THERMALLY EFFECTIVE AND EFFICIENT COOLING TECHNOLOGIES FOR ADVANCED GAS TURBINES

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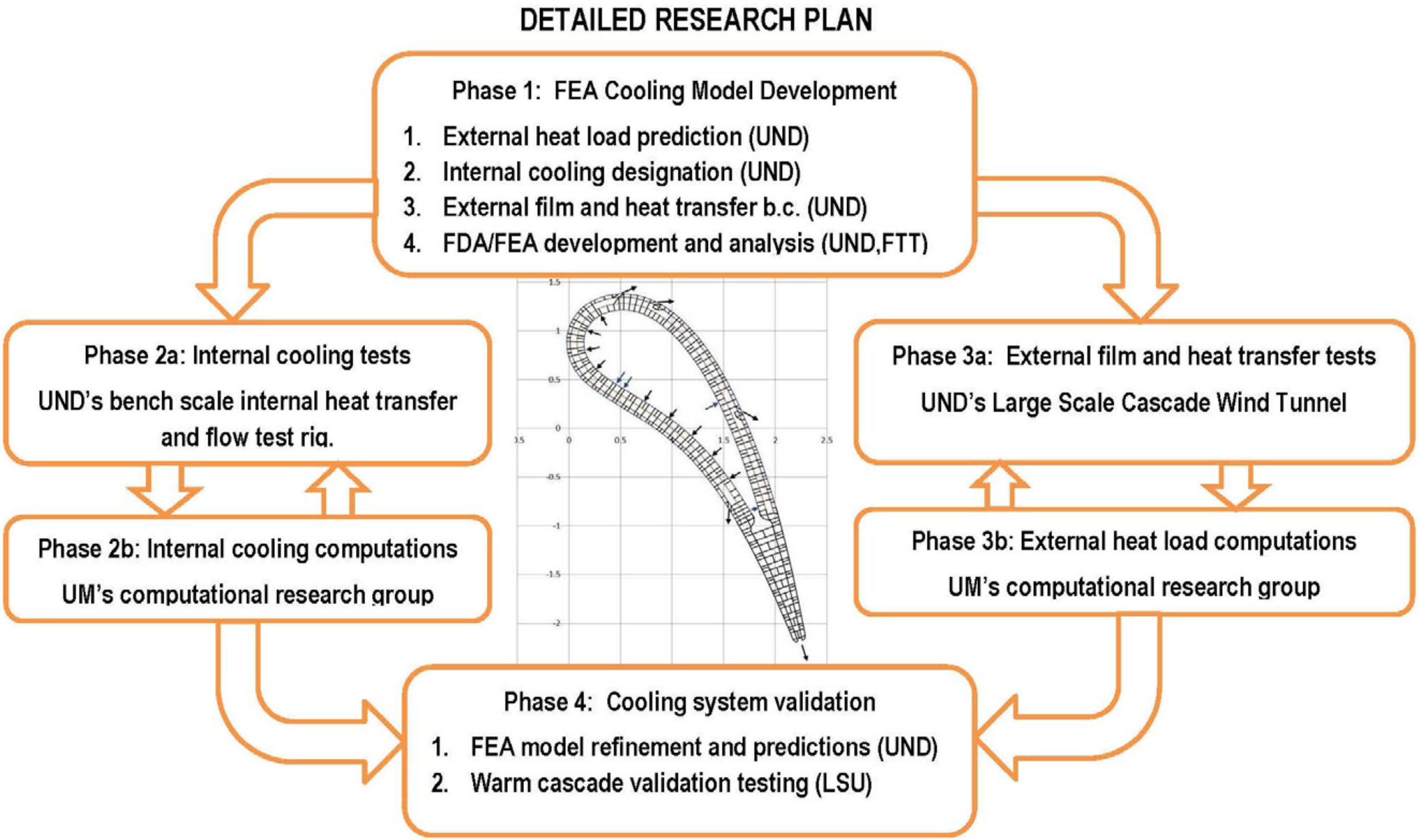
PRESENTATION OVERVIEW

- Motivation and conceptual approach
- Four phase program description
- FEA analysis that has been used to drive the development of internal and external boundary conditions:
- The FEA vane cooling model serves as a framework for integrating cooling technologies, both internal and external, for the leading edge, pressure & suction surfaces and the trailing edge.
- Bench scale rig is being used for internal cooling testing
- A low speed cascade will be developed for investigation of film cooling and heat transfer for external heat load evaluation
- Computational methods will clarify physics of film cooling and internal cooling and serve to refine model boundary conditions.
- Warm cascade testing will be used for cooling system evaluation and validation based on the enhanced FEA vane model.

MOTIVATION AND CONCEPTUAL APPROACH

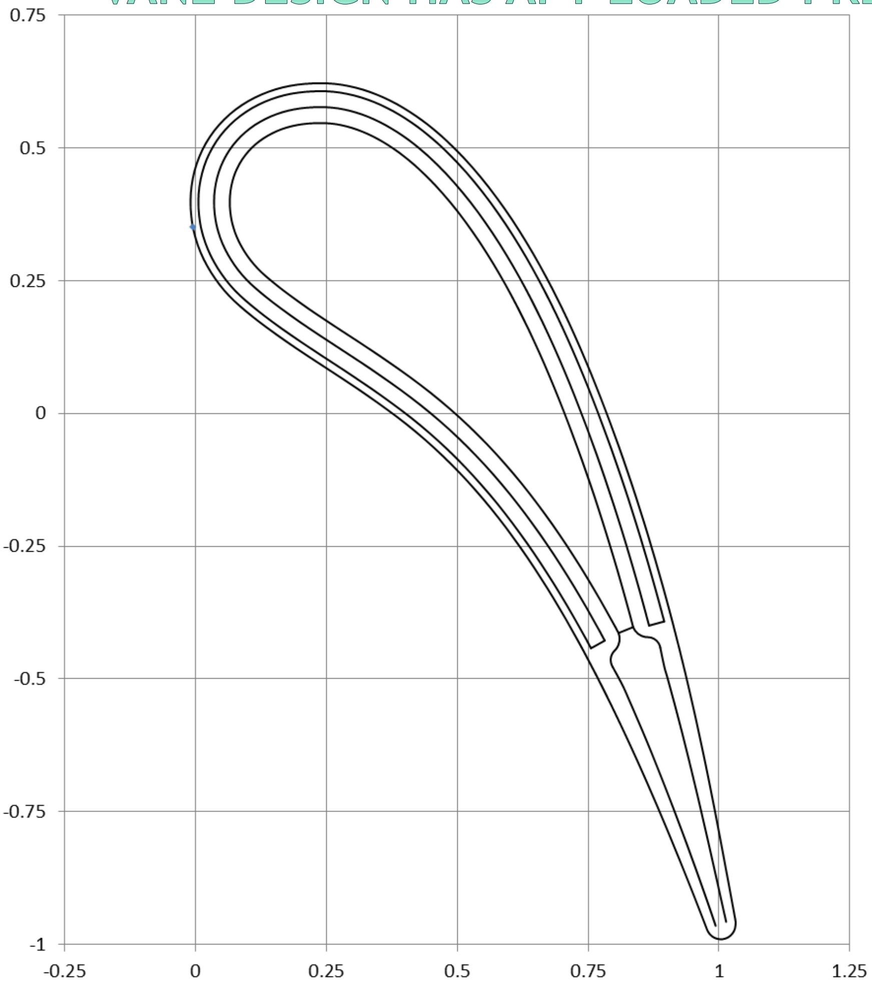
- Component cooling methods need to provide highly effective, reliable, and efficient cooling systems.
- Ideally, internal cooling methods need to achieve good levels of internal effectiveness before discharging cooling air onto surfaces in optimum films.
- While showerhead film cooling can be very effective, it can also very disruptive to the laminar boundary layers developing in the stagnation region and vicinity.
- Leading edge regions can be cooled internally to a high level of effectiveness eliminating the disruption of shower-head films and improving downstream film cooling levels.
- The efficiency and effectiveness of downstream cooling levels can be improved using more optimal internal cooling concepts and external films.
- Covered trailing edge designs offer the best thermal protection while there is no conclusive evidence of higher losses.

