Edge Cooling Heat Transfer on Turbine Blades With Rotation

Richard J. Goldstein, Steven J. Olson, E.R.G Eckert,
S.V. Patankar, and S.C. Garrick
(Phone: 612-625-5552, Fax: 612-625-3434; E-mail: rjg@me.umn.edu)
University of Minnesota, 111 Church St. SE, Minneapolis, MN 55455

and
C. Camci
The Pennsylvania State University, University Park, PA 16802

Abstract

The University of Minnesota and The Pennsylvania State University are conducting a cooperative experimental and computational study of turbine blade edge cooling, including the use of blade-tip film-cooling configurations. The Pennsylvania State University tests are conducted in a rotating tip, while the University of Minnesota tests are conducted in a large-scale linear cascade. Both test systems are used to investigate the flow and heat transfer in the edge regions of turbine blades, with particular emphasis on the tip region of the blade and the tip-leakage vortex that forms n the passage. Differences in the effects of the flow conditions of the two test facilities will be resolved by developing a numerical model of each of the systems and comparing with experimental test data so that a useful model of tip leakage flow and heat transfer is developed.

The potential of this research is threefold. First, it provides fundamental scientific information in the form of detailed measurements and computational results. In addition, the results of the experiments and computations will be presented in a generalized form so that they will be directly usable by design engineers in industry. Providing input to numerical computational activities will be used to familiarize graduate and undergraduate students with the gas turbine industry.

This poster presentation focuses on the flow and mass transfer at the tip of a simulated turbine blade with variable tip-gap spacing. The flow is visualized using a smoke-wire flow visualization and compared to numerical predictions of the tip flow using the Tasc-Flow Software package. The tip mass transfer results are also given and show a very high level of mass transfer at the tip that is dependent on the tip-gap spacing. The magnitude of the mass transfer at the tip is significantly higher than that on either the pressure or suction sides of the blade near the blade tip.

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Summary:

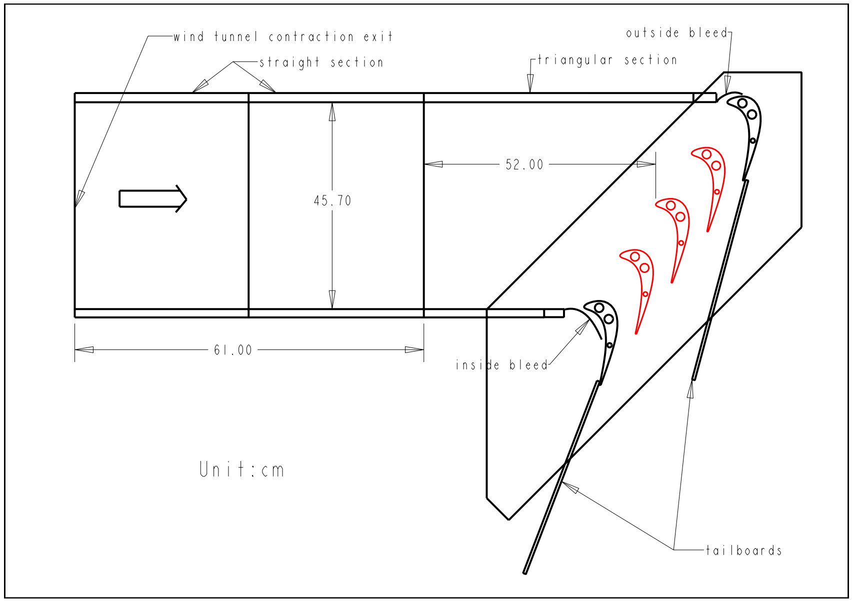
The University of Minnesota and The Pennsylvania State University are conducting a cooperative experimental and computational study of turbine blade edge cooling including the use of blade-tip film-cooling configurations. The Pennsylvania State University tests will be conducted in a rotating rig test setup, while the University of Minnesota tests will be conducted in a large-scale linear cascade. Both test apparatuses will be used to investigate the flow and heat transfer in the edge regions of turbine blades, with particular emphasis on the tip region of the blade and the effects of film cooling at the tip on heat transfer and the tip-leakage vortex that forms in the passage. Differences in the effects of the flow conditions of the two test facilities will be resolved by developing a numerical model of each of the systems and comparing with experimental test data so that a useful model of tip leakage flow and heat transfer is developed.

