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Team 11: Pressure Sensor for an MLI Blanket

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Abstract

The fuel in the rocket tanks used by NASA operates best at extremely cold temperatures. This cold temperature must be maintained as the rocket lifts off the launch pad and flies through space. A specially-designed thermal blanket uses an aluminum material to keep the fuel tanks cold and protect them from outside heat sources. This blanket, referred to as multilayer insulation (MLI), must maintain very low pressures. When too much gas leaks into the MLI, the fuel gets hotter and does not run effectively. We are designing a pressure sensor that can fit inside of the blanket and measure very low pressures. The sensor is less than a millimeter thick (roughly 1/25th of an inch). It can measure pressure from 10-3 torr to 10-8 torr, which is comparable to the pressure range an object orbiting the earth will experience. This range is considered to be a high vacuum and low pressure. Additionally, the sensor must minimize power consumption and complexity, and it must be able to operate at very low temperatures. Traditional pressure sensors, such as a tire pressure gauge, do not meet these requirements. Our selected design, the cold-cathode gauge, determines the pressure by measuring the amount of charged particles. It begins with a power source that emits electrons, which are negatively charged particles. If there is any pressure in the MLI, the electrons strike the gas molecules, ionizing a percentage of the molecules and providing a measured current. The amount of current then correlates to the pressure in the MLI. Although cold-cathode gauges already exist on the market, we are modifying the design to fit in an extremely small space. Our stakeholders include NASA - Marhsall Space Flight Center and Dr. Guo of the FAMU-FSU College of Engineering.

Acknowledgement

Senior Design MLI Pressure Sensor Team would like to thank our sponsors from NASA James W. Smith and Jim J. Martin.

We would also like to thank Dr. Guo from the National High Magnetic Field Laboratory for his guidance and advice.

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Notation

FOSS	Fiber Optic Sensing Systems
IDT	Interdigitated Electrodes
MLI	Multi-layer Insulation
NASA	National Aeronautics and Space Administration
NHMFL	National High Magnetic Field Laboratory
MSFC	Marshall Space Flight Center

Chapter One: EML 4551C

1.1 Project Scope

Project Description

Design a pressure sensor to monitor pressure from 760 torr to below 10^{-4} torr in between the layers of a Multi-Layer Insulation (MLI) blanket. MLI is used by NASA to protect space craft from thermal radiation, and its pressure must be accurately measured to ensure that it can operate properly.

Key Goals

The key goals of this project are to:

- Measure 10^{-3} torr to 10^{-5} torr
- Minimize size
- Minimize power consumption

Primary Market

Any research regarding multi-layer insulation can use this sensor. The primary market is the aerospace industry. Within this industry, NASA-Marshall Space Flight Center (MSFC) showed a tremendous interest in this technology.

Secondary Market

Other industries outside of the space industry could utilize this technology such as the NHMFL. They use the MLI blanket to wrap the magnets they develop, and vacuum seals them. In the meat-packing industry, vacuum conditions are used to store meat to improve the length of their shelf life. The amount of residual oxygen left in the packaging is directly proportional to the shelf life of the meat. Therefore, being able to measure the pressure would reveal the amount of oxygen and other gases left in the packaging. The meteorological field could also benefit from this technology when measuring and predicting weather patterns. Barometers are currently used to measure the vibrations in pressure to forecast weather conditions. However, a pressure sensor this sensitive could prove more accurate than the current capabilities of a barometer.

Stakeholders

The stakeholders of this project are the NASA sponsors and Dr. Guo from the National High Magnetic Field Laboratory. These entities have a vested interest in the success of the vacuum pressure sensor.

1.2 Customer Needs

Gather Customer Data

- Measure 760 torr to 10^{-4} torr
- Width of no more than 1mm to fit in the layers of the MLI blanket
- Minimize power consumption
- Sample 1 per second
- Operate at 77K

Reflect on Results

The most critical needs are that it operates between 10^{-3} torr to 10^{-5} torr and at 77K. The sensor is useless if these needs are not met. The customer asked for a width of 1mm so that it will fit within the layers of the blanket. The subsequent need is to be as minimally invasive to the MLI blanket as possible.

1.3 Functional Decomposition

Breaking down the pressure sensor project to its simplest parts and needs, it must satisfy the following:

- React to a change in pressure.
- Output a signal that is proportional to the change in pressure.
- Sample once every second.
- Avoid interference with MLI components.
- Maintain integrity under all experienced temperatures.

1.4 Target Summary

Through careful analysis of customer needs and functional decomposition, the team managed to establish 14 targets to achieve. The Marshall Field Laboratory advisors provided these metrics. The most important metrics the design team will focus upon is the ability to measure the pressure range, operate at 77 K, its reaction to the pressure change, its integrity across the temperature range, and its minimal width. Without achieving the important listed criteria, the sensor is considered inoperable under the experimental environment. The targets are listed in Appendix B Table 1.

1.5 Concept Generation

Piezoelectric Pressure Sensors

Piezoelectricity describes the process when a mechanical stress generates an electrical charge and stores it in a solid material such as a crystal or ceramic. The Piezoelectric effect is the linear electromechanical relationship within a solid material. This process is reversible on materials that generate a proportional electrical charge and mechanical strain. Piezoelectric pressure sensors use quartz crystals to sense a change in force applied to the material and measures an electric charge produced by the stressed solid material.

Pros:

- Able to fit well under the 1mm thick constraint
- Length and width are also within a reasonable size
- Minimal heat generated

Cons:

- Typically, will only operate in temperatures as low as -40ºC

Everyday models will not be able to measure the low temperatures we need to measure. However, after searching specifically for the piezoelectric pressure sensor that can measure down to a vacuum, some bigger sensors started to show up. We might be able to scale one down. Also, the price went way up. Unfortunately, it can only operate down to -40ºC.

Acoustic

Acoustic wave sensors use a piezoelectric material to generate the acoustic wave using two interdigitated electrodes (IDT) separated by some distance on the surface. One IDT takes a digital signal and transduces it to an acoustic signal sending it along the substrate. As the acoustic wave propagates through or on the surface of the material, any changes to the characteristics of the propagation path affect the velocity and amplitude of the wave.

