

OET (Optical Emission Tomography) a new Flame Front Diagnostic

&

PIV (Particle Image Velocimetry) in Transonic flows

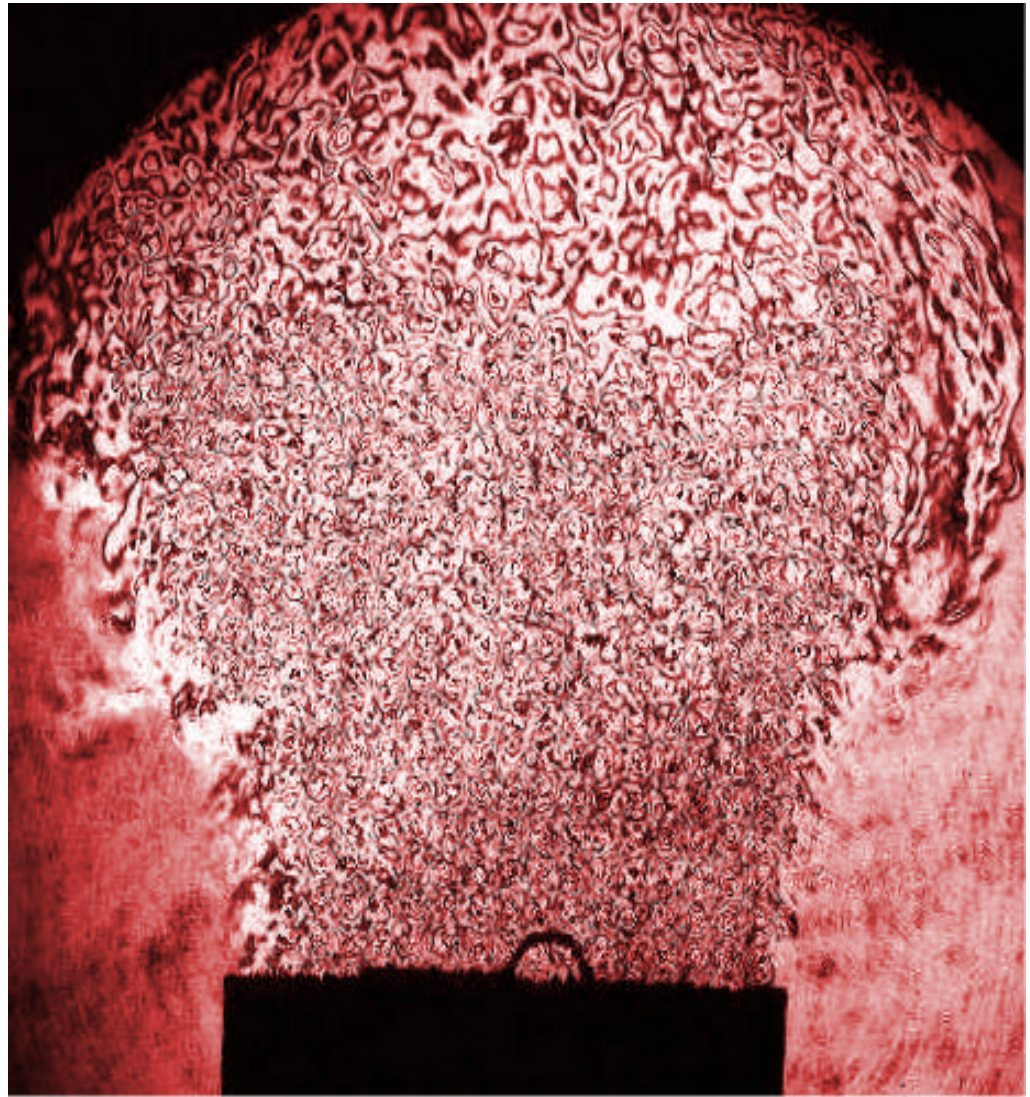
P. Dunkley, P. Bryanston-Cross, E. Moll & B. Timmerman

Optical Engineering Laboratory

The 16th Symposium on Measuring Techniques in Transonic and
Supersonic Flow in Cascades and Turbomachinery

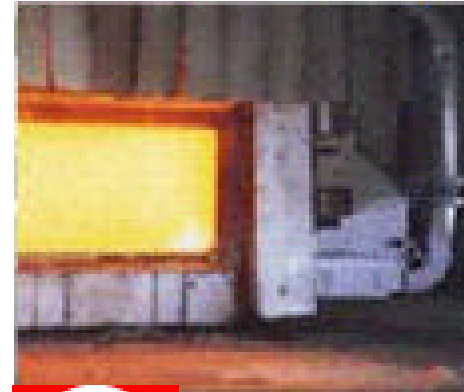
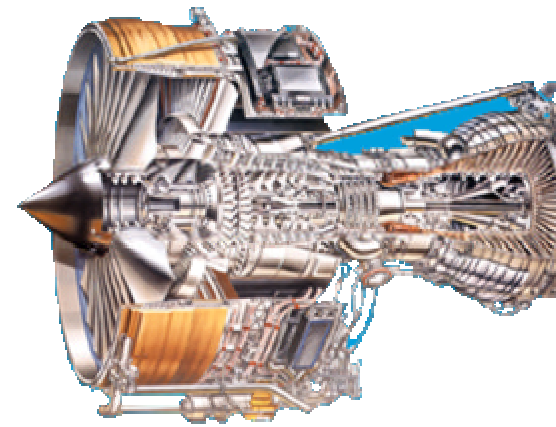
Cambridge 23 & 24th September 2002

The objective of OET (Optical Emission Tomography) is to create a three dimensional image of a flame structure by sampling the light emission from an array of diodes placed around the burner.



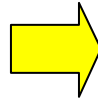
Project Members

- Rolls-Royce plc (Gas turbines)
- CORUS (Steel furnaces)
- Qinetiq
- NPL
- Wolfson Maintenance
- Warwick University
- Manchester University



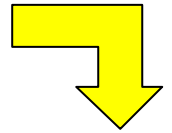
Problem:

- Pollution Regulations
- Efficiency
- Money

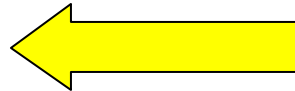


Possible Solution:

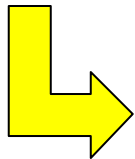
- Premixed Combustion



Instrumentation:
View and Evaluate
the Instabilities



Problem:
-Premixed
Combustion
Unstable

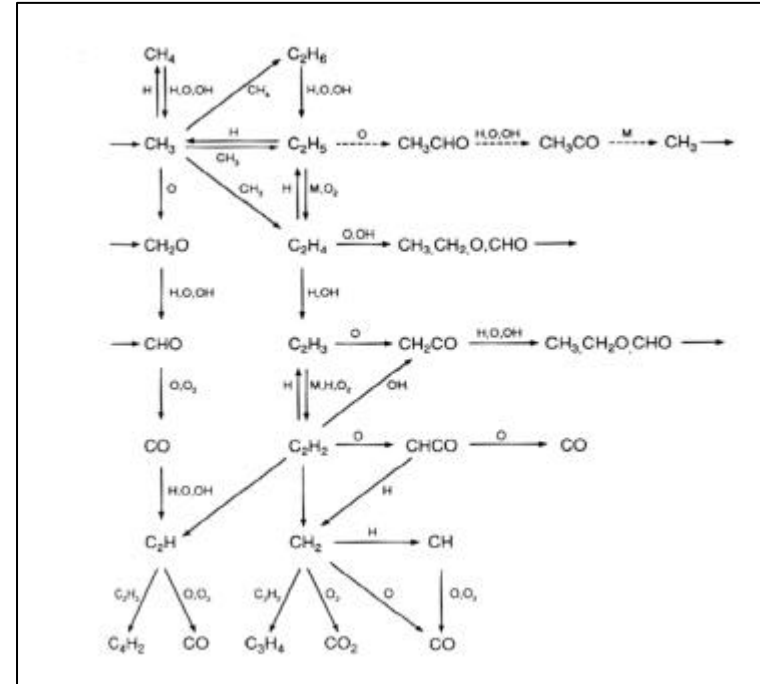


Specification:

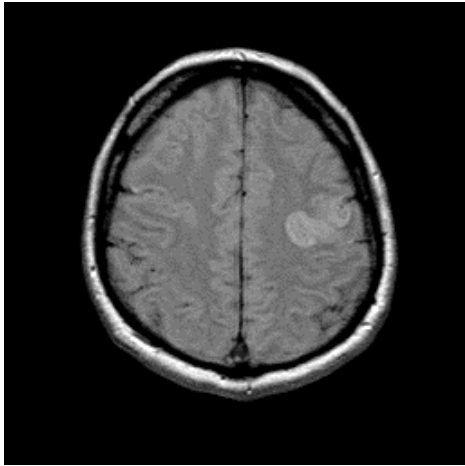
spatial resolution -10mm²
time resolution – 2kHz
high temperature – 1500°C
Pressure – atmospheric to
40 Bar

Why the Hydroxyl Radical?

- Branching Species
- Heat Release
- A/F Ratio
- Flame Front Indicator

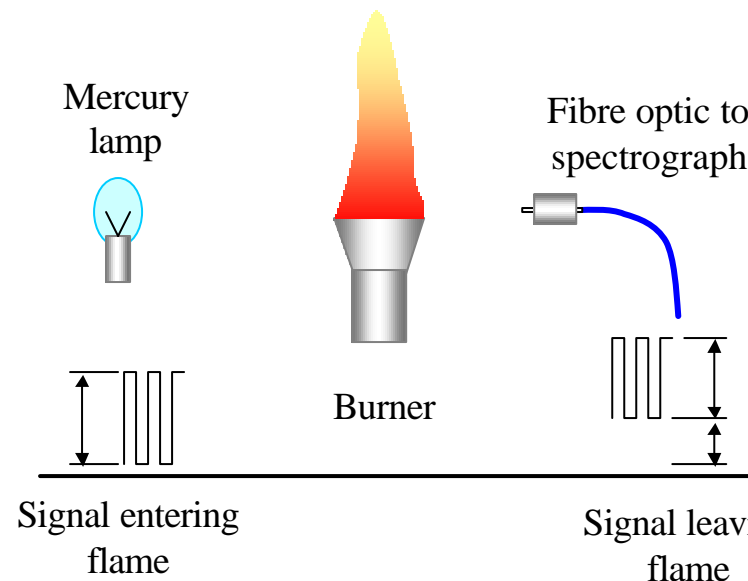


Tomography

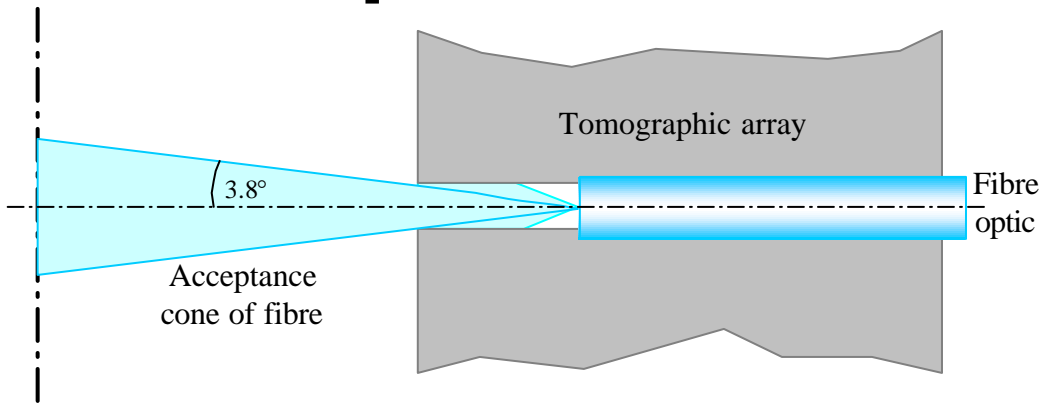


Reconstruct a slice of an object from either the absorption of an external source OR emission from the object itself.

