The influence of gaps on boundary layer transition

Chetan Jagadeesh
City, University of London

Study of the influence of surface gaps in the boundary layer stability and transition

VICTOR VICTORINO[1], CHETAN JAGADEESH[2], MICHAEL GASTER[2] AND MARCELLO MEDEIROS[1]

[1] SAO CARLOS SCHOOL OF ENGINEERING - UNIVERSITY OF SAO PAULO

[2] SCHOOL OF SCIENCE AND TECHNOLOGY - CITY ST GEORGE'S, UNIVERSITY OF LONDON

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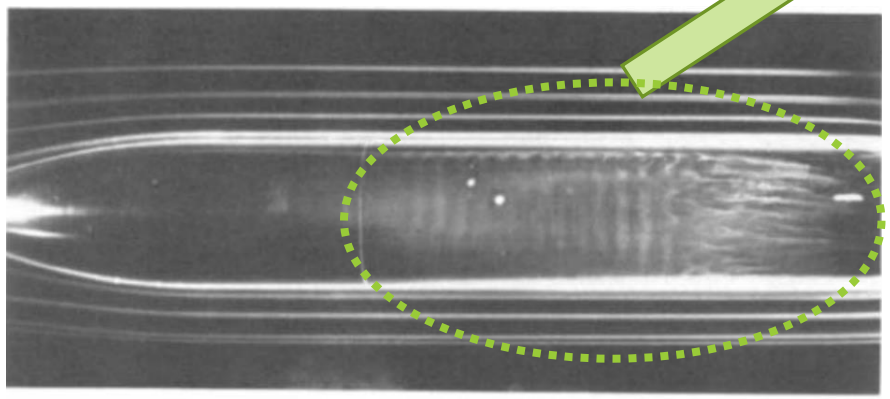
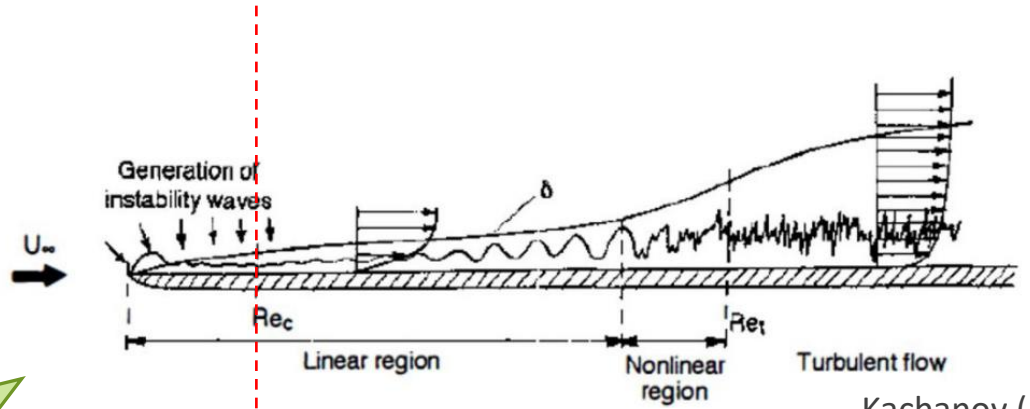
Introduction

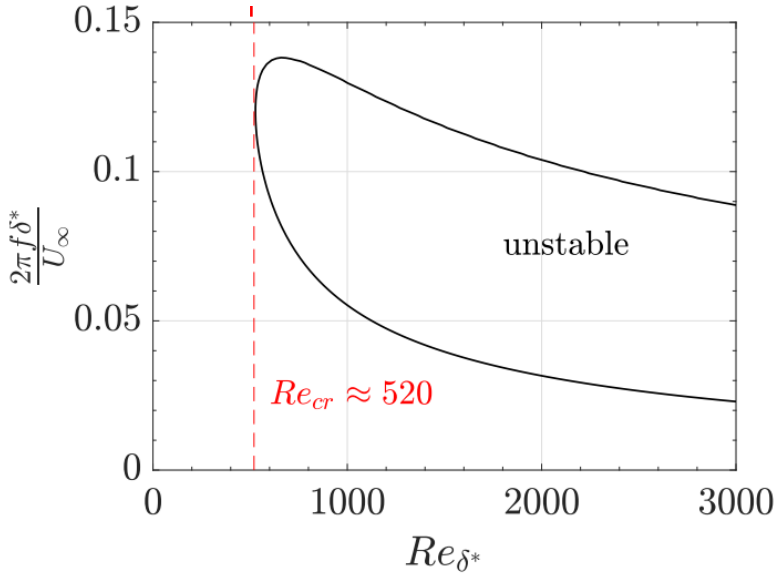
- 2D Boundary Layer transition
  - Growth of Tollmien-Schlichting (T-S) mode



Herbert (1988)

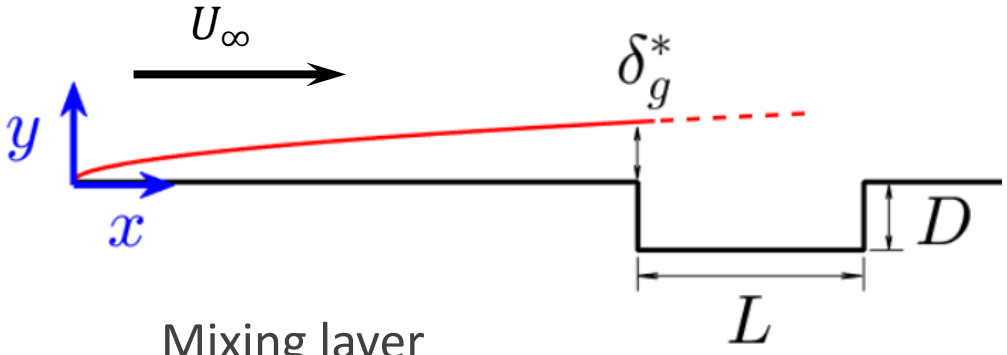


Kachanov (1994)

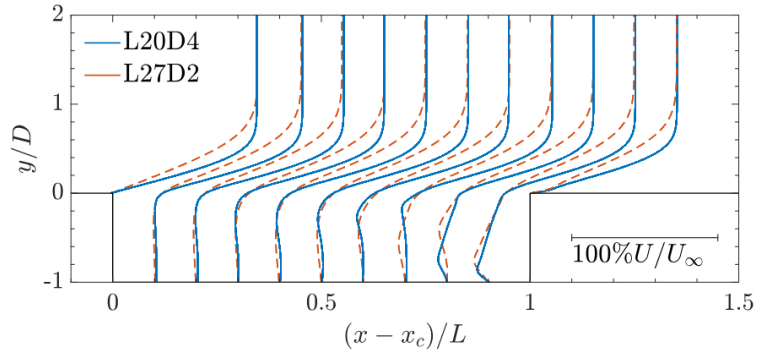


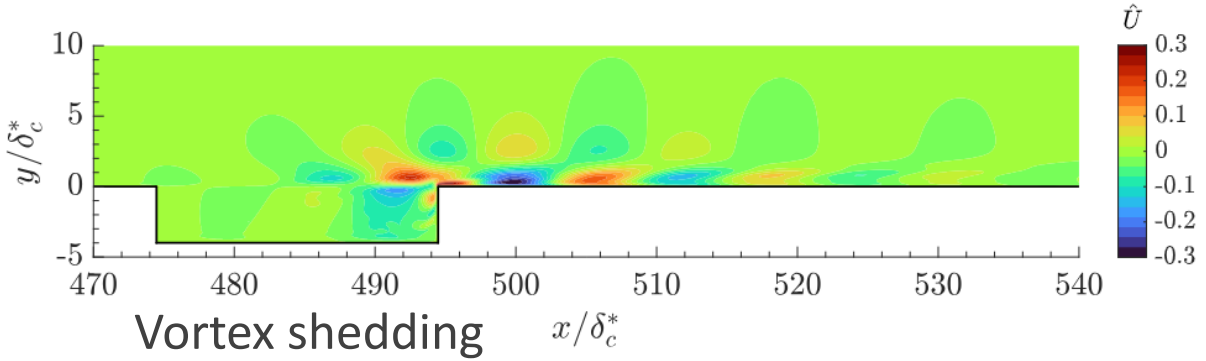
Introduction

- Surface gap (2D cavity)



Mixing layer





Vortex shedding (K-H)

