Environmental Control Subsystem Development

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Nomenclature

CUI	=	Compact Unique Identifier
ECS	=	Environmental Control Subsystem
EM-1	=	Exploration Mission 1
GFAST	=	Ground and Flight Application Software Teams
GN2	=	Gaseous Nitrogen
GSDO	=	Ground Systems Development and Operations
GSE	=	Ground Support Equipment
ICPS	=	Interim Cryogenic Propulsion Stage
KGCS	=	Kennedy Ground Control System
KSC	=	Kennedy Space Center
LCC	=	Launch Control Center
LCS	=	Launch Control System
NASA	=	National Aeronautics and Space Administration
PID	=	Proportional Integral Derivative Controller
PLC	=	Programmable Logic Controller
RH	=	Relative Humidity
RIO	=	Remote Input/Output
SLS	=	Space Launch System
SCCS	=	Spaceport Command and Control System
V&V	=	Validation and Verification
VBA	=	Visual Basic for Applications

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Abstract

Kennedy Space Center's Launch Pad 39B, part of Launch Complex 39, is currently undergoing construction to prepare it for NASA's Space Launch System missions. The Environmental Control Subsystem, which provides the vehicle with an air or nitrogen gas environment, required development of its local and remote display screens. The remote displays, developed by NASA contractors and previous interns, were developed without complete functionality; the remote displays were revised, adding functionality to over 90 displays. For the local displays, multiple test procedures were developed to assess the functionality of the screens, as well as verify requirements. One local display screen was also developed.

I. Introduction

NASA (National Aeronautics and Space Administration) has sought to push the boundaries of space exploration and continually innovate space flight systems. After the retirement of the Space Shuttle in 2011, NASA went back to the drawing board in order to design a rocket that would carry astronauts deeper into space than any other vehicle. Thus, the Space Launch System (SLS) project was started. The SLS would focus on carrying large payloads or crew into deep space to establish a research base on Mars. At the Kennedy Space Center (KSC), one of NASA's space exploration facilities, ground preparations are currently underway for the SLS missions planned for the coming years.

To support the launch of a new vehicle, the Spaceport Command and Control System (SCCS) was tasked with providing proper spacecraft processing. The SCCS is a new end-to-end command and control system developed to accommodate the SLS and other launch vehicles; thus, becoming a multi-user spaceport. SCCS is comprised of the Launch Control System (LCS), Kennedy Ground Control System (KGCS), and Ground Support Equipment (GSE). The KGCS is responsible for creating local display software and Programmable Logic Controller (PLC) code to support operations on the vehicle. GSE is responsible for designing and operating the hardware on the launch pad. LCS handles the remote display

Figure 1: Render of the Space Launch System

software for the firing room. The Environmental Control Subsystem (ECS) comprises all three of these components to support launch operations. During launch operations, LCS utilizes multiple computers – located in one of many Firing Rooms in the Launch Control Center (LCC) – to send out control commands and monitor thousands of sensors on the vehicle and ground support equipment. Compact Unique Identifiers (CUIs) are utilized by KGCS to communicate with the hardware. CUIs are 16-digit alphanumeric character sequences that are associated with specific command, indication, and feedback signals. For a command button, the associated CUI is directed from the remote display through the KGCS gateway where it relays the data to the PLCs, which manipulate the value with internal logic software, ladder logic. The PLCs have the capability to control Proportional Integral Derivative (PID) controller parameters both autonomously and manually. The PLC transmits the converted digital data to a Remote Input/Output (RIO) device which converts the digital signal into an analog signal. This signal both controls the hardware and provides the feedback signal (health, status, etc.) back to the RIO. The returning signal proceeds through the entire process in reverse order to present the console operator with the information.