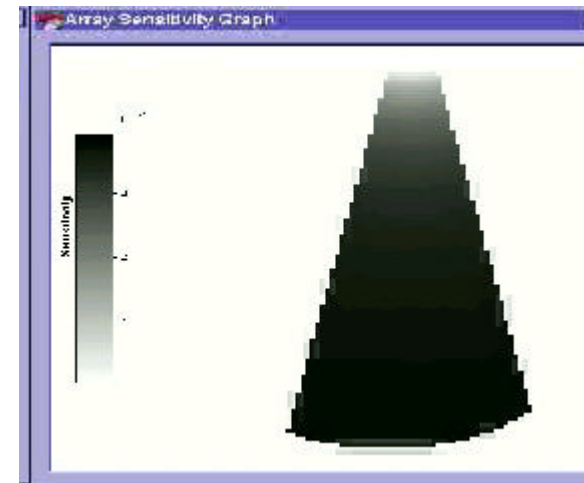
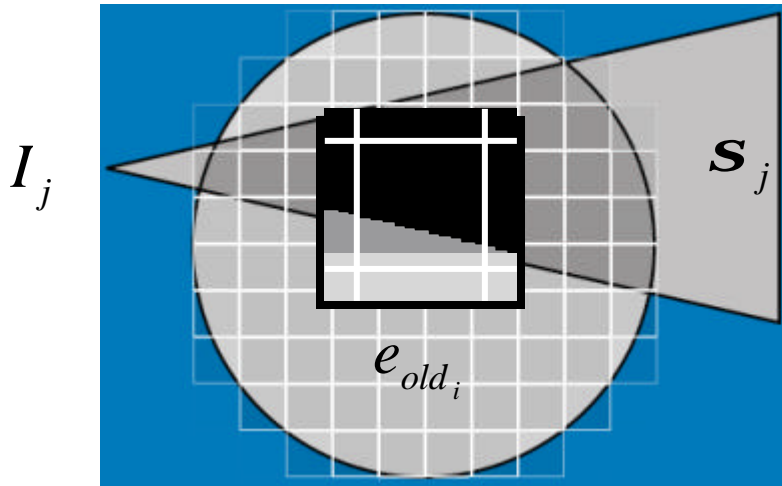
If a flame is to be reconstructed using only the emission, the self absorption of the flame needs to be assessed.



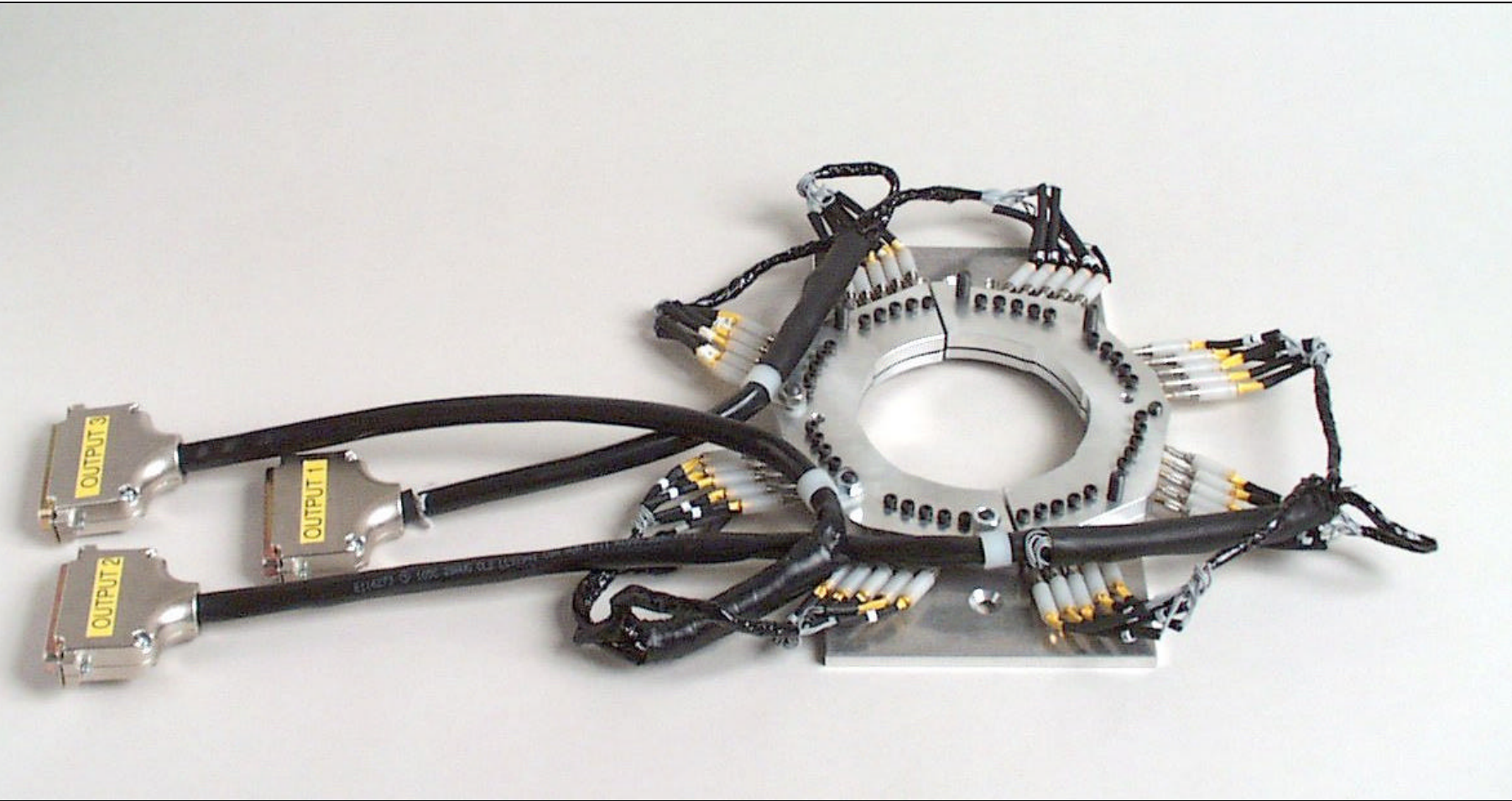
Development of Tomographic Array



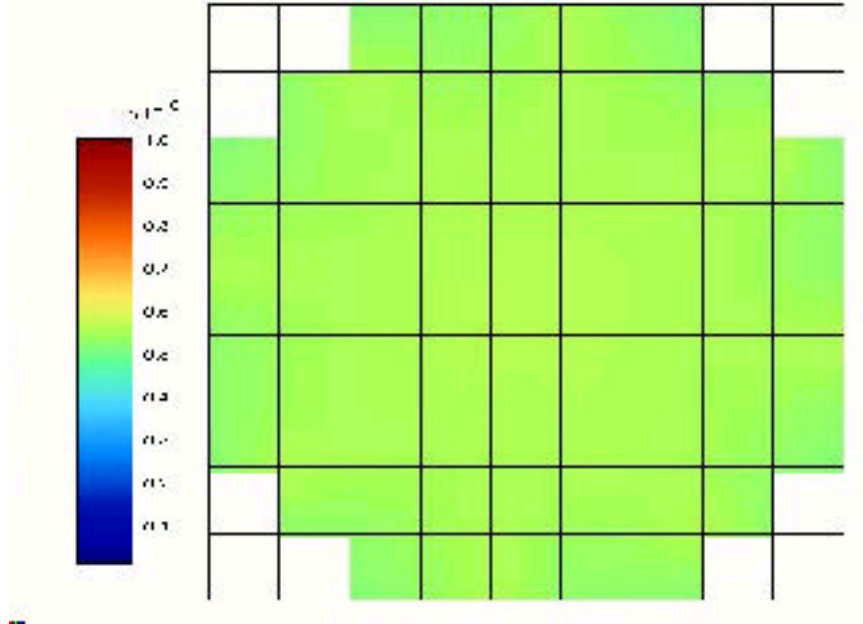
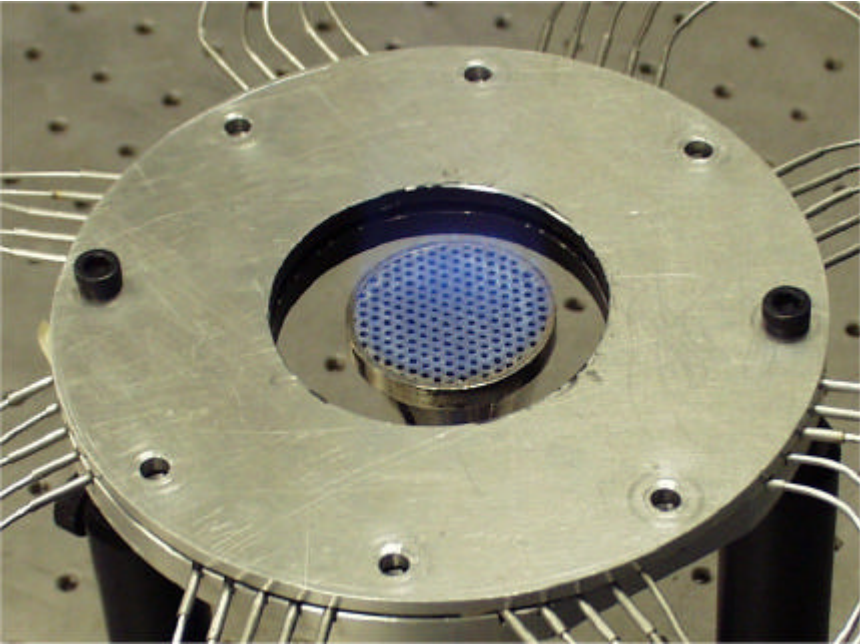
The acceptance cone of the fibres fitted to the area



