Environmental Control Systems for Exploration Missions One and Two

Mark A. Falcone

Kennedy Space Center

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Mark A. Falcone

Wentworth Institute of Technology, Boston, MA 02115

Abstract

In preparing for Exploration Missions One and Two (EM-1 & EM-2), the Ground Systems Development and Operations Program has significant updates to be made to nearly all facilities. This is all being done to accommodate the Space Launch System, which will be the world's largest rocket in history upon fruition. Facilitating the launch of such a rocket requires an updated Vehicle Assembly Building, an upgraded Launchpad, Payload Processing Facility, and more. In this project, Environmental Control Systems across several facilities were involved, though there is a focus around the Mobile Launcher and Launchpad. Parts were ordered, analysis models were updated, design drawings were updated, and more.

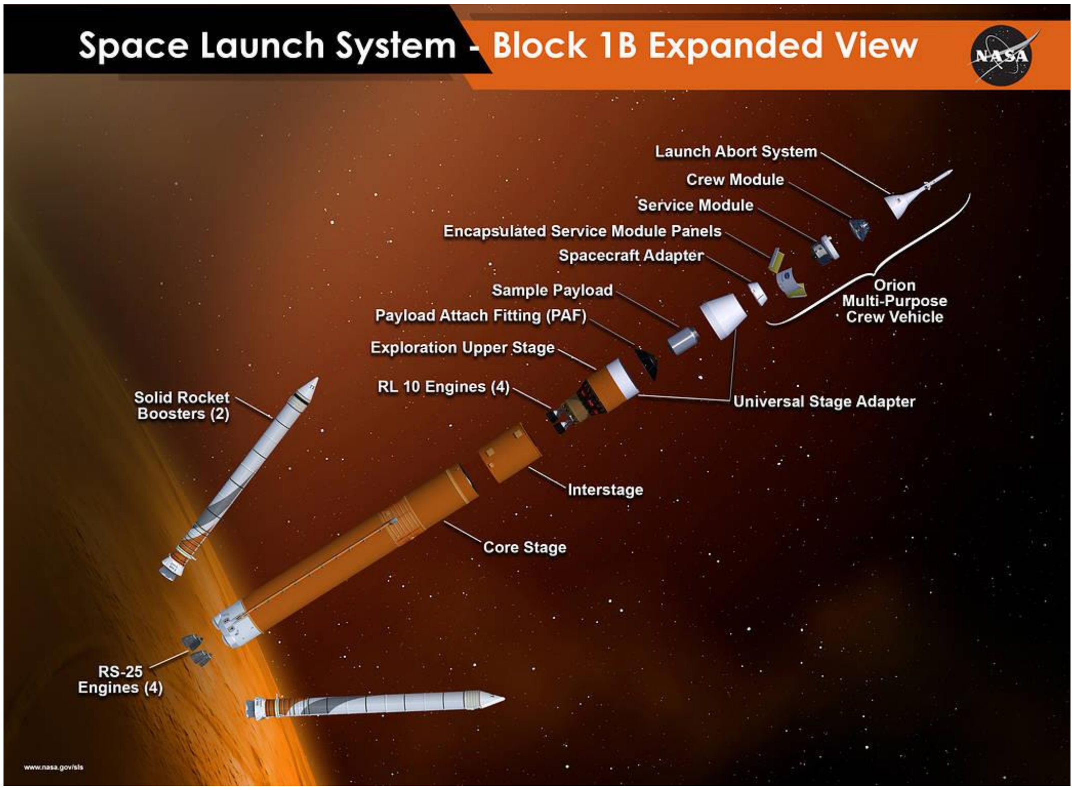

Figure 1. Space Launch System Configuration (image courtesy of NASA).

