Environmental Control System Development

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Environmental Control System

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Nomenclature

ECS	=	Environmental Control System
EM-1	=	Exploration Mission 1
EM-2	=	Exploration Mission 2
GN2	=	Gaseous Nitrogen
GSDO	=	Ground Systems Development and Operations
GSE	=	Ground Support Equipment
HMI	=	Human Machine Interface
KSC	=	Kennedy Space Center
LCC	=	Launch Control Center
ML	=	Mobile Launcher
NASA	=	National Aeronautics and Space Administration
Pad B	=	Launch Pad 39B
PLC	=	Programmable Logic Controller
PIV	=	Personal Identity Verification Card
SLS	=	Space Launch System
ISS	=	International Space Station
V&V	=	Validation and Verification
VAB	=	Vehicle Assembly Building

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Abstract

   Since before the first men landed on the moon, human beings have aspired to reach farther into space, to discover and answer the great mysteries that exist beyond imagination. To reach where no one has gone before. To able to see all the wonderful things that can be found in space and that only satellites have revealed to us during all this time. Considering the last trip to the moon, mankind has been evolving and improving their technology to reach destinations whose distances had been impossible to transit. To reach that goal, the National Aeronautics and Space Administration (NASA) has designed and developed the largest and most powerful rocket ever created by the human race, the Space Launch System - better known as the SLS. To be able to send this large rocket to space, Kennedy Space Center (KSC) is doing upgrades to their existing facilities and equipment. At Launch Pad 39B, they are setting up a new Environmental Control System (ECS) developed to supply the rocket with the correct gases and mixtures that will be needed for the rocket to launch. The ECS is similar to an air conditioning unit. The main functionality of it is to supply the SLS with the correct gas mixture for it to launch. Also the ECS has been required to reduce or eliminate the possibility of a complete system failure. The system is part of the Ground Support Equipment (GSE) for the SLS that will be going to the Moon and Mars.

I.   Introduction

"That's one small step for a man, one giant leap for mankind"[2] said Neil Armstrong (1969) when he first stepped on the surface of the moon. Years before that event, in 1957, the Space Race started between Russia and United States, when Russia sent to orbit a Soviet R-7 intercontinental ballistic missile called Sputnik, which became the world's first artificial satellite and the first man-made object to be placed into the Earth's orbit. That launch came as a huge surprise to the United States. Space was seen as the next frontier, a new way to extend human exploration and for the USA, it was crucial not to lose that ground to the Soviets. By 1958, the United States launched its own satellite, Explorer I, designed by the U.S. Army. Then, in 1959, the Russian space program took another leap forward with the launch of "Luna 2", which was the first space probe to hit the moon. When the United States thought things could not get worse, Russia sent the first Soviet cosmonaut to orbit the Earth; putting the United States in a bad position. By May of that year, the United States had sent astronaut Alan Shepard into space with Freedom 7, which was a single-orbit flight. After the United States achieved that milestone in history, President John F. Kennedy proposed a new goal that would change the entire world.

Figure 1. The first man on the Moon, Neil Armstrong, of Apollo 11.

   President Kennedy said: "We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard" [3] (1962). After project Mercury and Gemini were successful the United States began the preparations to achieve that goal and in that moment the Apollo era began. Project Apollo is the name given to the Lunar landing program. The Apollo program ended with Apollo 17, the last moon landing; no human has gone to the moon since. In this program there were struggles that created doubt of the United States reaching the moon. After many years of work, research, and testing, the day arrived for Apollo 8, the first manned mission to orbit the moon. After the Apollo missions 8, 9, and 10, laid the groundwork for when it came time to launch Apollo 11.

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[1] Apollo 11 Moon Landing, "NASA Images," NASA, [Online]. Available: https://images.nasa.gov/details-as11-40-5874.html

[2] Dunbar, B. (2015, February 19). July 20, 1969: One Giant Leap For Mankind. Retrieved February 5, 2018, from https://www.nasa.gov/mission_pages/apollo/apollo11.html

[3] John F Kennedy Moon Speech. (n.d.) Retrieved February 5, 2018, from https://er.jsc.nasa.gov/seh/ricetalk.htm

It was the first manned mission to land on the Moon; the first steps taken by humans on another planetary body. After 4 days in space, the moment the world was waiting for had arrived. History was made with the moon landing (seen in Fig. 1). The Apollo 11 mission was a total success. After Apollo 11, came another 6 missions, sending 12 more humans to the moon's surface.

