UNIVERSITY OF CAMBRIDGE

Whittle Laboratory

Stall Warning in Aero-Engine Compressors

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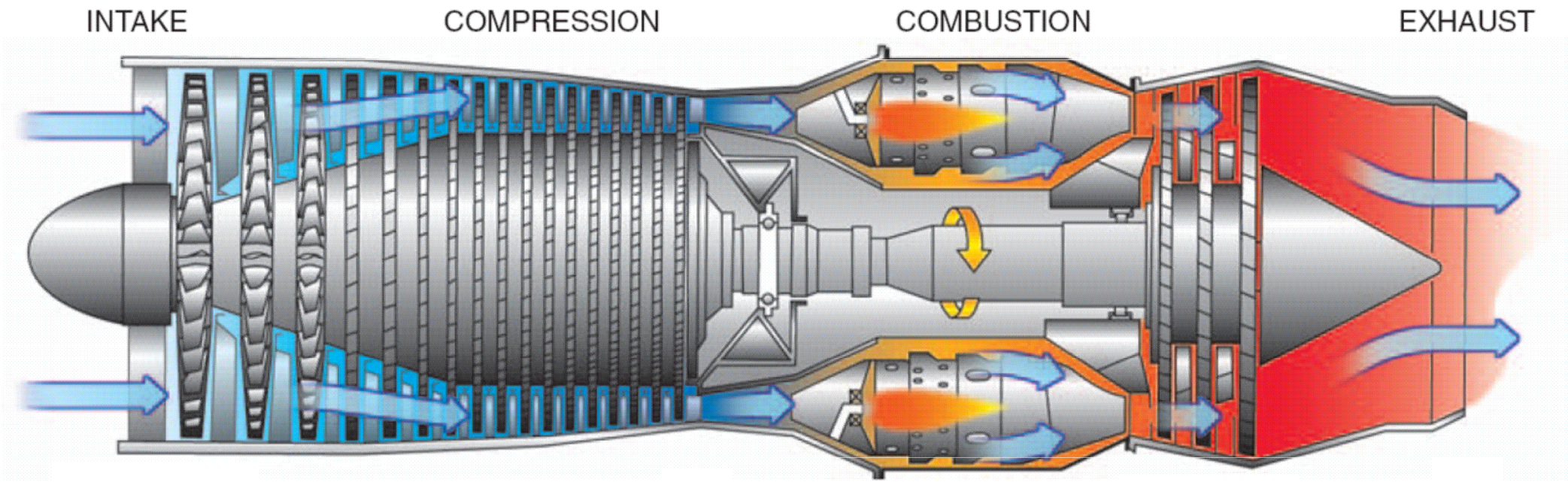
EPSRC Engineering and Physical Sciences Research Council

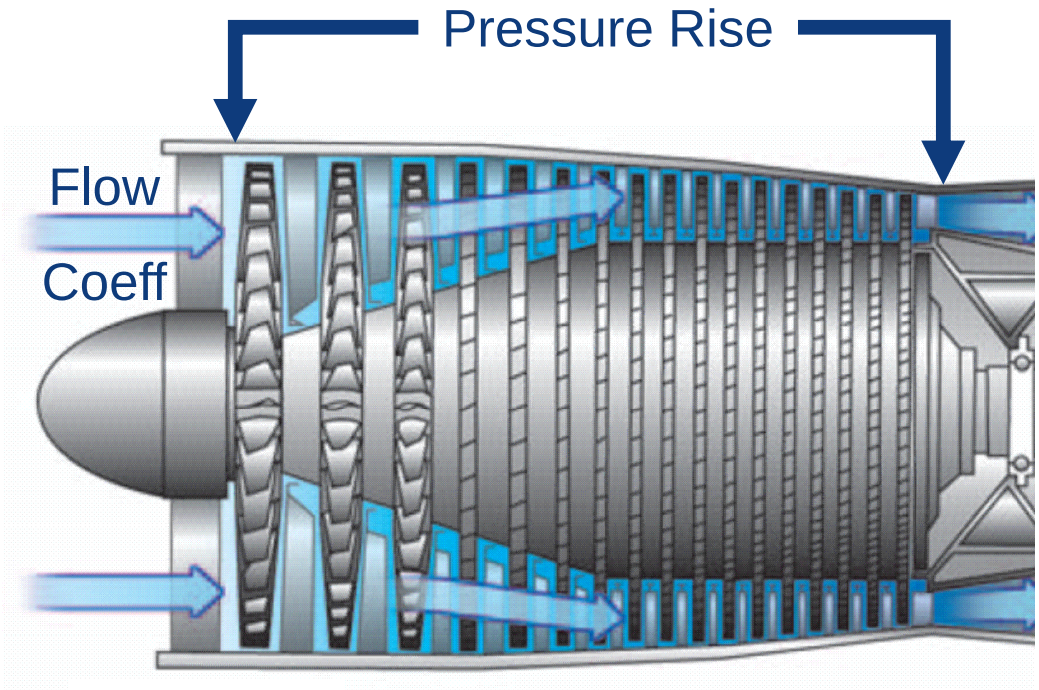
Why do we care if the compressor stalls?

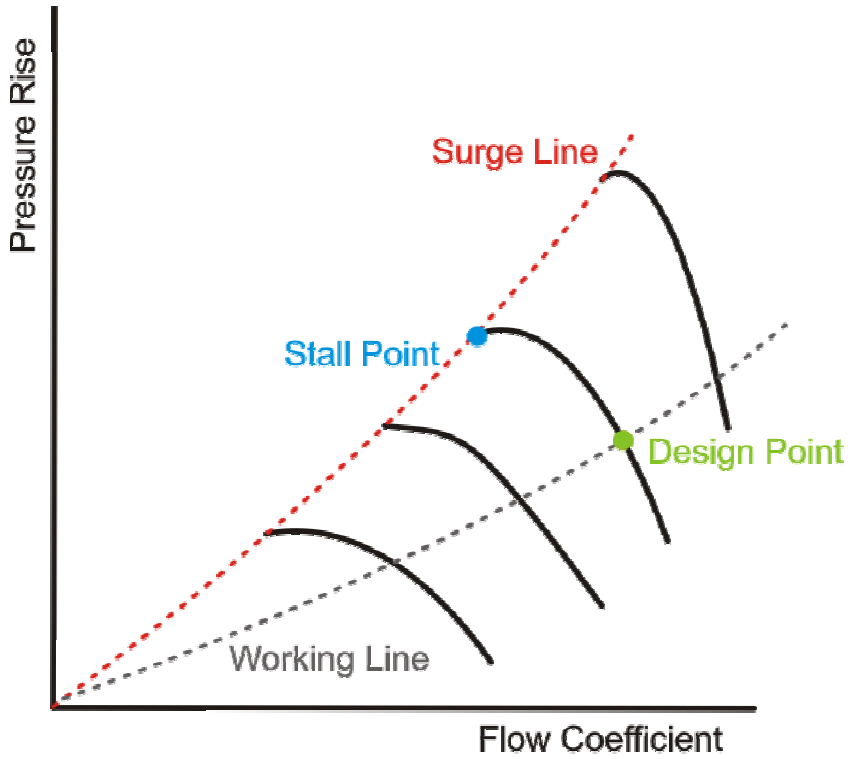
Why do we care if the compressor stalls?

What is Stall?