Nomenclature

IT	= Internet Technology
SLS	= Space Launch System
KSC	= Kennedy Space Center, the NASA center responsible for rocket assembly and launch
NASA	= National Aeronautics and Space Administration
GSDO	= Ground Systems Development and Operations
ECS	= Environmental Control System
EM	= Exploration Mission, referring to the launch series of the SLS, usually followed by the mission number
AFT	= Applied Flow Technology, a company that makes fluid modeling software
SCFM	= Standard cubic feet per minute
ACFM	= Actual cubic feet per minute
VAB	= Vehicle Assembly Building
MPPU	= Miniature Portable Purge Unit
PPU	= Portable Purge Unit
ICPS	= Interim Cryogenic Propulsion Stage
ML	= Mobile Launcher
GN2	= Gaseous Nitrogen

I. Introduction and Project Domain

This project revolves around the overarching goal of preparing the ECS infrastructure for EM-1 and EM-2. Preparing the equipment and infrastructure for these missions is currently one of NASA KSC’s primary goals. This encompasses an array of tasks, as construction for the EM-1 infrastructure is underway, while EM-2 is in the design phase at the time of this writing. This means that while analysis models and designs are being updated and fixed for EM-1 based on revisions and construction, new analysis models and statements of work are being created for EM-2 to obtain interface requirements and the like. This will allow engineers to obtain information based on a wide variety of scenarios for either infrastructure, which could be crucial when considering the open discussion on building a second mobile launcher and maintaining the infrastructure for either rocket configuration. The building of a second ML to maintain adequate infrastructure for both rocket configurations is unlikely. While this does save money up front, the proper documentation and drawings for both configurations will still need to be maintained, both configurations will still need to go through the approval process, both configurations will need to be tested and verified, and so on. While updating the EM-1 ML does save on materials and labor, much of the process is the same as it would be if an entirely new ML were being built, and much of the same could be said of the rocket.

To elaborate, ECS supplies air and GN2 from either the Launchpad or the VAB through the ML to the vehicle. This air and GN2 travels to all stages of the rocket through a system of hardline and flexible ducts while still meeting vehicle requirements. While much of the ECS equipment is relatively standard but on a large scale, there are exceptions to that. The MPPUs and PPUs for example, are used at the VAB and on the crawler-transporter, which is responsible for moving the launch vehicle from the VAB to the Launchpad. These were custom built for the purpose of supplying conditioned air to the vehicle and the facilities that support it. These are designed to supply air to meet the requirements of a variety of vehicles in nearly all potential conditions Florida has to offer, i.e. the units supported the Space Shuttle program will be modified to meet the SLS requirements, and they can do so on a 45 degree day or a 100 degree day.

II. Projects & Tasks

A. Preparation

The first major undertaking of the semester was effectively preparation for the internship. This included, but was not limited to; safety training, facilities training, IT Security training, elevated privileges training, downloading software, and becoming familiar with said software. This took up the better part of a week because of how some of the trainings were scheduled and how many of the trainings were necessary for all the tasks required throughout the term. Part of this was also learning how to use AFT Arrow, the chosen software for modeling ECS around the center, and simulating results based on those models.

B. AFT Arrow Modeling & Analysis

i. Dump System

The dump system is an exhaust system for the Launchpad, with redundant flow control valves to allow the dump system to be open or closed. The Launchpad ECS system had already been modeled, and that model was provided as a baseline. While the model that was in use provided reasonable results, it did not entirely represent the configuration that was built at Launchpad 39B. The first issue that needed addressing was the dump system for the North, South, and ICPS blowers all had an associated dump or purge line. The first major task in AFT Arrow was to model the dump system for the (LC 39B) Pad B ECS system according to the most recent drawings to which system is being built. This involved an understanding of how to design pipes in AFT Arrow with bends, elbows, connections, and more. However, information like heat transfer properties and insulation is not pertinent for this section because the air being transferred is being dumped to the atmosphere rather than flowing to a vehicle.

ii. Inlet System

The inlet system is responsible for taking air from the environment, filtering it, and providing it to the North, South and ICPS blowers to eventually be fed into the respective circuits. This is the beginning of the (LC 39B) Pad B ECS system, the furthest point from the vehicle interface. Similar to the dump system, the way the inlet system for each circuit provided reasonable results as modeled, but it was not an accurate representation of the inlet system in place. As it was modeled originally, the North, South, and ICPS all had independent inlets. Both the North and South circuits had an attached standby blower, so the standby blower could be activated in lieu of the North or South blower as it is intended. However, the actual system configuration involves two large intake plenums that pull in air from the atmosphere, filter the air, and run it into a duct circuit that leads to all four (North, South, ICPS, Standby) blowers. Accomplishing this correction required a significant amount of pipe and junction creation in AFT Arrow, per the drawings provided, in addition to some restructuring of existing sections of the model. The original structure was not ordered correctly, so some duct circuits had to switch positions with one another, and then ultimately be connected with the new inlet system.

