



Extending Swept-Wing Natural Laminar Flow using Discrete Roughness Elements

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Outline

- **Motivation**
- **Transition control using discrete roughness elements (DRE)**
- **Subsonic Aircraft Roughness Glove Experiment (SARGE)**
- **Crossflow transition in the absence of control**
- **Effect of control**
- **Concluding Remarks**



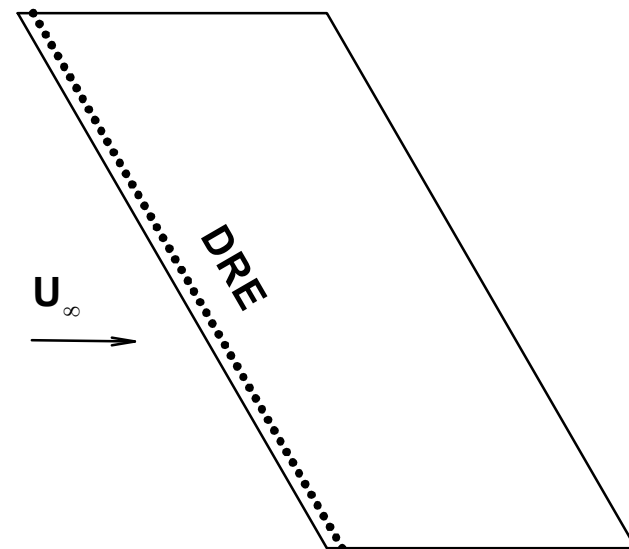
Motivation

- Laminar flow control
 - Fuel saving
 - Lower operational cost
 - Less environmental impact
- Discrete (distributed) roughness elements (DRE)
 - Used to delay crossflow dominated transition
 - Shown to work at low Re
- Intend to find out
 - Will DRE work for higher Re_c under transonic flight conditions?
- NASA's Environmentally Responsible Aviation (ERA) Project's funded activity
 - Subsonic Aircraft Roughness Glove Experiment (SARGE)



What do DREs do?

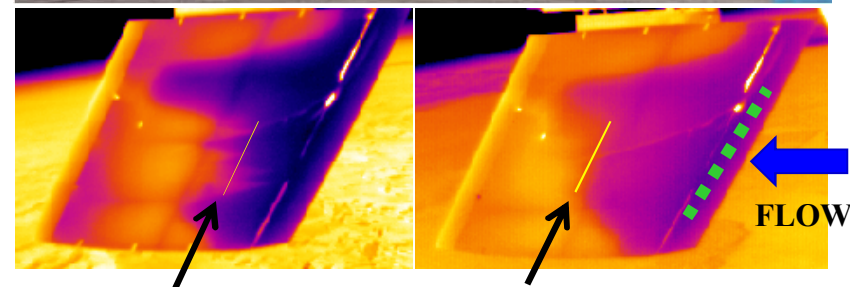
- Swept wing transition in quiet (flight) environment
 - Transition dominated by stationary crossflow vortices
 - Can design TS out of the problem
- Placing roughness array near leading edge
 - Transition is delayed
- Roughness spacing
 - Control mode has shorter wavelength than target mode (most unstable crossflow instability)





Texas A&M University Experiment

- Reynolds number of the experiment, $Re_c = 8 \times 10^6$
- Transition @ $x/c = .8$ with polished leading-edge
- Transition @ $x/c = .3$ with painted leading-edge
 - Transition delayed to $x/c = .6$, with DRE
- Maximum Re_c at which DRE demonstrated: 8×10^6



without

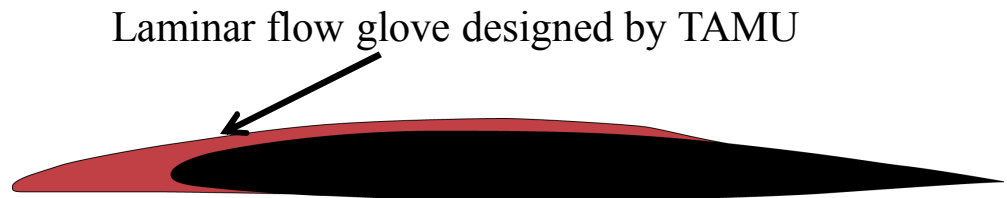
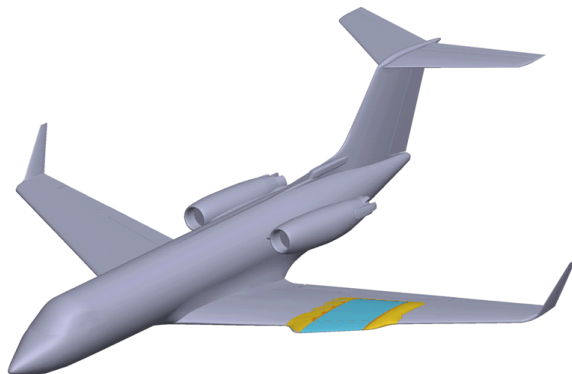
Transition with DRE



SARGE

- SARGE experiment aboard NASA Dryden's Gulfstream-III (G-3) aircraft
 - Demonstrate transition delay using DRE at Re_c of relevance to transport aircraft
 - Polished leading-edge
 - Painted leading-edge
- Two papers on Wednesday morning

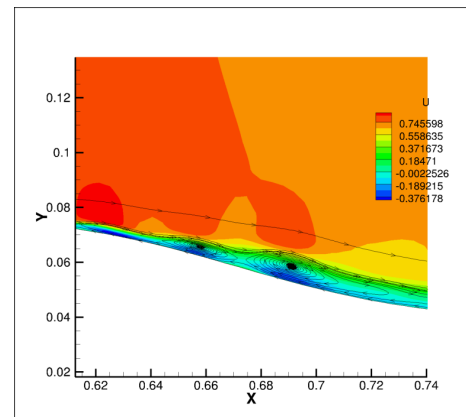
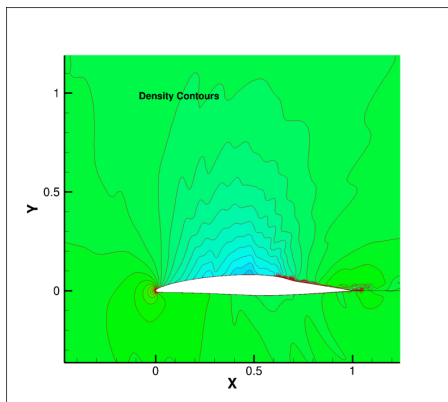
- ✓ Mach number range: .66 - .75
- ✓ Section $C_L \sim .5$
- ✓ Sweep angle = 34.6°
- ✓ Re_c range: 15 - 30 $\times 10^6$





Today's Presentation (that was not to be!)

- Attempted DNS of SARGE infinite-swept airfoil
 - Simulate flow-field, including natural roughness and DRE
 - Large oscillations originating from the glove-wing fairing region
 - Full DNS a grand challenge

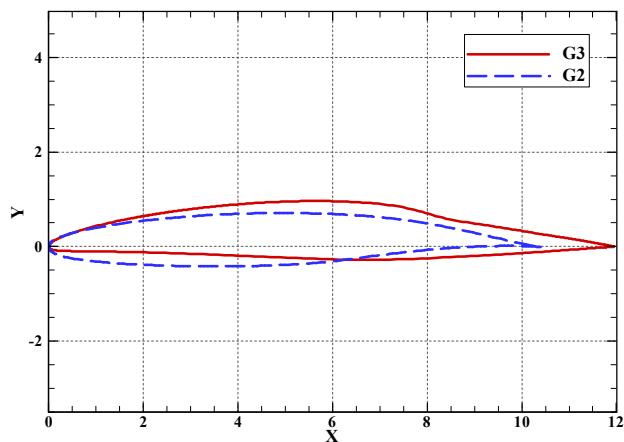


- Alternative: Secondary instability analysis of a related NLF airfoil
 - Presented earlier as AIAA 2010-4380 (Li et al.)
 - G-3 airfoil design still evolving

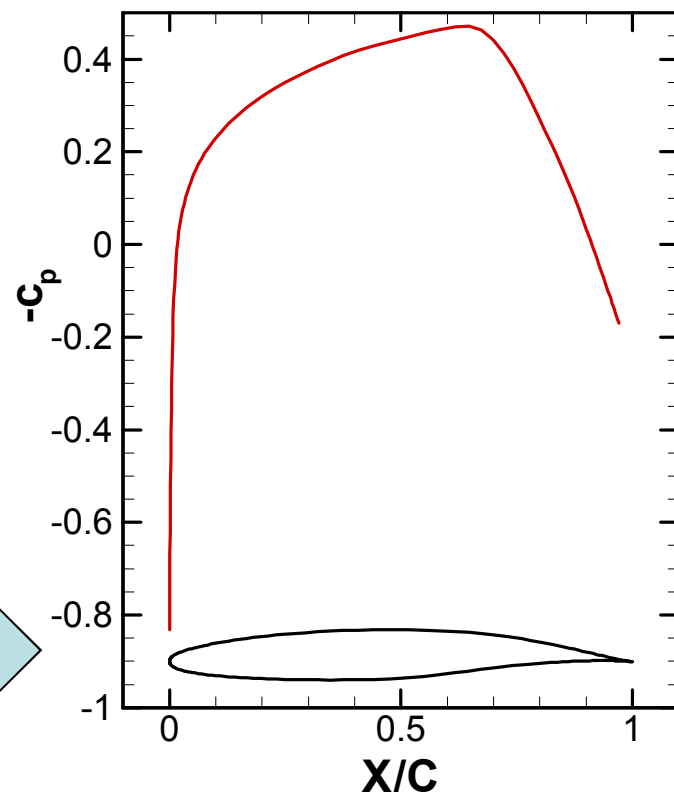
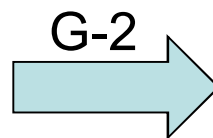


