Boundary Layer Development on a Turbine Blade in a Linear Cascade

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ABSTRACT

Several different boundary–layer development patterns for flow over the suction surface of a turbine airfoil in a linear cascade were studied and documented using a sliding surface hot–film sensor. The state of the boundary layer, whether laminar, transitional or turbulent, was determined at numerous locations along the airfoil suction surface from leading to trailing edge. Boundary–layer transition from laminar to turbulent flow through laminar separation and turbulent reattachment, or through a combination of bypass transition and strong and weak separation and turbulent reattachment, or through solely bypass transition without separation, was observed and benchmark data were recorded. Surface flow visualization and numerical boundary–layer analysis results are consistent with the hot–film data. Flow and geometry information necessary for numerical code operation is available.

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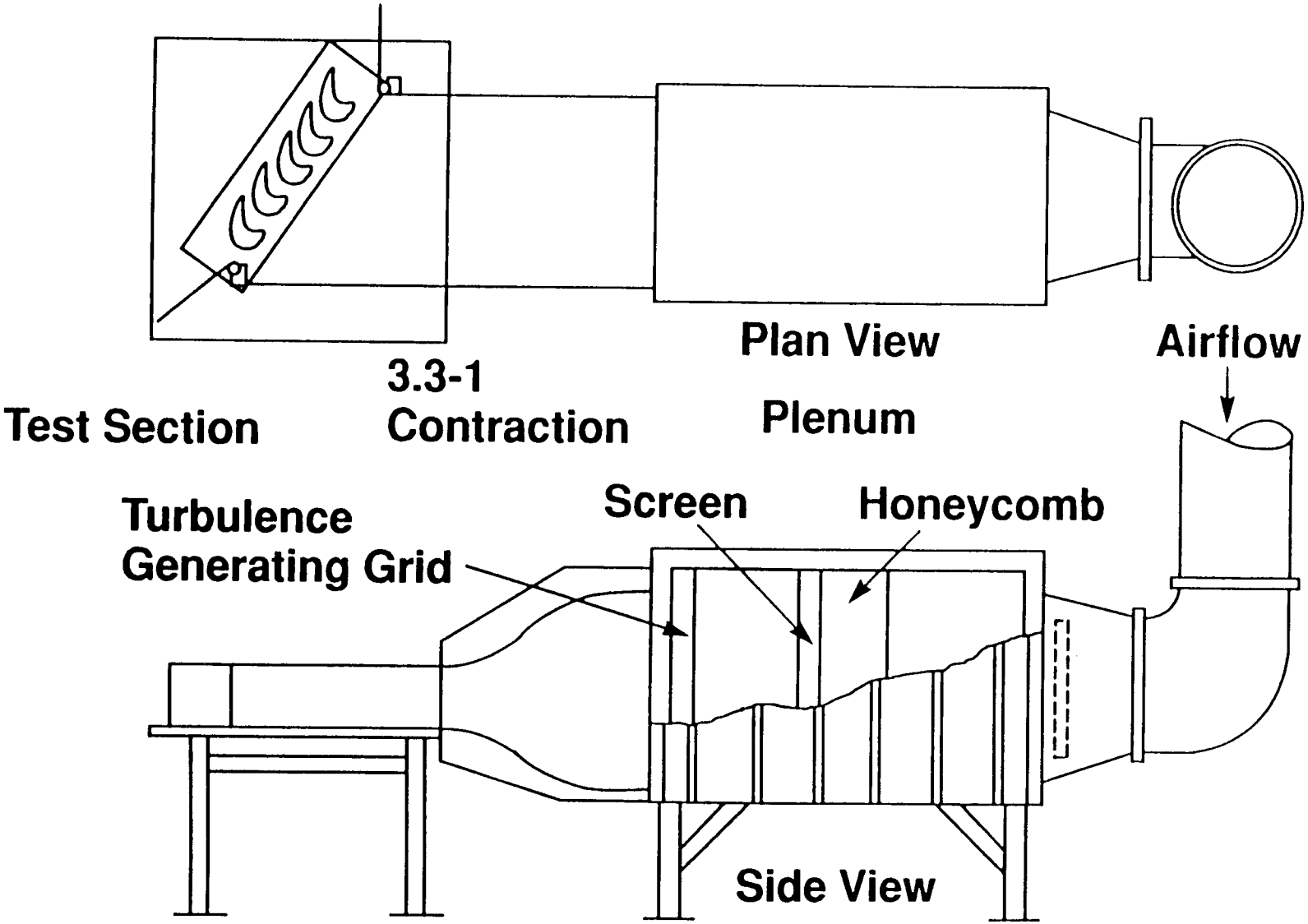
- Objectives
- Test Facility and Instrumentation
- Measurement Characteristics of Surface Hot–Films
- Hot–Film Boundary Layer Measurements
- Boundary Layer Calculations
- Observations / Conclusions

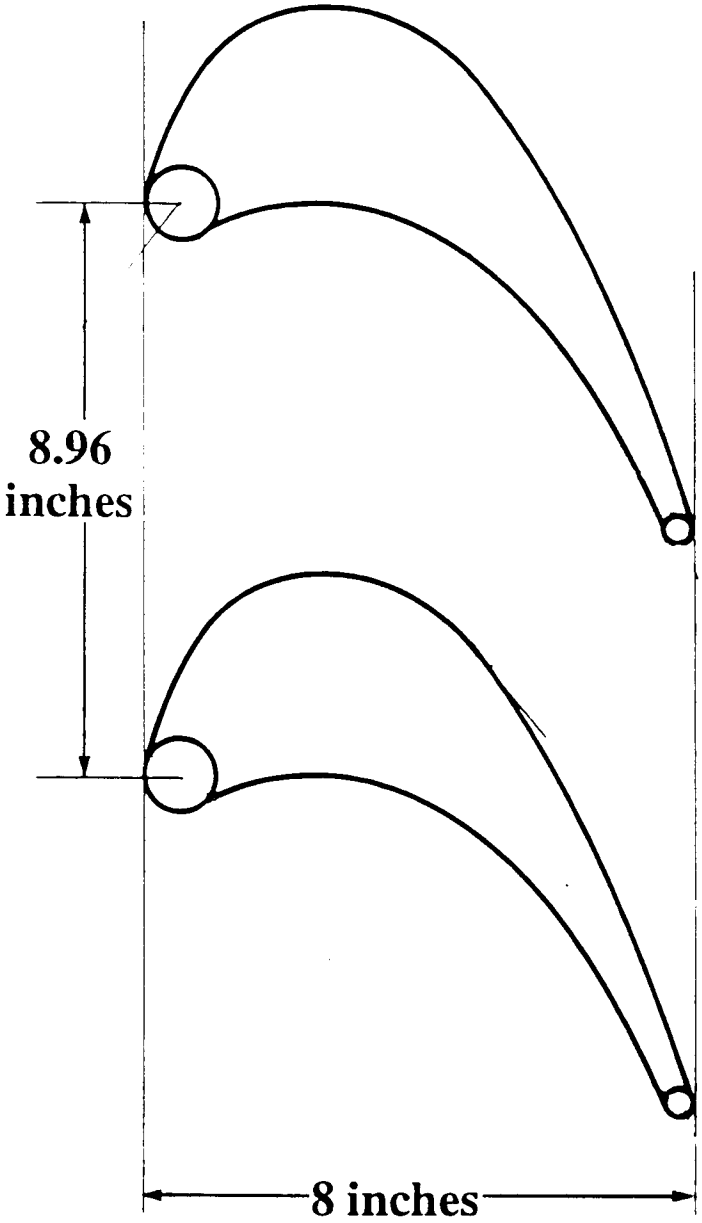
Objectives

- Determine boundary layer characteristics along a turbine airfoil using
  - surface–mounted hot–films
  - flow visualization
  - computational analysis.
- Assess consistency of experimental measurements and boundary layer computations.
- Develop a reliable measurement technique for multistage turbomachines.

