
KTH ROYAL INSTITUTE
OF TECHNOLOGY

# Large Eddy Simulations of Compressor Flows at Low Mass Flow Rates

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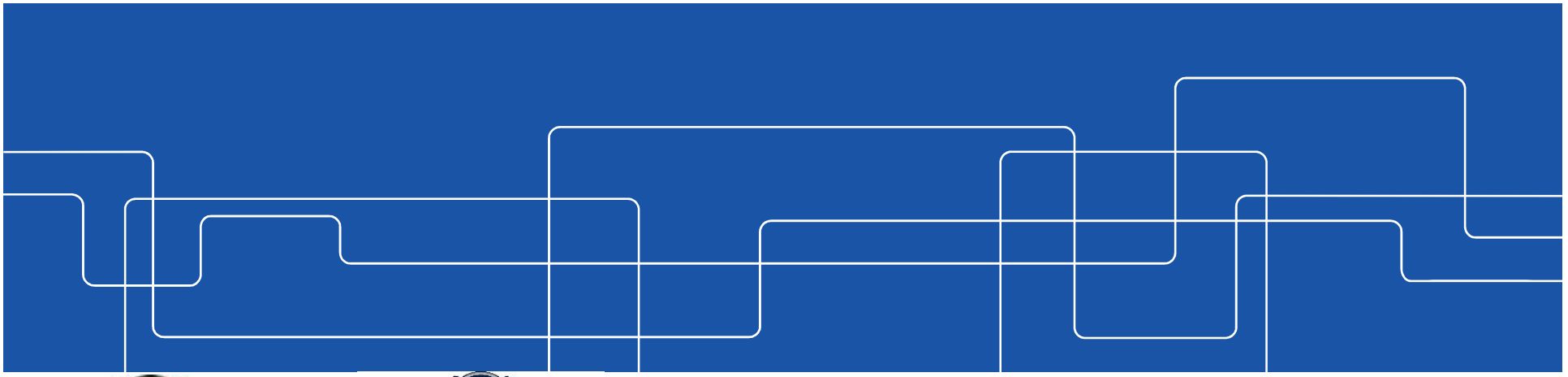


# Goals & research questions

Goals:

- Enhance understanding of flow instabilities at low mass flow rates

  > Increased turbocharging efficiency; wider and stable operating range, higher boost pressure, instability control / suppression

RQs:

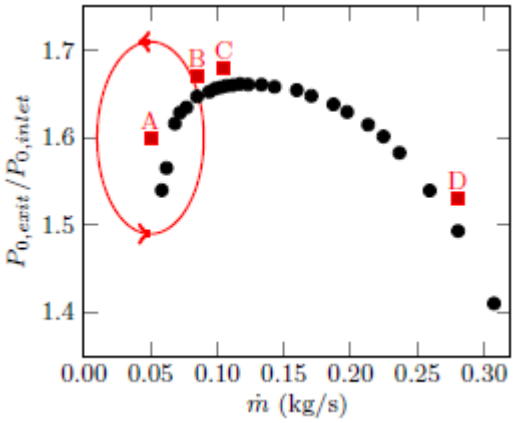
- Mechanisms for onset of stall instability in centrifugal compressors
- Impact of flow-acoustics coupling on the onset of instabilities

Method:

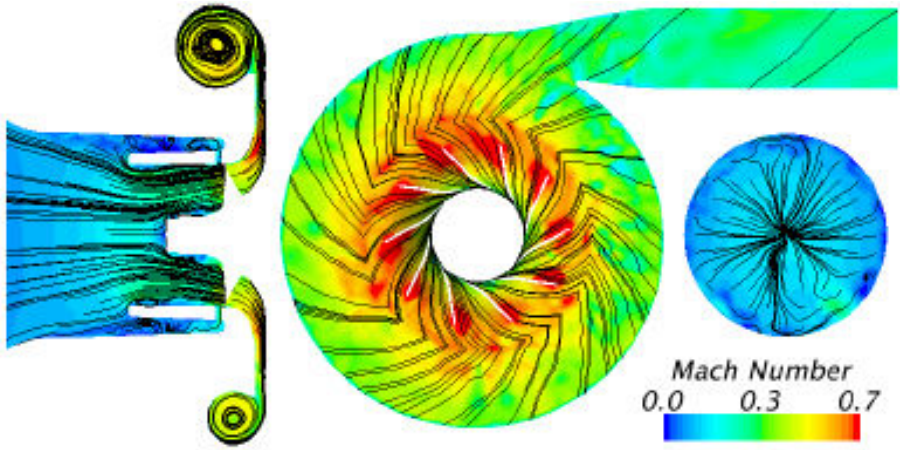
- Assessment by means of high-fidelity LES approach and advanced post-processing techniques

