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THESIS

IMPROVED AEROTHERMODYNAMIC MEASUREMENTS OF THE T63-A-700 GAS TURBINE ENGINE

by

Kristin B. Garrott

September 2005

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IMPROVED AEROTHERMODYNAMIC MEASUREMENTS OF A T63-A-700 GAS TURBINE ENGINE

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ABSTRACT

This thesis contains an analysis of the failure of the instrumentation ring for measuring the combustor exit temperature and total pressure in the T63-A-700 gas turbine engine. An improved ring design has been constructed and installed. Extensions to the exhaust stacks have been installed to keep the cell temperature reasonable. A water-cooled heat exchanger was installed in place of an air-cooled heat exchanger that was not adequately cooling the oil temperature while running the engine. In the program GASTURB, a compressor map with data from the manufacturer was created and an operating line from three separate speeds was plotted.

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I. INTRODUCTION

A. BACKGROUND

Gas turbines are widely used and very important in the military. These engines are used on most surface ships and aircraft in the United States Navy. As the Navy progresses into the 21st century the use of gas turbines on ships will become increasingly abundant.

Due to the rise in importance of gas turbines to the Navy, it is necessary to continue with the testing and analysis of this engine. Naval Postgraduate School is in place to provide higher education to those in the military as well as those involved with it, therefore it only makes sense that it should have a gas turbine engine for performance testing. The Marine Propulsion Laboratory contains a T63-A-700 gas turbine engine as well as all of the necessary means for testing and measuring. It is not only used for experimental purposes, but also for thesis research and a hands-on learning environment for the students.

B. MOTIVATION

After running the engine for a laboratory, several problems with the engine were identified. The engine could only run at full speed for a very limited period of time because the heat exchanger was inadequate in cooling the oil. Additionally, the hot exhaust gases that were supposed to be leaving the test cell were circulating throughout it, therefore causing temperatures in the cell to be too high. Data indicated that the majority of the temperature readings at the gas generator turbine inlet were faulty. This was a result of the thermocouples that were measuring that temperature being nonfunctioning. Performance measurements were compared to predictions made using a performance code. The availability of a manufacturer supplied compressor map allowed for more specific predictions of the engine performance.

C. OBJECTIVES

The purpose of this thesis was to solve the problems discovered with the engine and the facility. In order to keep the oil temperature cool enough to run the engine for unlimited time at full speed, a water cooled heat exchanger was to be installed. This would eliminate the problem of the stagnant air that was unable to cool the oil.

Extensions to the exhaust stacks were to be installed to allow the exhaust gases to escape from the test cell and therefore keep an appropriate cell temperature. The bad temperature readings at the gas generator turbine inlet were found to be due to an inadequate design of the thermocouple ring that was measuring the temperatures in the harsh environment. An improved design of the thermocouple ring was made and installed. Several issues with the original ring were taken into account and improved upon to make a more adequate design. Data were acquired from the manufacturer in order to create a compressor map that would be specific to the test cell engine. The map was imported into GASTURB, an engine performance prediction program, for more realistic predictions of the engine off-design performance.

D.   OVERVIEW OF THESIS CONTENTS

The remainder of this thesis further discusses the motivations as well as objectives and results aforementioned. Chapter II outlines the existing facility instrumentation throughout the entire engine. There is mention of arising problems with the instrumentation, but it is more clearly outlined in Chapter III. Chapter III also describes changes made on the facility, including the new heat exchanger and the exhaust stack extensions. Chapter IV covers the problems with the original thermocouple ring at the gas generator turbine inlet, considerations for the improved design, the improved design, and the installation of the new design. Chapter V discusses the process of making the engine specific compressor map and using the program GASTURB to create an operating line on the engine specific compressor map as well as predict the off-design performance such as power production and fuel consumption at off-design. Chapter VI covers the conclusions of the work completed in this thesis.

II.   EXISTING FACILITY INSTRAMENTATION

A.   OVERVIEW

There are various types of measuring devices throughout the engine, shown in figure 1, to measure temperature, pressure, and mass flows of fuel and air. This instrumentation was designed in 1996 and has not been altered since. This section will discuss the locations and types of measuring devices with which the engine is equipped [Ref. 2].

B.   MASS FLOW RATE MEASUREMENT DEVICES

Mass flow rates are derived from the volumetric flow rates of both air and fuel. First, in terms of air flow, dual turbine flowmeters are on the engine's inlet plenum. The values can be read on the Superflow 901 system display. Next, a calibrated bell mouth is installed on the compressor inlet. It is possible to calculate the mass flow rate with the following information: cross-sectional area of the bell mouth housing and both static and total pressures at the compressor inlet. Measurement of the fuel flow is also accomplished with a turbine flowmeter. Again, results are displayed on the Superflow 901 system.

C.   PRESSURE MEASUREMENT DEVICES

Both pitot tubes and Kiel-type probes are used to measure total pressures throughout the engine. Static pressures are measured with end wall static pressure ports. At the compressor inlet, there is a single pitot tube to measure the total pressure entering the compressor (P_{T1}). A static pressure ring is on the inner surface of the bell mouth with four inputs that are mechanically averaged. Because both static and total pressures are measured, the air flow is measured and compared to the air flow rate measured with the turbine flowmeters. At the compressor outlet, a Kiel-type probe measures the pressure (P_{T2}). Probes are positioned between the exits of the scroll type diffuser and the inlet to the two circular ducts. There is no measurement of pressure at the combustor inlet (P_{T3}) because the combustor casing is too thin to safely install a measurement device. The gas generator turbine inlet total pressure (P_{T4}) is measured by two pitot tubes installed on a thermocouple ring assembly. The pitot tubes are made from Inconnel 600 and are 1/8" in

diameter. They are placed 180° apart from each other. Both pressures are displayed in the results and they are also averaged to get the total pressure. A Kiel probe design is used to measure the gas generator outlet pressure. They are both inserted through two of the existing openings for the thermocouple harness. The probes are located 90° apart from each other and are at the midpoint of the flow path. Both pressures are separately measured and the average is taken to acquire the total pressure (P_{T5}). At the power turbine exhaust a static pressure is taken, which is an industry standard. There is a static pressure ring on each exhaust pipe which has 8 static pressure ports which are pneumatically averaged in the results.

D.   TEMPERATURE MEASUREMENT DEVICES

Temperature measurements throughout the entire engine are made with K-type thermocouples.   The K-type thermocouple was originally selected because of its operating range and accuracy in temperature measurements. There are thermocouples placed at each end of every major engine component (compressor, gas generator turbine, power turbine). At the compressor inlet, there are two K-type thermocouples placed at two different radii in the calibrated bell mouth. Both temperatures are averaged to get the total compressor inlet temperature (T_{T1}).   At the outlet, there are two more thermocouples, this time placed within the Kiel probe, which makes them combination probes.   The two temperatures are again averaged to obtain the total compressor discharge temperature (T_{T2}). The combustor inlet temperature (T_{T3}) is not measured to maintain the engine's integrity. The gas generator turbine inlet temperature measurement is the most complex of the instrumentation on the engine.   There is a large non-uniformity in the fuel burn at this stage and as a result there are hot spots and cool spots that develop.   As a result of this, a thermocouple ring containing 48 K-type thermocouples is placed at the entrance to the gas generator turbine as pictured in figures 2 and 3. Each thermocouple is places 7.5° apart and is placed at three different radial locations, giving 16 at each radius. Due to the extremely high temperatures at this stage, the thermocouples used are encased in a 1/16" Inconnel sheath for protection. The ring assembly is constructed of 347 stainless steel and the thermocouples are fitted in holes at the designated angles. All 48 measurements are taken then a mass average is used to compute the total temperature (T_{T4}). A concern with this instrumentation was the