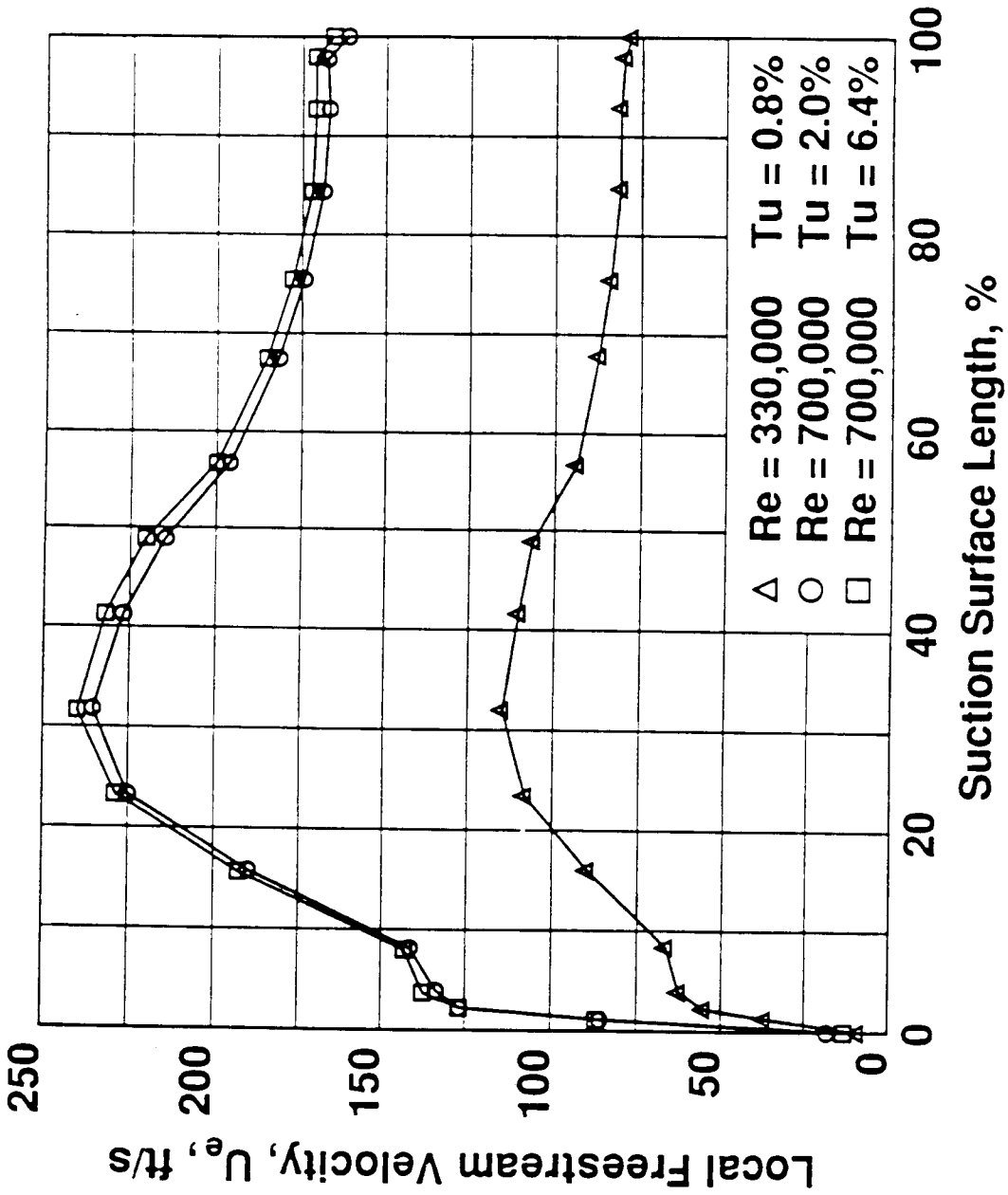
Turbine Cascade Facility



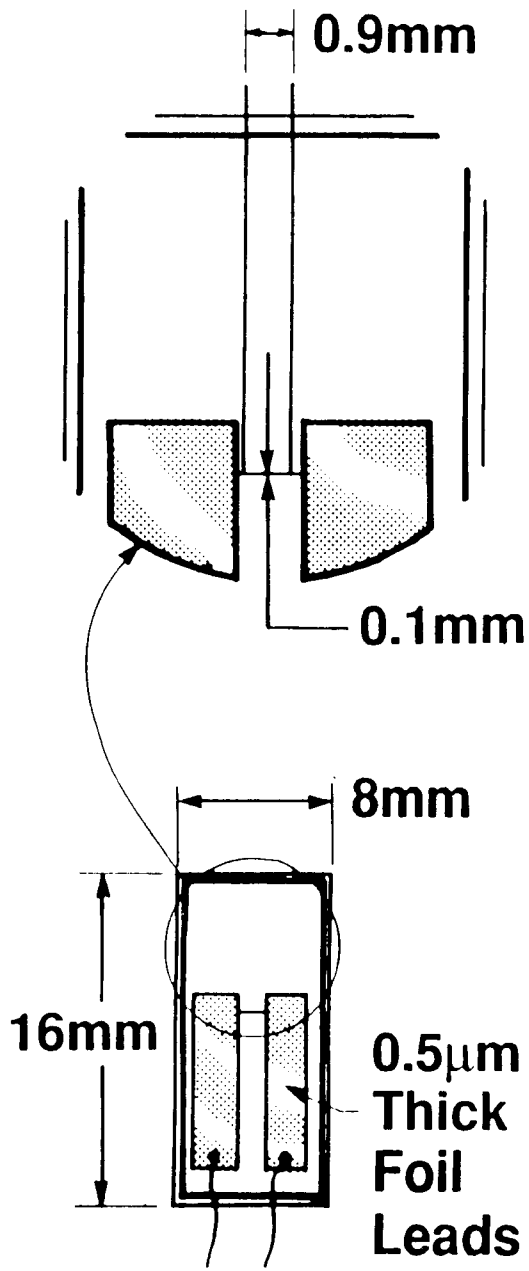
Turbine Cascade Blading



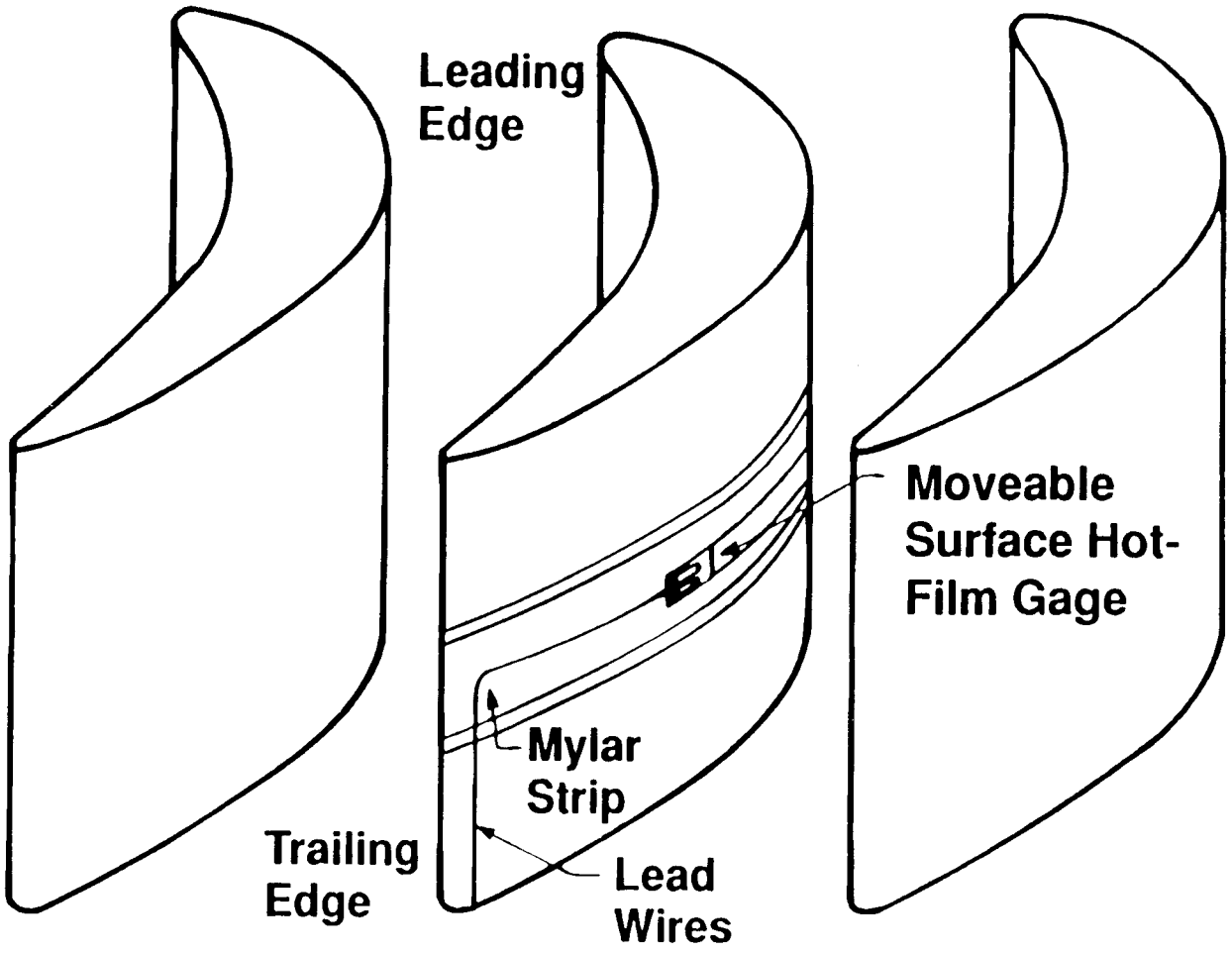
Suction Surface Velocity Distributions