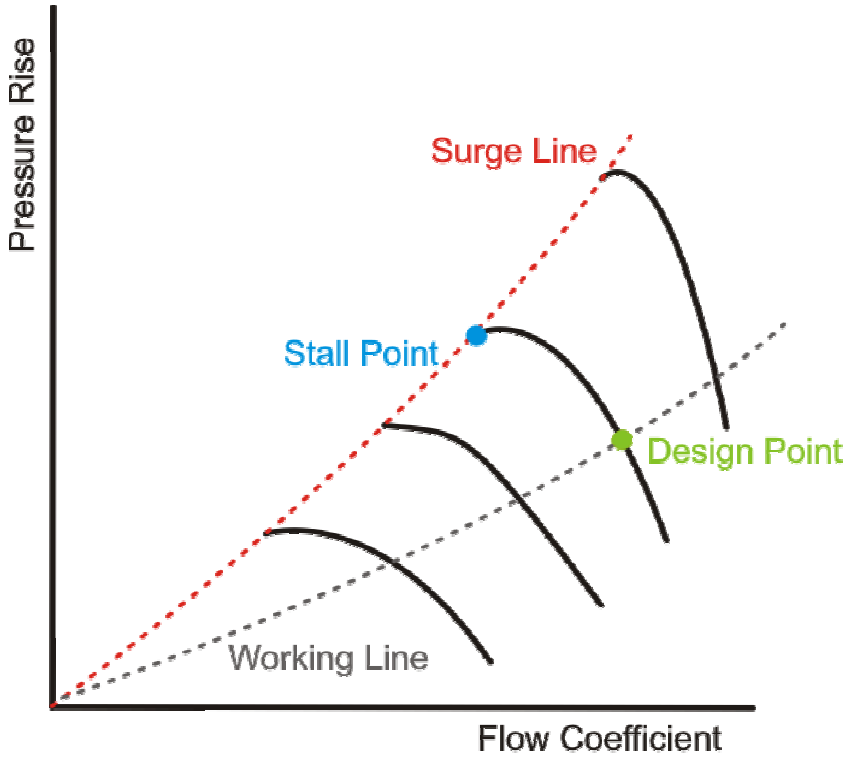


Compressor Performance Characteristic





Is There Any Warning Before Stall?



- **Is there an easy-to-measure parameter that can give stall warning?**

Blade Passing Signature

- Pressure fluctuations due to passing blades.
- Previous work suggests that the irregularity (non-repeatability) of blade passing signature increases near stall.
- Stall warning based on irregularity demonstrated (Dhingra et al. 2006).

BUT:

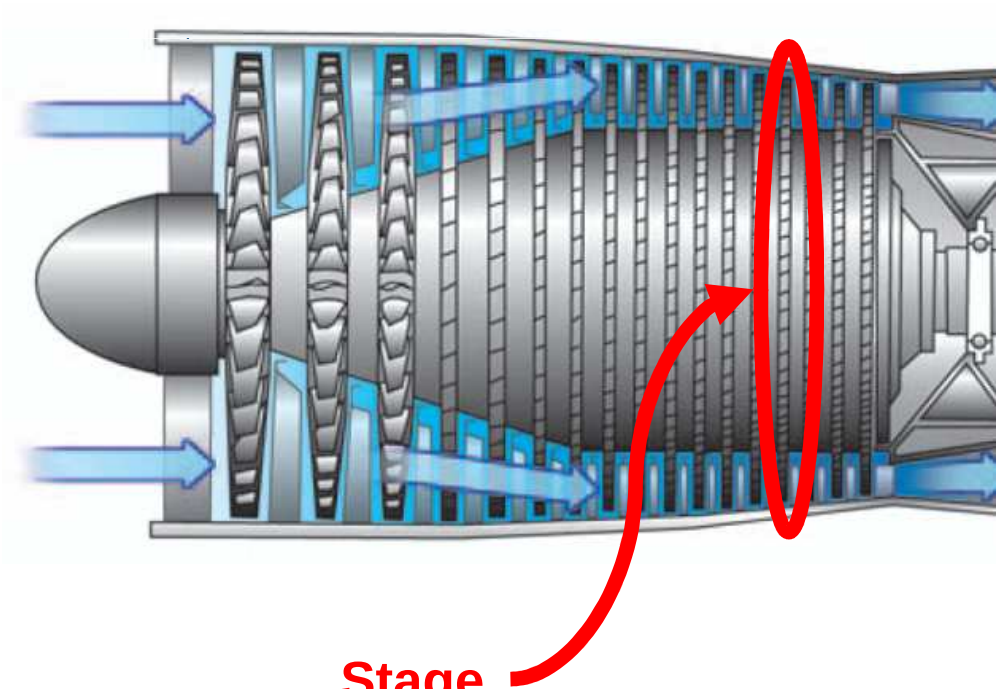
- In some cases, no correlation between irregularity and stall proximity is found (Gannon et al. 2010).

Aims of Current Work

Two questions:

1. **Under what conditions will a rise in blade passing irregularity occur?**
2. **Is there a physical explanation for the irregularity?**