Objectives:

- Study the tip flow and heat/mass transfer experimentally in a large-scale linear turbine cascade.
- Study the tip flow and heat transfer experimentally in a fully rotating annular rig.
- Study the effect of blade tip film cooling on blade tip heat transfer experimentally for both arrangements.
- CFD simulation of the blade tip flow and heat transfer using commercial software for both arrangements with the goal of developing a model of these flows suitable for future design work.

Linear Cascade Test Section:

Planview of the Test Section

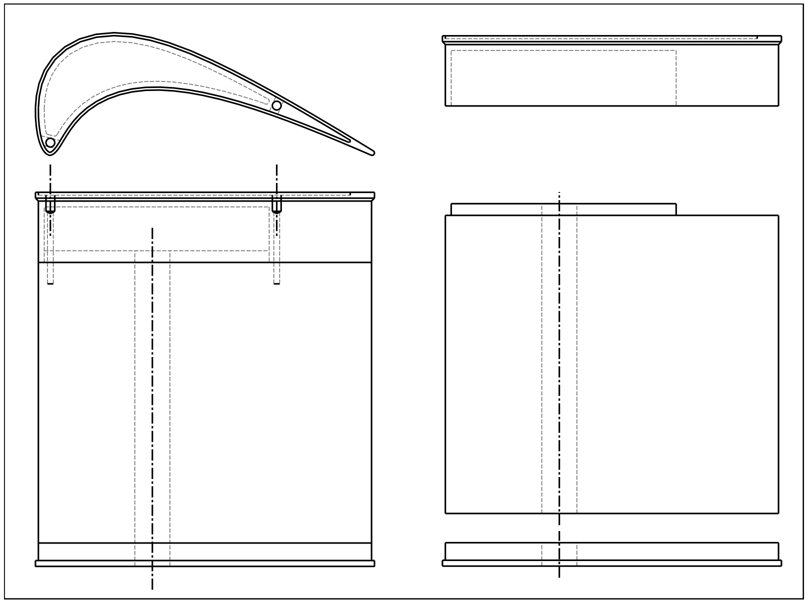


Cascade Data

Number of blades	5
Chord length of blade - C	18.4 cm
Axial chord of blade	13.0 cm
Pitch of cascade	13.8 cm
Height or width of cascade	45.7 cm
Aspect ratio (Span/Chord)	2.48
Blade inlet angle	35°
Blade outlet angle	-72.49°
Inlet/Exit area ratio of the cascade	2.72
Area ratio of the contraction	6.25
Highest exit Reynolds number - Re_{ex}	7.8×10^5

Test Blade:

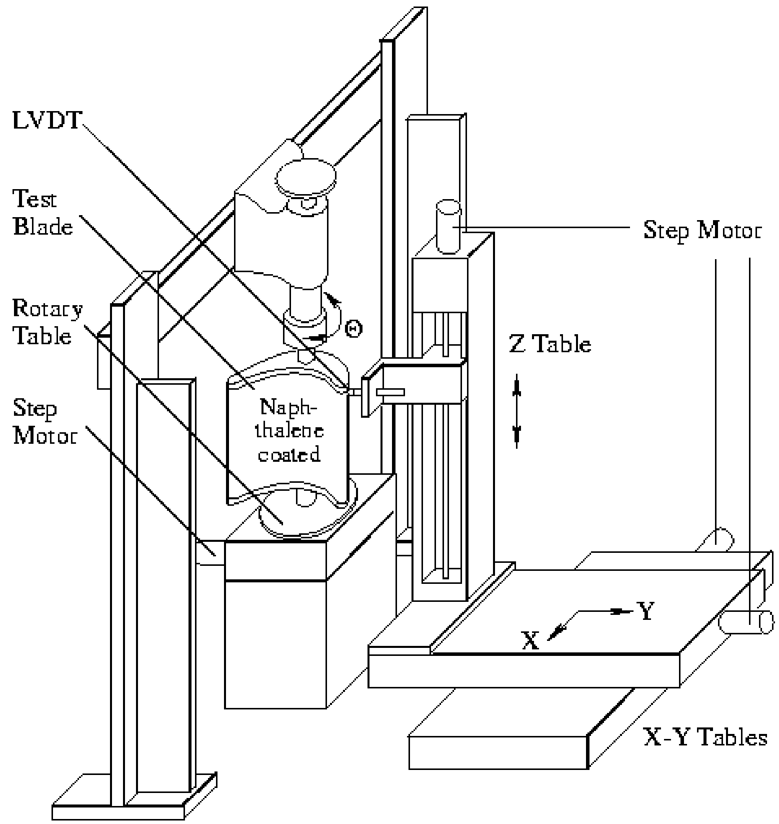
Naphthalene Mass Transfer Test Blade



- An aluminum hollow blade is used for naphthalene casting and cooling air injection.
- The top cap is used for blade tip casting. The middle part of blade is used for blade surface casting.
- The thin bottom cap side sits on a solid blade connected to the endwall.

Data Acquisition System:

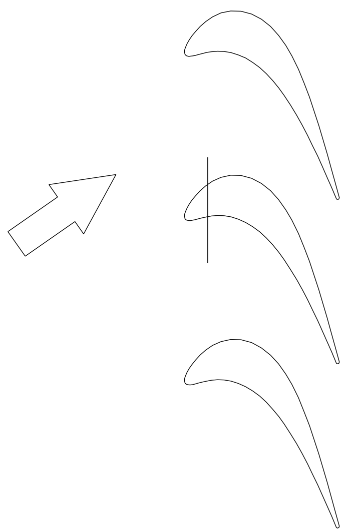
- Naphthalene casting on the tip and surface of the test blade.
- Scan the test blade twice the data acquisition system before and after a wind tunnel test.
- A special bi-directional probe is used to measure the naphthalene surface profile of the test blade.

