High Efficiency Internal Combustion Engine (Waste Heat Recovery)

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Problem Statement

Internal combustion engines currently operate at a thermal efficiency of around 35%[1]. That means there is about a 65% thermal energy loss, much of it is wasted as heat out of the exhaust and engine block. Because the internal combustion engine is so commonly used, we believe harvesting the wasted energy will not only allow for more output but will result in greener use of engines (less emissions).

Overview:

A waste heat recovery system was designed in order to accomplish a higher level of output from an internal combustion engine. The design relies on a generator to test the heat recovery system, in our project energy is recovered from the high-temperature exhaust gas, this is directly connected to the heat exchanger. Water is pumped from a reservoir to the heat exchanger where it is converted to high pressured steam and enters an expansion valve. The expansion valve allows the steam to expand inside of a steam engine, effectively moving a piston up and down, generating shaft work. Once the steam expands an exhaust stroke sends it through a series of condenser fans and back into the fluid reservoir. A flywheel is connected to the shaft of the steam engine, as the flywheel rotates this energy is converted to electrical energy by the connection of a belt to an automotive alternator. Effective power output is then easily measured. **Based on realistic working conditions, an efficiency increase of 13.6% was projected.**

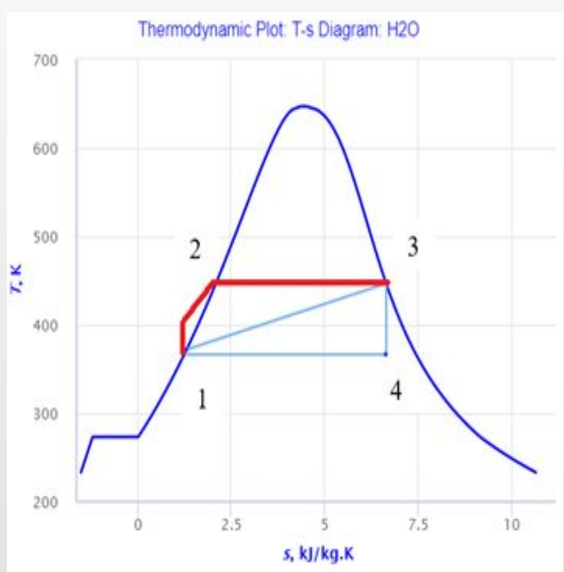
Project Sponsor

Automation Direct

http://www.formula1-dictionary.net/thermal_efficiency.html[1]

Technical Details and Analysis

Thermal Analysis (T-S Diagram)



- Pressurization occurs between states 1-2 (theoretical red line in depicted above) blue line is expected.
- Heat Exchanger is located between states 2-3.
- Steam engine is located between states 3-4.
- Condensers are located between states 4-1.

Take-Away Calculations

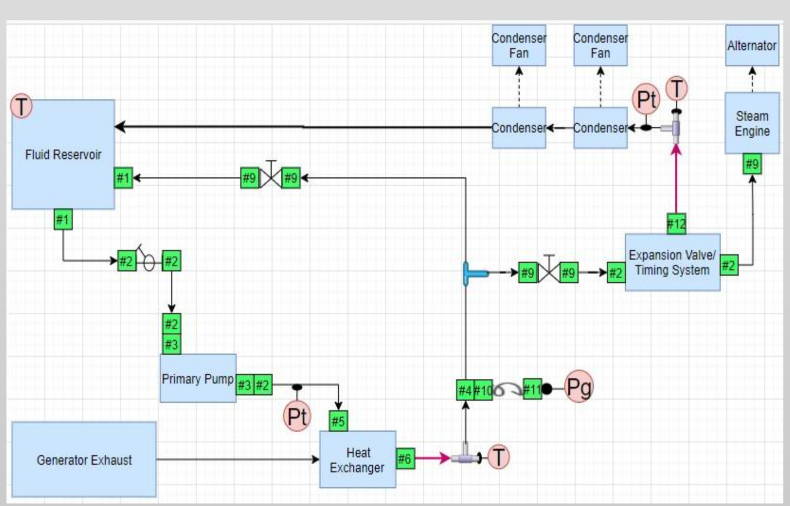
$W_{output} = \dot{M} * (h_3 - h_4) = 0.002(kg/s) * (2772.1 - 2372)[kJ/kg] = 800\ Watts$[2]