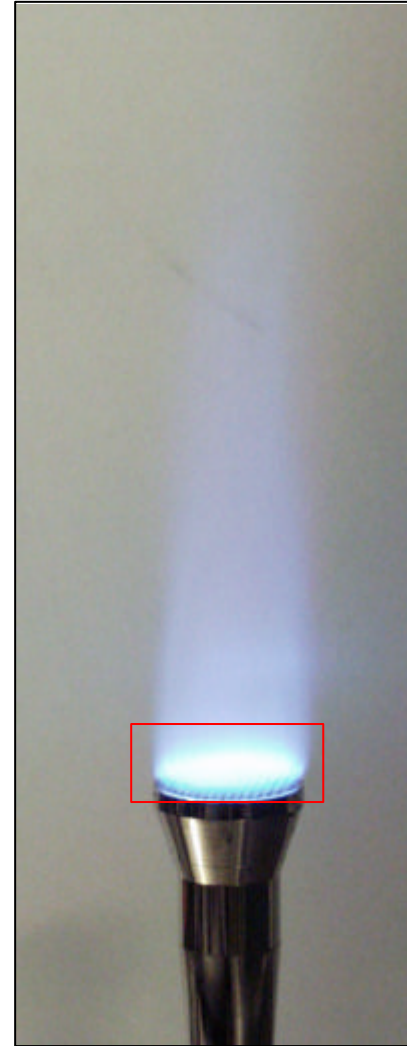
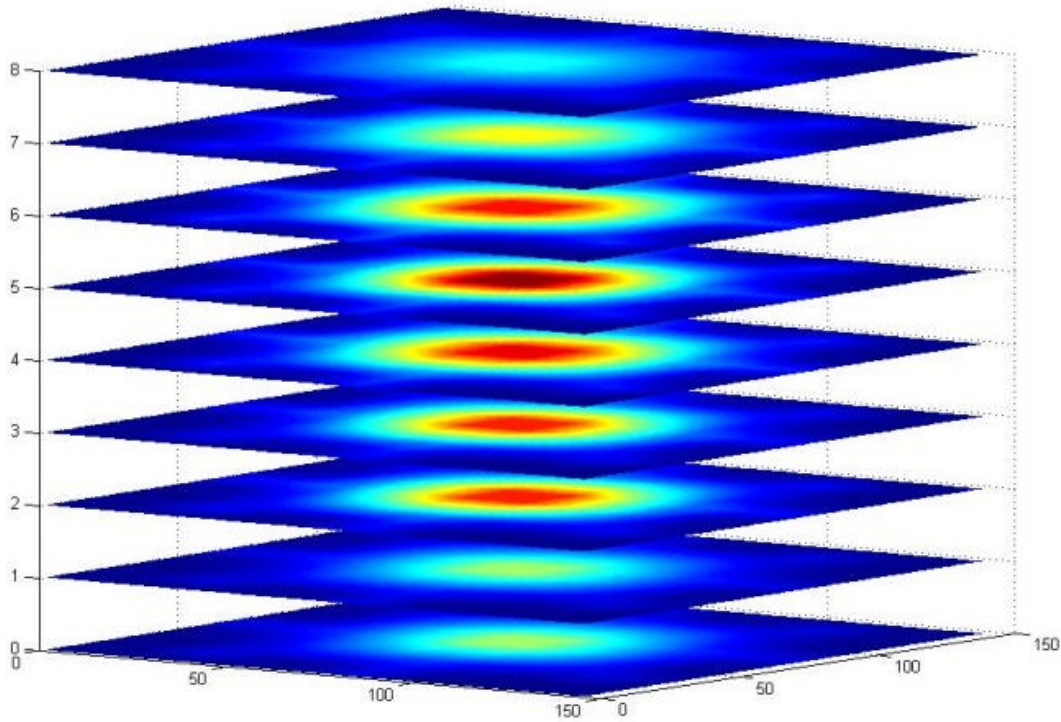
Photograph of Array



Preliminary Results

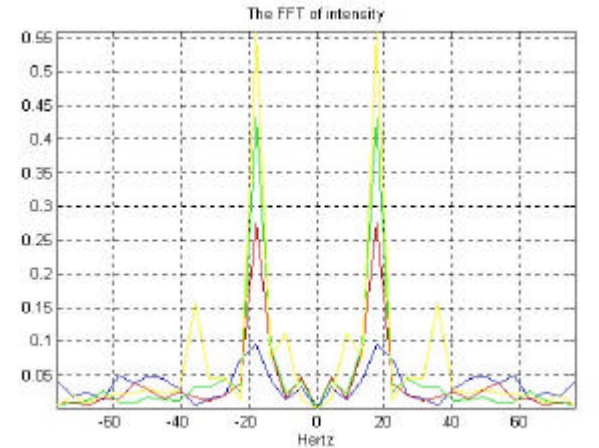
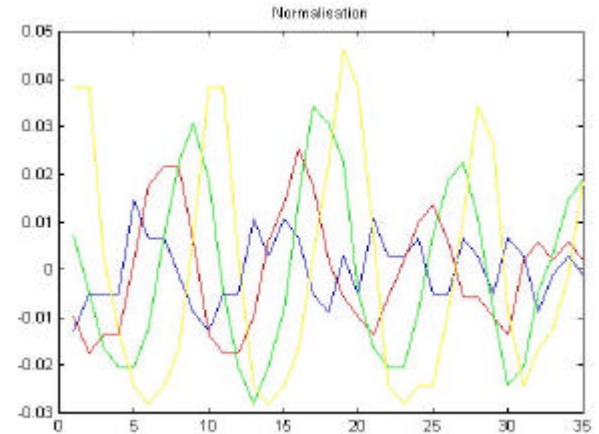
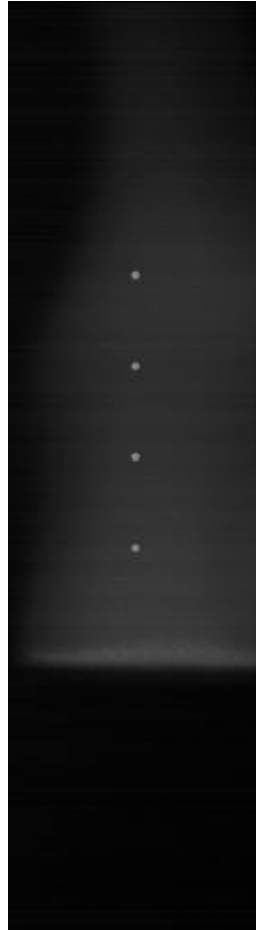


Preliminary Testing



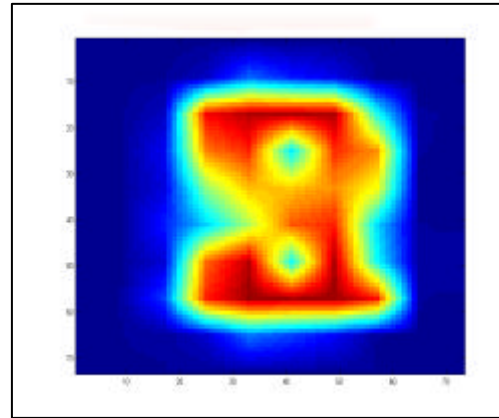
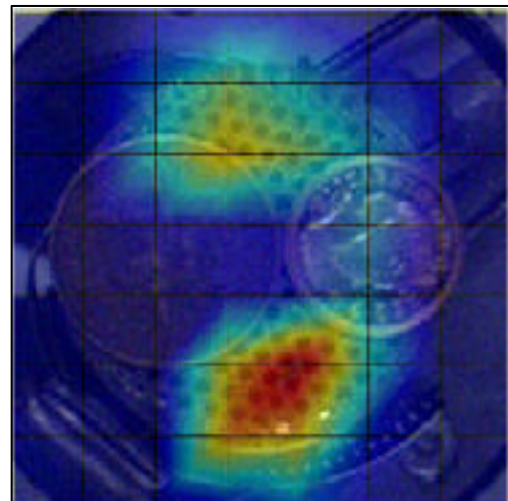
Preliminary Testing

- Images taken using a fast frame camera, 1000fps.
- FFT analysis completed using pixel intensities

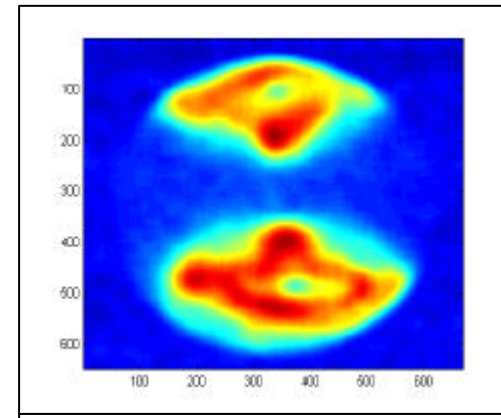


Preliminary Testing

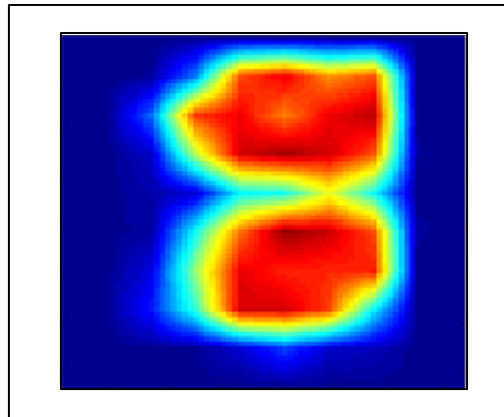
The burner has been modified by placing two coins on its base. The array result is shown, superimposed on a photograph of the modified burner.