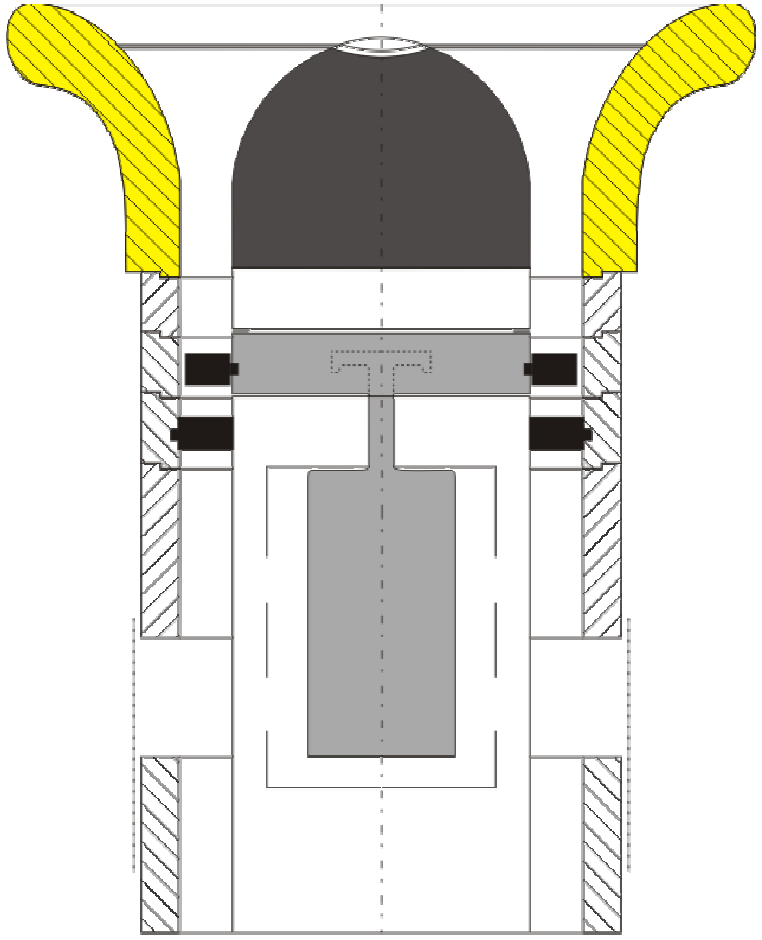
Test Compressor



Test Compressor

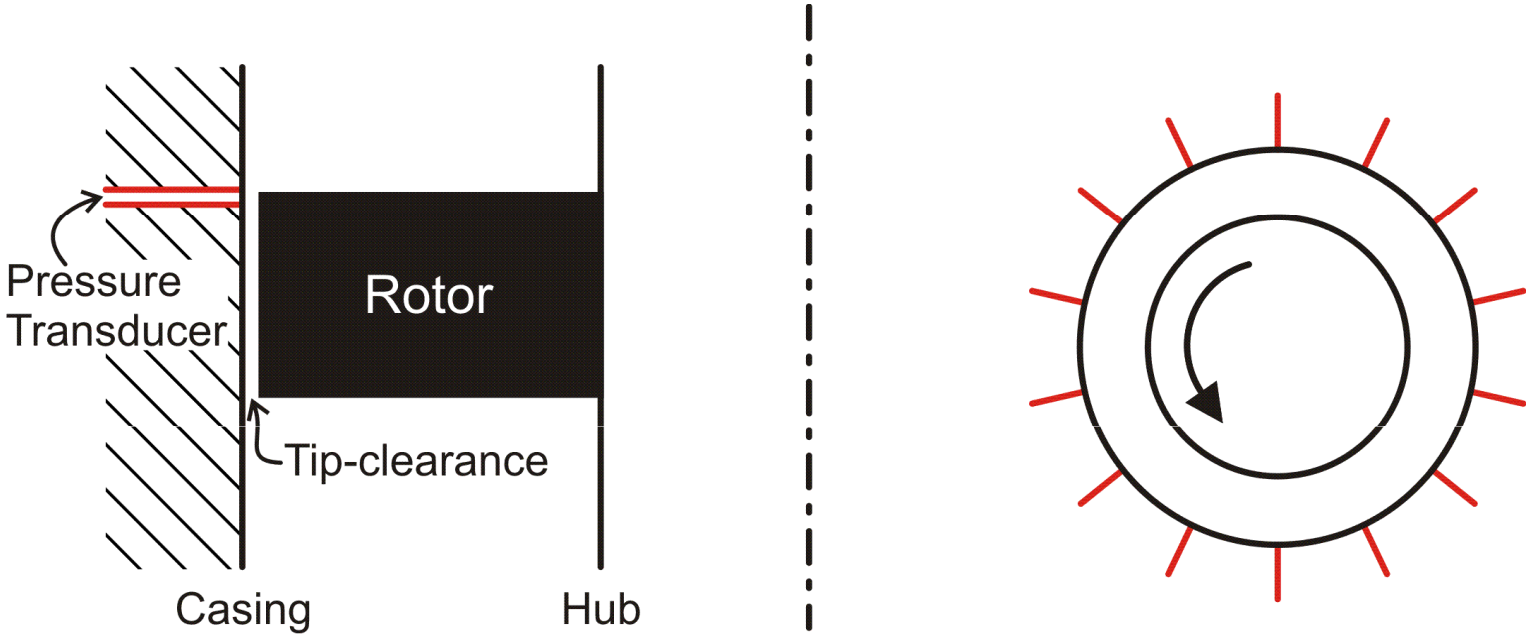
- **Single-stage, low-speed compressor.**

Tip Diameter	**488 mm**
Hub-to-tip ratio	**0.75**
Rotor Blades	**58**
Stator Blades	**56**
Rotor Chord	**36 mm**
Rotational Speed	**3000 rpm**
Rotor Re	**1.7×10^5**



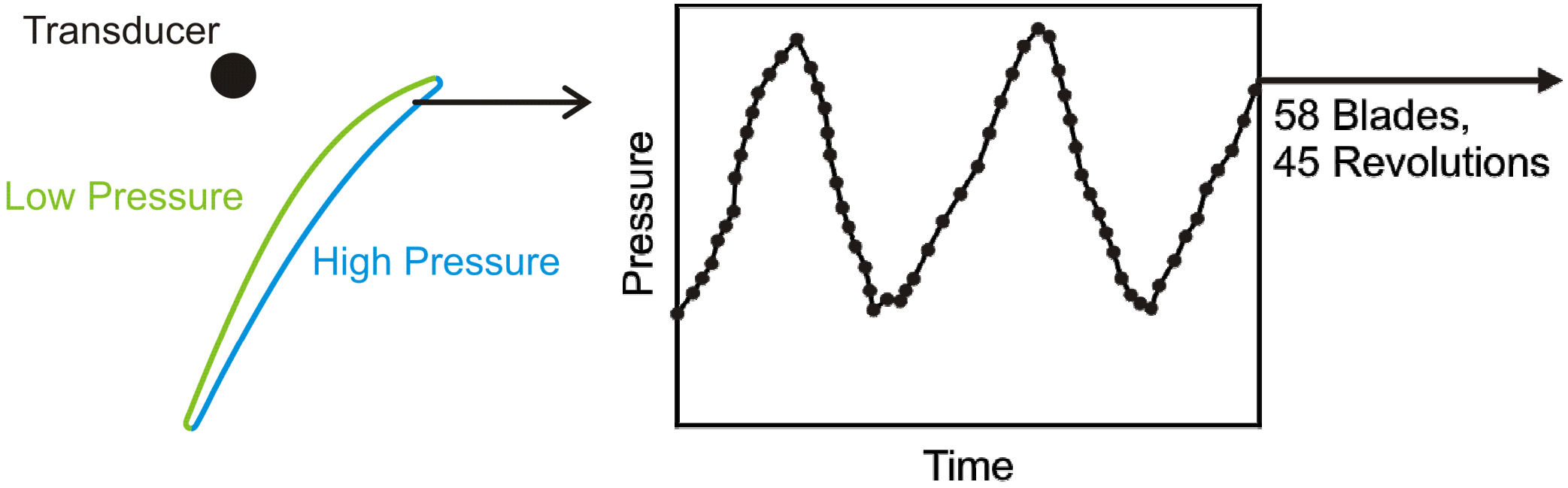
Instrumentation

- **Fast-response pressure transducers to measure blade passing signature.**
- **14 transducers around circumference.**