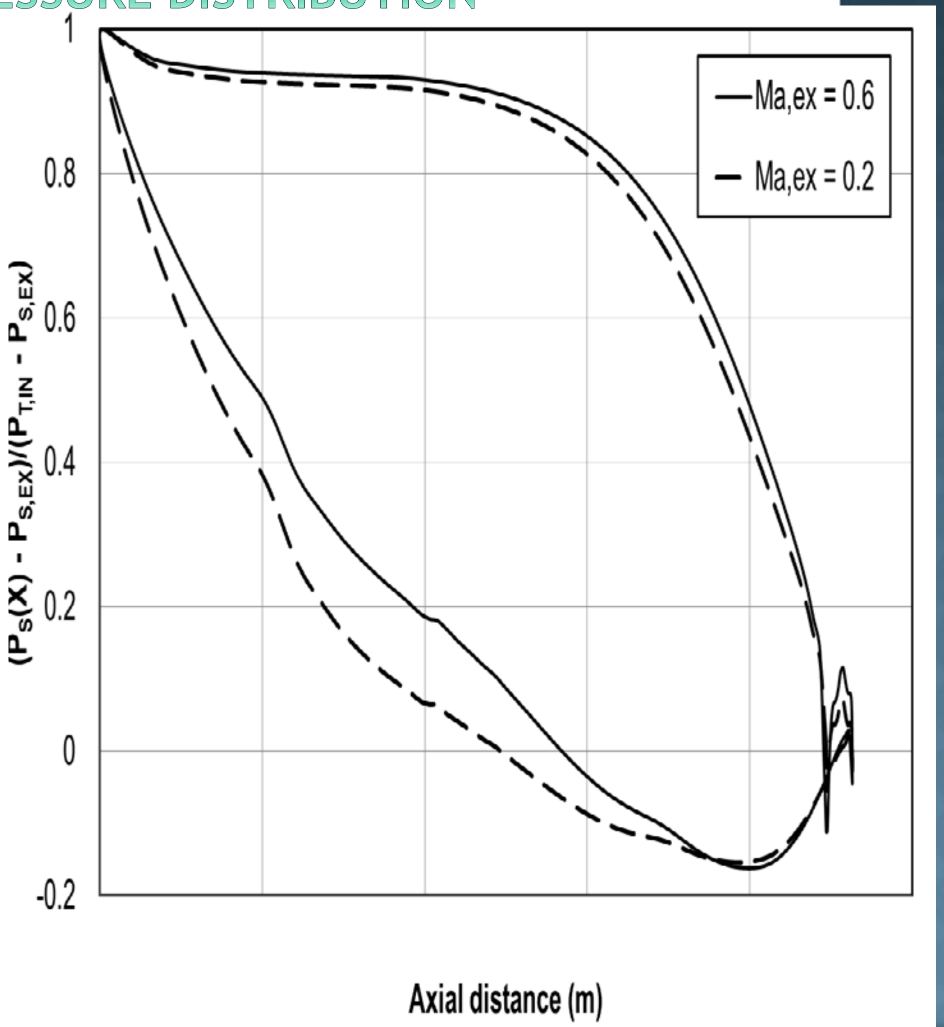
FOUR PHASE PROGRAM



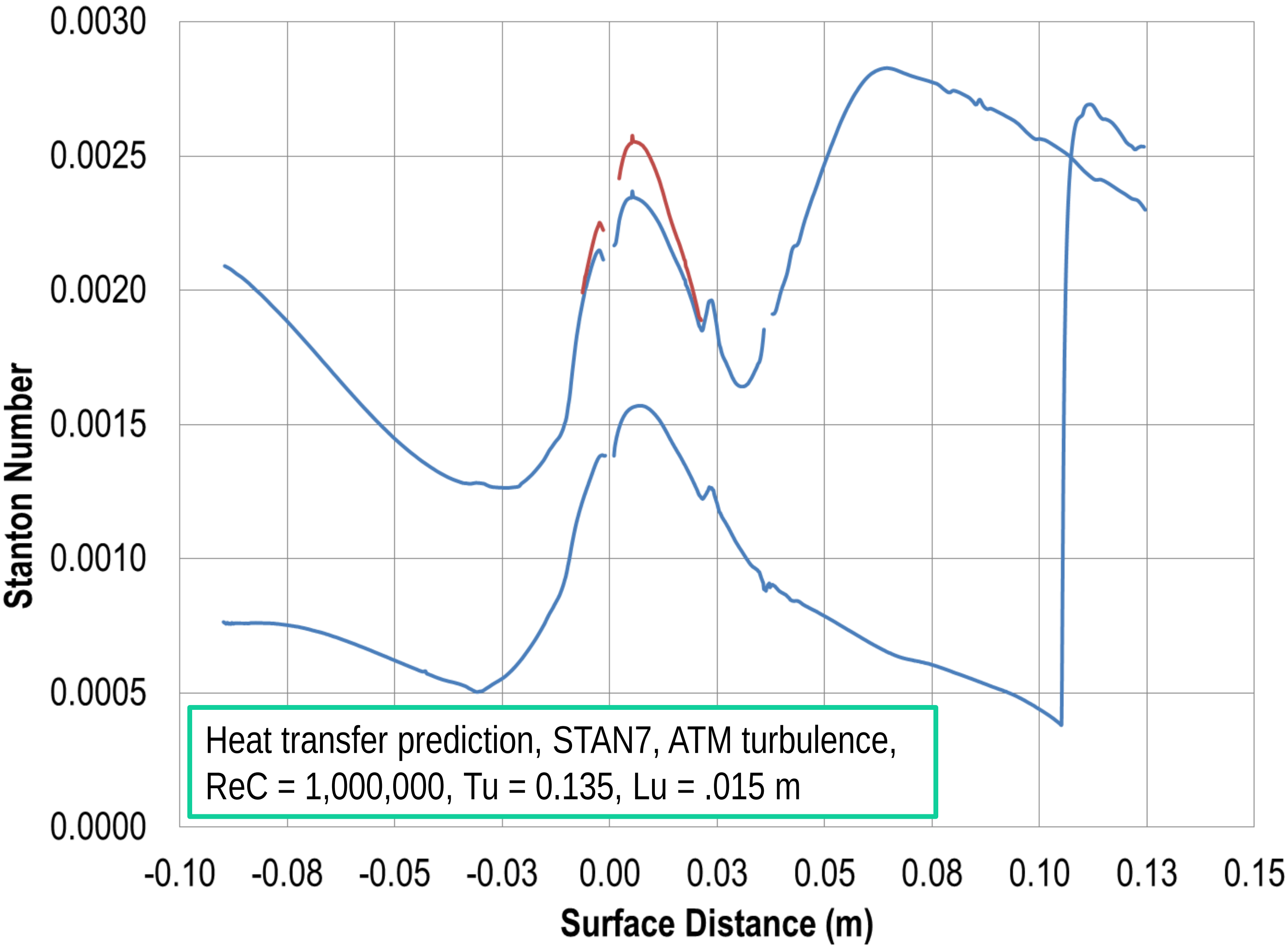
FEA Model provides a framework to integrate:

- External heat load prediction
- External film cooling and heat transfer adjustment
- The internal cooling boundary conditions
- The conductive smoothing
- Vane design has generous LE for double wall cooling
- Vane design has aft loaded pressure distribution

