

Visualization of Flow in a Transonic Centrifugal Compressor

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Summary

How is the flow in a rotating impeller. About 35 years have passed since one experimentalist rotating with the impeller of a huge centrifugal blower made the flow measurements using a hot-wire anemometer (Fowler 1968). Optical measurement methods have great advantages over the intrusive methods especially for the flow measurement in a rotating impeller. One is the optical flow visualization (FV) technique (Senoo, et al., 1968) and the other is the application of laser velocimetry (LV) (Hah and Krain, 1990). Particle image velocimetries (PIVs) combine major features of both FV and LV, and are very attractive due to the feasibility of simultaneous and multi-points measurements (Hayami and Aramaki, 1999).

A high-pressure-ratio transonic centrifugal compressor with a low-solidity cascade diffuser was tested in a closed loop with HFC134a gas at 18,000rpm (Hayami, 2000). Two kinds of measurement techniques by image processing were applied to visualize a flow in the compressor. One is a velocity field measurement at the inducer of the impeller using a PIV and the other is a pressure field measurement on the side wall of the cascade diffuser using a pressure sensitive paint (PSP) measurement technique. The PIV was successfully applied for visualization of an unsteady behavior of a shock wave based on the instantaneous velocity field measurement (Hayami, et al., 2002b) as well as a phase-averaged velocity vector field with a shock wave over one blade pitch (Hayami, et al., 2002a, b). A violent change in pressure was successfully visualized using a PSP measurement during a surge condition even though there are still some problems to be overcome (Hayami, et al., 2002c). Both PIV and PSP results are discussed in comparison with those of laser-2-focus (L2F) velocimetry and those of semiconductor pressure sensors.

Experimental fluid dynamics (EFDs) are still growing up more and more both in hardware and in software. On the other hand, computational fluid dynamics (CFDs) are very attractive to understand the details of flow. A secondary flow on the side wall of the cascade diffuser was visualized based either steady or unsteady CFD calculations (Bonaiuti, et al., 2002). EFD and CFD methods will be combined to a hybrid method being complementary to each other. Measurement techniques by image processing as well as CFD calculations give a huge amount of data. Then, data mining technique will become more important to understand the flow mechanism both for EFD and CFD.

References

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- Introduction
- PIV
- PSP
- CFD

Fowler, H. S., 1968

Fowler, H. S., ASME, J. Eng. for Power, 90 (1968), 239.

