Performance Measurement in a Transient Turbine Test Facility – Preliminary Instrumentation Development

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Introduction

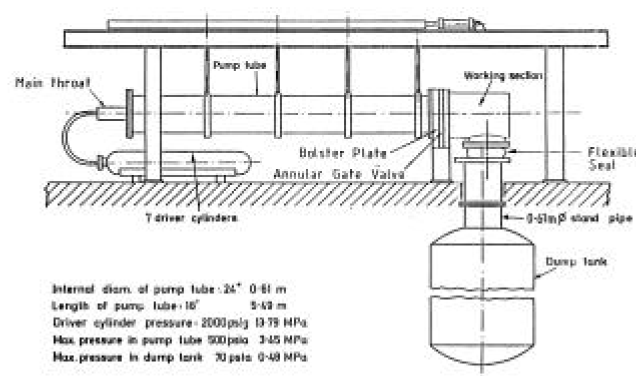
- The aims:
  - To help improve the aerodynamic performance/efficiency

    of future turbine designs!
  - To help the solution of design issues such as tip burn.

- The background:
  - Traditional design methods give performance predictions in the region of ±2% uncertainty. Full scale steady flow rig testing is needed.
  - This cycle of empirical design methods and full scale rig testing is an expensive and lengthy process. The effects of novel geometry changes are very hard to predict. This makes the implementation of design changes a potential risky and costly process.
  - Steady flow rigs can't measure heat transfer at the same time as aerodynamic performance.

Transient performance testing?

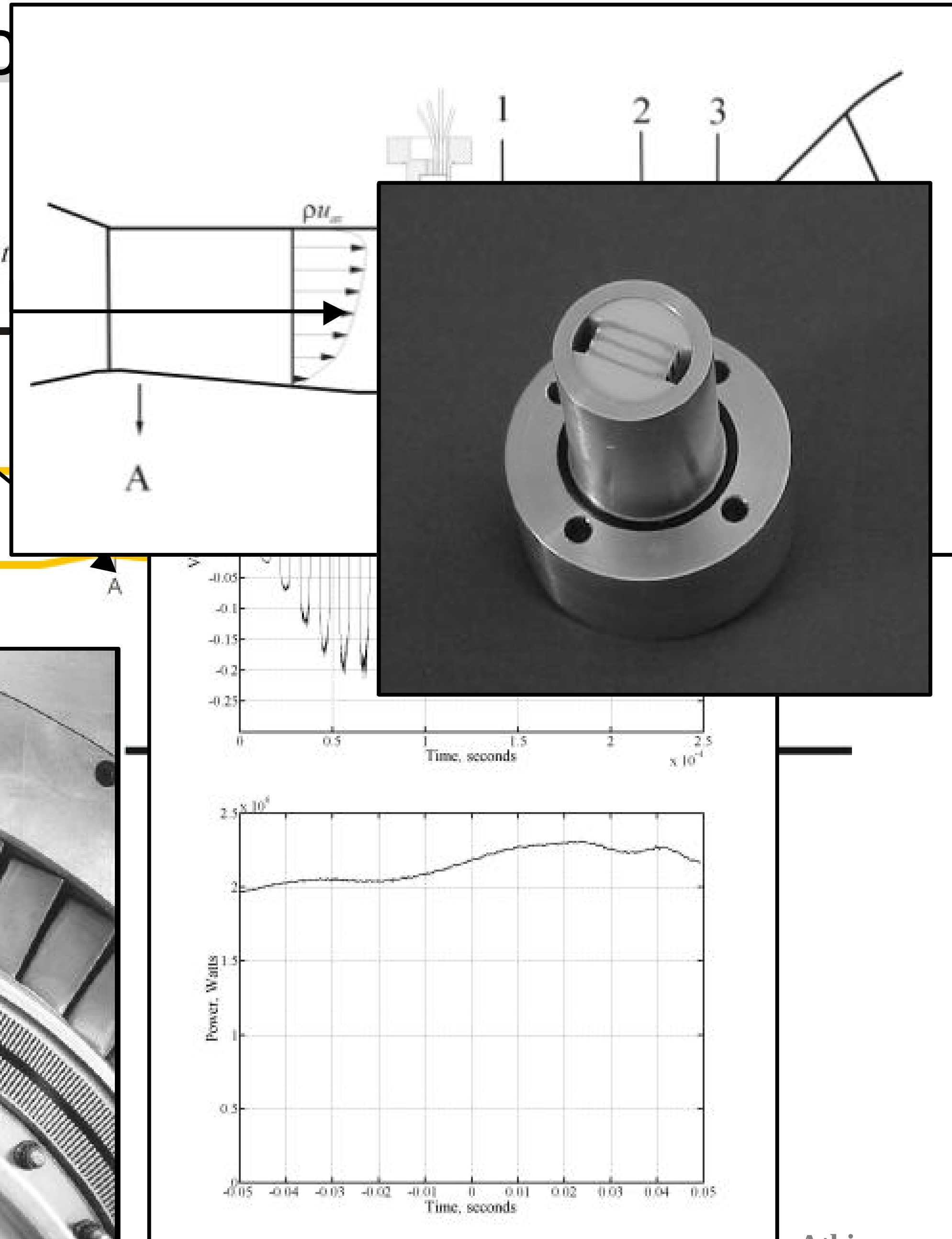
- Advantages
  - The performance gains/penalties associated with design changes motivated by heat transfer can be examined.
  - Efficiency testing in the ORF will provide a link between the wealth of data on the structure of the loss mechanisms and flow phenomena, and their actual quantitative effect on the overall performance of the turbine stage.
  - It has the potential to reduce uncertainty in the prediction of the performance of new designs to somewhere in the region of ±0.25% to ±0.5%, at a much earlier stage in the design process.
  - Transient testing is estimated to be about a fortieth of the cost of traditional full scale rig tests