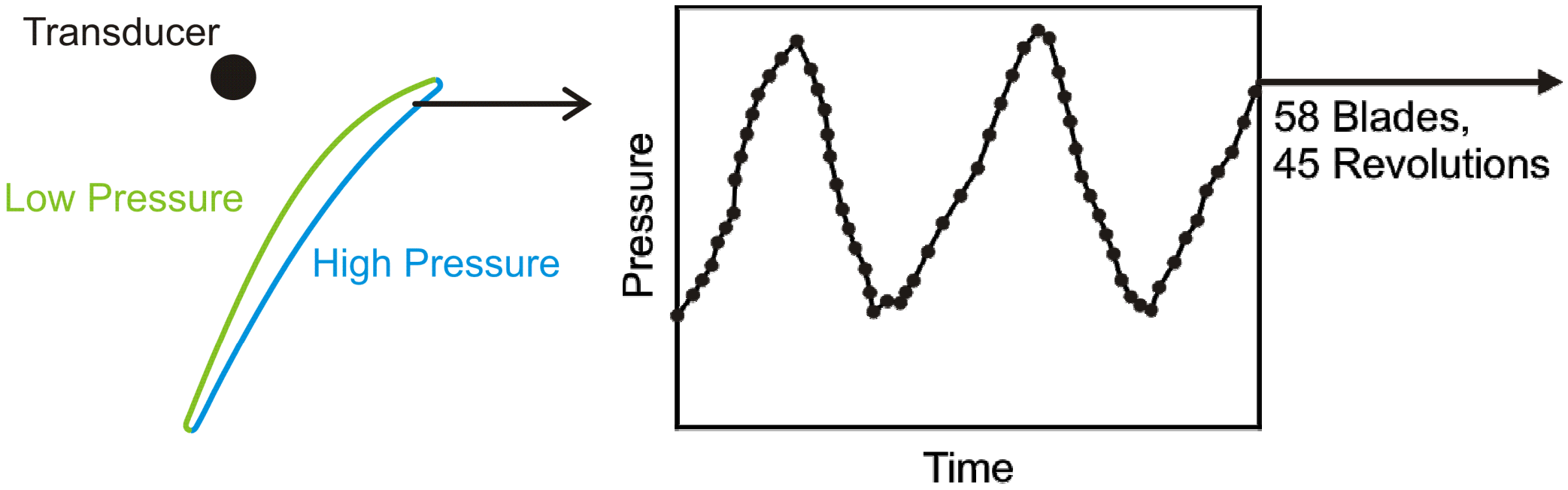
Data Acquisition

- **Pressure difference across blades causes saw-tooth pattern.**



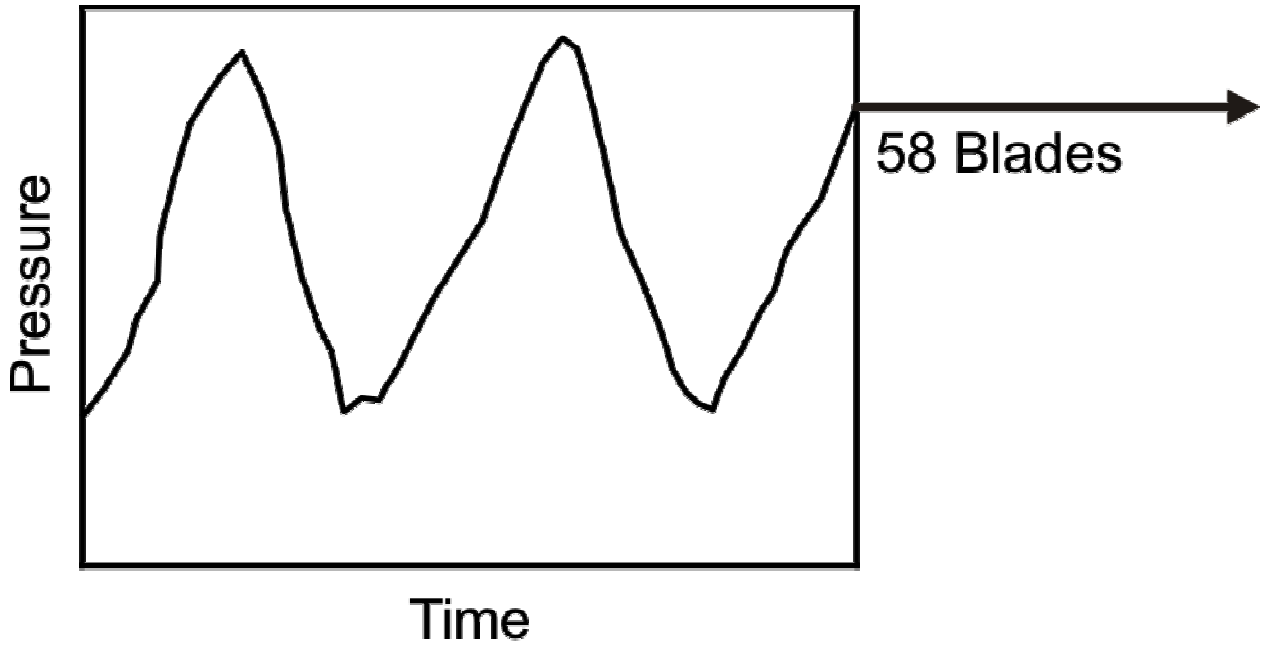
Data Acquisition

- **45 revolutions recorded at *fixed* flow coefficient.**



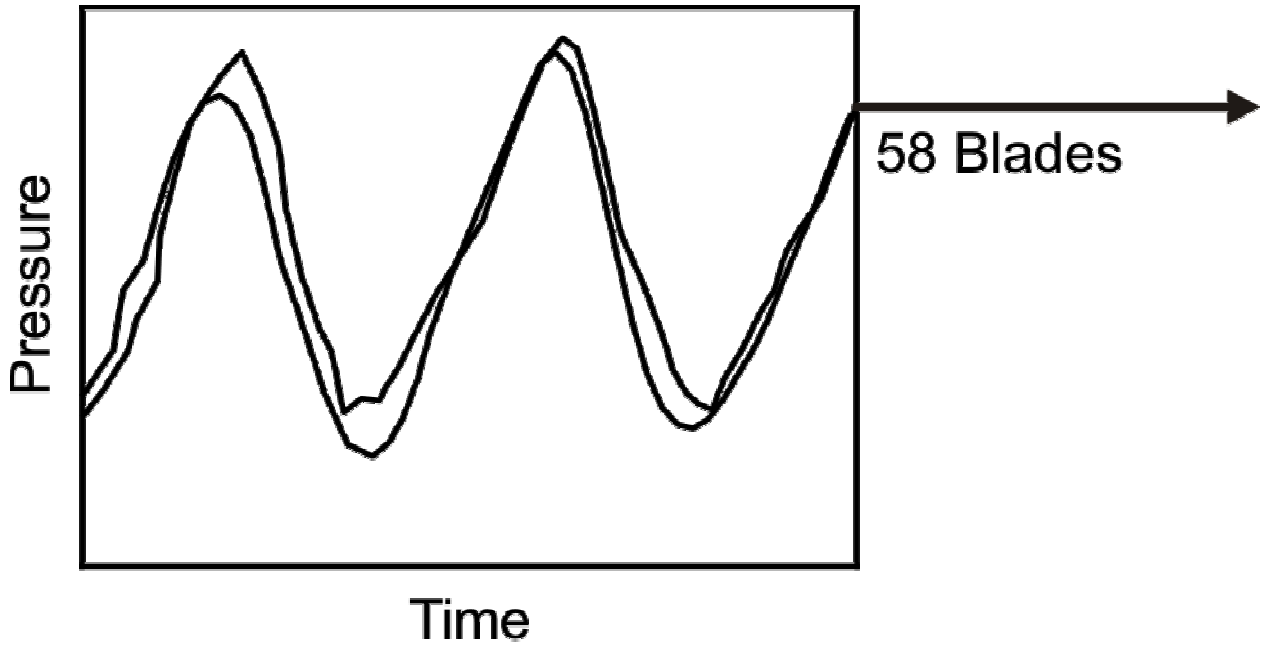
Data Analysis - 1

- **How different will the signal from the next revolution be?**



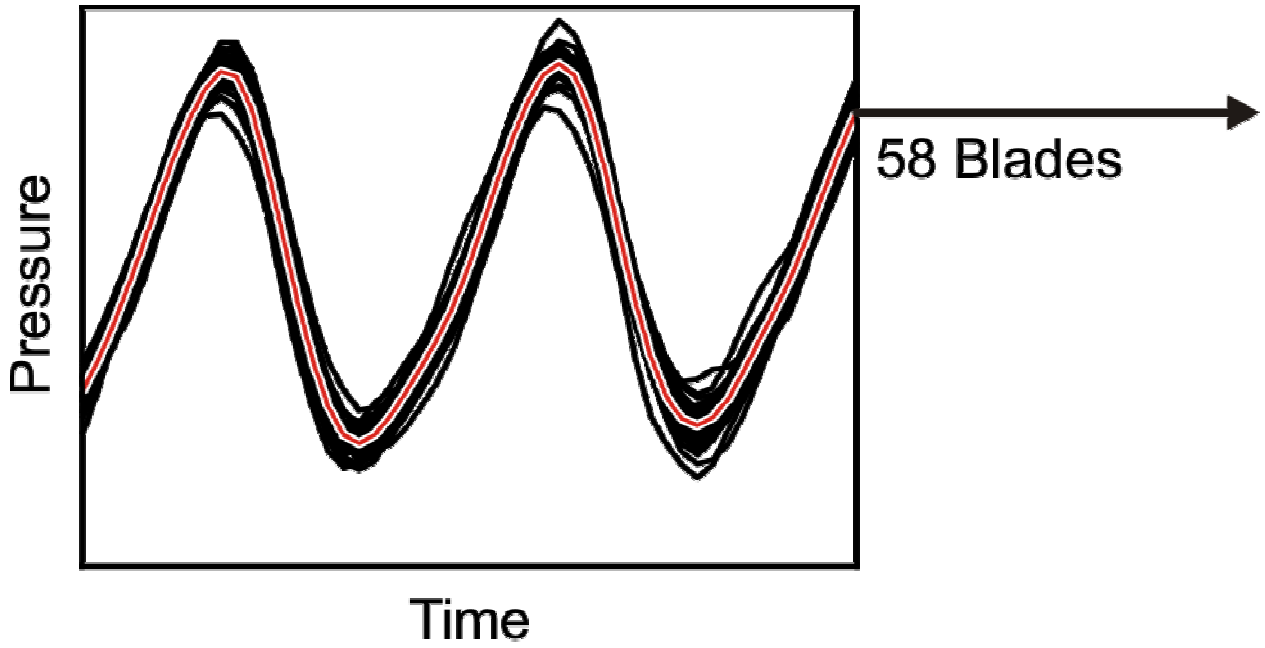
Data Analysis - 2

Data from first and second revolution.