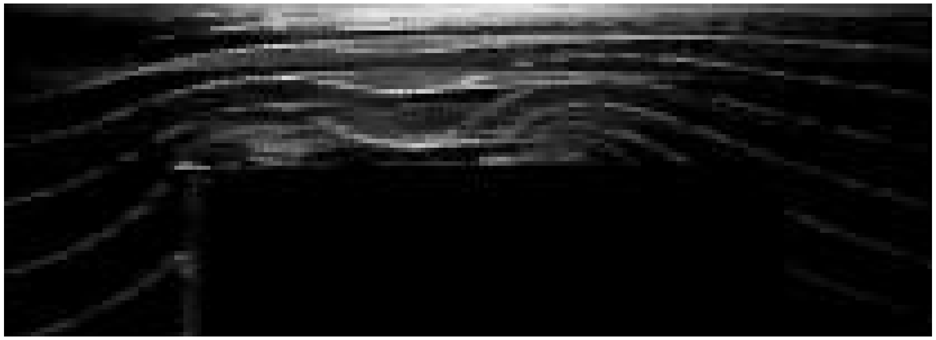


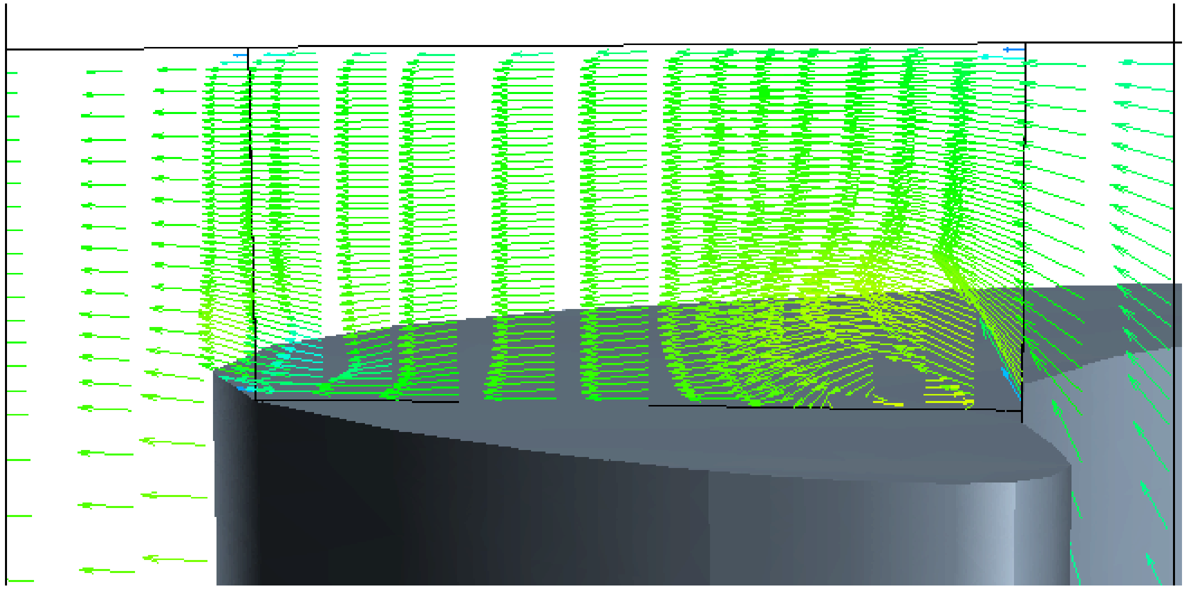
4-Axis Table

Flow Visualization/Numerical Calculations:

$X/C_X = 0.15$

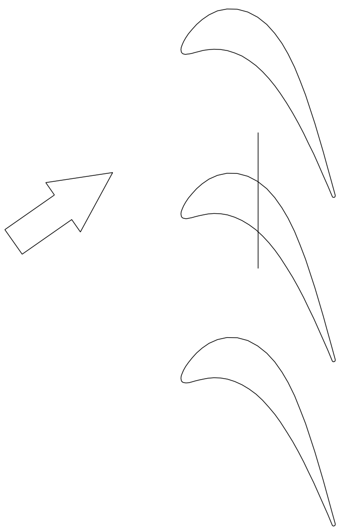


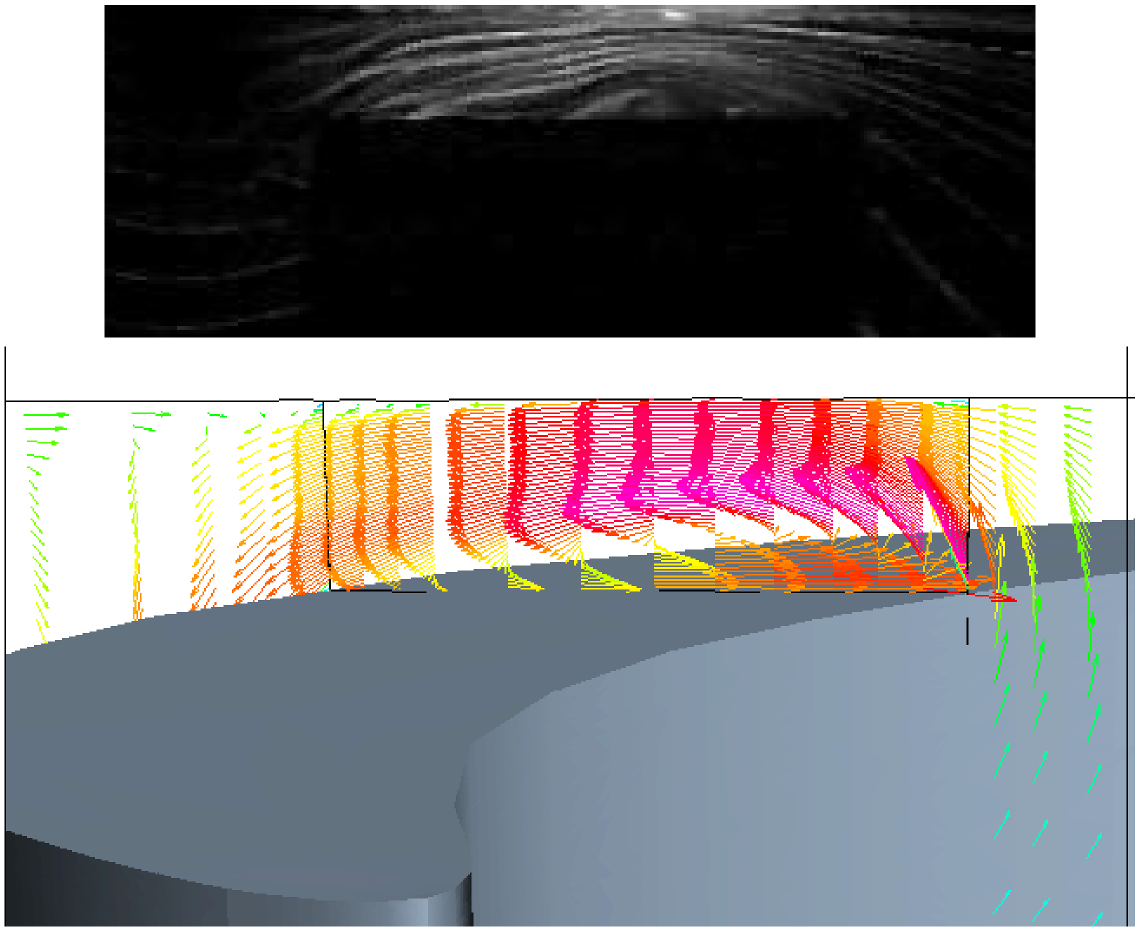




Flow Visualization/Numerical Calculations:

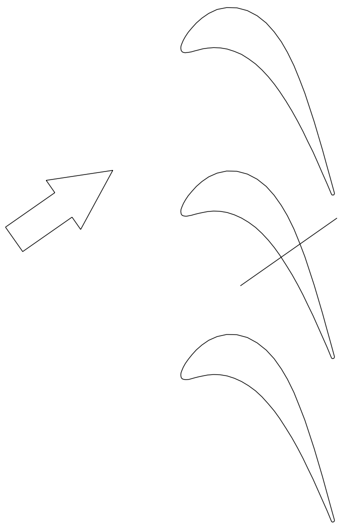
$X/C_X = 0.60$

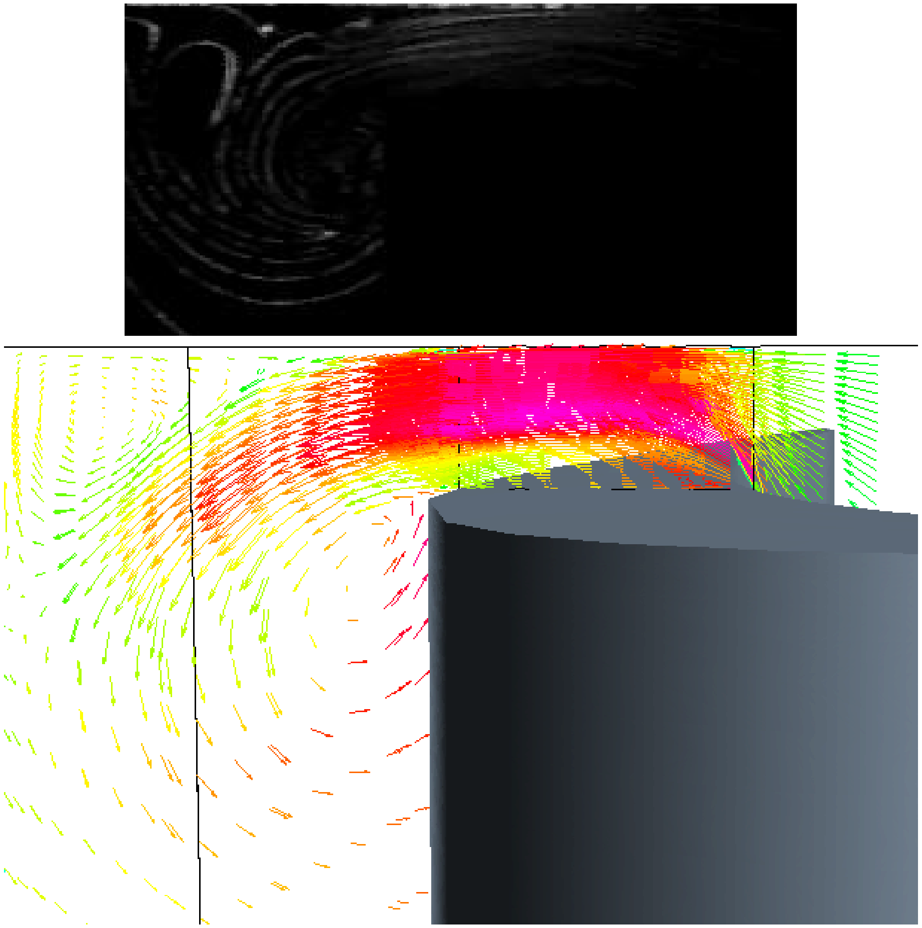




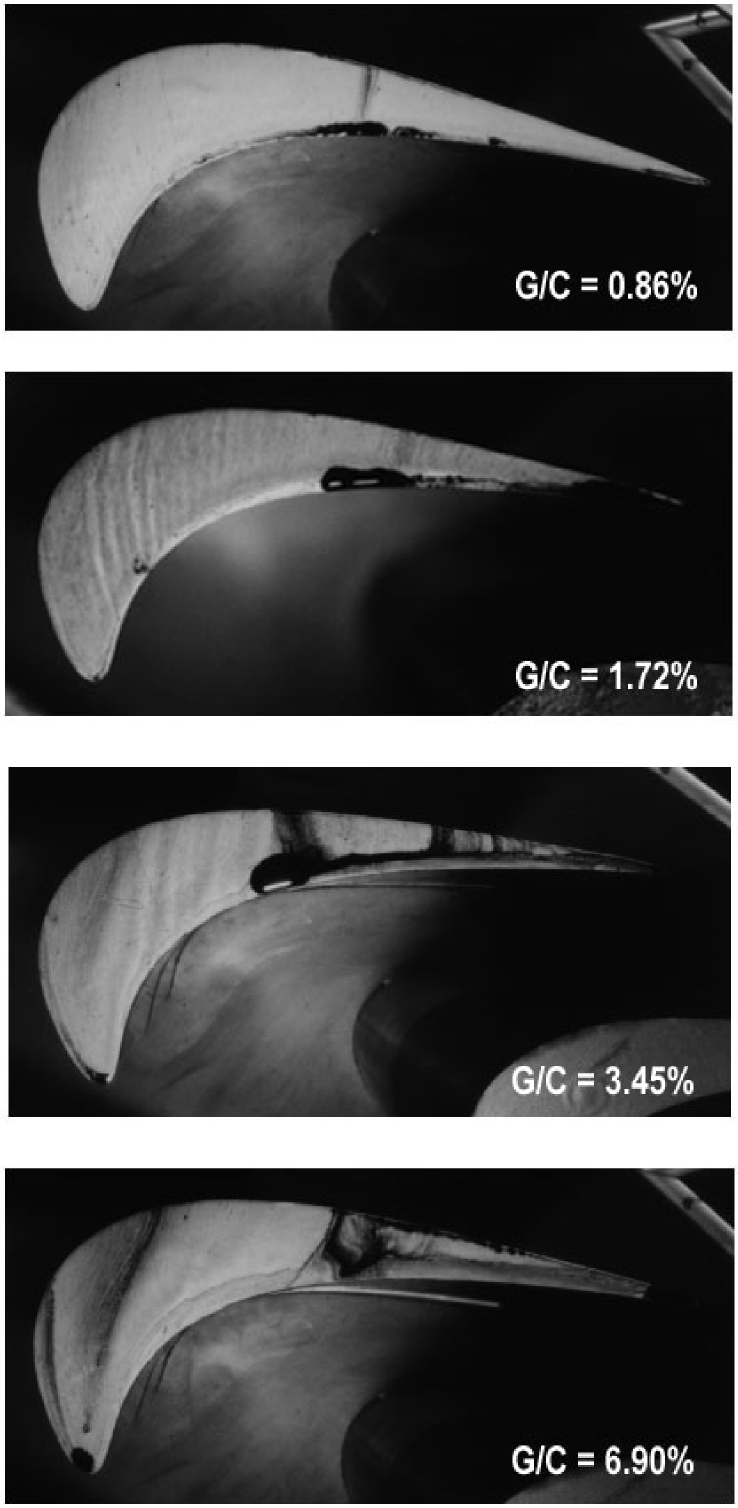
Flow Visualization/Numerical Calculations:

$Y = X tan(35°) + 0.5 C_X$

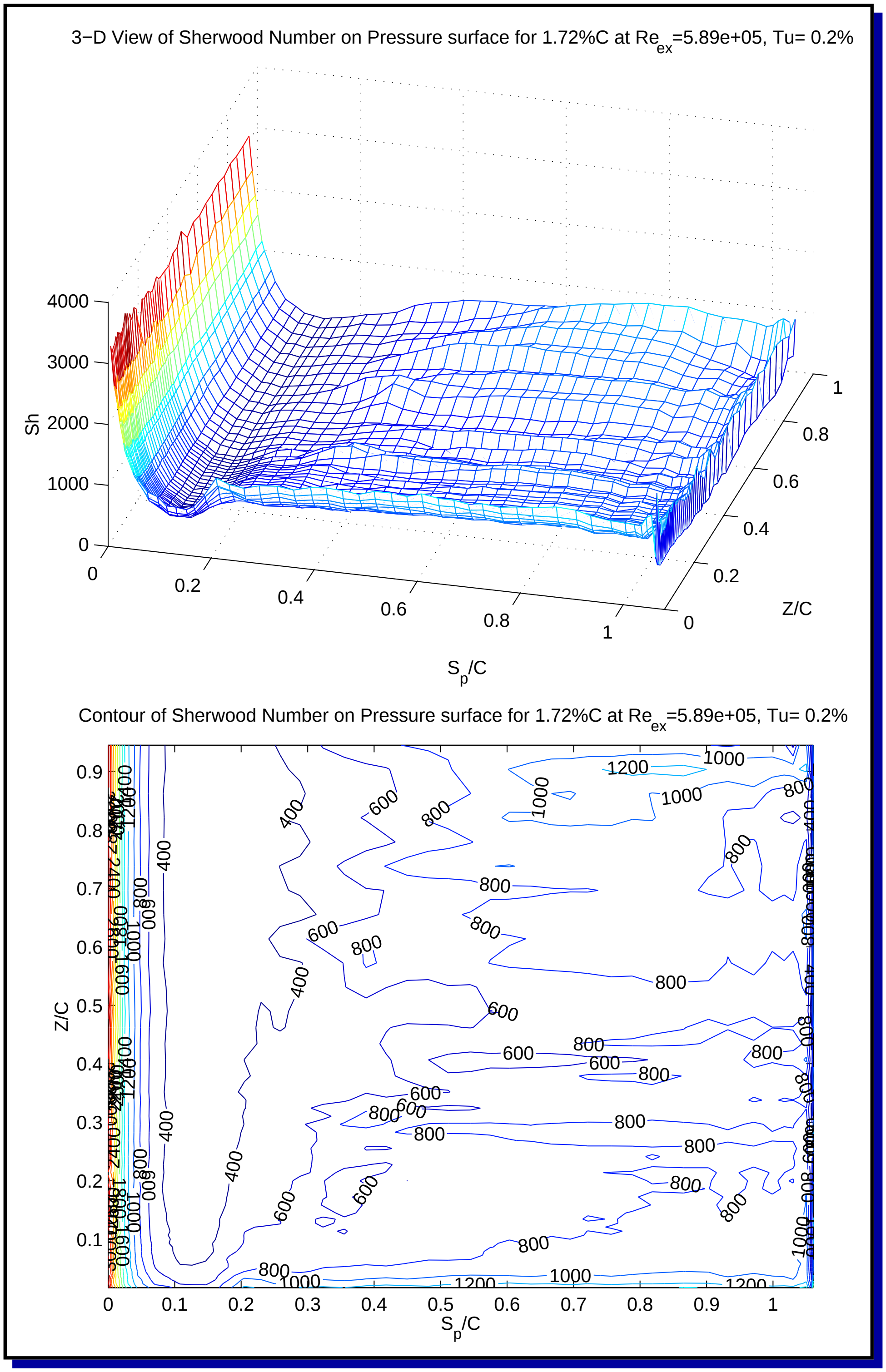




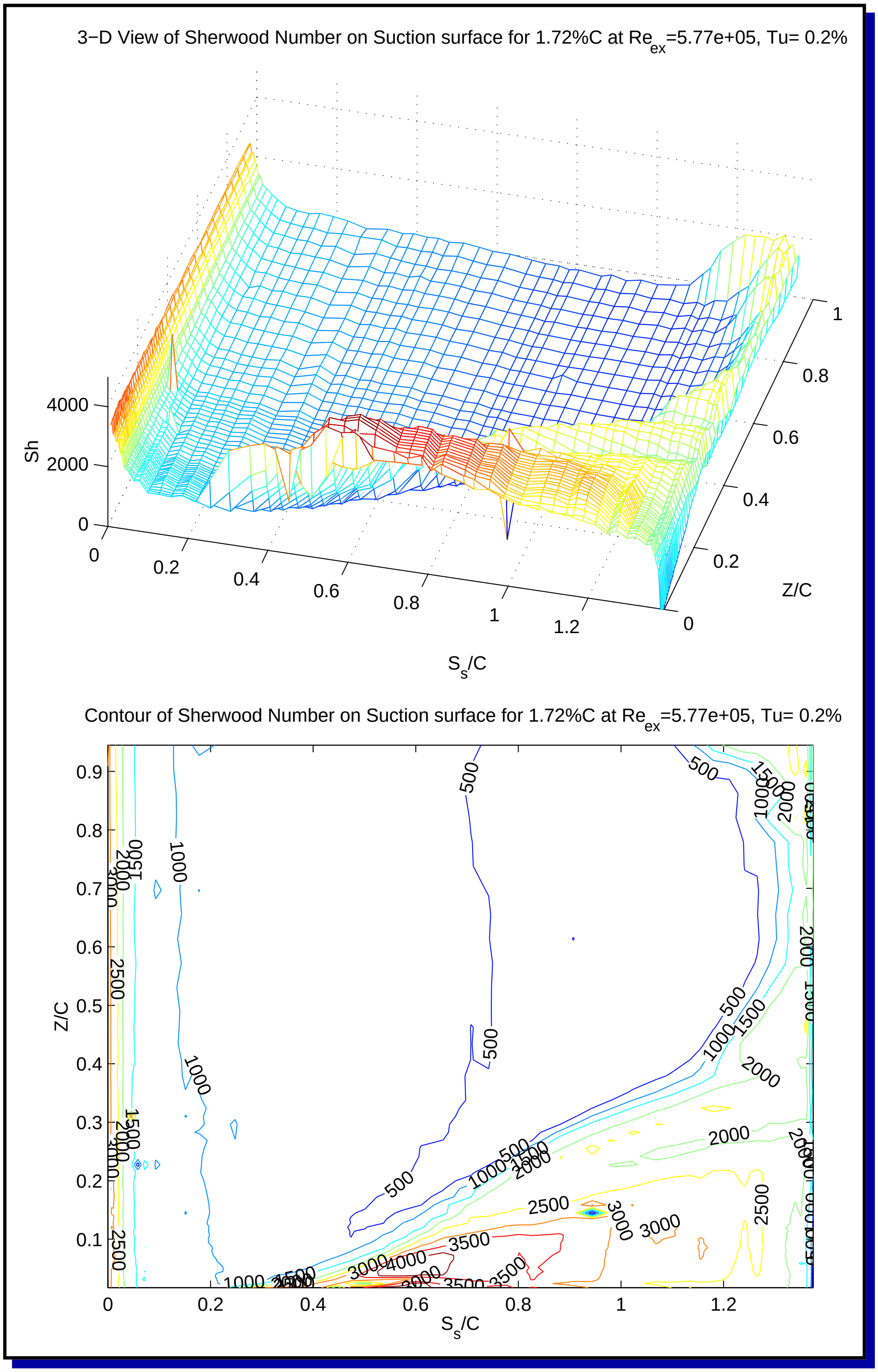
Tip Region Flow Visualization:



Pressure Side Mass Transfer Near the Tip:



Suction Side Mass Transfer Near the Tip:



Tip Mass Transfer: