Study of Oscillating Blades from Stable to Stalled Conditions

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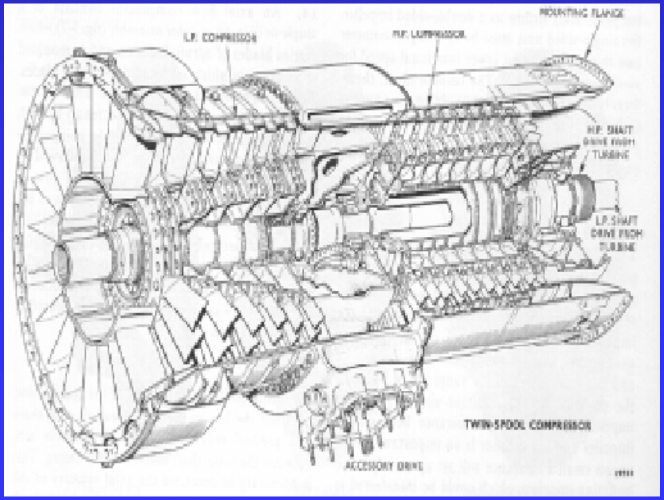
Motivation

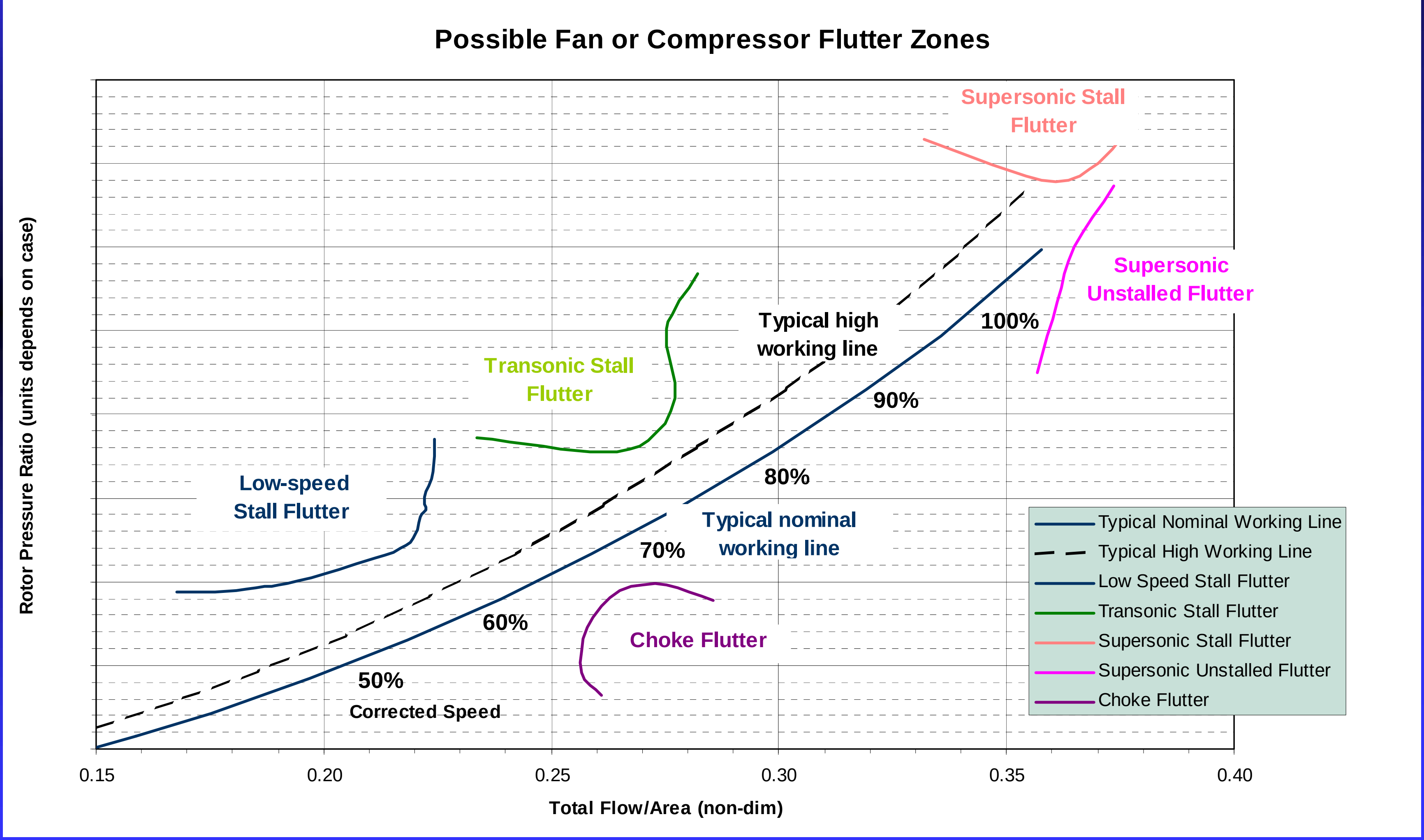
- Turbomachinery blades flutter
- During flutter blades may break
- Implications on the safe operation of the engine



Flutter

- Structural vibration involving bending and twisting
- A result of interactions between aerodynamics, stiffness and inertial forces
- Can be experienced on all flexible structures

Engine Working Line



Objectives

- Study a simple peculiar case of flutter
- Use CFD to assess the quality of experimental data
- Shed some light in the argument raised about this particular flutter case

Background

- Three key publications on the subject
  - (1) Parametric Study of the Pressure Stability of an Oscillating Airfoil from Stable to Stalled Flow Conditions (S. Svensdotter, U. Johansson, T. Fransson)
  - (2) Boundary-Layer Transition, Separation and Reattachment on an Oscillating Airfoil (T. Lee, G. Petrakis)
  - (3) An Experiment on Unsteady Flow Over an Oscillating Airfoil (L. He, J.D. Denton)

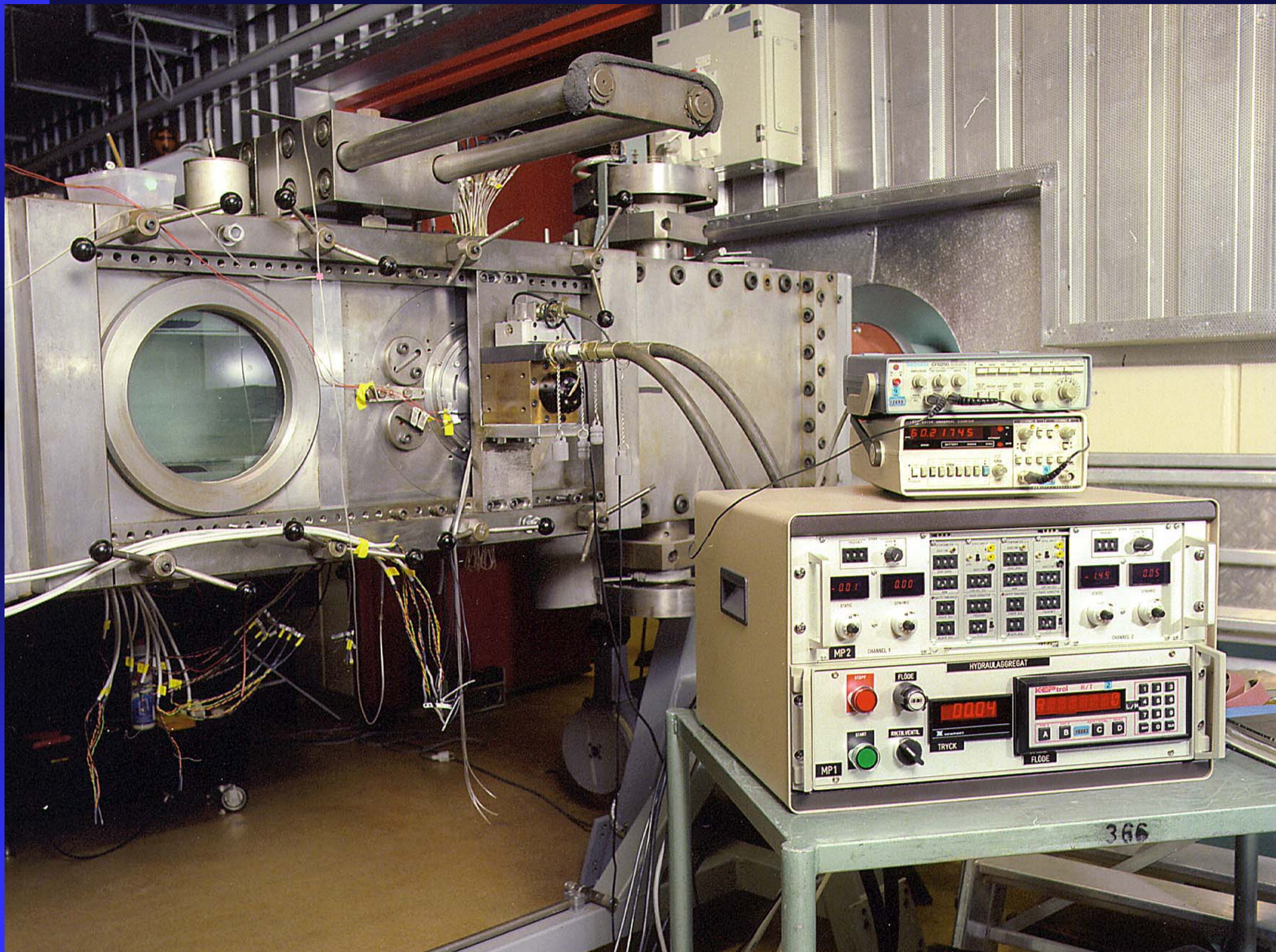
Experimental Method

- Equipment
  - Symmetrical 2D NACA 63A006, chord length 80mm, span 150mm
  - 13 pressure transducers on the suction surface of the blade
  - Pitching axis at 43% chord
  - Performed in a wind tunnel with test section 150mm by 180mm