Pros:

- Minimal heat generated
- Can work in tandem with a Piezoelectric Pressure Sensor and a Strain Gauge Pressure Sensor

Cons:

- Possible size constraint

Strain

The working principle behind strain gages is the increase in electrical resistance when a specimen that has currently running through it has a reduced cross-sectional area. The most common is a wire strain gage which uses standard metals adhered to a surface that will undergo some deformation. When that surface is elongated, a tensile stress is applied to the wire that reduces the cross-sectional area as the wire attempts to conserve its original volume. Frequently that wire will run back and forth multiple times in the tensile direction to allow more reduction of area in the wire; this increases the sensitivity of the system. Common strain gages look like the one shown below in figure [1].

Figure 1: Wire strain gage.

The sensor is fastened to a medium that will undergo deformation with a change in pressure. A simplified example would be a party balloon sealed off at atmospheric pressure if the balloon were to be let off into the sky the balloon would expand as the atmospheric pressure drops. If one were to adhere a strain gage to the balloon, the expansion of the rubber would put the wires of the gage under a tensile stress that would increase the resistance in the wire. The resistance would change a voltage reading between the two nodes at each end when running a current through it and that voltage would be proportional to the atmospheric pressure.

It is clear from figure [1] that such a strain gage is very thin. Most gages of this variety are on the order of tenths of millimeters which would fit the intermittent MLI sensor needs perfectly. Minimal current powers the sensor and coupled with low resistance causes its heat to dissipate well.

Though the functional part of the sensor is thin, the physical strain gage is only part of the pressure sensor. The challenge would be in manufacturing a medium that will deform with a change in pressure and stick to the size constraint. Most materials tend to deform uniformly in all directions when exposed to a hydrostatic pressure difference. The medium in this application would somehow need to be constrained to deforming in one dimension to maintain the thickness target. Another obstacle would be finding materials that react in the desired way under extremely cold temperatures. Both the medium and strain gage materials may become much more brittle as the temperature lowers to around 77K. It may be a challenge to find a medium that will stretch within the desired elongation at these temperatures and pressures.

Pros:

- Physical strain gage very thin relative to other devices
- Low power requirement for operation

Cons:

- Difficult to manufacture medium that will allow pressure measurement under size constraints
- Most elastic materials become brittle under extremely low temperatures

Pirani Gauge

This measurement principle utilizes the thermal conductivity of gases for the purpose of pressure measurements in the range from 10^-4 mbar/Torr to atmospheric pressure. The filament within the gauge head forms one arm of a Wheatstone bridge. The heating voltage which is applied to the bridge is controlled in such a way, that the filament resistance and thus the temperature of the filament remains constant regardless of the quantity of heat given off by the filament. Since the heat transfer from the filament to the gas increases with increasing pressures, the voltage across the bridge is a measure of the pressure. Improvements with regard to temperature compensation have resulted in stable pressure readings also in the face of large temperature changes, in particular when measuring low pressures.

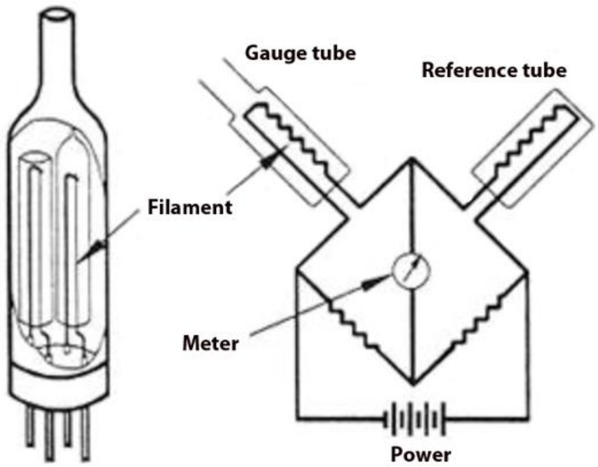

Figure 2. Pirani gauge example.

Pros:

- Reaches entire pressure range
- Operable at 77K
- Focus on gas particles

Cons:

- Gold wire could potentially be expensive
- Metal filament is difficult to manufacture

Capacitance Transducers

A capacitance transducer is a capacitor with variable capacitance. It comprises of two parallel metallic plates, typically separated by a gap of air (dielectric material). The value of capacitance changes due to changes in the value of the input quantity being measured. In this experiment's case, the input quantity will be the voltage in and the voltage out being examined. Change in capacitance is measured and calibrated against input quantity. This implies that the input signal flowing into the transducer will be read as a voltage reading directly.

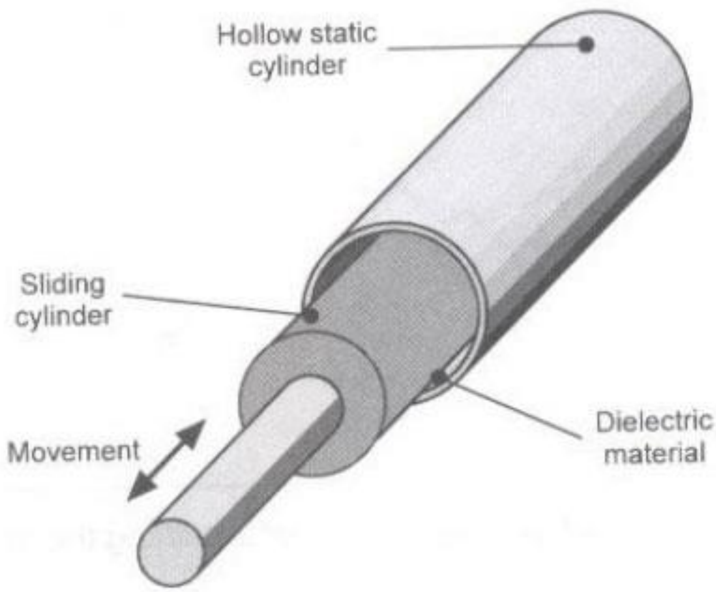

Figure 3. Capacitance transducer example.

The distance between the plates is variable, while the area of the plates and the dielectric constant remain constant. This is the most commonly used type of variable capacitance transducer. For measurement of the displacement of the object, one plate of the capacitance transducer is kept fixed, while the other is connected to the object. When the object moves, the plate of the capacitance transducer also moves, this results in a change in distance between the two plates and the change in the capacitance. The changed capacitance is measured, and it calibrated against the input quantity, which is displacement.