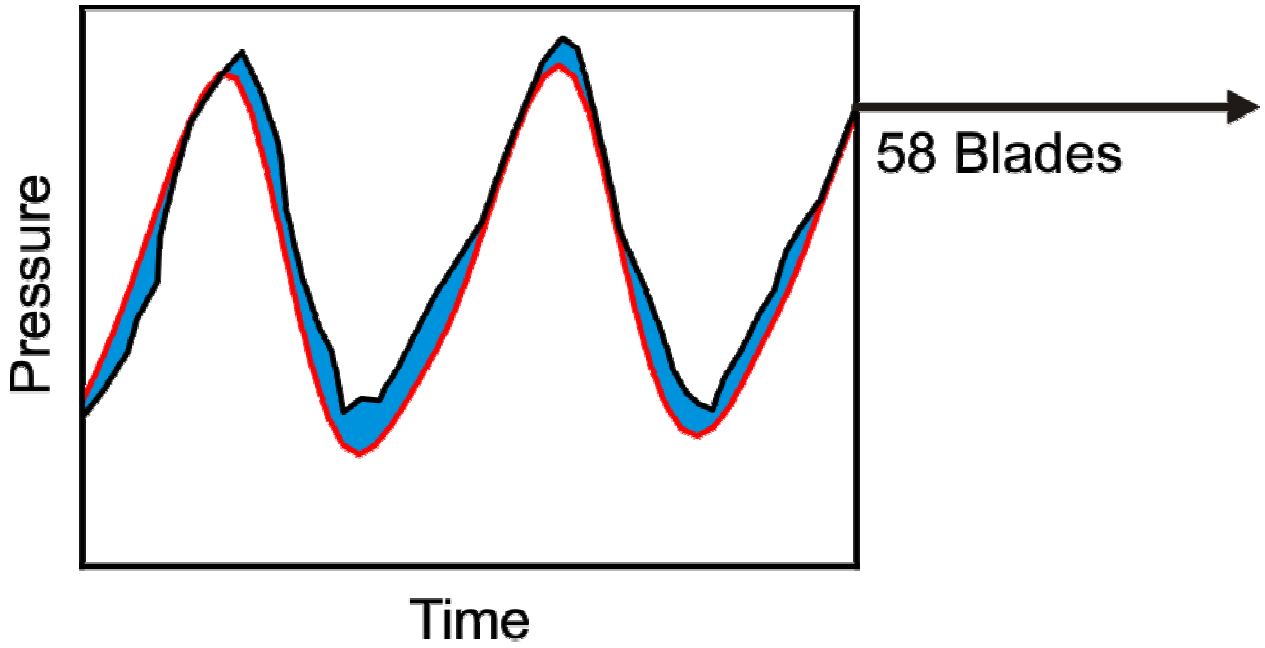
Data Analysis - 3

Data from all 45 revolutions – Average shown in red.



Data Analysis - 4

Difference between average trace and individual trace.



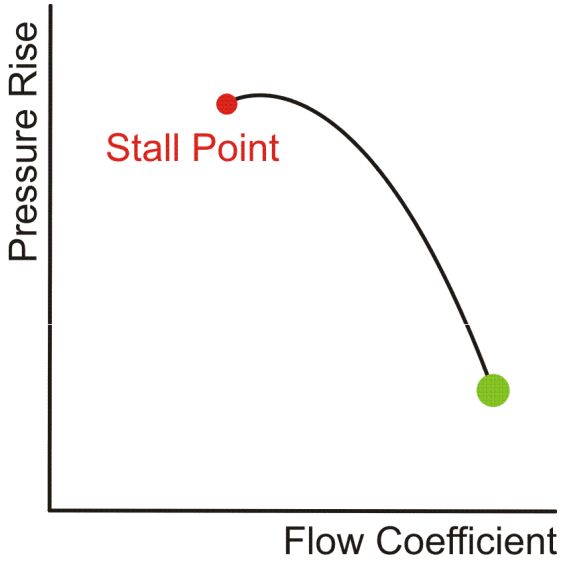
Quantify difference (RMS)

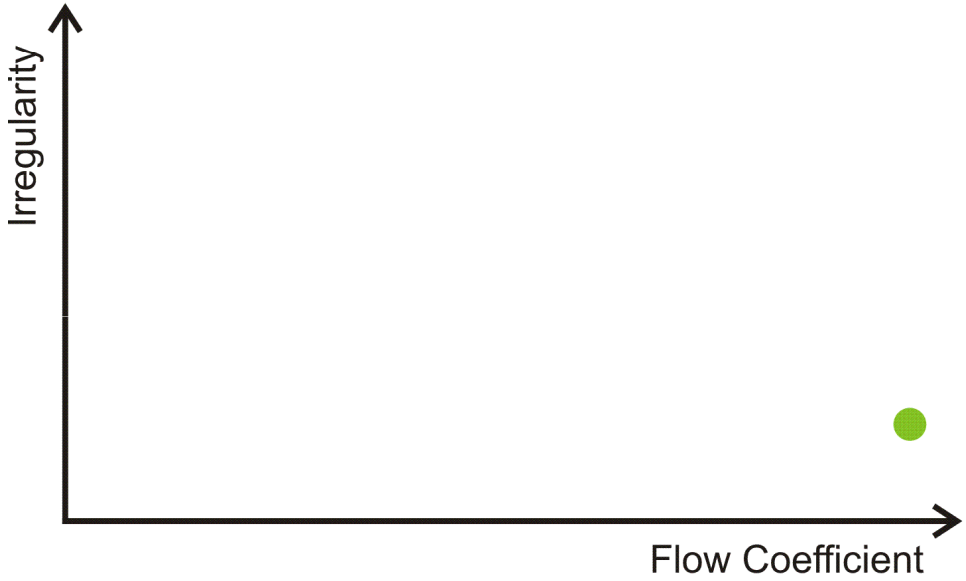
Data Analysis - 5

- RMS for each revolution – 45 values.
- Find mean of 45 values.
- Result: A single value for irregularity at a particular flow coefficient.

