University Turbine Systems Research (UTSR) Industrial Fellowship Program 2012

Final Report

Component Flow Test - Effective Area Flow Model

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Introduction:

General Electric, Inc. here in Greenville, South Carolina site is the largest Gas Turbine manufacturing plant in the world. Most of the advanced gas turbines are produced for global exports. With the combustor in particular, customers especially in Europe have emission regulations that vary at base load and turn down load conditions.

The design of the combustor is a very complex application which can be very time consuming. Each design activity requires some level of technical review. There are various types of technical reviews the combustor has to follow through in order to be successfully put into the gas turbine system.

The first stage is called a Conceptual Design Review. The CDR evaluates how the product's CTQ requirements will be met with the proposed design. At this point, the development team selects the best option and agrees to focus design effort on that concept.

The next stage is called the Preliminary Design Review. The PDR examines; how well the product requirements are being satisfied, whether feature- and process-level CTQ and design practice requirements are established, whether the design incorporates proven features and lessons learned, and results of optimization and trade-off studies. The review that the 9FB.05 team has been working on and my project fell into was the Preliminary Design Review.

The last review is called Detailed Design Review. The main objective of DDR is to perform a final assessment of the design prior to manufacture. These reviews sometimes are called Production Release Reviews. The DDR is directed to confirm adherence to design practices and procedures, and examining the justification for any departures from standard practice or deviations from required goals. Although there are three main stages, there also can be multiple other reviews to lead up with a final production.

Component flow Testing:

The Component Flow Skid is a vacuum based flow stand that is determined to measure an effective area relating to the combined open orifices in that geometry. The three key components that are used to quantify the effective areas are pressure drop, mass flow, barometric pressure, and air density. Some examples of such geometries include fuel nozzles, air curtain holes, swozzles, and tip purge areas. Below is picture of the main component flow stand:

Figure 1: Component flow stand in the Mech. Lab

There are some required inputs from engineering to successfully execute a component flow test. Test hardware needs to be gathered and organized when constructing on the flow stand. Hardware must have ID or a detailed description or drawing entered in e-TOS. Next a test plan must be created to determine specific flow sections of what holes to exactly flow. Test plan must be uploaded to e-TOS three days prior to the test. Adapters may be designed in order to seal and secure test hardware onto the skid top plate. Intricate geometries may require blocking certain flow paths in order to accomplish desired test requirements. Lastly, predictions of effective areas and pressure ratio(s) must be determined for the test engineer in order to determine which calibrated nozzle will be installed to conduct testing.

Objective:

The main objective of this project was to execute critical parts of PDR component flow-test plan. After completing some of the objectives on the test plan, the measured effective areas are used to make fired test-flow predictions. The three components from the combustor that were flow tested consist of piston rings, two types of fuel nozzles and a newer designed nozzle box.

Nozzle Box:

Before completing the nozzle box flow test, some modifications for an adapter had to be made in order for the new nozzle box to fit on the flow stand. The main holes that were being measured from the nozzle box were cooling holes. Cooling holes help the nozzle box from heating up to excessive temperature before cracking or fatigue. Stoppers and metal tape were used to seal other excess holes that were not a part of this specific test.

Piston Ring:

For the piston ring flow tests, adapter and mock burner tubes were designed and made in order to successfully measure the effective area. These adapters had to be a specific height and diameter in order for the piston ring to replicate the condition for when inside the combustor. There were two different center and outer types of piston rings that included different size scallops and different ring thicknesses.

The piston ring test had to be measured on a *Positive Pressure Flow Bench* instead of the flow stand that was used for the nozzle box and fuel nozzles. This flow stand is more precise and a different configuration had to be completed before running the test.

Fuel Nozzle:

The 2.6 and 2.6+ fuel nozzles were flow tested. The two different holes that were carefully being measured were the tip purge area holes and swozzle slots on the 2.6 nozzle. For the 2.6+ nozzle, the air curtain holes were the main focus.

