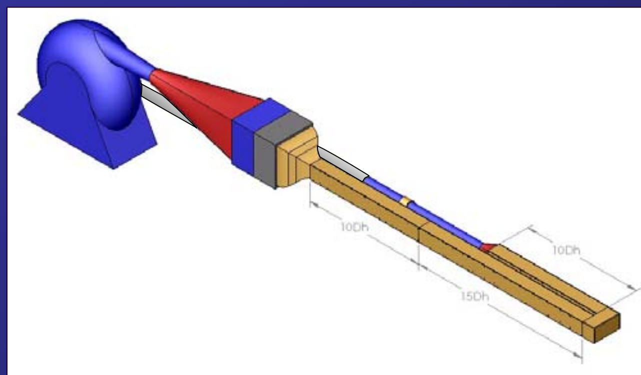
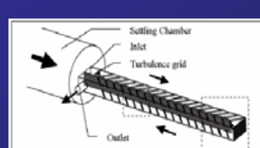
Design of a Test Rig to Simulate Flow Through a Ribbed Cooling Passage



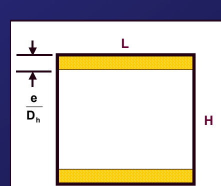
Todd Beirne, Rob Bellonio, Susan Brewton,
Avery Dunigan, Jeff Hodges, Scott Walsh, Al Wilder
Advisor: Dr. Karen Thole
Graduate Assistant: Evan Sewall
Mechanical Engineering Dept.
December 11, 2002

This design builds on thermo-fluids principles and previous research

Background and Motivation for Design

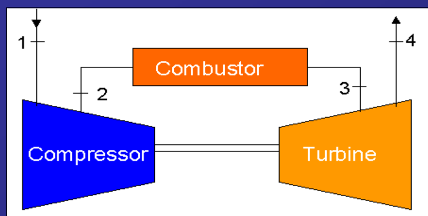


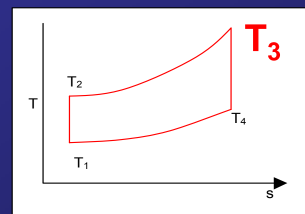
Review of Existing Test Rigs

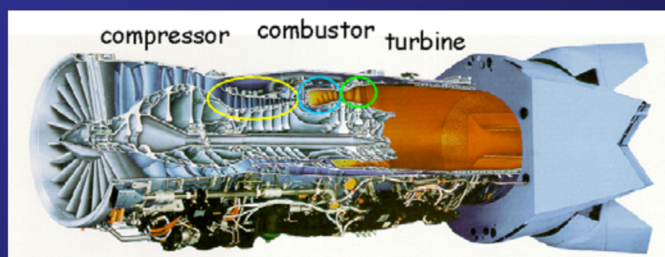


Overview of Final Rig Design

The Brayton Cycle remains the basis for the modern gas turbine engine







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The material melting points limit the rotor inlet temperature and engine performance

Average inlet temperature:

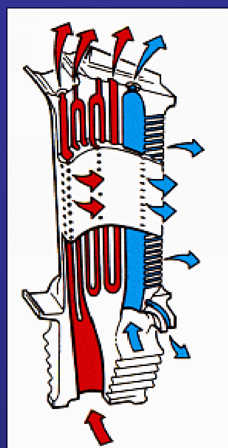
3000^{O}F

Melting point of metal:

~2400^{O}F

Virginia Tech

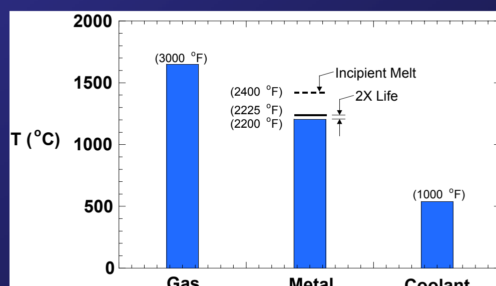
The drive to increase inlet temperatures leads to innovative blade design