Pros:

- High sensitivity, resulting in a higher resolution
- Good frequency response, capable of potentially reading 1 sample per second
- Useful in small systems
- Small power to operate (Usually operating at max of 5V)

Cons:

- Temperature sensitive
- Provides nonlinear behavior
- Capacitance may be affected by any moisture that could form on the transducer

Fiber Optic Sensors

Fiber Optic Sensing Systems (FOSS) use fiber optic cables to measure pressure, among other types of possible measurements. The guiding principle of fiber optic pressure sensors is that the intensity of the reflected light, and the phase between the light waves, correlate to pressure readings. These signals are relayed through the fiber with the principle of total internal reflection (Figure 3). The core has a high refractive index so that the light waves travel easily through the cable, while a cladding at the outer diameter of the cable has a low refractive index to ensure that the light waves remain in the cable as it travels through. Fiber optic cables are extremely thin, flexible, and transparent fibers. They are typically made up of an ultra-pure glass such as silicon dioxide. The two main types that would be viable for this project include Fiber-Bragg grating sensors and Fabry-Perot cavity sensors.

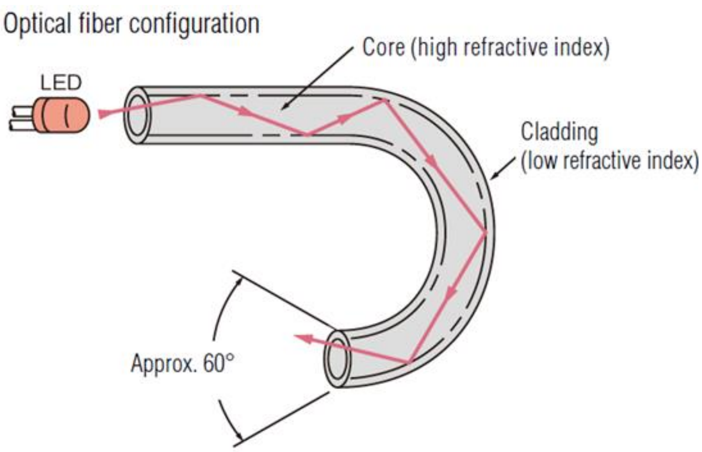

Figure 4: A representation of a strand of a fiber optic cable.

Fiber Bragg gratings include a strand of fiber with gratings in the centerline of the fiber (Figure 4). A broadband light is shown through the fiber with a periodic wavelength. The light's wavelength is dependent on the pressure inside the fiber, and as the periodic light passes through the gratings, the wavelength of light that passes through the filter can be correlated to pressure.

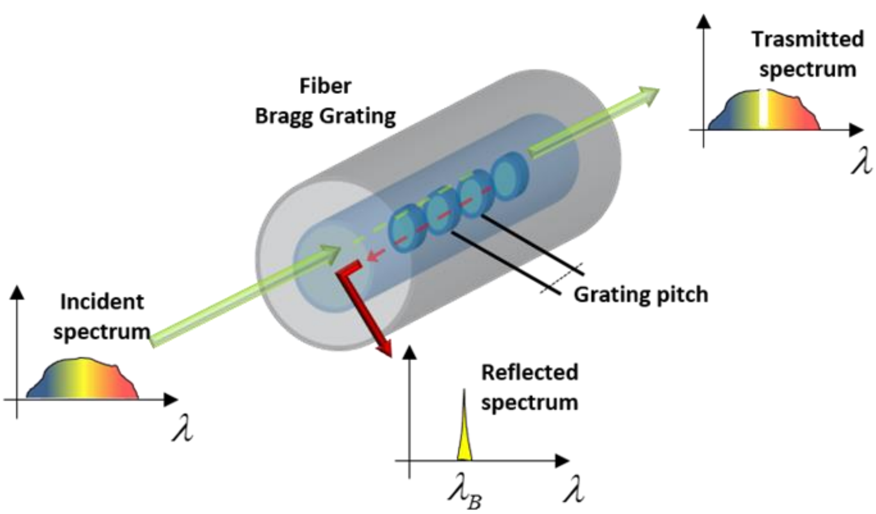

Figure 5: A strand of fiber optic cable with Bragg gratings.

Fabry-Perot sensors include a cavity of air with a diaphragm next to it. The external pressure from the sampled volume pressures on a flexible membrane that sits above a cavity. In Figure 5, the light travels up the fiber optic cable and is reflected onto the drum-like structure. Its reflected light waves will be recorded and measured based on their intensity and phase.

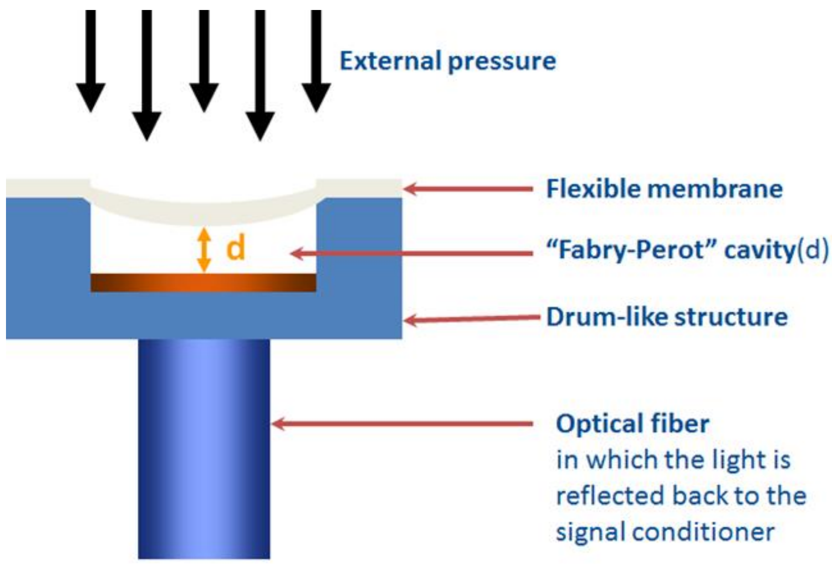

Figure 6: Representation of a Fabry-Perot sensor.

Pros:

- No interference with other electromagnetic waves, even under conditions with high solar and electromagnetic radiation
- Very high bandwidth
- Very fast
- Fits size constraint with a diameter as low as a quarter of a millimeter
- Can measure to 10-15 Pa

Cons:

- Can be expensive to manufacture with their minute size

1.6 Concept Selection

Our group chose to use a Pugh matrix to determine the most effective design concept for the following reasons:

- One of the major advantages of using a Pugh matrix is placing a weight on to the criteria that rates each design concept. There is no doubt that out of all the criteria of our project, there are a handful that are much more important to us than others. For instance, the goal of our project is to design a pressure sensor that can measure from 760 Torr to 10-4 Torr and that can be placed within the layers of an MLI blanket. While both criteria are crucial, the importance (0-9) for the pressure sensing ability was given a 9, while the width constraint was given a 7. This is because the sensor absolutely must measure that range of pressures, but the width of the sensor can be a little larger than the 1mm constraint. If the sensor deforms the blanket slightly, the blanket will be fine.
- It provided a visual representation of the strengths and weaknesses of each design relative to one another. This will help our group moving forward. It is possible that we will need to design a two-stage pressure sensor to accommodate to the large pressure change the sensor will experience. Having a numerical representation of where each pressure sensing technology performs well, we would be able to design a pressure sensor that utilizes the concept to the best of their abilities.