Flow Configuration

- Flow Configuration designed for natural laminar flow up to $x/c < 0.6$ (TAMU), for Gulfstream-II (G-2) Aircraft
 - TAMU-003T-75 (v.90) airfoil, 9.3% thick
 - $\Lambda = 30$, $\alpha = 0$
 - $M_\infty = 0.75$, $Re_c = 17 \times 10^6$
 - 40,000 ft. (flight altitude)



Comparison of G-2 and G-3 Glove Geometries





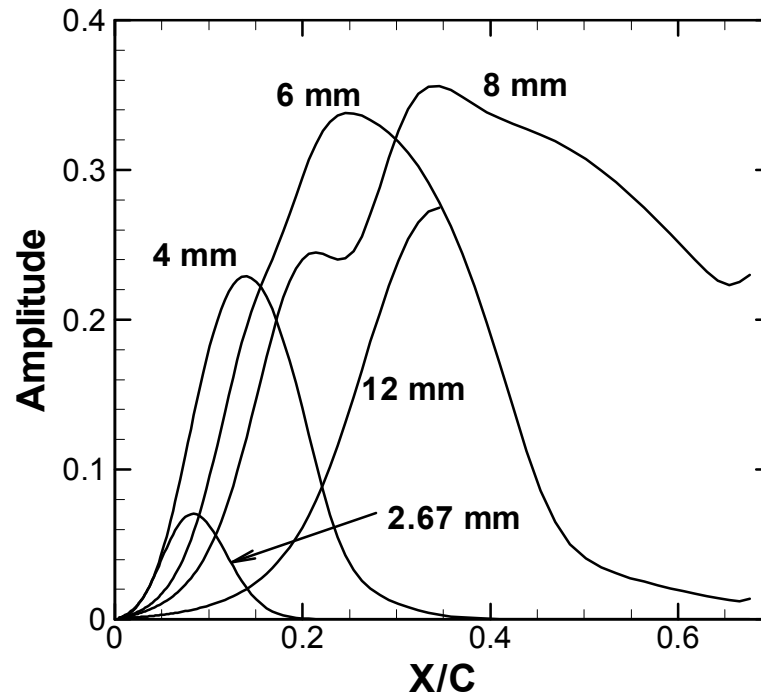
3D Transition Physics and Analysis Codes

- **Crossflow Transition Physics**
 - Require surface roughness (natural and DRE) as input
 - Receptivity
 - Linear and nonlinear growth of crossflow disturbances
 - Secondary instability
 - Breakdown to turbulence
- **Analysis Codes**
 - Boundary-layer code: BLSTA
 - Linear and nonlinear stability code: LASTRAC
 - Secondary instability: 2D eigenvalue solver for linear; NPSE for nonlinear
- **Missing Physics (from the analysis)**
 - Surface Roughness
 - Receptivity (initial amplitudes of control and target modes assumed, not computed)
 - Quantitative conclusions cannot be drawn
- **DNS Required for Definitive Conclusions**
 - In the absence of DNS, must rely on experiments