Flow Measurement in Rotating Impeller

Relative flow

• Steady

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Absolute flow

• Periodically unsteady

Rotating sensor

- HW
- Pitot tube
- FV
- LV
- PIV

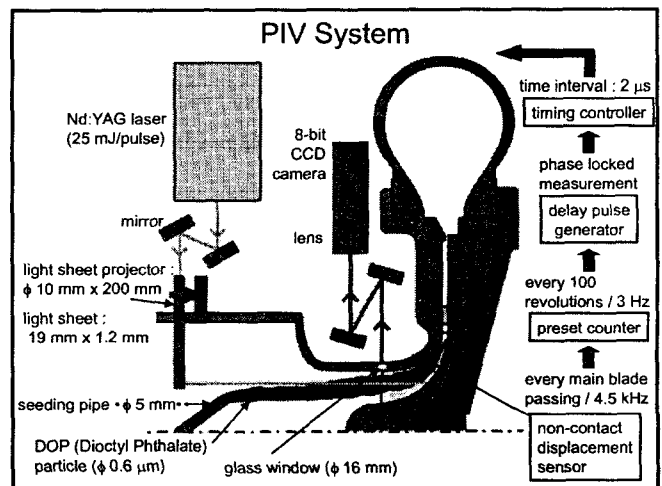
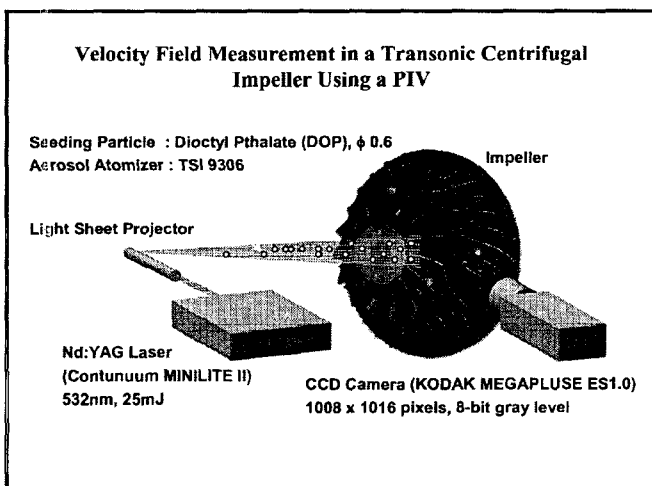
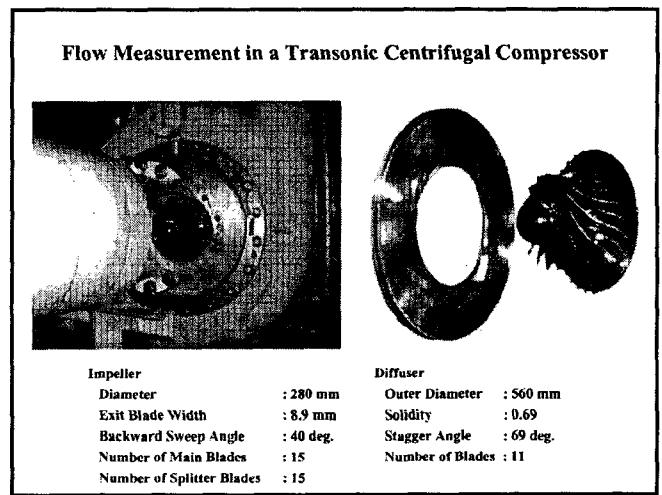
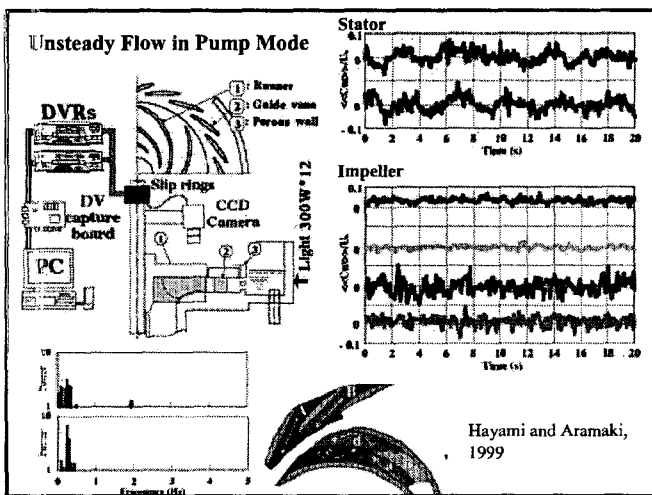
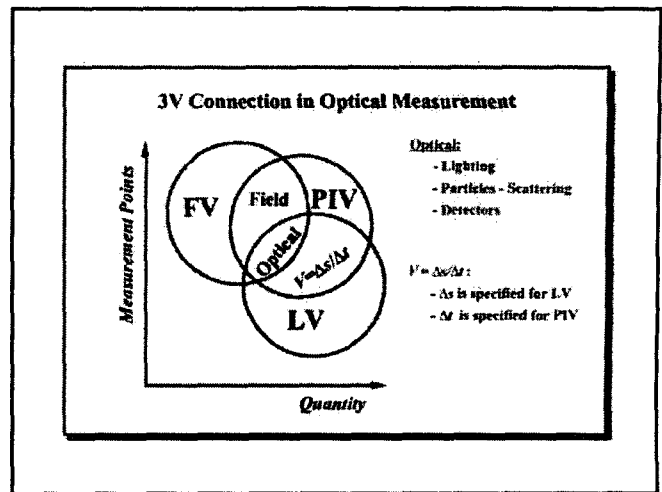
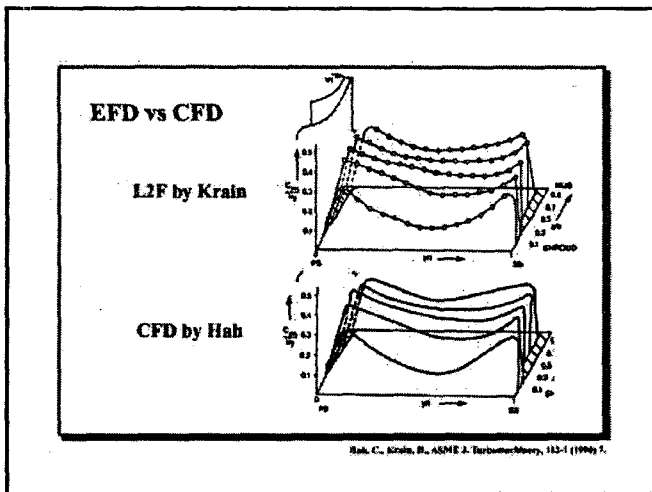
Stationary sensor