Data Analysis - 6

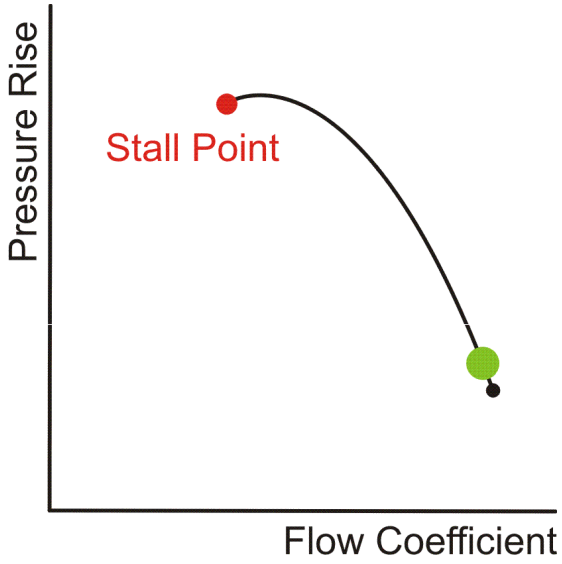
- **Presentation of results:**

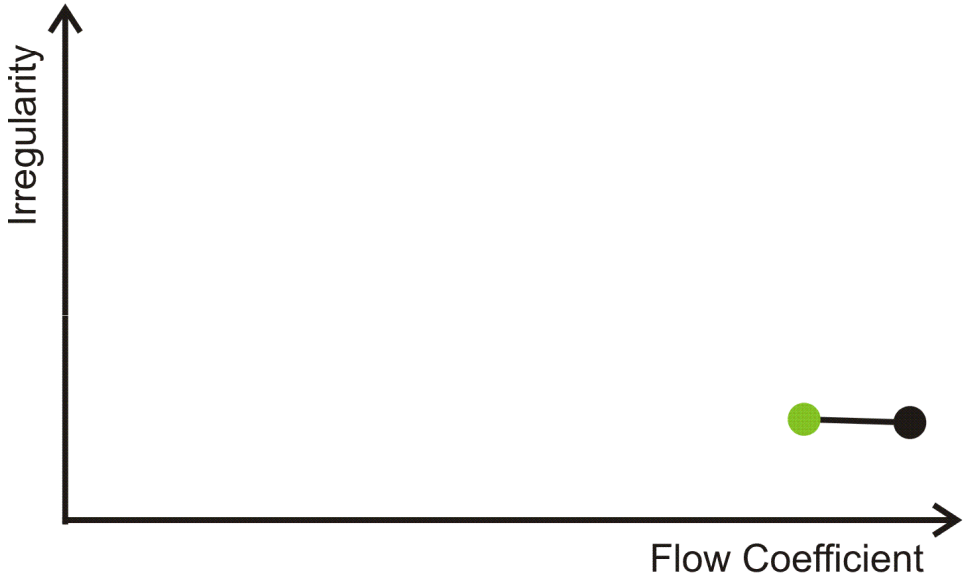




Data Analysis - 6

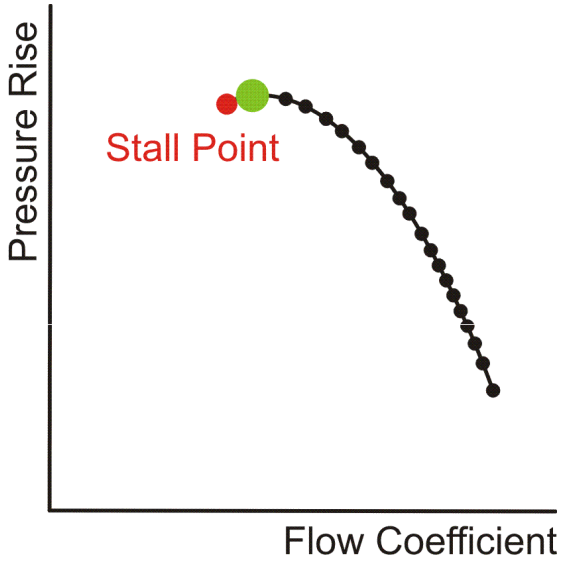
- **Repeat for next flow coefficient.**

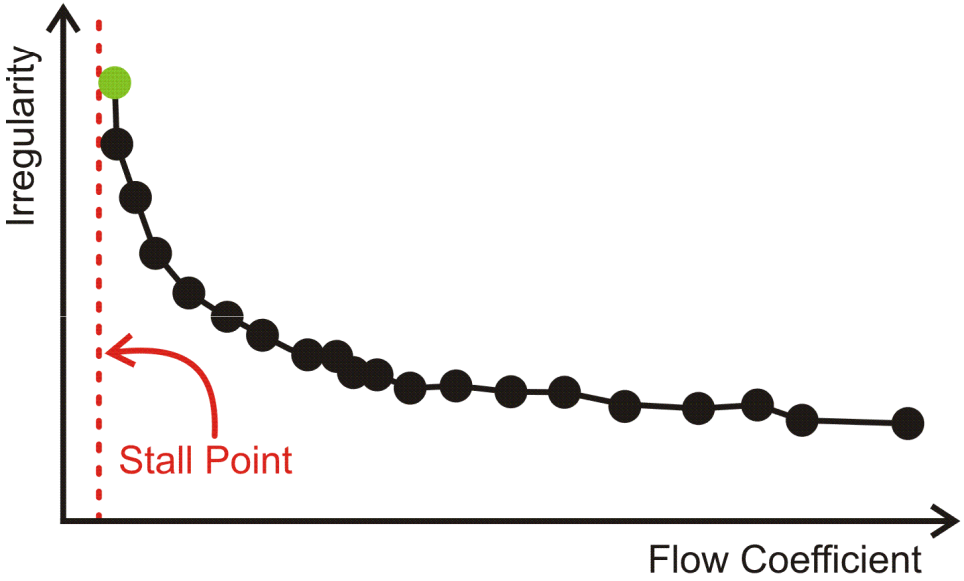




Data Analysis - 6

- **20 flow coefficients across flow range.**





Results – Datum Configuration

- **Uniform tip clearance; 1.7% chord.**

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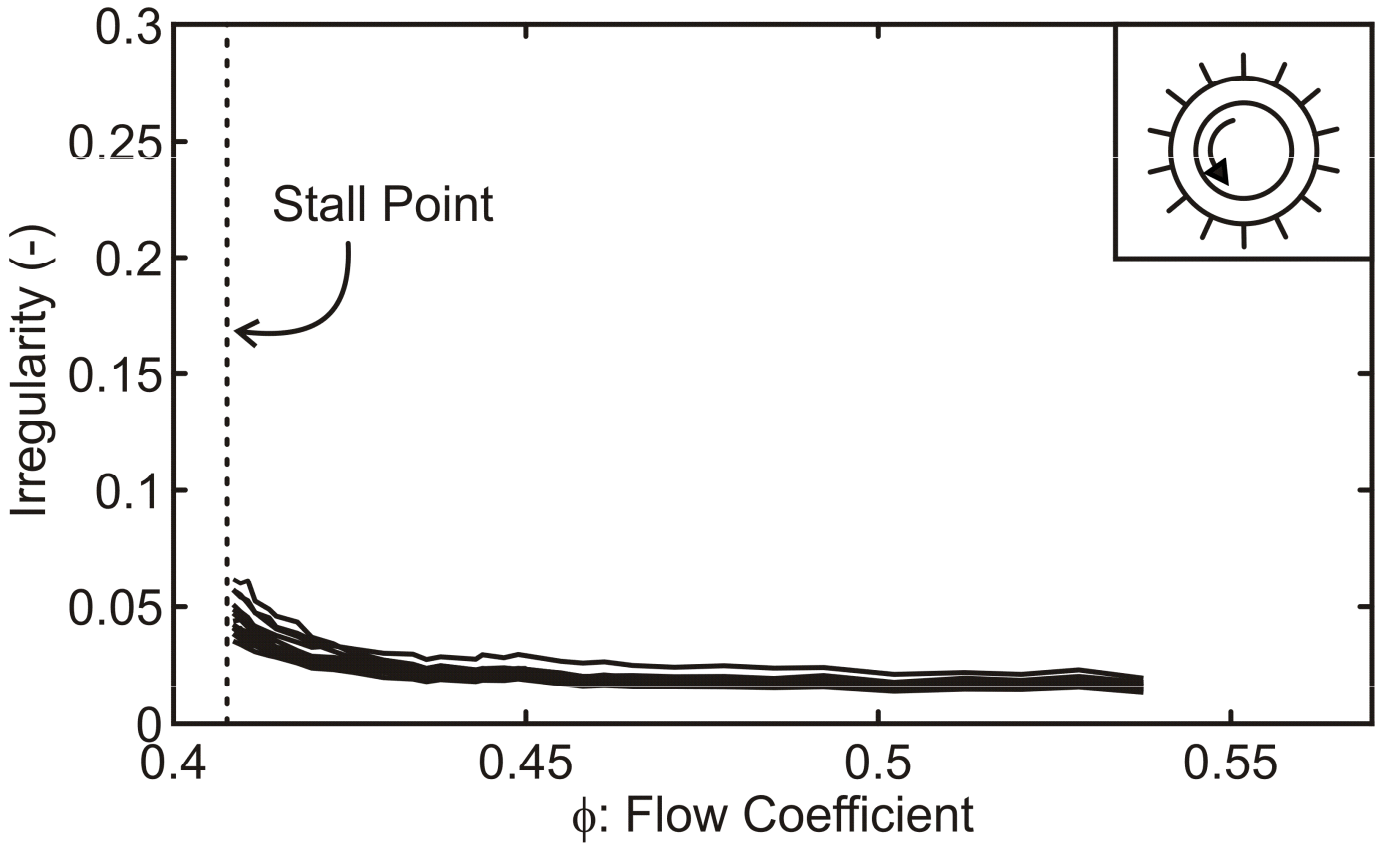
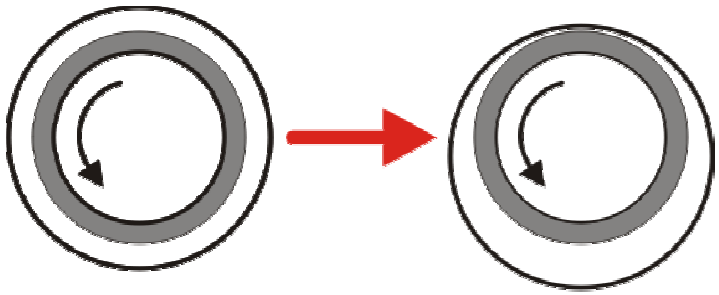
- **Uniform tip-clearance; 1.7% chord.**