- In addition to seeing the strengths and weaknesses of each of the design concepts, the Pugh matrix also allows for the comparison of the feasibility of each concept. Our group has many competitive concepts. The Pugh matrix allows us to see which concepts we should be focusing on and which concepts won't work. For instance, the low for the ability of the strain-based pressure sensors to sense vacuum pressures was rightfully scored low. This is due its reduced ability to strain under cryogenics temperatures. The Pugh matrix highlights points like these that eliminate designs and help us narrow down our choices.

Our group weighed the criteria that would evaluate each design on a scale of 0 to 9, with 9 being most important. Then each design would receive a rating on a scale from 1 to 5 for each criterion. For the individual criteria scores for each design, 5 was the maximum score a design could receive for having the ability to fit each of the criterion. The Pugh matrix our group designed to compare possible designs can be found below.

Table 1: Pugh matrix for design selection.

Metric	**Importance Rating**	**Maximum Value**	Strain Gauge	Piezoelectric	Capacitance	Fiber Bragg	Fabry-Perot	Pirani	Ion
Criteria									
Measure from Atmospheric to Vacuum Pressure	**9**	**5**	1	3	1	2	2	4	4
Operate at Cryogenic Temperatures	**8**	**5**	2	1	3	3	3	4	5
Sampling Rate	**4**	**5**	5	4	4	5	5	5	5
Design Simplicity	**4**	**5**	5	4	3	5	4	3	4
Signal Output Proportional to Pressure Change	**7**	**5**	5	4	2	2	2	4	5
Minimal Weight	**4**	**5**	4	5	3	4	3	4	4
Minimal Height (< 2 cm)	**3**	**5**	5	5	2	5	5	4	4
Minimal Length (< 2 cm)	**3**	**5**	5	5	2	5	5	4	4
Minimal Width (< 1 mm)	**7**	**5**	1	4	2	5	5	4	4
Minimal Heat Generation	**8**	**5**	4	2	4	5	5	2	5
Total		**285**	**185**	**189**	**145**	**217**	**209**	**212**	**255**

Importance Ratings

Measure from Atmospheric to Vacuum Pressure

The ability to measure the wide range of pressures from 10^{-3} torr down to 10^{-5} torr is the heart of this project and of upmost importance to NASA. Without reaching this constraint the project is effectively useless. Due to its importance, this metric received a maximum score of 9/9.

Operate at Cryogenic Temperatures

The next most important constraint imposed on the pressure sensor is its ability to measure at cryogenic temperatures. This is a close second to measuring the full range of desired pressures because if the constraint was not completely reached it would still be possible to do controlled tests of MLI at whatever slightly higher temperature would allow for and then it could be assumed that the material would behave similarly at colder temperatures. Due to having slightly more leeway, operation at cryogenic temperatures received a score of 8.

Sampling Rate

Sample rate, while important to the test, would not completely limit the sensor's functionality. The sampling rate simply must be fast enough to resolve the behavior of the system over time. In discussion with NASA it was agreed upon that a desirable rate would be about once per second since the gas contained in the MLI layers is trapped and escapes rather slowly. Due to the vagueness of the constraint importance is given a score of 4.

Design Simplicity

Simplicity is very important when discussing equipment that cannot be allowed to fail. If a sensor is on an unmanned spacecraft there will likely be no opportunity to replace or repair a dysfunctional sensor. Simplicity is key in creating a reliable sensor. If sensors are unreliable a higher quantity of them may be needed to reduce the risk of all failing and being left with no information on pressure. The reliability therefore may influence factors that come with a higher quantity of sensors like power consumption and heat dissipation. This receives a score of 4.

Signal Output Proportional to Pressure Change

It is desirable that the output signal given by the sensor is simple and works with a large range of values. Many sensors are linear in certain regions and easy to read. Others have asymptotic or exponential output readings that become hard to discern in certain ranges. The more straightforward, linear, and larger range an output is the more accurate the sensor will be in this application. If a measurement range is small there may also be a need for multiple stages of sensors again increasing complexity, power consumption, and heat dissipation. The large importance of this metric gives it a score of 7.

Minimal Weight

According to our sponsor's website (NASA Marshall Space Flight Center), one pound of payload costs about $10,000 to send to space. Due to the astronomical price, weight is an extremely important factor in any device onboard a spacecraft. In the context of this project, the sensor will be very small and therefore weight becomes a smaller factor since the weight difference between designs will be small. Considering these details, weight was rated a 4 for importance.

Height and Length

For this project, the height and length of the sensor are less important than the width of the sensor. Space is still a constraint in these dimensions, but much more forgiving since. If one sensor is slightly larger in these dimensions, it should not drive the decision to use that design. Because of the leeway available this receives a score of 3.

Width

Width limitation is one of the core driving factors of this project as there must be minimal interference with the MLI layers. Sensors limited to around 1mm in width are not common and almost nonexistent. This constraint receives a score of 7 for importance only because a small protrusion into the MLI layer can be tolerated so a sensor slightly larger than 1 mm would still be functional.

Minimal Heat Generation

Finally, the device must have minimal heat generation. This is very important as the application in question is in cryogenic insulation. If the device produced introduces heat into the system, it is defeating the entire purpose of the system. A small heat dissipation is extremely important as the sensor is desired to be functional throughout the life of the mission. In longer mission a small heat injection over time can add up to be problematic. This receives a score of 8.

Individual Concept Ratings

Strain Pressure Sensor

Measure from Atmospheric to Vacuum Pressure

Strain-based sensors have a problem sensing pressures down to values common in high-vacuums like the ones in question for our project. The sensors would require a material that is able to be deflected by the pressure created by air molecules banging into the diaphragm. Under a vacuum around 0.0001 torr, there are almost no air molecules to force this deflection. In our specific case, the air at this pressure range would be exerting around N of force on the diaphragm. Finding a material to deflect due to changes in pressure around that range of force may be possible but is not economically viable.

