NAU NORTHERN ARIZONA UNIVERSITY

Brayton Cycle Demonstration Unit

User's Manual

Operations

Troubleshooting

Maintenance

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Disclaimer

This device was built for use as an instructional tool in NAU Thermodynamics courses. As such, it should only be operated under the supervision of a qualified instructor and after full review of this manual. This device uses a powerful heater to simulate combustion and has fast moving parts; keep hands away from the heater and turbine at all times during operation.

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1 Operating the Device

This demonstration unit consists of four subsystems: The heat exchanger, the air compressor/air supply, the turbojet model, and the data acquisition system. Most functions are controlled through the control panel on the left side of the cart (the side with the handle) pictured in Figure 1. The operation of each subsystem is detailed below. Before beginning the experiment, ensure all three power cords (two black and one white) are plugged into the power strip on the bottom platform of the cart, shown in Figure 2. Next, plug the power strip into a standard wall outlet, and make sure the power strip's switch is turned on.

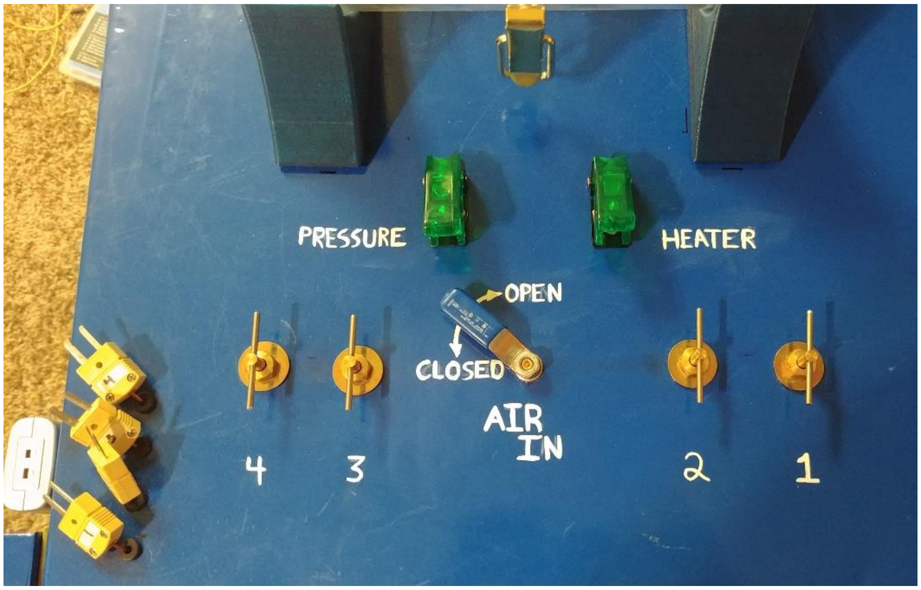

Figure 1: Control Panel

Figure 2: Power Strip

1.1 Heat Exchanger

This Brayton Cycle model uses an external heat exchanger in place of an internal combustion chamber. The heat exchanger, mounted below the top platform of the cart, is pictured below in Figure 3. For user safety, it is important that the user follows the operation procedure outlined below

Figure 3: Heat Exchanger

1.1.1 Setting Shutoff Temperature

The heat exchanger unit is heated by an electric band heater, controlled by a thermal fuse, which shuts off the band heater at a specified temperature. The thermal fuse allows a user to set the shutoff temperature between 210 and 250 °F, as shown in Figure 4 below. For safety purposes, it is strongly suggested that the shutoff temperature be set to 210°. However, if one desires to adjust the shutoff temperature, wait at least one hour after operation before handling the thermal fuse.

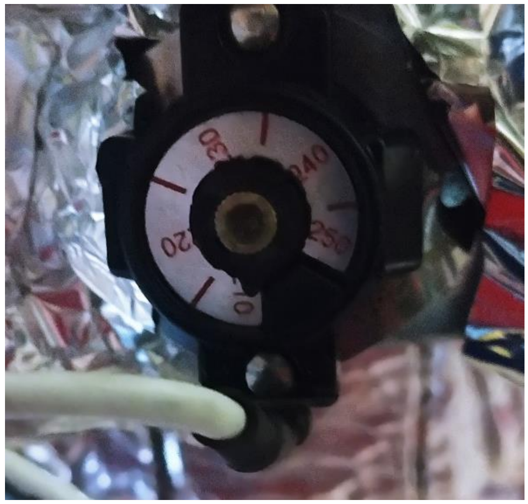

Figure 4: Thermal Fuse Temperature Adjustment

1.1.2 Turning on Heater

After setting the temperatures, the heater may be turned on. To turn on the heater, Locate the right toggle switch on the control panel labeled "heater." Lift the green switch cover and flip the switch upward. To turn on the heater, simply close the green switch cover. The operation is shown below in Figure 5.

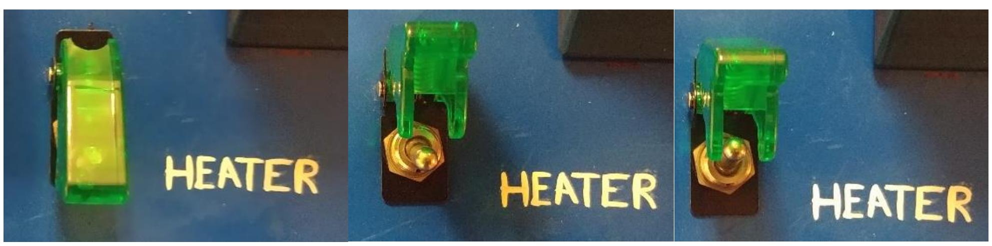

Figure 5: Heater Operation

1.2 Compressed Air Supply

This system relies on compressed air to operate. This is supplied by an external air compressor with two attached air tanks which are mounted on the bottom of the cart, shown below in Figure 6. Before beginning the experiment, this air tank must be filled using the attached compressor. It is recommended that this step be completed before a classroom demonstration as it is quite loud and takes about five minutes.

