Analytical Maps of Aerodynamic Damping as a Function of Operating Condition for a Compressor Profile

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Outline of Presentation

Motivation: analytical flutter map

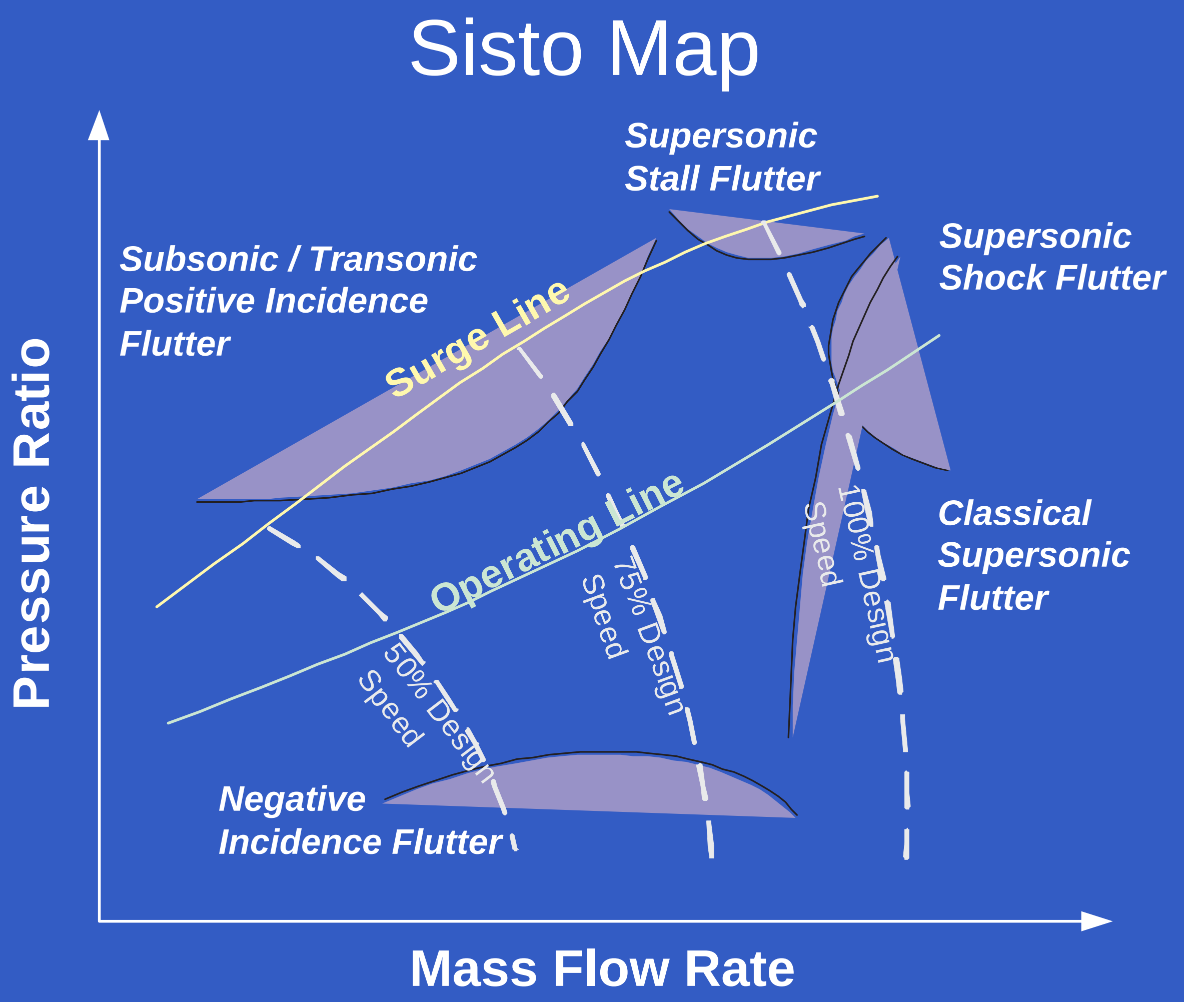
Method: linearized Navier-Stokes flow solver

Results: flutter maps - mode shape, frequency

Discussion: examination of deep flutter

Conclusions: flow separation important role

Motivation


Sisto Map
Supersonic
Stall Flutter
Supersonic
Shock Flutter
Subsonic / Transonic
Positive Incidence
Flutter
Surge Line
Operating Line
Classical
Supersonic
Flutter
100% Design
Speed
75% Design
Speed
50% Design
Speed
Negative
Incidence Flutter
Pressure Ratio
Mass Flow Rate

Motivation

Other Flutter Maps

- Manufacturers use proprietary flutter boundary maps
- Silkowski *et al.* (2001) analytical flutter map for a fan (10 OPs)

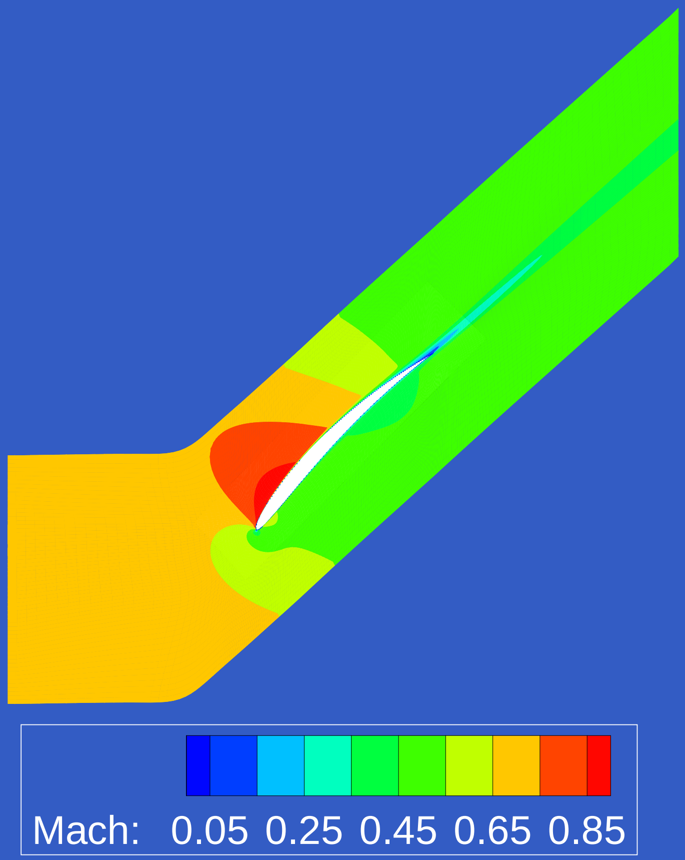
Aim: to calculate analytic flutter maps that resolve the flutter boundary over a wide range of operating conditions

Method

- Flow Model: 2D Navier-Stokes equations with Spalart and Allmaras turbulent model
- 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
- Possible to examine 200 operating points in one week
- 3D flutter map would take several months

Compressor Profile

- Standard Configuration 10
- 2D compressor profile
- chord length: 100 mm
- Total Pressure: 101.3 kPa
- Total Temperature: 300 K
- Design OP: $M_1 = 0.7$, $\beta_1 = 55^o$
- Reynolds number: 1.26×10^6



