Miami University

Department of Engineering Technology

ENT 498 Senior Design

High Temperature Limit Sensor for Compressor Connecting Rod

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Statement of Purpose

The purpose for this project is to investigate and suggest the most efficient solution to implement a reliable, inexpensive failsafe shutoff sensor on an Ariel Compressor connecting rod. Currently sensors at this location are only placed on units for research purposes. This project would entail coming up with the best solution to use these sensors for any compressor unit in the fleet.

It is known that a connecting rod will fail when the temperature on the large end connecting rod bearing exceeds a specific temperature. There are many different compressor sizes and each compressor will operate at a slightly different temperature range. The desired sensor will need to react to the difference in heat and shut down the compressor before this occurs. The difficulty in creating this sensor is that it needs to be reliable for up to 3 years and it will undergo strain from changes in temperature and pressure (-30°F to 300°F). The device will need to take measurements very close to the bearing on the large end of the connecting rod. The failure occurs quickly and the sensor will need to react within a few seconds after detecting a rise in temperature.

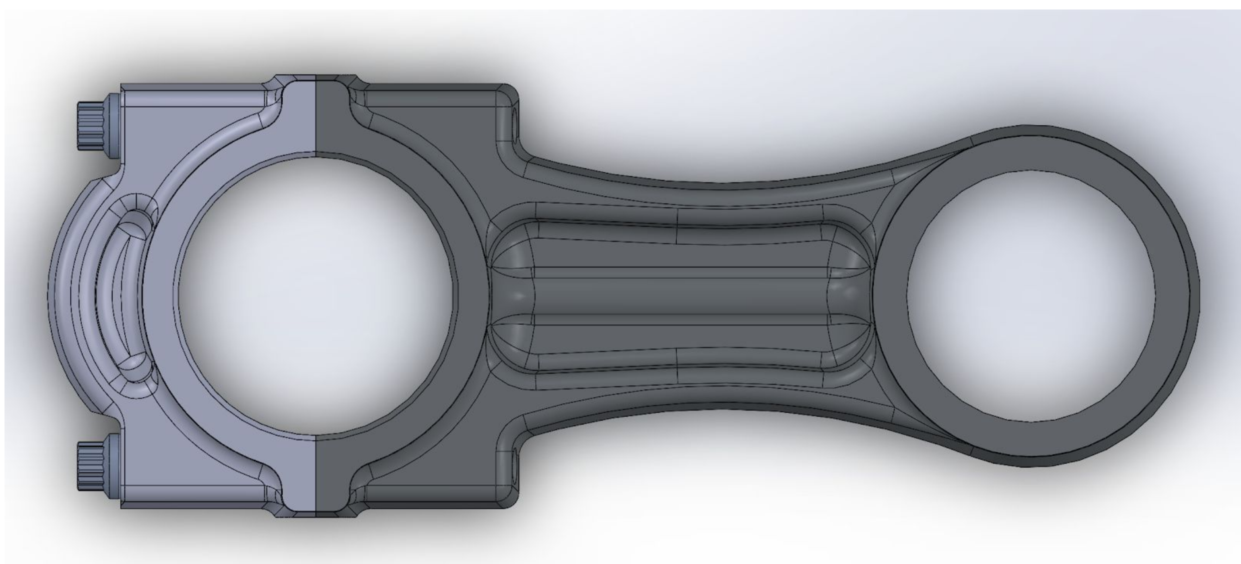

Figure 1. Connecting Rod

Battery operated systems are less reliable and therefore we are choosing to avoid these. The compressors are pumping natural gas so any electrical based system that is added to the compressor creates a potential risk of explosion. Also, with a battery operated system the battery would need to last in cycling temperatures environments for up to 3 years. Ideally, this sensor could be reset without removing having to to remove the top of the compressor..

This project has been requested by customers of Ariel Corporation in the past. The issue is that the connecting rod structural integrity will be weakened by boring a hole into the connecting rod to add a sensor. Part of this project is to verify that the weakened connecting rod will not have a reduction in infinite life.

If the connecting rod bearing overheats and the compressor does not shut off, there will be extensive damage that will occur. If the failure can be caught early enough it can limit the potential damage to smaller components, ideally the connecting rod and or crankshaft. A worst-case scenario will result in damage to the crankshaft, connecting rod, and frame. The cost of damaging the frame is orders of magnitude more expensive than replacing a connecting rod. The goal for this sensor is to shut down the system before excessive damage can be done to the compressor frame and potentially the crankshaft.

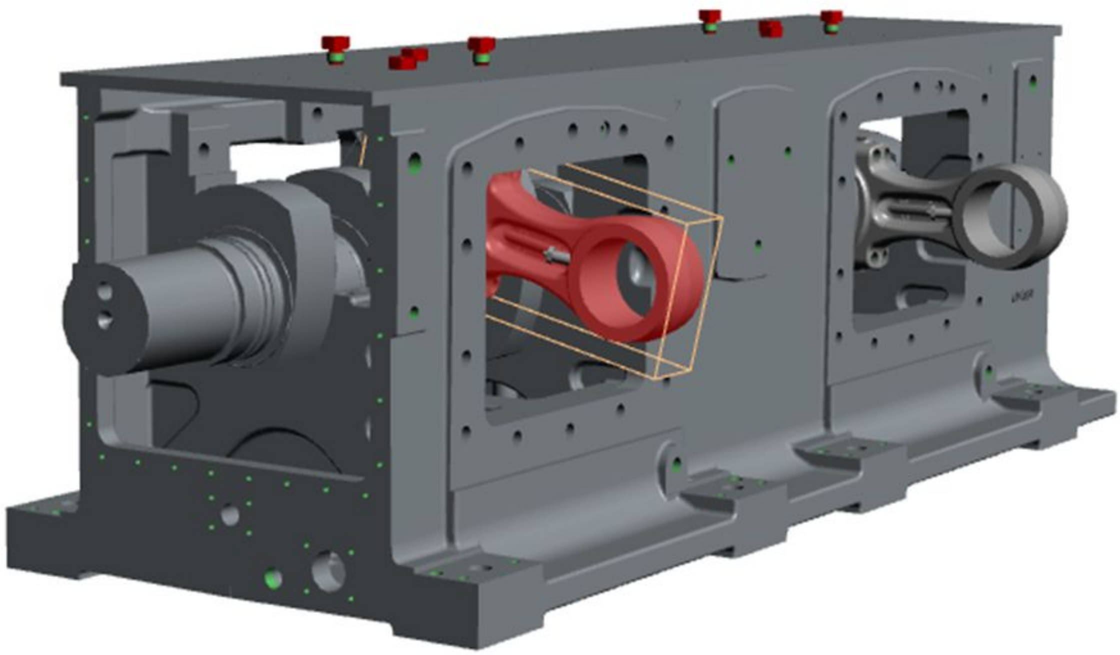

Figure 2. Compressor Assembly

Ariel Corporation is looking to market an Internet of Things (IoT) system for their compressors and this sensor would be incorporated into the data captured by their IoT system. It is very powerful to know the current status of compressor units that are in various locations worldwide. One specific benefit is that reactive maintenance becomes much simpler. If Ariel Corporation knows which sensor or sensors have failed they can reduce the number of trips by field service technicians. If the reason for failure is known the field service personnel can bring the right tools and spare parts to resolve the issue on the first trip. The goal for this project is to be able to display a simple signal to the Internet of Things system only when tripped.

Table of Contents

Scope and Methodology

On November 5th, 2019 the team met with several members from the Ariel Corporation research and development team to determine the scope and expectations for this project. The original scope was based on a purely mechanical or eutectics based device. After revision the original guidelines were revised to increase the scope of the project to all possible sensor type devices that could fit the scope of the project.

The requirements for this project are as follows:

1. The sensor will need to react quickly enough to detect a rise in temperature and output a signal within 2-3 seconds of the sensor temperature rising above 240°F.
2. A hole will need to be bored into the connecting rod on the large end close to the bearing. The current sensors are roughly located 1/8” away from the bearing. The distance between the bearing and the sensor can be adjusted, and will need to calculate the suggested distance between the bearing and the sensor.
3. Determine the diameter of the hole bored for the sensor head and determine the drilling angle of the hole.
4. Determine the structural integrity of the part after boring the sensor hole. Need to verify and test that the connecting rod maintains infinite life.
5. The sensor will need to be inexpensive, ideally something that is an off the shelf part.
6. The sensor will need to be reliable and able to withstand a temperature range between -30°F and 300°F.
7. The sensor will also need to be able to transmit a signal in oily conditions.
8. Need to calculate the rate of heat transfer through the connecting rod at 240°F.
9. Attach the sensor body to the frame of the compressor and sync with the Ariel controller.

In order to succeed with this project, this team has chosen to use a methodical approach to working on this project to completion. Below are the steps the team will take to make this project happen:

1. The team will work with the sponsor company, Ariel Corporation, to find out the scope of the project to successfully complete the objectives they are looking for.
2. Create a work breakdown structure, schedule, and budget for the project to have a path to follow.
3. This project requires mostly research to find the best sensor that fulfills the needs of the company's requirements.
4. The team will need to design mounting equipment for the sensors that will be used for the next step of testing.
5. Using Ariel’s testing facility, the team will perform tests on the sensors that were found suitable for the objective of the project.

Engineering Analysis

A variety of potential sensors were investigated for use in this application. Sensors were judged based on the following criteria; reaction time, cost, reliability.

AMOT Sensor

The first type of sensor that has been investigated is a eutectic based sensor. Eutectic fluids are made up of substances that when combined together have a lower melting point than the individual components. An example of a common eutectic is solder. The eutectic is located on the tip of the sensor and the sensors activated by a spring. The figure below shows what a typical eutectic sensor looks like. These sensors can be purchased between 2-14" long and will need to be bored into the connecting rod. Greater flexibility with drilling angles and locations will make it easier to produce from a design standpoint. After further looking into this sensor, the team has decided this is the best suitable sensor for this application.

Figure 3: AMOT Sensor Catalog

Our group has decided to use the Amot sensors for multiple reasons. First, they are a purely mechanical system which does not require a battery or internally mounted power source on the connecting rod. Batteries or power sources are unreliable over long periods of time. Second, they are lower cost than several of the other options. Eutectic sensors are mass produced and therefore can be ordered in large quantities which could reduce the price further. These sensors also have a quick enough reaction time for the application. As a final note, these sensors come in an array of sizes and temperature ranges which should work for a majority of Ariel compressors.

Laser Temperature Sensor

Another sensor that was investigated is a laser temperature sensor. The laser sensor uses a laser to read the temperature of the bearing through a small hole in the connecting rod body. The idea of this option is that the laser's beam is smaller than any other type of sensor allowing for a smaller holde to be drilled down to the bearing. The body of the sensor will be slightly bored into the end of the cap of the connecting rod. This is shown in figure 4 below inside the red box.

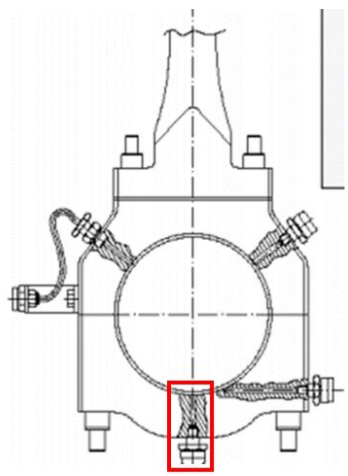

Figure 4: Laser Sensor Location

With this laser sensor, the team looked into how long it takes for the temperature to transfer to the outside of the connecting rod from the bearing. This does not happen quickly enough to see a slight change in temperature. This would allow for no holes to be drilled into the connecting rod eliminating the structural integrity problem of drilling a hole. After further research, this sensor has one issue with it, it will require a power source that could be done to work with the rotation of the motor, but the cost would be too expensive compared to other options. Laser sensors have been determined by the team that they could work but are not ideal due to higher cost per unit and less reliability from requiring a power source on the connecting rod.

Figure 5: Banner Laser Sensor

Thermocouples

Thermocouples are another sensor the team has researched during this project. These types of sensors are used in many automotive applications to read temperatures on an engine. For this application one end of the thermocouple would be attached to the top of the connecting rod and the other end would either be attached to the frame, or attached to a thermocouple reader on the connecting rod. It would then require an additional step to transmit a signal to the sensor receiver on the frame. Figure 6 is an example of a thermocouple.

Figure 6: Thermocouple

With this sensor requiring a separate transmitter, this will add to the cost of the sensor application. The team has found that there are other options that are more cost effective than this setup.

Vibration Sensors

Another possible type of sensor device would be a vibration type detector to listen for changes in vibration. This is common practice when measuring motors, pumps and bearings. However, it is unclear how much noise is inherent in the system whether or not this would be a feasible option. Further research of this sensor has shown that these sensors are expensive but also may be very difficult in determining a bearing failure quick enough. This will also require much further research and testing to be able to filter out noise in the vibration readings and determine a bearing failure when it does happen. Figure 7 below is an IFM brand vibration sensor that can be externally mounted to the machine using a magnetic mount that would be screwed on the metal threaded end. The idea behind this sensor is that it could be mounted farther away from the connecting rod and therefore require no reduction in structural integrity of the connecting rod.

