Three-Dimensional Viscous Flutter Analysis of Standard Configuration 10

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Presentation Outline

Three-Dimensional Viscous Flutter Analysis of Standard Configuration 10

- Motivation: establish 3D test case
- Problem description: geometry, flow conditions
- Method: flow solvers and meshes
- Steady-state results: corner separation
- Unsteady flow: aerodynamic damping
- Future work and conclusions

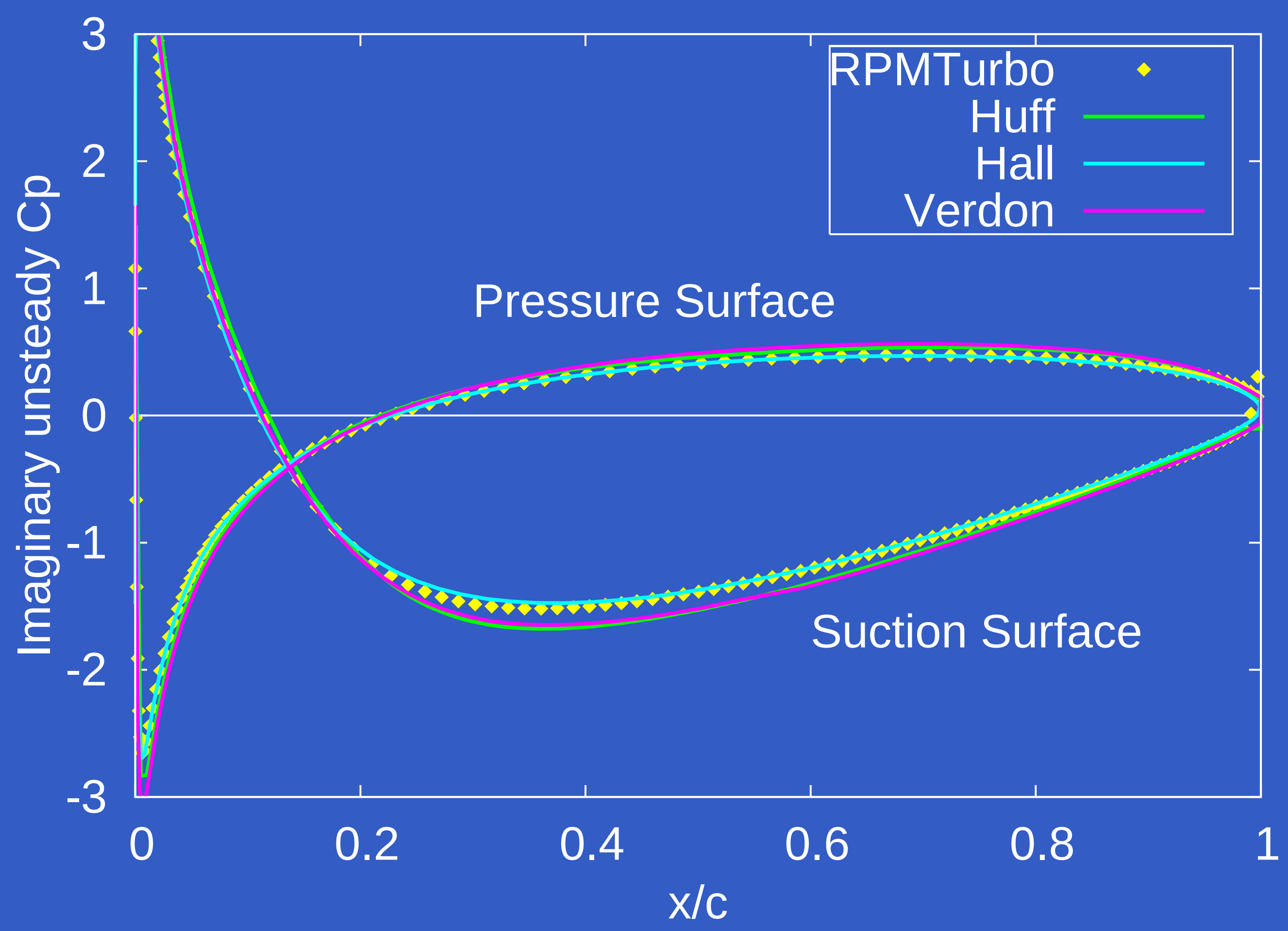
Motivation

Standard Configurations for Unsteady Flow Through Vibrating Axial-Flow Turbomachine-Cascades

- Eleven 2D profiles (flat plate, turbine, compressor)
- Database of CFD and experimental results
- Excellent for verifying unsteady CFD codes
- Shortage of 3D Test Cases

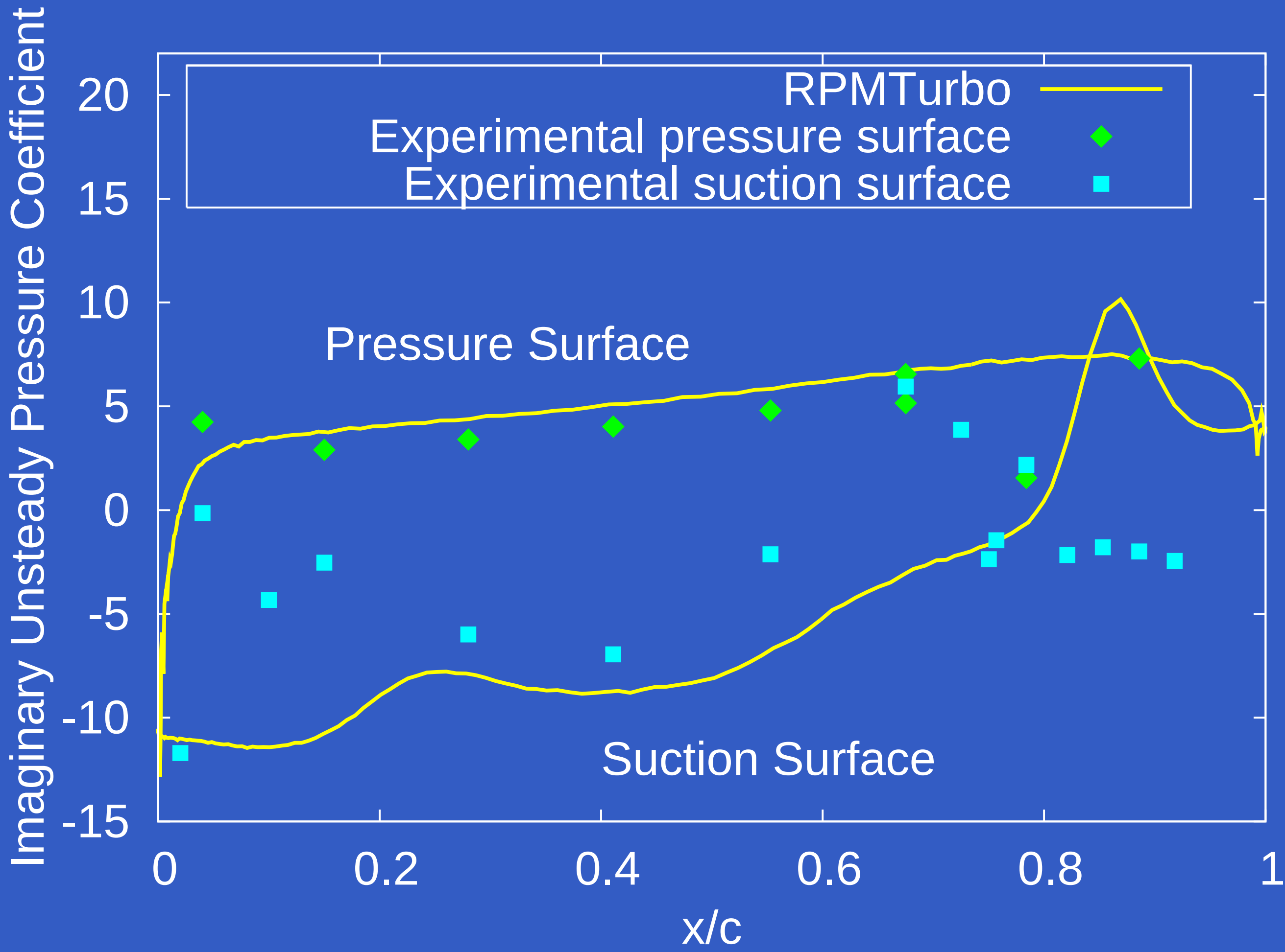
Aim: To establish a database of detailed unsteady CFD results for a 3D compressor profile.

Test Case: Standard Configuration 10



Unsteady flow due to torsion ($\omega^* = 0.5$, $\sigma = 0^o$)

