# 20th SYMPOSIUM ON INDUSTRIAL APPLICATIONS OF GAS TURBINES

## Experimental Investigation of the Influence of Service Exposure Upon the Aerodynamic Performance of Transonic Turbine Vanes

**13-IAGT-305**


| | |
|---|---|
| **Ray Woodason** | **StandardAero** |
| Dr A. Asghar | Royal Military College |
| Dr W.D.E. Allan | Royal Military College |



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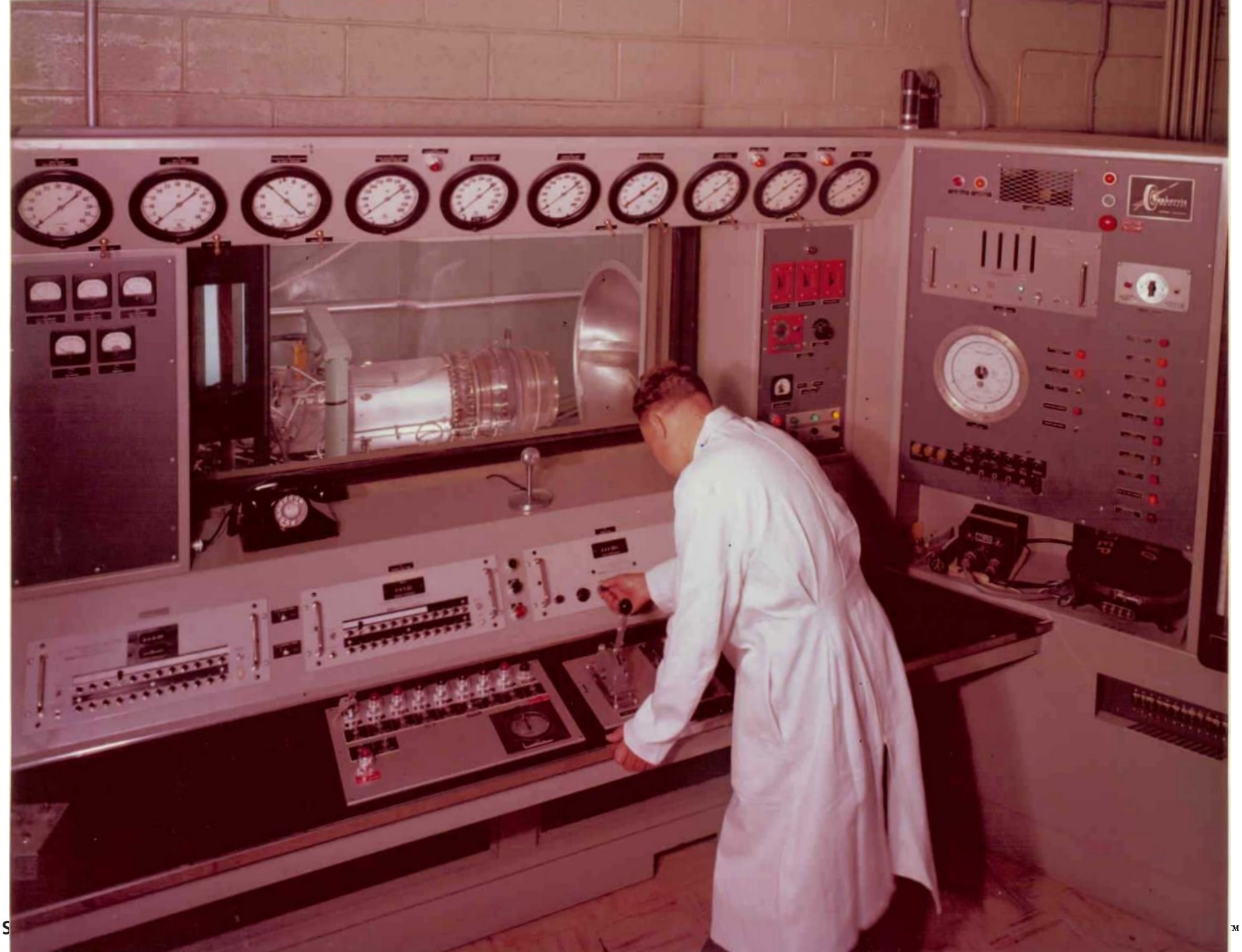
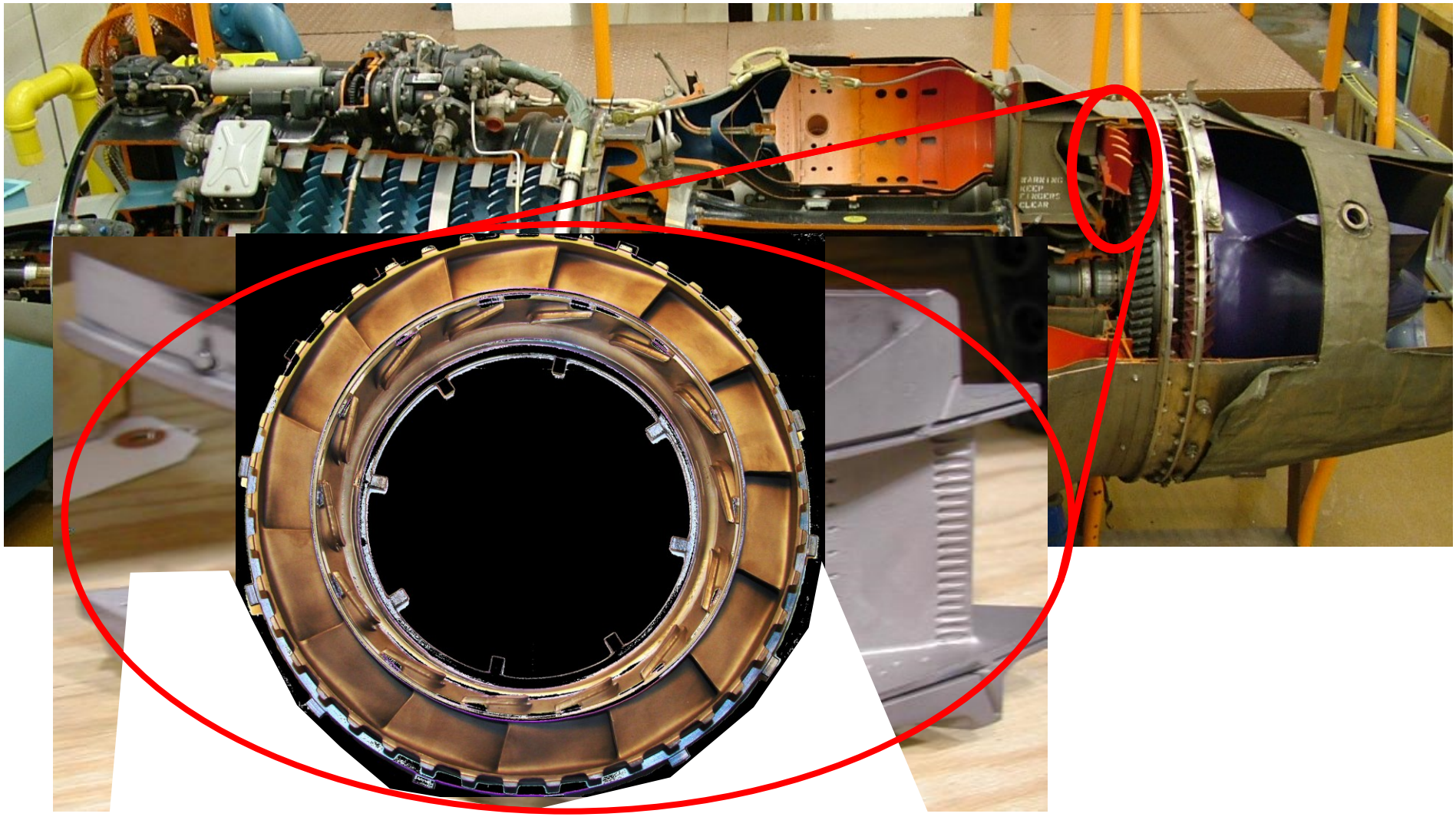


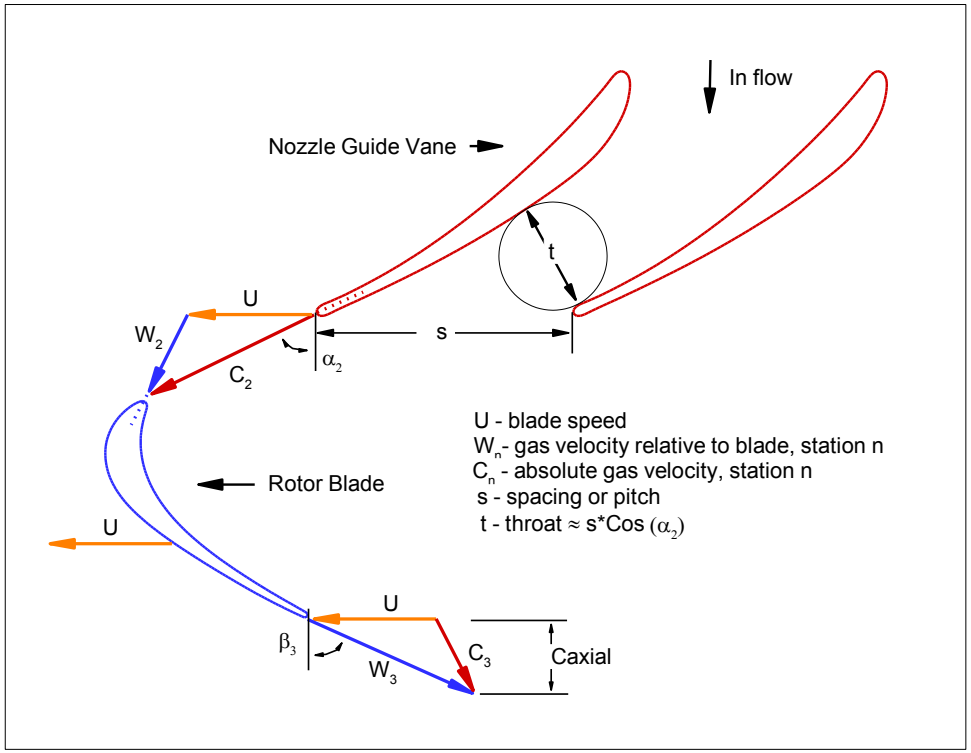
# Outline

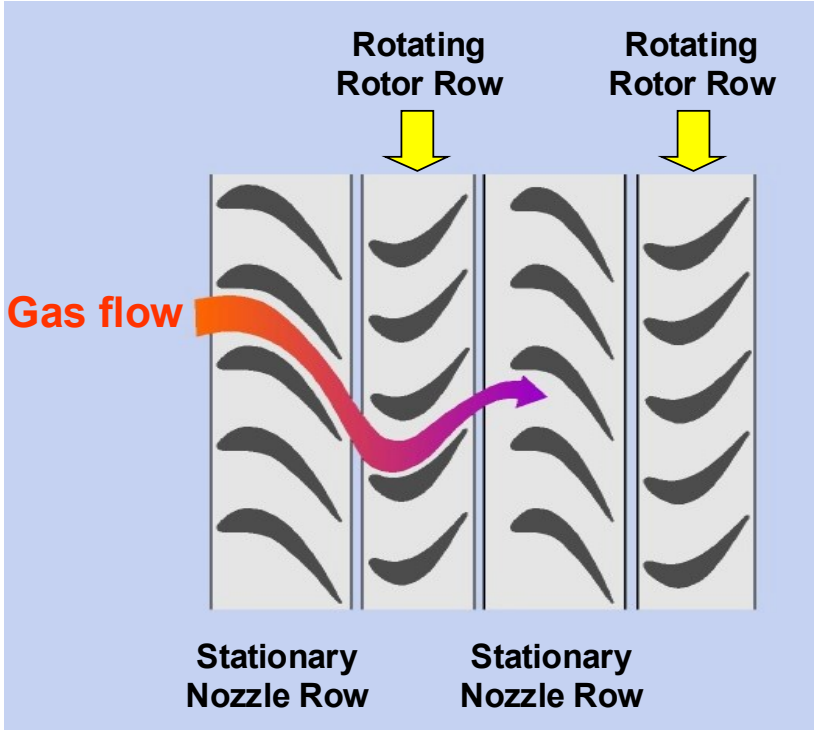
- Turbine Nozzle Guide Vane Backgrounder
  - Purpose and function
  - Typical repairs
- Motivation and Objectives
- Experimental Method
- Selected Results
- Conclusions

# Turbine Nozzle Orientation



# NGV Exit Flow Angle




## *Principle* :

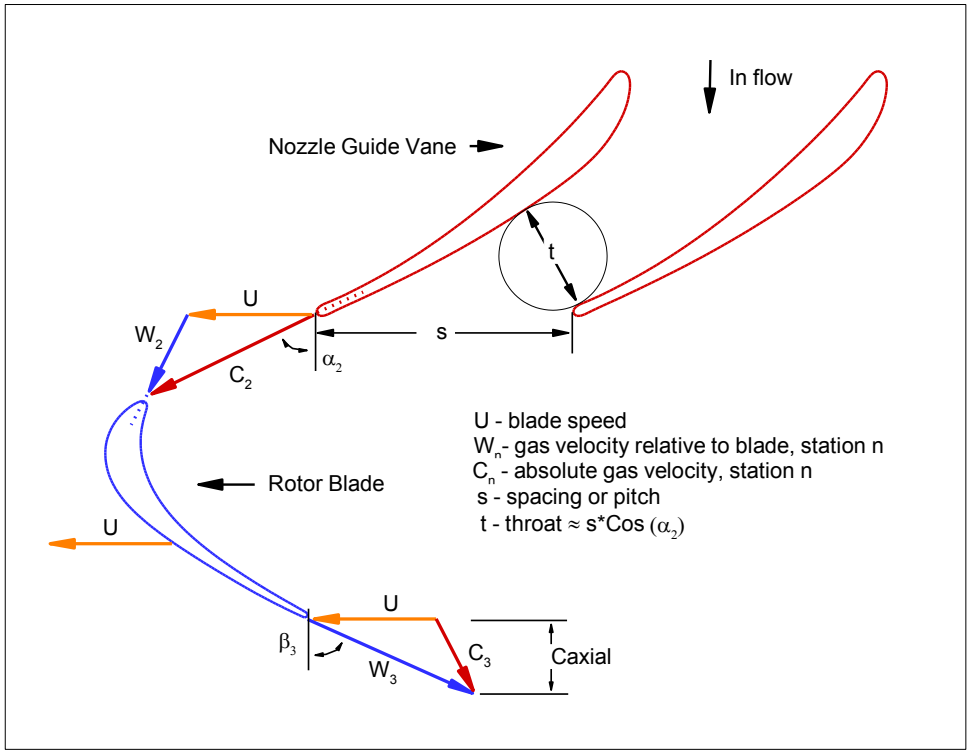
- turbine power is tied to angular momentum
- using gas angles relative to blades:

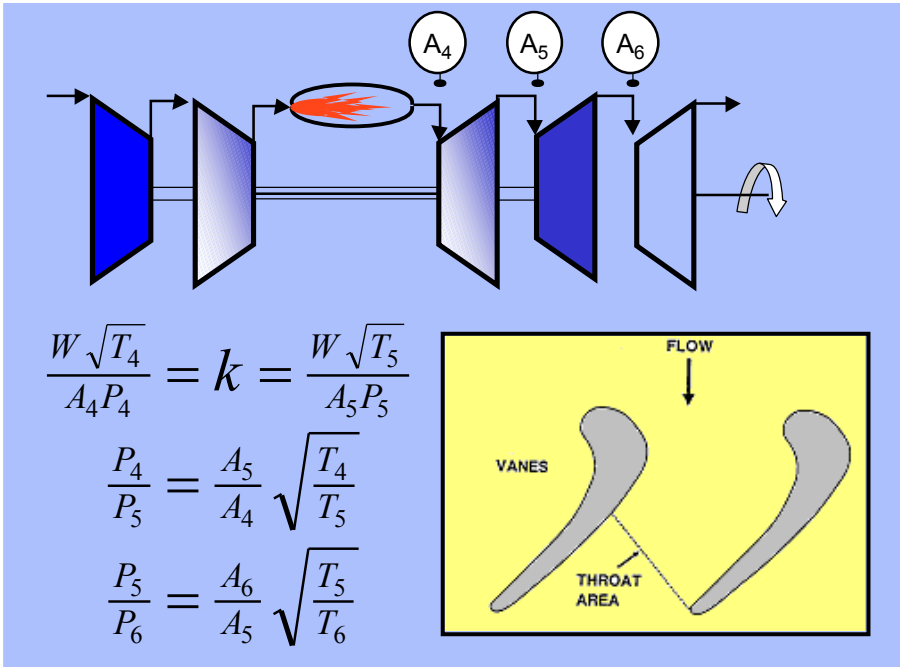
$$W_{stage} = U^2\left[\frac{C_{axial}}{U}(\tan\alpha_2 + \tan\beta_3) - 1\right]$$

## *Sensitivity* :

- $\Delta$work/ $\Delta\alpha$ ~ -3% pwr / 1° angle

# NGV Flow Capacity




$$\frac{W\sqrt{T_4}}{A_4 P_4} = k = \frac{W\sqrt{T_5}}{A_5 P_5}$$

$$\frac{P_4}{P_5} = \frac{A_5}{A_4}\sqrt{\frac{T_4}{T_5}}$$

$$\frac{P_5}{P_6} = \frac{A_6}{A_5}\sqrt{\frac{T_5}{T_6}}$$

*Principle* :

- turbine power must match compressor load
- turbine power is related to pressure ratio and vane area ratio

*Sensitivity* :

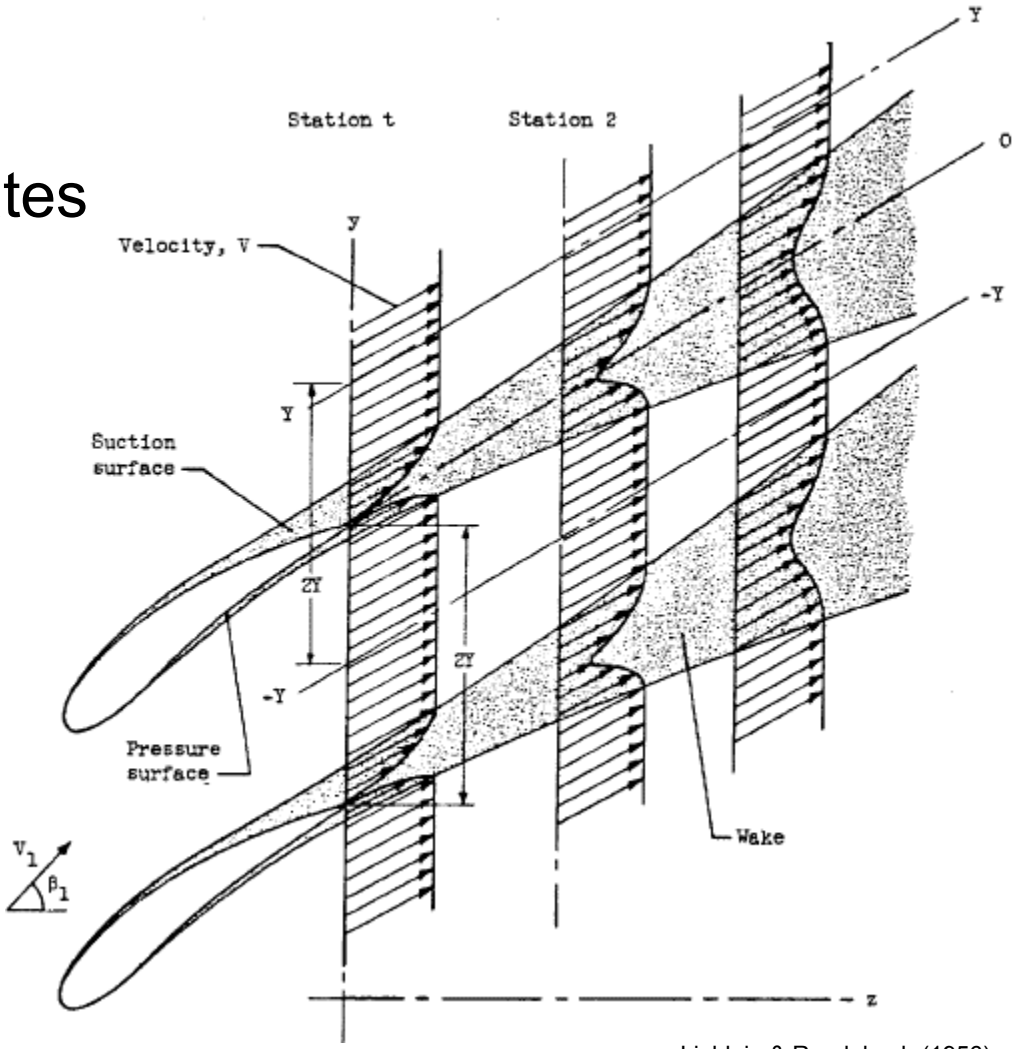
- working targets of ±1.0 % throat area are typical

# NGV Pressure Losses

*Principle*:

- Viscous dissipation creates pressure loss
- Pressure loss deplete turbine efficiency
- Losses ascribed to:
  - ***profile losses***
  - ***shock losses***
  - ***mixing losses***

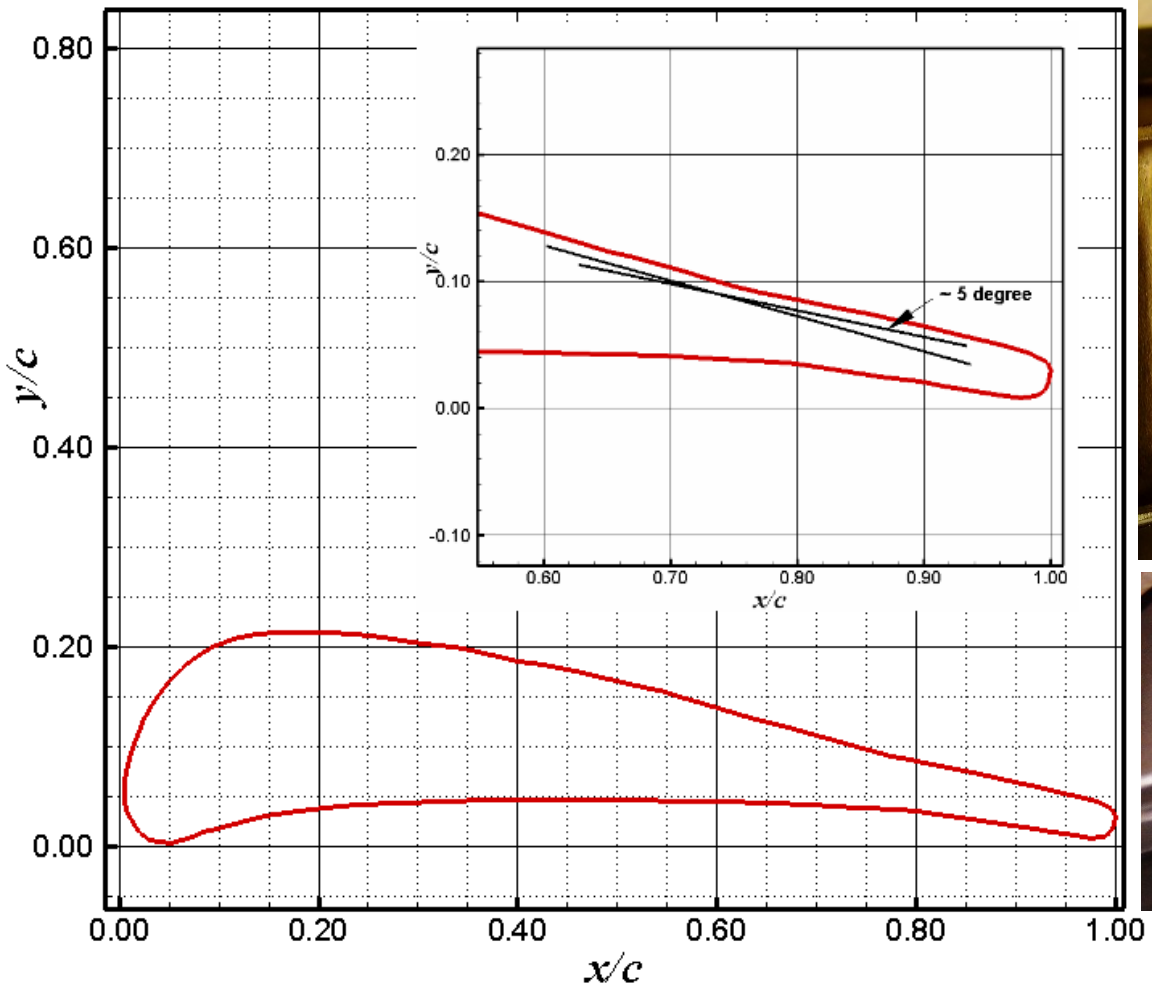
$$s_2 - s_1 = -R \ln\left(\frac{P_{o2}}{P_{o1}}\right)$$

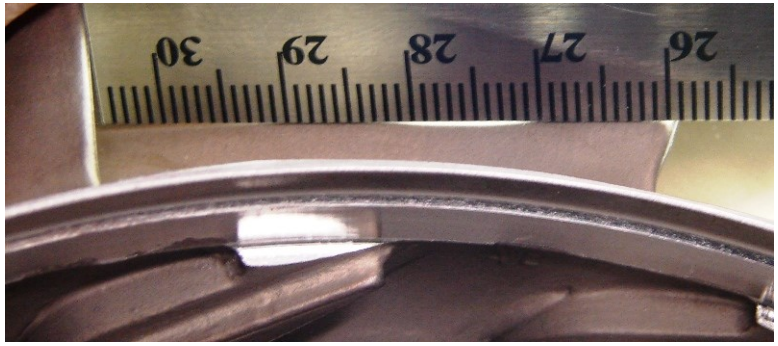



Lieblein & Roudebush (1956)