Figure 7: IFM Vibration Sensor

Bi-Metallic Strip

Another concept that the team initially investigated was the use of a bi-metallic strip sensor. The concept was investigated because it utilizes a purely mechanical method which would improve reliability. A bi-metallic strip uses two different strips of metal that are adhered together. Because the two metals have different thermal expansion rates the metallic strip will bend and either close or open an electric circuit. It was determined that bi-metallic strip was unable to meet the reaction time necessary for the connecting rod sensor, therefore this idea has been eliminated. Figure 8 is a diagram showing how the bi-metallic strips work.

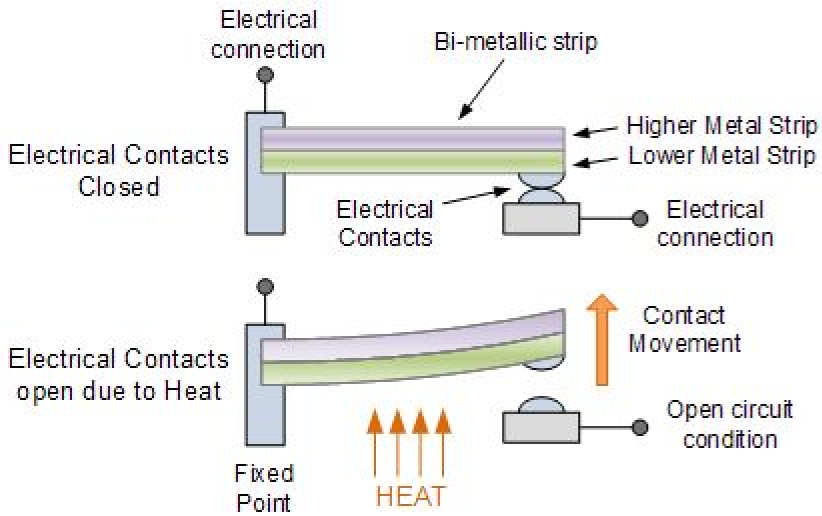

Figure 8: Bi-Metallic Strip Sensor Concept

Wifi Sensor

Another concept that is possible is using wifi as a transmitter to emit a temperature reading from the crankshaft to Ariel's programmable logic controller. This concept has been eliminated, however there are still issues that have yet to be proofed for possibilities later. If the wifi signal is stopped, deflected, blocked, altered, or through some other means rendered ineffective it will render the sensor useless. It is difficult to know if there are other devices at the compressor's location that are emitting wifi signals. The use of a wifi sensor will have to be proven and investigated to see if these sensors are cost effective.

These sensors will use a transmitter that is on the connecting rod/crankshaft and a receiver attached to the frame. Using the rotation these two will pass each other and while passing, they will transmit a signal with the temperature to the receiver to be sent to the PLC. If the PLC sees a temperature that is too high, the compressor will shut off.

Kongsberg System

It was expected that the Kongsberg system would work for this application. The issue with the Kongsberg system is that it requires an additional programmable logic controller. The additional controller adds a significant amount to the cost of the project. This system has been proven and will serve as a baseline comparison to other sensors. Currently this option is used in the R&D lab at Ariel, but to implement these to each and every compressor that is installed currently is not cost effective. Also, due to the complexity of the programming that needs to be done between the Kongsberg PLC and the Ariel PLC it will also add to the cost as each compressor is different.

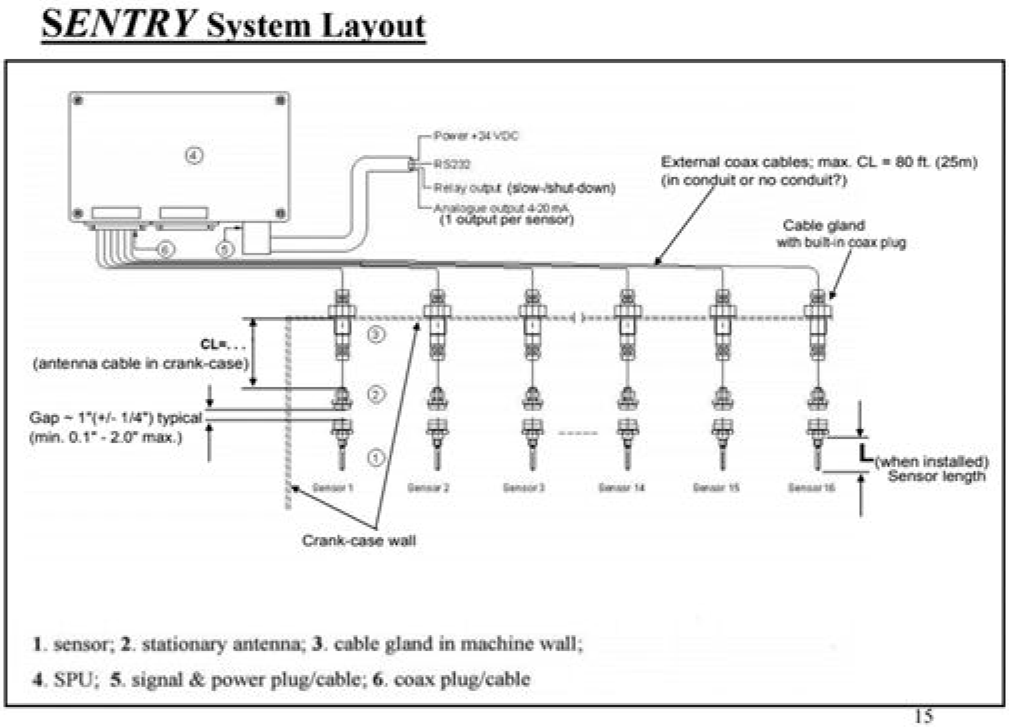

Figure 9: Kongsberg System PLC & Sensors

Expected Findings

Mounting the Sensor

There were multiple design criteria for properly mounting the sensor within the head of the connecting rod. One of the design criteria was to mount the sensor in a way that makes the system easier to use and maintain. In the past there have been issues with mounting the sensor receiver on the lid or top of the frame. Each time the lid is removed the sensor receiver has to be either adjusted or manipulated which adds time to general maintenance procedures.. The sensor can be mounted through the side of the frame which will make for better system maintenance.

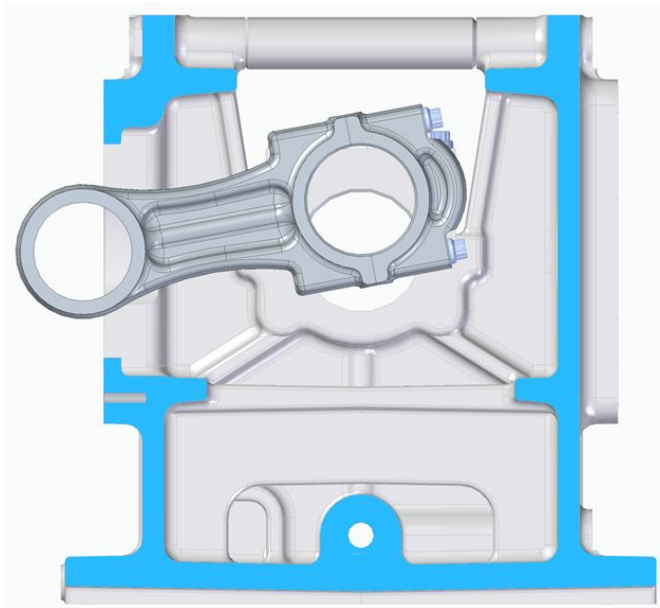

Figure 10: Compressor side view cutaway lid removed from drawing.

The purpose of this sensor is to get as close to the large end bearing of the connecting rod as possible. There is not enough material between the bolt heads for the sensor to be mounted in that orientation see Figure 11. Also, there is not enough clearance between the connecting rod horizontally along the crankshaft axis to mount a sensor and align that sensor with a receiver on the frame. Simple, inexpensive proximity sensors have a relatively short range (less than 2 inches) which makes this a bad option. This leaves the only possible mounting location as the radiused part on the head of the connecting rod.

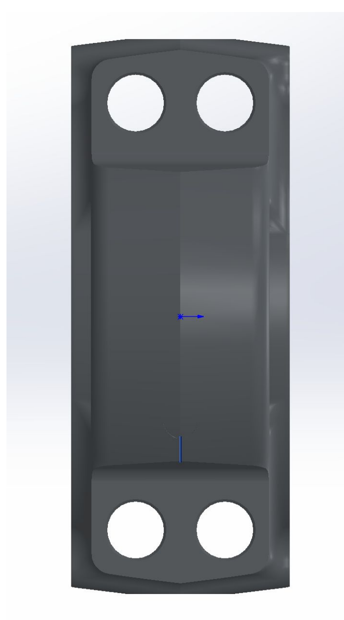

Figure 11: Connecting rod space between bolts.

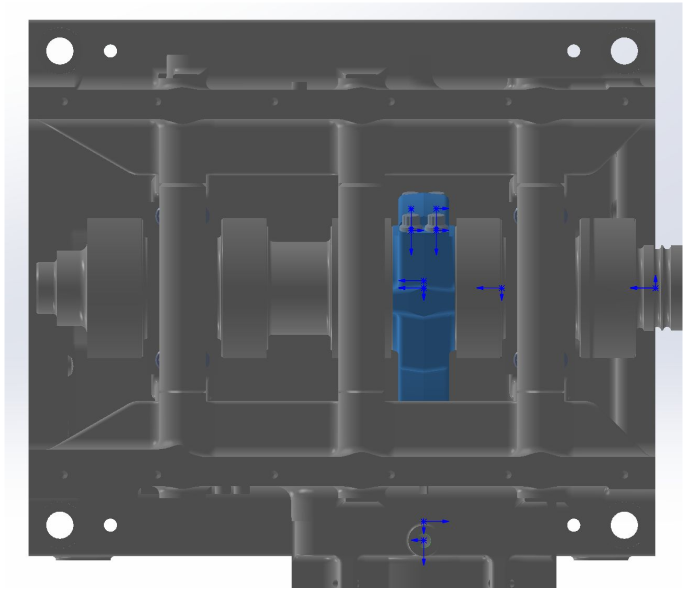

Figure 12: Connecting Rod Top View Connecting rod in blue.

Another constraint is the bearing has an oil groove along its center. Because any measurements taken along the groove will provide higher temperature readings the sensor head will have to be mounted to the side of the groove. This is complicated by the fact the connecting rod head has recesses in each side. Therefore the entry hole for the sensor has to be placed on the opposite side to avoid drilling through either recess.

Figure 13: Bearing with grease groove along center.

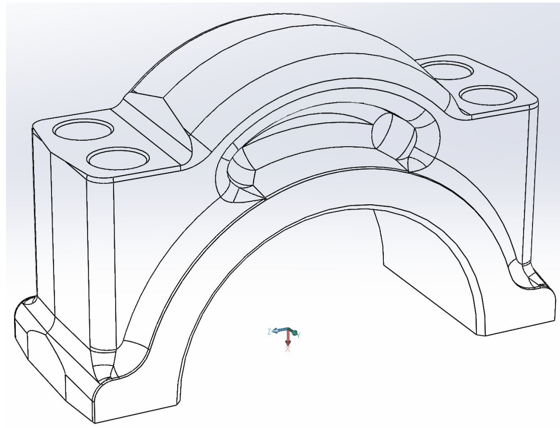

Figure 14: Recess shown on top of connecting rod head.

The sensor also had to be mounted in a way that supports the specifications of the sensor manufacturer. For this reason we chose the smallest sensor body size which was 5/16” diameter as our sensor (AMOT 4012M).. The following figure 15 shows our finished drawing for the connecting rod head.

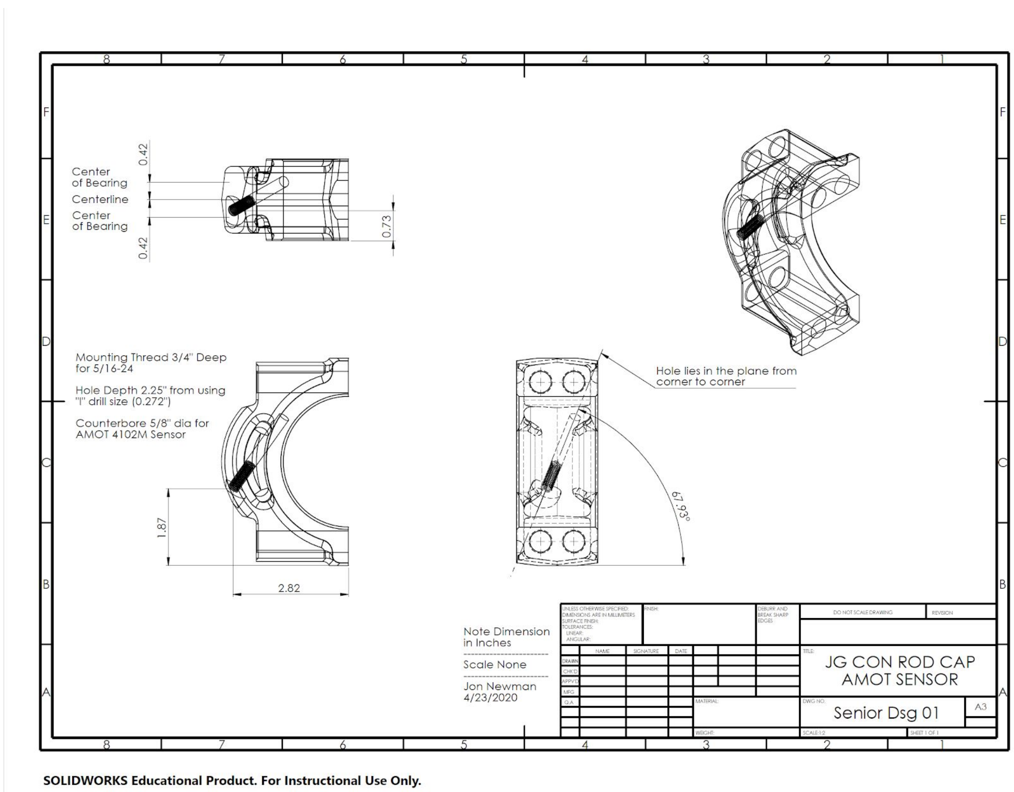

Figure 15: The team’s drawing for Ariel Corp. to use for mounting.