# Flow instabilities

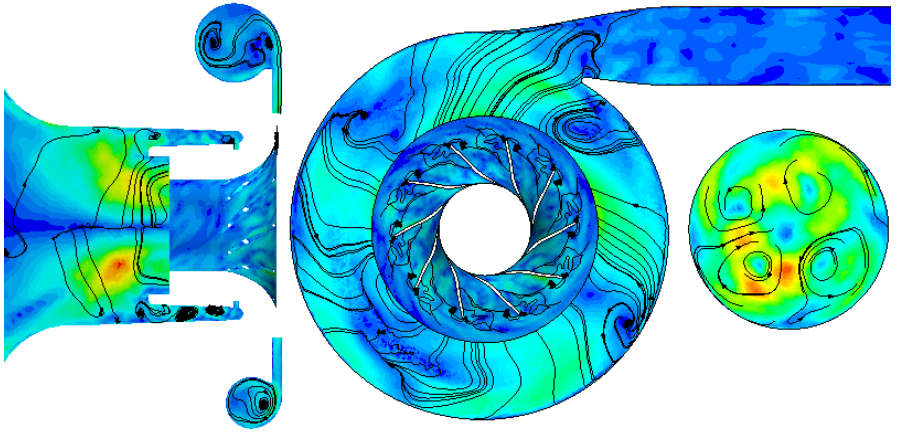
Unstable ← Stable



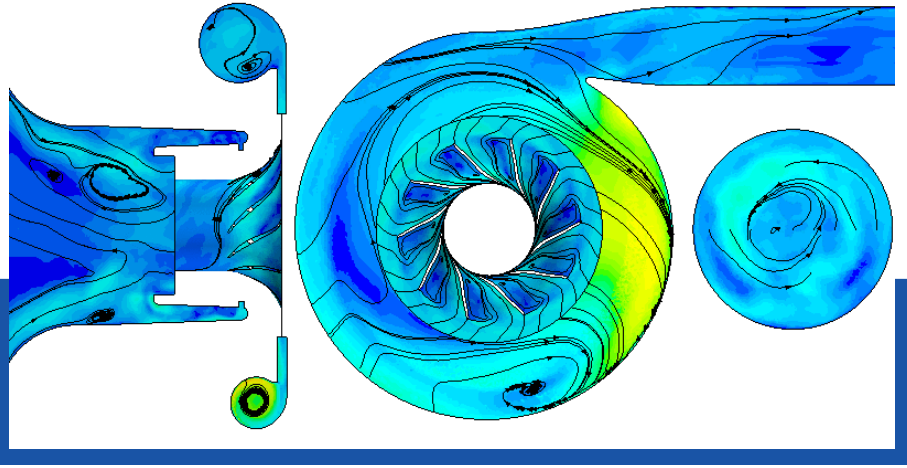

Stable
(Case D)