Test Case: Standard Configuration 11



Unsteady solution due to flap mode

$$(\omega^* = 0.309,\, \sigma = 180.0^o)$$

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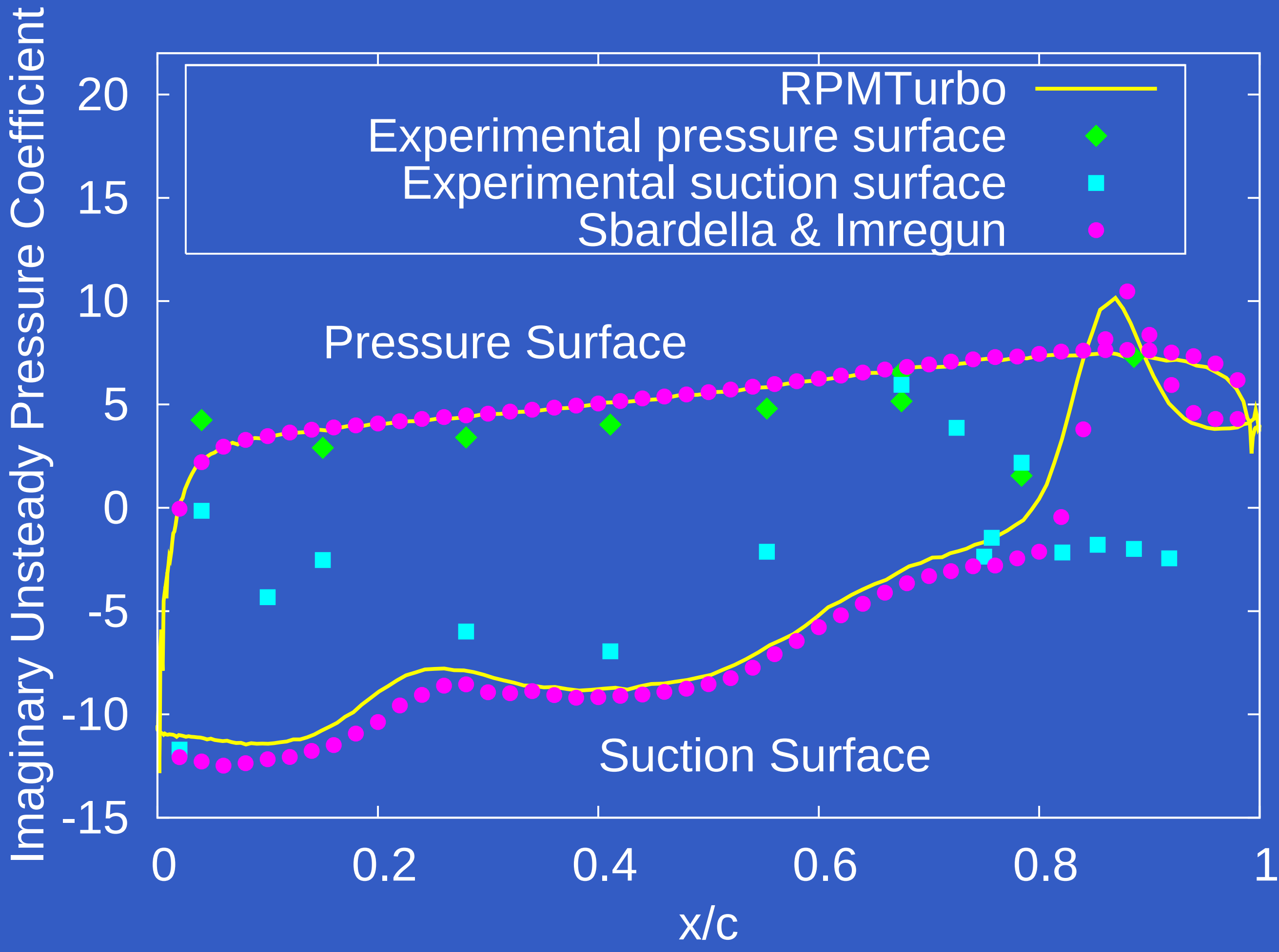
Test Case: Standard Configuration 11



Unsteady solution due to flap mode

$$(\omega^* = 0.309,\ \sigma = 180.0^o)$$

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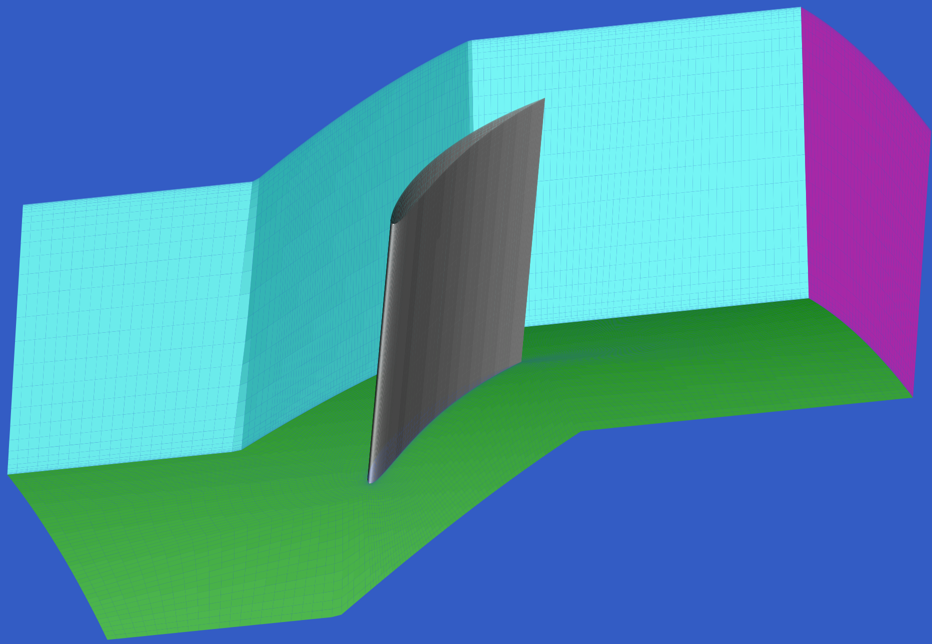
3D Standard Configuration 10

Geometry and Flow Conditions

Number of Blades	24
Blade Shape	untwisted
Chord Length	100 mm
Hub Radius	339.5 mm
Shroud Radius	424.4 mm
Stagger Angle	45.0^o
Inlet Mach Number	0.7
Inlet Flow Angle	55.0^o
Reynolds Number	1.25×10^6



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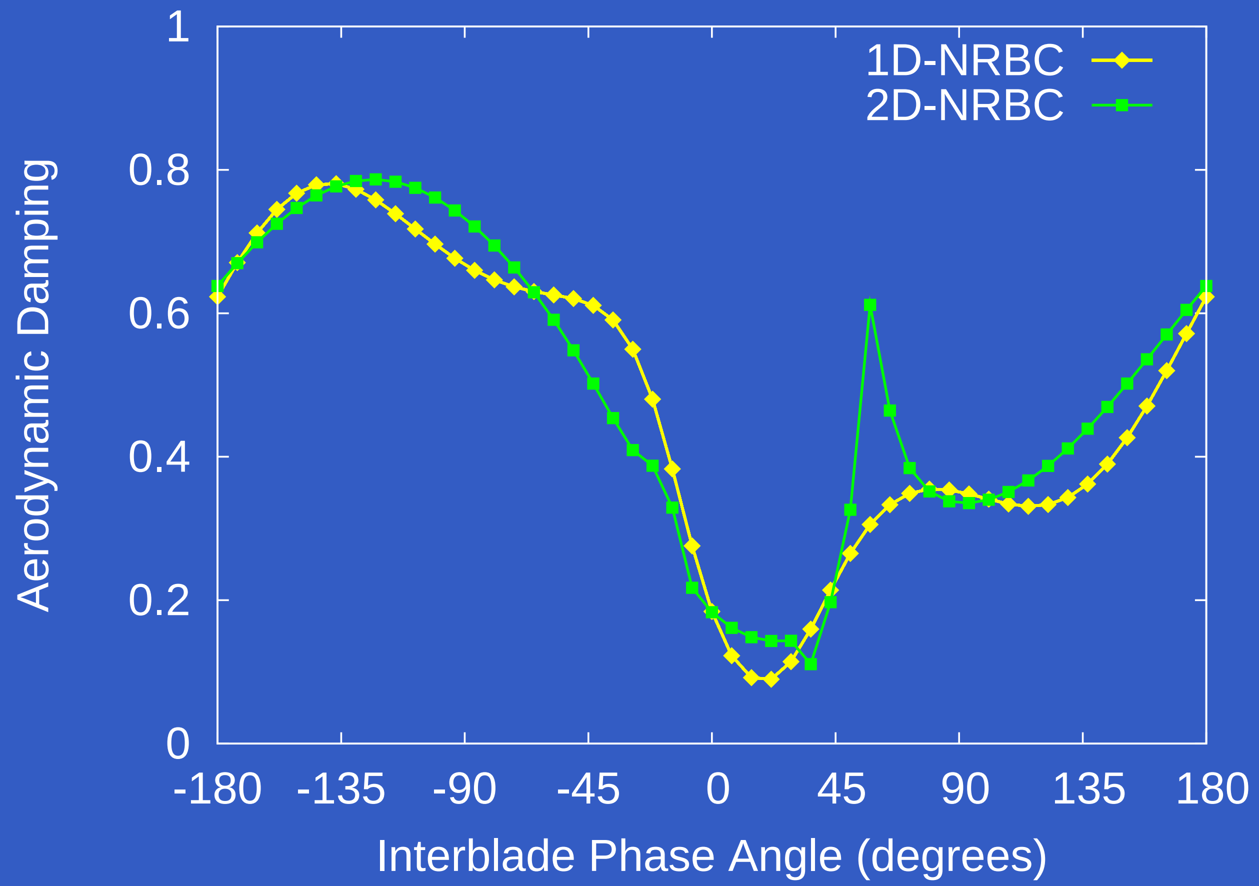
Computational Method

- Flow Model: 3D Navier-Stokes equations with Spalart and Allmaras turbulencet model
- No wall functions and no transition modeling.
- 1D non-reflecting boundary conditions
- RPMTurbo's in-house steady-state and time-linearized Navier-Stokes flow solvers
- Efficient Parallel Solver for Linear Systems
- Hardware: Blackhole, Computer Cluster at the University of Queensland with 180 processors and 360 Gbytes RAM

Non-Reflecting Boundary Conditions

Standard Configuration 10: torsion mode ($\omega^* = 0.5$)

2D Viscous Flow



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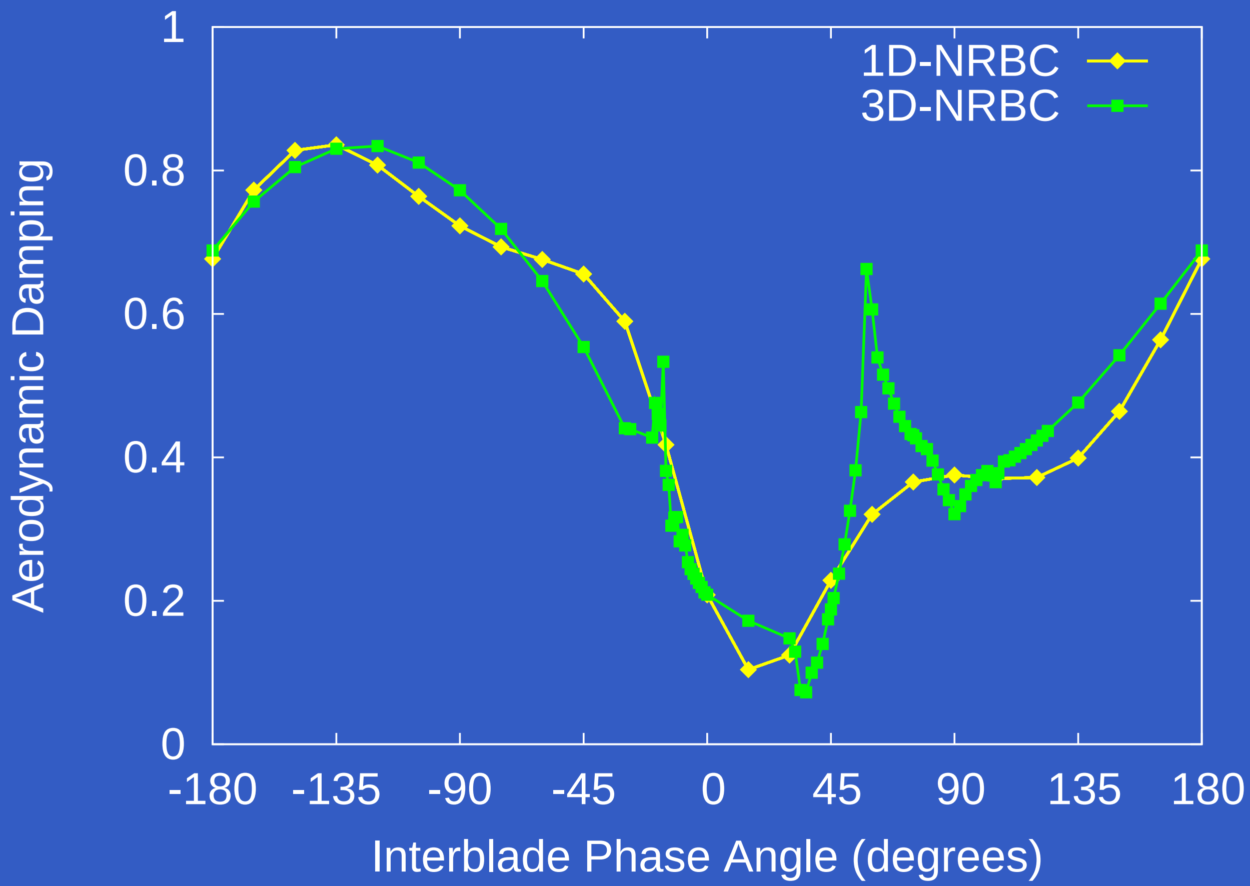
Non-Reflecting Boundary Conditions

