Development of the JHU ROV II Power and Electronics Housings

Katie Mao

Collaborators: Florian Pontani, Tyler Paine, Andy Cohen, Louis Whitcomb

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1. Introduction

Remotely Operated underwater Vehicles (ROVs) are uninhabited underwater vehicles connected to the surface via cable through which they receive power and commands from and send data and video to the surface. These vehicles are remotely controlled by pilots from the surface. ROVs were originally developed for oceanography research. Today, they are commonly used for the development of offshore oil fields, underwater construction, shipwreck location and recovery, and military operations.[1]

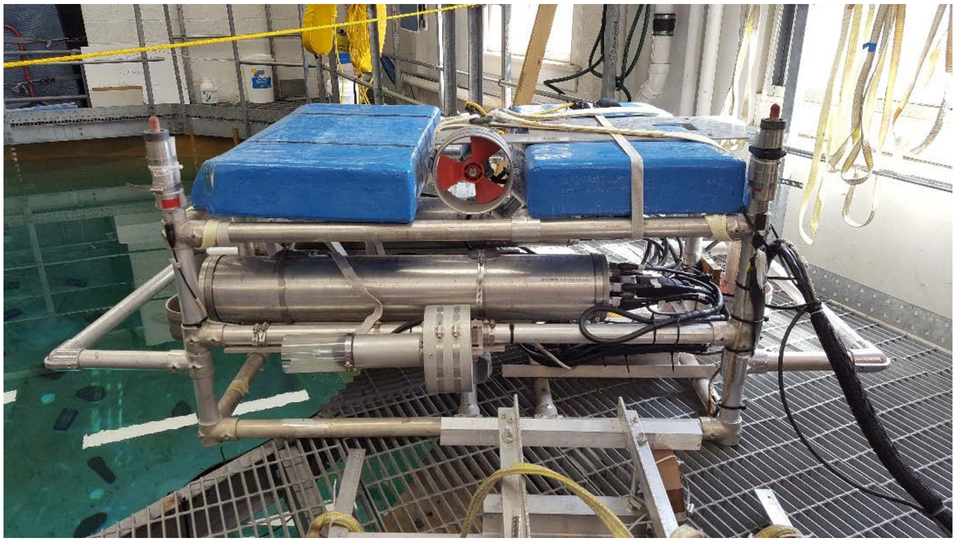

Figure 1: JHU ROV sitting on deck in the Dynamics System and Control Laboratory (DSCL)

The Dynamical Systems and Control Laboratory (DSCL) in Johns Hopkins works on developing control and navigation algorithms for ROVs. Because field deployment is time-consuming and costly, the DSCL has a tank within the lab for testing as well as a testbed ROV, the JHU ROV, in the lab to work on (Figure 1).

The JHU ROV, developed in 2002, is old and in need of replacement and improvement. A JHU Research Experiences for Undergraduates (JHU REU) student last summer began the designs for the JHU ROV II and my work this summer builds on this previous work.

2. Project Goals

The research this summer focused on the following four aspects of the JHU ROV II system:

Power Housing – With the bulk of the CAD finalized before the summer, the next phase of the housing would be the acquisition of commercial off-the-shelf (COTS) parts and hardware manufacturing.

Electronics Housing – While the outer structure design of the tube had been finished, the layout of the electronics components and housing connectors was still undetermined.

KVH Housing – Unlike the other housings, the KVH housing is made entirely of titanium. A pre-existing titanium endcap is being retrofitted for a smaller penetrator through the use of a plug.

Thrusters – The thrusters on the JHU ROV are custom designed, with an oil compensation system. With the JHU ROV II, it would be ideal to switch to COTS thrusters, which require testing to ensure a proper depth rating.

3. Power Housing

3.1. Background

With the bulk of the CAD for the power housing finished (Figure 2), attention turned to the manufacturing phase. An important consideration before ordering stock was choosing materials. Since the outer structure of the housing would be exposed to water, it was imperative that materials resistant to corrosion through long-term water exposure be chosen. Taking into account price and weight, the two materials considered were 316 Stainless Steel and 6061 Aluminum. While 316 is cheaper than 6061, it also has three times the density.[2], [3] The weight of fasteners such as bolts and nuts is negligible and 316 was chose. However, for parts such as the six rods surrounding the housing, material weight is an important factor in keeping the weight of the housing as low as possible.