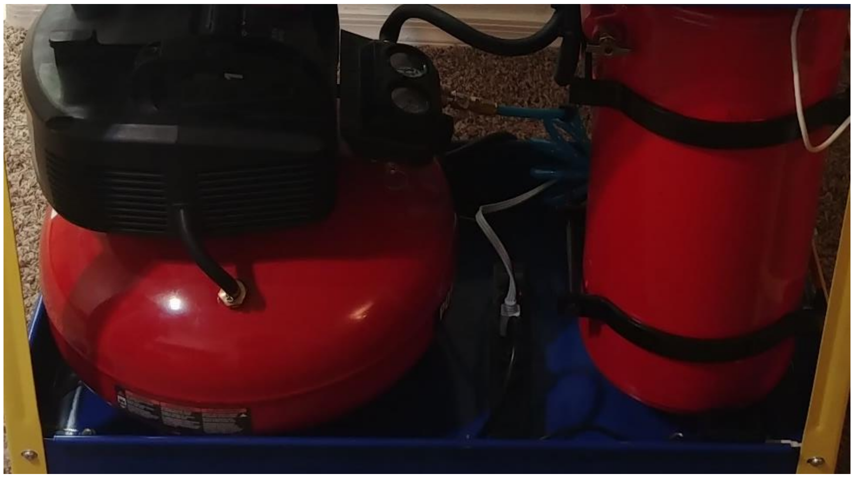

Figure 6: Air Compressor and Tanks

1.2.1 Filling the Air Tank

Before attempting to fill the air tanks, ensure the blue air supply hose is attached to the larger air tank. To attach the air hose, locate the brass collar protruding from the air tank underneath the two pressure gauges. Lift the collar upward, then insert the hose fitting. This is demonstrated below in Figure 7.

Figure 7: Air Supply Hose Attachment

Next, ensure the pressure release valve is closed. This is located near the top of the second air tank, shown in Figure 8. To close the valve, turn clockwise until tight. Once the valve is close and the hose is attached, the compressor may be turned on using the red power switch above the pressure gauges, shown in Figure 9.

Figure 8: Pressure Release Valve

Figure 9: Compressor Power Switch

A gauge on the top of the air compressor, pictured in Figure 10, shows the current pressure in the air tank. Filling to maximum pressure of 150 psi is recommended; this should take approximately 5 minutes.

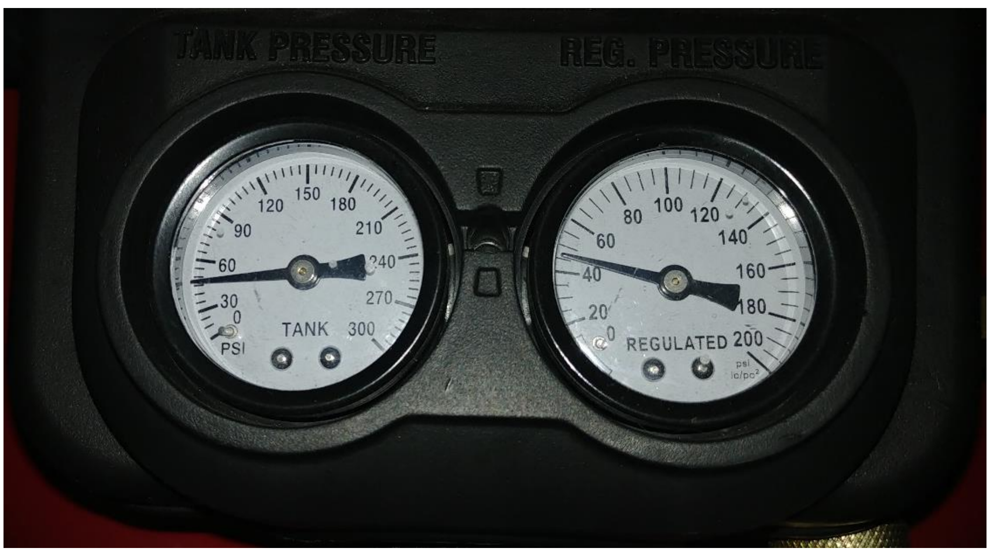

Figure 10: Compressor Pressure Gauge

The air compressor will automatically switch off once it reaches 150 PSI. It is recommended that the user switch the air compressor off after filling the tank completely. Leaving the switch on will cause the compressor to automatically restart while the tank is emptying during the experiment. This will slightly extend the runtime of the experiment but will be very loud.

1.3 Turbojet Model Operation

The turbojet model is encased in acrylic tubing on the top of the cart behind the control panel, shown below in Figure 11.