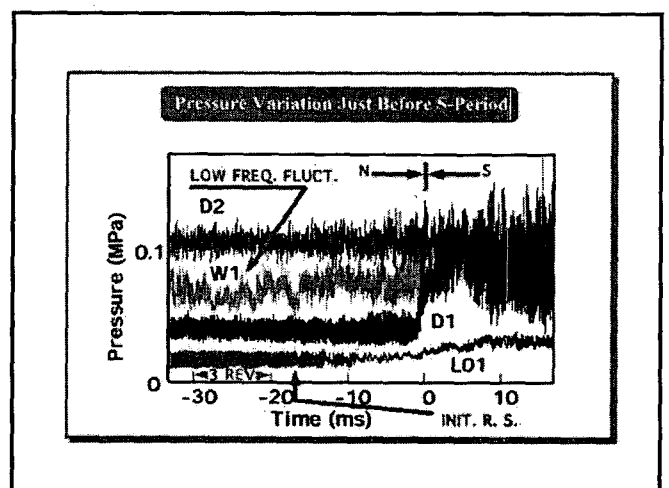
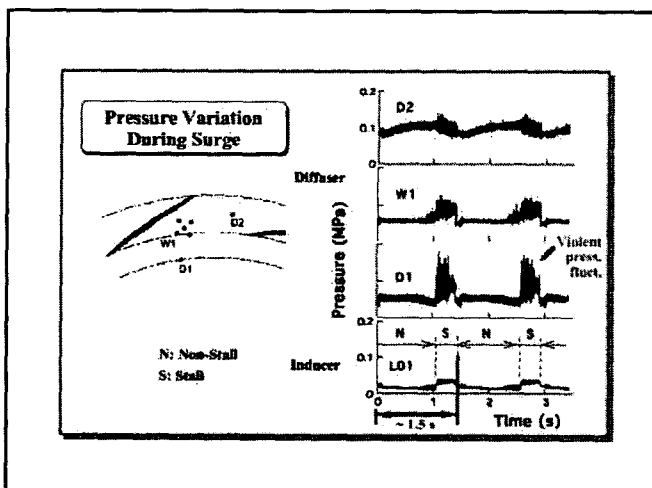
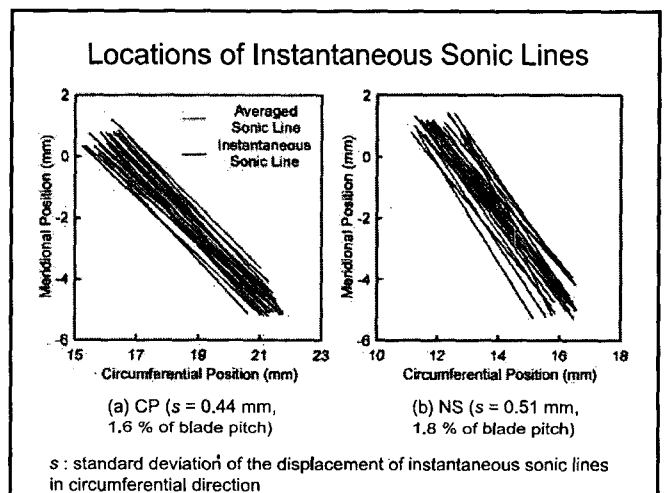
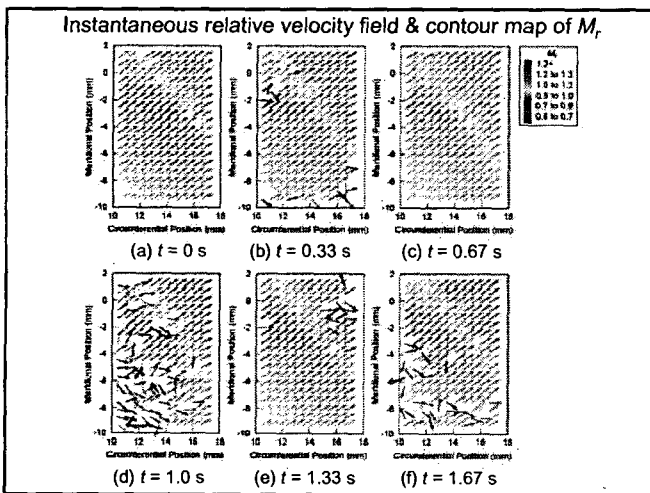
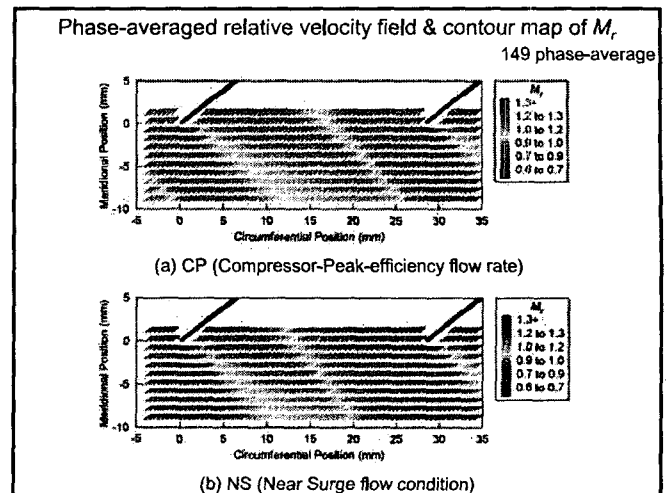
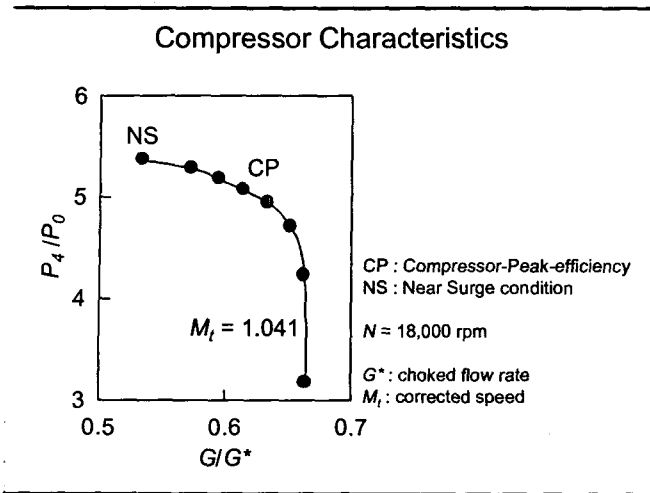
- FV
- LV
- PIV (non-intrusive)