Estimated Thermal Efficiency increase = 750(net gain)/5500 (Watts) = 13.6%

For a detailed thermal analysis view: "shorturl.at/BDFK9"

2 Bhattacharjee, S., "TEST: The Expert System for Thermodynamics," Electronic Resource, Entropysoft, San Diego, CA, http://www.thermofluids.net. Last accessed on: April 20th, 2020

System Level Diagram

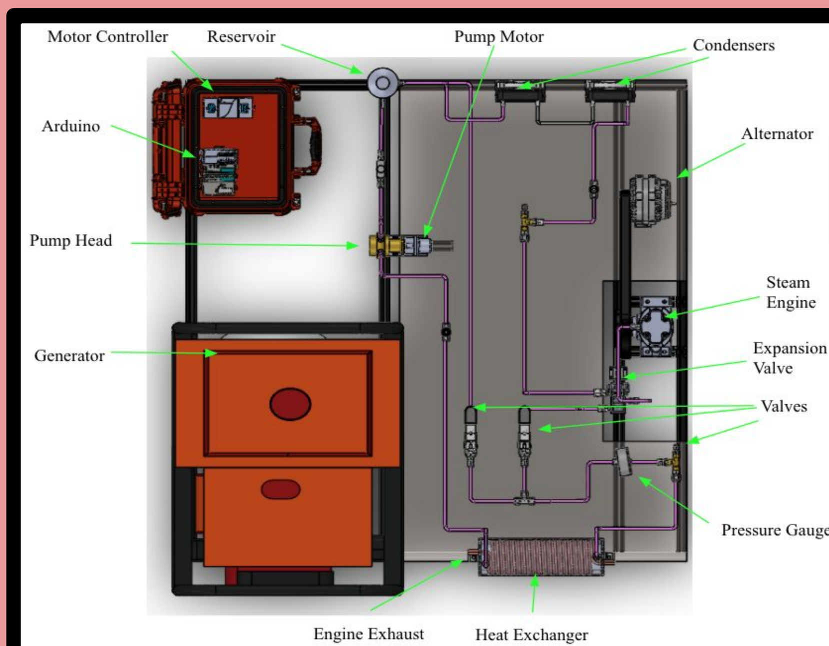


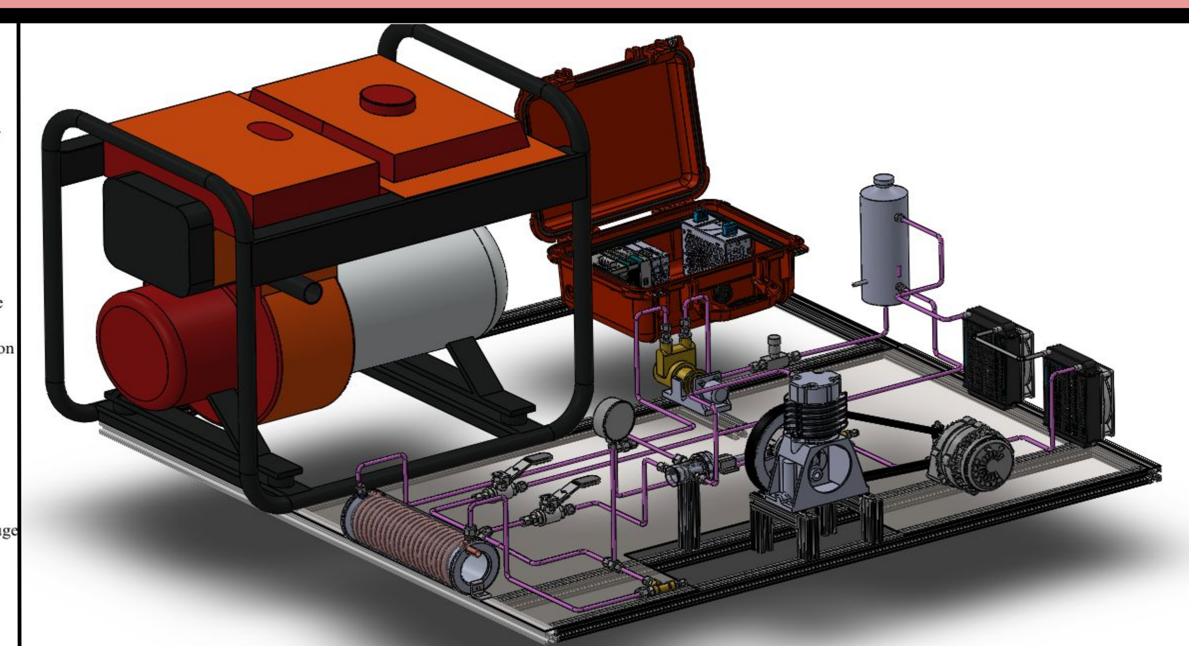
Fitting	Fitting Type
#1	AN-4 Fitting Weld On w/ Compression Nut -4
#2	1/8 NPT to -4AN Flared w/ Compression Nut -4
#3	3/8 NPT to 1/8 NPT Reducer
#4	-4 AN to -4 AN w/ 1/8 NPT Sensor Port w/ Compression Nut -4 (See Below)
#5	-4 AN Stainless Weld On w/ Compression Nut -4
#6	-6 AN Stainless Weld On w/ Compression Nut -6
#7	1/4 NPT to -6 AN Straight Flare w/ Compression Nut -6
#8	TC: 1/4 NPT w/ 1/8 Probe
#9	1/4 NPT to -4 AN w/ Compression Nut -4
#10	1/8 NPT Female to 1/4 NPT Female Reducer
#11	1/4 NPT Female to 1/4 NPT Female Coupler
#12	1/8 NPT to -6 AN Straight Flare w/ Compression Nut -6
	1/4 NPT Tee All Female (See Below)
	-4 AN Tee All Male w/ Compression Nut -4 All Sides