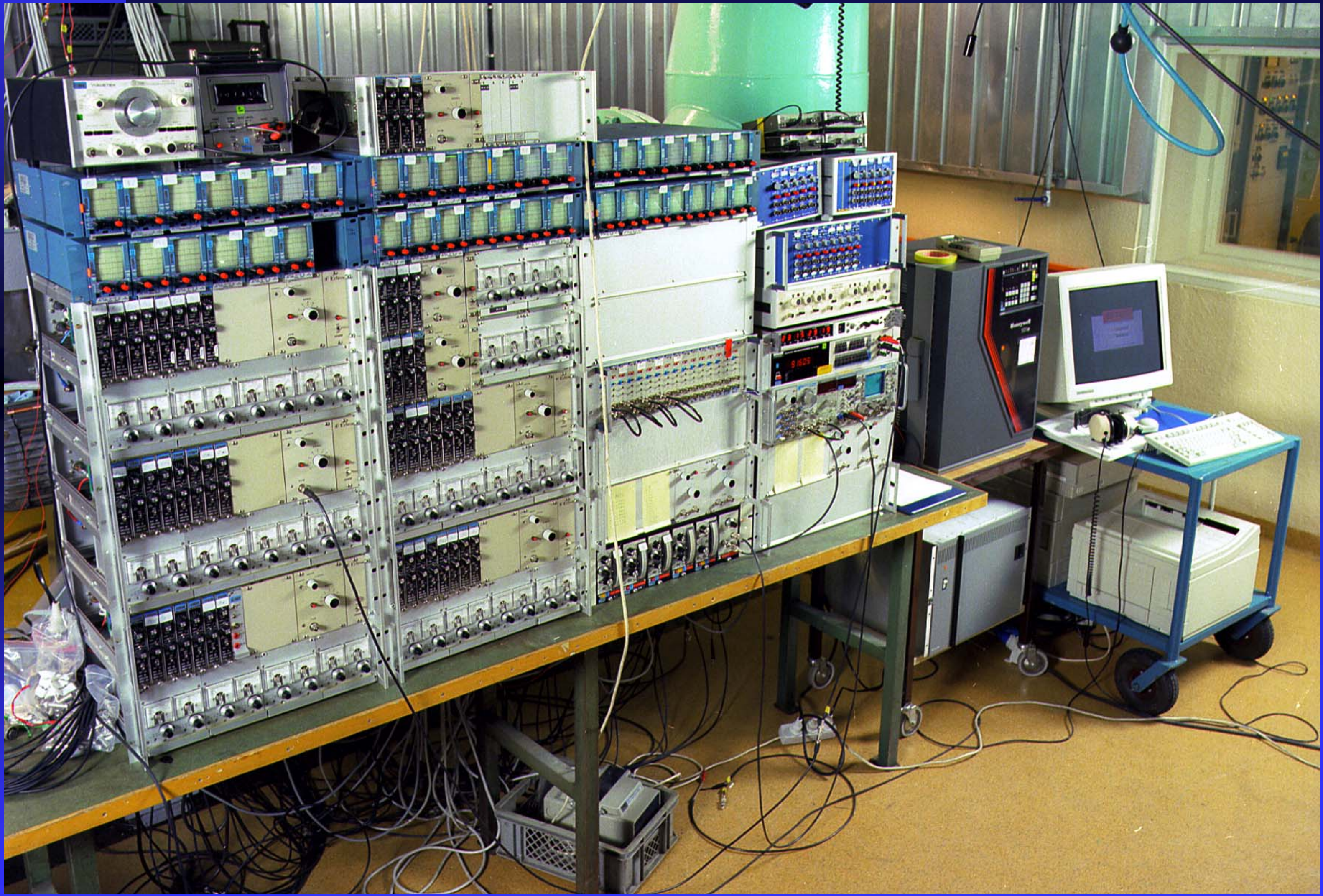
Experimental Method

- Test program and data interpretation
  - High oscillating frequencies (up to 210Hz)
  - Inlet Mach number was 0.5
  - Reynolds number was 850 000
  - Unsteady pressure signals were analysed in terms of amplitude of perturbation and the phase difference between the pressure signal and blade motion