Senoo, Y., Yamaguchi, M., Nishi, M., 1968 Streak Lines in Radial Compressor

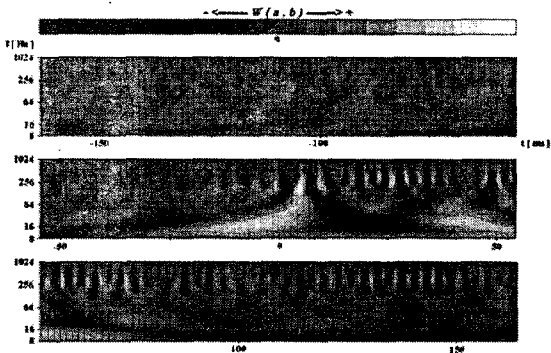
(a) Relative flow

(b) Absolute flow

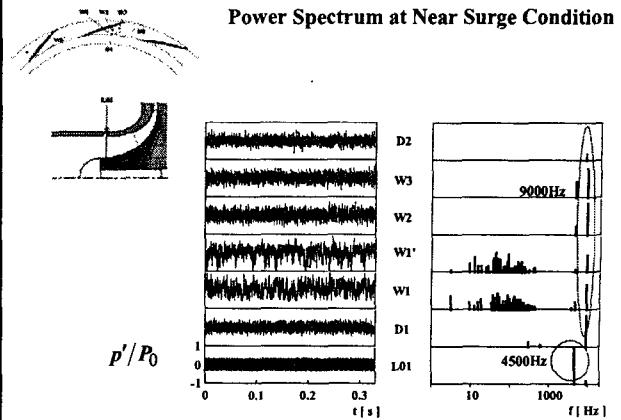




Wavelet Analysis of Pressure History in Surging (Low Frequency Part)