Standard Configuration 10: torsion mode ($\omega^* = 0.5$)

3D Inviscid Flow



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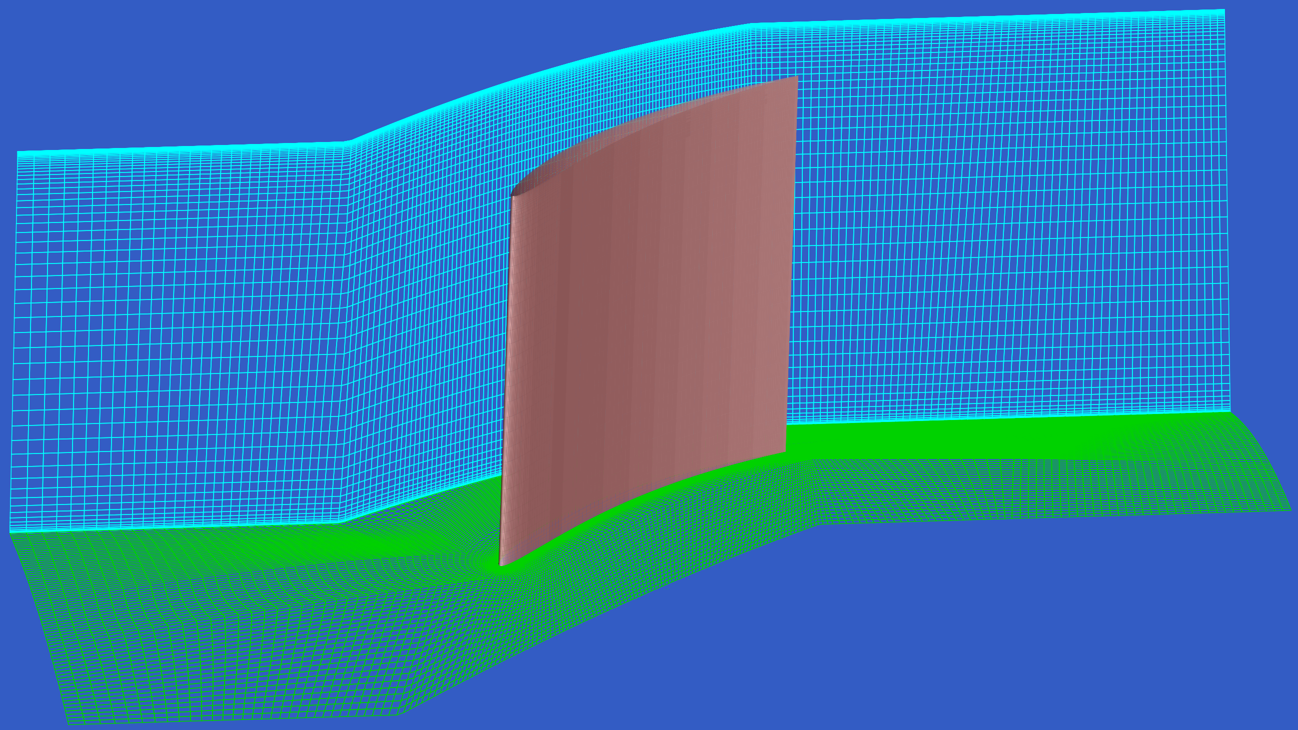
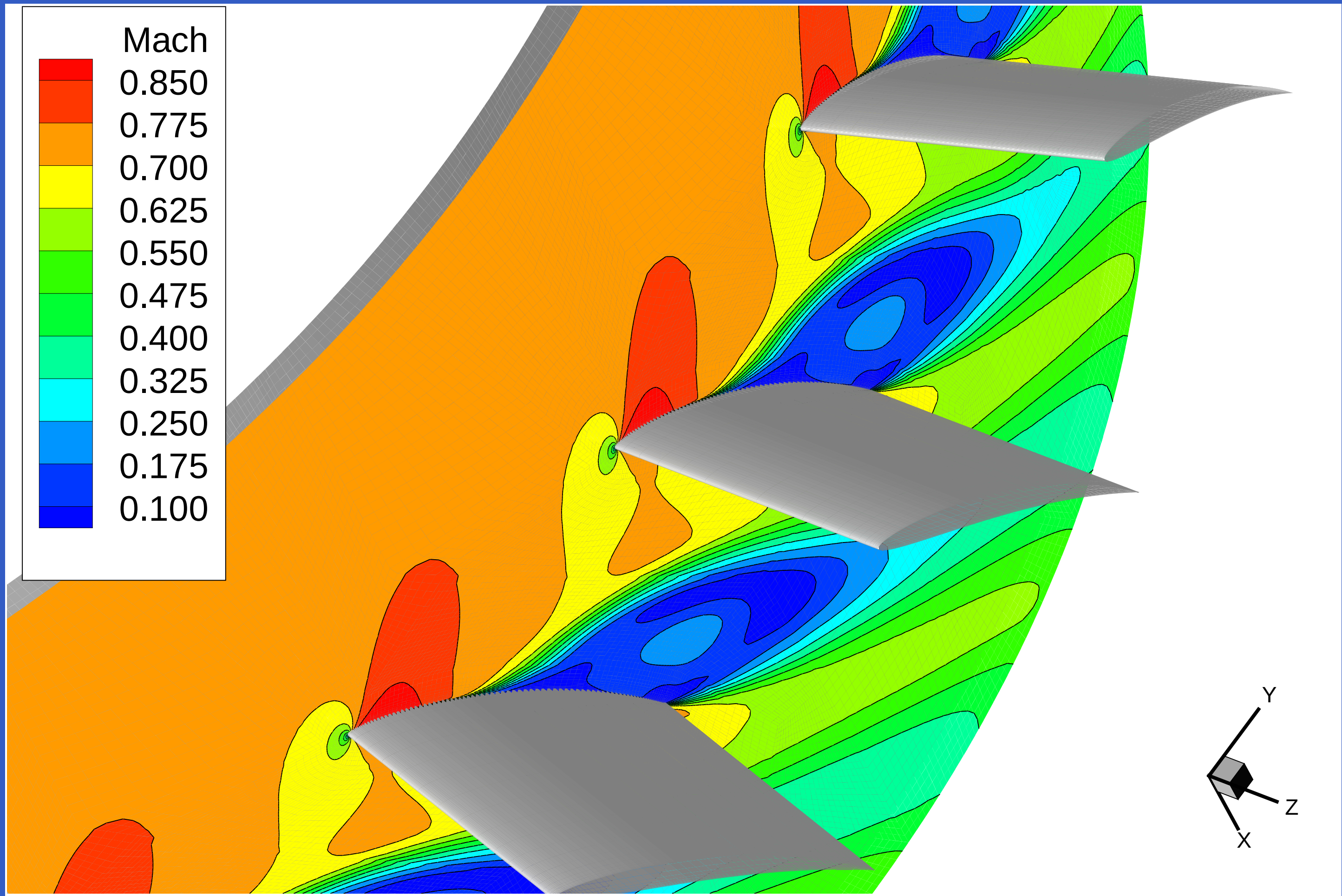
Meshes

Resolution	Low	High
Number of Cells	455 988	1 594 728
Cells in Radial Plane	11 692	22 149
Cells in Radial Direction	39	72
Profile $y^+_{\max}$	6.4	2.4
Hub/Shroud $y^+_{\max}$	4.1	2.3



3D Standard Configuration 10

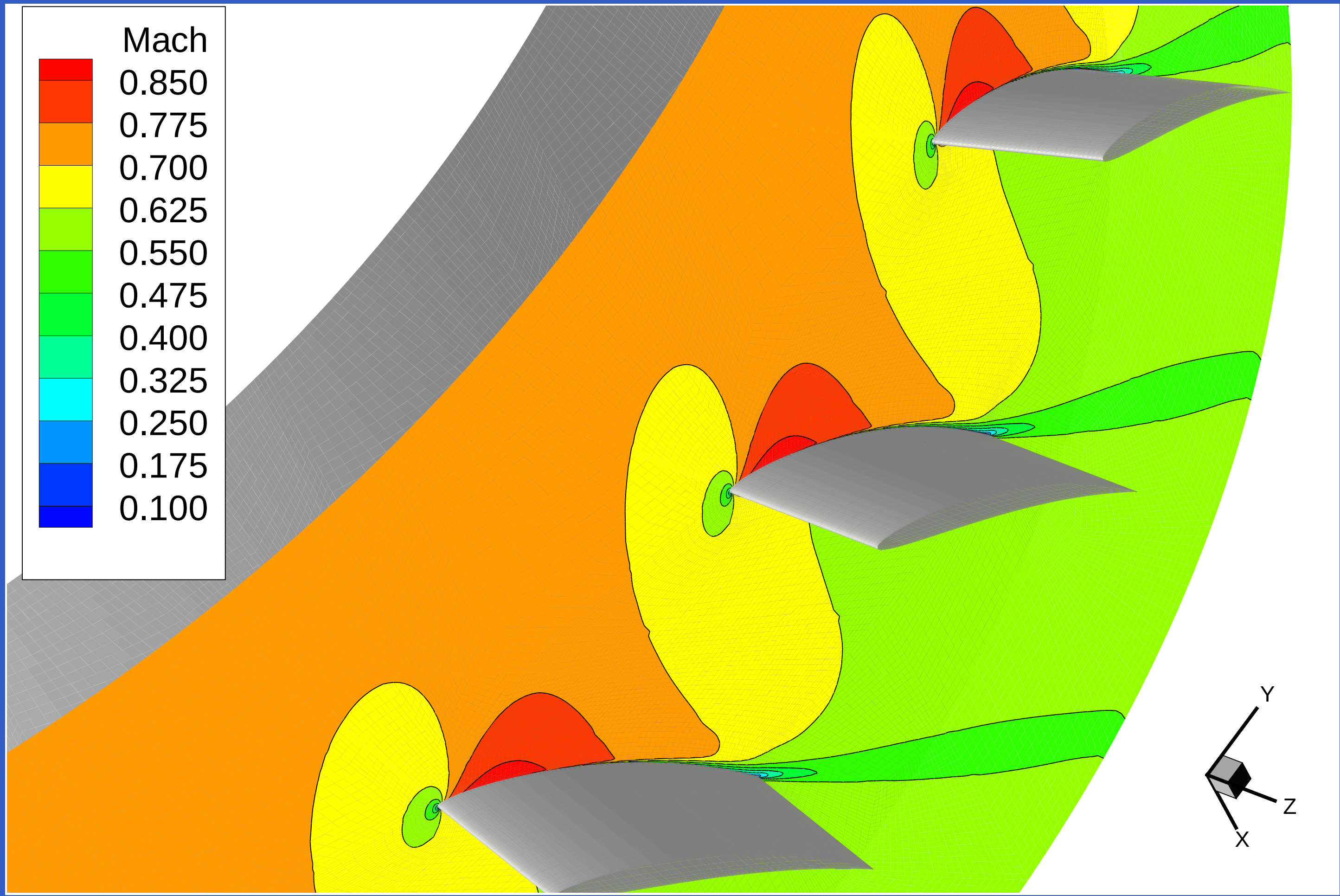
Steady-State Solution $M_1 = 0.7,\ \beta_1 = 55.0^o$