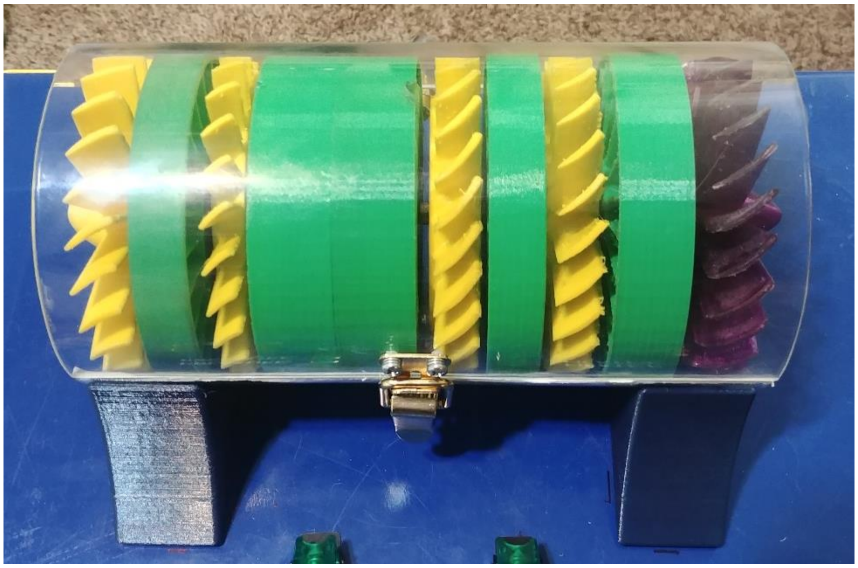

Figure 11: Turbojet Model

1.3.1 Running the Model

Once the heater is switched on and the air tank is filled, the model can now run. Before starting the model, ensure that the latch on the front is properly secured, and the two halves of the tubing are securely attached and properly aligned. Rotate the blades by hand to ensure they spin freely and that there is no interference between any components. Also ensure that no objects or wires are blocking either end of the acrylic tubing, and keep hands and objects away at all times. If the user would like to collect data for the experiment, refer to section 1.4 before proceeding.

The turbojet can now be started. To start airflow, locate the center valve on the top of the cart labeled "AIR IN", shown in Figure 12, and rotate from 'CLOSED' to 'OPEN'. The user can control the air flowrate by adjusting the position of the valve between open and closed. However, for best results, fully opening the valve is recommended.

Figure 12: Compressed Air Supply Control

1.3.2 Opening the Model

This model was also designed as a visual aid to demonstrate principles behind the Brayton Cycle. The outer casing is clear to allow a user to easily view the internals. However, the casing can also be opened to further enhance interactivity. To open the model, lift the brass latch at the center of the model, remove the clasp, and fold the top portion of the tube back. This procedure is shown below in Figure 13.

Figure 13: Procedure for Opening the Model

1.4 Data Acquisition

This model is designed to collect temperature and pressure measurements at four locations: Before the compressor section, between the compressor and combustion chamber, between the combustion chamber and turbine, and after the turbine section; these sections are numbered 1, 2, 3, and 4, respectively. Measurements will be displayed and stored using a laptop computer with LabVIEW installed. To collect data, place a laptop on the top platform next to the model as shown in Figure 14. The device can accommodate laptops up to 15.6"; however, the USB cord can also be extended to attach to a desktop or larger laptop. Locate the USB cord which protrudes from a hole in the left side of the cart (Figure 15) and plug into the computer.