Unstable
(Case B)
Rot stall

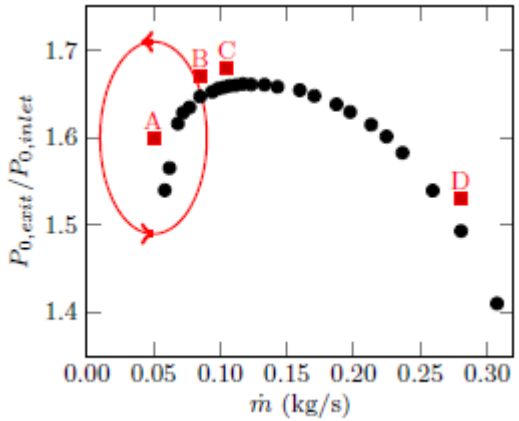


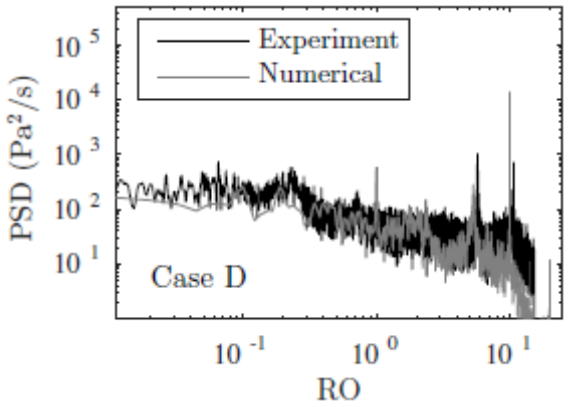
Very unstable
(Case A)
Surge pulsation

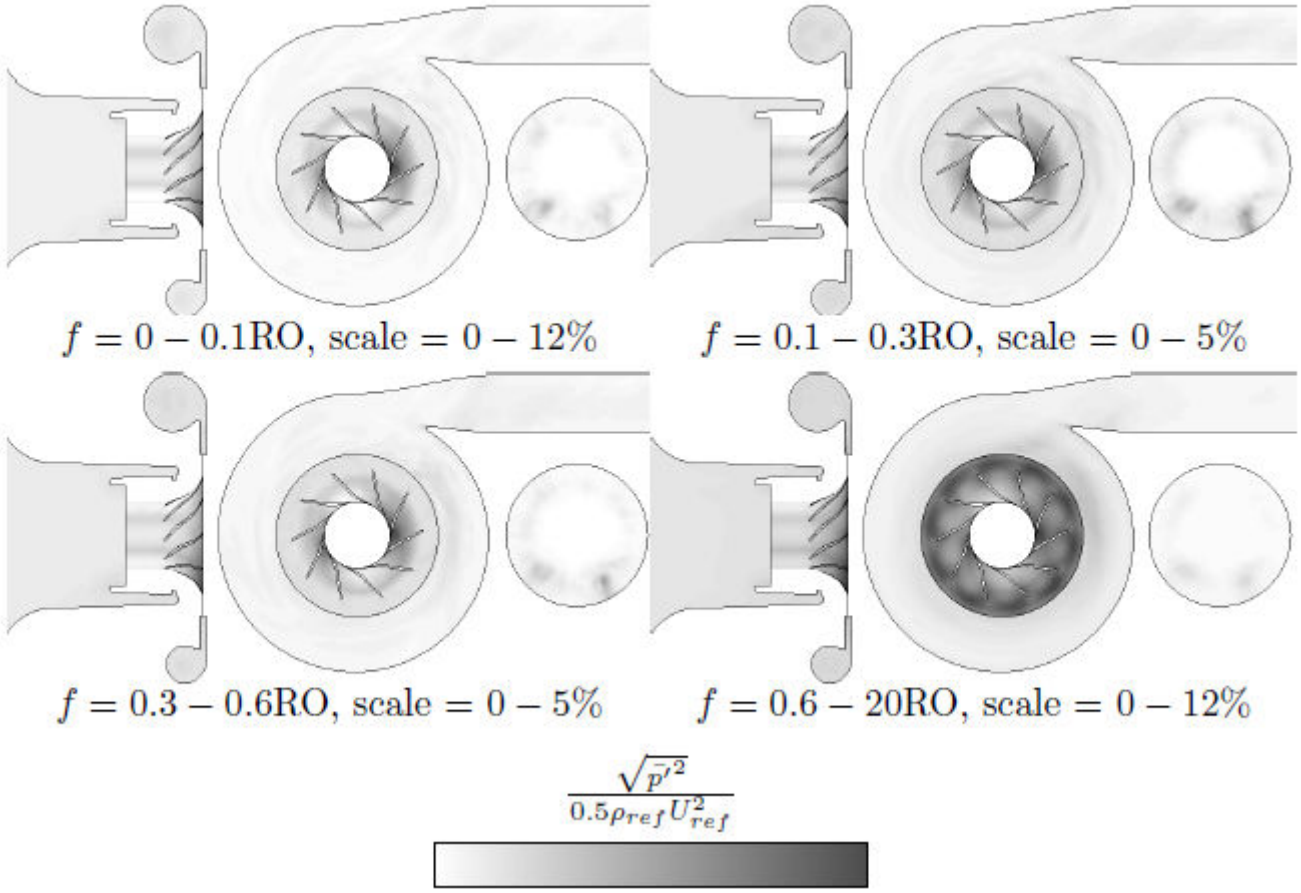


# RMS pressure fluctuation, stable (Case D)

Unstable ← Stable