iii. Model Merging

Once the dump and inlet systems for the (LC 39B) Pad B ECS system had been properly modeled, the new models had to be incorporated into the model of the entire ECS system ductwork for Pad to ML system. This involved using AFT Arrow's "Merge' function to get the models into the same files, then dragging the sections around to get each section mating the way it should. An important lesson learned here about AFT Arrow is that the display length of each pipe is entirely different from the pipe length used for calculation, allowing pipes to be elongated and slanted to fit the connection points. In this particular case there was no way to put both new systems in the same model without pipe sections crossing one another, which did make the moving and fixing of the system more delicate to ensure that at no point was a pipe moved that should not be moved.

iv. EM-2 Model

One of the first major steps in a project like EM-1 or EM-2 is to come up with the requirements of each system and interface (cleanliness, humidity, pressure, temperature, etc.). The upper-level engineers come together to compile these requirements in excel to be disseminated to the engineers who need this information. When this information has been compiled in excel, that spreadsheet is called the interface data book for that mission. Once the interface data book for EM-2 was developed based on Interface Control Documents (ICD) Requirements, the infrastructure for an EM-2 flow model in AFT Arrow was begun. This started with duplicating the model structure used in the EM-1 model, because the EM-1 ductwork should remain the same for the most part, with some small alterations and additions. Once the groundwork had been laid, minor fixes like elevation changes were made, and the new branches were added to the model as described in the data book. These new branches, like the old branches, had provided flow rate, temperature, pressure range, and more requirements to meet. The model is built around these requirements, so a constant pressure inlet at the start of each new branch is iterated to obtain the required flow rates.

v. AA2 Results

AA2 was a mission, which had its own set of requirements and its own configuration for the MPPU and flow control valve settings. A model was provided for analysis to determine what the operational margins were relative to the requirements. For the AA2 model, a specified list of results were needed from AFT Arrow analysis for a study. The required results included pressure, temperature, and flow rate measurements at various points in the model, in addition to the pressure and temperature margins across the model. Once the model was run, the relevant data were extracted from the results and compiled in a table, then proposed to the GSDO program office to show that the GSDO ECS subsystem teams equipment could support new outlier missions beyond baseline scope, currently slated for EM-1.

vi. Renumbering

Though the work involved in renumbering an AFT Arrow model is simple, the reasoning for it proved to be a valuable lesson. The model was run prior to the renumbering and it became abundantly clear that result gathering became fruitless unless the user is interfacing directly with the model in Workspace Mode. The model data was so disorganized that the model results could not be inferred from the model, because a single branch had pieces numbered in the 10,000s and in the 100s, meaning some pieces fell at the beginning of the dataset while others fell near the end of the dataset. Fixing this involved simply assigning number designations for each branch and renumbering accordingly, but it made the model efficient to extract results and follow.

vii. Heat Transfer Properties

With the new Pad B ECS system being installed, the AFT Arrow design analysis model heat transfer properties were among those needing to be updated as design modifications as a result of construction changes are ongoing. The insulation parameter settings had to be updated on all the ducting for the duct wall and material, as well as the properties for each additional layer of insulation. This involved an understanding of the insulation material properties and performance in place for both hardline and flexible ducts, as well as how the global pipe edit feature in AFT Arrow works. Once there was sufficient understanding of both of these, it was a matter of implementing these changes by section based on whether the section represents flexible duct or hardline duct.

C. SCFM Conversion[2]

$$\boxed{\mathrm{ACFM}} = ? \left(SCFM \cdot \frac{P_s - (RH_s \cdot PV_s)}{P_b - (RH_a \cdot PV_a)} \frac{T_a}{T_s} \frac{P_b}{P_a} \right)$$

Figure 2. Screenshot from Mathcad of SCFM to ACFM conversion (SCFM).