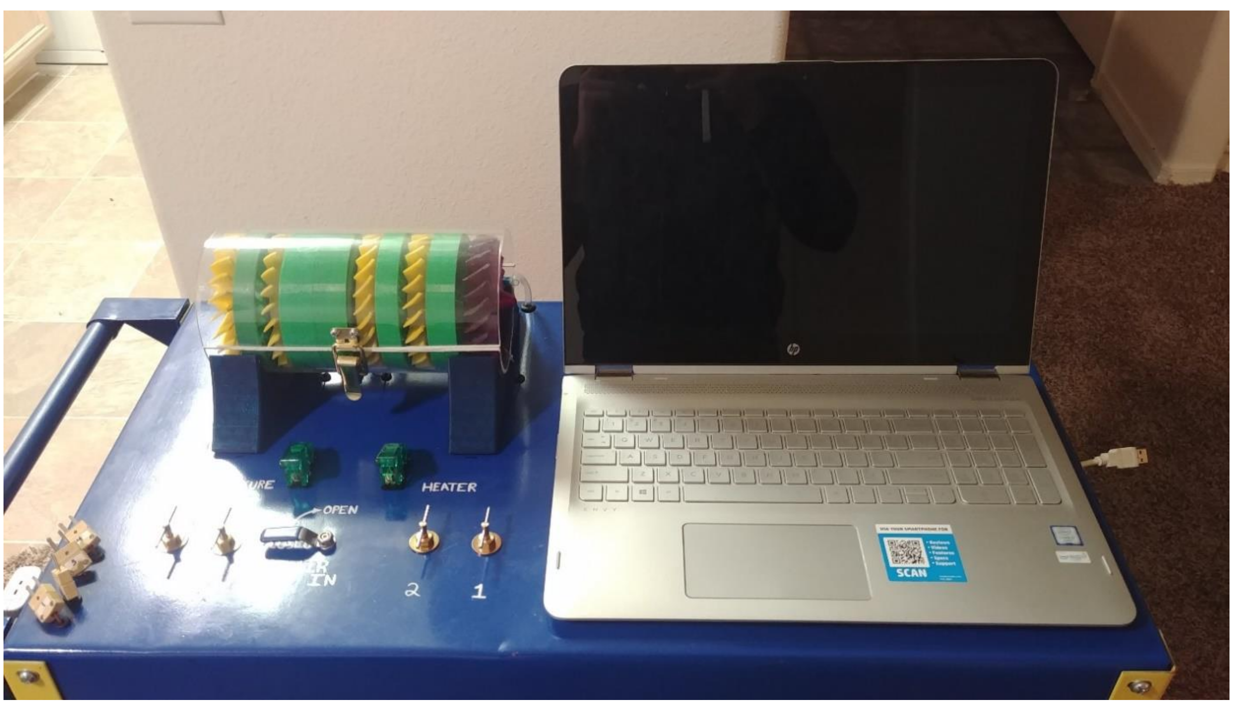

Figure 14: Computer Placement

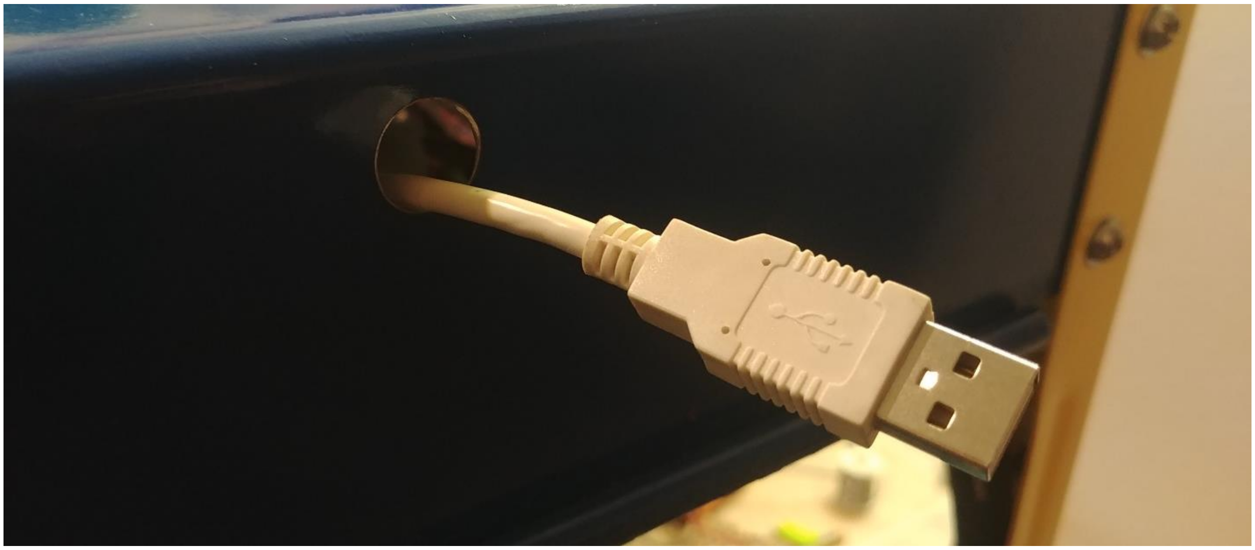

Figure 15: USB Cord

1.4.1 Temperature Measurement

Temperature measurements are accomplished using four thermocouples, each with its own plug with labels corresponding to the numbers above. The four plugs are grouped together in order on the left side of the control panel with the thermocouple DAQ, shown in Figure 16. Temperature measurements can only be taken at one state at a time. To measure temperature at a desired state, select the thermocouple with the correct state label, and plug into the DAQ, as shown in Figure 17.

Figure 16: Thermocouple Location

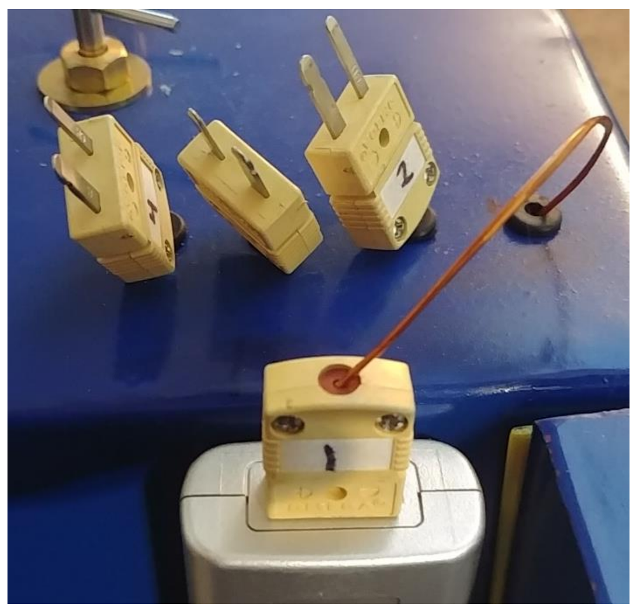

Figure 17: Thermocouple Operation

Next, return to the open LabVIEW program on the laptop. This program should be divided into two halves, the “Front Panel” on the left, which has a gray background, and the “Block Diagram” on the right which has a white background, shown in Figure 18. If the Block Diagram does not open, press CTRL+E on the computer keyboard, and it will appear. On the Block Diagram window, press the run button, which is a white arrow on the top tool bar, labelled in Figure 18. Measurements are now being taken, and should appear as a voltage and a temperature on the front panel. To store the temperature data for use in analysis, press the “Store Data” button on the Front Panel, shown in Figure 18. To specify a location to save the file, click the folder icon above the “Store Data” button, also shown in Figure 18. This program will store measurements as a .lvm file, which can be opened in Microsoft Excel, and subsequently transferred to MATLAB.

