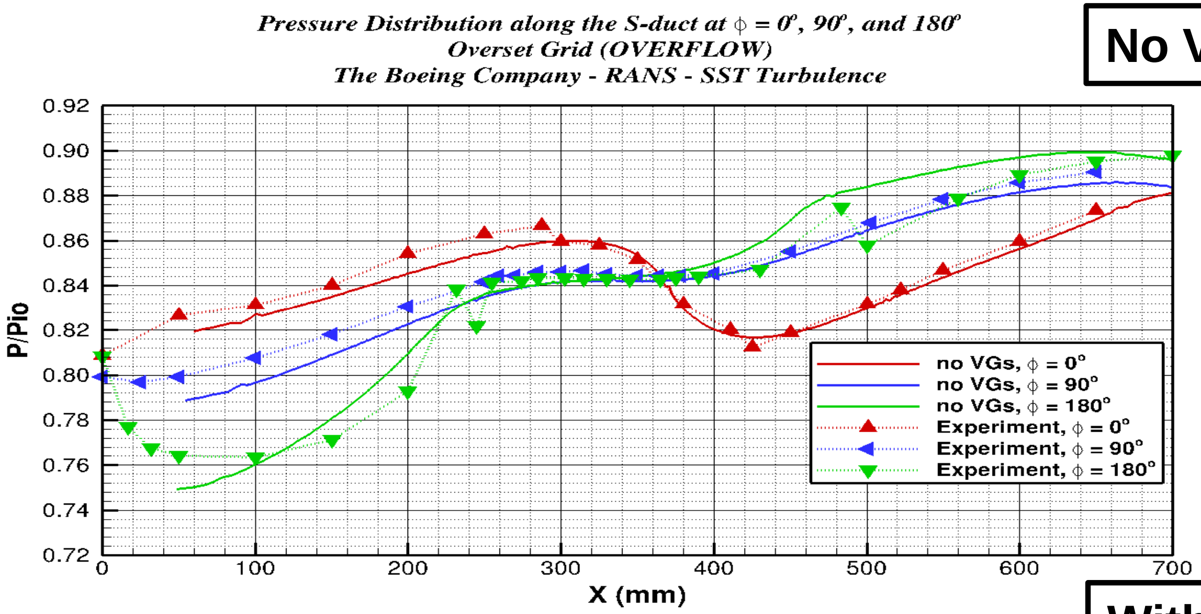
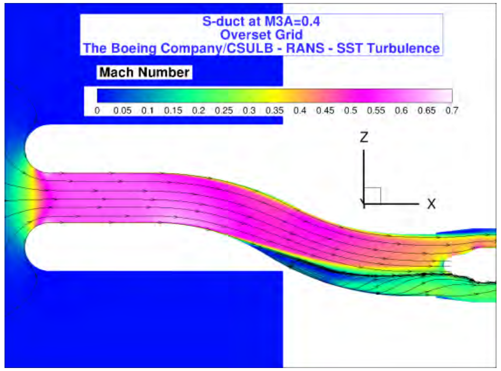
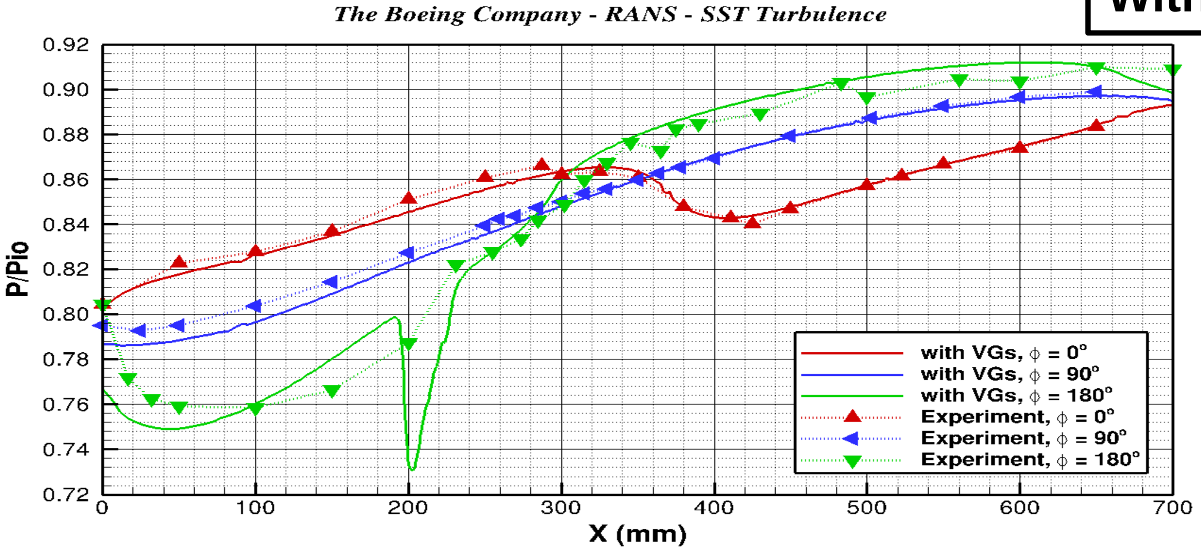
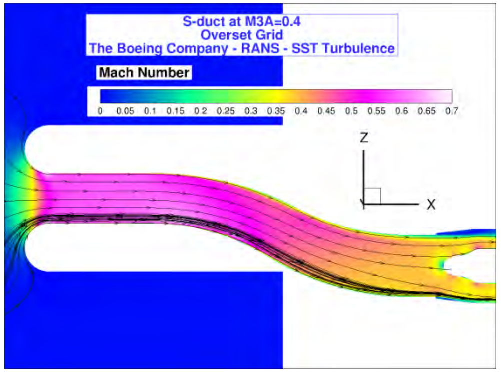


No VGs



With VGs





Validation – Pressure Contours at AIP

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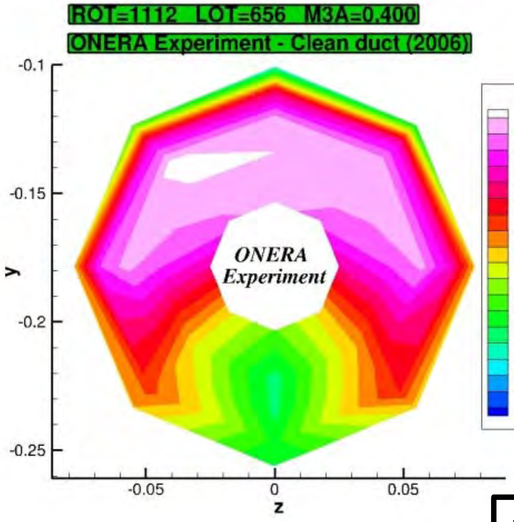
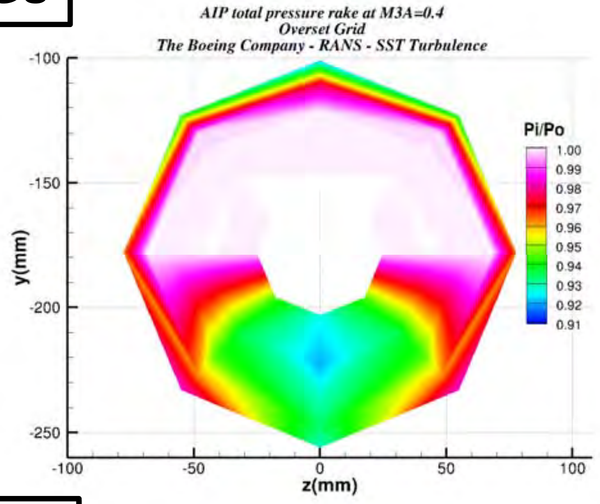
No VGs

Exp.

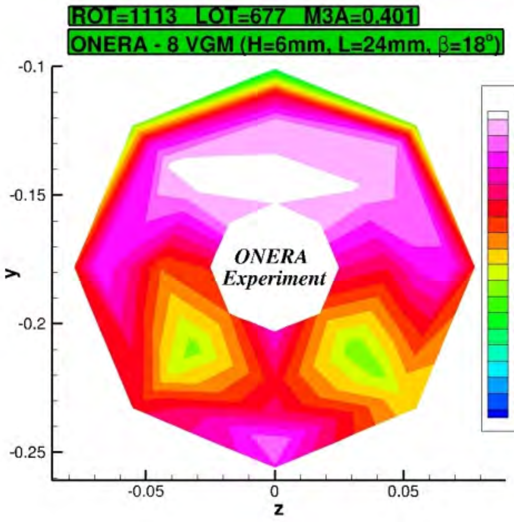


CFD

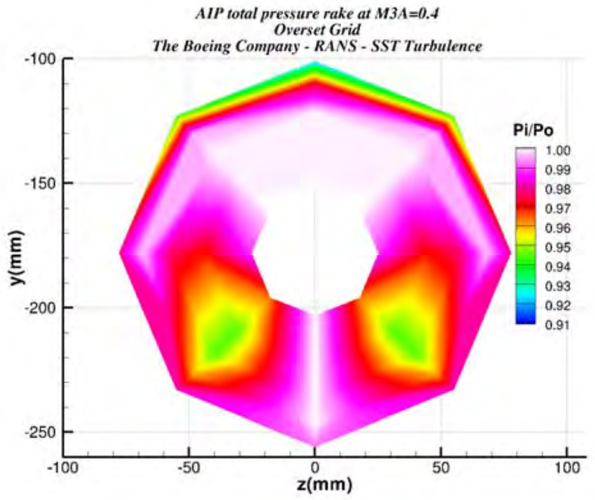


With VGs

Exp.

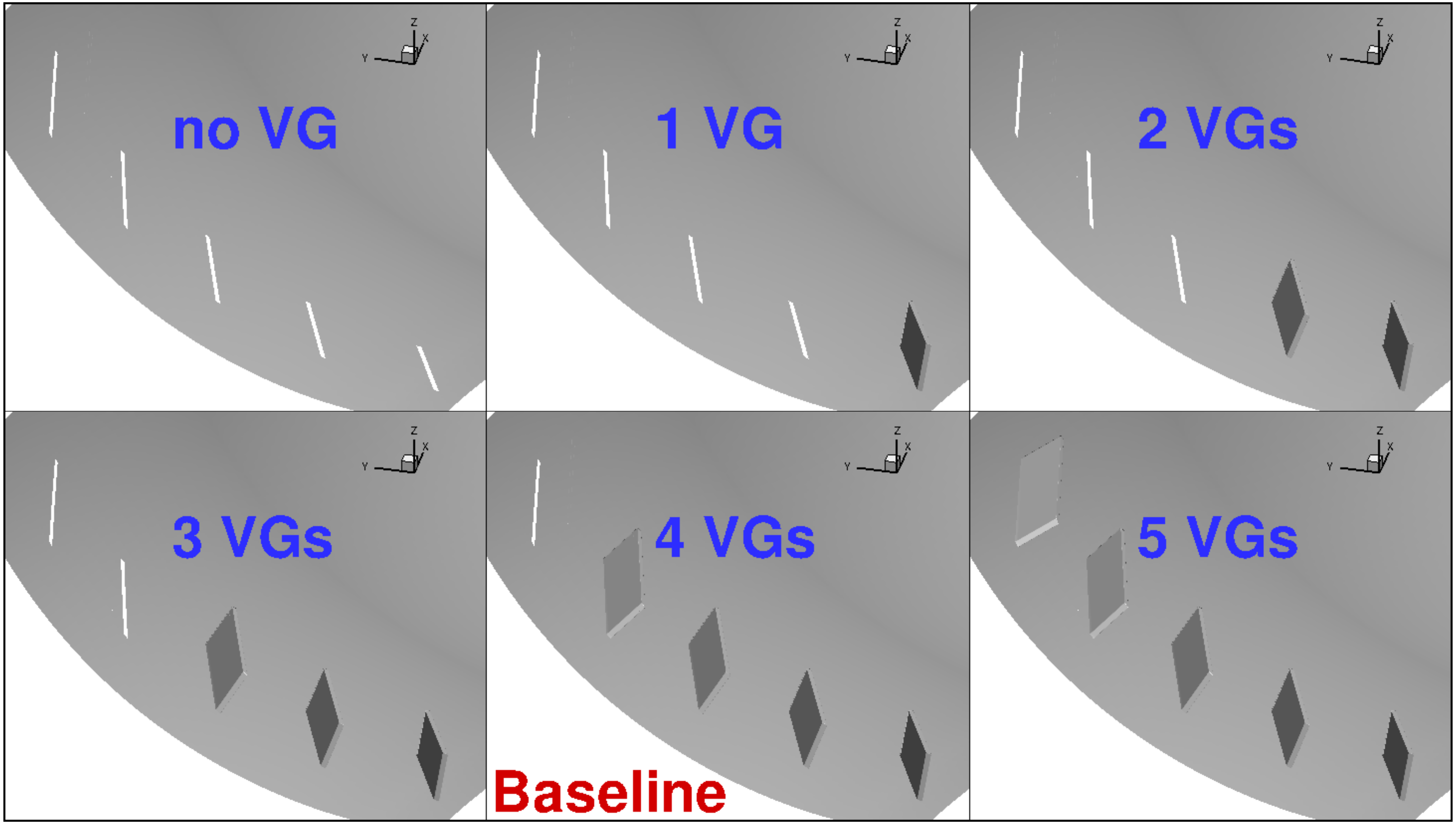


CFD



Passive Flow Control - VGs

Passive Flow Control - VG Number Effect



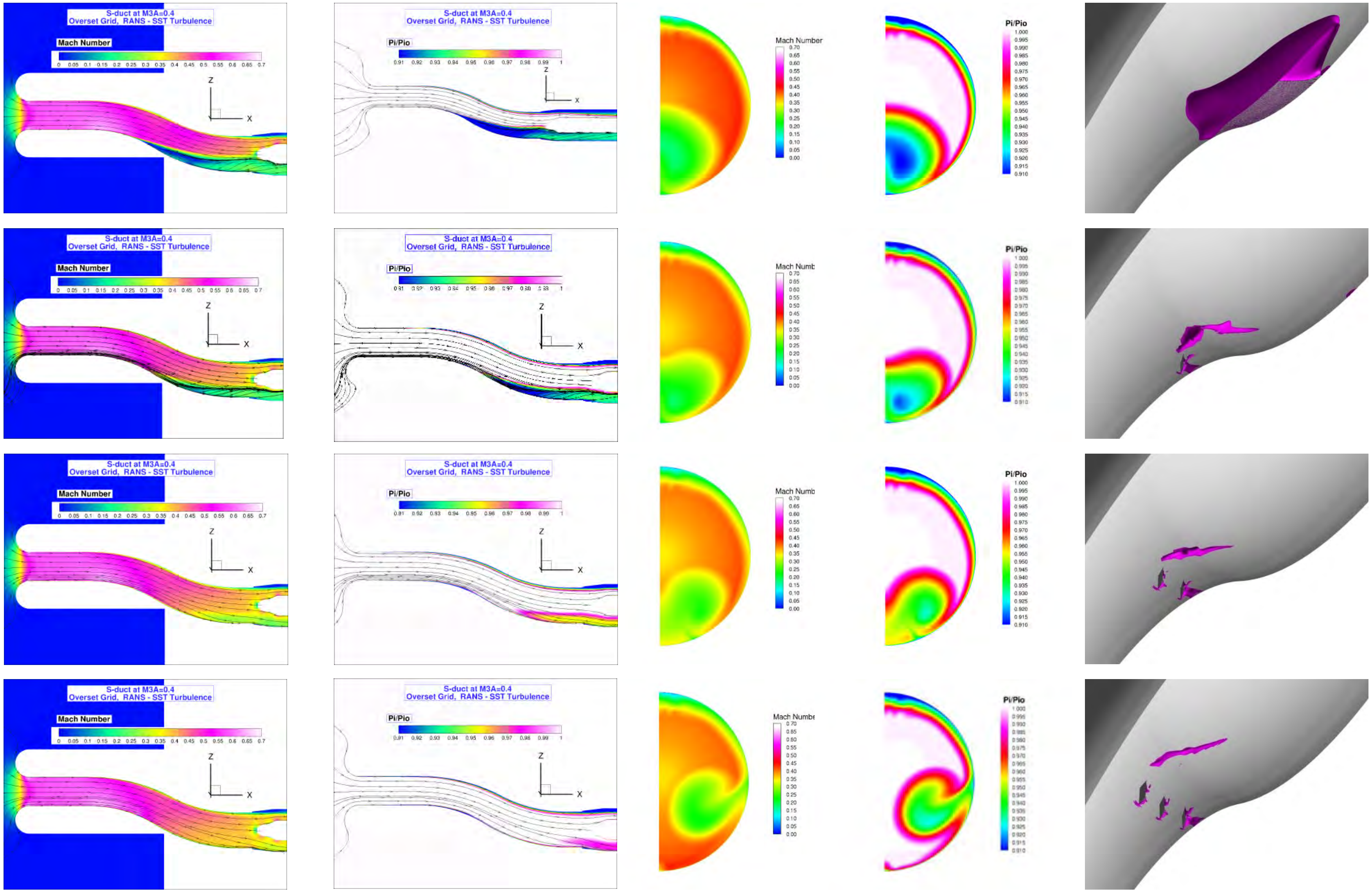
Passive Flow Control - VG Number Effect

No VGs

1 VGs

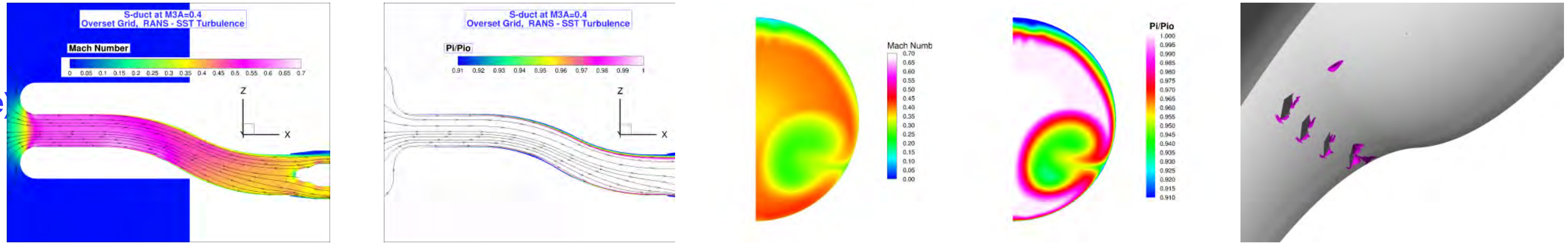
2 VGs

3 VGs

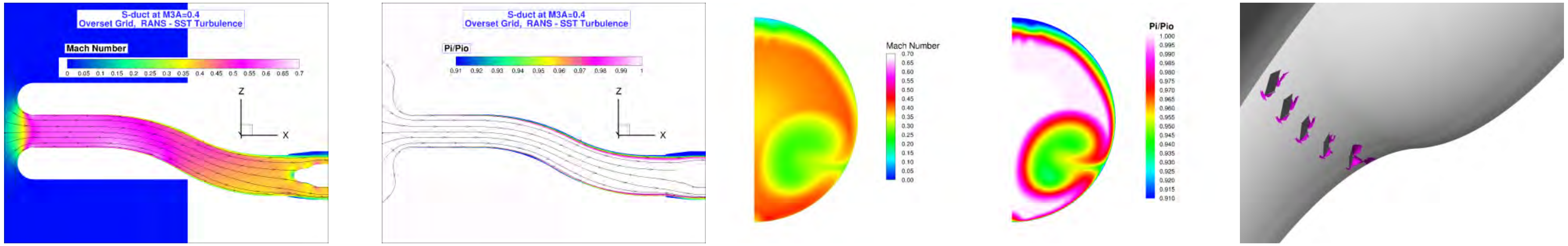


Passive Flow Control - VG Number Effect

4 VGs
(baseline)



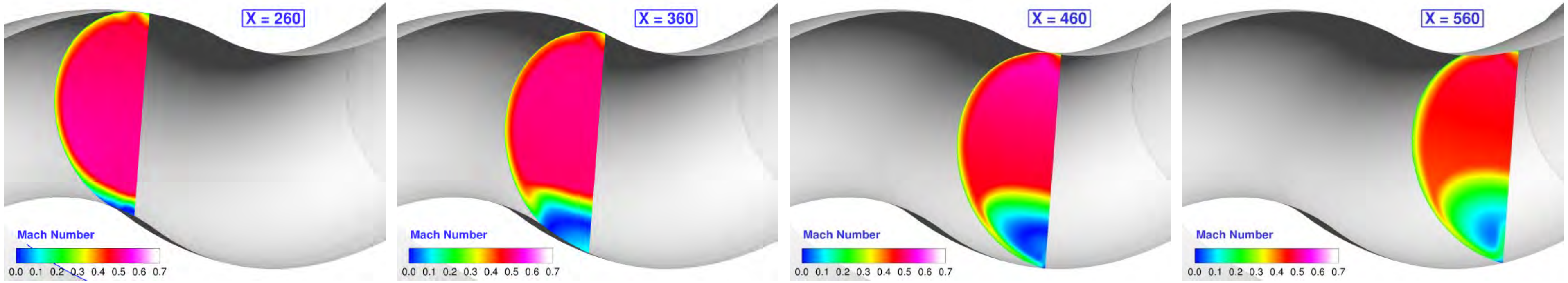
5VGs



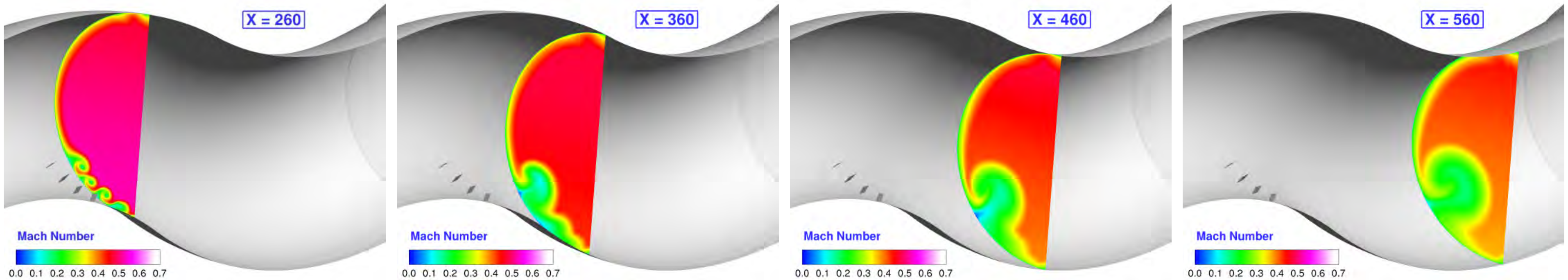
Mach contours at different X cut

No VGs vs With VGs (mass flow = 2.427 kg/s)