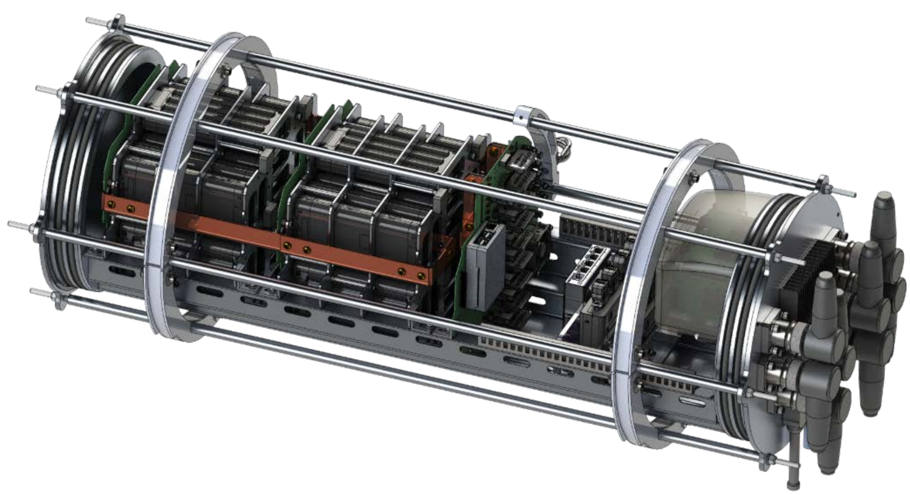

Figure 2: Rendering of the Power Housing without the exterior tube

3.2. Manufacturing Process

Figure 3: Manufactured Bent Sheet Metal Chassis

After choosing materials, a Bill of Materials (BOM) for both COTS parts and stock for manufacturing was compiled and parts were ordered. The following month was primarily spent on manufacturing the pieces seen to the right and below (Figure 3, Figure 4). It was quickly determined that the acrylic tube and the aluminum endcaps could not be manufactured to the proper tolerances by two summer interns. Instead, drawings of the parts were made and sent to professional machine shops to be manufactured. Unfortunately, many of the COTS parts and parts sent for machining did not arrive by the end of the summer. The circuit board for the batteries was also yet to be designed and manufactured. Thus, it was impossible to being assembling and testing of the subsystems of the power housing.

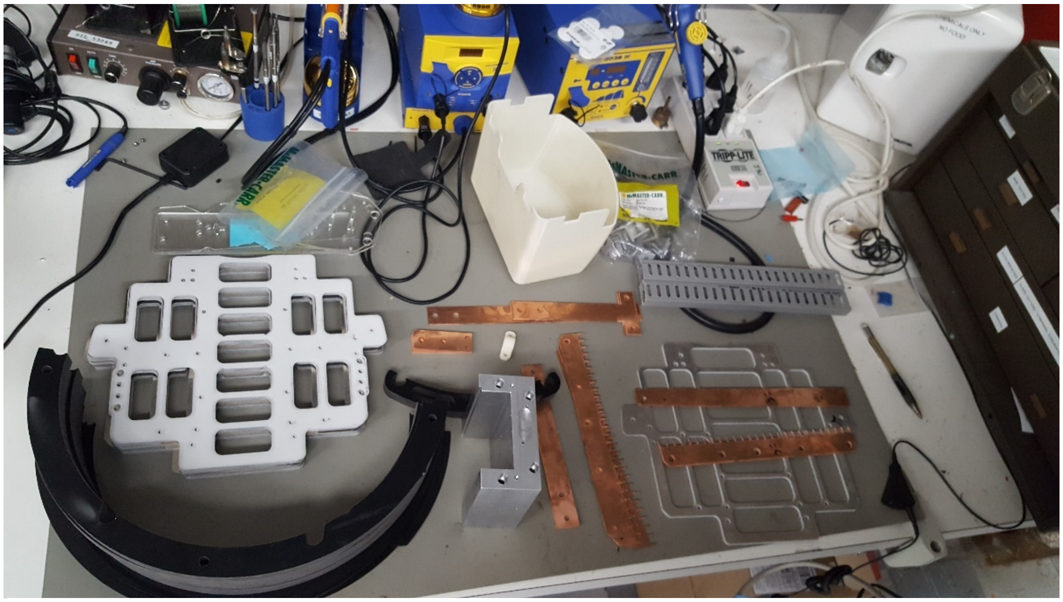

Figure 4: Manufactured parts of the Power Housing

4. Electronics Housing

4. 1. Goals and Design Considerations

The electronics housing for the JHU ROV II will contain the following components:

- Vicor DC-DC Converters
- CPU Stack
- MOXA nPort serial device server
- Ethernet switch
- Weatherboard
- MicroStrain 3DM-GX3®-35

- SubConn Power/Ethernet 13-pin connectors
- SubConn Micro Circular 8-pin connectors

In addition, several design constraints were taken into account. First, it is anticipated that the housing will gain components throughout its lifetime. Therefore, it was important to keep the layout compact to leave as much room for possible future components. Second, it was important to maximize the distance between the MicroStrains and the other components. The MicroStrain is a small Inertial Measurement Unit (IMU) that contains extremely sensitive magnetic sensors. Putting these magnetic sensors close to other magnetic-field inducing components such as the CPU, MOXA, and Ethernet switch could potentially disrupt the readings, leading to excess noise in collected data.

4.2. Design

Figure 5 shows part of the interior of the Electronics Housing. The outside of one endcap of the electronics housing holds four power/ethernet connectors mounted on the bottom, three female heads and one male head. The male head takes power from the power housing to minimize the possibility of injury from touching an exposed pin. One of the other connectors transmits power/ethernet, while the last two are left as spares. There are also eight utility connectors placed in a radial pattern along the edge, all with female heads. Finally, a heatsink and a pressure release valve are mounted near the center of the endcap. On the inside of the endcap are three Vicor DC-DC converters, covered by an ULTEM heatshield to maximize saftey.

Adjacent to the Vicors are the MOXA and Ethernet switch, mounted vertically to the chassis via acrylic trays. Next to the MOXA and Ethernet is the CPU stack, with a weatherboard mounted horizontally underneath. Muffin fans are placed strategically to the sides of the Ethernet tray to circulate air through the housing. Finally, on the interior of the opposing endcap are the MicroStrains. The CPU stack was placed behind the MOXA and Ethernet Switch to allow for better hardware access during repairs. While this places the stack closer to the MicroStrain, it was determined that there is enough distance between the two components that effects would be minimal.

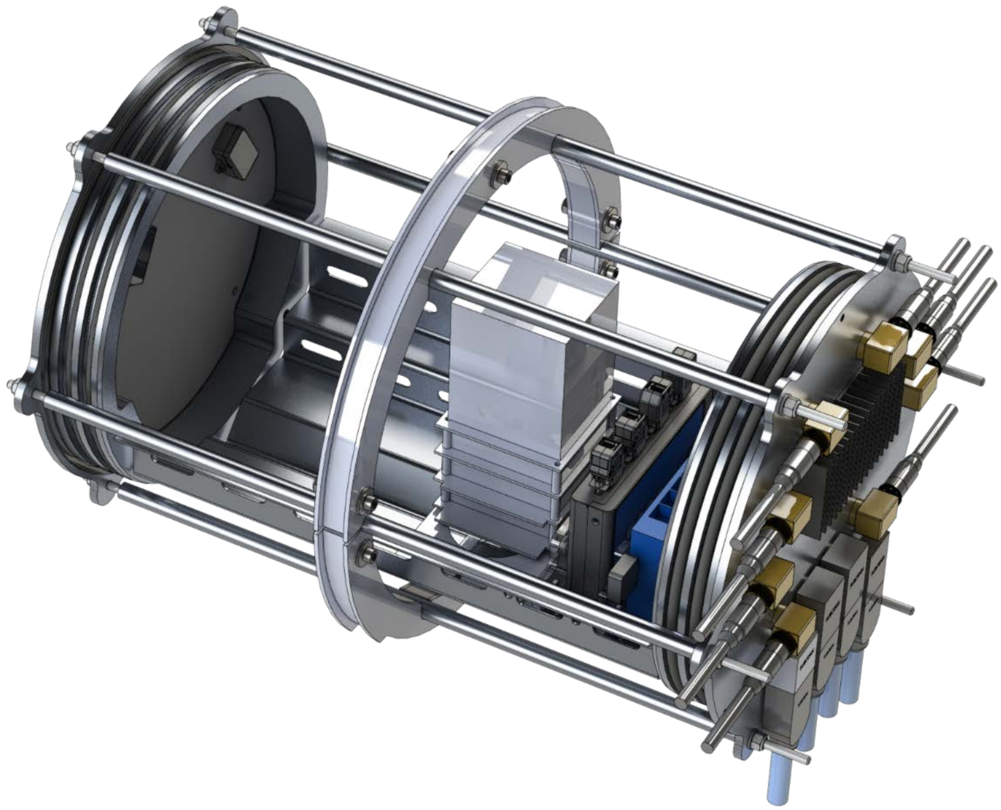

Figure 5: The interior of the electronics housing

5. KVH Housing Endcap Plug

5.1. Background

The KVH Housing holds an extremely sensitive IMU. To minimize potential noise sources, it has been given its own housing unit. This housing will be tested initially with the JHU ROV but is intended for the open ocean. The housing has been rated to a depth of 6500 meters and both the tube and the endcaps are made of titanium. However, titanium is a very expensive metal and is also difficult to machine. For this reason, a pre-existing titanium endcap will be re-used, instead of manufacturing a new endcap entirely, and will be connected with a SubConn Ethernet/Power 13-pin connector. However, this endcap has a hole with a diameter larger than what the SubConn connector requires.

5.2. Design Challenges

To remedy this problem, a plug (Figure 6) was designed that would fit the existing hole and allow for the connector to pass through while keeping the housing watertight. This plug would also be made of titanium to match metals with the endcap. Initially, the plug threaded into the endcap with the connector able to spin freely inside the plug.

Figure 6: Rendering of the KVH Housing Endcap Plug

Unfortunately, it was quickly noted that the threads on the connector would not be long enough to pass all the way through the endcap. Attempting to fit a socket head through the hole of the endcap to attach a nut to the connector would require extra machining on the endcap itself, something to be avoided. Instead, the connector threaded into the plug and the plug and the connector together spun freely inside the endcap, with a nut on the end of the plug to keep it in place, as shown in Figure 7.

Another point of concern was the elevation of the connector and in turn, the connector whip. Because of the elevation, the whip is now cantilevered, giving it an extra range of movement. This could lead to a loosened or possibly lost connection during a dive. To minimize such concerns, a support piece was designed to keep the head of the whip at the same height as the connector

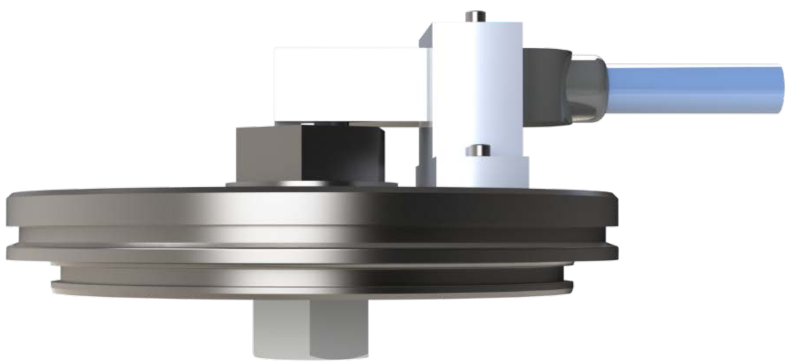

Figure 7: Rendering of the modified KHV Housing Endcap assembly

6. Thruster Testing

6.1. Background

The JHU ROV currently uses custom designed thrusters with an oil compensation system to prevent flooding. There were several problems with these thrusters, including the lack of commercial support and the unique failures of the oil compensation system, that were to be addressed for the JHU ROV II. Previously, the lab had chosen the Torqueedo Travel 1003 L thrusters to be used on the JHU

ROV II. These thrusters are intended for small- to medium-sized boats with a depth rating of up to 3 ft.[4] The tank in the DSCL has a depth of 14 ft., so these thrusters would need to be tested to ensure waterproofing at a greater depth than rated.

As expected, the lip seals that came installed in the thrusters failed at 14 ft. of depth. They were replaced with ceramic/graphite face seals (Figure 8) from John McCrane. A custom tool (Figure 9) was designed and manufactured to install these seals.

