Viscous Flutter Analysis of a Three-Dimensional Compressor Blade

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Presentation Outline

- Problem Description: geometry, flow conditions
- Method: grids and flow solvers
- Steady-State Results: corner separation
- Unsteady Flow: aerodynamic damping
- Conclusions

Standard Configurations

- 11 Standard Configurations for 2D profiles
- Excellent for verifying unsteady CFD codes
- Shortage of 3D Test Cases

3D Test Cases

- Helical Fan (inviscid flow)
- 3D Standard Configuration 11 Rzadkowski *et al.* 2006
- 3D LPT Vogt & Frannson 2005

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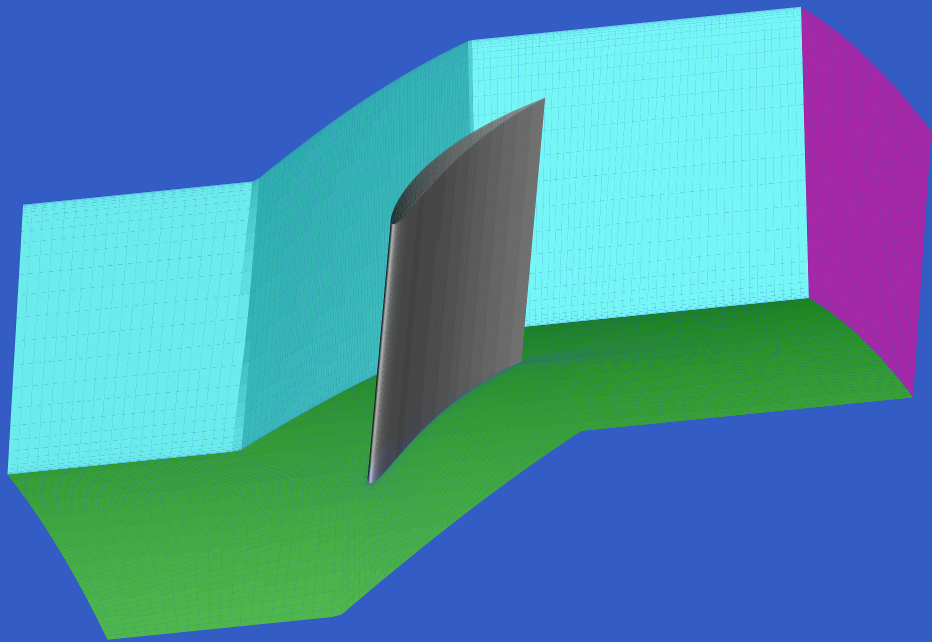
3D Standard Configuration 10

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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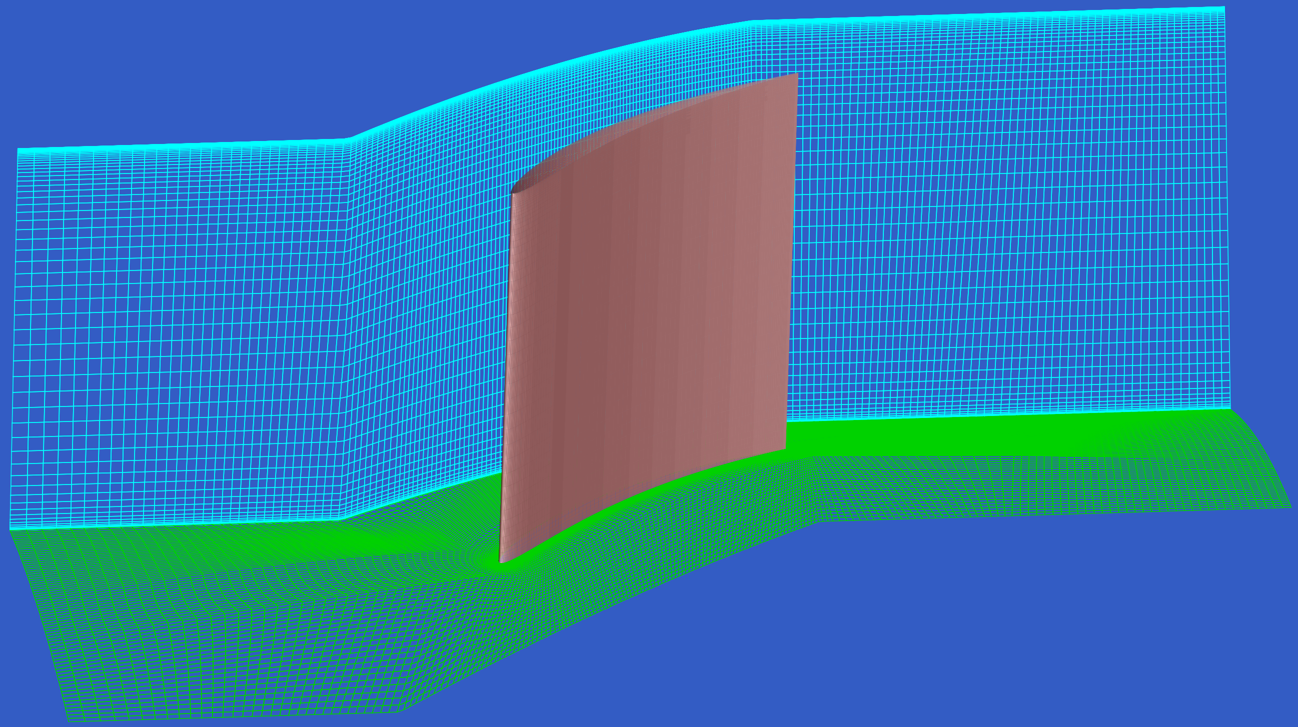
Computational Method

- Flow Model: 3D Navier-Stokes equations with Spalart and Allmaras turbulent model
- No wall functions and no transition modeling.
- RPMTurbo's in-house steady-state and time-linearized Navier-Stokes flow solvers
- Hardware: Computer Cluster at the University of Queensland with 180 processors and 360 Gbytes RAM