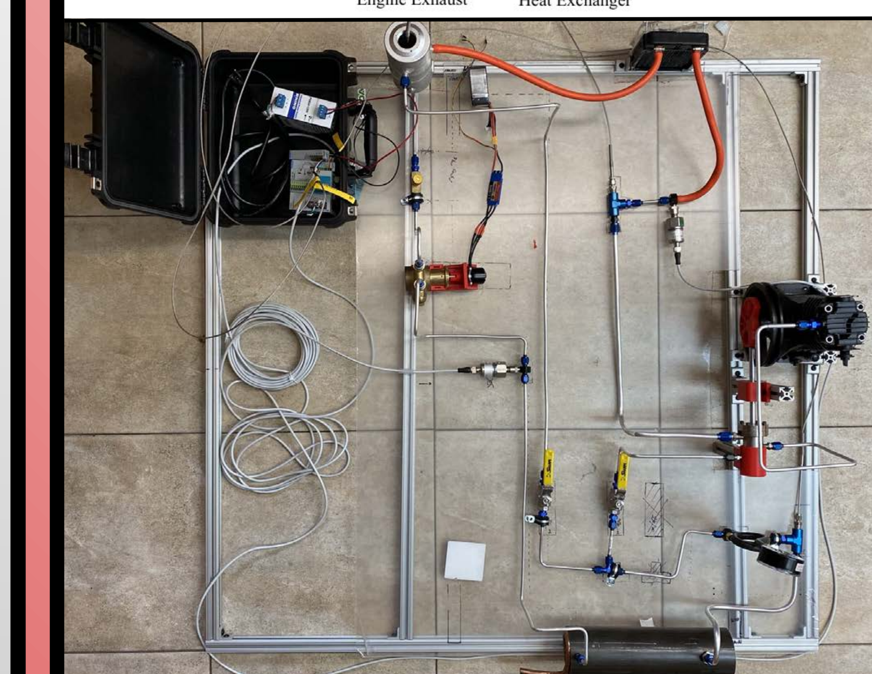
The Systems Level Diagram is a high level visual representation of our system. Thermocouples, pressure-transducers, a pressure gauge, and physical sub-assemblies are mapped out for reference. Exact AN/NPT fittings are labeled and represent the inner connections within the testing system.