Figure 8: John McCrane ceramic/graphite Face Seals

It was noticed after the installation of the seals that the added height of the ceramic and graphite seals made reassembly of the thruster more difficult, as more pressure had to be used to force the housings together. At the time, this issue was dismissed, but it would later have significant implications.

Figure 9: Rendering of the Face Seal Install Tool

6.2. Thruster Failures

While reassembling the housing of the first thruster tested, one of the screws in the housing was overtightened and the threads were stripped. It is possible that the extra height the face seals added to the housing allowed the housing to strip more easily. While there was a small visible lift between the housing components around the hole of the stripped threads, the other three screws appeared to keep the housing properly sealed and watertight. The thruster was then placed in the tank at approximately 14 ft. without the propeller and run for thirty minutes. After removing the thruster and checking for water leakage, the internal components of the housing appeared dry.

The next planned test was to run the thruster in the tank with the propeller on. While disassembling and reassembling the thruster, another screw was overtightened and threads were stripped. An important factor to note was that the two stripped holes were adjacent. Since the thruster stayed watertight with one hole stripped, it was assumed that it would also stay dry for two, and the thruster was placed in the tank at approximated 14 ft. of water with the propeller on. Attempting to run it saw no movement from the thruster despite being at the current limit of the power supply. Several minutes into testing, there was a sudden spike which likely signified a short. Retrieving and disassembling the thruster showed that the entire thruster housing had been flooded. Inspection of the circuit board showed dried residue from the tank and what was likely several corrupted diodes (Figure 10). The circuit board was cleaned with diH_2O and alcohol then left to dry for a day in an attempted revival, which failed.

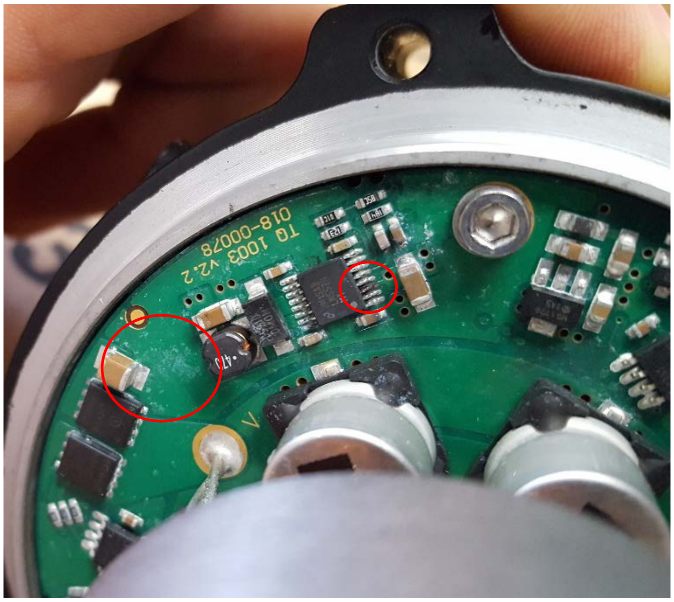

Figure 10: A section of the flooded circuit board. Water damage and corroded diodes have been highlighted.

A second thruster was acquired to finish this thruster seal testing. The first thruster was attached to a power source through a series of cables designed in the lab. Instead of attempting to recreate these cables, they were simply transferred from the original thruster to the new one. While attaching the wire terminals to the terminal studs on the thruster, the nut was overtightened and the stud was sheared off (Figure 11). It was then noted that the studs were not aluminum as originally thought, but brass, a softer metal, with a solder coating to give them a silver sheen.

