Satellite Servicing Capabilities Office Testing

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Nomenclature

KSC	=	Kennedy Space Center
PTS	=	Propellant Transfer System
HMA	=	Hose Management System
SSCO	=	Satellite Servicing Capabilities Office
N2O4	=	Nitrogen Tetroxide
TRL	=	Technology Readiness Level
ETU	=	Engineering Test Unit

Abstract

While at the KSC, I was given the opportunity of assisting the Satellite Servicing Capabilities Office (SSCO) specifically the Propellant Transfer System (PTS) lead by my mentor, Brian Nufer. While waiting to test different components in the PTS, I was able to assist with testing for the Hose Management Assembly (HMA) and was able to work on a simulation in Labview. For the HMA, I was able to help with testing of a coating as well as to help test the durability of the pinch rollers in space. In Labview, I experimented with building a simulation for the PTS, to show where fluids and gases were flowing depending on which valves in the PTS were opened. Not all of the integrated parts required assembly level testing, which allowed me to test these parts individually by myself and document the results. I was also able to volunteer to assist project NEO, allowing me to gain some knowledge of cryogenic fluid systems.

Introduction

During my co-op spring semester at the NASA Kennedy Space Center, I worked in the NE-F5 branch as a test engineer assisting full time engineers with research and design tasks on current fluids testing and propulsion projects. Most of the work I performed was associated with a proposed NASA mission from the SSCO. The SSCO mission is focused on the creation of a satellite spacecraft to be launched into orbit in order to repair, reposition, and refuel existing satellites for both government and commercial interests. For my work on the SSCO mission, I was the intern for Brian Nufer who was in charge of the fluid system of the Propellant Transfer System (PTS) at Kennedy Space Center. The PTS is the fluid system that will transfer propellant from the SSCO spacecraft into existing satellites so that they can remain functional past their original service life. The PTS was supposed to begin testing during my internship, however, the tests have been in the review process for the entirety of my internship and are now scheduled to begin in the last couple of weeks after this report is written. In connection with this mission, I also was able to assist with basic tests on the Hose Management System (HMA). Also, I was given the opportunity to volunteer and assist Project Neo prepare for testing.

Testing

The primary goal for my internship at the Kennedy Space Center is to assist with testing of low technology readiness level (TRL), see Table 1 below, components such as pumping technologies, flow meters, and a bellows accumulator to see whether or not they are viable candidates for the PTS and to increase the TRL of these components and the system. These components will be surrounded by the necessary tubing, valves, sensors and fluids so that a high fidelity simulation of their capabilities can be conducted. The primary concern of the tests is the interactions of the components with each other in regards to their mechanical and electrical performance. These integrated components would first be tested using a non-hazardous fluid, CFC-113 or water, as a simulated propellant and then tested later using the actual propellant such as nitrogen tetroxide (N_2O_4) oxidizer or hypergolic fuel. Other components such as a “pick and hold” inductor linked to solenoid valves have been tested in a component level test as opposed to the assembly level test that the other components will undergo.

Table 1: SSCO TRL Definitions

TRL 1.0	Realized need for the item and basic principles observed and reported
TRL 2.0	Thought of a way to do it
TRL 3.0	Prototype designed and analyzed
TRL 4.0	Prototype tested at component level
TRL 5.0	Prototype tested with interface hardware in the loop
TRL 6.0	ETU tested with interface hardware in the loop in a flight environment

[1]Table 1 shows the Technology Readiness Levels (TRL) as used by the SSCO project. Currently the test readiness of the components that are being utilized are fairly low as some of the components are not prototypes specifically made for this system, however, with the completion of the test, it is expected that the technology readiness level will be significantly increased.

Table 2: SSCO Test Matrix

Transfer Qty. [kg]	[lb]	Temp [deg F]	Supply Press. [psig]	Return Press. [psig]	Return Ullage Vol. [gal]	Config.	Pump Technology Perameters

[1]Table 2 shows the Test Matrix that will be used for the assembly level testing of different integrated components.

The intentions of the testing of these integrated components is to highlight any non-compatibility of the individual hardware systems when operated together. Other components will be added to replicate satellite fluid system components to give a more in depth simulation of the assemblies. System properties such as pressure drop, layout, and valve timing will be simulated. Mechanical simulators will be used to measure the properties of the simulant and actual fluids as well as to supply, transport, and control the temperature of the fluids. Electrical simulators shall be used to measure the temperatures, pressures, forces, currents, and voltages. [1]The purpose of the pumping technology that as being integrated is to increase the pressure from what is in the SSCO propellant tanks to what is needed for the client, overcoming the pressure drop in between. The purpose of the SSCO flow meter is to measure flow rate and totalized mass that is transferred to a client.

There are several primary objectives for the integration testing that will be performed. We want to characterize the performance of the pumping technology and control electronics package as part of the PTS, performing confidence and endurance runs as well as creating performance maps for each pumping technology. Another objective is to characterize the performance of the flow meter sensors for measurement of flow rate and totalized transfer mass as part of a satellite based fluid transfer system. The bellows accumulator test objective is to characterize the mechanical and electrical performance of the assembly. Characteristics such as pressure drop and component leakage needs to be quantified and recorded. Lastly, we will test the pumping technology during start up and shutdown, purge different sections of the system.

Other components, such as the “pick and hold” inductor, were able to be tested through component level tests designed to provide a general reference of the effect on the system. The main purpose of these inductors was to reduce the amount of heat gained through prolonged use of the solenoid valves. This solenoid heat is transferred into the test fluid which can substantially increase the pressure in a hydraulically locked fluid line. The “pick and hold” inductors were tested to determine whether or not the reduction of heat gained would be significant enough that implementation of this component would be worthwhile. The solenoid valves were wired to a laboratory DC power supply, which is adjusted to the desired voltage (+/- 0.1 volts). The inductor was set to barely let enough current through to open the solenoid valve which is between 0.18 Amps and 0.23 Amps, while the other solenoid valve received a current of about 0.67 Amps directly from the laboratory DC power supply. Although it was predetermined that the solenoid valves would be powered by 28V, additional trials were conducted to see the effects of using different voltages (within the valve’s allowable input voltage range) without an inductor. The temperatures of the solenoid valves were monitored and recorded once every ten minutes for around three hours. The solenoid valves’ temperatures were monitored at two locations, on the side of the body and on top of the coil. The true measurement of how the heat gained by prolonged use would be gained from measuring the change in temperature of the body of the solenoid valve is the part touching the hypergolic fluids. The measurement of the coil was to inform on the amount of heat that would be gained by the component as a whole, and to see how the inductor would reduce the total heat gained. The test matrix used is shown below in Fig. 1.

Figure 1: Test Matrix

	Valve	Voltage	Inductor	Sensor Location	0 min	10 min	20 min	…	180 min
Test 1	Solenoid Valve 1	28V	Yes	Coil Temp (°C)					
				Body Temp (°C)					
Test 2			No	Coil Temp (°C)					
				Body Temp (°C)					
Test 3	Solenoid Valve 2	28V	Yes	Coil Temp (°C)					
				Body Temp (°C)					
Test 4			No	Coil Temp (°C)					
				Body Temp (°C)					
Test 5		32V	No	Coil Temp (°C)					
				Body Temp (°C)					
Test 6	Solenoid Valve 3	28V	Yes	Coil Temp (°C)					
				Body Temp (°C)					
Test 7			No	Coil Temp (°C)					
				Body Temp (°C)					
Test 8		24V	No	Coil Temp (°C)					
				Body Temp (°C)					

The data in Fig. 2 and Fig. 3 show that compared to the other trials, the trials using the "pick and hold" inductor had a much slower increase of solenoid body temperature. With the "pick and hold" inductor, solenoid valves body temperatures increased by 2 °C within the first hour and then had an increase of only 1 °C per hour for the next 2 hours. This is compared to the average 28V trial temperature which increased by 8 °C in the first hour, the 24V trial temperature which increased by 6 °C in the first hour, and the 32V trial temperature which increased by 10 °C in the first hour.