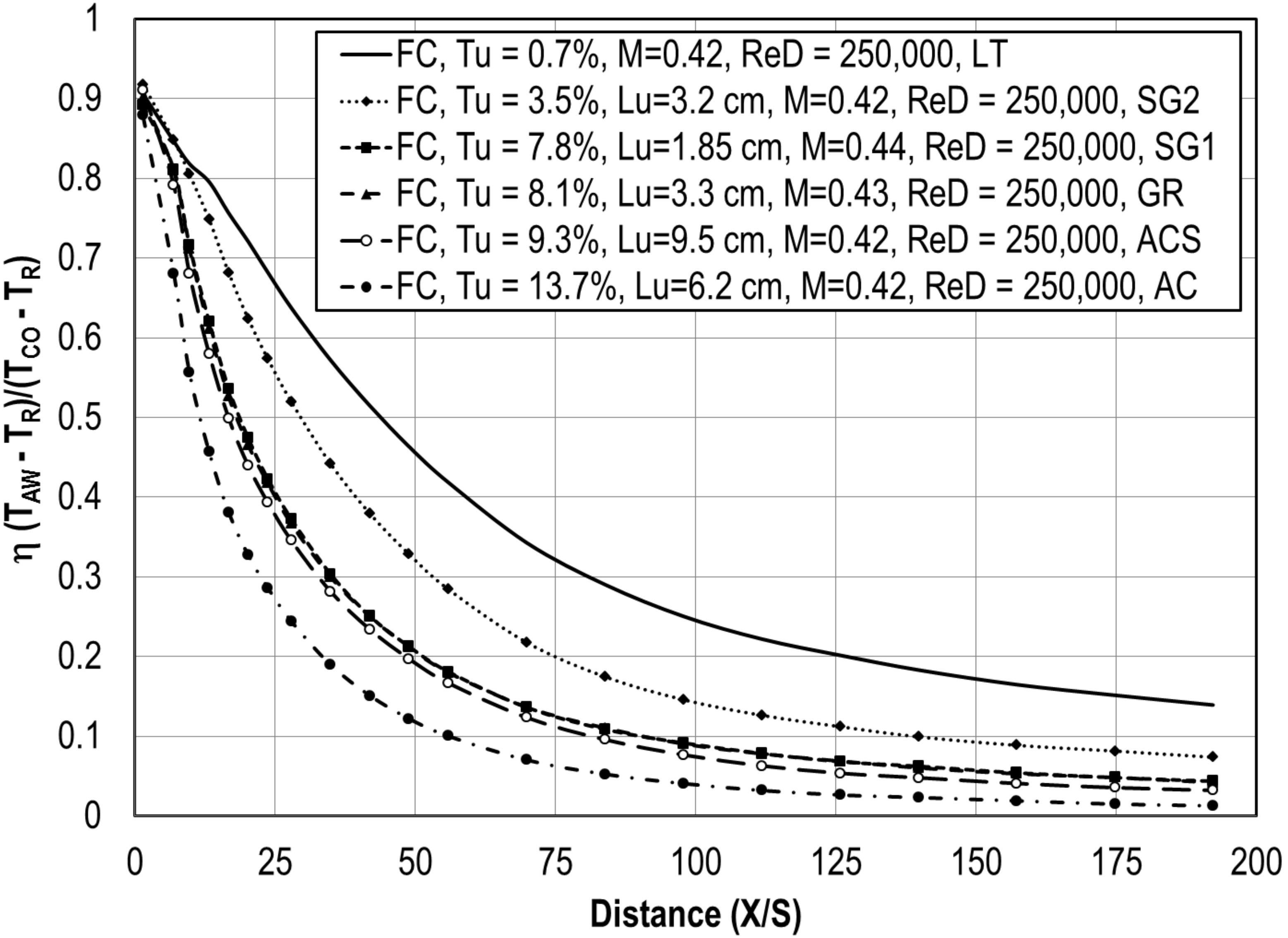




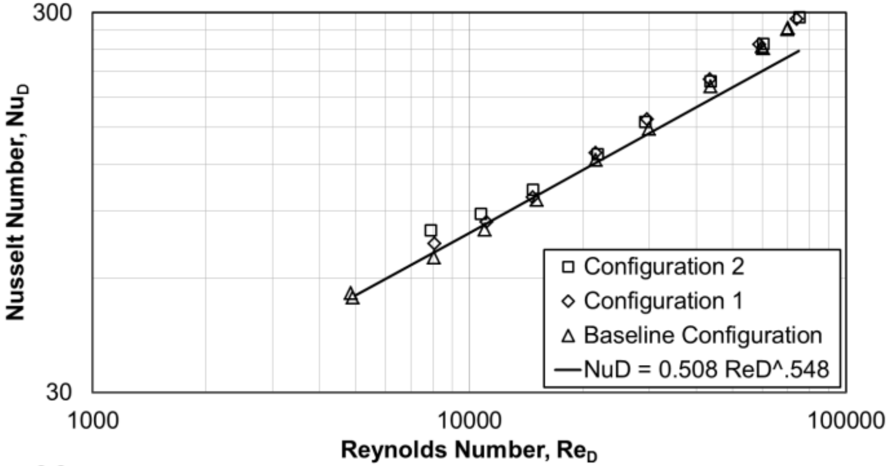
EXTERNAL HEAT LOAD PREDICTION WAS USED IN THE INITIAL FEA MODEL DEVELOPMENT

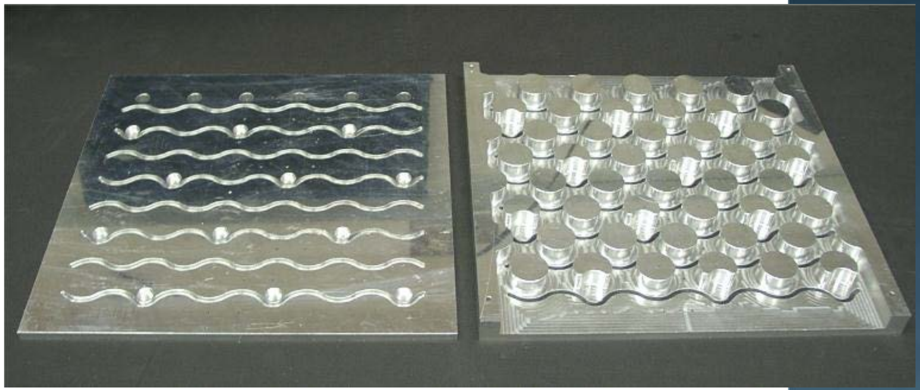


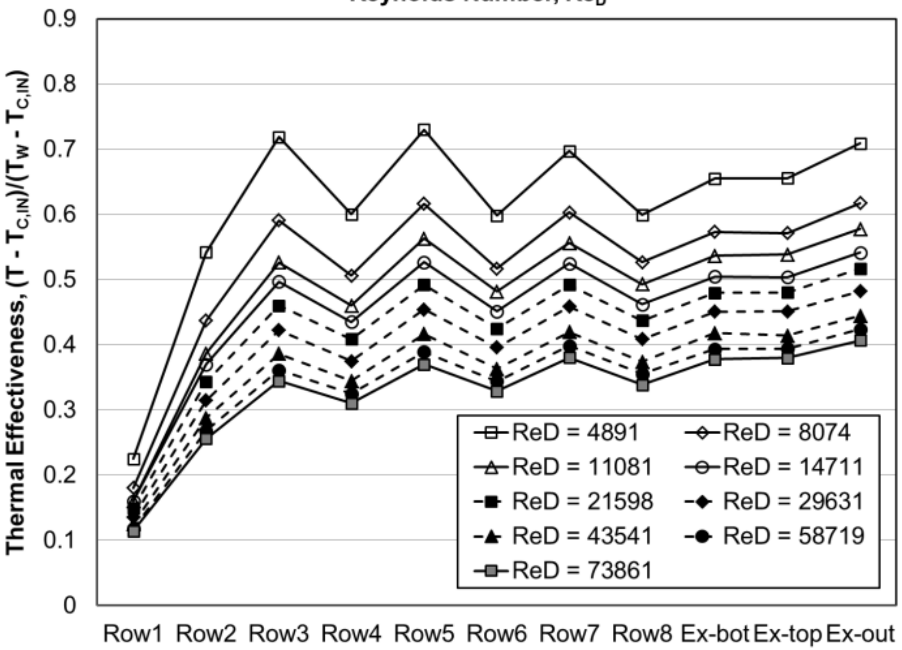
Slot Film Cooling and Heat Transfer Data Have Been Used to Provide The Initial η and Heat Transfer Augmentation Levels. Surface Location is Key.

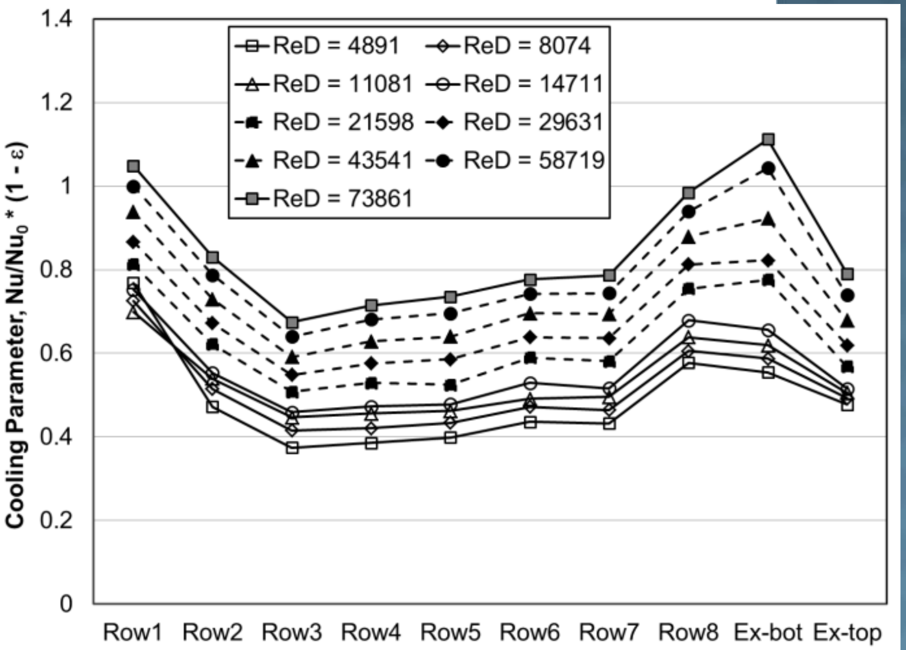


Internal heat transfer boundary conditions were supplied using existing data acquired for basic configurations. Shown here is incremental impingement data which was applied to the leading edge.