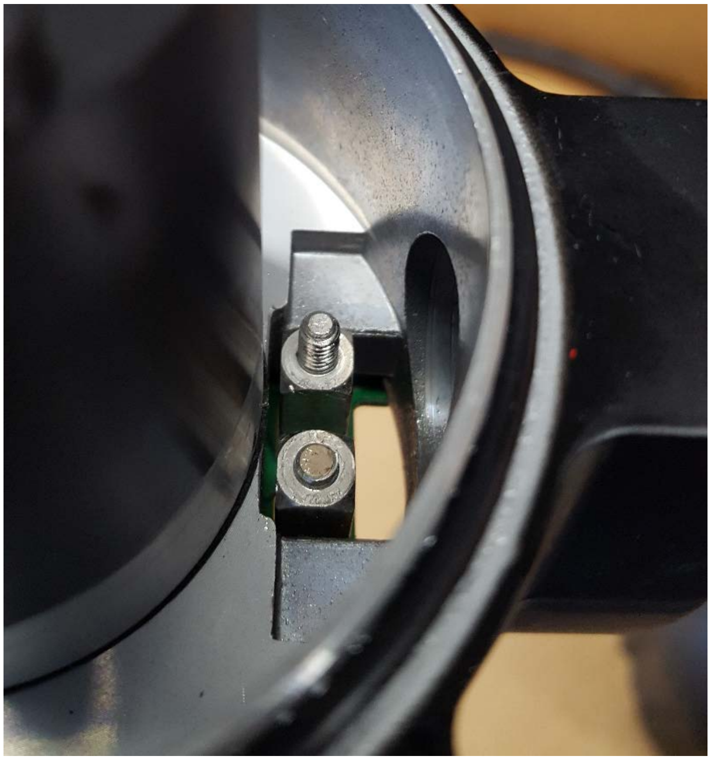

Figure 11: The sheared terminal stud of the second thruster

To repair this, the remains of the stud were faced off on the mill and the terminal was drilled into and threaded. The wire terminal was then reattached to the thruster and held in place with a bolt. An insulating foam sealant was used to shield the circuit board from any stray metal chips during the machining process.

6.3. Long Term Solutions

Two long term solutions to prevent further similar problems have been considered. Firstly, an oil compensation could be installed into the new thrusters. The central oil distributor has already been designed and the COTS parts picked out. This not an ideal however, as the notion for the new COTS thrusters was to move away from the oil system. Secondly, based on how the oil compensation system is designed, there is a chance that if one of the thrusters fail, the five other thrusters will fail with it. Finally, oil is simply a messy liquid to work with.

The second solution would be to redesign the housings to compensate for the added height of the face seals and to use aluminum to minimize the possibility of stripping threads. While the upfront difficulty and cost of designing and machining these parts would greater than the oil compensation system, the long-term benefits would include minimizing the number of systems on the JHU ROV II and the amount of maintenance necessary through its lifetime.

7. Future Work and Conclusion

There is still much more work to be done on the JHU ROV II. The following four areas have been identified as areas of interest:

Power Housing Assembling and Testing – Many of the COTS parts and the items sent for professional machining haven not arrived at this time. The circuit boards for the battery wheels also have not been designed yet. Thus, it was impossible to begin assembling of the power housing. Once assembled, subsystems of the power housing should be bench tested before being fully assembled.

Electronics Housing Manufacturing – The electronics housing CAD should be checked for updated design considerations and given a final inspection before beginning the manufacturing phase.

Thruster Testing – The thrusters will likely need new custom aluminum housings. After the housings are machined, the face seals can be reinstalled and testing can resume.

Frame Design – While the previous year's REU student drafted a notional frame design, multiple frame shapes should be considered before moving forward with a design.

8. Acknowledgements

I would like to acknowledge my collaborators Florian Pontani for his help with manufacturing and thruster testing, Tyler Paine for doing extensive design work for the CAD of the battery housing, designing the thruster testing tools, and providing support, and Andy Cohen for beginning the designs for the JHU ROV II. I would also like to thank my PI Dr. Louis Whitcomb for working with me and mentoring me throughout the summer. Finally, I would like to thank the National Science Foundation for providing funding and Johns Hopkins University for hosting the REU program

9. Appendices

9.1. Research Ethics - This lab did not work with human or other living organisms. The JHU ROV II is expected to stay in a controlled environment and not leave the lab. Therefore, I did have not have to give research ethics as strong of a consideration as some projects would. However, the research that will be performed on the JHU ROV II could have large impacts so it was important that I ensured all my work was up to standard to ensure future projects run as smoothly as possible.

9.2. Value of the Program – As a member of the Purdue ROV team, I expect I will be able to put much of the information I have learned throughout this program to direct use for future competition seasons. Aside from just ROV material, this REU have given me an insight to the experiences of a graduate student's workload and has encouraged me to pursue a Master's and possibly Ph.D. degree in the future.

9.3. Overview of the program – Personally, I thought this program was great. It had a good time line that gave enough time for a proper research experience, with tours that were interesting and relevant to the program and much of the research that was being done. One small thing that I thought could be improved would be to provide gym passes for the students, but honestly I thought the program was great.

References

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