Flow Mach Number at 10% Blade Height

3D Standard Configuration 10

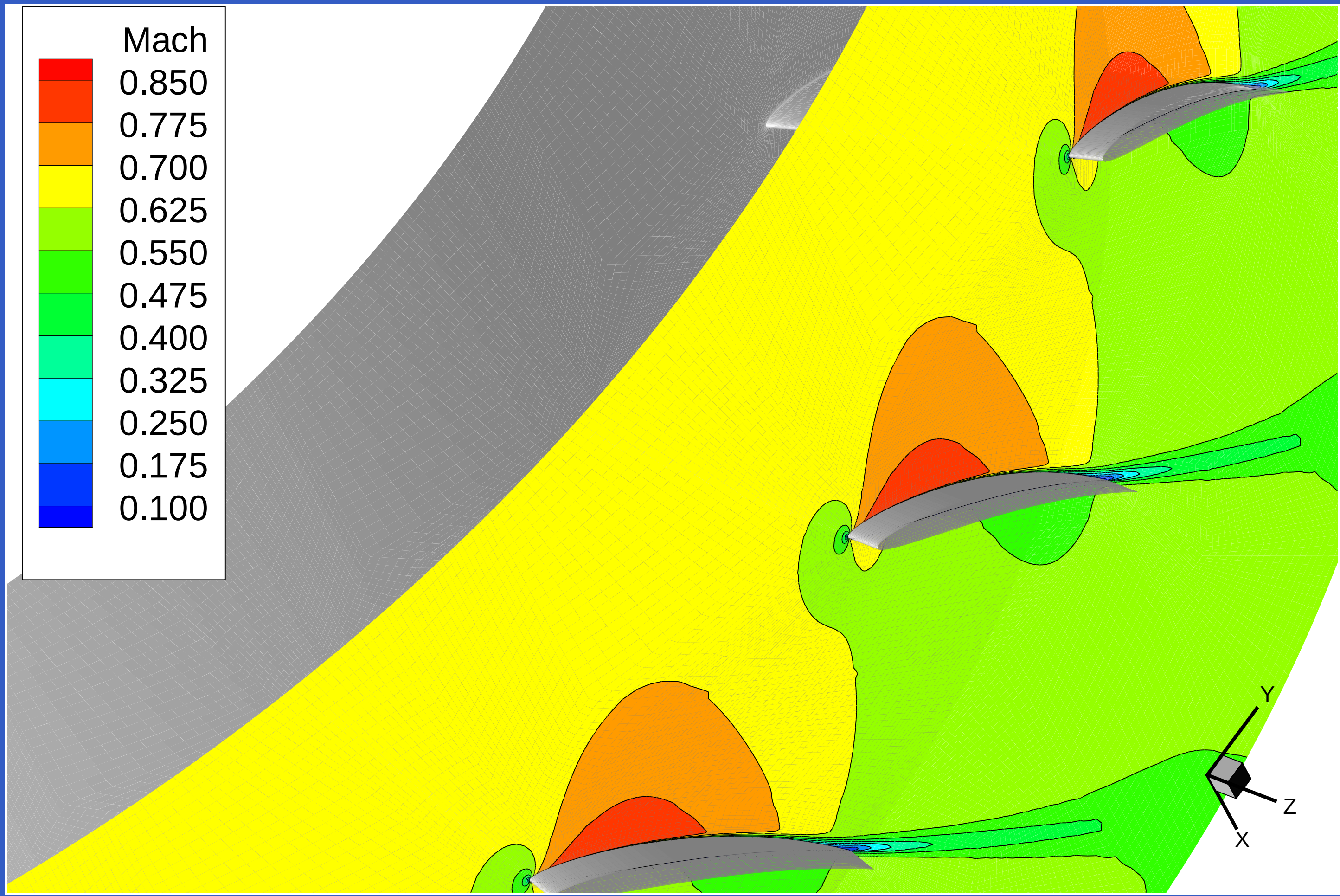
Steady-State Solution $M_1 = 0.7$, $\beta_1 = 55.0^o$