blockage in flow caused by the great number of thermocouples; however, it was outweighed by the inaccuracy that would occur if fewer thermocouples were utilized. After inspection of results from recorded data, it was determined that this device was no longer sufficient in measuring the temperature at the gas generator turbine inlet. The determination was due to bad temperature readings from more than half of the thermocouples. At the power turbine inlet, which is also the gas generator outlet, there is an onboard thermocouple harness. The original harness contained four locations for thermocouples, but two were replaced by Kiel probes to allow for pressure measurement at this stage. The thermocouples came with internal wiring so there is no need for averaging results to get the total temperature (T_{T5}). At each duct of the power turbine exhaust there is two K-type thermocouples. The final power turbine outlet temperature (T_{T6}) is averaged from the two readings.
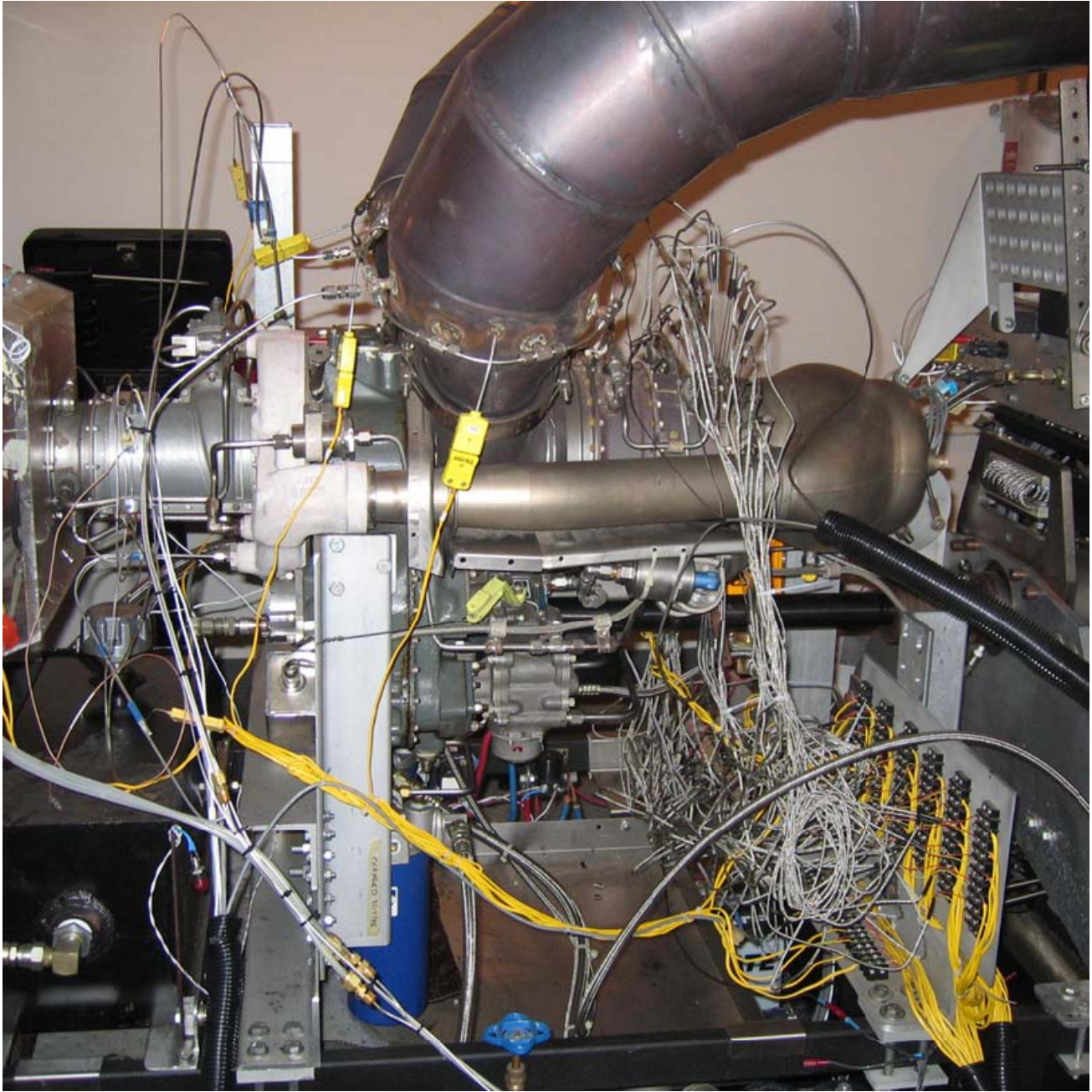
Figure 1.   T63-A-700 Gas Turbine Engine
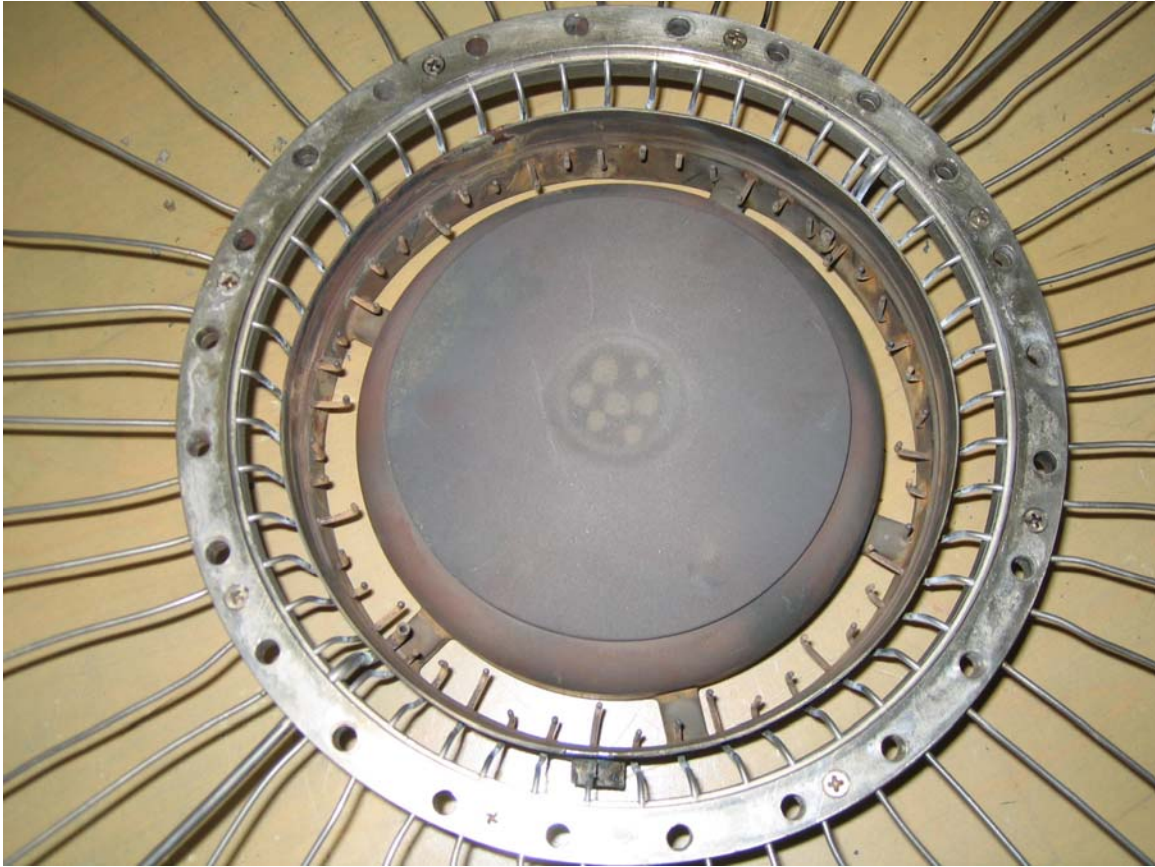
Figure 2.   Fabricated GGT ring assembly (old)
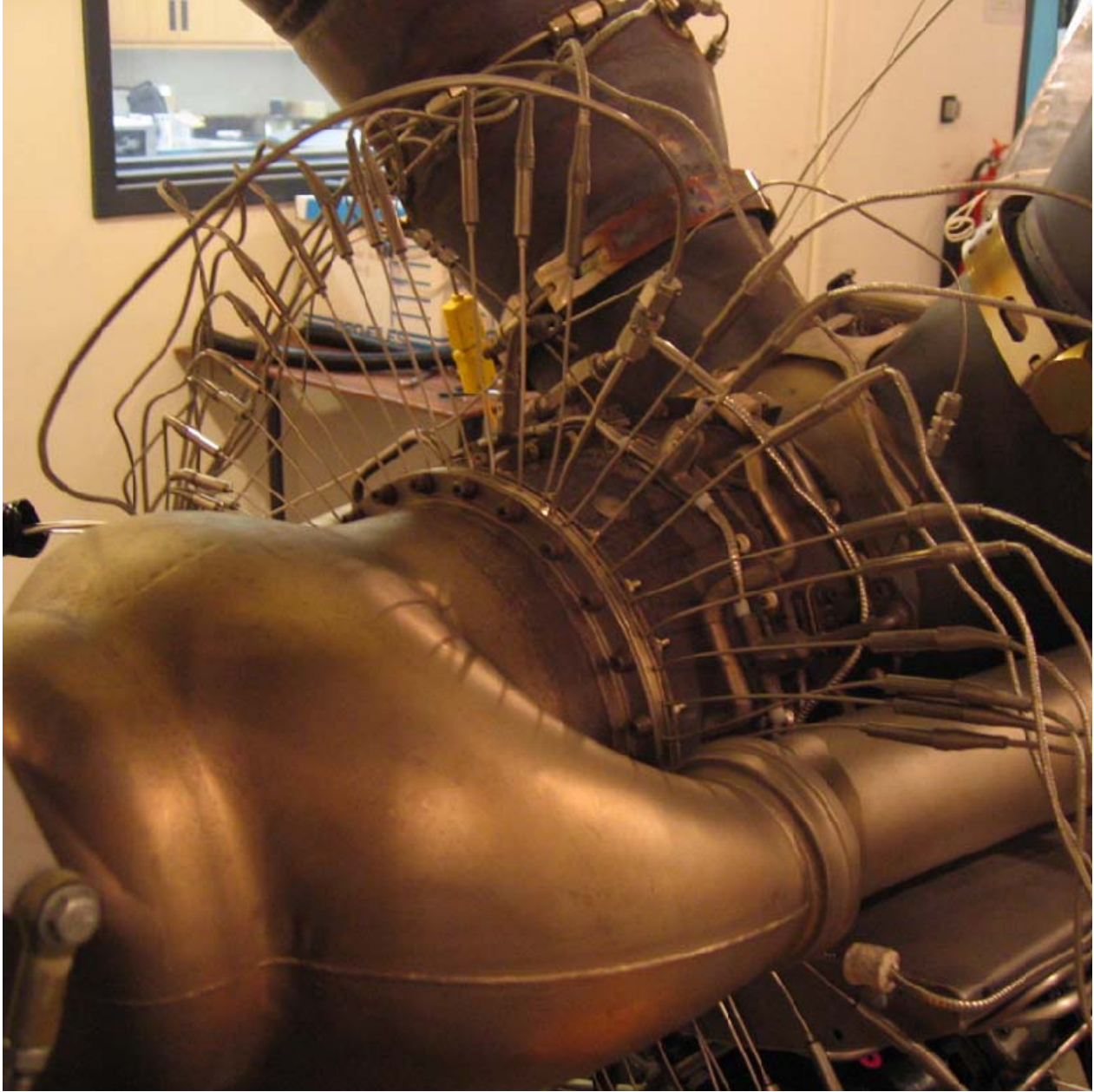
Figure 3.   Installed GGT ring assembly

III.   FACILITY CHANGES

A.   PROBLEMS WITH THE FACILITY

After initially running the engine, there were two areas in which the facility seemed to be inadequate: the temperature of the test cell after operating the engine for only a short amount of time and the oil temperature were excessively high. The temperature of the test cell was too high because the existing exhaust stacks were no long enough, causing hot exhaust gases to leak into the cell. The time allowed for testing was being severely limited due to the oil temperature rising too fast. This was determined to be the fault of the air-cooled heat exchanger that was in place.

B.   EXHAUST PIPE EXTENSIONS

After a class of students tested the engine in a lab, the cell temperature was significantly higher than the outside temperature that it is supposed to maintain. It was decided that this was due to the length of the exhaust pipes leading out of the cell. The exhaust pipes did not reach the ceiling of the room, therefore allowing hot exhaust air to flow throughout the cell rather than escaping directly outside. The length of the original exhaust pipes is shown in figure 4.   To remedy this, longer exhaust pipes were constructed and inserted before the final convergent nozzles as pictured in figure 5. They are slight tapered at the exit to allow for more certainty that the exhaust gases will not be able to escape into the test cell, but rather blow directly outside. The new exhaust pipes are 1.5 feet longer than the original design. This should allow the test cell to remain at the desired temperature, being that of the outside air.