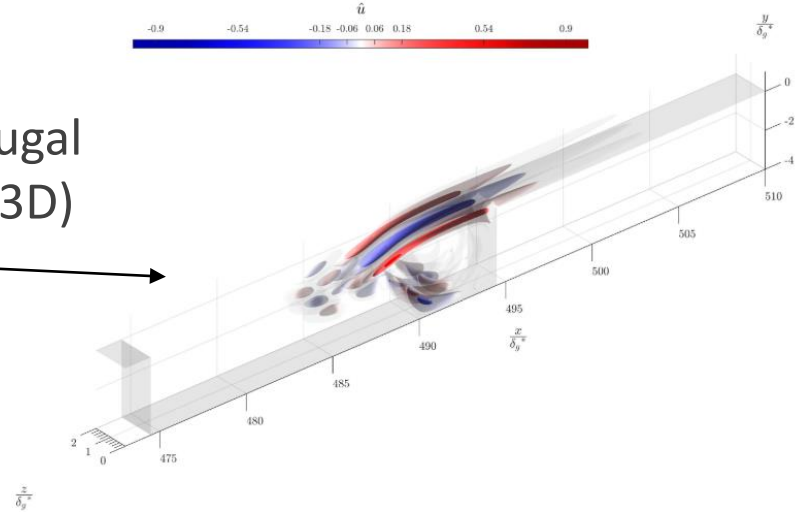
Resonance

Rossiter mode (2D)

acoustic

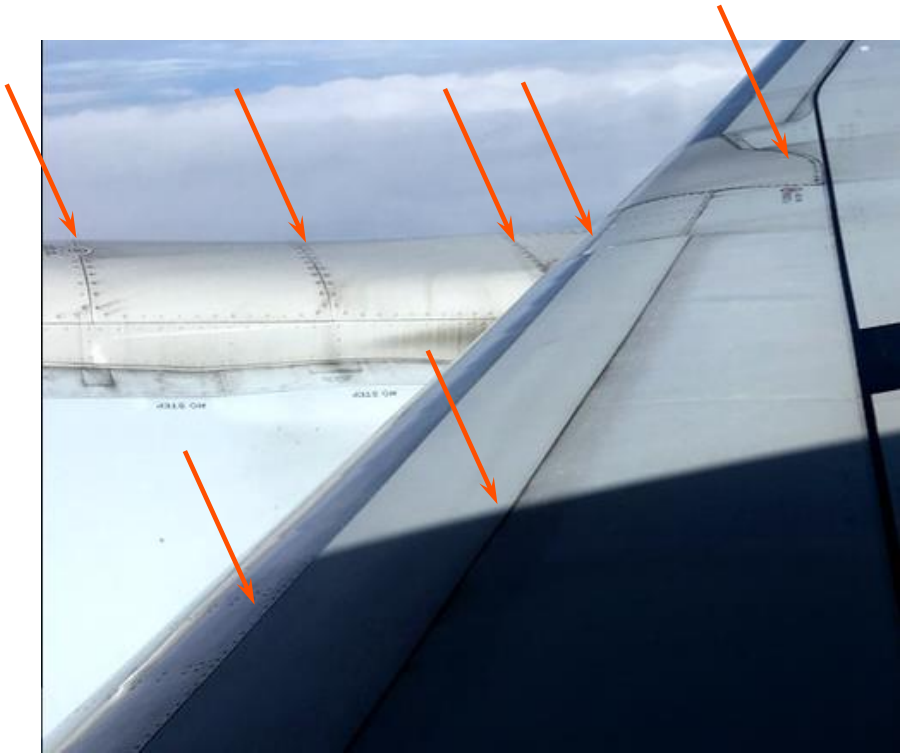
Rowley (2002)

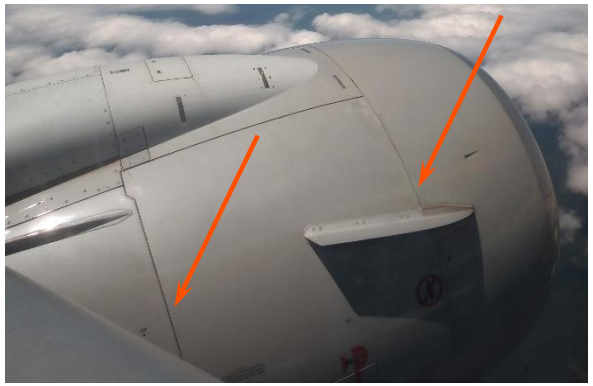
Centrifugal mode (3D)



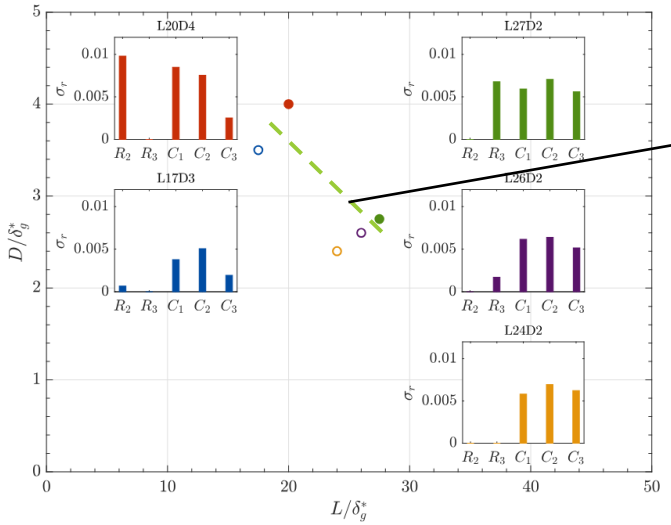
Motivation

- Surface gaps are among us!