No VGs



With VGs



Passive Flow Control - VG Height Effect

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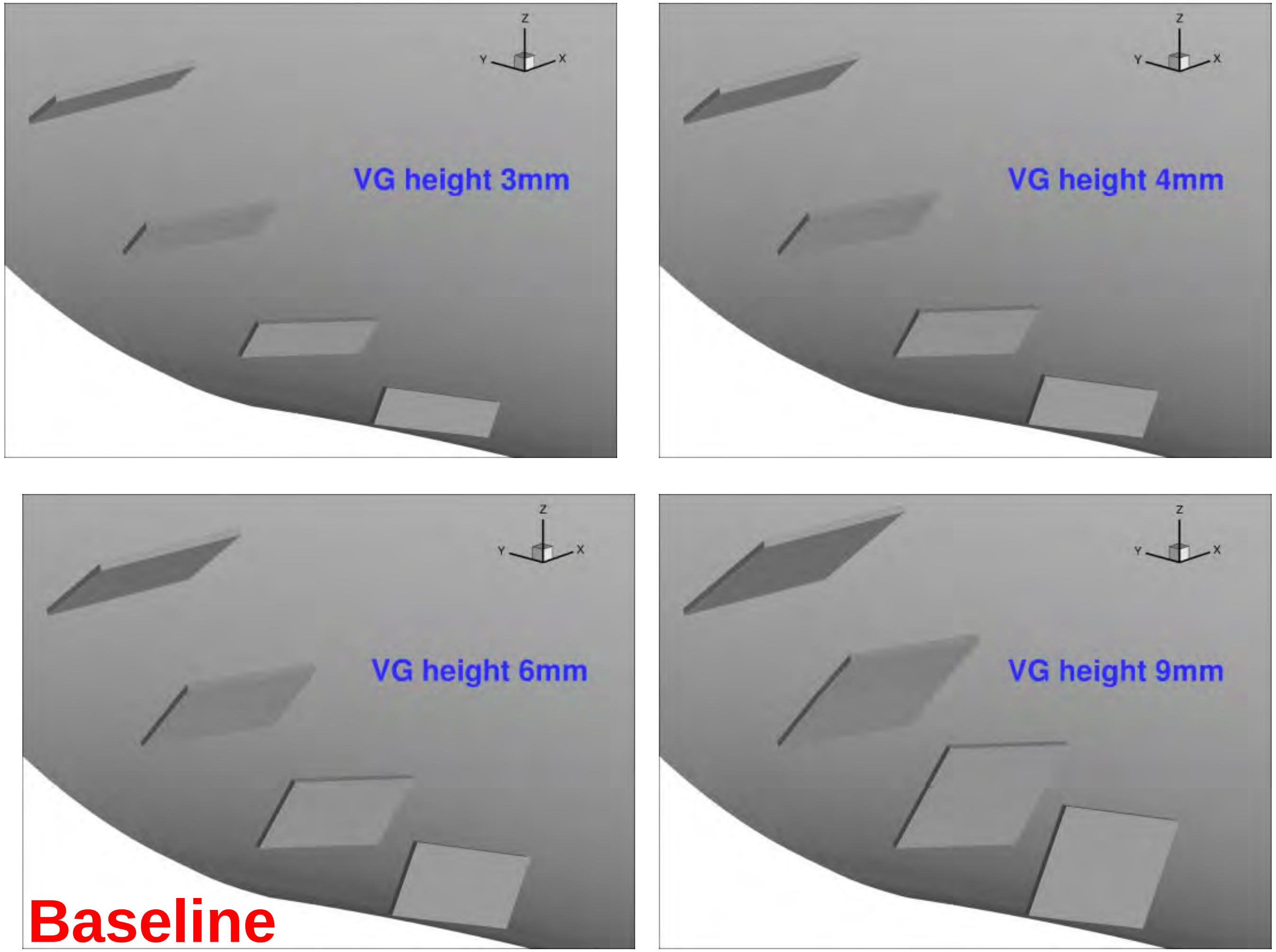


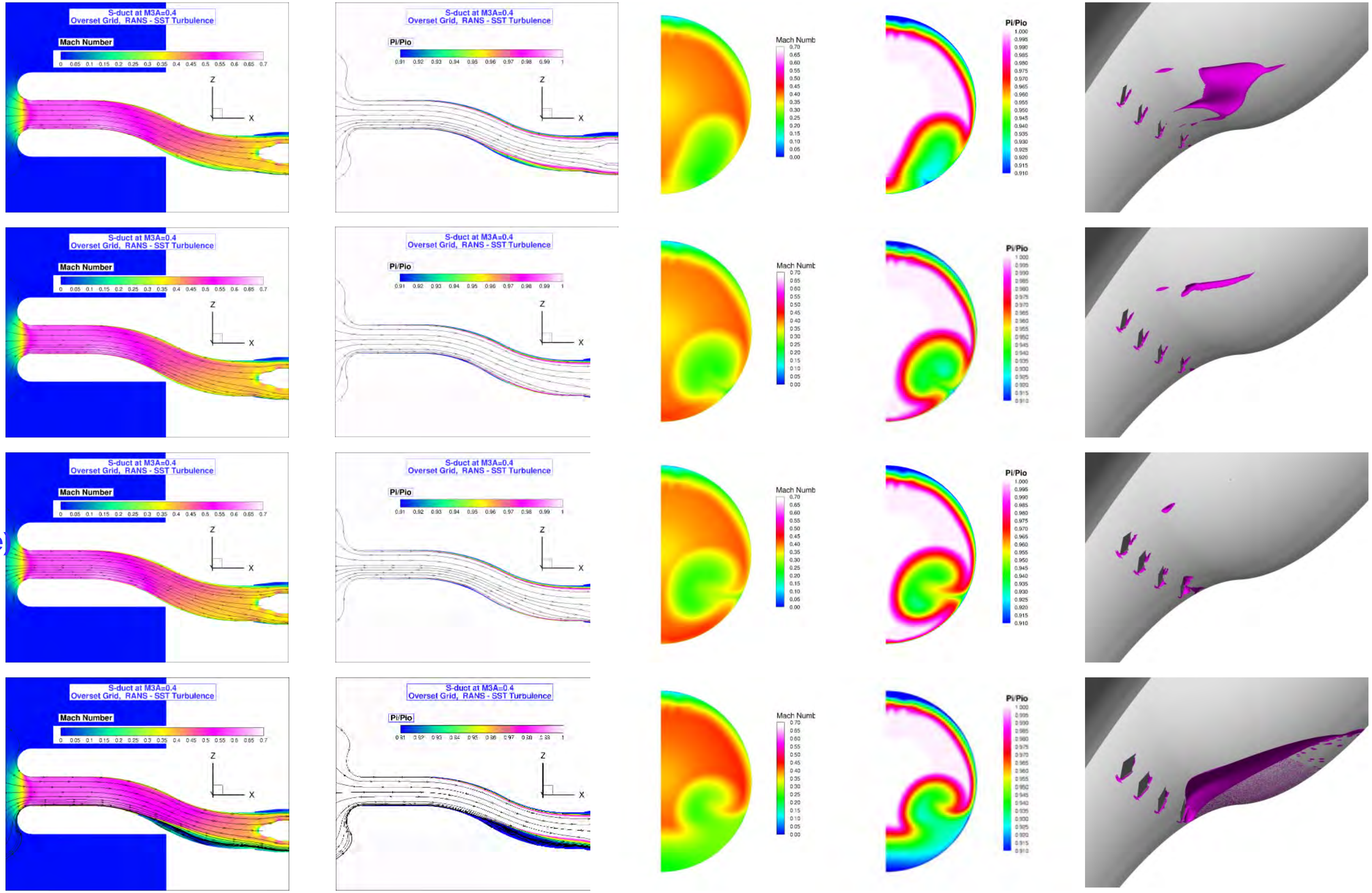
Passive Flow Contorl - VG height Effect

3mm

4mm

6mm baseline)

9mm



Passive Flow Control – VG Angle Effect

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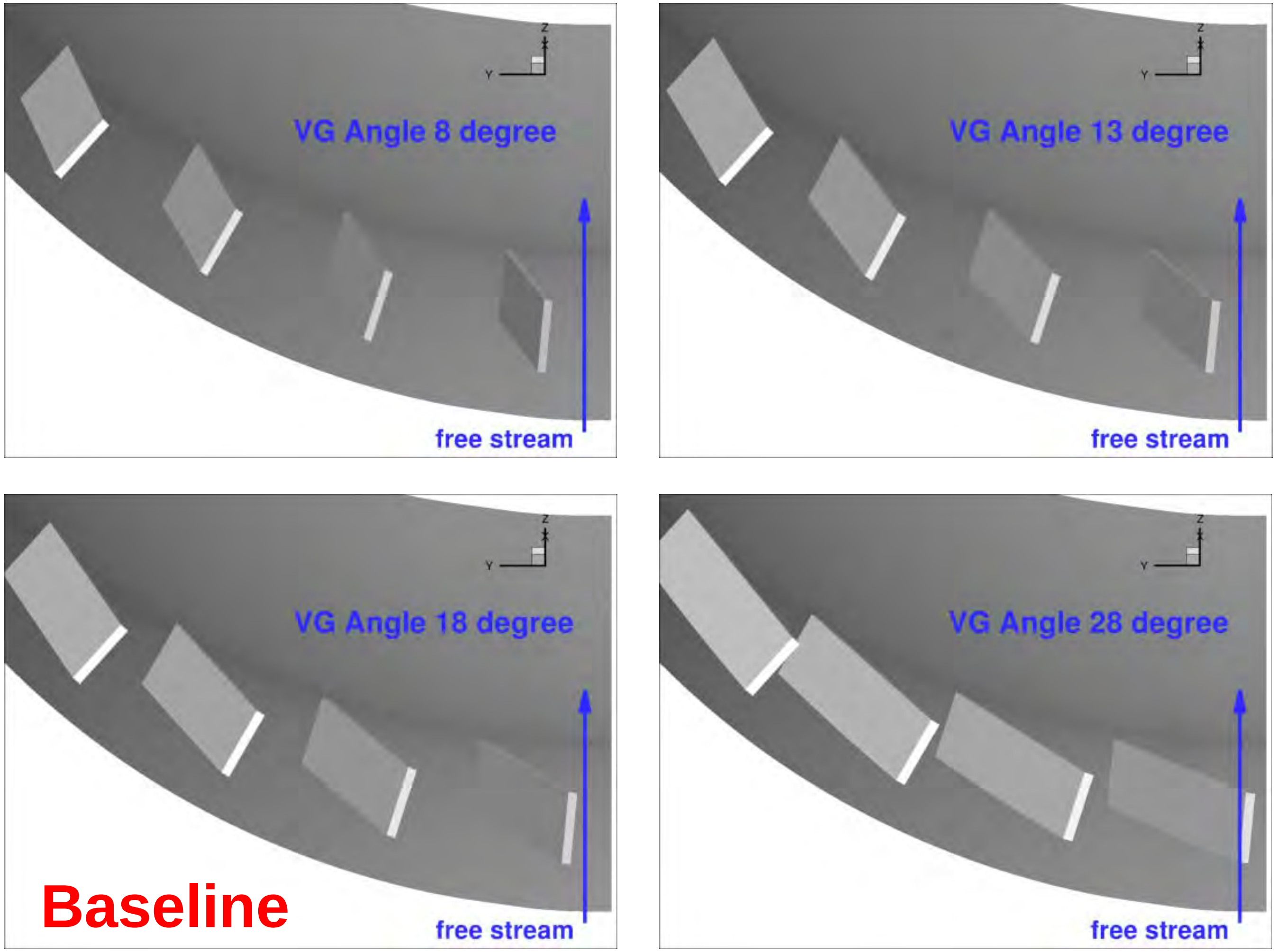

Passive Flow Control - VG Angle Effect

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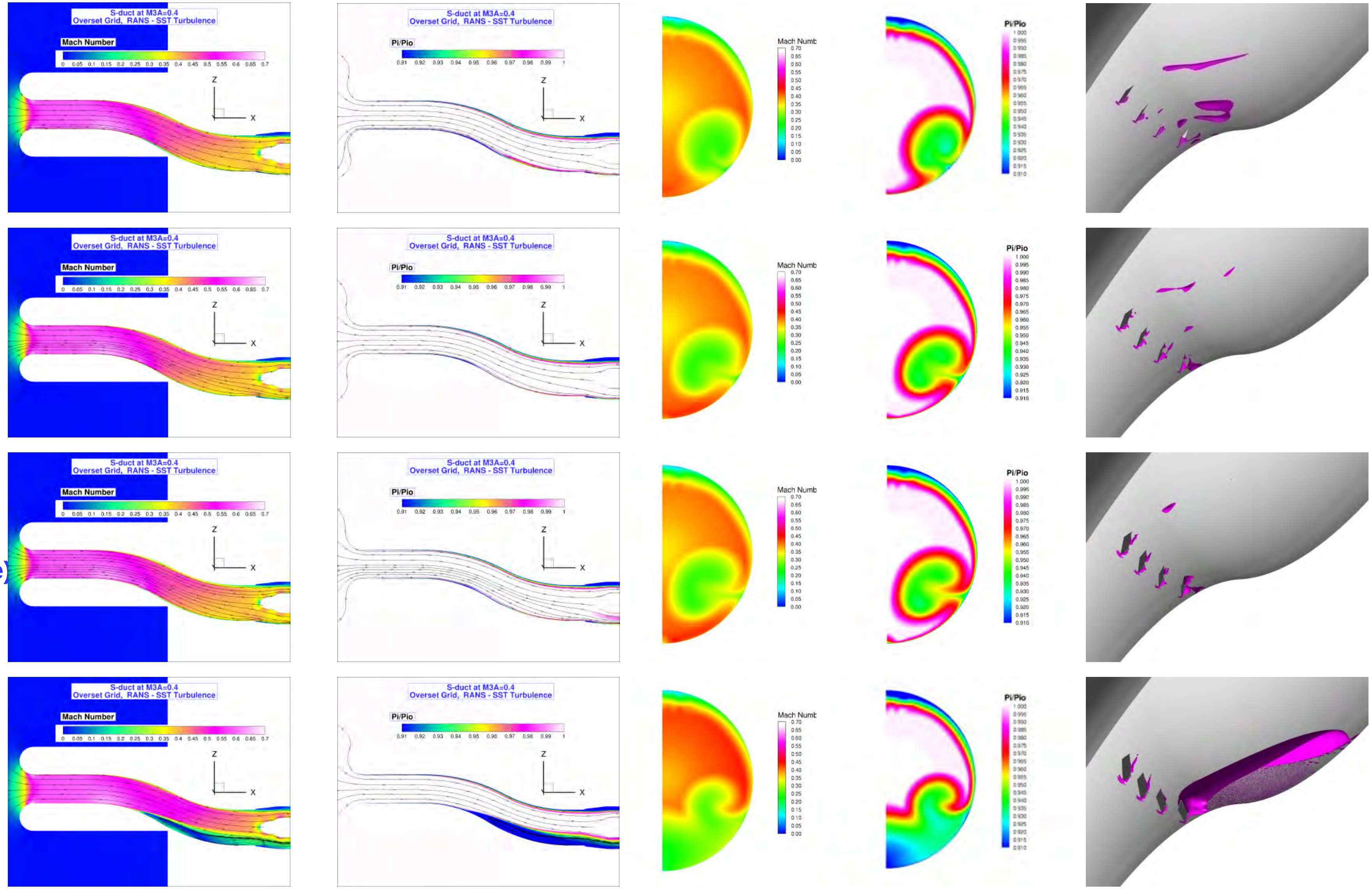
VG@ 8 deg

VG@ 13 deg

VG@ 18 deg baseline)

VG@ 28 deg



Passive Flow Contorl - VGs

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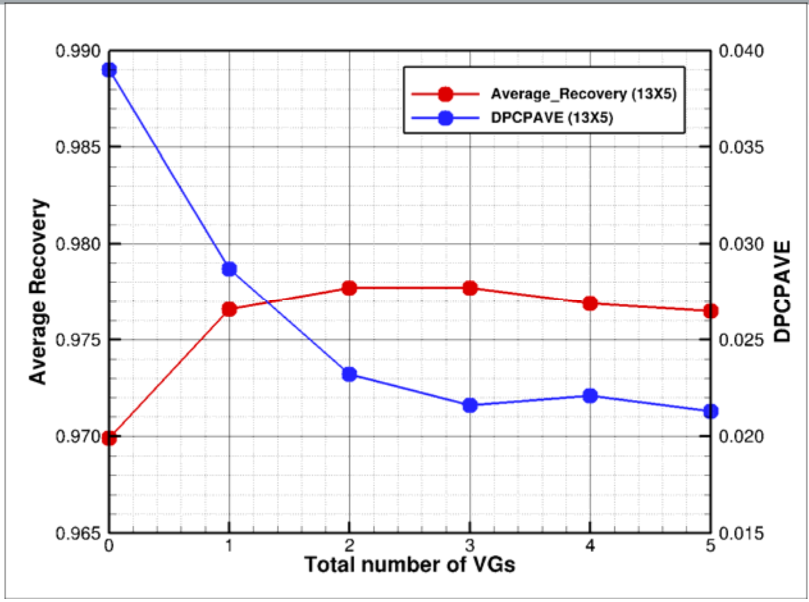
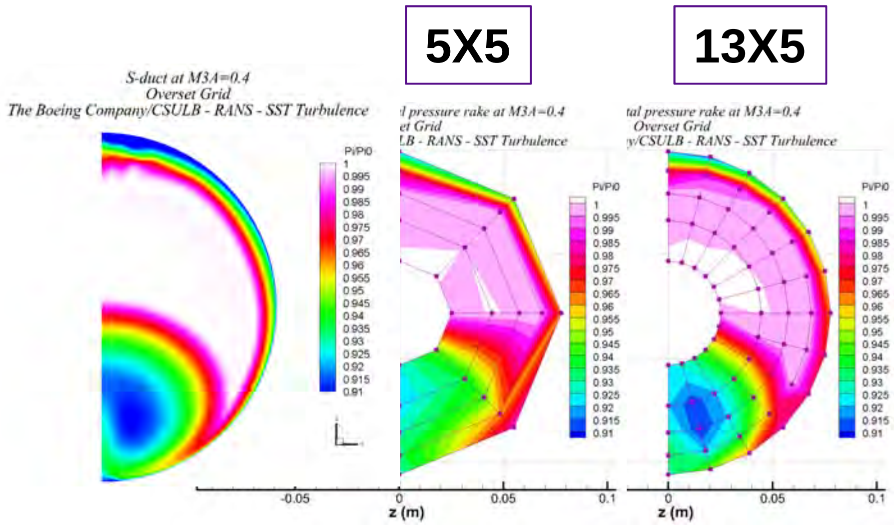
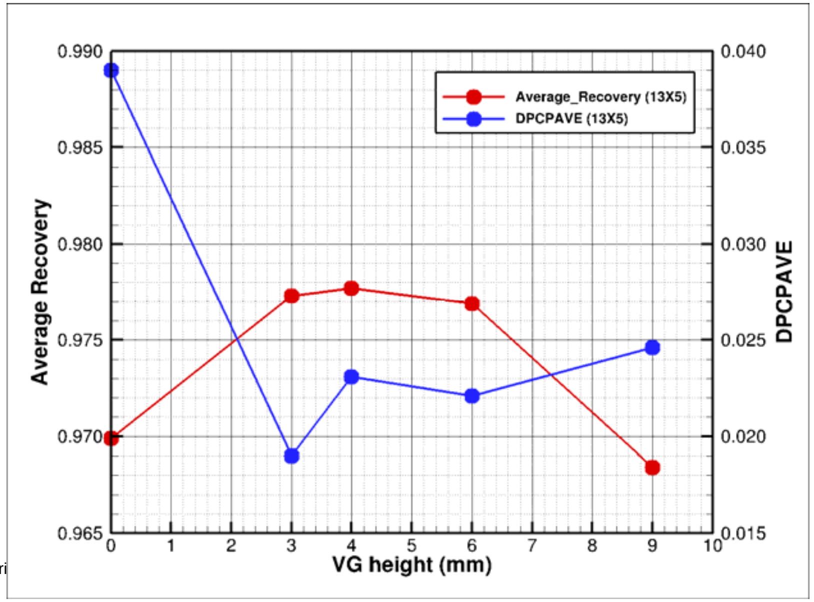
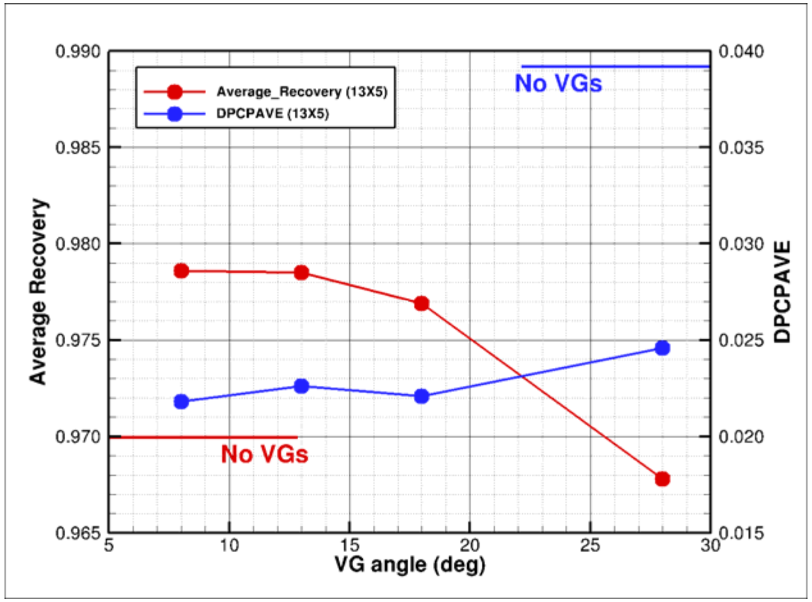
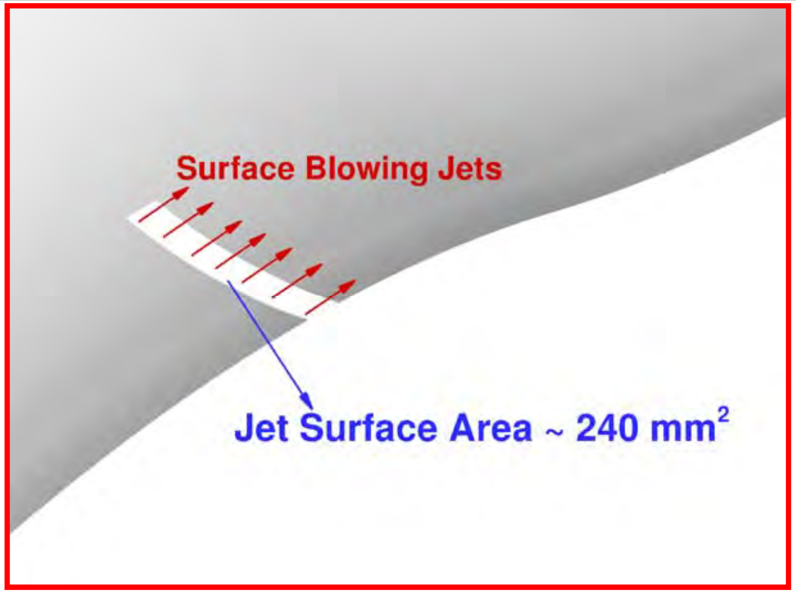






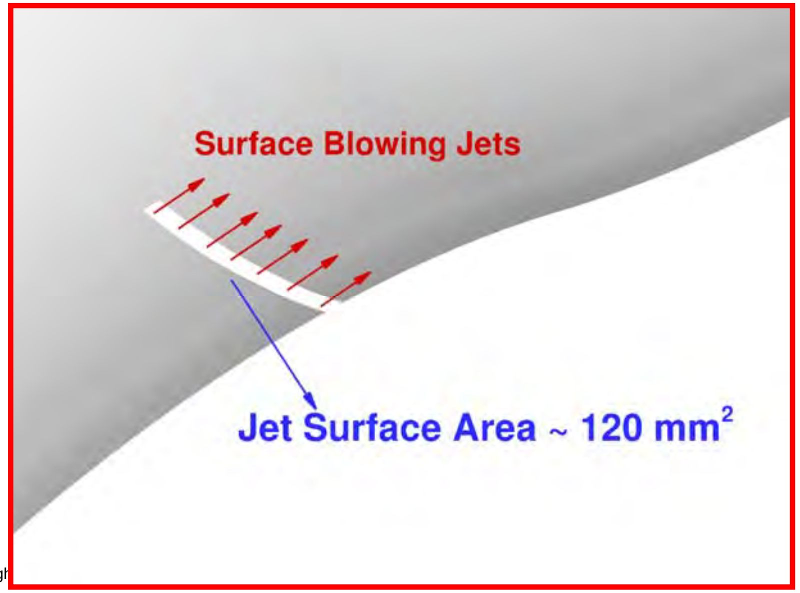


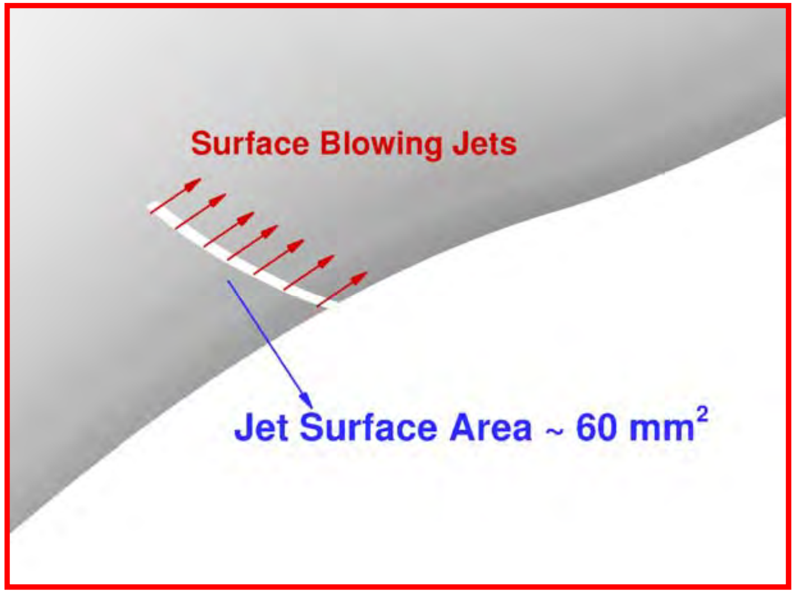
Active Flow Control – Surface Blowing Jets



- Blowing jets applied at surface with pre-defined velocity and direction
- Jet velocity is controlled by P/P_∞
- Mass flow rate of the jets is decided by the jet velocity and area it applies

- Three AFC configurations (areas) each with three different mass flow rate are simulated





Active Flow Control – Surface Blowing Jets

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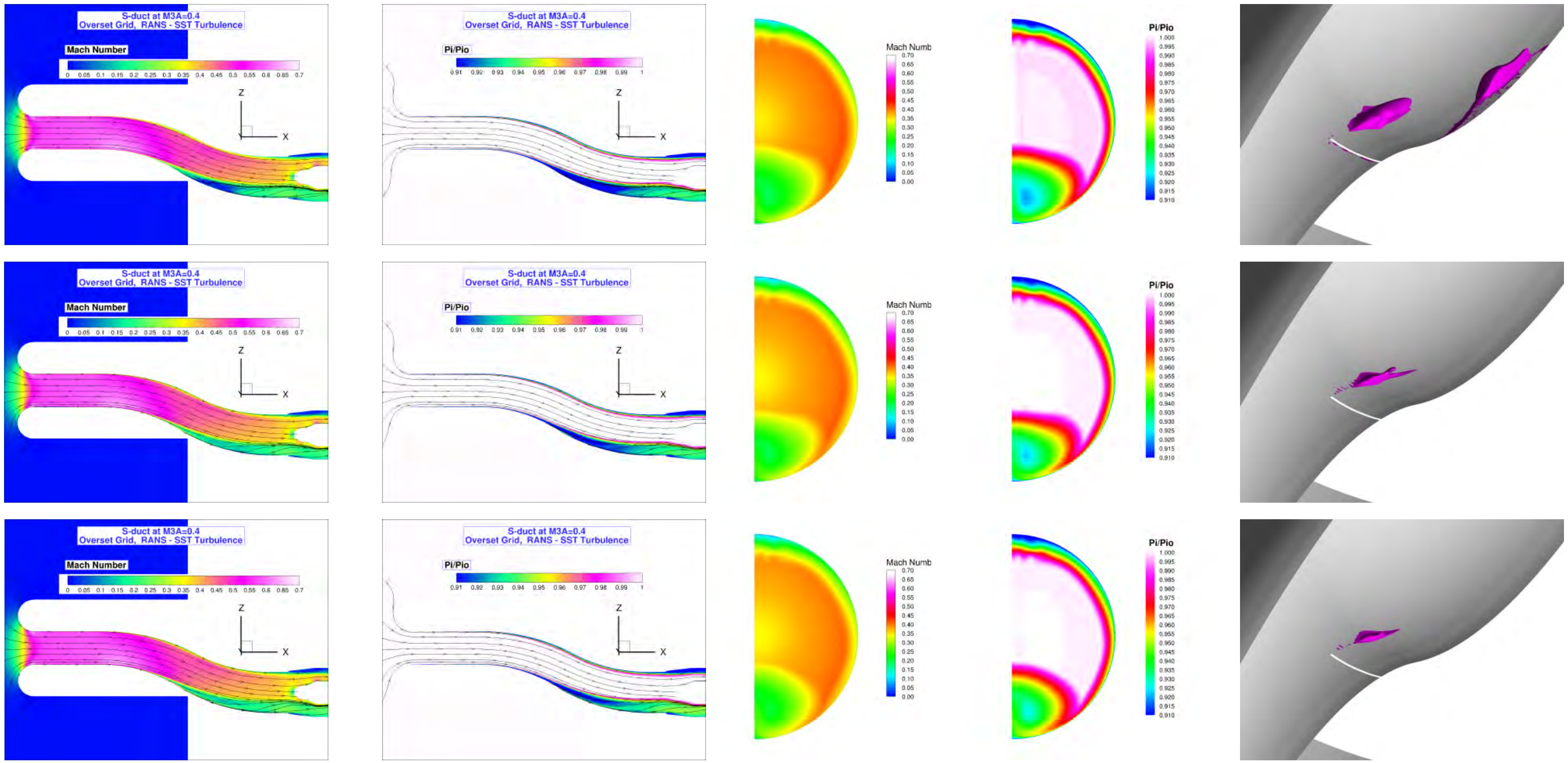
60mm^2 Pt22.4

60mm^2 Pt29.2

60mm^2 Pt36.5



Active Flow Control – Surface Blowing Jets

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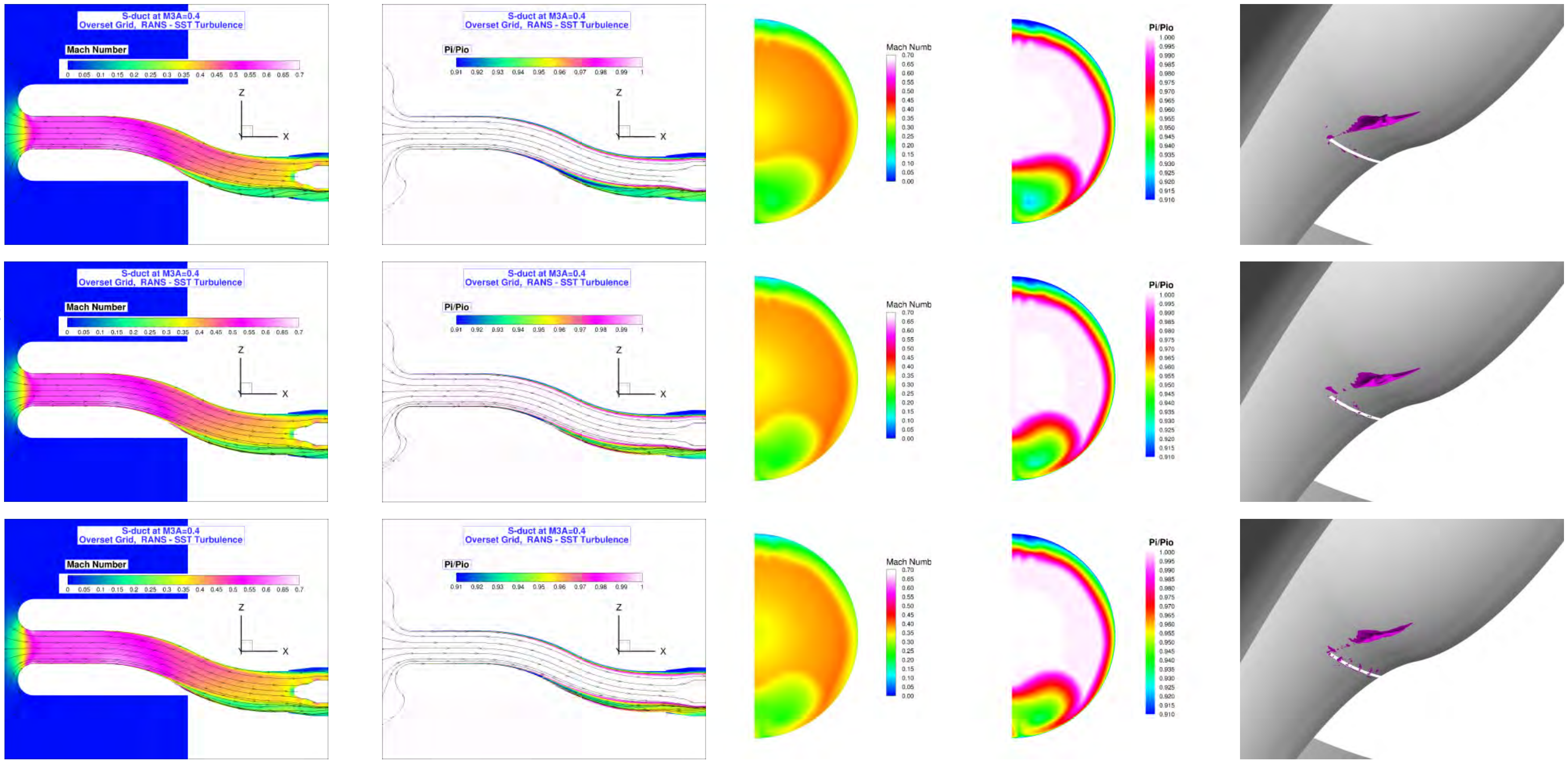
120mm^2
Pt22.4

120mm^2
Pt29.2

120mm^2
Pt36.5



Active Flow Control – Surface Blowing Jets

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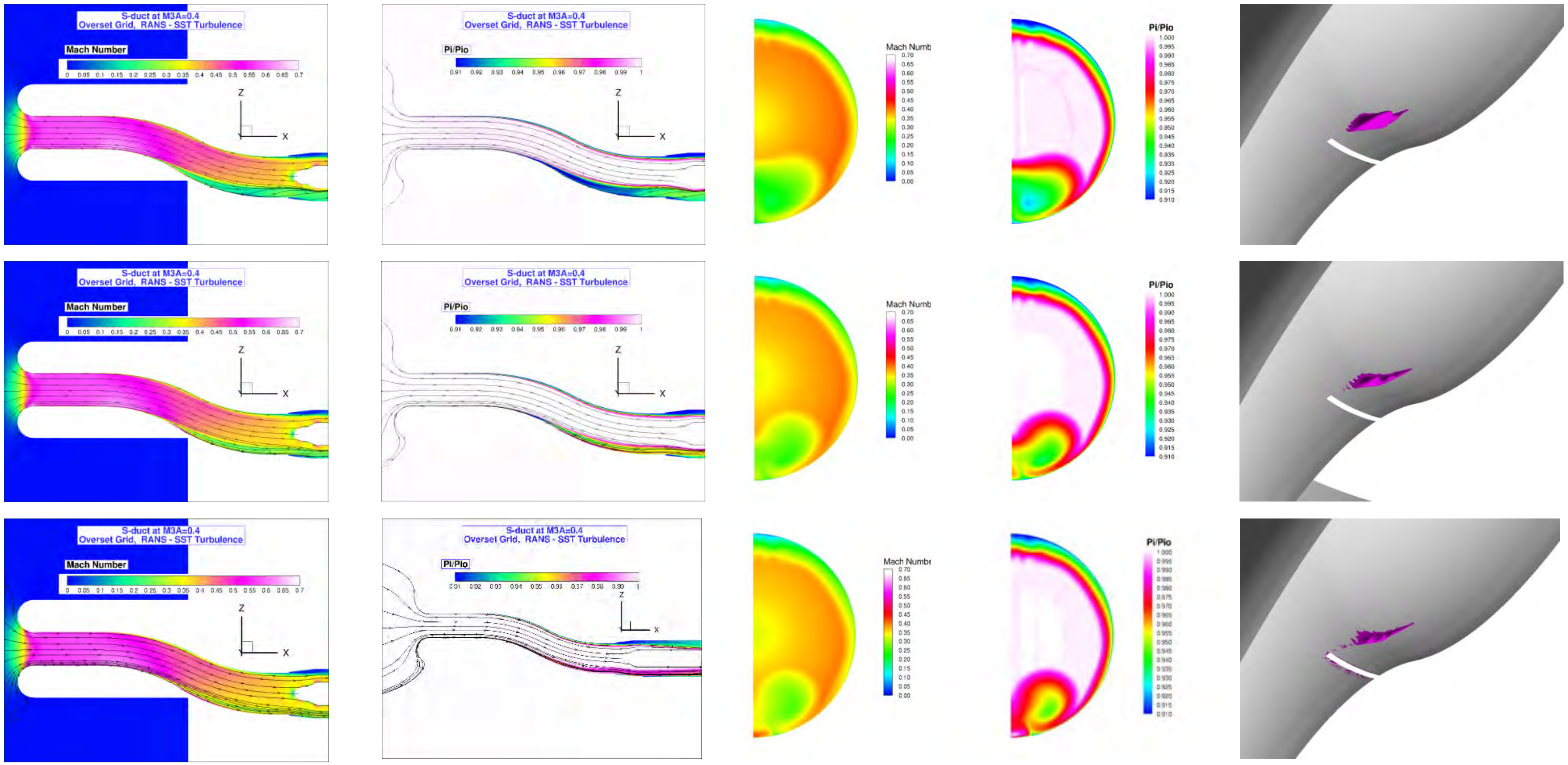
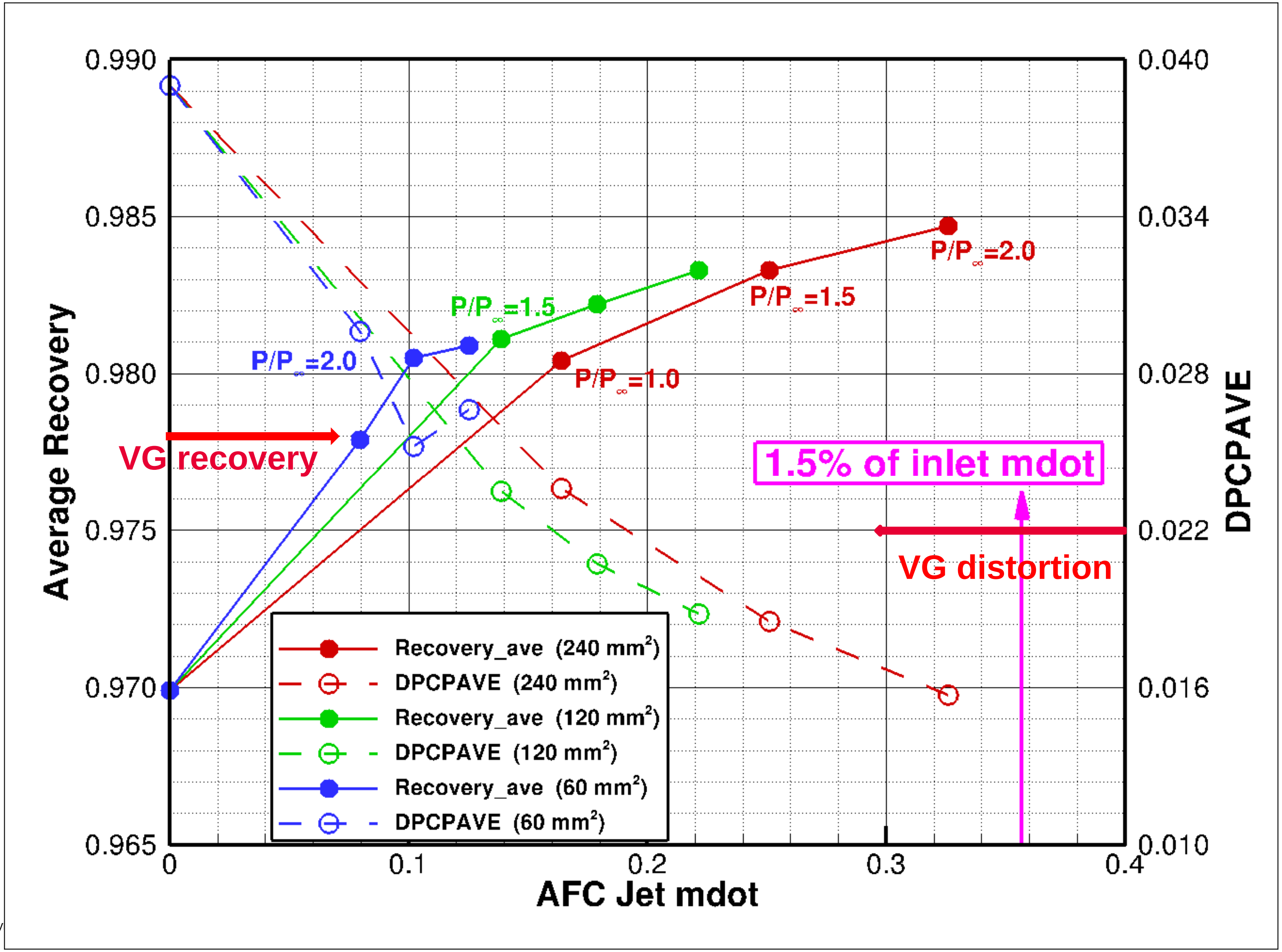
240mm^2 Pt14.6

240mm^2 Pt22.4

240mm^2 Pt29.2



Active Flow Control – Surface Blowing Jets



Active Flow Control – Surface Blowing Jets

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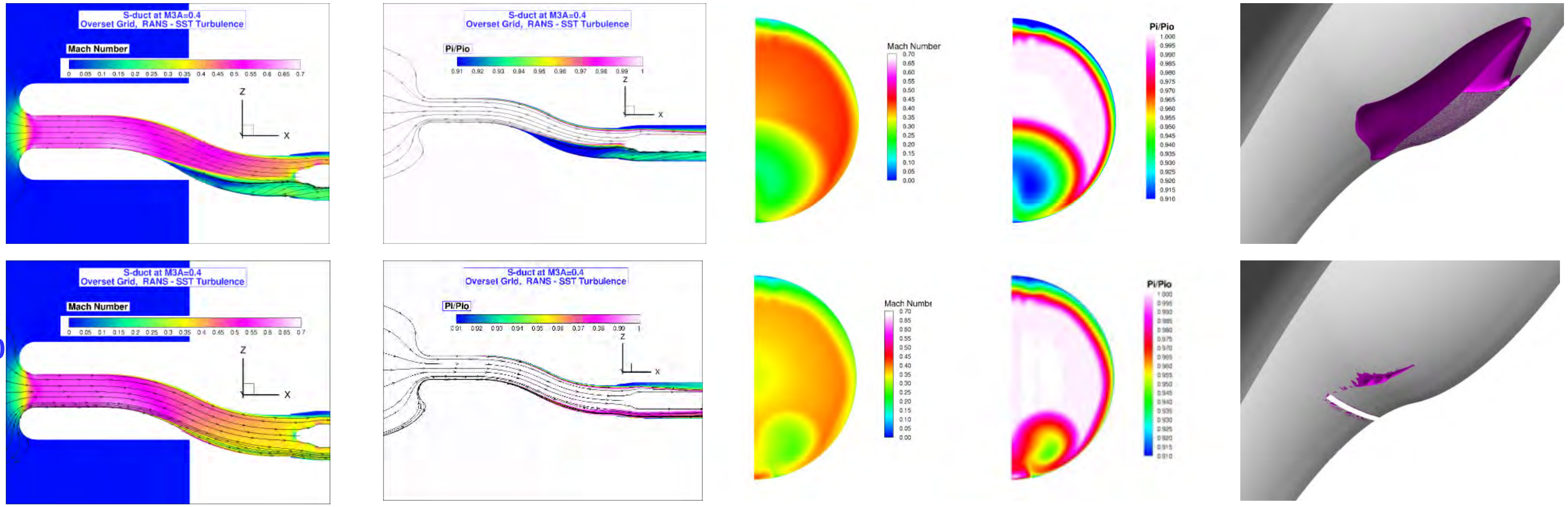
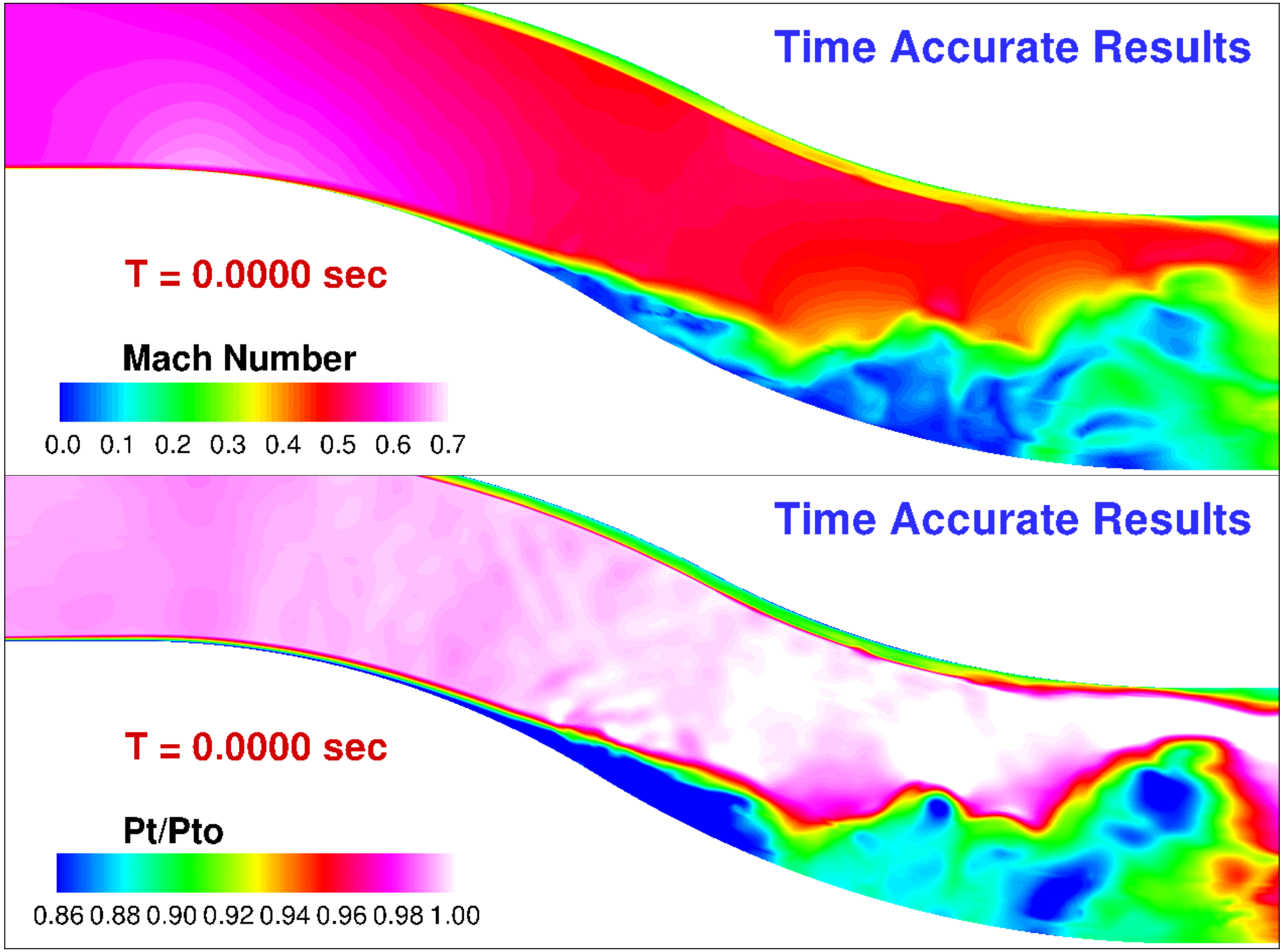
baseline

240mm^2
P/P0=2.0



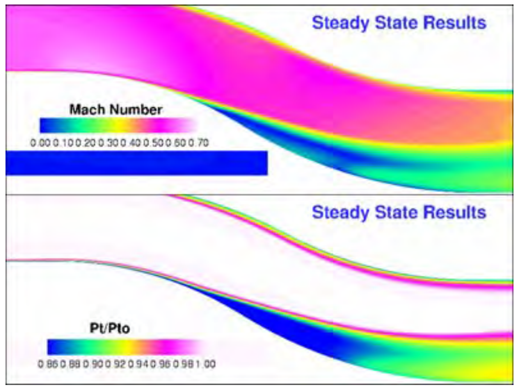
Time Accurate Run (URANS)

Time Accurate Results – ONERA S-Duct



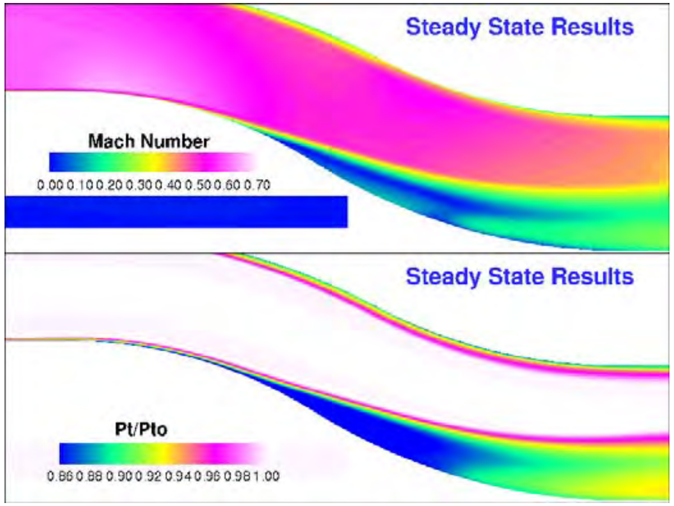
AIP Face Recovery
0.9707

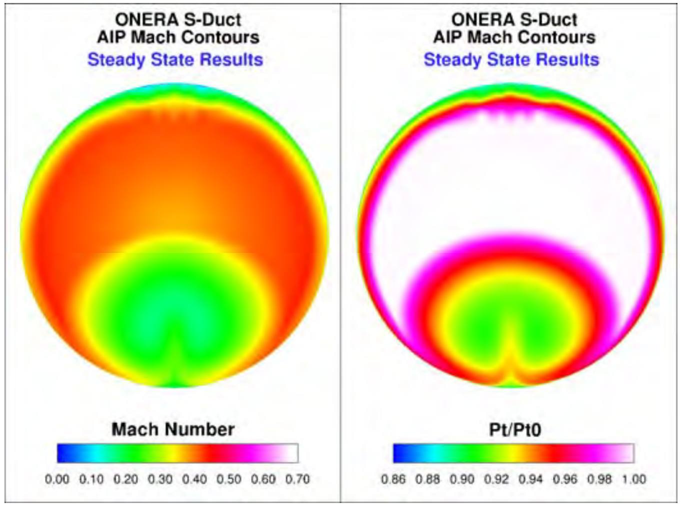
SAE DPCPAV for all rings
0.0374



Time Accurate Results – ONERA S-Duct

Steady State Results

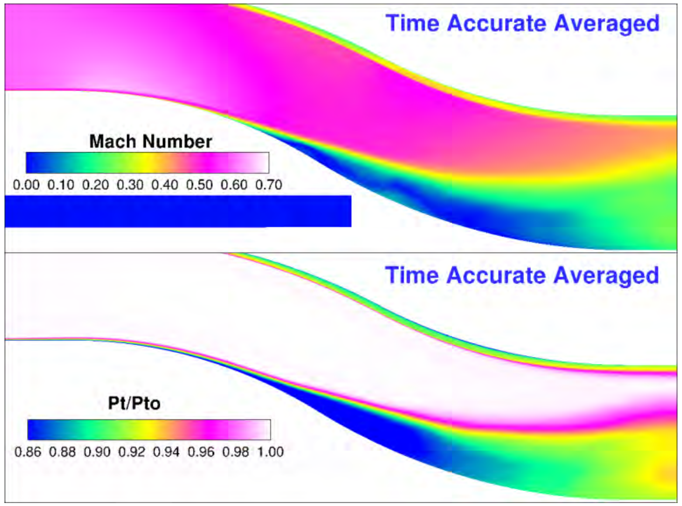


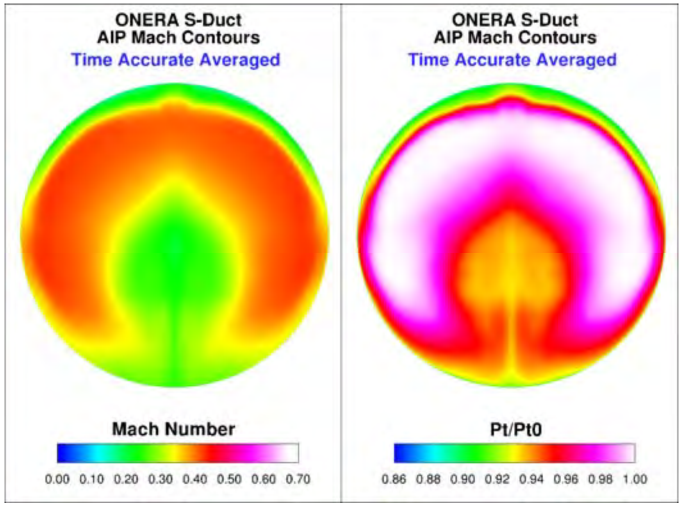


AIP Face Recovery
0.9707

SAE DPCPAV for all rings
0.0347

Time Accurate Averaged





AIP Face Recovery
0.9691

SAE DPCPAV for all rings
0.0231

Conclusions

- CFD simulation using Overset grid approach is conducted for serpentine S-duct with and without VGs
- CFD results are validated with experimental data
- VG configurations include VG number, height, and orientation angle are simulated and studied
- Recovery and circumferential distortion are computed to measure flow quality
- CFD based AFC technique is employed to improve the flow quality
- AFC offers better improvement relative to passive control