Single-Sensor Hot-Film Gage



Surface Hot-Film Gage Mounting Technique



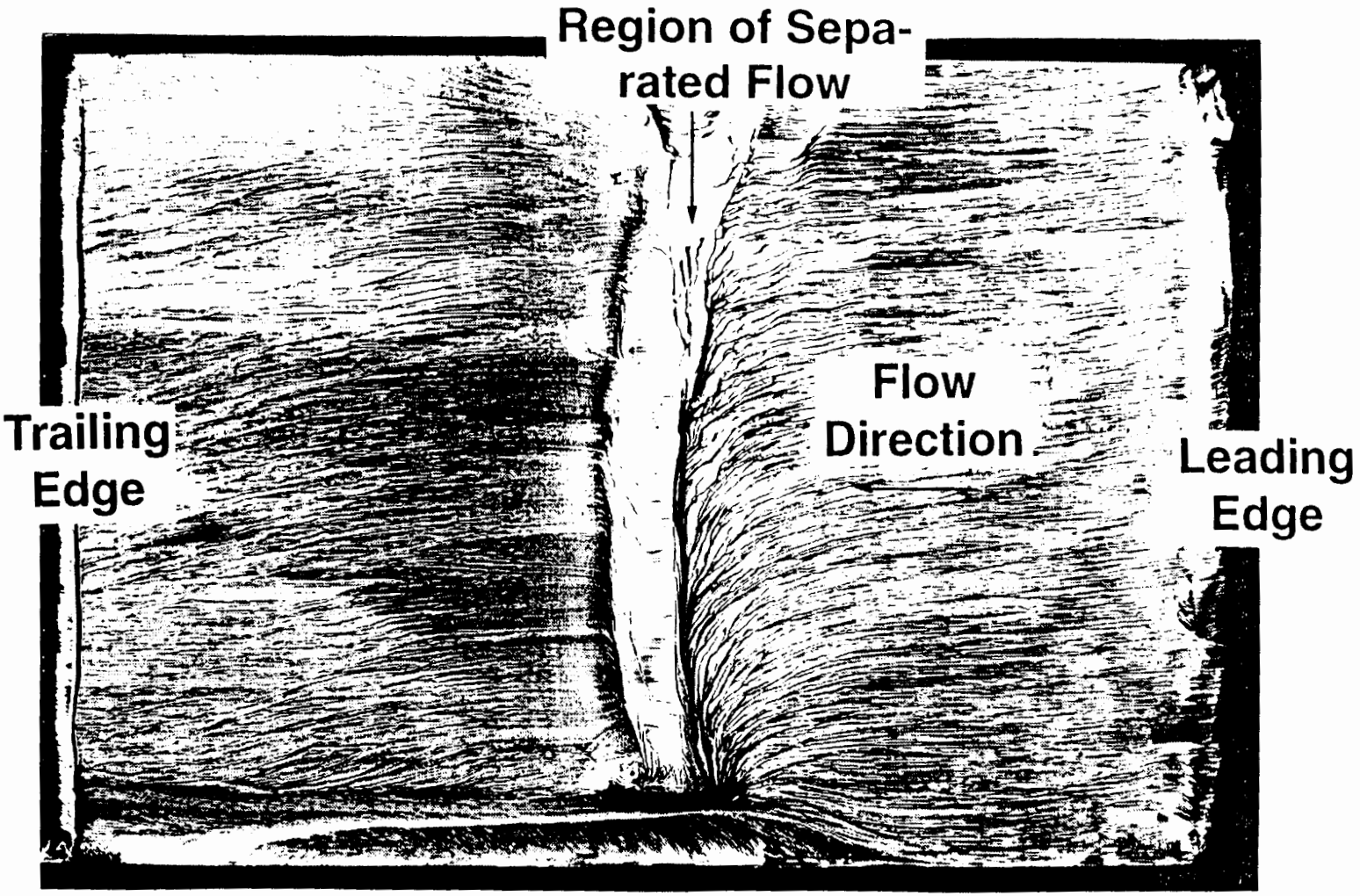
Measurement Characteristics of a Hot–Film Sensor

(Bellhouse and Schultz, 1966)