Uncontrolled Crossflow Transition

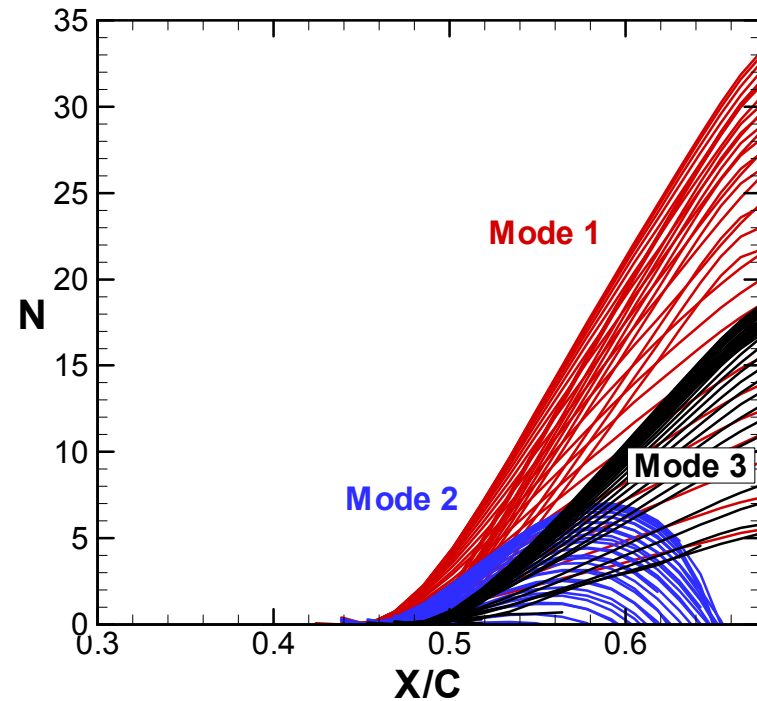
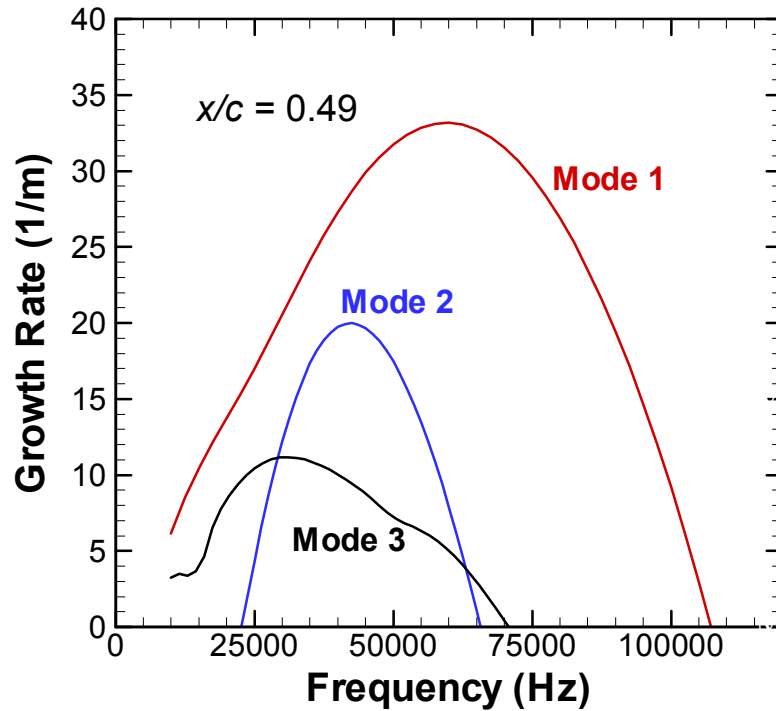
- Linearly most unstable: 8 mm stationary crossflow vortex
- Max. amp. in nonlinear evolution: ~38% of freestream velocity
- Modes most likely to lead to transition: ~ 6 – 12 mm



Nonlinear evolution of fundamental mode amplitudes at a $A_{init} = 10^{-3}$

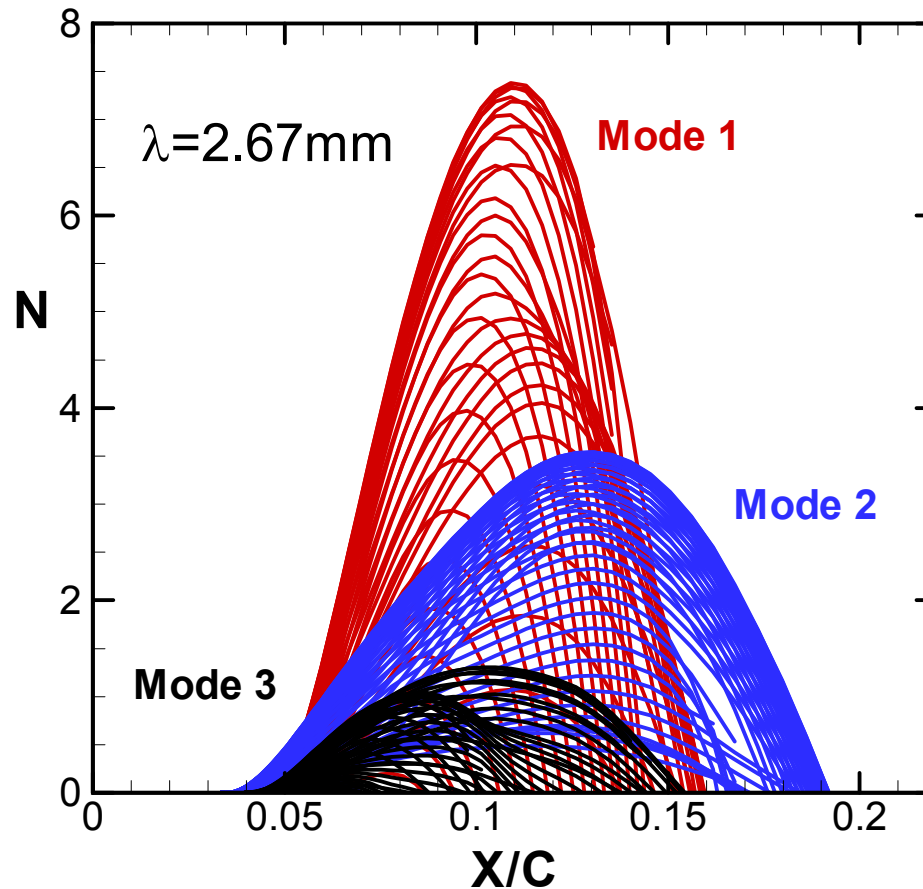


Secondary Instability (8 mm)