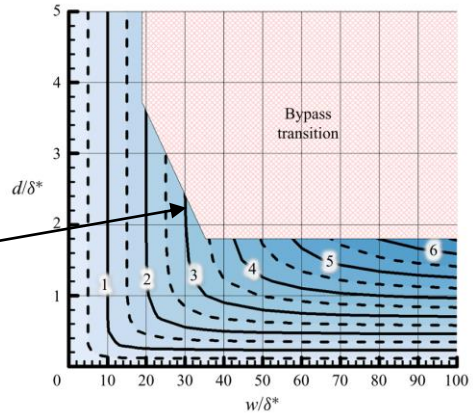


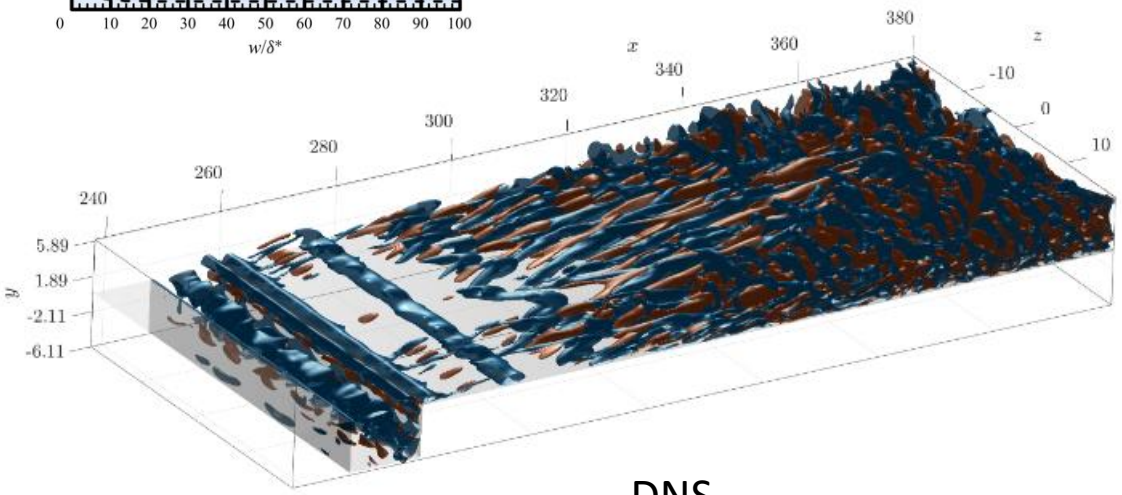


Previous research

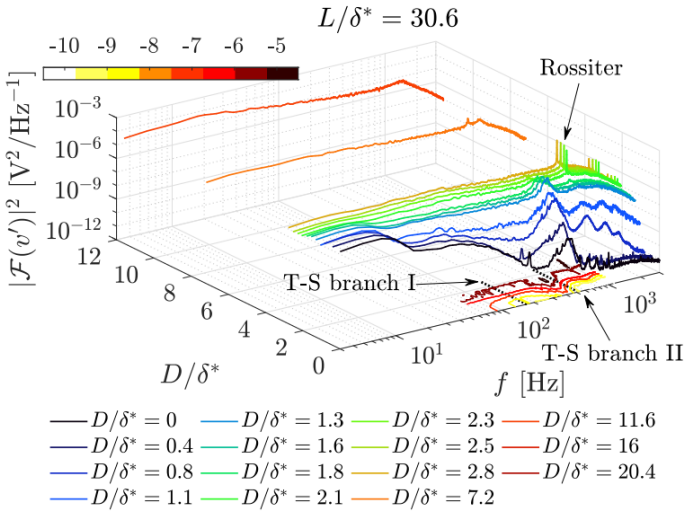


Stability analysis





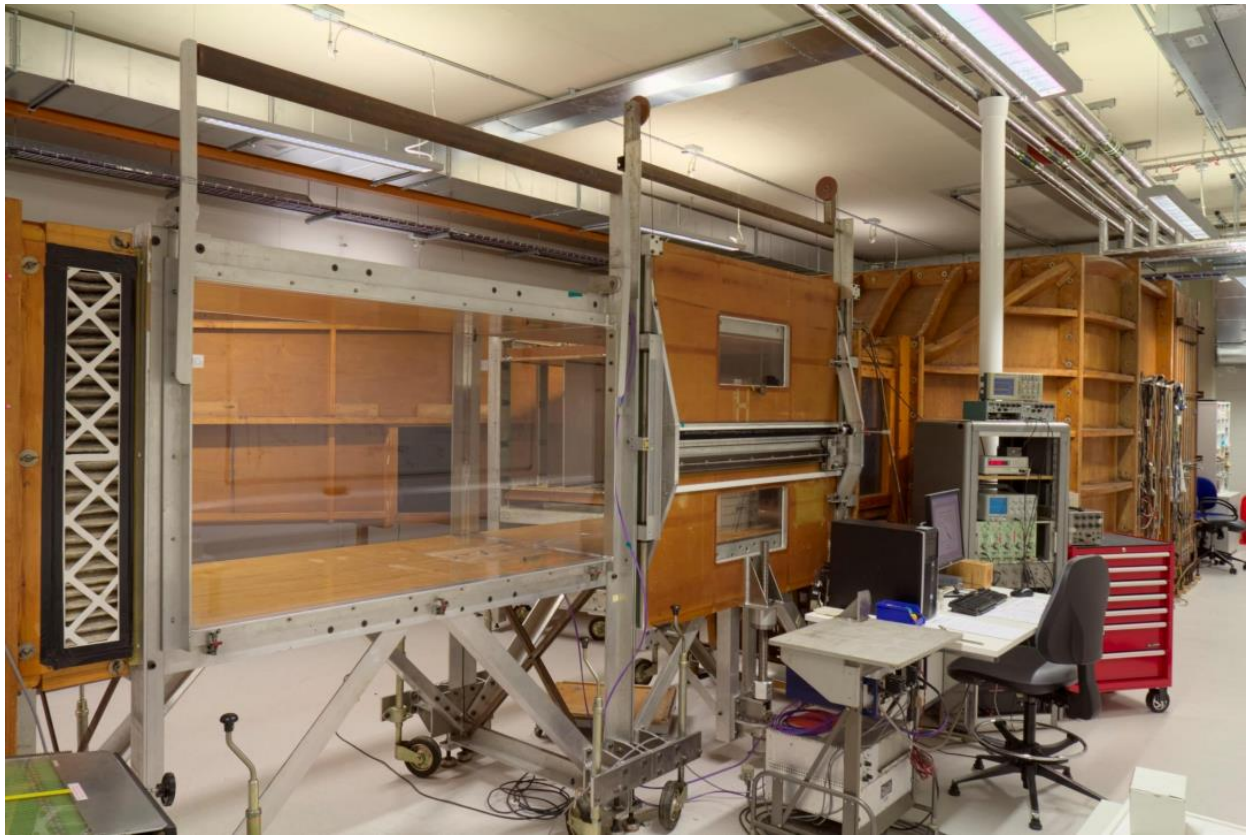
DNS



Experiments

Experimental setup

- Gaster wind tunnel



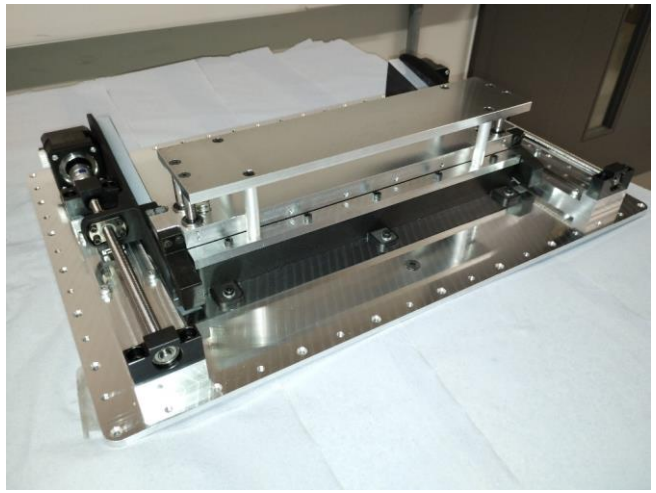
- Test Section Dimensions
  - 0.91 m x 0.91 m x 3m

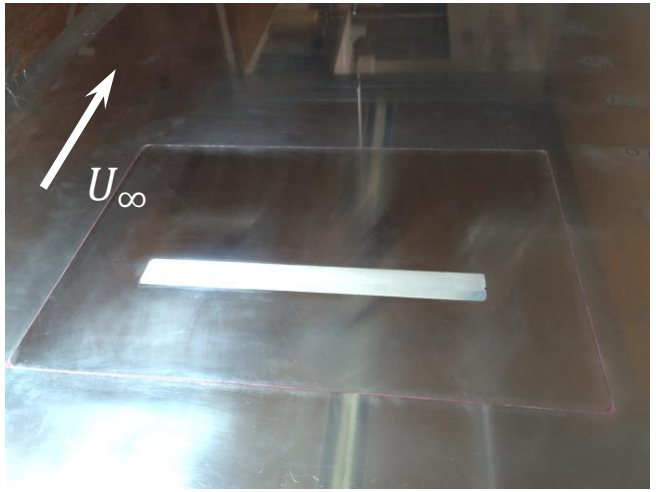
Experimental setup

- Variable-depth cavity system

Cavity depth Travel:

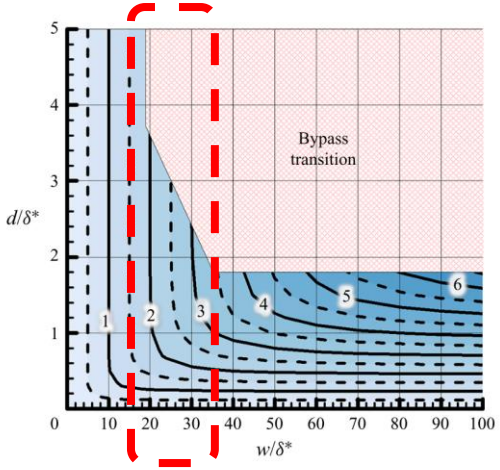
$-4.0 \leq D \leq 28.5$ [mm]