Flow Mach Number at 50% Blade Height

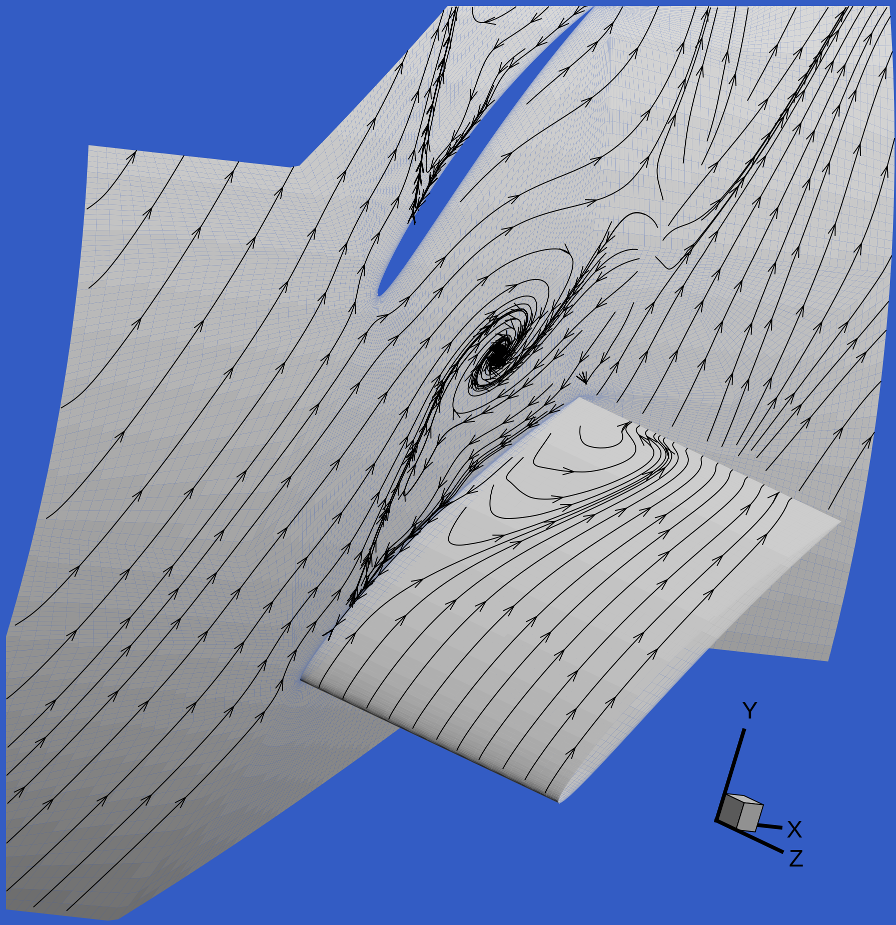
3D Standard Configuration 10

Steady-State Solution $M_1 = 0.7$, $\beta_1 = 55.0^o$



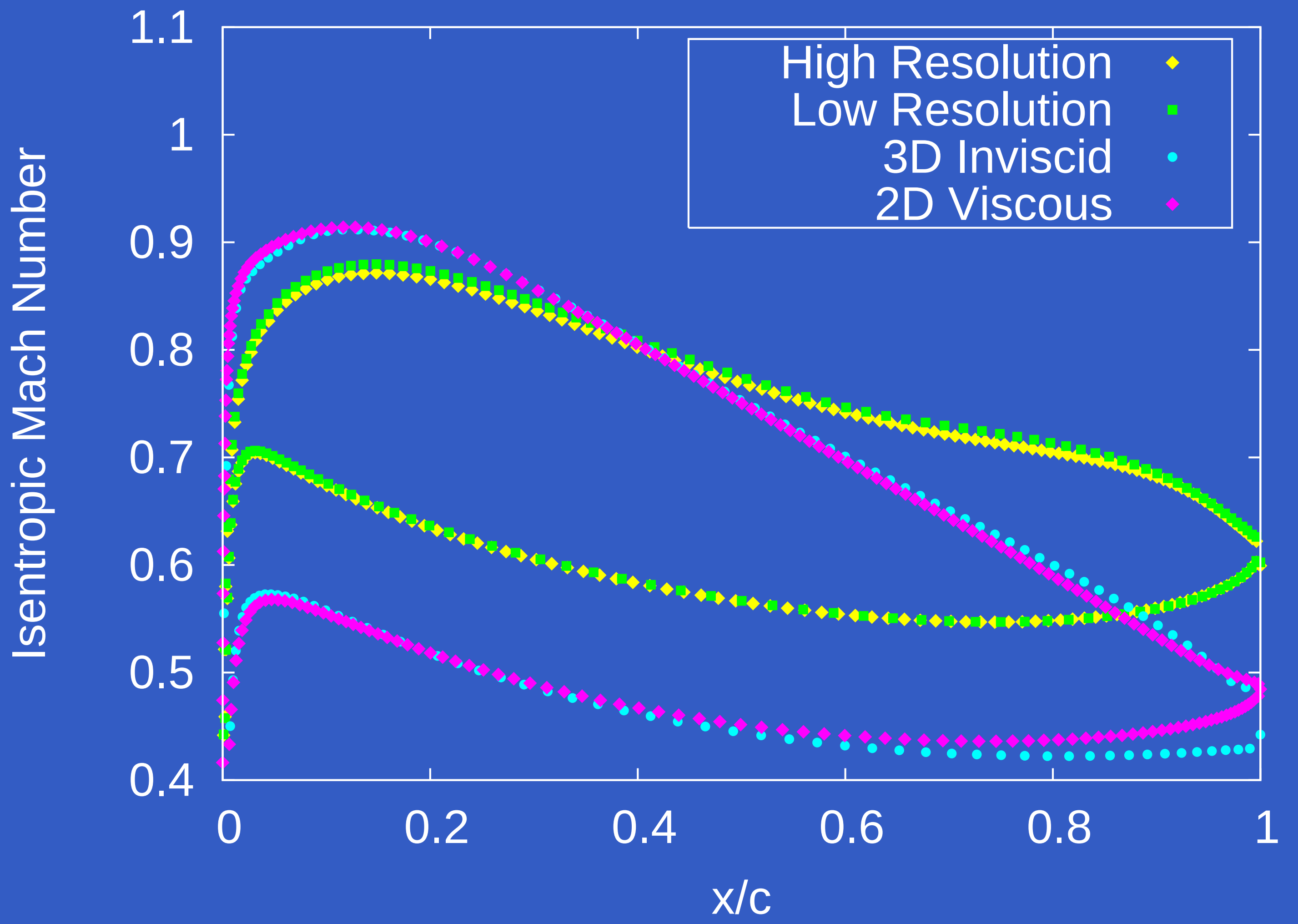
Flow Mach Number at 90% Blade Height

3D Standard Configuration 10: Steady-State



Stream lines on hub and profile: $M_1 = 0.7$, $\beta_1 = 55.0^o$

3D Standard Configuration 10: Steady-State



Steady-state at 50% blade height $M_1 = 0.7$, $\beta_1 = 55.0^o$

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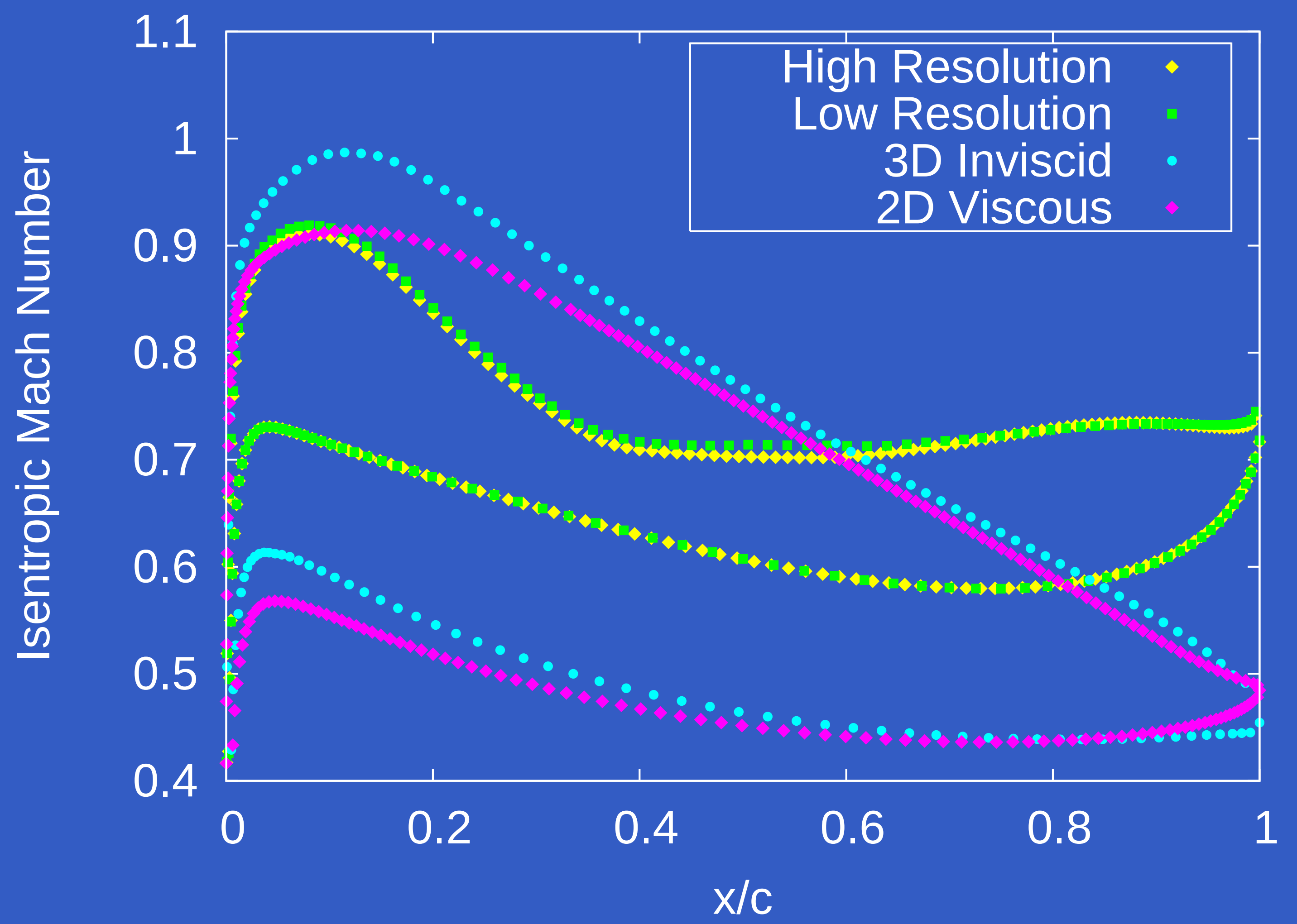
3D Standard Configuration 10: Steady-State



Steady-state at 10% blade height $M_1 = 0.7$, $\beta_1 = 55.0^o$

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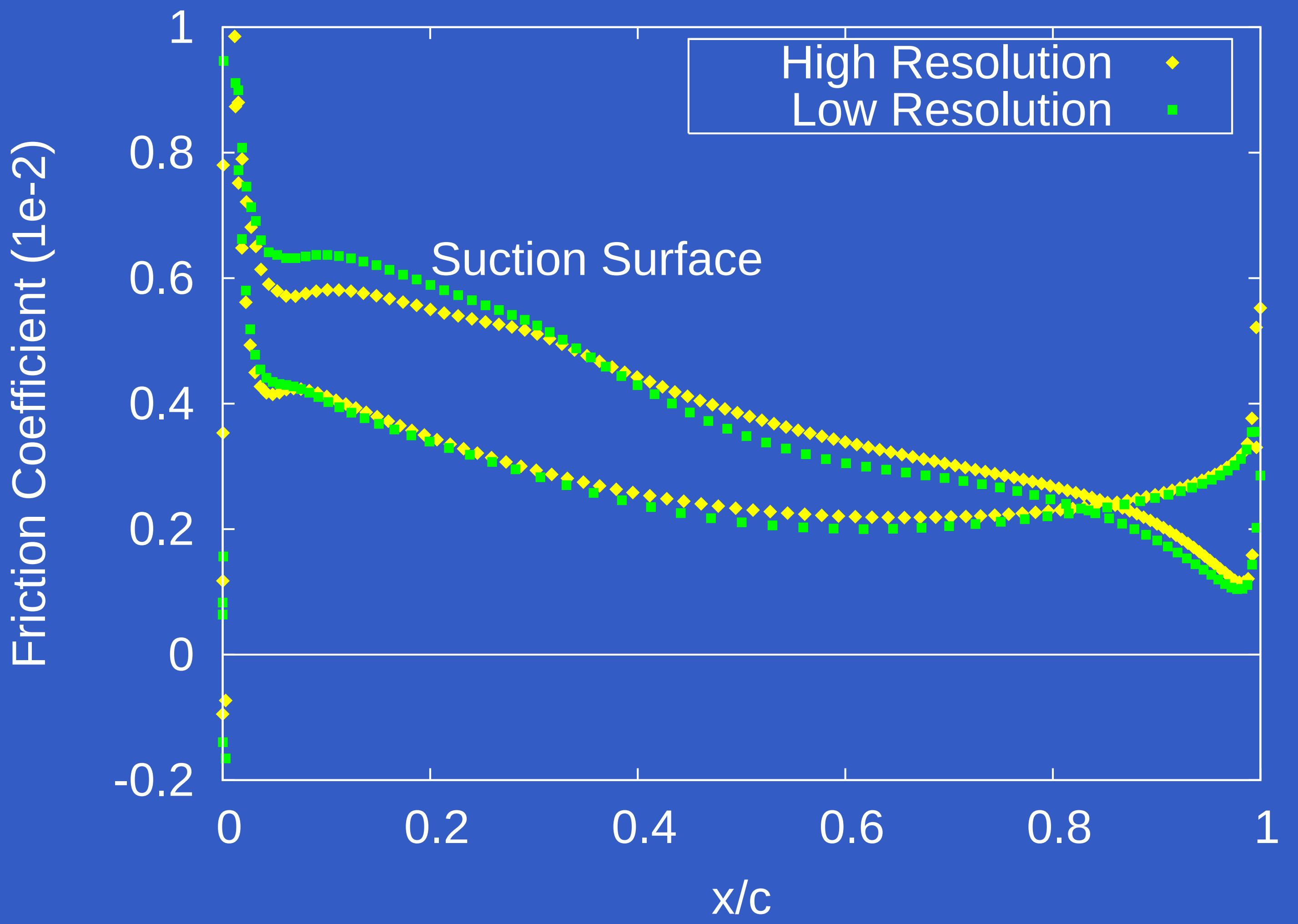
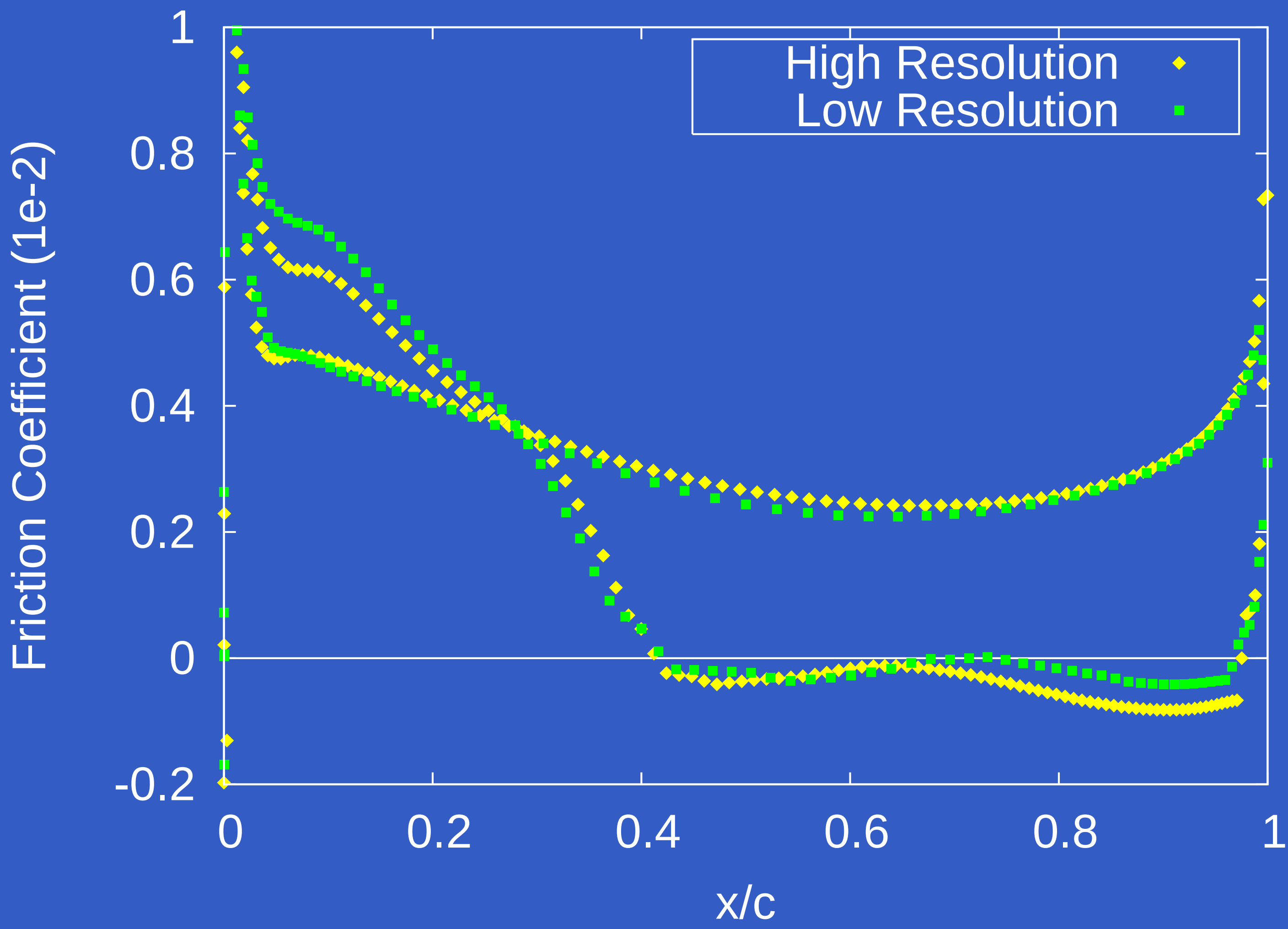
3D Standard Configuration 10: Steady-State