Figure 2. Columbia Shuttle of the Shuttle Program

Nine years after the Apollo era ended, a new chapter began for the United States and NASA with the Space Shuttle Program, (Fig. 2). It was the first reusable spacecraft. The space shuttle surpassed the boundaries of discovery even further, requiring a lot of advances in technology and a huge workforce to build it. The concept of the Space Shuttle was to take off like a rocket and glide back to earth and land like an airplane. The purpose of the Shuttle was to launch satellites and serve as an orbiting science laboratory. Also, the crew repaired and improved the technology that had previously been sent to space. The space shuttle carried as many as seven astronauts into and from space. The first shuttle was first launched on April 12, 1981. The shuttle was used as the main point of transportation for large payloads into space and for their maintenance. The shuttle was then used to work on the assembly of the International Space Station (ISS) (Fig. 3). The International Space Station is a large space station and a science lab. It is in low Earth orbit (LEO). Many countries worked together to build it and continue to work together to use it. The last flight of the Space Shuttle program was July 21, 2011. To this day, the ISS continues to orbit around the Earth, enabling research to improve knowledge for human deep space exploration.

Figure 3. International Space Station (ISS)

The Space Launch System will be larger than any launch vehicle ever created. It will have an immense payload mass to be able to launch four humans into deep space using the Orion space capsule. Kennedy Space Center is doing several major upgrades and modifications to its structures to be able to facilitate the rocket size and the new Orion space capsule. There have been many changes occurring in the Vehicle Assembly Building (VAB) and an entire remodel of the Launchpad 39B (Pad B) for the Space Launch System (SLS) (Fig. 3). Since the SLS will be the biggest rocket ever created by mankind, it will have more environmental requirements; requiring extensive modifications to pad 39B. With that said, we need to improve the HMI displays, controls and all functions so that they are adequate and work to the maximum level required while having the SLS on the pad. For the SLS ground system, two HMI display are needed, one local and one remote. The local will be located pad B. The remote display will be used in the firing room, which is in the Launch Control Center (LCC). Both HMI display have the same functions; the only difference is where it is used and its location. The development of the displays, and the software are in progress. Once development is completed, these displays have to go through a long process of approval. They have to meet the requirements needed to be approved by Human Factor personnel and the chief engineers, and tested with Quality Assurance witnessing. These displays will be used for EM-1, which will be launched without crew members; this will be the first test flight of SLS. EM-2 will be the second launch of the SLS but the rocket will be a different configuration from that of EM-1. EM-2 will have crew members, which means everything will be held to even more stringent standards, as human life will be involved.

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[2] Columbia Shuttle, "NASA Images," NASA, [Online]. Available: https://images.nasa.gov.

[3] International Space Station (ISS), "NASA Images," NASA, [Online]. Available: https://images.nasa.gov.

II. Projects and Tasks

A. Preliminaries

At the beginning of this internship, it took several days to get all the access and the ID badge to access the Kennedy Space Center facilities. After getting access to KSC property, the author attended the training that the Education Office gave at the beginning of the internship. After that the author was targeting and completing all of the necessary training to acquire IT access as well as the necessary accounts that he needed to be able to complete all of the tasks of the internship. Just before requesting IT accounts, the author needed to understand the subsystem support structure and the various subsystem roles. With all the required accounts and the understanding of the subsystems the author was able to share documents and status among support personnel. Also, the author needed to acquire elevated privileges for his work computer to install all the required software and get access to others accounts. Once the author has installed that software, he was able to get access to a domain account that was used to access the firing room computers. After the author obtained all the software and IT access he required, he went to the launch complex and the firing room to work on the software and hardware for the Environmental Control System. He also performed hardware testing at the launch complex, modifying the local and remote displays; and testing the local and remote Applications.