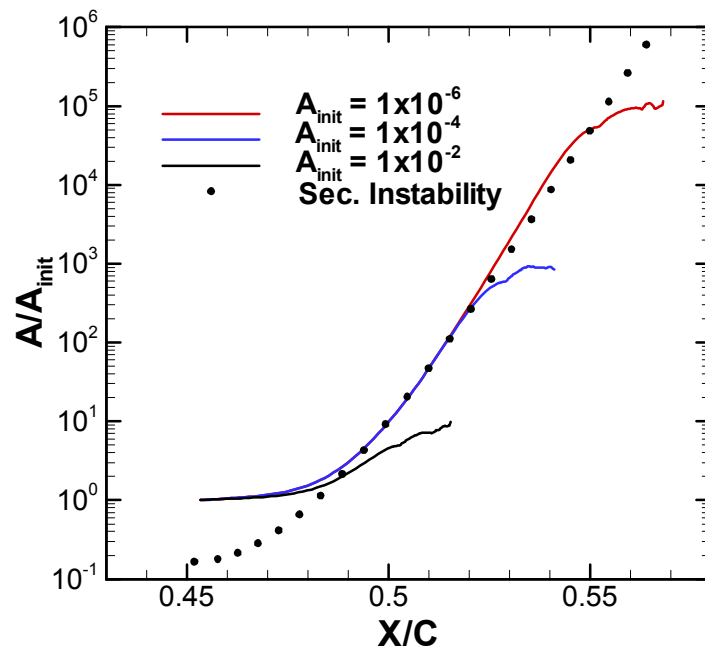
Secondary Instability ($8.0/3 = 2.67\text{mm}$)



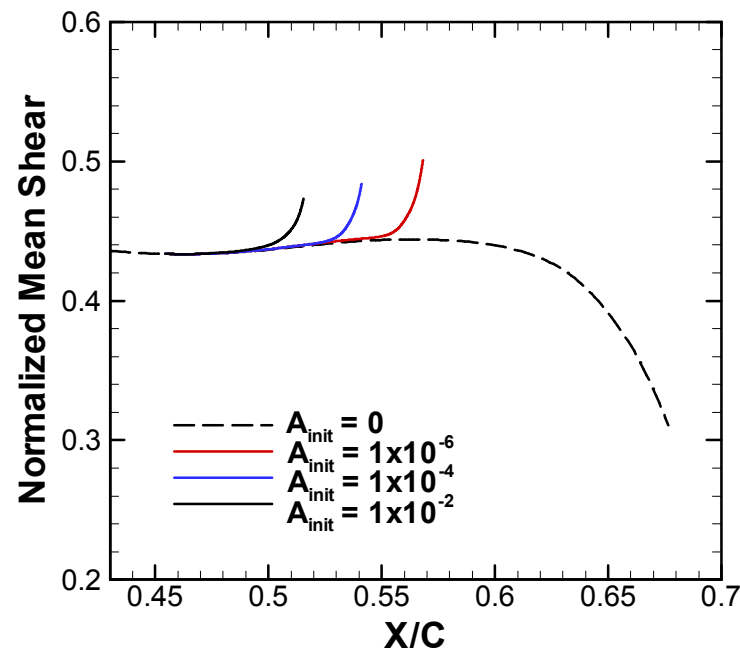


Secondary Instability Breakdown

Spanwise RMS amplitude



Wall shear

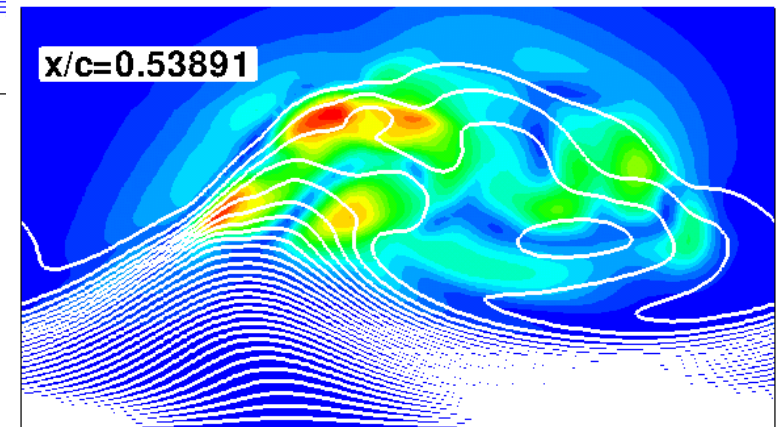
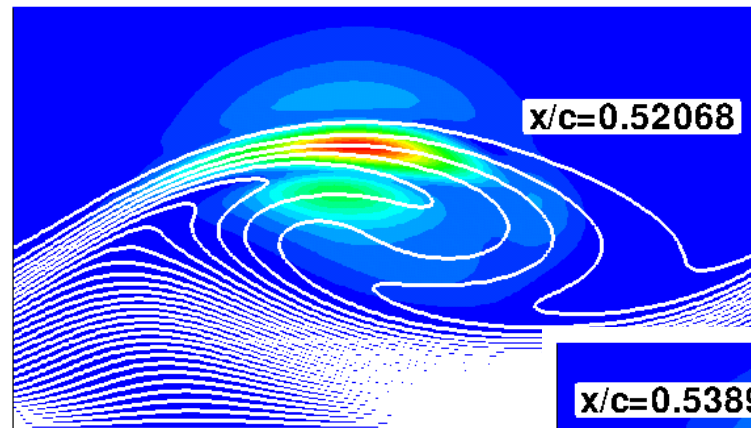
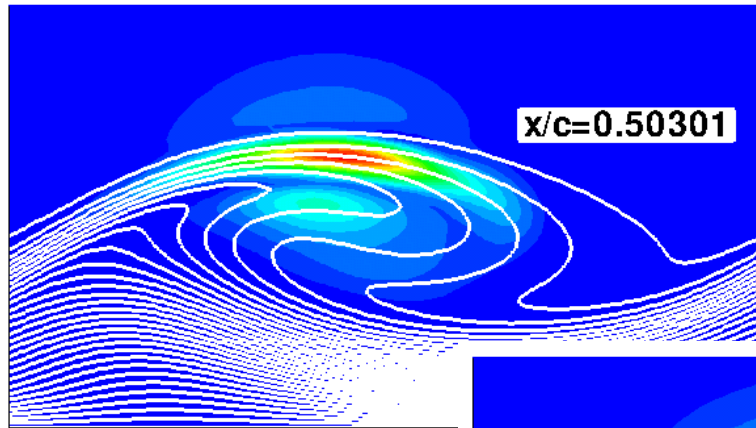