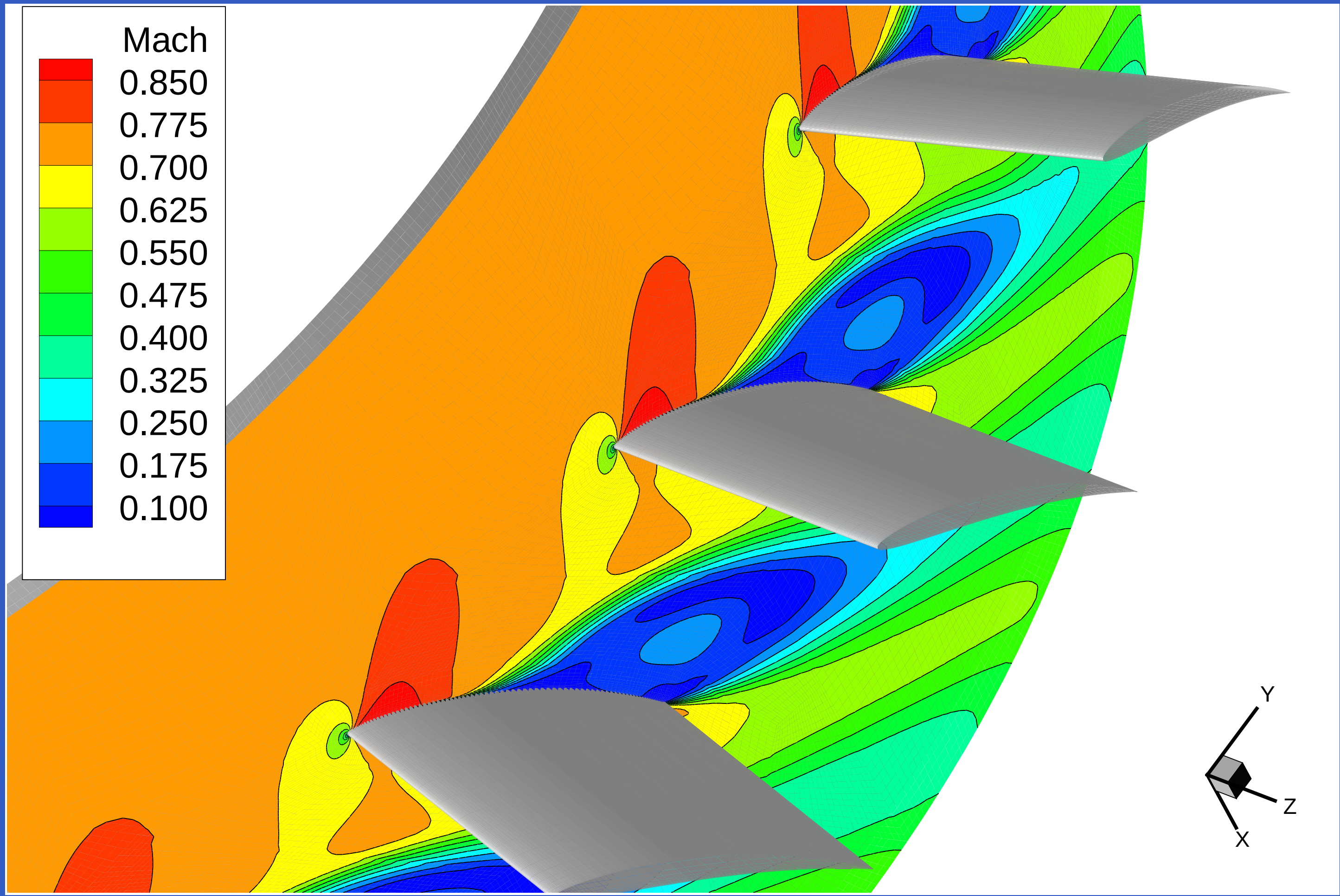
Meshes

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

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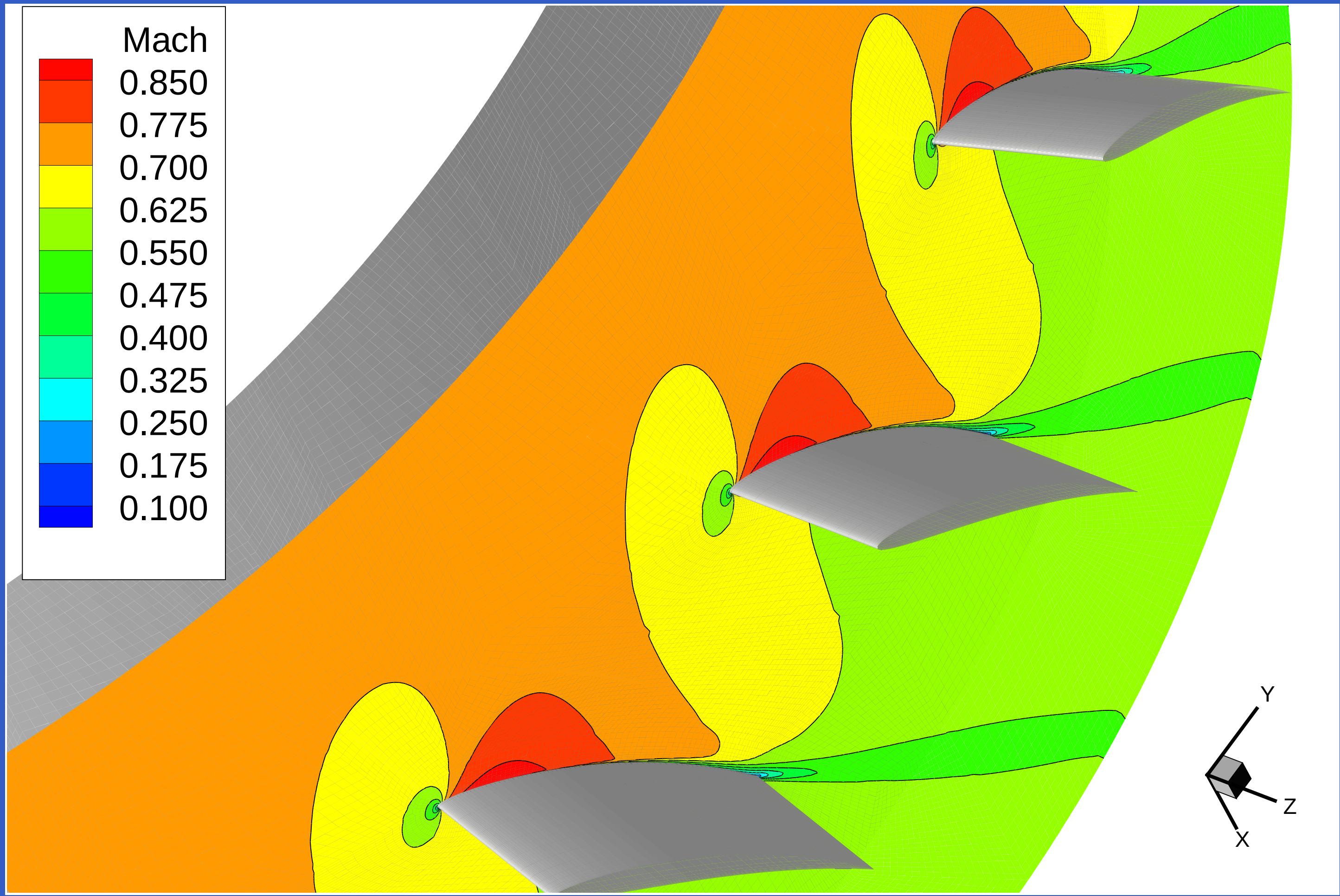
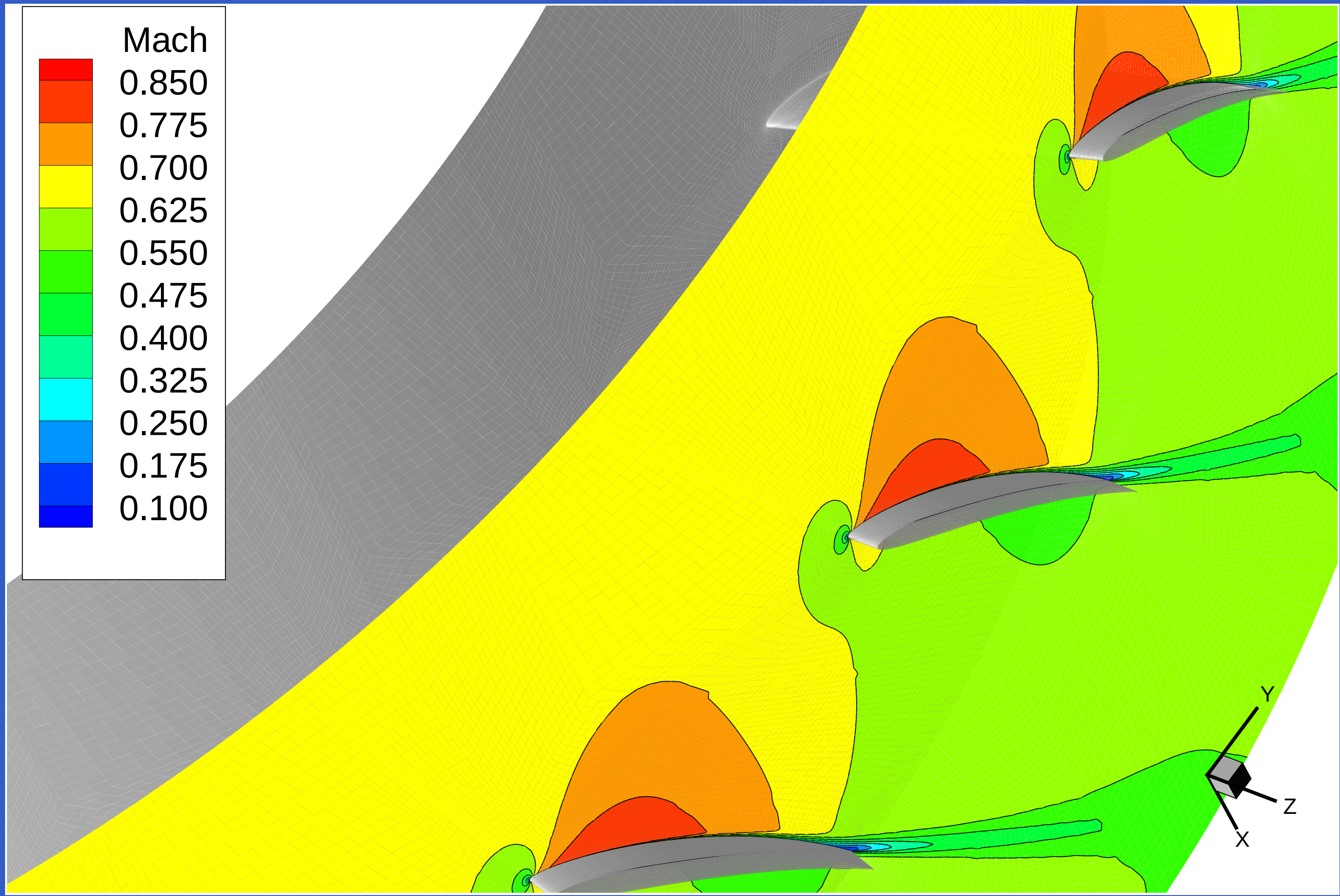


