

Optimized Film Cooling Hole Design

William McDonald

University of Central Florida

UTSR Fellowship Summer 2008

at Pratt & Whitney, East Hartford, CT



Introduction:

This report is a summary of my UTSR summer internship experience at Pratt & Whitney, East Hartford, CT. Specifically, the internship position was within the Turbine Durability department under my mentor Atul Kohli. At Turbine Durability, the overall goal is to generate airfoils that have been intelligently designed so as to withstand the intense thermal and structural demands turbine airfoils face during operation while still maintaining the ultimate goal of overall gas turbine efficiency.

Problem Statement/Overall Objective:

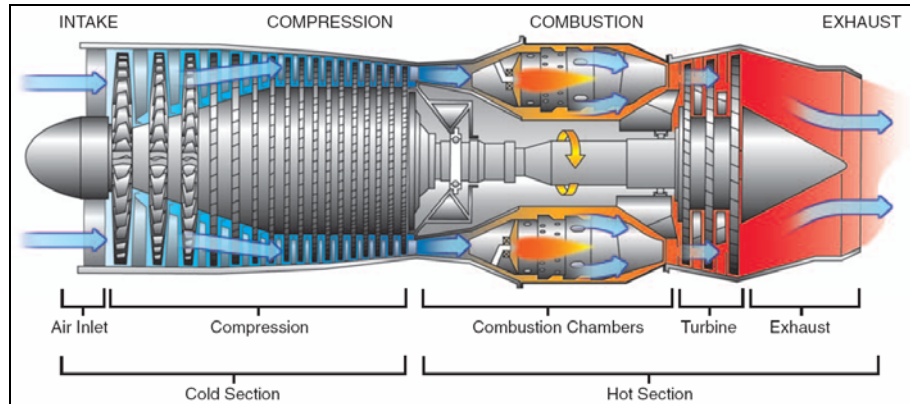


Figure 1. Basic Gas Turbine Cycle [FAA 2004 Airplane Flying Handbook]

Figure 1 shows an image of a typical gas turbine engine. Temperatures in the hot section of the engine can reach 3000°F, which is roughly 500°F hotter than the melting temperature of the turbine's airfoils. To protect the airfoils from melting, many cooling schemes are used, but the focus for this internship was film cooling. This type of

protection scheme involves placing small holes on the outer airfoil surfaces that leak relatively cold gases (roughly 1000°F bleed-off from the compressor stage) over the airfoil and into the hot main flow. If designed properly, this cool gas will spread evenly over the airfoil surface and form a protective blanket over it that will greatly reduce the metal temperature of the airfoil, preventing it (in conjunction with the other cooling methods) from reaching its melting temperature.

While technology in other parts of the turbine have improved, the majority of the cooling holes are still machined by processes that limit the hole shape to basic geometries. However, there are new machining processes that could be used to make film cooling holes that are much more complex that have not been taken advantage of yet. By removing some of the design constraints of the more traditional hole creation methods, there is the potential for finding an optimized hole geometry in the new design space that could result in lower airfoil temperatures while using less coolant gas. This is very critical because by reducing the amount of gas needed to be bled from the compressor, the overall engine efficiency can be improved.

The overall goal of my internship was to lay the foundation for an optimization scheme that could be used to automatically generate this “most efficient” cooling hole based on user-defined parameters such as cooling effectiveness and manufacturing cost.

Methodology:

An outline of the steps needed for the optimization is shown below (note that, while separate software performs the individual steps, iSIGHT is required to manage the inputs and outputs for each step):

1. Modify the film cooling hole shape using a parametric CAD model
2. Generate mesh of CAD model for computational fluid dynamics (CFD) analysis
3. Run CFD simulation of the flow under realistic conditions
4. Analyze the results
5. Compare optimization parameters of this iteration to previous results
6. If convergence criteria for run not met, use results from 5 to generate new parameters to be passed to 1 and repeat cycle.

Prior to my internship, my mentor developed a similar optimization scheme using iSIGHT software. However, the CAD model that the scheme used did not filter out designs that were impossible to manufacture, leading to optimized results that were not always physically possible. Furthermore, by the time of my internship, the software being referenced by the iSIGHT model was outdated.