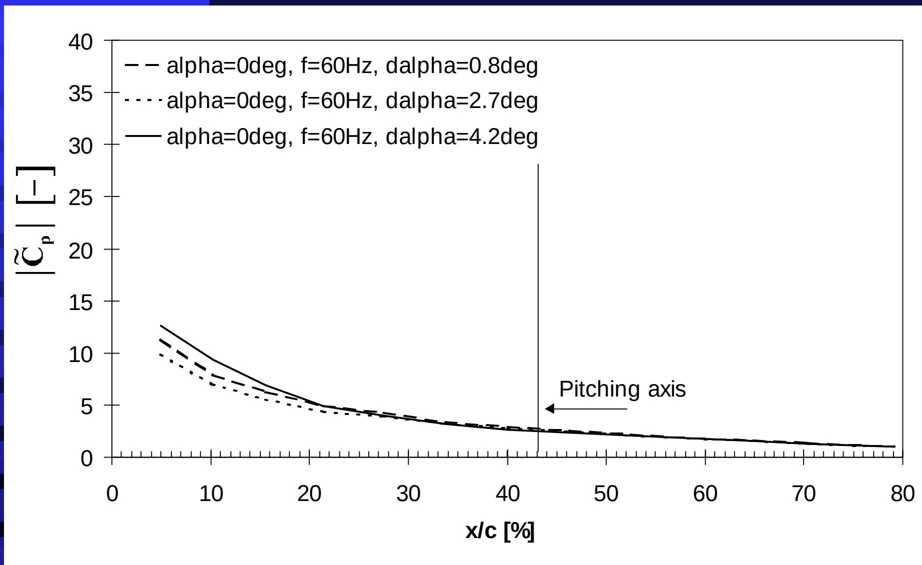
Test rig

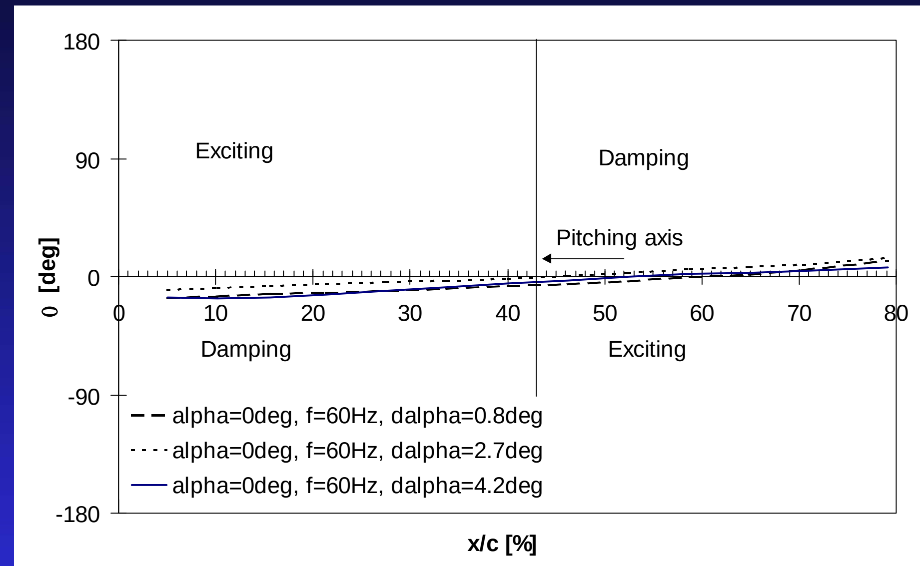


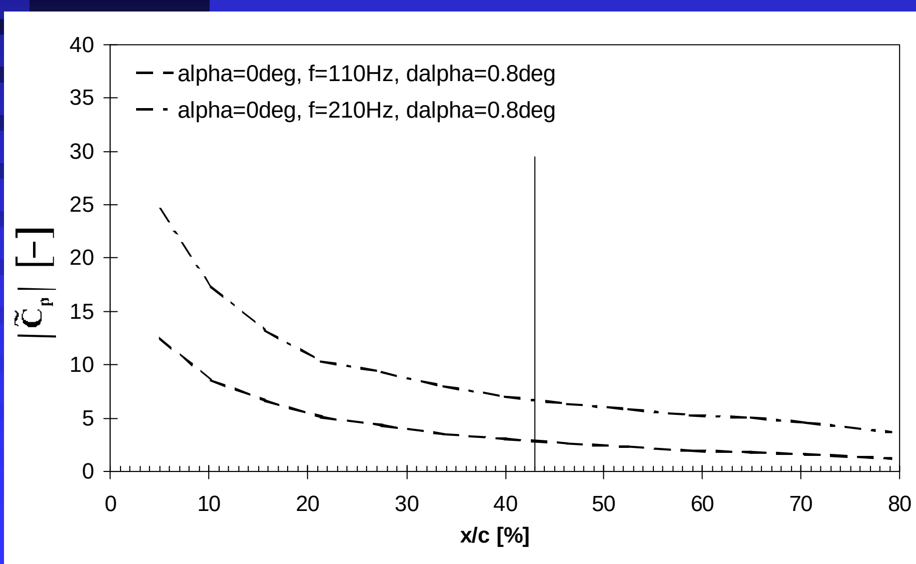
Test equipment

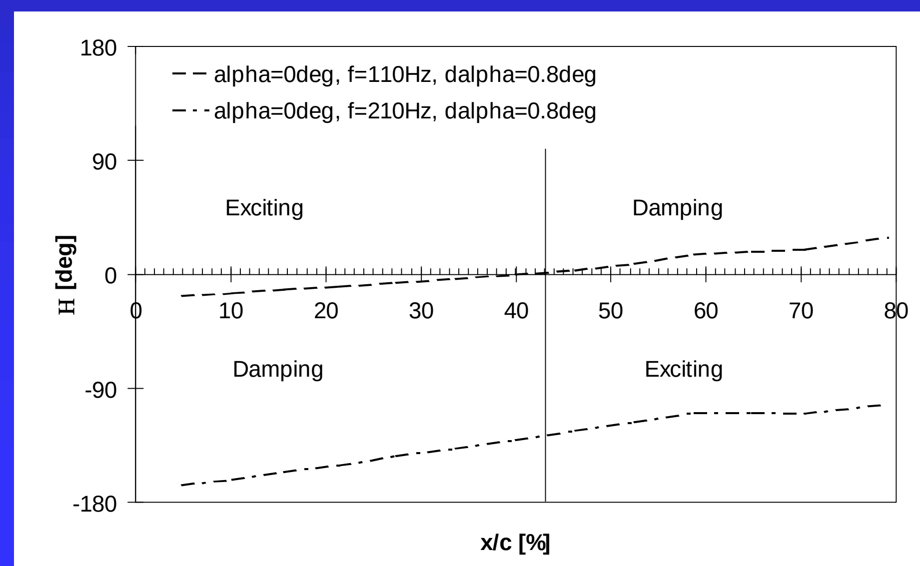


Amplitude and Phase, 0° Incidence

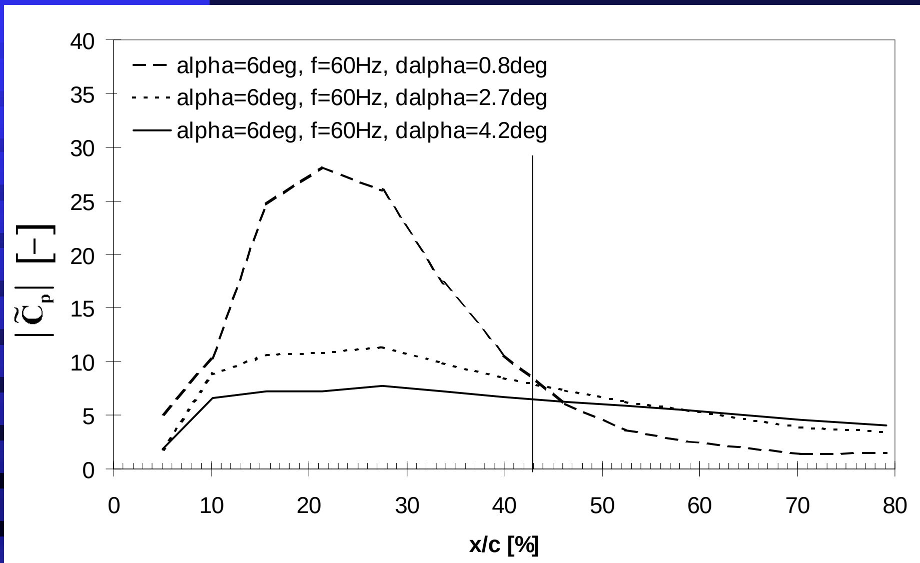


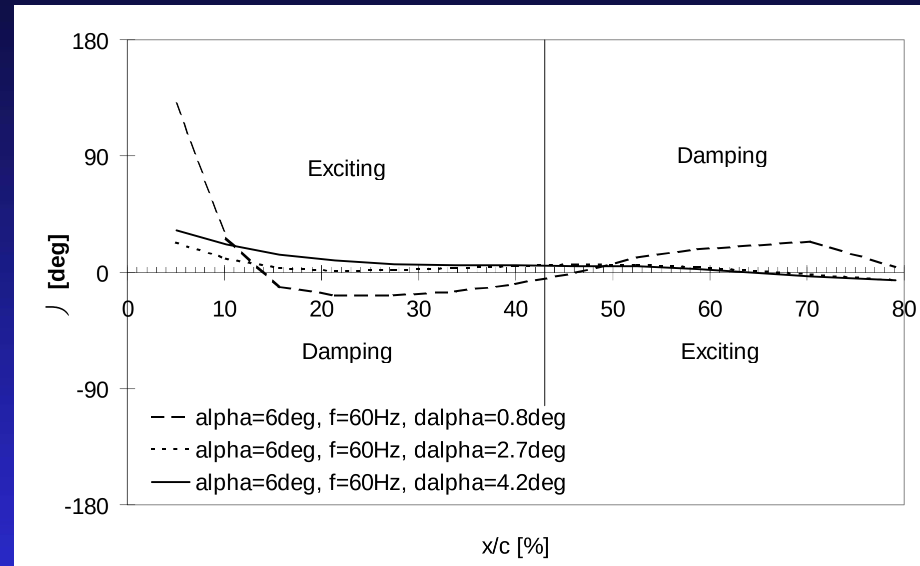


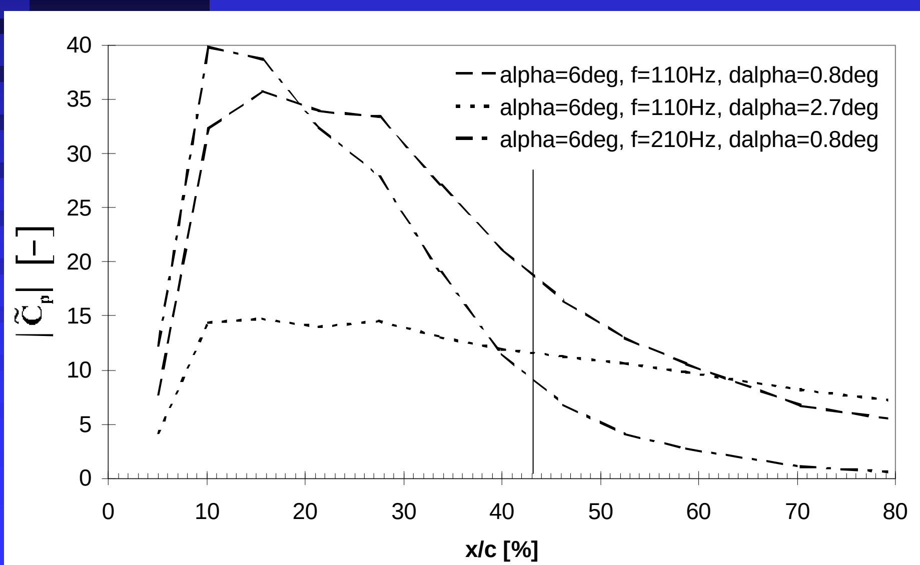


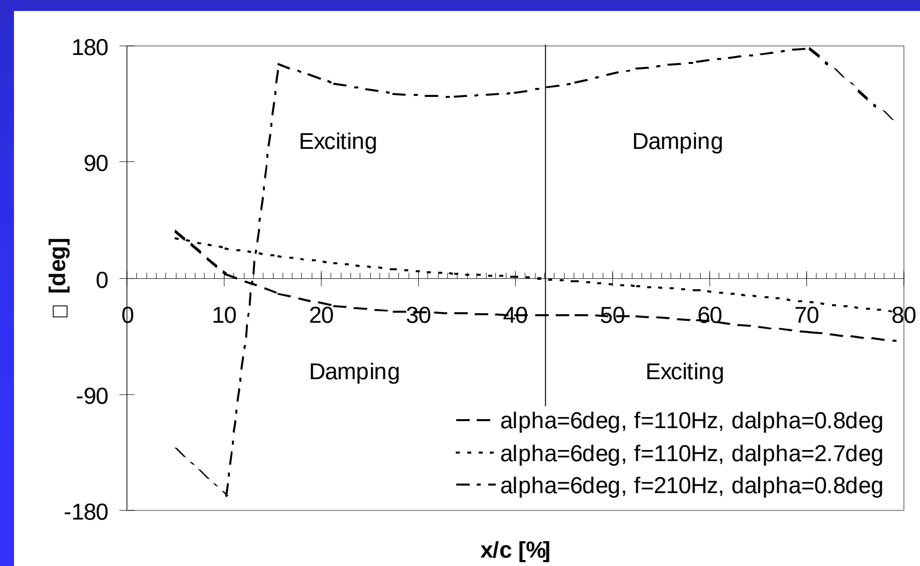


Amplitude and Phase, 6° Incidence









Summary of measurements

- Highly non-linear behaviour at and above static stall angle
- Below stall angle
  - Airfoil damped
  - Increase amplitude => increased excitation
  - Increase to 210Hz => blade excited
- Above stall angle
  - Airfoil excited
  - Increased amplitude => decreased excitation
  - Increase to 210Hz => blade damped