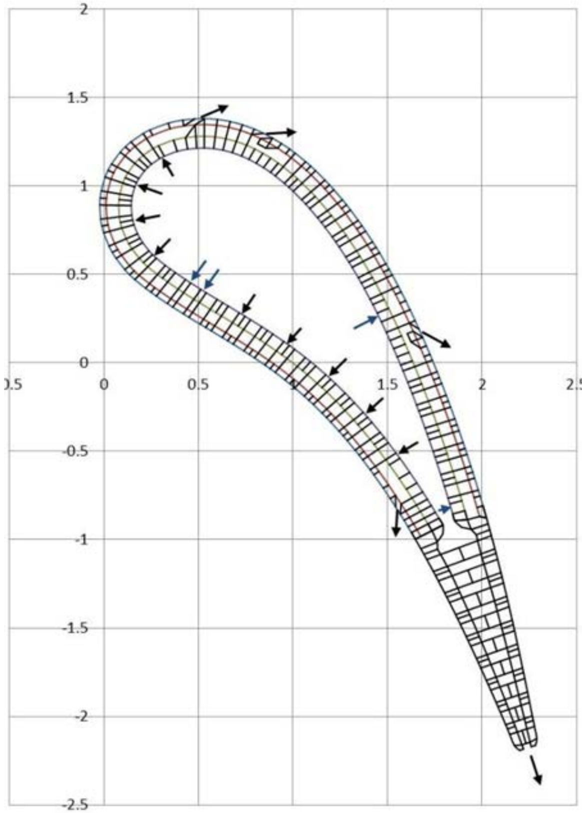


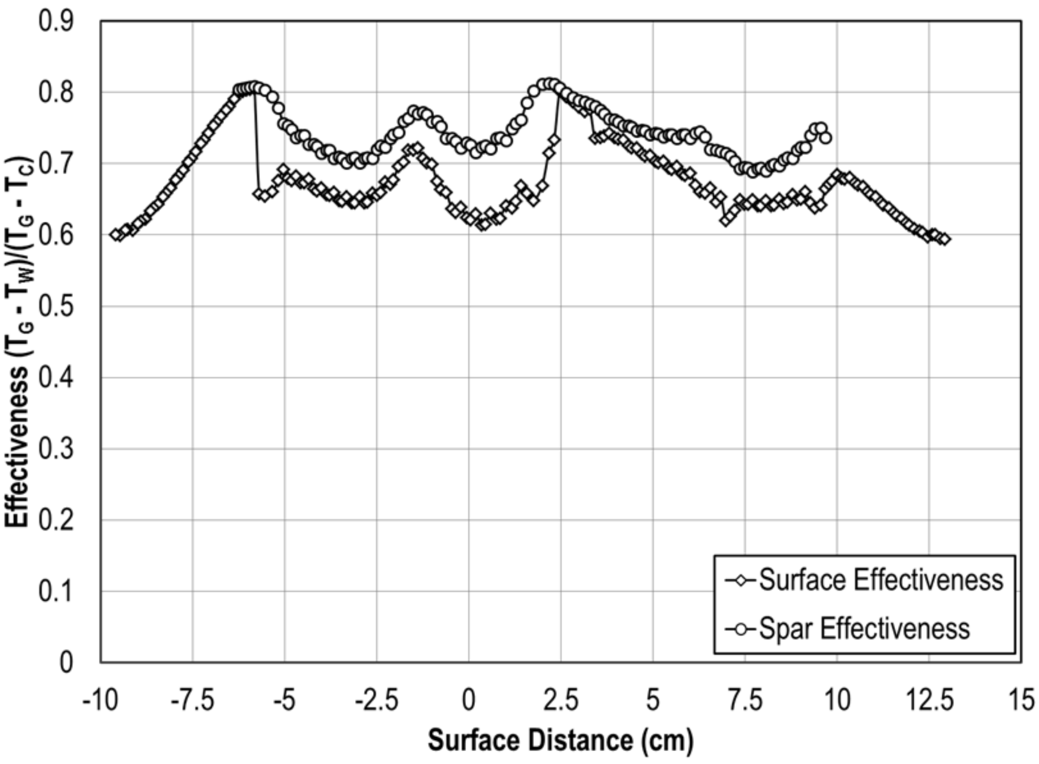
FINITE DIFFERENCE ANALYSIS

A finite difference analysis was used to initiate the analysis of the vane cooling model allowing the tuning of the coolant flows to meet cooling objectives.

The overall objective was to develop a design which achieved a minimum effectiveness level, $\phi = 0.61$

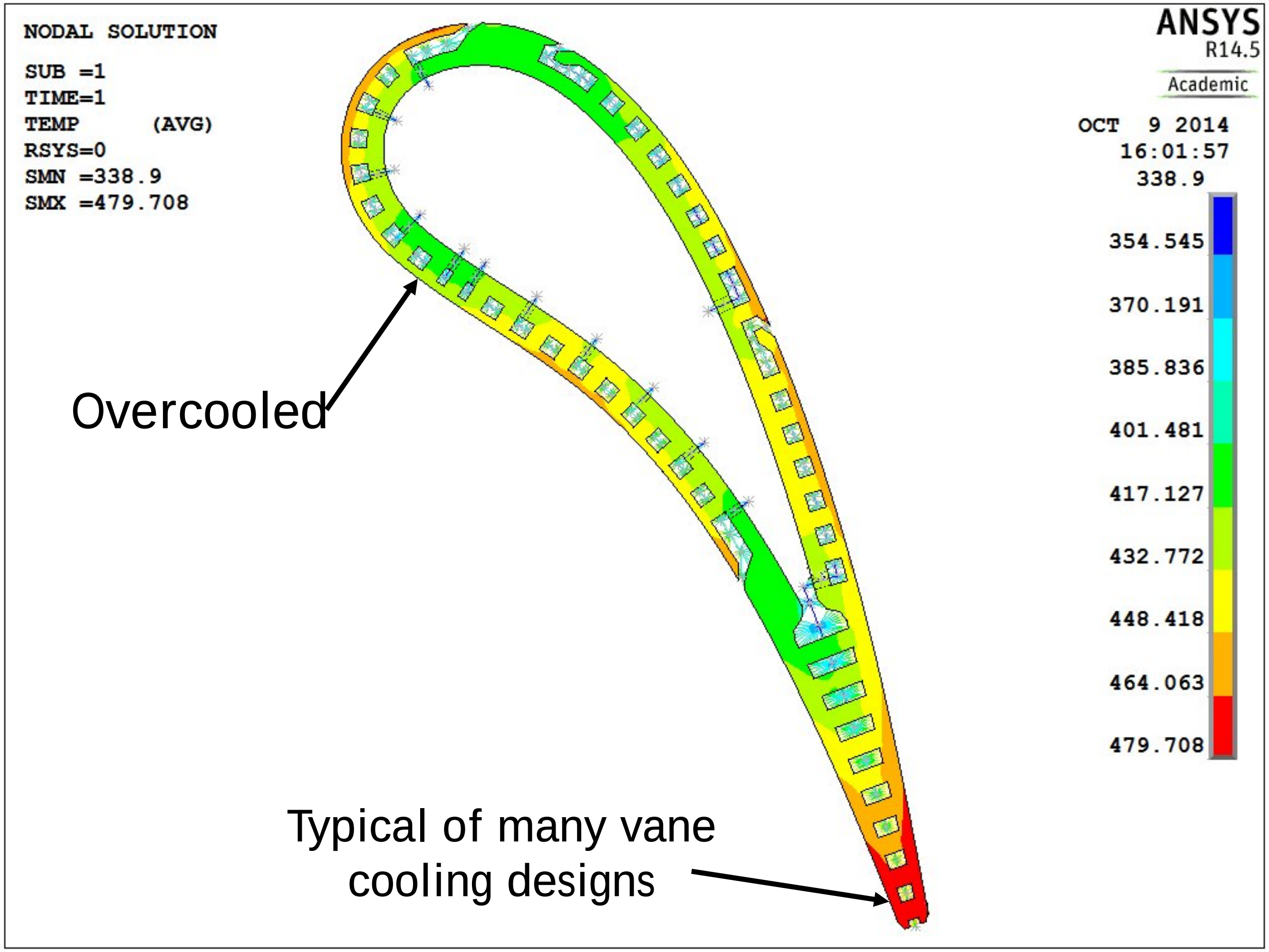
This objective was met except for the end of the trailing edge.