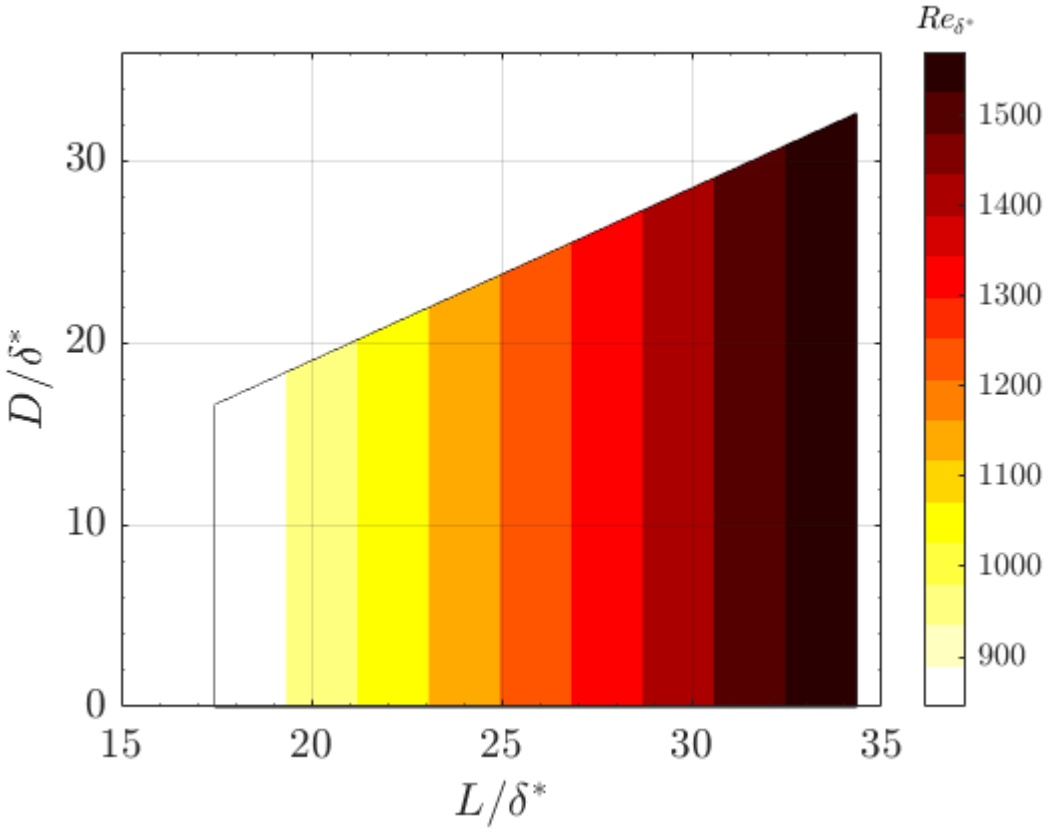




Experimental setup

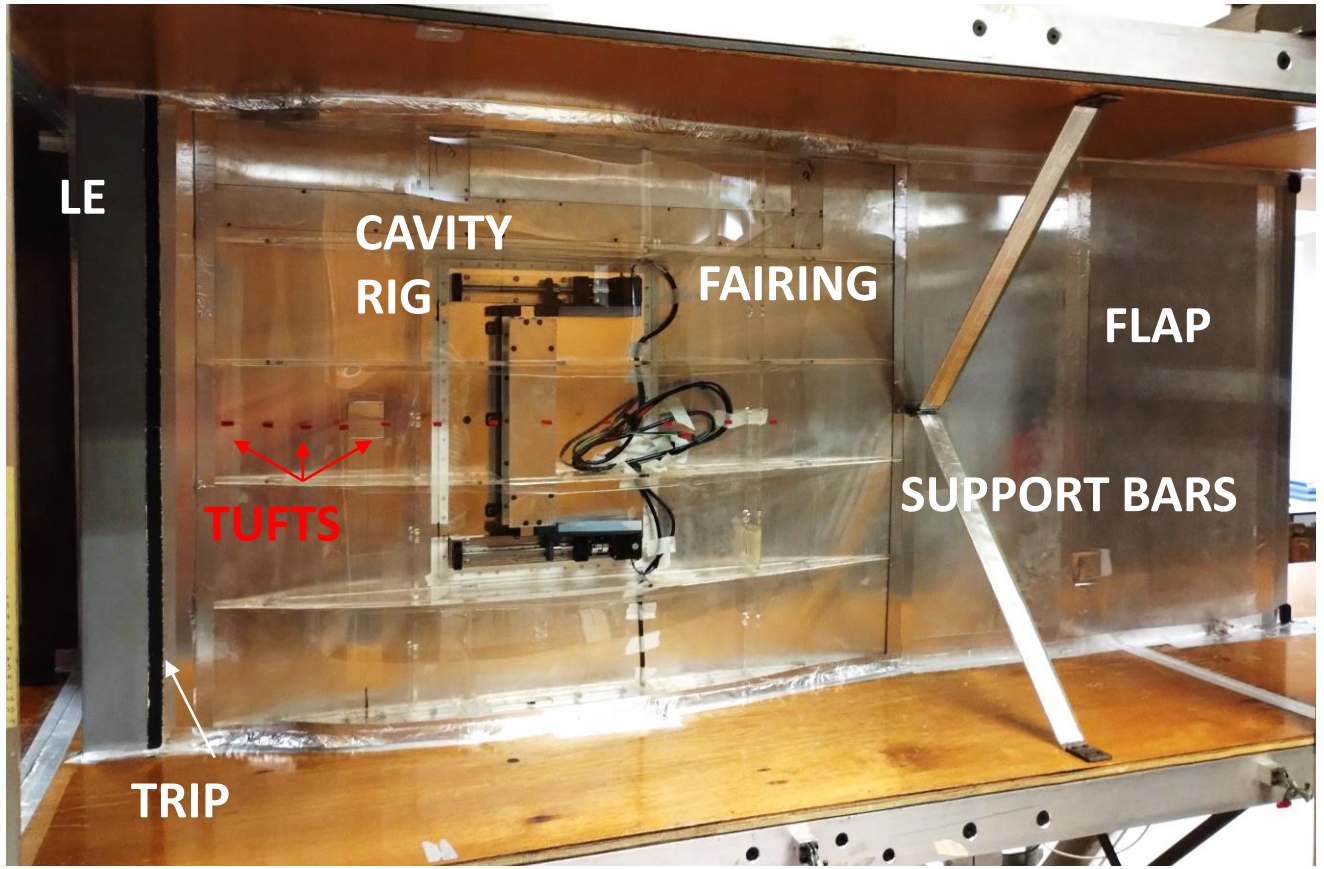
- Parametric space
  - L/δ^* increases with U_∞
  - D/δ^* increases with U_∞ or D
  - L/δ^* and Re_{δ^*} are mutually dependent on U_∞
- Designed to achieve “bypass” transition according to Crouch et al. (2022)





Experimental setup

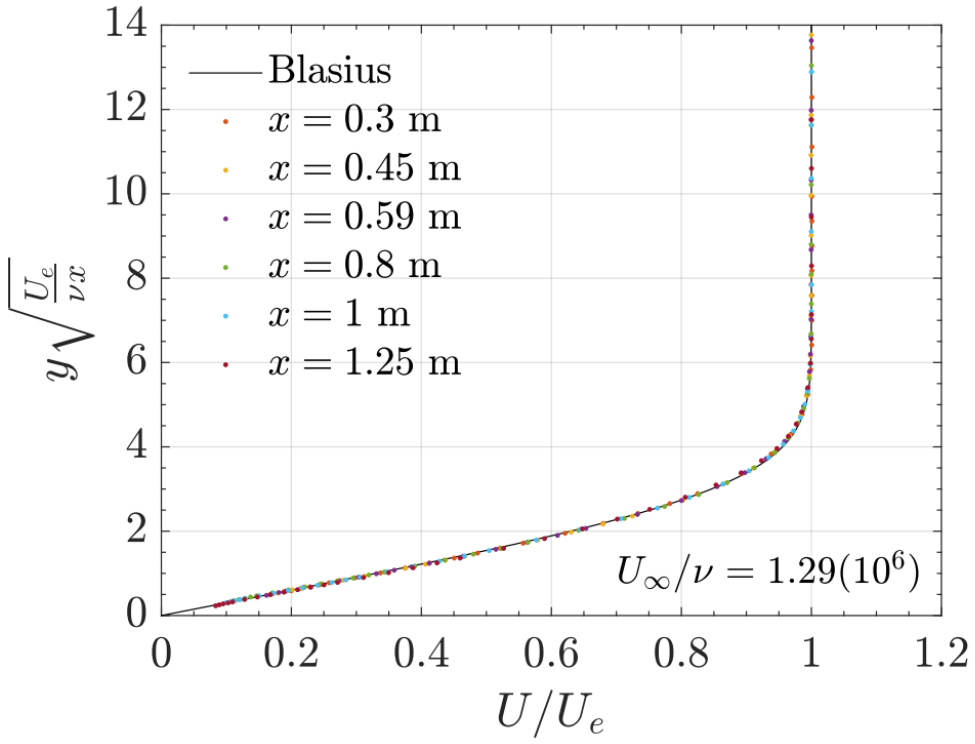
- Flat plate model



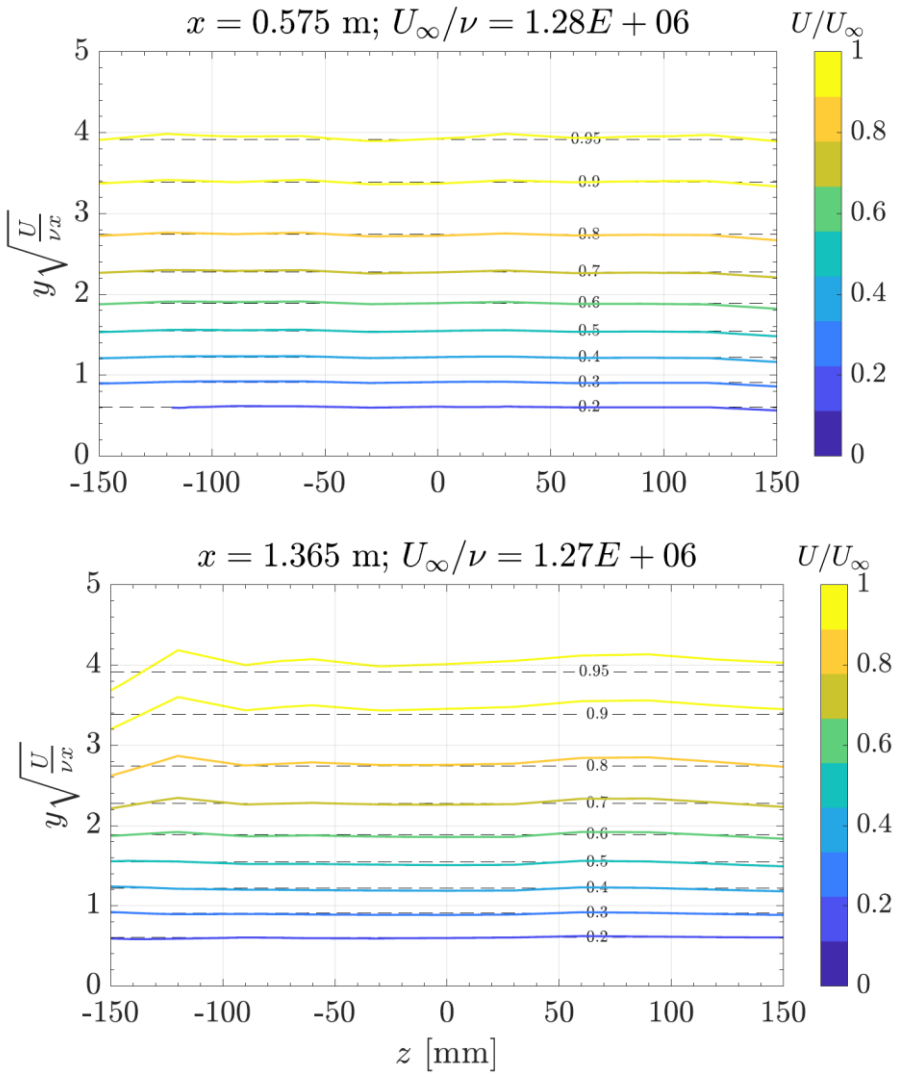
Flow characterization

- Mean profiles

Streamwise Velocity



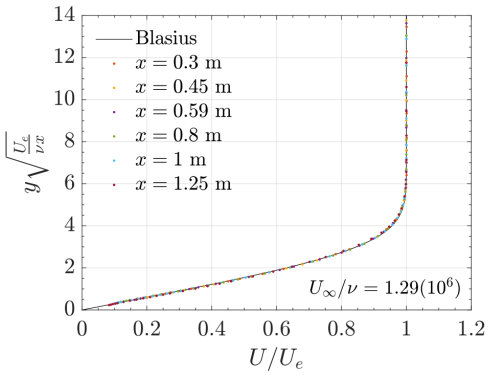
Spanwise Velocity



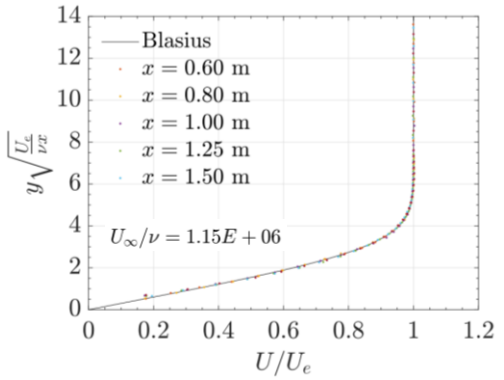
Wind tunnel comparison

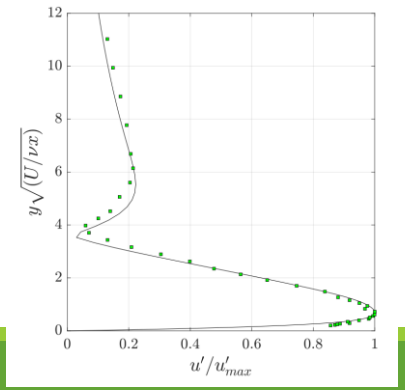
- Part of the experimental campaingn was designed to collect data to compare the LANT wind tunnel (Brazil) with the Gaster Wind Tunnel (City)