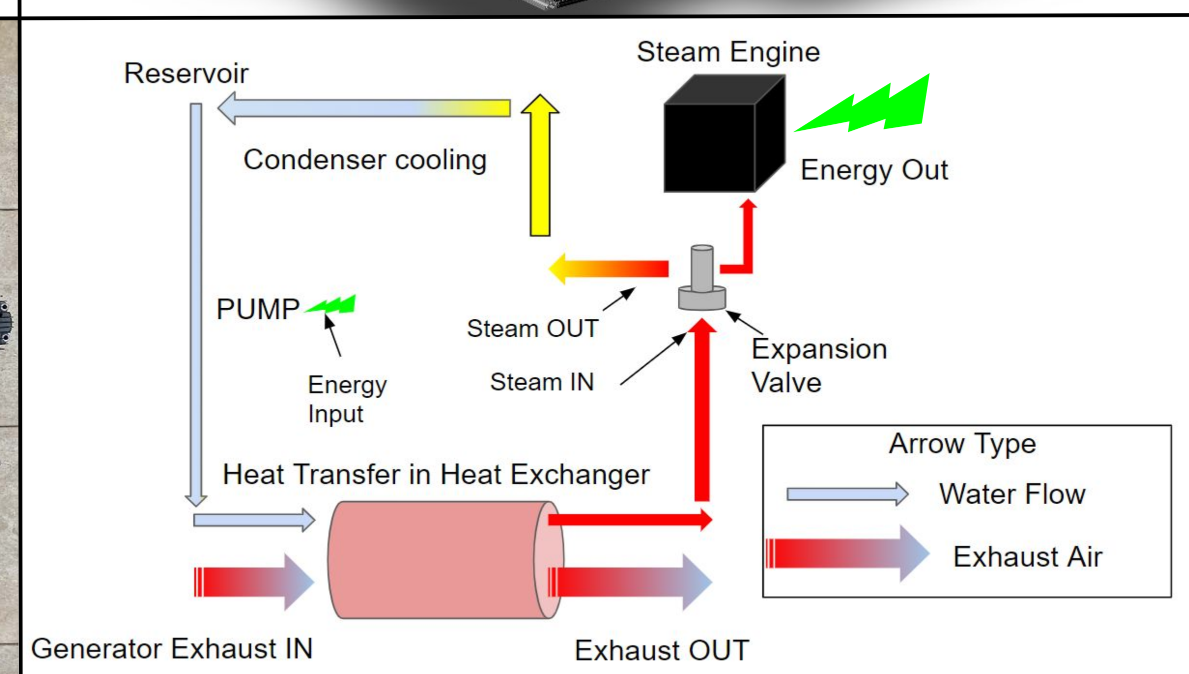
Data Acquisition

- The goal of the data acquisition was to gather pressure and temperature data at various points throughout the system in order to make adjustments and update our thermodynamic model.
- The components of the data acquisition system were: 3 thermocouples, 2 pressure transducers, an industrial arduino, an arduino power supply, a thermocouple input module, an analog I/O, and a 24V power source for the Pressure Transducer I/O.

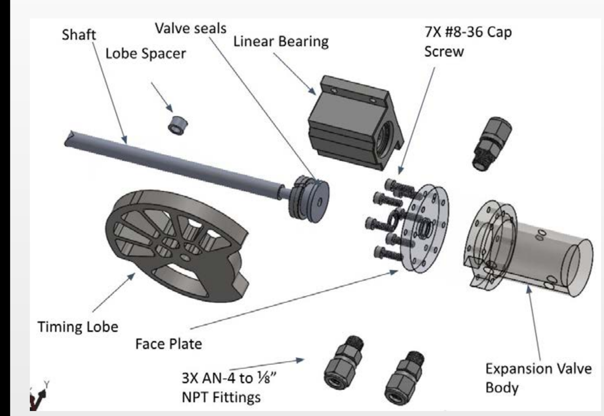


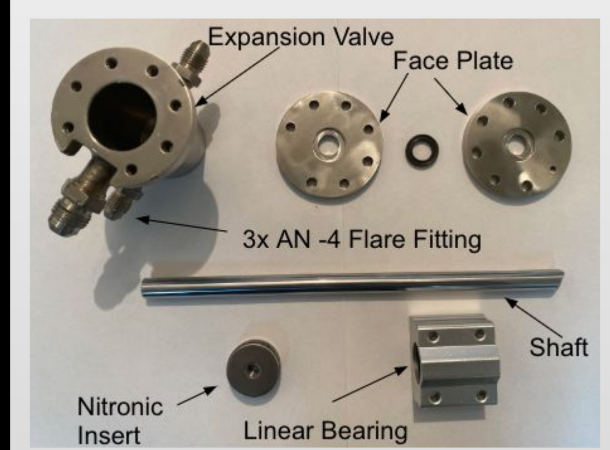






Sub-Assembly Detail





Expansion Valve Assembly

The Expansion valve is a key component in the heat recovery system. This converts a standard piston-driven air compressor into a positive work steam engine.