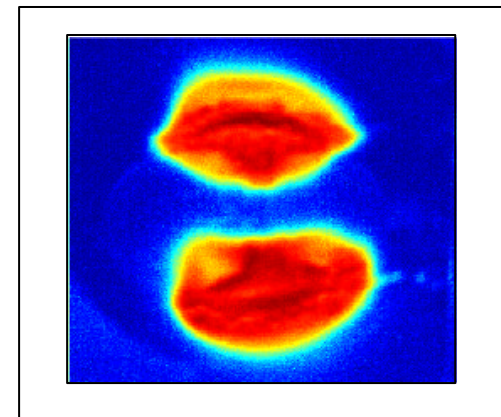
Single thermocouple scan



Single Photograph of OH modified for colour intensity

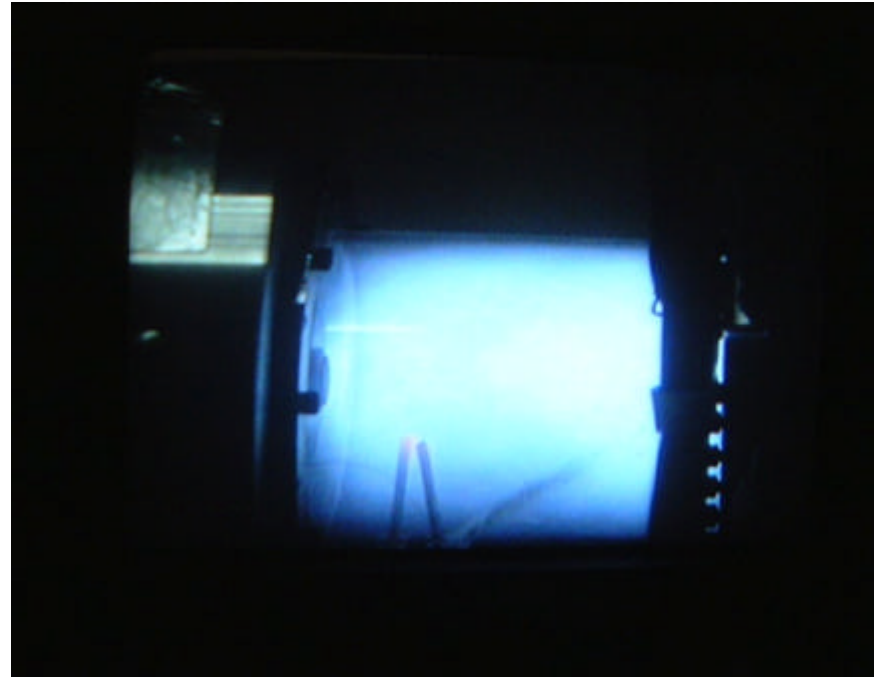
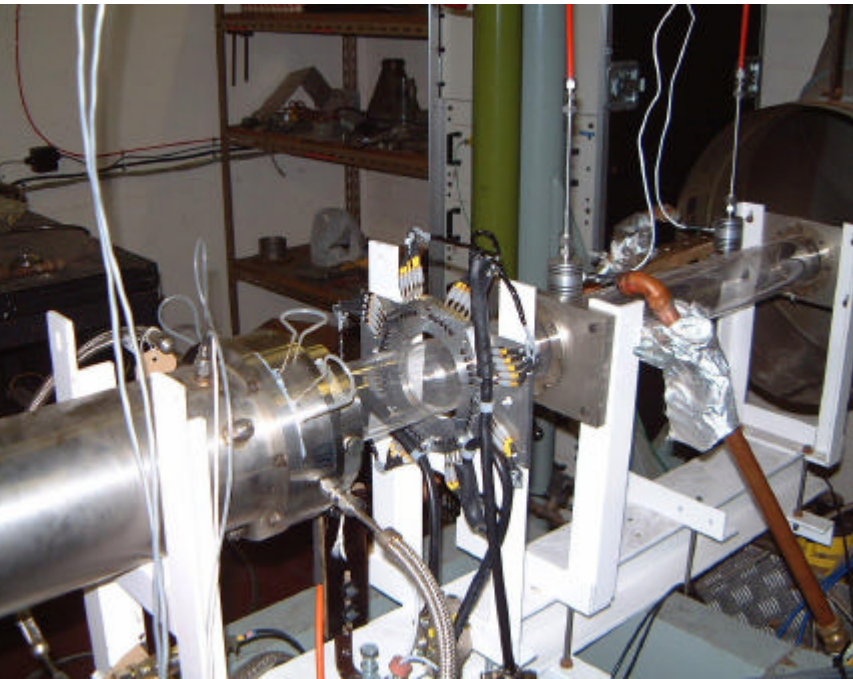


Averaged thermocouple result



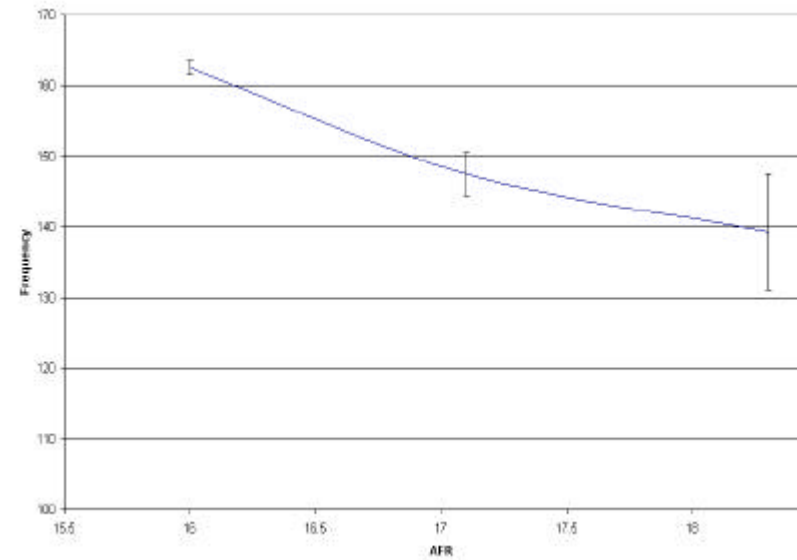
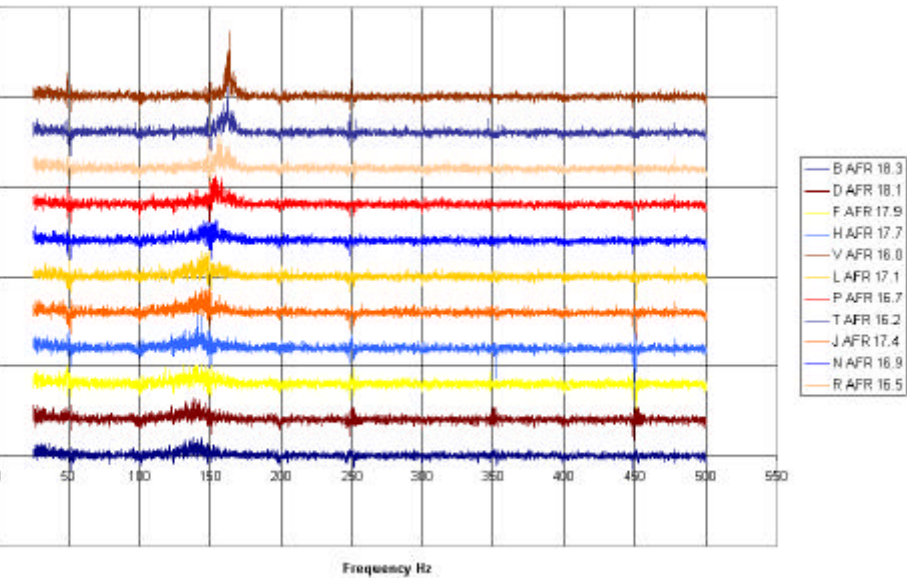
Average of three photographs

Rolls-Royce Testing



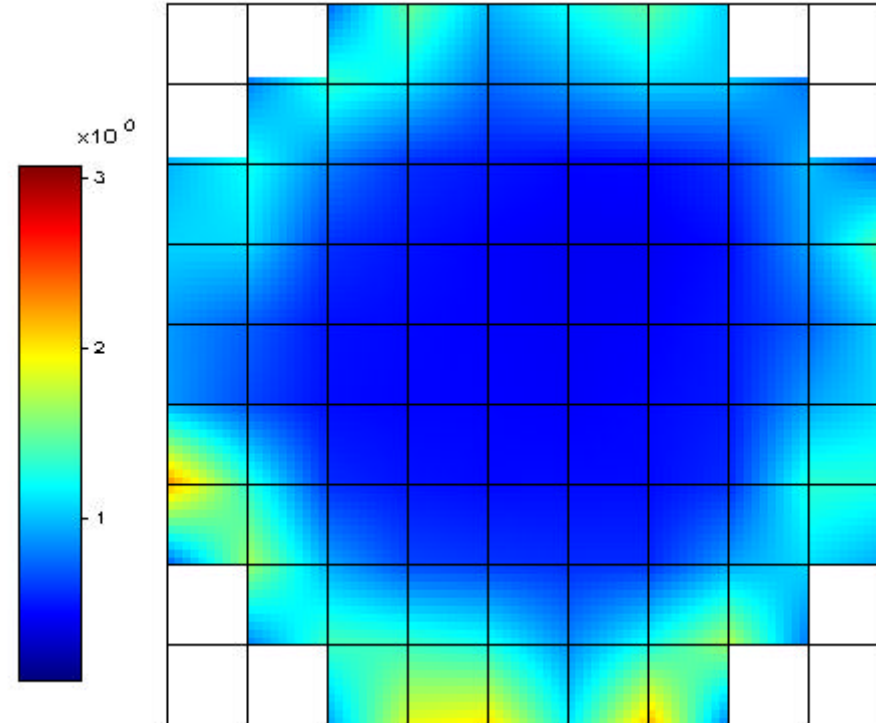
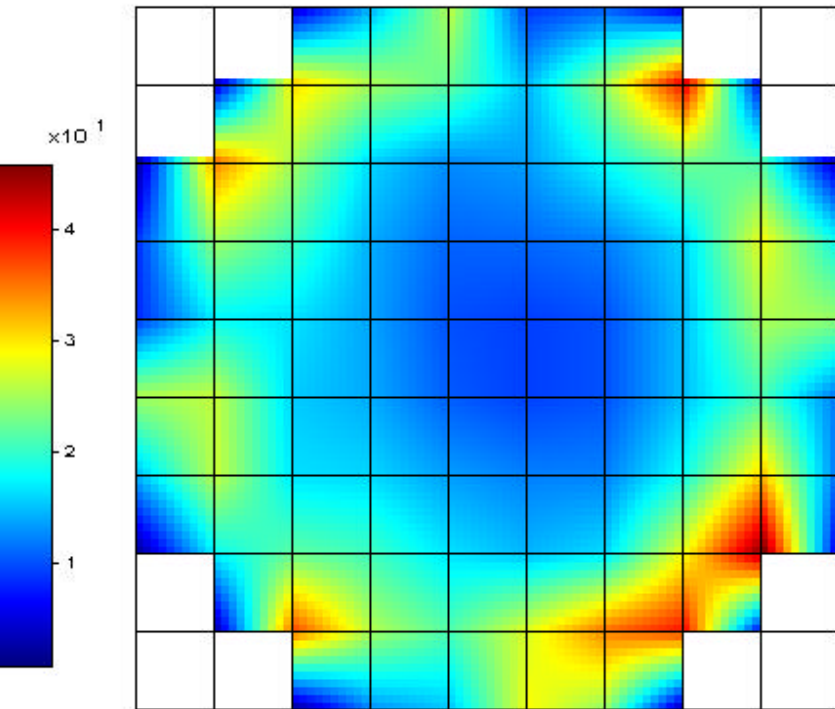
Rolls-Royce Testing