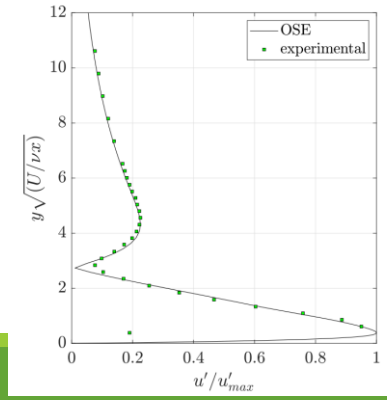
Gaster



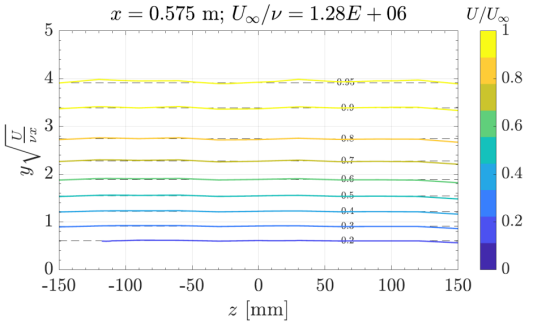
LANT



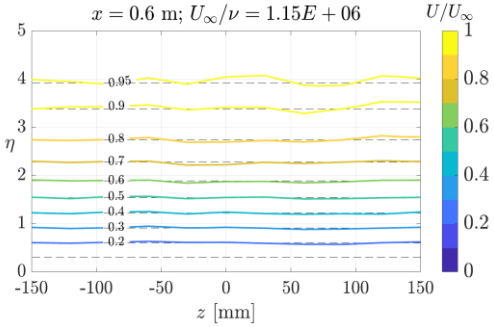


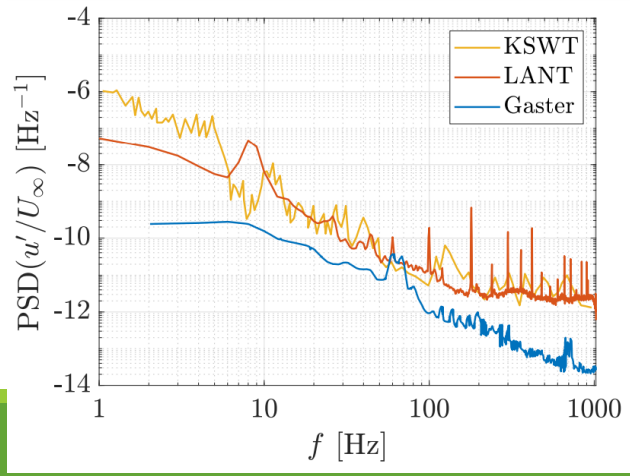


Gaster



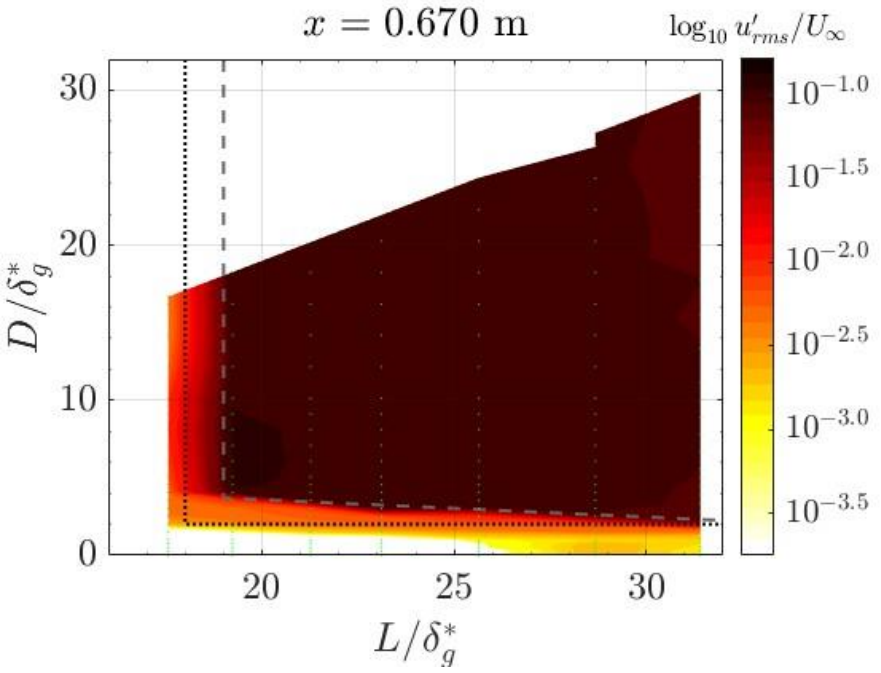
LANT

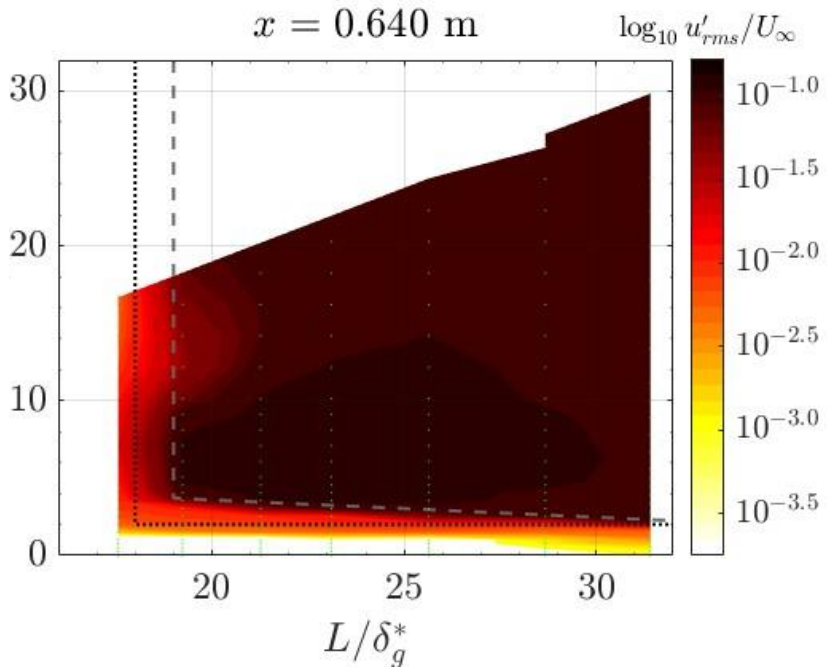




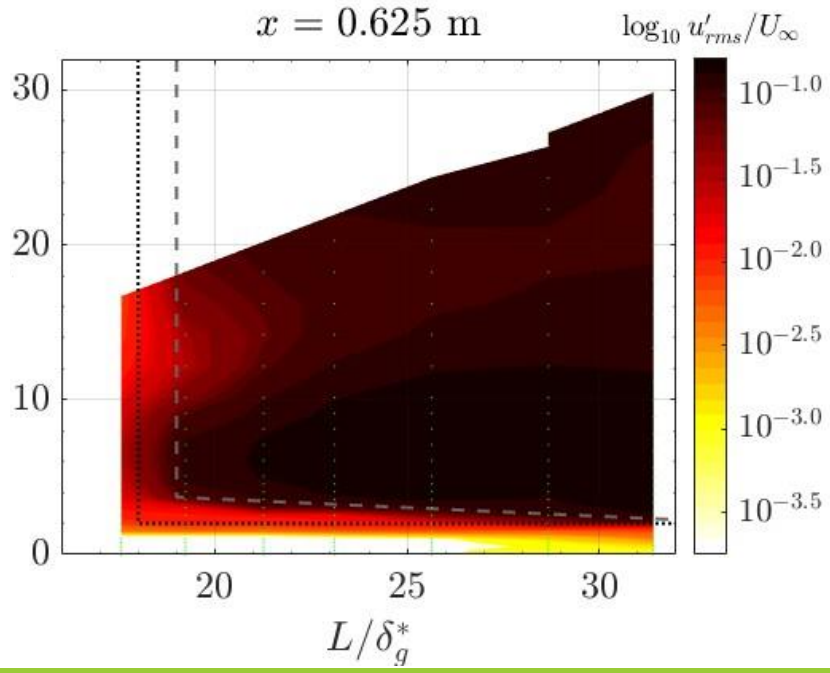
$Tu = 0.030\%$ (LANT)
$Tu = 0.007\%$ (Gaster)