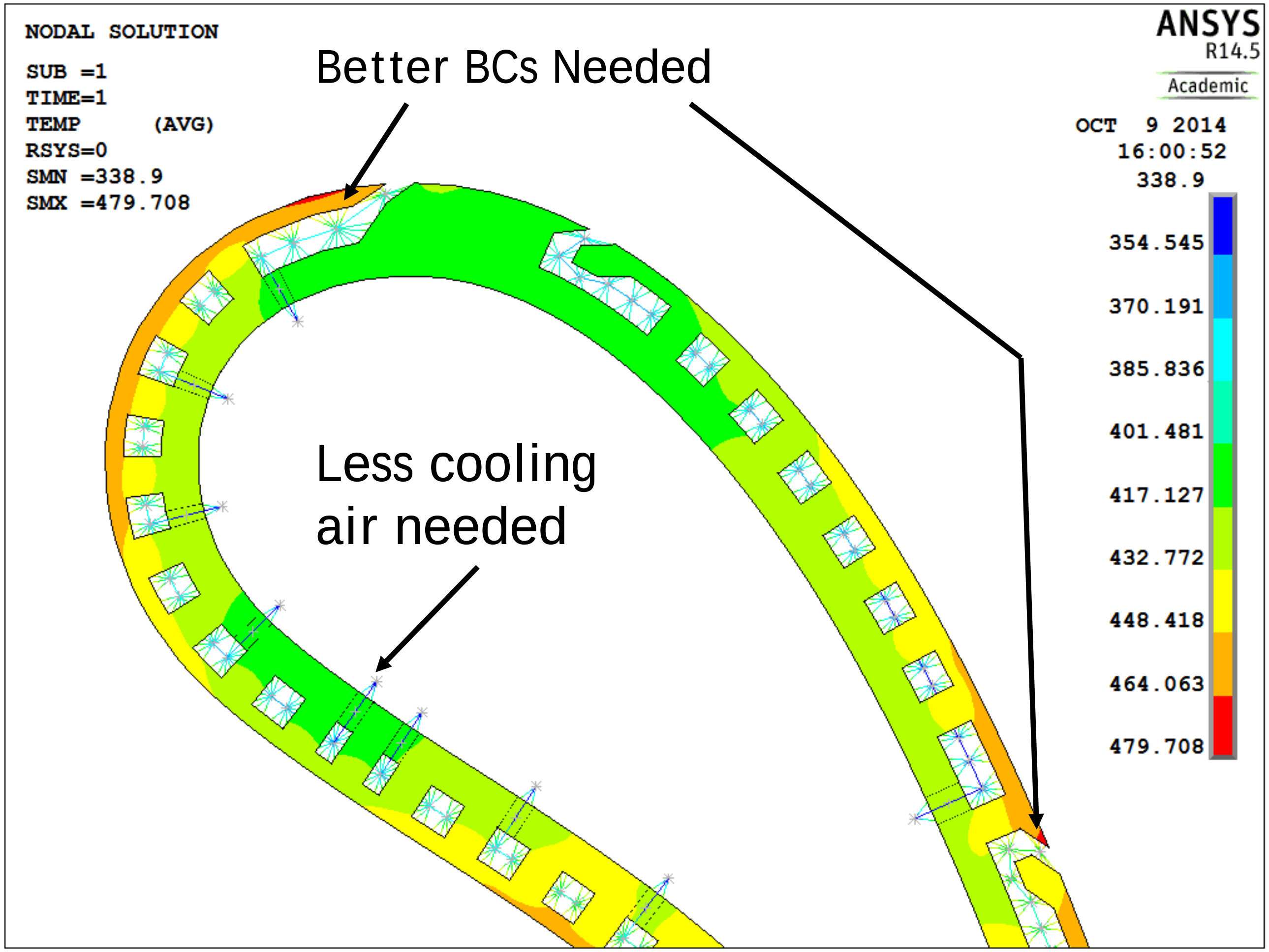
FINITE ELEMENT ANALYSIS ANSYS

The boundary conditions developed for the FDA were imported into a 2D FEA in ANSYS. The FDA and FEA analyses point to areas were cooling levels can be optimized.



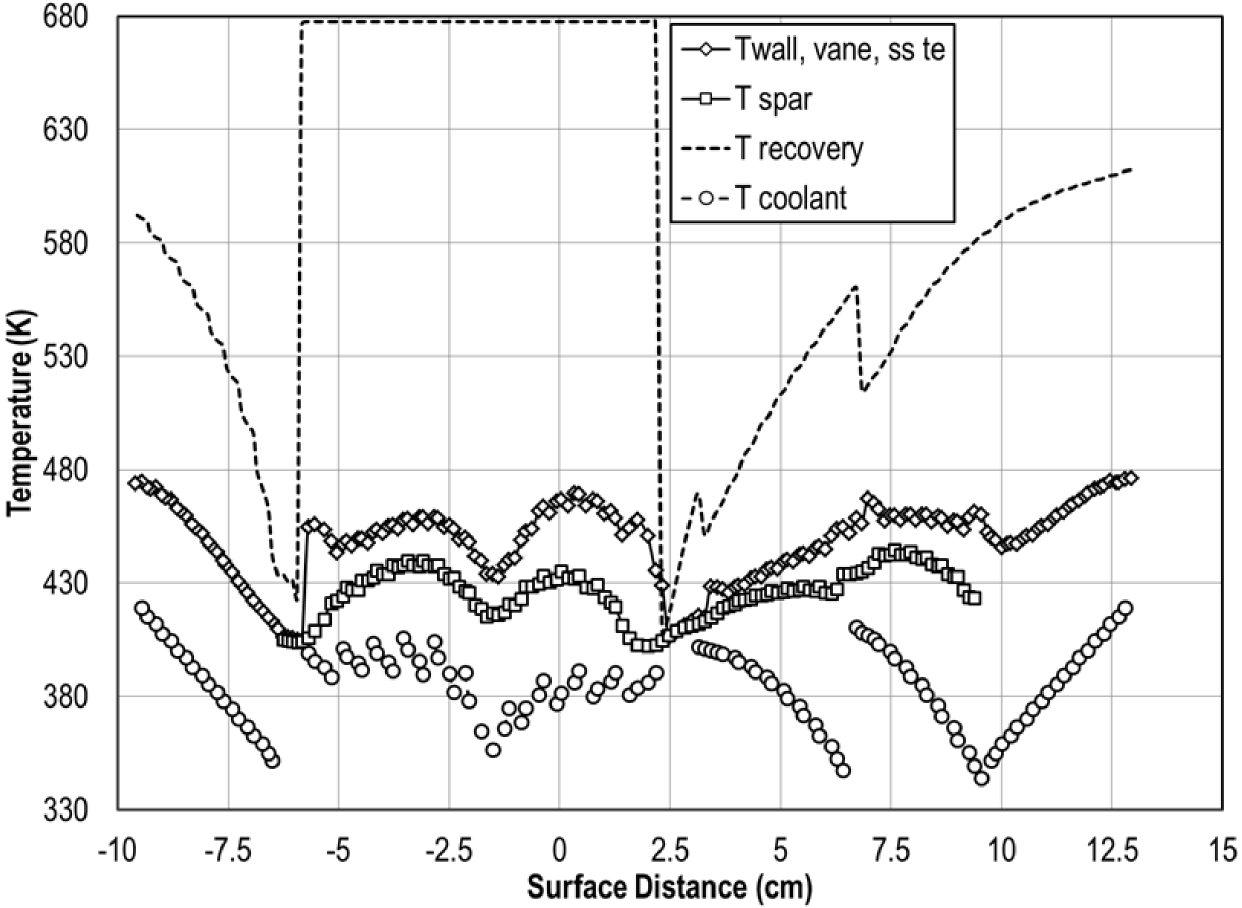
FINITE ELEMENT ANALYSIS ANSYS

The finite difference and finite element analyses also pointed to areas where better boundary conditions are needed.
This better information will be developed through a combination of bench scale testing with accurate inlet/exits and CFD.



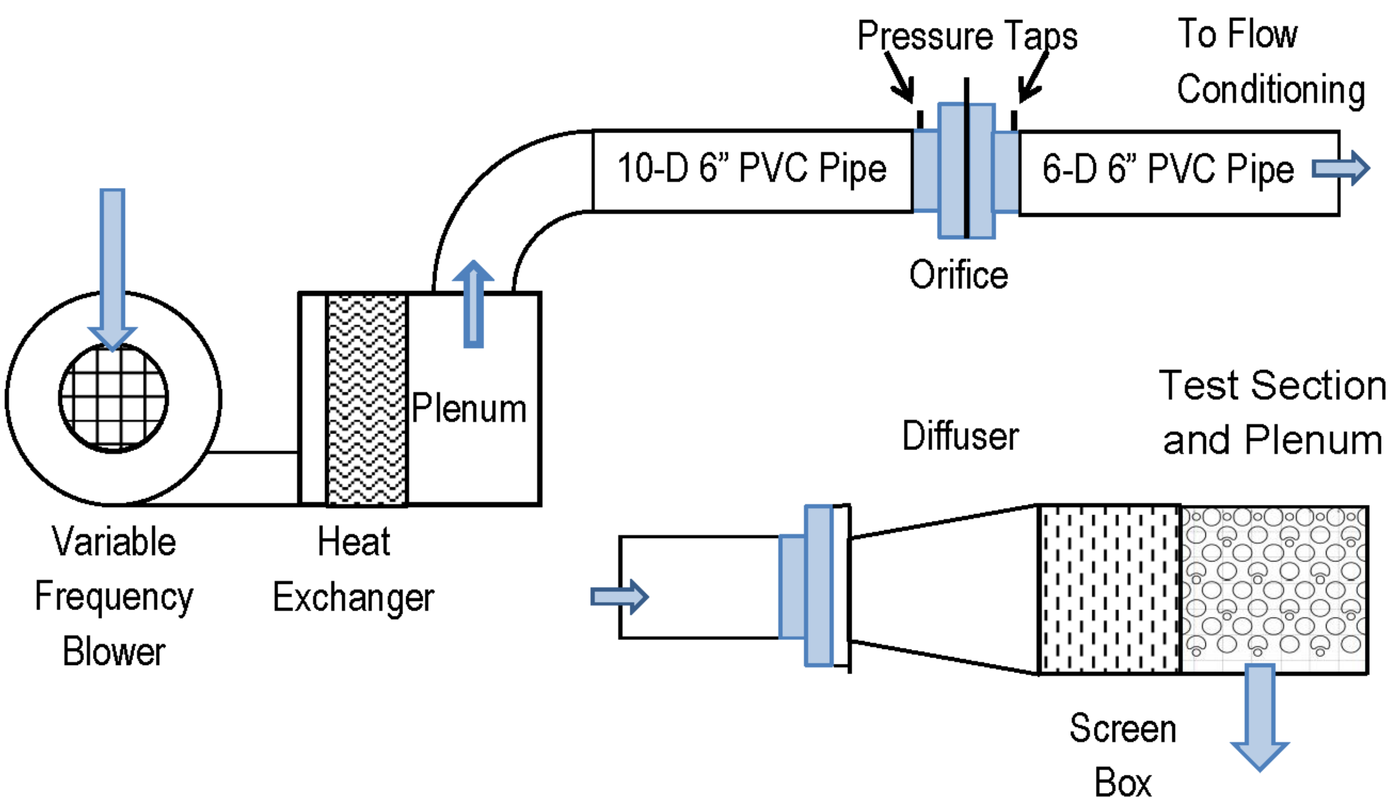
THE LEADING AND TRAILING EDGE REGIONS REMAIN DIFFICULT TO COOL

The non-filmcooled leading edge is challenging to thermally manage at this relatively low chord exit Reynolds number. This region should be more manageable at higher Re_C. The trailing edge remains difficult.



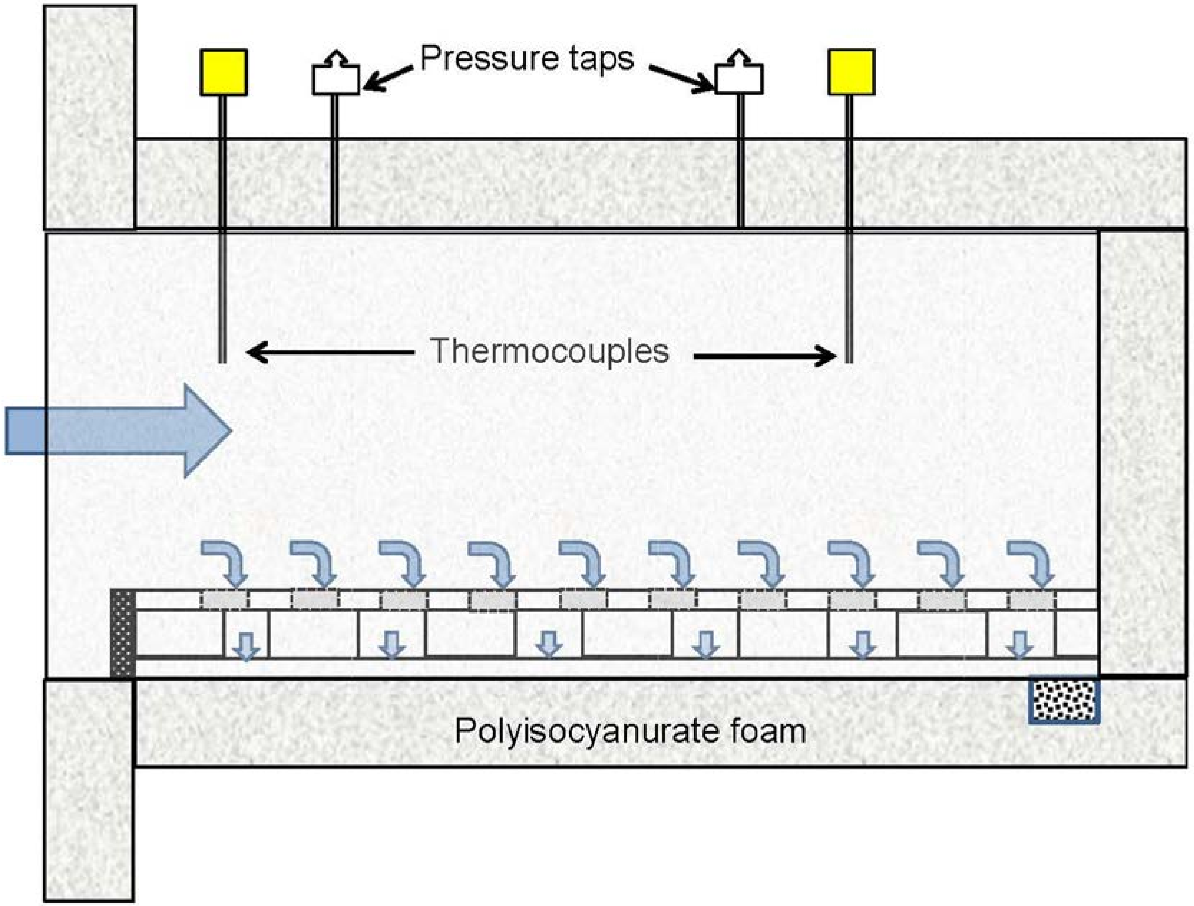
INTERNAL COOLING INVESTIGATION

This bench scale internal cooling, flow and heat transfer rig, will be used for investigating configurations of incremental impingement, counter cooling, sequential impingement, and converging high solidity arrays. The internal cooling rig includes a high pressure blower with variable frequency drive, a plenum with heat exchanger, an orifice tube, a downstream diffuser section and a flow conditioning section flow or screen box.



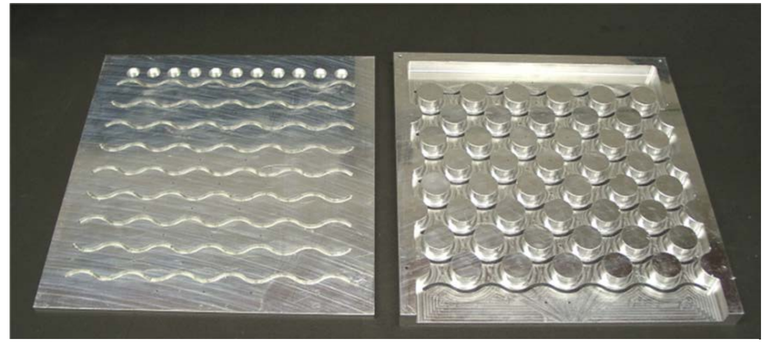
INTERNAL COOLING INVESTIGATION

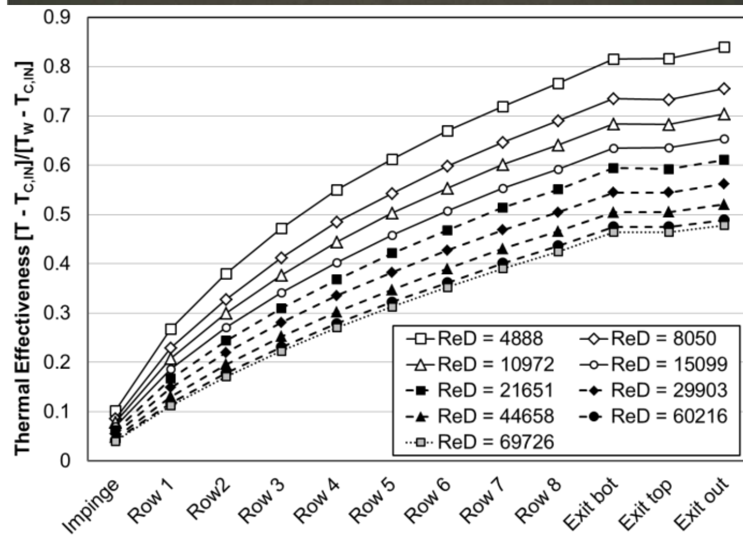
The general arrangement for the leading edge, pressure surface and suction surface internal heat transfer and pressure measurements are shown below. The flow approaches slowly over the top of the plate and is forced through the various feed holes in the top plate. The flow discharges out the array exit which would be out of the page from our view.

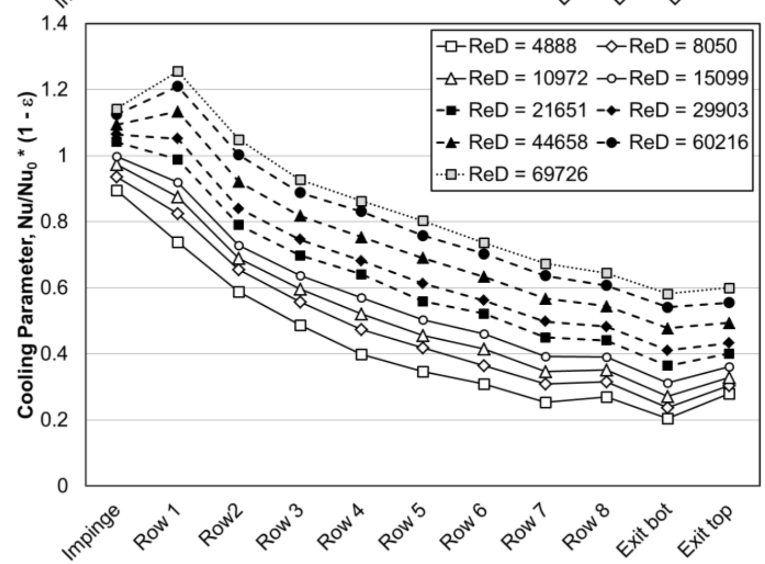


INTERNAL COOLING METHODS

- In conventional high solidity arrays, cooling air temperatures rise rapidly resulting in a reduced ability to cool component surfaces adequately.
- In the configuration above air is injected into a cooling channel through a row of impingement holes.
- The thermal effectiveness increases quickly row by row, with a result particularly difficult at lower Reynolds number.
- The resulting potential to cool can be estimated based on a cooling parameter (1-ε) Nu/Nu_0
- This cooling parameter quickly drops to unusable values.

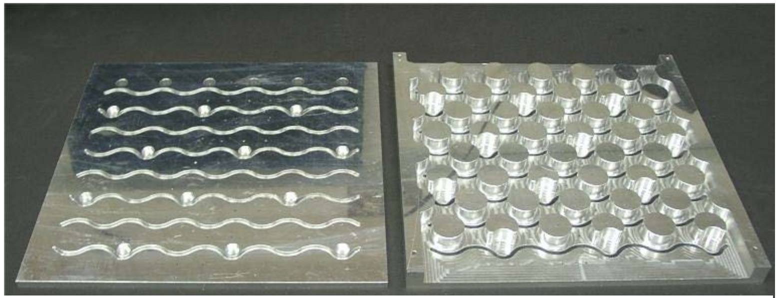


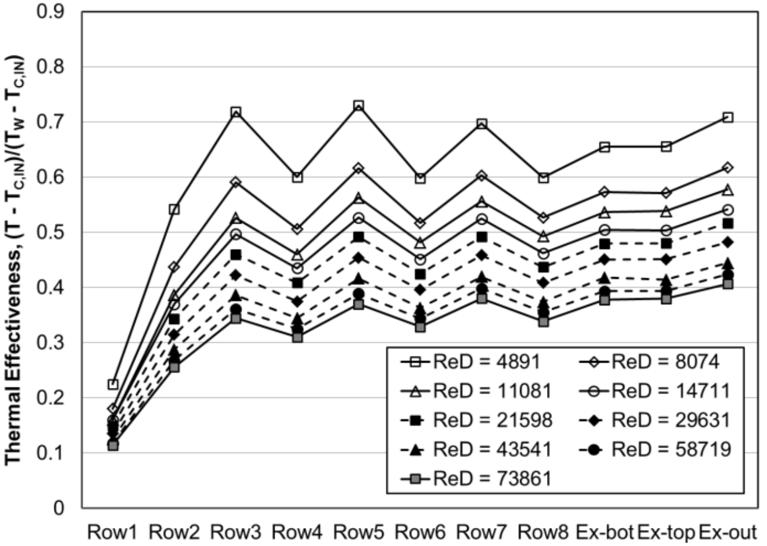


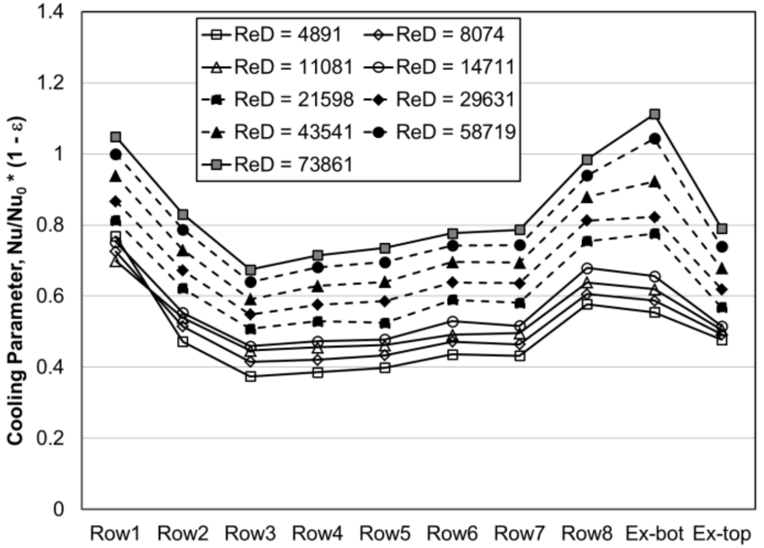


Incremental impingement

- Incremental impingement overcomes the streamwise increase in air temperature by adding air using impingement holes.
- In typical impingement arrays cross-flow deflects jets and insulates the surface.
- Incremental impingement overcomes crossflow by hiding jets in recesses behind pedestals.
- Based on leading edge heat load balances this approach should be very effective in the stagnation region.
- Holes can be sized to adjust cooling as needed along the array.

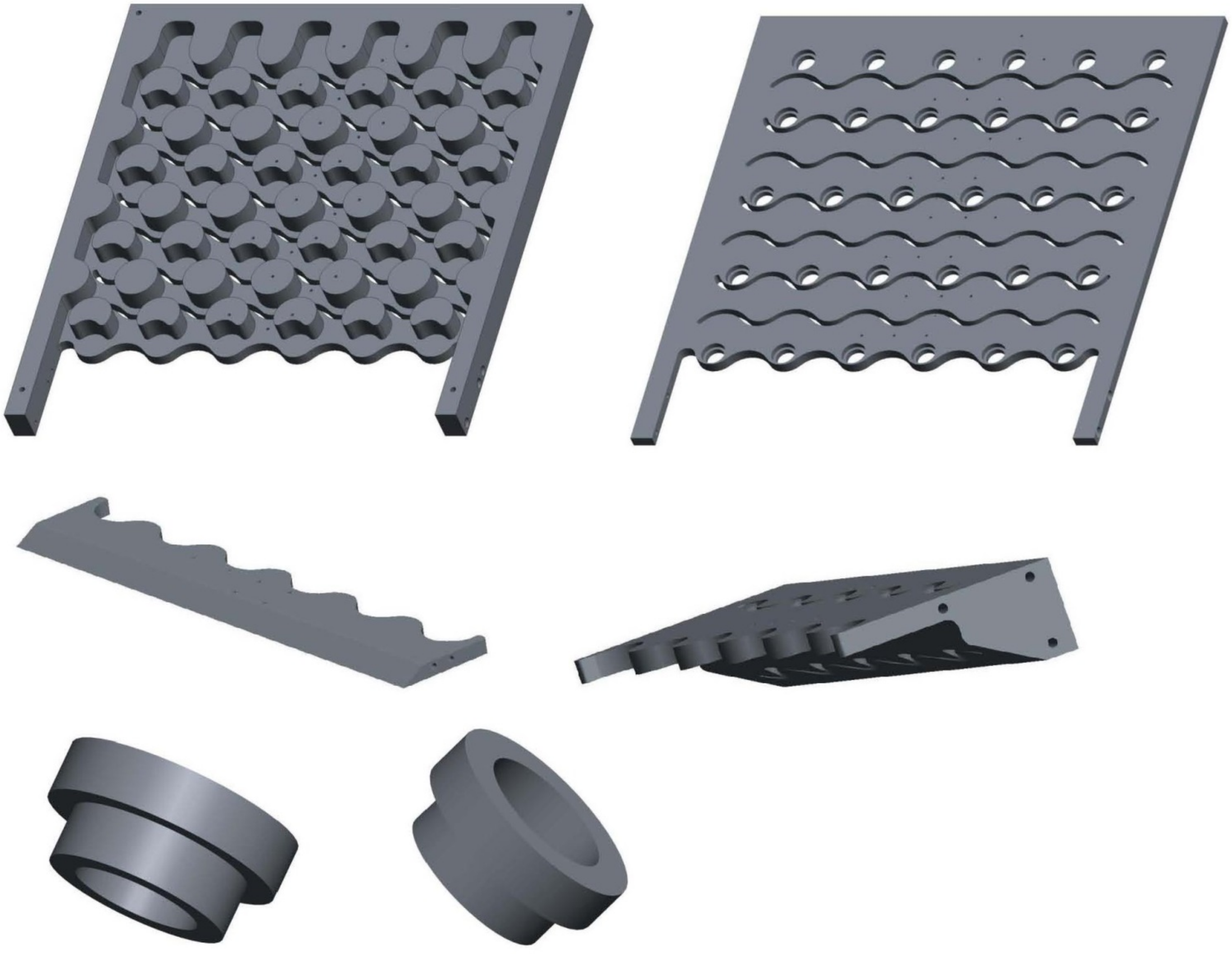






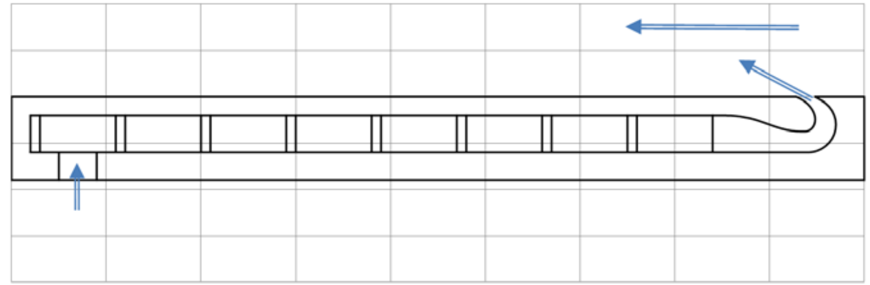
INCREMENTAL IMPINGEMENT GEOMETRY

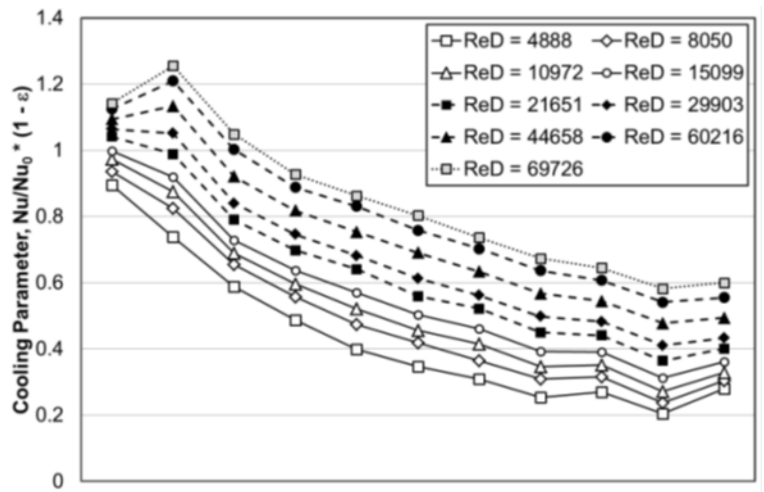
Testing will include relevant inlet and exit geometries along with variable hole size to allow optimization of the cooling hole distribution for a given application.

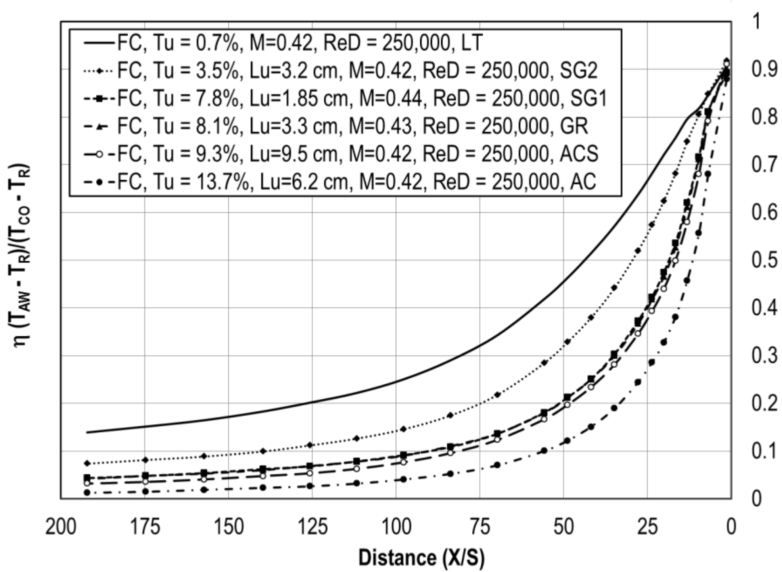


COUNTER COOLING

- Driving cooling air toward a high internal effectiveness level is optimal from a thermodynamic standpoint.
- Subsequently, discharging the used coolant onto the surface can maximize its overall effectiveness.
- One way to accomplish both is to drive coolant counter to the external flow before discharging it on the surface in an optimal flow.
- In the present study we plan to apply this approach to the vane pressure and suction surfaces.

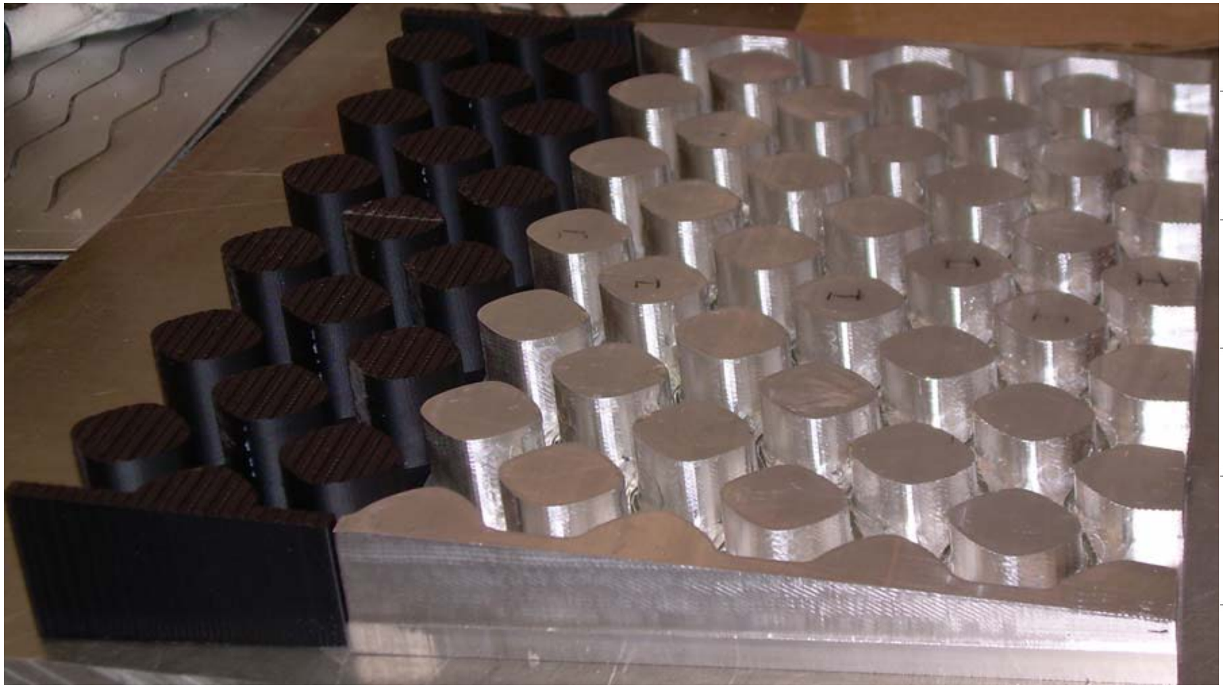


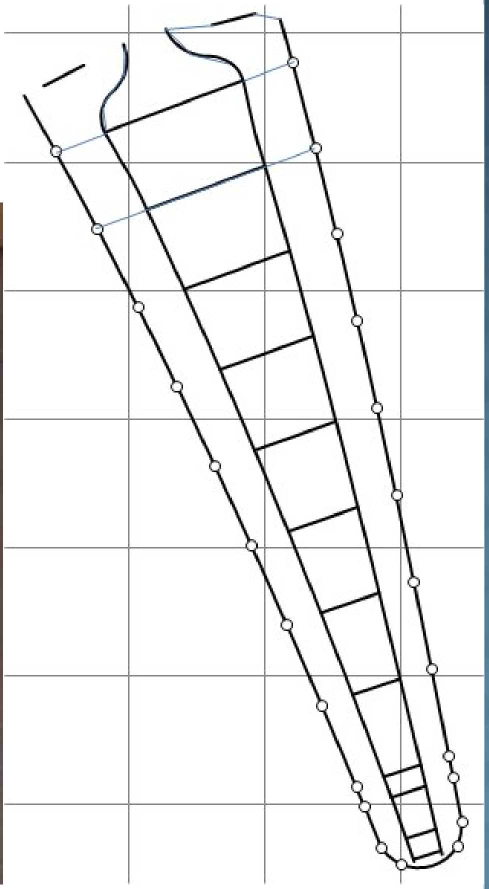




Covered Trailing Edge with Converging Array

- Converging pedestal arrays in trailing edge regions have often been attractive due to an increasing streamwise heat transfer coefficient which tends to overcome the coolant warm-up problem.
- We are looking at relevant inlet geometries including both symmetrical and off center inlets to reflect the possible design options. These realistic geometries are expected to help refine boundary conditions.
- We are currently in the test geometry design phase.





Large Scale Low Speed Cascade Testing

- UND is developing a large scale cascade to evaluate the film cooling effectiveness and the influence on heat transfer of the individual films subjected to a relevant range in turbulence conditions.
- UND/UM will use this information to help refine the heat transfer boundary condition for the LSU cascade.
- The detailed design of the cascade is nearly complete.
- We have cast four vanes, built inlet bleed flows and we are currently working on the design and fabrication of the endwalls.