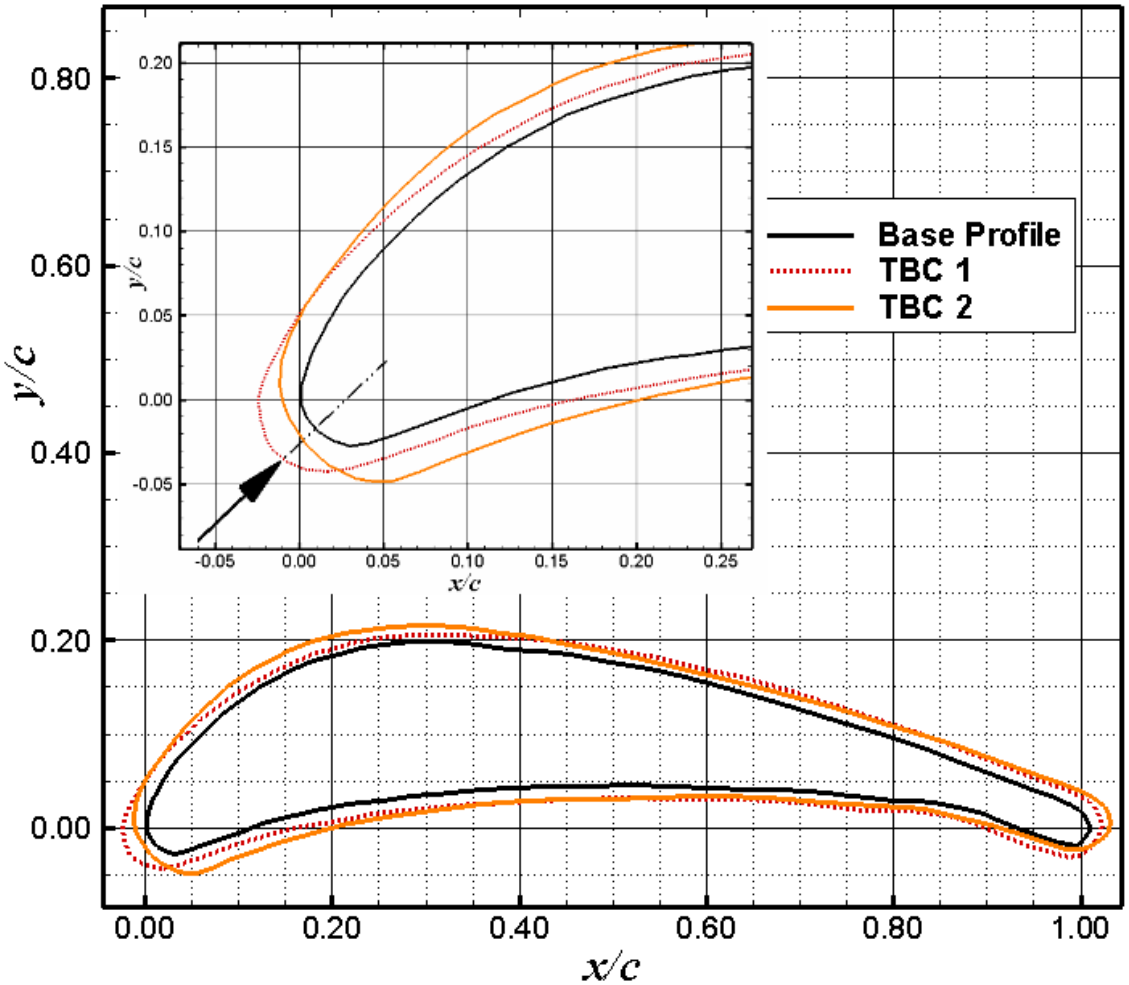
# Example Repairs

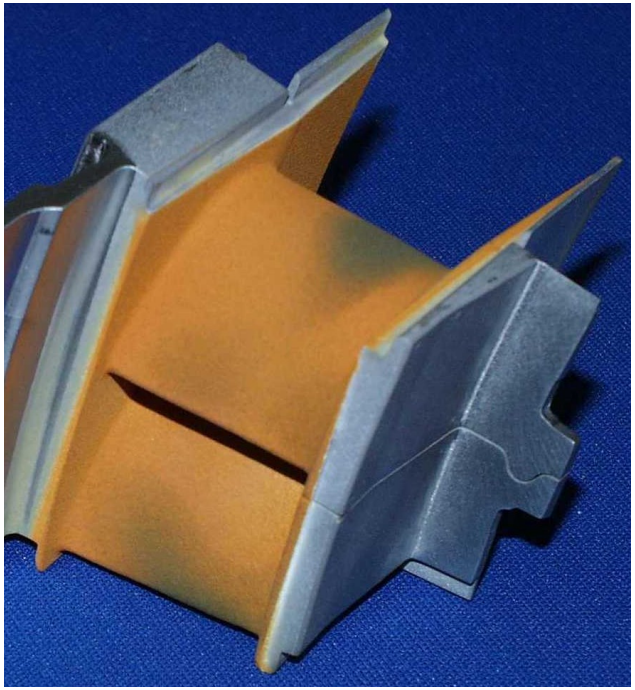
# Laminate Repair



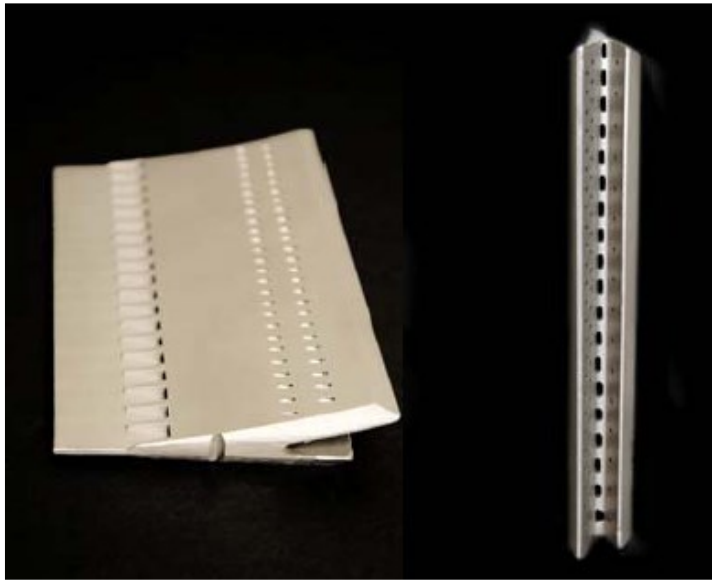
# Thermal Barrier Coating



# Coupon Repair

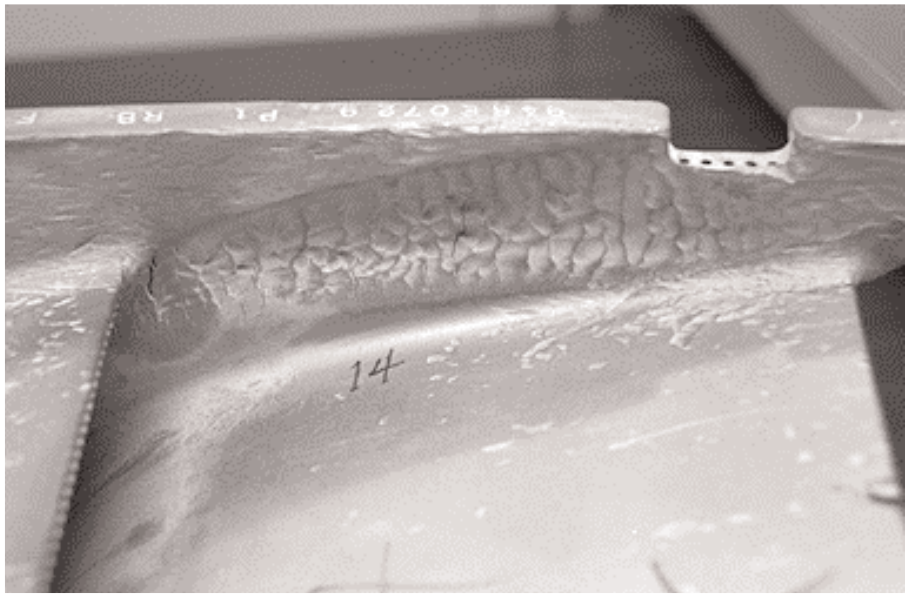
GE Frame engine nozzle segment with foreign object damage, for proposed coupon repair.



Trailing edge coupon for patch repair.

Source: Frarendi

# Activated Diffusion Healing

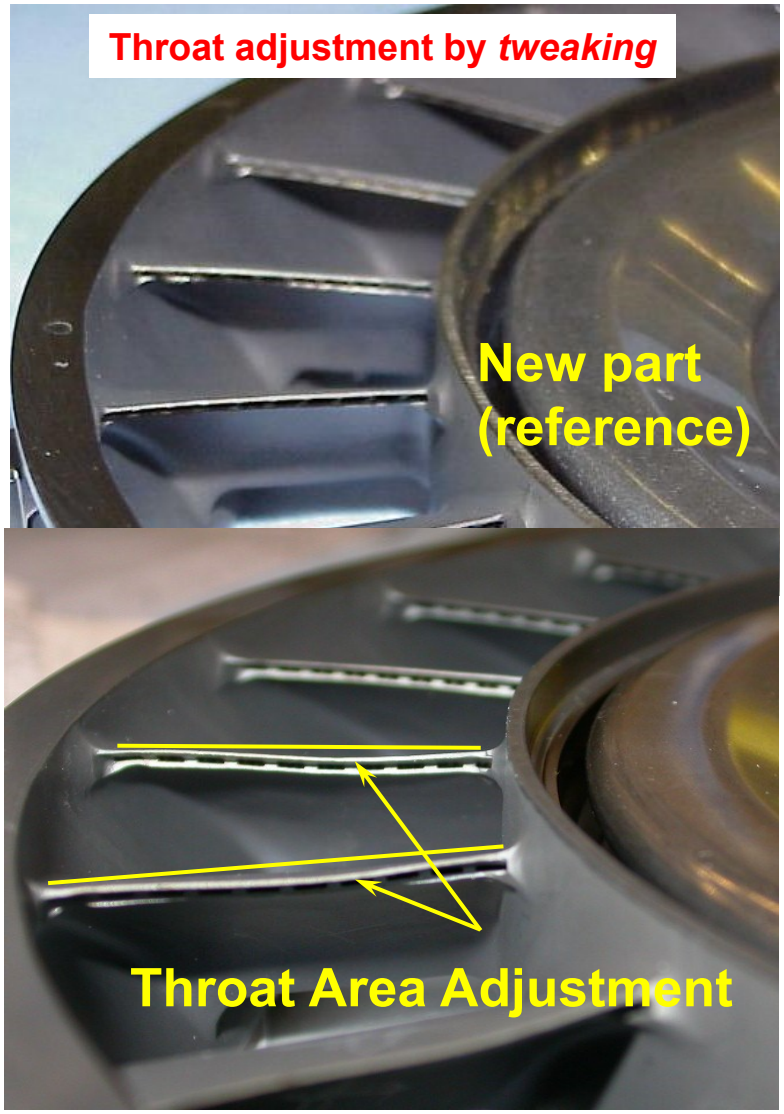



Nozzle sidewall and fillet erosion may be repaired by ADH

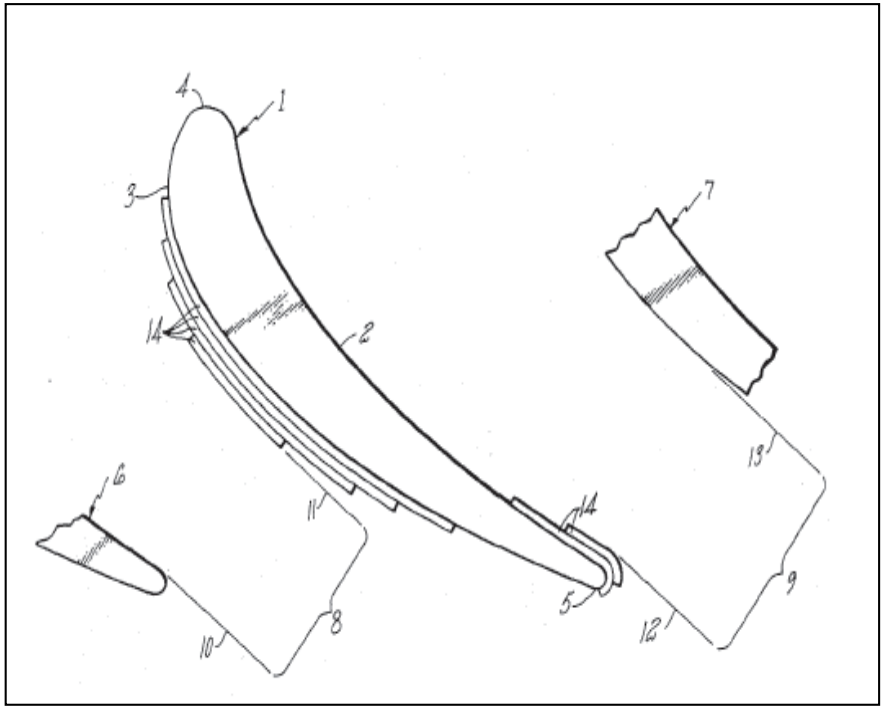
Applying ADH with syringe.

Source: GE bulletin GER-3957B (04/01)

# Throat Adjustment

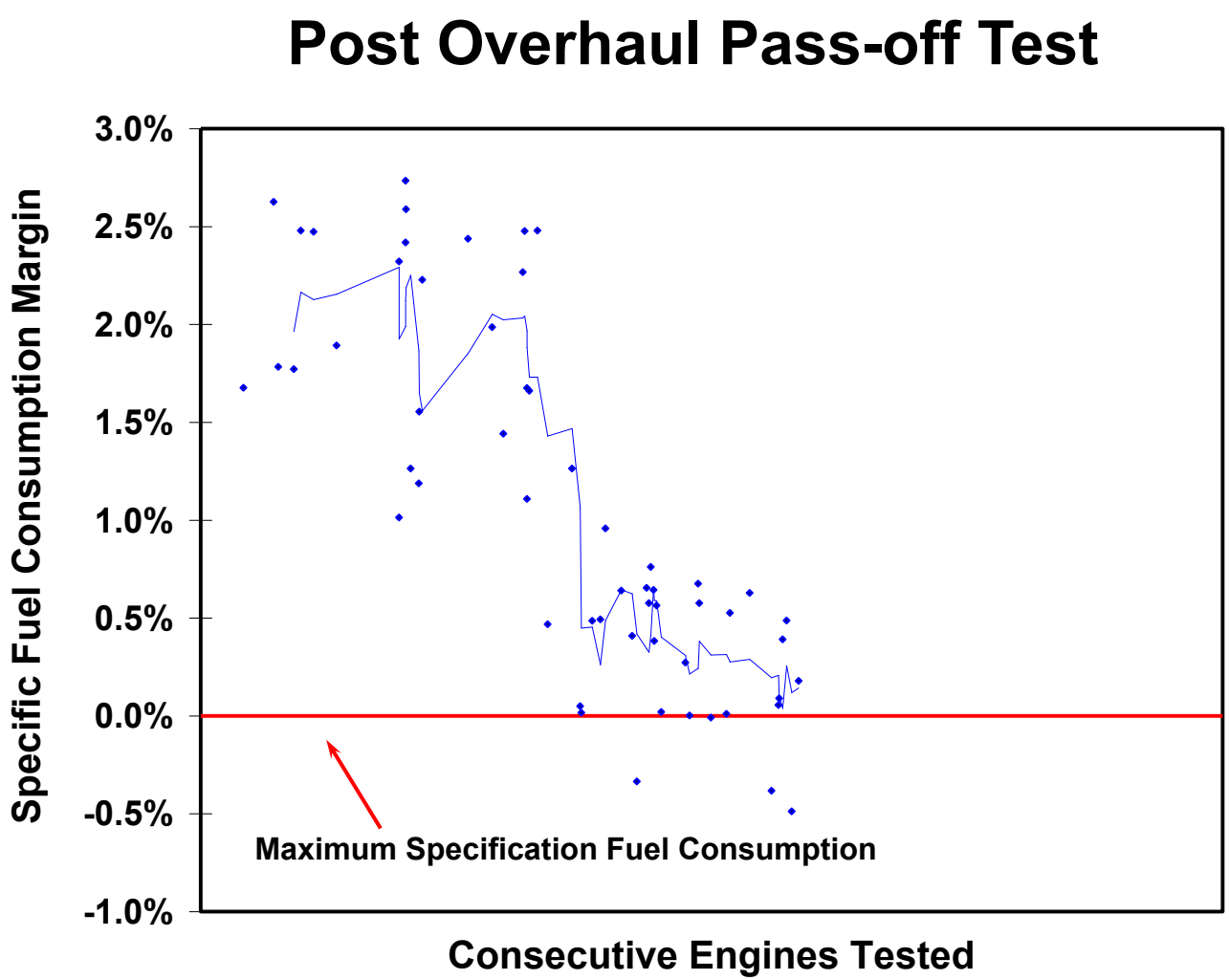


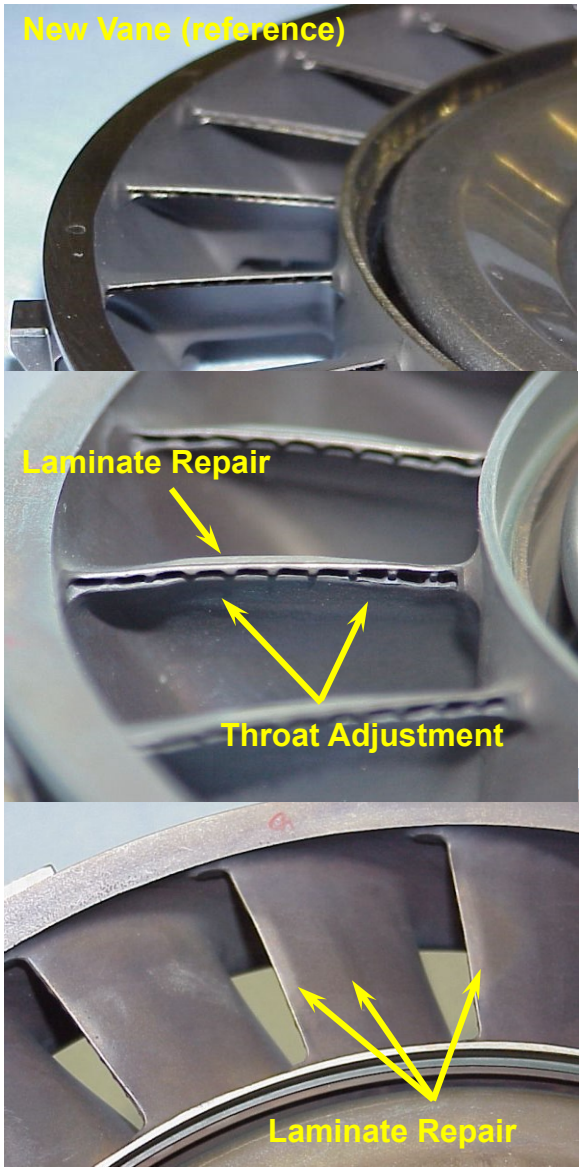

**Throat adjustment scheme using braze overlay**




US Patent 4726101 (1988)

