BTR v.1 Pneumatic Oleo Strut System

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***Abstract*– The Landing Gear is designed to cushion the impacts of taxiing and also allows landing with a payload capacity of up to 150 tons. Although it is one of the most important elements in all aircraft, it falls short when it comes to the method used for servicing and maintenance of the strut inside of the landing gear. The solution is to create an electronic system where mechanics and pilots can monitor and perform routine maintenance checks. The aim is to implement a system where pilots and aircraft mechanics are able to know the length of all three struts at all times directly from the cockpit. This system will consist of three sensors that will be attached directly on the strut, based on its function. These simple modifications save mechanics time, prevent flight delays, and reduce errors that may occur by measuring the strut manually.**

***Keywords* – Air Pressure Sensor, Arduino Software, Distance Sensor, Liquid Level Senor, Modified Pneumatic Oleo Strut, Ultrasonic**

I. INTRODUCTION

Airplanes come in a variety of shapes and sizes and vary in speed and range. All aircrafts have one thing in common; they must all be maintained. Aircraft Maintenance is a crucial component to the longevity of an aircraft. An aircraft mechanic is responsible for the maintenance and repair of the airplane. This is an extremely important job because airplanes have many small parts that, if damaged, can cause cataclysmic damages.

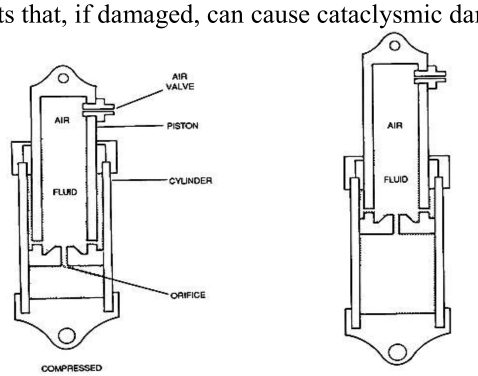

Figure 1: Compressed and Extended Oleo Strut

An oleo strut is attached to the landing gear on an airplane. The strut is designed to support the static load of the aircraft. It is also designed to absorb the shock exerted on the aircraft as a result of taxiing and landing. Oleo struts are telescoping tubes composed of two compartments, one for gas and one for oil. The gas compartment is typically filled with air and the oil compartment is typically filled with hydraulic fluid. The oil chamber is located on the lower region of the strut which is the cylinder. The air chamber is located on the uppermost region of the oleo strut; this along with an orifice inside of it, acts as a piston. The oleo strut is activated when downward force is applied. The force causes the air chamber to become a piston which compresses inside of the fluid compartment which acts as a cylinder, which is displayed in Figure 1. There is an orifice located at the piston head. As the strut compresses, the orifice allows air and oil to pass through the chambers. This movement of air and oil, combined with the compression of air, allows the strut to absorb the energy generated from down force. When the force on the oleo strut is disengaged, it extends back to its original length.

Servicing for the oleo strut takes place when there are no passengers or baggage onboard the aircraft. The piston and the cylinder are approximately the same length. When the Schrader valve, located on the top of the strut, is opened, the strut depresses. When all the air is released, the vertical distance between the piston and cylinder is zero, which is referred to as full compression or bottoming out. Subsequently, the Schrader valve is removed from the strut and replaced by the hydraulic fluid nozzle. Hydraulic fluid is filled until it levels with the top of the valve opening, which indicates that the piston is fully filled. The valve is then replaced on the top of the strut. The cap on the top of the Schrader valve is removed and the nitrogen or air bottle is screwed onto it. A minimum of two aircraft mechanics are required to fill the nitrogen or air inside of the strut. One person slowly inflates the strut with air or nitrogen while the other one holds a ruler in between the piston and the cylinder. The strut is inflated until it reaches the exact extended measurement, based on the aircraft maintenance manual for the particular aircraft. [1]

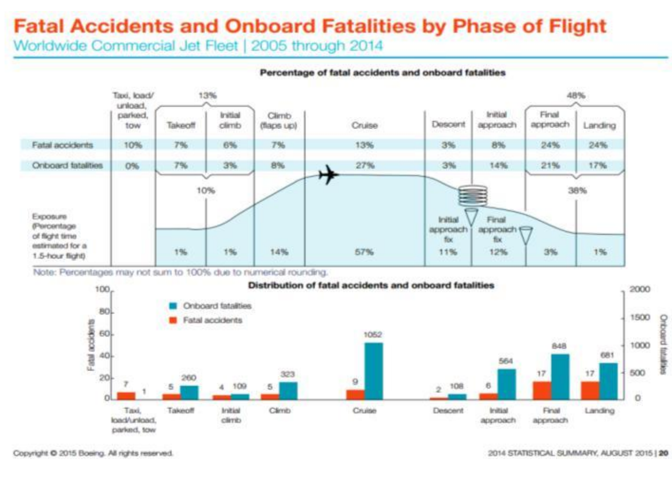

Figure Figure 2: Fatal Accidents and Onboard Fatalities by Phase of Flight. [Source: Boeing][3]

Currently, there is no system where an aircraft mechanic can determine the length of the strut with the empty aircraft weight or with the gross weight of an airplane. It is crucial for pilots and mechanics to know the status of the landing gear because it is such an important component of the aircraft. According to Boeing's statistics of fatal accidents and onboard fatalities between 2005 and 2014, 24% of fatal accidents occurred during landing and 17% of onboard fatalities occurred during landing. Figure two displays that the landing phase of flight has the highest recorded percentage value of fatal accidents out of all phases of flight for aircrafts.

II. OBJECTIVE

The objective of the project is to implement a system where pilots are able to know the length, hydraulic fluid levels, and air pressure of all three struts at all times directly from the cockpit. In order to accomplish this task, a strut will be designed in Computer Aided Three-Dimensional Interactive Application. The oleo strut is based on the Beechcraft B55B landing gear system.

Figure 3: Beechcraft B55B Landing Gear Configuration

The Beechcraft B55B, seen in Figure 3, was selected because it is has a simple landing gear configuration. The oleo strut of the aircraft is pneumatic and is filled with air instead of nitrogen. The strut is ideal because compressed oxygen is easier to obtain and use as opposed to compressed nitrogen. The aircraft was also selected because it is located in the hangar at Vaughn College of Aeronautics and Technology.

III. ENGINEERING REQUIREMENTS

In order to complete the project, two main engineering requirements were set. Below are the major requirements.

1) The incorporation of the three sensors must not change the main design or interfere with the functionality of the landing gear. It is important that the design will be versatile and able to be incorporated with any aircraft.

2) The goal was to use sensors that operate in extreme temperature because most commercial aircraft fly at altitudes of 30,000 and 40,000 feet. The temperatures at those altitudes range between -44.4 °C and -56.5 °C (-48 °F and -69.7 °F). Unfortunately there are no current sensors that are fully operational at those temperatures. [4]

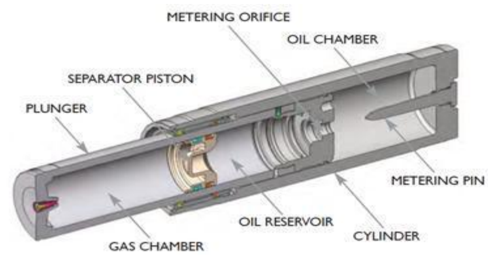

Figure 4: *Pneumatic piston-cylinder design for the BTR v.1 Oleo Strut*

IV. ENGINEERING DESIGN

The composition of the strut was based on the pneumatic strut structure displayed above in figure 4. This particular pneumatic piston-cylinder was selected because it is a simple design configuration. The modified oleo strut will consist of three sensors that will be attached directly on the strut, based on its functional use. In other to achieve this goal the project is divided into three engineering design objectives:

1. **Air Pressure Detection**
2. **Liquid Level Detection**
3. **Distance Detection**

Air Pressure Detection

The modified oleo strut will be designed to compress and extend through manual compression. This will simulate air pressure within the strut. Figure five displays the BMP 180 barometric pressure sensor will be used to detect air pressure. It is a multifunctional sensor, consisting of an analogue to digital converter that is able to detect air pressure, temperature, and altitude. The operational temperature range for the sensor is

Figure 5: BMP 180 Barometric Pressure Sensor

between -40 °C through +85 °C range. For this project, the BMP 180 sensor was used to detect air pressure within the cylinder. It is located inside of the sensor and wired up through a hole in the top of the cylinder. The sensor was soldered onto male header pins and wired onto the Arduino Uno board which displays the temperature, altitude, and air pressure. The barometric pressure sensor is engaged when the strut is compressed. This particular sensor was chosen because it is able to withstand pressures up to 10,000hPa. It is able to withstand pressures at altitudes which aircraft operate. The wiring diagram for the BMP 180 and Arduino Uno board are displayed in figure 6 below. The sensor is placed inside of the cylinder, soldered to jumper cables, and connected to the Arduino breadboard, which will display the air pressure throughout the landing gear system.

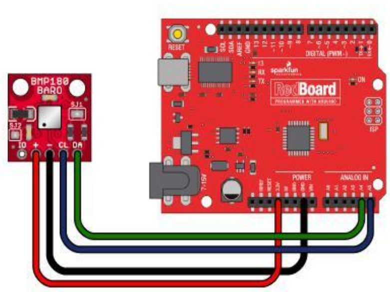

Figure 6: BMP 180 Wiring Diagram

Liquid Level Detection

The oleo strut of the Beechcraft B55B is a pneumatic air and hydraulic fluid strut. In this experiment, water will be used as a substitute for hydraulic fluid. The Honeywell 105000 liquid level sensor will be used to determine the level of fluid at different heights within the piston, and is displayed in figure 7 and figure 8 below.

Figure 7: Honeywell 105000 Liquid Level Sensor

The sensor is placed inside of the piston and wired up through a hole in the top of the cylinder and on to a breadboard. The sensor is able to detect continuous or point value level measurements. It is equipped with an LED and phototransistor chip which reflects light internally. The phototransistor produces a digital output which measures the presence and or absence of liquids. It has an operating temperature range of -13°F to 176°F. The sensor will detect a drop in the level of fluid, which will cause an LED to illuminate to warn the aircraft mechanic and pilot that attention is required.

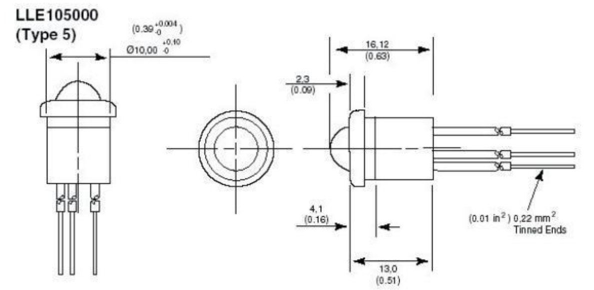

Figure 8: Honeywell 105000 Liquid Level Sensor Specifications

Distance Detection

The distance sensor is the alternative sensor used as backup in the unlikely event that the air or liquid level detection sensors malfunction. Figure nine below displays the HC-SR04 ultrasonic distance sensor is attached to a platform designed on the bottom portion of the cylinder.

Figure 9: *HC-SR04 Ultrasonic Distance Sensor*

The sensor is calibrated specifically for the strut length required range for ideal operation. The sensor uses sonar to determine distance. It generates high frequency sound waves and sends it out to the nearest object and receives it through echo. The interval of time taken to receive the signal is then converted to distance. The distance between the piston and cylinder helps to indicate the level of fluid and air/nitrogen in the system. The sensor is calibrated specifically for the required range for optimal operation. The ultrasonic sensor is soldered to wires and connected to the Arduino breadboard which will display the range of distances the strut reaches throughout compression and extension, as shown in figure 10.

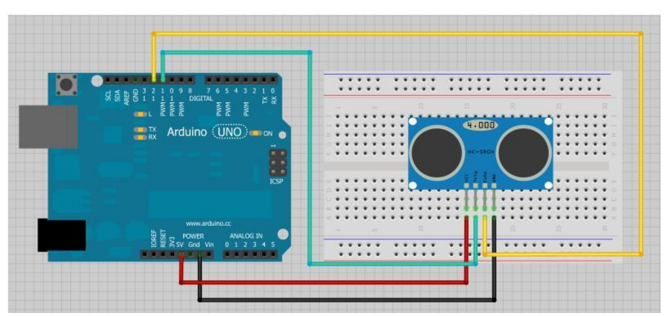

Figure 10: Wiring Schematic for the HC-SR04 Ultrasonic Distance Sensor

The Evolution of the Modernization of the Oleo Strut (3D Drawing Design)

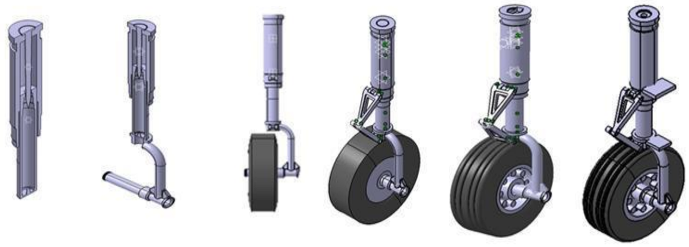

Figure 11: *Evolution of the BTR v.1 Pneumatic Oleo Strut [CAD Model]*

The original design of the BTR v.1 pneumatic oleo strut incorporated the metering pin inside of the top portion of the cylinder. The metering pin was eventually taken out due to the placement of the BMP 180 and Honeywell lle105000 liquid level sensors. The metering orifice was left in the design of the strut because it slows the amount of compression within the strut. The orifice was engineered with a diameter that would allow the liquid level sensor to be wired through it. The evolution of the design modifications of the BTR v.1 Pneumatic Oleo strut is displayed above in Figure 11.

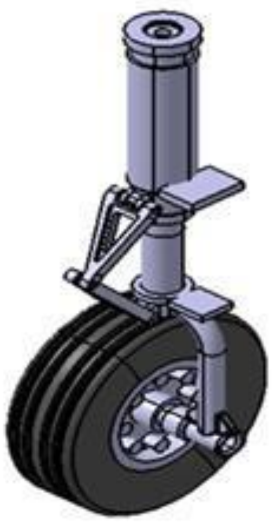

Figure 12: *Final Design of the BTR v. 1 Pneumatic Oleo Strut [CAD Model]*

The last major design modification of the BTR v.1 Pneumatic Oleo strut was the addition of the platforms to the bottom of both piston and cylinder. The platform on the cylinder secures the ultrasonic distance sensor in place while the platform on the piston is used to echo the distance. The final design for the BTR v.1 Pneumatic Oleo Strut with the housing for the distance sensor can be seen above in Figure 12. Figure 13 shows the exploded view of all parts assembled to complete the assembly of the strut.