Back Up Charts

Validation – Turbulence Model

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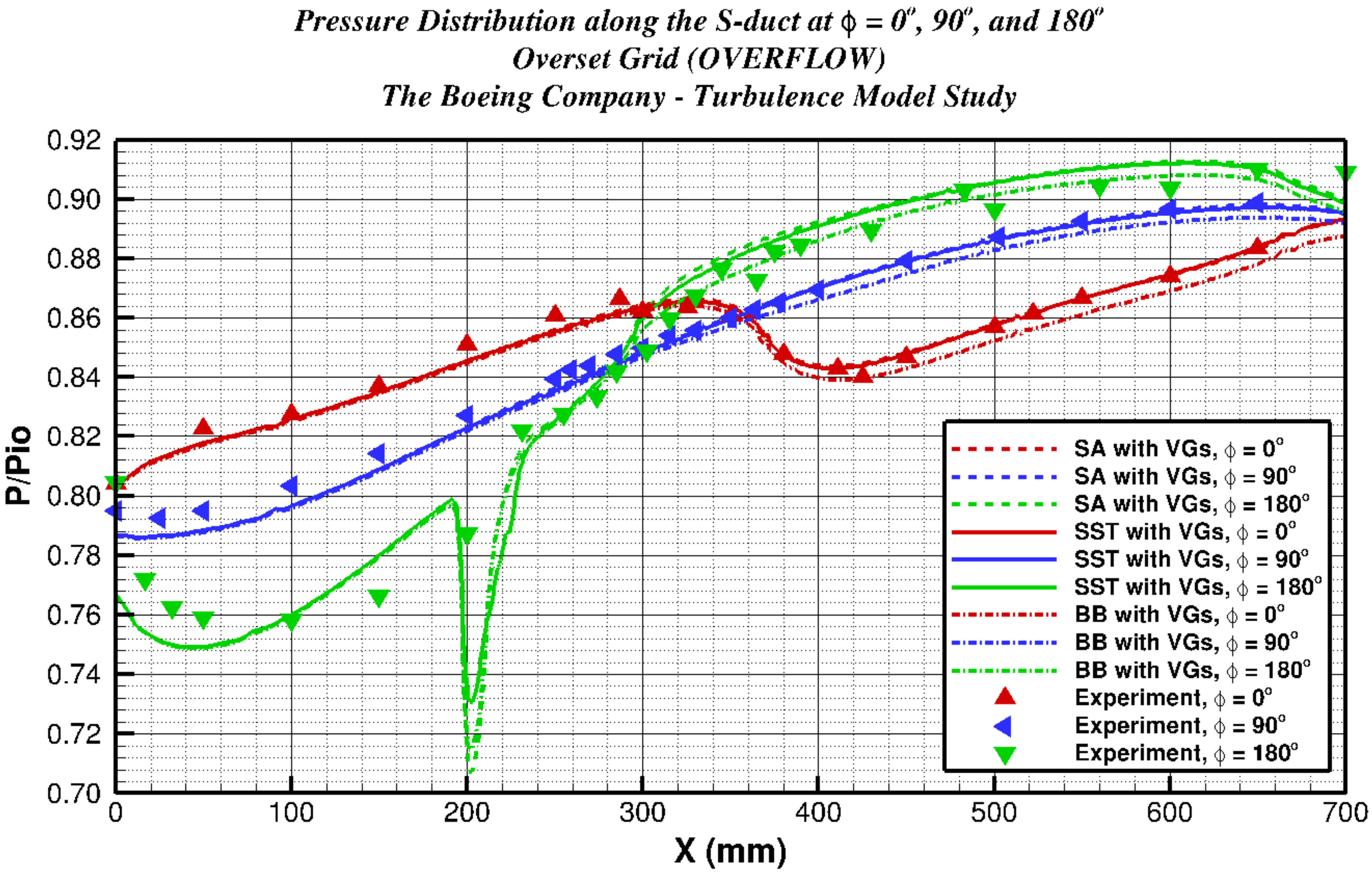
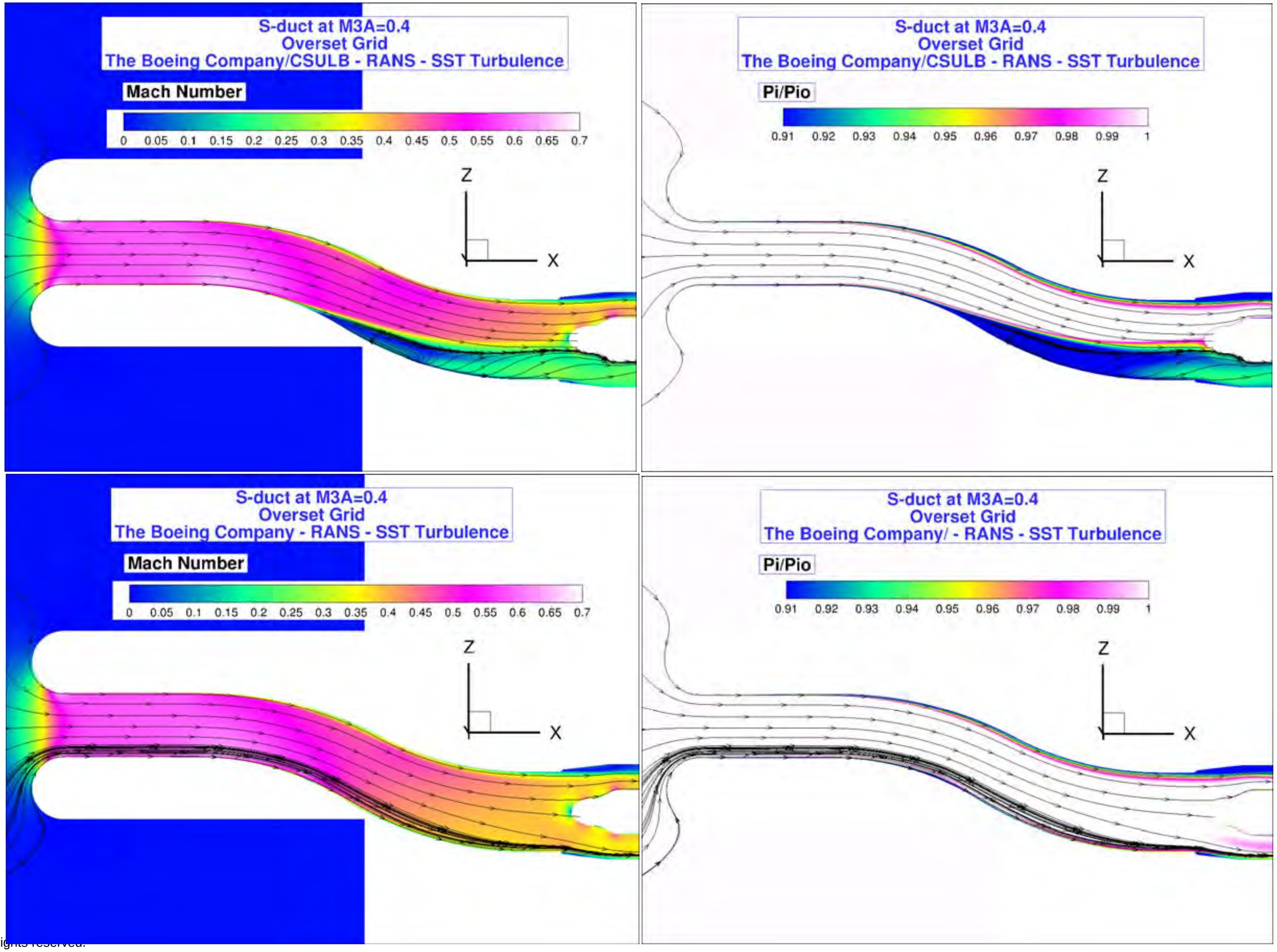


Results – Symmetric Plane Mach and Pi/Pio Contours

No VGs vs With VGs (mass flow = 2.427 kg/s)

No VGs

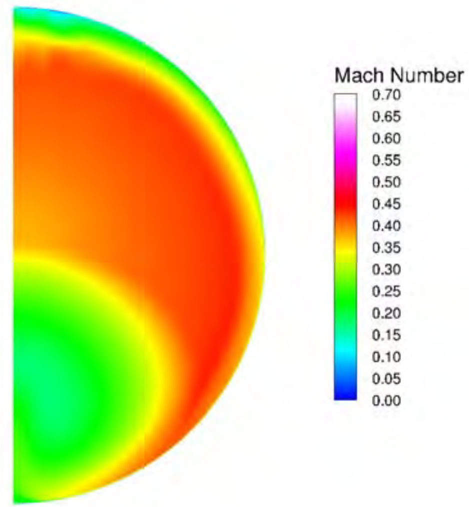
With VGs

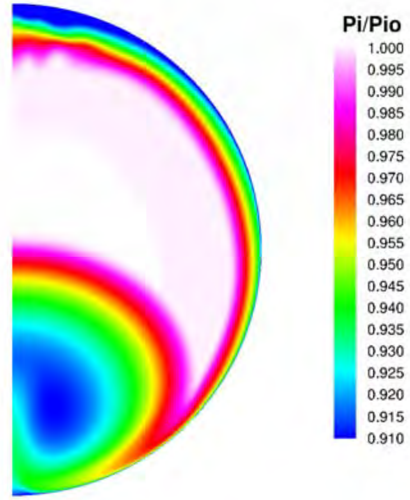


Results – AIP Mach and Pi/Pio Contours

No VGs vs With VGs (mass flow = 2.427 kg/s)

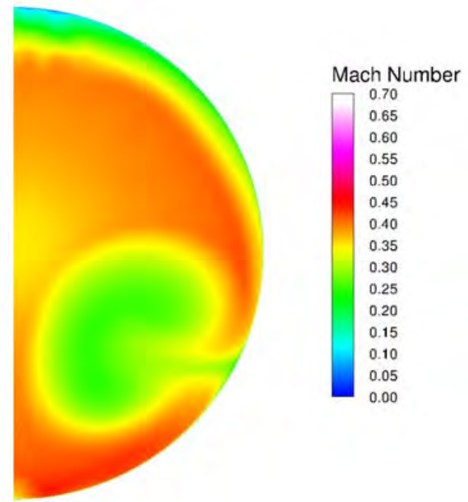
No VGs

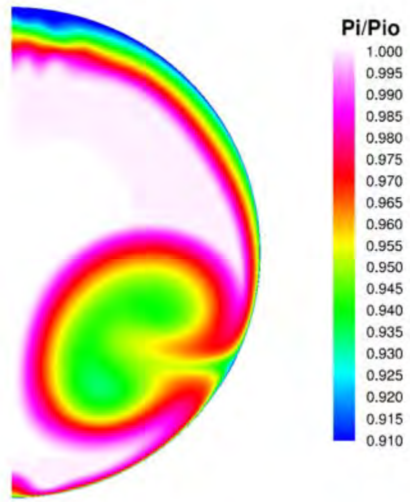




AIP

With VGs





Results – Mach contours at different X cut

No VGs vs With VGs (mass flow = 2.427 kg/s)

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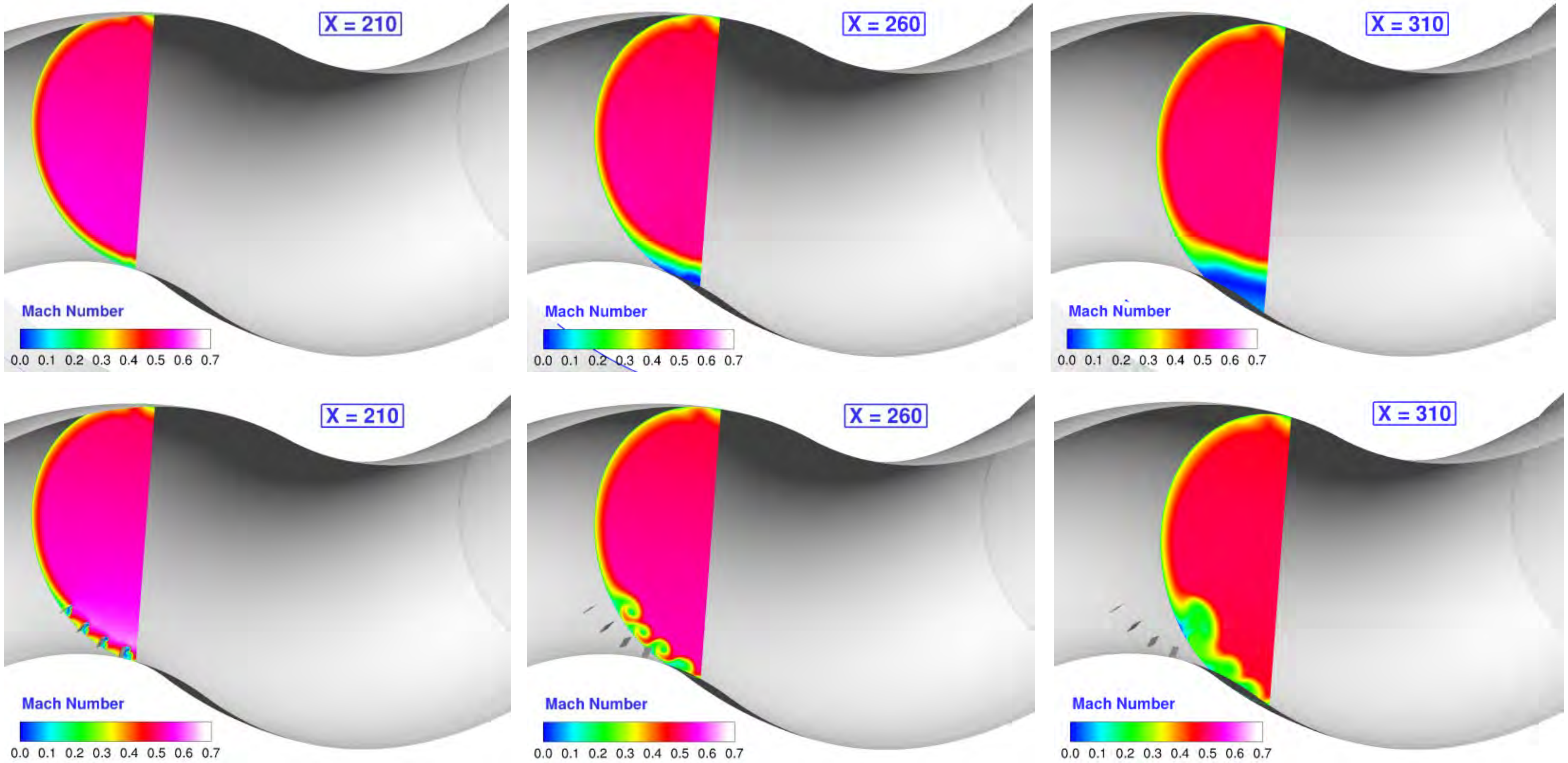
No VGs

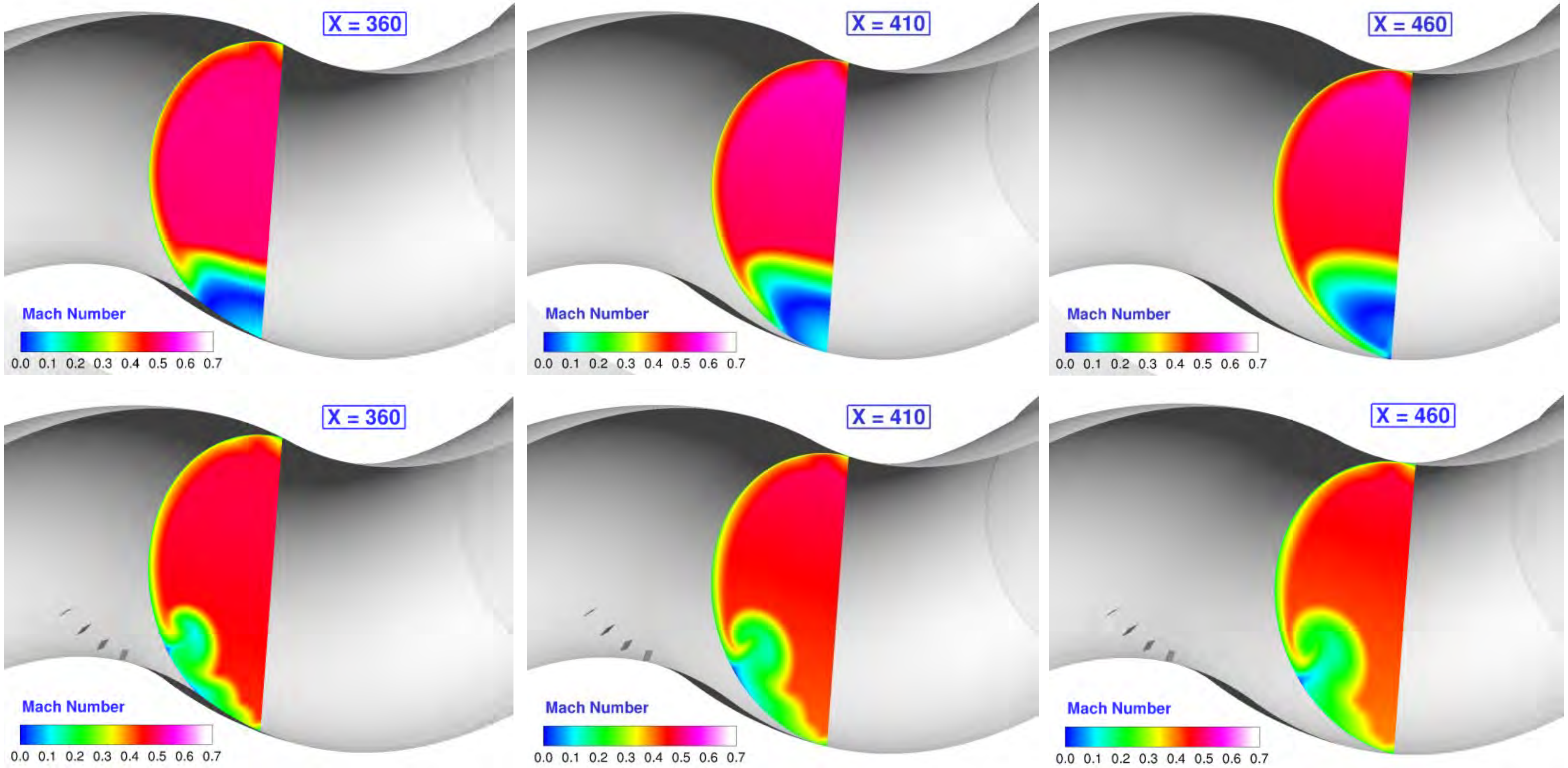


With VGs

Results – Mach contours at different X cut

No VGs vs With VGs (mass flow = 2.427 kg/s)

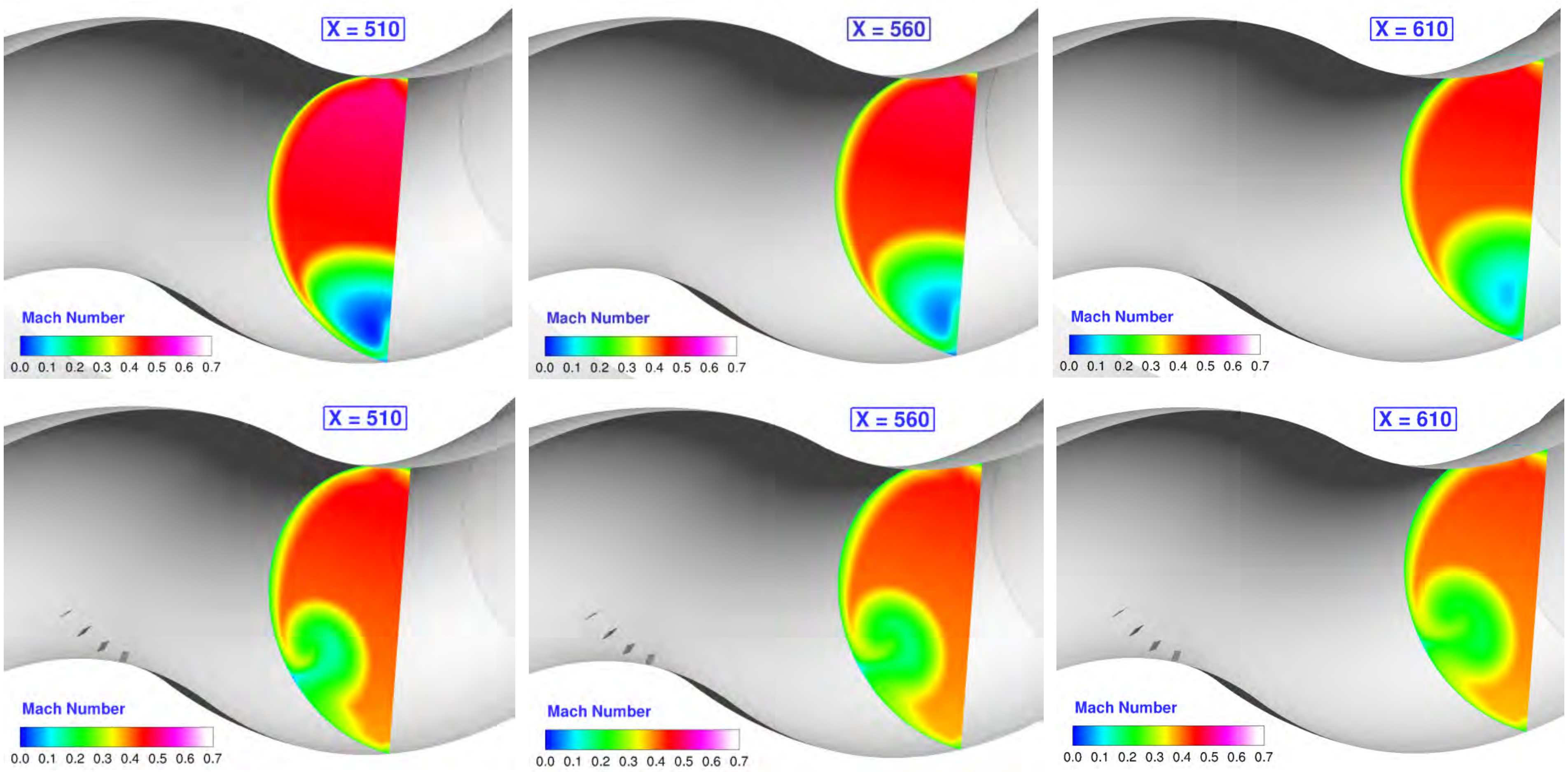
No VGs



With VGs

Results – Mach contours at different X cut
No VGs vs With VGs (mass flow = 2.427 kg/s)

No VGs



With VGs

Results – Pi/Pio Contours at different X cut

No VGs vs With VGs (mass flow = 2.427 kg/s)