Gap near-field





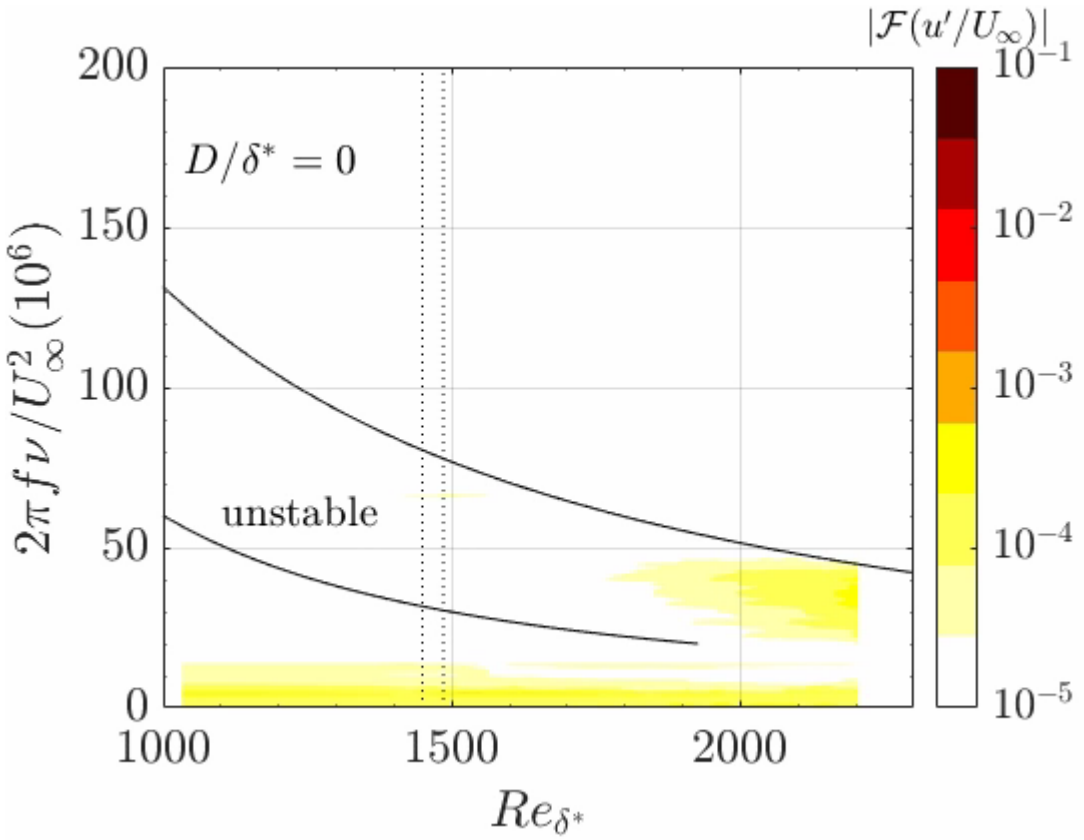
downstream



Gap LE: x=0.59 m
Gap TE: x=0.62 m

Streamwise disturbance amplification

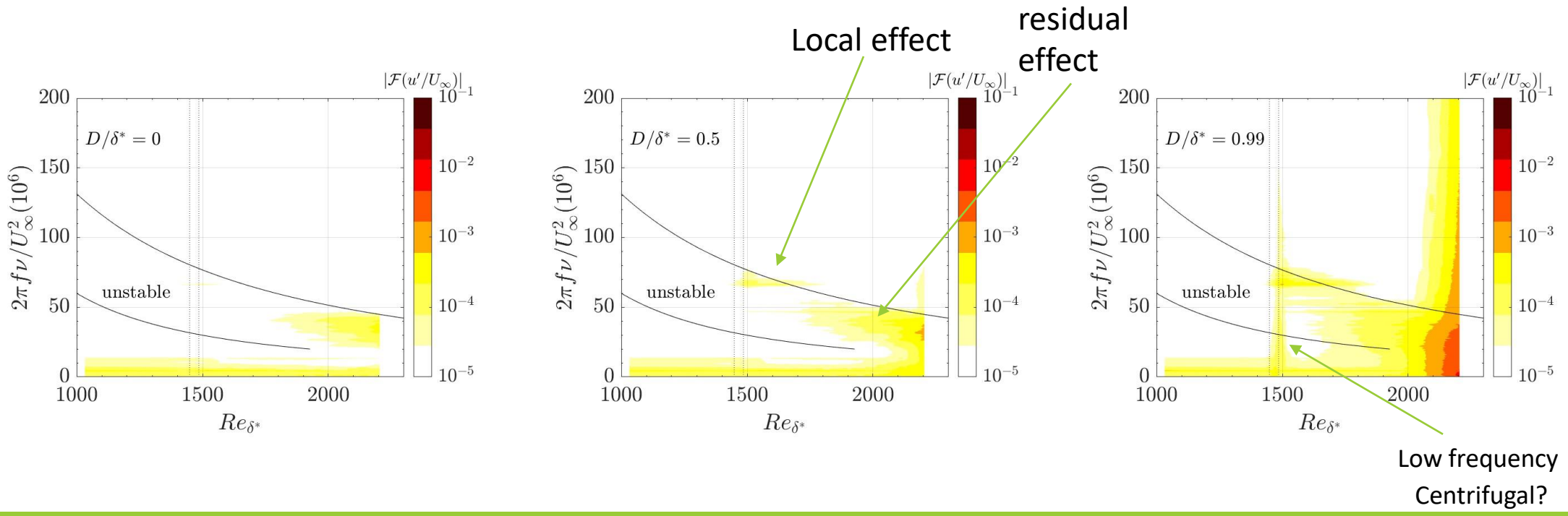
$U/\nu = 1.54\ (10^6)$
$L/\delta^* = 30.7$
$Re_{\delta^*} = 1505$



1. Regime: T-S wave affected by the gap

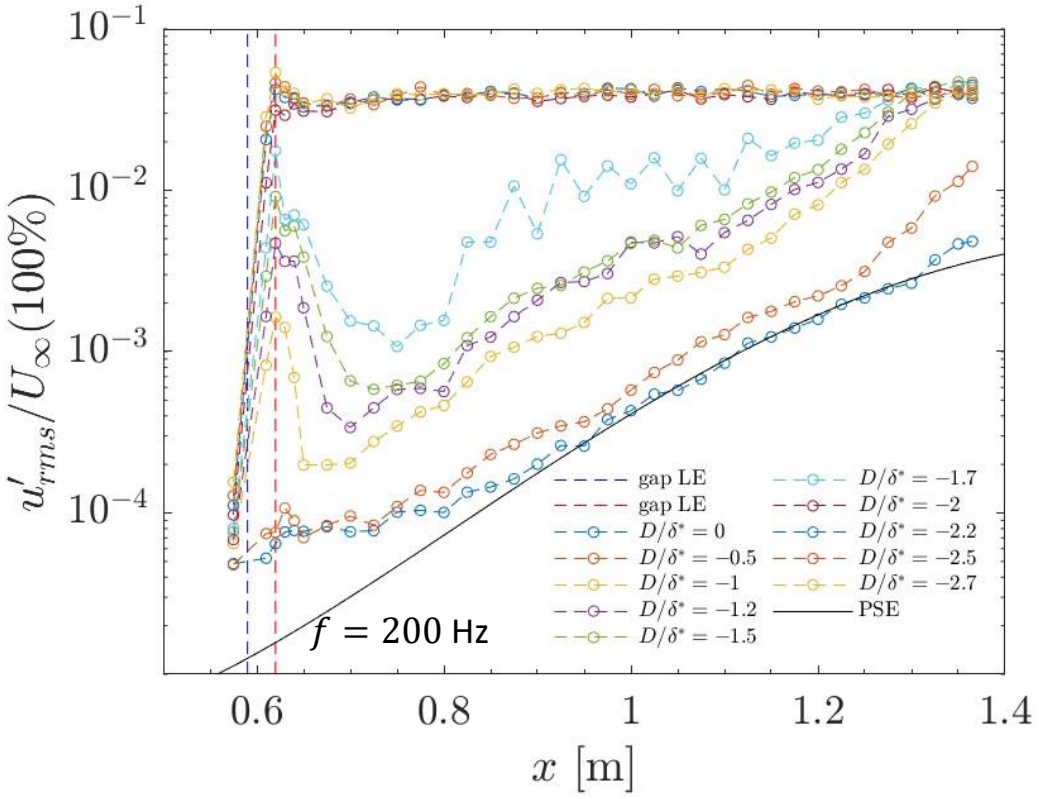
- Shallow gaps affects the T-S waves
  - Local effect
  - Residual effect

$U/\nu = 1.54\ (10^6)$
$L/\delta^* = 30.7$
$Re_{\delta^*} = 1505$



1. Regime: T-S wave affected by the gap

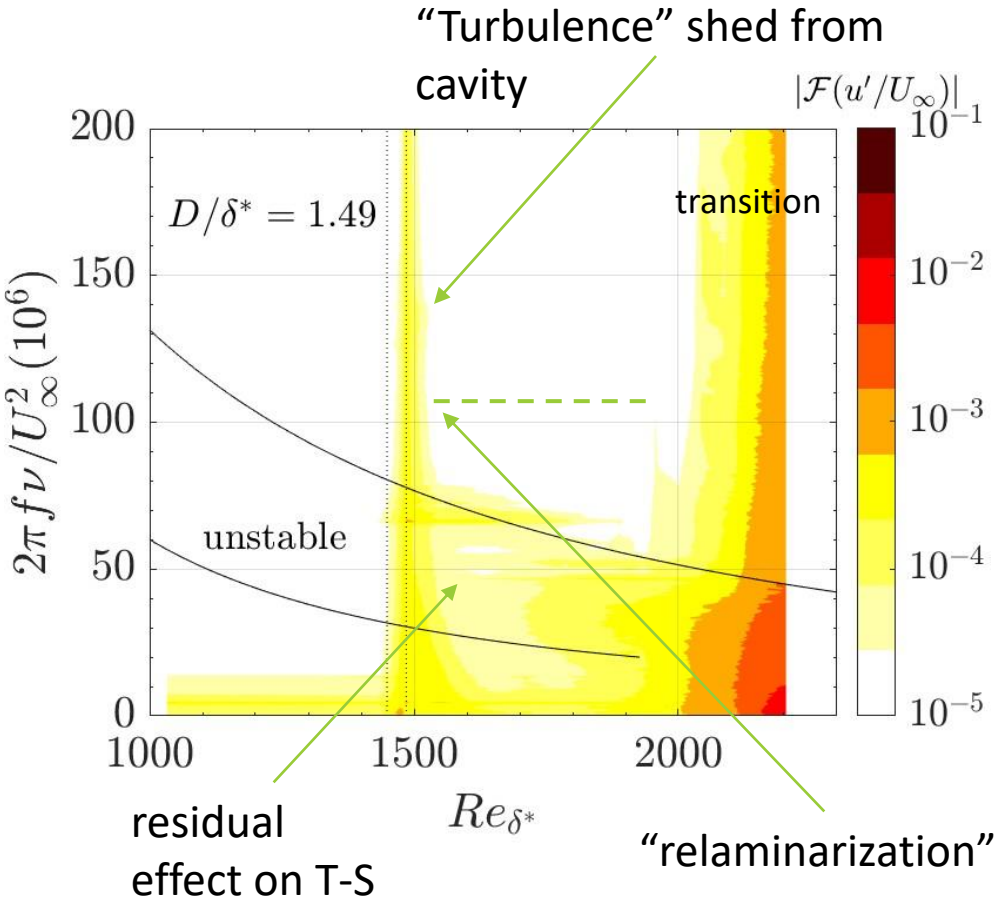
- Streamwise growth of the dominant T-S frequency