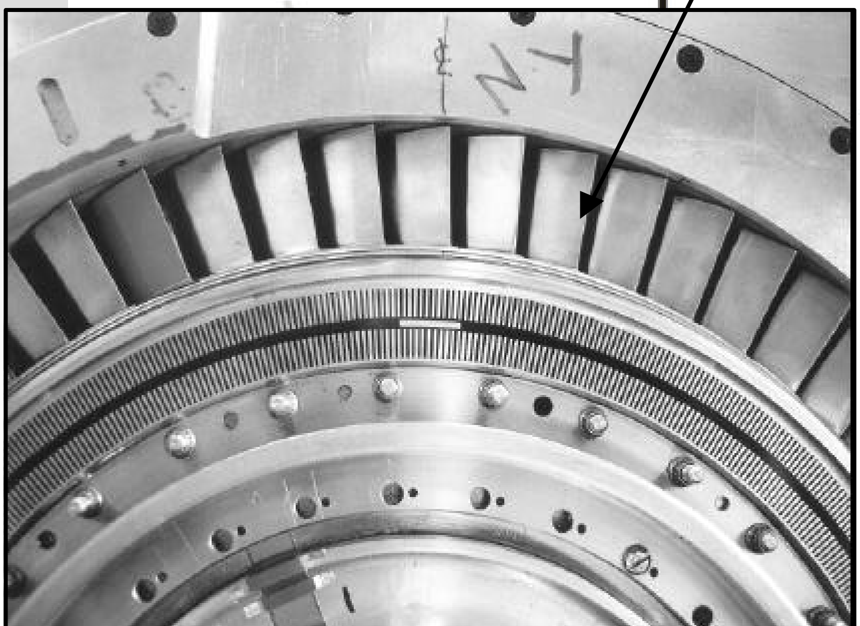


Performanc

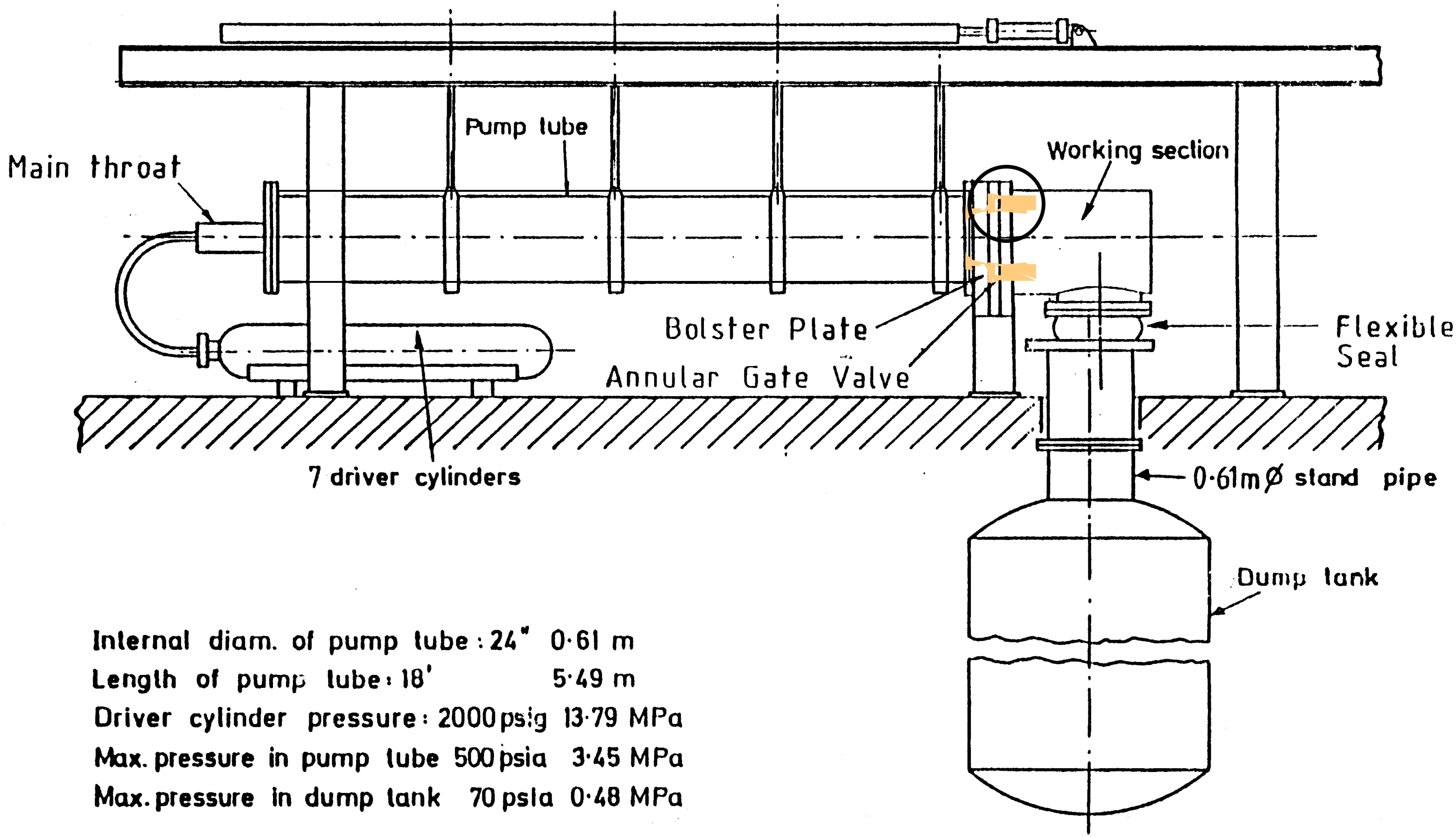
$$\dot{W}_{actual} = \dot{W}_{measured} + \left(\dot{W}_{heat\_t}\right.$$

$$\eta = \frac{\dot{W}_{actual}}{\dot{W}_{isentropic}} = 1 - \frac{\dot{W}_{irreversibility}}{\dot{W}_{isentropic}}$$