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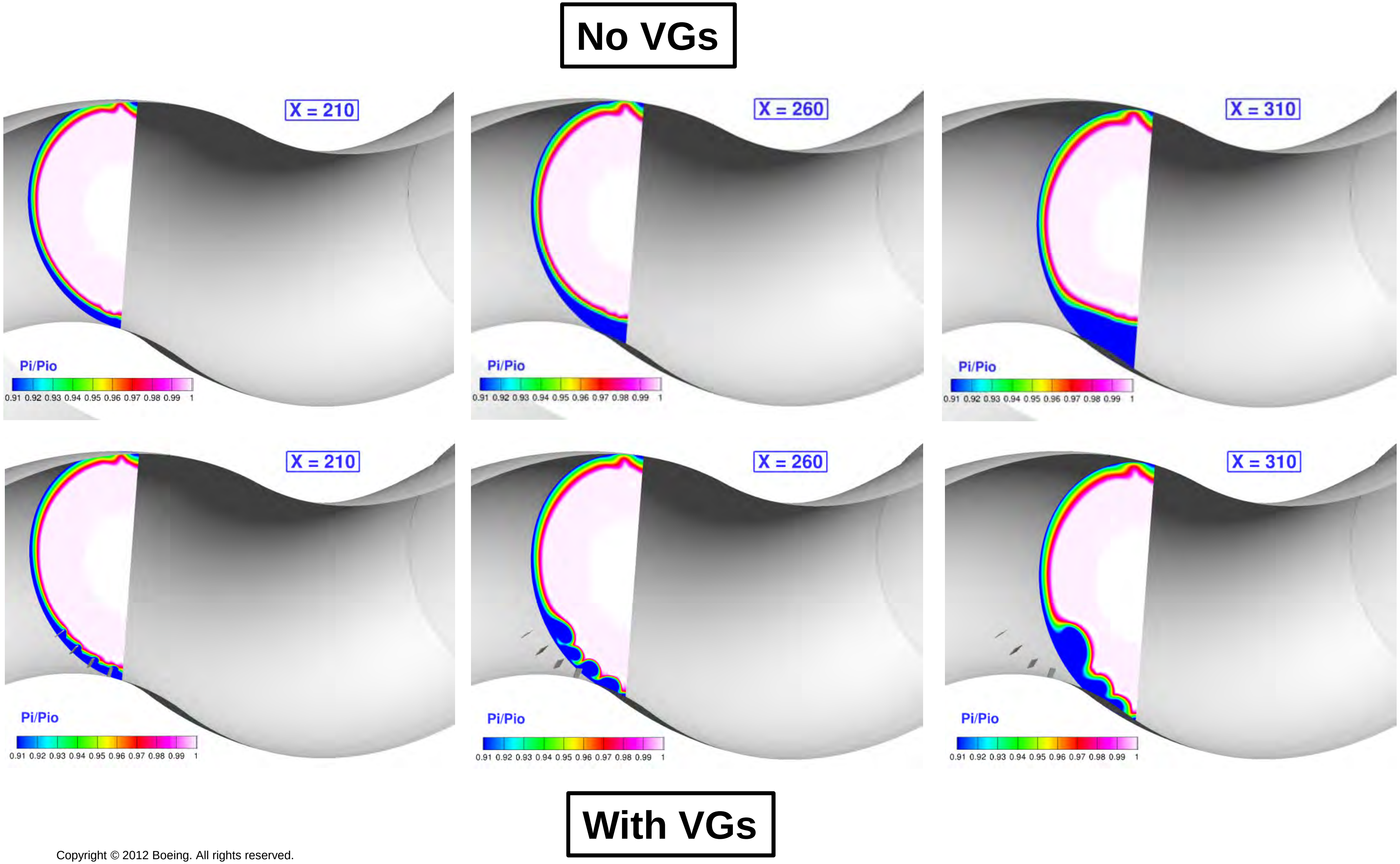
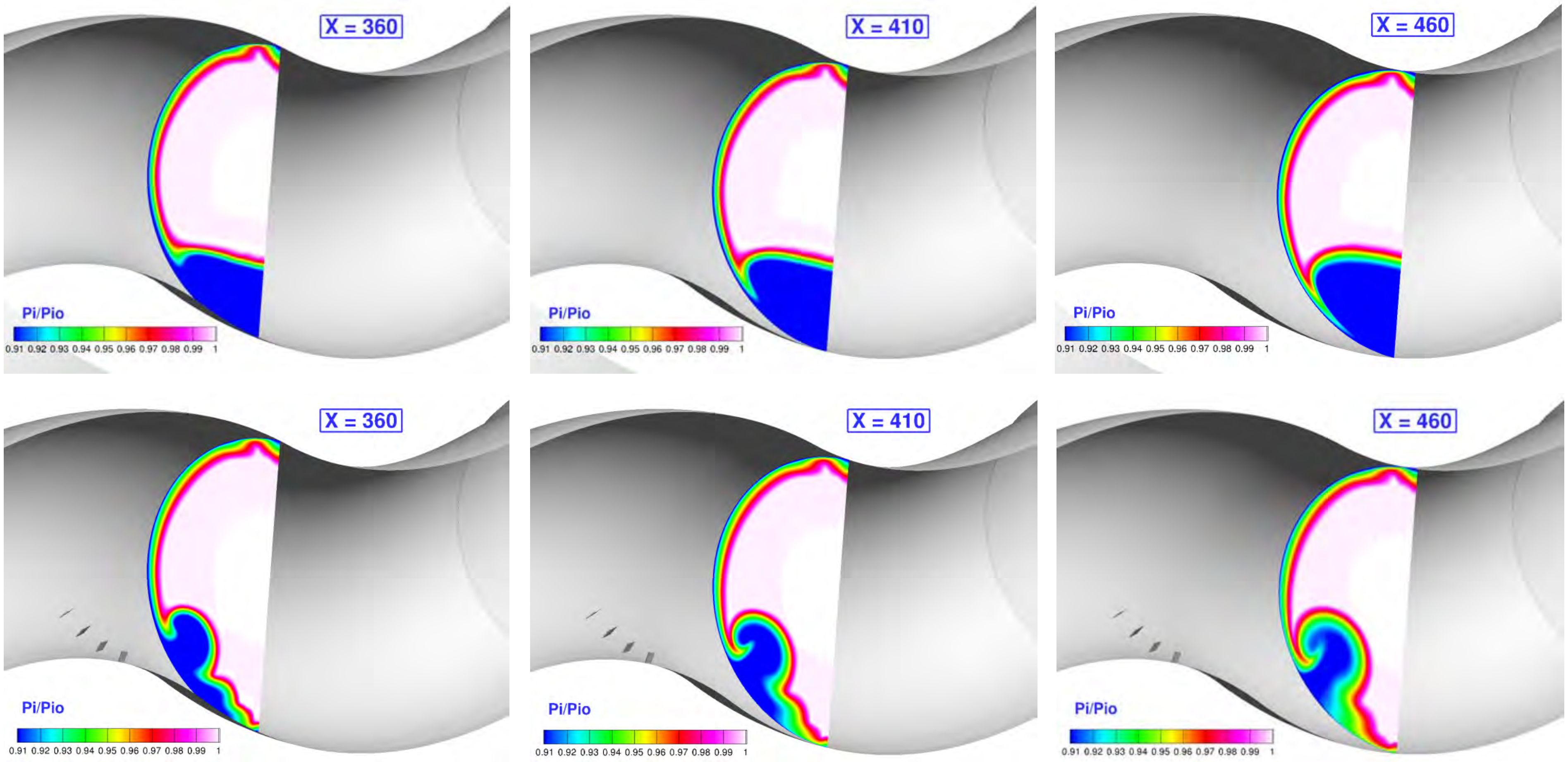


Results – Pi/Pio Contours at different X cut

No VGs vs With VGs (mass flow = 2.427 kg/s)

No VGs



With VGs

Results – Pi/Pio Contours at different X cut

No VGs vs With VGs (mass flow = 2.427 kg/s)

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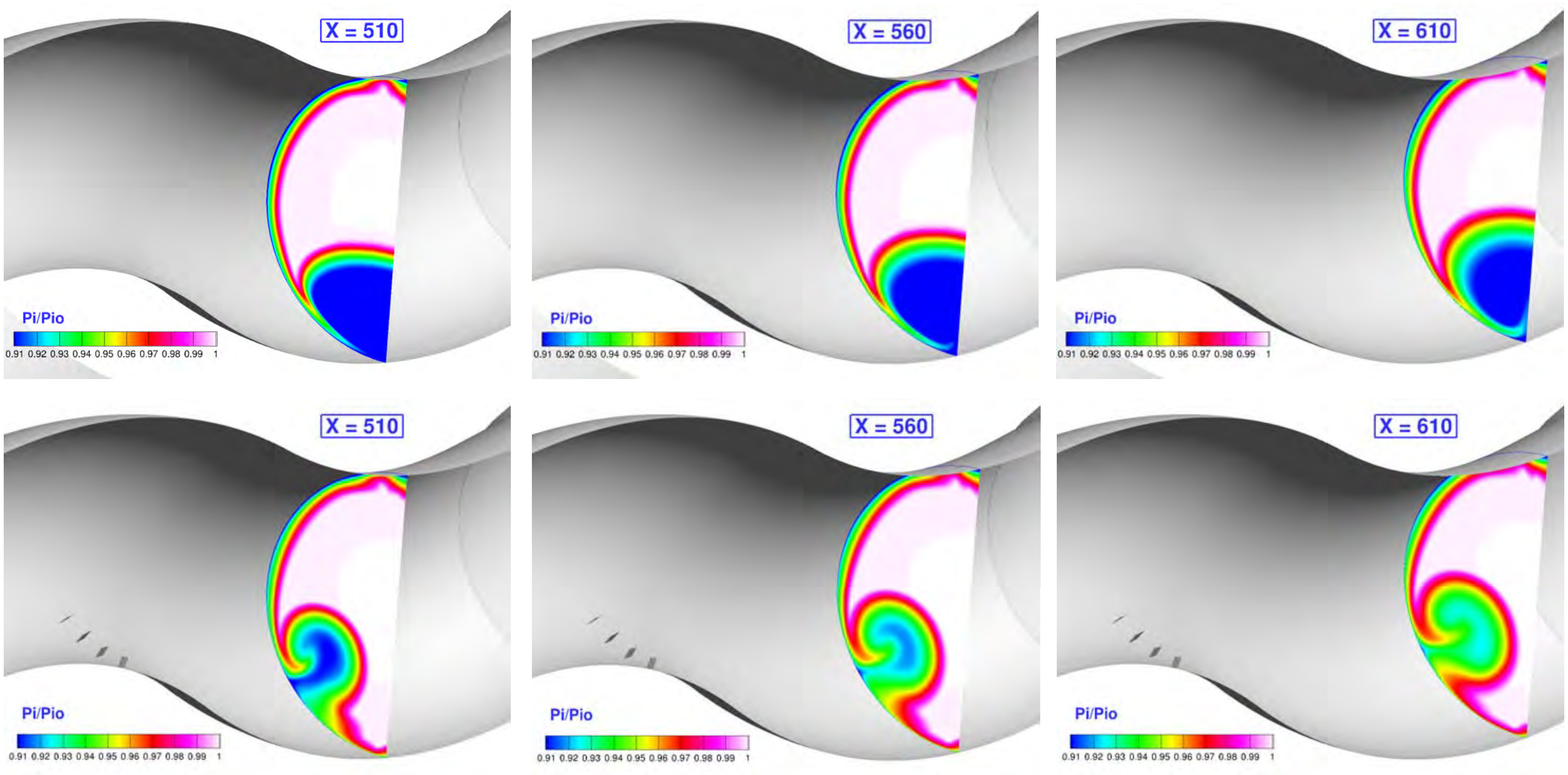
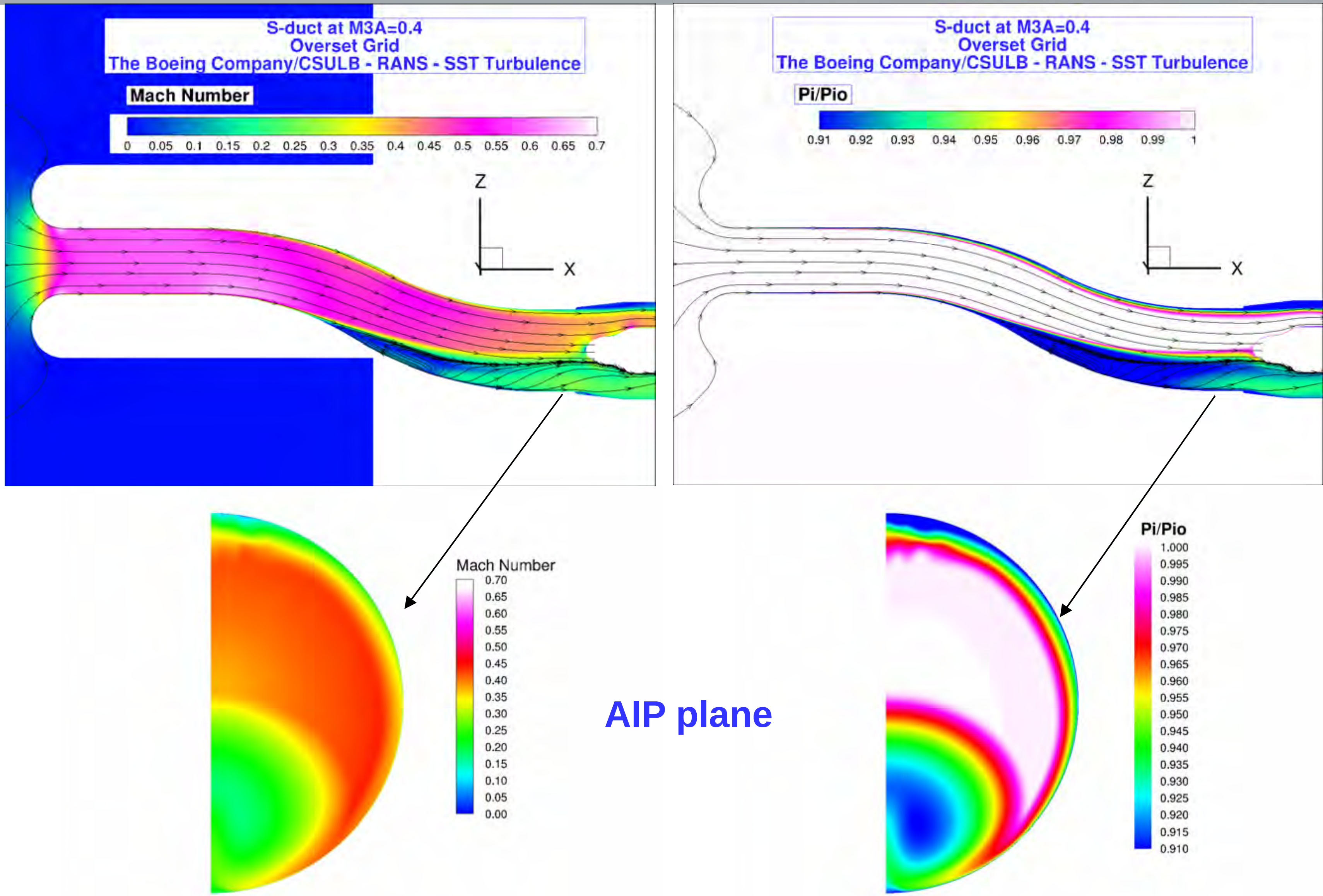
No VGs



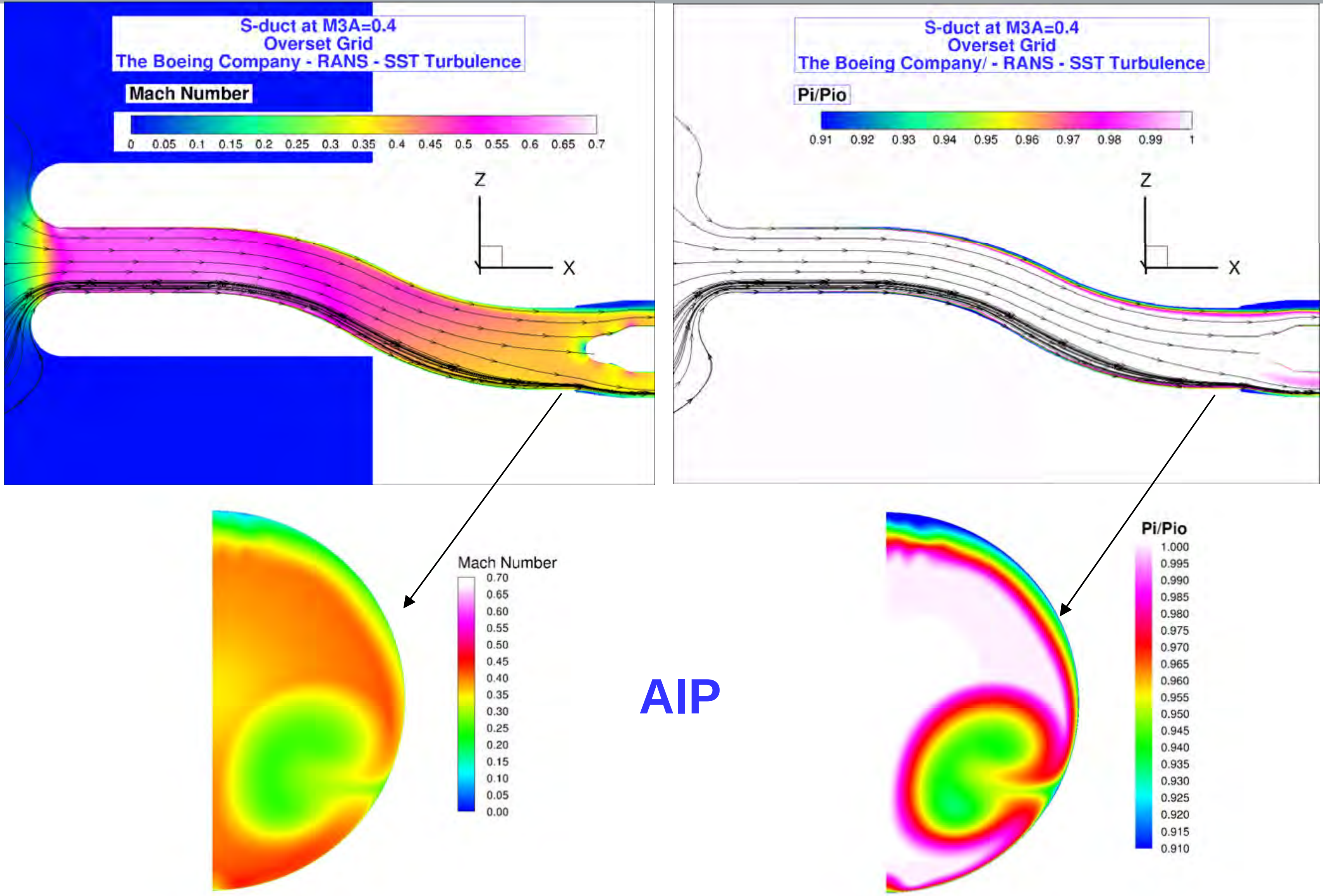
With VGs

Results – Mach & Pi/Pio Contours

No VGs (mass flow = 2.427 kg/s)