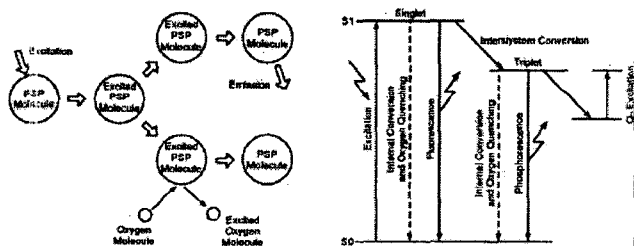
Power Spectrum at Near Surge Condition



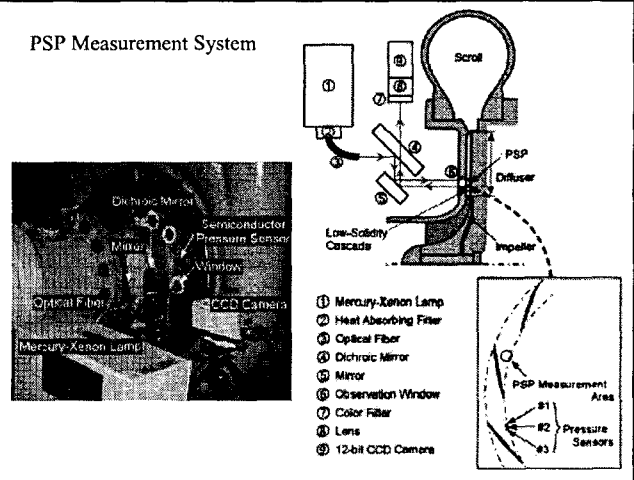
Application of PSP to Pressure Measurement Between Diffuser Vanes

$$\frac{I_{ref}}{I} = A + B \cdot \frac{P}{P_{ref}} + C \cdot \left(\frac{P}{P_{ref}}\right)^2 + \dots$$

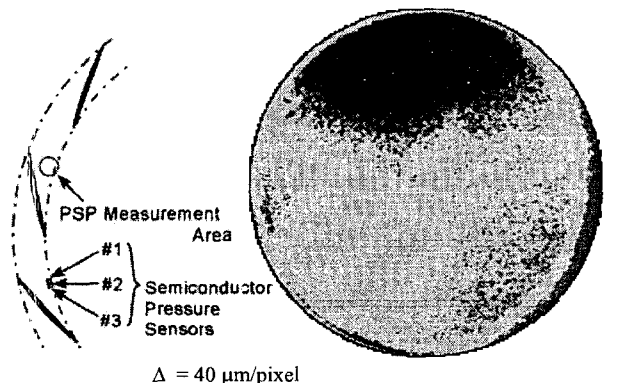
I : luminescent intensity
 P : pressure
 A, B and C : constant coefficients
 ref : value of reference condition