Lines: NPSE.

Dots: Linear secondary instability theory



Secondary Instability Breakdown (continued)

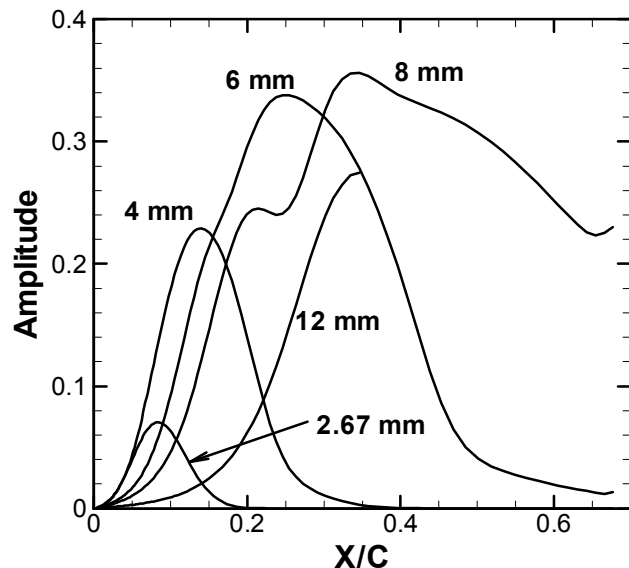




Selection of Control Input

Basic Requirement for Control Input

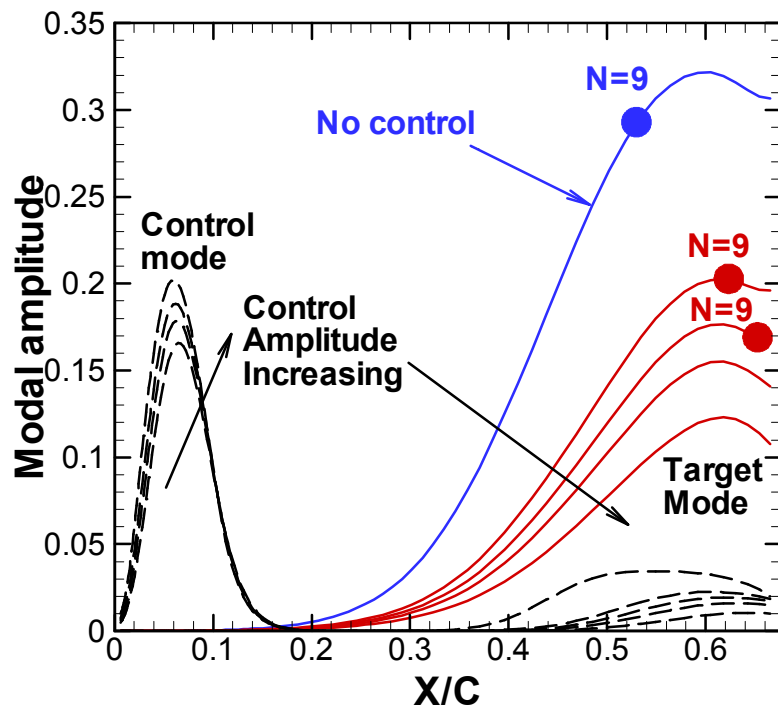
1. Must be able to reduce target mode growth
2. Must not be too unstable to cause transition itself