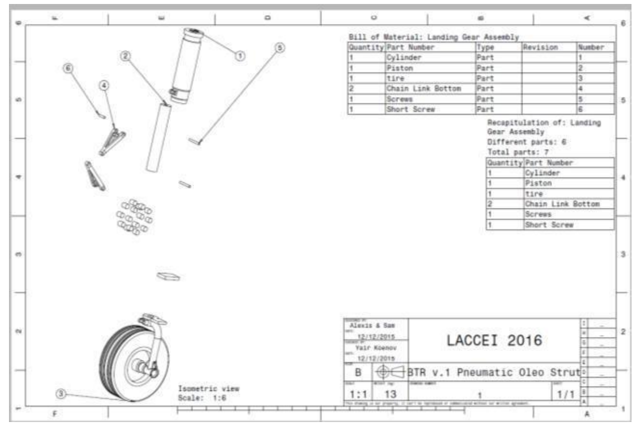

Figure 13: *Exploded view of the Pneumatic Oleo Strut*

V. WIRING AND CONFIGURATION

An aircrafts' electrical system produces power for the avionics and all the systems on an aircraft such as: navigation, radios and flight deck display. This allows the system to be connected directly to the aircraft existing electrical system proving its ability to adapt to any aircraft system and any strut. Each sensor within the system will be hardwired into the wheel-well as well as into the cockpit to provide a full display of the system to the maintenance crew while the plane is grounded and to the flight crew at any stage during the flight. For demonstration purposes, the system will be powered using alternative power sources. The sensors that are connected via an Arduino code are powered by USB connection. While the liquid level sensor is powered by a 9V battery.

Air Pressure Sensor Coding

The Barometric Pressure Sensor was used to fulfill the requirements of this project to measure the pressure maintained in the strut. This sensor required a code which was done using an Arduino board and Arduino software. The code written for this sensor can be seen in Figure 14:

```
status = pressure.getPressure(P,T);
if (status != 0)
{
  // Print out the measurement:
  Serial.print("absolute pressure: ");
  Serial.print(P,2);
  Serial.print(" mb, ");
  Serial.print(P*0.0295333727,2);
  Serial.println(" inHg");

  // The pressure sensor returns abolute pressure, which varies with altitude.
  // To remove the effects of altitude, use the sealevel function and your current altitude.
  // This number is commonly used in weather reports.
  // Parameters: P = absolute pressure in mb, ALTITUDE = current altitude in m.
  // Result: p0 = sea-level compensated pressure in mb

  p0 = pressure.sealevel(P,ALTITUDE); // we're at 1655 meters (Boulder, CO)
  Serial.print("relative (sea-level) pressure: ");
  Serial.print(p0,2);
  Serial.print(" mb, ");
  Serial.print(p0*0.0295333727,2);
  Serial.println(" inHg");
```

Figure 14: *Air Pressure Code*

Liquid Level Sensor Coding

The Honeywell Liquid Level Sensor was used to monitor and ensure that the level of hydraulic fluid is at or above functioning level. The sensor was hardwired using a breadboard and electrical components to demonstrate its functions. The configuration for this sensor can be seen in Figure 15, the led shown activates only when the hydraulic fluid is approaching dangerous levels, also signifying that the hydraulic fluid needs to be refilled.