NASA, "Space Launch System Images," NASA, [Online]. Available: https://www.nasa.gov/exploration/systems/sls/multimedia/images.html
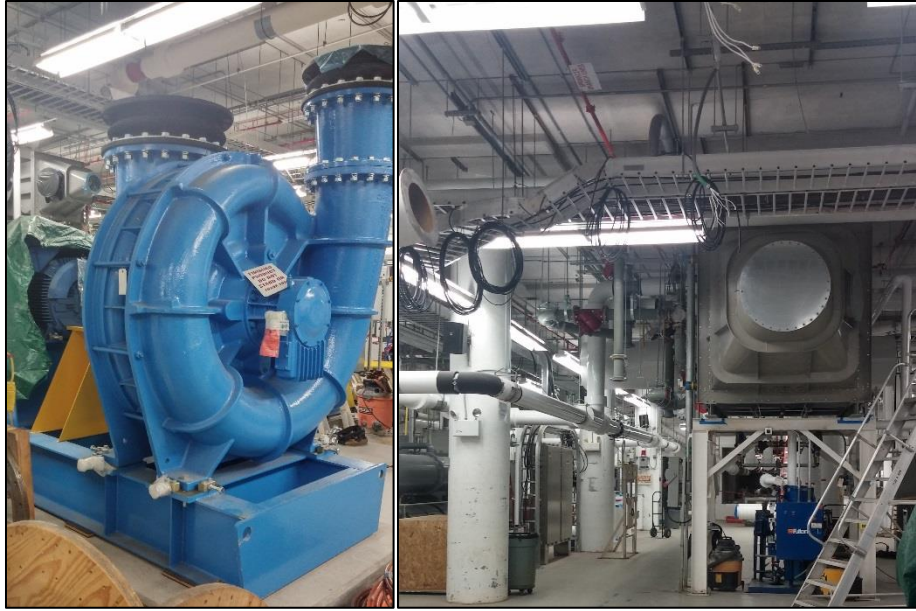
Figure 2: ECS Blower [Left] and the end of a Cooling Chamber [Right]

One of the subsystems that KGCS controls and monitors is the Environmental Control Subsystem (ECS), which is comprised of ten major components: main plenum blowers, north ducts, south ducts, Interim Cryogenic Propulsion Stage (ICPS) blower, ICPS ducts, cooling towers, chillers, cooling chamber, steam boilers, and the Gaseous Nitrogen (GN2) System. The majority of the system is housed in a large room underneath Launch Pad 39B (hereinafter referred to as "the launch pad"). The various blowers force large amounts of air into the system's ducts (GN2 supply is introduced after the blower since it is compressed from the facility); the fluid – either Air or GN2 – is distributed into the Cooling Chambers, which reduces the temperature and humidity of the chosen fluid. The fluid is then dispersed into the final sets of ducts and into various hardware configurations. All configurations have a heating chamber which raises the temperature of the fluid. Certain ducts are required to provide the vehicle with a purge at a certain Relative Humidity (RH), therefore those ducts have humidifiers attached to them. The humidifier works by taking water vapor from the Steam Boilers and integrating the vapor into the heated air. ECS uses air to cool and purge the vehicle during normal operations, but switches to the GN2 System for the terminal launch sequence. GN2 is used for the terminal launch sequence because it creates a dry atmosphere environment, removes condensation, and displaces oxygen (suppressing a flame or explosion) [1].