The circuit will be completed by a simple proximity sensor with a flag. A flag mounted on a hinge will be mounted on the frame of the compressor. The AMOT sensor is spring activated and will extend ½" once the temperature rise is detected. The flag will be struck by the AMOT sensor and physically moved away from the proximity sensor. This solution is cost effective as the flag can be easily reset by maintenance personnel when troubleshooting why the compressor shut down.

Heat Transfer

One of the design constraints for this project was to determine how far away from the bearing the eutectic sensor needs to be mounted. The closer the sensor is mounted to the bearing the faster the temperature difference will propagate through the steel. Due to the drilling angle geometries and the rate of heat transfer our design has the sensor mounted roughly ⅛" away from the bearing.

The table below, figure 16, shows the rate of heat transfer in a single plane environment. The first column is the thickness of the plane, and the table of data displays the temperature through the wall given a certain amount of time in seconds. The temperature gradient is the difference between the ambient temperature in the system and peak temperature of the bearing overheat. For example if the system is running at 200 degrees F and the bearing overheats at 300 degrees F a temperature gradient of 60% of the difference or 260 degrees F would be observed through the plane at (2 seconds time (t), ⅛" wall thickness).

These temperature measurements are not exact but they are sufficient to prove that the sensor is capable of the quick response time needed in this application.

Heat Conduction in 1D					
Wall Thickness	Temperature Gradient (seconds)				
Inches	1	2	5	10	30
0.0625	0.7226	0.8018	0.8739	0.9106	0.9483
0.125	0.4777	0.6157	0.7509	0.8224	0.8969
0.25	0.1556	0.3154	0.5254	0.6534	0.7955
0.5	0.0045	0.0446	0.2041	0.3692	0.6041

Figure 16: Heat Transfer Table for Connecting Rod Material

Structural Integrity

The size of the hole that is bored into the side of the connecting rod is one of the main concerns the team will need to consider. If the hole is too big it could compromise the structural integrity of the connecting rod. The structural integrity of the connecting rod is one of the constraints for this design project. The connecting rod needs to maintain its infinite life.

Assumptions made in FEA analysis. The force applied is 6750 lbs applied on the interior wall of the large end of the connecting rod. The force is supported by the bolts of the connecting rod.

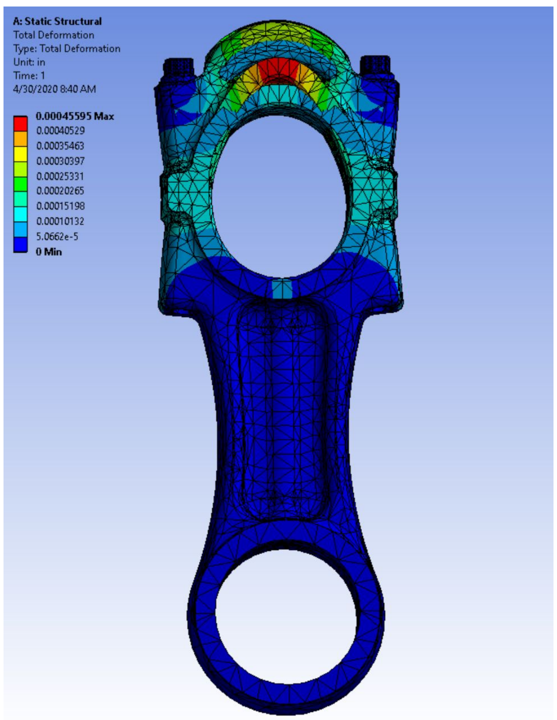

Figure 17: Total Deformation

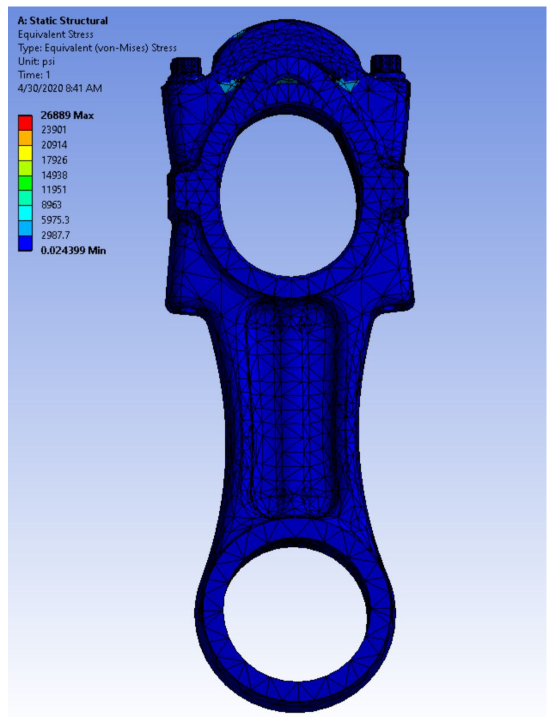

Figure 18: Stress

The finite element analysis shows that the stress concentrations are located by the bolts, in the recessed areas, and by the counterbore of the hole. The greatest stress concentration on the part is shown to be 26,889 psi. The ultimate tensile strength of forged steel is 60,900 psi. Therefore the factor of safety for this test is 2.26. This is sufficient for the trial, and therefore these sensors should be sufficient for similar sized or larger compressors.

Conclusion and Recommendations

The final test will be completed at the Ariel Corporation facilities shortly after this report has been written. The team will follow up with Ariel Corporation to see the results of the trial. We believe that AMOT 4102M sensor will work in this specific application and will work for a majority of the applications in the compressor fleet. The sensor will react quick enough to the changes in temperature, does not reduce structural integrity significantly, and is relatively inexpensive compared to other sensors on the market.

References

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Appendices

Appendix A: AMOT Sensor Manual

amot

Model 4102 D, E, F, J

Temperature Detectors

U.S. PATENT NO. 3,401,666

4102D, E, F & J Temperature Detector with projection

4102D, E, F & J Temperature Detecto r

6702X Replaceable Fuse Rod Assembly

FEATURES

Protect bearings, shafts, and other moving parts from damage due to unsafe high temperature levels.

- **RELIABLE PROTECTION**
- **INSTANT RESPONSE TO EXCESSIVE BEARING TEMPERATURES**
- **COMPACT DESIGN**
- **EASE OF INSTALLATION**
- **USE WITH OIL, AIR, OR GAS**
- **SIZES TO FIT MOST ENGINES**

APPLICATIONS

- **HIGH BEARING AND FLUID TEMPERATURE DETECTION**
- **POWER OR COMPRESSOR CYLINDER OVERLOAD**
- **HIGH PACKING GLAND TEMPERATURE DETECTION**

AMOT Model 4102 Temperature Detectors, like the 4103 Valve Series, incorporate an time proven heat detecting principle to provide a safety device suitable for modern low and medium speed engines. A thin film of eutectic alloy, less than 0.001 cubic inch in volume, secures a spring loaded fuse rod until the temperature at the sensing end of the rod melts the alloy. The fuse rode is then instantly released and moves outward 5/16". Model 4102's instant response, in addition to its relatively small size, makes it ideal for use in moving parts such as connecting rod bearings which must be protected from excessive temperatures. Such temperatures may arise from tight, worn or out-of-round bearings, tight packing glands, cracked or broken shafts, torsional vibration, power or compressor cylinder overload, lack of lubricant flow and many other sources.

Model 4102 has been thoroughly field tested by AMOT and several of the largest engine and compressor users. They have proven accurate and reliable in many types of engines in gas compression, power generation, pipeline, marine and general industrial service. They have the most efficient response of any mechanical device now in use. Due to their small eutectic mass, the detectors are nearly as responsive as, and in some cases, more reliable than thermocouples. AMOT Model 4102 Temperature Detectors do not require the impractical electrical wiring of electrical sensors.

To convert the detector tripping action into a usable signal, an AMOT Model 4095 Vent Valve is required as shown in Fig. 1.

AMOT Model 4102 Temperature Detectors are designed for use in moving parts such as connecting rod bearings. For stationary bearing applications, refer to AMOT model 4103 in which the vent valve is incorporated in the temperature detector.

FORM 651

INSTALLATION

AMOT Model 4102 Temperature Detectors are the basic sensing units in a safety system. They trip a vent valve which must be tied into the system through connecting tubing. Control pressure may be clean dry air, gas, or a non-corrosive liquid such as lubricating oil.

Air or gas can be used on many applications, however, the use of gas may not be desired in a hazardous location. Air/gas systems are more versatile and will give faster response than an oil pressured system.

Oil is normally used in systems within an engine as shown in Figure 2. Connecting tubing should be 5/16" O.D. Close-tee each sensing device to the control pressure line and pipe them in series with the Master Safety Control or Alarm being the last component in the line.

Model 4102 is not recommended for installation where oil pressure may leak along the unsealed Fuse Rod shaft.

Maximum pressure to the IN port of the 4095 Vent Valve is 60 psi.

Figure 1 illustrates the general method of installing Model 4102 in a moving part. An AMOT 4095 Vent Valve is mounted on a bracket near the Fuse Rod tip. If possible, the vent valve should be installed above the oil level in the sump. This makes visual checking possible and aids in manually resetting the valve when hot. This type of installation further prevents the possibility of a "drag" effect tipping the vent valve lever when the fuse rod tip passes in very cold oil. Normally, a 1/8" gap is left between the valve trip lever and the fuse rod tip. When the 4102 trips, the extended rod will strike the vent valve handle on the next pass and initiate the alarm or shutdown sequence.

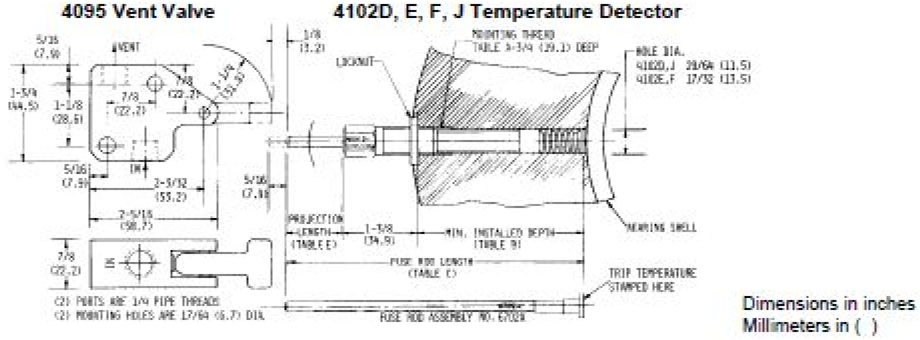
Model 4102 must NOT be installed with the fuse rod tip permitted to dip in the sump.

As shown in Figure 1, the unit should be screwed into a mounting hole in the bearing support until the proper projection length is obtained. This may be measured or a simple tubing gauge of the proper length may be made to slip over the fuse rod tip. Tighten in place with the locknut.

DIMENSIONS / INSTALLATION

FIG. 1

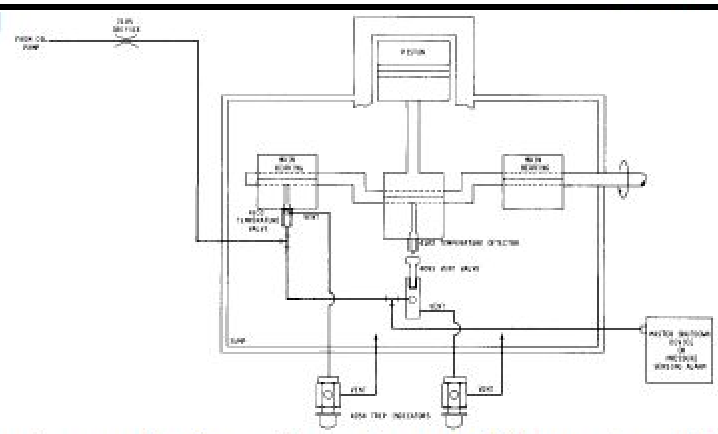
4095 Vent Valve **4102D, E, F, J Temperature Detector**



Dimensions in inches
Millimeters in ( )

TYPICAL APPLICATION

FIG. 2



This safety circuit will shut down the engine or sound an alarm on either low oil pressure or high temperature as detected in the stationary main bearings or the moving connecting rod bearings. Model 4054 Trip Indicators will show the origin of the shutdown signal. Additional sensors can easily be added for water jacket temperature, overspeed, water pump output, crankcase pressure and additional bearing temperatures.