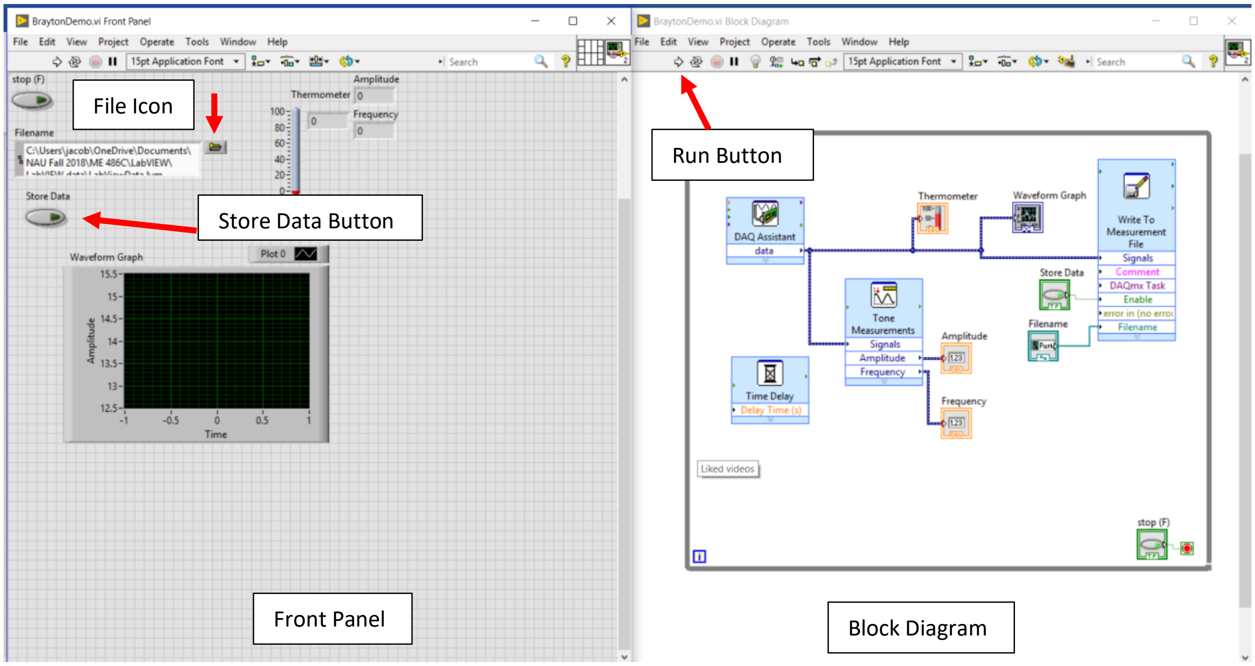

Figure 18: LabVIEW Program

1.4.2 Pressure Measurement

Pressure measurement is accomplished using two pressure transducers mounted underneath the cart. Each transducer can measure pressure at two states. The first transducer measures pressure at states 1 and 2, and the second at states 3 and 4. Switching between these states is accomplished by means of the four small valves on the control panel, labelled and grouped together in sets of two corresponding to the two states measured by each transducer. This is shown in Figure 19.

Figure 19: Pressure Measurement Control Valves

To select a pressure measurement, first switch on the pressure measurement system. To do this, located the left toggle switch labelled pressure, open the green cover, and flip the switch upward in the same manner as the heater switch. This is shown below in Figure 20.

Figure 20: Turning on Pressure Measurement System

Next, locate the valve corresponding to the state number of the location of interest. Turn this valve counterclockwise until rotation stops. Then, turn the adjacent valve clockwise until rotation stops. For instance, if you wish to measure pressure at state 1, turn valve #1 all the way to the left, and valve 2 all the way to the right. This design allows one pressure from each pair to be measured simultaneously; i.e. pressure can be measured at states 1 and 3, 2 and 3, 1 and 4, or 2 and 4 simultaneously.

Currently, the pressure measurement system is plumbed and wired to a National Instruments USB-6009 DAQ. However, a LabVIEW program will need to be created by the user to obtain accurate pressure readings.

2 Troubleshooting and Maintenance

This section details possible issues that may be encountered when using this device, and solutions to these issues, as well as instructions for part replacement.

2.1 Possible Heat Exchanger Issues

2.1.1 Heater doesn't turn on

The band heater used in this device takes several minutes to heat up. Before moving forward, wait five minutes with the heater plugged in and switched on, and check its temperature with an infrared thermometer to verify it is not heating, and safe to handle. If the heater is still room temperature after being plugged in five minutes, switch off the heater and unplug power cord. Visually inspect for any broken or exposed wires. Also check all connections. The heater should be wired according the wiring diagram in Figure 21.

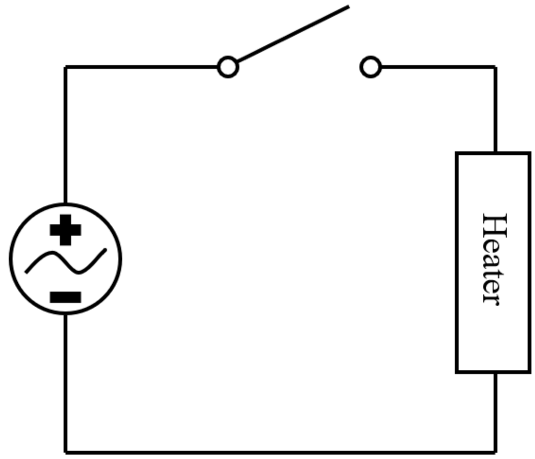

Figure 21: Band Heater Wiring Diagram

If the circuit is wired correctly and no wires are damaged, the band heater may need to be replaced. Refer to the Bill of Materials in Appendix A to source a replacement heater.

2.2 Air Supply Troubleshooting

2.2.1 Leak in Air Supply Lines

The air supply for the system has numerous threaded fittings. If there is a leak from one of these fittings, ensure it is completely tightened using the appropriate wrench. If the leak persists, remove the connection and Teflon tape, apply new Teflon tape to the threads, and reattach and tighten the fitting.

If a leak develops in any of the air supply tubing, the tubing section should be replaced. DO NOT ATTEMPT to patch any leaks in the tubing as they will not be able to withstand the high pressures. The correct replacements can be found in the Bill of Materials in Appendix A.

