ISS and Shuttle Payload Research Development and Processing

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NASA's ISS and Spacecraft Processing Directorate (UB) is charged with the performance of payload development for research originating through NASA, ISS international partners, and the National Laboratory. The Payload Development sector of the Directorate takes biological research approved for on orbit experimentation from its infancy stage and finds a way to integrate and implement that research into a payload on either a Shuttle sortie or Space Station increment. From solicitation and selection, to definition, to verification, to integration and finally to operations and analysis, Payload Development is there every step of the way. My specific work as an intern this summer has consisted of investigating data received by separate flight and ground control Advanced Biological Research Systems (ABRS) units for Advanced Plant Experiments (APEX) and Cambium research. By correlation and analysis of this data and specific logbook information I have been working to explain changes in environmental conditions on both the flight and ground control unit. I have then compiled all of that information into a form that can be presentable to the Principal Investigator (PI). This compilation allows that PI scientist to support their findings and add merit to their research. It also allows us, as the Payload Developers, to further inspect the ABRS unit and its performance.

I. Introduction

The Payload Development sector of NASA's International Space Station and Spacecraft Processing Directorate (UB), led by David R. Cox, is an integral part in fulfilling the Fundamental Space Biology (FSB) Science Plan. The goals of the FSB plan are to solicit and then sponsor research that expands knowledge of biology adaption to space that will hopefully benefit plant functions on Earth, use the International Space Station (ISS), orbital vehicles, and ground based analogous facilities to conduct this research on, develop new hardware to meet the specific parameters on certain research to be conducted on orbit, and maintain the United States as a international competitor in biological research. Payload Development uses a specific process and various hardware to successfully complete these goals.

A. Payload Development Project Life Cycle

The Payload Development Project Life Cycle is the main process that is used to successfully complete the goals called on by the FSB Science Plan. The process consists of six stages and the duration of each phase can vary based on the maturity of the science that is being researched, how the experiment may be implemented, the hardware maturity, and what launch vehicle is needed to achieve a microgravity platform for the experiment. Tasks in each phase can be separated into three separate areas; science, hardware, and integration. These three areas of the Payload Development team must work together throughout all phases to successfully complete experimentation with verifiable results.

The beginning stage of the Project Life Cycle is Pre-Phase A and has the main function of selecting a scientifically meritorious and technically feasible research proposal. NASA headquarters will begin by developing and releasing a NASA Research Announcement (NRA) to inform the biological science community of a microgravity research opportunity. After the release of the NRA, several competing Principal Investigators (PIs) submit their proposals to be reviewed by both their biological research peers and the Agency. Then the International Space Life Sciences Working Group (ISLSWG), consisting of representatives from various space agencies including NASA, ESA, CSA, CNES, DLR, NSAU, and JAXA, come together to determine what research proposal would satisfy the mutual interests of each agency and finally the selection and notification of the winning proposal is

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made. Once the Proposal Assignment is given out, authority to proceed (ATP) is ordered to the Payload Development team to move forward into Phase A.

The next step of the Project Life Cycle, Phase A, begins with a site visit of the Payload Developers to meet with the newly selected PI. In this meeting, the Payload Developers go over with the PI details of the Payload Development Life Cycle and what knowledge needs to be gained before the specific research is integrated into hardware and placed on a mission. To achieve this, the PI then begins definition experiments. These experiments, performed on Earth, will determine the spaceflight and biocompatibility of the plants with certain hardware materials, along with gaining vital statistics on ideal environmental conditions required to complete successful experimentation. Once the experimental parameters and specifications are defined fully, the engineering team can move forward by assessing if new hardware needs to be designed or if there is existing hardware that meets those experiment definition specifications. When all of the experimental requirements are determined to be compatible with hardware and integration onto a mission, ATP is given to the Payload Development team.

Phase B is the development stage of the Project Life Cycle. During this stage, the PI works to develop the actual experiment that is to be flown on orbit. Once the experiment protocol and procedures are developed, the full experiment is conducted to verify that meaningful scientific results can be obtained and to trouble shoot any complications with the experiment. On the hardware side, engineers work to design and fabricate a prototype for the experiment housing hardware and then test to see if the plants are able to grow and perform within that hardware. If hardware that is determined to be compatible with the plants already exists, than the same verification tests, termed Science Verification Tests (SVT), are performed. Already existing hardware will be discussed later in the paper. While these development experiments and hardware fabrications are taking place, the Payload Developer begins work to find a mission that the research will be able to fly on, completes the first phase of a Flight Safety Review, and develops a Payload Integration Agreement (PIA) to insure the smooth transition from ground to flight research. A Ground Support Requirements Document (GSRD) is also drawn up to lay out what ground equipment and service will be needed to implement a successful experiment on orbit. Finally, when the SVT is completed, the Payload Development team is authorized to move ahead to Phase C.

