Heat Transfer Analyses of Internal Cooling Passages of Turbine Blades and Nozzles

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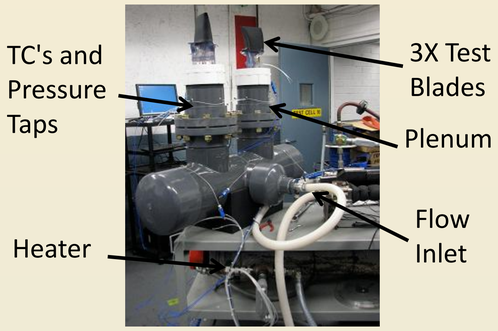
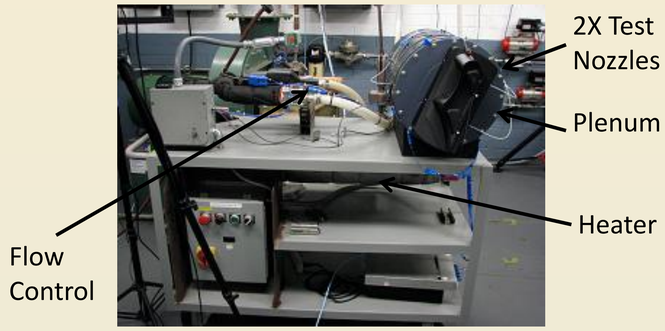
Introduction:

Two heat transfer experimental studies utilizing thermochromic liquid crystal (TLC) paints were conducted in the Aero, Thermal and Performance department at Solar Turbines, Inc. The first experiment study sought to determine the internal convective heat transfer coefficient (HTC) for three proposed modifications of a first stage turbine blade. Stereolithography (SLA) models of the three modified designs and a baseline model were scaled three times original size. The second experimental study looked at two proposed modifications to the first stage nozzle of a gas turbine. SLA models were also constructed, which were scaled two times original size with the baseline nozzle for a comparative analysis.

Typical heat transfer studies involving TLC's record the transition color with a CCD (charged coupled device) camera as an airflow impinges on the surface coated with the TLC. Properties of the airflow and transition time are then used to calculate the HTC. The experiments conducted on the turbine blade and nozzles were conducted with known airflow conditions in the inner cooling passages with the TLC applied to the outer surface of the SLA model. Due to the air supply not contacting the TLC, the TLC transition was delayed by the conduction through the SLA material. This aspect of the test configuration required new software to analyze the time delay from conduction to determine the internal convective HTC.



Blade Test Fixture



Nozzle Test Fixture

Experimental Setup:

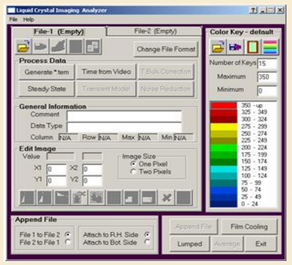
The thermal experimental setup for both blade and nozzle are seen in the above pictures. Both test fixtures contain mixing chambers connected to a 2" silicone air supply hose which feeds into a plenum. Perforated plates are positioned inside the plenums between the inlet flow and test models. The perforated plates aid in decreasing any spanwise variations in the velocity field as the airflow travels to the blades and nozzles. The test fixtures were constructed from PVC, which has a low thermal conductivity aiding in the reduction of heat loss and maintaining steady state conditions. Each test fixture was instrumented with thermocouples and static pressure taps to monitor inlet and outlet airflow conditions.

Testing and Data Acquisition:

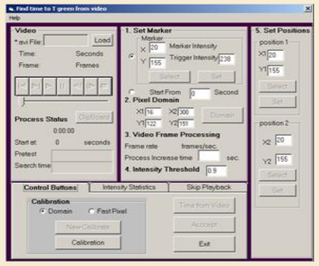
The test process evaluated a modified model alongside a baseline model. The transition of both models was recorded by two Sony Handycam CCD-TRV608 cameras with one viewing the pressure side and the other the suction side. A LED light in view of each camera was illuminated when the 195 °F airflow was sent through the test fixture and out the model. Temperature and pressure data was recorded during the duration of each test which was later used to establish boundary conditions for the convection and conduction heat transfer analysis.

Data Analysis:

The captured video of the liquid crystal transition was then analyzed with a Liquid Crystal Image Analyzer program (LCIA). LCIA analyzes the domain in the video pixel by pixel from the time the test begins to the time each pixel changes to a green color. The color green indicates a surface temperature of 95 °F. The program then assigns the pixel a time stamp, which is used to create a contour plot of transition time per pixel.

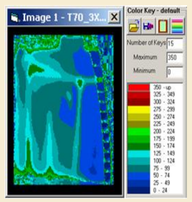


LCIA Main User Interface



LCIA Video Analysis

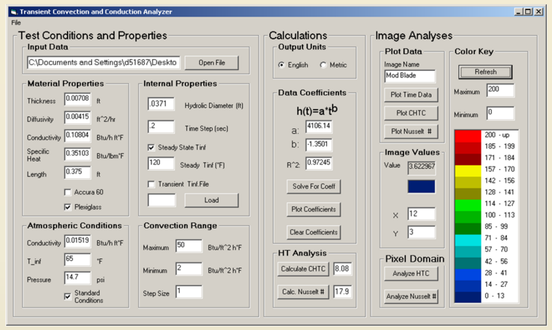
Test Video



LCIA Image Result

Transient Program Development:

A program was written in Visual Basic Studio, which accounted for transient convection and conduction through the SLA model. The program was then used to perform a HTC analysis of the turbine blades and nozzles with the use of the time data generated by LCIA.



Transient Conduction/Convection User Interface

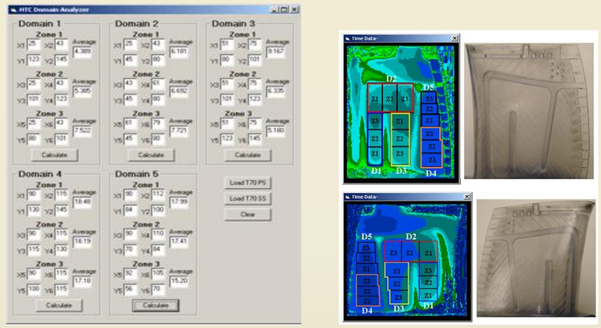
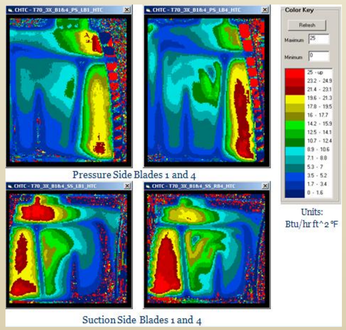
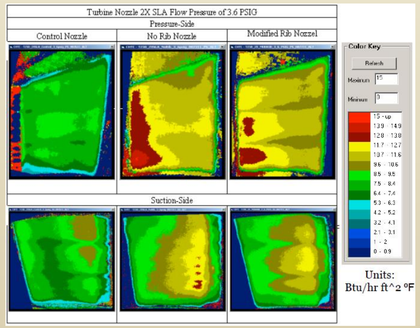


Image Domain Analysis User Interface

Results:



The final results indicated proposed modified blade design four had the greatest improvement of convective heat transfer with an increase of 25 and 27 percent for the pressure and suction sides respectively.



The final results indicated the modified rib design provided the most uniform improvement of convective heat transfer.

Acknowledgements:

Thank you to the UTSR Program, SwRI, and Solar Turbines, Inc for supporting and providing this project.