- 210Hz phase shift possibly due to lagging LE separation vortex or migration of stagnation point

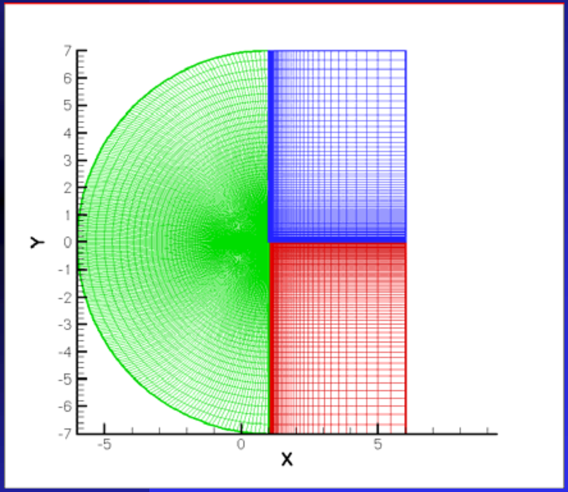
Summary Of Findings

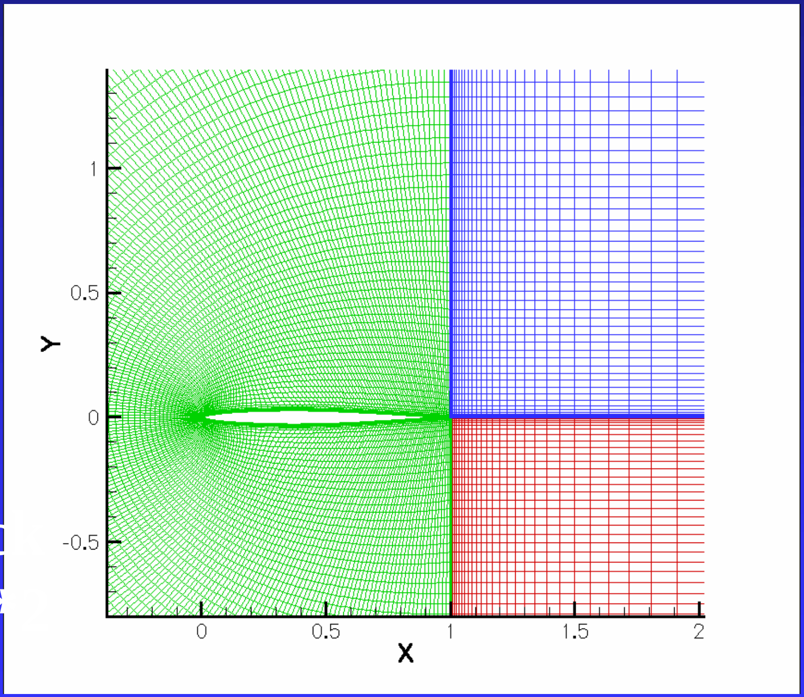
- (2) Transition & Separation, Relaminarisation & Reattachment delayed with increasing reduced frequency (T. Lee, G. Petrakis).
- (3) Increasing frequency delays dynamic stall (L. He, J.D. Denton)

Analysis

- Use CFD to simulate the experiment
- Used the University of Glasgow PMB code to analyse the data
- Cross-plotted the CFD results and the experimental results in order to make a comparison

CFD Grid





1st block
41*85*2

2nd bloc
222*85*

3rd block
41*85*2

CFD results on the pressure field

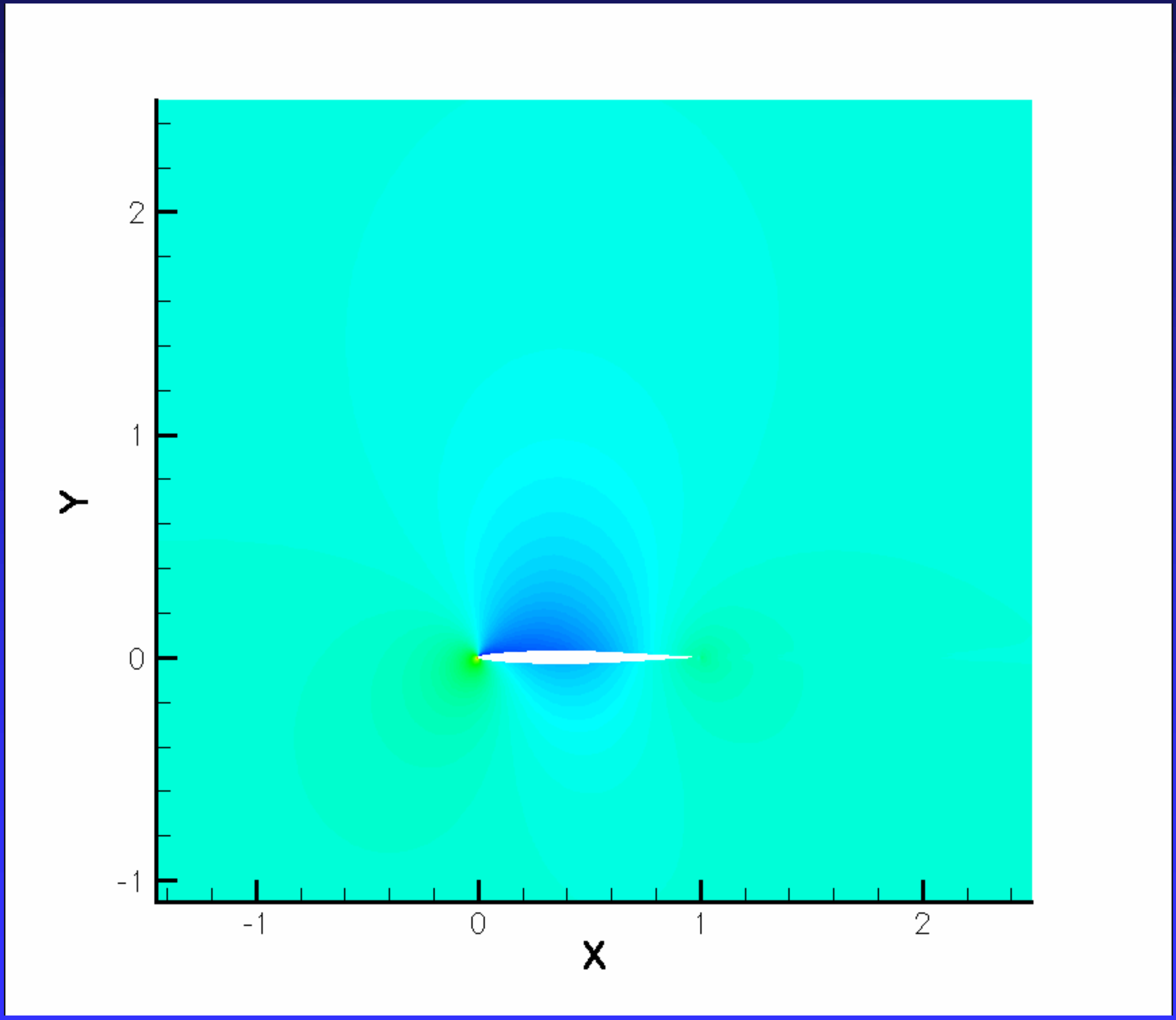
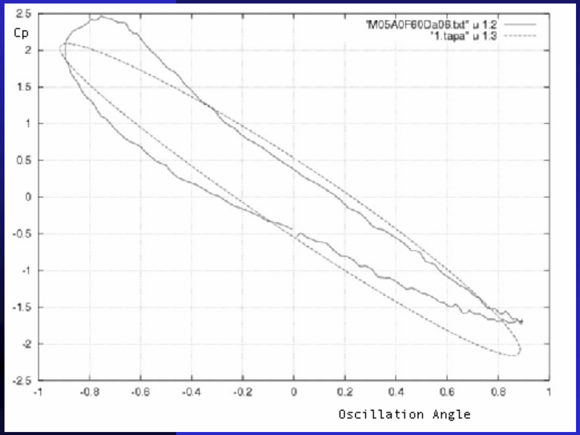
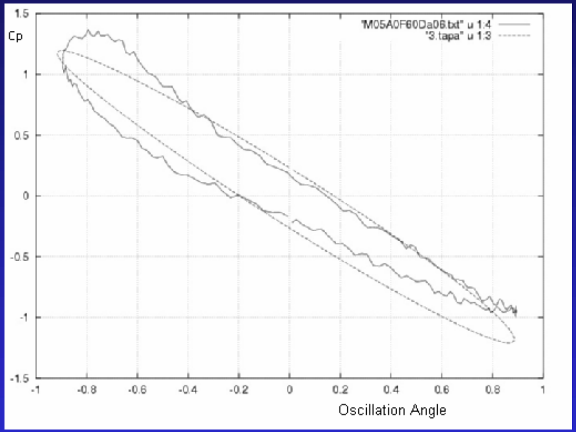


