To determine the effects of space travel on the bacteria Shewanella Oneidensis and Graphene coated fiber optic cables.

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Stevens Institute of Technology sponsored by The New Jersey Space Grant Consortium

August 7, 2015
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1.0 Mission Statement

Bacteria
Previous research shows varying bacterium can survive outside Earth’s atmosphere. Shewanella Oneidensis is a particularly interesting bacteria as it can survive both with and without oxygen. It can break down heavy metals and is showing some possible applications in nanotechnology and microbial fuel cells. The team felt that its resilience coupled with its potential usefulness would make it an excellent candidate for use in future space travel. Our goal is to determine how the bacteria is impacted by the ascent into space itself. We expect the bacteria to exhibit changes in shape and growth rate.

Graphene
Electronics coated in graphene show enormous future potential. Fiber optic fiber coated in graphene is currently being found to have applications in both sensor as well as communications networks. The team felt that these applications would be useful on future space missions and therefore opted to coat our graphene onto fiber optic cable. Our goal is to determine the feasibility of sending graphene coated electronics into space for future use. We expect the graphene to fracture due to vibrations and high g forces.

2.0 Mission Requirements and Description

Bacteria
The greatest difficulty in getting accurate results for the launch’s impact upon the bacteria was to ensure that the bacteria does not continue to grow after the launch. Since the team would not have access to a biology laboratory with the necessary equipment at Wallops, it became necessary to keep the bacteria cooled between 0 and 4 degrees Celsius. If the temperature went under 0 degrees Celsius, the bacteria would be killed and the results of the experiment would be invalidated. If the bacteria was allowed to exceed 4 degrees Celsius, than the bacteria would be able to grow and any post-launch growth would also invalidate the experiment. This issue was further complicated by the length of time necessary to keep the bacteria cooled after launch but before recovery. Given the results of previous Rock-SAT-C launches, the team determined that at least six hours of cooling was necessary to keep the bacteria growth in check. Once the payload had been recovered, the team was able to keep the bacteria cool with an ordinary cooler until returning to the biology laboratory.
Graphene
The graphene experiment underwent considerable change between inception and final result. The initial plan to take real-time data during the flight was eventually disregarded in favor of simply performing infrared spectroscopy on the graphene coated fiber optic samples both before and after launch.

While the engineering challenge of trying to collect real-time data was an attractive aspect of the initial plan, it was important for the team to reassess the actual intention of the experiment. If the intention was simply to determine graphene’s ability to survive in the extreme environment of a rocket launch, it was unnecessary to know exactly when it failed, but only that it did fail. Therefore, it was really only necessary to apply the graphene to the fiber optics and mount the samples securely within the payload to prevent any physical contact between the samples and the rest of the payload. It has already been established that ablative contact can damage graphene and therefore it was important to minimize surface-to-surface contact.

3.0 Payload Design

When designing the payload there were many considerations to be taken into account. This became difficult when trying to balance the size, shape, and critically of individual components. The key was to start final implementation only after each subsystem was validated. This is because any changes to a subsystem, within a system this compact and integrated would have cascaded changes and redesign. Managing size and shape was most difficult with the batteries. In order to get the highest energy density, the team procured 20 lithium polymer batteries. In order to optimize space, it was determined that the best course of action to follow was to place the bacteria samples in a row between two separate battery packs of 10 batteries. All of the electronics were compressed into a single layer to allow for maximum airflow to be utilized by the four the heat exchangers. Managing power was most difficult due the the power intensive Peltier plates. At 15 watts consumption this was difficult to manage in a space and weight restricted environment. Eventually, it was determined to only cool three samples instead of four due to power constraints.

It was determined that the battery holders should be 3D printed in order to reduce the impact to both mass and monetary budgets. 3D printing the holders also allowed for
greater flexibility in making further design modifications that might later become necessary. The foundation of the payload itself was composed of Makrolon plates that were machined into the correct shape.

One of the larger concerns of having so many lithium polymer batteries on the payload was their instability. While being unable to charge the batteries at Wallops was only a mild inconvenience, the very real concern of a short circuit was paramount while designing the electronics subsystem. Having even one battery short circuit while surrounded by 19 others could have catastrophic results for the entire payload section and not just the Stevens payload.

The team elected to safeguard this system by using thermistors located in each of the two battery packs. If the Arduino controller detected a temperature over 110 degrees Fahrenheit, the entire payload would shut down. Furthermore, the Peltiers themselves were only activated by MOSFET transistors. Therefore, should there be any power interrupts to the payload, the Peltiers should be inoperable. While this did create the possibility of ruining the experiment in the event of a power loss, it was determined that the safety of the entire rocket was of far greater importance than the results of the experiment.