Following the development of the research and hardware, the Payload Development team moves forward to a verification stage, Phase C. During this stage the PI works to finalize and tweak his experimental procedure and then locks in his payload experiment design. The engineers on the hardware side fabricate the final hardware selected for flight and then proceed to begin Flight Certification Tests. These tests insure that the hardware is able to endure an orbital environment and also to make sure that it does not negatively affect the launch vehicle or orbiter to cause unnecessary or excessive risk. The project integration team during Phase C begins with making final selections for which flight the experiment will ride on, and insures its place on the manifest. They then work to complete Phase 2 of the flight safety review. This is followed by the development of an experimental timeline and crew procedures to successfully implement the experiment on orbit. When all of these tasks are completed by each division of the Payload Development team, the payload goes through a Payload Verification Test (PVT) and then is given a Payload Readiness Review before the team is authorized to move onto the next Phase.

The next stage, Phase D, involves the actual integration of the payload onto the launch. The engineers continue with their flight certification tests which include testing thermal, acoustic, power, EMI, and weight properties of the hardware. At the same time, the integration team completes the final flight and ground safety reviews and personally trains the crew on working with the experiment and its respective hardware. Finally, the Biosafety Review Board (BRB) gives their approval for the payload to fly and last minute flight preparations are made.

The final, and arguably most exciting stage of the Project Life Cycle, Phase E, includes the operations and post-flight analysis and reporting. This stage begins with the actual launching and implementation of the plant research payload on orbit. While on orbit, the Payload Development team makes sure that on orbit hardware and operations are being executed properly and address any anomalies or re-plans that take place. Once the payload samples return or the experiment is completed, the PI then has a year to complete their analysis and finally report their experimental results. This report is submitted to the Life Sciences Data Archive as well as various research publications which completes the Payload Life Cycle.

B. Payload Development Hardware

Over the years, the Payload Development team has designed and fabricated several pieces of hardware to satisfy specific experimental requirements and mechanical/electrical limitations set by the launch vehicle. Having this wide range array of hardware inventory expedites the Project Life Cycle process by allowing the hardware engineers to bypass the design and fabrication of a new piece of hardware. A small selection of this hardware will be further explained in detail to portray the capabilities of the Payload Development team.

A commonly used piece of hardware used for biological experimentation on orbit is the Biological Research in Canisters (BRIC). BRIC units are anodized-aluminum cylinders used to provide passive stowage for investigations studying the effects of space flight on small specimens. Many variations have been made to the original BRIC design to accommodate a wide array of experimental requirements. The most current variation has been the BRIC-LED which utilizes a accompany set of hardware, the Petri Dish Fixation Unit (PDFU). The PDFU serves as the holder for a standard 60 mm petri dish and has the ability to deliver a fixative or fertilizer to the sample within the petri dish. The BRIC-LED can house up to six PDFUs and requires just 6 watts to run. Holes on the lid of the BRIC-LED above each PDFU are used to insert the fixative or fertilizer using a caulk gun type actuator. The lid of the BRIC-LED houses red surface mount Light Emitting Diodes (LEDs) that provide the biological specimen with illumination. A fan is also enclosed in the BRIC-LED to prevent samples from reaching temperatures out of their required range. Because of the BRIC simplicity and ability to be easily integrated into a launch vehicle, it has been the hardware of choice for relatively low requirement research.

Another crucial piece of hardware utilized by the Payload Development team is the Kennedy Space Center Fixation Unit (KFT). KFT's use formaldehyde, RNALater, and other chemical fixatives to "freeze" plants and preserve their tissue for inspection and analysis on return from flight. This means that biologist can experiment on plants that have lived their entire lives, from germination to termination, on orbit in microgravity. The genius of the KFT lies in its ability to contain level two hazardous chemicals and still be safe enough to be handled in a short sleeve environment, especially on the ISS. This is achieved by its unique three separate o-ring and chamber design, as seen in Image 1. The KFT has become a vital tool for any biological research performed on orbit.

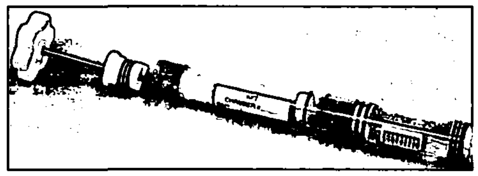

Image 1. **View of the Kennedy Fixation Tube (KFT)**

C. Advanced Biological Research System (ABRS)

My work this summer, which I will go into further detail later in this paper, consisted of analyzing data received from a very important and useful piece of hardware in the Payload Developer's arsenal of hardware, the Advanced Biological Research System (ABRS) unit, as seen in Image 2. The ABRS unit has the unique capability of providing a very controlled and monitored environment and caters to research with extensive experimental and environmental requirements. The size of ABRS allows it to replace a middeck locker on the Space Shuttle. It also is compatible to fit into an ISS Expedite the Processing of Experiments to Space Station (EXPRESS) rack. ABRS can be used both as a primary and permanent facility or as an up and down transportation device for experimental payloads. There currently is an ABRS unit on the ISS that is not in use but is poised to house further research in the future. One of the great advantages of ABRS is its remote control and sensing capabilities. This allows for commands to be set up to the unit to change environmental conditions and also to monitor environmental conditions via data sensors that can be mimicked by the ground control ABRS unit. This means that the Payload Development team is able to create

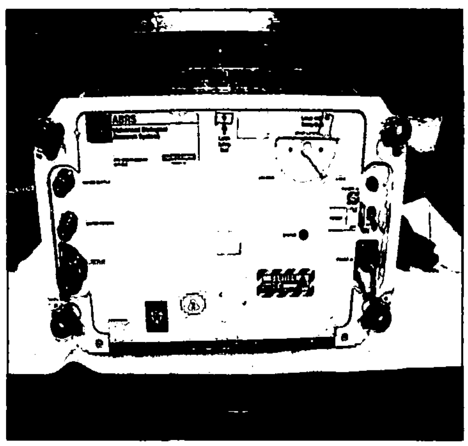

Image 2. **Front view of an Advanced Biological Research System (ABRS) unit used for ground control experimentation**

an identical atmosphere for the ground control unit with the only variable condition being gravity. The ABRS unit contains two separate Environmental Research Chambers (ERCs) which can function independently to provide several services including temperature control to 8 degrees C below ambient, controllable atmospheric carbon dioxide level, relative humidity control between 60-90%, chamber imaging from three cameras, and the Green Fluorescent Protein (GFP) imager. The GFP imager specifically has been successfully demonstrated to provide biological remote sensing and telemetric capabilities. This unit opens up countless doors in the world of space flight research and has huge potential to accommodate cutting edge research on orbit for years to come.

II. Summer Internship

About ten weeks ago I joined Dave Cox and the Payload Development team as an intern. Prior to my internship term, the team had been working and ultimately completing seven month long on orbit research payloads, Advanced Plant Experiments-Cambium (APEX-Cambium), using the ABRS unit. APEX-Cambium consisted of three separate research payloads, NASA sponsored Transgenic Arabidopsis Gene Expression System (TAGES), and the CSA sponsored willow and spruce tree experiments. It was my responsibility for the summer to analyze much of the data obtained from these payloads to assist in the research being performed, especially with TAGES experimentation. Many challenges were encountered along the way but in the end a product was yielded that will allow the PI's to insure the validity of their findings.

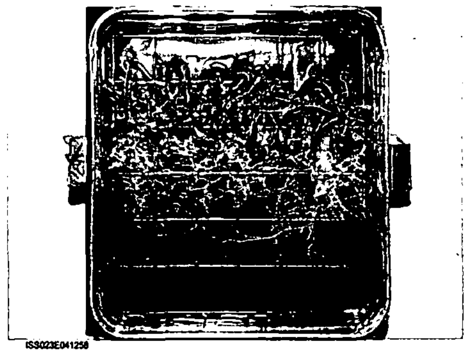

Image 3. **View of the Arabidopsis plant used in the Transgenic Arabidopsis Gen Expression (TAGES) research. Courtesy of the TAGES Research Team**

A. Work Conducted

As mentioned, the majority of my work this summer consisted of analyzing the environmental conditions data obtained from the ABRS unit for the TAGES research. Throughout the course of experimentation, sensor nodes took temperature, carbon dioxide, relative humidity, and a slew of other measurements at eight to twelve minute intervals. This data was down linked to the ground control ABRS unit to be mimicked and provide for a true control with gravity being the only variable between flight and ground experimentation. My assignment was to take this data from both the ground and flight runs and compare to verify that indeed, environmental conditions were congruent over experimental

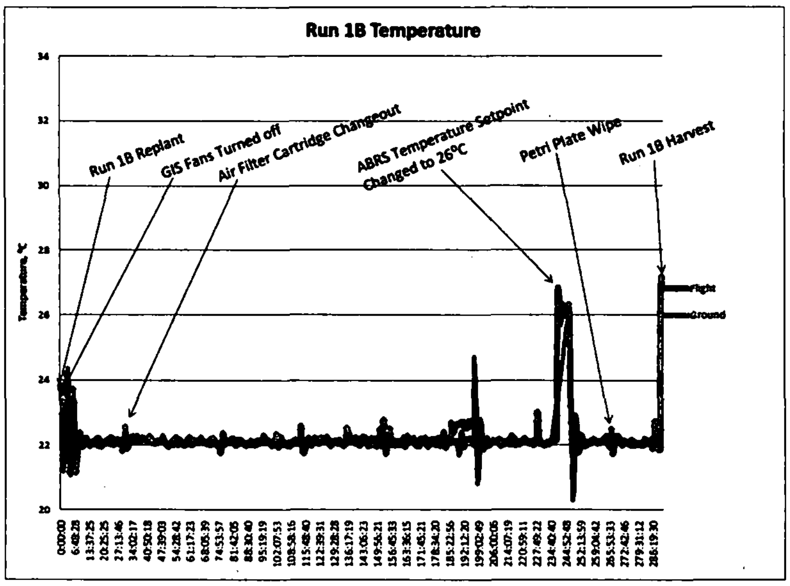

Figure 1. Temperature as a function of Experimental Elapse Time (EET) for TAGES Run 1B experimentation. *Figure represents how data from the flight and ground unit was graphically compared and how change in data and anomalies were explained by the labels derived from the logbooks. The graph and labels are color coordinated to distinguish flight from ground. Courtesy of the TAGES Research Team.*

elapsed time and then use the flight and ground logbooks to explain any anomalies or trends in the data. A view of what a typical graphical comparison of the flight and ground environmental data would look like can be seen in Figure 1. As you can see, events like shuttle launch, ABRS activation, and cooling loop purge can explain the rises and falls of the graph. Graphs similar to this, were drafted up for temperature, relative humidity, and carbon dioxide levels for all runs of the TAGES experiment.

B. Challenges Encountered

Although the task at hand was ultimately completed, several complications and challenges arose as I worked more and more with the data. First off, the shear amount of data that needed to be combed over was a challenge in itself. With somewhere around one hundred different data sets taken every ten minutes or so for seven months straight, managing and compiling excel sheets with over six million cells proved to be a huge challenge. Another major challenge encountered was discovering that times of the ABRS data were calibrated wrong for some of the ground and flight unit runs. This made the linking of the logbook, which was time specific, to the data invalid. To calibrate back to the correct time I used specific data that indicated when separate runs began and ended as reference points. In the end I was able to match up the correct data to the logbook information within minutes of accuracy. Other issues included logbook information that simply did not make sense. Some events were out of order or duplicated, such as Run B coming after Run C or there being a Run D followed by another Run D. To elucidate these logbook discrepancies, I met with several of the engineers to go line by line through the timeline of events. Eventually, all was cleared up and an accurate product was attained. Although these challenges definitely slowed down the process of putting together figures to pass along to the PIs, it is my belief that encountering them was beneficial. Several of the problems gave us insight into some of the issues of the ABRS unit itself or the process in which the experiment was carried out, and the subsequent methods on how to solve those problems will prove to expedite the environmental data analysis in the future.

C. Ramifications of Work Done

One of the things I am most grateful for in regards to this internship is that the work I conducted this summer actually served a purpose as opposed to being asked to do something meaningless. With the graphical representations and comparisons of the environmental data, the PIs will be able to either verify or nullify the validity of specific experiments. It will also give them insight and explanation into why certain plants have certain characteristics in response to the environmental conditions they were grown under. This knowledge will ultimately allow them to publish their findings and advance the overall knowledge of plant growth and function in microgravity. Also, presenting the data in a way that is easy to evaluate and understand makes the PI's job much easier and improves their overall experience working with NASA and the Payload Development team. This satisfaction with the team potentially could encourage others in the science community to pursue space flight research.

III. Overall Experience

All in all this internship has been one of the more enlightening experiences of my life. I have learned that there is a lot more involved in engineering than just math, science, and design. It requires you to work with people, come to compromises, and lead a group of people to a common goal. Biological research has a rich future in the space program as a whole, and I am honored to be a part of that while I was here.

Acknowledgments

I would like to first and foremost thank Dave Cox, my mentor for this summer internship. Dave could not have been more helpful and easy to work with. I greatly admire his passion for what he does and can only hope to enjoy my future career as much as he loves his. He personifies the true meaning of a great mentor by not only just leading me to what to do, but also opening up for my input. I cannot thank him enough for all of his support.

I want to thank Chris Comstock and Janet Letchworth for taking me in my first week and making me feel at home. I would not have been able to survive those first couple weeks without them.

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I want to give a big thank you to the entire UB staff for making me feel like I was a part of the family.

Finally, I would like to thank NASA KSC, USRP, and UB for the graciously giving me opportunity of a lifetime. Lessons I have learned this summer will have an effect on me for the rest of my life and I could never be grateful enough for giving me this opportunity.