C.   HEAT EXCHANGER

The heat exchanger in the original setup was a typical helicopter engine's heat exchanger that used air to cool the oil. The test cell has only stagnant air, therefore rendering the heat exchanger inadequate to keep the oil cool enough. A fan was added in an attempt to cool this stagnant air that was flowing through the engine, but was unsuccessful. It was mounted on two blocks of wood and a rod approximately under the bell mouth as shown in figure 6. The new heat exchanger is water cooled. It uses the dynamometer water tank as its source for water. There is a small pipe inside of the inlet

pipe into the tank that runs to the opposite end of the engine where it is connected to the heat exchanger. Since there is a constant mass flow through the inlet pipe of the dynamometer tank, sufficient pressure will exist to get the water flowing and keep the oil at the proper temperature. The new heat exchanger has been installed under the oil drip pan on an existing panel that was used to support the old heat exchanger's cooling fan. This facility improvement should allow for unlimited use of the engine at full speed [Ref. 4].

Figure 4.   Old Exhaust Pipe setup

Figure 5.   Exhaust pipe extensions
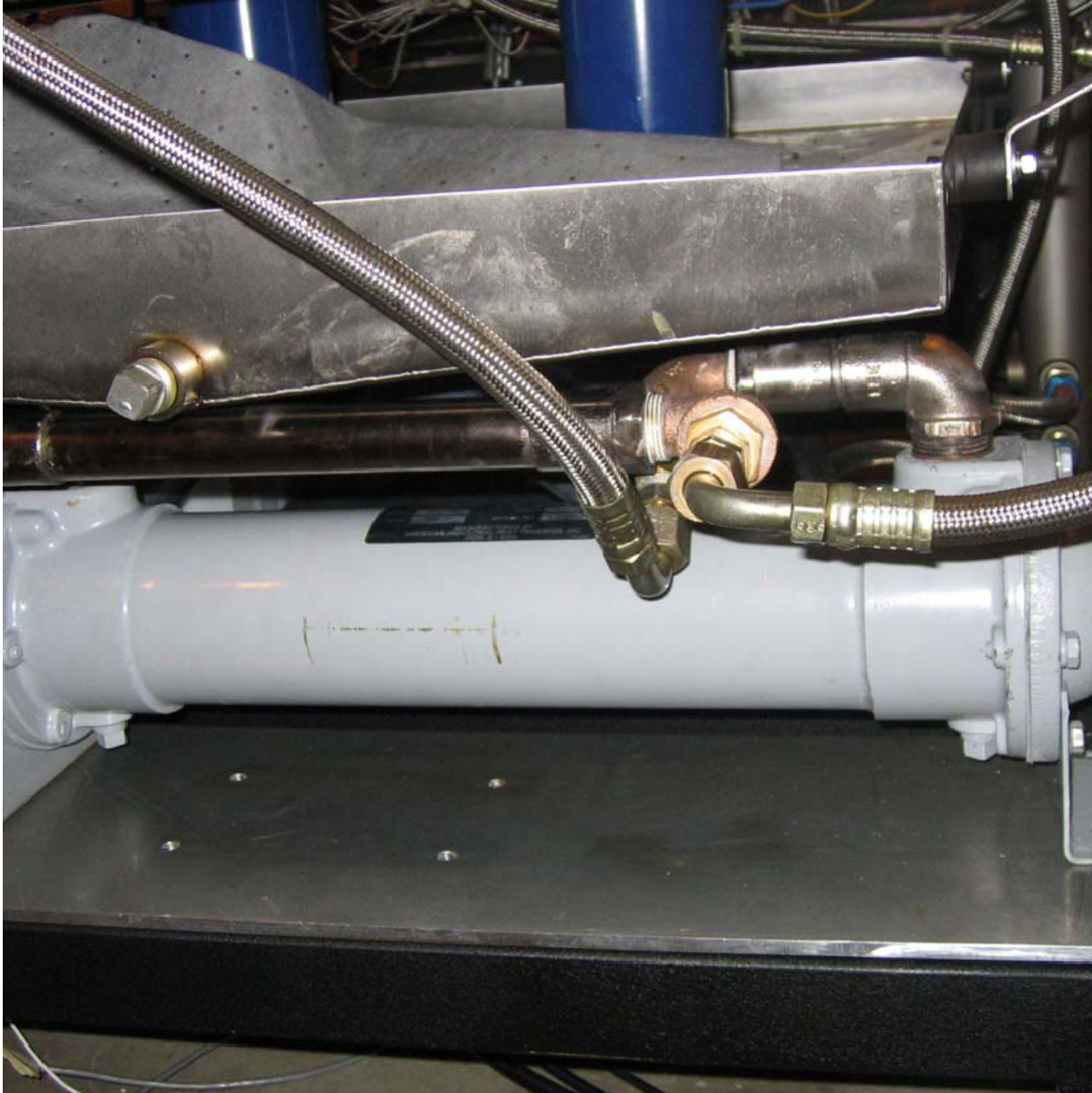
Figure 6.   New heat exchanger

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IV. IMPROVED DESIGN OF THE THERMOCOUPLE RING AT GAS GENERATOR TURBINE INLET

A. PROBLEMS WITH THE ORIGINAL RING DESIGN

Examining the gas generator turbine inlet temperatures showed that there was a lot of inconsistency in the readings; it was too great to be accounted for with the known hot and cool spots in the temperature distribution. The assembly was disconnected and taken out for observation. Each individual thermocouple was examined for both integrity and working condition. Over half of the thermocouples were found to be nonfunctioning, leading to the conclusion that a redesign of the ring was necessary.

The original ring, as shown in figure 2, placed all of the stress of the setup on the bends in the thermocouples that connected to the turbine heat shield, which is made of AMS5536 steel. The ring was essentially free in that the only things holding it in place were the 48 thermocouples that were bent to go into the turbine heat shield. As a result, several thermocouples had been overstressed at their bending point due to the differences in thermal expansion rates of the varying materials used in the structure. There were also a great deal of what appeared to be failures due to vibration [Ref. 3]. Additionally, assembly of the ring was imprecise in that the thermocouples appeared to have been put in one at a time without any guidance through the slots of the ring that would eventually hold them in their places. This must have proved to be a grueling task, as all of the thermocouples were eventually spot welded to the turbine heat shield, possibly another cause for thermocouple failure. This was something that was not accounted for in the instrumentation records.

B. NEW THERMOCOUPLE RING DESIGNS

The new design of the thermocouple ring, pictured in figures 7 and 8, was to allow for the thermocouples (Omega TJ48-CAIN-116U-6-SB-LUG) to endure less stress by not requiring them to support the ring, as well as protect them from vibrations, and make the ring itself easier to construct. The original design was kept in that it was the same size and material, as well as the use of 48 thermocouples and 2 pressure probes. A sleeve was designed so that each thermocouple would be guided into the holes of the turbine heat shield. This would avoid the thermocouples' bent sections from absorbing

all of the stress from thermal expansion differences. The guide section is made of the same material as the heat shield so that thermal expansion occurs at the same rate. The new design will be put together by guiding the thermocouples through the bent sections and putting the ends at the right radii and distance inside the heat shield space. After that is complete, the ring will be placed onto the structure and the 48 thermocouples will be put into the slots. The top section of the ring will be clamped and screwed together. Once this is complete the engine can be put back together and all of the thermocouple ends can be screwed into their respective ports on the control board for data acquisition. After a few runs of the engine, the ends of the thermocouples will be tested to ensure that they have not been damaged as severely as they had been in the previous design setup. Due to time constraints in ordering and installation of the new design, it has not yet been implemented.

With the decision not to install the new ring design, an alternate design was chosen to be utilized in its place. The alternate design was the same as the original design with the exception of the heat shield being slotted at each thermocouple location rather than a drilled hole. This allowed for the thermocouple ring to be free of the heat shield, and therefore less vulnerable to vibrations that were believed to have broken many of the original thermocouples.

The bending of the thermocouples into place is an extremely time consuming task, and very inaccurate if attempted by hand. Because there are only three different distances at which the thermocouples were to be bent, jigs were made to ease in the bending as well as to increase the uniformity of the thermocouples. Three jigs have been constructed using a scrap piece of stainless steel and a few pegs. When designing the jigs, the bending radius of the thermocouples was taken into account. The manufacturer suggests never bending a thermocouple sharper than three times its diameter. In this case 1/16" thermocouples were to have a bending radius of less than or equal to 3/16". Sixteen thermocouples were bent in each of the three jigs and were compared to a full-size design to ensure uniformity. The distances from the outer liner inner surface to the thermocouple center points are: 0.08", 0.23", and 0.40". This remained the same in both new designs. In the original design, the sixteen thermocouples that were to be 0.08" from the interior of the outer edge of the turbine heat shield had bends sharper than that