- **Small ramp-up in irregularity near stall.**

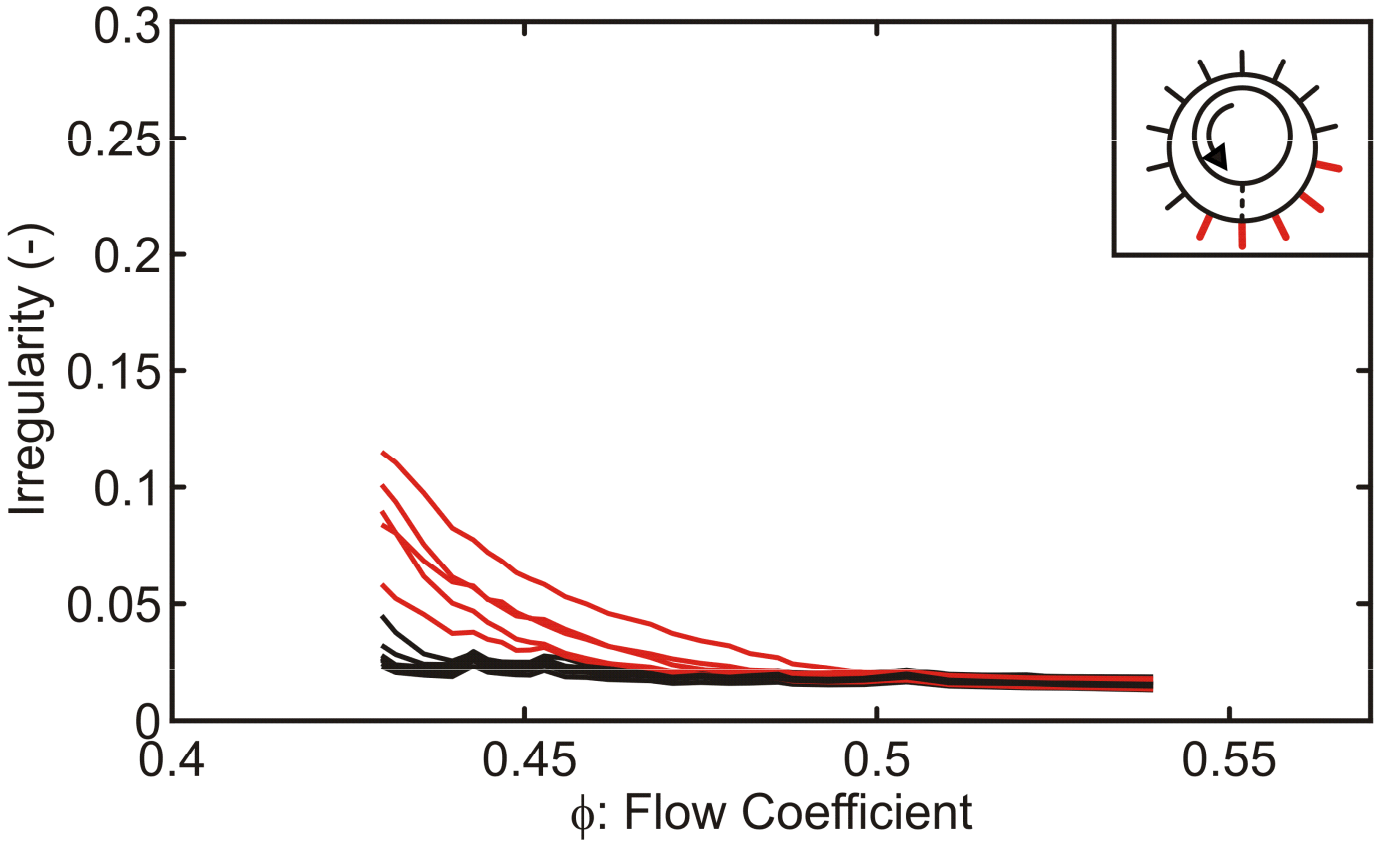
Results – Eccentric Tip-clearance

- Real compressors do not always have concentric tip-clearance
- Eccentric tip-clearance makes compressors stall early.
- Tests repeated with eccentric clearance.



Results – Eccentric Tip-clearance

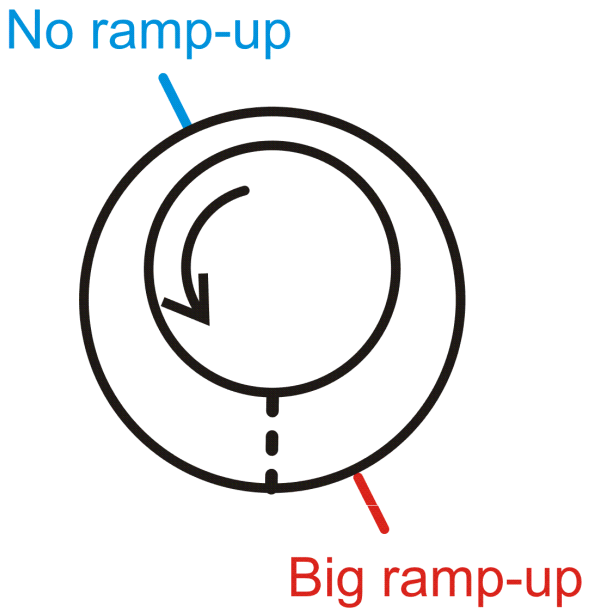
- **Clearance 1.7% chord, 75% eccentricity:**



- **Some pressure transducers give pre-stall ramp-up, others do not.**
- **Ramp-up occurs in large tip-clearance region only.**

Results – Eccentric Tip-clearance

- **Contradictions in literature can now be explained.**
- **Moving pressure transducer completely changes the conclusion!**