Aerodynamic Damping

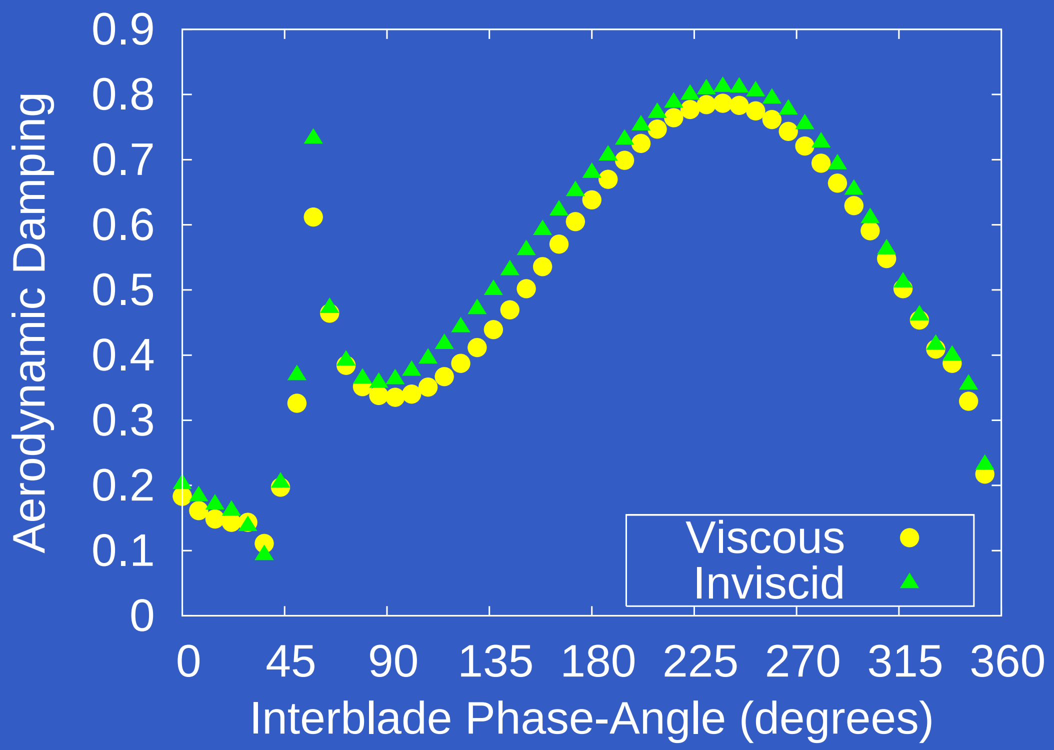
Design OP

$M_1 = 0.7$, $\beta_1 = 55^o$

Pitching Mode

$f = 184.6$ Hz

$(\omega^* = 0.5)$

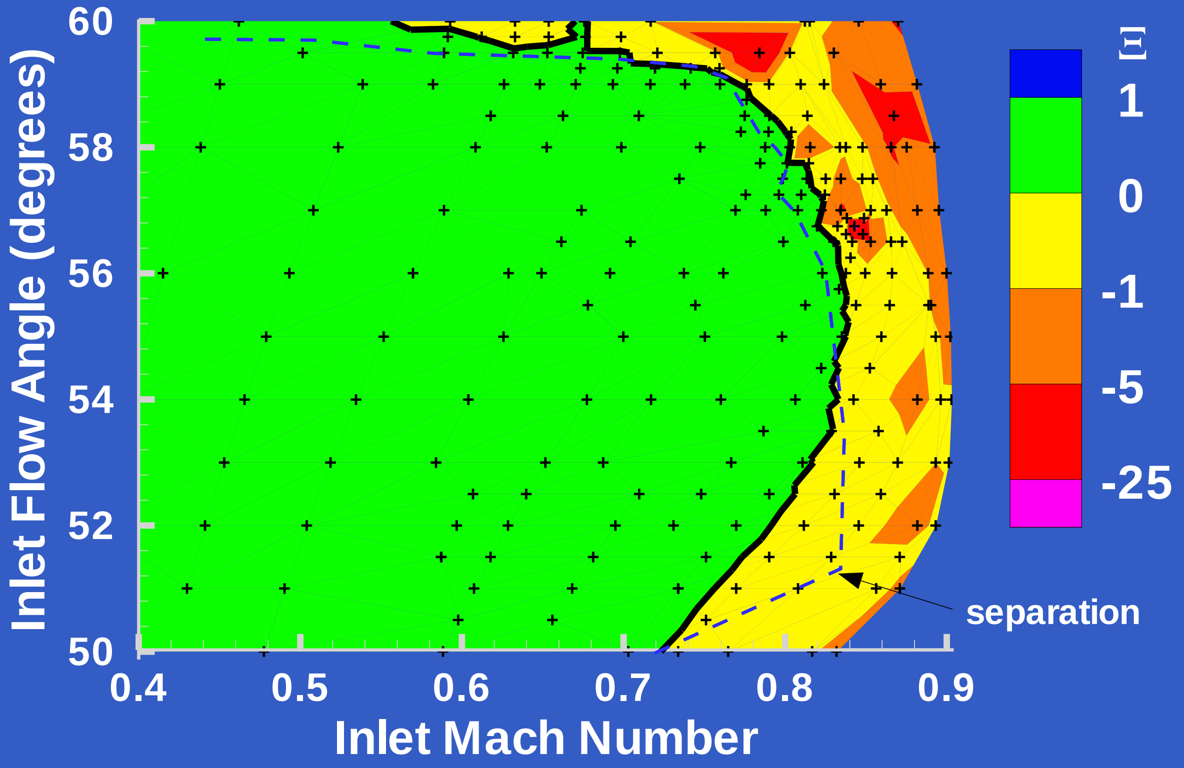


Flutter Maps