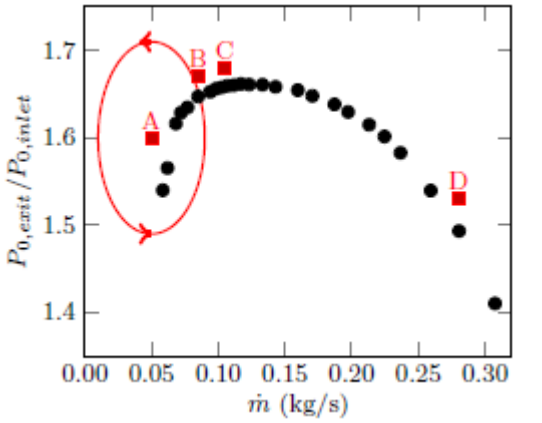



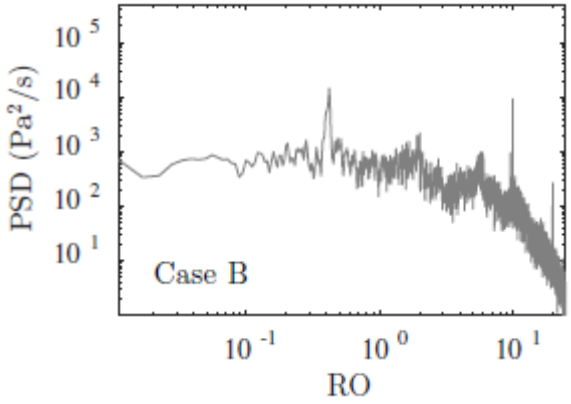



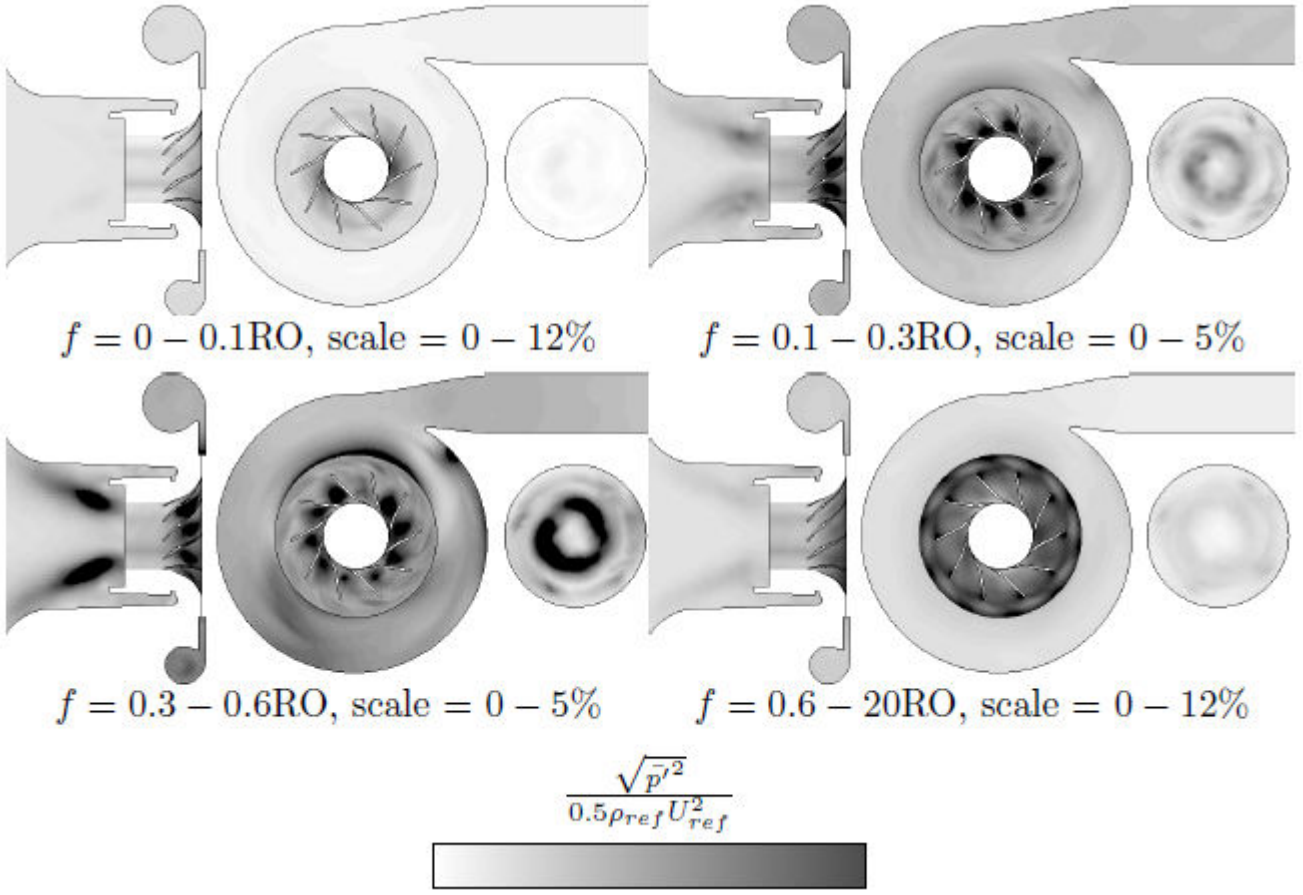

- Fluctuations mainly in the impeller region, high freq range
- Tonalities at RO, BPF