$$\tau_w^{1/3} = a\ E^2 + b$$

$$\tau_w^{1/3} \propto Q \qquad Q^{1/2} \propto \frac{E-E_0}{E_0}$$

$$\tau_w^{1/6} \propto \frac{E - E_0}{E_0}$$

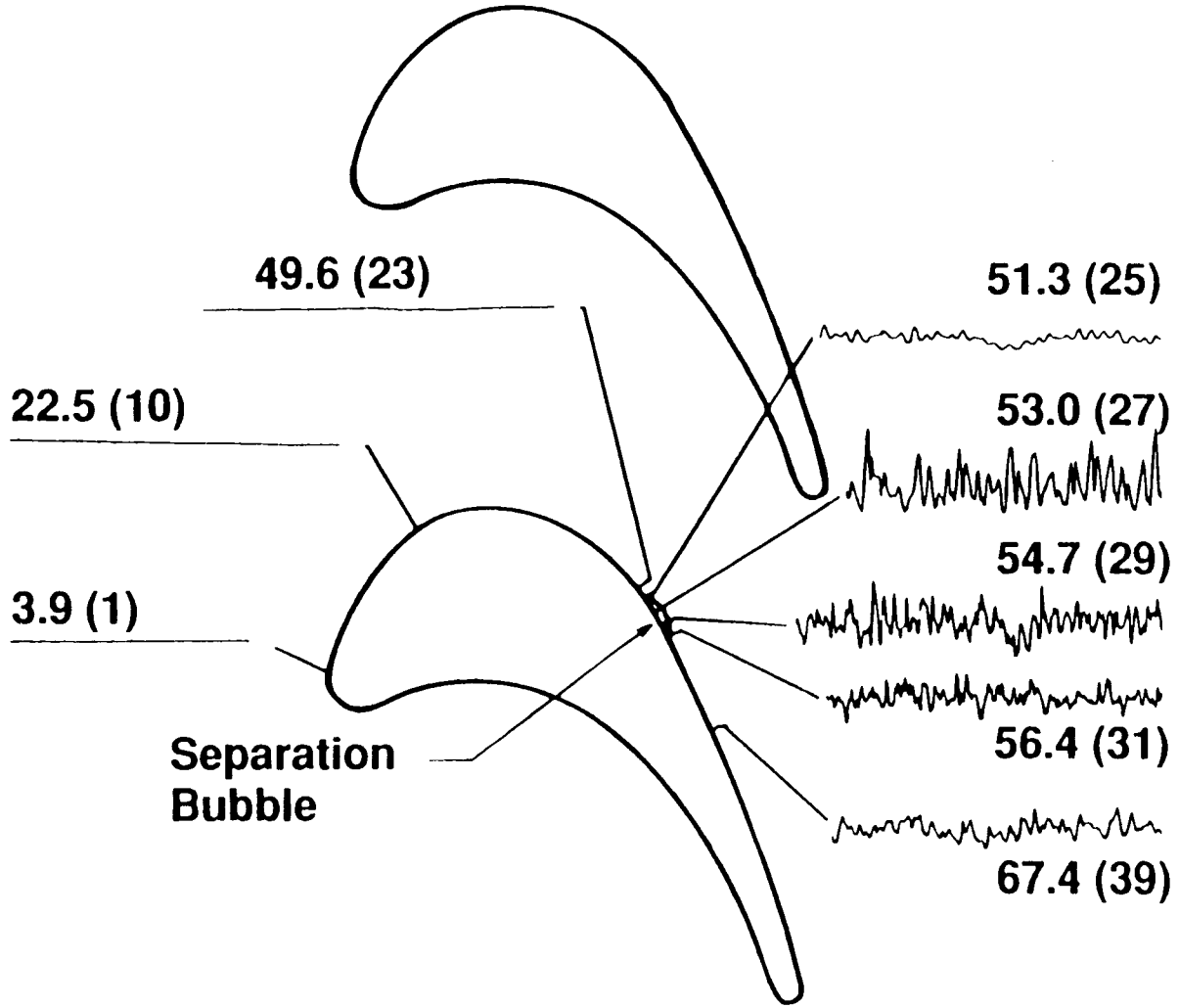


Suction–Surface Flow Visualization

Re = 330,000 Tu_0 = 0.8%

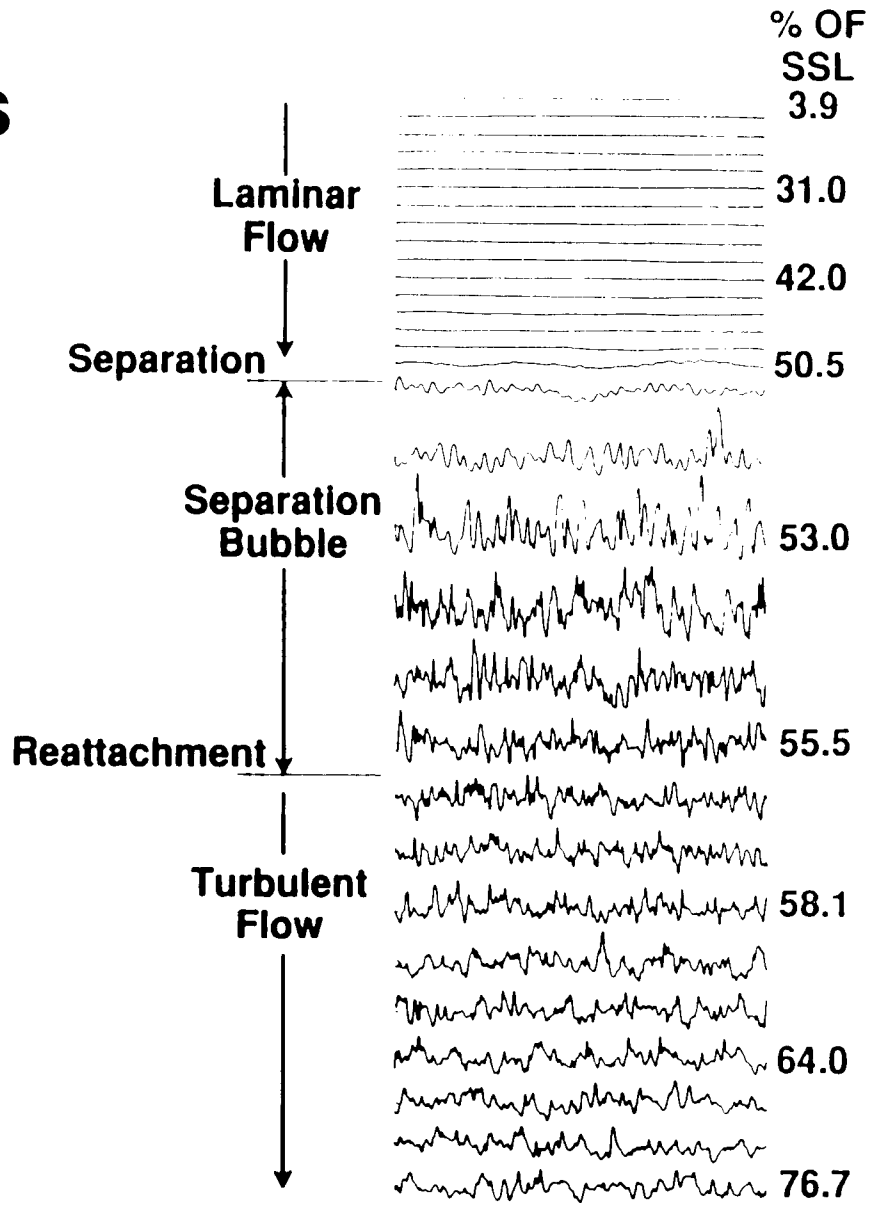
Selected Hot–Film Traces

Re = 330,000 Tu = 0.8%



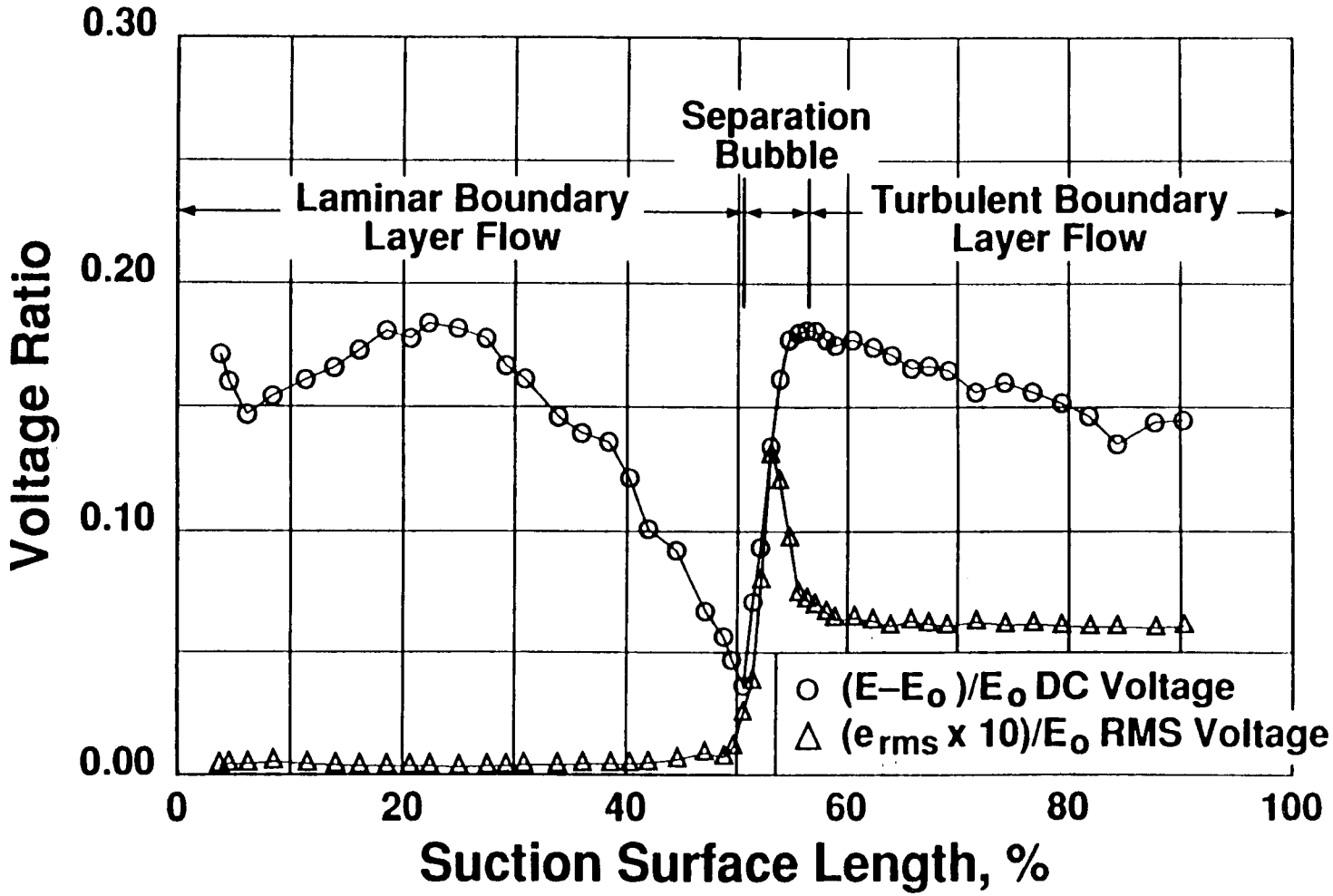
Instantaneous Hot–Film Traces