Features

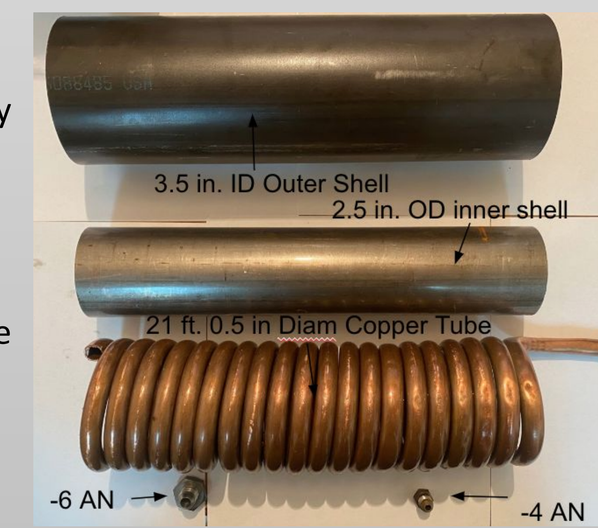
- Valve states (position) direct steam in/out of the steam engine
- Valve state is determined based on radial position of the timing lobe
- Burst pressures in excess of 1000 psi (FEA Modeling)
- Modular design that allows for the unbolting and disassembly of the entire valve

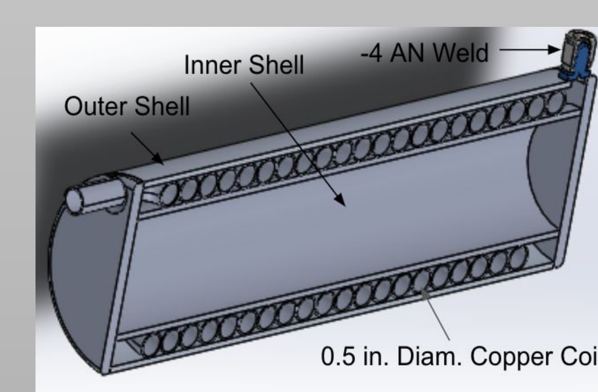
Composition

- Stainless Steel body composition
- Stainless Steel weld-on AN fittings
- Anti-galling Nitronic Steel internal sealing component
- Contains dynamic seals (allows piston to linearly oscillate without steam loss)
- Linear bearing insures concentric linear reciprocation

Heat Exchanger

- The main function of the heat exchanger is to convert the pressurized water to high pressured steam. This is commonly referred to as "constant pressure heat addition"
- The log mean temperature difference and the effectiveness/NTU method was used to determine the required internal geometry and general sizing
- The main components of the heat exchanger (pictured to the right) are the helical coil (bottom), inner shell (middle) and outer shell (top) *Note the two end caps are not pictured*
- A helical coil design was chosen, allowing the exhaust gas pressure to drop due to friction, effectively increasing the exhaust temperature
- Copper was chosen due to its favorable conductive heat transfer properties
- Water flows between the coils and the outer/inner shells, water is expected to boil near the outlet
- Heat Exchanger outlet is designed to direct back to the reservoir (allows for water preheating), or directly to the expansion valve





Traveled Work

Due to the impact of COVID-19, our senior design project will require traveled work (work to be completed on a future date). In order to meet our original design requirements and manufacture a functional system, the following rework tasks are required:

- Team needs to acquire a generator in order to test the heat recovery system (sized for 5500 running Watt generator)
- Due to shipping and availability delays, the team needs to complete rework for the timing lobe (water-jet) after receiving the steel stock and also finish procurement of an alternator
- Complete full assembly of Heat Exchanger unit: weld end caps and fittings of heat exchanger,
- The team will need to connect the alternator to the steam engine with v-band belt
- Postpone all tests until system is assembled: temperature and pressure test for the heat exchanger, steam engine power output test, pump motor test, electronics data acquisition calibration, and verification of generator load and efficiency change
- Reserve additional time for any rework (likely need to test a few different sealing methods within the valve) needed to address any future complications of the expansion valve and heat exchanger

Meet the Team

Pictured left to right:

Zach Arellano - Project Manager

Andrew Smith - Team Leader

Alex Graham - Project Member

Julio Leyva - Project Member

Josue Gutierrez - Project Member

Spring 2020