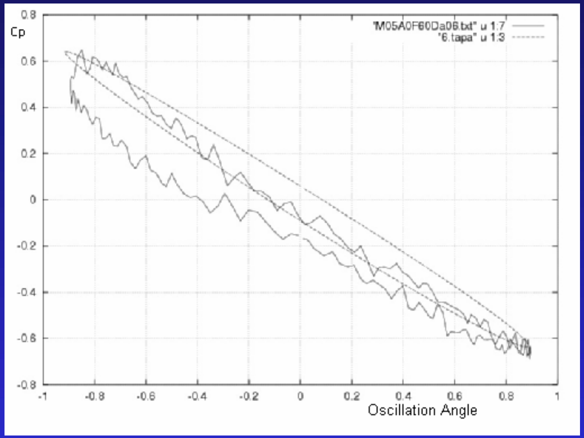
Table of Cases

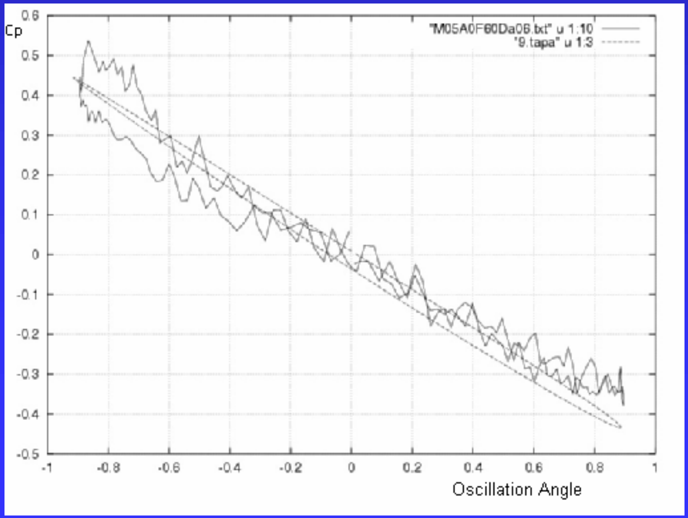
Frequency	60Hz	110Hz	210Hz
Inlet mach No.	0.5	0.5	0.5
Inlet stagnation temperature	280K	280K	280K
Reynolds number	850 000	850 000	850 000