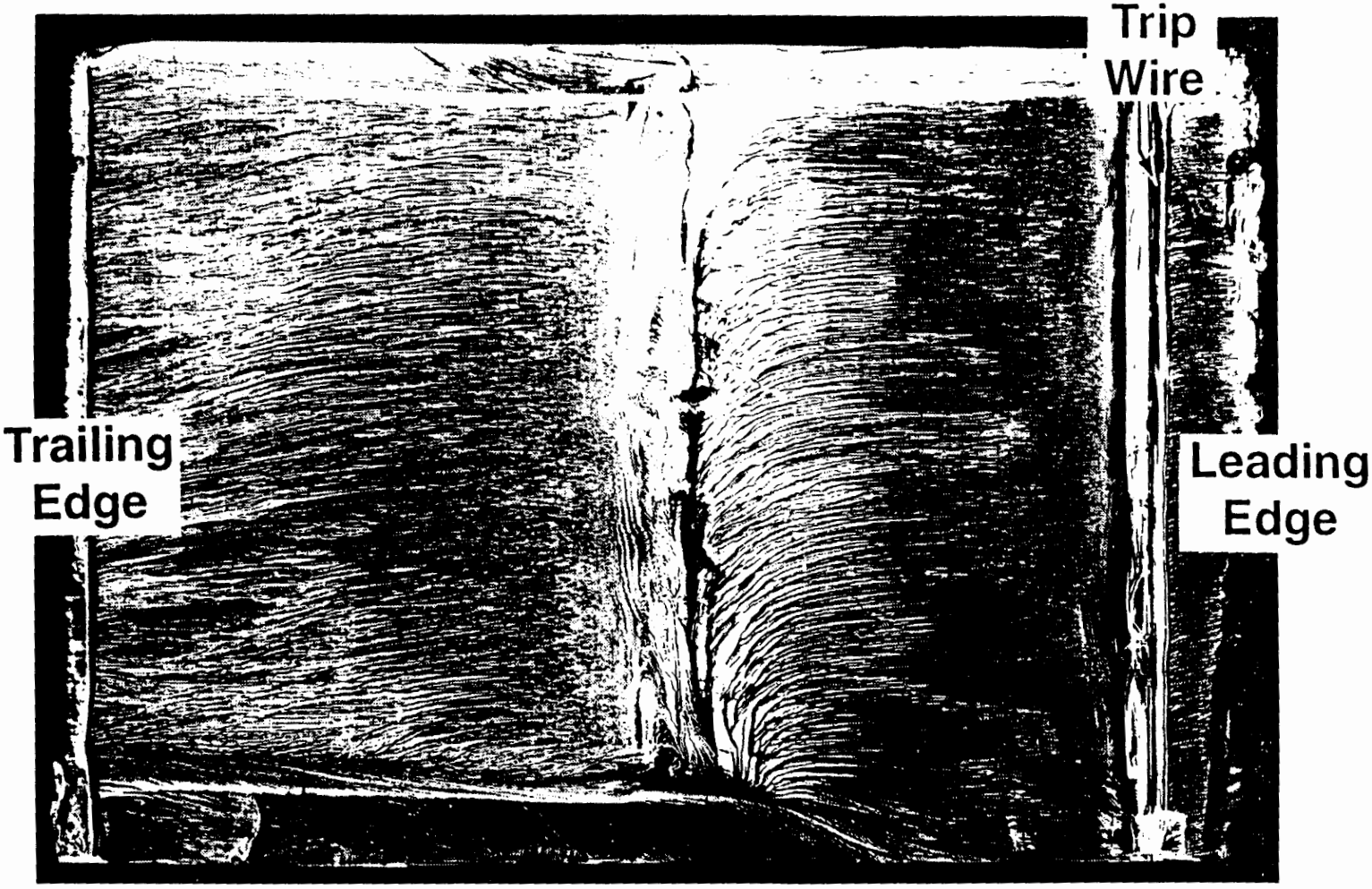
Re = 330,000 Tu = 0.8%



Time–Averaged Measurements

Re = 330,000 Tu = 0.8%



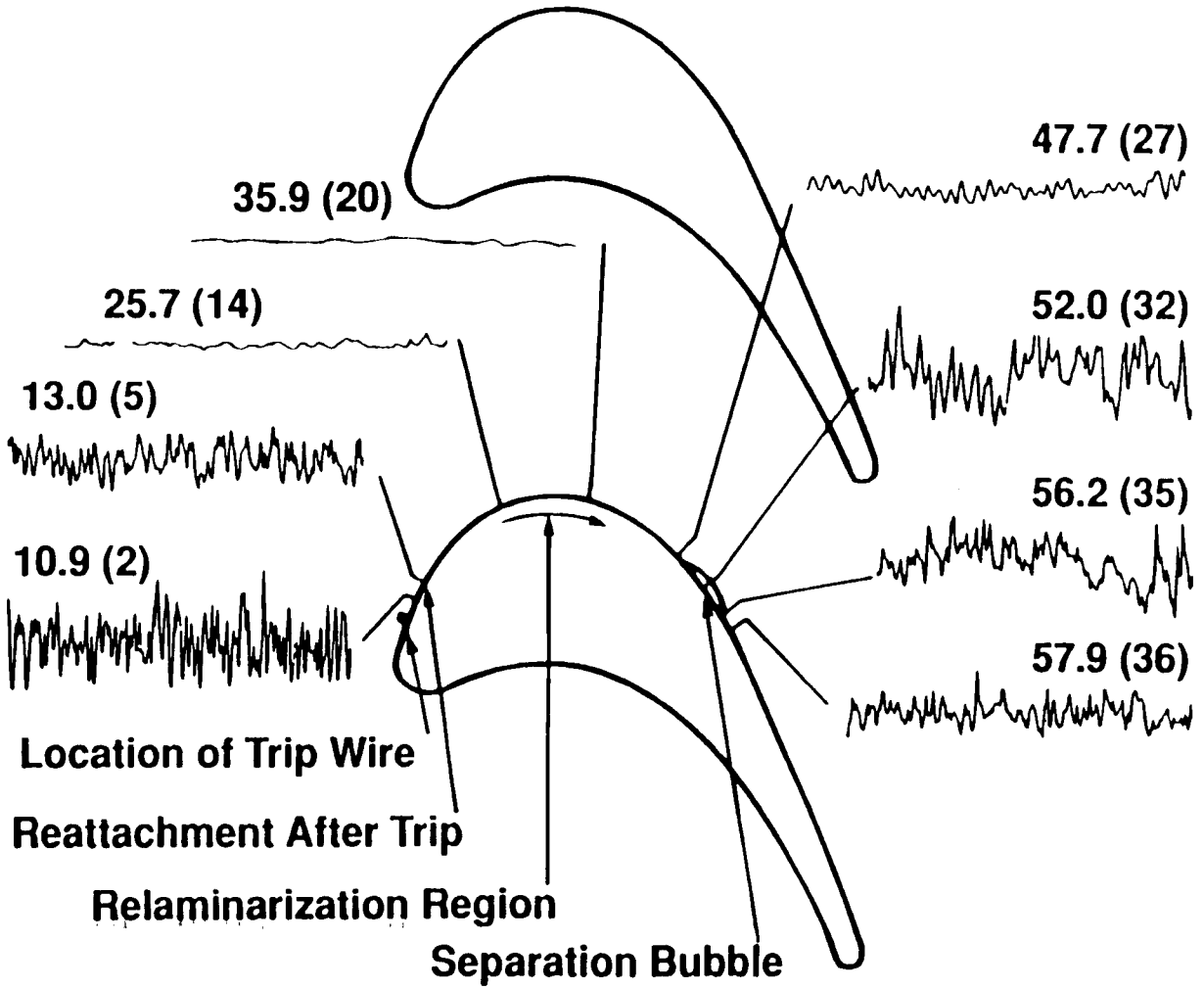


Suction–Surface Flow Visualization

Re = 330,000 Tu_0 = 0.8% with Tripwire

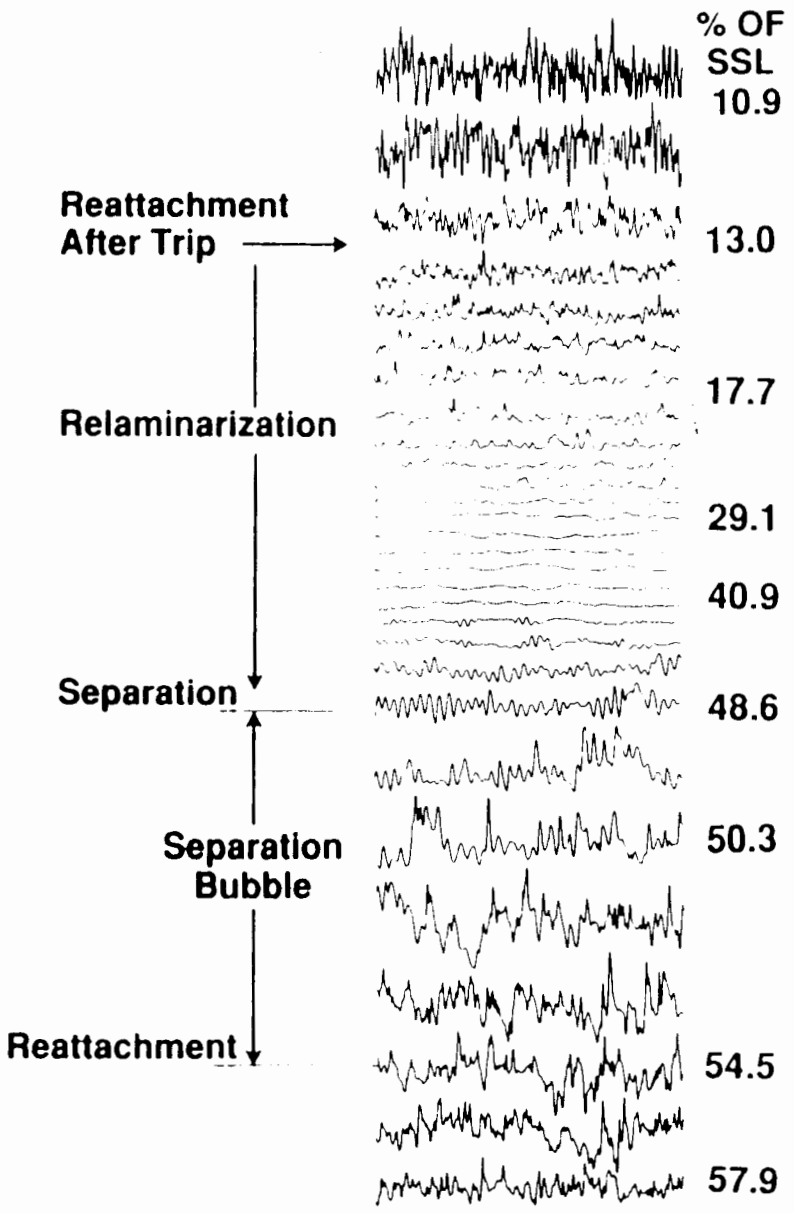
Selected Hot–Film Traces

Re = 330,000 Tu = 0.8% With Tripwire



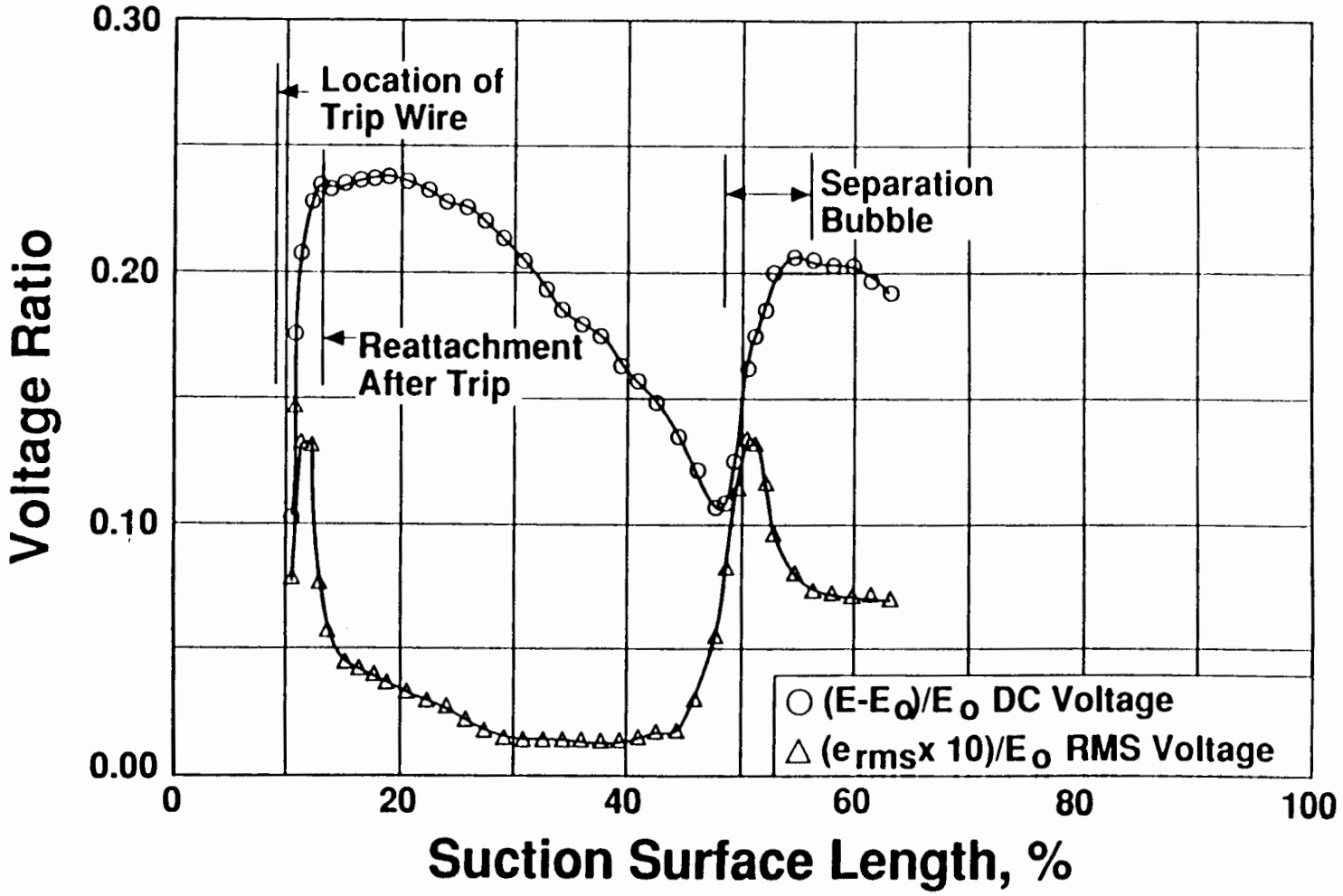
Instantaneous Hot–Film Traces