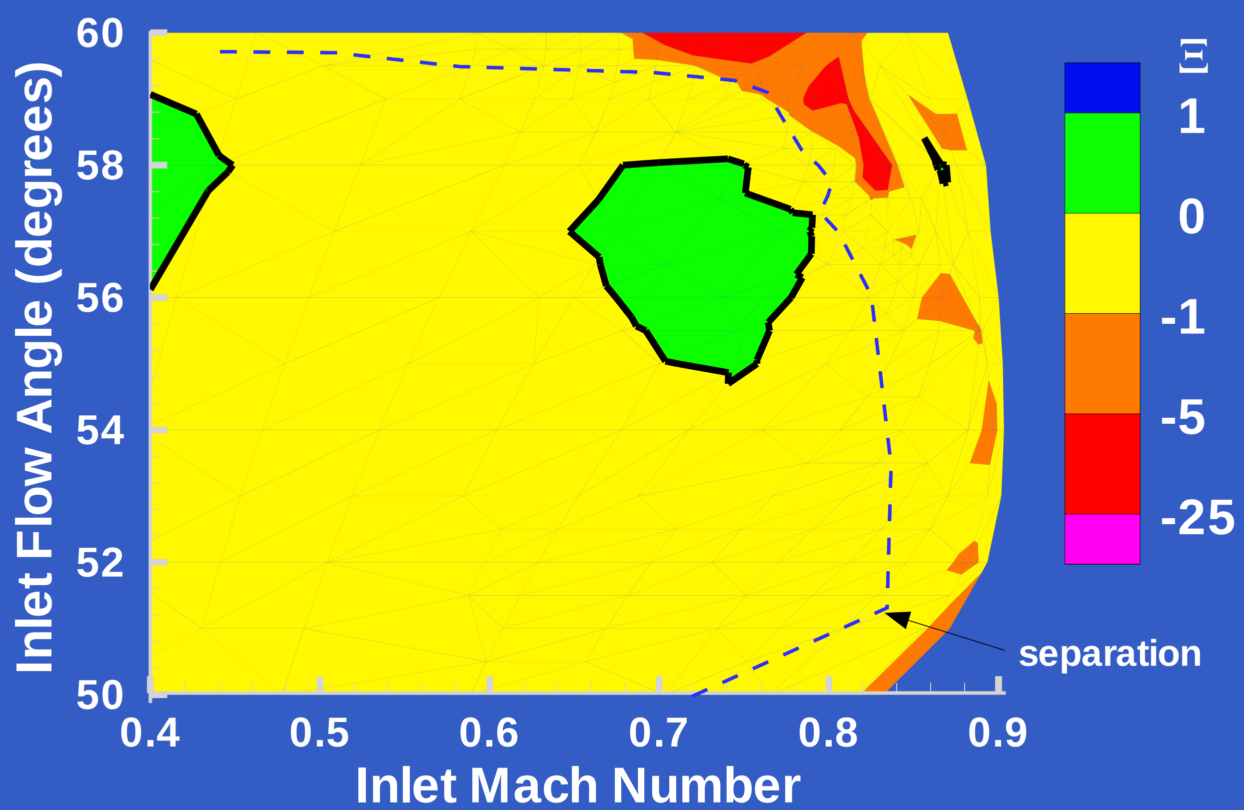
Pitching Mode

$f = 184.6$ Hz

$(\omega^* = 0.5)$

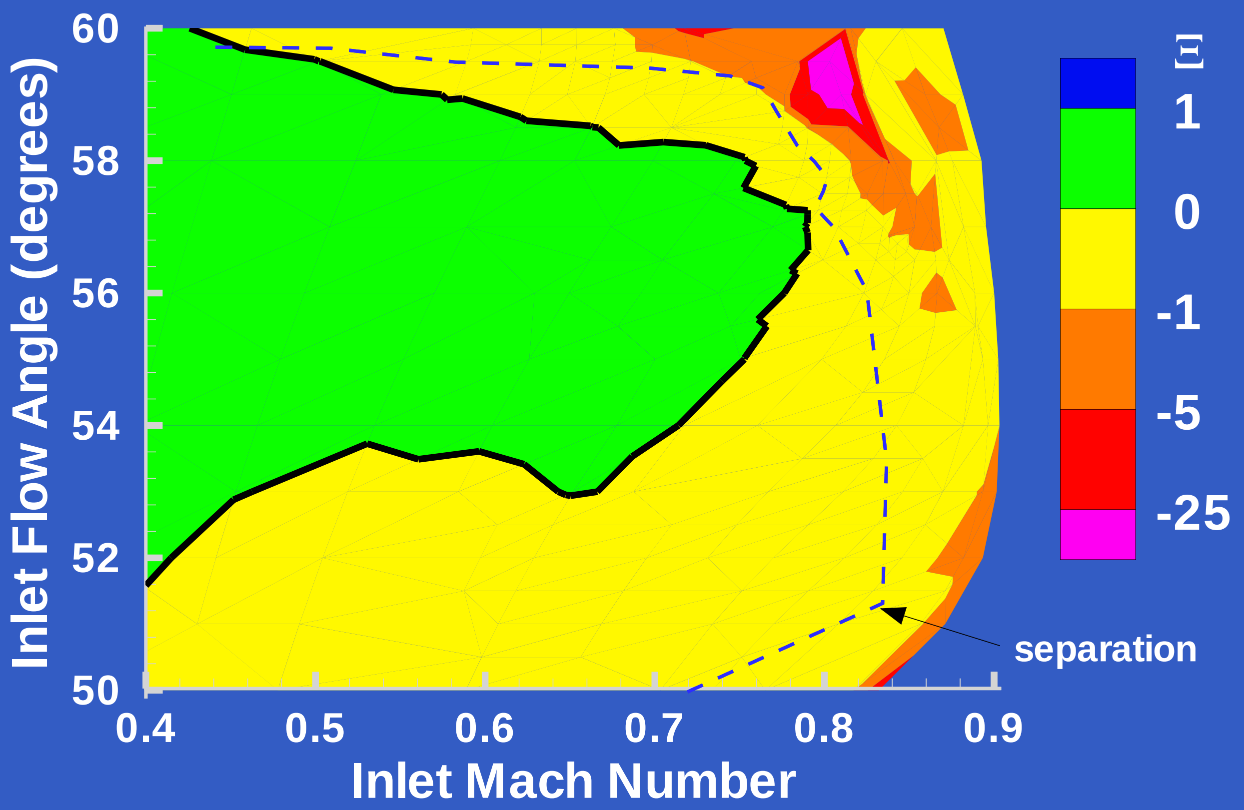


Flutter Maps - SC10 Pitching



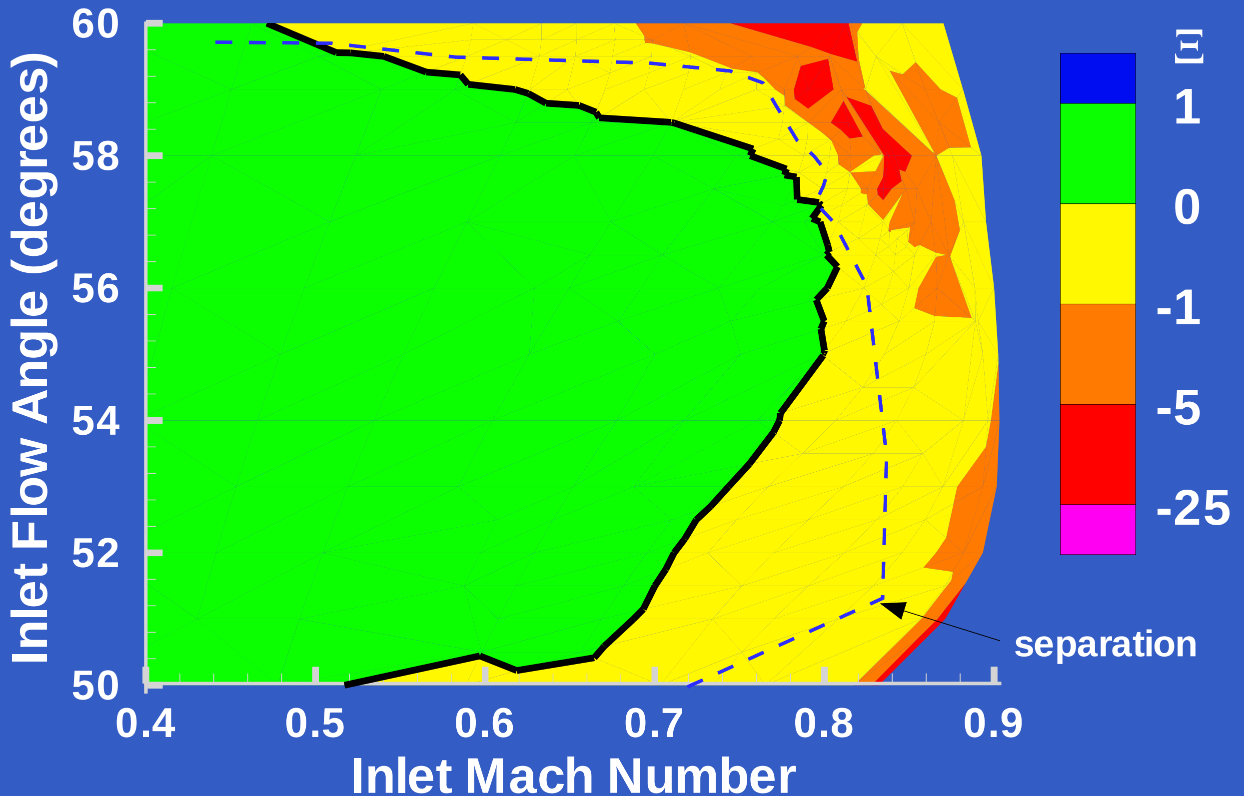
$f = 92.3$ Hz ($\omega^* = 0.25$)