2.3 Turbojet Model Troubleshooting

2.3.1 System does not Spin Freely

If the blades in the turbojet model do not spin freely or interfere with any components, do not attempt to operate the model. Before attempting any repairs, ensure that the air supply valve is closed, and the air hose is disconnected. Once this is verified, open the turbojet model according to the procedure outlined in Section 1.3.2.

Once open, manually rotate the blades to pinpoint the location of interference. First ensure that the blades are snugly fit into the bottom of the tubing. Check the thermocouples to verify they are still securely attached to the sides of the combustion chamber. Inspect the foam seals on each side of the tube to confirm they do not extend into the interior of the tube. Also check the three threaded brass adapters to make sure they have not been inserted too far.

If there are no issues with these components, inspect each blade section to look for broken pieces. If any damage is found, the blade will need to be replaced; do not attempt to operate the device until replacing the damaged blade, and do not attempt to repair a damaged blade section. A new blade section can be printed using the attached CAD drawings and a 3D printer. Once a replacement has been made, the entire assembly can be removed from the tubing and disassembled. Refer to section 2.5.2 for complete blade replacement instructions.

2.4 Measurement System Troubleshooting

2.4.1 Temperature Measurements are Incorrect or Absent

If there is an error reading temperature, there is likely an issue with a thermocouple wire. First, locate the thermocouple wire which is experiencing the error. Verify that the wire is not broken and the insulation is fully intact. If the wire is damaged in any way, it will need to be replaced. If no damage is found, check the thermocouple connection at the plug. Unscrew the two screws on the top of the thermocouple miniplug. Verify that the wires are connected to the correct posts. The device uses a J-type thermocouple wire, which means the red wire should be connected to the negative post, and the white wire should be connected to the positive post. Also check to ensure that the wire is insulated until it passes into the miniplug. Exposed wire outside of the miniplug will cause errors in temperature measurement.

If a thermocouple needs to be replaced, it first must be removed from the miniplug. Unscrew the two screws on the top of the thermocouple and lift away the cover. Next, unscrew the two internal screws holding in the wires. Reverse the process to install a new thermocouple. Refer to Figure 22 for an illustration.

Figure 22: Thermocouple Miniplug Wiring Diagram

Even if these steps are followed and the wire does not appear to be damaged, replace the wire if the issue persists. The wire may have internal damage that is not visible. Replacement thermocouple wire can be sourced from the Bill of Materials in Appendix A.

2.4.2 Pressure Measurements are Incorrect or Absent

If a user experiences error in the pressure measurement system, first verify that the proper measurement procedure is being utilized; this is outline in section 1.4.2. If this is not the issue, first verify that the pressure transducers are plugged into their connectors. The transducers are located on the bottom of the cart’s top tray, shown in Figure 23 below.

Figure 23 Pressure Transducers

If the plugs are attached, next check the wiring of these plugs to the thermocouple DAQ, mounted underneath the cart, picture in Figure 24. The transducers should be wired according to the diagram in Figure 25.

Figure 24: Pressure Transducer DAQ

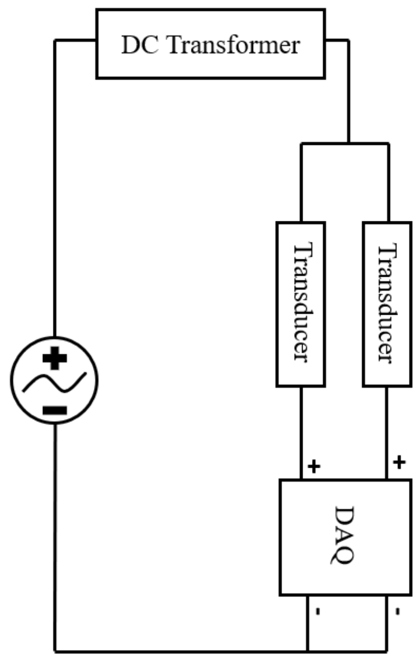

Figure 25: Pressure Transducer Wiring Diagram

If the transducers are wired properly, visually inspect the tubing on the top of the cart and ensure the fittings on the back of the turbojet model, shown below in Figure 26, are securely tightened.

Figure 26: Pressure Measurement Fittings

If these components are undamaged and properly installed, next move to the fittings on the bottom of the cart. Inspect all vinyl tubing for any damage, and confirm the tubes are securely attached to the brass fittings. If damage is found in the tubing, the tube should be replaced. Leaks in this system may be patched safely, as the pressure is relatively low. However, this may affect measurement accuracy, so replacement is recommended. If any tubing needs to be replaced, refer to the Bill of Materials to source replacement.

2.5 Part Replacement

If part failure occurs, follow the steps outlined below to aid in repair or replacement.

2.5.1 Insulation Replacement

The turbojet model is designed to be easily opened and closed. To ensure a tight seal, a foam insulation is used on each side of the tube. This insulation could wear or fray after extended usage. If the insulation no longer provides an adequate seal, or begins to interfere with blade rotation, it should be replaced. Some spare insulation is included, but refer to the Bill of Materials to source a new roll if more is needed. If the insulation on the rear of the device needs replacing, it is recommended that you remove the hinges before replacing insulation. Simply unscrew the screws and remove the screws and the washers.

Measure out the correct length of insulation, and cut from the roll. Next, carefully align the insulation with the inner surface of the tube, leaving a small gap (less than 1 mm) between the edge of the insulation and the edge of the acrylic tubing. Firmly press the insulation into place. Next, align the two halves of the tube. Firmly press the two halves together, and using a sharp razor blade, trim the excess insulation. Next, reattach the hinges if applicable, and lock the two halves together with the latch. Allow to sit for one hour before opening again.