recommended by the manufacturer [Ref. 2]. This had to be done because each thermocouple was placed in individually. With the new design, a continuous bend was made for the 0.08" distance to keep within the suggestions of the manufacturer. Prior to bending the thermocouples, each was marked at the point in which it would enter the thermocouple ring. After all of the thermocouples were bent, they were lined up in their places around the bottom half of the ring. The top half was then carefully clamped on, as not to move any of the thermocouples out of place. Due to some inaccuracies in the drilling of the slots for the thermocouple ring, small pieces of shim stock were used to make the thermocouples snug inside their slots. Since the heat shield was slotted, as mentioned before, the ring slid right into the slots. This eliminated a lot of the time it originally took to insert each thermocouple into the heat shield then hand-bend it into place. Engineering drawings of both a recommended design and the alternate design that was constructed and installed are found in Appendix A.
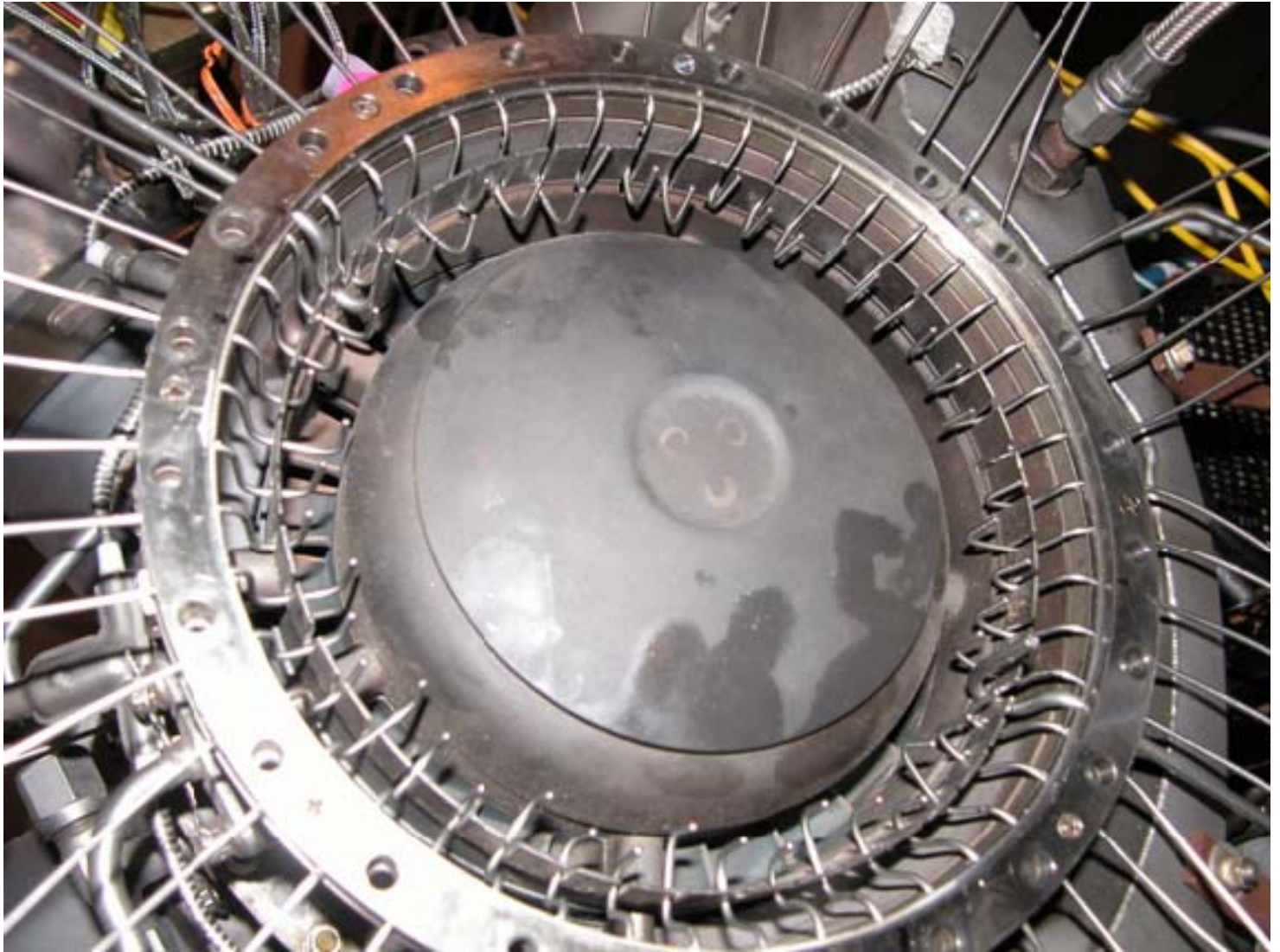
Figure 7.   Assembled thermocouple ring
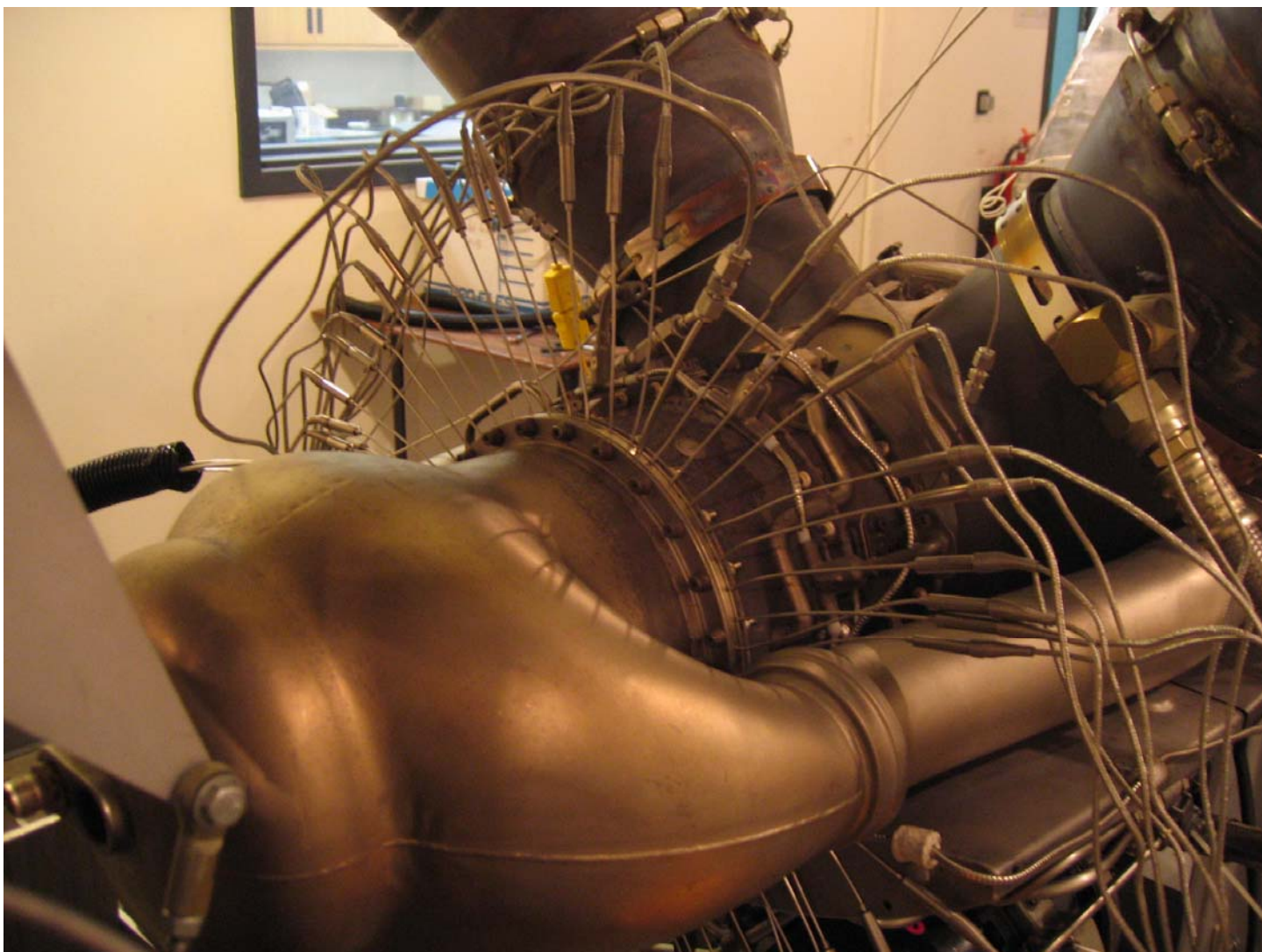
Figure 8.   Installed thermocouple ring

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V.   THE GASTURB MODEL

A.   PUTTING COMPRESSOR DATA INTO PROPER FORMAT

Compressor map data were obtained in text format [Ref. 5] and is shown in Appendix B. This was then imported into the MATLAB program so that it could be manipulated into the compressor map format that is most commonly seen and used. The program used to import the text file and make this map is included in Appendix C. After the compressor map was put into the correct format, the contour lines and efficiencies were checked over to ensure that it looked correct and is shown in figure 9.

B.   IMPORTING DATA INTO SMOOTHC

The SMOOTHC program has an option to manually input data and create a compressor map. The data provided by the manufacturer were loaded into SMOOTHC using this method. From that data a compressor map which matched the MATLAB figure was produced. This map however, was not in the correct format, which is what GASTURB requires. Using the SMOOTHC Program Manual, it was converted into .map format, and then imported into the Special Maps section of GASTURB [Ref. 6]. The step by step procedure for accomplishing this is outlined in Appendix D.

C.   USING GASTURB TO PLOT THE OPERATING POINTS

With the program GASTURB, an off-design parametric study may be performed in order to plot the engine specific data onto the manufacturer's data which comprises the compressor map. The model should be run under the Turboshaft/Turboprop option with generic fuel. First, a single cycle calculation must be performed under the Design option in the main GASTURB menu. Once this is accomplished, the Special Maps option may be chosen and a parametric study with various gas generator spool speeds can be performed, one at a time. When the manufacturer's map is opened in GASTURB the mass flow units must be chosen for scaling purposes. Limiters must be set in order to hold the gas generator speed constant. The output for the parametric study will be plotted on the special compressor map from SMOOTHC [Ref. 7]. The operating point results from the GASTURB model are presented in figure 10. Table 1 compares the results of lab data, the generic compressor map, and the model compressor map. By using the