Flow Mach Number at 50% Blade Height

3D Standard Configuration 10

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



Flow Mach Number at 90% Blade Height

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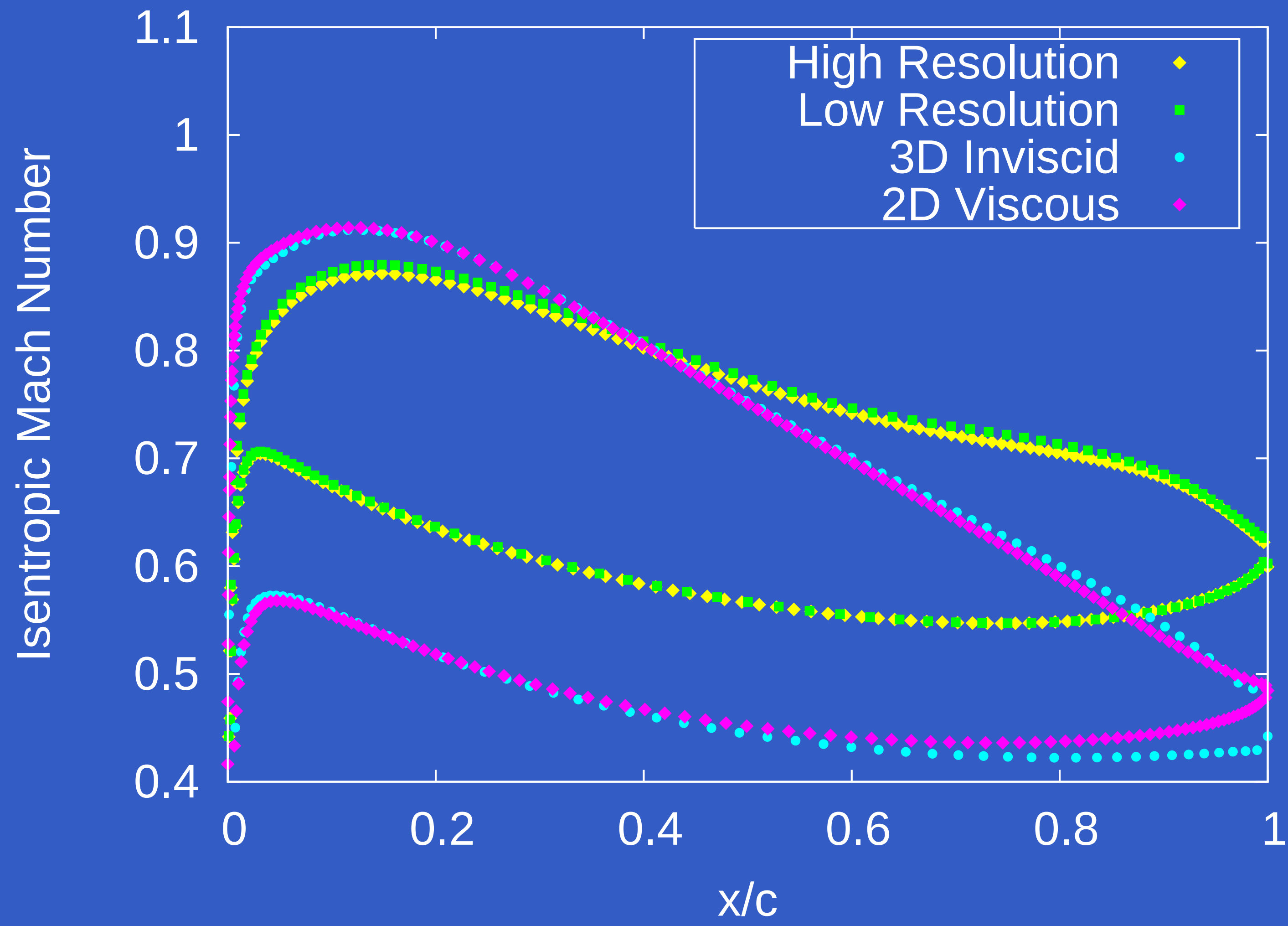
3D Standard Configuration 10: Steady-State