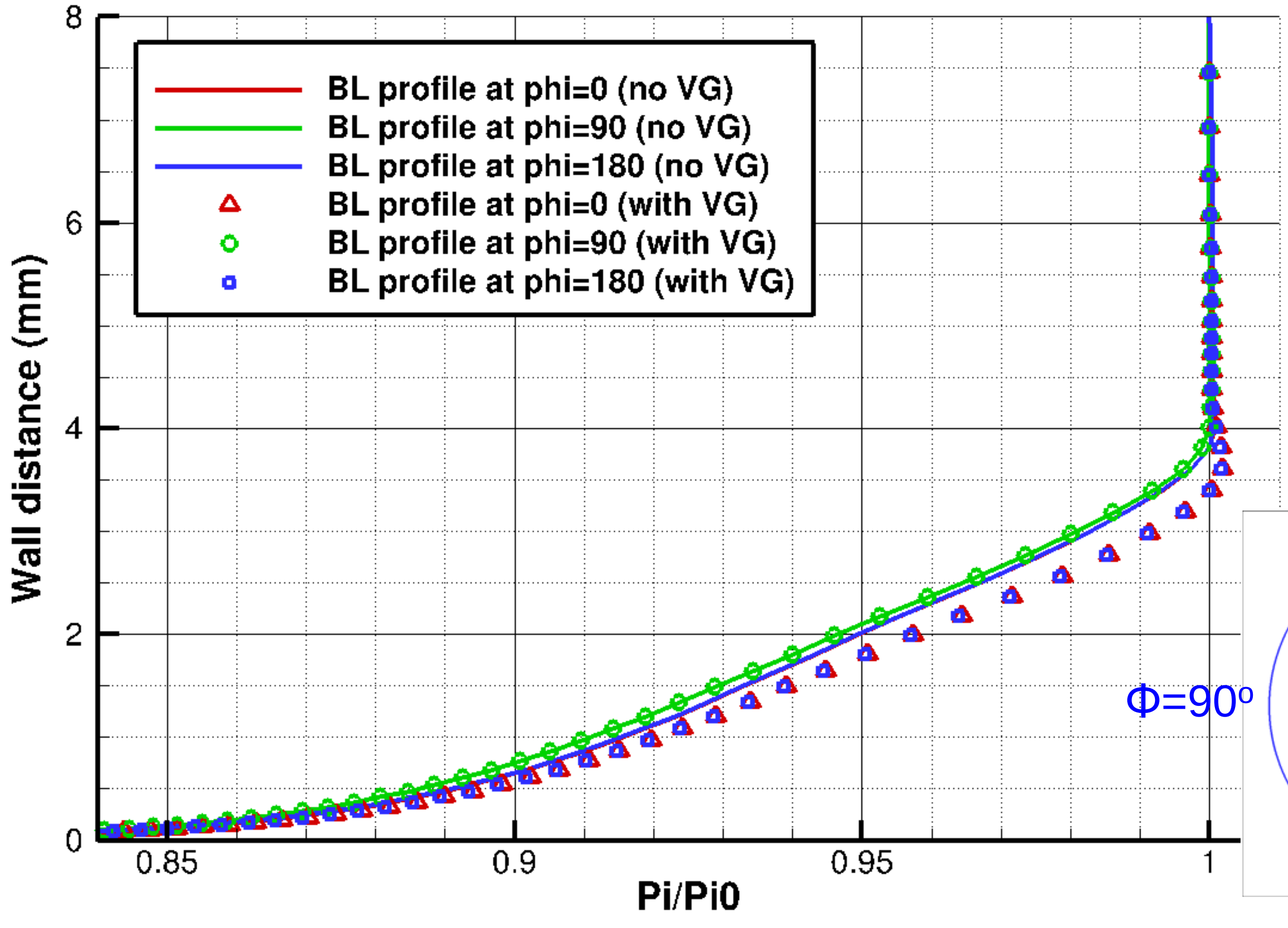


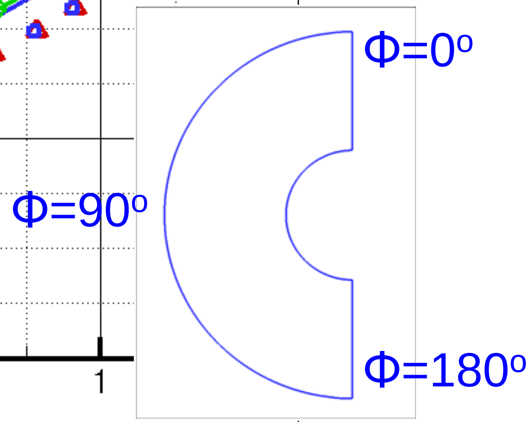
Results – Mach & Pi/Pio Contours
With VGs (mass flow = 2.427 kg/s)



Results – BL Profiles (x=-76.58 mm)

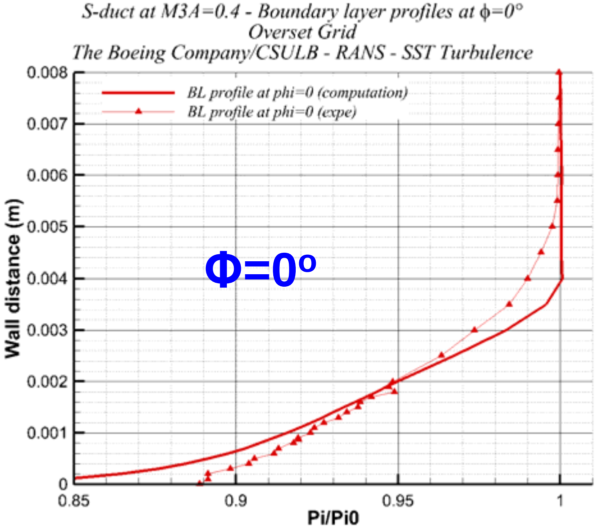
VGs vs No VGs (mass flow = 2.427 kg/s)

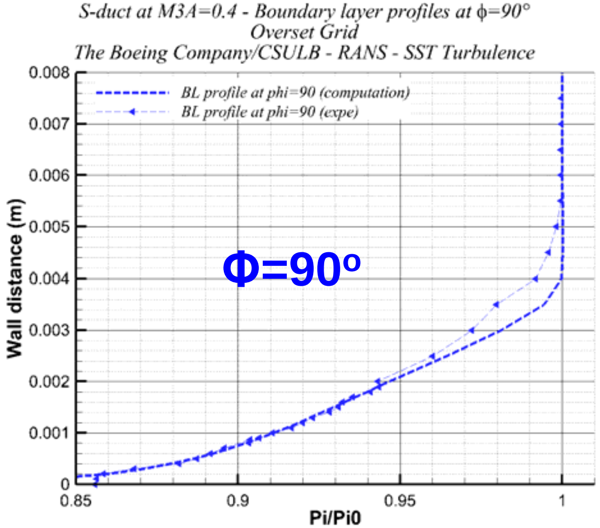


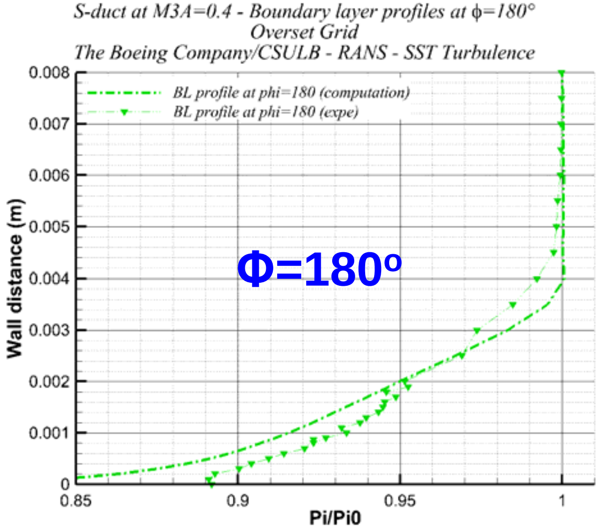


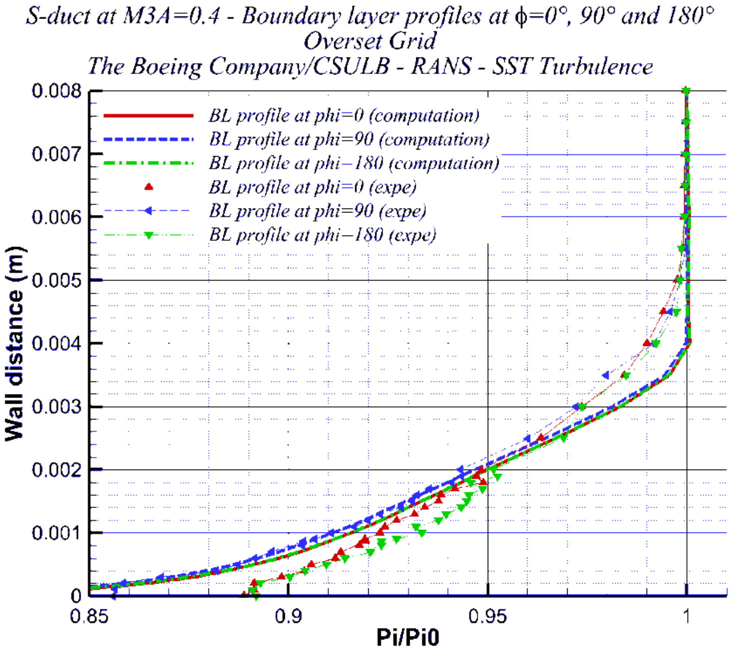
Results – BL Profiles (x=-76.58 mm)

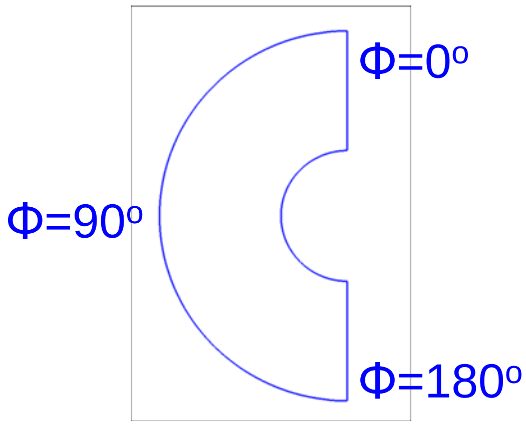
No VGs (mass flow = 2.427 kg/s)











Results – AIP Mach Contours

No VGs vs With VGs (mass flow = 2.427 kg/s)

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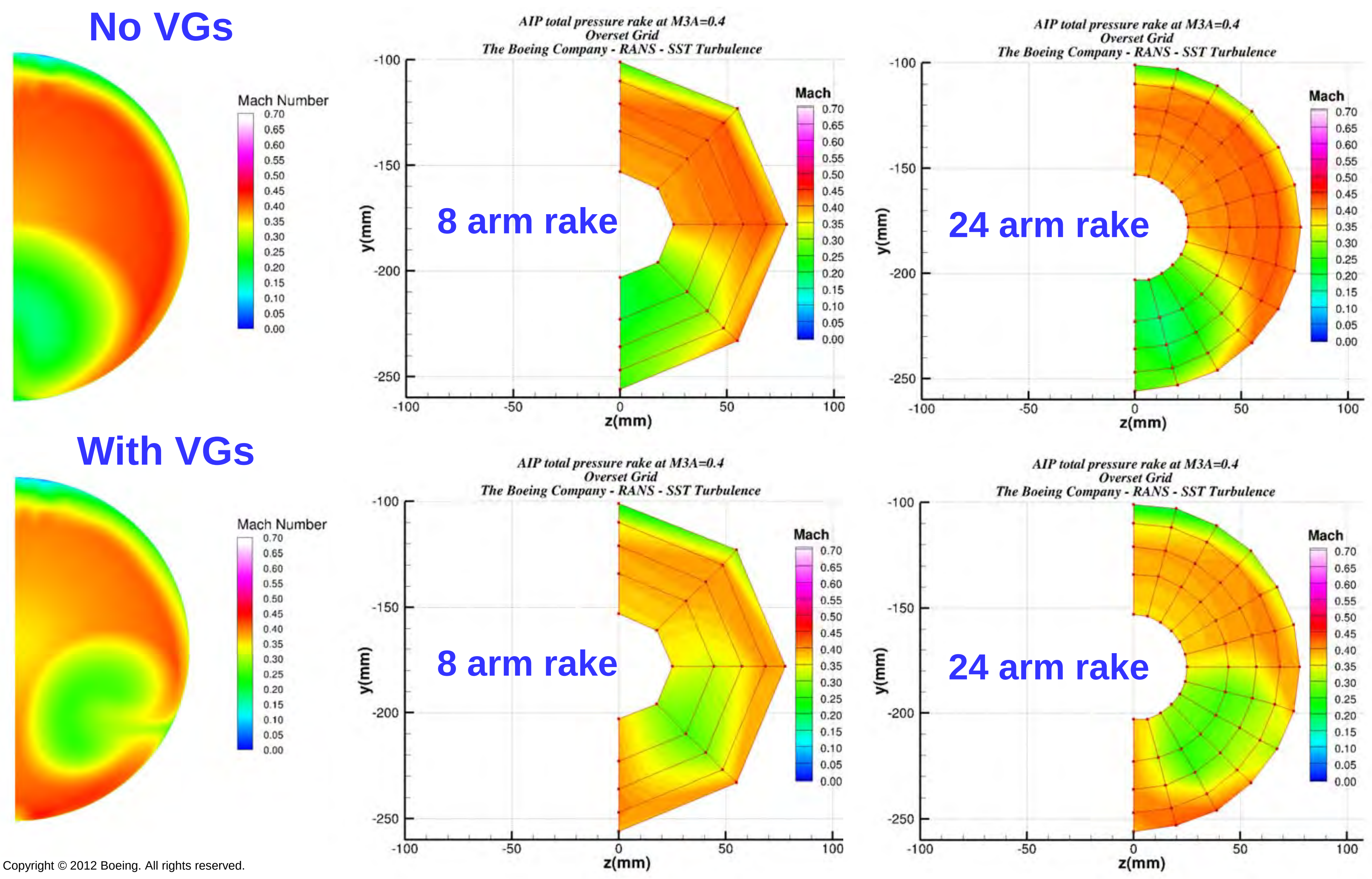
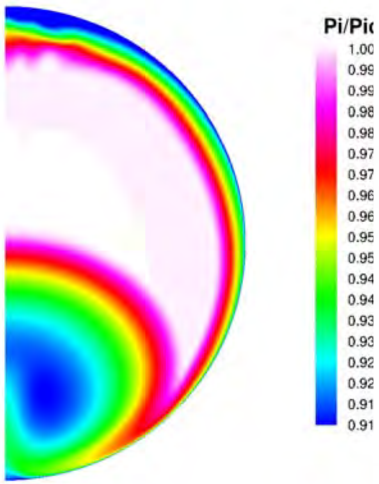
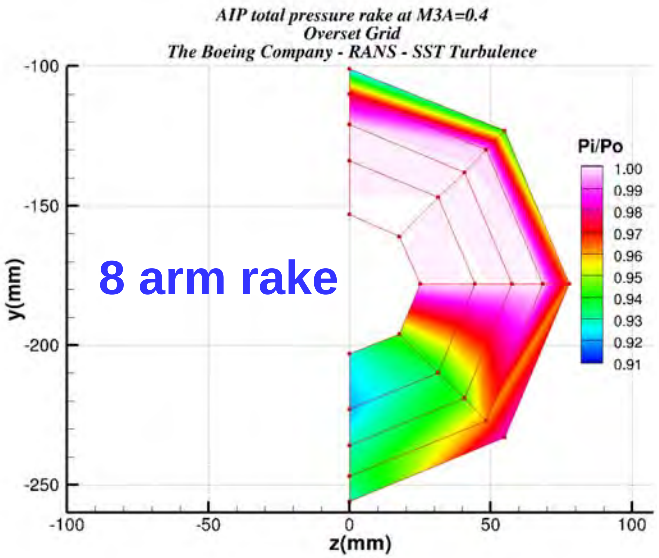


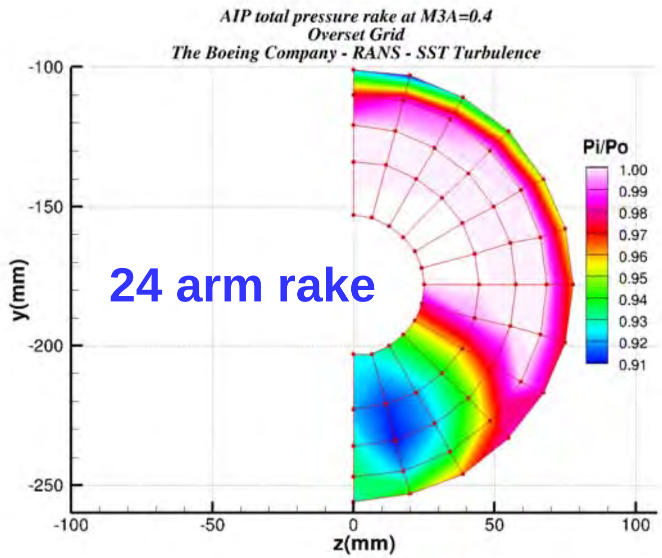
Results – AIP Pi/Pio Contours

No VGs vs With VGs (mass flow = 2.427 kg/s)

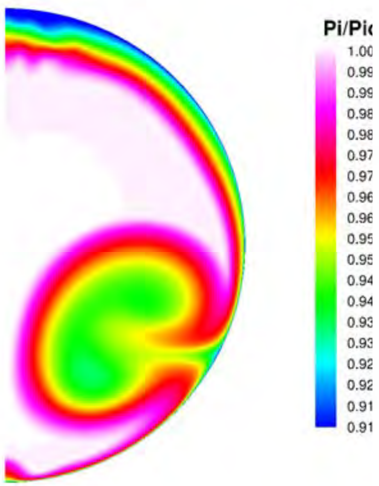
No VGs

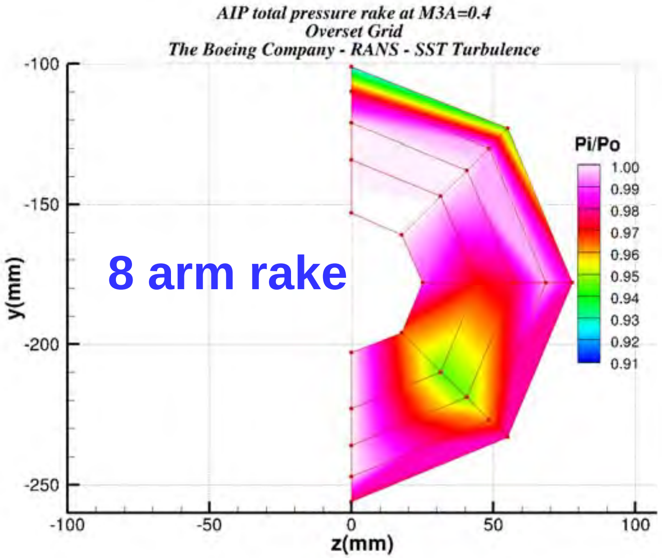


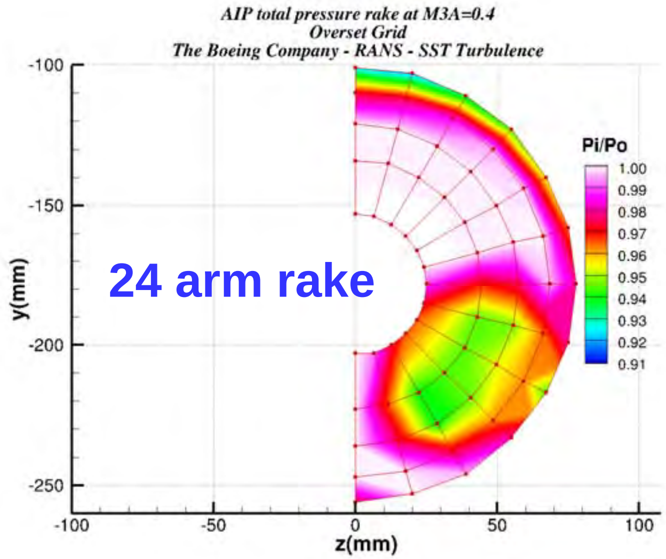




With VGs







Passive Flow Contorl - VGs

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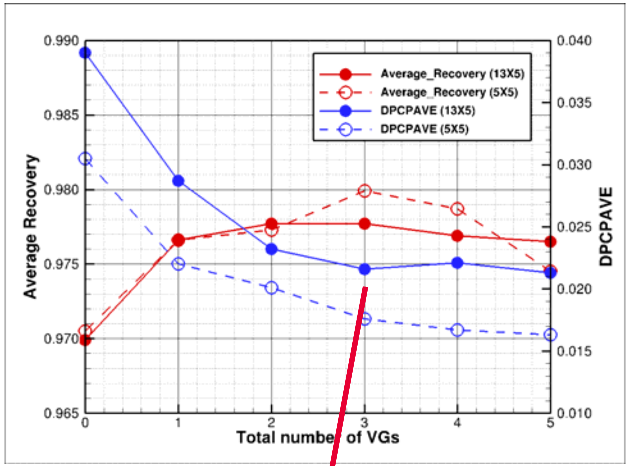
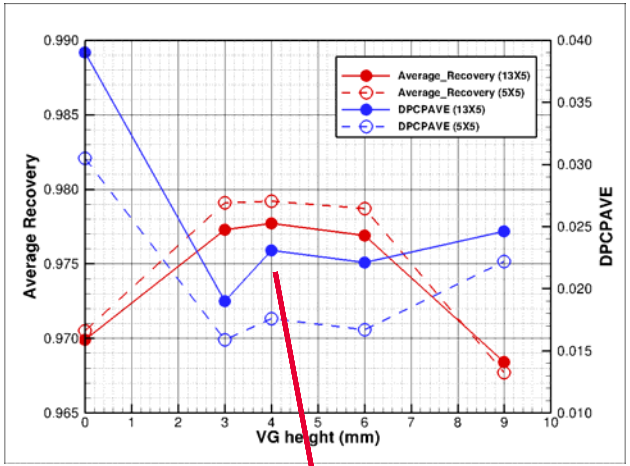
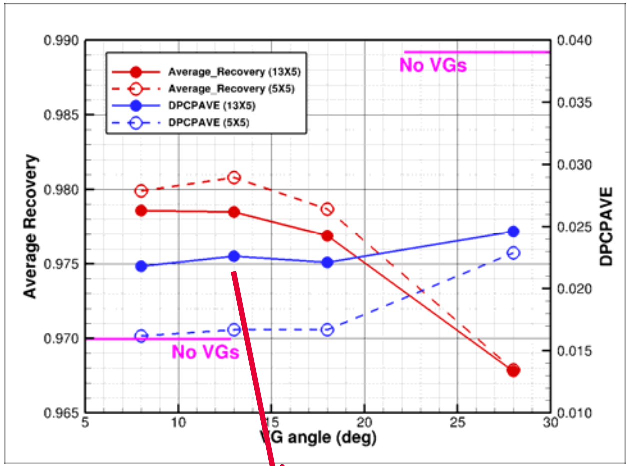


