Emissions Testing and Arctic Turbine Option

UTSR Fellowship Program

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Introduction:

FlexEnergy is a leading manufacturer in the small gas turbine industry. With FlexEnergy's innovative technology, they guarantee one of the cleanest power platforms in the world. During my twelve week stay with FlexEnergy in Portsmouth, New Hampshire, I worked on a variety of projects, including emissions testing and the arctic turbine option. A newly designed, improved version of the MT250 must pass the CARB (California Air Resources Board) emission requirements for distributed generation. Strict emissions standards required the modification of the combustor in the redesigned turbine to the low NOx emissions level. My role with FlexEnergy included testing the 250 kW recuperated gas turbine for levels of NOx, CO, and VOCs. Lean blowout testing was also performed to ensure that any changes to the combustor would have sufficient static stability (lean blowout margin).

FlexEnergy is also in the business of microturbines for very cold (-40° C and below) temperature applications. One objective of the arctic turbine option was to determine the how cold a modified turbine could survive in an unenclosed application. Currently, Flex is manufacturing microturbines for an outdoor site, which must withstand low ambient temperatures (-40°C) and a high altitude of 7,000 ft. My research at Flex required identifying parts of the MT 250 that would need modification or replacement at -40°C and colder.

Test I: Emissions and Blowout Testing

According the new CARB emissions specifications, the following standards must be met:

Table 1: CARB standards after 2007

Pollutant	Emission Standard (lbm/MW-hr)
NO_x	.07
CO	.10
VOC	.02

These CARB standards are significantly stricter than those in years prior to 2007, and adjustments to combustor had to be made to ensure that the machine would pass such criterion. The first emissions tests were done using a combustor with dilution hole size of XX.xx mm, as seen in the figure below:

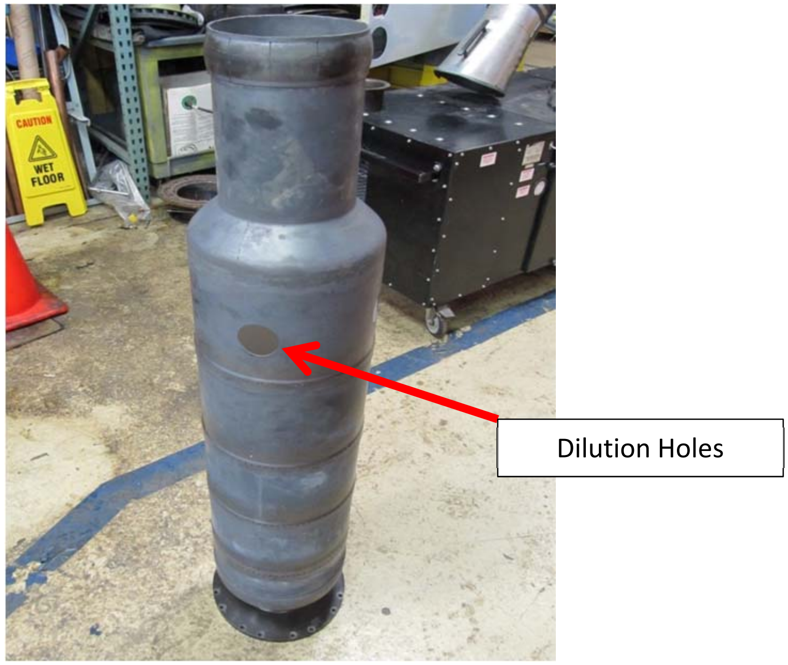

Figure 1: Combustor for first emissions tests (Dilution Hole Size Ø XX.xx mm)

Each emissions test conducted was considered to use the maximum amount of cogeneration credit of XXX. NOx and CO levels were found to be as follows for this combustor with varying flowpath temperatures:

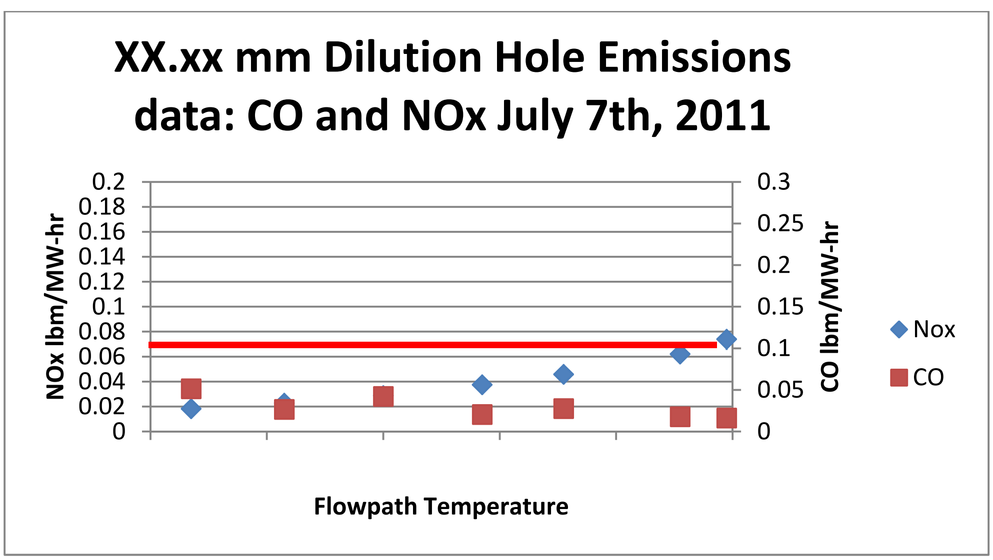

Figure 1: Emissions data for XX.xx mm Dilution Hole Size

The data shows that CO emissions will always pass the CARB emission requirements, but NOx will fail at the higher flowpath temperatures. A design change in the combustor will lower emissions. Reducing the dilution hole size will lead to leaner flow through the combustor, which decreases NOx emissions. Leaner flow will increase CO emissions, especially at lower temperatures, and will also cause a flameout at a higher power rating.

To see the effect of smaller dilution holes, a new combustor with dilution holes of diameter YY.yy mm was tested for emissions, and the following results were found:

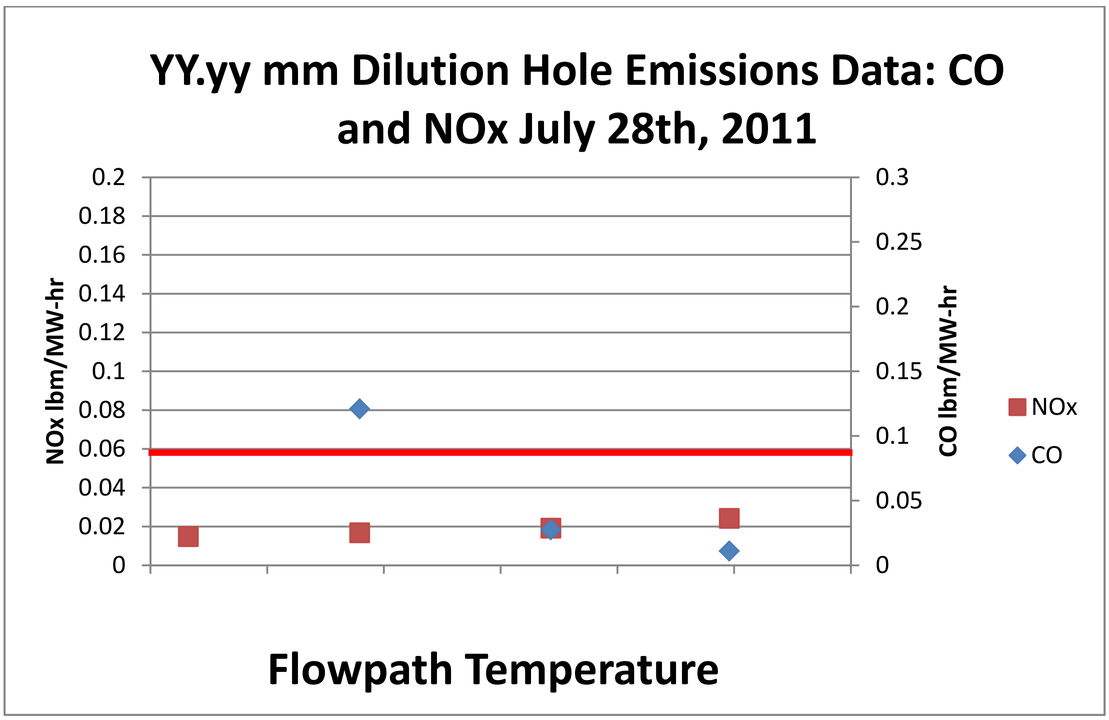

Figure 2: Emission data for YY.yy mm Dilution Hole Size

The second test with the smaller dilution holes shows that NOx drops significantly, and it always remains under the CARB standards for all flowpath temperatures. CO emissions, for lower flowpath temperatures, increases. Fortunately for the range of concern in terms of the flowpath temperature, these CO emissions levels are acceptable and will pass CARB emissions standards.

The downfall of having smaller dilution holes in a combustor is the possibility of flameout at a lower power rating. Lean blowout tests were performed on both combustors to find the power rating at which G3 flames out. The following results were obtained:

Table 2: Lean Blowout Tests for XX.xx mm Dilution Holes and YY.yy mm Dilution Holes

LBO Data		
Dilution Hole Size	**YY.yy mm Rating**	**XX.xx mm Rating**
Trial 1	1.05	0.88
Trial 2	1.05	1.08
Trial 3	1.03	0.97
Average	1.04	0.98

After three trials, the YY.yy mm dilution holes average a higher rating at which flameout occurs. The ambient temperature during the XX.xx mm test averaged between 90°F - 95°F. The ambient temperature during the YY.yy mm test averaged between 80°F - 85°F. A higher ambient temperature will cause a flameout to occur at a high power rating. The data in Table 2 was corrected to ISO day conditions, and normalized against the objective lean blowout limit. The number of less than 1.0 is the goal.

Considering the above results, a hot day with the YY.yy mm dilution holes could result in a flame out at a much higher power rating. Also, ruling out the 1.08 power rating, the average for the XX.xx mm dilution holes is much lower than the given rating of 0.98. The YY.yy mm dilution holes do not meet the required blowout standards for FlexEnergy, so a new dilution hole diameter must be determined.

Since CO emissions pass CARB standards for all flowpath temperatures of concern, only a careful analysis of NOx levels is required. Also, to keep emissions levels low, COGEN credit may be used. The following results were obtained, showing the difference between 0% COGEN used and 100% COGEN used.

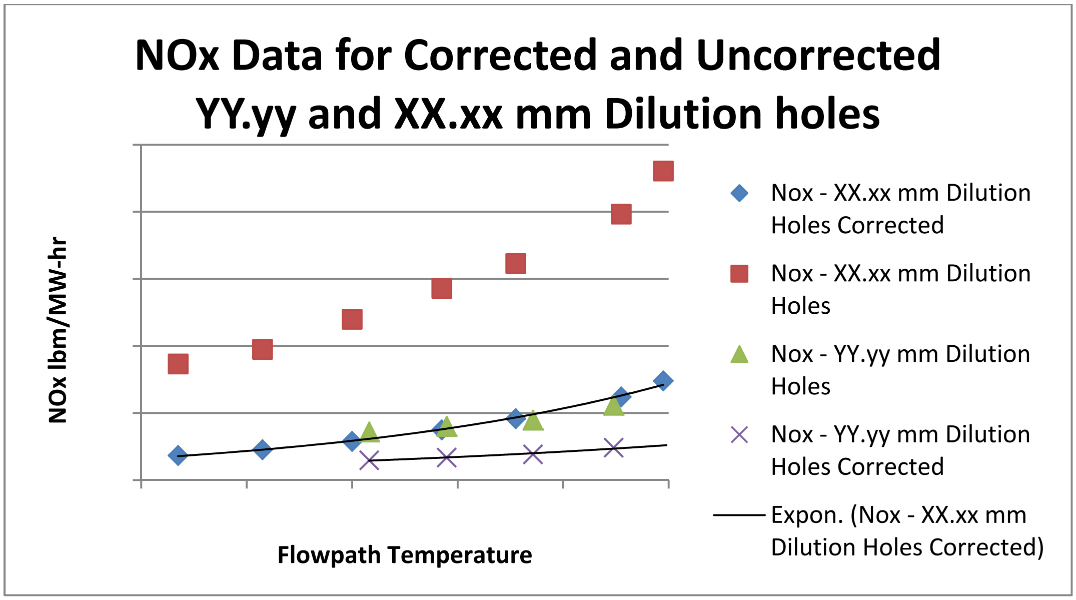

Figure 3: NOx emissions from XX.xx mm and YY.yy mm dilution holes, with and without COGEN credit