Frequency Analysis:



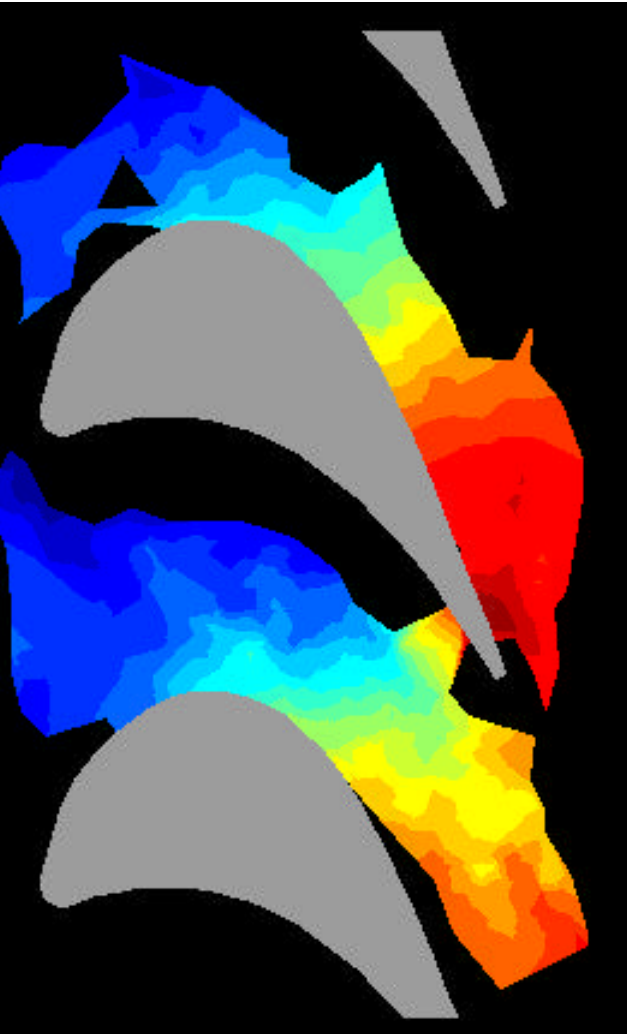
Rolls-Royce Testing

Reconstruction:



Conclusions

- The array has met the original specifications
- The array can accurately reconstruct the OH radical from optically thin hydrocarbon flames.
- The array has proven to be a valuable diagnostic in viewing flame instabilities



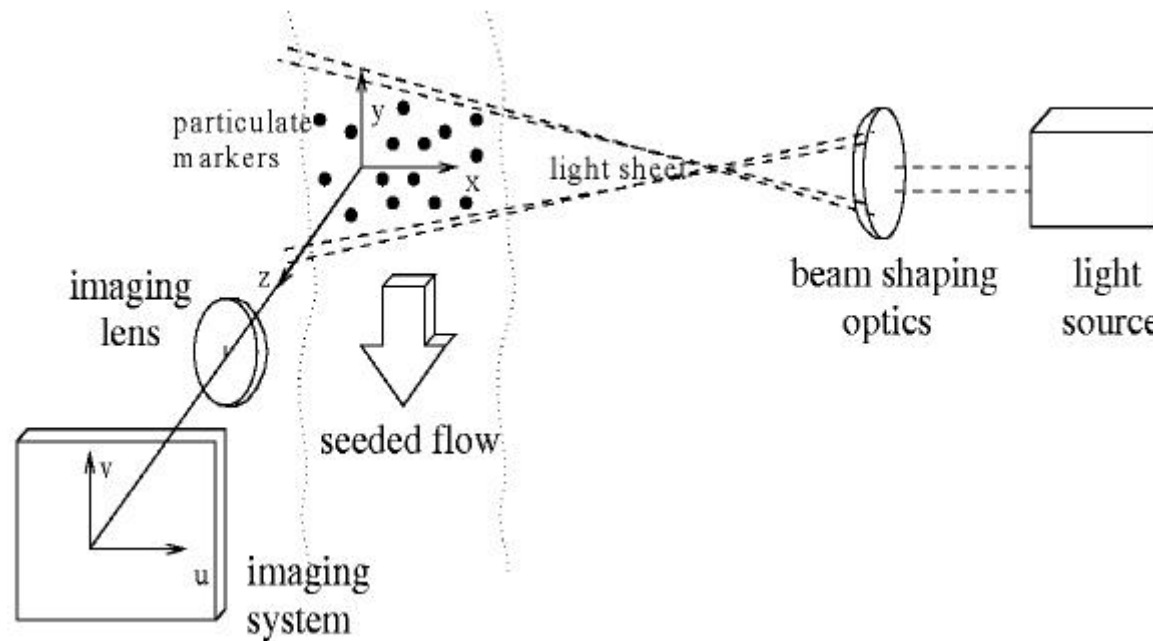
The objective of PIV (Particle Image Velocimetry) in this transonic application was to velocity map the flow through a rotating transonic annular cascade.

The measurements also show an instantaneous mapping of the turbine wake.

Particle Image Velocimetry (PIV)

Principle of Operation

A schematic representation of a PIV system



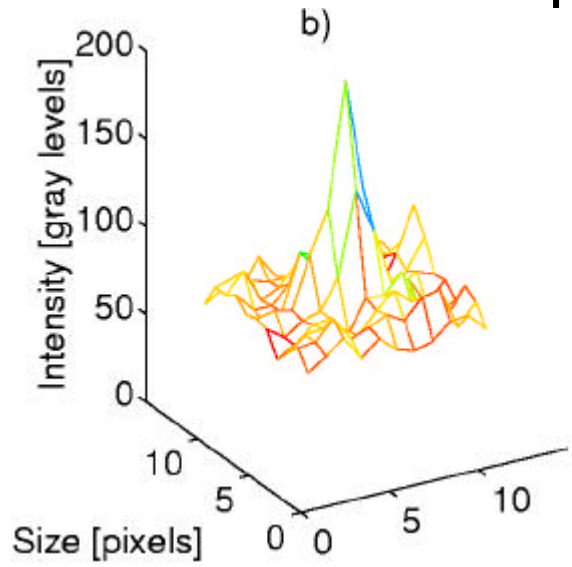
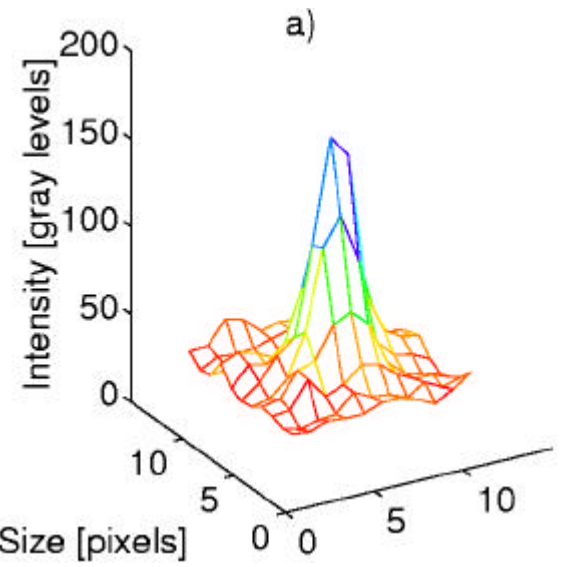
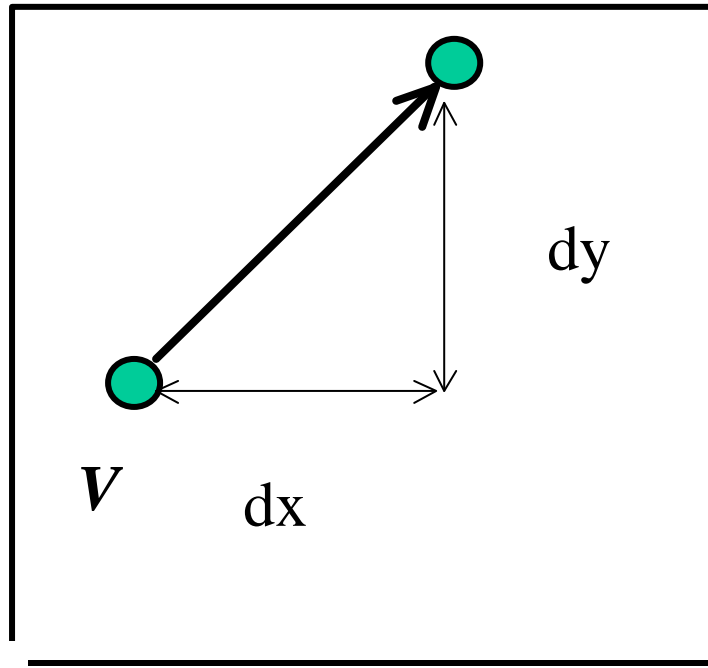
PIV is a technique that has the potential to make an instantaneous velocity measurement of the whole flow field.

In concept the technique is simple.

It reduces the instantaneous measurement of the flow to an imaging process

P.I.V.