# Engine Maintenance Experience



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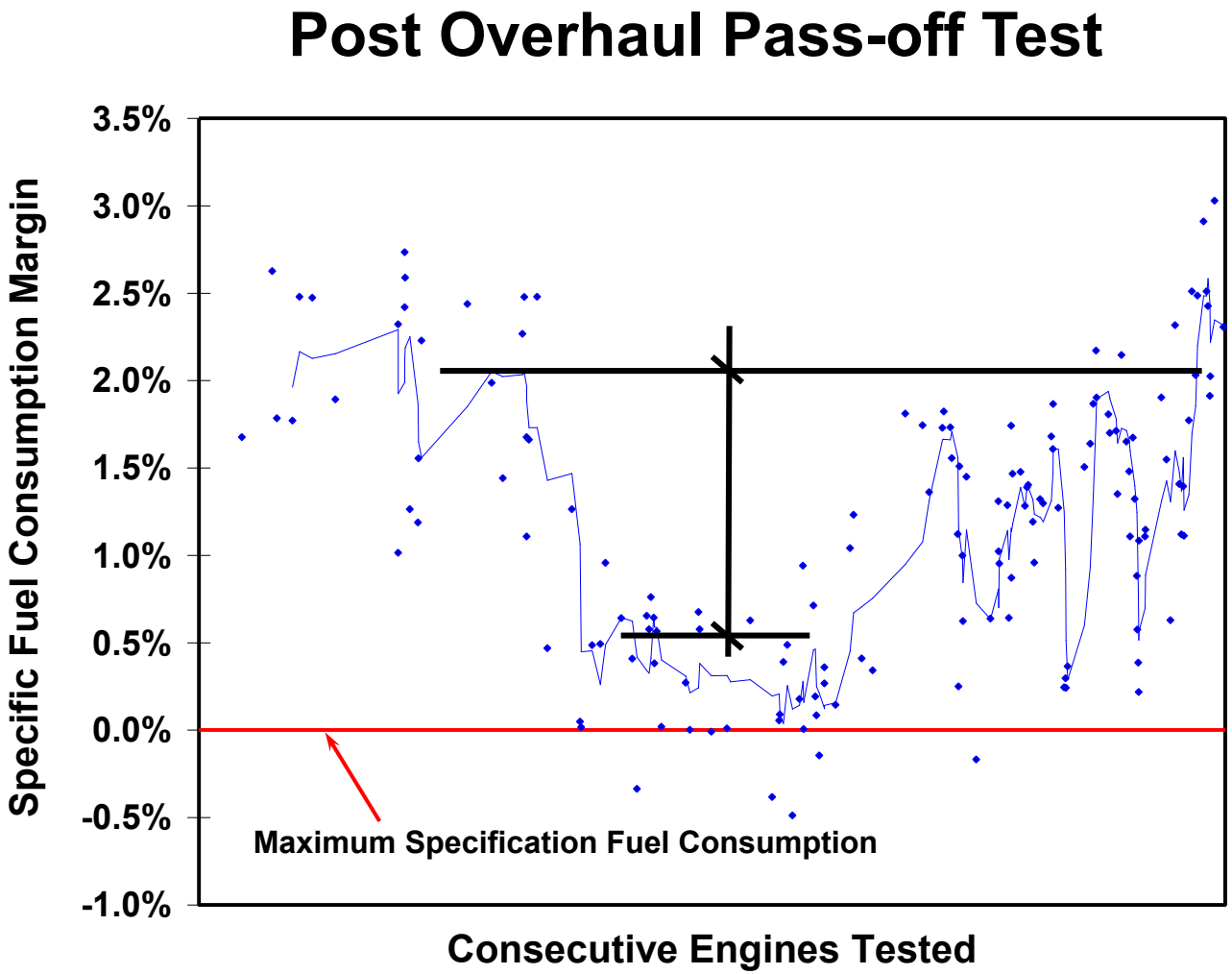
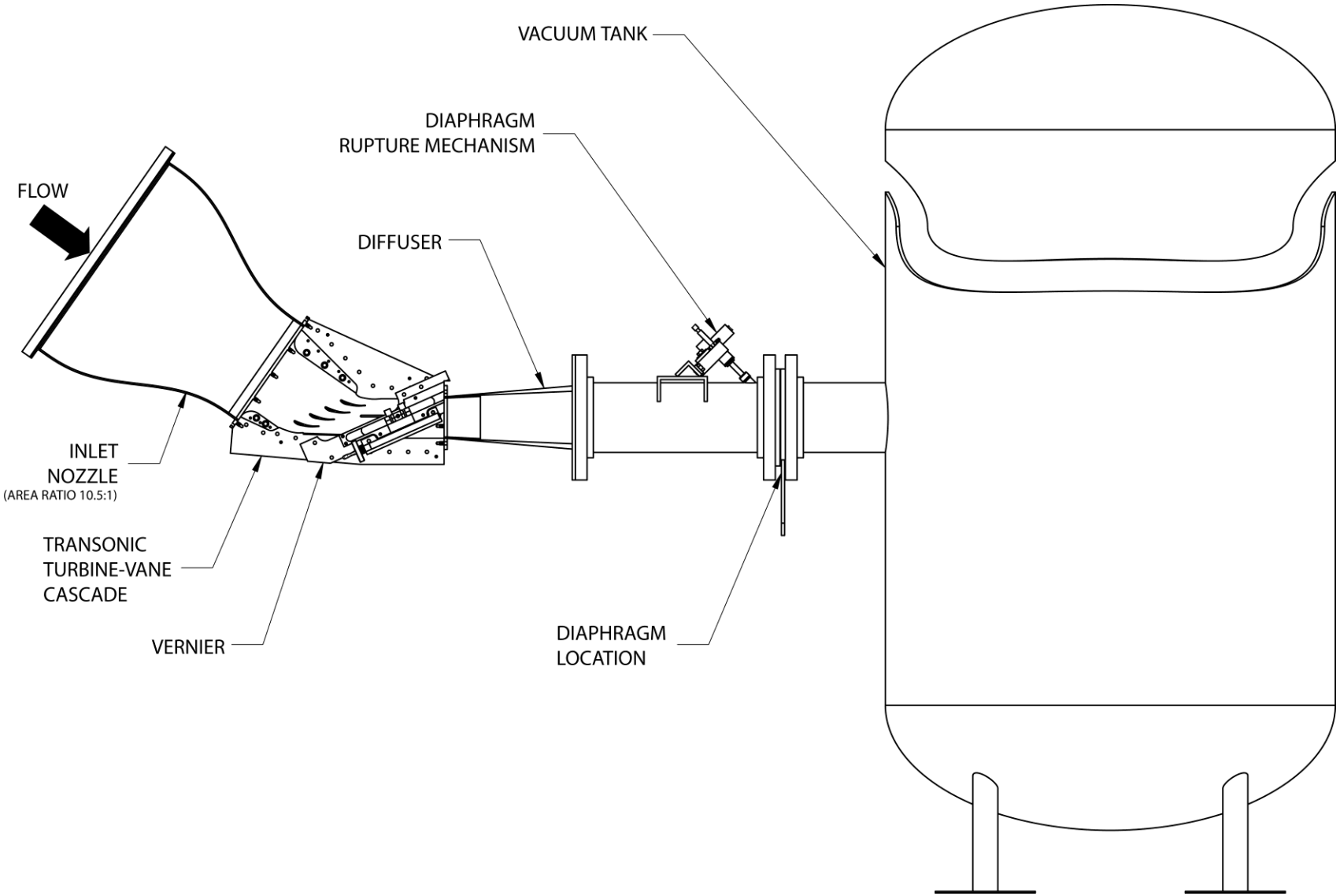



~1.5% fuel burn attributed to part condition

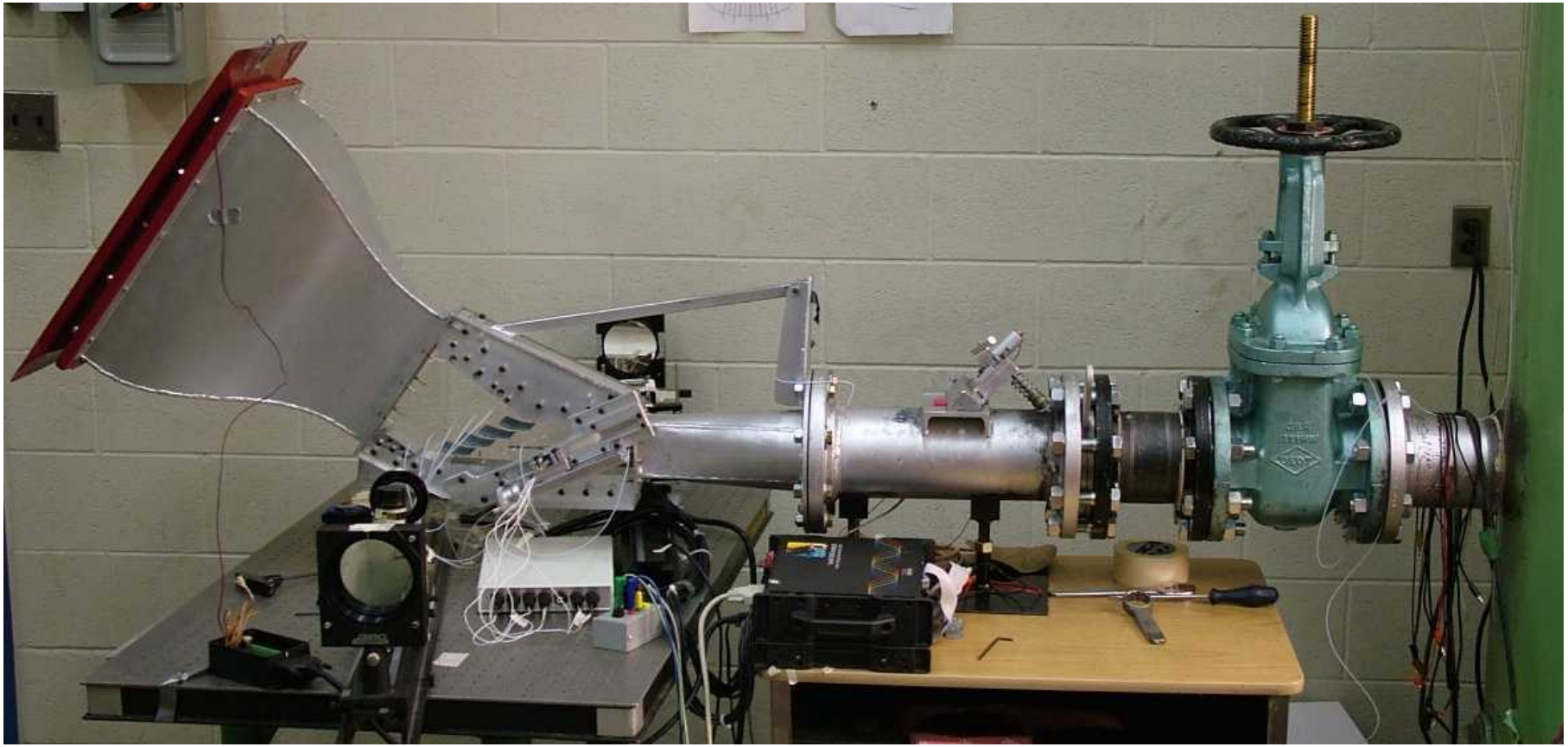
# Experimental Objectives

- Measure real-world airfoil profiles
  - replicate selected for wind tunnel test
- Assemble and commission cascade rig:
  - short-duration blow-down arrangement.
  - fast response pressure probe for cascade exit survey.
- Collect experimental data:
  - Airfoil surface flow visualization using oil.
  - Compressible flow structure by Schlieren optics.
  - Measure exit pressure
- Goal:
  - document actual airfoil condition.
  - investigate influence of geometry on aerodynamic performance.