Flutter Maps - SC10 Pitching



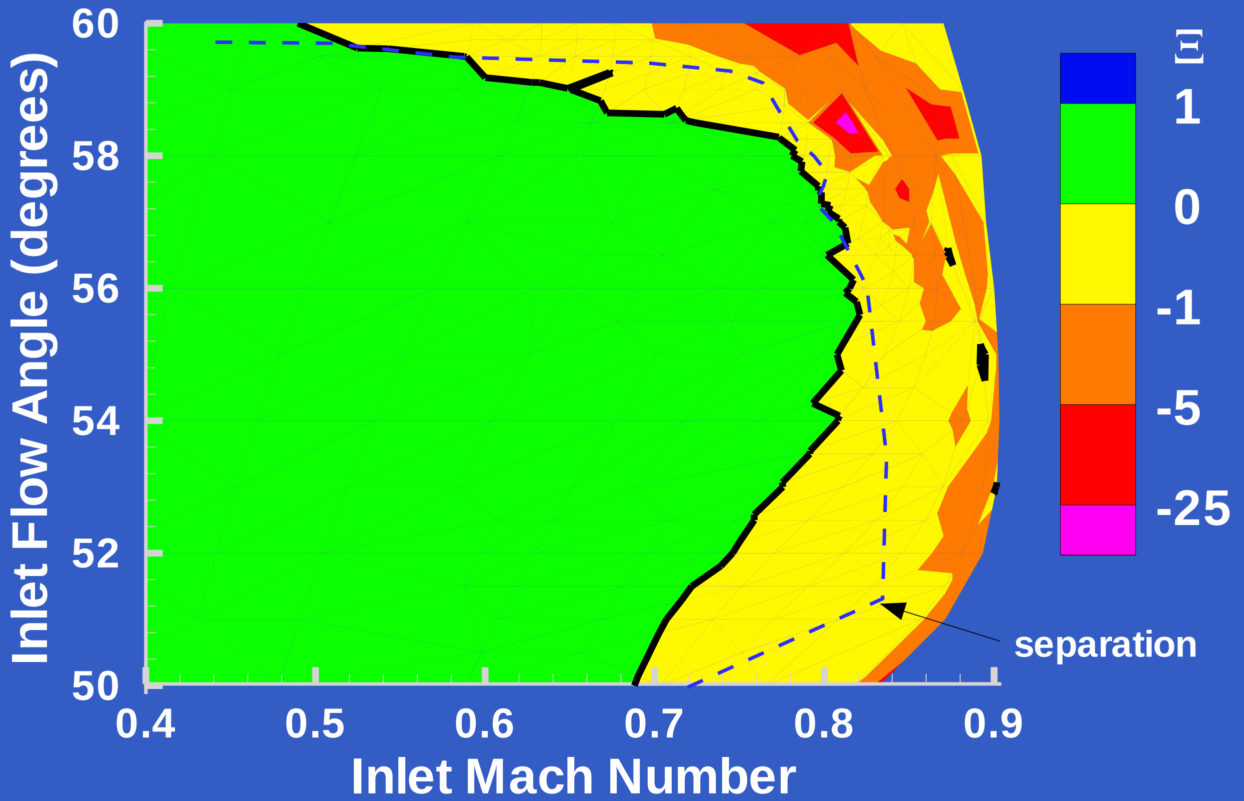
$f = 110.8$ Hz $(\omega^* = 0.3)$

Flutter Maps - SC10 Pitching



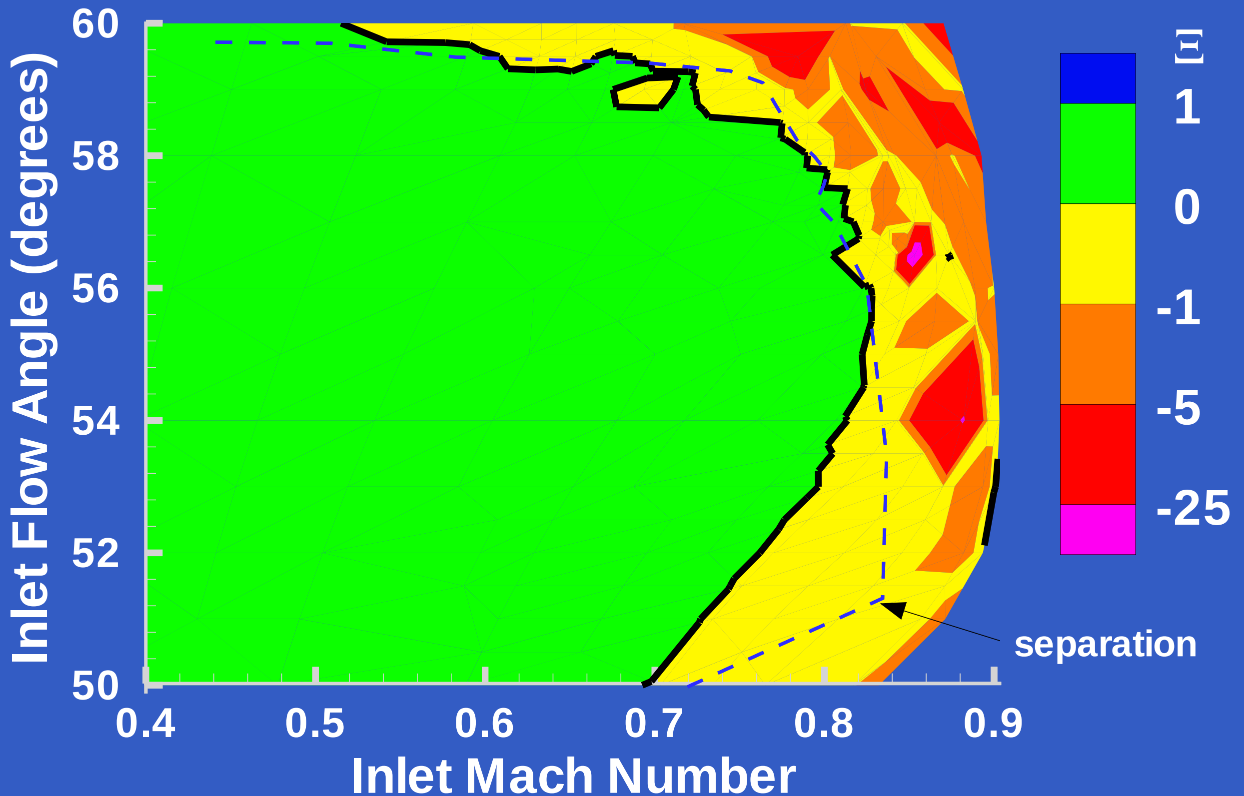
$f = 129.2$ Hz ($\omega^* = 0.35$)