- Particle Image Velocimetry (PIV)
- Pulsed, narrow 2-d, plane of light
- Flow seeded with tracers
- Images captured



$$\bar{V} = \left(\frac{\Delta x}{\Delta t}, \frac{\Delta y}{\Delta t} \right)$$

Cross-correlation

- Initial positions of particles recorded on separate image to final positions

Advantages:

- velocity direction as well as magnitude is known
- zero and near-zero velocities can be measured
- more robust velocity results are obtained

Cross-correlation example

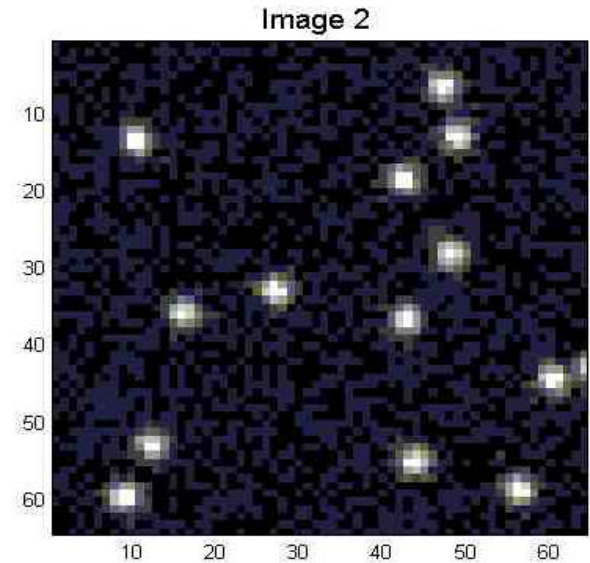
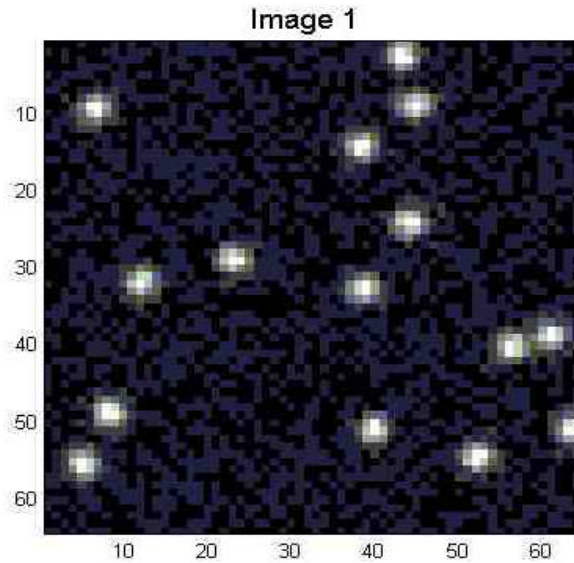


Image 1 and Image 2 show simulated particle images at time instants $t = t_1$ and $t = t_2$ respectively. Particles are shifted by 4 pixels in positive x and y directions as they move from Image 1 to Image 2.

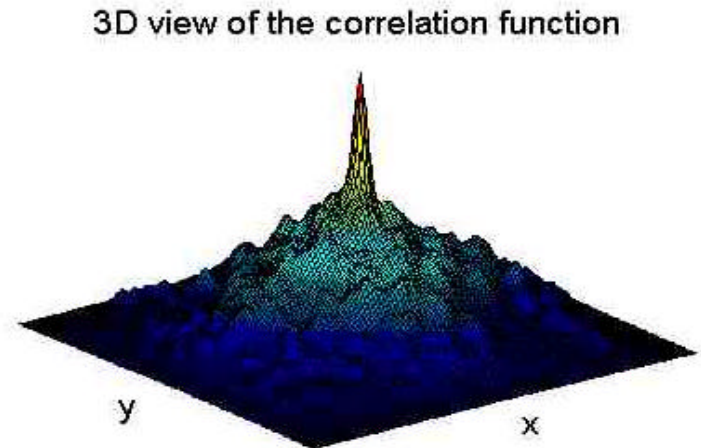
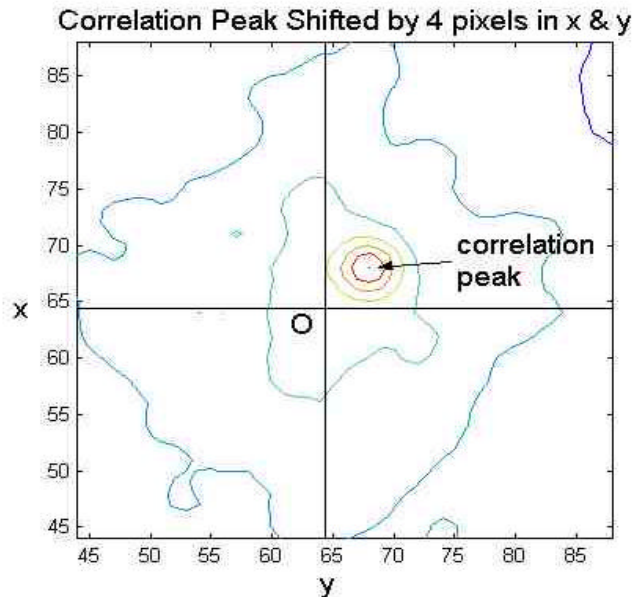
Cross-correlation example

The average displacement obtained by performing cross-correlation.

A statistical method aiming to determine the relation of the data contained in the images.)

The correlation function yields a maximum value corresponding to the shift in pixels.

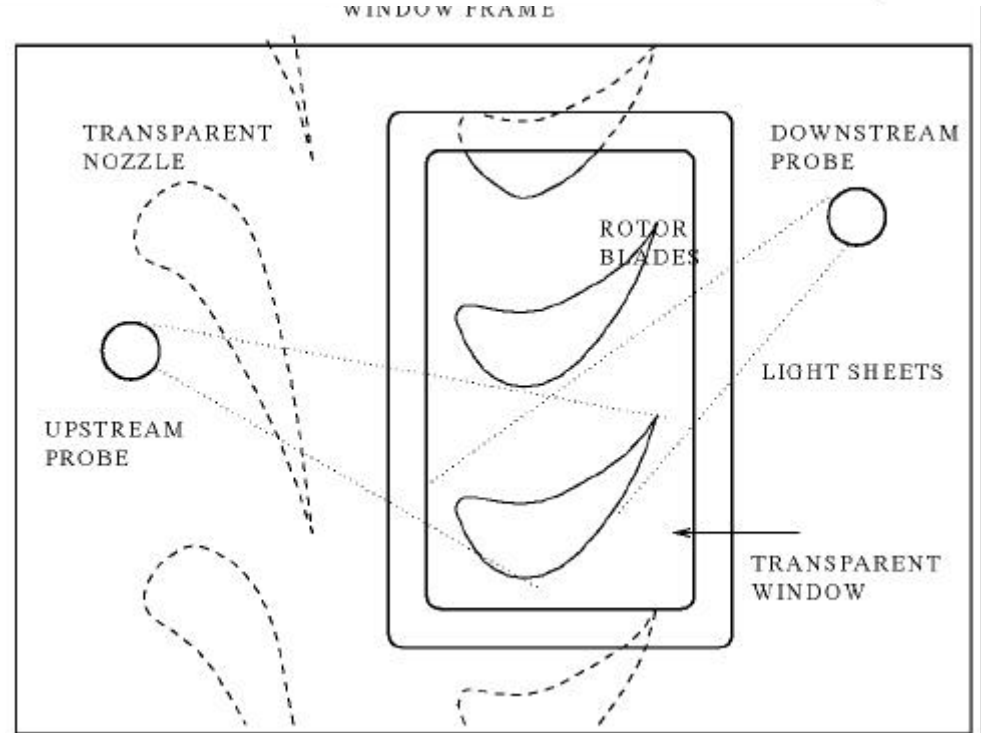
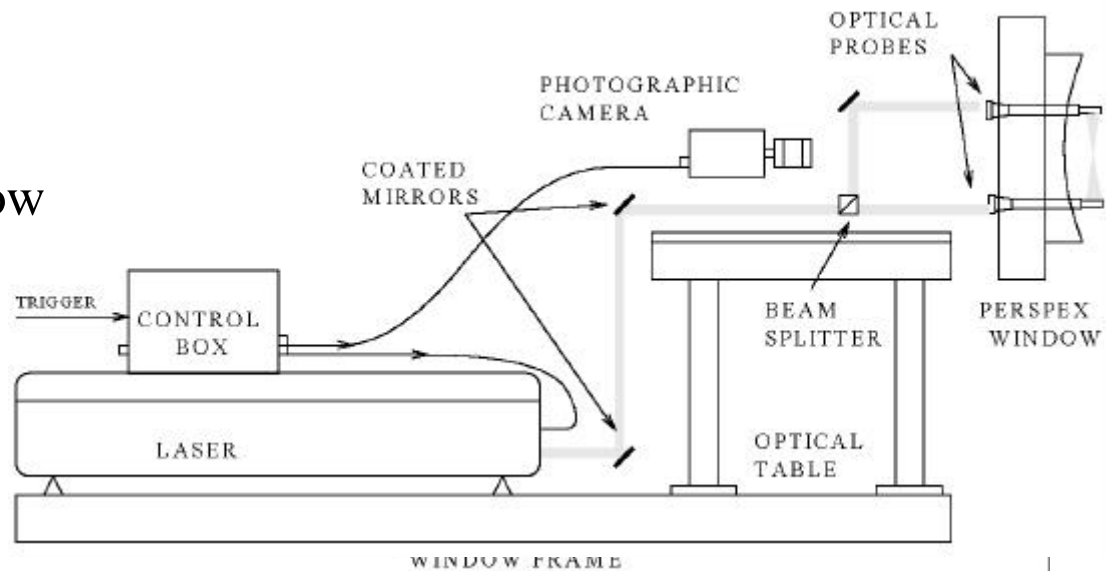
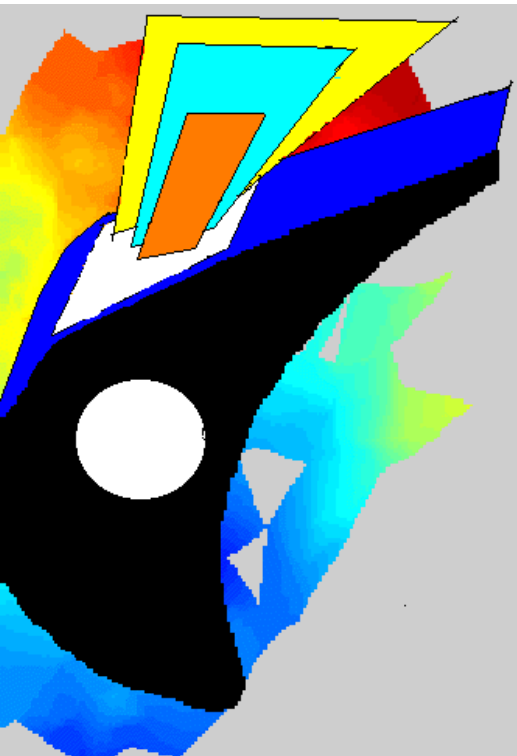
The diagrams show the peak is shifted by 4 pixels in each direction with a distinctive maximum value.