HOW TO ORDER

When ordering please specify the following:

1. Indicate Model 4102.
2. Mounting Thread:
   1/2-20 NF
   5/8-11 NC
   5/8-18 NF
3. Installed Depth, see Table B.
4. Fuse Rod Length (in 1/2" increments up to 3"), see Table E.
5. Trip Temperature in deg. F; 174, 197, 217, 228, 253, 291, or 343.
6. The following special features if required:
   a. M14 x 2 metric Mounting Thread
      Available from UK factory only.

This unit may be ordered using the full description as shown above or by constructing a Model No. using the Model Code System.

MODEL CODE SYSTEM

4102 D 04 C 09 197 ( )

Basic Model No.

Revision Level

Special Requirements (MTO) Made-to-Order

Replacement Fuse Rod: 6702X 09 T 197

TABLE A	
Mounting Thread	
Code No.	Thread
D	1/2-20 NF
E	5/8-11 NC
F	5/8-18 NF
J**	M14 x 2

TABLE B				
Installed Depth				
Code No.	Minimum *		Maximum *	
04	2	(50.8)	2-1/2	(63.5)
05	2-1/2	(63.5)	3	(76.2)
06	3	(76.2)	3-1/2	(88.9)
07	3-1/2	(88.9)	4	(101.6)
08	4	(101.6)	4-1/2	(114.3)
09	4-1/2	(114.3)	5	(127.0)
10	5	(127.0)	5-1/2	(139.7)
11	5-1/2	(139.7)	6	(152.4)
12	6	(152.4)	6-1/2	(165.1)
13	6-1/2	(165.1)	7	(177.8)
14	7	(177.8)	7-1/2	(190.5)
15	7-1/2	(190.5)	8	(203.2)
16	8	(203.2)	8-1/2	(215.9)
17	8-1/2	(215.9)	9	(228.6)
18	9	(228.6)	9-1/2	(241.3)
19	9-1/2	(241.3)	10	(254.0)
20	10	(254.0)	10-1/2	(266.7)

TABLE C		
Fuse Rod Length		
Code No.	Length *	
04	3-3/8	(85.7)
05	3-7/8	(98.4)
06	4-3/8	(111.1)
07	4-7/8	(123.8)
08	5-3/8	(136.5)
09	5-7/8	(149.2)
10	6-3/8	(161.9)
11	6-7/8	(174.6)
12	7-3/8	(187.3)
13	7-7/8	(200.0)
14	8-3/8	(212.7)
15	8-7/8	(225.4)
16	9-3/8	(238.1)
17	9-7/8	(250.8)
18	10-3/8	(263.5)
19	10-7/8	(276.2)
20	11-3/8	(288.9)
21	11-7/8	(301.6)
22	12-3/8	(314.3)
23	12-7/8	(327.0)
24	13-3/8	(339.7)
25	13-7/8	(352.4)
26	14-3/8	(365.1)

TABLE D	
Trip Temperature	
°F	(°C)
174	(79)
197	(92)
217	(103)
228	(109)
253	(123)
291	(144)
324	(162)
343	(173)

TABLE E							
Fuse Rod Selection Chart (use with Table C)							
Install Depth Code No. (From Table B)	Projection Length						
	Flush	1/2"	1'	1-1/2"	2"	2-1/2"	3"
04	04	05	06	07	08	09	10
05	05	06	07	08	09	10	11
06	06	07	08	09	10	11	12
07	07	08	09	10	11	12	13
08	08	09	10	11	12	13	14
09	09	10	11	12	13	14	15
10	10	11	12	13	14	15	16
11	11	12	13	14	15	16	17
12	12	13	14	15	16	17	18
13	13	14	15	16	17	18	19
14	14	15	16	17	18	19	20
15	15	16	17	18	19	20	21
16	16	17	18	19	20	21	22
17	17	18	19	20	21	22	23
18	18	19	20	21	22	23	24
19	19	20	21	22	23	24	25
20	20	21	22	23	24	25	26

NOTE: Letters or numbers in the MTO space, other than nothing, A1 or AA, indicate the unit is built to special requirements and some of the other code numbers may not be valid. Check with the factory for full specifications of such models.

* Dimensions in inches; millimeters in ( ).
See Figure 1 for dimension identification.

HOW TO ORDER REPLACEMENT FUSE RODS

When ordering please specify the following:

1. Indicate Fuse Rod Assembly Model 6702X.
2. Fuse Rod length; see Table C.
3. Trip Temperature in deg. F; see Table D.

[shaded box] = Non Standard Product, special charges may apply.

MAINTENANCE

It is recommended that the overall safety system be checked monthly for proper functioning by simulating an unsafe condition.

AMOT recommends maintenance including visual inspection at the major overhaul of the engine or yearly if lacquering of the lube oil is observed. Excessive lacquering can cause sticking which impairs operation. Unscrew the Detector from the mounting hole and remove Fuse Rod Assembly (4) with a twisting motion. Hold it by the ends and visually examine the eutectic alloy area for exposed alloy. Visible alloy should be a clean fillet around the two brass sections of the Fuse Rod Assembly. Look for cracks in the brass. A stable Fuse Rod Assembly moves slightly showing no wear. Fuse Rod Assemblies should be replaced if the crimp section becomes loose.

Life expectancy of Fuse Rod Assemblies is five (5) years under normal operating conditions and proper maintenance.

If desired, maintenance of the Fuse Rod Assemblies themselves may include random sampling and test firing to ensure correct temperature.

WARNING
When unrestrained Fuse Rod Assemblies are heated, they fire with sufficient force to cause injury or damage. Be sure that the Fuse Rod is restrained or aimed in a safe direction.

Heat a mixture of 50% glycol and 50% water, stirring constantly. Place the Fuse Rod in the heated liquid. Use a mercury thermometer to check the temperature of the liquid. The Fuse Rod Assembly should trip within 4 °F of the temperature stamped on the bottom of the rod. DO NOT resolder a eutectic Fuse Rod; the Rod extends upon firing.

FUSE ROD ASSEMBLY REPLACEMENT

When a Model 4102 Temperature Detector trips, it has detected excessive heat. Check for proper operating temperature of the oil and check the bearing for signs of distress to determine the source of the heat. To replace Fuse Rod Assembly (4), remove the entire Temperature Detector from the mounting hole and withdraw the expended Fuse Rod with the rod tip and Loading Spring (5). Insert the new Fuse Rod Assembly and reassemble the Temperature Detector with the Loading Spring fully seated on the Rod Tip. Reinstall the unit in the mounting hole and adjust the depth as described under installation.

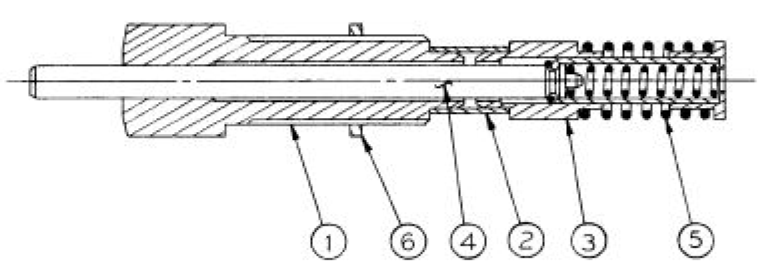
STATEMENT OF POLICY

AMOT Controls Corporation is ready to aid the user in the applications of Model 4102 Miniature Temperature Detectors to the extent of its knowledge and experience. Decisions such as actual location of the installation, insertion length, details of machining, mounting of vent valves and connection to the safety system should only be made by the user after he has physically checked the equipment under consideration.

AMOT can be responsible only for proper operation of the devices providing they have been installed according to AMOT's instructions. AMOT cannot be responsible for improper adjustment, location, connections, or problems arising from stress concentration. Should there be any reservations or unresolved details concerning the application, the user should contact the manufacturer of the protected equipment for additional information.

SERVICE PARTS

Replacement Fuse Rod Assemblies (5) are ordered by Basic Part No. 6710X plus the proper code numbers from Tables C & D of the Model Code System



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Form 651 C971

Appendix B: Heat Transfer

1-D Thermal Diffusion Equation and Solutions

3.185

Fall, 2003

The 1-D thermal diffusion equation for constant k, ρ and c_p (thermal conductivity, density, specific heat) is almost identical to the solute diffusion equation:

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2} + \frac{\dot{q}}{\rho c_p} \tag{1}$$

or in cylindrical coordinates:

$$r\frac{\partial T}{\partial t} = \alpha \frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + r\frac{\dot{q}}{\rho c_p} \tag{2}$$

and spherical coordinates:[1]

$$r^2\frac{\partial T}{\partial t} = \alpha \frac{\partial}{\partial r}\left(r^2\frac{\partial T}{\partial r}\right) + r^2\frac{\dot{q}}{\rho c_p} \tag{3}$$

The most important difference is that it uses the thermal diffusivity $\alpha = \frac{k}{\rho c_p}$ in the unsteady solutions, but the thermal conductivity k to determine the heat flux using Fourier's first law

$$q_x = -k\frac{\partial T}{\partial x} \tag{4}$$

For this reason, to get solute diffusion solutions from the thermal diffusion solutions below, substitute D for both k and α, effectively setting ρc_p to one.

[1] Most texts simplify the cylindrical and spherical equations, they divide by r and r^2 respectively and product rule the r-derivative apart. This gives

$$\frac{\partial T}{\partial t} = \alpha\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right) + \frac{\dot{q}}{\rho c_p}$$

for cylindrical and

$$\frac{\partial T}{\partial t} = \alpha\left(\frac{\partial^2 T}{\partial r^2} + \frac{2}{r}\frac{\partial T}{\partial r}\right) + \frac{\dot{q}}{\rho c_p}$$

for spherical coordinates. I prefer equations 2 and 3 because they are easier to solve.

1-D Heat Conduction Solutions

1. Steady-state
   (a) No generation
      i. Cartesian equation:
      $$\frac{d^2T}{dx^2} = 0$$
      Solution:
      $$T = Ax + B$$
      Flux magnitude for conduction through a plate in series with heat transfer through a fluid boundary layer (analagous to either 1st-order chemical reaction or mass transfer through a fluid boundary layer):
      $$|q_x| = \frac{|T_{fl} - T_1|}{\frac{1}{h} + \frac{L}{k}}$$
      (T_{fl} is the fluid temperature, analagous to the concentration in equilibrium with the fluid in diffusion; T_1 is the temperature on the side opposite the fluid.)
      Dimensionless form:
      $$\pi_q = 1 - \frac{1}{1 + \pi_h}$$
      where $\pi_q = \frac{q_x L}{k(T_{fl} - T_1)}$ and $\pi_h = \frac{hL}{k}$ (a.k.a. the Biot number).
      ii. Cylindrical equation:
      $$\frac{d}{dr}\left(r\frac{dT}{dr}\right) = 0$$
      Solution:
      $$T = A \ln r + B$$
      Flux magnitude for heat transfer through a fluid boundary layer at R_1 in series with conduction through a cylindrical shell between R_1 and R_2:
      $$|r \cdot q_r| = \frac{|T_{fl} - T_2|}{\frac{1}{hR_1} + \frac{1}{k}\ln\frac{R_2}{R_1}}$$
      iii. Spherical equation:
      $$\frac{d}{dr}\left(r^2\frac{dT}{dr}\right) = 0$$
      Solution:
      $$T = \frac{A}{r} + B$$
   (b) Constant generation
      i. Cartesian equation:
      $$k\frac{d^2T}{dx^2} + \dot{q} = 0$$
      Solution:
      $$T = -\frac{\dot{q}x^2}{2k} + Ax + B$$
      ii. Cylindrical equation:
      $$k\frac{d}{dr}\left(r\frac{dT}{dr}\right) + r\dot{q} = 0$$
      Solution:
      $$T = -\frac{\dot{q}r^2}{4k} + A \ln r + B$$

iii. Spherical equation:

$$k\frac{d}{dr}\left(r^2\frac{dT}{dr}\right)+r^2\dot{q}=0$$

Solution:

$$T=-\frac{\dot{q}r^2}{6k}+\frac{A}{r}+B$$

(c) (Diffusion only) first-order homogeneous reaction consuming the reactant, so $G=-kC$

i. Cartesian equation:

$$D\frac{d^2C}{dx^2}-kC=0$$

Solution:

$$C=Ae^{\sqrt{\frac{k}{D}}x}+Be^{-\sqrt{\frac{k}{D}}x}$$

or:

$$C=A\cosh\left(\sqrt{\frac{k}{D}}x\right)+B\sinh\left(\sqrt{\frac{k}{D}}x\right)$$

ii. Cylindrical and spherical solutions involve Bessel functions, but here are the equations:

$$D\frac{d}{dr}\left(r\frac{dC}{dr}\right)-krC=0$$

$$D\frac{d}{dr}\left(r^2\frac{dC}{dr}\right)-kr^2C=0$$

2. Unsteady solutions without generation based on the Cartesian equation with constant k and ρc_p:

$$\frac{\partial T}{\partial t}=\alpha\frac{\partial^2 T}{\partial x^2}$$

where $\alpha=\frac{k}{\rho c_p}$.