B. Programmable Logic Controllers (PLCs)

One of the author's first tasks was to learn about and work with PLCs. A PLC is a computer control system that continuously monitors the state of the input devices, makes decisions based on a custom program created by a user, and controls the state of output of a device. It can be said that it also is a specialized computer used to control machines and processes. The PLC has a central processing unit, memory, and software and communication system. This computer can be divided into three components which are the power supply and rack, the central processing unit (CPU) and the input and output better known the I/Os; they provide the physical connection between the equipment and the PLC. The I/O sections are composed of the digital inputs and outputs, analog inputs and outputs and the TC inputs and outputs. The PLC is compose of:

1. Power Supply

2. Backplane

3. The EtherNet/IP module

4. The DC Input module

5. The DC Output module

6. The Analog Input module

7. The EtherNet/IP module

8. Missing are the Processor & ControlNet module to connect to the RIOs

C. HMI software

The software is configured for developing machine-level applications. This program has two settings, Machine Edition (ME) and Site Edition (SE). The Machine Edition is a stand-alone runtime environment for machine-level applications. The Site Edition is an integrated software for developing and running-machine interface (HMI) applications that can involve multiples users and servers, all around a network. It consists of several pieces of software you can use to build network and local HDMI applications, and it can be customized to worker needs. This software is the configuration for creating and testing your Site Edition network and local applications. It contains editors for creating complete applications and includes client and server software for testing the applications created.
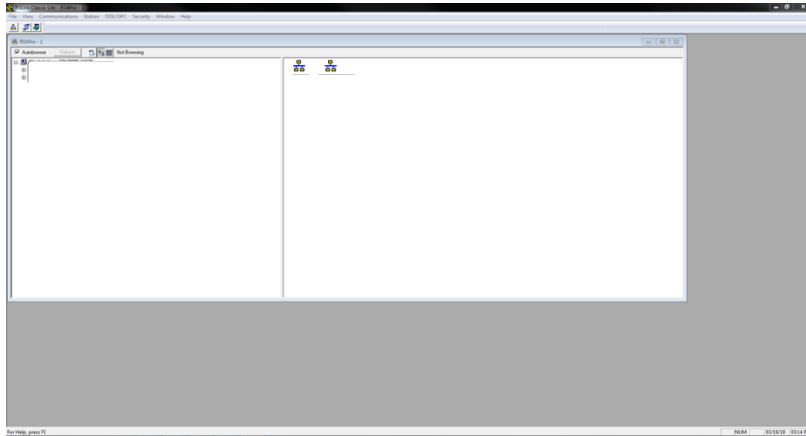
Figure 5. HMI Interface [6]

D. PLC Controller and Connection Tab

The PLC software delivers standardized framework for discrete, process, batch, motion, safety and drive-based systems and helping save programing time. Connection Tab is a window based in communication software package developed.

Figure 6. Main Controller Interface Display [7]

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[6] Image has been edited to protect sensitive information.
[7] Image has been edited to protect sensitive information.

Figure 7. Main Connection Tab Interface Display [8]

E. Local Display

The local displays were created using Human Machine Interface (HMI) software. This type of software communicates with the PLC controller, which controls the events that occur in the HMI display and in the equipment. Before the HMI project goes to the pad 39B and is connected to the PLCs located there, the displays must be tested with the PLC equipment found in of the labs on-center. After NASA finish with the tests and the ECS team affirm the HMI display is ready for Validation and Verification (V & V) testing, NASA will be bringing Quality Assurance and Human Factors personnel to test the displays. If they find everything working at 100% they will give the approval and allow the team to go to the pad to do functional testing. For the accomplishment of this verification, test procedures were written to simulate the signals being sent from the equipment to the PLCs. The official test procedures go into more detail to allow the person doing the testing to easily find the specific displays needed, and what to look for on each display. An example of a test procedure can be found in Table 1.