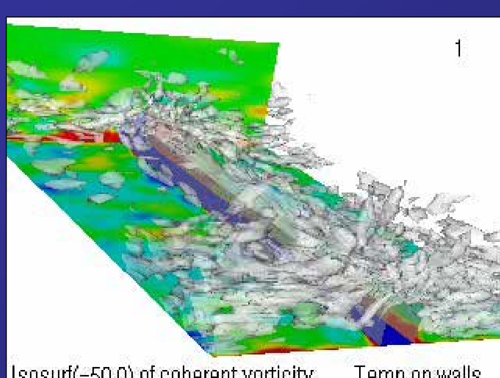
Improved materials

External film cooling

Internal cooling channels



Internal channels have ribs that create complex flow and enhance cooling

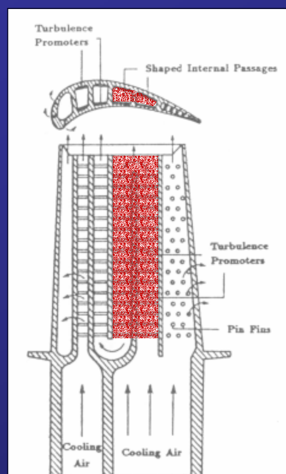


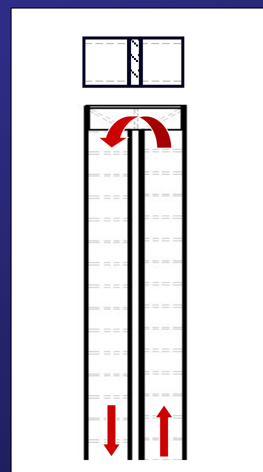
[Tafti, 2002]

Two problems with ribs:

- Flow behavior difficult to model
- Lack of detail limits prediction ability

We want to create a large-scale environment that simulates the flow

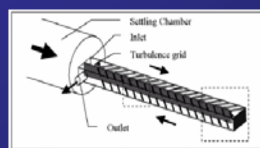




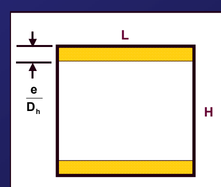
Our clients include researchers, the government, and the engine industry

This design builds on thermo-fluids principles and previous research

Background and Motivation for Design

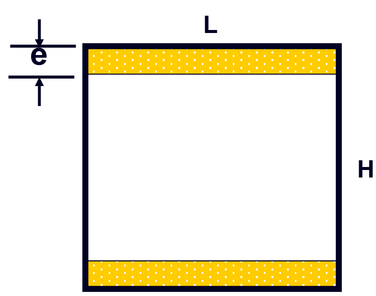


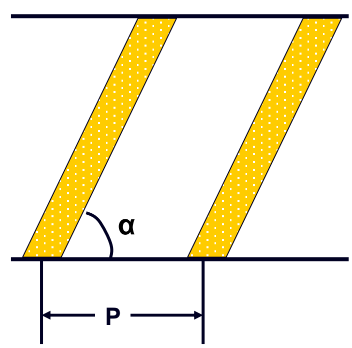
Review of Existing Test Rigs



Overview of Final Rig Design

The arrangement of the ribs in the channel can be defined with several parameters

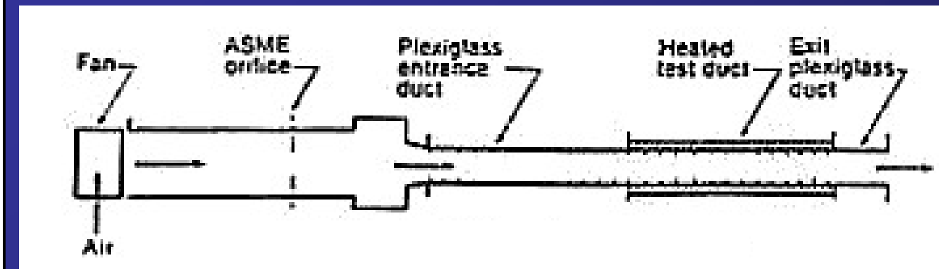




Aspect Ratio=H:L

$$Re = \frac{D_h V}{\nu}$$

Han studied the heat transfer and friction in channels with two opposite rib-roughened walls



Parameters	Test Values
Aspect Ratio	1:1
P/e	10>P/e>40
e/Dh	0.021 > e/Dh > 0.063
alpha	90
Re	7K > Re > 90K
Entrance L	20Dh
Test L	20Dh