2.5.2 Blade Replacement

Under normal operation, the blades should not require replacement. However, blade damage may occur from mishandling when the casing is opened. Should a blade develop a crack, do not operate the device until the blade has been replaced. A blade replacement can quickly be made by submitting the correct CAD file to a 3D printer. First, determine the correct replacement file by referring to the exploded view in Figure 28. Next, locate a 3D printer that can accommodate the file. This device is intended to be used at Northern Arizona University; in which case, it is recommended to submit a print request to the MakerLab in the NAU Cline Library.

After printing a replacement, open the turbojet model as outlined in Section 1.3. Next, remove the turbine assembly from the casing by grabbing the point on the outer blades, and lifting upward, shown in Figure 27. Next, slide off the necessary blades until the damaged blade can be removed and replaced. Refer to the exploded view in Figure 28 for a complete schematic.

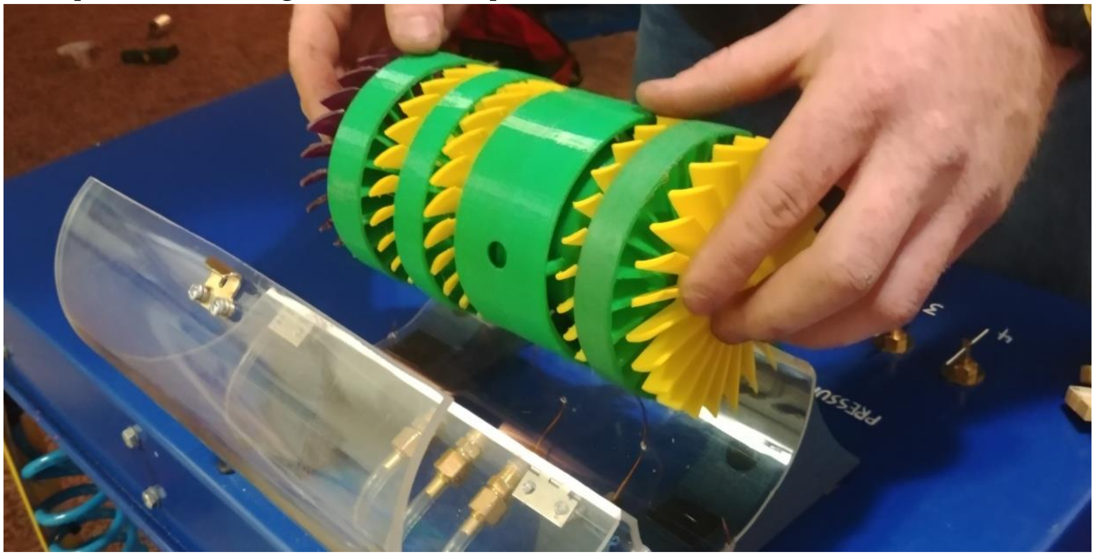

Figure 27: Blade Removal

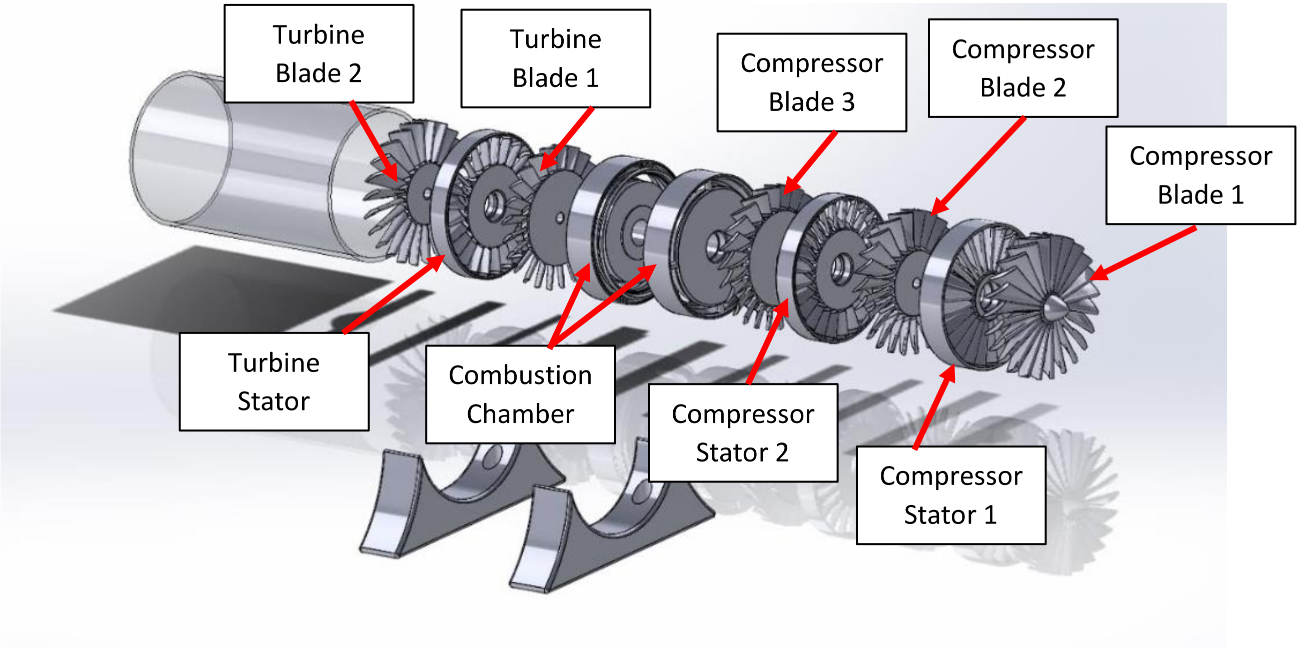

Figure 28: Exploded View for Blade Replacement

If any other components need to be replaced, refer to the Bill of Materials in Appendix A to source a replacement.