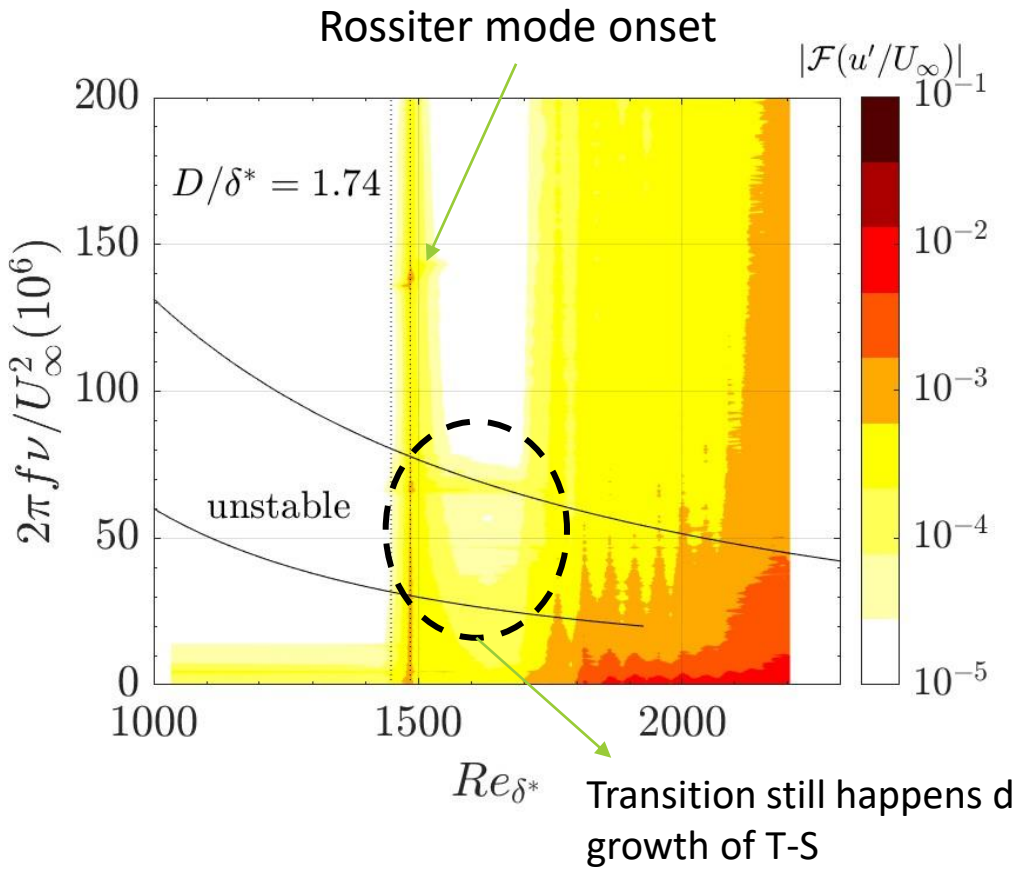


$U/\nu = 1.54\ (10^6)$
$L/\delta^* = 30.7$
$Re_{\delta^*} = 1505$

2. Regime: “Relaminarization”

$U/\nu = 1.54\ (10^6)$
$L/\delta^* = 30.7$
$Re_{\delta^*} = 1505$

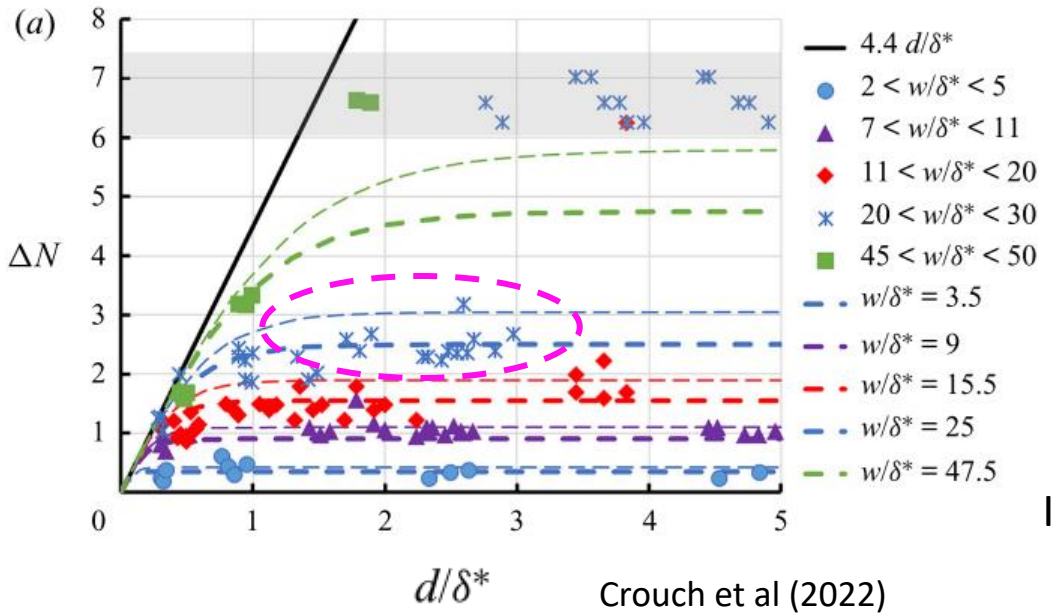




2. Regime: “Relaminarization” (deep-gap limit)

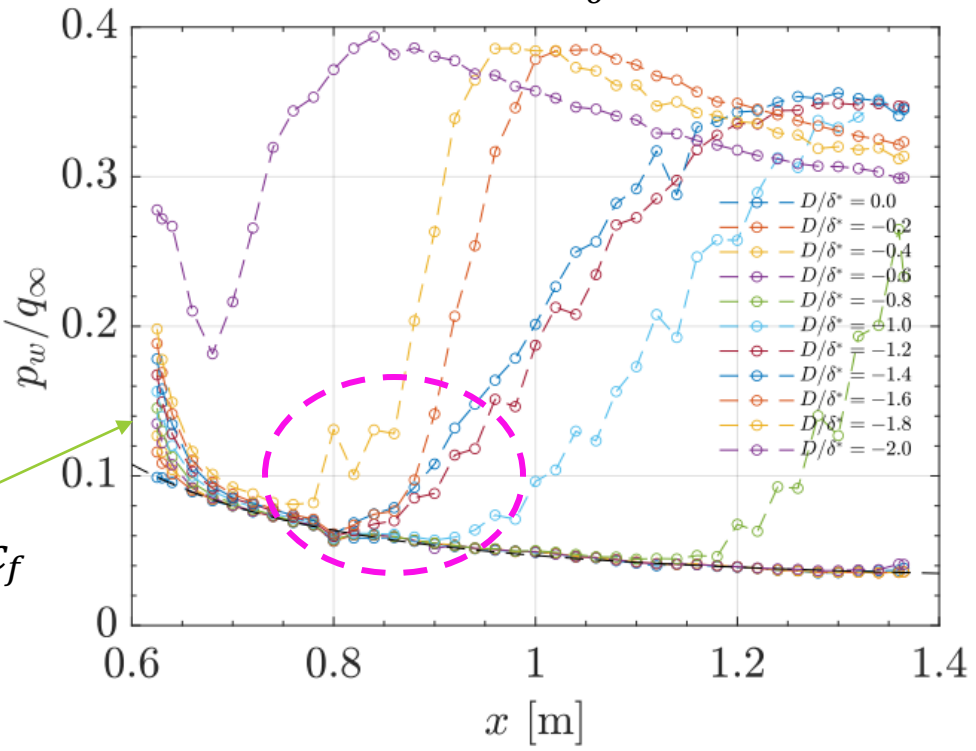
- Transition impact insensitive to cavity depth