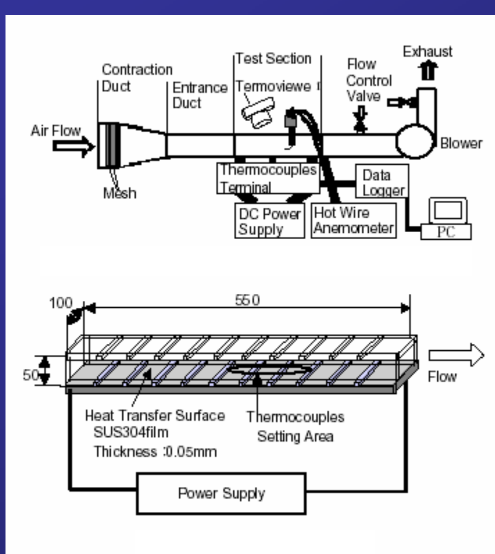
Focus: The effect of entrance conditions on the heat transfer coefficient

Features: Constant wall heat flux

Unheated Ribs

[Han, 1984]

Watanabe and Takahashi simulated and measured a fully developed ribbed channel flow



Focus: Flow and heat transfer measurements

Features: Constant heat flux on bottom wall only

Top wall held adiabatic

Parameters	Test Values
Aspect Ratio	2:1
P/e	10
e/Dh	0.10
alpha	90
Re	100,000
Entrance L	0.5 m
Test L	0.55 m

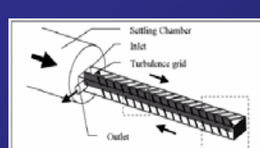
[Watanabe and Takahashi, 2002]

Past research provides some guidance for the parameters of our test stand

Parameters	Past Research Parameters	Virginia Tech Parameters
Aspect Ratio	0.5-1	1:1
P/e	10	10
e/Dh	0.021-0.100	0.100
alpha	30, 45, 60, 90	90
Re	240 -100K	10K-100K
Entrance Length	0-20Dh	10Dh
Test Section Length	7-20Dh	15Dh
Average Temp. Difference	15-30C	10-15C

This design builds on thermo-fluids principles and previous research

Background and Motivation for Design



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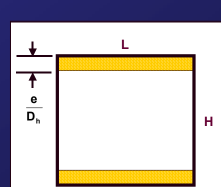
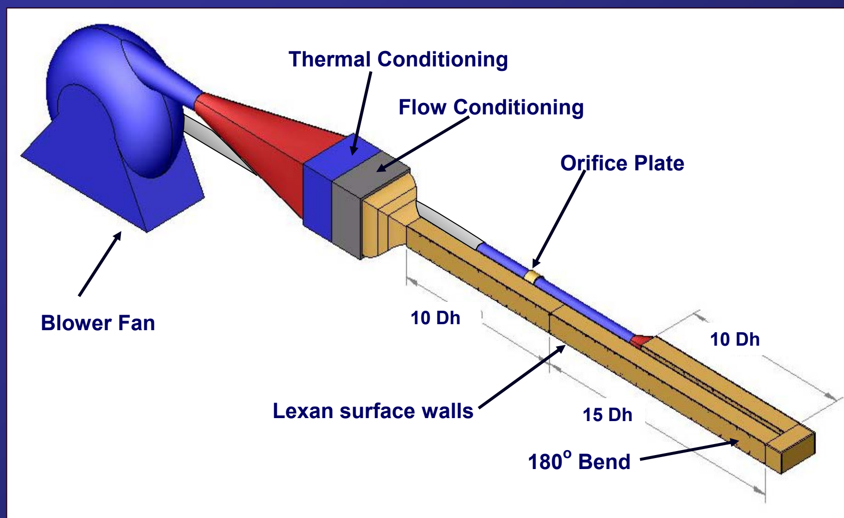
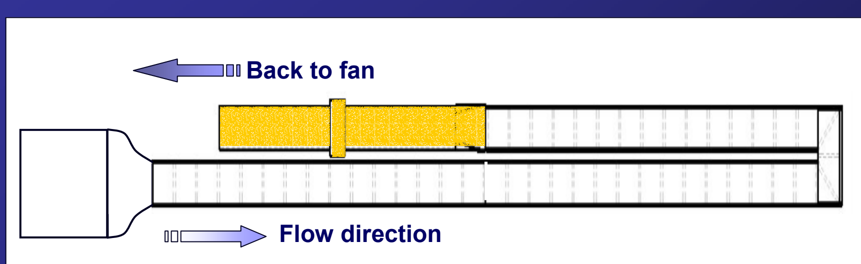