Appendix A: Bill of Materials

Bill of Materials

Item	Quantity	Cost per uni	Subtotal	Manufacturer	Item #	Vendor	Hyperlink
Acrylic Tubing	23 7/8 in	$0.10	$17.99	estreetplastics	ET0450042524	estreetplastics	https://goo.gl/rmKMEm
Compressor Chamber Side 1	77.5 g	$0.10	$7.75	MakerBot	N/A	NAU Cline Library	N/A
Compressor Chamber Side 2	88.1 g	$0.10	$8.81	MakerBot	N/A	NAU Cline Library	N/A
Compressor Stator 1	82.7 g	$0.10	$8.27	MakerBot	N/A	NAU Cline Library	N/A
Compressor Blade 1	69.3 g	$0.10	$6.93	MakerBot	N/A	NAU Cline Library	N/A
Compressor Blade 2	51.2 g	$0.10	$5.12	MakerBot	N/A	NAU Cline Library	N/A
Compressor Blade 3	57.3 g	$0.10	$5.73	MakerBot	N/A	NAU Cline Library	N/A
Compressor Stator 2	255 g	$0.10	$6.68	MakerBot	N/A	NAU Cline Library	N/A
Turbine Blade 1	292 g	$0.10	$4.27	MakerBot	N/A	NAU Cline Library	N/A
Turbine Blade 2	53.8 g	$0.10	$5.38	MakerBot	N/A	NAU Cline Library	N/A
Turbine Stator	62.8 g	$0.10	$6.28	MakerBot	N/A	NAU Cline Library	N/A
Saddle	142 g	$0.10	$14.22	MakerBot	N/A	NAU Cline Library	N/A
3D Printed Test Fitting #1	77.58 g	$0.10	$7.76	MakerBot	N/A	NAU Cline Library	N/A
3D Printed Test Fitting #2	64.28 g	$0.10	$6.43	MakerBot	N/A	NAU Cline Library	N/A
Aluminum Shaft	2 ft	$5.62	$5.62	MetalsDepot	R3516	Metals Depot	https://goo.gl/CezFTP
Ceramic 608 Bearings	2	$3.33	$6.66	VXB	608-2RS-DRY	VXB	https://goo.gl/zPNP8M
Air compressor with tank	1	$89.00	$89.00	Porter Cable	C2002	CPO Commerce	https://goo.gl/KRQu8p
Band Heater	1	$28.50	$28.50	Tempco	NHL00100	Grainger	https://goo.gl/WnqnU8
K Type Thermocouple Wire	25 ft	$0.86	$21.50	TIP Industries	TIPWRK004	TIP Industries	https://goo.gl/AETaH8
Thermocouple Connectors	4	$2.30	$9.20	Omega	OST-U-M	Omega	https://goo.gl/mftfh2
Thermocouple DAQ	1	$107.00	$107.00	National Instrumen	USB-TC01	National Instrumen	https://goo.gl/U5soAU
1/4 in. x 1/4 in. MIP Brass Compression Adapter	2	$4.40	$8.80	Everbilt	801079	Home Depot	https://goo.gl/z6qf8e
Brass Pipe Coupling 1/4 in. FIP	3	$4.16	$12.48	Everbilt	801889	Home Depot	https://goo.gl/VR7m58
Brass Compression Tee 1/4 in	2	$7.51	$15.02	Everbilt	800849	Home Depot	https://goo.gl/Nh2w24
1/4 in. Compression Angle Needle Valve	4	$8.80	$35.20	Everbilt	800539	Home Depot	https://goo.gl/NpVaUW
1/4 in. O.D. x 0.170 in. I.D. x 10 ft. PVC Clear Vinyl Tub	1	$2.82	$2.82	Everbilt	701906	Home Depot	https://goo.gl/pECLr4
1-1/2 in. x 6 in. Galvanized Steel Nipple	1	$6.36	$6.36	Mueller	567-060HN	Home Depot	https://goo.gl/UXY4mM
1-1/2 in. x 1 in. Galvanized FPT x FPT Reducing Couplir	2	$7.28	$14.56	Southland	511-375HN	Home Depot	https://goo.gl/Ce8sVk
1 in. x 1/2 in. Black Malleable Iron Hex Bushing	2	$3.18	$6.36	Mueller	521-953HN	Home Depot	https://goo.gl/9MQn86
5/16 in. Stainless Steel Flat Washer (5-Pack)	1	$1.18	$1.18	Everbilt	800351	Home Depot	https://goo.gl/fDHng4
Latch	1	$5.69	$5.69			HomCO	
Hinges	1	$2.99	$2.99			HomCo	
Machine Screws	14	$0.11	$1.54			HomCo	
Foam Insulation Tape	1	$2.99	$2.99			HomCo	
Pressure Transducer	2	$49.00	$98.00	Transducers Direct	TDH30BG025003B0C	Transducers Direct	https://goo.gl/ZAUC21
Pressure Transducer DAQ	1	$250.00	$250.00	National Instrumen	USB-6009	National Instrumen	https://goo.gl/xaw9sP
Cart	1	$37.99	$37.00	US General	5107	Harbor Freight	https://goo.gl/gR9cP3
		Total:	**$880.09**				
		Our Cost:	$414.59				