(a) Uniform initial condition $T=T_i$ (or $T=T_\infty$), constant boundary condition $T=T_s$ at $x=0$, semi-infinite body; or step function initial condition in an infinite body.

Solution is the error function or its complement:

$$\frac{T-T_s}{T_i-T_s}=\mathrm{erf}\left(\frac{x}{2\sqrt{\alpha T}}\right)$$

$$\frac{T-T_i}{T_s-T_i}=\mathrm{erfc}\left(\frac{x}{2\sqrt{\alpha T}}\right)$$

Semi-infinite criterion:

$$\frac{L}{2\sqrt{\alpha t}}\geq 2$$

Note: this also applies to a "diffusion couple", where two bodies of different temperatures (or concentrations) are joined at $x=0$ and diffuse into each other; the boundary condition there is halfway between the two initial conditions. This works only if the (thermal) diffusivities are the same.

(b) Fixed quantity of heat/solute diffusing into a (semi-)infinite body (same semi-infinite criterion as 2a), no flux through $x=0$, initial condition $T=T_i$ (or $T=T_\infty$) everywhere except a layer of thickness δ if semi-infinite or 2δ if fully infinite where $T=T_0$.

Short-time solution consists of erfs at the interfaces, like a diffusion couple.

Long-time solution is the shrinking Gaussian:

$$T=T_i+\frac{(T_0-T_i)\delta}{\sqrt{\pi\alpha t}}\exp\left(-\frac{x^2}{4\alpha t}\right)$$

(c) Uniform initial condition $T = T_i$, constant boundary condition $T = T_s$ at $x = 0$ and $x = L$ (or zero-flux boundary condition $q_x = -k\partial T/\partial x = 0$ at $x = L/2$), finite body; *or* periodic initial condition (we've covered sine and square waves) in an infinite body.
Solution is the Fourier series:

$$T = T_s + (T_i - T_s)\sum_{n=0}^{\infty} a_n \exp\left(-\frac{n^2\pi^2\alpha t}{L^2}\right)\sin\left(\frac{n\pi x}{L}\right)$$

For a square wave or uniform IC in a finite body, $a_n = \frac{4}{n\pi}$ for odd n, zero for even n, T_s is the average temperature for a periodic situation or the boundary condition for a finite layer, L is the half period of the wave or the thickness of the finite layer.
The $n = 1$ term dominates when $\frac{\pi^2\alpha}{L^2}t \geq 1$.

(d) *Uniform initial condition $T = T_\infty$, constant flux boundary condition at $x = 0$ $q_x = -k\frac{dT}{dx} = q_0$, semi-infinite body (same semi-infinite criterion as 2a).
Solution:

$$T = T_\infty + \frac{q_0}{k}\left[2\sqrt{\frac{\alpha t}{\pi}}\exp\left(-\frac{z^2}{4\alpha t}\right) - z\left(1 - \text{erf}\frac{z}{2\sqrt{\alpha t}}\right)\right]$$

(e) *Uniform initial condition $T = T_\infty$, heat transfer coefficient boundary condition at $x = 0$ $q_x = -k\frac{dT}{dx} = h(T_{fl} - T)$, semi-infinite body (same semi-infinite criterion as 2a).
Solution:

$$\frac{T - T_{fl}}{T_\infty - T_{fl}} = \text{erfc}\left(\frac{x}{2\sqrt{\alpha t}}\right) - \exp\left(\frac{hx}{k} + \frac{h^2\alpha t}{k^2}\right)\cdot\text{erfc}\left(\frac{x}{2\sqrt{\alpha t}} + \frac{h\sqrt{\alpha t}}{k}\right)$$

*These solutions are neither covered nor required, but are here for your edification and future reference.

3. Moving body

If a body is moving relative to a frame of reference at speed u_x and conducting heat only in the direction of motion, then the equation in that reference frame (for constant properties) is:

$$\frac{\partial T}{\partial t} + u_x\frac{\partial T}{\partial x} = \alpha\frac{\partial^2 T}{\partial x^2} + \frac{\dot{q}}{\rho c_p}$$

Note that this is the diffusion equation with the substantial derivative instead of the partial derivative, and nonzero velocity only in the x-direction. Recall the definition of the substantial derivative:

$$\frac{D}{Dt} = \frac{\partial}{\partial t} + \vec{u}\cdot\nabla$$

Applied to temperature with $u_y = u_z = 0$:

$$\frac{DT}{Dt} = \frac{\partial T}{\partial t} + u_x\frac{\partial T}{\partial x}$$

Therefore:

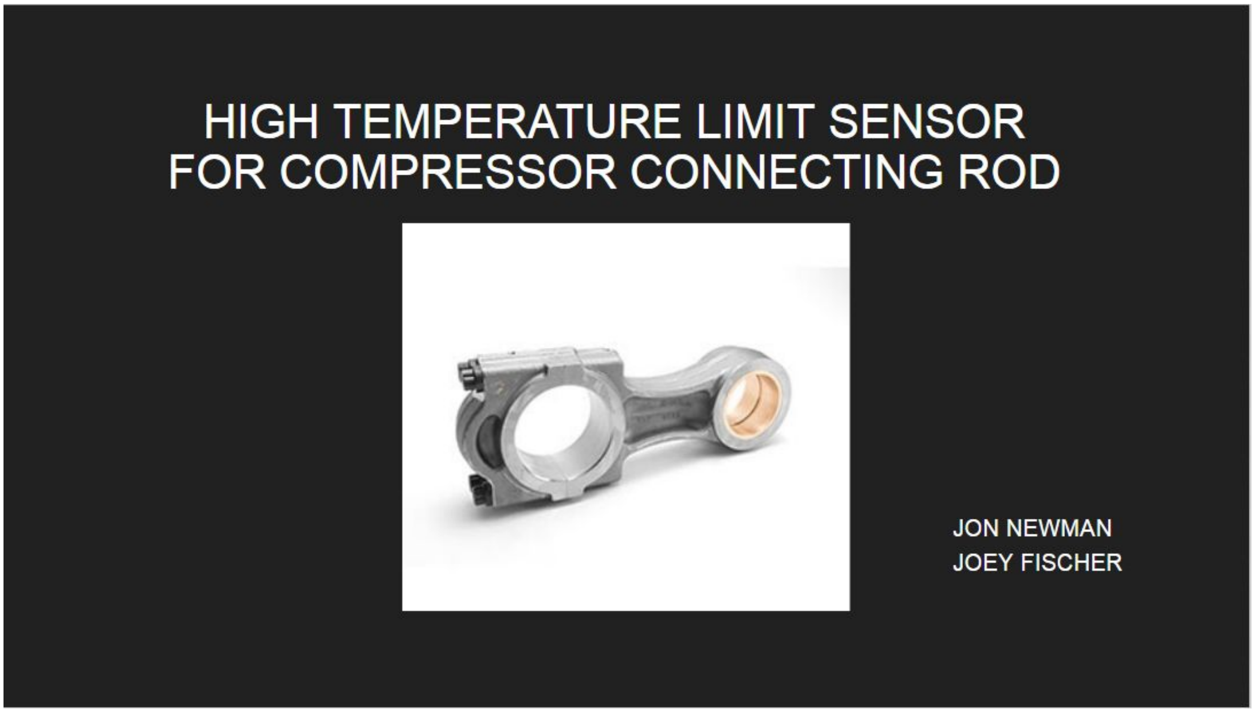
$$\frac{DT}{Dt} = \alpha\frac{\partial^2 T}{\partial x^2} + \frac{\dot{q}}{\rho c_p}$$

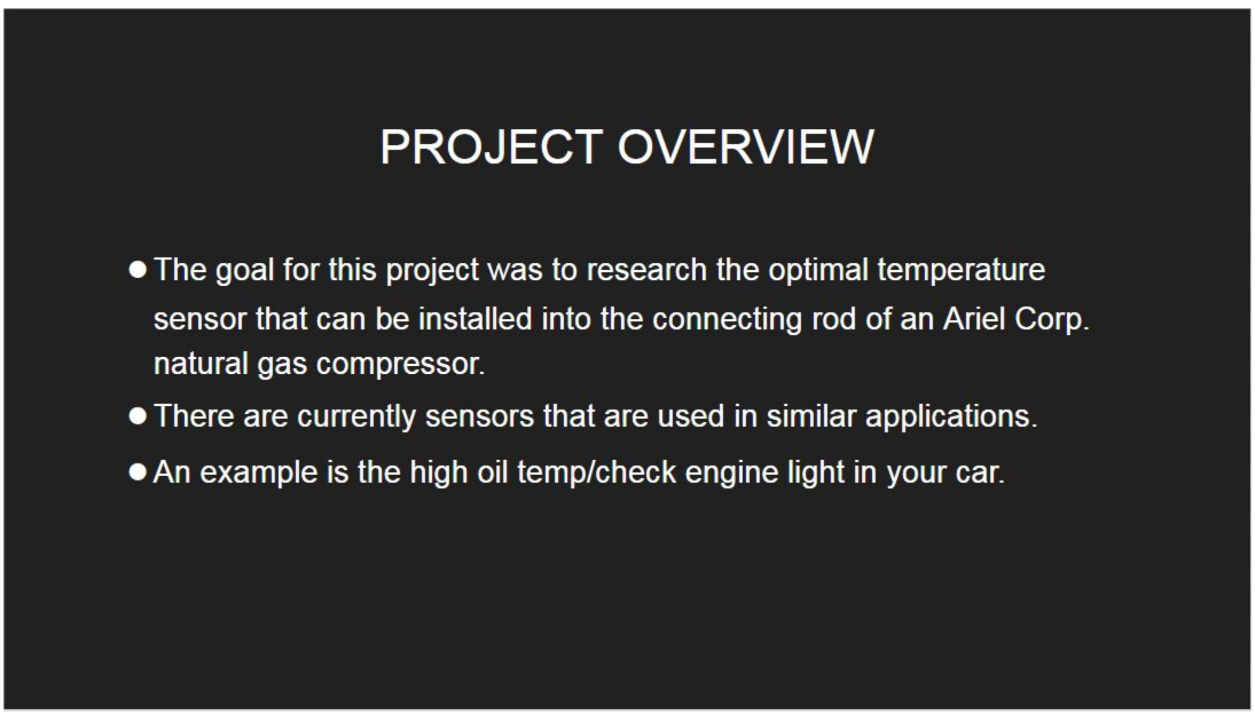
When this reaches steady-state, so $\frac{\partial T}{\partial t} = 0$, then the solution in the absence of generation is

$$T = A + Be^{u_x x/\alpha}$$

```
% erfcSoln - Error Function (complimentary) Solution to transient 1D Conduction
%
% 04/28/20 FAN

alpha = 1e-5 * m2in^2;      % thermal diffusivity steel in^2/sec.

x     = 1 ./ [16 8 4 2];
t     = [1 2 5 10 30];
nX    = length(x);
nT    = length(t);
dTR   = NaN(nX,nT);

for jX=1:nX
    for jT=1:nT
        dTR(jX,jT) = erfc( x(jX) / ( 2*sqrt(alpha*t(jT)) ) );
    end
end
```

Appendix C: Powerpoint





- Ariel Corporation is a leading manufacturer in the field of natural gas compressors.
- Natural gas compressors are used worldwide.
- Internet of Things sensor project
- This project has been sponsored by Ariel Corporation.

PROJECT OBJECTIVE

- The desired outcome was to find a simple, reliable, cost effective sensor while researching all options.
- Current sensors that have been used in research and development are not cost effective to mass produce.
- After finding the best sensor option, the sensor will be mounted on the large end of a connecting rod of an existing unit to test sensor reliability.
- Each compressor may have between 4-8 sensors attached.

ENGINEERING DESIGN TEMPERATURE AND PRESSURE

- Possible sensors must be able to withstand very cold temperatures if the compressor is not running while in a cold environment, and also need to withstand operating temperatures near 300°F.
- With these compressors being a closed operating system, the sensors must be able to withstand the slight pressure inside and also the oil that keeps these bearings cool.

ENGINEERING DESIGN REACTION TIME

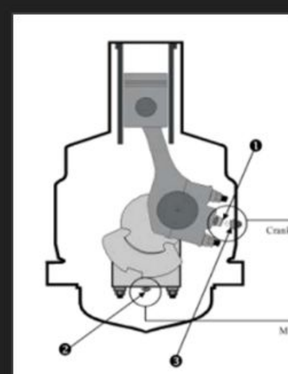
- From the point that the failure begins, the sensor has to send a signal to the controller within 2 to 3 seconds.
- This will determine how close to the bearing the sensor will need to be for this reaction time.
- This will also require for heat transfer equations to be used.

