Powering OSCAR

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Major: Electrical Engineering, Robotics Option
Program: NASA Internship and Fellowship (NIF) Spring Session
Date: 12 04 2019

Powering OSCAR

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Recycling waste has been an issue on Earth for decades. The OSCAR project seeks to find ways to make sure that it does not become an issue in space. The main focus of OSCAR is the combustion of waste and reclamation of gaseous products in microgravity. The first phase of testing relies on a ground rig that operates both under normal (Earth) gravity and in drop tower tests that briefly simulate a microgravity environment. In the second phase, a test will be performed during a suborbital flight were the experiment will be carried out in microgravity. Throughout the spring term, interns have played an integral part in continuing the progress made by the project. They performed work in upgrading the electrical and mechanical systems that make up OSCAR. They made multiple improvements to the test rig's operating software to improve readability and usability. They prepared and edited documents that were vital to the engineering process. And, they were responsible for performing lab tests and refining the lab operations document and procedure. The interns were a big help in maintaining the rigorous test schedule.

Nomenclature

cDAQ = *the data acquisition and control unit series name*
Con-Ops = *concept of operations*
fps = *frames per second, the refresh rate of a visual device such as a monitor or a camera*
g = *the acceleration felt by an object at the surface of the Earth, typically 9.81 meters per second*
HFWS = *high-fidelity waste simulant*
Hz = *unit of frequency, one per second*
kHz = *1000 Hz*
mAh = *milli-ampere hour, the amount of current that will exhaust a battery's capacity in one hour of discharge*
NI = *National Instruments*
OSCAR = *Orbital Syngas Commodity Augmentation Reactor*
PT = *pressure transducer*
SV = *solenoid valve*
TC = *thermocouple*
VI = *virtual instrument, the name given by national instruments for an individual program component*
W = *Watts, a unit of electrical power*
V = *Voltage, electrical potential*

I. Introduction

The goal of OSCAR, which stands for Orbital Syngas Commodity Augmentation Reactor, is to find a way to turn astronaut waste into chemical energy. The two parts of this are important: finding a way to dispose of waste generated in space, and seeing if there is a way to recycle that waste into chemical energy.

The importance of the disposal aspect is that there is currently no way to dispose of, or recycle, waste that is created in space other than jettisoning it (which is what the ISS does via empty supply capsules). As manned missions go deeper into space, that method will no longer be viable, as a craft would essentially be littering the space and planets that they visit.

Energy reclamation is also important because of the high monetary and spatial costs of sending supplies on space missions. Every little bit extra that can be reused out of what is sent can save room and funds for other supplies.

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The facet of this problem that the OSCAR project is focusing on is how to combust waste in zero gravity. Combustion in the presence of gravity is one of those things that is taken for granted. When something burns on Earth, the flames rise above the fuel as oxygen flows from underneath. In microgravity, the flames surround the object completely, which restricts the amount of oxygen that can reach the fuel, and retards the combustion. OSCAR uses a vortex reaction chamber to counter this phenomenon.

The OSCAR test rig will eventually be tested on a suborbital flight to see if it is an effective solution to the issue in real-world conditions. Currently, there is a prototype test rig that is fully functional. This rig has been previously tested in a 2 second drop test at Glenn Research Center's (GRC) Zero Gravity Facility (ZGF). (The free-fall conditions of the drop mimic microgravity, if only for a brief period of time).

This session's focus was on upgrading the test rig and software, updating the paperwork, performing additional lab tests, and readying the rig for the five second drop test, again at GRC.

II. Upgrades

The state of the testing rig at the start of the session was in between its configurations for the two second drop tower and the five second drop tower. The rig needed upgrades to address various insufficiencies that either were discovered during the two second campaign or were a direct result of the differences between the two drop tower setups. The main differences that had to be handled were the increase in shock loads from 30g to 65g, a difference in drop indicating signal (on the falling edge of a pulse instead of a change from high to low), and the ambient pressure of the test apparatus (the two second tower dropped the rig in atmosphere, while the five second tower drops in vacuum).

A. Hardware

1. Pressure Transducers

One of the first upgrades performed on the rig was the addition of two more PTs (pressure transducers). These PTs took the place of pressure gauges at the accumulator tube and the back pressure regulator. It was found that accessing these gauges during the test was difficult while the rig was in the drop capsule. Using PTs instead of physical gauges also allows for greater accuracy on the pressure readings.

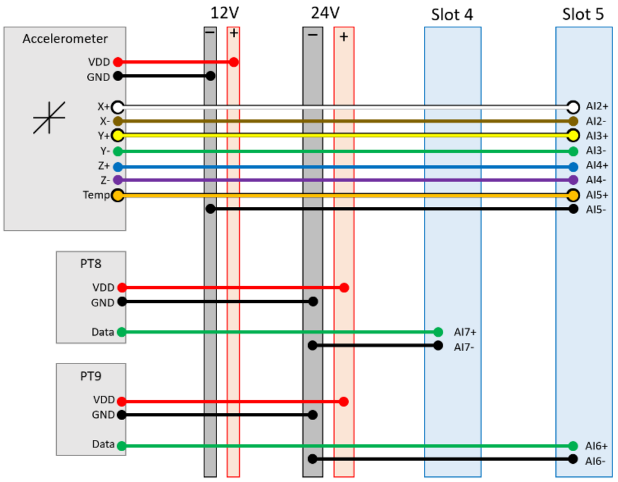


Figure 1- Wiring Diagram for new Pressure Transducers and Accelerometer

Installation of the PTs involved both electrical and mechanical components. The electrical side of the task involved creating a pig-tail of three wires twisted together that were screwed into the PT connector on one end, and fed through the rig to the analog input cards on the controller. This portion was relatively simple as it just involved looking at the data sheet for the PTs to find the connections and looking through the schematic to find an open spot to wire into the controller.

The mechanical portion involved actually connecting the PTs to the tubing on the rig. In order to make the connection, hours were spent searching for a combination of NPT, AN, and Swage-Lock fittings that would join the PT to the tube. Inevitably, someone else would find that magical fitting that would remove one or more connections.

2. Accelerometer

A three-axis accelerometer was added to supplement data about the timing and quality of simulated microgravity achieved during the test. Since the accelerometer was a new sensor to the project, some bench testing was performed to learn how to connect and read data from the sensor before incorporating it in the rig.

3. Supplemental Battery Pack

The rig utilizes two or more GoPros during a test to capture the reaction in the manifold and the rig as a whole. Because of the added time in the five second tower that is required to depressurize and re-pressurize the test apparatus, there was a real concern on whether capacity of the internal GoPro batteries would suffice. The solution to that problem was to find an external battery pack to power the GoPros instead of their internal batteries.

Considerations were made to ensure that the battery had enough capacity, could deliver enough power to both GoPros, and could withstand the shock at the end of the drop. Unfortunately, few manufacturers post information about the shock rating of their battery packs, so determining whether a battery pack would be rugged enough was more qualitative than quantitative.

Determining the actual electrical requirements lent itself to a more analytical approach. A quick search of the GoPro website revealed that the GoPro Hero6 Blacks that are used on the rig have a capacity of 1200 mAh. The website also revealed that a Hero6 Black could last for about an hour while recording at 1080p, 240fps. Thus, the minimum power output of the battery pack needed to be:

$$Power = 2 * (1220 \text{ mAh} * 4.4 \text{ V}) = 10.736 \text{ W} \tag{1}$$

Where the 4.4 V come from the voltage of the internal batteries, and the factor of two accounts for there being two cameras. The value of 10.736 W was rounded up to 12 W to give a little extra padding.

The last part of the electrical requirement was that the capacity of the pack needed to be at least 2400 mAh for each hour of operation, but the external batteries on the market today tend to be large enough that this amount was trivial.

B. Software

Software upgrades ranged from quality of life improvements for the operators, back-end changes to improve expandability and readability, and changes incurred by the difference between the drop towers. The software itself is written using LabVIEW's G language. LabVIEW features a graphical programming environment, where the programming involves wiring together VIs (virtual instruments) in a way that resembles the flow of data through the system.

The main controller for the system is an NI (National Instruments) cDAQ (control and data acquisition). It is essentially a computer with a multi-core processor that runs an instance of LabVIEW. It has eight expansion slots built in for adding interface cards that allow the cDAQ to read and provided the various analog and digital signals that control the SVs (solenoid valves) and heaters and reads data from the PTs, TCs (thermocouples), FMs (flow meters), and accelerometer.

1. *GUI Maintenance*

The state of the UI (user interface) at the start of the term was one of bare utility. It had all of the controls and indicators that were needed to operate the test rig, and that was all of the consideration made. Few of the positions of the controls and indicators were aligned, and the legends for the history graphs were placed where there was room.


TC1-Ox Sply 22
TC2-OX 22
TC3-MIX 22
TC4-STM 23
TC5-Leg1Top 22
TC6-Leg1Mid 22
TC7-Leg1Bot 22
TC8-Leg2Top 22
TC9-Leg2Mid 22
TC10-Leg2Bot 22
11-Leg3Top 22
TC12-Leg3Mid 22
TC13-Leg3Bot 22
TC14-RctrBot 22
TC15-RctOut 2288
TC16-HX 22
TC17-Smplln 2288
TC18-Srf_MIX 22
TC19-Srf_Stm 22
TC20-Srf-Rctln 22
TC21-Srf_Trsh 22
TC22-Srf_RctOut 22
TC23-Htr4 2288
TC24-Htr5 2288
TC25-Htr6 2288
PT1-Ox 38.01
PT2-Stm 14.81
PT3-Mix 14.81
PT4-RctOut 14.78
PT5-Pre 14.65
PT6-Drop 14.65
PT7-Post 14.7
PT8-ATube 14.84
P9-BPR 14.62
FM1-Ox 0.01
FM2-Stm 0.74
X-Acc -0.01
Y-Acc -0.01
Z-Acc 3.965
T-Acc 1.223
Drop 0

TC1-Ox Sply 21
TC2-OX 21
TC3-MIX 21
TC4-STM 22
TC5-Leg1Top 21
TC6-Leg1Mid 21
TC7-Leg1Bot 21
TC8-Leg2Top 21
TC9-Leg2Mid 21
TC10-Leg2Bot 21
TC11-Leg3Top 21
TC12-Leg3Mid 21
TC13-Leg3Bot 21
TC14-RctrBot 21
TC15-RctOut 21
TC16-HX 21
TC17-Smplln 21
TC18-Srf_MIX 21
TC19-Srf_Stm 21
TC20-Srf-Rctln 21
TC21-Srf_Trsh 21
TC22-Srf_RctOut 21
TC23-Htr4 2286
TC24-Htr5 2286
TC25-Htr6 2286
PT1-Ox 14.6
PT2-Stm 14.84
PT3-Mix 14.86
PT4-RctOut 14.82
PT5-Pre 14.53
PT6-Drop 14.61
PT7-Post 14.65
PT8-ATube 14.62
P9-BPR 14.66
X-Acc -0
Y-Acc -0
Z-Acc 0.991
T-Acc 1.228
FM1-Ox 0.01
FM2-Stm 0.01
Drop 0

Figure 2 - Comparison of the GUI Before and After Improvements

The maintenance involved going through and grouping controls and indicators according to their functions and using LabVIEW's built-in alignment and spacing tools for organization. These groups of controls and indicators were placed in boxes, and these boxes were in turn arranged.

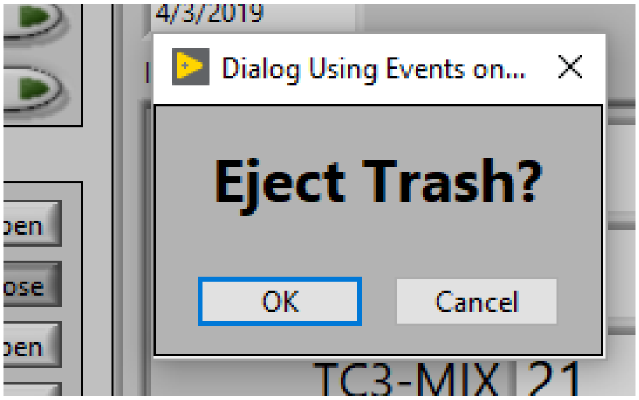
LabVIEW's legends for their graphs can be unwieldy when dealing with large data sets (as is done in the OSCAR system). In order to reduce the size of the legends (so as to only show the data points being used in the graph), boxes that matched the background color were layered on top of the unused portion of the legends. The result was both clean and readable.

2. *Premature Injection Protection*

The trash injection system uses an SV coupled with a pressurized accumulator tube. At the point in the procedure when it's time to inject the trash (stored in the trash tube) into the reactor manifold, the operator presses a button in the UI that opens the SV, and the pressure differential between the accumulator and the reactor forces air (or helium, depending on the test parameters), and the trash, from the accumulator, through the trash tube, and into the manifold.

If the operator miss-clicks on the trash injection button at the wrong time, the trash could be prematurely injected into the manifold, which would ruin the test. In order to protect against such an eventuality, it was decided that a confirmation window should pop-up when the user presses the trash injection button. In the pop-up, the user has the option to confirm or cancel the injection.

LabVIEW has a built-in template for a pop-up VI which was utilized for the confirmation pop-up. While this pop-up was successful in preventing premature injections, it posed a problem in the pre-programmed drop sequence. During the drop sequence, the trash button is activated programmatically, and this also causes the pop-up to show. In order to get around this, logic was introduced to bypass the pop-up when the system is in its armed state (which the operator initiates when they are getting ready to inject the trash). Requiring the system to be in an armed to bypass the pop-up ensures that the button still essentially still has a two-step process (arming and then injecting instead of injecting and then confirming).



Eject Trash?

Figure 3 - Trash Injection Confirmation Pop-up

3. *Heater Control Expansion*

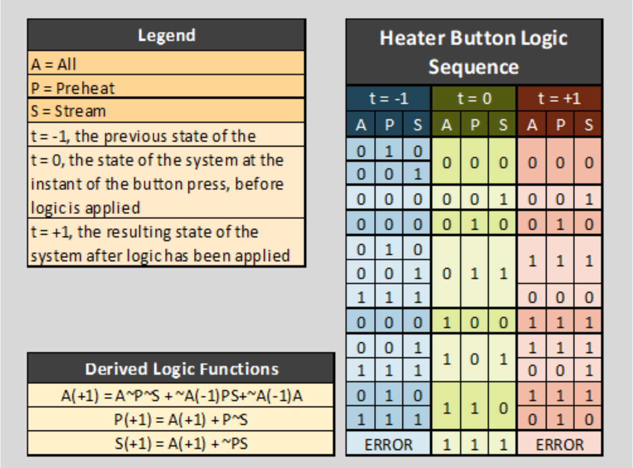
The OSCAR test rig has six heaters. Three of the heaters are cartridge heaters in the reactor manifold, and are responsible for combusting the trash. One of the other heaters creates steam (there is a syringe pump that slowly flows water into the steam generating portion of the rig). The final two heaters heat the oxygen (which serves as an oxidizer in the system to aid in combustion) and the steam/oxygen mixing portion. Before injecting the trash into the reactor, each of these areas (reactor, steam, oxygen, and mix) need to be at their operating temperatures.

In the actual test, all of the heaters except the steam heater are turned on at the start, and the steam heater is only turned on once the others are close to their set points. The reason for this being that it takes the steam line far less time to heat than the other sections.

Originally, the heater controls consisted with an array of boxes to enter the set points of the individual heaters, and a button to activate the heaters. At pre-heat, the operator would enter the set points for all the heaters and leave the set point of the steam heater as zero. Then, they would turn on all of the heaters together, and the steam heater would not turn on until the operator would change its set point from zero to the test value.

It was determined that the addition of two buttons could simplify the heater controls, allowing the user to just enter the final set points of all the heaters during test setup, and controlling the pre-heat and steam heaters directly (instead of entering an initial set point of zero). The resulting control had a "Pre-Heat" button that toggled all of the heaters with the exception of the steam heater, a "Steam" button that toggled only the steam heater, and an "All" button that turned all of the heaters either on or off.

Table 1- Heater Button Logic Derivation



Legend
A = All
P = Preheat
S = Stream
t = -1, the previous state of the
t = 0, the state of the system at the instant of the button press, before logic is applied
t = +1, the resulting state of the system after logic has been applied

Heater Button Logic Sequence								
t = -1			t = 0			t = +1		
A	P	S	A	P	S	A	P	S
0	1	0	0	0	0	0	0	0
0	0	1						
0	0	0	0	0	1	0	0	1
0	0	0	0	1	0	0	1	0
0	1	0	0	1	1	1	1	1
0	0	1						
1	1	1				0	0	0
0	0	0	1	0	0	1	1	1
0	0	1	1	0	1	1	1	1
1	1	1				0	0	1
0	1	0	1	1	0	1	1	1
1	1	1				0	1	0
ERROR			1	1	1	ERROR		

Derived Logic Functions
A(+1) = A~P~S + ~A(-1)PS+~A(-1)A
P(+1) = A(+1) + P~S
S(+1) = A(+1) + ~PS

This three-button control design does not produce a "one-to-one," or surjective relationship between the set of input states to the set of output states of the three buttons. Pressing either the "Pre-Heat" or the "Steam" button will cause two different results depending on the state of the other button. If the result of pressing one of those buttons is that both buttons are on, then the "All" button also needs to be turned on. Instead, if the result is that either one or both of the buttons are off, then the "All" button also needs to be turned off.

This functionality cannot be described solely with combinational logic blocks and requires the past state of the system (i.e. the system uses sequential logic). It was discovered that using sequential logic could be avoided if the state of the heaters themselves could be captured before they were changed by the buttons, or at the same time that the state of the buttons are gathered. By knowing if the steam heater and any one of the other heaters was on before applying the button press logic, the next state of the system can be determined solely with combinational logic blocks.

4. *cDAQ Task Integration*

The original programmer that made the OSCAR software used an additional tool, called NI MAX, to handle the hardware level interface between the software and the cDAQ. While NI MAX makes it easier to quickly get a system up and going, it can complicate the process of upgrading the software. Also, it means that the software requires an extra program to run.

In NI MAX, all of the data and control groups are created, and scaling is applied to them. When the software needs to access one of these groups, it simply makes a reference to it. When a programmer wants to add a sensor or control, they need to open NI MAX, make the addition, and go back into the software to make sure the program still agrees with the updated group.

In order to avoid using NI MAX, these groups (called tasks) are instead created inside the main VI using the DAQmx library. The program now creates a task at startup, the individual channels are programmatically added to the tasks (along with their scaling factors), and the task is started. These tasks are then piped into locations in the block diagram where they are used, and are terminated at the end of the program execution. Now, when a sensor or control needs to be added, the programmer just adds the channel to the appropriate task.

5. *Parameter Populating Buttons*

One tedious part of testing is the need to manually type in several numbers into text boxes in the UI. These numbers will be one of a small set of standard number, and therefore lend themselves to an automated fill.

The UI now has two sets of radio button groups. One group allows the user to choose the heater set point, and the other group allows the user to choose the drop delay time. By simply pressing a button or two, all of the values that the user would normally type in by hand are entered in by the program.

III. Repairs

A. Drop Indicator LED

The rig uses two GoPros to capture the view of the reactor. In order to synchronize the data stream with the camera footage, an LED is posed in view of the cameras. When the rig is dropped, the LED turns off. Simultaneously, the drop signal input turns from high to low, and the data stream can be matched up with the camera footage.

Towards the beginning of the term, after the initial upgrades had been completed and lab testing had resumed, it was discovered that the drop indicator did not light up even though the signal read by the software was high. An investigation into the wiring of the LED found that it was connected into to the cDAQ with no path to ground. So, while the cDAQ was able to detect the voltage provided by the closed drop signal, there was no current to light up the LED.

It was decided that the best approach was to wire the indicator in parallel with the drop signal so that when the signal closes, a path to ground through the LED is provided so that it can light up. And, when the drop signal opens, the path also opens so that the LED turns off.

B. Shock Test

Part of the preparation for the five second drop tower was shock testing, where the test rig is subjected to the loads that it will experience during drop testing in order to ensure that it will last through the duration of the tests. While the OSCAR rig was designed to withstand the forces of the drops, it was not designed to withstand those of the Vibration Test Lab. In order to subject the rig to the appropriate downward force that it will experience, it must build up to it in a series of oscillations. Because of this build up, the rig experiences an upward force that far exceeds any that it will experience during testing. It is because of these inappropriate testing conditions that the rig inevitable fails during the shock testing.

After going through the shock testing that was intended to verify the rig for the five second drop tower, there were a number of areas that required attention. The team worked together as a group to identity the causes for the damages, fixes, and the implementation of those fixes.

1. *DC to DC Converter Fell Off the DIN Rail*

The relays, power buses, diode module, and DC to DC converters are all fastened to the test rig using DIN rails. One of the DC to DC converters came off to the rail during the shock test. After reviewing the video of the test and looking at the position of the converter on the rails, it was determined that the converter likely came off because it was on the very end of the rail, and may not have had a secure connection. Also, it was thought this would not be an issue during the actual drop. So, the converter was just moved further on the rail.

2. *Lifted PTs*

The PTs on the rig were originally resting on 3D printed supports in the instances where they were mounted horizontally (i.e. cantilever). During the shock test, the PTs bent upwards. While it was determined that this would not be a problem during the drop tests, new PT mounts were 3D printed with through holes to accommodate mounting screws.

3. *Lifted Tubing*

A large section of tubing and fittings hangs in midair, supported mainly by 1/8th inch tubing. This tubing bent, and the heavy section lifted during the drop testing. It was determined that this was a potential weak spot in the system, and that a rest should be installed directly under the tubing to counteract the high downward loads. The main complication of that fix is that the tubing that needed to be supported gets heated during testing, so a plastic mount would melt, and a metal mount that is directly connected would transfer heat into the chassis. So, the rest was designed to fit underneath the insulation around the tubing to avoid direct heat induction.

4. *Broken Pressure Gauges on Sample Collection Rack*

The bottles used for collecting the gas samples from the test are mounted on a rack below shelf in the rig where most of the mechanical components are mounted. During the shock test, the gauges on the sample collection rack shatter. During the shock test, that shelf flexes considerably. There was an L-bracket under the main shelf which was directly above the pressure gauges on the sample collection rack. To resolve the issue, it was decided that the L-bracket could be rotated so that the vertical portion was no longer positioned directly above those gauges.

IV. Documentation

An important part of any project is keeping track of the way things work and what has been done to get the work to where it is at any given state. Often, either documenting such milestones is overlooked, or other constraints such as time prevent the writing of such documentation, so it often comes down to interns to carry the load. The electrical and software systems of OSCAR were no exception to this.

A. Master Measurement List

The OSCAR test rig is a complex system of several digital and/or analog input and output components. A master measurement list keeps track of all of the individual components, where they exist in the system, where they connect to the controller, and any other pertinent information that might be needed when reproducing the system.

At the start of the term, there already existed a rough list of information about most of the components in the five second drop tower rig. Work was taken to verify and correct the information about the listed components, add missing components, and compile all of that information into an easy-to-read document.

B. Electrical Schematic

The electrical schematic contains information about the electrical components of the system. This information describes how they are interconnected, how they are powered (and how those power supplies are generated), and information about the specific components.

The five second test rig is the same rig that was used in the two second test campaign. This means that it has all of the hotfixes and upgrades that took place during the two second test campaign, along with any upgrades necessary to make it compatible with the five second drop tower. The electrical schematic for the five second drop tower rig was created by copying that of the two second drop tower rig. This meant that the whole schematic had to be analyzed and corroborated with the physical rig. Also, additions had to be made to account for the new PTs, new accelerometer, and corrections to the drop indicator.

C. Software User Guide

A crucial part of the development of any software that is sometimes doesn’t happen because of time constraints, or because it is simply overlooked, is documentation on how to operate that software. Making such a guide to the software can not only benefit potentials users, but also the developer, as it is easy to forget how to use one’s software months or years after it has been written.

At the start of the term, no such user guide existed for the OSCAR software. One was crafted using explicit, details instructions (with copious visual aids) to explain how to power and connect to the cDAQ, launch and control the software, load a newer version of that program onto the cDAQ, and download the test data from the cDAQ.

D. Reactor Connections Diagram

The OSCAR reactor is a complex assembly of various thermocouples. During the data analysis process, it can be difficult to trace where in the reactor space a particular reading exists. In order to assist in this aspect of analysis, a diagram depicting the copper cartridge insert to the reactor in 3D space in relation to the input and output tubing and thermocouples was generated. The diagram allows data analyzers to directly see where the various temperature readings came from.

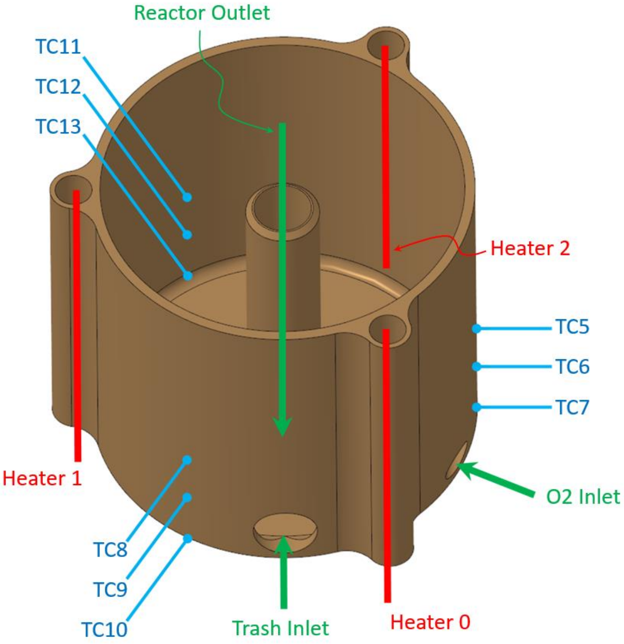


Figure 4 - Reactor Connections Diagram

V. Ground Testing

The ground testing phase of the OSCAR project incorporates all of the lab testing and the two drop tower testing campaigns. The spring term resumed testing at the phase of retesting runs from the two second drop tower campaign, and moved on to pre-testing for the five second drop tower campaign. It will continue on into the actual five second campaign and resume retests of runs from both of the drop tower campaigns.

A. Con-Ops Refinement

The test procedure and physical data acquired through the course of a test are all captured within the Con-Ops document. The document tells the operator and technicians which valves to turn, what data points to measure, and what order to do each in.

At the beginning of the term, the Con-Ops were out-of-date and needed to be updated to make sure that the correct information was obtained during the course of a test. This was an iterative process that grew through the course of working through the test procedure and with the addition of insights from the data analyzers as they dug into the data of previous tests.

The updated document describes improved processes for obtaining input and output products and includes built-in equations to calculate such things as the mass conversion rate and the moisture retention.

B. Lab Testing

Lab testing constituted the majority of the effort in the spring term. After the initial effort to upgrade the rig, an effort was made to attempt two tests a day. These tests fell under two major test configurations: a two second drop and a five second drop (where drop refers to the period in which the rig would be in simulated microgravity if a test were to be performed using a drop tower). The various tests previously performed using the two second drop tower had to be repeated in the lab, and those of the five second drop tower and to be pre-tested, under normal gravity in the lab.

Materials used in the test replicated those that would be present during a space mission, including clear plastic, food packaging, white cotton, a mixture of food packaging and white cotton, high-fidelity waste simulant (HFWS), and foam. Parameters such as oxygen flow rate and the presence of steam had previously been investigated, so material size and temperature were the only subjects of change during this phase.

1. Procedure

The beginning of the test consists of making sure the removable parts of the rig (the downstream components, the heat exchanger, the copper cartridge from the reactor and the reactor lid, and the trash storage tube) are cleaned and weighed. Additional weighing is performed on the water collecting desiccant in the heat exchanger and the actual mass stored in the trash tube. With these initial measurements recorded, full assembly of the rig can be completed.

Once assembly is complete, the test moves into the preparation phase. All of the electrical and mechanical connections are verified, and all of the hand valves are checked to ensure that they are closed. Then the cDAQ is started and the electrical components are cycled through. The accumulator, drop bottles on the sample collection tray, and section upstream of the reactor are leak checked, purged, and pressurized to their test pressures. Then the system goes through a pre-heat that ensures that the each section is at the test set point prior to trash injection.

Once the rig is fully prepped, data recording switches to high speed (the sample rate is kept at 1 Hz during setup to reduce file size, then ramped up to 1 kHz to capture the drop event) and camera recording commences. After steam flow and oxygen flow are started, the operator injects the trash into the reactor, and the technician activates the drop signal as soon as combustion is observed.

After combustion completes and the drop sequence ends, the test procedure devolves into breaking down the test rig and obtaining test samples. These samples include the gas samples from the three sample bottles, the gasses left in the reactor, and a swab of the residue on the reactor lid. Final masses are also taken of various components and the remnants within the reactor.

2. *Discussion*

The testing involved combusting a number of different materials. The materials were selected during the project's design phase to correspond with actual astronaut waste. From the standpoint of the testers, each material posed its own unique challenges.

Prior to the start of the test, the material is cut, by hand, into squares of the required size (either 3mm or 6mm) and loaded into a tube. The tube is then placed into a pipe that leads into the reactor manifold. After the test rig has finished its preparations and preheating, the trash is injected into the manifold via compressed air or helium. Once in the manifold, it will combust and produce the waste products.

White cotton was one of the easier materials to work with. While cotton can be difficult to cut with scissors, it was easy to load into the tube. When it came time for injection, all of the material in the tube injected without issue on almost every test (it was found that packing the cotton into the tube too tight would cause it to become wedged). When it came to combustion, the time from injection to ignition varied more than any other material (from a few seconds to over a dozen seconds), but the burn was always clean and consistent.

White food packing was the worst of all the materials to deal with. It is essentially aluminum foil coated with a layer of plastic. This make-up makes it easily electrically charged, which makes it stick to every surface it comes in contact with, including the trash tube as one tries to load it. Consistently, a significant portion of the material would become stuck in the trash tube at injection. There are many possible causes for this: the material sticks to the side of the trash tube do to static build-up; excessive moisture is causing the material to ball up and become wedged; heat is somehow propagating into the trash tube and melting the material to the sides; or some combination of all three. When material manages to make it within the manifold, it does not ignite uniformly. The individual clusters of material will ignite in the position that they land.

White cotton and food packaging mixed. The mixture had all of the same preparation issues as the white food packaging, along with the problems with injection. The one positive part of the mixture is the combustion. Since the food packaging has a consistent, almost instantaneous ignition after injection, it lights up the cotton, which adds its burn consistency. The result is a fast ignition with a constant burn.

High-fidelity waste simulant is relatively easy to work with. It is also the closest of the materials in terms of astronaut waste simulation. The team has had limited experience with the material as it pertains to the OSCAR test rig, but it seems the largest challenge will be in data analysis as it is difficult, if not impossible, to prepare the samples to be uniform. Each batch contains gloves, cloth, bath tissue, plastic, aluminum foil, and simulated waste, among others. The sample preparer does their best to include equal parts of each material. The team hasn't encountered any issues with trash injection. Ignition was almost instantaneous, and combustion was accompanied by sporadic eruptions of flames, which were not to be seen in any other material.

The packing foam was even more difficult to prepare than the white food packaging (do to its light weight and static build-up), and gave interesting results. There were no issues with the foam injecting into the manifold. At the time of this paper, the team ran two tests with the foam. On the first test, the foam didn't ignite. It just blackened and melted. On the second test, the foam ignited quickly and burned intensely. It will be interesting to find out the cause of this discrepancy as testing continues in the months to come.

C. Five Second Drop Tower Testing

The lab testing during this term has ultimately lead to the five second drop tower campaign at Glenn Research Center. As the interns ran the lab testing leading up to the five second campaign, and they rewrote the Con-Ops, it was decided that one of the interns should be there on each week of the campaign.

VI. Conclusion

The work of the spring term was but a small portion of the overall work previously, and yet to be, put into this project. Prior to this term, the team brought the rig from concept to a working test rig that was used in the two second drop campaign. Yet to come are the retesting of all the drop tower tests, design and building of the sub-orbital test rig, and verification testing of the sub-orbital rig up through its flight.

Still, if it weren't for the help of interns, this project would not have kept on schedule. The OSCAR team is comprised of around a dozen members who only work on the project part time. Having a couple extra sets of hands to work on the project full time for a few months meant that there would always be people to ensure that lab testing could occur on a daily basis. It also meant that there were a couple extra pairs of eyes always on the project, ready to find and correct any issues as they came up.

During the summer, there will be more interns to share the work, but there will also be more work as the project accelerates through its final phase.

Acknowledgments

I would like to note that this project is a collaborative process, and seldom are any tasks (including those performed by me) performed by just one member of the team. This project would not be possible without everyone working together toward a common goal, and I'm grateful to have been a part of that work.

Special thanks to my mentor, Jake Hochstadt, for selecting me for this internship, and to Anne Meier, the lead of the project, for making this opportunity possible.