Step	Description	Tag	Tag 1	Tag 2	Tag 3	Tag 4	Tag 5	Indicator Color	Indicator Value	Pass/Fail	Requirements	Comments
								Acceptance Criteria				
25	XXX ### Setpoint Slider	Tag 1:[[XXXXXXX_XXXX_XXXX]EXAMPLE_XXX001_J10_412_CC_ST]	low low						Tag 1	☐PASS ☐FAIL		
			low						Tag 1			
			mid						Tag 1			
			high						Tag 1			
			high high						Tag 1			
26	XXX ### PV Slider	Tag 1:[[XXXXXXX_XXXX_XXXX]EXAMPLE_XXX001_J10_412_CC_PV]	low low						Tag 1	☐PASS ☐FAIL		
			low						Tag 1			
			mid						Tag 1			
			high						Tag 1			
			high high						Tag 1			
27	XXX ### PV	Tag 1:[[XXXXXXX_XXXX_XXXX]EXAMPLE_XXX001_J10_412_CC_ST]	1	x	x			red	Tag 3	☐PASS ☐FAIL		
		Tag 2:[[XXXXXXX_XXXX_XXXX]EXAMPLE_XXX001_J10_412_CC_CV]	0	1	x			red	Tag 3			
		Tag 3:[[XXXXXXX_XXXX_XXXX]EXAMPLE_XXX001_J10_412_CC_PV]	0	0	x			green	Tag 3			

Table 1. Example Test Procedure

Before the displays are finished and pass through the process of Verification and Validation (V&V), it first need to pass several other test and procedures. Then they are put in production for testing against hardware, if it is approved it then goes to Verification and Validation (V&V) and Design Certification Review (DCR). NASA need to compare their display to the Vendor display and their system because NASA displays have fewer screens while the vendor has a lot more screens. Another reason why NASA display is being compare to the Vendor display is to modify ours and have an idea how the system works and behave because the Vendor is almost finish with the functional testing on the pad meaning that their display has already been tested on the equipment and hardware. There are some differences between the NASA and the Vendor displays. The first difference is that the Vendor is using two interfaces, for one of the interfaces; however, NASA is using only one display for two different interfaces with the functionality of some several commands that are toggling between them. The functionality behind this display is using a procedure that controls and sends out a signal that goes directly to a system and from there it goes to the controller. In other words, the procedure is sending the function that is being called to appear on the interface that it supposed to show. The last

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[8] Image has been edited to protect sensitive information.

major difference is the Blower screen. The Vendor Blower display is divided into separate configuration while NASA interfaces does not have that functionality.
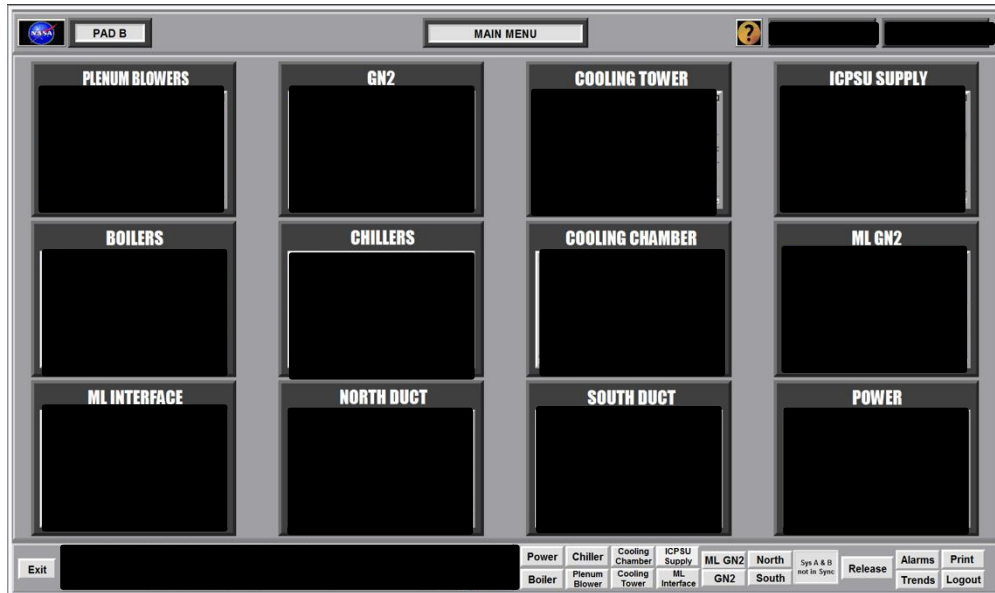