model compressor map, the results in GASTURB for power remained approximately equal, while the results for the fuel consumption were closer to design values. For 100% design speed, the power predictions were the same for both the generic and model maps. For 90% and 80% design speeds, the power prediction was about 2% and 12% different, respectively. The power predictions for both the generic map and the model map were higher than measured in the lab for the 100% and 90% speeds, possibly because of inaccuracies in instrument measurement in the engine facility. The values measured for fuel consumption improved for all three speeds with the model map. With decreasing speed, the fuel consumption prediction of the model increasingly improved over the prediction of the generic values. At 100% design speed, the results of both generic and model predictions were about equal. At 90% design speed the model prediction was approximately 2% better than the generic prediction, and at 80% design speed the model prediction was about 8% improved.
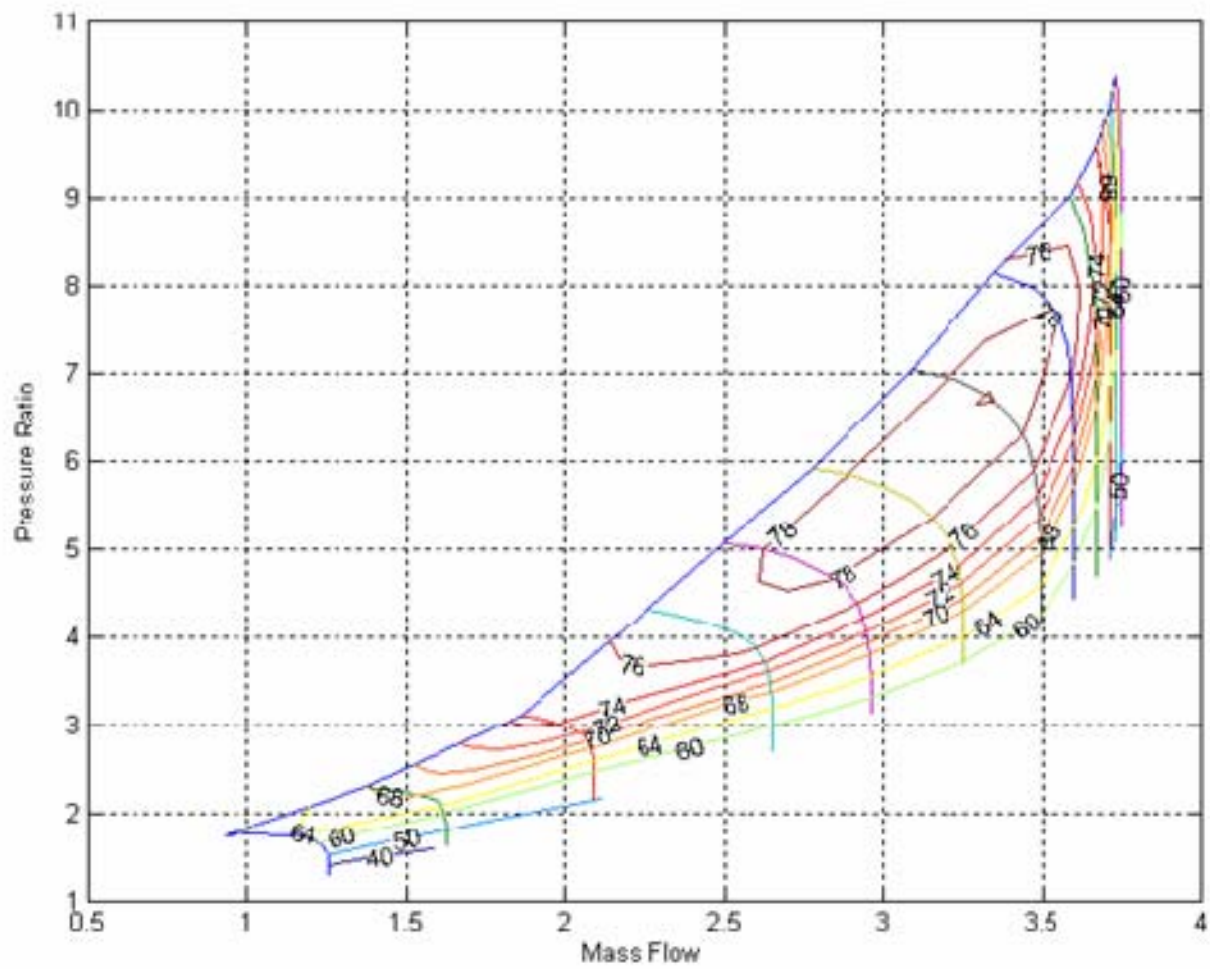
Figure 9.   Matlab figure for compressor map data (mass flow in lb/s)
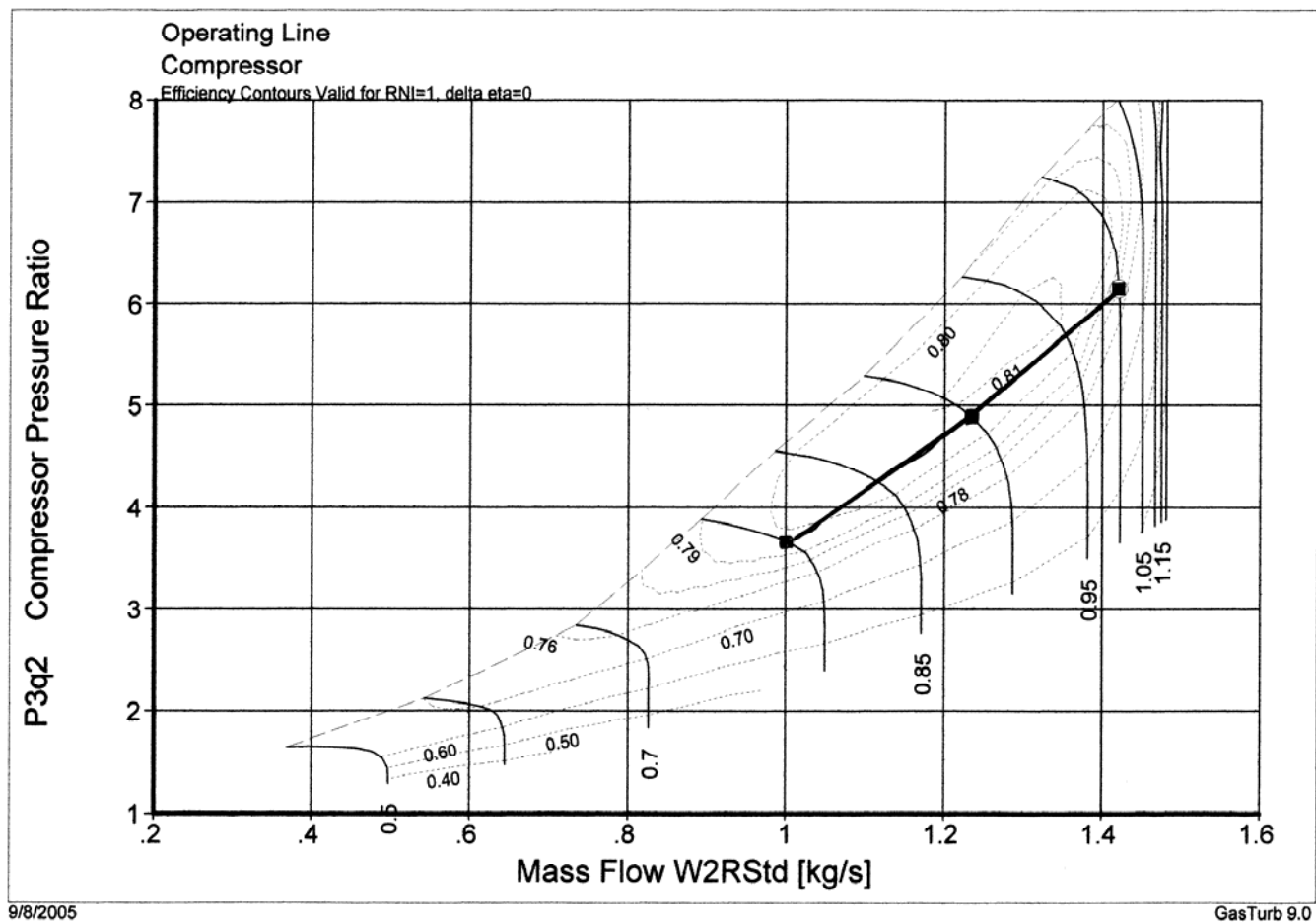
Figure 10.   Operating line on the engine specific compressor map created in GASTURB with points at 100%, 90%, and 80% speeds.

Power Comparison

N1 (RPM)	kw (lab)	kW (generic)	kW (model)
35000	174.57	220.7	220.7
31500	110.44	117.5	120
28000	56.3	44.7	49.4

Specific Fuel Consumption Comparison (SFC) in kg/(kW*h)

N1 (RPM)	SFC (lab)	SFC (generic)	SFC (model)
35000	0.4228	0.43359	0.43359
31500	0.4732	0.54326	0.52383
28000	0.6703	0.94806	0.86071

Table 1.   Results for both the generic and model compressor maps

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VI.   CONCLUSIONS AND RECOMMENDATIONS

The improvements on the T63-A-700 gas turbine engine, the facility, and the engine specific compressor map are complete. The heat exchanger has been installed, but not yet validated due to engine having not yet been run at full speed for any length of time. Exhaust stack extensions are in place, but again have not been verified to work because of the condition of the engine. The improved thermocouple ring design is installed. Data has not yet been collected to validate the improved design. The GASTURB model was created from previous data taken in a class laboratory. With the operating line model, the results when running off-design calculations have been improved. To further improve the results of this model, a turbine map model should be created and used in conjunction with the new compressor map model.

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APPENDIX A. THERMOCOUPLE RING DRAWINGS

A. RECOMMENDED DESIGN (NOT USED DUE TO TIME CONSTRAINTS)

## B.	DESIGN DRAWING (INSTALLED IN ENGINE)

Notes:

1. Material: 347 Stainless Steel

2. Fifty (50) probe slots to be done. The two slots labled as probe slots, are located 11.25° counter-clockwise, and clockwise relative to the Angular Reference Axis. The other 48 slots are spaced 7.5° apart with the exception of A', B', C', and D' which are located with respect to the Angular Reference Axis as shown.

3. All diameters are to be concentric within 0.005 in T.I.R.

4. Finish 32 ∇.

APPENDIX B. COMPRESSOR MAP DATA FROM MANUFACTURER

Note: SPD= speed (100%=51,120 rpm), FLOW= mass flow, RC= compressor pressure ratio, EFF= compressor adiabatic efficiency, DTOT= unknown, WBL= bleed mass flow, HP= power required

(% design speed)						
SPD	FLOW	RC	EFF	DTOT	WBL	HP
50	1.2579	1.2816	0.2919	0.2513	0	55.7108
50	1.2579	1.4002	0.4013	0.2514	0	55.733
50	1.2558	1.5164	0.4986	0.2531	0	56.0173
50	1.2398	1.614	0.577	0.2538	0	55.457
50	1.2077	1.6861	0.6236	0.2579	0	54.8963
50	1.1574	1.725	0.6398	0.2632	0	53.6937
50	1.0956	1.7363	0.6336	0.2692	0	51.9898
50	1.0398	1.746	0.6209	0.2777	0	50.9055
50	0.985	1.7468	0.6012	0.287	0	49.842
50	0.93	1.737	0.5793	0.2946	0	48.3098
SPD	FLOW	RC	EFF	DTOT	WBL	HP
60	1.6329	1.635	0.4167	0.3611	0	104.0667
60	1.6329	1.7546	0.4811	0.3614	0	104.1536
60	1.6305	1.8715	0.5412	0.3615	0	104.0295
60	1.6227	1.9814	0.594	0.3624	0	103.7821
60	1.6121	2.0866	0.6417	0.3636	0	103.4474
60	1.5836	2.1657	0.6723	0.3666	0	102.4612
60	1.5317	2.2069	0.683	0.3707	0	100.2167
60	1.4778	2.2375	0.6855	0.3765	0	98.2108
60	1.4245	2.2611	0.6838	0.3829	0	96.2854
60	1.3736	2.281	0.6796	0.3899	0	94.5528
SPD	FLOW	RC	EFF	DTOT	WBL	HP
70	2.0918	2.1361	0.4987	0.4836	0	178.8461
70	2.0918	2.2863	0.5494	0.4831	0	178.6598
70	2.0918	2.4365	0.5962	0.484	0	178.9839
70	2.0922	2.5872	0.6416	0.4844	0	179.1785
70	2.088	2.7319	0.6799	0.4872	0	179.8605
70	2.0687	2.8552	0.71	0.4902	0	179.3039
70	2.026	2.9417	0.7282	0.4937	0	176.8661
70	1.9804	3.0177	0.741	0.4985	0	174.5799
70	1.9224	3.0674	0.7455	0.504	0	171.3532
70	1.8599	3.1012	0.7453	0.5099	0	167.7386