Steady-state at 50% blade height $M_1 = 0.7$, $\beta_1 = 55.0^o$

3D Standard Configuration 10: Steady-State



Steady-state at 10% blade height $M_1 = 0.7$, $\beta_1 = 55.0^o$

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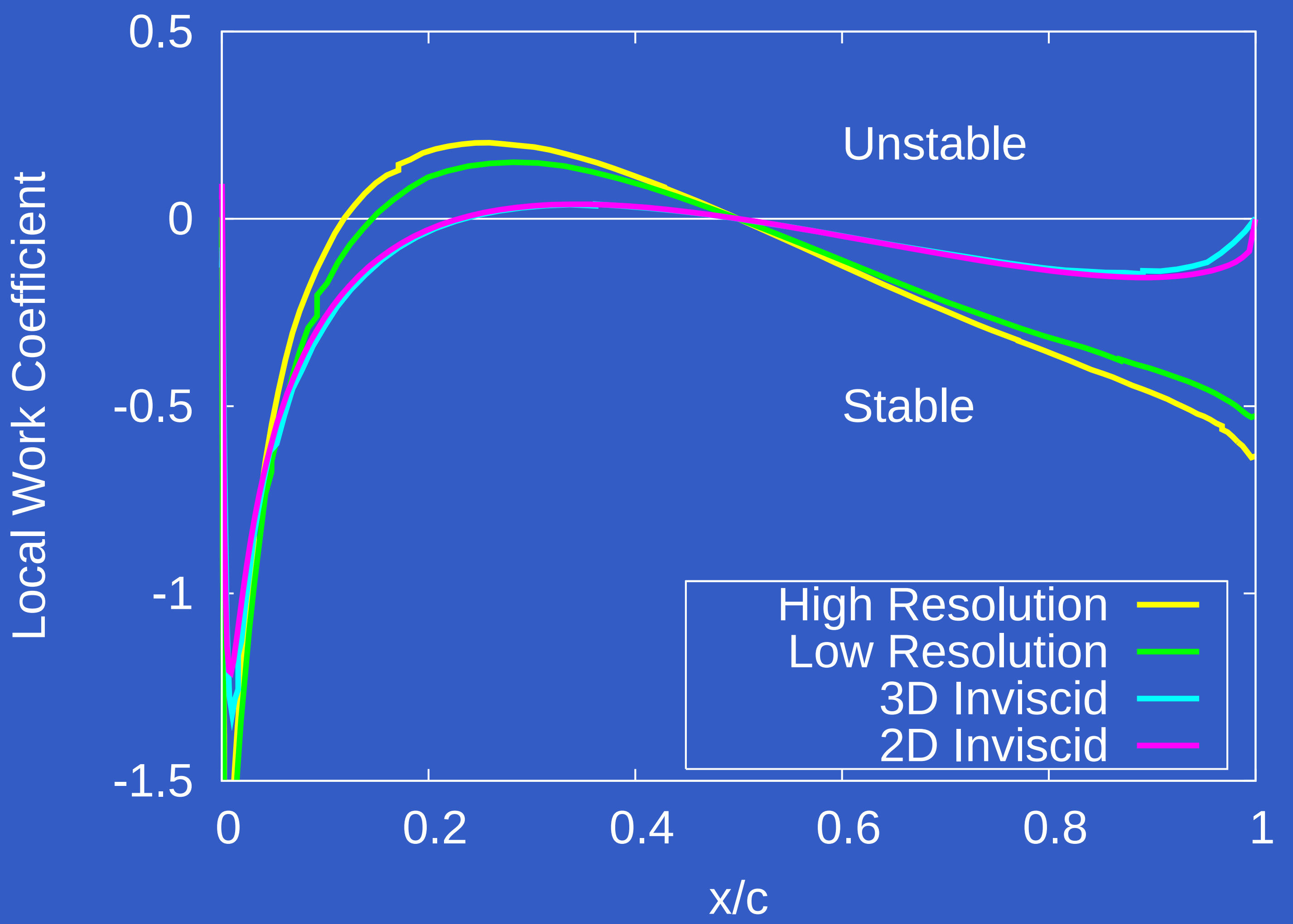
3D Standard Configuration 10: Unsteady Flow



Pressure surface at 50% blade height
Torsion ($\omega^* = 0.5$, $\sigma = 0^o$)

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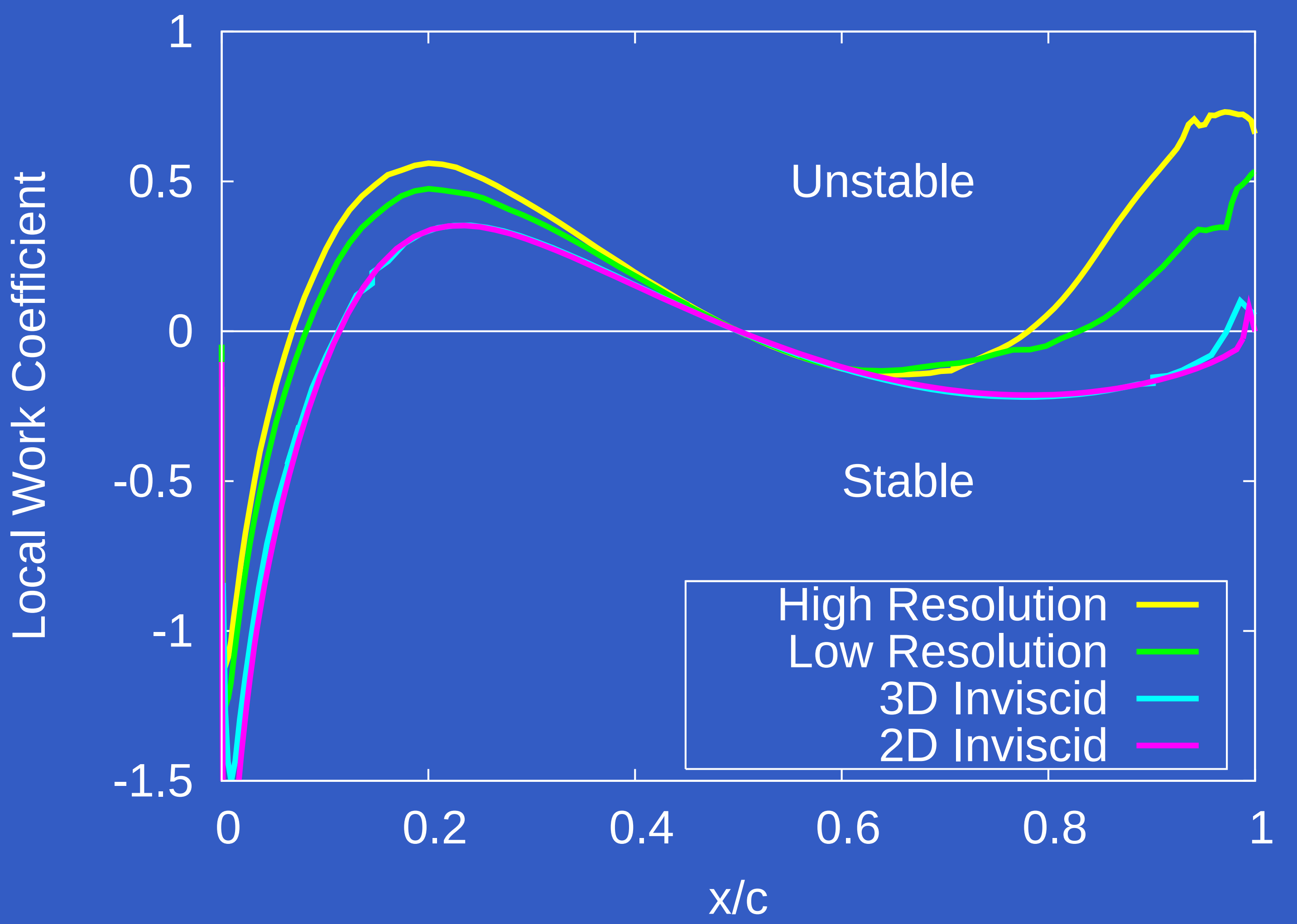
3D Standard Configuration 10: Unsteady Flow