Overview of Final Rig Design

Our design allows the study of flow and thermal patterns in a ribbed channel



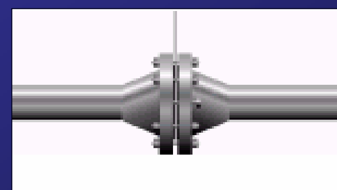
The size of the fan must overcome the pressure losses through the system



Two main options exist to determine the flow rate of the air in the channel

[www.quickpage.com/T/triflo]

Venturi Tube



[www.quickpage.com/T/triflo]

Orifice Plate

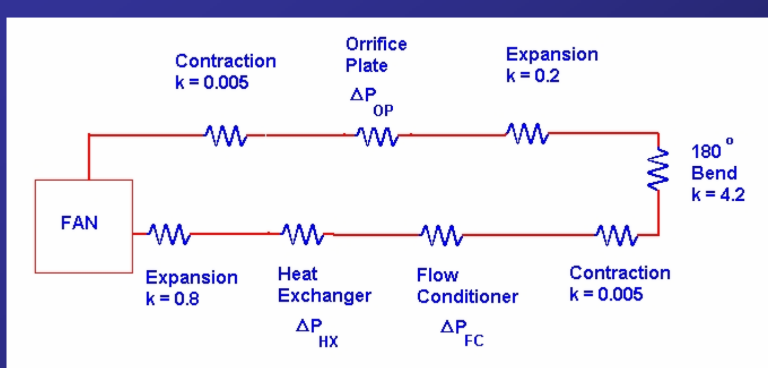
10% permanent pressure loss

High cost ($900)

44% permanent pressure loss

Low cost ($250)

A circuit diagram helps to visualize system losses

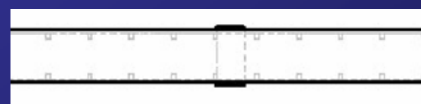


$$\Delta P_{total} = \rho \sum k_i \frac{\overline{v}_i^2}{2} + \rho \sum f_i \frac{L_i}{D_i} \frac{\overline{v}_i^2}{2} + \sum \Delta P_{other}$$

Review of the literature suggests a friction factor for 2-wall ribbed channels

$$\bar{f} = \frac{Hf_s + Wf_r}{H + W}$$

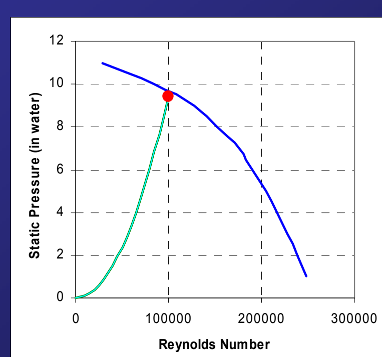
[Han 1984]



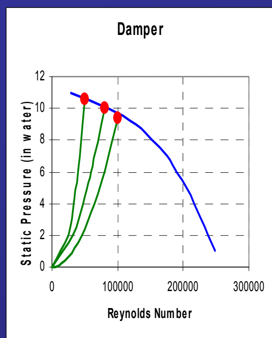
$$f_r = \frac{2}{\left[0.95\left(\frac{P}{e}\right)^{0.53} - 2.5\ln\frac{2e}{D_e} - 2.5 - 2.5\ln\frac{2W}{H+W}\right]^2}$$

[Han 1984]

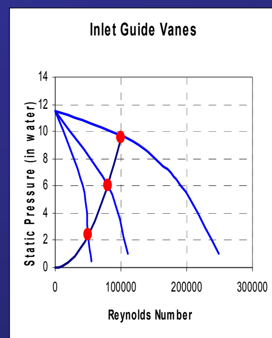
The system characteristic curve was used to select the fan