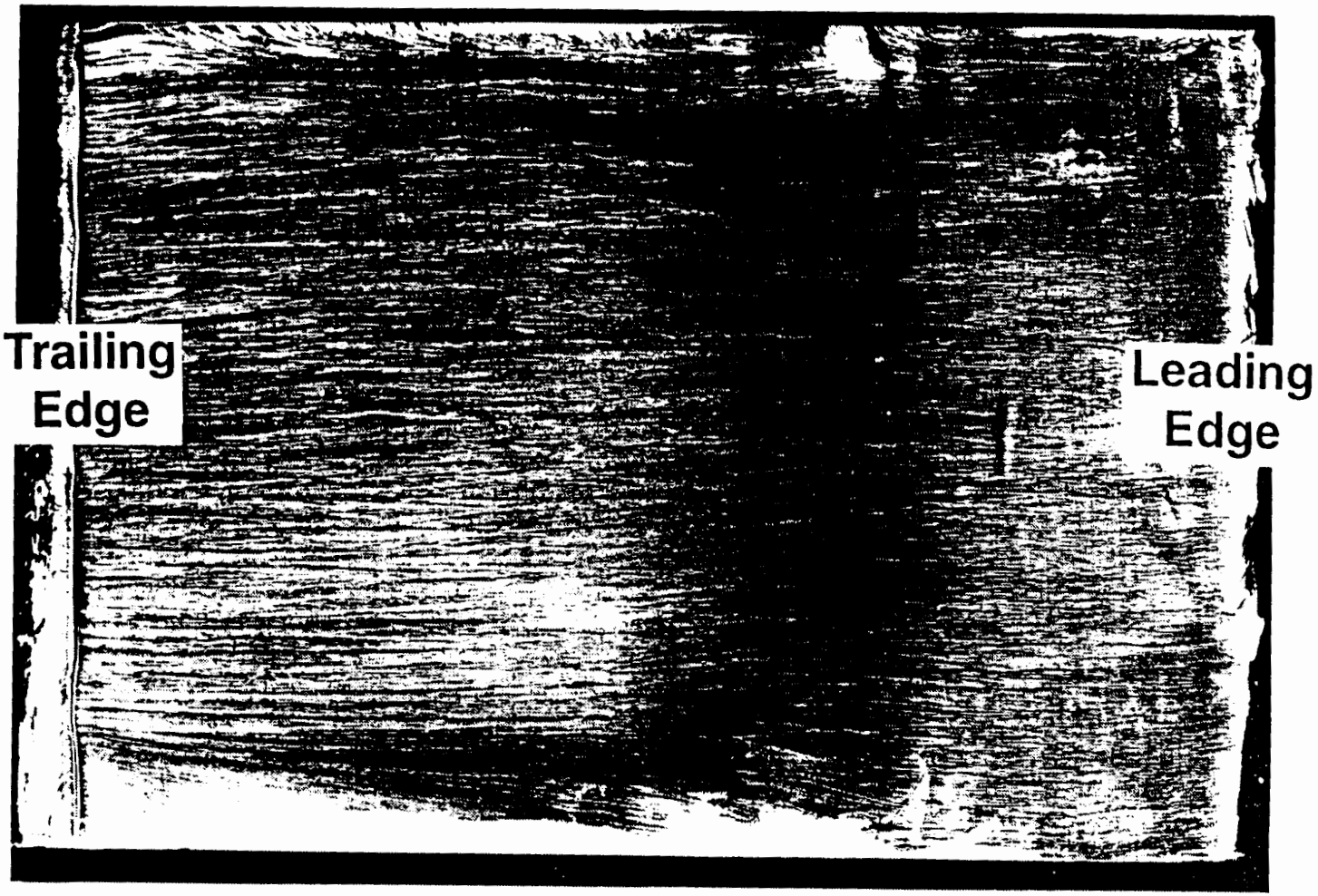
Re = 330,000 Tu = 0.8%
With Tripwire



Time–Averaged Measurements

Re = 330,000 Tu = 0.8% With Tripwire



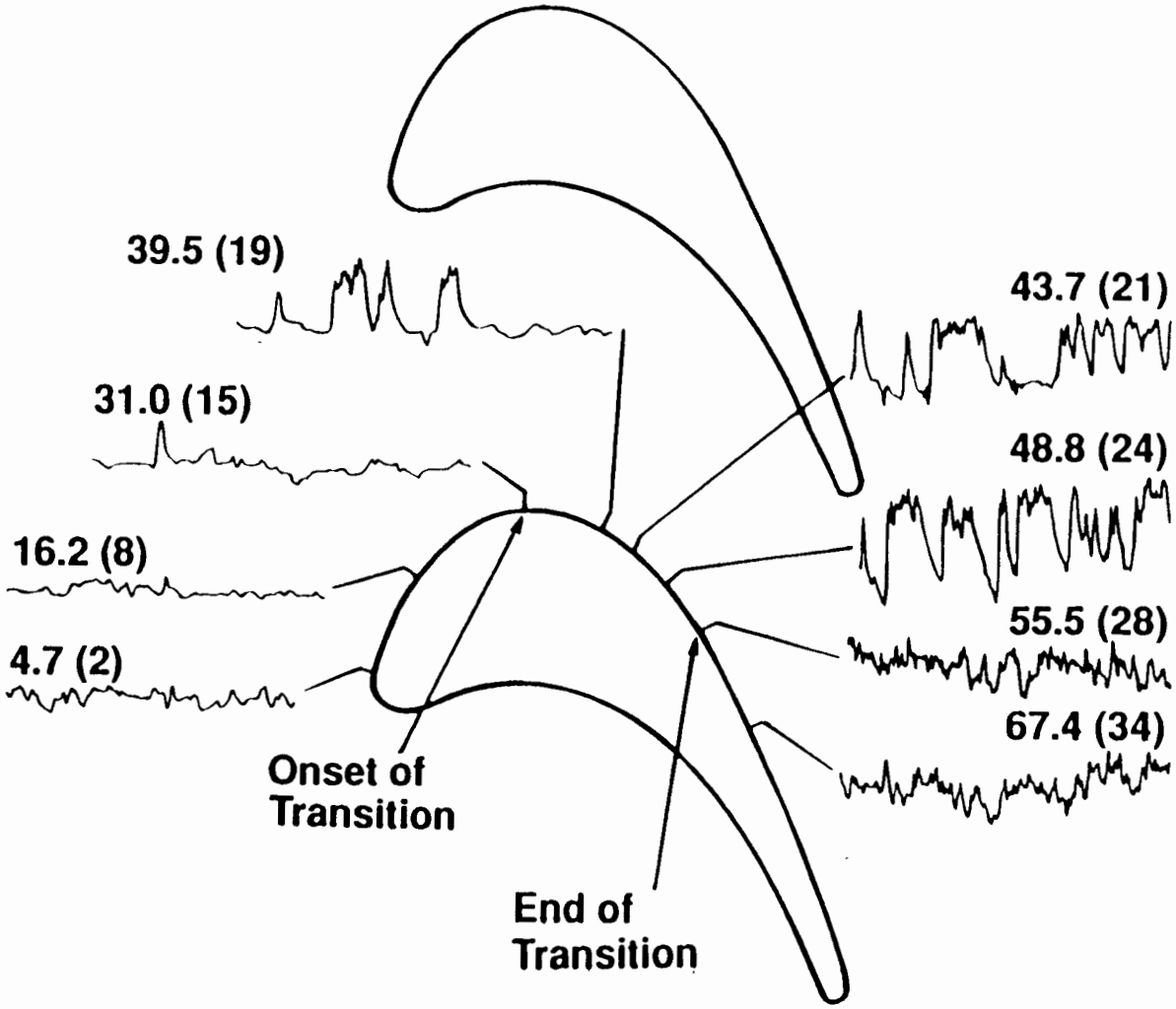


Suction–Surface Flow Visualization

Re = 700,000 Tu_0 = 6.4%

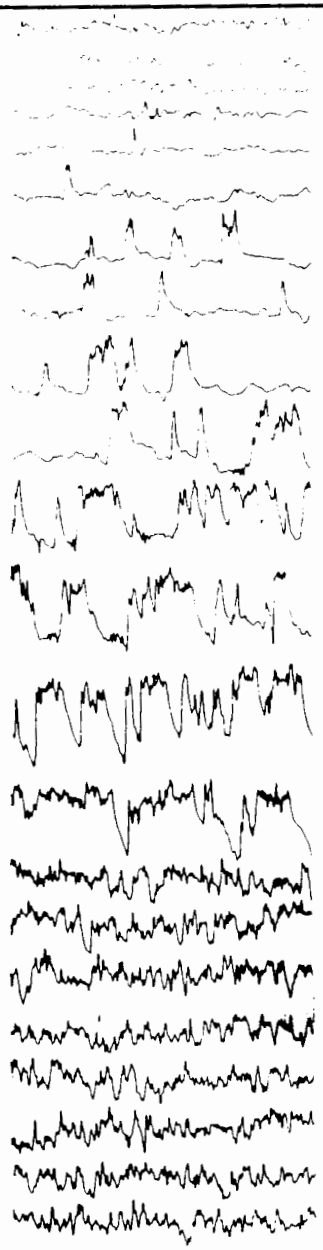
Selected Hot–Film Traces

Re = 700,000 Tu = 6.4%



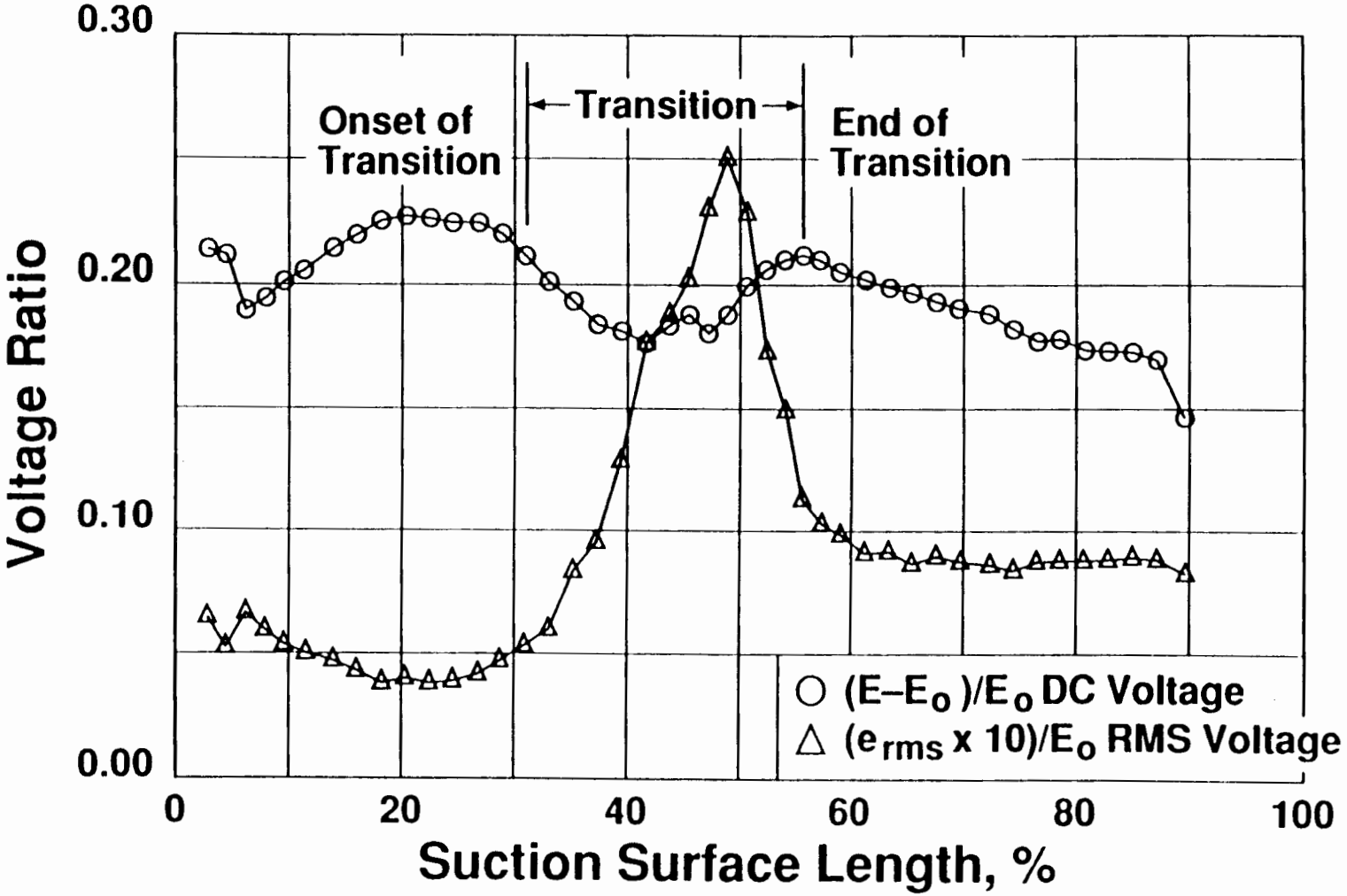
Instantaneous Hot–Film Traces