Suction surface at 50% blade height

Torsion ($\omega^* = 0.5$, $\sigma = 0^o$)

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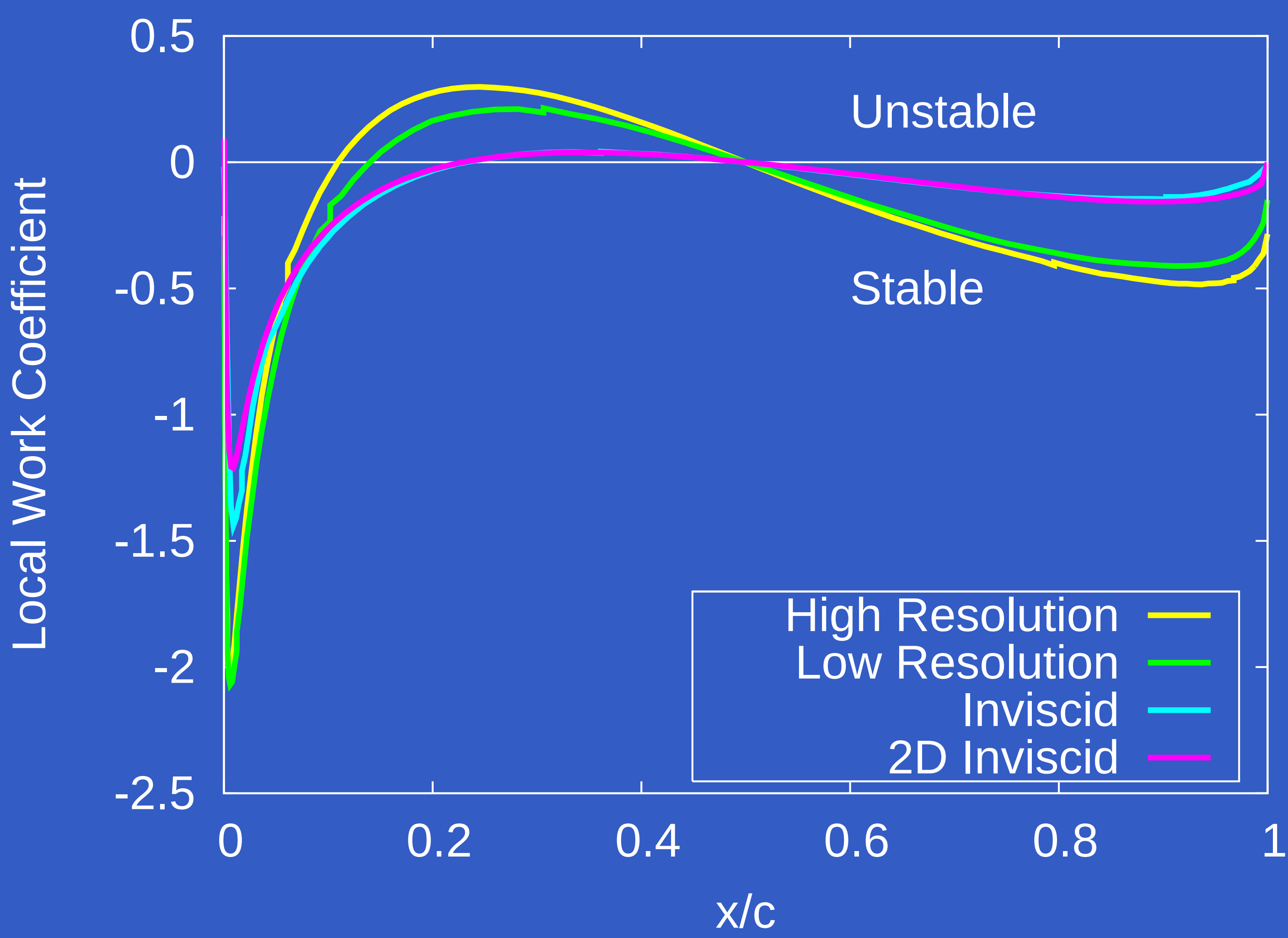
3D Standard Configuration 10: Unsteady Flow



Pressure surface at 10% blade height

Torsion ($\omega^* = 0.5$, $\sigma = 0^o$)

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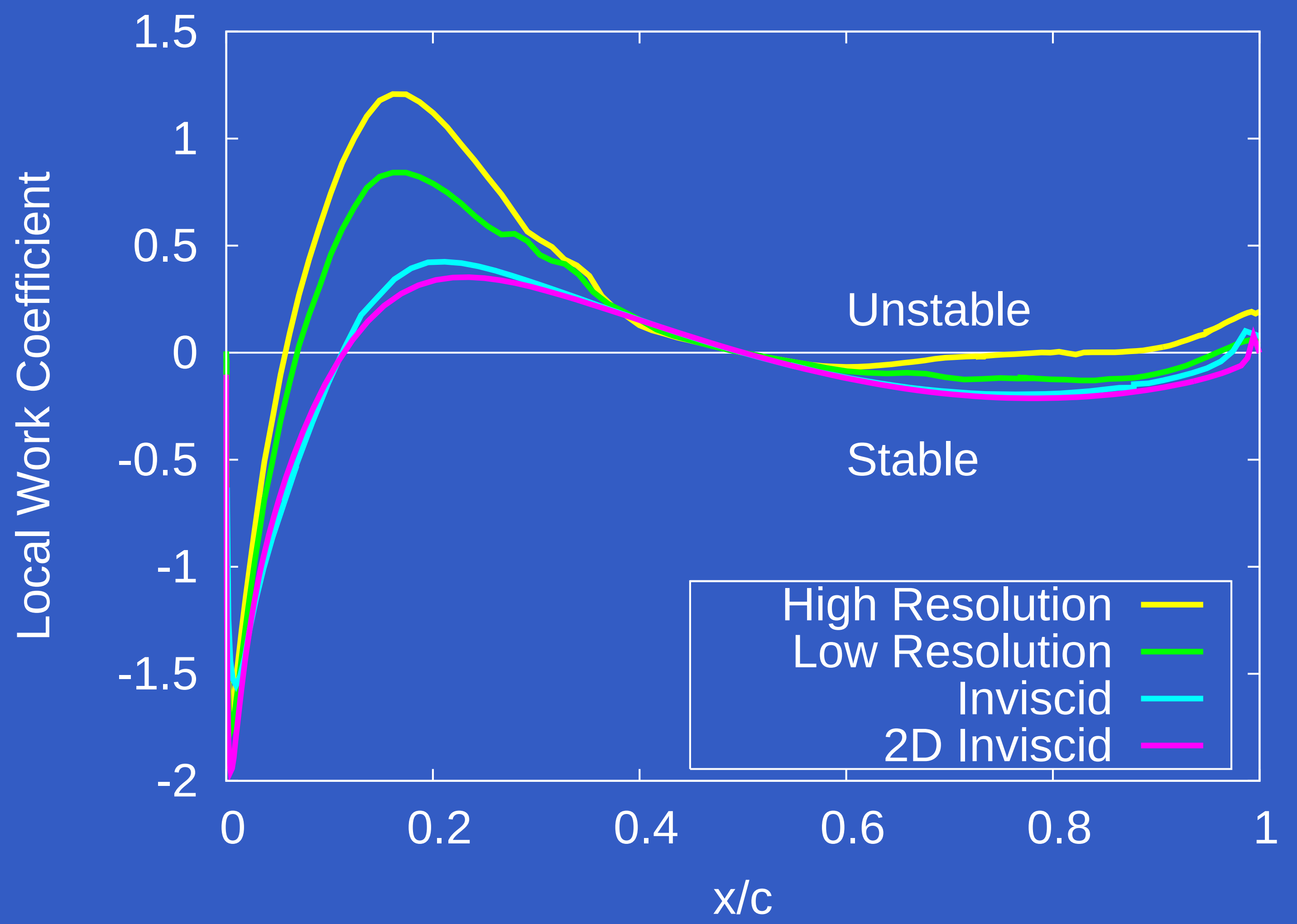
3D Standard Configuration 10: Unsteady Flow



Suction surface at 10% blade height

Torsion ($\omega^* = 0.5$, $\sigma = 0^o$)