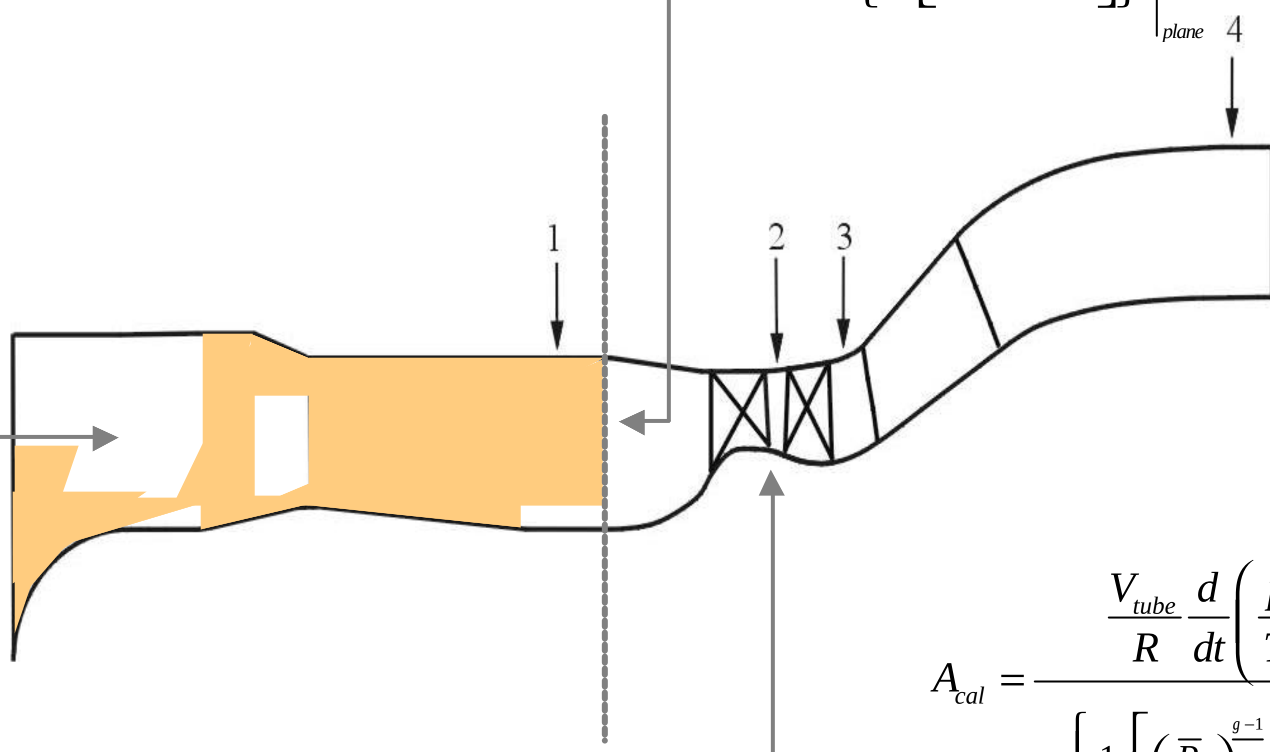
- Blowdown Calibration Theory



Mass flow rate measurement - 1

$$\dot{m}_{tube} = \frac{V_{tube}}{R}\frac{d}{dt}\left(\frac{p_{tube}}{T_{tube}}\right)$$