Figure #1: Exploded View of Payload
Figure #2: Schematic of Electronic Subsystem
The graphene experiment went through several different iterations before arriving at our final design. Initially, the team wanted to take real-time data during the launch that would monitor the graphene. The plan was to simply utilize a simple fiber optic receiver/transmitter system that would measure the light intensity received during the launch. The transmitter would simply be sending a continuous light intensity without any variation or pulsing. Graphene’s absorption coefficient would result in a diminished reading in the receiver from the transmitter beyond what one would find in an uncoated fiber optic cable.

Unfortunately, the group ran into two issues during this process. The first being that graphene is extraordinarily expensive and the team delayed actually using and testing the graphene until the full mission simulation. Second, the group did not consult a subject matter expert in graphene until full mission simulation as well. The fiber optics purchased were polymer based but the process of coating them with graphene involves an acetone bath. The team needed to quickly acquire silica based fiber optics but was unable to obtain fibers of sufficient diameter to utilize the transmitter/receiver system. As such, the team eventually determined to simply use infrared spectroscopy on the graphene both before and after the launch. Despite the disappointment of having less data than initially desired, the team determined that the data would be sufficient to at least get a concept of the graphene’s ability to survive a launch.
4.0 Student Involvement

**Primary Members:**
Miklos Nyary - Mechanical Engineering - Project Manager
Andrew Isherwood - Chemical Engineering - Chief Engineer
Katelyn McClung - Chemical Engineering - Chief Programmer
Ethan Hayon - Electrical Engineering - Project Advisor
Melissa Conklin - Biology - Chief Biologist
Michael Marnell - BioMedical Engineering - 3D Printing Manager

**Graduate Student Advisors:**
Jun Jun Ding - Graphene Advisor
Jing Liang - Bacteria Advisor

**Contributing Members:** These members contributed to the project early in the project year but were eventually lost to other commitments:
Joshua Bloom, Daniel Cleary, Andrew Cupo, Claire Griffin, Dave Harman, Andrew Mignola, Paul Sferrazza, Jeremy Simoes, and Greg Widmaier
5.0 Testing Results

**Structural**
The bacteria sample tray containment was tested by filling it with colored water and checking for leaks to the structure. This process was also used to determine the safest and most efficient way to load the actual bacteria before departing for Wallops. The bacteria sample tray was found to be completely watertight.

![Figure #5 Structural Testing Bacteria Specimen Tray](image1)

![Figure #6 Bacteria Specimen Tray Successfully Maintains Seal](image2)

**Cooling**
Peltier efficiency and cooling capabilities were tested. While the aluminum plate did not reach target 4 Celsius, the achieved 8 degrees Celsius should have provided sufficient cooling.

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Figure #7 Testing Cooling System

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Ambient Temp (C)</td>
<td>22.6</td>
</tr>
<tr>
<td>3 Peltiers</td>
<td></td>
</tr>
<tr>
<td>Voltage (V)</td>
<td>5</td>
</tr>
<tr>
<td>Avg Current (A)</td>
<td>1.1</td>
</tr>
<tr>
<td>Avg Temp Al Plate (C)</td>
<td>8</td>
</tr>
<tr>
<td>Avg Temp Heatsink (C)</td>
<td>38</td>
</tr>
<tr>
<td>Fans</td>
<td></td>
</tr>
<tr>
<td>Voltage (V)</td>
<td>5</td>
</tr>
<tr>
<td>Avg Current (A)</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Figure #8 Cooling Subsystem Test Results

Software
Data collection software used in testing other components and subsystems. Verified data collection capabilities and storage capabilities confirmed possible run time > 24 hours.
Full Mission
The batteries were fully charged and the a full simulation of the mission was conducted. The g-switch activation was removed from the software code and a purely time-based system was used to ensure the proper activation of all components. The system activated as desired and all three Peltier plates were allowed to operate until a near complete discharge of all the batteries. Full discharge of the batteries would take approximately seven hours.

6.0 Mission Results

Bacteria
The payload performed as intended and the Peltier plates all activated at the correct time. We can confirm this with data logged from the current draw of the payload.
Figure # 10: Current Draw vs Time

The three tiers all correspond to the three Peltiers and are within expected current draws for the three Peltiers.

Upon returning to Stevens, the bacteria samples were analyzed by Jing Liang.