Operate at Cryogenic Temperatures

Again, the strain-based sensors are tough to utilize because of material constraints. The elasticity of materials changes drastically down to cryogenic temperatures. Measuring pressure through a material medium deflection is not economically feasible.

Sampling Rate

This metric is not a problem for strain-based sensors. The sensor's sensing mechanism reacts relatively quickly to a change in pressure as it is relying on the elasticity of a material. Sampling rate is effectively only limited by the data acquisition equipment chosen.

Minimal Heat Generation

Strain gauge sensors require very little power to run. The heat dissipation should be very minimal when using very little current and a sensitive voltmeter.

Design Simplicity

The strain-based sensor is simple in operation and only requires a few wires connected to the actual device and a data acquisition system reading the voltage drop across the resistor.

Signal Output Proportional to Pressure Change

The change in voltage can be directly related to pressure change and is generally linear allowing for easy measurement at good ranges.

Weight, Height, Length and Width

The strain-based pressure sensor is small, but it is difficult to get one dimension down to the desired 1mm target. Constraints in other dimensions are reachable. The design would be very lightweight, sensors multiple times the size of the constraints in this project are around 5 grams.

Piezoelectric Pressure Sensor

Measure from Atmospheric to Vacuum Pressure

Piezoelectric pressure sensors use the voltage produced by the deformation of the piezoelectric material. The piezoelectric material has a tough time measuring the difference in pressure change once the values reach the magnitude of 10^{-4}. Eventually the deformation in the material would be too small to measure.

Operate at Cryogenic Temperatures

Measuring the voltage from a change in deformation from a piezoelectric material would suffer at cryogenic temperatures. As the material drops in temperature, the material becomes less and less ductile and the deformation becomes harder to read.

Sampling Rate

The sampling rate on a piezoelectric pressure sensor can sample at a rate that matches our requirement of sampling at one rate per second.

Minimal Heat Generation

A piezoelectric pressure sensor only requires power to read the voltage produced by the deformation of the material.

Design Simplicity

The typical design of a piezoelectric pressure sensor is minimal as it only requires the piezoelectric material, a diaphragm, and the electrodes of a voltmeter.

Signal Output Proportional to Pressure Change

The voltage produced by the deformation of the piezoelectric material is proportional to the change on pressure. Therefore, the signal output from a pressure sensor of this type will be proportional to the pressure change.

Weight, Height, Length and Width

Fortunately, piezoelectric materials can operate in multiple configurations. If our group chose to use a piezoelectric pressure sensor for our project, the sensor's size and shape would be flexible and would be able to fit well under the 1mm thickness constraint.

Fiber Bragg Pressure Sensor

Measure from Atmospheric to Vacuum Pressure

Fiber-Bragg sensors operate using mechanical strain, and at low pressures, the strain is too small to detect with any accuracy or resolution.

Operate at Cryogenic Temperatures

Fiber-bragg sensors can measure at varying temperatures but must include calibration as the mechanical strain varies with temperature. The design is robust enough to withstand extremely low temperatures.

Sampling Rate

Fiber-bragg sensors can measure at orders of magnitudes greater than 1 Hz, so they are well-suited to measure at one sample per second.

Minimal Heat Generation

The only power required for this sensor is the power to emit the light and the power to run the data acquisition software, which is already required for any type of sensor. There will not be much power dissipation in the form of heat, and light waves do not create heat.

Design Simplicity

The sensing device is completely contained within the wire, making it ideal to avoid interference with other parts of the MLI blanket. The design is simple and robust enough that it should last throughout the duration of its usage in space.

Signal Output Proportional to Pressure Change

The mechanical device used to determine strain contains natural vibrations, making it difficult to determine the pressure with high accuracy at extremely low pressures.

Weight, Height, Length and Width

The width of the Fiber-Braggs is simply the width of a fiber optic cable, which can be as small as 80 m, and satisfies the target of less than 1 mm. The length of the cable that includes the gratings is around 2 mm long.

Fabry-Perot Pressure Sensor

Measure from Atmospheric to Vacuum Pressure

The Fabry-Perot sensing system relies on a mechanically-strained diaphragm. Due to natural vibrations within the diaphragm, measuring with high accuracy and high resolution will not be attainable.

Operate at Cryogenic Temperatures

Fabry-Perot sensors can be operated at fluctuating and extremely low temperatures, but the readings will vary and, so they must be calibrated with a temperature sensor. Although calibration is a possibility, it would add a degree of complexity and uncertainty to the pressure sensor.

Sampling Rate

The Fabry-Perot sensor can measure at frequency greater than 1 Hz as long as the acquisition system is capable of it.

Minimal Heat Generation

Similar to Fiber-Braggs, Fabry-Perot sensors use light to detect the pressure and require no voltage or electricity except in the data acquisition component. The only power required is the power needed to shine the light. Therefore, not much heat will be added to the MLI blanket. Additionally, the use of light waves for detection completely limits interference with any other electrical components.

Design Simplicity

The design of the Fabry-Perot sensor relies on light waves and is simple enough that it will not interfere with other components or weaken over the duration of its use.

Signal Output Proportional to Pressure Change

Due to the mechanical vibrations of the diaphragm, it will be difficult to measure with a high resolution and with high accuracy.

Weight, Height, Length and Width

The diameter of the fiber optic cable can be as small as 80 m, while the width of the cavity can be as small as 400 m and the length and height can be as small as 100 m through micromachining.

Pirani Thermal Conductivity Gauge

Measure from Atmospheric to Vacuum Pressure

The Pirani Thermal Conductivity Gauge relies on the exposed gauge tube's reaction to atmospheric pressure. Due to its independence of mechanical strain, this method is effective in a low pressure setting. However, its precision primarily depends on the filament quality and resistance consistency. It has the potential of measuring from atmospheric pressure to vacuum pressure with the right configuration with proper calibration.

Operate at Cryogenic Temperatures

As long as the Pirani's Wheatstone Bridge configuration maintains a uniform temperature, the voltage reading from the middle terminal should still present a proportional pressure reading. However, there may be the slight chance that this cryogenic temperature may fluctuate the voltage reading due to slight resistance changes

Sampling Rate

The Pirani Thermal Conductivity Gauge can measure at frequency greater than 1 Hz as long as the acquisition system is capable of it.