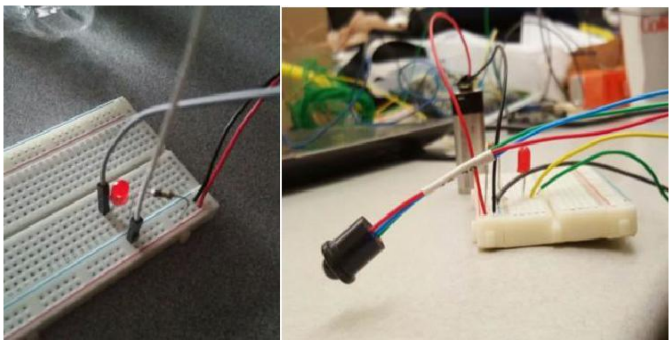

Figure 15: Honeywell Liquid Level Sensor connected to breadboard

Distance Sensor Coding

The Ultrasonic Distance Sensor was also connected to the Arduino board and software as well and programmed accordingly, Figure 16. It measures the height of the piston. The height of the pistons depends on the type of aircraft and its aircraft maintenance manual. The distance sensor measures this precisely. When the piston extends, it displays an increase in measurement (in inches). Whereas, a decrease in the height of the piston can alert aircraft maintenance to perform further inspections to determine if the piston length is within limits or not.

```
#include <NewPing.h>

#define TRIGGER_PIN  12  // Arduino pin tied to trigger pin on the ultrasonic sensor.
#define ECHO_PIN     11  // Arduino pin tied to echo pin on the ultrasonic sensor.
#define MAX_DISTANCE 200 // Maximum distance we want to ping for (in centimeters). Maximum sensor distance is rated at 400-500cm.

NewPing sonar(TRIGGER_PIN, ECHO_PIN, MAX_DISTANCE); // NewPing setup of pins and maximum distance.

void setup() {
  Serial.begin(115200); // Open serial monitor at 115200 baud to see ping results.
}

void loop() {
  delay(50);                     // Wait 50ms between pings (about 20 pings/sec). 29ms should be the shortest delay between pings.
  Serial.print("Ping: ");
  Serial.print(sonar.ping_cm()); // Send ping, get distance in cm and print result (0 = outside set distance range)
  Serial.println("cm");
}
```

Figure 16: Distance Sensor Code

VI. RESULTS

Many processes lead up to the final three-dimensional print of the BTR v.1 Pneumatic oleo strut. The oleo strut was designed to accommodate all three sensors in their respective ideal placements. A clash analysis was performed on the assembled part, displayed in figure 17 below. This ensured that the strut would be able to function without any issues, preventing smooth transition between the piston and cylinder. The strut was also designed with dimensional tolerance to fit the 3D printer. A tolerance of 5% was also applied for all screws and holes in the strut. This allowed the parts to fit the strut snuggly. It took approximately 80 hours to print the strut.

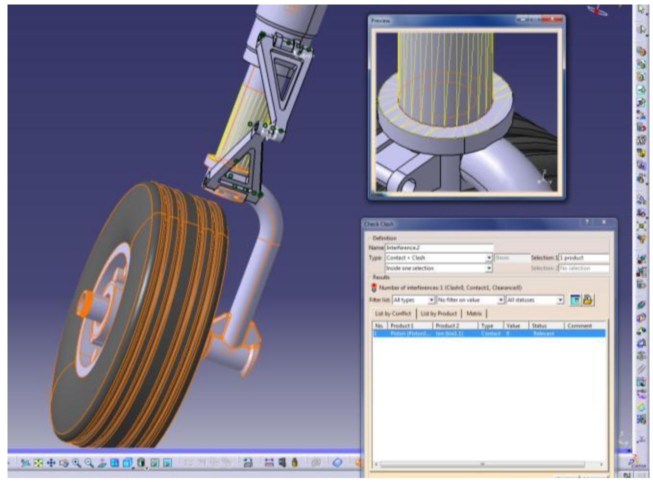

Figure 17: Clash analysis of the Pneumatic strut on CATIA

Upon completion of the three-dimensionally printed part, a chisel was used to peel away the support material from the build material. When all the excess build material was removed, a thin layer of spackle was applied onto the surface, which was sand papered to allow a smoother surface. The surface was then spray painted white, except for the piston which was spray painted metallic silver. The spray paint gave the appearance of the strut on the Beechcraft B55B. After several coats of the spray paint were applied and dried fully, the assembly of the 3D printed part began. The torsion links were screwed in nuts, washers, and bolts bought from Home Depot.

Due to the design of the strut, the strut could not be completely sealed off to allow an air pressurized chamber. In order to simulate the effects of a pressurized chamber within the strut, hot glue was applied in the center of the hole where the barometric and liquid level sensors were wired. This allowed the air to become pressurized when the strut was manually compressed. A spring was also glued to the center inside the piston, which, when compressed, allowed the strut to return to its natural extended state.