Flutter Maps - SC10 Pitching



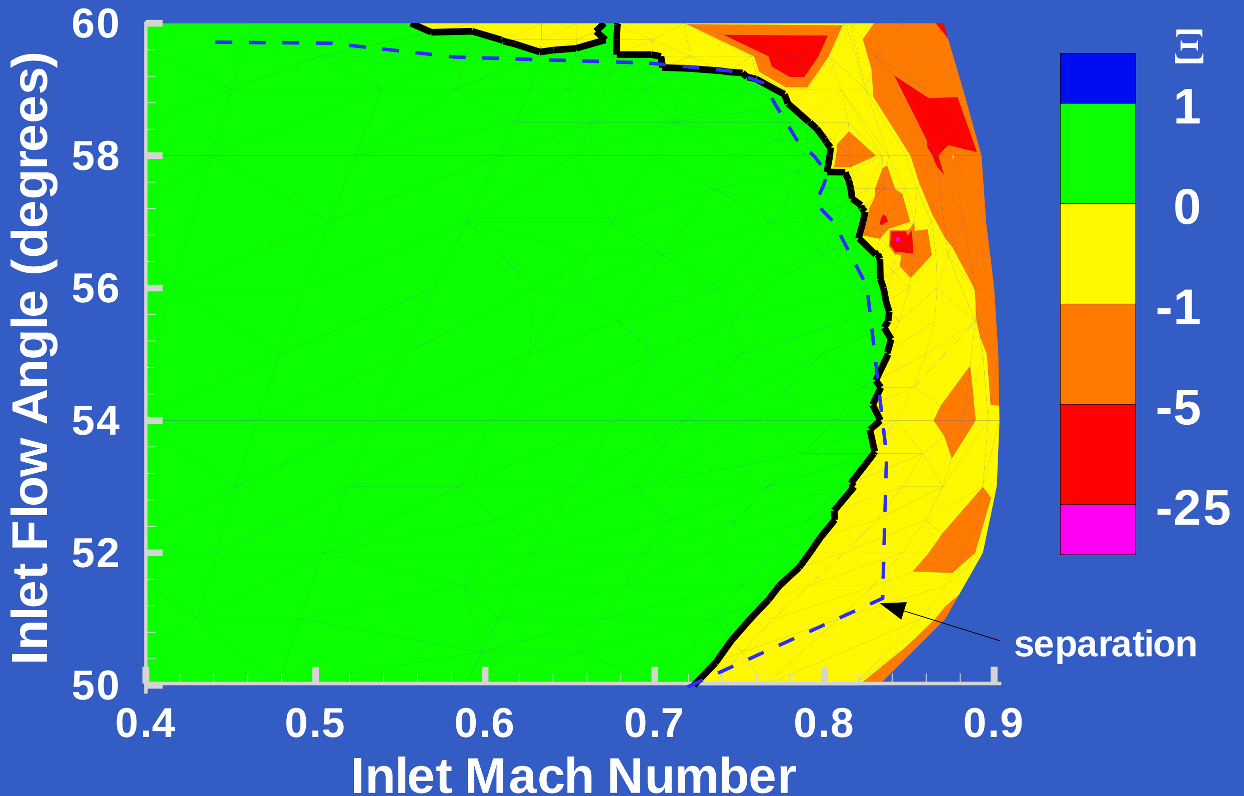
$f = 147.7$ Hz $(\omega^* = 0.4)$

Flutter Maps - SC10 Pitching



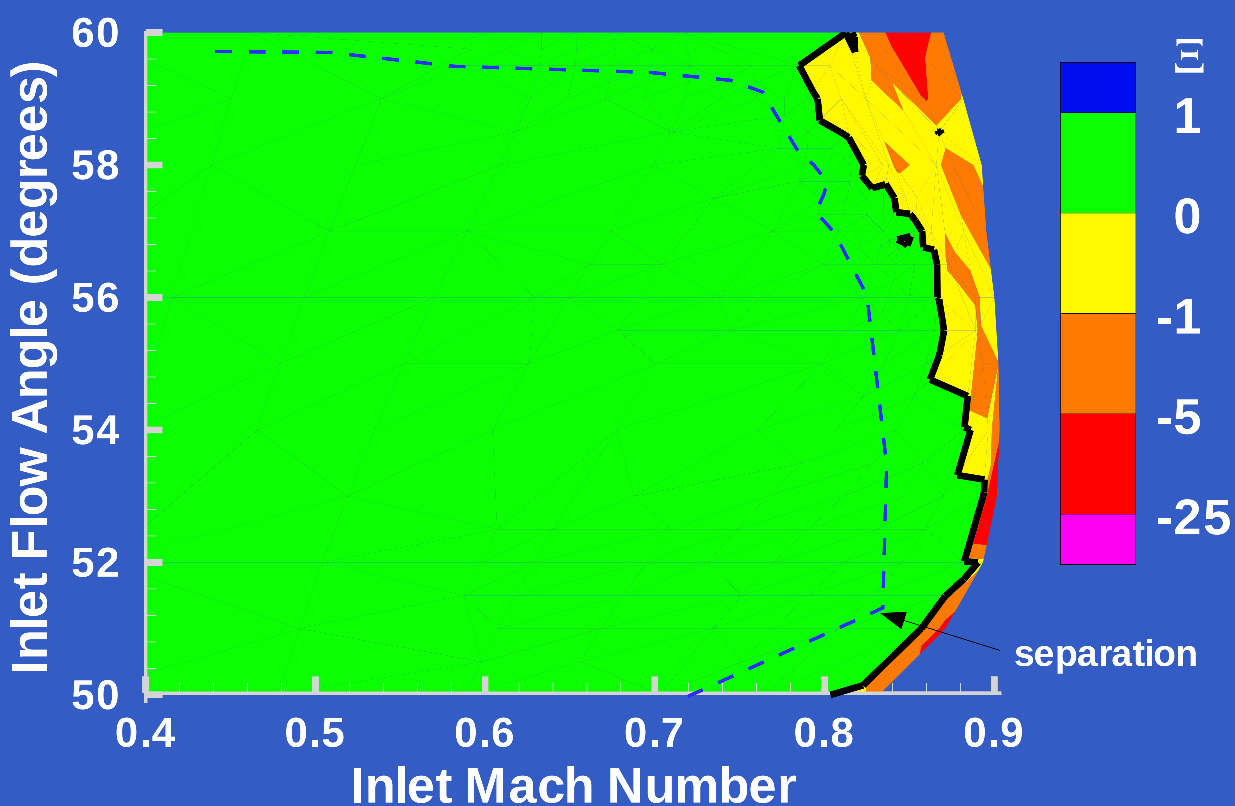
$$f = 166.2 \text{ Hz } (\omega^* = 0.45)$$

Flutter Maps - SC10 Pitching



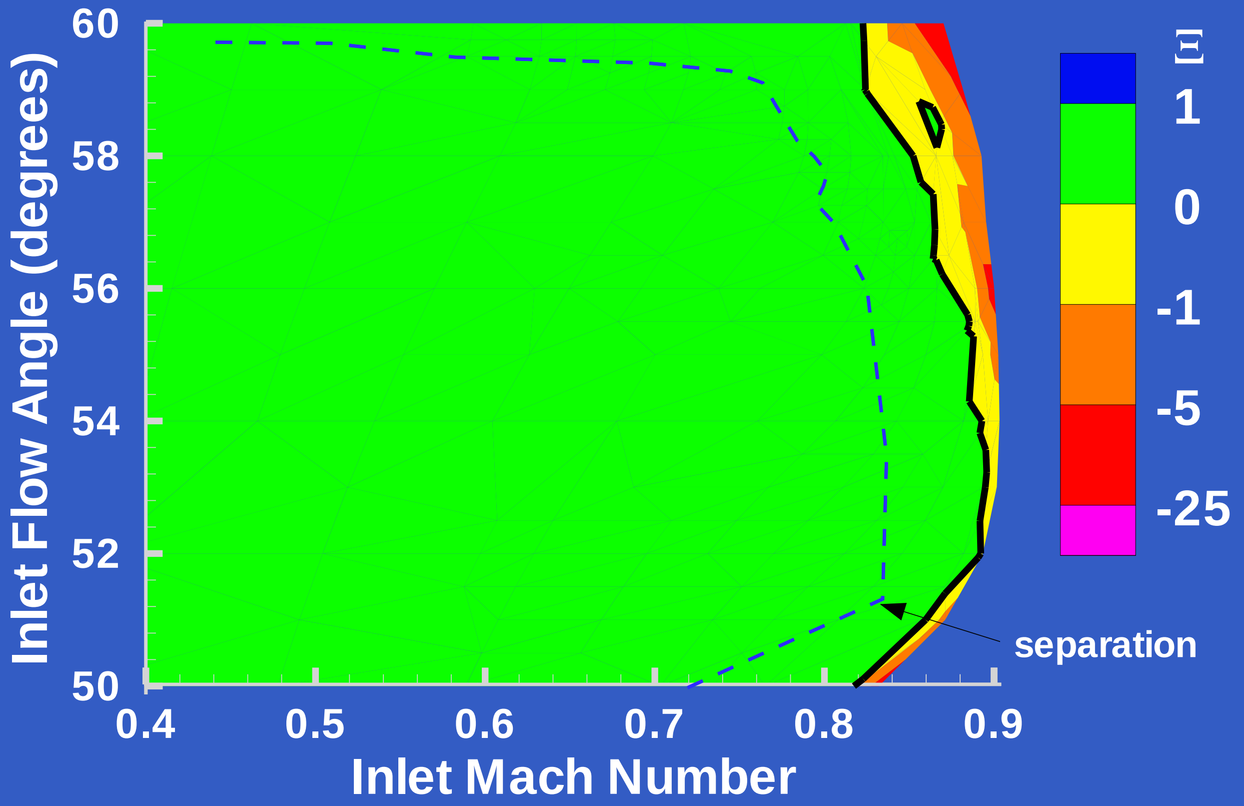
$f = 184.6$ Hz $(\omega^* = 0.5)$

Flutter Maps - SC10 Pitching



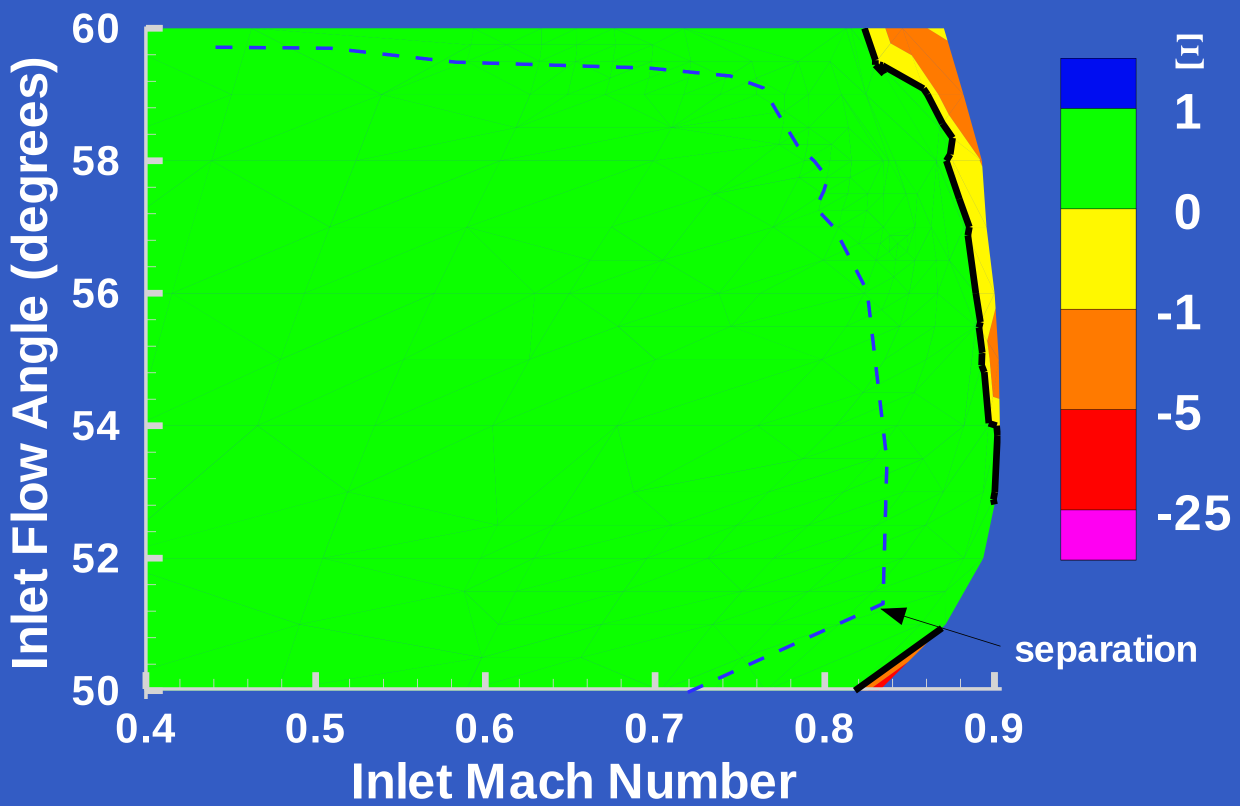
$f = 276.9$ Hz ($\omega^* = 0.75$)