ENGINEERING DESIGN
POWER SUPPLY

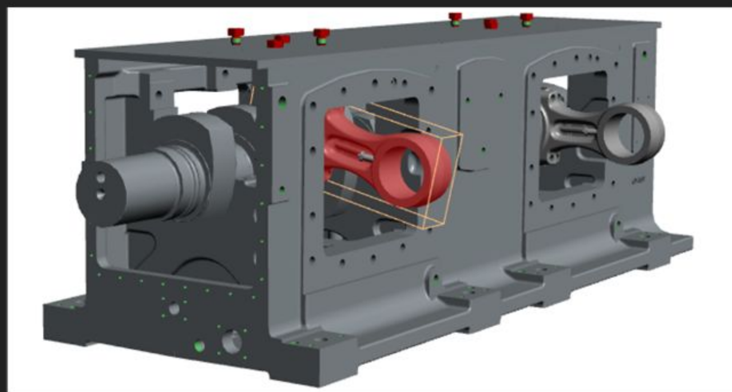
- Battery reliability is a major restriction for what kind of sensors that can be used.
- If a battery were to be used, it must be able to hold a charge for up to 3 years in the field.
- It also must be able to withstand major temperature differences while still keeping a charge.

ENGINEERING DESIGN
POWER SUPPLY

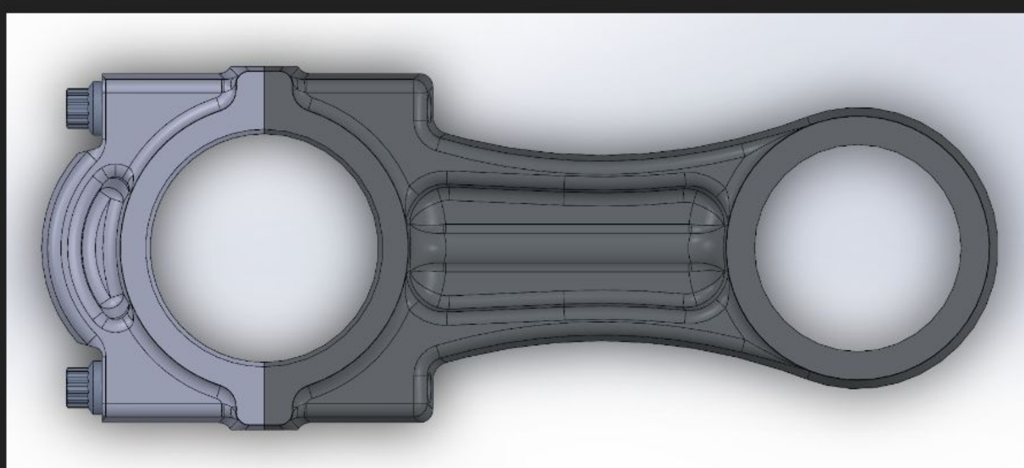
- One option for powering the sensors internally, would be using the rotational motion of the connecting rod.
- For this, a magnet mounted to the frame and a pickup on the shaft would use magnetic fields to produce a charge.



PARTIAL ASSEMBLY

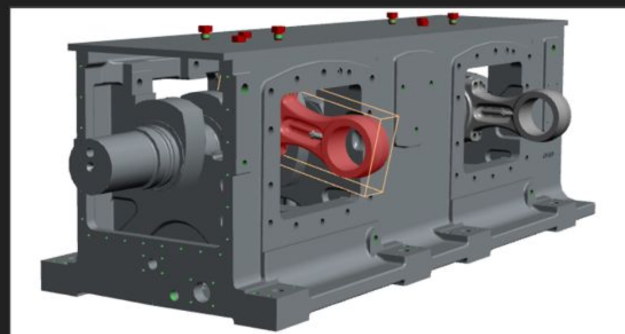


CONNECTING ROD



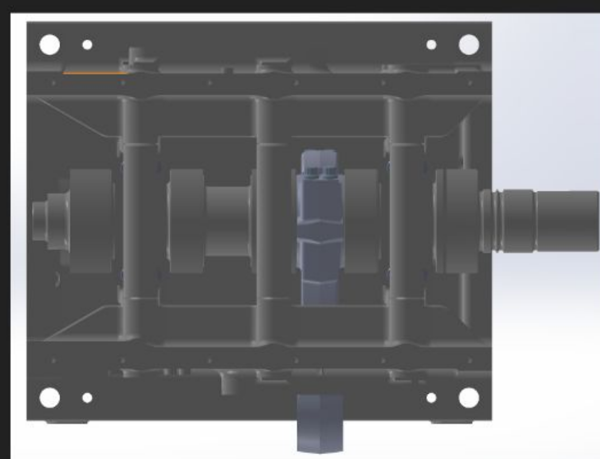
PROJECT JUSTIFICATION

- When a compressor fails there are multiple failures that can occur.
- If a failure can be caught early enough, the damage can be greatly reduced.

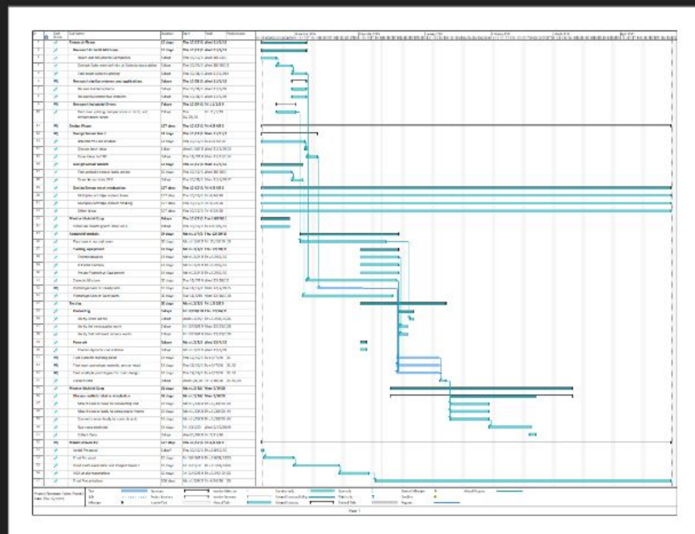


PROJECT JUSTIFICATION

- This sensor will be chosen with the intention to save the compressor frame, which is one of the highest cost components.
- This project has been requested in various forms by Ariel's customers.



GANTT CHART

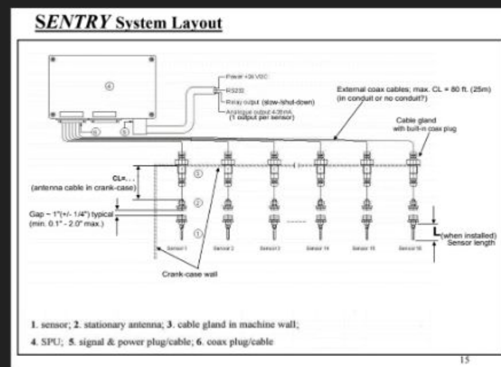


BUDGET

Part	QTY	Cost	Total Cost
AMOT Sensor			
Mount: 4102M03C10197	1	$ 405.64	405.64
Sensor: 7334X10T197	5	$ 122.57	612.85
Sensor: 7334X10T217	5	$ 122.57	612.85
Laser Concept			
Laser Sensor	1	$ 950.00	$ 950.00
Mount	1	$ 100.00	$ 100.00
Thermocouple Concept			
Thermocouple	1	$ 750.00	$ 750.00
Mount	1	$ 125.00	$ 125.00
Kongsberg System			
Kongsberg Sensors	1	$ 800.00	$ 800.00
PLC**	1	$20,000.00	$20,000.00

KONGSBERG SYSTEM

- This system is very expensive.
- Requires a separate PLC to control sensors.
- It will be very complex to program the Kongsberg PLC to the Ariel PLC.



VIBRATION SENSORS

- Vibration sensors are very commonly used on many machines to detect and prevent failures.
- These sensors are very costly and may not react quick enough to detect the failure if heat is only a sign.

WIFI SENSOR

- A WiFi sensor would use WiFi to transmit a temperature reading on the connecting rod back to the compressor PLC.
- The sensor would use a transmitter attached to the connecting rod and a receiver attached to the frame.
- Each time the two pass by each other, the sensor reading will be transmitted.
- This sensor has not yet been proven far enough to be a feasible option for this application.

THERMOCOUPLES

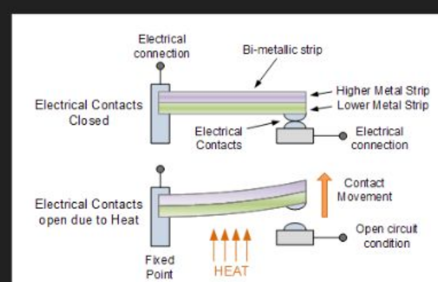
- Thermocouples was an option as well, that are used in many automotive applications.
- These sensors are not as expensive bit will not react as fast and require a power source.

LASER TEMPERATURE SENSOR

- Laser temperature sensors was an option researched for this system.
- This would fill the requirement of the reaction time, but the power supply needed will make it complex and expensive.

BI-METALLIC STRIP

- Bi-Metallic Strip sensor was an option that will not work for our application.
- This is due to the reaction time of the bearing failure and the time it takes for the metal to bend is not quick enough.



AMOT SYSTEM

- These sensors are commercially available and mass produced.
- These sensors fulfill the cost and reliability requirements.
  ****
- This sensor has been chosen to be tested at Ariel Corp.

REASONS FOR AMOT SENSOR

- No Power Supply or battery required.
- Can sit outside in environments where the temperature varies.
- Low Cost compared to other options.
- Quick enough response time.

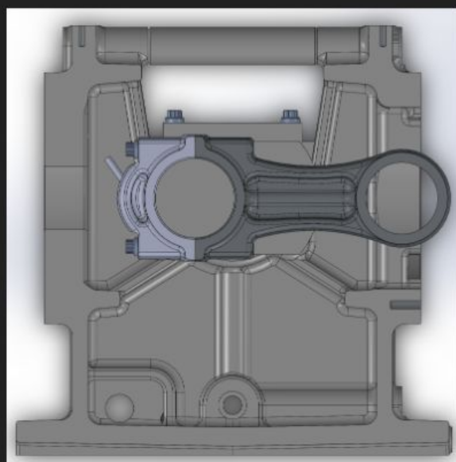
ENGINEERING QUESTIONS

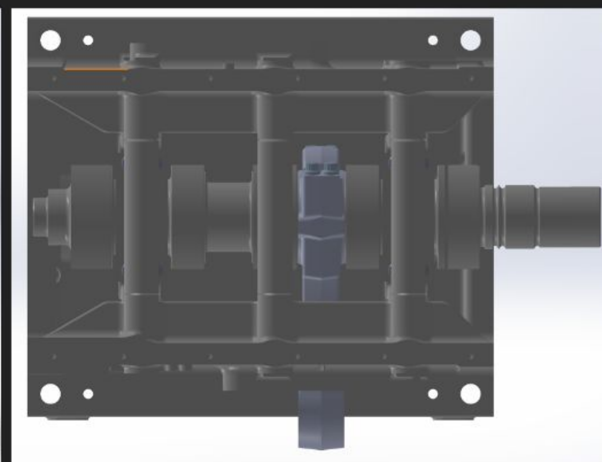
- How do we mount the sensor in the system?
- After drilling a hole will the connecting rod retain its structural integrity?
- How close to the bearing does the sensor have to be mounted in order to respond quickly to changes in temperature?

MOUNTING ISSUES

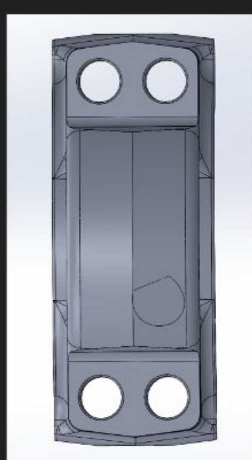
- Avoid placing the sensor in the lid or top of the frame for maintenance reasons.
- Where on the connecting rod should the sensor be mounted.
- The bearing has an internal groove along the center which has to be avoided.
- Mounting hole is 5/16” diameter, which is the smallest diameter sensor.