$U/\nu = 1.89\ (10^6)$
$L/\delta^* = 34$
$Re_{\delta^*} = 1668$



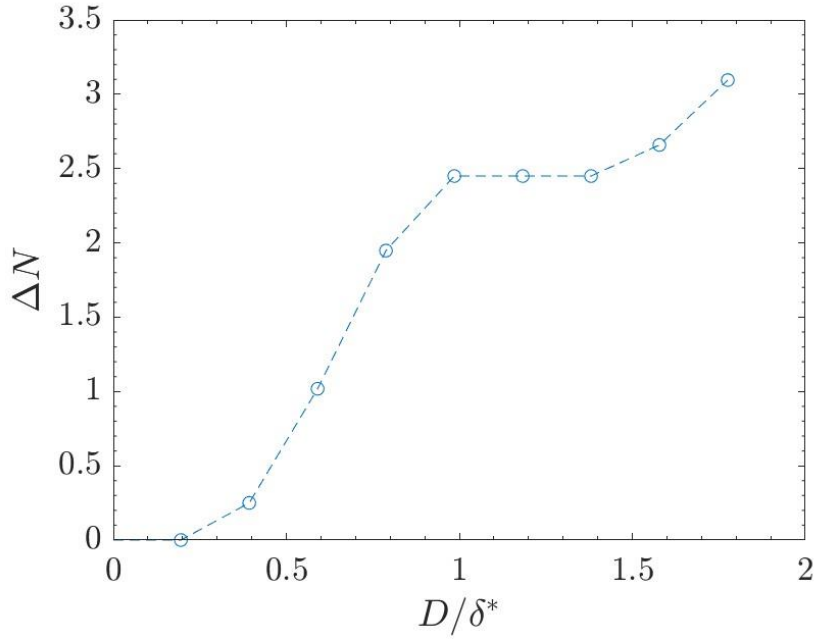
Crouch et al (2022)

Increase in c_f



2. Regime: Relaminarization (deep-gap limit)

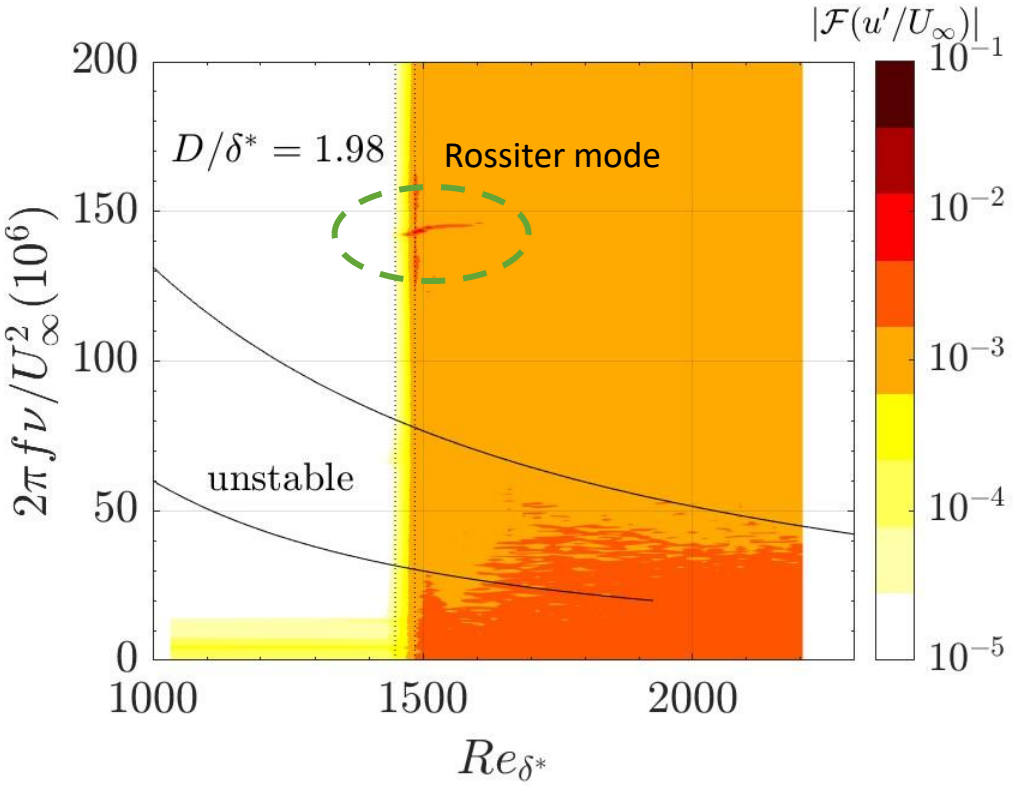
- ΔN model before deep-gap limit is similar to BFS model from Wang & Gaster (2005)

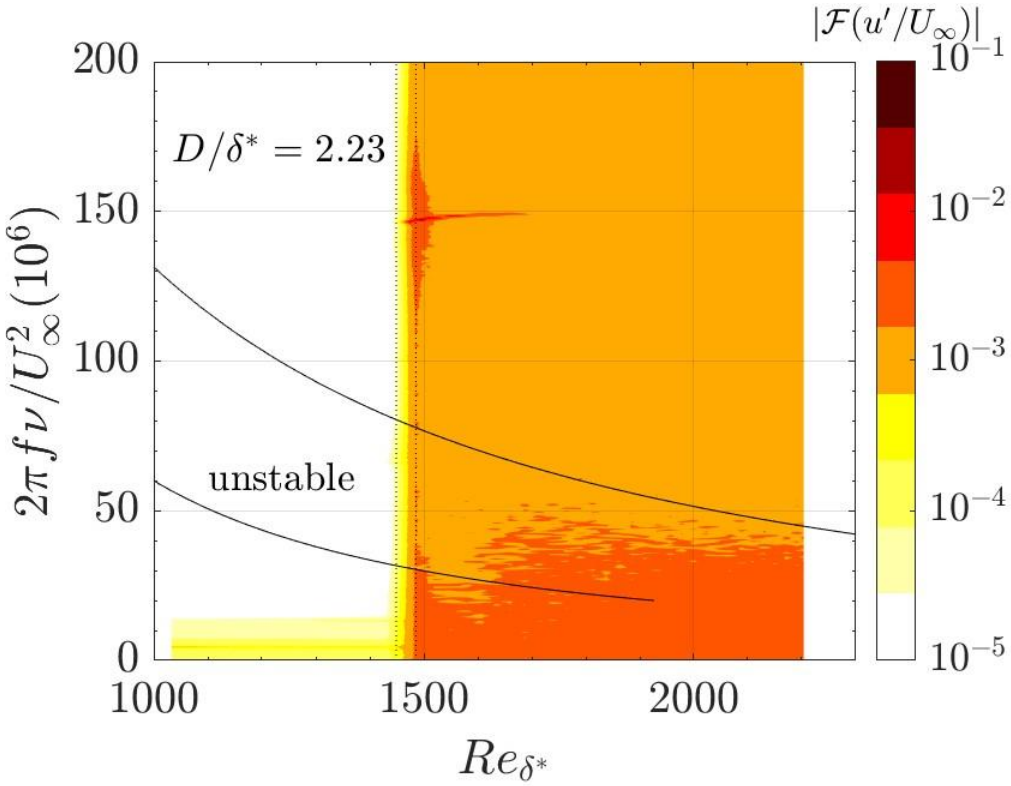


$U/\nu = 1.89\ (10^6)$
$L/\delta^* = 34$
$Re_{\delta^*} = 1668$

3. Regime: Bypass transition

$U/\nu = 1.54\ (10^6)$
$L/\delta^* = 30.7$
$Re_{\delta^*} = 1505$

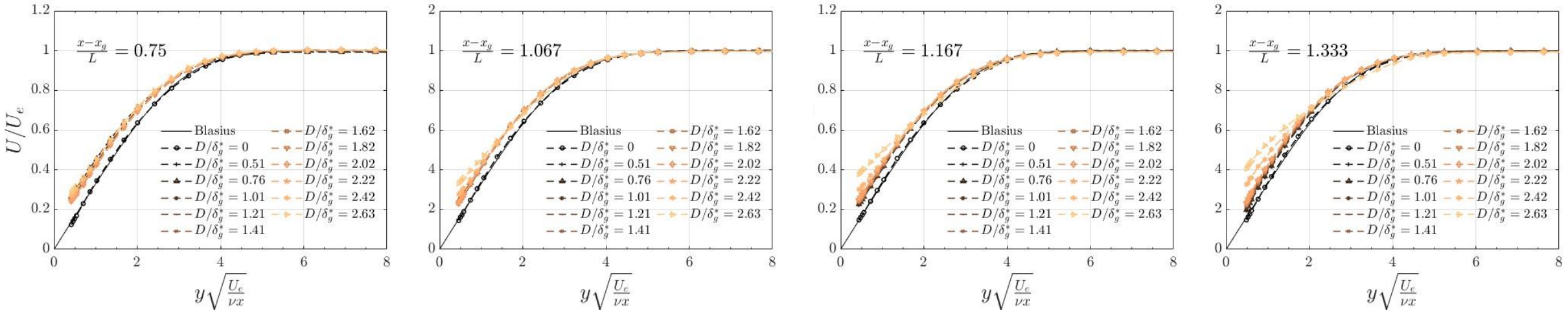




Profiles

- Mean profiles

$U/\nu = 1.26\ (10^6)$
$L/\delta^* = 28.6$
$Re_{\delta^*} = 1352$



Final remarks

- A flow characterization was employed to compare the flow quality in both wind tunnels
- The effect of a gap in the BL stability and transition was experimentally investigated. The following regimes were found

  - 1. T-S affected by the gap
    - Shallow gaps
    - ΔN behaves similar to the backward-facing step model
  - 2. Relaminarization
    - A turbulent mixing layer undergoes relaminarization downstream of the gap leaving a residual boost in the T-S wave
    - This might be correlated with the deep-gap limit found by Crouch et. al. (2022)
  - 3. Bypass transition
    - After a strong Rossiter mode develops transition is trigged right at the gap trailing edge
    - The threshold bound depends on the gap streamwise length
    - Experiments confirmed results from experiments done in Brazil (LANT) and numerical/theoretical results