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

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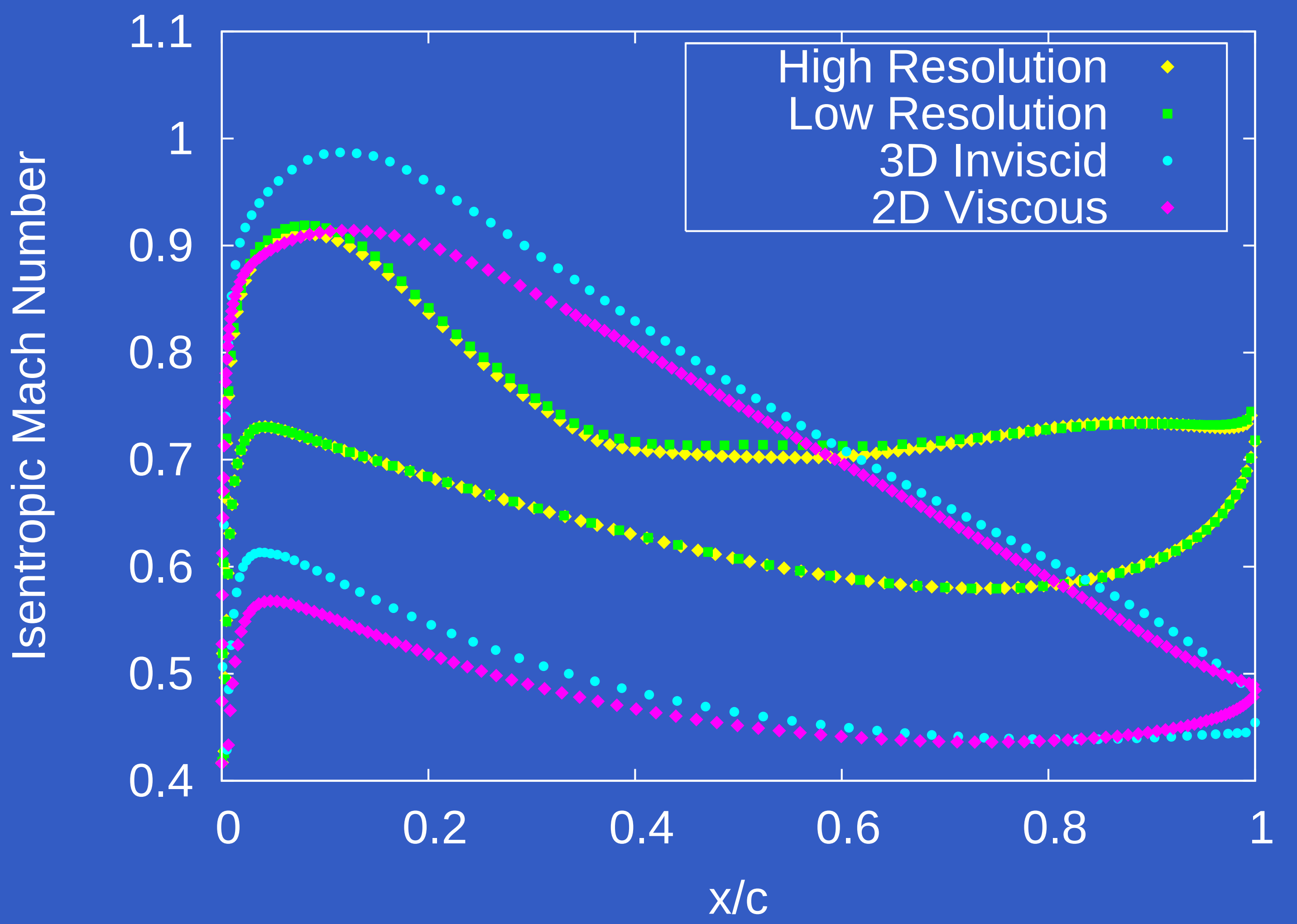
3D Standard Configuration 10: Steady-State



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

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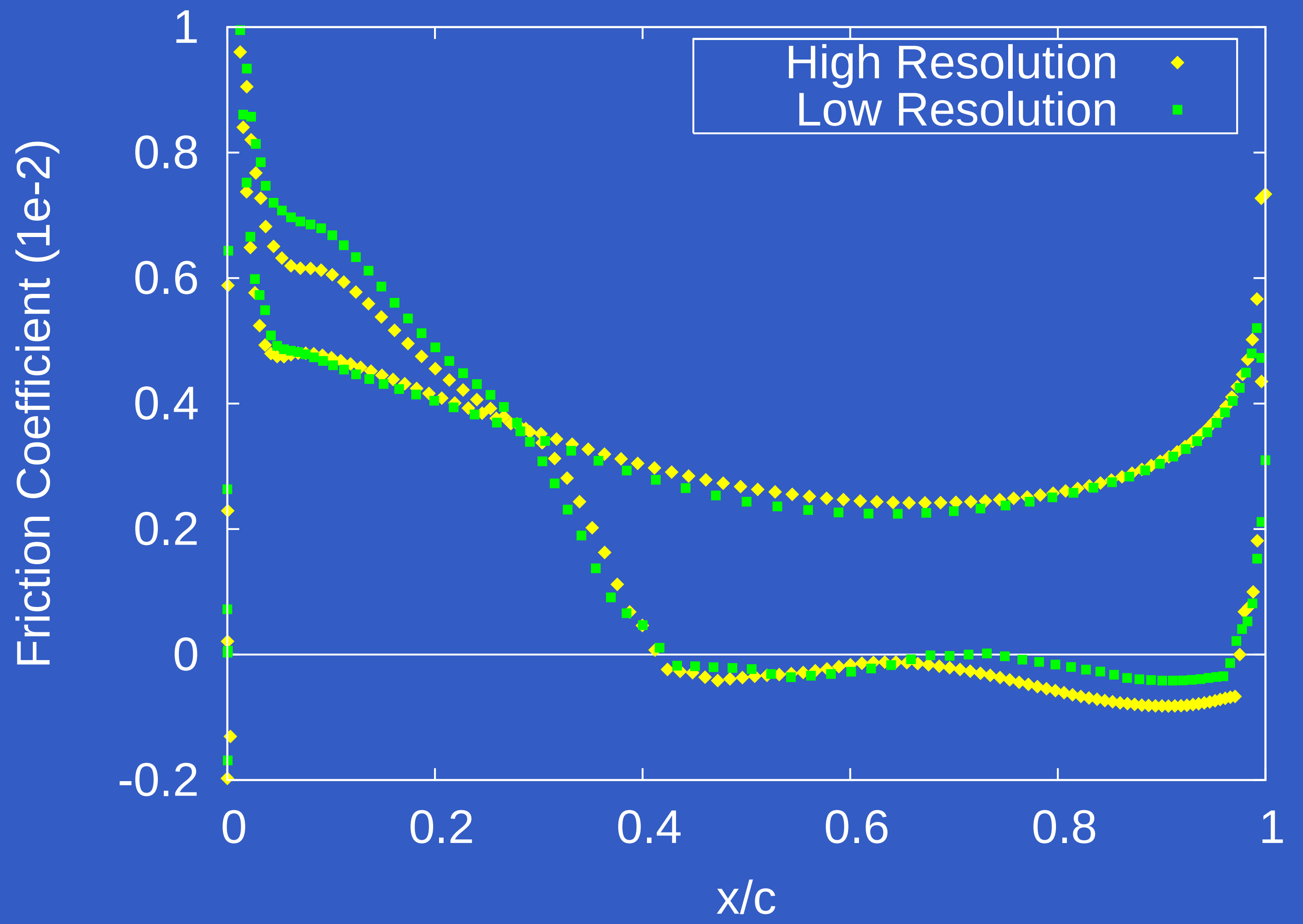
3D Standard Configuration 10: Steady-State