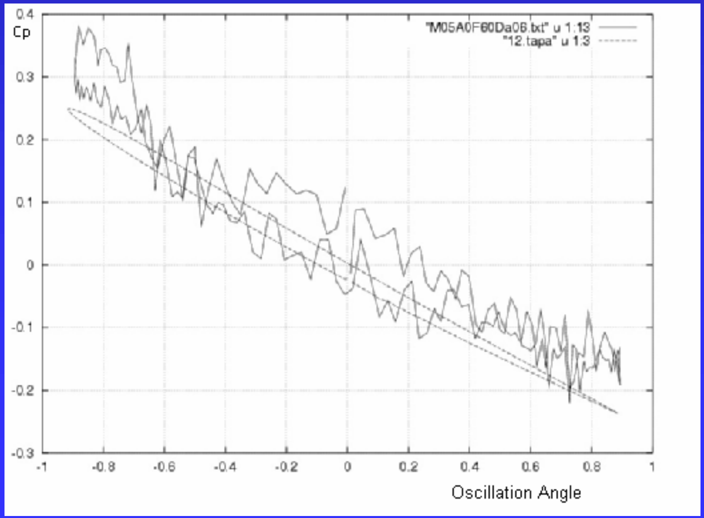
Time Domain Comparison 60Hz



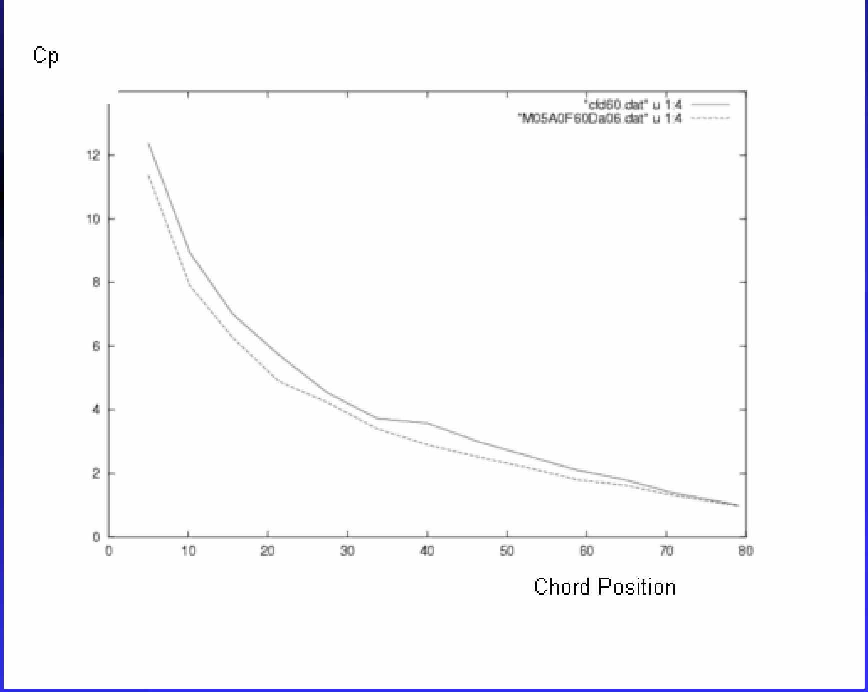


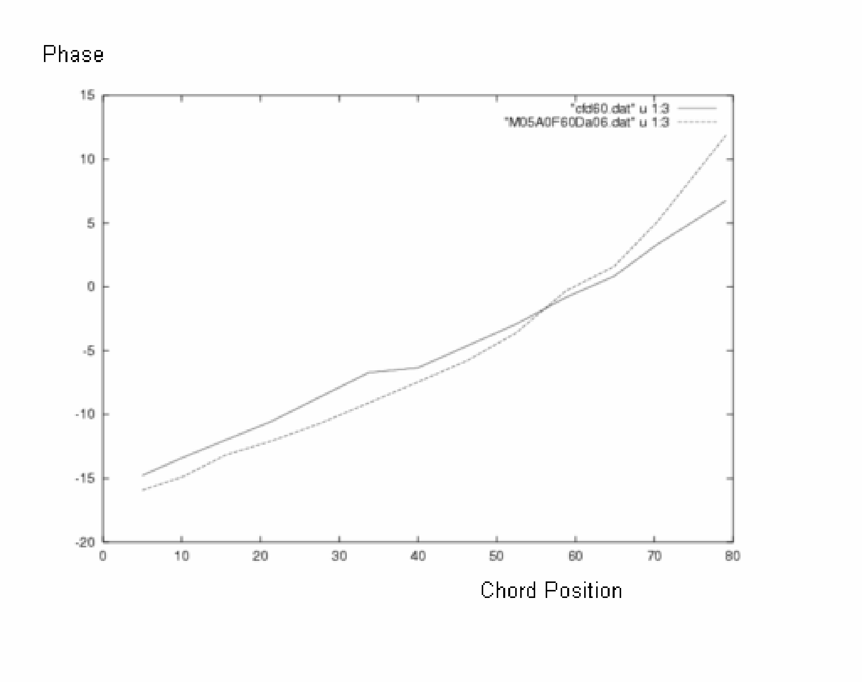




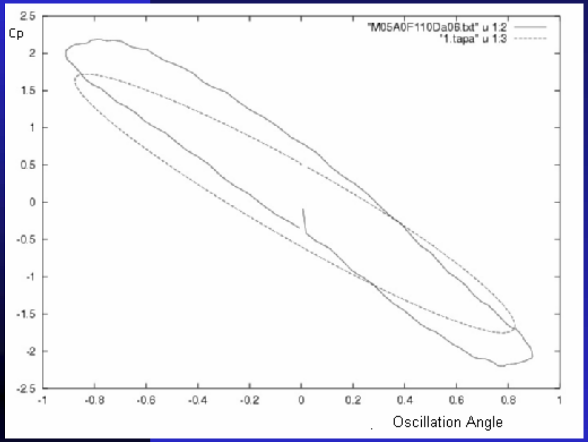


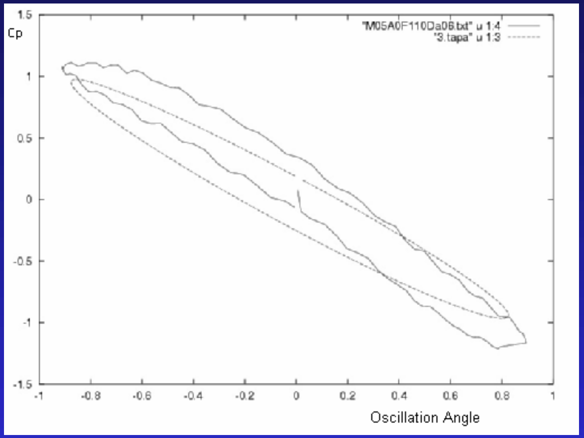
Frequency Domain Comparison 60Hz

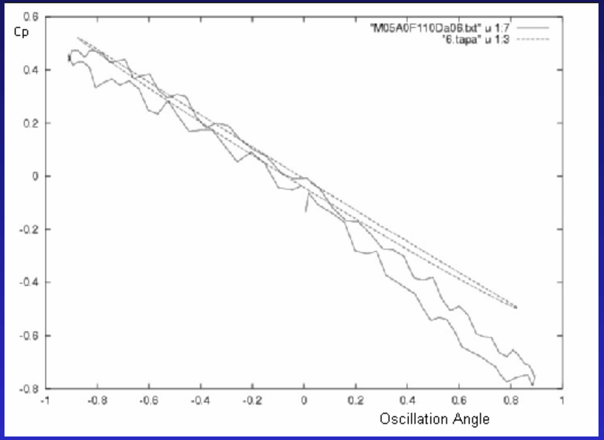


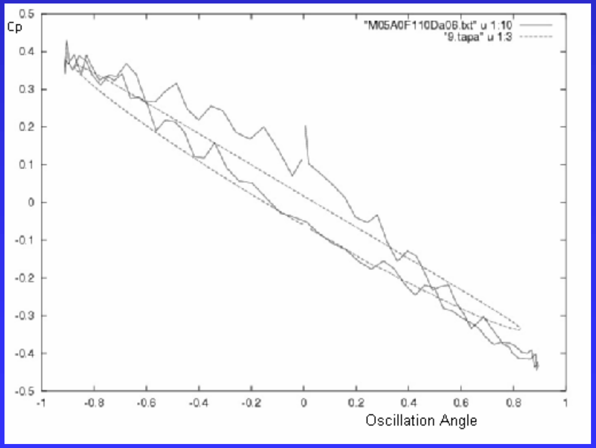


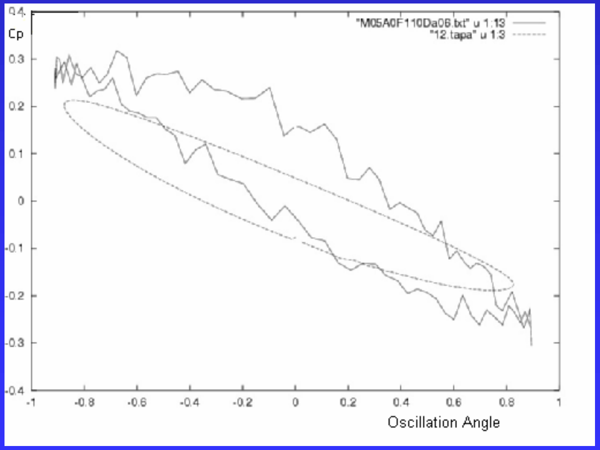
Time Domain Comparison 110Hz



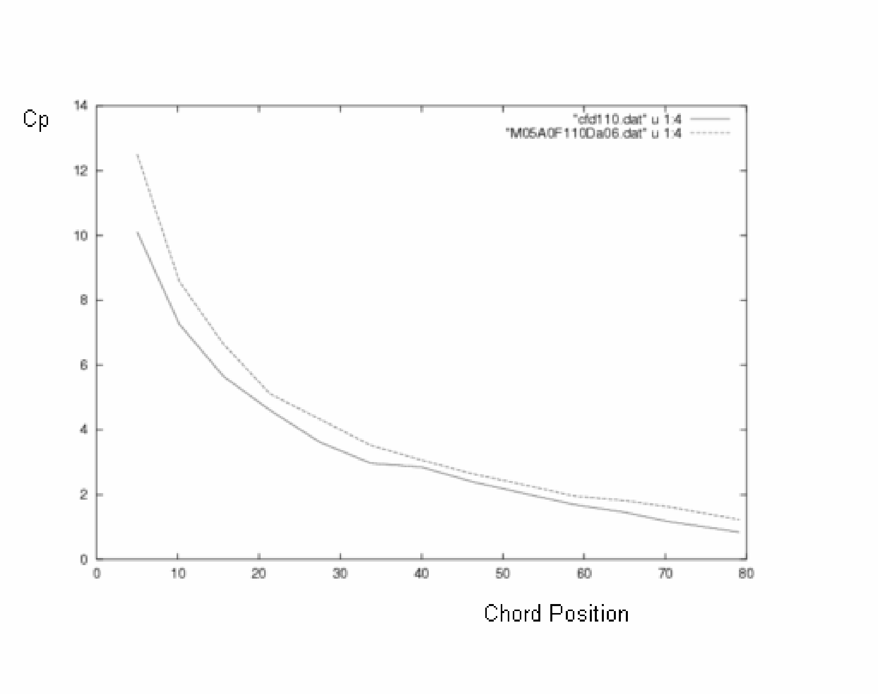


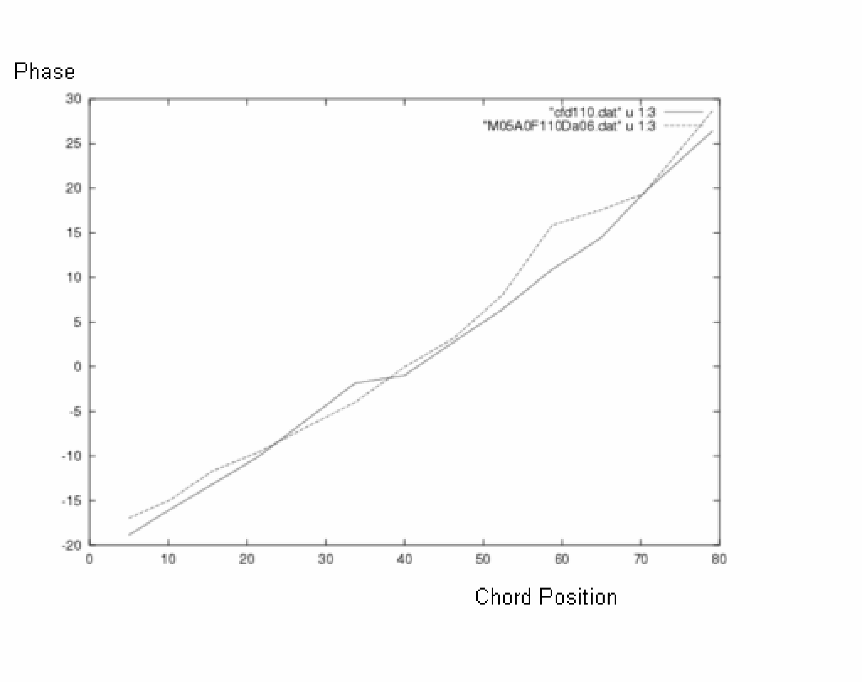




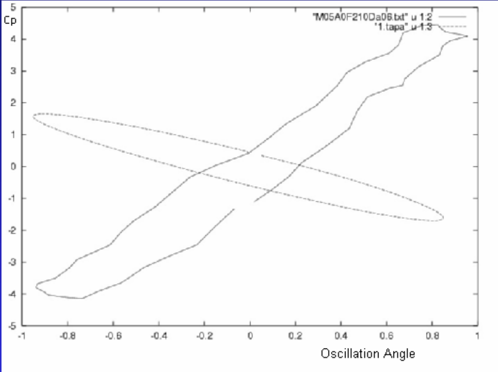


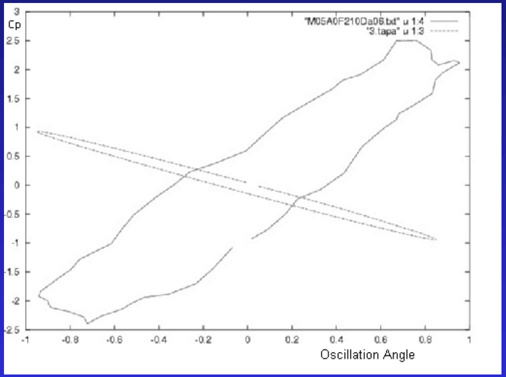
Frequency Domain Crossplots 110Hz

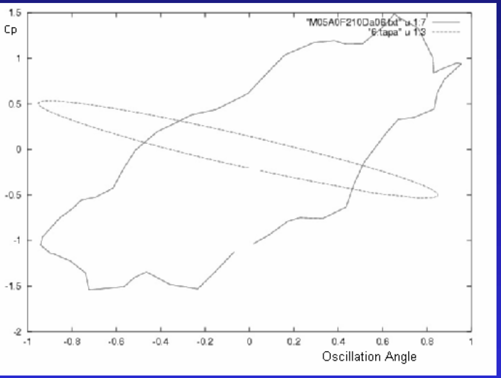