SPD	FLOW	RC	EFF	DTOT	WBL	HP
80	2.6573	2.6956	0.5351	0.6083	0	286.3948
80	2.6573	2.9576	0.5938	0.6078	0	286.1567
80	2.6572	3.2195	0.6487	0.6076	0	286.0507
80	2.6522	3.475	0.6987	0.6079	0	285.6551
80	2.6347	3.7118	0.7402	0.6102	0	284.8558
80	2.5953	3.9122	0.7662	0.6179	0	284.1774
80	2.5241	4.0538	0.774	0.6308	0	282.2196
80	2.4389	4.1575	0.774	0.6445	0	278.6893
80	2.3494	4.2366	0.7705	0.6577	0	274.0305
80	2.26	4.2982	0.766	0.6695	0	268.3934
SPD	FLOW	RC	EFF	DTOT	WBL	HP
85	2.9648	3.1292	0.5666	0.6749	0	354.9663
85	2.9648	3.4488	0.6235	0.6754	0	355.2382
85	2.9635	3.7667	0.6762	0.676	0	355.402
85	2.9516	4.0697	0.723	0.677	0	354.5054
85	2.9244	4.3475	0.7572	0.6836	0	354.7091
85	2.8781	4.5889	0.778	0.6953	0	355.1512
85	2.7984	4.7634	0.7832	0.7114	0	353.427
85	2.7073	4.9002	0.7833	0.7271	0	349.5803
85	2.6072	5.0001	0.7792	0.7422	0	343.7552
85	2.4982	5.0603	0.7714	0.7565	0	335.8299
SPD	FLOW	RC	EFF	DTOT	WBL	HP
90	3.2587	3.694	0.5982	0.7496	0	433.9925
90	3.2587	4.0527	0.6494	0.7499	0	434.1748
90	3.2566	4.4085	0.6973	0.7499	0	433.9008
90	3.243	4.7471	0.7377	0.7526	0	433.6692
90	3.2126	5.0562	0.7641	0.7631	0	435.6944
90	3.1637	5.3274	0.7794	0.7782	0	437.6944
90	3.0896	5.5428	0.7853	0.7952	0	436.9416
90	2.9995	5.7113	0.785	0.8128	0	433.7557
90	2.8966	5.8342	0.7804	0.83	0	427.9036
SPD	FLOW	RC	EFF	DTOT	WBL	HP
95	3.4986	4.1388	0.5879	0.8417	0	524.2885
95	3.4986	4.5612	0.6381	0.841	0	523.8065
95	3.4973	4.9817	0.684	0.8413	0	523.8082
95	3.4915	5.3949	0.7246	0.8437	0	524.4598
95	3.4792	5.7959	0.7542	0.8542	0	529.2426
95	3.4542	6.1713	0.7765	0.8674	0	533.7198
95	3.4052	6.4949	0.7865	0.8869	0	538.2191
95	3.3291	6.7516	0.7872	0.9094	0	539.8251
95	3.2266	6.9333	0.7821	0.9314	0	536.1426
95	3.0939	7.0216	0.7663	0.9581	0	529.1696

SPD	FLOW	RC	EFF	DTOT	WBL	HP
100	3.6022	4.434	0.5607	0.9331	0	599.7024
100	3.6022	4.9139	0.6092	0.9326	0	599.341
100	3.6022	5.3939	0.654	0.9327	0	599.4066
100	3.6022	5.8738	0.6949	0.9343	0	600.4579
100	3.6015	6.3525	0.7275	0.943	0	606.0587
100	3.5985	6.8267	0.7542	0.9553	0	613.6342
100	3.5866	7.282	0.7738	0.9716	0	622.2875
100	3.5507	7.6822	0.7807	0.9966	0	632.2998
100	3.4725	7.9756	0.777	1.0249	0	636.384
100	3.3485	8.137	0.7623	1.0572	0	633.5181
SPD	FLOW	RC	EFF	DTOT	WBL	HP
105	3.6732	4.685	0.5324	1.0253	0	673.468
105	3.6732	5.1893	0.5762	1.0259	0	673.8387
105	3.6732	5.6936	0.6179	1.0251	0	673.2861
105	3.6732	6.1979	0.6552	1.0271	0	674.6472
105	3.6732	6.7022	0.6864	1.0346	0	679.7023
105	3.6732	7.2065	0.7119	1.0469	0	687.9978
105	3.6708	7.7058	0.7324	1.0626	0	698.1384
105	3.6579	8.1809	0.748	1.0804	0	707.6632
105	3.6333	8.6247	0.7528	1.1087	0	721.8776
105	3.592	9.0198	0.7479	1.146	0	738.4125
SPD	FLOW	RC	EFF	DTOT	WBL	HP
110	3.7138	4.8925	0.5021	1.1223	0	747.1707
110	3.7138	5.4241	0.543	1.1228	0	747.5199
110	3.7138	5.9557	0.5812	1.1229	0	747.6028
110	3.7138	6.4874	0.6164	1.1241	0	748.4247
110	3.7138	7.019	0.6453	1.1324	0	754.117
110	3.7138	7.5506	0.6684	1.1466	0	763.8632
110	3.7138	8.0822	0.6877	1.1636	0	775.5425
110	3.7133	8.6127	0.705	1.1806	0	787.128
110	3.6999	9.1112	0.7167	1.2015	0	798.627
110	3.6732	9.5713	0.72	1.231	0	812.9879
SPD	FLOW	RC	EFF	DTOT	WBL	HP
115	3.7341	5.0711	0.4737	1.2199	0	818.7921
115	3.7341	5.6274	0.5123	1.2196	0	818.5422
115	3.7341	6.1838	0.5479	1.22	0	818.8336
115	3.7341	6.7401	0.5799	1.2232	0	821.0536
115	3.7341	7.2964	0.6064	1.233	0	827.8564
115	3.7341	7.8528	0.6259	1.2522	0	841.1927
115	3.7341	8.4091	0.641	1.276	0	857.7512
115	3.7334	8.9637	0.655	1.2981	0	872.9868
115	3.7254	9.4996	0.6669	1.3198	0	886.2195
115	3.7138	10.0233	0.6702	1.3545	0	907.585

AT SURGE:

NC	WA	RC	RC/WA
50	0.93	1.737	1.8677
60	1.3736	2.281	1.6606
70	1.8599	3.1012	1.6674
80	2.26	4.2982	1.9019
85	2.4982	5.0603	2.0256
90	2.78	5.9053	2.1242
95	3.0939	7.0216	2.2695
100	3.3485	8.137	2.43
105	3.592	9.0198	2.5111
110	3.6732	9.5713	2.6057
115	3.7138	10.0233	2.6989

APPENDIX C. MATLAB PROGRAM TO PLOT COMPRESSOR MAP

```
clear all

% Raw data is loaded
Raw_data   = load('compressor map data raw.txt');
% Surge data is loaded
Surge_data = load('compressor map data surge.txt');

% Data is named
Speed_lines    = Raw_data(:,1); % first column are the speed lines
Mass_flow      = Raw_data(:,2); % second column is mass flow
Pressure_ratio = Raw_data(:,3); % third column is pressure ratio
Efficiency     = Raw_data(:,4); % efficiency of compressor
Surge_Mass_flow= Surge_data(:,2); % surge mass flow rate
Surge_Press_ratio= Surge_data(:,3) % surge pressure ratio

% Data is reshaped to be one column per speed line
Speed_lines    = reshape(Speed_lines,10,12);
Mass_flow      = reshape(Mass_flow,10,12);   % may need to change the number
of column and rows depending on the number of speed lines
Pressure_ratio = reshape(Pressure_ratio,10,12);
Efficiency     = reshape(Efficiency,10,12);

figure(1); close; figure(1);
plot(Mass_flow,Pressure_ratio)
hold on
plot(Surge_Mass_flow,Surge_Press_ratio)

figure(2); close; figure(2);
[c,h] = contour(Mass_flow,Pressure_ratio,100*Efficiency,[40 50 60 64 68 70 72
74 76 78 78.7]);
clabel(c,h)

figure(3); close; figure(3);
plot(Mass_flow,Pressure_ratio)
hold on
plot(Surge_Mass_flow,Surge_Press_ratio)
[c,h] = contour(Mass_flow,Pressure_ratio,100*Efficiency,[40 50 60 64 68 70 72
74 76 78 78.7]);
clabel(c,h)
grid on
xlabel('Mass Flow')
ylabel('Pressure Ratio')
```

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APPENDIX D.   PROCEDURE FOR SMOOTHC DATA INPUT AND EXPORTATION INTO GASTURB

1. **Manual Input:**

    a. Select menu option **File**

    b. Select **New**

    c. Select **Measured Data**

    d. Enter a map title and indicate which sort of data you have (Map type: Compressor, Efficiency: isentropic, The data are: non-revitalized)

    e. Type the measured values in the corresponding column and mark the surge point by clicking in the second column under **Surge.**

    f. Repeat step e. for all speed lines. A minimum of three are required to plot the data.

    g. Graphically check the data by clicking on the **Plot Data** button on the right side of the window.

    h. Save file as **.MEA** (measured data) and as **.SMO** (smooth data).

2. **Smoothing and defining Beta lines:**

    a. Select menu option **File**

    b. Select **Read**

    c. Select **Measured and Smooth Data**

    d. A prompt will appear that all data will be erased. Select **Yes** to continue.

    e. Select **Define beta line grid** from the picture toolbar.

    f. Close the beta line picture once it is defined.