Re = 700,000 Tu = 6.4%



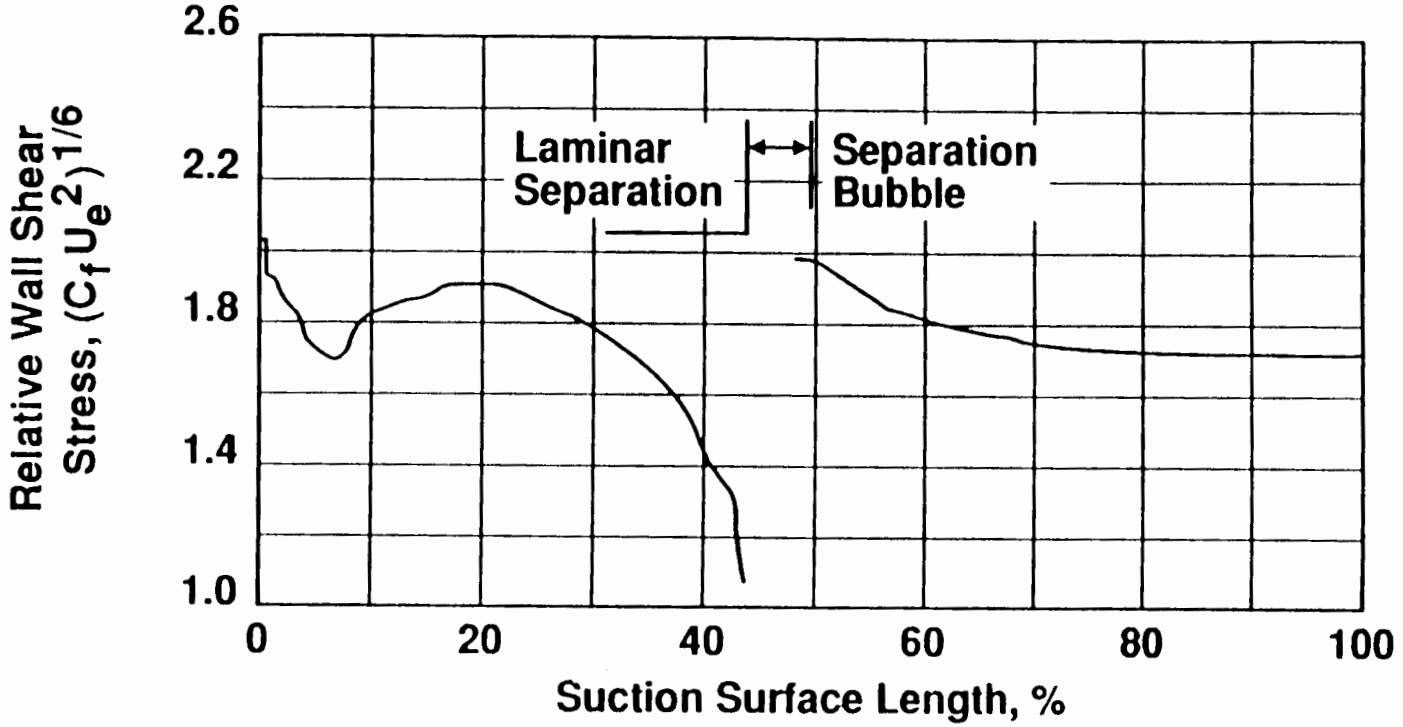
Time–Averaged Measurements

Re = 700,000 Tu = 6.4%



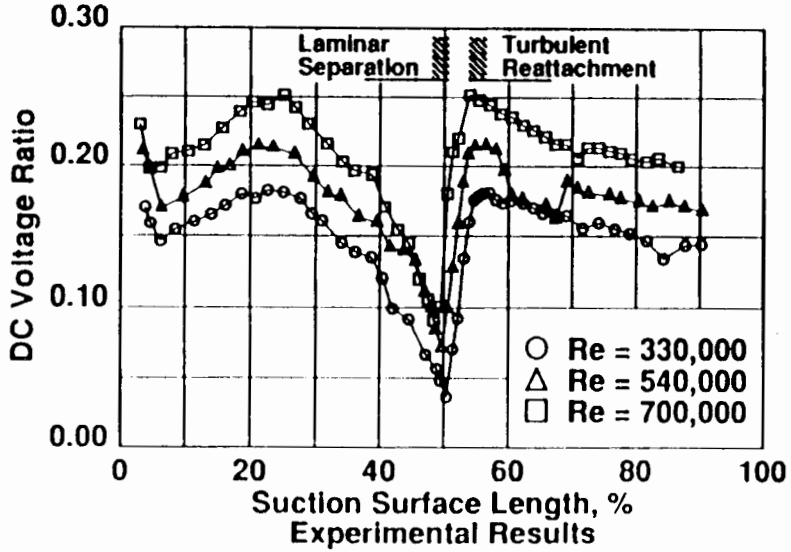
Boundary Layer Calculations

Re = 330,000 Tu = 0.8%

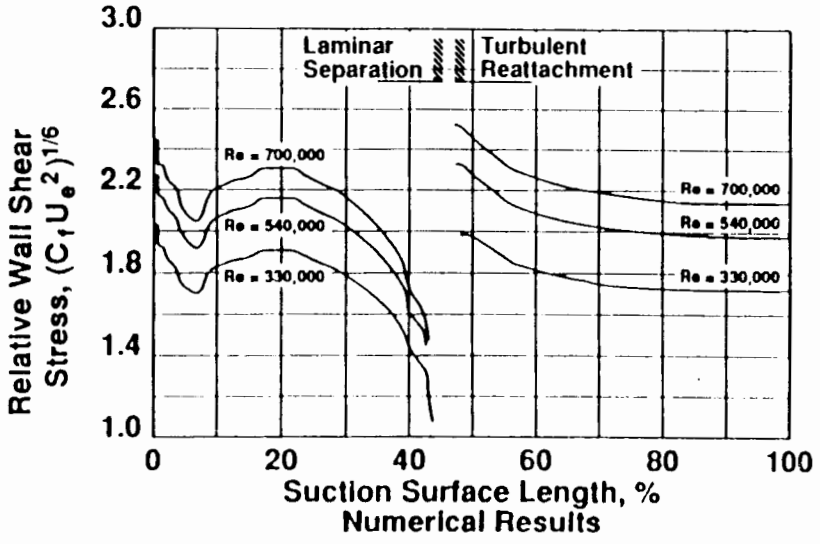


Comparison of Calculations and Measurements

Measurements



Calculations



Observations / Conclusions

- Measurements from surface hot–film sensors provide details of principal features of boundary layer development
  - laminar
  - separated
  - relaminarized
  - transitional
  - turbulent.
- Comparison of experimental measurements and boundary layer calculations indicate consistent relationship between wall shear stress and anemometer output voltage.
- Direct calibration of hot–film sensor output with wall shear stress is not required to discern boundary layer development features.