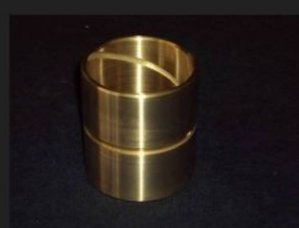
SPACE CONSTRAINT

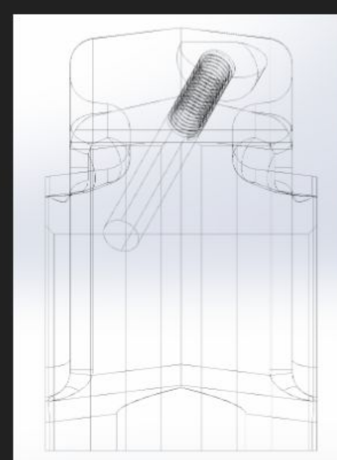




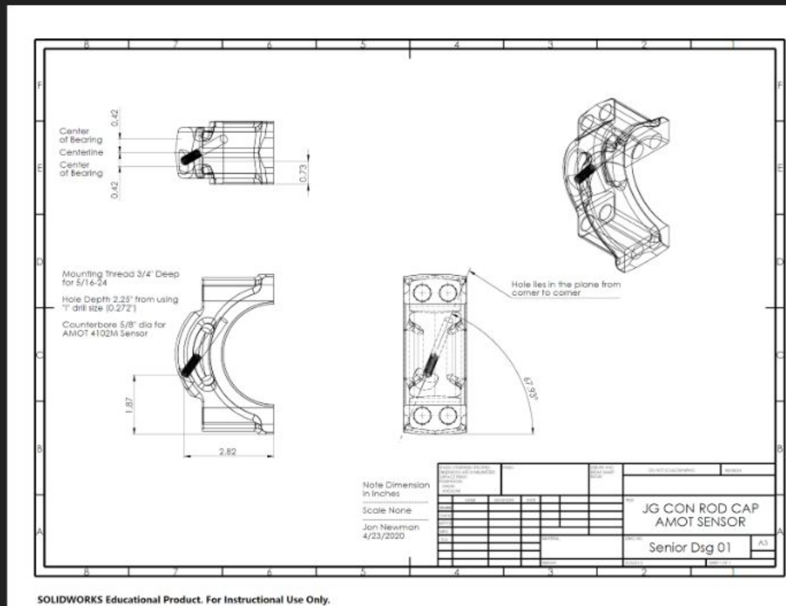
SPACE CONSTRAINTS







SENSOR MOUNTING

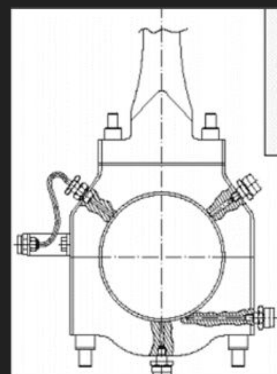


HEAT TRANSFER REACTION TIME

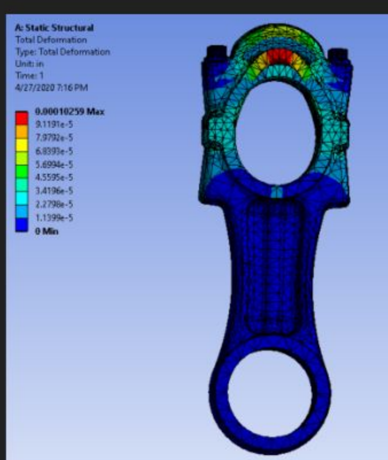
Heat Conduction in 1D					
Wall Thickness	Temperature Gradient (seconds)				
Inches	1	2	5	10	30
0.0625	0.7226	0.8018	0.8739	0.9106	0.9483
0.125	0.4777	0.6157	0.7509	0.8224	0.8969
0.25	0.1556	0.3154	0.5254	0.6534	0.7955
0.5	0.0045	0.0446	0.2041	0.3692	0.6041

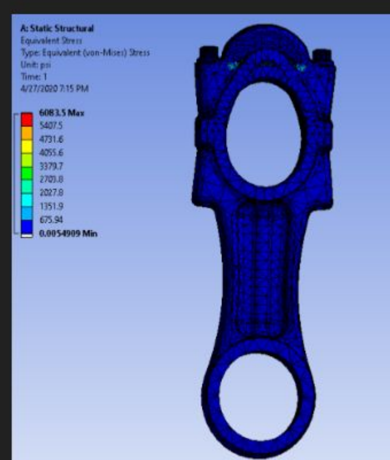
LOSS OF STRUCTURAL INTEGRITY

- An issue in the past has been the concern of the loss of structural integrity of the connecting rod.
- Due to having to drill a hole to mount the sensor, this could risk structural integrity.



FINITE ELEMENT ANALYSIS





ENGINEERING ETHICS

- If we present a new idea or concept have we violated someone's patented idea.
- There is a huge safety risk with reducing the structural integrity of the connecting rod.

FINAL STEPS

- All parts are on site and Ariel Corporation will run the trial shortly. Our group will follow up to see the results.
- Our prediction is that the sensors work. Our projects results show that the Amot sensors meet the requirements for system response time and that the structural integrity of the connecting rod will not be greatly affected.

QUESTIONS
EMAIL US

JON NEWMAN
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JOEY FISCHER
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Appendix D: Meeting Journal

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Unknown

		Present
Advisor:	Gary Drigel	[ ]
Student:	Joey Fischer	[ ]
Student:	Jonathan Newman	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	9/5/2019
Meeting Location:	Middletown

Topics Discussed

We discussed a couple of our project ideas
Decided to do more research on our ideas and other ideas and discuss on class 9/12

Responsibilities/ Actions Taken

Discussed ideas we had for project ideas
more research needed and will discuss more on 9/12

Next Meeting Date: 9/12/2019 Location: Middletown

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Joey Fischer**	[ ]
Student:	**Jonathan Newman**	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	9/12/2019
Meeting Location:	Middletown

Topics Discussed

We chose a project
We decided to go with a project with Ariel Corp. to create a temp. sensor for a connecting rod on a Natural Gas Compressor.
We are starting to work on the proposal and gantt chart

Responsibilities/ Actions Taken

Working on gantt chart
Working on proposal

Next Meeting Date: ###### **Location:** Middletown

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Joey Fischer**	[ ]
Student:	**Jonathan Newman**	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	9/19/2019
Meeting Location:	Middletown

Topics Discussed

We discussed what our plan of attack was for what order We will do our project.
We discussed what tools we will need to make our project happen.
We discussed where we will meet to do our work.
Talked about a few ideas on how to make the sensor work once it reaches the goal temp.

Responsibilities/ Actions Taken

We got a multi-meter from Gary Drigel to have the capability to read temperatures.
This is for us to see if this method of testing temps will work or not.
We are going to research some solders that would melt at specific temps.
We will also be working on the proposal and gantt chart as well.

Next Meeting Date: 9/26/2019 **Location:** Middletown

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Joey Fischer**	[ ]
Student:	**Jonathan Newmaı**	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	9/26/2019
Meeting Location:	Middletown

Topics Discussed

We discussed our proposal and gantt chart to see if everything makes sense for timing and to make sure we arent forgetting anything that we know of.
We discussed possibly setting up a time to go to the plant to see what they do in person instead of just using the website.
We discussed also trying to get a good contact that we can ask question when we need to.

Responsibilities/ Actions Taken

We are still researching some eutectic material to use for our sensor trigger.
Finishing up our proposal and gantt chart after going over what we had.
Figure out a good way to be able to test our sensors so that we know what we will need for the testing process.

Next Meeting Date: 10/3/2019 **Location:** Middletown

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	Gary Drigel	[ ]
Student:	Joey Fischer	[ ]
Student:	Jonathan Newmai	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	10/3/2019
Meeting Location:	Middletown

Topics Discussed

We discussed where we were with the proposal and should be pretty much ready to submit.
We discussed a couple more design ideas and how we could possibly build these ideas.

Responsibilities/ Actions Taken

Starting to think about the best way to build our sensor ideas.
Research the best ways we will test our sensors to be able to record acurate data.
Start coming up with some rough sketches on what the sensors will look like.

Next Meeting Date: 10/10/2019 **Location:** Middletown

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Joey Fischer**	[ ]
Student:	**Jonathan Newmai**	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	10/10/2019
Meeting Location:	Middletown

Topics Discussed

Made sure we had everything we knew of on the proposal for submission.
Talked about a couple companies for eutectic suppliers.
Talked about researching an oven to use for the testing process.

Responsibilities/ Actions Taken

Finish the proposal for submition on October 19th.
Research the best ways we will test our sensors to be able to record acurate data.
Research ovens to use for testing and prices.

Next Meeting Date: 10/17/2019 **Location:** Middletown

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Joey Fischer**	[ ]
Student:	**Jonathan Newmai**	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	10/17/2019
Meeting Location:	Middletown

Topics Discussed

Made sure we had everything we knew of on the proposal for submission.
Talked about a couple companies for eutectic suppliers.
Talked about researching an oven to use for the testing process.
Submitted Proposal

Responsibilities/ Actions Taken

Submit Proposal
Contact Eutetic suppliers.
Research ovens to use for testing and prices.

Next Meeting Date: 10/24/2019 **Location:** Middletown

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	Gary Drigel	[ ]
Student:	Joey Fischer	[ ]
Student:	Jonathan Newmai	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	10/24/2019
Meeting Location:	Middletown

Topics Discussed

Working on resubmission of proposal.
Found out from the company that we need to change the direction we are taking our project.
We are now to compare sensors that would be cheapest and most compatible for their system.
We are also to possibly find other options that could be used that may not be on the market.

Responsibilities/ Actions Taken

Rewrite proposal to new direction from the company.
Resubmit the proposal.
Start research on the sensors given and also still continue with possible designs of sensors.

Next Meeting Date: 10/31/2019 **Location:** Middletown

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Joey Fischer**	[ ]
Student:	**Jonathan Newmai**	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	10/31/2019
Meeting Location:	Middletown

Topics Discussed

Resubmitted proposal.
Went and visited the company on 11/4/2019 and were able to see parts in person.
The visit allowed us to ask the questions we needed to get an exact objective of this project.

Responsibilities/ Actions Taken

Continue research on the sensors given and also still continue with possible designs of sensors.

Next Meeting Date: 11/7/2019 **Location:** Middletown

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Joey Fischer**	[ ]
Student:	**Jonathan Newmaı**	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	11/7/2019
Meeting Location:	Middletown

Topics Discussed

Discussed a few sensor designs such as laser, and still possibly a eutectic material.
Looked at existing sensors that Ariel already has.
Based on our visit to Ariel, we will be mostly testing at their facility where they can test with, or without us there.
Discussed a couple possible ways of wirlessly charging the sensor if needed.

Responsibilities/ Actions Taken

Continue research on the sensors given and also still continue with possible designs of sensors.
Research more about the laser temperature sensors.
Find other sensor options on the market.

Next Meeting Date: 11/14/2019 **Location:** Middletown

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	Gary Drigel	[ ]
Student:	Joey Fischer	[ ]
Student:	Jonathan Newmai	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	11/14/2019
Meeting Location:	Middletown

Topics Discussed

Talked about our next step of researching and how long we want to spend on that.
Made sure our timeline sounds reasonable to get where we want it by spring.
Discussed how we will divide up our presentation.

Responsibilities/ Actions Taken

Continue research on the sensors given and also still continue with possible designs of sensors.
Research more about the laser temperature sensors.
Find other sensor options on the market.
Finished our Ethics assignment and liberal education assignment.
Started working on our presentation and paper.

Next Meeting Date: 11/21/2019 **Location:** Middletown

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	Gary Drigel	[ ]
Student:	Joey Fischer	[ ]
Student:	Jon Newman	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	2/6/2020
Meeting Location:	Middletown

Topics Discussed

Started to discuss a possible and more feasible sensor.
Discussed where we are with the final paper.
Discussed that Ariel will be letting us use a much smaller compressor for testing allowing for more sensor options, but also could restrict us.

Responsibilities/ Actions Taken

Look further into this possible AMOT sensor for use on a smaller compressor.
Ask Ariel for dimmensions of the new compressor and also new temperature ranges.
Start to add new incoming information to the final paper.
Also ask Ariel for a solid model to start looking into doing finite element analysis on the connecting rod with different mounting location.

Next Meeting Date: 2/13/2020 **Location:** Middletown

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Joey Fischer**	[ ]
Student:	**Jon Newman**	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	2/13/2020
Meeting Location:	Middletown

Topics Discussed

Discussed more reasearch on the AMOT sensor and found that this may be a very good choice.
Discussed that we need to start finding suppliers for this sensor.
This sensor will be reusable once triggered with the purchase of a very inexpensive capsule.
Need to start looking for lead times and pricing for these sensors.
Waiting on Ariel for solid model and dimmensioned parts.

Responsibilities/ Actions Taken

Start finding suppliers and get pricing and lead times.
Keep in touch with Ariel to try and get the solid model and dimmensions neeeded.
Ask Ariel how we shouldbe going about purchase these parts and sensors.
Keep working on the final paper.

Next Meeting Date: 2/20/2020 **Location:** Middletown

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Joey Fischer**	[ ]
Student:	**Jon Newman**	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	2/20/2020
Meeting Location:	Middletown

Topics Discussed

Ariel sent us the solid model of the compressor and dimmensions.
Discussed how we wanted to go about doing the finite element analysis for the connecting rod.
Discussed that Ariel will have the new smaller compressor installed for testing of these sensors.
Need to start looking for lead times and pricing for these sensors.

Responsibilities/ Actions Taken

Start finding suppliers and get pricing and lead times.
Ask Ariel how we shouldbe going about purchase these parts and sensors.
Keep working on the final paper.

Next Meeting Date: 2/27/2020 **Location:** Middletown

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Joey Fischer**	[ ]
Student:	**Jon Newman**	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	2/27/2020
Meeting Location:	Middletown

Topics Discussed

We put the solid model in the ANSYS software and it looks like we will be able to do it.
Discussed that we need to find out from our professor how to do the test we are wanting.
Looked more into the AMOT sensors and we are able to get sensors in various sizes and temperatures. The sensors dimmensionally will fit, but will need to find out where we want the mounting place to be based on ANSYS testing.
Found that many suppliers have these sensors in stock and discussed we need to see who has the cheapest pricing and best lead time.

Responsibilities/ Actions Taken

Ask professor about our project for testing in ANSYS.
Start deciding how we will want to mount the sensor to start creating solid models with mounting holes in these locations.
Keep working on final paper.
Need to order sensors to be sent to Ariel.