3. Exporting into GasTurb:

    a. From the picture toolbar select **Output tables**. This looks like a sheet of paper with a red arrow pointing towards the right.

    a. From the toolbar in the **Output Performance** screen select **Scale.**

    b. Choose **Manually Scale** and enter whatever scaling values you wish.

    b. Select **File**

    c. Select **Save as GasTurb Map**

    d. Name your compressor map to be accessed in GasTurb under **Special Maps** when doing an off-design calculation.

For further instruction reference the SmoothC8 manual included with the program.

APPENDIX E. OUTPUT DATA IN GASTURB USING COMPRESSOR MAP MODEL

A. OUTPUT FOR 100% DESIGN SPEED

```
Station    W          T
 amb                288.1
  2        1.406    288.1
  3        1.392    516.0
 31        1.314    516.0
  4        1.341   1242.0
 41        1.341   1242.0
 43        1.341   1040.8
 44        1.411   1016.8
 45        1.411   1016.8
 49        1.411    879.4
  5        1.425    875.2
  6        1.425    875.2
  8        1.425    875.2
P2/P1 = 0.9900
Efficiencies:    isentr
 Compressor      0.7800
 Burner          0.9900
 HP Turbine      0.8400
 LP Turbine      0.8700
 HP Spool mech   0.9980
 PT Spool mech   0.9780

  Fuel            FHV
Generic          42.796
```

B. OUTPUT FOR 90% DESIGN SPEED

```
Station     W          T
  amb                288.1
   2       1.226     288.1
   3       1.214     472.7
  31       1.146     472.7
   4       1.164    1038.5
  41       1.164    1038.5
  43       1.164     868.7
  44       1.225     850.0
  45       1.225     850.0
  49       1.225     760.8
   5       1.237     757.4
   6       1.237     757.4
   8       1.237     757.4
P2/P1 = 0.9900
Efficiencies:      isentr
 Compressor        0.8063
 Burner            0.9848
 HP Turbine        0.8383
 LP Turbine        0.8866
 HP Spool mech     0.9980
 PT Spool mech     0.9780

  Fuel              FHV
Generic            42.796
```

C.   OUTPUT FOR 80% DESIGN SPEED

Station	W	T
amb		288.1
2	0.993	288.1
3	0.983	433.9
31	0.928	433.9
4		
41	0.940	913.6
43	0.940	776.0
44	0.989	759.6
45	0.989	759.6
49	0.989	713.5
5	0.999	710.38
6	0.999	710.38
8	0.999	710.38

P2/P1 = 0.9900

Efficiencies:	isentr
Compressor	0.7965
Burner	0.9769
HP Turbine	0.8267
LP Turbine	0.7754
HP Spool mech	0.9980
PT Spool mech	0.9780

Fuel	FHV
Generic	42.796

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APPENDIX F. STANDARD OPERATING PROCEDURES FOR ALIGNMENT AND OPERATION OF THE GAS TURBINE AND DYNAMOMETER TEST SYSTEM

Note: Changes from Standard Operating Procedures [Ref. 2] are:

OIL SYSTEM VERIFICATION: No longer turn on the lubrication oil cooling fan (no longer part of facility)

MASTER LIGHTOFF PROCEDURE (MLOP)

<u>SYSTEM VERIFICATION ALIGNMENT PROCEDURES AND OPERATING PROCEDURES</u>

PROCEDURE

<u>PLACING THE GAS TURBINE TEST CELL INTO OPERATION</u>

1.   Conduct visual inspection of gas turbine test cell and verify the following:

 a. Ensure all drip pans, piping trenches, and the deck are free of oil, fuel, or any flammable liquids.

 b. Ensure all flammable liquids are stored properly in the flammable liquids locker.

 c. Ensure all small parts, equipment, tools, or objects, which may become airborne debris, are properly stored.

 d. Verify that the gas turbine cell and work area fire extinguishers are fully charged.

 e. Inspect all piping runs and accessories for loose connections, damage, or leaks.

 f. Ensure all valve handwheels are installed and valve labels are in place.

 g. Inspect the air intake louvers for blockage.

 h. Check the engine battery voltage. Place the batteries on charge if voltage is below 22 VOLTS.

 i. Check fuel level in fuel oil storage tank. Ensure enough fuel is present to support gas turbine operations.

j. Verify that the water storage tank is full.

2.   If the gas turbine test cell and the diesel test cell have been idle for more than 30 days, the water system and fuel system must be recirculated prior to placing the systems into operation. Proceed to the fuel oil service recirculation procedure (FOSRP) and the cooling water system recirculation procedure (CWSRP).

3.   If the ambient air temperature is less than 50°F, the fuel system must be recirculated in order to ensure no paraffin separation is present. Proceed to the fuel oil service recirculation procedure (FOSRP).

4.   Ensure the cooling water system filter is clean and free of excessive particulate.

WATER SYSTEM ALIGNMENT

1.   Ensure the following valves are in the fully open position:

a. Water storage tank suction valve	CW-1
b. Water supply pump suction valve	CW-2GT
c. Water supply pump discharge valve	CW-4GT
d. Dynamometer sump tank supply valve	CW-6GT
e. Return pump discharge valve	CW-9GT
f. Heat exchanger inlet valve	CW-10
g. Heat exchanger discharge valve	CW-12

2.   Ensure the following valves are in the full closed position:

a. Diesel supply pump suction valve	CW-2D
b. Gas turbine to diesel cross connect valve	CW-5
c. Dynamometer bypass valve	CW-7GT
d. Diesel return pump discharge valve	CW-9D
e. Heat exchanger bypass valve	CW-11
f. Dynamometer boost valve	CW-12GT

3.   Place the local heat exchanger breaker [ ] in the AUTO position.

4.   Place the local cooling water supply pump breaker [ ] in the AUTO position.

5.   Place the local cooling water return pump breaker [ ] in the AUTO position.

FUEL OIL SYSTEM ALIGNMENT

1.   Ensure the following valves are in the fully open position:

          a. Fuel oil supply pump suction valve   FOS-2GT

          b. Fuel oil supply pump discharge valve   FOS-5GT

          c. Fuel oil supply cell isolation valve   FOS-6GT

          d. Fuel oil return valve   FOS-12GT

2.   Place the local fuel supply pump breaker [ ] in the AUTO position.

3.   Ensure the following valves are in the fully closed position:

          a. Diesel fuel oil supply pump suction valve   FOS-2D

          b. Fuel oil supply cross-connect valve   FOS-3

          c. Fuel oil recirculation valve   FOS-9GT

          d. Diesel fuel oil return valve   FOS-10D

4.   Ensure the dynamometer to engine fuel quick disconnect is properly connected.

AIR SYSTEM ALIGNMENT

1.   Place the remote LOUVER switch to the OPEN position.

2.   Ensure air flow turbine meters are connected to the dynamometer instrumentation rack.

3.   Remove exhaust covers from gas turbine exhaust stacks.

OIL SYSTEM VERIFICATION

    WARNING: *Synthetic lube oil mil-l-23699 can cause dermatitis or paralysis. If lube oil contacts skin, immediately flush with water. If clothing becomes saturated remove promptly.*

1.   Verify the lubrication oil level in the oil storage tank is above the fill mark (6 gallon level).

2.   Ensure the oil pressure sensing line is connected to the dynamometer instrumentation rack connection.

3.   Ensure the oil supply and discharge lines are properly connected to the accessories gearbox.

4.   Ensure the shaft is free to turn by rotating manually.

ENGINE CHECKS AND ADJUSTMENTS

1.   Check gas generator (N1) fuel control lever travel from the control console throttle knob. Ensure full travel from 0 - 90° settings. For full travel lever must contact lever stop. Also ensure that the 0° position actuates the spring fuel cut-off on the governor actuator.

2.   Verify the power turbine governor (N2) is lockwired in the MAX position.

3.   Ensure all protective covers and plugs are removed from all vents and drains.

4.   Ensure the battery charger is disconnected from the storage batteries.

5.   Ensure the voltage regulator circuit breaker switch is in the ON position.

6.   Obtain the latest barometric reading.

7.   Verify the DYNO PRIME switch and FUEL PUMP switch located on the control console are in the OFF position.

8.   Place the LOAD CONTROL switch to the servo position.

9.   Ensure the LOAD CONTROL knob is set to 600.

       CAUTION: *The LOAD CONTROL knob reads one order of magnitude less than ordered speed. Increasing LOAD CONTROL dial indicator above 630 may results in a power turbine overspeed and engine failure.*

10.   Verify the LOAD CONTROLLING RPM switch is in the LOAD CONTROLLING RPM position. This switch is located inside the control console.

11.   Place the THROTTLE CONTROL switch in the MANUAL position.

12.   Ensure the THROTTLE CONTROL knob is in the fully closed position.

13.   Press the POWER ON push-button to energize the dyno control console.

14.   Set the shaft OVERSPEED at 6,300 RPM.

15.   Set the TORQUE/POWER display knob to the LOW scale.

16.   Set the SPEED display knob to the LOW speed scale.

17.   Adjust the UPPER TEST SPEED knob to 6,250 RPM.

18.   Either set the fuel specific gravity knob to the proper setting or input the fuel specific gravity into the SF-901 computer monitoring system in accordance with factory technical manuals.

19.   Set the FUEL mode knob to the A configuration.

20.   Set the AIR-FUEL meter knob in the AIR/2 configuration.

21.   Set the FLOWMETER knob to the 9" position.

22.   Set the DISPLAY knob to the TORQUE position.

23.   Set the control console switch to the TENTHS scale.

24.   Adjust the TORQUE ADJUST knob to zero.

25.   Set the DISPLAY knob to the EXHAUST position.

26.   Set the water vapor pressure knob to the correct setting.

27.   Turn the shutter motor switch [ ] to the OPEN position. Ensure that the intake shutters move to the open position.

28.   Ensure both test cell entrance doors are closed and latched.

ENGINE STARTING PROCEDURE

1.   Depress the remote COOLING WATER SUPPLY PUMP start push-button [ ]; verify the MOTOR RUN light illuminates.

2.   Depress the remote COOLING WATER RETURN PUMP start push-button [ ]; verify the MOTOR RUN light illuminates.

3.   Adjust CW-9GT to ensure CW return pump does not become air bound.

4.   Depress the remote FUEL OIL PUMP start push-button [ ]; verify the MOTOR RUN light illuminates.

5.   Depress the remote HEAT EXCHANGER start push-button [ ]; verify the MOTOR RUN light illuminates.

6.   Turn the DYNO PRIME switch to the ON position.

         WARNING: *The DYNO PRIME switch must be on for at least 10 seconds prior to engaging starter to ensure the dynamometer has sufficient priming water.*

7.   Turn the FUEL PUMP switch to the ON position.

8.   Verify   both   engine   test   cell   doors   are   closed   completely.

9.   Depress and hold the STARTER push-button.

10.   Verify positive lubrication oil pressure on lube oil pressure gage.

11.   Monitor all consol warning lights.

12.   Advance the gas generator throttle lever (N1) to the 30° (idle position – 6.4V) after N1 speed passes 8,000 RPM (16%).