Figure 2: Graph of temperatures at 28V

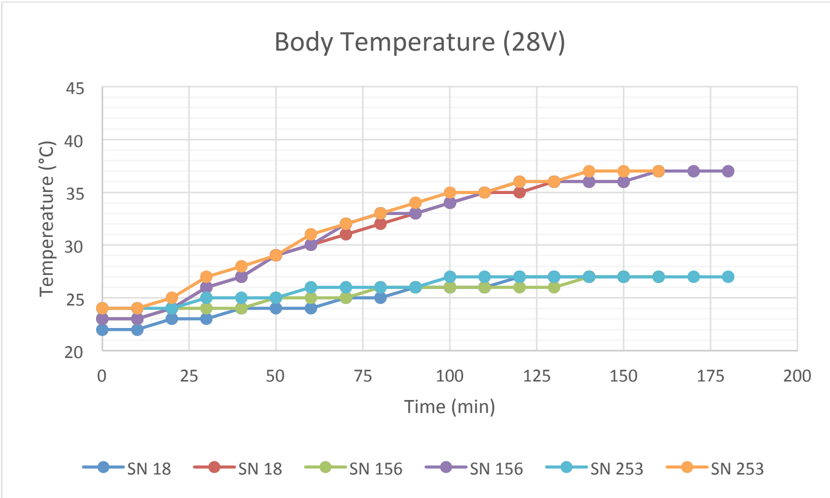

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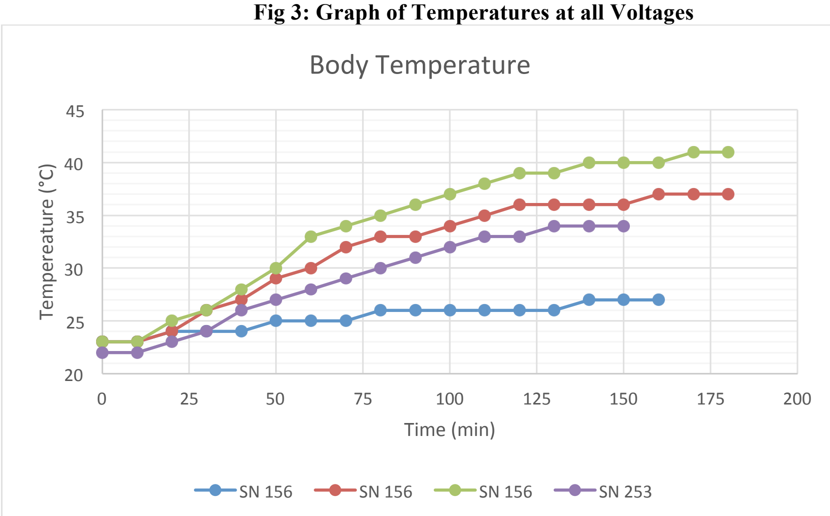
Fig 3: Graph of Temperatures at all Voltages



While the maximum temperature for the three hour inductor tests were 27 °C, the 32V trial reached this temperature in little more than 30 minutes, the 28V reached this in 40 minutes, and the 24V reached this temperature in 50 minutes.

A trial was later run to find out how hot these solenoid valves could get when open for around 48 hours using the "pick and hold" inductor as well as without an inductor set at 28V. After the 48 hours, the solenoid hooked up to the inductor was 29 °C at the body and 34 °C at the coil. While the solenoid that was not hooked up to the inductor was 43 °C at the body and 65 °C at the coil.

This data showed that the use of the "pick and hold" inductors would greatly increase the amount of time the solenoid valves could be held open without heating to an undesirable temperature. Compared to the other trials, the rate of temperature increase at the body was very low. Trials using the "pick and hold" inductors reduced temperature increase by 69% when compared to other 28V trials and 67% when compared to the 24V trial. As a result, the implementation of these inductors was deemed worthwhile and implemented to the PTS.

In connection with Satellite Servicing Capabilities Office (SSCO), I was able to assist Jenna Valle with testing of the Hose Management Assembly (HMA). The HMA is responsible for providing a means of connecting the Propellant Transfer System (PTS) to the client's fluid system interface. Recently, the HMA has been testing different conduits and coatings to rate their properties and determine which conduit and coating would best fit the requirements in the environment of space. [2]Mechanically, the conduit had to work with the current HMA pinch roller design and provide protection of the hose's minimum bend radius. [2]From a thermal perspective, the goal was for the coating to have a low absorptivity level and high emissivity level. [2]The conduit had to have a surface resistivity below a desired value, protection against internal charging, and necessary shielding of internal components. [2]Lastly, these conduits must have a minimal amount of off gassing and debris, cameras with light must be able to detect markings on conduit, and must provide protection against radiation in space. I was able to assist with testing one of the more promising conduit coating options which was a metallic thermal surface coating that has flight heritage on numerous other satellites.