Minimal Heat Generation

Due to the power running through the gauge tube's filament, this can cause excess heat generated into the interstitial environment. Overtime, this heat could gradually rise the temperature between the interstitial layers and disrupt its cryogenic environment.

Signal Output Proportional to Pressure Change

As the pressure decreases, the expose gauge's filament increases in resistance. This resistance increase translates into a voltage drop across its Wheatstone bridge. The voltage drop vs. pressure reading is ideally proportional.

Weight, Height, Length and Width

With proper micromachining and thin resistance wires, the thickness of its Wheatstone configuration is minimizable. With a proper filament choice for each gauge tube, this component can be the same width as a small conventional Christmas light bulb. However, the bottom resistances of the Pirani's configuration must be established at the same length. This will ideally provide the same amount of resistance for both the exposed gauge tube and vacuum gauge tube. Due to this constraint, the height and length rating of 3 averages out with the width rating of 5.

Hot Filament Ionization Gauge

Measure from Atmospheric to Vacuum Pressure

The Ion Gauge reliability on ionized particles collected between a negative and positive terminal allows for more precision in the lower pressure ranges than the other technologies However due to the variety of molecules at atmospheric pressure, the current reading at these higher ranges can be disrupted due to these noises. That is why this technology was ranked one below a perfect score.

Operate at Cryogenic Temperatures

Since the ion gauge focuses on the ionization of electrons within interstitial layers, there are no mechanical dependencies. Despite what temperature the ion gauge operates, its ability to create an electric field should be not disrupted.

Sampling Rate

The Ion Gauge can measure at frequency greater than 1 Hz as long as the acquisition system is capable of it.

Minimal Heat Generation

The Ion Gauge requires constant voltage or current running through its terminals to produce an electric field. This will consume slightly more power than the strain-based sensors that but around the same amount as the Pirani Thermal Conductivity Gauge. However, due to the lower intensity of its generated electric field, little heat is ideally dissipated.

Signal Output Proportional to Pressure Change

Due to the ionization process, the current reading at the lower pressure range is more proportional to the experienced pressure change. However around atmospheric pressure, the higher concentration of foreign molecules can affect the consistency of ionized electrons.

Weight, Height, Length and Width

A small system is manufacturable if the gauge's positive and negative terminals are small enough to fit between the multilayer insulation. Despite its size, an electric field is formable. As long as the gas is ionized, the electrons from this process will travel to the positive terminal and the charged particles will flow into the negative terminal. This ultimately allows a current that travels through the system.

Results

The results yielded by the Pugh matrix matched our thoughts about the feasibility of each design concept. Our group was focused on fiber optic, Pirani, and ion pressure sensors and the Pugh matrix verified the concepts our group was considering as front-runners. Fortunately, the ion pressure sensor concept scored much higher (255 out of 285) than fiber optic and Pirani sensors. Before filling out the Pugh matrix our group considered the ion pressure sensor to be the most viable concept due to its pressure sensing accuracy at vacuum pressures. It should also have no issue operating at cryogenic temperatures or fitting in between the layers of the MLI blanket. Due to its ability to meet the customer needs and functions of the project, our group has chosen to move forward with the ion pressure sensing concept.

1.7 Project Plan

Budget

The budget amount that has been promised by the college of engineering for our project is $500. However, our group is fortunate enough to have most necessary resources supplied by Dr. Guo or our sponsors at NASA-MSFC. If we need additional resources, such as sensors for studying and examination, our industry sponsors have agreed to send us anything they can to help. Below is a list of parts and resources that we need to complete the construction and testing of our ion gauge and how we plan to allocate our budget.

Table 2: Resources and plan to acquire them.

Part	Cost or Plan of Acquiring
Cirlex (Circuitry)	TBD
Tungsten / Iridium (Filament Material)	$48-$62
Power Supply	Exists in NHMFL (National High Magnetic Field Laboratory)
Testing Apparatus	Exists in NHMFL
LabVIEW Data Acquisition Program	Exists in NHMFL
Test Leads	Exists in NHMFL
UL Recognized; UL Flame Rated VW-1; UL 1007; UL 1569 (Wiring) **Order Number: 8054T15**	$62.29
Leybold Vacuum Pump	Exists in NHMFL

The only resource that we don't know the price of yet is the material we will be creating our circuitry out of. We chose this material because of its ability to fit into the size constraints while providing the flexibility to be oriented in any way we require. Currently, most of the resources we need are accounted for and assembled in the NHMFL as will be using an experimental rig that is already being used. Therefore, the most conservative amount still available is $375.71.

Bottlenecks

Some expected issues that might cause our group to use more time than originally planned for each time include:

- Designing
- Material Pricing
- Delivery Time
- Sponsor Communication
- Calibration Runs
- Custom Material Welding Time

Our group has chosen to go with a pressure sensing technology that is newest and has the least amount of research behind. Currently, there is only one orientation that you can purchase these sensors in. Since we have a strict thickness constraint, we will need to modify the geometry of the sensor which will then change the sensitivity of the sensor. Since this is the case, it is likely that we will be challenged along the way as we learn about and construct the sensor. Other possible bottlenecks include waiting for parts to be delivered, communicating between faculty and industry advisors, and calibrating the sensor once it is built.

Task Ownership

Our group has assigned each member a role that makes them responsible for final product of each task or assignment that falls under their category. The titles for each member can be found below.

Table 3: Team member and their title.

Team Member	Title
Jordan Eljaiek	Team Lead
Benjamin Hallstrom	Assistant Team Lead
Marie Medelius	Treasurer
Justin DiEmmanuele	Secretary/Webmaster
Qinjie Chen	Design Lead

However, our experience is that our group works best when collaborating which has made each task much more well-rounded. Each task that we have completed has benefitted from multiple perspectives and in-depth analysis. Once the assignment seems ready to be submitted, the team member assigned to this task makes any final changes and polishes it into a finished product. However, not all tasks can be addressed by every member without being an overuse of our time. A good example of this scenario would be the "Web Page Development" task. Justin will be responsible for learning how to code HTML. While we will all be supply the information and documents that are published on the website, multiple team members learning how to code would be excessive and wasteful. Moving forward, we would like to apply the same tactics to completing each task. The table below shows what responsibilities each team member has been tasked with.