Steady-State at 10% Blade Height $M_1 = 0.7$, $\beta_1 = 55.0^o$

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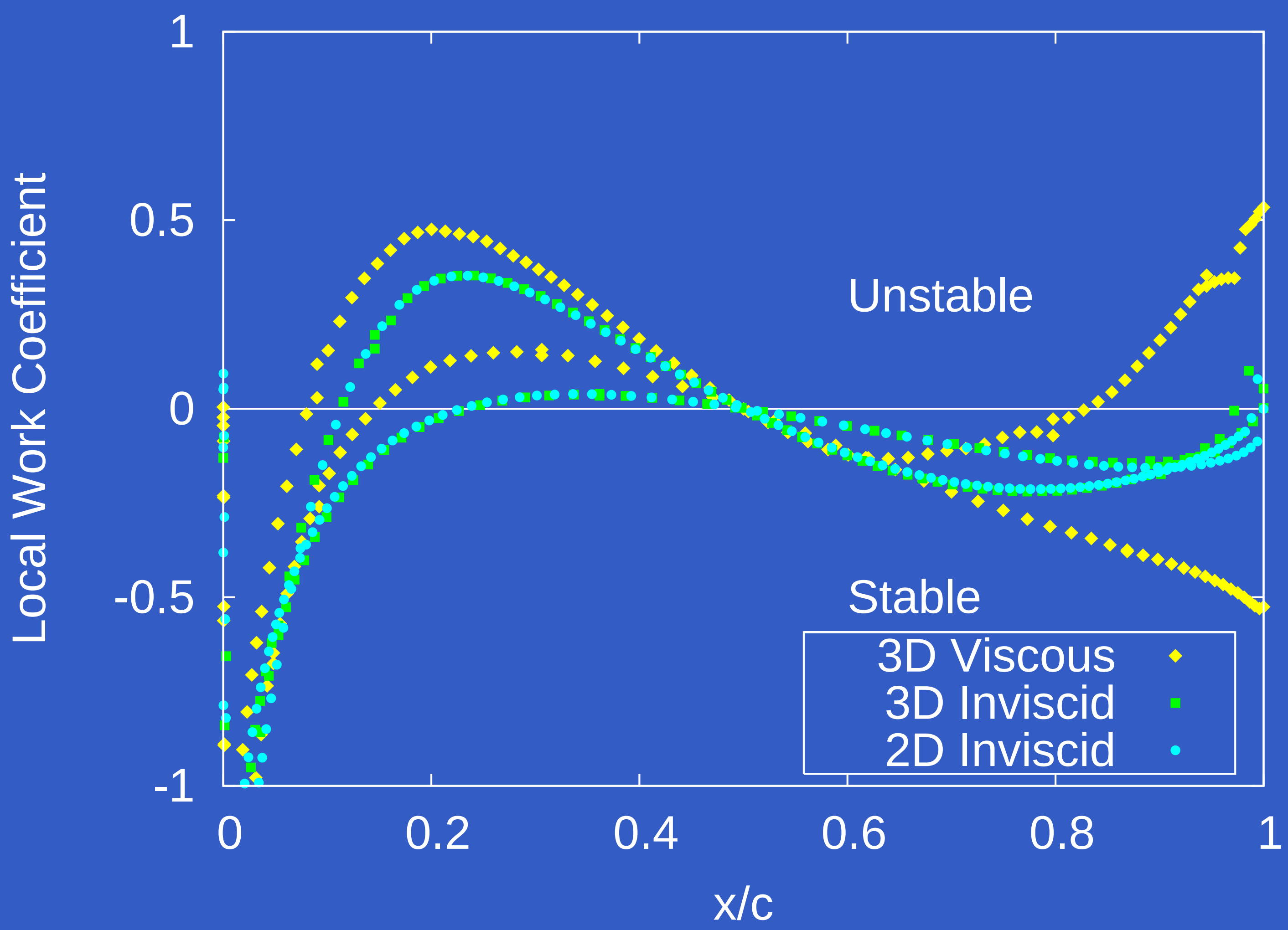
3D Standard Configuration 10: Unsteady Flow



50% Blade Height: Torsion ($\omega^* = 0.5$, $\sigma = 0^o$)