Without COGEN credit, the NOx emissions on the XX.xx mm will not pass CARB standards. When corrected with COGEN credit and engine degradation, the XX.xx mm dilution holes will still fail at the maximum flowpath temperature. The YY.yy mm dilution holes pass CARB standards with- and without-COGEN credit.

Considering the gap between the XX.xx mm and YY.yy mm dilution holes, it was decided to increase the dilution hole diameter to ZZ.zz mm. The following results were found:

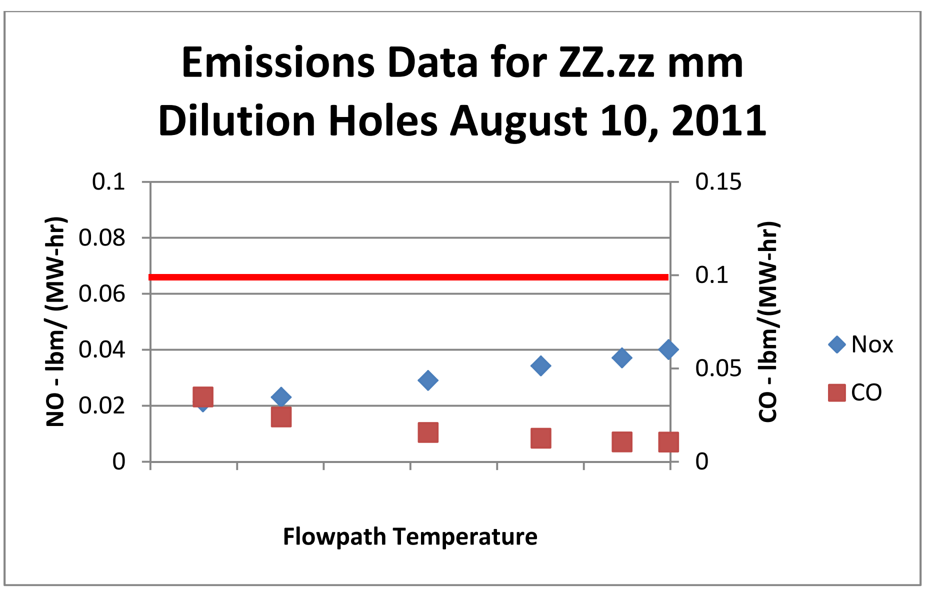

Figure 4: Emissions for ZZ.zz mm dilution holes (with COGEN)

NOx and CO emissions with this combustor pass for all flowpath temperatures by a large margin. Lean blowout tests were also conducted on this combustor, and the following results were obtained:

Table 3: Lean Blowout Ratio for ZZ.zz dilution holes

LBO Data	
Trial	**KWpct**
1	0.93
2	0.98
3	0.96
Average	0.96

Lean blowout data shows that this combustor will not flameout under normal conditions. Table 3 shows the corrected ISO day blowout ratios relative to the objective. Taking a close look at the NOx emissions, which were of concern, shows that this modified combustor will pass emissions and is a good choice for emissions testing:

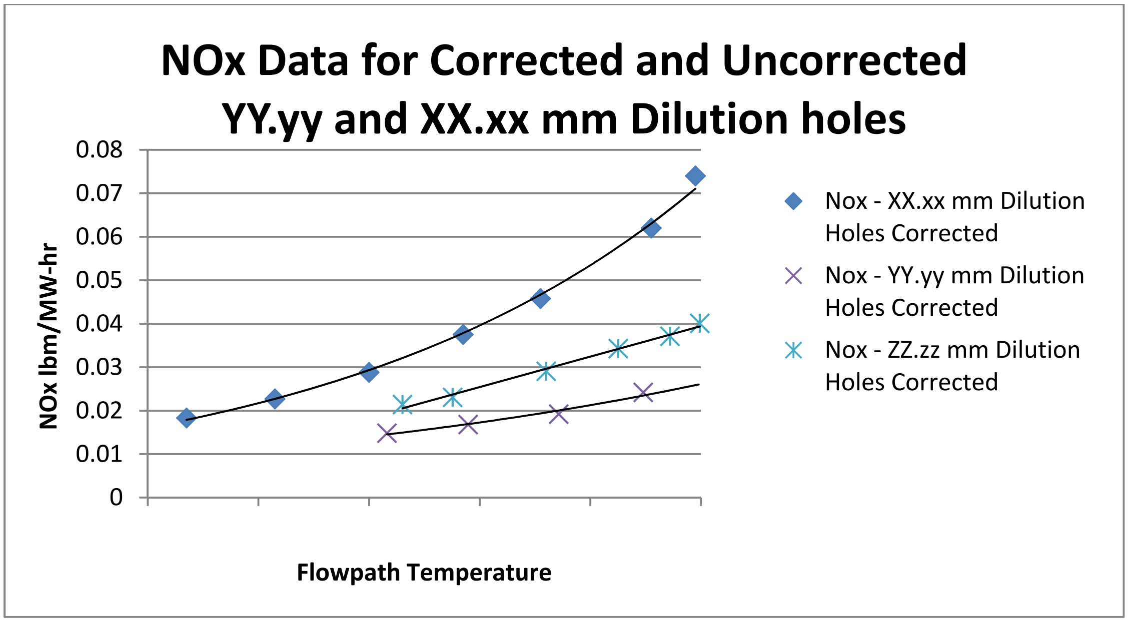

Figure 5: NOx emissions for each combustor

The ZZ.zz mm combustor will be used in the official CARB emissions test in early September.

Arctic Turbine Option

FlexEnergy has recently been marketing their microturbines in cold weather locations, and looks to manufacture a turbine that will start and function after being cold-soaked to below -40°F. Part of my responsibilities during my UTSR Fellowship internship was to begin the initial design phase of this arctic option.

To begin my research on this turbine, I reviewed all parts of the current design and distinguished which parts would require change for the arctic temperature. All elastomers and seals were identified, and replacement parts were found. The lubricant system was completely analyzed, and the proper heating equipment was used to insure that warm oil was circulated through the machine.

Considering that the compressor would receive inlet air at a temperature below -40°F in this scenario, a complete material analysis of the compressor blade alloy was also necessary. Key material properties were examined, and alloys were ranked in order of their appropriateness for the arctic turbine option:

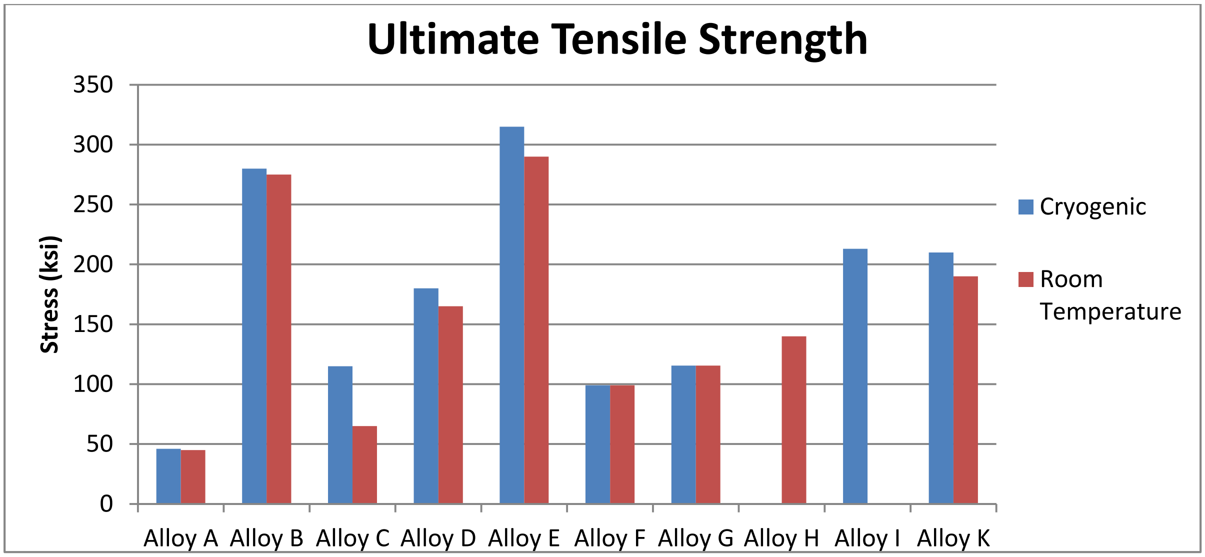

Figure 6: Tensile Strength of Examined Alloys

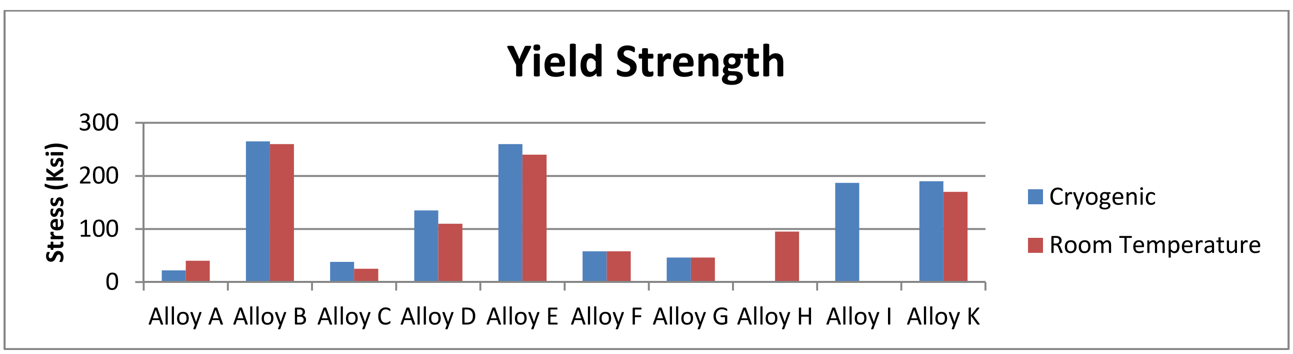

Figure 7: Yield Strength of Examined Alloys

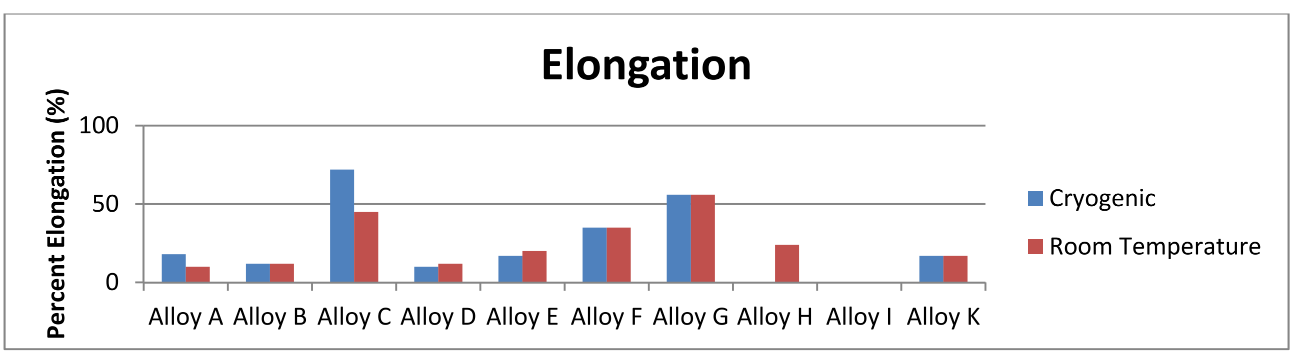

Figure 8: Percent Elongation of Examined Alloys

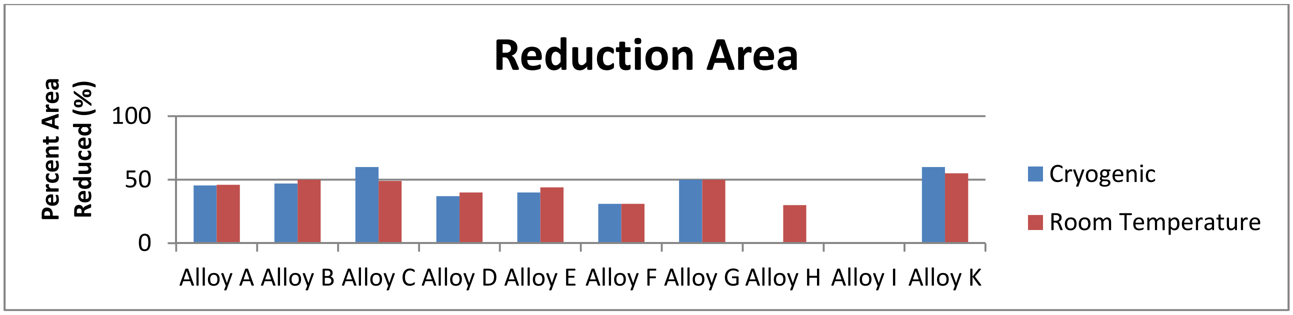

Figure 9: Percent Area Reduction of Examined Alloys

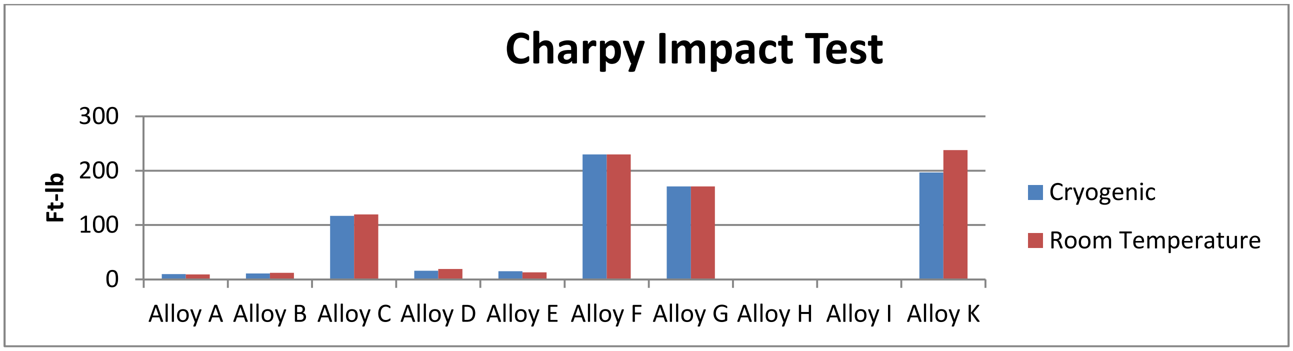

Figure 10: Chary Impact Test of Examined Alloys

From the above characteristics, three alloys were chosen as the top candidates for the new compressor blade material. Further testing is required to choose from these three alloys.

Ultimately, there are many parts of the MT 250 that can't be verified to function at a temperature below -40 °C. All but seven of one hundred and eighty-four electrical components are known to function at this cryogenic temperature. Test strategies to freeze individual components were identified, and ultimately, a plan to freeze a cryogenically functioning turbine to below the -40°C temperature was established.

Acknowledgements:

The UTSR Fellowship Program has been incredibly rewarding for me this summer. My experience at FlexEnergy has greatly expanded my knowledge of emissions, heat transfer, and materials science. This fellowship has also served as a valuable transition from the academic to the industrial world.

I'd like to particularly thank Jeff Armstrong, Thomas Hackett, Robert Mayoral, and many others who made my stay at FlexEnergy great. Thanks for your knowledge, guidance and patience throughout this summer!

I would recommend the UTSR program to all engineers interested in the gas turbine field. I'd also like to thank the Southwest Research Institute. Without them, this opportunity would not have been possible.