Flutter Maps - SC10 Pitching



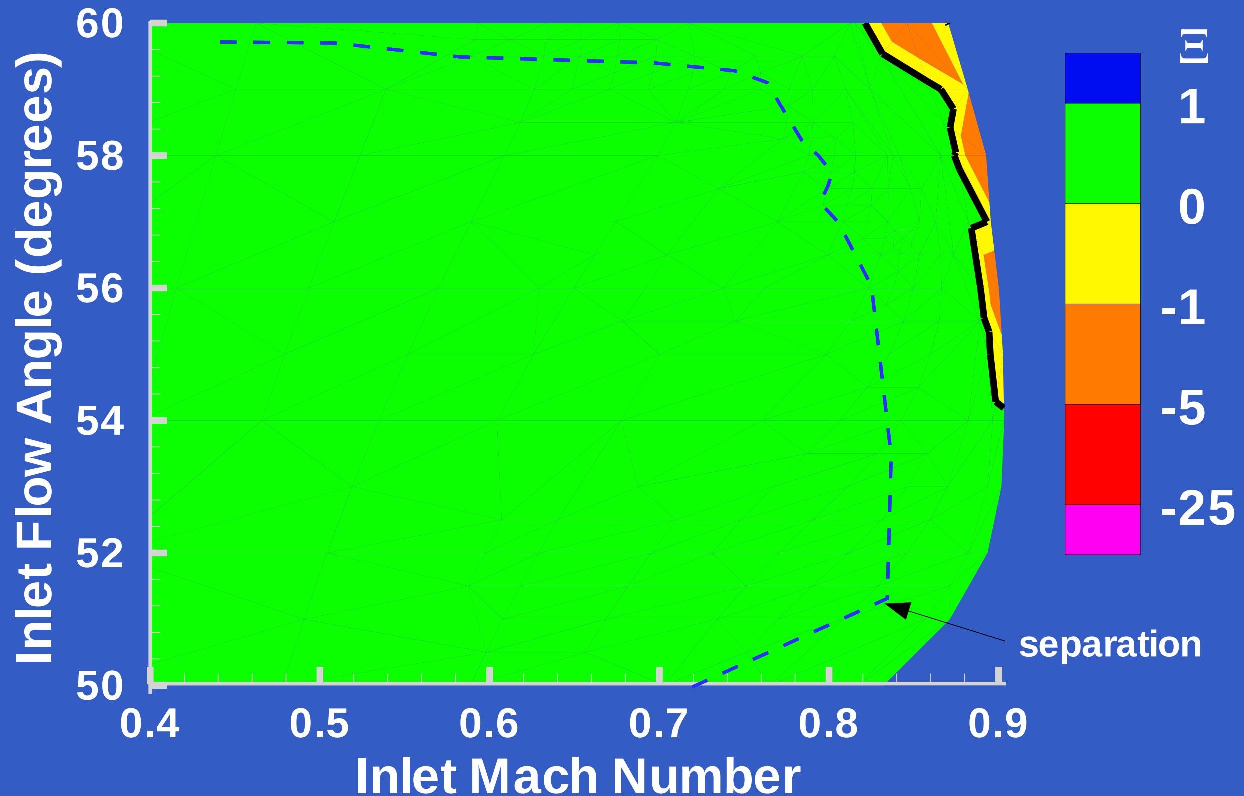
$f = 369.3$ Hz $(\omega^* = 1.0)$

Flutter Maps - SC10 Pitching



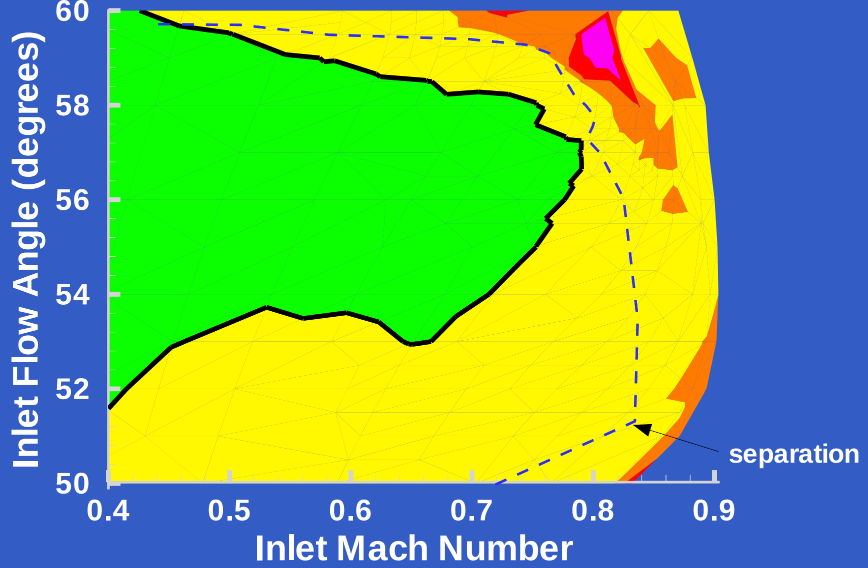
$f = 461.6$ Hz $(\omega^* = 1.25)$

Flutter Maps - SC10 Pitching

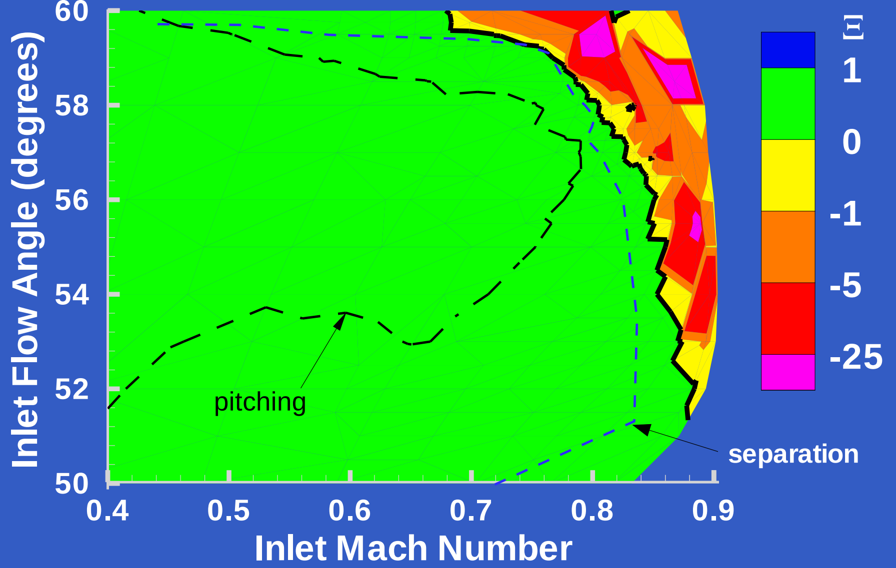


$f = 553.9$ Hz $(\omega^* = 1.5)$