	Major Tasks	Owner / Priority				
1	Restated Project Definition, Scope, and Plan	o	o	o	o	o
2	Web Page Development 1					o
3	Risk Assessment	o	o			
4	Web Page Update 1					o
5	Conference Paper	o	o	o	o	o
6	Executive Summary			o	o	
7	Operation Manual	o	o	o	o	
8	Web Page Update 2					o
9	Final Report	o	o	o	o	o
10	Prototype Demo	o	o	o	o	o
11	Design Review 4	o	o	o		
12	Design Review 5			o	o	o
13	Engineering Design Day-Poster	o	o	o	o	o
14	Engineering Design Day-Presentation	o	o	o	o	o
15	**Determine the Necessary Components and Materials**	o	o	o	o	o
16	**Iterate CAD Designs**			o		
17	**Research Part Costs/ Create Bill of Materials**		o		o	
18	**Buy/Order Parts**	o	o	o	o	o
19	**Build Prototype of Ion Gauge**	o	o	o	o	o
20	**Build Prototype of Pirani Gauge**	o	o	o	o	o
21	**Join and Calibrate Gauges**		o			
22	**Determine Where to Borrow LabView/ Modify Block Diagram for LabView**	o	o	o	o	o
23	**Final Testing/Prototyping**	o	o	o	o	o
		Ben	Sam	Jordan	Marie	Justin

Figure 7: Team member responsibilities.

Timeline

Our team has created a Gantt chart to outline our daily timeline. We have highlighted each major step in our project and grouped them into four “umbrellas” labeled “Designing & Buying”, “Construction”, “testing”, and “Wrap Up”. The daily progress log will allow us to visualize our accomplishments and prepare for deadlines we have planned.

Table 4: Gantt chart outlining the future of our project.

MLI Compact Pressure Sensor

Weeks start on Sundays | **Period Highlight:** - | Plan Duration | Actual Start

ACTIVITY	Start	Notes	Phase	Date	28-Jan-18	29-Jan-18	30-Jan-18	31-Jan-18	1-Feb-18	2-Feb-18	3-Feb-18	4-Feb-18	5-Feb-18	6-Feb-18	7-Feb-18
				-	1	2	3	4	5	6	7	8	9	10	11
Determine the necessary components and materials	8-Jan-18		**Designing & Buying**												
Research Part Costs	8-Jan-18														
Iterate CAD Designs															
Buy/Order Parts															
Build Prototype of Ion Gauge			**Construction**												
Build Prototype of Capacitance Based Gauge															
Join and Calibrate Gauges		Subject to change if NASA wants only one sensor	-												
Determine where to borrow a LabView controller			**Testing**												
Design Block Diagram for LabView															
Final testing/Prototyping															
Unexpected Complications/ Delays			**Wrap Up**												
Engineering Design Day															

% Complete　Actual (beyond plan)　% Complete (beyond plan)

8-Feb-18	9-Feb-18	10-Feb-18	11-Feb-18	12-Feb-18	13-Feb-18	14-Feb-18	15-Feb-18	16-Feb-18	17-Feb-18	18-Feb-18	19-Feb-18	20-Feb-18	21-Feb-18	22-Feb-18	23-Feb-18	24-Feb-18	25-Feb-18	26-Feb-18	27-Feb-18	28-Feb-18	1-Mar-18	2-Mar-18	3-Mar-18	4-Mar-18	5-Mar-18	6-Mar-18	7-Mar-18	8-Mar-18	9-Mar-18	10-Mar-18	11-Mar-18	12-Mar-18
12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44

13-Mar-18	14-Mar-18	15-Mar-18	16-Mar-18	17-Mar-18	18-Mar-18	19-Mar-18	20-Mar-18	21-Mar-18	22-Mar-18	23-Mar-18	24-Mar-18	25-Mar-18	26-Mar-18	27-Mar-18	28-Mar-18	29-Mar-18	30-Mar-18	31-Mar-18	1-Apr-18	2-Apr-18	3-Apr-18	4-Apr-18	5-Apr-18	6-Apr-18	7-Apr-18	8-Apr-18	9-Apr-18	10-Apr-18	11-Apr-18	12-Apr-18
45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75

Appendices

Appendix A: Code of Conduct

Article 1 – Name and Purpose

Section 1.1 Name

1. The name of the organization shall be MLI Pressure Sensor Team ("The Team"). It shall be a team of students under the guidelines of EML4551C-0001.fa17: SR DESIGN PROJECT I.

Section 1.2 Purpose

1. The Team shall be organized exclusively for academic purposes. Those purposes include completing Senior Design matters incidental to doing so.

Article 2 – Membership

Section 2.1 Membership

1. Membership shall consist of the assigned team members.

Article 3 – Team Members

Section 3.1 Quorum

1. A quorum shall consist of three of the members of the team. No business shall be considered by the team at any meeting at which the required quorum is not present, and only the only motion which the chair shall entertain at such meeting is a motion to adjourn.

Section 3.2 Majority Action as Team Action

1. Every act or decision done or made by a majority of the team members present at a meeting duly held at which a quorum is present is the act of the team.

Section 3.3 Qualifications

1. Team members shall be appointed by the EML4551C instructor.

Section 3.4 Terms

1. Each team member shall hold office for a period of one year.

Section 3.5 Notice of Meetings

1. Regular Meetings

   Regular meetings will be help Mondays and Wednesdays from 8:30am-12:30pm.

2. Special Meetings

   Notice of special meetings shall be sent out by the secretary to each board member at least two weeks in advance.

Section 3.6 Meetings

1. Meetings shall be held at the FAMU-FSU College of Engineering unless otherwise provided by the team leader or at such other place as may be designated from time to time by resolution of the team members.

2. Regular Meetings

   Regular meetings will be help Mondays and Wednesdays from 8:30am-12:30pm.

3. Special Meetings

   Special meetings of the team may be called by the team leader or any two team members.

Section 3.7 Conduct of Meetings

1. The team leader shall preside over meetings of the team. In the in the team leader's absence, the assistant team leader, or in the assistant team leader's absence, by a team member chosen by a majority of the members present at the meeting.
2. The secretary of the team shall act as secretary of all meetings of the team. In the secretary's absence, the team leader shall appoint another person to act as secretary of the meeting.
3. Meetings shall be governed by Robert's Rules of Order.

Section 3.8 Resignation and Removal

1. Any team member may resign their position effective upon giving written notice to the team leader, the secretary, unless the notice specifies a later time for the effectiveness of such resignation.
2. Team members may be removed from their position, with our without cause by a two-thirds of all votes of the members. If more than one member is being removed at a meeting, there shall be a separate vote for each member whose removal is sought.
3. Any member who resigned or was removed from their position shall turn over to the team within 72 hours any and all records of the project in his or her possession.