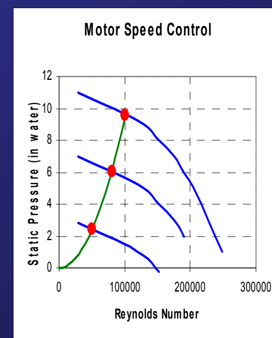
Air flow can be controlled through a variety of options



Low cost, but will change system curve

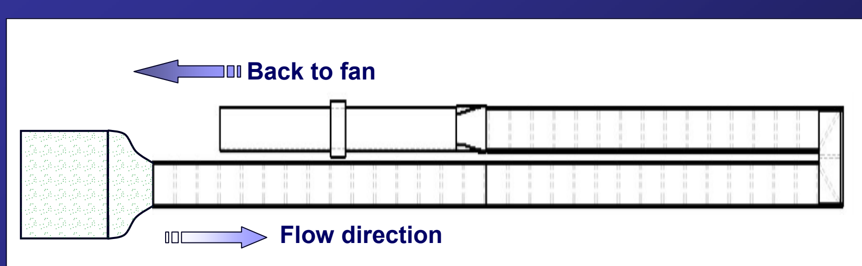


Low cost, but low resolution of control

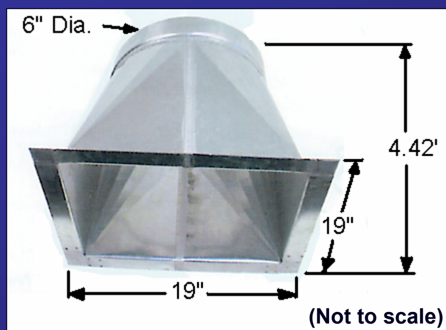


High cost, but highest resolution of control

Several components following the fan cool the air and create uniform flow



Air from the fan passes through a diffuser to prepare flow for conditioning

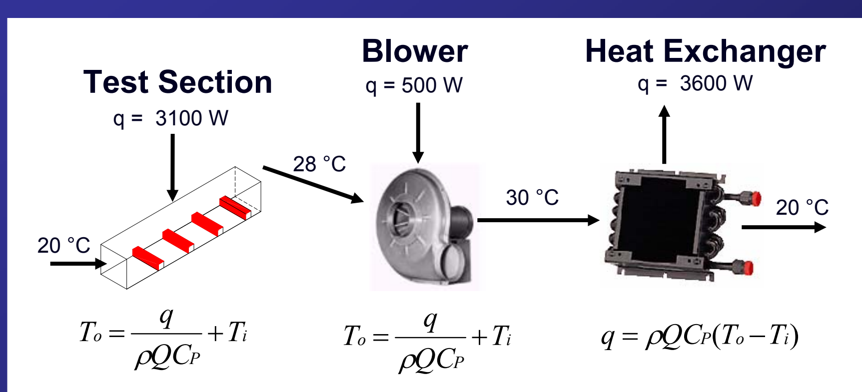


3–Dimensional diffusion to shorten length

7° diffusion to avoid flow separation

Vendor: Spiral Manufacturing Co., Inc., Minneapolis, MN

A heat exchanger is required to remove thermal energy added by the test section and the blower



Heat exchanger reduces incoming air temperature to room temperature

Performance Requirements

Heat Load, q	1100 - 3600 W
Air Flow, Q	0.047 – 0.36 m^3/s
Face Velocity, V	0.20 – 1.6 m/s
Entering Air Temp	30 - 39 °C
Exiting Air Temp	20 °C
Water Flow, Q	2 GPM
Entering Water Temp	16 °C
Exiting Water Temp	24 °C

Liquid cooled – Tap water

Limited fouling with water at 2 GPM

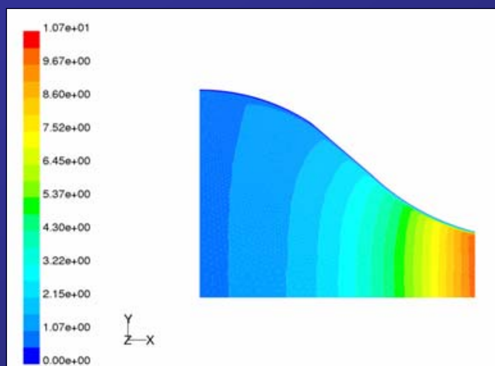
Vendor – Super Radiator Coils: Richmond, VA