# RMS pressure fluctuation, unstable (Case B)

Unstable ← Stable



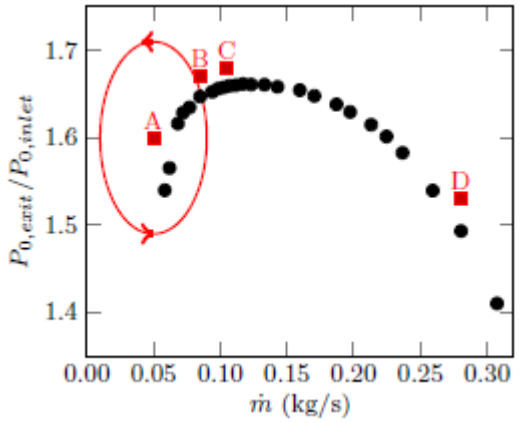



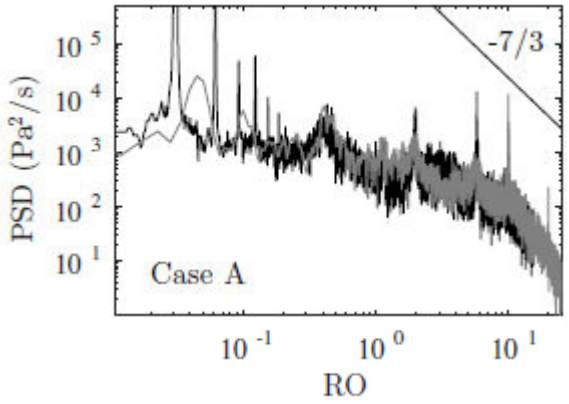



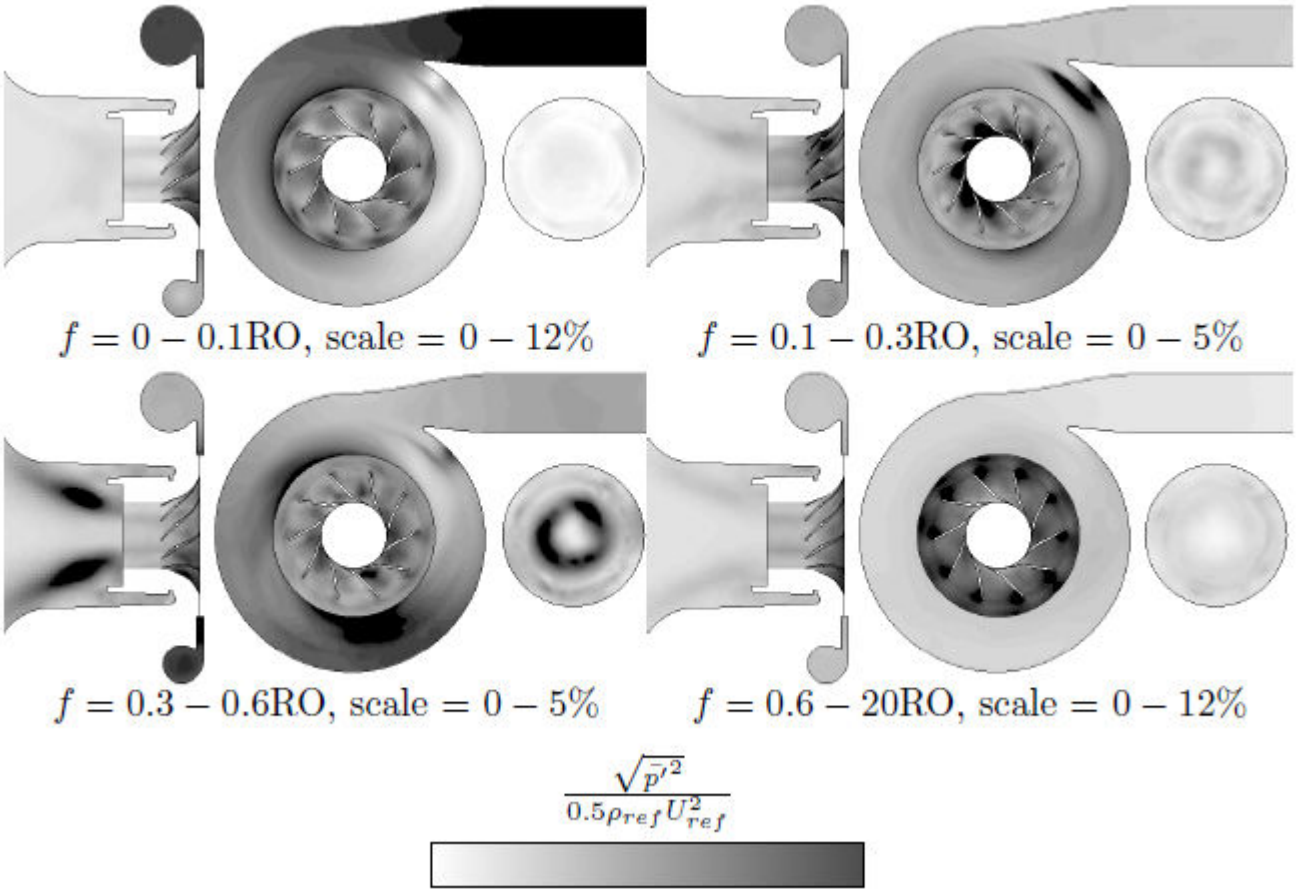

- Amplified fluctuation at inlet and diffuser
- Tonality at 0.5RO (rotating stall)