During the modification of the BTR strut, the liquid level sensor was installed directly in the piston, where the hydraulic fluid would normally be stored; and the wiring was run through the spring and out the top of the cylinder at the service port where the wires for the air pressure sensor were also connected. A spring was added in order for the strut to retract from the manual compression applied. The last sensor to be connected was the ultrasonic distance laser sensor. Two holes were drilled through the platform on the bottom of the cylinder for the housing of the sensor. The sensor was wired and read the echo distance when the strut was compressed. Figure 17 shows the completed 3D printed strut, displayed at different angles.

Figure 17: Chiseled Part of the 3D Oleo Strut

VII. CONCLUSION

The initial purpose of this project was to implement a system that would increase the safety of landing gears to in order to prevent aircraft accidents, which would not only save airlines money, and delay the rising costs of flying, but will also increase the safety when landing an aircraft.

The engineering tools used during the life of the project were not limited to, but included CATIA, Fortus 250mc Stratasys 3D Printer, and Arduino (coding program). So much was learned, using CATIA, from simple geometrical designs to running clashes. Clashes allowed the assembled strut to be printed with tolerances; without it the 3D printing of the strut would have resulted in all parts being fused together producing a static strut, which cannot demonstrate the realistic movements of a strut. The Fortus 250mc Stratasys 3D Printer provided us with limitations of the size of the strut that can be printed. This issue was solved using CATIA to modify the dimensions of the strut. While Arduino enabled us to program the sensors to perform the desired functions. When the correct coding was written the issue arose on connecting the sensor to the program.

The Honeywell 10500 liquid Level sensor was able to detect a change in the water level. As stated in the sensors description and purpose, this sensor turned activated a led light to denote when the there was a drop in the water level. This sensor will alert the plot when the hydraulic fluid is approaching dangerous or non-operable levels. Water was used to simulate the hydraulic fluid to test the effects of the sensor and its functions. Although water is less dense than hydraulic fluid it can be concluded that this sensor will produce no issues when there is a drop in the hydraulic fluid.

The HC-SR04 distance sensor was calibrated to detect a distance of 0cm/in to 30in/cm. The values utilized for calibrating the sensor was determined based on the length of the strut when fully extended and fully collapsed. For the model, the 1in was detected as it fully collapsed value and 8in was recorded as its fully extended value.

The BMP 180 Air Pressure sensor was also calibrated to measure the air pressure between -1000 ft. below sea level and 50,000 above sea level within the strut. This pressure is measured in Atmosphere pressure or barometric pressure (inHg). The model of the Oleo Strut was not designed simulate the reading recorded when compressed with respect to the pressure applied. Thus producing an accurate pressure reading during maintenance on the strut.

Figure 18: *Completed assembly of 3D printed BTR v. 1 Oleo strut with sensors attached*

In choosing a sensor, many obstacles arose from where the sensor should be implemented to the costs of the sensors. All sensors were chosen for their economical values and dimensions. The implementation of the sensors had to be thought of during the CATIA design phase to ensure all sensors had suitable housing. All these and other obstacles were overcome and the process of completing the project proceeded. Having little knowledge of programming the sensors with Arduino also proved to be a real challenge. An Arduino workshop, along with online videos, aided in finding the correct coding needed. Arduino was used to connect the laser distance sensor and air pressure sensor while the liquid-level sensor was connected, using a series of electrical components connected to a breadboard.

At the commencement of the project, the strut, Figure 18, and all sensors connected were fully functioning and their objectives were met. All programs, challenging in their own ways, performed the separate tasks that aided in the completion of the project. This signifies that the project was a success and, therefore, can be easily implemented on any aircraft.

VIII. ACKNOWLEDGEMENTS

The completion and success of this project would not be possible without a few notable people. To our professor and advisor Dr. Yougashwar Budhoo for his help, guidance and support. To the chairman of the Engineering and technology, Dr. Hossein Rahemi. To our professor Manny Jesus for his support and patience with finalizing all parts created on CATIA to ensure a successful 3D printed prototype. To fellow student Yair Koenov and lastly, to Shridath Balram for the inspiration behind this project. We would like to extend our deepest gratitude to all of you who supported even when our challenges were great. Thank you.

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