# Transonic Cascade Rig



# Transonic Cascade Rig



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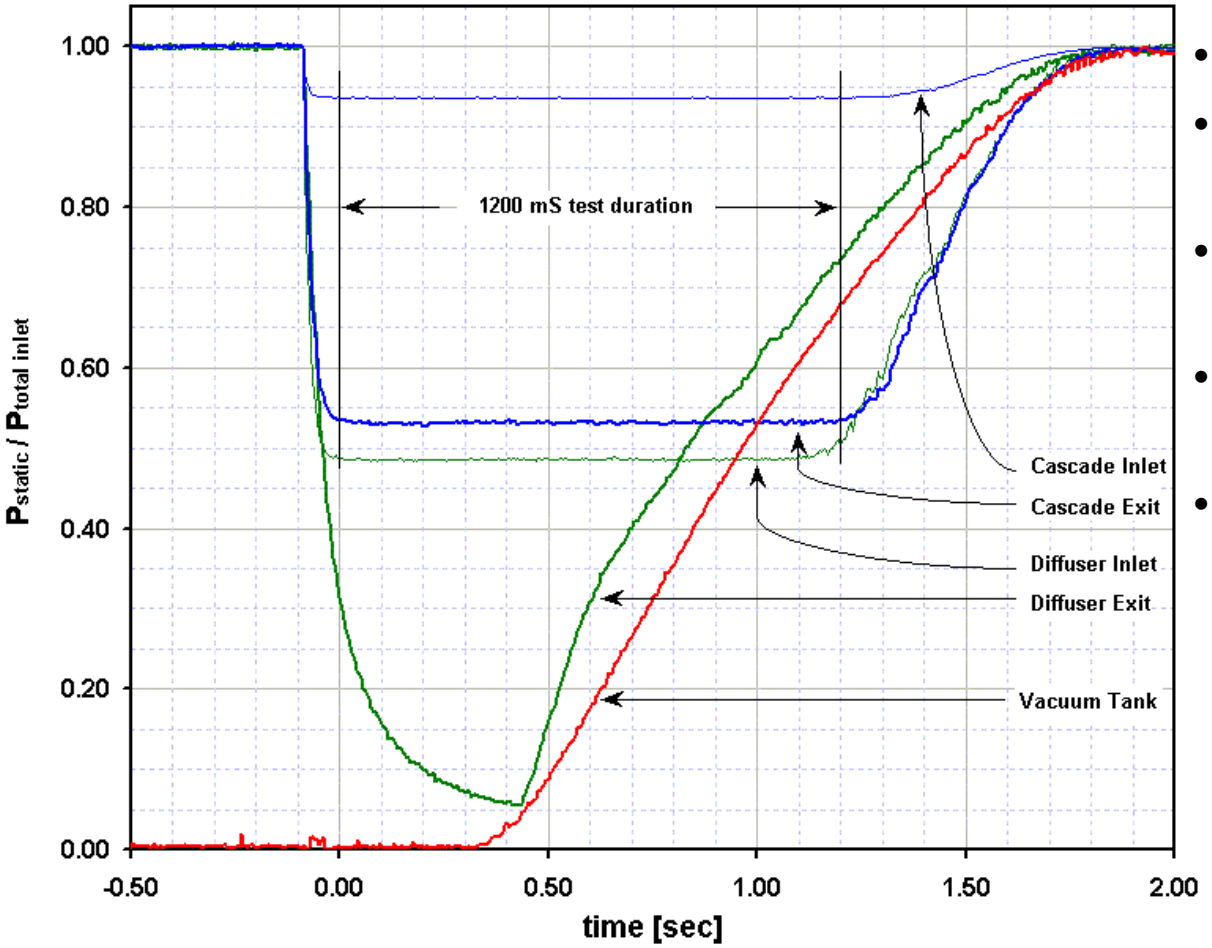
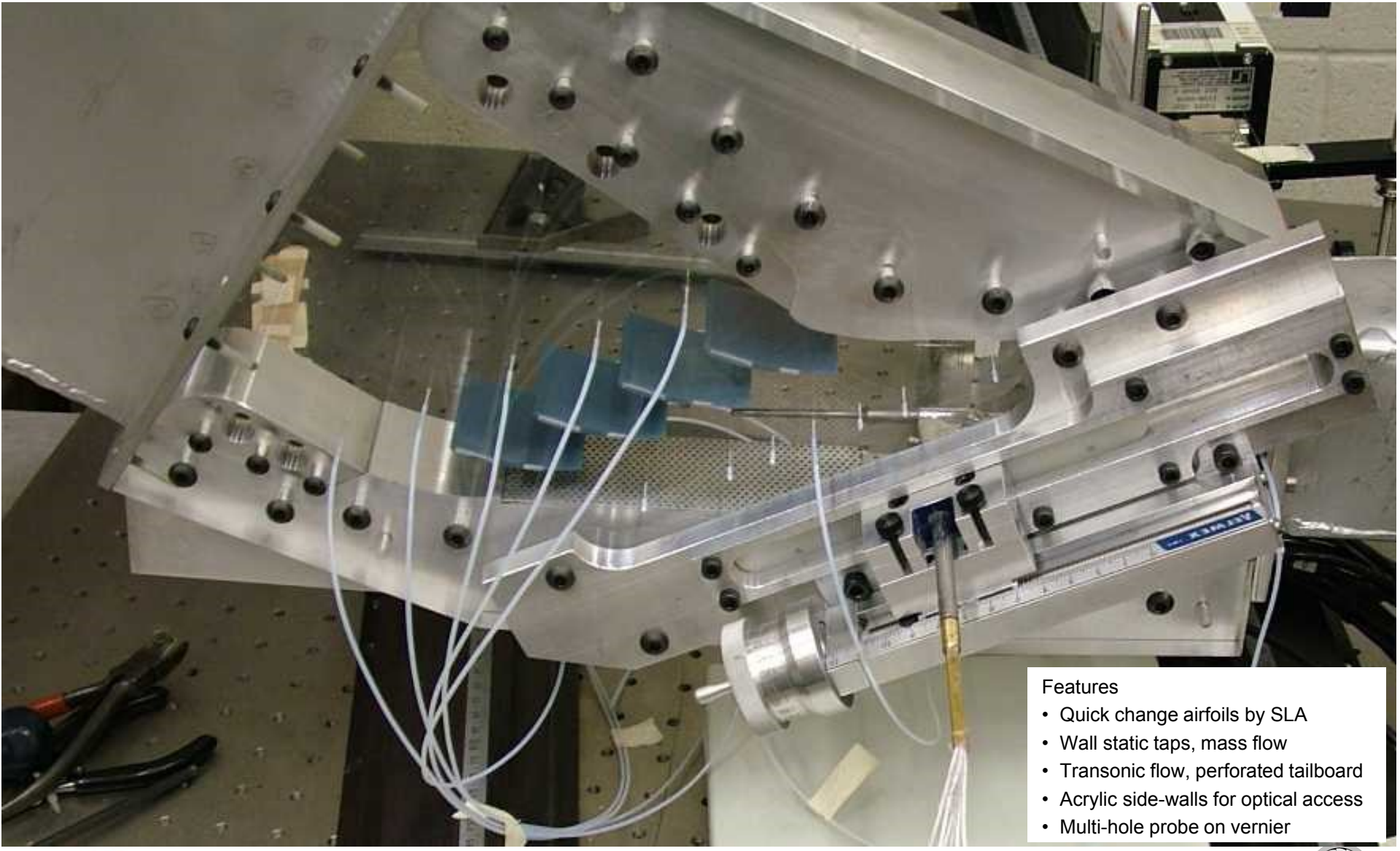


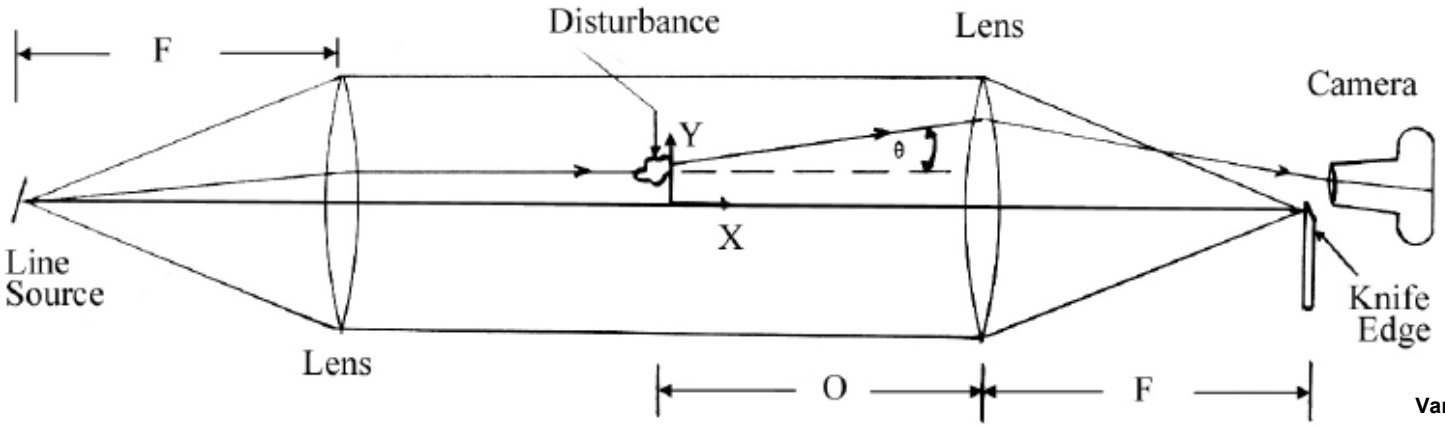

- Short duration blow-down
- Rupture diaphragm to initiate test run
- Working section choked for 1200mS
- Test duration extended by diffuser
- 16 channel data acquisition

# Working Section

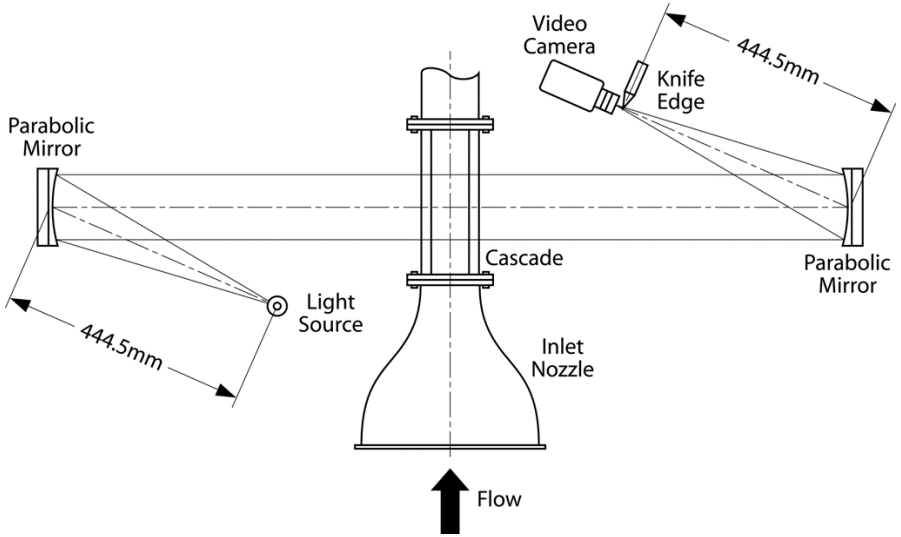


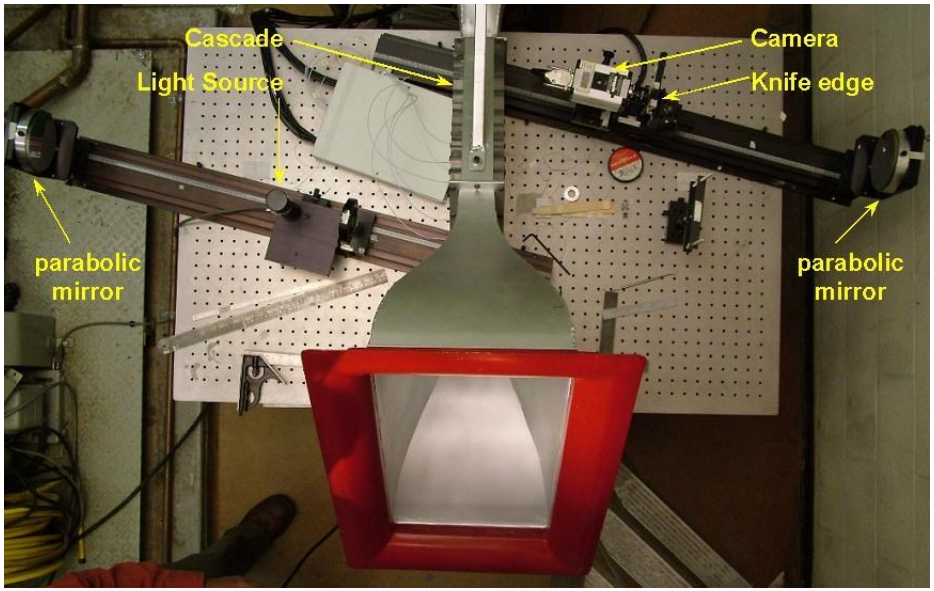
Features
- Quick change airfoils by SLA
- Wall static taps, mass flow
- Transonic flow, perforated tailboard
- Acrylic side-walls for optical access
- Multi-hole probe on vernier

# Schlieren Flow Visualization

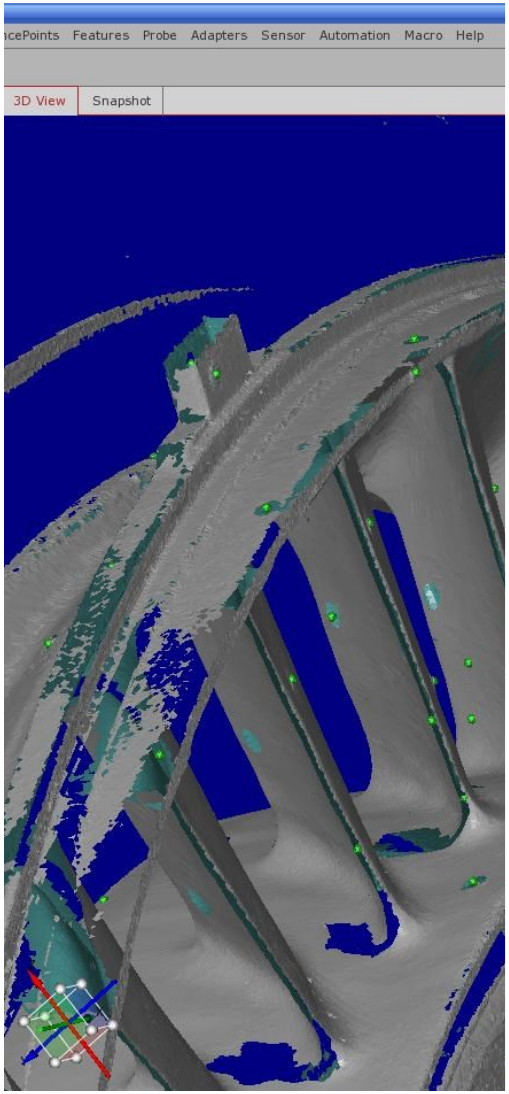


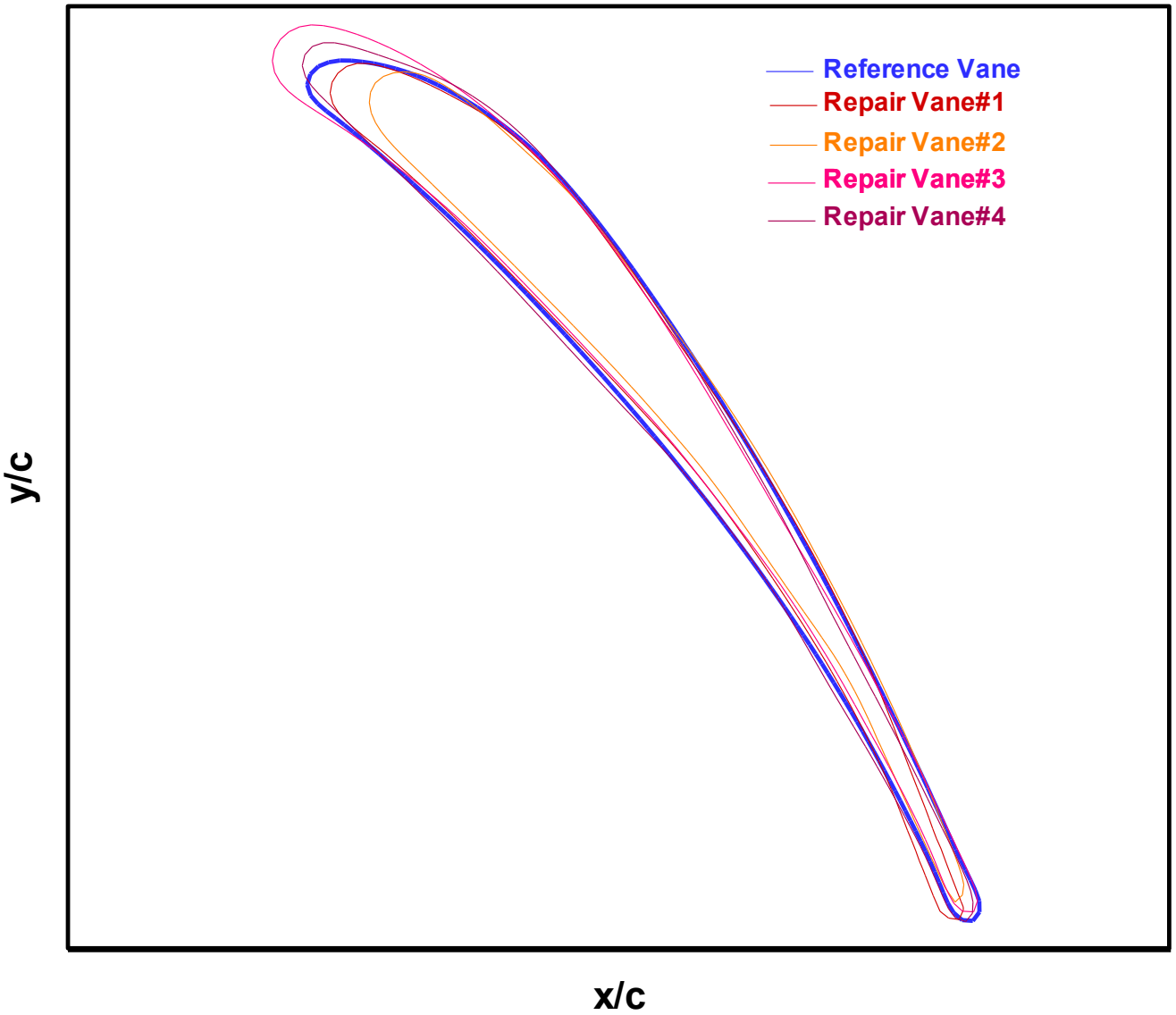

Vandiver (2002)



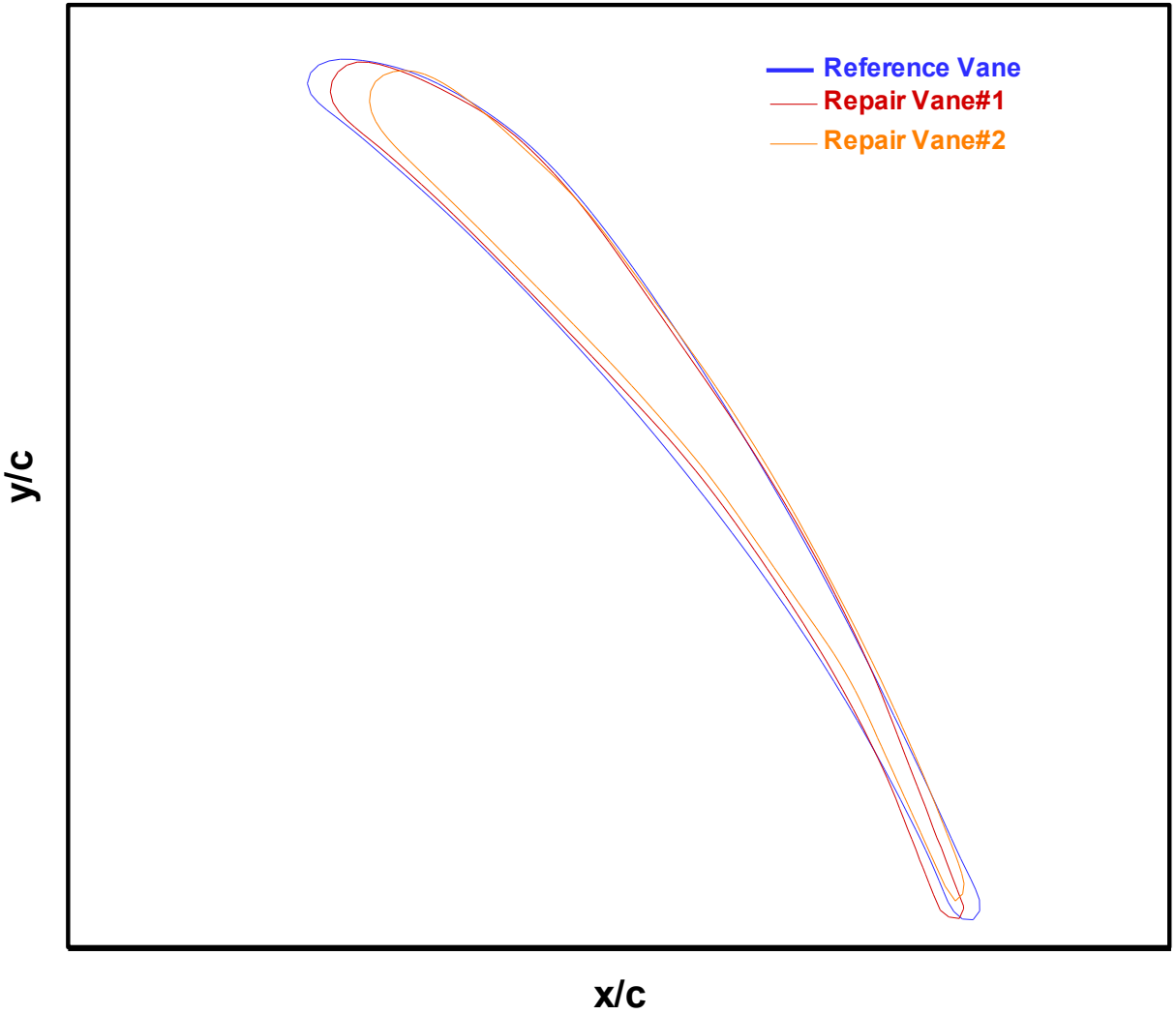



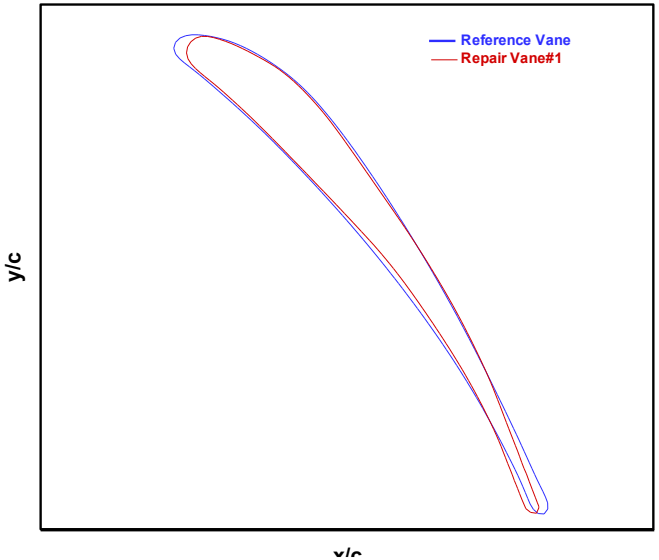
# Determination of Airfoil Profile

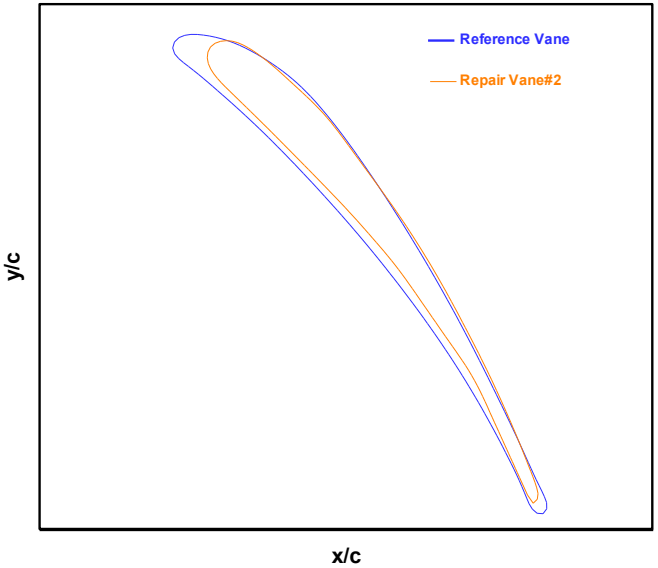


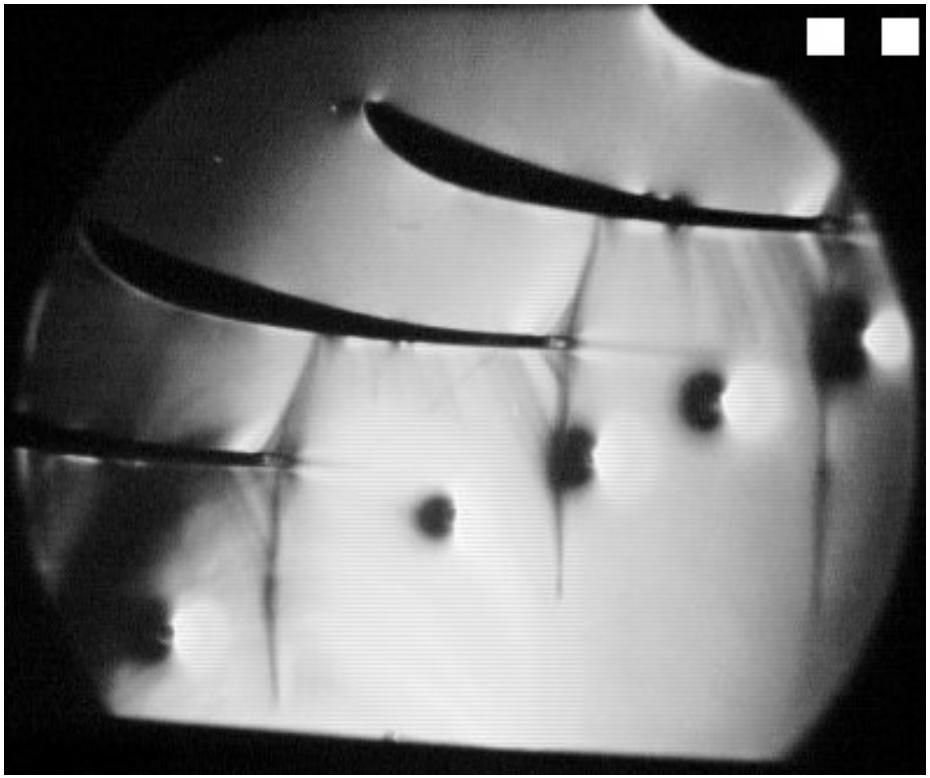
# Selected Profiles

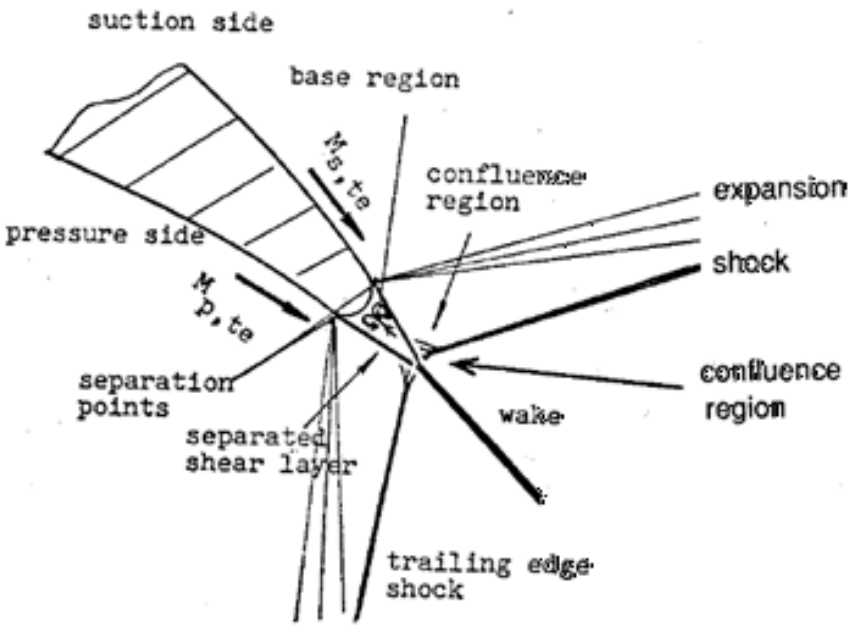


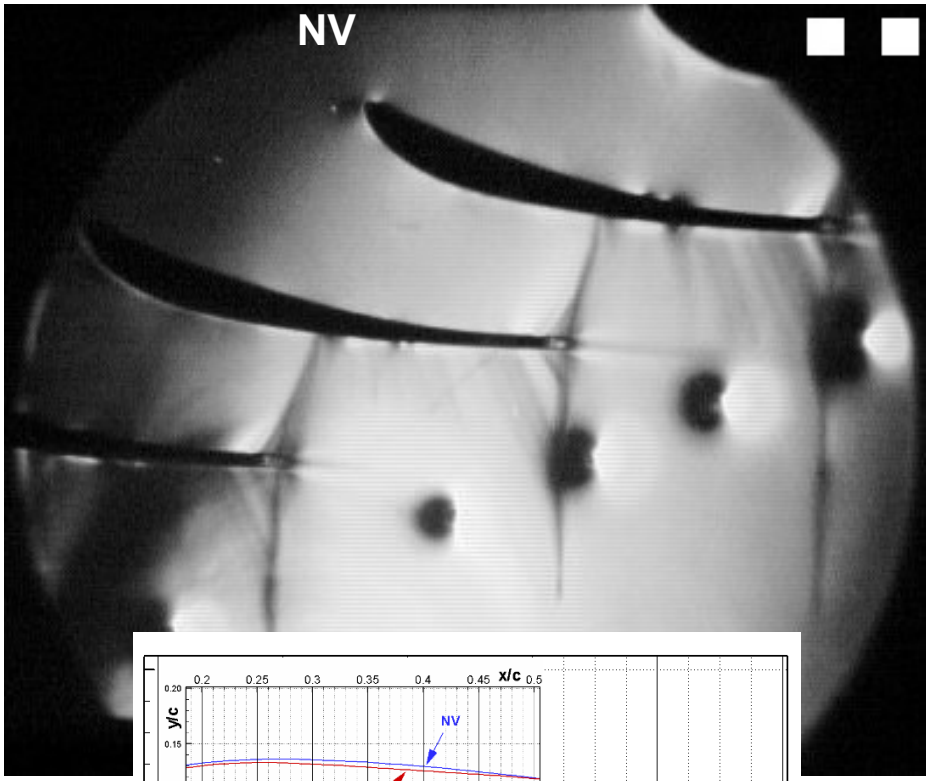
# NV Shock Structure

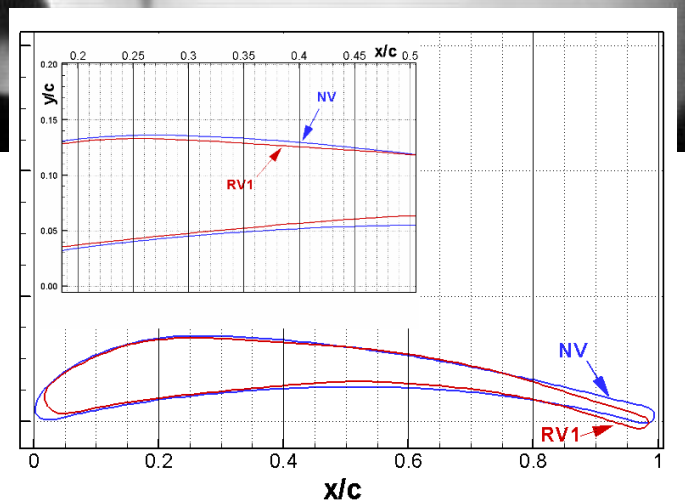


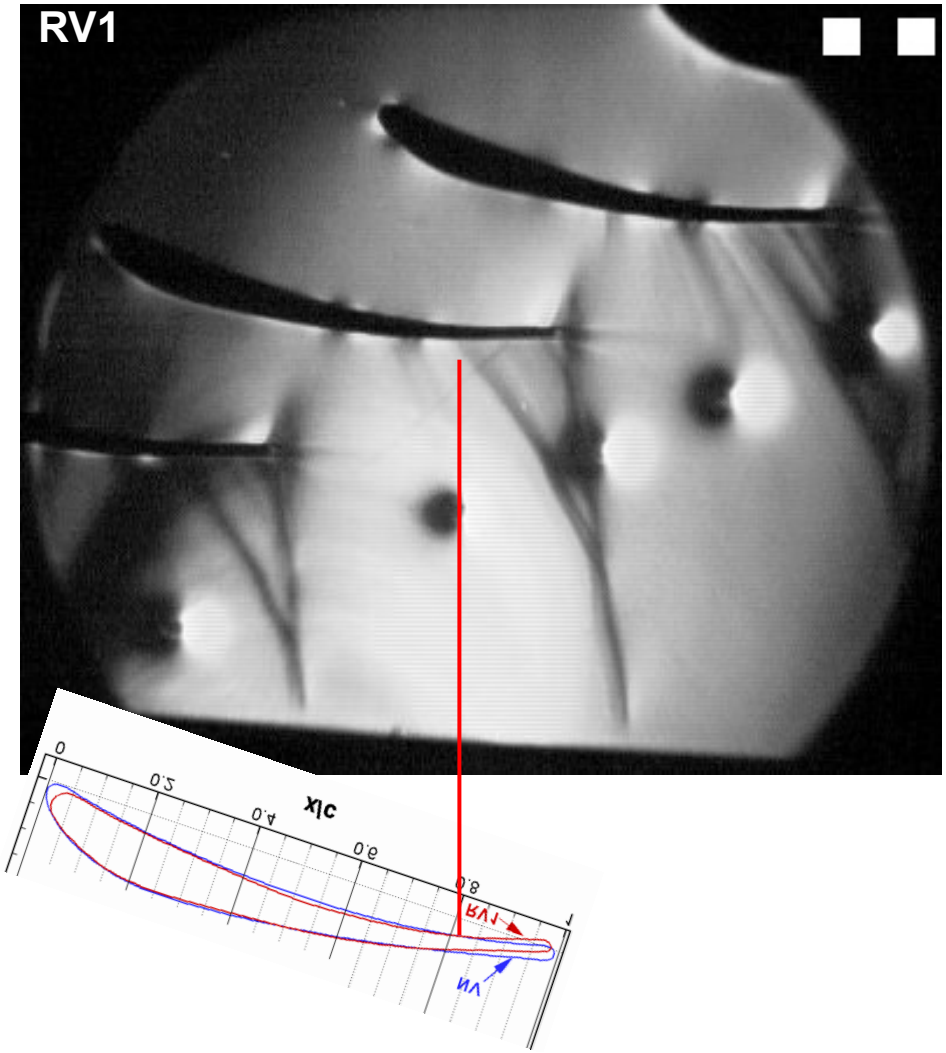



Denton & Xu

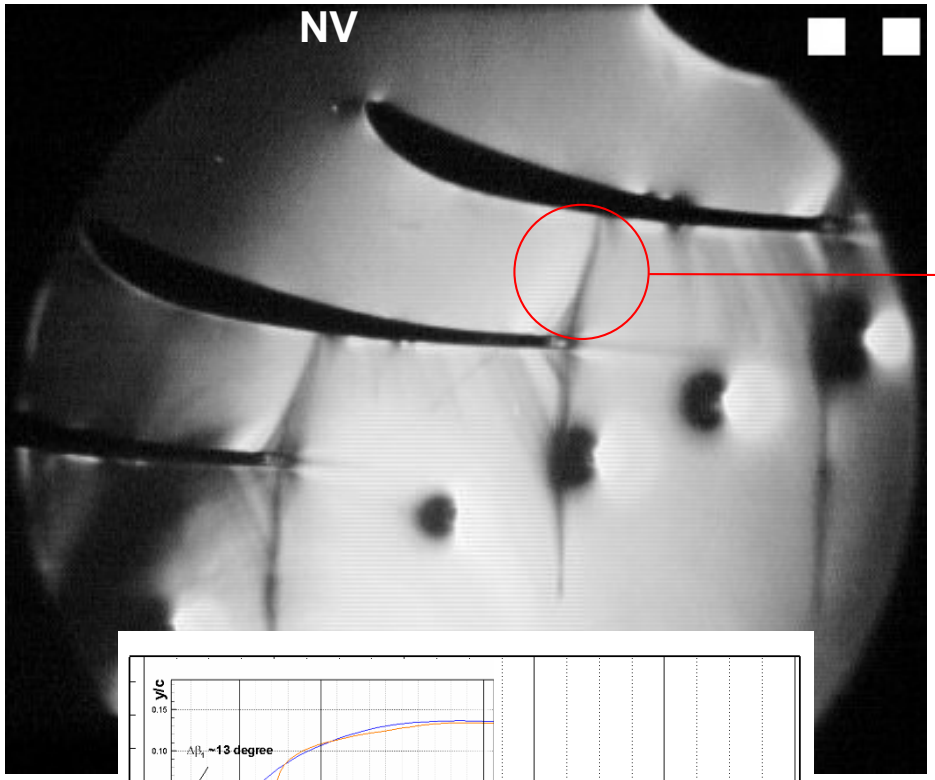
# RV1 Shock Structure

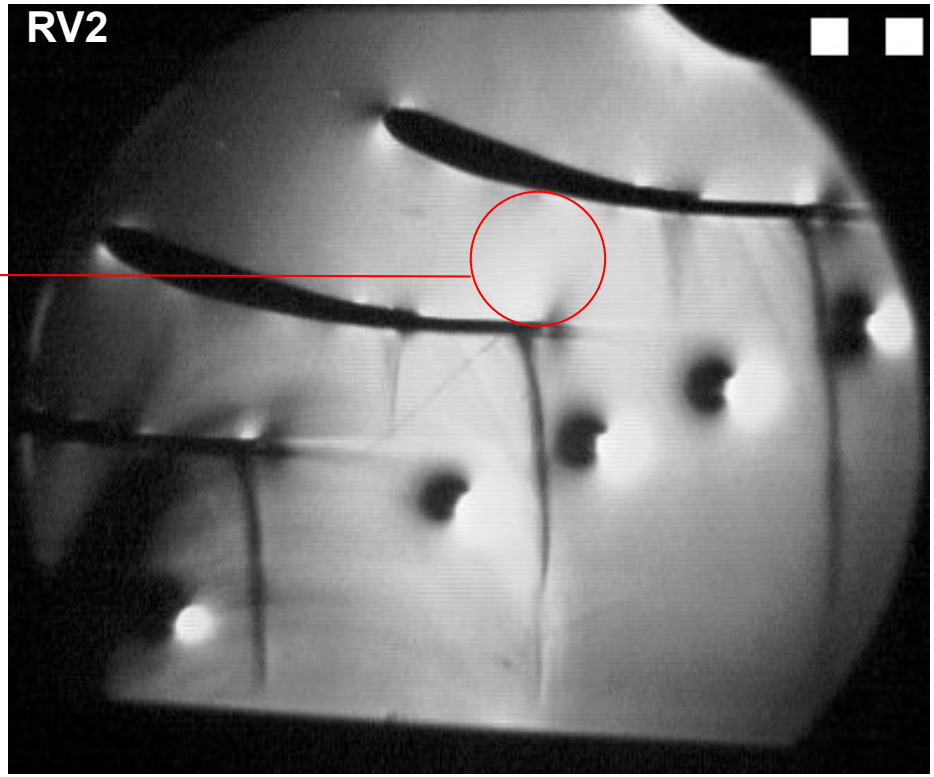


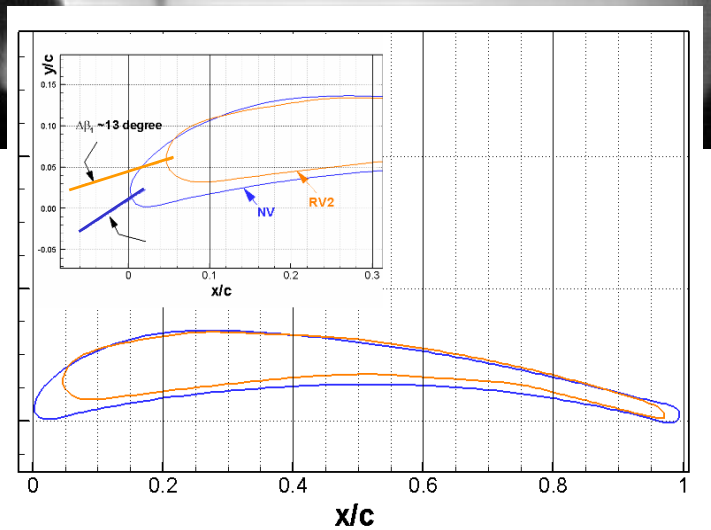



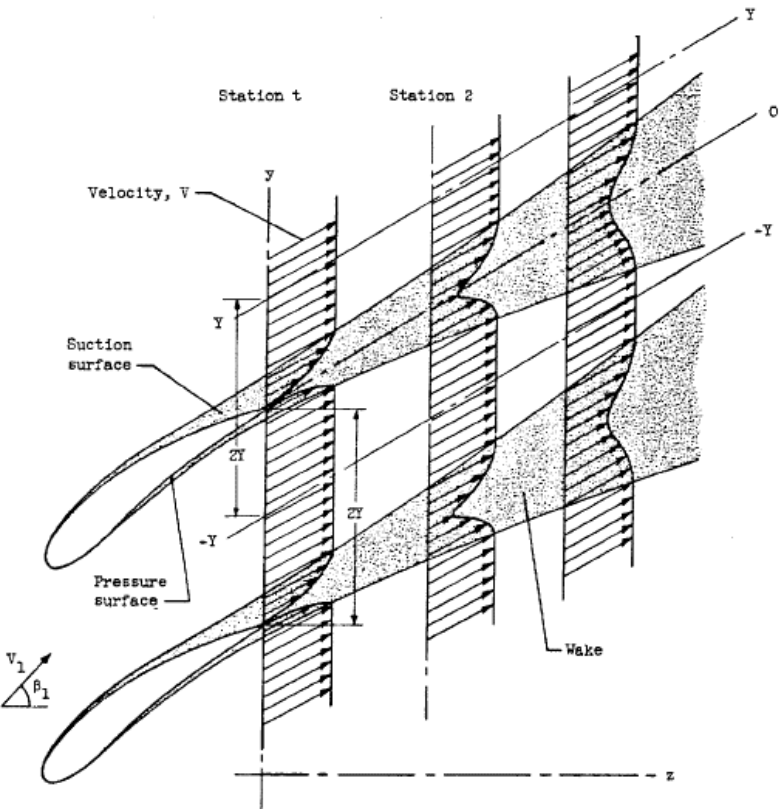
# RV2 Shock Structure



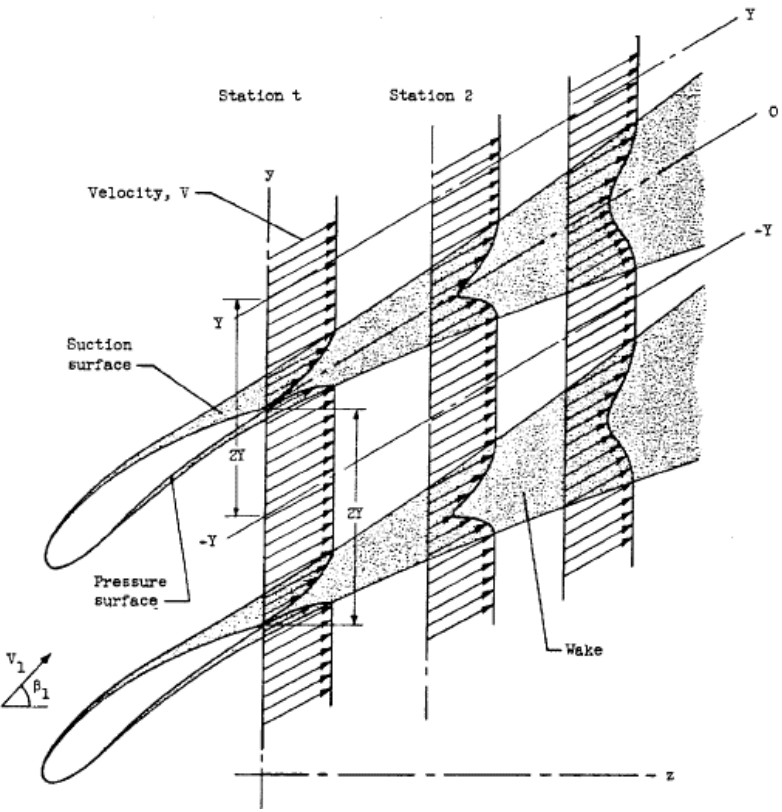



# NGV Pressure Loss

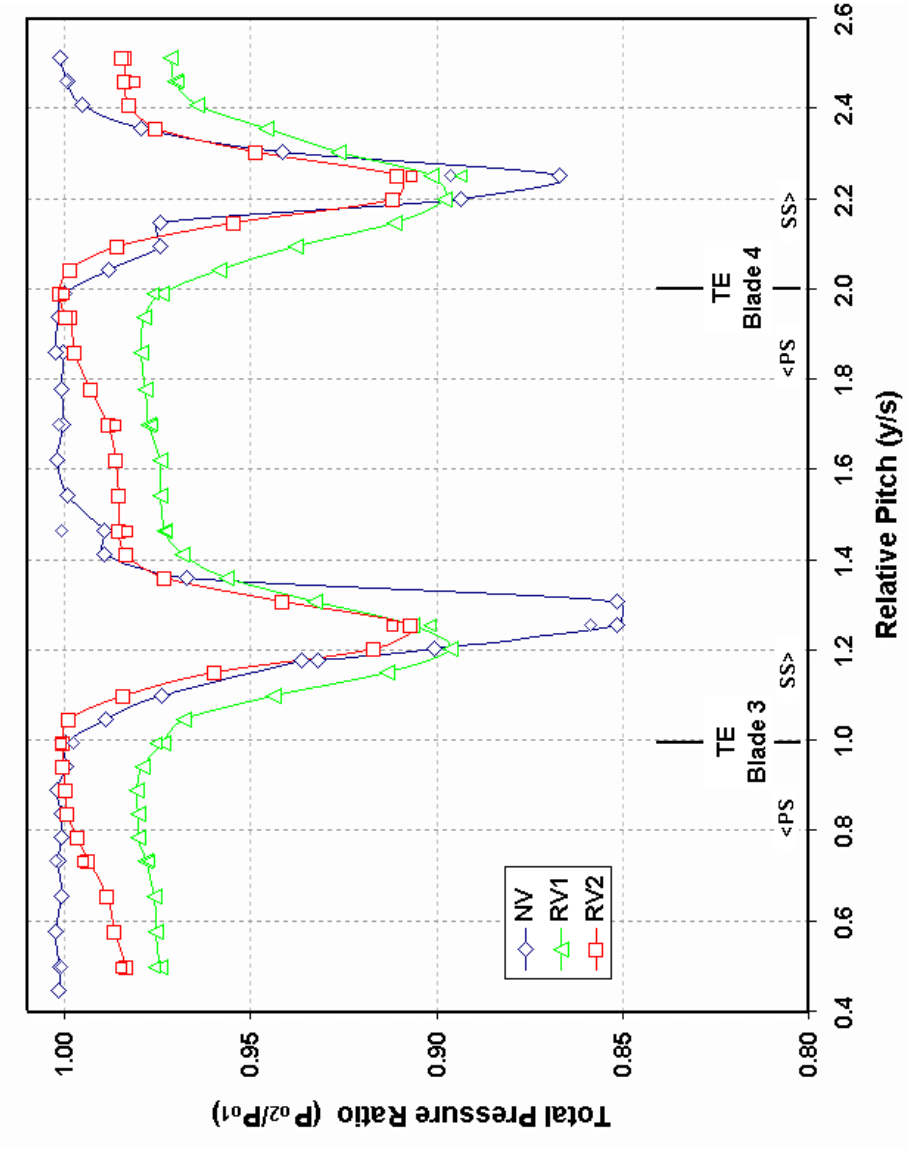



Lieblein & Roudebush (1956)