Question

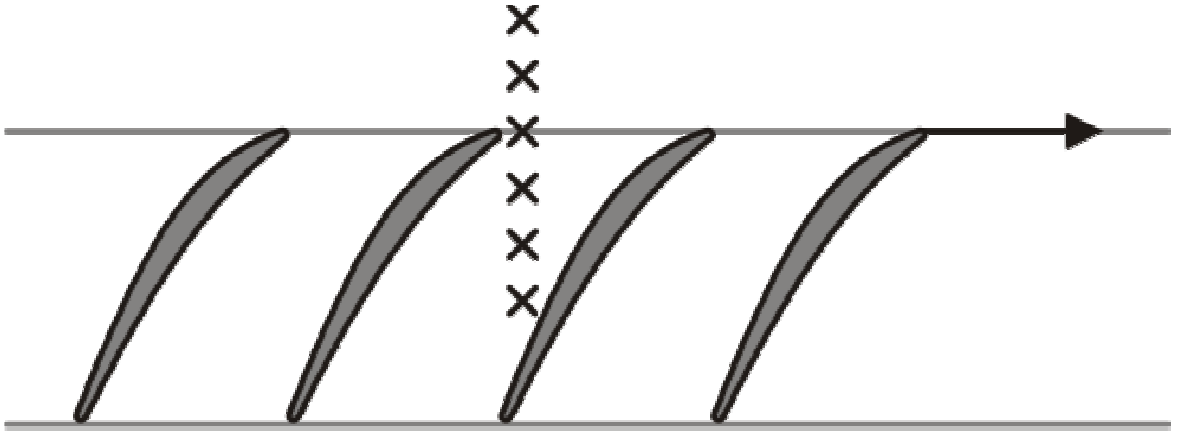
What causes the rise in irregularity:

- **Random turbulent fluctuations?**
- **Coherent structures?**

What causes the rise in irregularity?

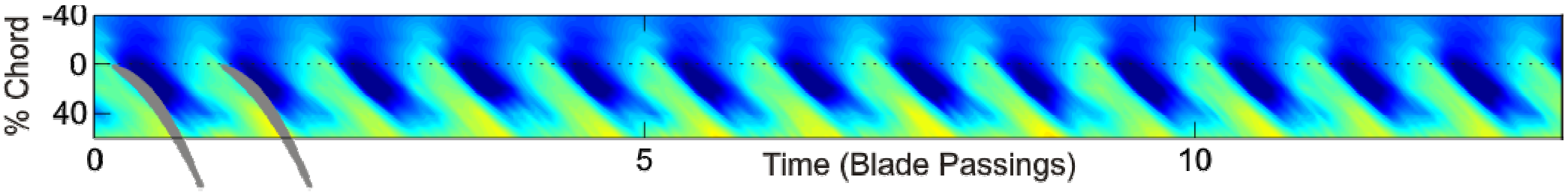
TEST SET-UP:

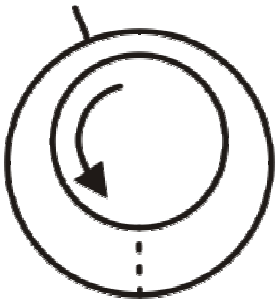
- **6 pressure transducers fitted to rotor casing.**

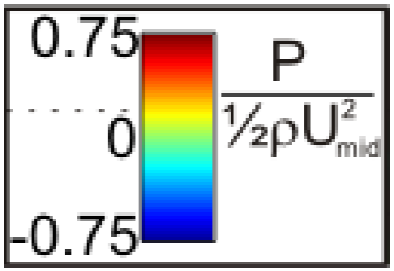


Unsteady Casing Pressure

Casing static pressure contours:

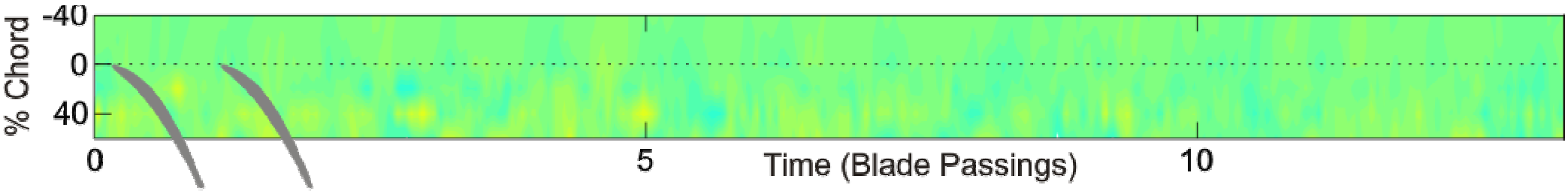


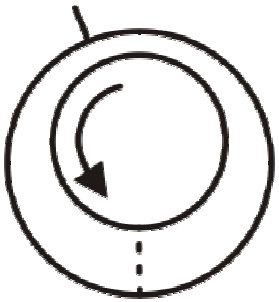


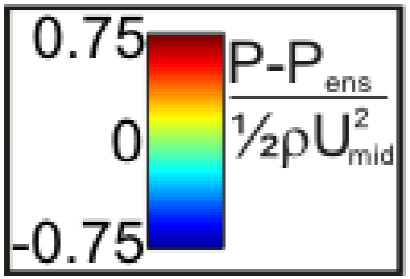


Irregularities in Casing Pressure

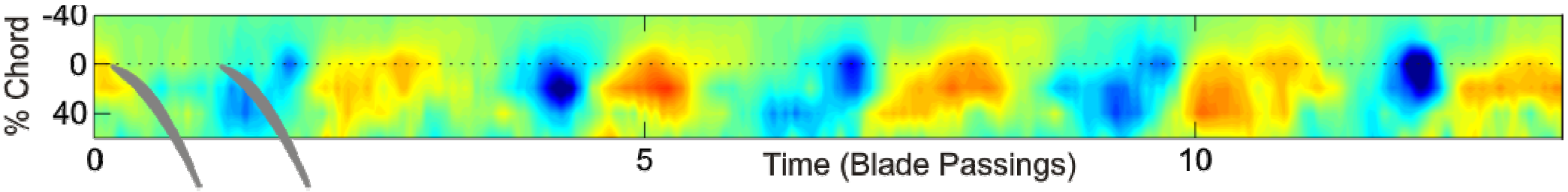
Ensemble-average subtracted:

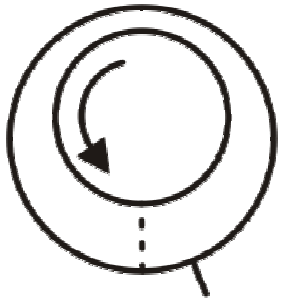


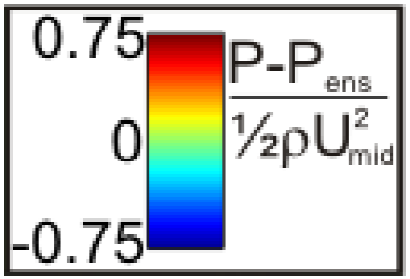




Irregularities in Casing Pressure







Blue Holes – Something New!

- Disturbances suggested in the literature, but not clearly identified. (Mailach et al. 2001, Inoue et al. 2001).
- Link between pre-stall disturbances and blade passing irregularity not previously made.
- Blue holes seen in new Whittle Laboratory CFD. Watch this space!

Conclusions

1. **A rise in irregularity can usually be detected as stall is approached.**

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2. **Irregularity depends on tip-clearance eccentricity:**
   - **Concentric clearance: Small, uniform ramp-up.**
   - **Eccentric clearance: Large ramp-up, but only in large tip-clearance.**
   - **Explains contradictions in literature.**

Conclusions

1. A rise in irregularity can usually be detected as stall is approached.

2. Irregularity depends on tip-clearance eccentricity:
   - Concentric clearance: Small, uniform ramp-up.
   - Eccentric clearance: Large ramp-up, but only in large tip-clearance.
   - Explains contradictions in literature.

3. ‘Blue holes’ (discrete patches of low pressure in the tip region) identified as coherent flow features that cause blade passing irregularity.