II.   Remote Displays

The Environmental Control Subsystem uses remote displays in the firing room to observe and operate their system's hardware to support the SLS rocket. Remote displays are created in the Display Editor, a Linux-based development environment, and consist of drawing primitives and symbols. Unlike Local Displays, remote displays cannot be programmed to have additional logic. Remote displays can only have one object associated with each CUI. The three objects that can have CUIs attached to them are text measurements, command buttons and state components. An example of a text measurement in a display is an alphanumeric number such as a temperature or pressure reading. A state component is an enumerated measurement where an image is displayed for a certain state. In a state component, there are three total states associated with each object: default, on, and off. The default state is true when there is no value or communication with the hardware. The majority of ECS hardware can be controlled either autonomously by the PLC, or manually by the console operator; therefore, one frequently used state component is an auto/manual state component. This component displays an "A" with a white background to indicate that the default state is true. If the device is autonomously controlled by the PLC, it will display an "A" with a green background. Finally, if the device is in manual control, it displays an "M" with a yellow background. When the displays were created, the associated CUIs were not available to the developers, so placeholder CUIs were used initially. During this project, the correct CUIs were added to over 90 remote displays.
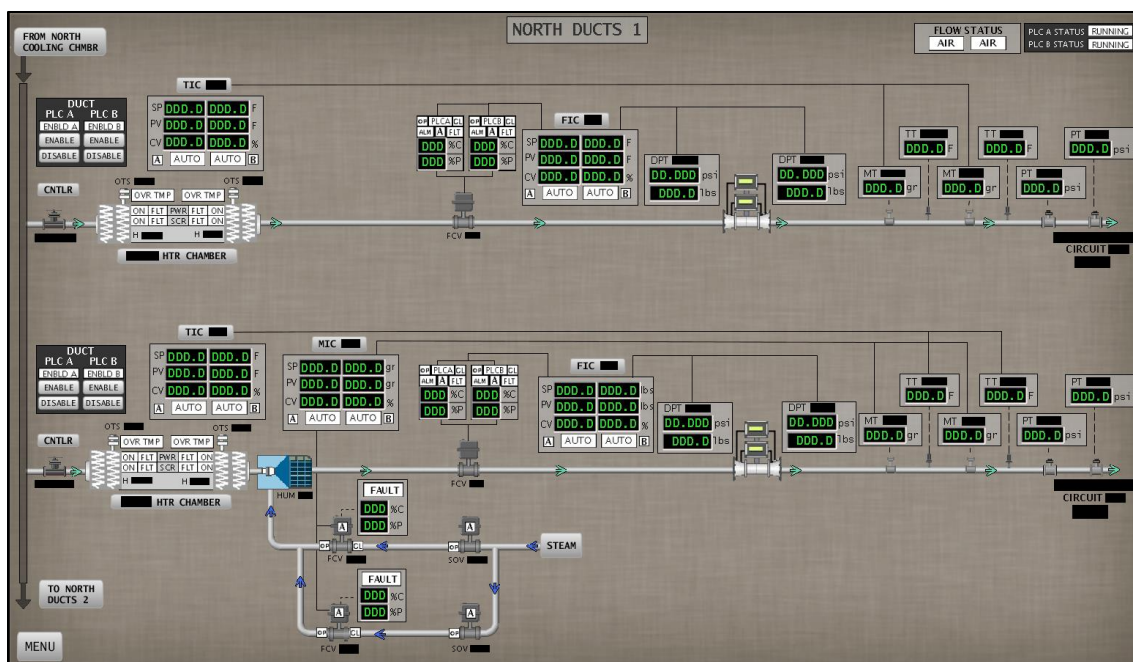
Figure 3: North Ducts Remote Display 1 of 2[4]

The state component images were tested by using the Test Driver application on the Linux Virtual Machine. The Test Driver is a simulation application that toggles all of the state components between States One and Two, as well as iterating through the allowable range of numbers for the text measurements. Each of the fourteen main displays were evaluated with Test Driver; many of the errors found during these evaluations were incorrect image states.
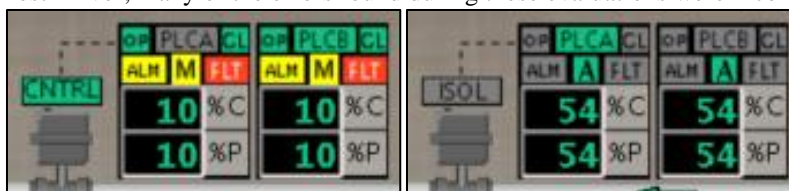

Figure 4: Test Drive Comparison of a Valve.

In the figure above, the two different states of a Main Plenum Blower valve are shown. One of the valve state components depicts the current controlling PLC, while other objects include status indications for alarms, faults, and the position of the valve. The entire system has multiple redundancies engineered into it; every valve, duct, heater, etc. has a secondary, identical component. To ensure the safety of the system, two PLCs have commanding capability. If one PLC were to fail to during launch or other operations, the system would automatically switch itself to the other PLC while continuing to support the vehicle. In the modification of ECS for the SLS missions, the whole system was designed for redundancies and failure circumstances. The north ducts have two safety valves between the GN2 supply ducts and the rest of the system to ensure that a GN2 leak could not occur while operators were present in the ECS room, or while the vehicle is supported by the ECS hardware. Mechanical as well as software mechanisms protect the GN2 safety valves from inadvertent operation. Even if one valve were to fail, the other valve would prevent any GN2 from flowing into the system.

III.   Local Displays

The local displays for ECS are being developed with a suite of Allen-Bradley software – including FactoryTalk View – which has different functionality compared to the remote displays. One main difference is the utilization of parameter files (text files with information about the screens), which can reduce the overall number of total screens. For example, the display screen for similar hardware only has to be developed once. Any recurring instances only require loading the correct parameter file, which is part of the functionality of the navigation buttons.

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

Expressions/logic are also available to the local display developers. Since the local displays utilize tags instead of CUIs, one multistate indicator (hardware has multiple states: On, Off, Starting, Error) can combine all states into one display object, whereas the remote display has to incorporate multiple objects. There exists a multitude of other differences between remote and local development, but the parameter file and expressions are two relevant differences.
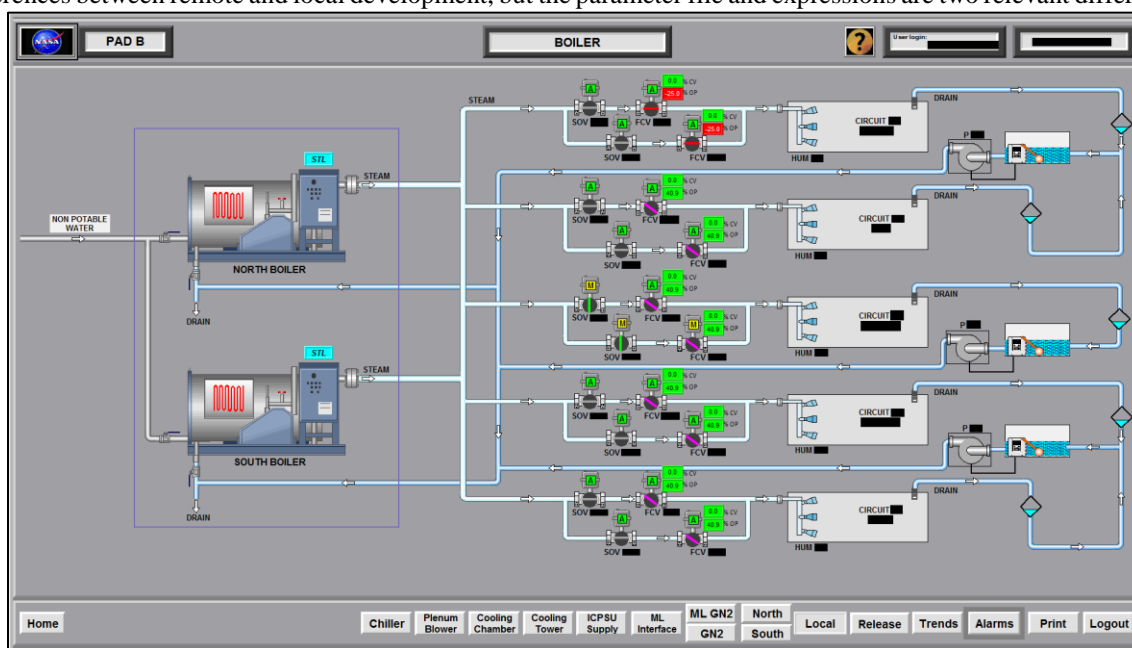

Figure 5: Boilers Local Display[5]

Local displays are used in three primary locations throughout KSC: the development laboratory, the Firing Rooms, and the launch pad. In the development lab, developers utilize Allen-Bradley software and hardware to construct, review, and revise the local displays used by various subsystems, including ECS. The Firing Rooms will be used in Verification and Validation (V&V) testing of the local displays as well as controlling all ECS equipment for Exploration Mission-1 (the debut flight of the SLS). Similar to the Firing Rooms, local displays will be utilized at the launch pad to control the ECS equipment and test the hardware. As previously stated, the remote displays are limited in their command and control functionality due to many limitations; however, the local displays require complete command and control functionality due to its roles at the launch pad and with EM-1.

A. Navigation Test Procedures
Each set of displays – remote and local – must undergo comprehensive testing prior to their implementation and application for a launch. **Table 1** describes the different software tests.

Table 1: NASA's Levels of Software Testing

Step	Type of Test	Description	Location
1	Unit Testing	Performed by the developer of the displays. No formal test procedure or requirements.	Launch Pad
2	Integration Testing	Testing performed with PLCs. Written test procedures are required.	Launch Pad, Firing Room
3	Level 5 Testing	Testing of the "final product" version of the displays against computer simulations of the mechanical systems and hardware. Written test procedures as required.	Firing Room
4	Regression Testing	Retesting of issues found in Level 5 testing after they have been fixed.	Firing Room
5	Validation and Verification (V&V)	Final testing of the entire system; fully operational mechanical systems are controlled by the displays.	Firing Room

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

The first set of manually-generated test procedures involved assessing the functionality of the local display's navigation buttons; for example, any button that displays an entirely new screen or a pop-up menu has to be tested as part of each level of testing. First, a standard testing template was developed for the navigation testing procedures; an example of the template is shown below in **Table 2**.

Table 2: Navigation Test Procedure Template Example

Step	Description	Acceptance Criteria	Pass/Fail	Requirements	Comments
1	From 'A' screen, perform 'X' action	'X' action occurs	□PASS □FAIL		

The two text placeholders in the 'Description' and 'Acceptance Criteria' columns were written as a template for all test steps. The majority of testing will be conducted by ECS team members, but the procedures were written with explicit detail so that an independent operator could execute the test procedures. The 'Description' column always starts by specifying the current screen the operator should have displayed before it states which action item to perform, whether that may be a button, panel, or polyline. The 'Acceptance Criteria' column defines the action(s) that *must* occur to in order to ensure the expected outcome equals the actual outcome. The 'Requirements' column was intentionally left blank; project leaders would later populate those columns with subsystem level requirements that were satisfied by each test step. In the event of a failed test, the operator would fill in the 'Comments' column with the actual outcome of the test so that the developers can fix the issue.

In order to generate the navigation test procedures, a comprehensive list of all navigation buttons, panels, and polylines were created. From this directory, each of the main display screens were broken down into a flowchart to easily compare the differences. It was determined that each main display screen should have its own test procedure. Each main screen's test procedures were then populated with all of the correct steps. The following figure depicts the flowchart for the Chillers display screen.
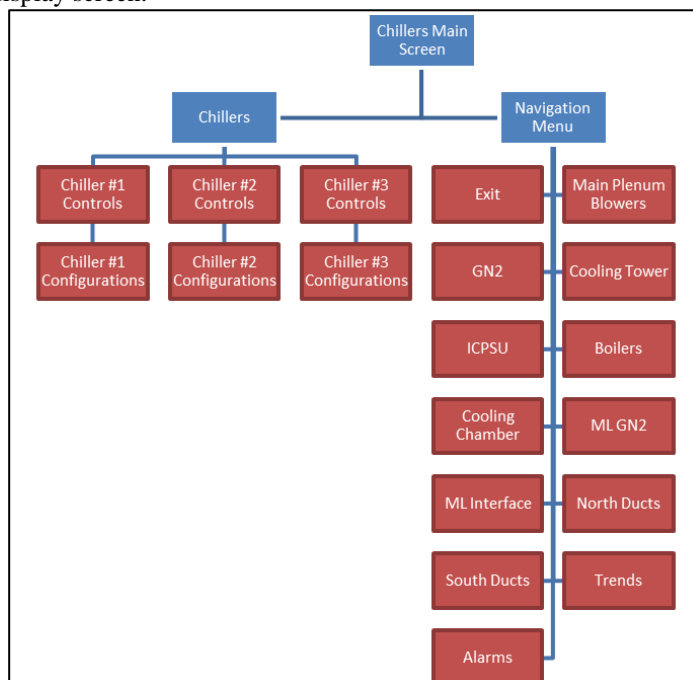

Figure 6: Navigation Button Flowchart for Chillers Display

B. Visual Basic for Applications

Visual Basic for Applications (VBA) is an event-driven programming language and is widely used in creating the local displays for ECS. FactoryTalk View utilizes the VBA code to run an action behind the scenes of the display.

One of the functions of the VBA code in the creation of local displays was to generate a trend graph. This trend graph displays real time data on the PLC for a certain subsystem of ECS. Also, historical data for the subsystem can be viewed from previous months in order to gain insight on the system for trending or troubleshooting purposes. This display was generated using the default Allen-Bradley trend object and pens collection. The trend graph is a configurable window that displays tag values – called pens – at the request of the operator. Each trend displays has a specific collection of pens that can be added or removed to the graph. Therefore, any real time modifications to the PLC tag values will be reflected in the trend graph.
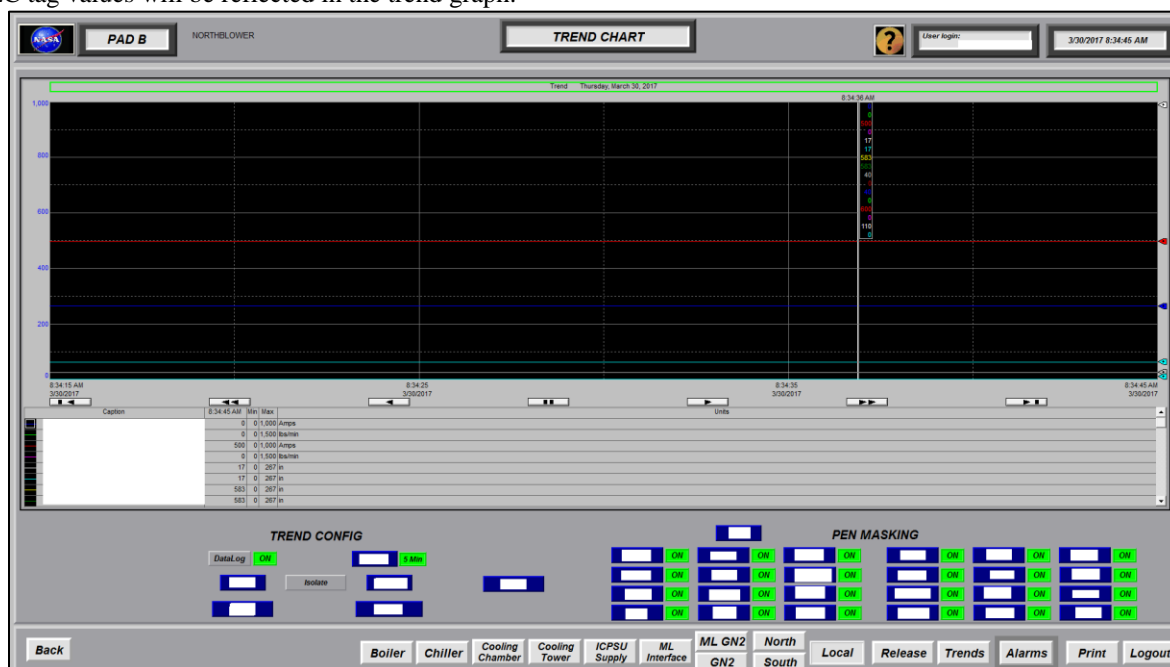
Figure 7: Trend Chart Display[6]

IV.   Conclusion

For the duration of the internship, the authors gained valuable experience in the ECS by modifying/creating remote displays, creating test procedures and programming code behind the displays. Modifying the remote displays was rewarding because extensive knowledge of ECS is necessary to understand the necessary modifications. Stephen Camick provided knowledge about each detail in the subsystem and explained the design decisions that drove the software and hardware configurations. Writing the test procedures provided insight into the Verification and Validation part of the software development cycle. When the ladder logic behind the displays is complete, the test procedures will be used to ensure the accuracy of the buttons on the display. Overall, the navigation test procedures are complete, most of the CUIs available were integrated into the remote displays and the functionality of the local display test procedures is in work.

Acknowledgments

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

References

[1] Test Equity LLC, "What is GN2 Purge?," [Online]. Available: https://www.testequity.com/static/130. [Accessed 4 April 2017].