Honeycomb and screens straighten the air flow to establish a uniform velocity profile

Modular design uses:

- **Various types of screens**
- **Optional turbulence grid**
- **Multiple number of screens**

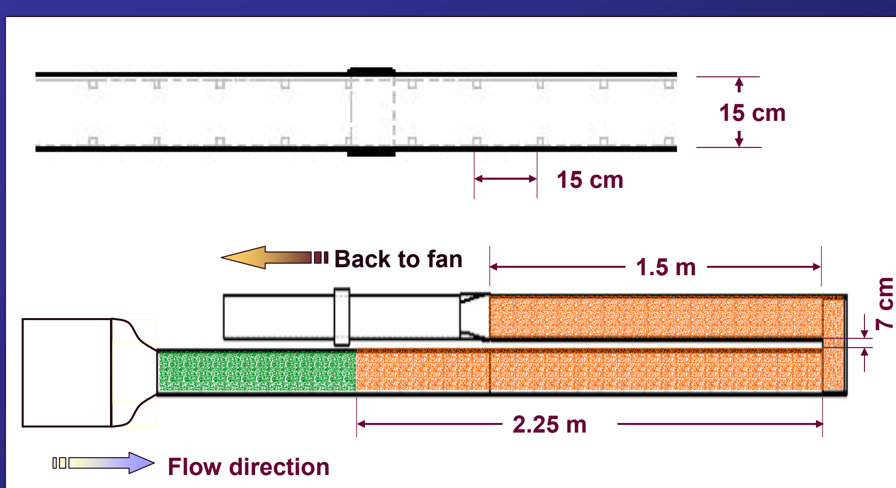
Nozzle contracts flow creating a uniform velocity profile at the entrance plane



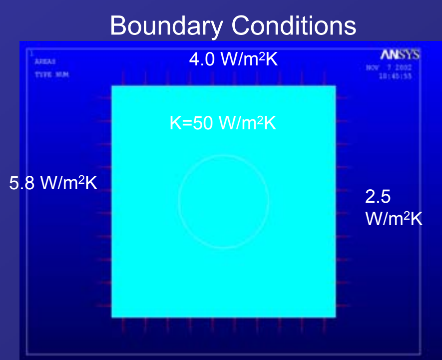
3–D contraction

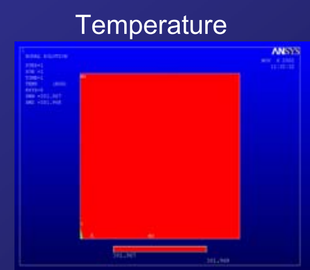
Contraction Ratio = 10:1

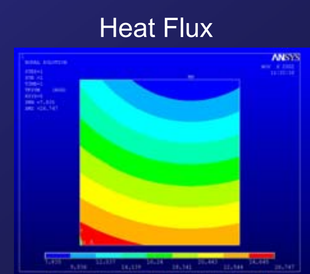
The test section provides access for flow and heat transfer measurements



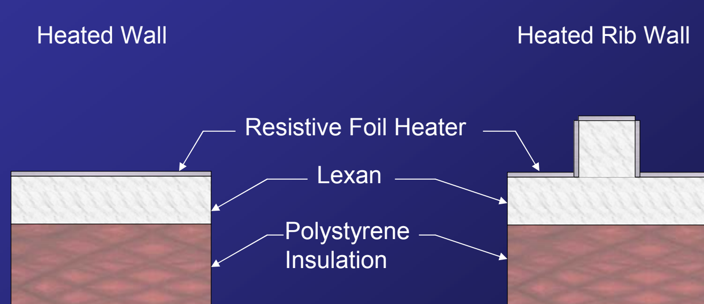
ANSYS provided the necessary analysis to validate the rib design