Figure 8. Main Menu Local Display [9]

By mid-February the ECS team received the latest Vendor update for the HMI displays. Receiving the new update helped us to have a better idea of the changes and functions the Vendor display has and what we need to add and/or change in ours. When we started to analyze the displays to see which functions changed, which new objects were added to the interface and most importantly, how many Tags were removed and how many new were added, we found out things were added to several interface. Two good examples are the display 1 and the display 2. In the display 1 a panel was added were you can see everything that is connected to this display 1. In that panel it was also included a button to control the startup without the need to go to a different screen or interface. Since we had those buttons on the panel, we needed to add a two-step procedure for each button because it is mandatory for the Human Factor personnel to see it since we will be doing a high level of testing. Also, several new features were added to the display 2 interface. Those interface had more than the limit of features required for the interface which created a problem, because the program did not read more than the limitation. Several days later we managed to change that limit and were able to show all the features require for that interface. Furthermore, an object was added to be able to display the extra features on the interface, but this object only works on the interface that have more than the limit of the default features. The concept that was used to make this object was to add a function for it to be able to call the features that were needed and missing on the interface.

F. Remote Display

The remote displays will be used on the consoles in the Launch Control Center (LCC). The displays are still not finished since to complete the Remote displays we need to wait until the new ECS display is tested at Launch Complex 39B and then is turned over to NASA. NASA has already built the displays, but with the vendor updating the HMI displays, system configurations and settings are requiring changes to our displays. Once all the changes have been made and finished, the displays will be loaded into the firing room.

G. Field Work

The Environmental Control System (ECS) is currently being installed and tested by the vendor hired to perform the task. Once the vendor finishes their version of the program NASA will start their own software tests to complete their version of the control software. The ECS worksite has cooling tower, chillers, pumps, blowers and several other equipment. It also includes 12 ducts that will reinforce the rocket conditioning as it is processed through launch. These

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[9] Image has been edited to protect sensitive information.

past few weeks, the Vendor has been doing functional testing at pad 39B before turning over the system to NASA. The reason for functional testing is to test the displays and systems the vendor was contracted to create and ensure they perform at 100% before handing it to NASA. The functional testing is required for the Vendor and NASA because that is how they can look for defects and malfunctions, as well as check if the system has good communication with the machinery and equipment connected at the pad. The last time the author was at the pad while the Vendor was completing the functional testing, they were making a list of the technical and non-technical problems they encountered while doing the steps of their own test procedures. While that was happening, the author had the chance to head up to the pad and go to some pipes to take several pressure and temperature measurements that the Vendor needed. The Vendor wanted us to do those measurements because he wanted to see if the set point he was entering in the system was the actual reading of the outlet of the pipes, and how much time it took for the system to get to that set point. After the Vendor finished functional testing, they will have to troubleshoot and fix all items that were added to the list of fixes. When they fix everything in the system they will need to retest the system to be certain it is functioning at 100%. Then, the Vendor needs to go through the commissioning process and a third-party Vendor before handing it to NASA. When NASA receives the final version of the Vendor's software, they will start doing their own testing on the software. NASA needs to test their software before or during the time the ML is on the pad.

Figure 9. Launch Complex 39B [10]

[10] Launch Complex 39B, "NASA Images," NASA, [Online]. Available: https://images.nasa.gov.

III. Conclusion

It was an honor for the author to be part of Kennedy Space Center (KSC) and part of such a great team. The culmination of this internship for the author results in an unforgettable experience. Leaving NASA, the author had the opportunity to expand his knowledge in the aerospace and engineering industry and acquire new skills which can only be developed by hands-on in the field. The author was able to learn about how the process of designing and decision making that engineers go through in the development of a project. The knowledge and understanding of systems and controls, together with the skills acquired and used for software development is an important trait for a well-rounded mechanical engineer. During the process of developing new skills and knowledge, the author was able to assist Kennedy Space Center in their preparations for EM-1 and EM-2. The displays, code and test procedures created will not only be used to validate the local displays, but also to be able to start testing them on the launch pad 39B. Hopefully, these new upgraded displays and equipment can be used for the development and modifications for future deep space launch systems.

Acknowledgments

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