Using my mentor's previous experience as a basis for this new scheme, I was given the task of rebuilding the iSIGHT model to use up-to-date versions of the software involved (including iSIGHT itself), to incorporate a new CAD model that only produced viable geometries, and to ensure that the scheme could take advantage of parallel processing.

Results:

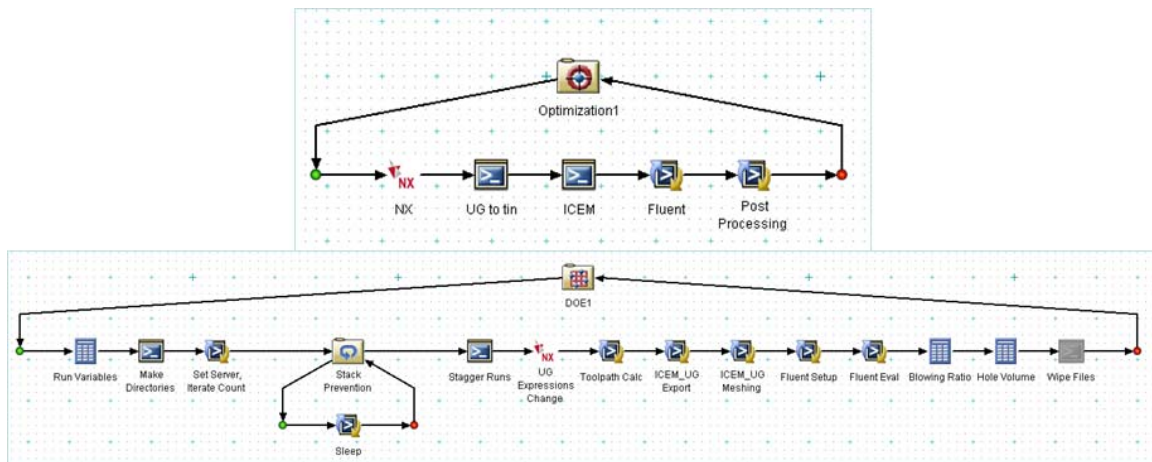


Figure 2. Overview of iSIGHT flowchart s (Top is initial version, bottom is final version)

Due to the proprietary nature of my internship's work, I am unable to show specific film cooling hole designs generated by the optimization model. However, Figure 2, which shows iSIGHT's flowchart of the optimization scheme, gives some idea of the complexity of the optimization process. In the figure, each small box represents an instance of a code run (either one written by myself or a pre-existing Pratt & Whitney code) that performed a function such as creating a directory, passing inputs to a program and/or launching it, or analyzing results. The top flowchart in Figure 2 shows the scheme in its early stage and the bottom flowchart shows the final version that was able to, among other things, run in parallel and recognize and discard iterations that returned bad results. In addition to getting the iSight model rebuilt, in the latter part of my internship I also developed a C code that was able to take parameters from the CAD model and generate the exact XYZ coordinates the machining tool would have to travel (i.e. the toolpath) to create that same hole.

Future Work:

The main purpose of my internship was to develop a tool more so than to investigate something myself, so most of the future work done on this topic would involve utilizing the tool that was developed and then making it more robust. A good starting point would be to perform a complete optimization analysis of the design space to yield the “optimized” film cooling shape, something that I did not have time to do during my internship (some sample cases were run, but the entire design space was not looked at). Next, a look into the structural stability of the designed hole should be performed to make sure that it would not stress the airfoil to failure. Lastly, a validation of the toolpath code that I wrote is required before its output can be fully trusted.

Value:

My internship experience at Pratt & Whitney was phenomenal. I enjoyed everything about the East Hartford facility from the pictures of aircraft operating Pratt & Whitney engines hanging from the walls to being able to go walk out on to the manufacturing area and actually see the airfoils being machined. I was constantly surrounded by intelligent people who were more than willing to share their knowledge on anything I asked about, be it of a technical or personal nature. This experience, without a doubt, has persuaded me to seek a career in the turbine industry. In fact, I enjoyed my position so much that I got an internship position at Siemens Power Generation to go with my Masters studies.