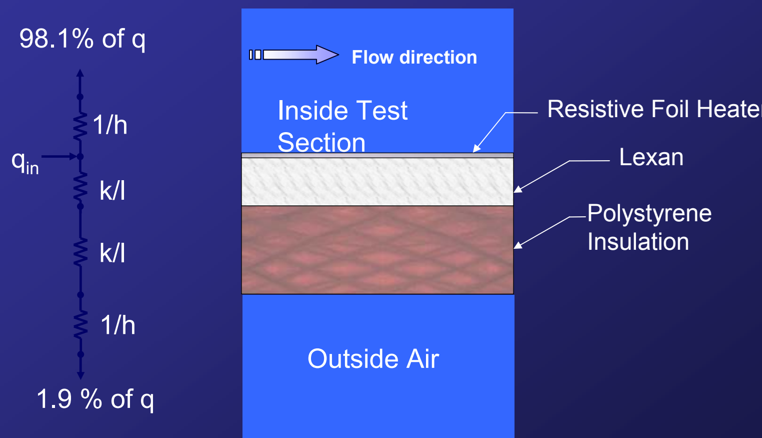




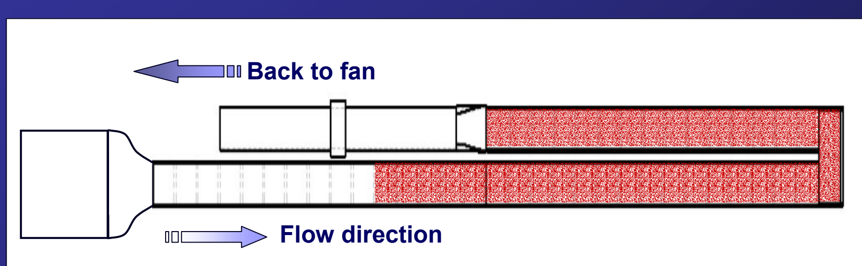
The final rib design provided a uniform heat flux



Insulation helps keep the heat flux inside the test section



The heat transfer testing depends on a uniform heat flux on the channel walls



Estimating surface heat transfer is essential for accurate power supply design

Heat flux is dependent on the convection coefficient and temperature difference

$$q'' = h(T_s - T_m)$$

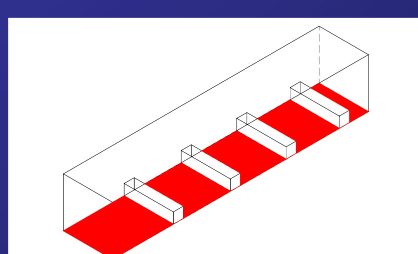
Convection coefficient is based on Nusselt number for turbulent flow in a smooth pipe