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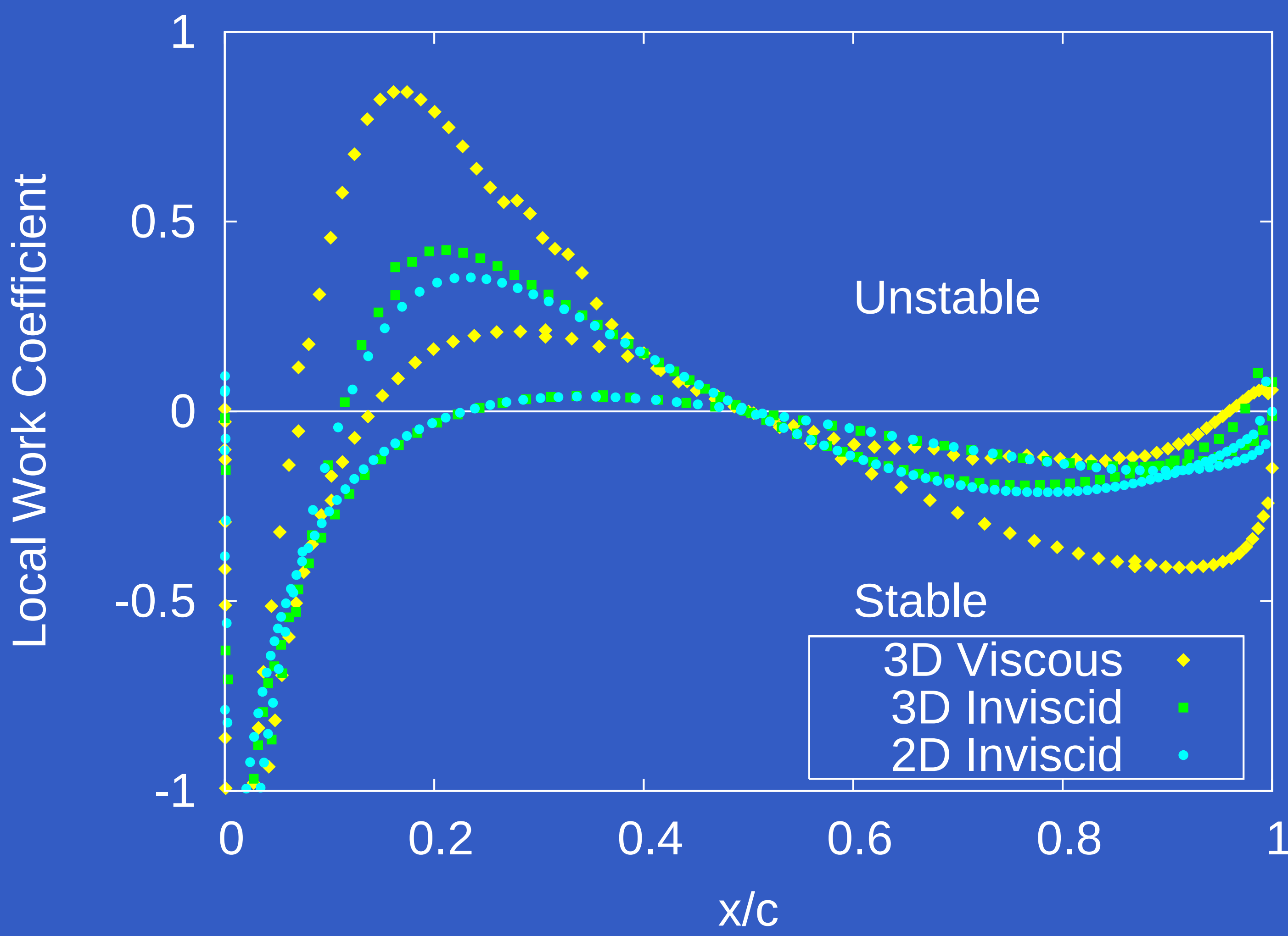
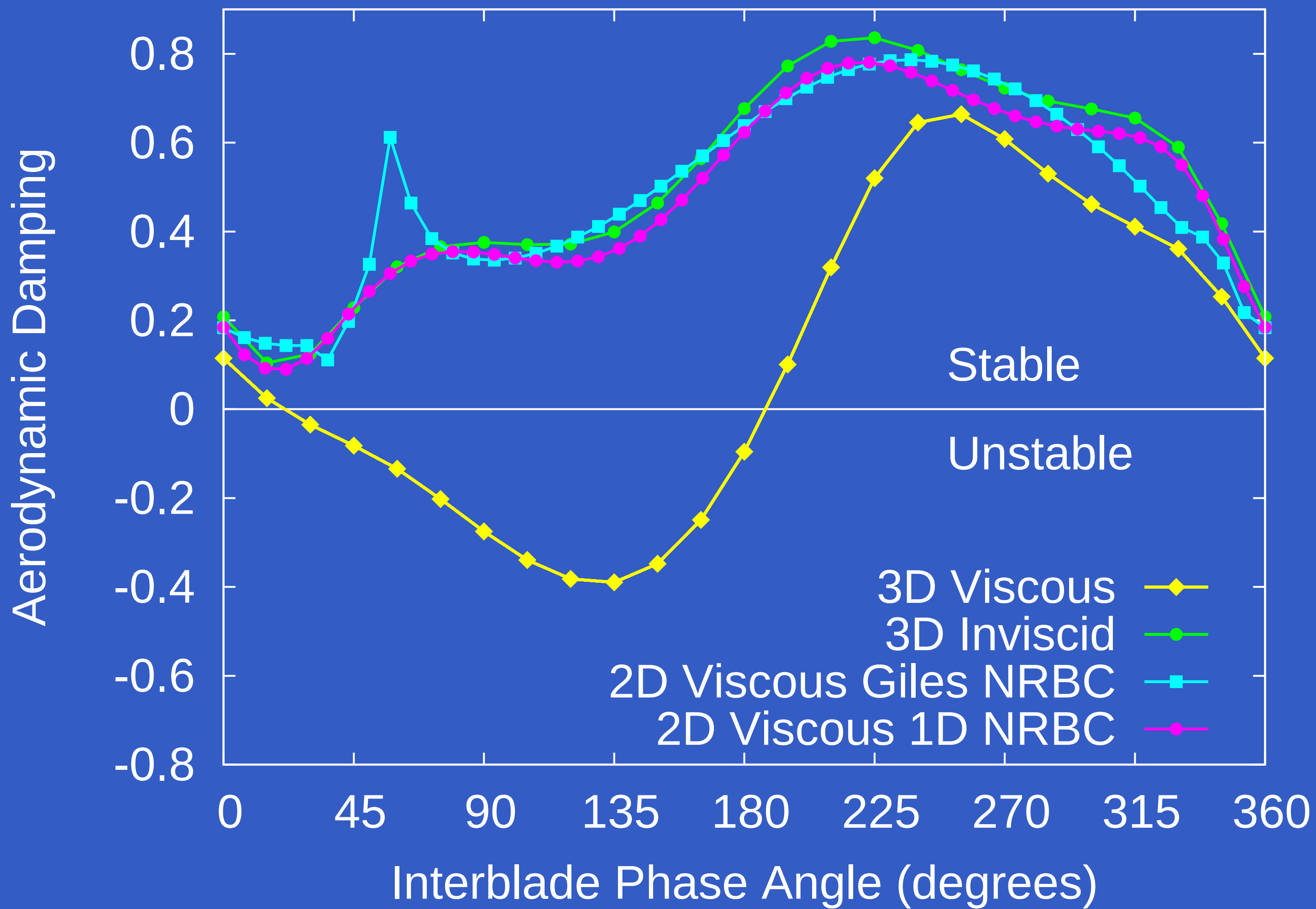
3D Standard Configuration 10: Unsteady Flow



10% Blade Height: Torsion ($\omega^* = 0.5$, $\sigma = 0^o$)

Aerodynamic Damping



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

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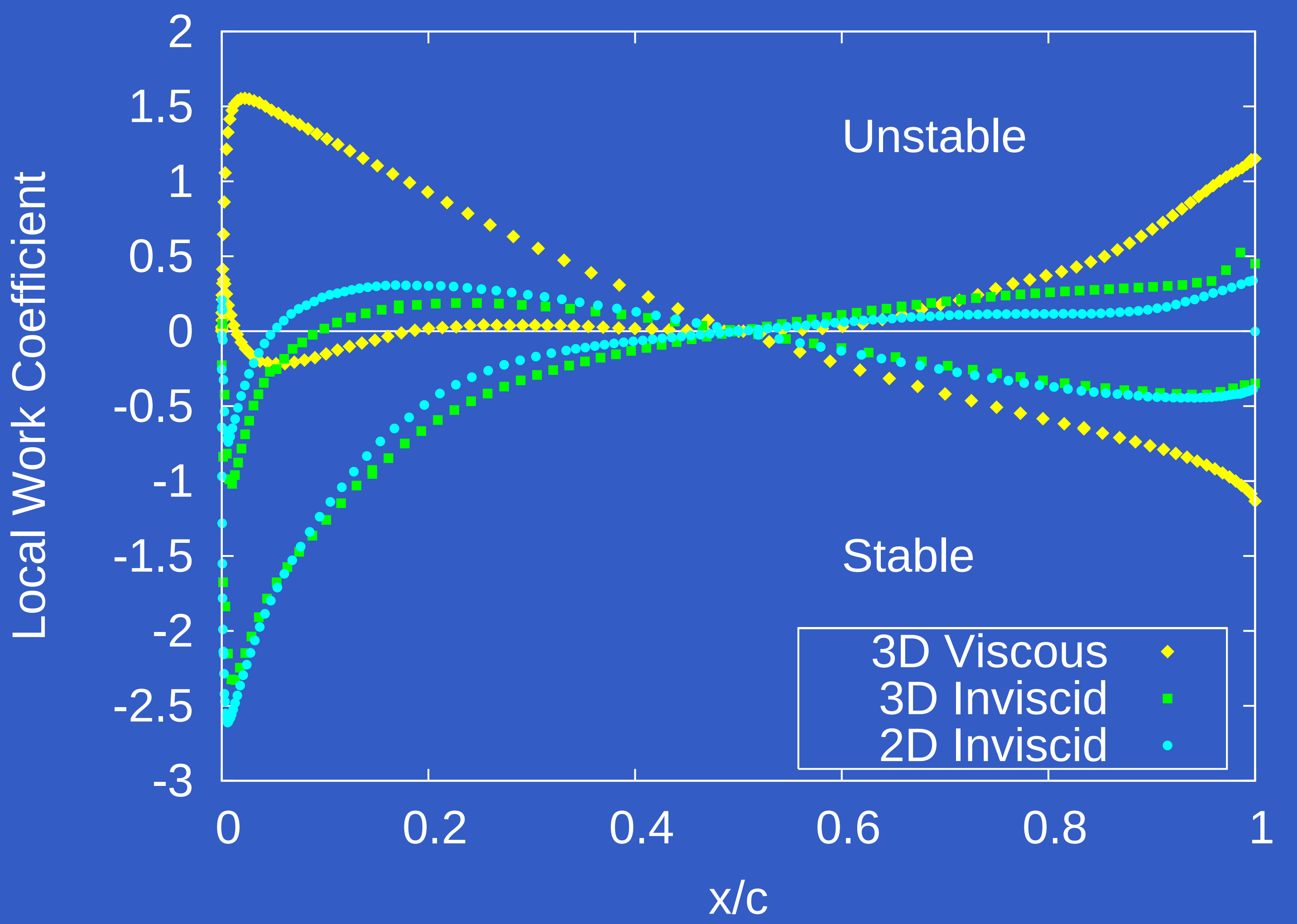
3D Standard Configuration 10: Unsteady Flow



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

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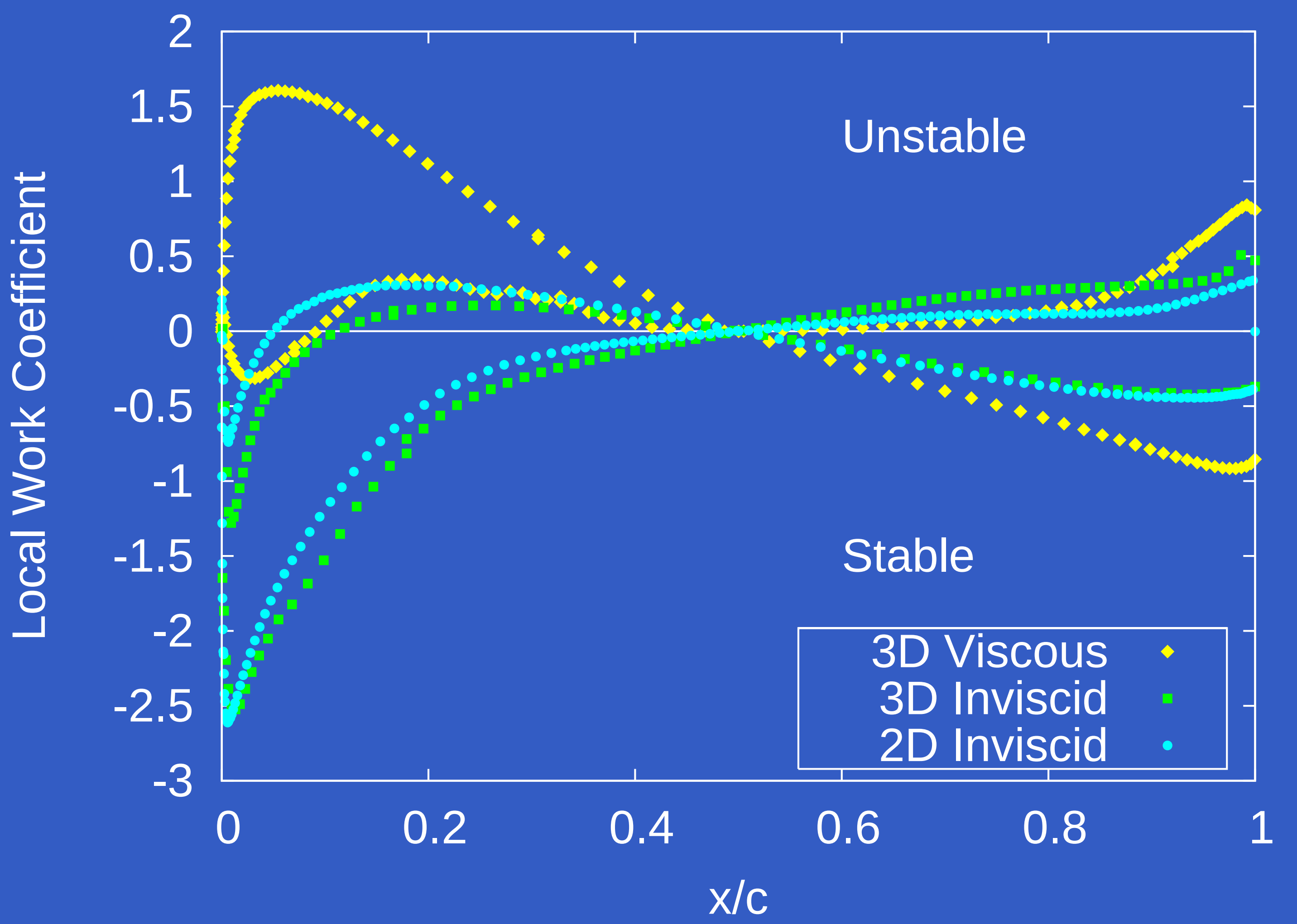
3D Standard Configuration 10: Unsteady Flow



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

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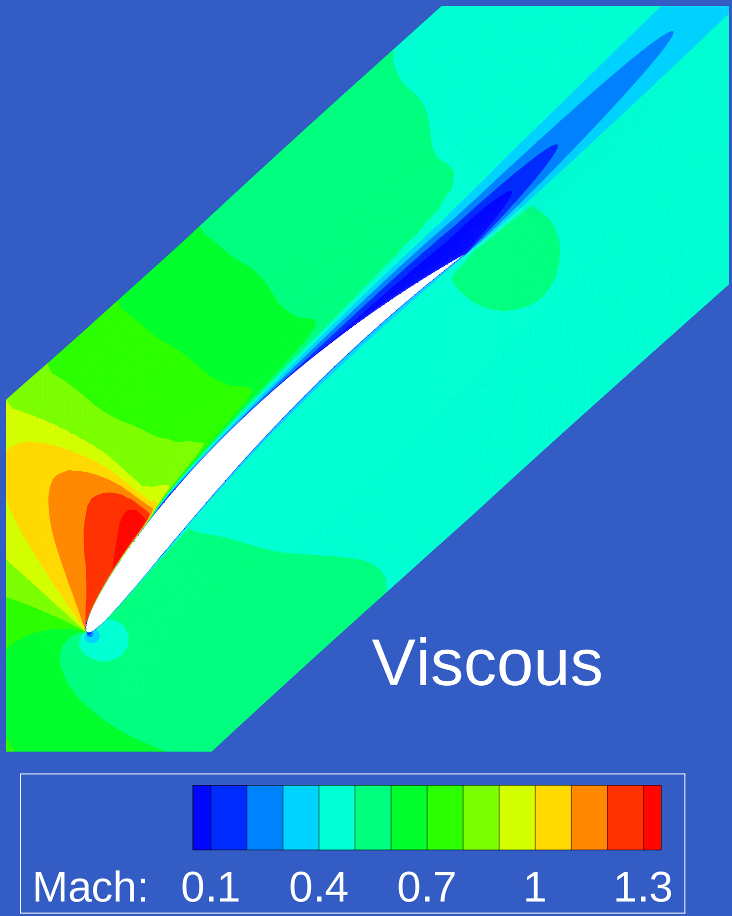
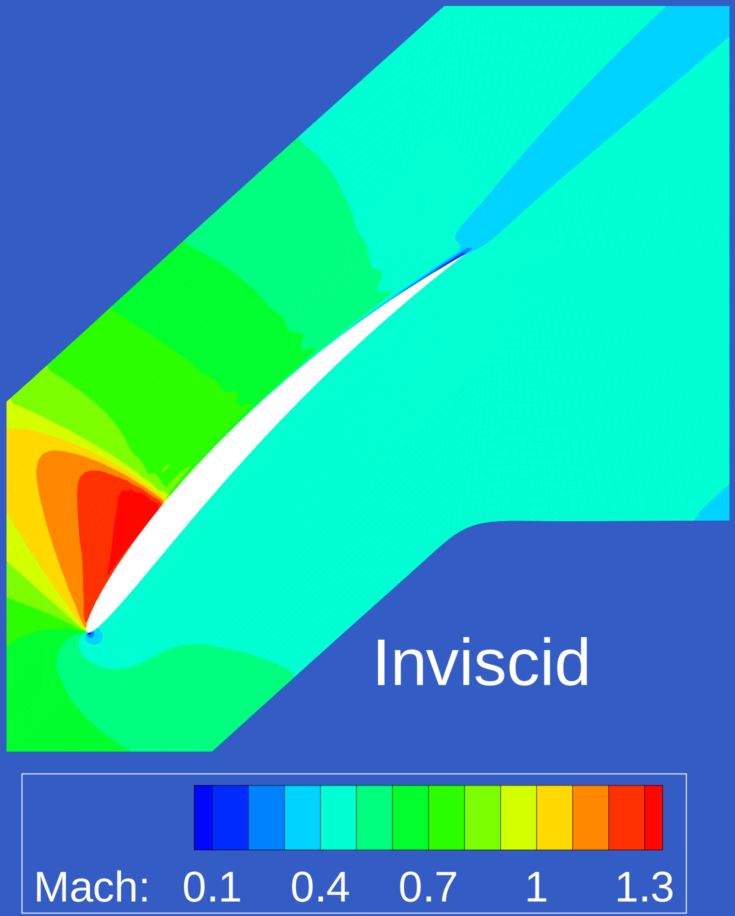
2D Standard Configuration 10: Off-Design Flowfield





$$M_1 = 0.81,\ \beta_1 = 59.0$$

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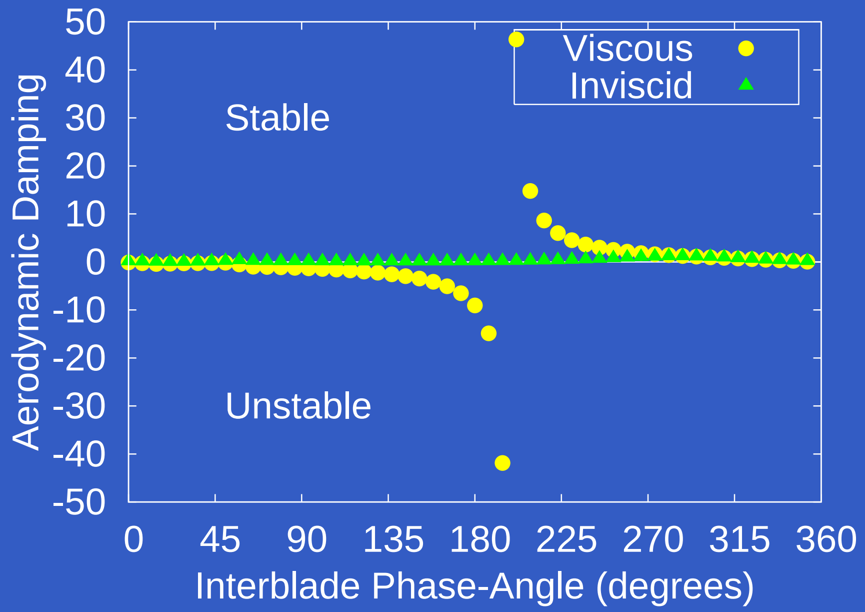
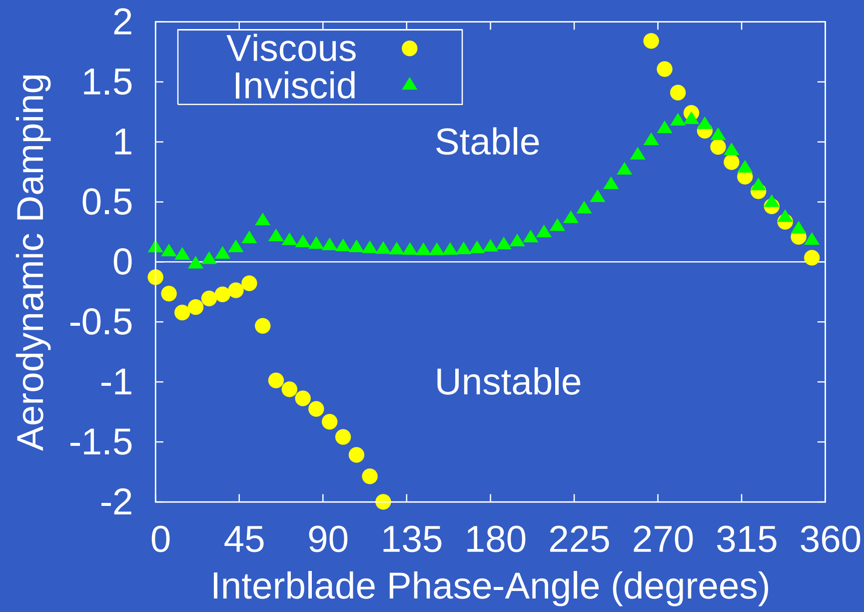
Off-Design: Aero. Damping





Flow Condition: $M_1 = 0.81$ and $\alpha_1 = 59.0^o$

Pitching at 110.8 Hz

Farfield acoustic resonance: 56.9, -7.6, 18.8, and -9.3 degrees

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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
- Aerodynamic unstable (2D viscous and 3D inviscid stable)
- Data can be downloaded from www.rpmturbo.com