# RMS pressure fluctuation, unstable (Case A)

Unstable ← Stable

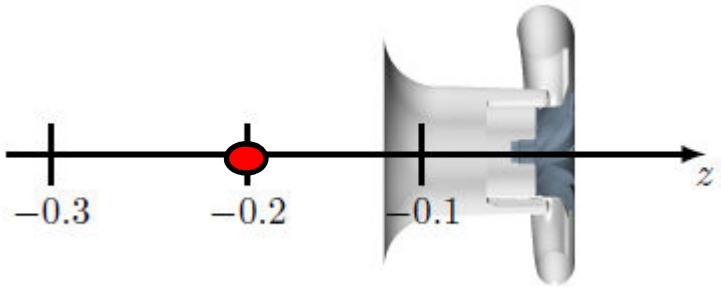


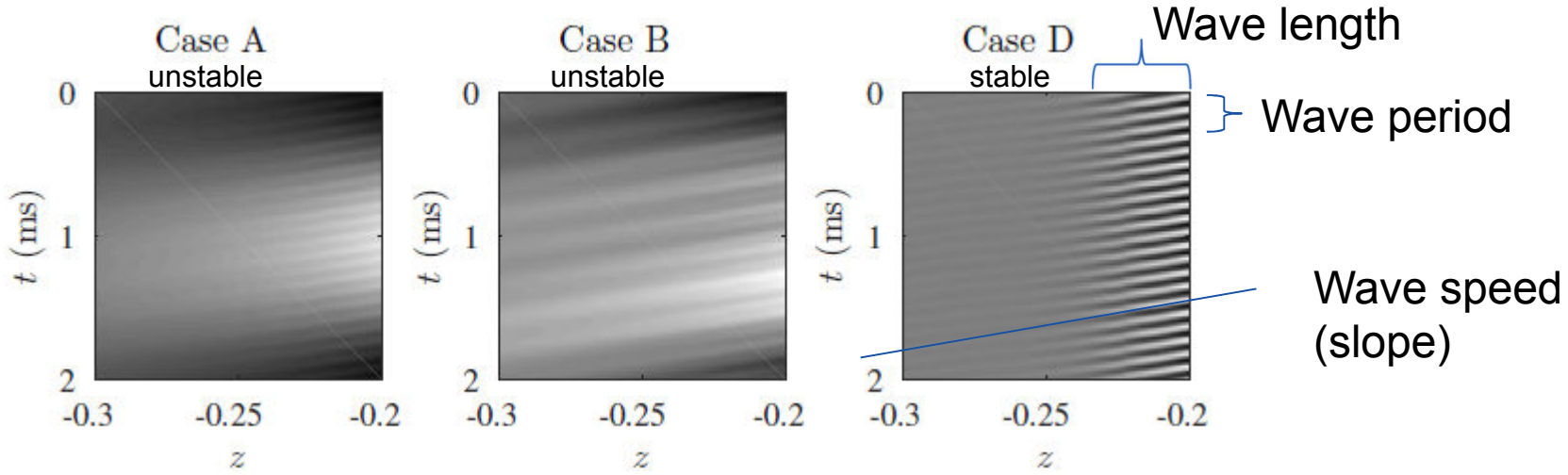




- Amplified fluctuation in outlet volute pipe, low freq range
- Tonality at 0.04RO (surge, system pulsation)