Optical systems:

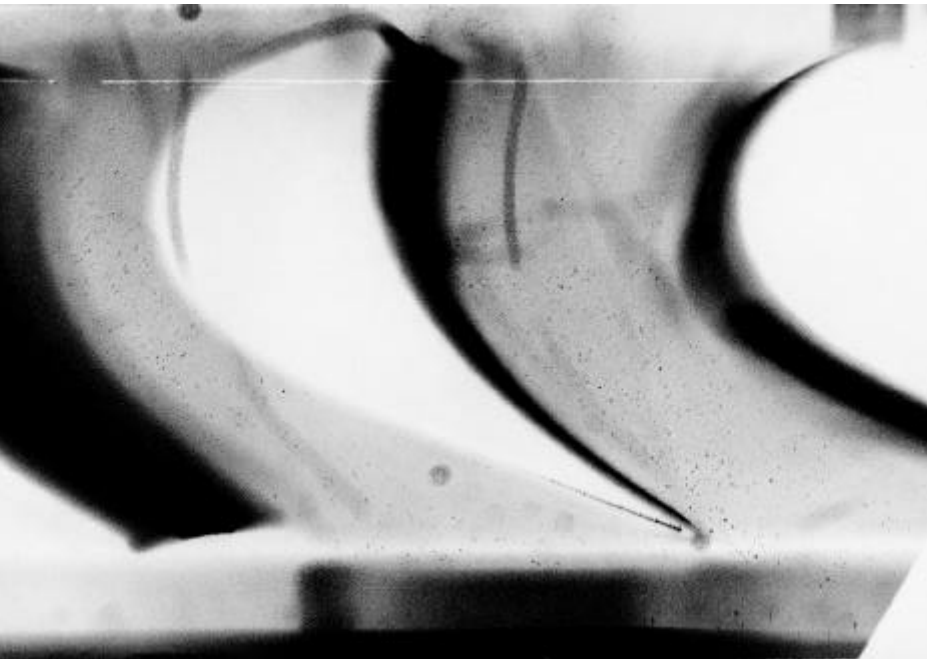
for RAe the stator was made hollow

for MIT the stator was made of transparent material



The application of PIV

Particle measurement is non-trivial



Density of seeding

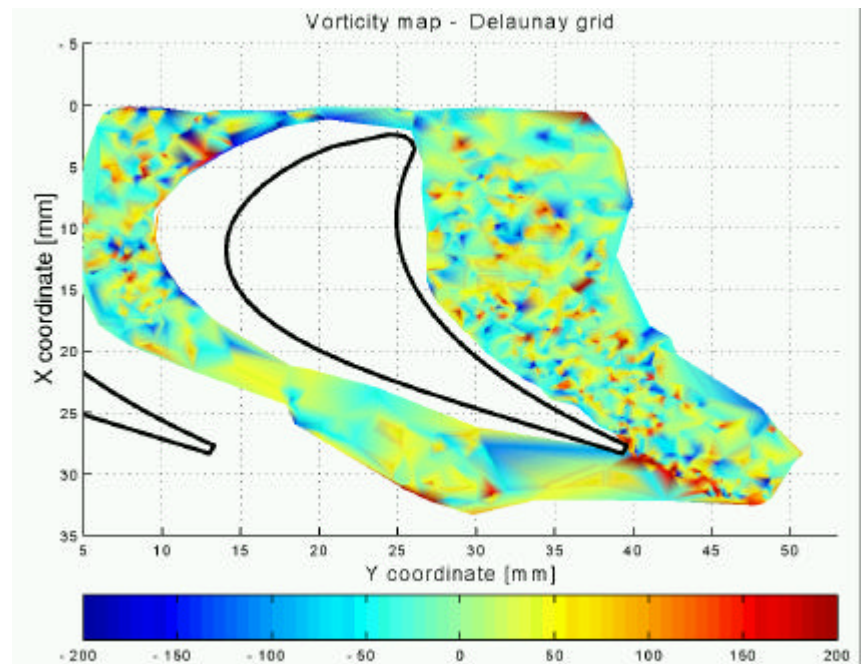
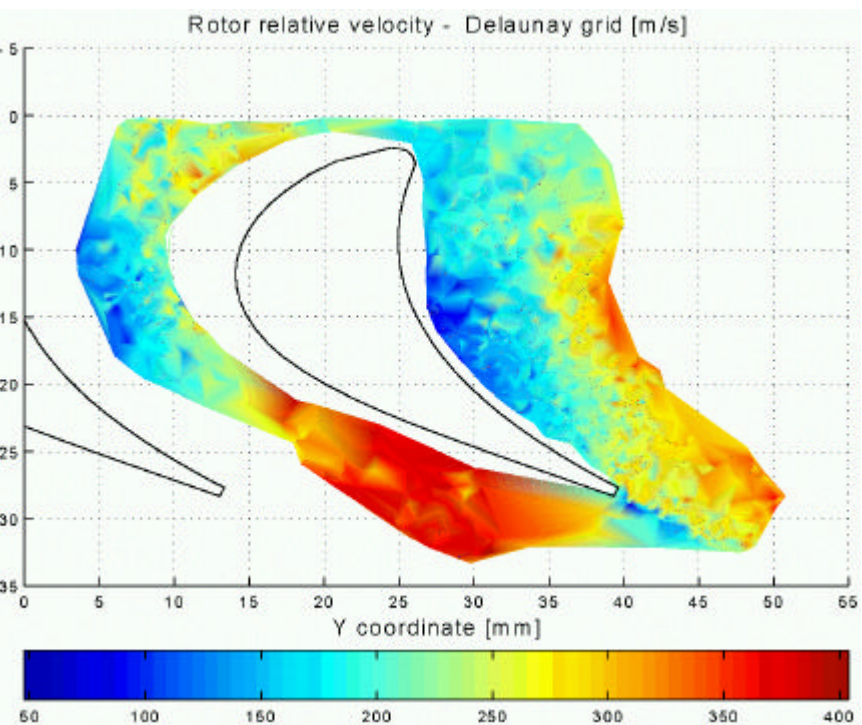
Size of seeding (0.2-1 micron)

3-D nature of the flow

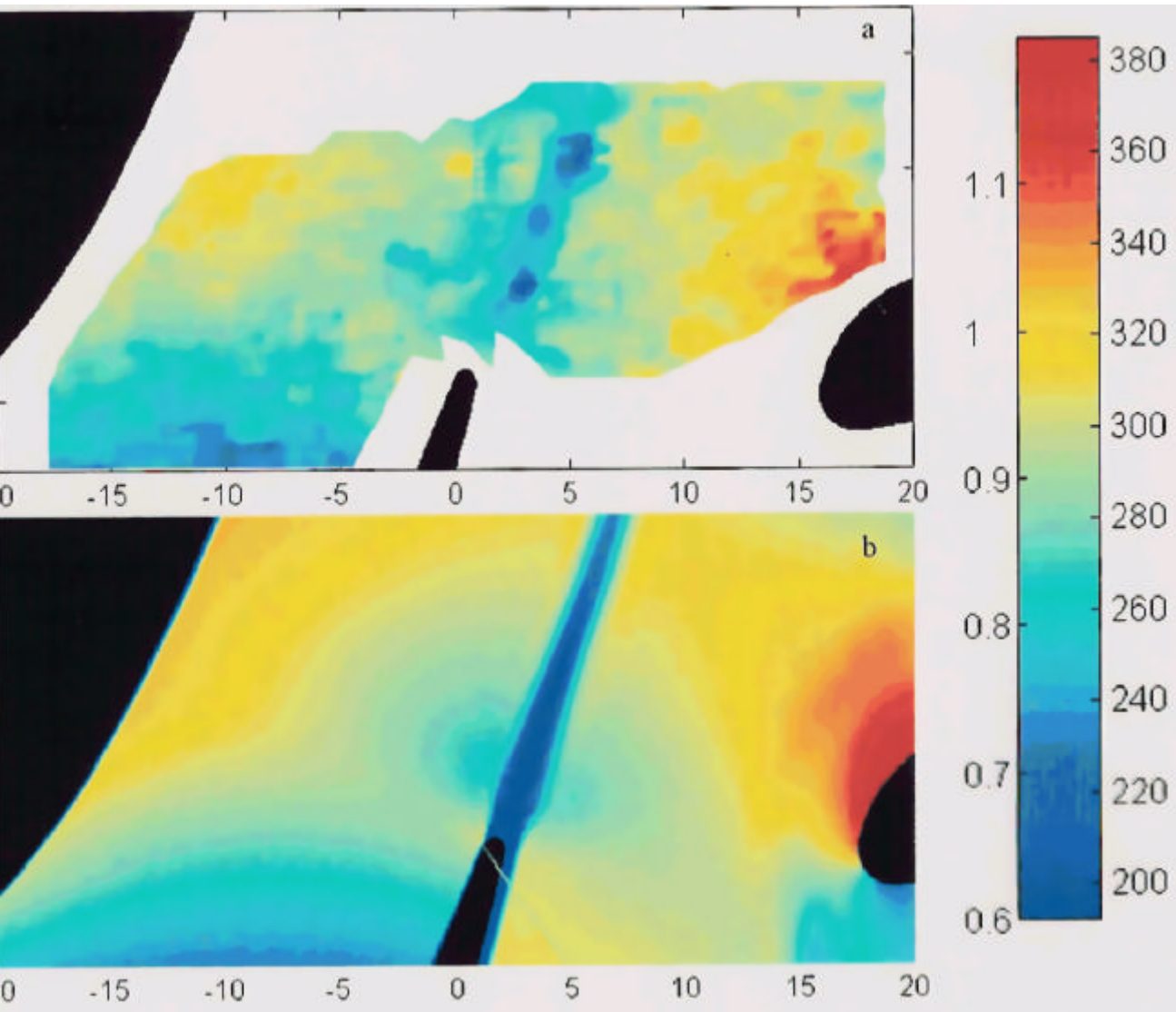
Type of light source

Resolution and type of digital camera

The application of PIV to Turbomachinery



The Application of PIV.