Flutter Maps - Pitching vs Bending



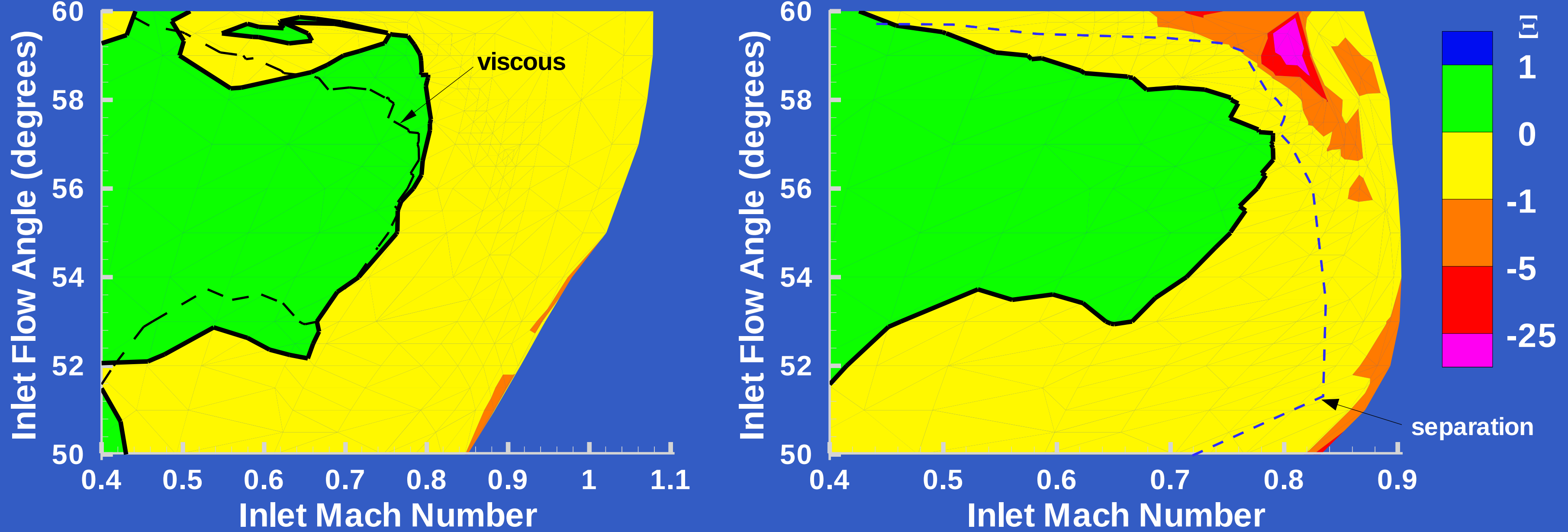
Pitching mode



Bending mode

$f = 110.8$ Hz ($\omega^* = 0.3$)

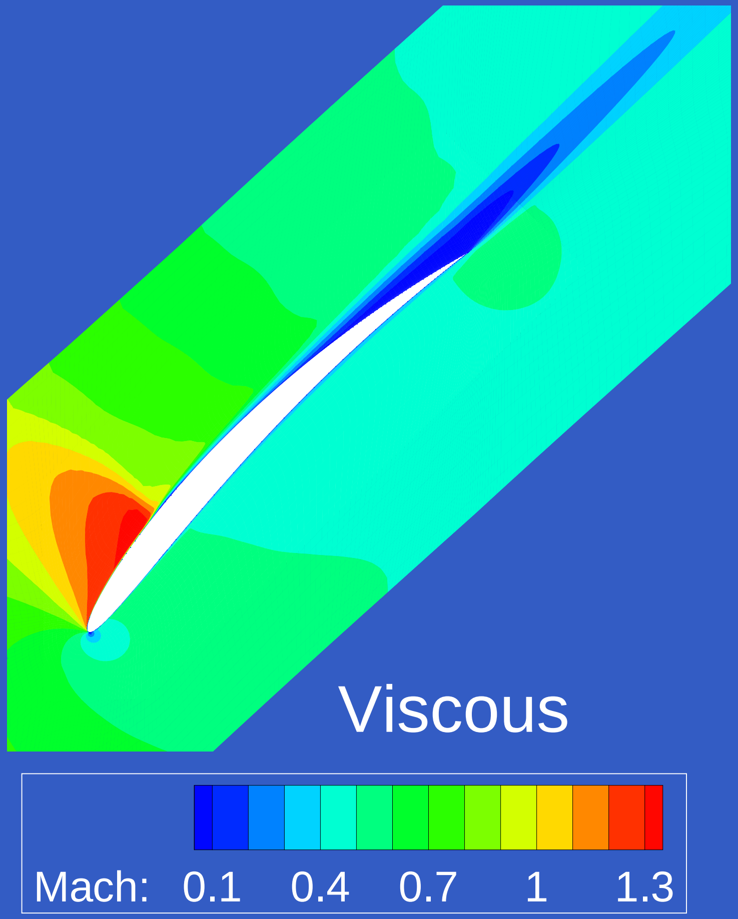
Inviscid v Navier-Stokes

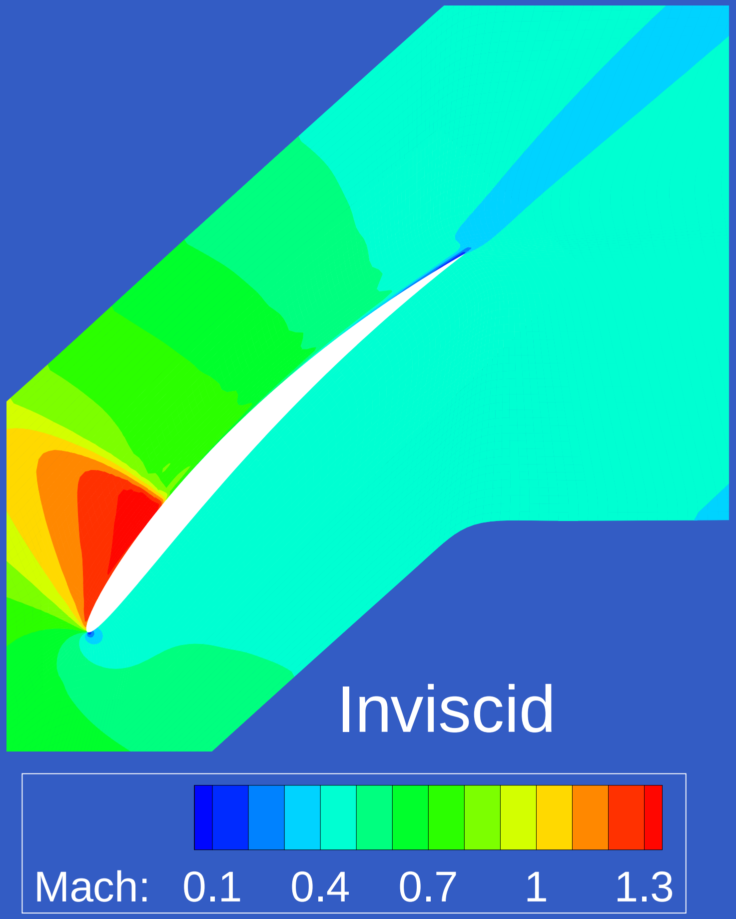


Inviscid Viscous

Pitching mode $f = 110.8$ Hz ($\omega^* = 0.3$)