The HMA is currently designed to have the hose move in and out of a protective container, meaning that while doing so, the hose will rub against other surfaces. These surfaces include the conduit of the hose rubbing against other sections of the conduit, the conduit rubbing against the walls of the protective box, the conduit rubbing against the roller guide, and the conduit rubbing against the pinch rollers used to move the hose inside and outside of the protective container. With metal rubbing against metal, abrasion is inevitable which is why the HMA test was performed, to see how the hose as well as other parts last when performing multiple cycles of having the hose travel in and out of the protective container. There were three main areas that were being tested for their durability in these tests, the conduit coating, the markings on the conduit, and the pinch rollers.

First, the HMA was thoroughly cleaned to make sure that the only dirt or metal particles in the container would be debris from the testing. After the HMA has been cleaned thoroughly, the conduit was marked at even intervals so that the durability of the markings moving through the container. The conduit coating was tested by having the hose moved inside and outside of the protective container a total of 20 times. After each trial, the conduit and its markings were examined for signs of abrasion and the protective container was checked for debris and pictures were taken. After these 20 tests were performed, the conduit coating was reviewed and compared to other conduits and was chosen as the best option.

After completion of the conduit coating testing, the pinch rollers were replaced by pinch rollers that had been baked in an oven to simulate the effects of heat in space on the pinch rollers and to see whether this would cause any issues with the durability of the pinch rollers. The HMA was tested for another 20 trials to see if there was any debris or noticeable wear on the pinch rollers.

While waiting on the PTS test to be approved, I was allowed to work with Labview to gain experience. I was provided with the old Labview set up for reference that had been used for a test prior to the PTS being updated, and given the task of experimenting with creating a new visual graphical user interface (GUI) of the updated PTS. If properly coded, the GUI would be able to give a visual representation of which valves are open and which pipes had fluids or gases moving through them. The coding required to create such a GUI was further complicated due to the various directions fluid would be required to move through the PTS. This was quite a struggle as prior to this I only had experience with a select few text based coding programs such as Matlab as opposed to the entirely graphical based code used in Labview. While working with Labview, I began to gain insight on the benefits that a graphical based coding program provides, as well as insight onto how challenging and seemingly overwhelming a graphic based code can become. Due to this opportunity, I was able to gain some experience with a new coding software that is being used for the PTS testing.

Near the beginning of the internship, I was introduced to the head of Project Neo, Kyle Dixon. Project NEO is an entirely volunteer based project which aims towards creating a cryogenic fluid system to power a rocket engine. With Project NEO nearing completion, I was mostly able to assist with the construction of a command trailer which would be used for the test at a safe distance from the firing zone. I was also able to assist with some documentation, such as the creation of an updated pressure vessel system (PVS) certification report, to attempt to expedite the safety review process for the test. By volunteering, I was able to talk with Kyle Dixon and other volunteers and gain knowledge of cryogenic fluids systems.

Conclusion

While interning under Brian Nufer, I was given many different opportunities to expand my knowledge and experience in the area of Mechanical Engineering. While waiting on the testing for the Propellant Transfer System

(PTS), I have been able to assist other projects such as the HMA with testing and volunteer for project NEO. These opportunities to work with other groups has provided me with the chance to gain a variety of experience and understanding of the different projects I have been associated with. I also was able to perform component level tests and evaluate whether or not the implementation for these components would be worthwhile. Lastly, I was given free reign with updating the PTS Labview file so that I could gain experience and knowledge with graphic based coding programs. Despite not yet being able to run the assembly test for the PTS, this internship has given me a great opportunity to gain valuable experience in the field of Mechanical Engineering, and to expand my capabilities in skills such as coding.

Acknowledgements

I would like to express my deepest appreciation to Brian Nufer for giving me the amazing opportunity of being his intern. During my internship, Brian Nufer was always willing to teach me more about my academic field and gave me insight into Hypergolic Fluid Systems.

I would also like to thank Kyle Dixon for allowing me to volunteer for Project Neo. While volunteering, I was able to gain a basic understanding of the challenges faced when working with a cryogenic fueled engine system.

I also must thank Cara Evers for having the patience to answer my questions about Labview while I was creating a graphical user interface for the PTS.

Lastly, I would like to thank the Kennedy Space Center for providing me with this amazing opportunity of working at the center and for the grant which allowed me to live in Florida so that I could take advantage of this opportunity.

References

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[2]Valle, Jenna. Patel, Bharat. “HMA Conduit Status” PowerPoint Presentation. OSB 2, Kennedy Space Center, Fl. 3 Mar 2015.