Comparison between prediction & measurement

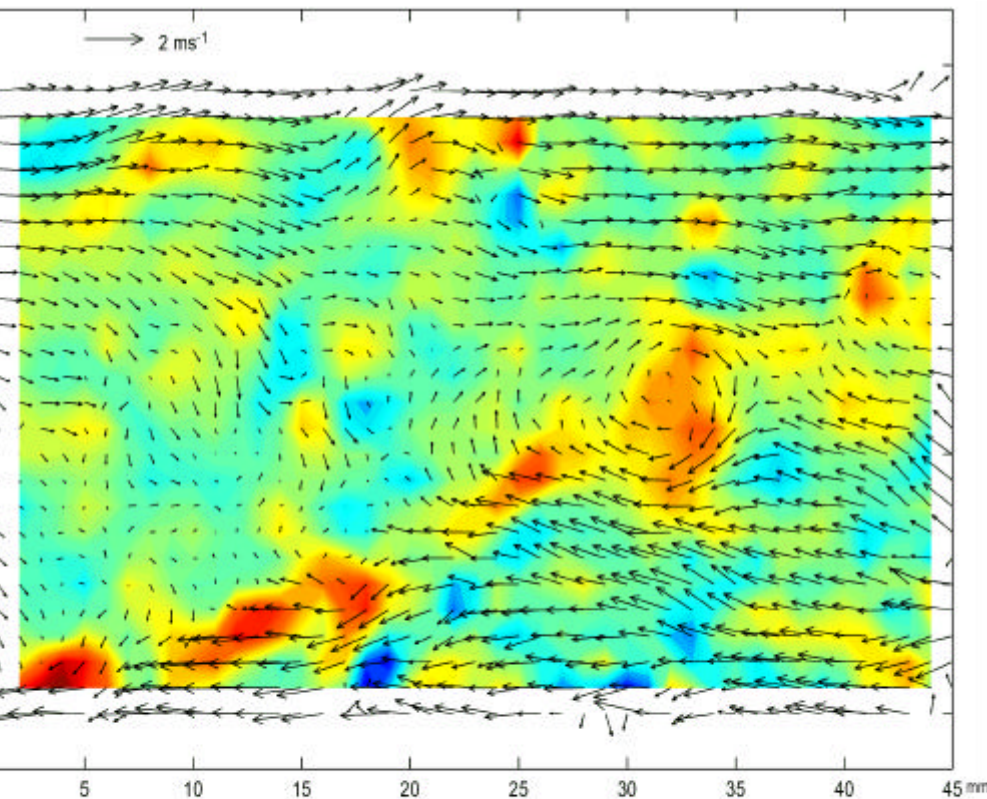
Velocities are shown in m/s and the X,Y coordinates are given in meters

The calculation was run on the spinning rotor in a 'blow-down' transonic turbine test facility at Pyestock

Turbulent flow Structures

PIV has a major advantage in that it can show the instantaneous structure of the flow

The example shows how a turbulent boundary layer structure can be resolved.

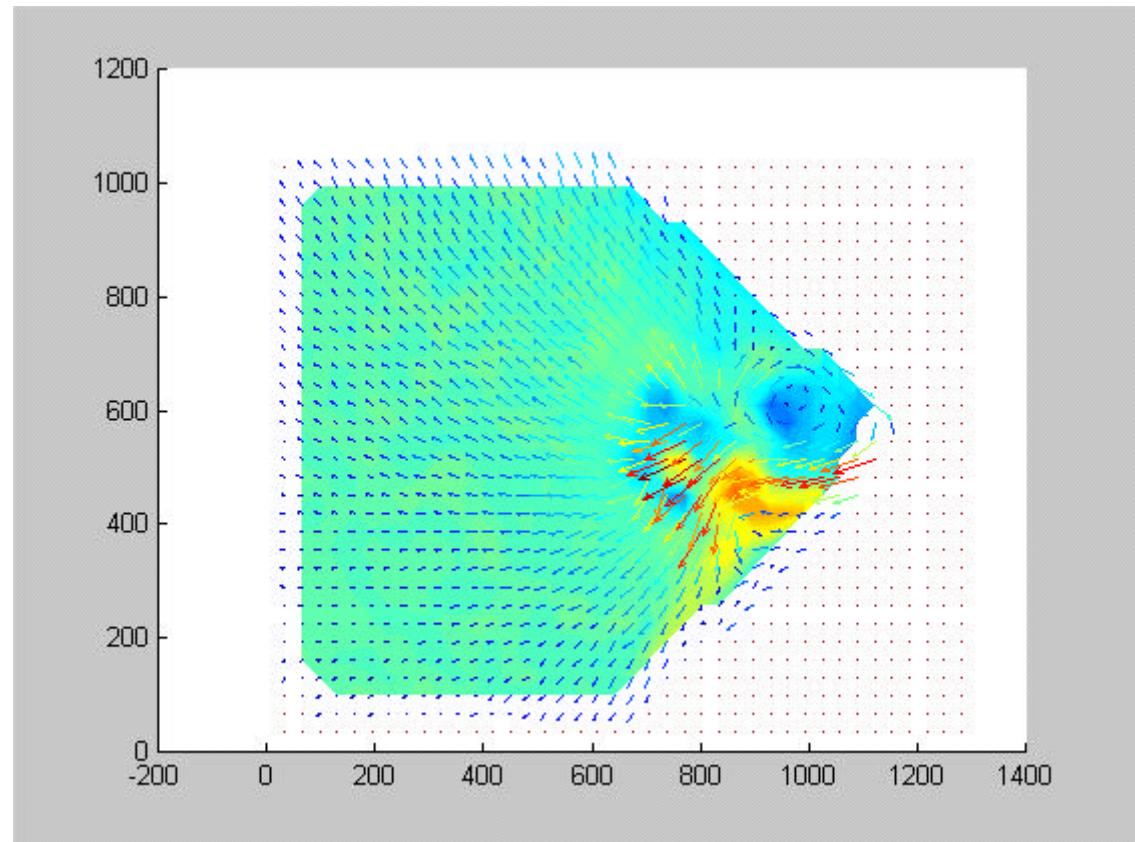


Multiple Frame PIV

This is an experiment on a very slowly rotating flow. Using this flow it has been possible to explore mathematical processing needed to solve PIV images.

Firstly a detailed velocity map has been created.

Then, the vortex structure has been calculated and a sequence of digital images have been animated to show the starting jet.



The application of PIV to Turbomachinery: Conclusions

Seeding at transonic speeds at a suitable density is very difficult.

The previous sequence was made at 4Hz over a series of experimental runs of 2s duration. Multifame sequential images are needed to track large scale disturbances.

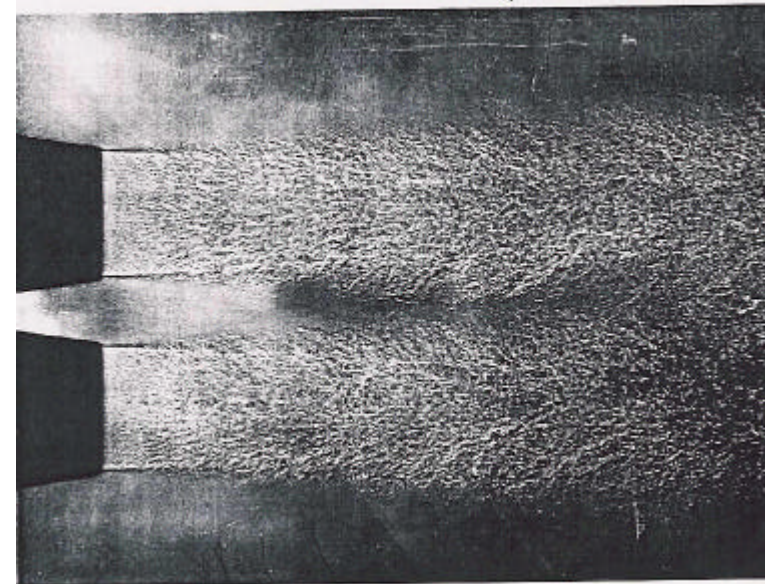
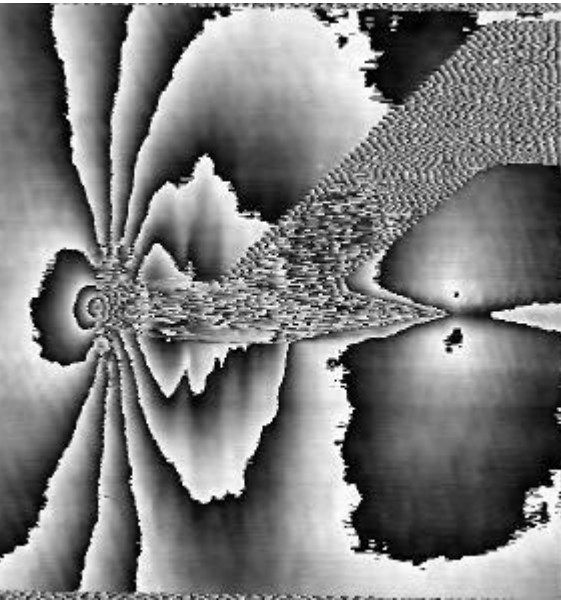
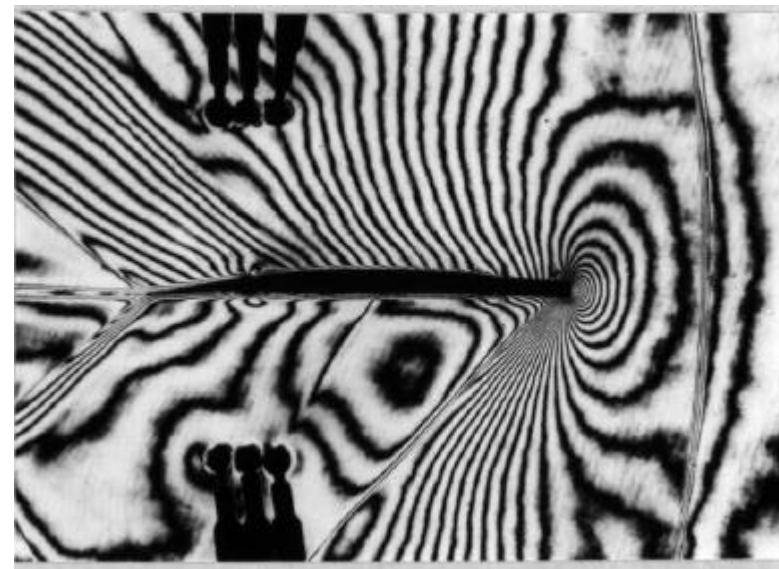
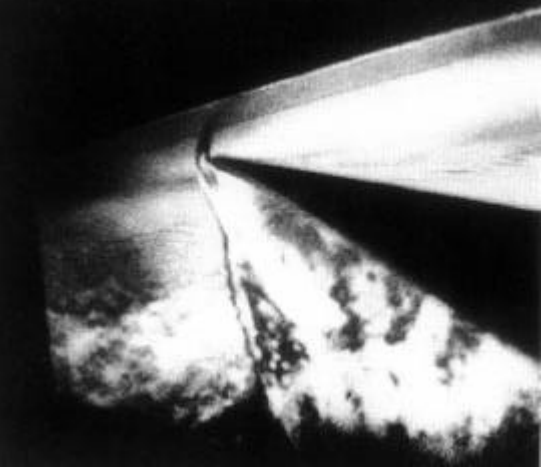
The shocks were very weak and were not visualised in this exercise.

It did not show wake structures passing through the passage at transonic speeds.

It did not show the 3D nature of the flow. This possible, but requires a two camera approach.

The velocity measurements were accurate to 4%.





Tomographic Array for Combustion Measurement