$$Nu_D = 0.023 \, \mathrm{Re}_D^{4/5} \, \mathrm{Pr}^{0.4}$$

Hydraulic diameter and thermal conductivity influence heat transfer

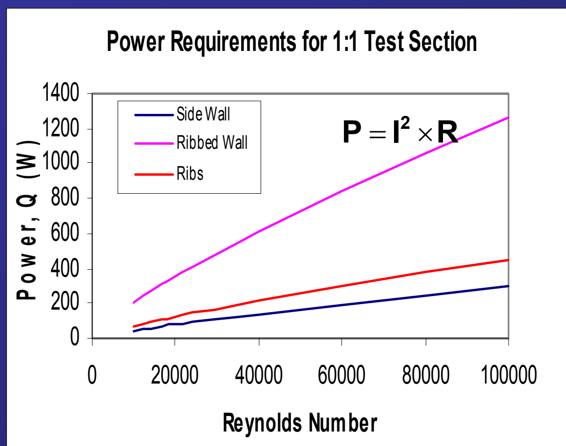
$$h = \frac{k \times Nu_D}{D_h}$$

Heat fluxes in test section are estimated to be larger than for smooth pipe



Previous research indicates that ribbed surfaces create higher Nusselt numbers

The amount of power needed for each heated surface will be different

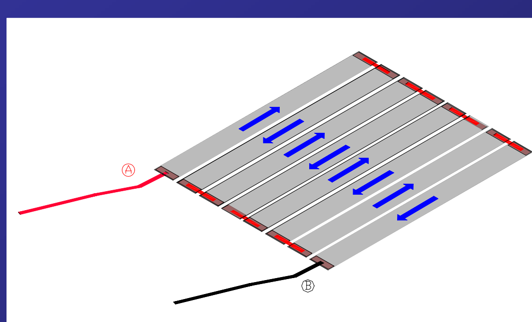


Higher Reynolds numbers increase heat transfer

Ribbed wall requires a majority of power

Virginia Tech

The heater strips are connected in series to create the proper resistance



$$R_T = 1\ \Omega/_{strip} \times 8\ strips = 8\ \Omega$$

$/R1 + /R2 + \cdots /R_n$

$$R_T = \frac{1}{8\times\left(1/_{1\ \Omega}\right)} = 0.125\ \Omega$$

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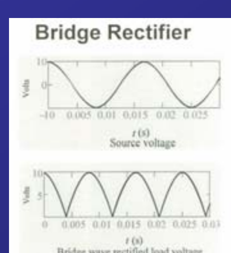
Sufficient power must be produced to heat the test section surfaces

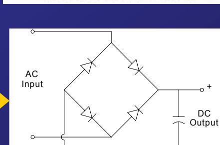
Commercial DC power supplies are available but are too costly

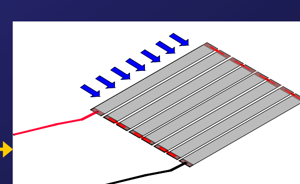
Homemade power supplies are difficult to make for the high power requirements

Variable transformers are relatively cheap and provide a high levels of power

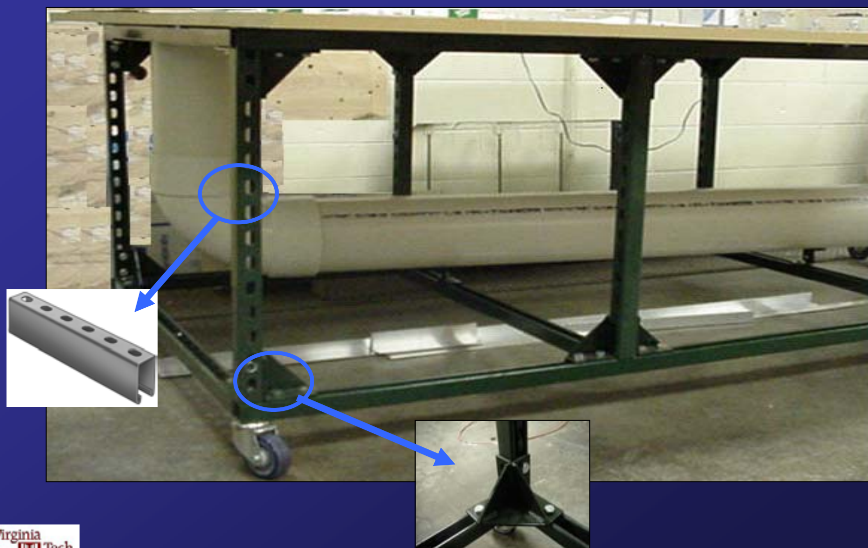
A rectifying circuit provides direct current to the heating elements







The Unistrut system provides a strong and adaptable structural support for the test rig



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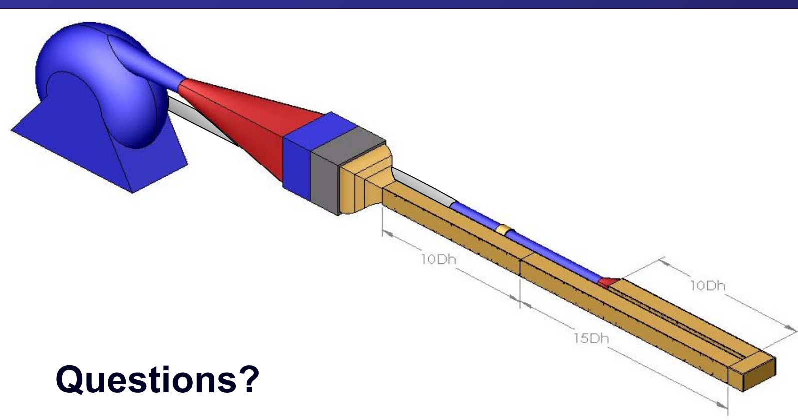
In summary, our rig design will help researchers better understand flow inside turbine blades



Questions?

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