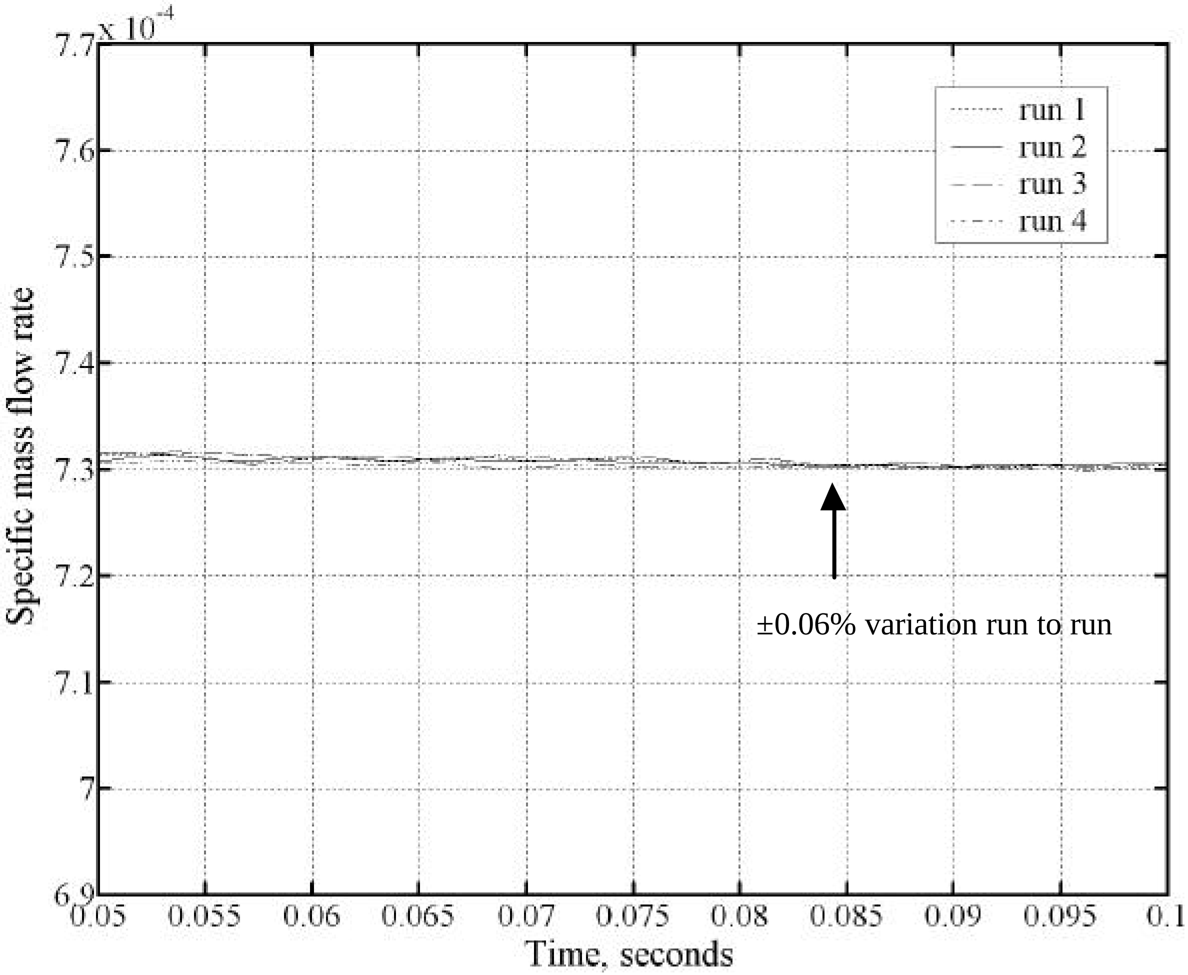
$$\dot{m}_{plane} = A_{cal}\, p\left\{\frac{1}{\overline{T}_s}\left[\left(\frac{\overline{P}_0}{p}\right)^{\frac{g-1}{g}} - 1\right]\right\}^{\frac{1}{2}}\Bigg|_{plane}$$



$$A_{cal} = \frac{\dfrac{V_{tube}}{R}\dfrac{d}{dt}\left(\dfrac{p_{tube}}{T_{tube}}\right)}{p\left\{\dfrac{1}{\overline{T}_s}\left[\left(\dfrac{\overline{P}_0}{p}\right)^{\frac{g-1}{g}} - 1\right]\right\}^{\frac{1}{2}}\Bigg|_{plane}}$$

- Preliminary Testing

Mass flow rate measurement - 2



Q263 Through flow results, mass flow = 29.2 kg, specific mass flow =$7.2x10^{-4}$

Mass flow rate measurement - 3

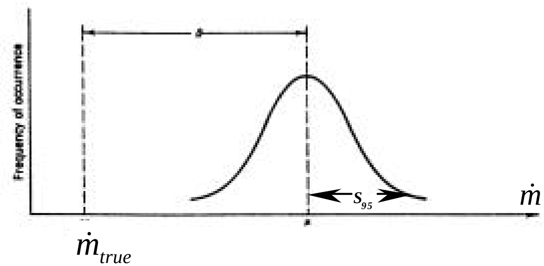
- Uncertainty Analysis

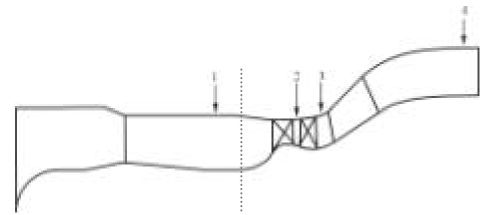
DESCRIPTION	COEFFICIENT
Calibration constant	$C_{A_{cal}} = 1$
Stage inlet total temperature	$C_T = -\frac{1}{2}$
Measurement plane mean static pressure during a test run	$C_p = 1 - \frac{1}{2}\frac{(?-1)}{?}\left\{\frac{\left(\frac{P_{01}}{p}\right)^{\frac{(?-1)}{?}}}{\left[\left(\frac{P_{01}}{p}\right)^{\frac{(?-1)}{?}} - 1\right]}\right\} = 1 - \frac{1}{2}\frac{(?-1)}{?} - \frac{1}{?M^2}$
Measurement plane total pressure during a test run	$C_{P_{01}} = \frac{1}{2}\frac{(?-1)}{?}\left\{\frac{\left(\frac{P_{01}}{p}\right)^{\frac{(?-1)}{?}}}{\left[\left(\frac{P_{01}}{p}\right)^{\frac{(?-1)}{?}} - 1\right]}\right\} = \frac{1}{2}\frac{(?-1)}{?} + \frac{1}{?M^2}$

- Uncertainty Analysis

$$\dot{m} = A_{cal} p \left\{ \frac{1}{\overline{T}_s} \left[\left(\frac{\overline{P}_0}{p} \right)^{\frac{g-1}{g}} - 1 \right] \right\}^{\frac{1}{2}} \Bigg|_{plane}$$

$$C_* = \frac{\partial \dot{m}}{\partial *} \cdot \frac{*}{\dot{m}}$$





$$\frac{S_{\dot{m}}}{\dot{m}}\% = \left[\left(C_{A_{cal}} \frac{S_{Acal}}{A_{cal}} \right)^2 + \left(C_{P_{01}} \frac{S_{P_{01}}}{P_{01}} \right)^2 + \left(C_p \frac{S_p}{p} \right)^2 + \left(C_T \frac{S_T}{T} \right)^2 \right]^{\frac{1}{2}}$$

DESCRIPTION	COEFFICIENT
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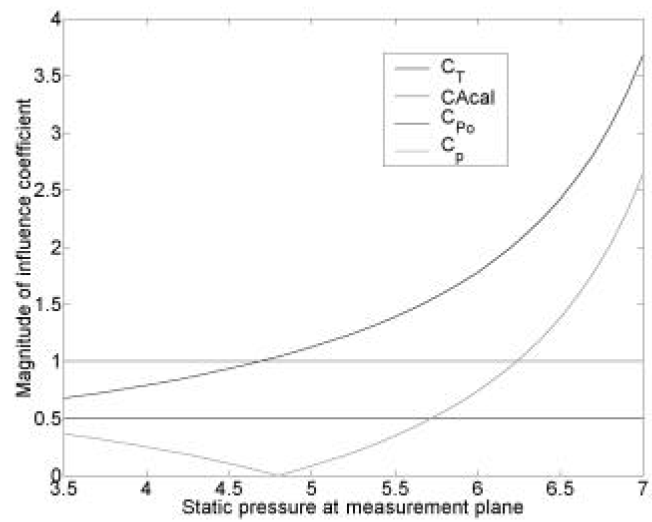
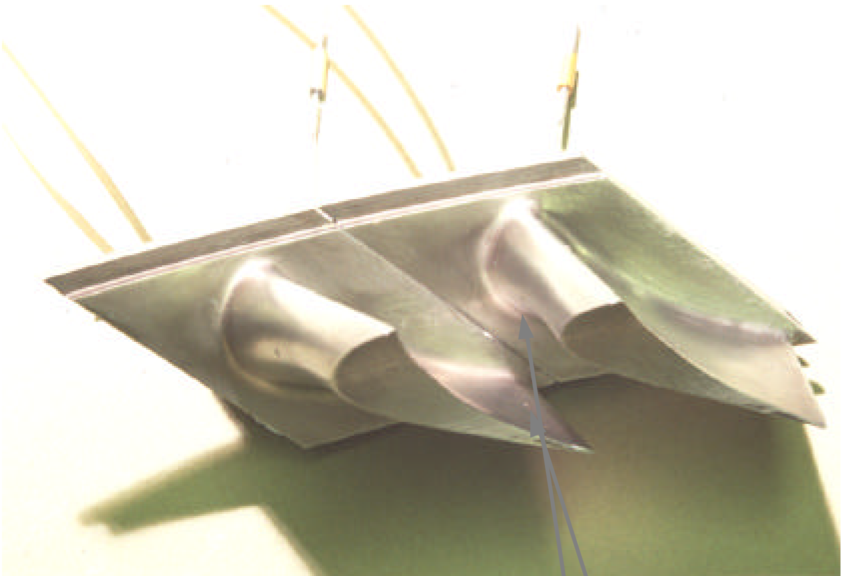
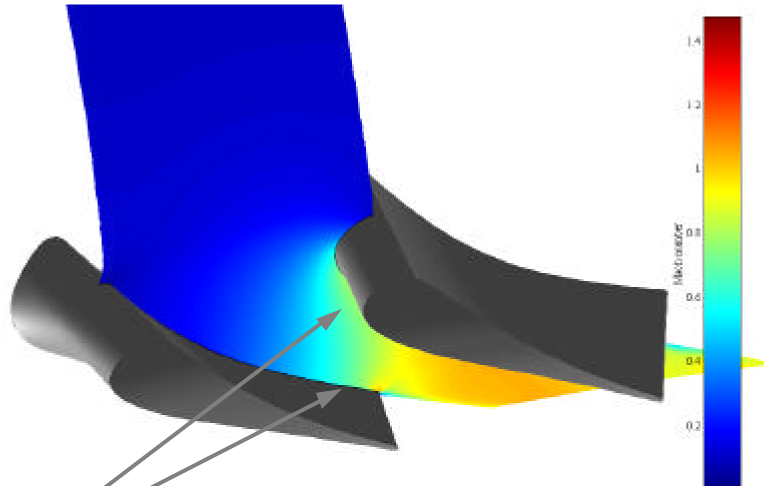
Measurement plane total pressure during a test run	$C_{P_{01}} = \frac{1}{2}\frac{(?-1)}{?}\left\{ \frac{\left(\frac{P_{01}}{p}\right)^{\frac{(?-1)}{?}}}{\left(\frac{P_{01}}{p}\right)^{\frac{(?-1)}{?}} - 1} \right\} = \frac{1}{2}\frac{(?-1)}{?} + \frac{1}{?M^2}$



Instrumentation Design





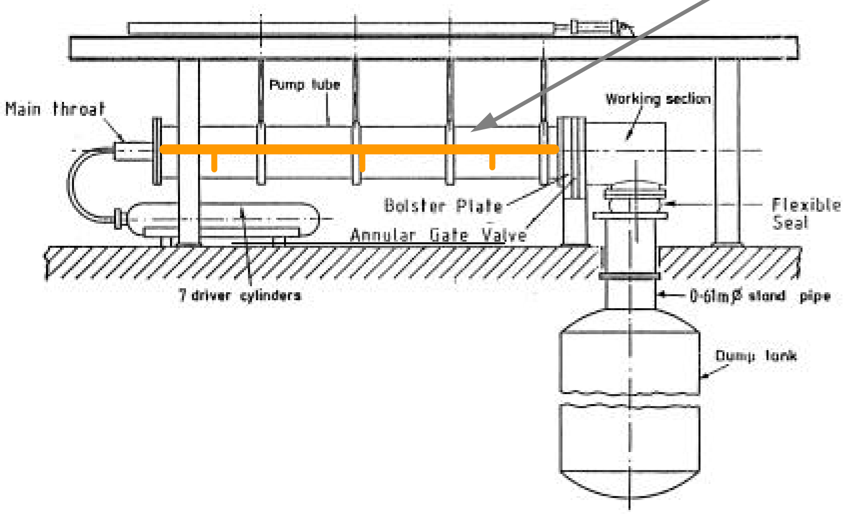
Four instrumented NGV's spaced around the annulus

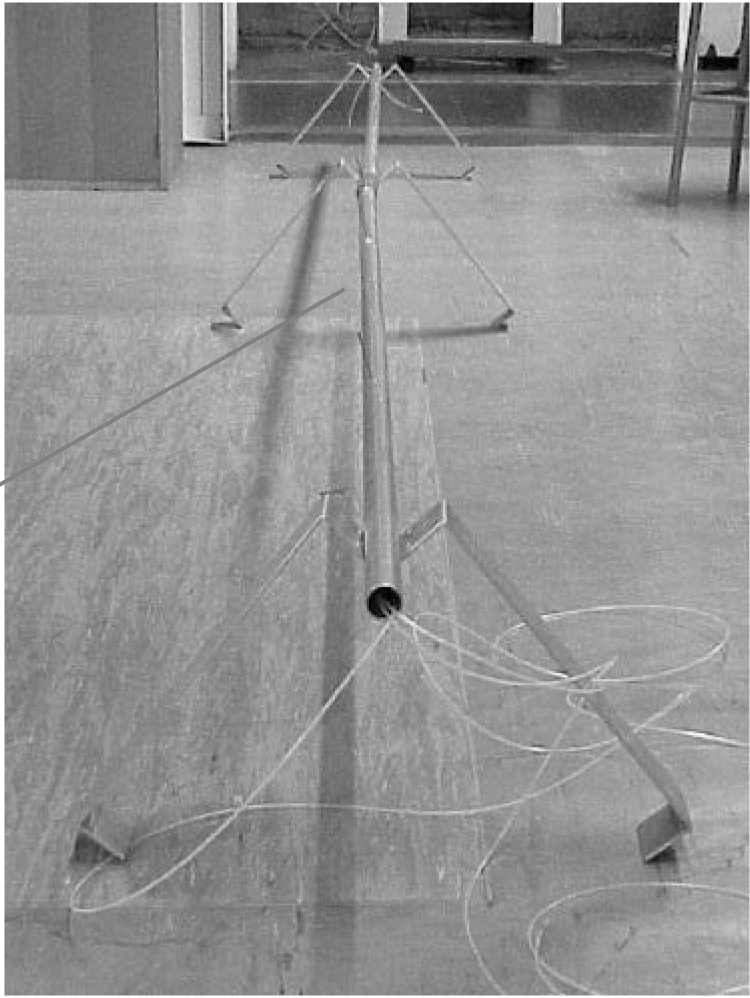
–PS static tapping at 90% of C_{ax}

–SS static tapping at 30% C_{ax}

–Total tapping on aerodynamic LE

- Tube instrumentation
  - 5m long rake positioned in the centre of the piston tube.
    - 6 static pressure tappings. Absolute and differential sensors, both calibrated to Druck DPI 515.
    - 8 thermocouples. Aspirated to ensure the have suitable time constant and calibrated to approximately ±0.1ºC.





Conclusions-Future Work

- Prototype systems have been designed, and thoroughly tested in preparation for the measurement of:
  - Rotor speed and acceleration.
  - Mass flow rate
  - Inlet flow conditions
  - Automated pressure and temperature calibration systems

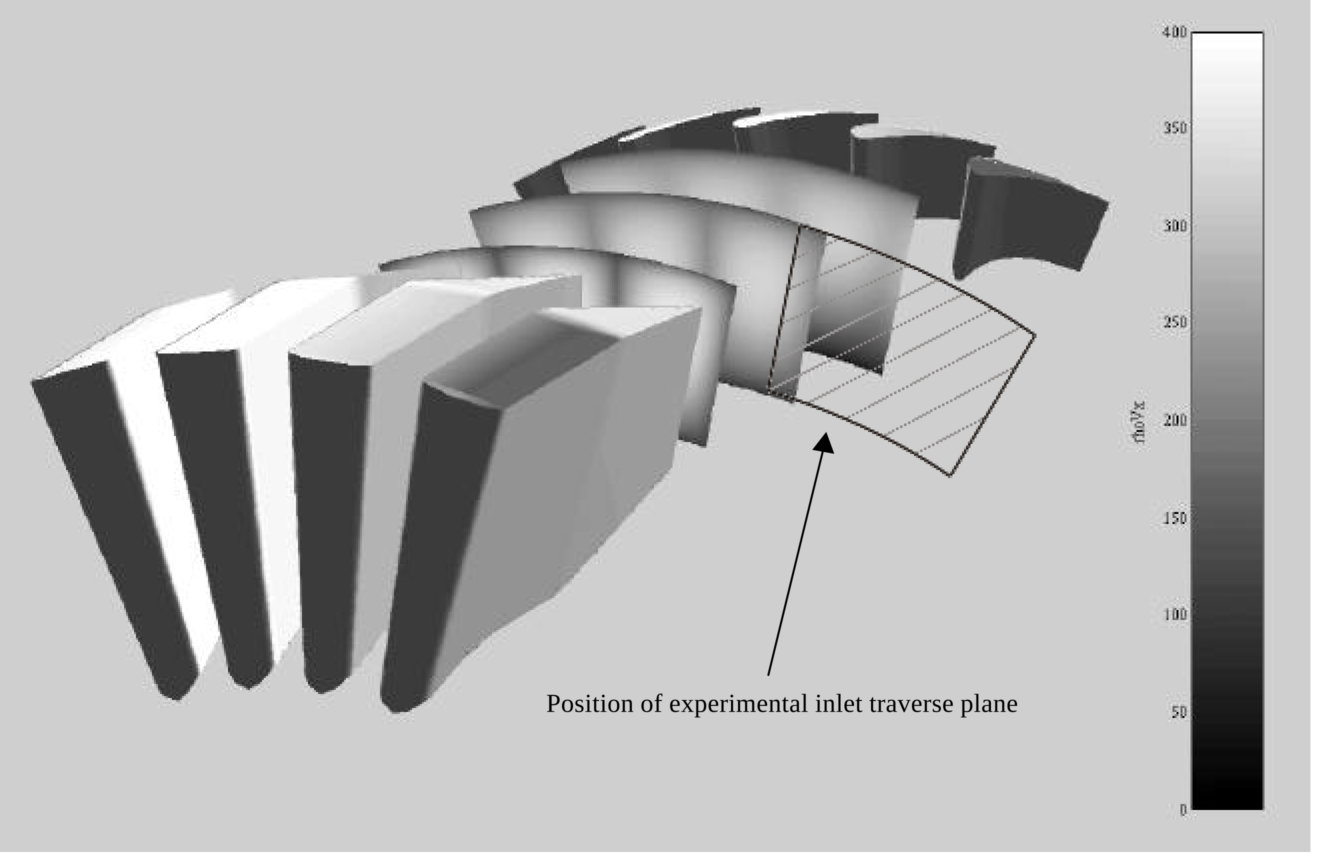
- The results of the preliminary testing indicates that performance testing with a relative resolution in the region of ±0.25% will be possible in the Oxford Rotor Facility.

- Final testing with the full instrumentation.

- Geometry changes.

- Acknowledgements: Rolls Royce PLC

Photos



400
350
300
250
200
150
100
50
0
rhoVx
Position of experimental inlet traverse plane

Photos