Article 4 – Officers

Section 4.1 Designation of Officers

1. The officers of the team shall be a Team Leader, Assistant Team Leader, Design Lead, Secretary, and a Treasurer.

Section 4.2 Duties of Team Leader

1. The Team Leader shall:

a. Manage the team as a whole; delegates tasks among group member according to their skill sets.

b. Finalizes all documents and provides input on other positions where needed.

c. Develops a plan and timeline for the project.

d. Keeps the communication flowing, both between team members and Sponsor.

e. Takes the lead in organizing, planning, and setting up of meetings.

f. Gives or facilitates presentations by individual team members and is responsible for overall project plans and progress.

Section 4.3 Duties of Assistant Team Leader

1. The Assistant Team Leader shall:

a. Assume role of Team Leader in the absence of.

b. Assists in the organizing, planning, and setting up of meetings.

c. Secures locations for work hours.

d. Locates and secures resources needed for meetings, design tasks, and any such requirement for the course.

Section 4.4 Duties of Design Lead

1. The Design Lead shall:

a. Takes charge of the mechanical design aspects of the project.

b. Responsible for knowing details of the design.

c. Presenting the options for each aspect of the design to the team for the decision process.

d. Keeps all design documentation for record and is responsible for gathering all reports.

e. Communicates with advisor on any and all design needs.

Section 4.5 Duties of Secretary

1. The secretary shall:

a. Responsible for keeping a record of all correspondence between the group and 'minutes' for the meetings.

b. Enforces the correct usage of letterhead, report formatting, and presentation formatting.

c. Be custodian of the records and executed documents of the team.

d. Exhibit at all reasonable times to any team member, or to the course instructor, on request therefor, the bylaws, the membership book, and the minutes of the proceedings of the team members.

Section 4.6 Duties of Treasurer

1. The treasurer shall:

a. Have charge and custody of, and be responsible for, all funds of the team, and deposit all such funds in the name of the team in such banks, as shall be selected if needed by the course instructor.

b. Receive, and give receipt for, monies due and payable to the team from any source whatsoever.

c. Disburse, or cause to be disbursed, the funds of the team as may be directed by the team, taking proper vouchers for such disbursements.

d. Keep and maintain adequate and correct accounts of the corporation's properties and business transactions, including accounts of its assets, liabilities, receipts, disbursements, gains, and losses.

e. Exhibit at all reasonable times the books of account and financial records to any team members, or to his or her course instructor, on request therefor.

f. Render to the team, whenever requested, an account of any or all of his or her transactions as treasurer and of the financial condition of the team.

g. Prepare, or cause to be prepared, and certify, or cause to be certified, the financial statements to be included in any required reports.

h. In general, perform all duties incident to the office of treasurer and such other duties as may be required by law, by the articles of incorporation of the corporation, or by these bylaws, or which may be assigned to him or her from time to time by the board of directors.

Article 5 – Decision Making and Conflict Resolution Policies

Section 5.1 Decision Making Procedures

1. Duty to Disclose. In connection with any actual or possible conflict, an interested person must disclose the existence of the conflict and be given the opportunity to disclose all material facts to the team members considering the proposed decision.

2. Procedures for Decision Making.

a. An interested person may make a presentation at the governing team meeting.

b. The problem is then defined by the team as a whole.

c. Brainstorm tentative solutions and discuss, in turn with no interruptions, the most plausible solutions.

d. After exercising due diligence, the team leader can call a vote on pursuing plausible solutions.

e. All members of MLI Pressure Sensor Team are eligible to vote.

f. A majority vote and passes the resolution and shall be noted in the minutes.

Section 5.2 Conflict Resolution Procedures

1. Duty to Disclose. In connection with any actual or possible conflict, an interested person must disclose the existence of the conflict and be given the opportunity to disclose all material facts to the team members considering the proposed conflict.

2. Procedures for Addressing the Conflict.

a. An interested person may make a presentation at the governing team meeting.

b. The problem is then defined by the team as a whole.

c. Brainstorm tentative solutions and discuss, in turn with no interruptions, the most plausible solutions.

d. After exercising due diligence, the team leader can call a vote on pursuing plausible solutions.

e. All members of MLI Pressure Sensor Team are eligible to vote.

f. A majority passes the vote and the resolution shall be noted in the minutes.

Article 6 – Code of Ethics

Section 6.1 Code of Ethics

1. MLI Pressure Sensor Team will be familiar with and follow the NSPE Code of Ethics.
2. The team will also follow the team code of ethics as follows:

a. The team member will deliver on commitments.

b. The team will listen and contribute constructively to the team.

c. The team will be open minded to other's ideas.

d. The team will respect other's roles and ideas.

e. The team member will understand that they represent the entire team, Senior Design class, and the FAMU-FSU College of Engineering and will be an ambassador to the outside world in own tasks

Article 7 – Amendment of Bylaws

Section 7.1 Amendment

1. Subject to the power of the members, if any, of this team to adopt, amend, or repeal the bylaws of this team and except as may otherwise be specified under provisions of the course, these bylaws, or any of them, may be altered, amended, or repealed and new bylaws adopted by approval of the team members and the course instructor.

Appendix B: Functional Decomposition

Breaking down the pressure sensor project to its simplest parts and needs is in the following order:

1. Must react to a change in pressure.
2. Output a signal that is proportional to the change in pressure.
3. Sample once every second.
4. Avoid interference with MLI components.
5. Maintain integrity under all experienced temperatures.

Appendix C: Target Catalog

Table 5:Numeric targets from functional decomposition.

Mertic #	Metric	Target	Unit	Importance
1	Measure from Atmospheric to Vacuum Pressure	760 to 1*10^-4	Torr	High
2	Operate at 77K	77<K<293	Kelvin	High
3	Minimally invasive to the MLI blanket	<1	mm	Medium
4	Sample 1 per second	1	Hz	Medium
5	Minimal power consumption	5 V (Max)	mW	Medium
6	Minimal parts and wires	TBD	#	Low
7	Must react to a change in pressure	yes	yes/no	High
8	Has to output a signal that is proportional to a change in pressure	yes	yes/no	High
9	Avoid interference with MLI components		mm	Medium
10	Maintain integrity under all experienced temperatures	yes	yes/no	High
11	Add minimal weight	TBD	lb	Medium
12	Height	TBD	mm	Medium
13	Length	TBD	mm	Medium
14	Width	1	mm	High

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