Summary of Results:

- Bacteria from all groups alive
- Bacteria from all groups maintain ability to proliferate
- No significant observation of change in bacteria morphology

Group 1: Bacteria not cooled during flight
Group 2: Bacteria cooled at T-3 minutes
Group 3: Bacteria cooled at T+86 seconds
Group 4: Bacteria cooled at T+173 seconds
Optical Density Results:

<table>
<thead>
<tr>
<th>Group</th>
<th>O.D</th>
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<tbody>
<tr>
<td>Control</td>
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<tr>
<td>1</td>
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<tr>
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<td>4</td>
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</table>

These results seem to indicate that the launch had negligible impact upon the growth of the bacteria. There is no clear trend or difference between the groups. While the groups did have a lower optical density than the control bacteria, whether this is due to the launch itself or due to other environmental factors is unclear. This was a failure in planning the experiment. The control group remained secured in the temperature controlled biology laboratory while the other groups were subjected to the stresses of traveling and storage in equipment that lacks advanced control systems.

Microscopic images of the bacteria groups are provided in the Appendix.

**Graphene**

Initially, the team was determined to take real-time data on the state of the graphene during launch. However, the receiver instrument did not pose the sensitivity necessary to capture any of the small changes in refractive index of the fiber coating. To reserve resources on the payload including energy and data storage spectroscopy on the three graphene samples was performed before and after the launch. After analyzing the FTIR spectra, it was determined that the graphene coating was unaffected by flight. The nature of the graphene made it difficult to see changes in bond structure of conformation. The IR energise given off by the SIO₂ (the fiberoptic) could have overpowered the that of the graphene.
7.0 Conclusions

These experiments by themselves are insufficient to draw any meaningful conclusions. It would require significantly more bacteria samples to make any real determination. However, the evidence does seem to indicate that the stresses of the launch, while extreme, are insufficient to have any real impact upon the graphene or bacteria.
It should be noted that all of the bacteria groups survived and were still capable of reproducing. This strongly indicates that Shewanella Oneidensis is viable for use in space.

While the cooling system for the bacteria was a great engineering challenge and the Peltier plate system was proven to be highly effective, the experiments themselves were not robust enough to really present enough data points to be meaningful.

8.0 Potential Follow-on Work

If the experiments were widened with significantly larger sample sizes, the data would be much more valuable. Shewanella Oneidensis remains a fascinating organism with some interesting applications. Furthermore, since all of the bacteria survived, it opens up the potential to examine using the bacteria in space-based nanotechnology creation. For example, the possibility of determining free fall impacts Shewanella Oneidensis’ ability to reduce metal ions. This information could lead to further exploration of nano-material fabrication in orbit.

While graphene remains a fascinating material with a constantly growing list of applications, it does not seem to be impacted at all by the stresses of a rocket launch. Since graphene can apparently endure the stresses of a launch, now further experimentation can be done on graphene in space itself. Graphene’s coefficient of absorption poses some interesting possibilities for sensors and photovoltaics.

9.0 Benefits to the Scientific Community

These experiments are simply a few data points to be added to a collective whole. They provide a stepping stone towards further experimentation and study but they are not in and of themselves groundbreaking. By proving definitively that both the bacteria and the graphene are capable of enduring the rocket launch, new avenues of research become more likely and practical.

These experiments have shown the feasibility for future experiments in space with both graphene and Shewanella Oneidensis. Now the problem becomes to determine how to best utilize these materials in space.
10.0 Lessons Learned

The bacteria control group should have been stored with the rest of the bacteria while at Wallops. The control group’s results are somewhat suspect as the control was kept in a dramatically different environment than the other samples for about two weeks. These huge environmental differences are an issue. In that vein, the team should have made earlier contact with subject matter experts when doing initial design for the payload and experiment. If the team had had more conferencing with graduate students and professors early on, it would have made the results of the experiments that much more reliable.

An over reliance upon certain team members was also dangerous for this group. Between Fall and Spring semester, the group’s member list underwent a dramatic change and nearly all teammates needed to be replaced due to the initial team’s waning interest. A more aggressive recruitment plan is already in place for next year.

11.0 Appendices

Bacteria Images (post-launch)
Appendix - Figure #A1: Live Control
Appendix - Figure #A2: Dead Control
Appendix - Figure #A3: Live Group 1
Appendix - Figure #A4: Dead Group 1
Appendix - Figure #A5: Live Group 2
Appendix - Figure #A6: Dead Group 2
Appendix - Figure #A7: Live Group 3
Appendix - Figure #A8: Dead Group 3
Appendix - Figure #A9: Live Group 4
Appendix - Figure #A10: Dead Group 4