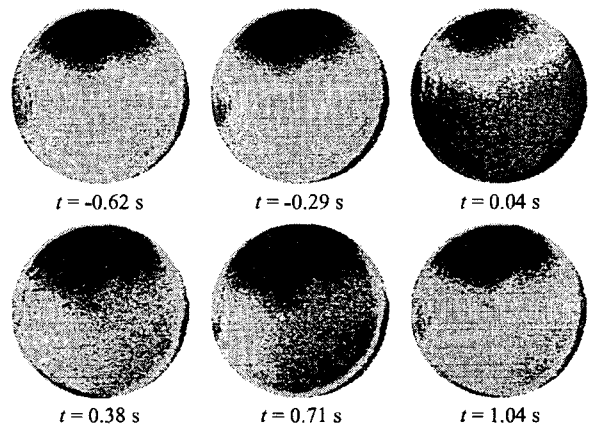
PSP Measurement System

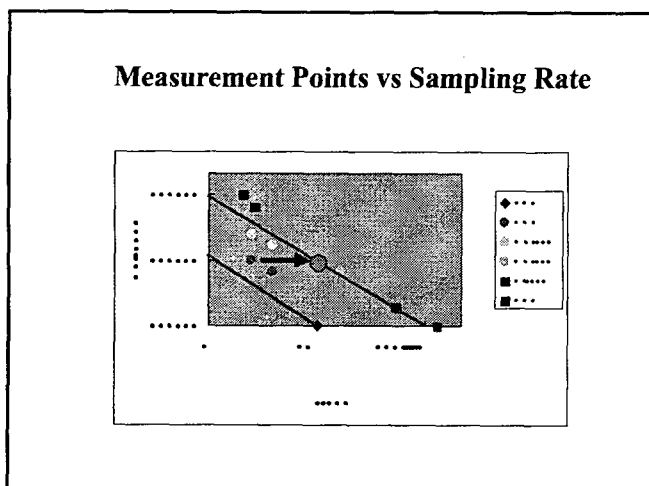
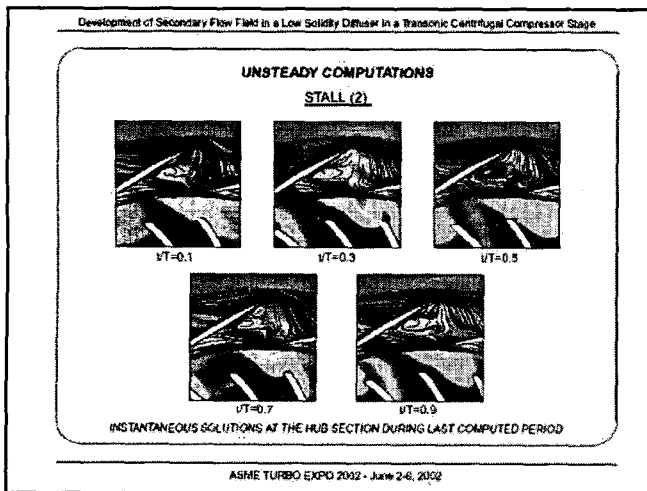
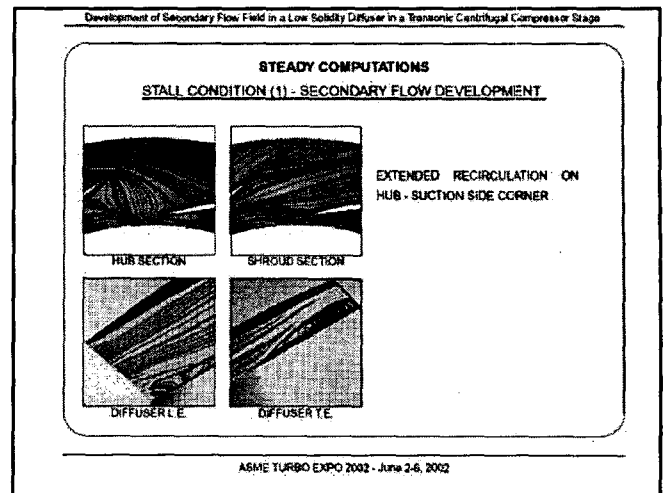
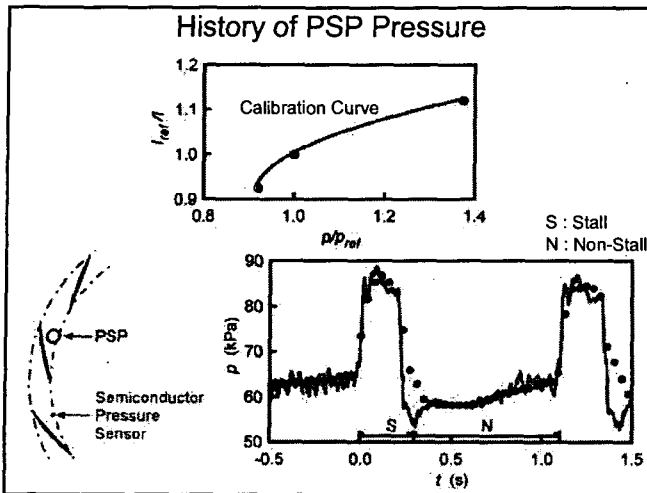


Visualized Pressure Field During Surge



Time Sequence of Luminescent Intensity for 1.66 s





Conclusions

- PIV was successfully applied to catch the instantaneous location of shock waves.
- PSP was successfully applied to catch the surge phenomenon.
- CFD demonstrated the complex secondary flow on the side wall of cascade diffuser.
- Measurement techniques by image processing as well as CFD calculations give a huge amount of data. Then, data mining technique will become more important to understand the flow mechanism both for EFD and CFD.