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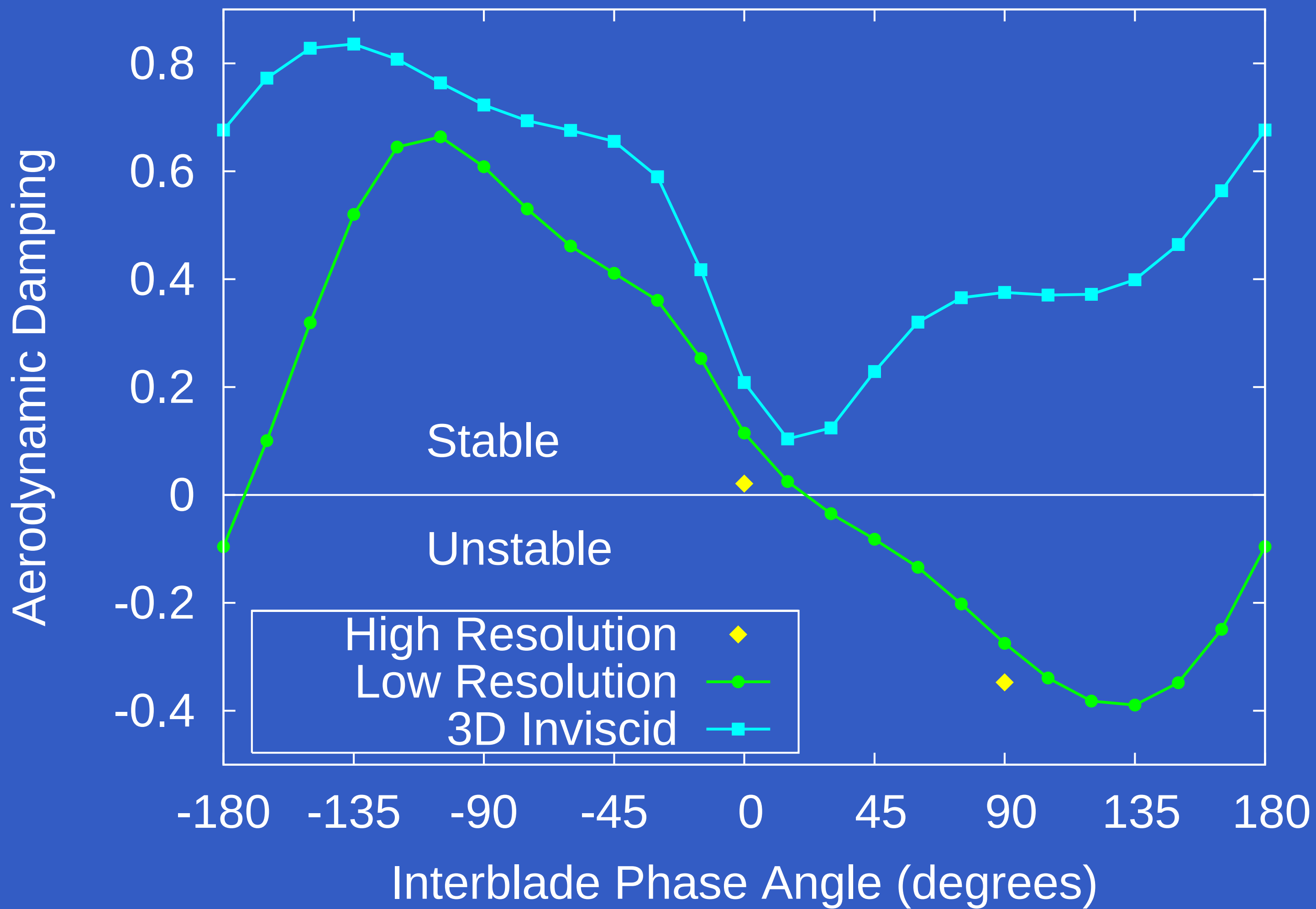
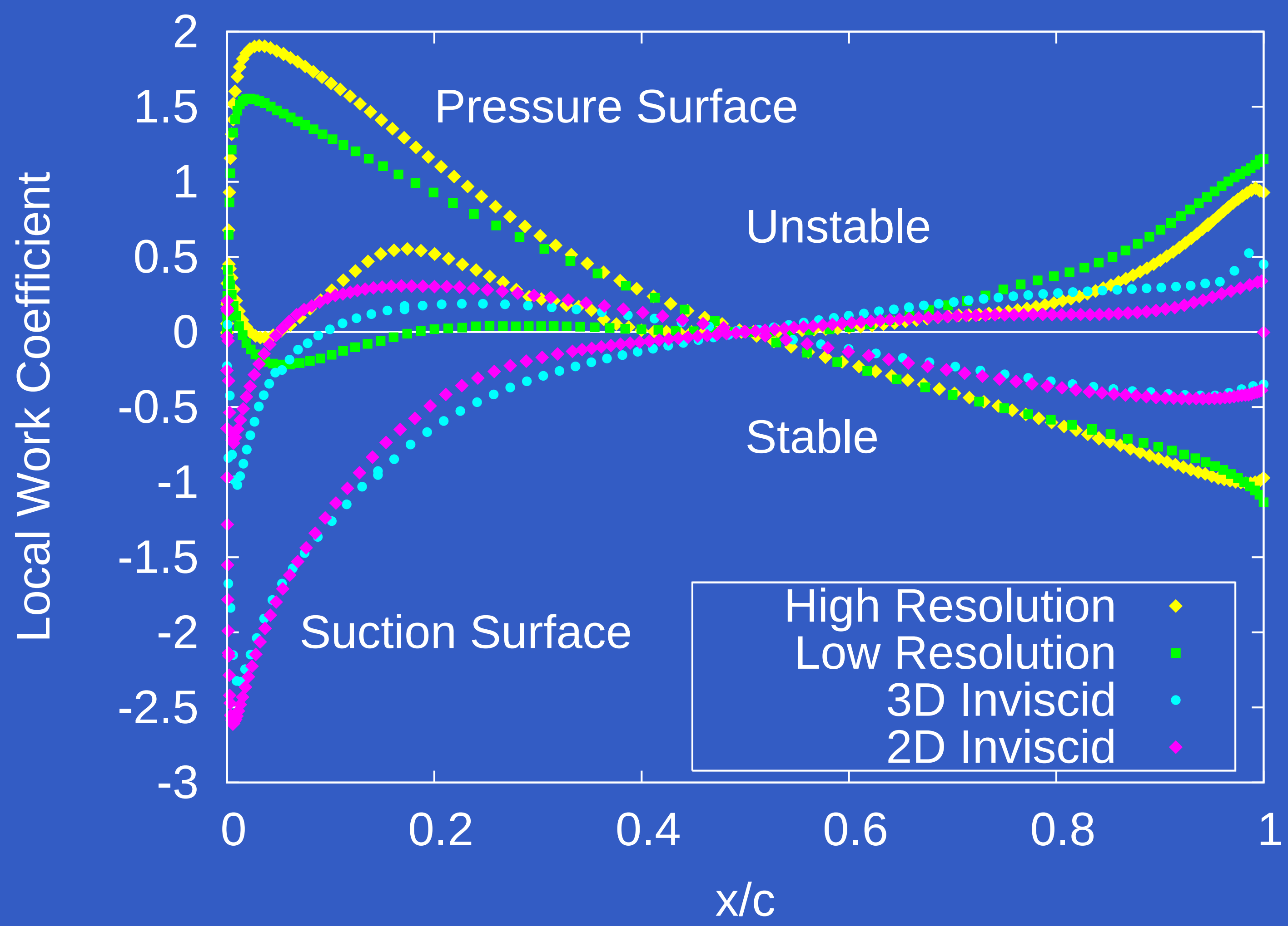
Aerodynamic Damping



Aerodynamic damping due to torsion ($\omega^* = 0.5$)

3D Standard Configuration 10: Unsteady Flow



50% blade height: torsion ($\omega^* = 0.5$, $\sigma = 90^o$)

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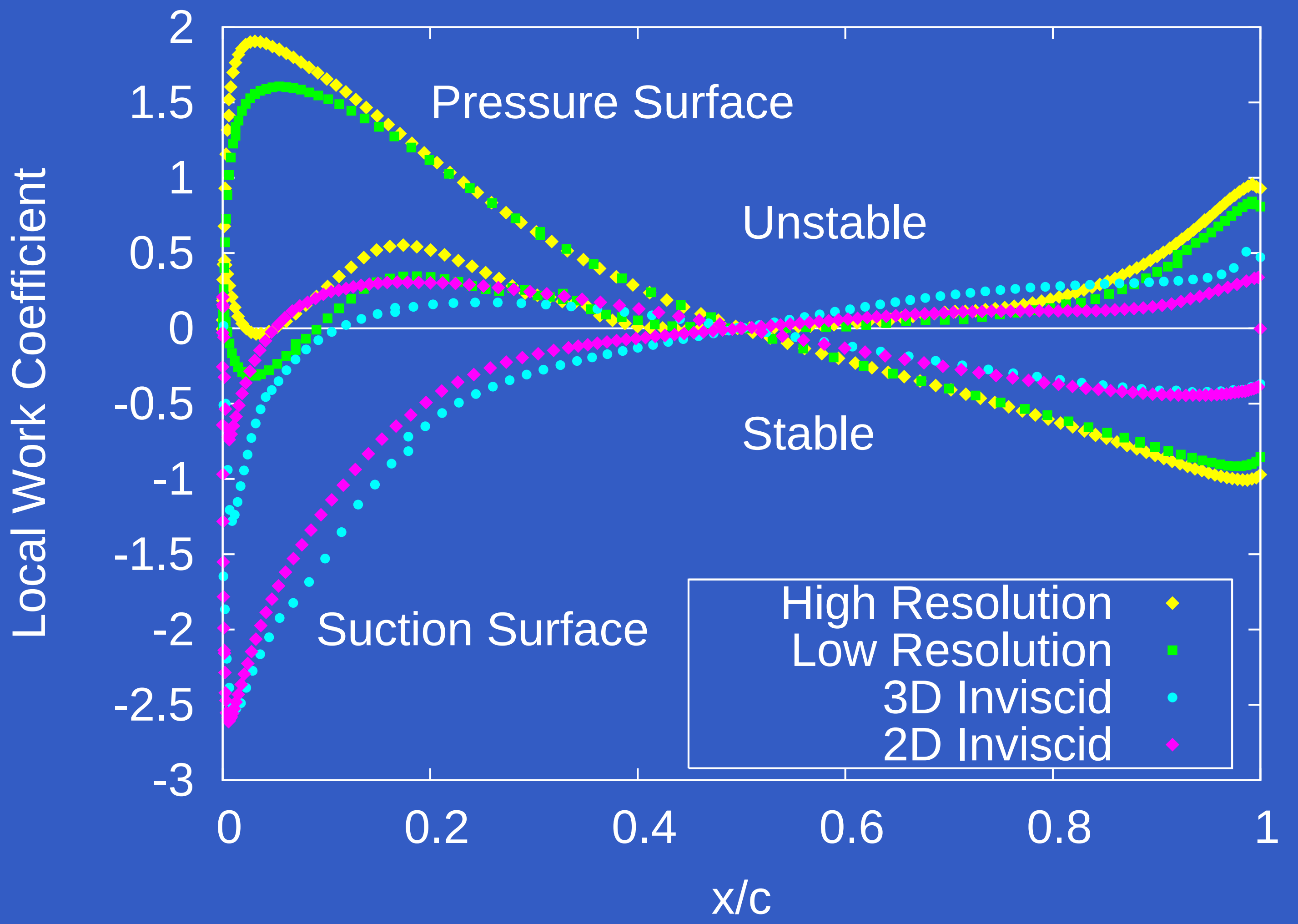
3D Standard Configuration 10: Unsteady Flow



10% blade height: torsion ($\omega^* = 0.5$, $\sigma = 90^o$)

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Computational Effort

3D Viscous Unsteady Flow Simulation

Resolution	Low	High
Number of Cells	455 988	1 594 728
Number of Processors	35	63
Memory per Processor (Gb)	2	4
Run Time (minutes)	27	75

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Future Work

Three-Dimensional Standard Configuration 10

- Include 3D non-reflecting boundary condition
- Grid convergence study
- Solutions from other CFD codes
- Solutions for other popular turbulence models

Conclusions

- Results of unsteady viscous simulations of a 3D Compressor (Standard Configuration 10) have been presented
- Corner separation predicted on suction surface at hub causes significant flow blockage
- Flow significantly different than that predicted by 2D viscous or 3D inviscid simulations
- Aerodynamically unstable (2D viscous and 3D inviscid stable)
- Data can be downloaded from www.rpmturbo.com