Effective Area calculations:

The main importance on calculating the effective area for different elements in the combustion is to test the assumption in order to find the correct Discharge coefficient for a specific flow master model. In order to find the effective areas, first, what type of orifices will be blocked off in order to find the correct effective area for specific orifices? Once the configuration on which holes will be blocked off or kept open, a flow test can then be performed to reach your goal of finding the different effective areas at different pressure ratios.

$$C_d = \frac{A_{eff}}{A_{geo}}$$

The geometric area could be calculated from having the diameter of the orifices. A C_d was assumed in order to calculate for the effective area. Once the flow test was performed, the data can then be used to check predications that were made in the beginning. The Cd is then found using the measured effective area from the flow test and the geometric area that was calculated from the beginning of the experiment. The overall measured effective areas are used then to make fired- test flow predictions.

Flow Test Results and Analysis:

The main focus for the *nozzle box* was to flow test the cooling areas. In the beginning before the test, we learned that this new nozzle box had fewer amount of holes drilled than the older box nozzle and expected a lower area going into the test. After running the test, we learned that the effective area came out a lot lower than what we expected. After looking at the data, we thought it was important to inspect the box, using a 25 mill pin gage and finding that some of the holes were still too small for the pin gage to go inside. The conclusion that the group discussed with the lab team was there were issues with the thermal barrier coating blocking some of the holes in the new nozzle box and for that reason the box should not be used for any fire tests.

The *piston ring test* included both center and outer front rings that had two different scallops' sizes and ring thicknesses. Adapters and burner tubes had to be designed in order to replicate the test as if the piston rings were in the combustor.

There was another test run on the high and low flow *outer piston rings*. The graph below shows the difference between the two flows at the same range of pressure ratios. As you can see the effective area was slightly larger on the high flow ring than the low flow ring.

The last flow test I ran was on the two different style nozzle tips, and main focus was looking at the purge areas for the 2.6 and 2.6+ nozzles. For the 2.6 nozzle, the two main area features included swozzle tips only and the full area of the tip passage. The swozzle tip passages were tested by opening all of the area below the slots to strictly measure the swozzle passages only. Please refer to *Figure x* in *Appendix C* to see where the slots and cartridge hole are located:

A characterized bypass hole was added in parallel to bring the areas up to a reasonable range for the flow stand to measure. The graph describes the comparison between using the bypass whole and flow testing without the whole.

The second fuel nozzle that was flow tested, was the 2.6+. The main focus was analyzing the air curtain passages. Below in Figure 12 in Appendix C will show where the passages are located. The one thing to keep in mind was the 2.6+ nozzle only had 5 swozzle slots opened compared to the 2.6 nozzle that had 10 slots opened. The effective area was a little lower due to fewer amounts of slots being opened.

***Fired Test Results*:**

The 9FB.05 combustion team evaluated multiple tip configuration changes during fired testing with some uncertainty in the initial assumptions of total tip flow for each test configuration. By determining the total effective areas, and pressures from the fire tests, a new total tip flow was able to be calculated for base load as wells as for turndown load conditions.

The mass flow of the cap had to be calculated first by using a list of parameters such as; upstream pressure, downstream pressure, overall effective area, air inlet temperature, and air constants limits.
By finding the effective areas from the 2.6 and 2.6+ cold flow test, the total effective areas could then be determined. These parameters such as, curtain effective area, passive and active cartridge areas were all used to calculate the total effective area from each fire test. The overall total tip flow was calculated by adding the mass flow from the cap to the total effective area.

Acknowledgments:

The experienced I gained working for General Electric has been tremendously rewarding for my understanding on the combustor and different elements that make up the full combustion can. All of the different test that I was able to be a part of was not only a learning experience, but was very exciting to see a live all day test for the combustor that the team is working on. Being able to also work with a vendor was another learning block to see what the different qualifications were to have parts made. General electric here is a very diverse environment which has really helped me to gain and improve my engineering skills in every direction.

I would like to thank Mohan Bobba for his guidance and support for organizing a test plan to run a test on the component flow stand. . I would also like to thank Brad Crawley for his patience and giving me positive input throughout my project. Thanks to the whole 9FB.05 team not only letting me sit through all of the fire tests, but for the knowledgeable information on understanding the combustor.

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