# NGV Pressure Loss




Lieblein & Roudebush (1956)



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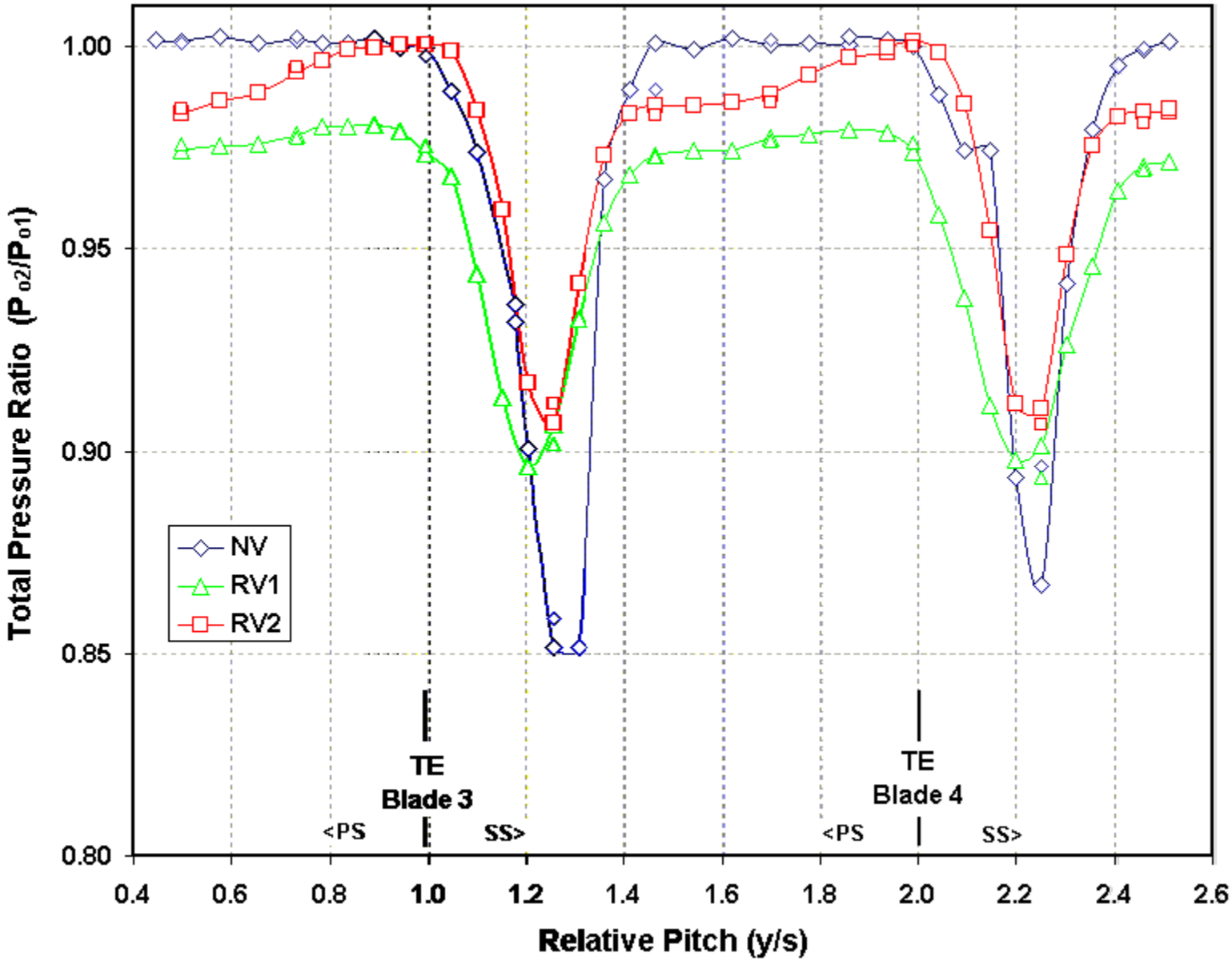

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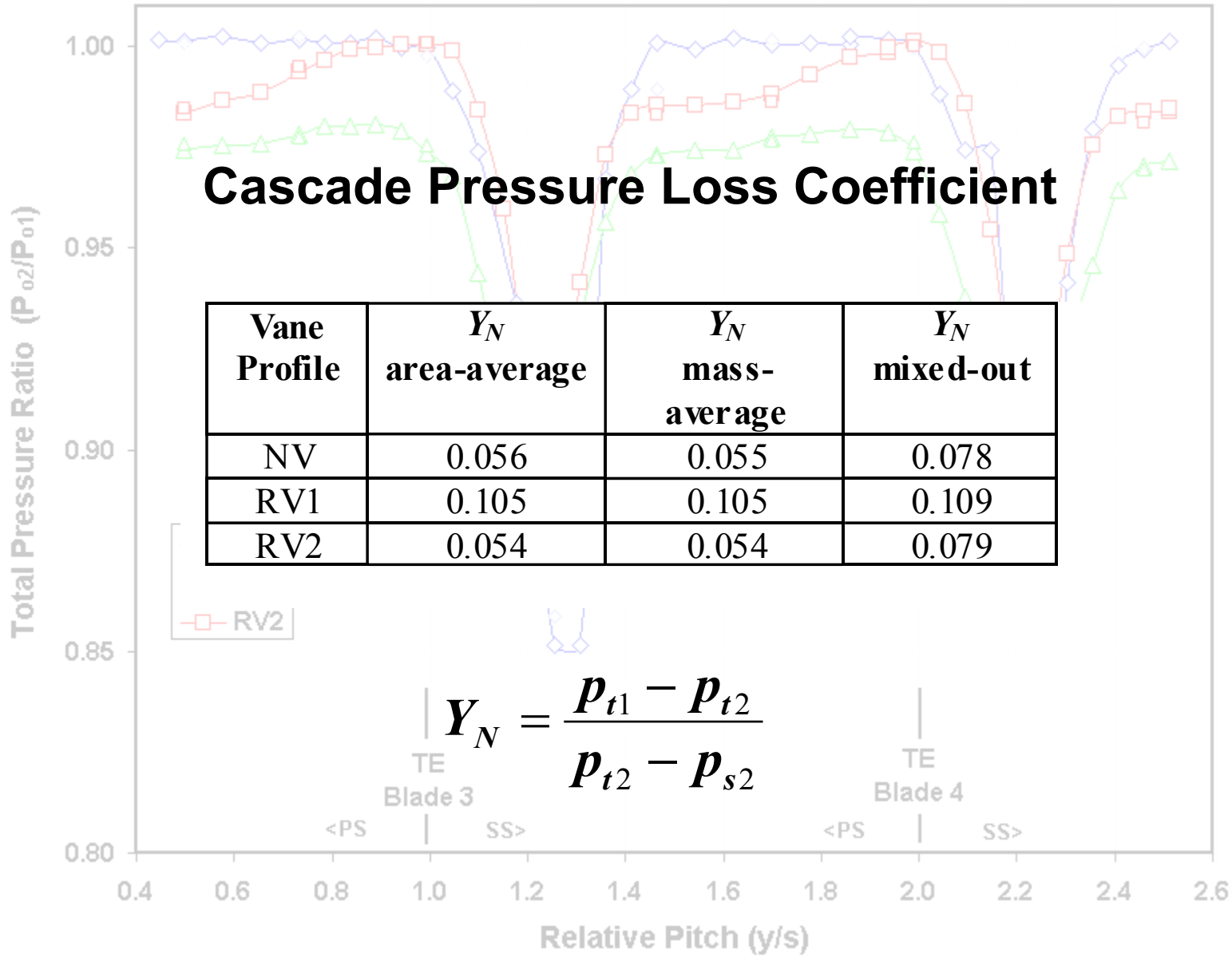
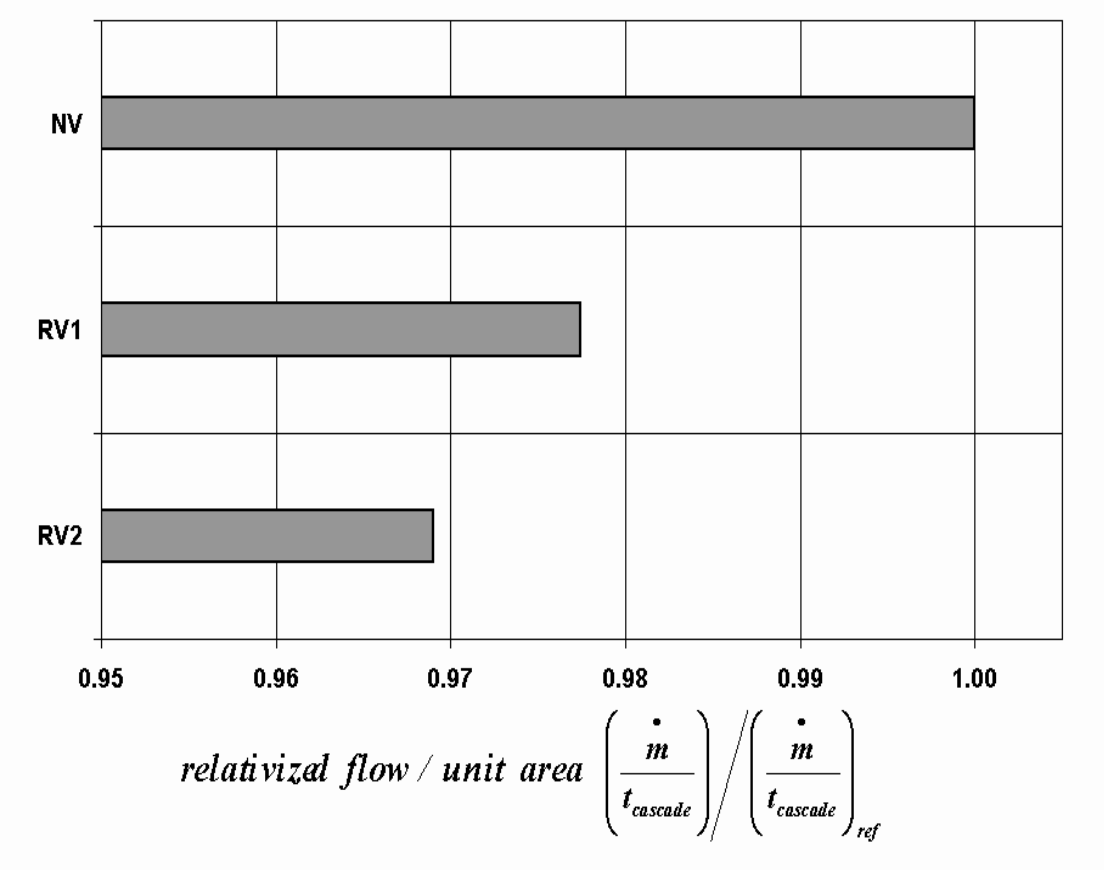


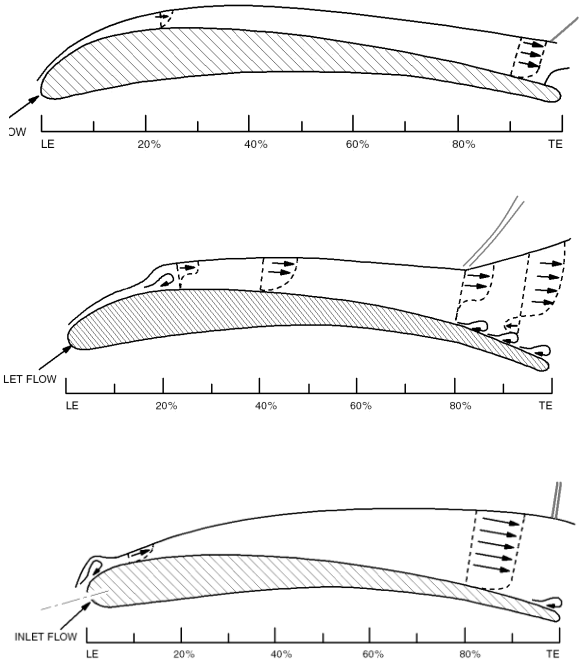

## Cascade Pressure Loss Coefficient

| Vane Profile | $Y_N$ area-average | $Y_N$ mass-average | $Y_N$ mixed-out |
|---|---|---|---|
| NV | 0.056 | 0.055 | 0.078 |
| RV1 | 0.105 | 0.105 | 0.109 |
| RV2 | 0.054 | 0.054 | 0.079 |

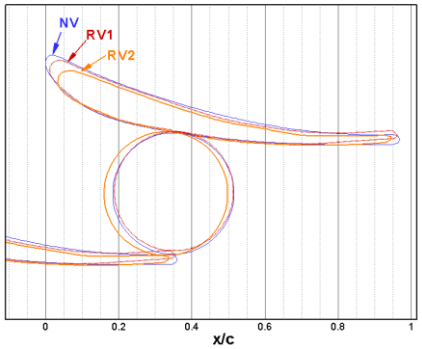
$$Y_N = \frac{p_{t1} - p_{t2}}{p_{t2} - p_{s2}}$$

# Cascade Flow Capacity



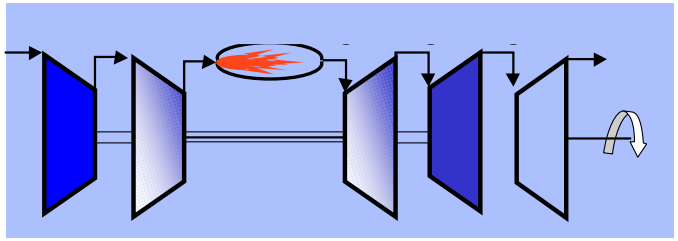




**Geometric Flow Area**



# Effect on Overall Engine Performance

- Blade Row
  - dP/P: increase from 2% to 4%
  - flow angle: may vary
- Turbine Module
  - efficiency: down 0.6 – 1.5 %
  - flow capacity: may vary
- Engine Performance
  - General
    - Power: down 0.5–1.5%
    - Fuel: up 0.5-1.5%
  - Rematching considerations
    - Spool speeds
    - Compressor surge



# Conclusions

- Profile deviations do occur.
- Profile deviations do matter:
  - observable shifts in shock structure & pressure loss shown.
- GFA may not be reliable nozzle throat indicator
  - up to 3% discrepancy from present work
- GasTurbine power and fuel consumption are affected.

# Acknowledgements


- StandardAero Ltd
- Royal Military College of Canada
  - Dr WDE Allan
  - Dr A Asghar
- National Research Council
- NSERC