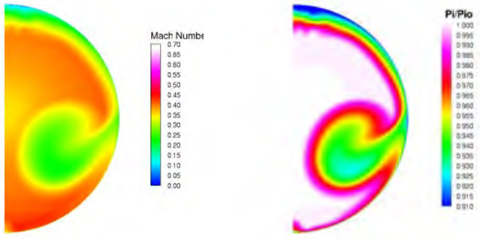


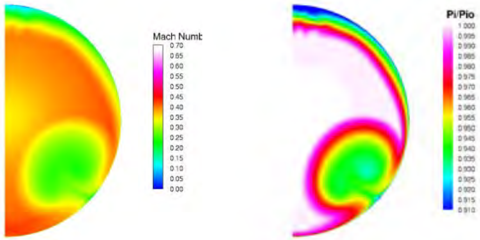


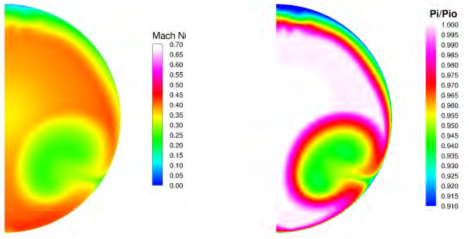
3 VGs, 6mm height, 18 deg

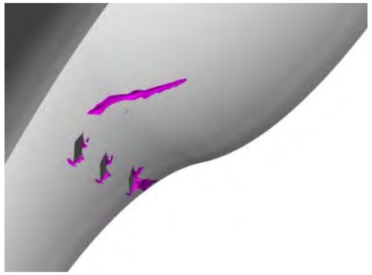
4 VGs, 4mm height, 18 deg

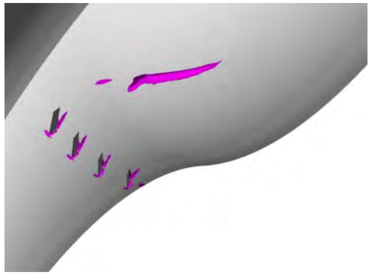
4 VGs, 6mm height, 13 deg

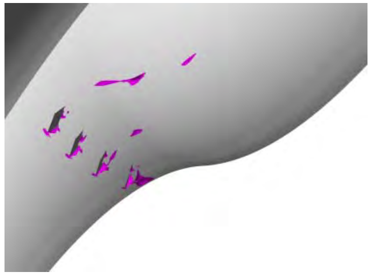












Passive Flow Contorl - VGs

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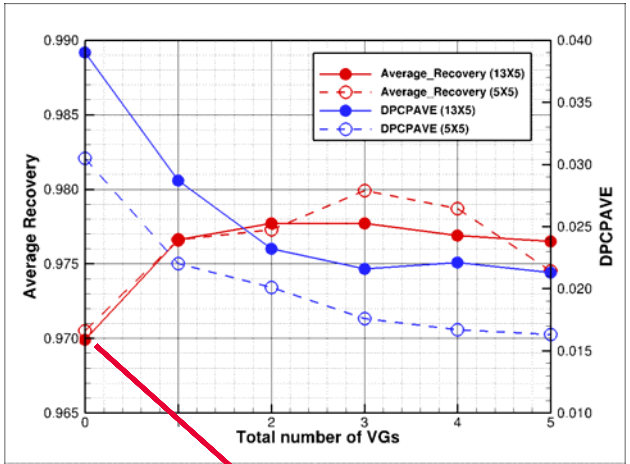
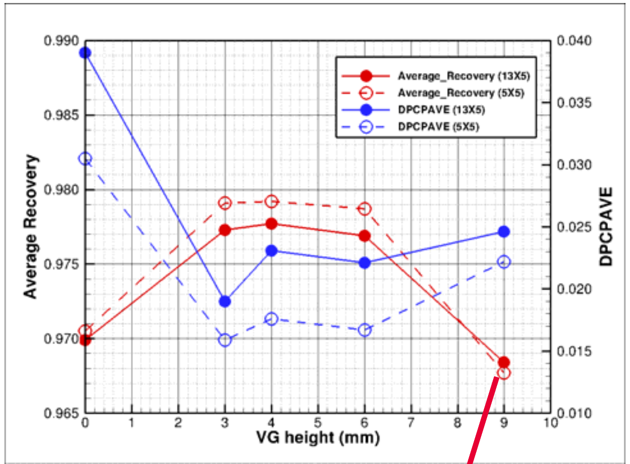
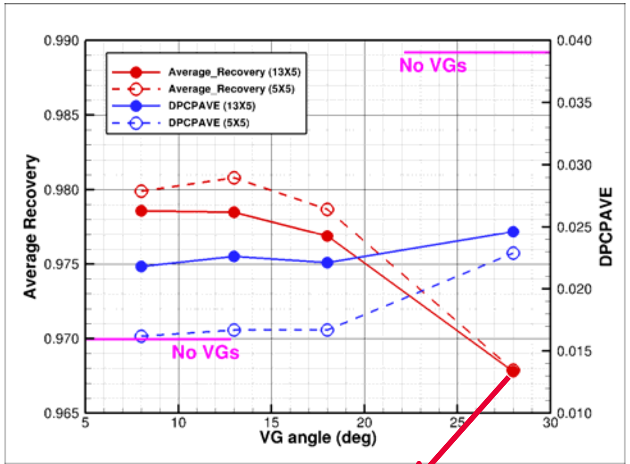


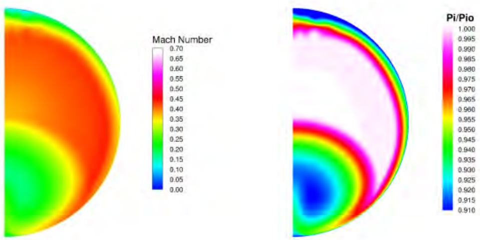


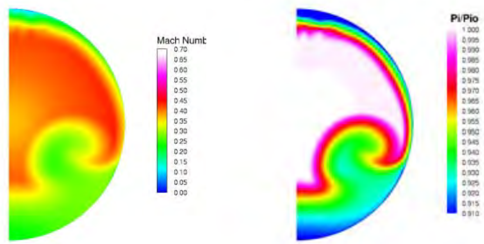


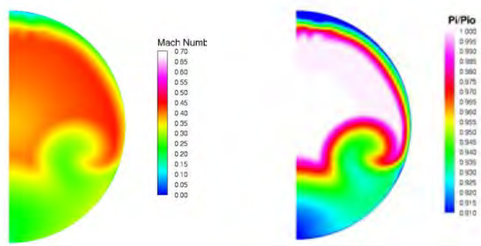
No VGs,

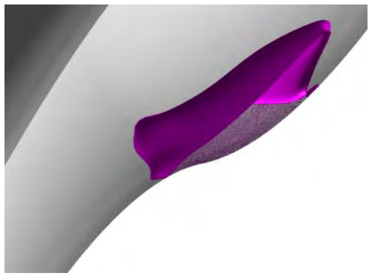
4 VGs, 9mm height, 18 deg

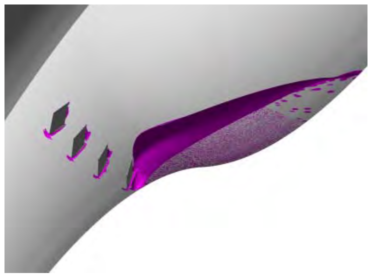
4 VGs, 6mm height, 28 deg

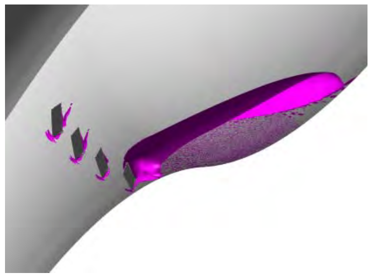






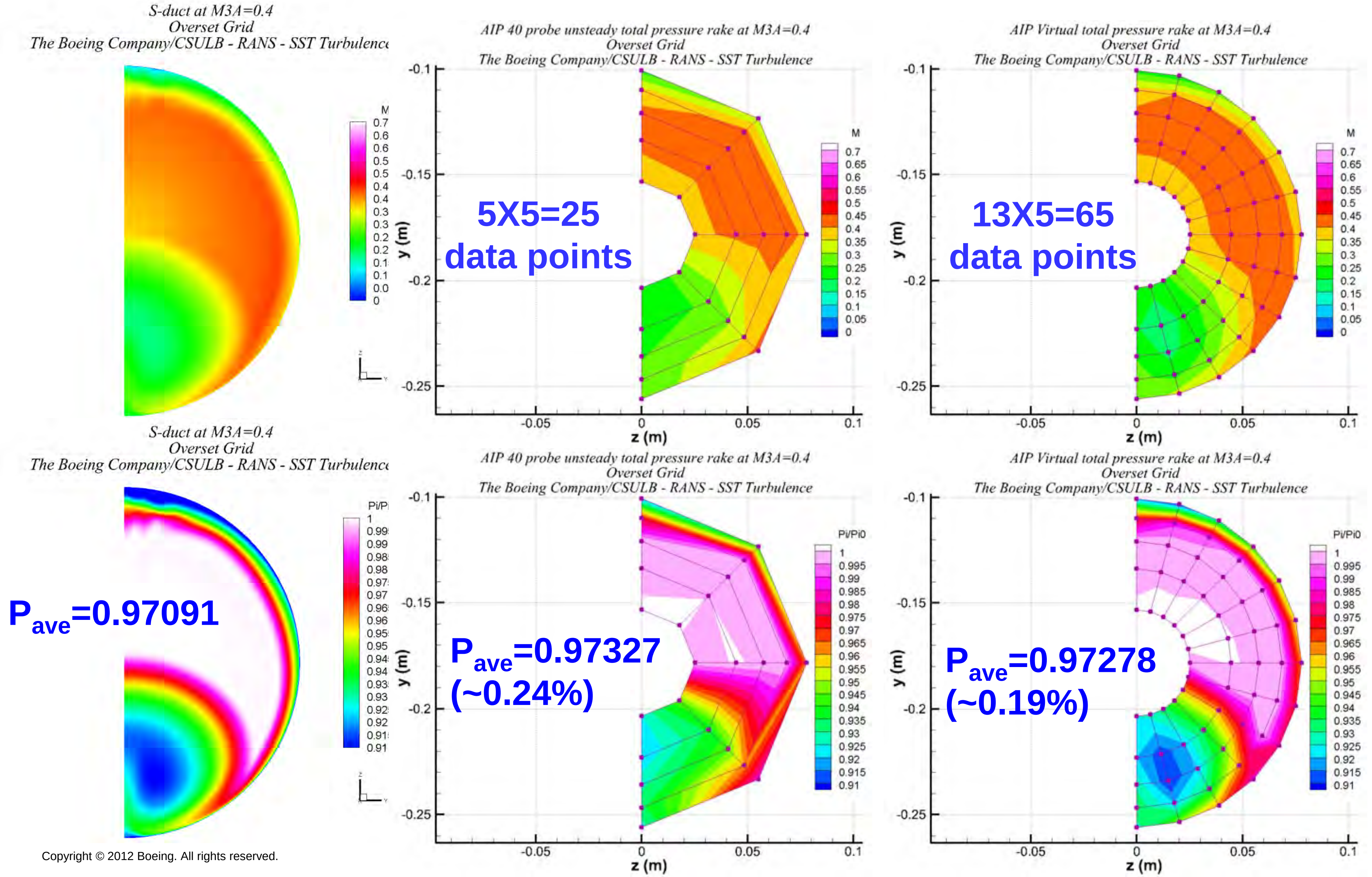






Results – Mach & Pi/Pio Contours

Standard Case (mass flow = 2.427 kg/s)



Active Flow Control – Surface Blowing Jets

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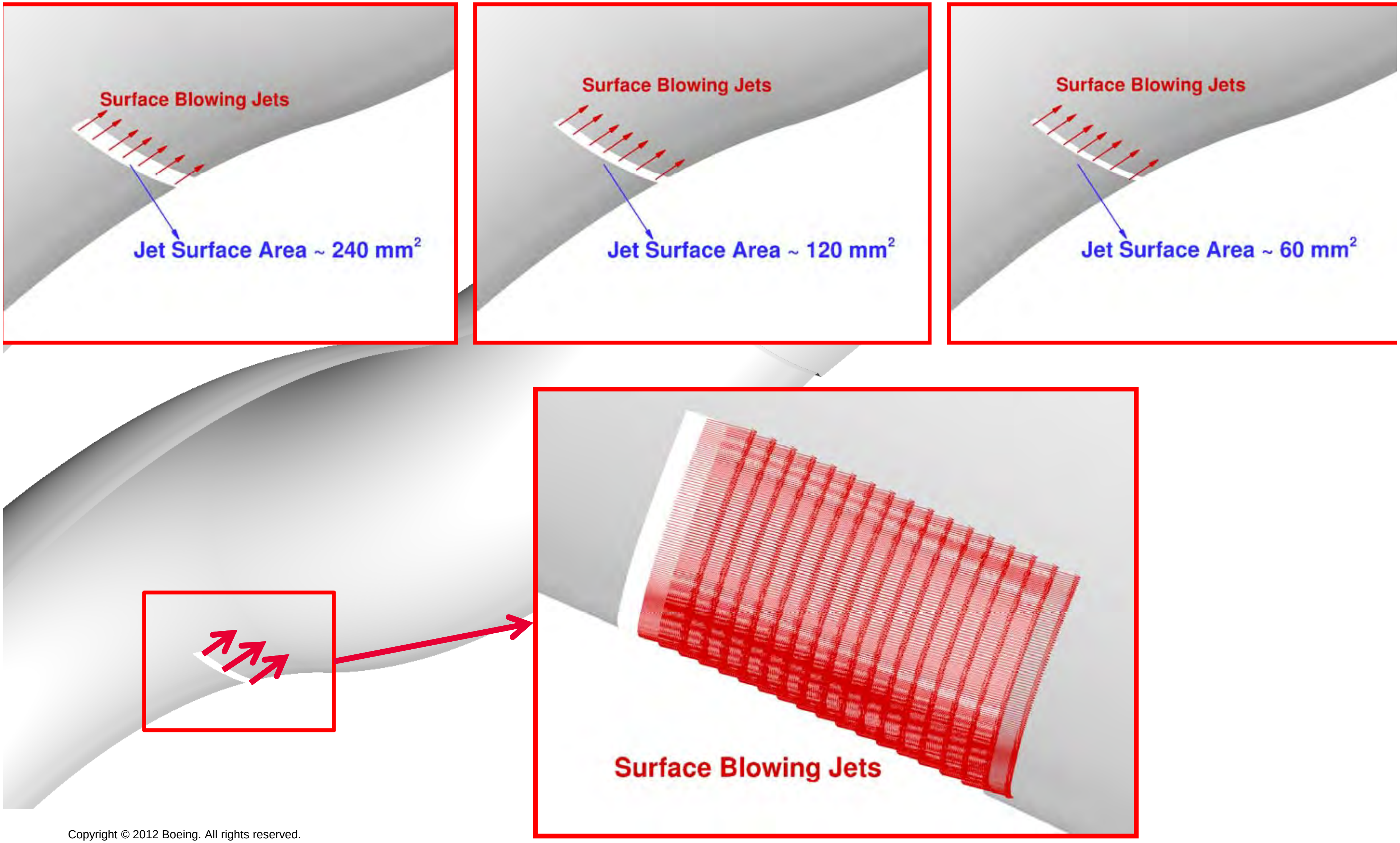
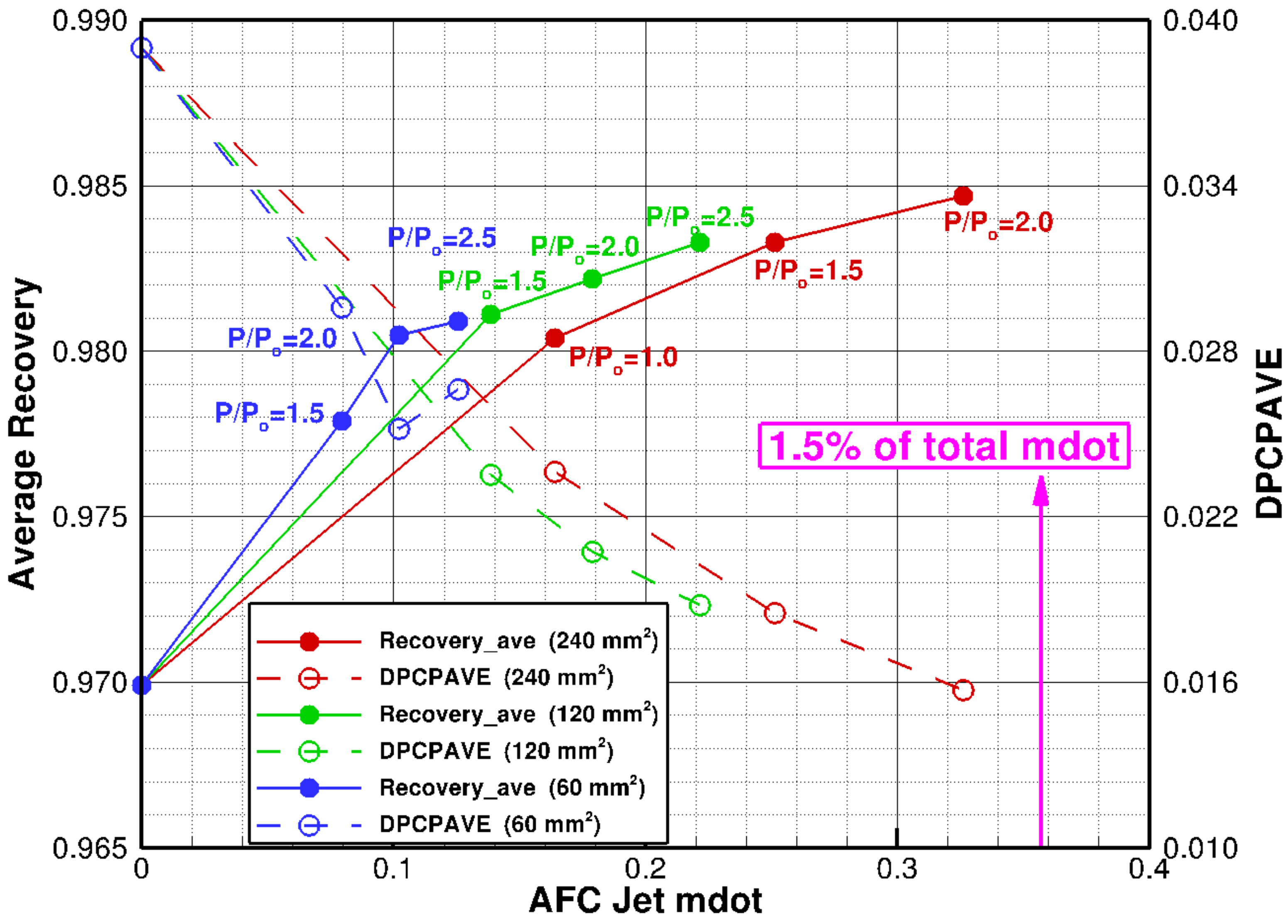


Active Flow Control – Surface Blowing Jets

Engineering, Operations & Technology



Passive vs Active Flow Control

Passive vs Active Flow Control

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3 VGs
Recovery = 0.9777
DPCP_ave=0.0216

60 mm^2, P/P$_o$=1.5
Recovery = 0.9779
DPCP_ave=0.0296

120 mm^2, P/P$_o$=2.0,
Recovery = 0.9822
DPCP_ave=0.0207