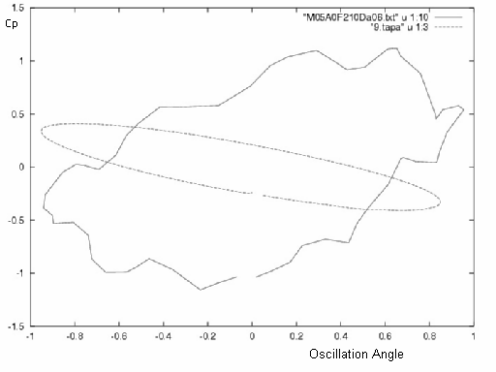


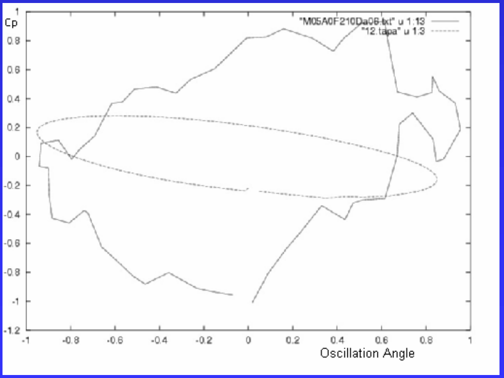
Time Domain Crossplots 210Hz





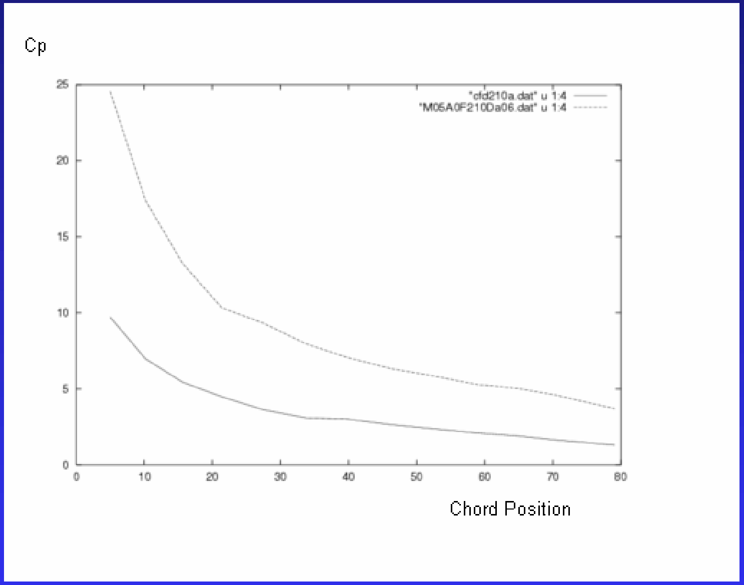


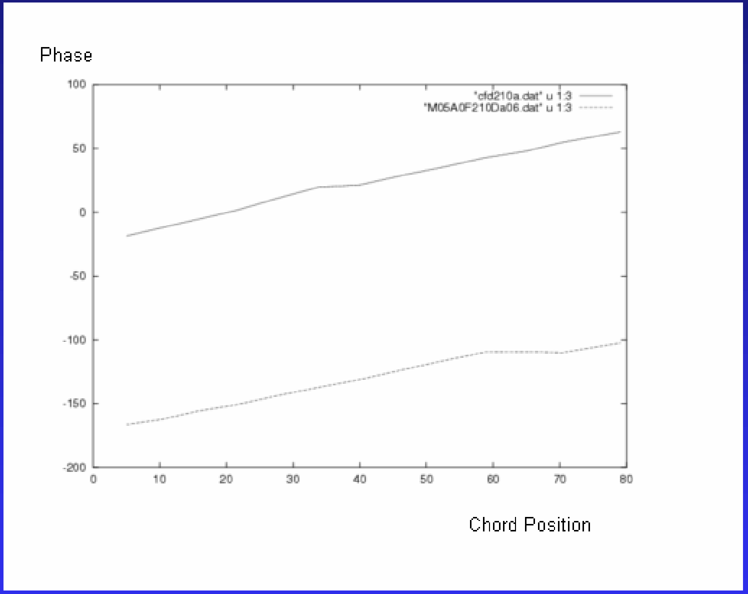




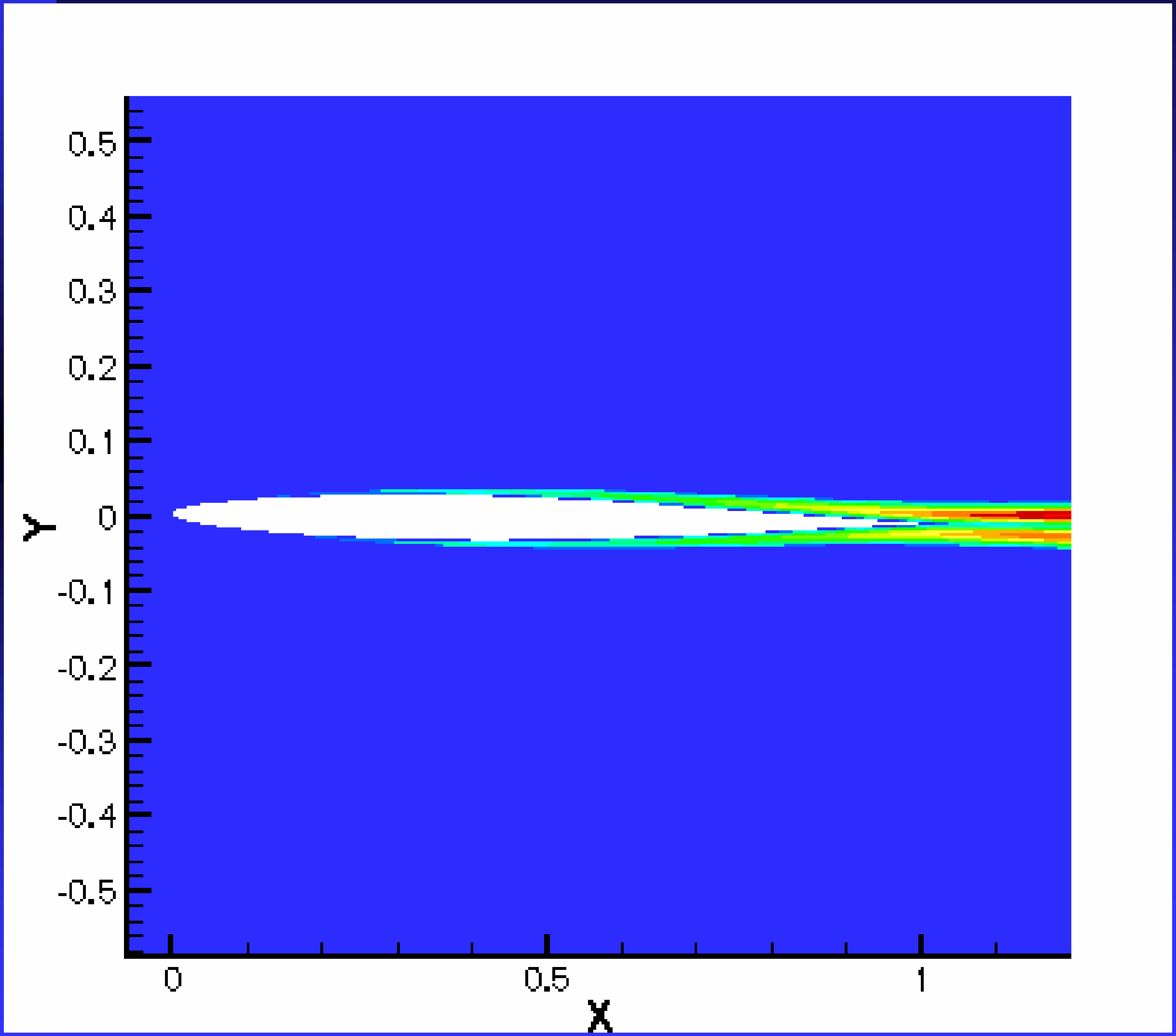
Frequency Domain Crossplots 210Hz

Reference case





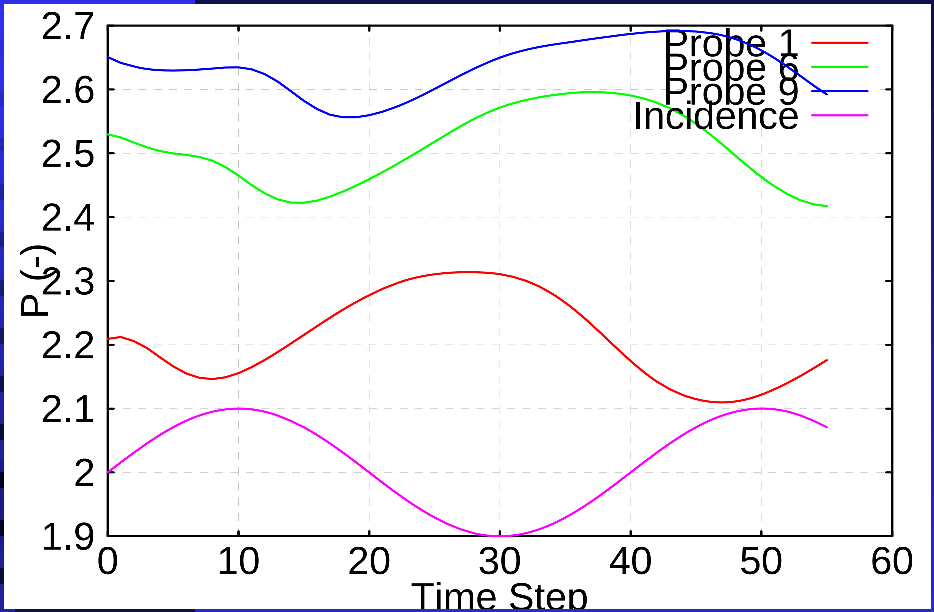
Boundary layer behaviour



Turbulent Reynolds Number indicating laminar flow up to 30% of the chord

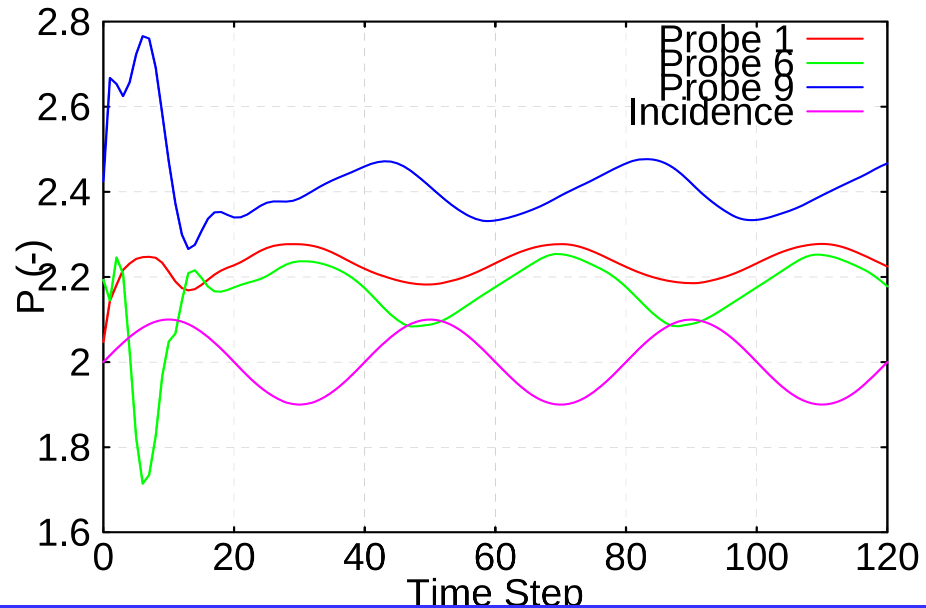
Pressure taps indicating transition at ~50% chord

BL trip at 50% chord



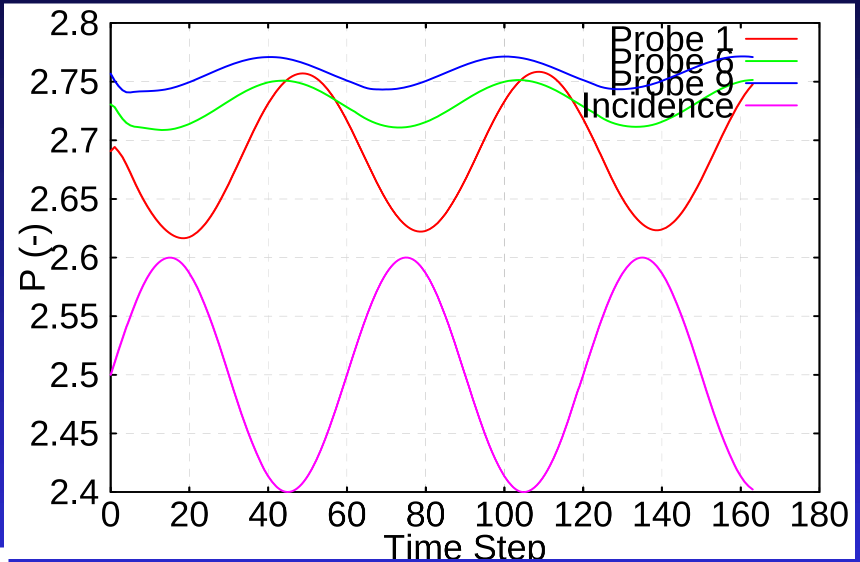
Mean incidence 7 degrees
Amplitude 1 degree
Frequency 210 Hz

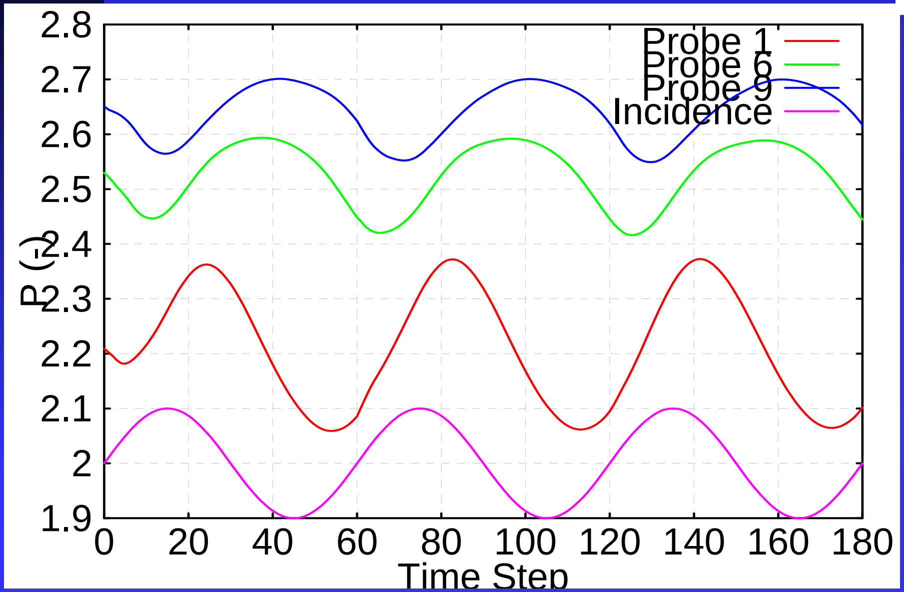
Mean incidence 7 degrees
Amplitude 1 degree
Frequency 210 Hz
Trip x/c=0.5



BL trip at 50% chord

Mean incidence 0 degrees
Amplitude 1 degree
Frequency 210 Hz
Transition at x/c=0.5





Mean incidence 0 degrees
Amplitude 1 degree
Frequency 120 Hz
Transition at x/c=0.5

Conclusions

- The 60Hz and 110Hz cases were reasonably the same
- 210Hz Experiment suggests a change in phase, CFD maintains the same trend, for reference case
- BL trip at 50% chord gives phase shift, even for zero incidence
- The higher mean incidence the easier to get phase shift
- State of boundary layer seems to affect phase
- Investigate difference of BL between 110Hz and 210Hz frequences
- Further work needs to be carried out