13.   Verify an increase in power turbine speed (N2) by the time N1 speed reaches 20,000 RPM (40%).

14.   Monitor turbine outlet temperature. Ensure that TOT does not exceed 1,380 °F for more than ten seconds or 1,700 °F for more than one second.

15.   Ensure gas generator speed reaches a steady state idle speed of approximately 31,000 RPM +/- 1,000 RPM (60%).

16.   Release the STARTER push-button when N1 is at 31,000 RPM +/- 1,000 RPM.

17.   Adjust the servo control LOAD CONTROL knob and manual THROTTLE CONTROL knob as required for engine testing.

WARNING: *Abort start by returning the gas generator THROTTLE CONTROL knob to the 0° position and secure the dynamometer fuel pump if any of the following abnormal conditions occur during system start up:*

1.   Time from STARTER push-button depressed to idle speed exceeds one minute.

2.   No engine oil pressure is indicated on the control console.

3.   Engine oil pressure does not start to increase before N1 speed reaches 10,000 RPM (20%).

4.   No indication of power turbine speed N2 before gas generator speed N1 reaches 20,000 RPM (40%).

5.   Turbine outlet temperature exceeds 1,380 °F for more than 10 seconds or 1,700 °F for more than one second.

6.   A WATER SUPPLY warning light illuminates which indicates a supply water pressure of less than 15 PSIG is available to the power absorber.

7.   A DYNO PRIME warning light illuminates indicating the power absorber must be reprimed.

8.   A FUEL PRESSURE warning light illuminates indicating less than 4 PSIG fuel pressure.

9.   The OIL PRESSURE warning light illuminates after N1 speed reaches 10,000 RPM (20%).

10.   An unusual sound of vibration occurs.

11.   A fuel or lubrication oil leak is observed.

FUEL OIL SYSTEM RECIRCULATION PROCEDURE (FOSRP)

PROCEDURE

SYSTEM ALIGNMENT FOR RECIRCULATION

1.   Conduct visual inspection of gas turbine test cell and verify the following:

       a. Ensure all drip pans, piping trenches, and decks are free of oil, fuel, or any flammable liquids.

       b. Ensure all flammable liquids are stored properly in the flammable liquids locker.

       c. Verify that the gas turbine test cell and work area fire extinguishers are fully charged.

       d. Inspect all piping runs and accessories for loose connections, damage or leaks.

       e. Ensure all valve handwheels are installed and valve labels are in place.

       f. Check fuel level in fuel oil storage tank. Ensure enough fuel is present to support gas turbine operations.

       g. Ensure the intake shutters are closed.

       h. Ensure that the battery charger is disconnected.

2.   Ensure the following valves are in the fully open position:

a. Fuel oil supply pump suction valve	FOS-2GT
b. Fuel oil supply pump discharge valve	FOS-5GT
c. Fuel oil supply isolation valve	FOS-6GT
d. Fuel oil recirculation valve	FOS-9GT
e. Fuel oil return valve	FOS-12GT

3.   Ensure the fuel oil service flow regulator is adjusted between 6-10 PSIG.

4.   Ensure the following valves are in the fully closed position:

        a. Diesel fuel oil supply pump suction valve   FOS-2D

        b. Fuel oil supply cross-connect valve   FOS-3

        c. Diesel fuel oil return valve   FOS-10D

5.   Place the local fuel oil supply pump breaker [ ] in the AUTO position.

6.   Turn the remote fuel oil pump breaker [ ] to the ON position.

7.   Monitor system for possible leaks.

     NOTE: The system will recirculate and filter at a rate of 60 gallons per hour. The total storage tank capacity is 500 gallons.

COOLING WATER SYSTEM RECIRCULATION PROCECURE (CWSRP)

PROCEDURE

SYSTEM ALIGNMENT FOR RECIRCULATION

1. Conduct visual inspection of gas turbine test cell and verify the following:

    a. Inspect all piping runs and accessories for loose connections, damage, or leaks.

    b. Ensure all valve hand wheels are installed and valve labels are in place.

    c. Verify that the water storage tank is full.

    d. Ensure the cooling water system filter is clean and free of excessive particulate.

2. Ensure the following valves are in the fully open position:

    a. Water storage tank suction valve   CW-1

    b. Water supply pump suction valve   CW-2GT

    c. Water supply pump discharge valve   CW-4GT

    d. Dynamometer bypass valve   CW-7GT

    e. Heat exchanger bypass valve   CW-11

    f. Dynamometer boost valve   CW-12GT

3. Ensure the following valves are in the fully closed position:

    a. Diesel supply pump suction valve   CW-2D

    b. Gas turbine to diesel cross connect valve   CW-5

    c. Dynamometer sump tank supply valve   CW-6GT

    d. Diesel return pump discharge valve   CW-9D

    e. Return pump discharge valve   CW-9GT

    f. Heat exchanger inlet valve   CW-10

    g. Heat exchanger discharge valve   CW-12

4.   Place the local cooling water supply pump breaker [ ] in the AUTO position.

5.   Monitor system and check for leaks.

NOTE: The water will recirculate at 50 gallons per minute. A full tank will recirculate once every 20 minutes. It is recommended that the system be placed into recirculation mode for a minimum of 40 minutes if the system has been idle more than 30 days.

MASTER NORMAL SHUTDOWN PROCEDURE (MNSP)

PROCEDURE

NORMAL ENGINE AND DYNAMOMETER SHUTDOWN PROCEDURES

1.   Return the gas generator control lever (N1) to the IDLE position 30,000-32,000 RPM (60%).

2.   Adjust the manual LOAD CONTROL knob to read 8 volts on the TEMPERATURE VOLT meter scale.

3.   Allow the engine to run at idle for two minutes to facilitate a sufficient engine cool down.

4.   Return the gas generator throttle control to the 0° (cut-off) position.

5.   Turn the dynamometer FUEL PUMP OFF and monitor for decrease in N1 speed and turbine outlet temperature (TOT).

   NOTE: If N1 speed fails to decrease, secure remote fuel oil pump breaker [ ] and monitor N1 speed.

   If TOT temperature does NOT decrease and N1 speed does not decrease, a post shutdown fire exists. Depress STARTER push-button and motor engine for two minutes.

6.   Turn the remote fuel oil supply pump breaker [ ] to the OFF position.

7.   Turn the remote cooling water supply pump breaker [ ] to the OFF position.

8.   Turn the remote cooling water return pump breaker [ ] to the OFF position.

9.   Turn the remote heat exchanger breaker [ ] to the OFF position.

10.   Return all local power panel breakers to the OFF position.

11.   Depress the POWER ON push-button to de-energize the dynamometer control console.

12. Close the following valves:

      a. Fuel oil supply suction valve   FOS-2GT

      b. Fuel oil supply pump discharge valve   FOS-5GT

      c. Fuel oil return valve   FOS-12GT
      d. Water storage tank suction valve   CW-1

      e. Water supply pump suction valve   CW-2GT

      f. Return pump discharge valve   CW-9GT

13. Ensure all protective covers and plugs are repositioned on all vents and drains.

14. Turn the remote shutter motor breaker [ ] to the CLOSE position. Ensure that the intake shutters move to the closed position.

15. Turn off the installed cell cooling fans from the wall mounted thermostat when the cell is sufficiently ventilated.

EMERGENCY SHUTDOWN PROCEDURE (ESP)

IMMEDIATE AND CONTROLLING ACTIONS FOR EMERGENCY SHUTDOWN OF THE GAS TURBINE TEST CELL

NOTE: Emergency shutdown of the T63-A-700 gas turbine engine and dynamometer is directed for any one or combinations of the following casualties:

a. A WATER SUPPLY warning light illuminates which indicates a supply water pressure of less than 15 PSIG is available to the power absorber.

b. A DYNO PRIME warning light illuminates indicating that the power absorber has lost prime.

c. A FUEL PRESSURE warning light illuminates indicating that there is less than 4 PSIG fuel pressure.

d. A fuel oil leak occurs.

e. A WATER TEMP. warning light illuminates indicating a power absorber cooling water discharge temperature of over 210 °F. A normal shutdown should be initiated IAW EOP MNSP if a cooling water discharge of 160 °F or above is observed.

f. An oil pressure of less than 60 PSIG is observed. An automatic shutdown should occur if an oil pressure less than 50 PSIG occurs.

g. An oil leak occurs.

h. An unusual metallic of vibration sound occurs.

i. The overspeed warning light is illuminated.

j. A fire of any type of severity is observed.

k. A gas generator overspeed of 53,164 RPM (104%) is observed.

l. A power turbine overspeed of 36,400 RPM (104%) is observed.

m. A compressor stall is observed.

n. Erratic control console readings occur.

o. Uncontrolled dyno load fluctuations occur.

p. A turbine outlet temperature (TOT) of 1,380 °F for more than 10 seconds occurs.

q. A TOT of 1,700 °F occurs.

r. An oil temperature of 225 °F of above is observed.

PROCEDURE

1. Turn the dynamometer FUEL PUMP OFF and return the gas generator throttle control to the 0° (cut-off) position. Monitor for a decrease in N1 speed and TOT temperature.

   NOTE: If N1 speed fails to decrease, secure remote fuel oil pump breaker [ ] and monitor N1 speed.

   If TOT temperature does <u>NOT</u> decrease and N1 speed does decrease, a post shutdown fire exists. Depress STARTER push-button and motor engine for two minutes.

2. After N1 speed reaches 0 RPM (0%) proceed with normal shutdown IAW SOP MNSP.

   NOTE: In the event of a fire, call the fire department at extension 2333. Attempt to put out fire with CO_2 extinguisher only after calling fire department.

3. **Troubleshoot and investigate malfunction prior to attempting a restart of the engine.**

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