# Inlet cross correlation based on pressure

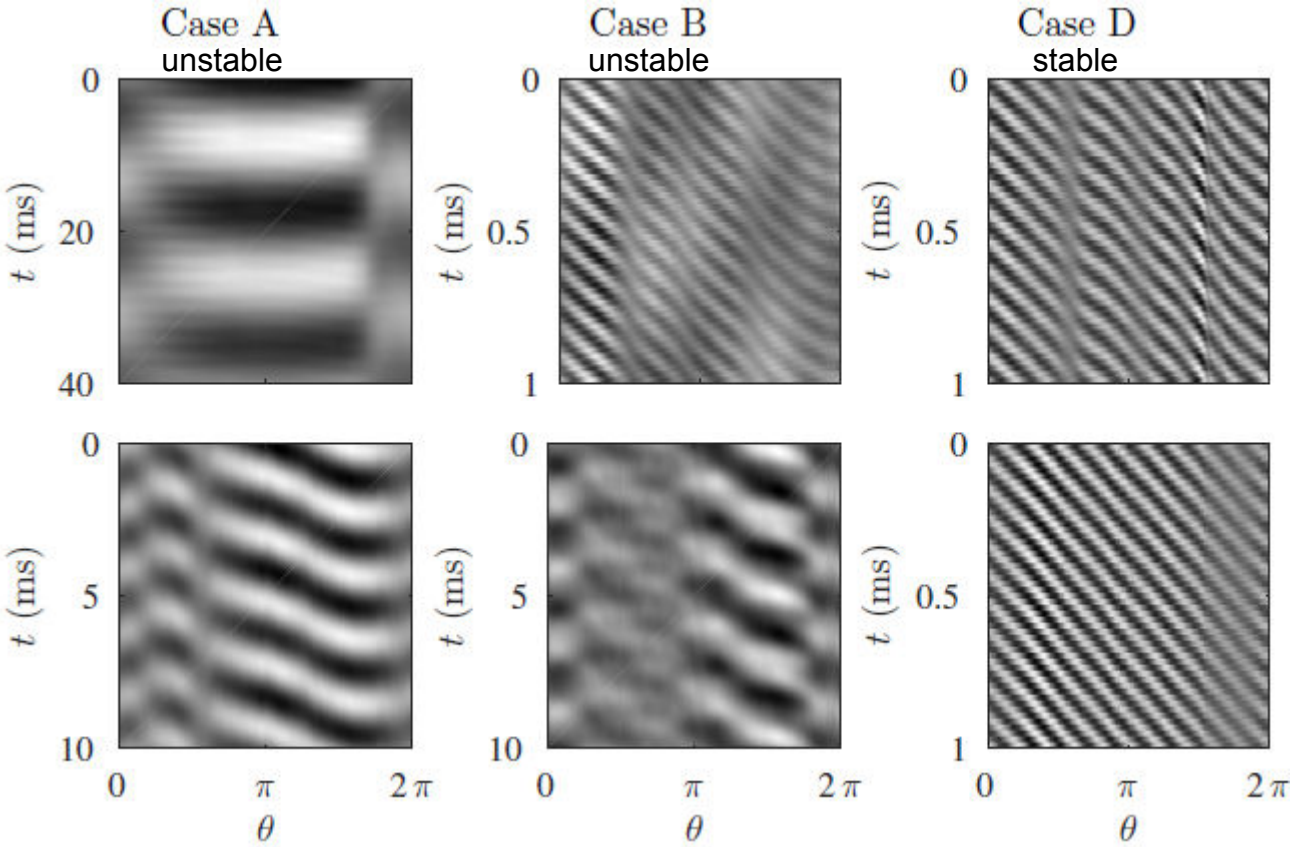


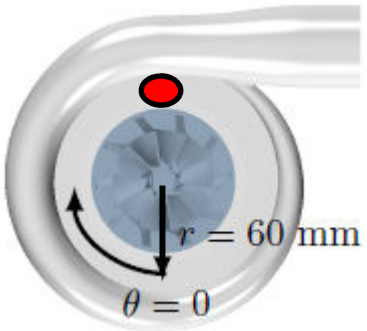

$$R(r_i, \Delta t) = \frac{< u'(x_i, t)u'(x_i + r_i, t + \Delta t) >}{\sqrt{(u'^2(x_i, t)}\sqrt{(u'\text{^}2(x_i + r_i, t + \Delta t)}}$$