Next Meeting Date: 3/5/2020 **Location:** Middletown

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	Gary Drigel	[ ]
Student:	Joey Fischer	[ ]
Student:	Jon Newman	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	3/5/2020
Meeting Location:	Middletown

Topics Discussed

Found a company to buy the sensors from.
We also found backup companies to order from incase of a long lead time.
Continued playing with the Finite Software to see how we should run the test.
Decided we need to do thermal calculations to see how fast heat transfers through the material.

Responsibilities/ Actions Taken

Need to order sensors to be sent to Ariel.
Need to finish deciding the locations for the sensors.
Keep working on the ANSYS.
Keep working on the report.

Next Meeting Date: 3/12/2020 **Location:** Middletown

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Joey Fischer**	[ ]
Student:	**Jon Newman**	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	3/12/2020
Meeting Location:	Middletown

Topics Discussed

Met with Ariel on Monday 3/9 to discuss where we were and what else we need to do.
At Ariel, we were able to get more info on the ANSYS testing.
They also gave us some of the temperature data for heat transfer through the material.
They also gave us the materials we need for ANSYS and thermal calculations.
We are waiting for an invoice for the sensors to submit to Ariel for purchase.
We are looking at testing here within the next three weeks to give them time to make a mounting hole for the sensor.

Responsibilities/ Actions Taken

Need to make a drawing for Ariel to make a mounting hole for the sensor.
Send the invoice to Ariel as soon as we get it to be purchased.
Work on the ANSYS testing.
Work on the final report and presentation.
Setup a day to go to Ariel for testing.

Next Meeting Date: 3/19/2020 **Location:** Middletown

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	Gary Drigel	[ ]
Student:	Joey Fischer	[ ]
Student:	Jon Newman	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	3/19/2020
Meeting Location:	Middletown

Topics Discussed

Parts are ordered and are expected to arrive in 2-3 weeks.
We need to schedule a test to be ready for when the sensors get in.
We need to find a computer with solidworks to be able to dimension our connecting rod mounting holes for Ariel to build.
This may be difficult to find with no access to campus.

Responsibilities/ Actions Taken

Need to make a drawing for Ariel to make a mounting hole for the sensor.
Find a computer with solidworks.
Keep working on the report.
Setup a day to go to Ariel for testing.

Next Meeting Date: 3/26/2020 **Location:** Middletown

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Joey Fischer**	[ ]
Student:	**Jon Newman**	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	3/26/2020
Meeting Location:	Middletown

Topics Discussed

We did not meet in person this week due to break.
We have been working on getting the solid edge model done to be put into Finite Element Analysis.
Discussed what other information we need to add to our paper.

Responsibilities/ Actions Taken

Need to make a drawing for Ariel to make a mounting hole for the sensor.
Downlaoded solidedge to make our model for Finite Element Analysis.
Keep working on the report.
Waiting for parts to get in and need to figure out how to do testing with everything shutdown.

Next Meeting Date: 4/2/2020 **Location:** Middletown

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Joey Fischer**	[ ]
Student:	**Jon Newman**	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	4/2/2020
Meeting Location:	Middletown

Topics Discussed

We discussed where we were on our finite element analysis.
We have been working on getting the solid edge model done to be put into Finite Element Analysis and should be close to putting it in the software.
Discussed what other information we need to add to our paper.

Responsibilities/ Actions Taken

Need to make a drawing for Ariel to make a mounting hole for the sensor.
Downlaoded solidedge to make our model for Finite Element Analysis.
Reorganizing some of our report to fit the outline and adding sections for the element analysis.
Waiting for parts to get in and need to figure out how to do testing with everything shutdown.
Make sure that we have the heat transfer information correct and correct calulations to add to the report.

Next Meeting Date: 4/9/2020 **Location:** Middletown

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Joey Fischer**	[ ]
Student:	**Jon Newman**	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	4/9/2020
Meeting Location:	Middletown

Topics Discussed

We discussed where we were on our finite element analysis.
We have been working on getting the solid edge model done to be put into Finite Element
Solid model is just about finished and will be ready to be put into ANSYS.
Paper is just about all organized and ready to put the final information in.
Disgusted how we planned on doing the video presentation.

Responsibilities/ Actions Taken

Finish organizing the paper and add the rest of the information.
Finish the solid model and do the ANSYS testing.
Figure out how to do the video presentation.

Next Meeting Date: 4/16/2020 **Location:** Middletown

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Joey Fischer**	[ ]
Student:	**Jon Newman**	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	4/16/2020
Meeting Location:	Middletown

Topics Discussed

We discussed that we want to have the paper done by 4/21.
We discussed that we will do a practice presentation video on 4/21.
We will then do our final video presentation 4/28.
We are not sure if the parts have arrived at Ariel as they have been closed.

Responsibilities/ Actions Taken

Finish up getting the paper done and all together.
Rework or powerpoint with our new information.
Do a practice presentation on 4/21 and a final video on 4/28.

Next Meeting Date: 4/23/2020 **Location:** Middletown

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Connecting Rod Temp Sensor

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Joey Fischer**	[ ]
Student:	**Jon Newman**	[ ]
Student:		[ ]
Student:		[ ]

Meeting Date:	4/23/2020
Meeting Location:	Middletown

Topics Discussed

We want to have the paper done by 4/24
We discussed that we will do a practice presentation video on 4/24.
We will then do our final video presentation 4/28.

Responsibilities/ Actions Taken

Finish up getting the paper done and all together.
Rework or powerpoint with our new information.
Do a practice presentation on 4/24 and a final video on 4/28.

Next Meeting Date: 4/30/2020 **Location:** Middletown

Appendix E: Individual Reflective Essays

Jon Newman

ENT 498 Reflective Essay

4/29/2020

Communication is an useful but underrated skill in the field of project management. The ability to communicate, resolve conflicts and negotiate are very important. Senior design is a class where the design project requires significantly more teamwork than any other course. The basic engineering skills are known to students by their senior year, however communication and skills related to groupwork may require students to resolve conflict in ways that they hadn't anticipated.

I am older than many of my peers in this course. I have spent roughly 7 years in a full-time project management position in the steel industry. Prior job experience has helped me understand from the beginning the total amount of work that is required. This understanding has helped in various ways including scheduling tasks with extra time, knowing when to delegate tasks to my partner, and understanding that there are unforeseen issues that will occur. I am pretty sure that nobody in our class anticipated the corona virus situation we are in currently. As a capstone project this requires the use of engineering skills acquired from many different core classes. A few of these skills include scheduling and budgeting learned in project management, finite element analysis, thermodynamics and heat transfer as well as a number of soft skills including the ability to work as team, the ability to communicate, and the ability to resolve conflicts.

Team work is necessary for any group project to succeed. I believe that our teamwork has been successful throughout the project. There are always minor issues that will arise either due to scheduling conflicts, or unexpected issues. However, despite these issues we have been able to hit the project deadlines. I also believe that the the workload has been split fairly up to this point. A point worth mentioning is that our group has two members which is smaller than some of the other teams. Because there are only two members we are able to schedule and communicate issues slightly quicker than larger groups. One example of this is the ability to use google docs to work on documents concurrently. This is significantly easier than anything that was available in the early 2000s and the document saves edits so it is easy to determine how much work each group member has added to the report. There issue with a small group is that each member has to do more work to complete the project.

The most important skill utilized in this course is the ability to communicate. Communication is present is almost all aspects of this project. Communication in the forms of student-student, student-faculty, and student-corporation require the different methods because each audience is different. The ability to communicate in written form including emails, texts, PowerPoint, written reports and in spoken form through phone calls, small group meetings, and formal presentations are all necessary skills for an engineer to succeed. I believe that our groups

Senior design is a unique course in the that problem is not defined and the students make their own schedule. Most courses are the opposite in that class schedules, syllabus, and problems are defined by the professor and are completed within a schedule determined before the semester begins. In the this course a student finds a problem to solve and then creates their own timeline to solve the issue. This requires a different mindset and different set of skills than simply showing up to class. I chose to be the project leader for this project as it gave me a little more control over the timeline and direction of the project. Similar to scope creep in industry the problem has changed multiple times over the course of the semester. Often the project would run into minor issues that could be resolved by altering the problem statement. However, over time the project statement needs to be checked to verify that the project is still on track to meet deliverables. An example at the beginning of the project we were originally investigating placing the sensor on one of Ariel's largest compressors. In order to make the trial easier to run Ariel Corporation decided to change the trial to run on a much smaller compressor. While all of the deliverables remained the same it greatly changed the issues we needed to solve. The smaller connecting rod has a much greatly loss of structural integrity and is much harder to place a sensor into.

Senior design requires a significant amount of general engineering skills and knowledge. There are two specific examples in this project that require higher level engineering knowledge. First, we will need to calculate the speed at which temperature propagates through steel which will require knowledge of thermodynamics and heat transfer. Another specific application for this project is to verify the structural integrity of the connecting rod and to verify its expected infinite life. In order to resolve these issues we have made good use of Solidworks and Ansys software packages.

I have been pleased with the results of this class. There have been multiple conflicts and issues that have existed during the project. Our group has been able to resolve them in a timely manner. In addition, I think that the workload has been fairly distributed. There are times when one student did more than the other, but these times were balance between both students over the length of the project. On the other hand, I can always look at ways to improve. I am a little bit disappointed that we fell behind the schedule I had originally set. Our project has changed its framework a couple of times, but we should have been able to move past that stage a bit faster.

To conclude, senior design requires technical engineering knowledge and the ability to communicate and work as a team. Over time I see that projects and teams are more successful when they are able to communicate and resolve conflicts effectively. The skills in both communication, problem solving, and engineering that we have learned at Miami University will be important as we move into the future.

Joey Fischer

ENT 498

29 April 2020

Throughout the year in Senior Design, I find that the class was as expected where we would use our knowledge of previously taken classes to our advantage to work with a company to solve a problem or with ourselves to create something new. With this class we selected a group and a project requiring us to work as a team and manage our time correctly. This requires us to use project management skills, communication, and many other class skills that we have learned over the course of our degree.

Regarding many of the classes we take with the Miami Plan, these classes help greatly with building up to the senior year of taking senior design. In some way or another, we use these classes to either do calculations or to do design or just using examples we've seen in classes before that could be implemented into our project or modified to make it work. Many of our previous knowledge and calculations have been used throughout this project to get heat transfer answers and also finite element analysis. We used many other previously taken classes, but these were our main focus to help us choose the correct sensor.

Our teamwork for this project was good throughout this year where we have been trying to work together with the challenge of the project being changed on us late in the first semester. This type of problem will happen in the work force and is a great opportunity for us to learn from. We had divided the workload evenly between us to be able to finish in a timely manner. Obviously with the circumstances of everything shutting down we were not able to get as far as we hoped, but were able to take the project to the point where it would've been in Ariel's hands anyway for testing.

Our team communicated very well, as there were a couple rough spots, we were able to work it out and get the project accomplished. We didn't have a whole lot of communication with the company as they wanted us to have the chance to problem solve on our own with the necessary data and information we need. As we got further into our research, we had found more information, data, and questions that we wanted to ask Ariel as they were expecting us to do. Ariel was very happy with us to ask questions and was happy to answer these questions.

For the design portion of our project, we had used FEA calculations for structural integrity. For this we used the FEA ANSYS software to do so and were able to include diagrams and pictures of this in our powerpoint and paper. This allowed us to check how boring holes into the connecting rod would affect the structural integrity of the connecting rod and its infinite life. We also calculated the thermodynamics/heat transfer equations to see how fast the heat from the bearing transferred through the material of the connecting rod. This allowed us to see other possibilities for sensors and tell us how close to the bearing the sensor needed to be.

General skills for our project included some of our AutoCAD skills to perform some of these calculations for the testing. This also went into using Solid Edge to create our 3D model to use in ANSYS for FEA. We also used Solid Edge to create our drawing for Ariel to make modifications to the connecting rod for mounting the sensor. With all the research we have done for this project, we used our computers a lot, requiring us to use our research knowledge from many previous classes to accomplish this. Two of the main skills we used are critical thinking and theory, where we needed to think through what the problem is and use theory to find the best possible solution for the problem.

Learning to learn on our own has been a major skill that has been taught over the course of the degree. When it comes to certain subjects, we are required to understand the material we are given but then also learn it on our own and know the information for future use in other classes and our careers. This prepares us for our careers, because if we are given something to work on that we don’t know anything about and are only given a small bit of information on, we will know how to find this information we need to be able to work on the project given. We will also know how to work around unknown problems that pop up last second, such as the shut downs, and be able to finish the project to our best abilities.

I would evaluate my performance as good, as I can still improve on knowing more about the equipment we are working to put sensors on. I have learned to ask more questions about getting more data and information on the machine. I find that I have helped greatly by writing a good bit of the final report and doing the PowerPoint. What I would improve on is communicating with my group member on what has been done and what has not been done and what he may need help on. I would say a lesson learned from this experience is to start out by using a google doc to be able to see where the report and PowerPoint progress is and we can also work on it at the same time or our own time without having to send a document back and forth not knowing what was changed. This problem we had run into in the first semester of the project and it worked out perfect for our final report and also the powerpoint.