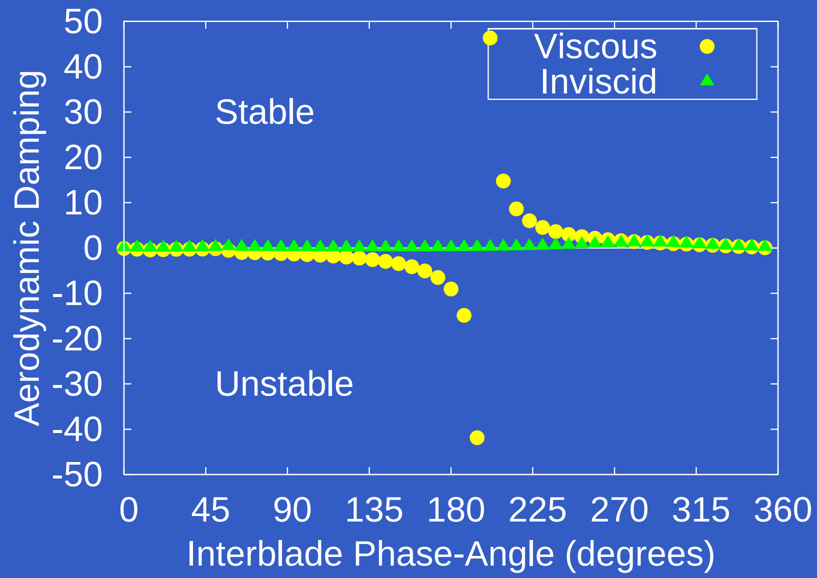
Off-Design Flowfield

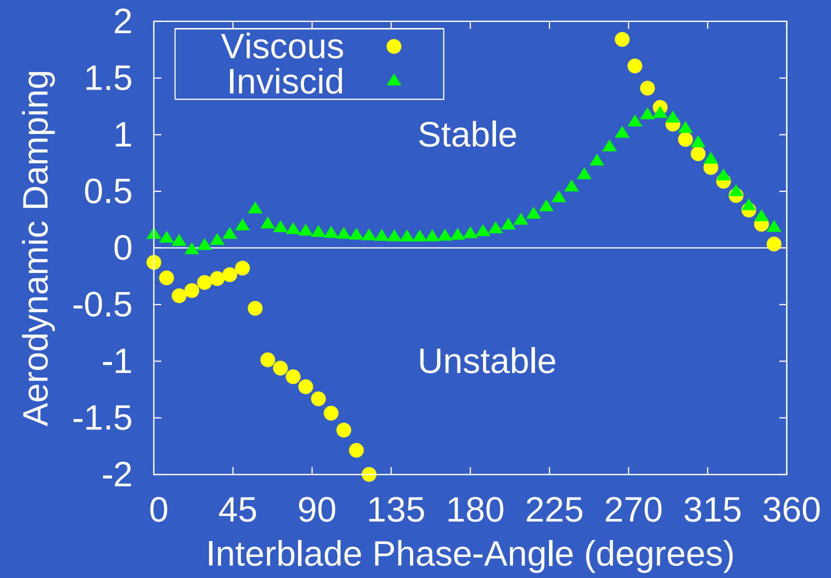




$$M_1 = 0.81, \beta_1 = 59.0$$

Off-Design: Aero. Damping



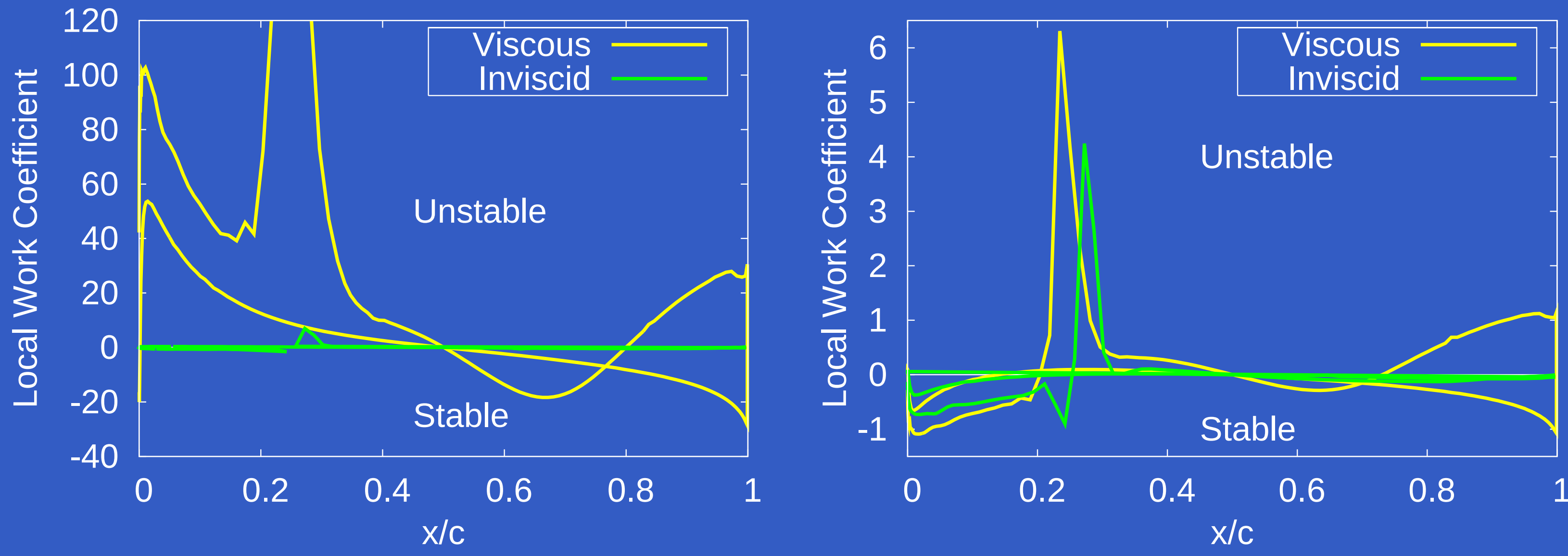


Flow Condition: $M_1 = 0.81$ and $\alpha_1 = 59.0^o$

Pitching at 110.8 Hz

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

Off-Design: Local Work Coefficient

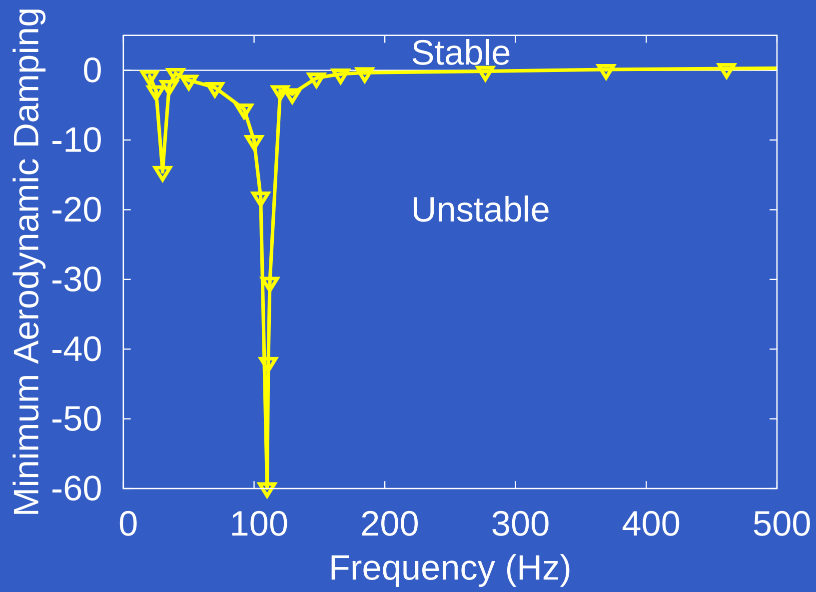


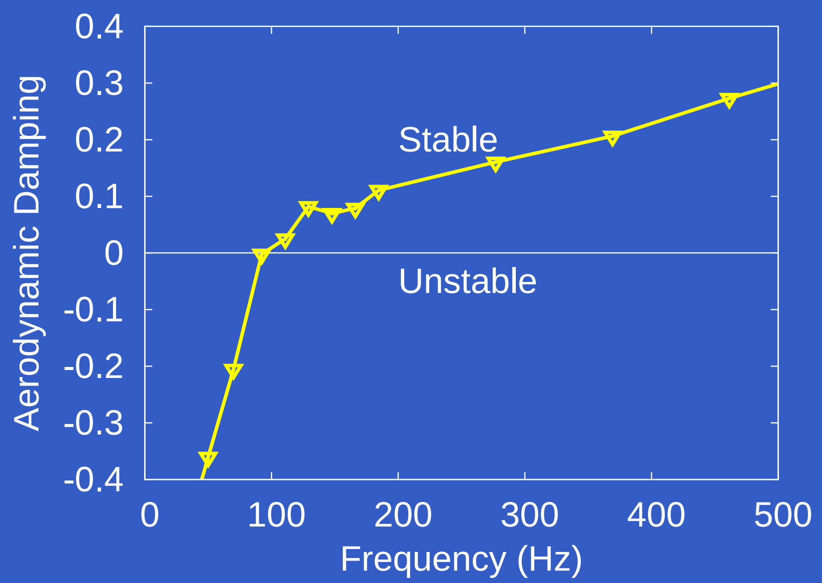
$\sigma = 194.4^o$ $\sigma = 0.0^o$

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

Pitching at 110.8 Hz

Aero. Damping v Frequency





Off-design OP

$M_1 = 0.81$ and $\alpha_1 = 59.0^o$

Design OP

$M_1 = 0.7$ and $\alpha_1 = 55.0^o$

Conclusions

- Analytical flutter maps successfully computed
- Flutter boundaries fully resolved
- Flutter boundary dependent on mode shape, mode frequency, and flow model (inviscid or viscous)
- Deep flutter predicted at some off-design conditions by viscous simulation but not inviscid
- Flow separation appears to play an important role in deep flutter