Wave speed = 340 m/s (reference point z = -0.2)
Waves propagate upstream (positive slope)
Longer wave length/period disturbances for unstable conditions

# Diffuser cross correlation based on pressure and tangential velocity



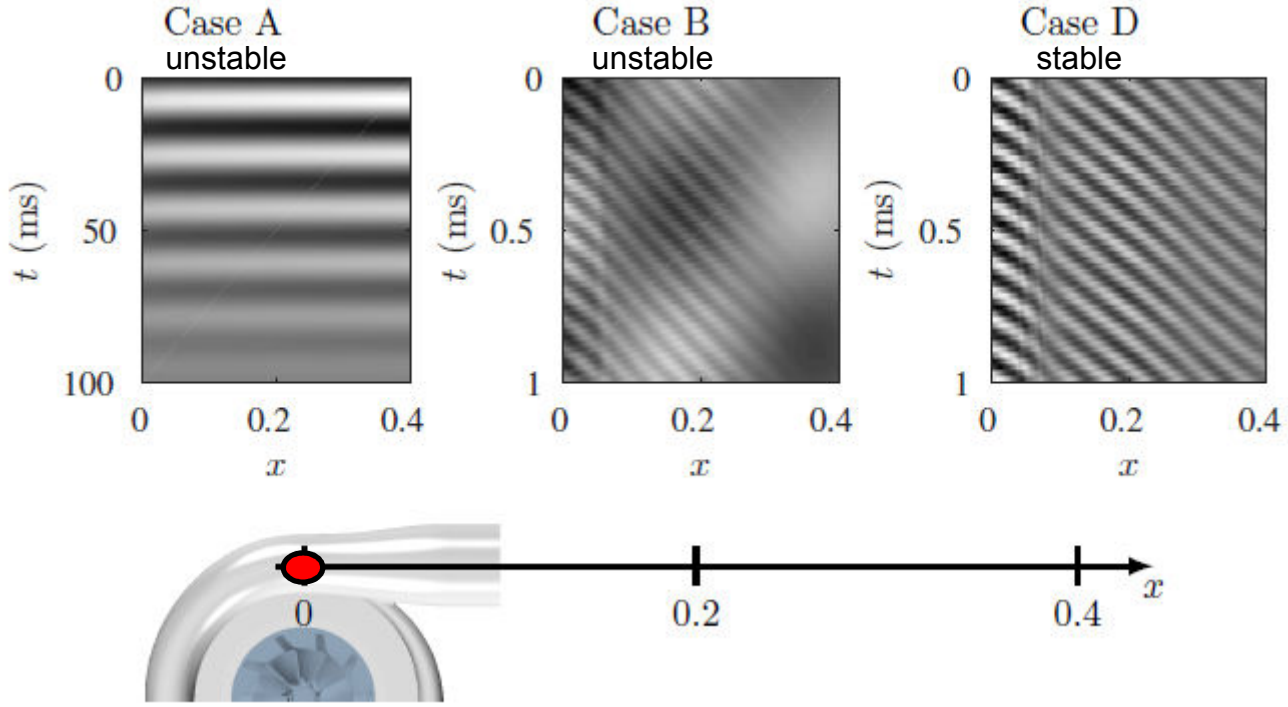




pressure

Tangential velocity

Wave speed = 380 m/s for stable Case D (reference point Φ = π)
Rotating stall slope for unstable Case B (speed 50 m/s)
Standing wave for unstable Case A (Surge condition)

# Outlet cross correlation based on pressure




Wave speed = 380 m/s (reference point x = 0)
Longer wave length/period emerge for unstable Case B
Standing wave for unstable Case A (surge condition)

# Summary & outlook

- Low-frequency narrowband features emerge at unstable conditions
  - Identified as rotating stall and surge
- Amplified fluctuation level regions
  - Rotating stall: circulating vortical structures inducer/diffuser
  - Surge: limit cycle with complete flow reversal
- Two-point cross correlation
  - Disturbances propagate upstream at sound speed
  - Diffuser rotating stall depends on clockwise orientation
  - Emerging standing wave for unstable conditions (surge)

Outlook

- Cross correlation for longer time range for unstable conditions

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