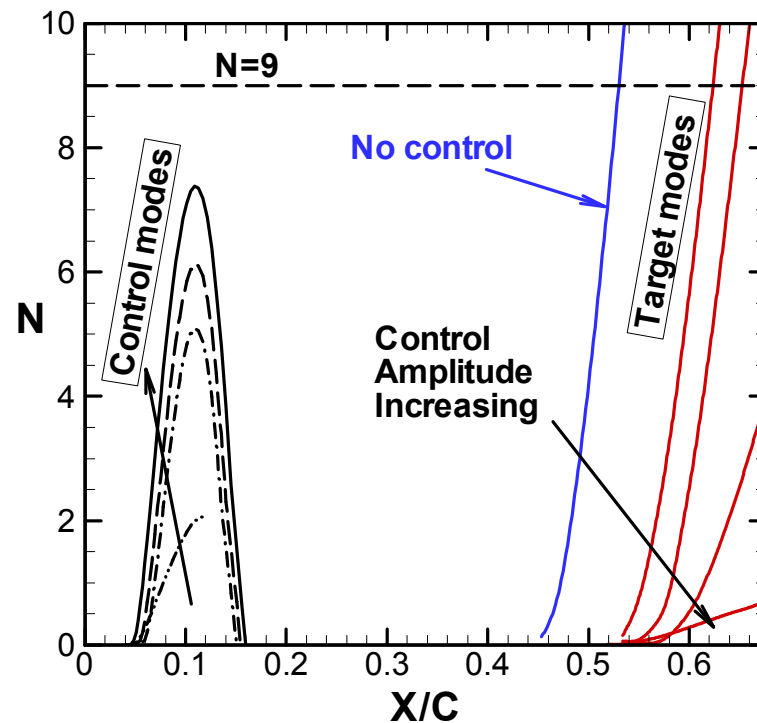
Candidates for Control Mode

- $\lambda = 2.67$ mm
 - Does not amplify much
 - Acts over short chordwise distance
- $\lambda = 4$ mm
 - Relatively moderate amplification
 - Acts over longer chordwise distance

Effect of Control: 2.67 mm controlling 8 mm



8 mm primary crossflow
vortex amplitude



8 mm secondary instability N-factor



Interaction of 2.67 mm and 4 mm modes

Possible Bad Scenario:

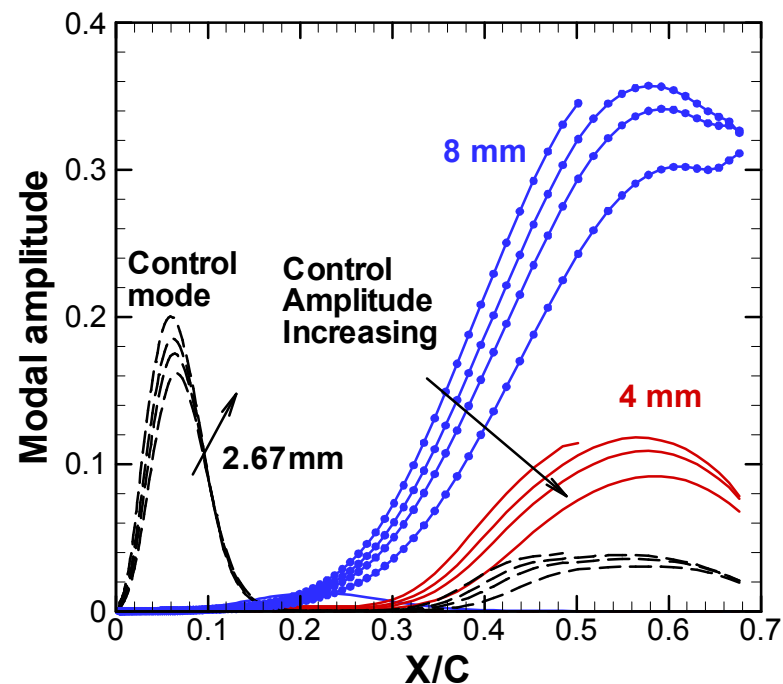
- 2.67 mm mode used as control input
- significant initial presence of 4 mm
- quadratic interaction:

$$\exp(i2\pi / 2.67) \exp(-i2\pi / 4) = \exp(i2\pi / 8)$$

leading to



- dashed lines: 2.67 mm
- solid lines: 4 mm
- dots: 8 mm



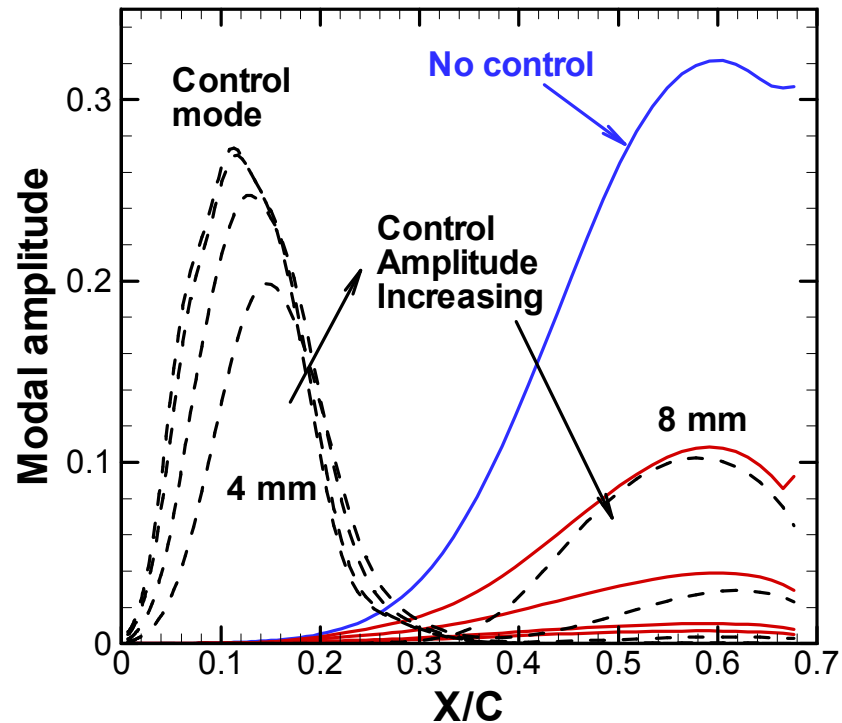


4 mm mode as control input

What to do to avoid exciting unwanted modes?

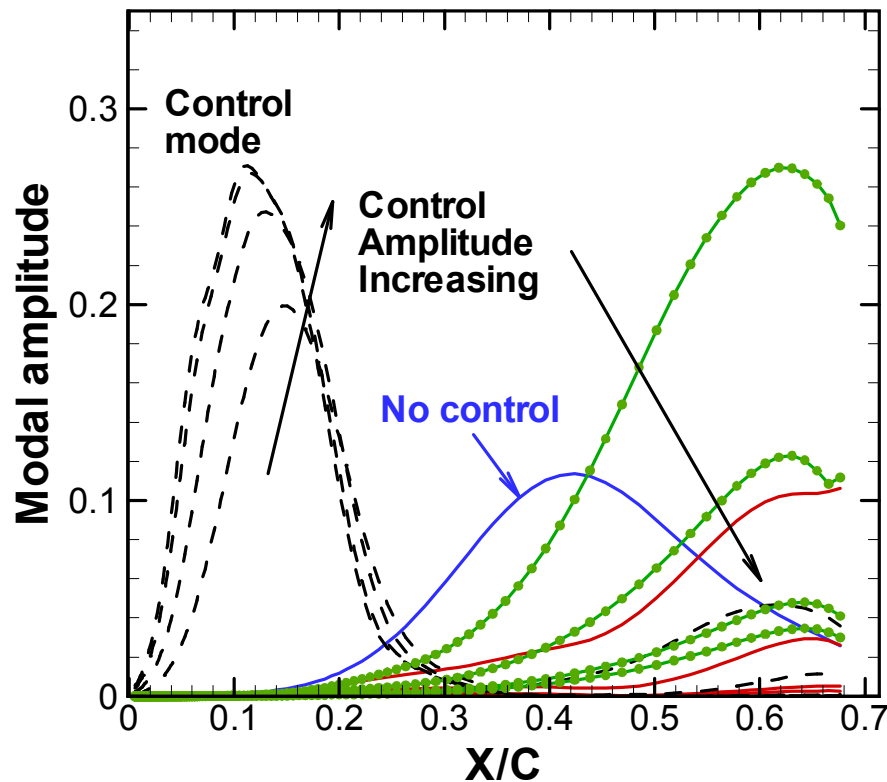
- try 4 mm mode as control input
- does control 8 mm mode well
- but reaches large amplitude itself

- Dashed lines: 2.67 mm
- Solid lines: 8 mm





Effect of 4 mm Mode on 6 mm Mode



dashed lines: 4 mm; solid lines: 6 mm; dots: 12 mm

quadratic interactions:

$$\exp(i2\pi/4) \exp(-i2\pi/6) = \exp(i2\pi/12)$$

$$\exp(i2\pi/6) \exp(i2\pi/12) = \exp(i2\pi/4)$$

$$\exp(i2\pi/4) \exp(-i2\pi/12) = \exp(i2\pi/6)$$



Concluding Remarks

- $Re = 17 M \Rightarrow \lambda = 6 - 17$ mm can potentially cause transition
- DREs at $\lambda = 2.67 - 4$ mm reduce the growth of naturally dominant stationary crossflow instability modes at high Re_c
 - Indirectly also weaken the secondary instability growth
- Overcontrol (i.e. premature transition) can be avoided if control input is suitably small (o.k. if surface is sufficiently smooth)
- Possibility of exciting unwanted modes exists
 - Interactions between short wavelength control and target modes could lead to significant growth of longer waves
- DRE control at high Reynolds numbers is a delicate balance between reducing target mode amplitude and avoiding over-control
- Definitive conclusions cannot be drawn from computations until details of surface roughness and receptivity information are available
 - DNS is challenging
 - Experiments justified