Where:

P_s = Standard pressure (PSIA)
P_b = Atmospheric pressure - barometer (PSIA)
P_a = Actual pressure (PSIA)
RH_s = Standard relative humidity
RH_a = Actual relative humidity
PV_s = Saturated vapor pressure of water at standard temperature (PSI)
PV_a = Saturated vapor pressure of water at actual temperature (PSI)
T_s = Standard temperature (°R)
T_a = Actual temperature (°R)

While this was a simple conversion, it required a great deal of background research prior to the actual calculation. Given the instructions of converting SCFM to lb_m/min (pounds mass per minute) and the data book, the first step was to find an equation for converting SCFM to ACFM from a credible source. Once the equation was found and understood, the standard air property conditions that were used were inquired about because as it was explained, there are variations in standard air property conditions used by different sources. Once a basis was established for what is considered “standard,” the air property conditions for the actual were inferred using psychrometric charts based on the known temperature and pressure. This provides values for relative humidity, barometric pressure, and saturated vapor pressure at relevant temperature. These prove to be viable inputs to the equation, leaving nothing but running the calculation in Mathcad, a mathematical computation program. This completes the conversion from SCFM to ACFM.

D. VAB Backdraft Damper

While the VAB standalone ECS system is supporting the ML during Verification and Validation (V&V) Testing that the ECS Subsystem is responsible for providing backdraft dampers to simulate SLS vehicle back pressures. These parts are designed and procured to be special test equipment for testing the system, using it as a means of simulating the vehicle. A rough sketch of the system and what should be included was provided, with instructions to find and procure parts that satisfied design intent and requirements. The first step in completing this task was becoming familiar with the specifications that the system must meet. The system must conform to ASME B31.3, which is the American Society of Mechanical Engineering’s standards for process piping and the code that this system must conform to, so this meant becoming familiar with what sort of pressure requirements need to be met according to that code. The code outlined burst pressure conditions that had to be met, and a formula for converting the design pressure into a burst pressure. This meant finding parts and converting each pressure to ensure it conforms to the required specifications, however, many of the parts listed codes they conformed to other than ASME B31.3, so those codes were also looked over and understood to comply with ASME B31.3 concurrently. Some of the other codes (ASTM codes and the like) gave burst pressure requirements that manufactured parts must meet to be in conformance with the code, in addition to the procedures used for testing. Many of the parts had three or four common codes that they met, so it was a matter of showing that those codes were sufficient evidence for meeting design requirements.

E. Launchpad

Much of the work this term was focused on the LC 39B ECS Pad B Launchpad refurbishment, and because of the state of the construction, some of that work involved being in the Launchpad ECS room. This allowed for an opportunity to connect the model design to the actual product, as well as a learning opportunity in coordinating between the designers for a project and the construction team that makes that design a reality. While the focus of this internship is of course engineering, these trips served as a reminder of how important effective communication is in ensuring the effectiveness of the engineering. This is not to imply that communication was lacking on these trips, but rather to highlight the value of it between customer, contractor, designer, and so on. The opportunity also arose to watch some of the initial startups and testing for some of the equipment, which involved observing, taking notes, and walking the system during startup to look for any potential leaks or issues in the ducting or equipment.

F. Approved Equal Verification

A part change was made in one of the MPPU drawings, but the part needed verification with an electrical engineer. As with many things in engineering, this was not as simple as it sounds. Upon checking with the electrical engineer, questions arose regarding the reason for the change of parts, and the advantage to the replacement part. The involved parties did not already know the reason for this change, so this required some digging into the variations in the parts, in addition to finding the full part number, as the number in the drawing was incomplete. The full part number was provided, and the advantages came from comparing the specifications for each part to find that while the old part could measure humidity in grains of water per unit mass, the new part could measure in grains of water per unit volume, which better suited the needs of the GSDO ECS Subsystems Software group to support ECS purge from the newly refurbished MPPUs.

G. Risk Assessment

A risk assessment was needed for outlying issues at Pad 39B that needed addressing. This list was comprised of both familiar and unfamiliar concerns, so some additional information was needed for the completion of this task. The GSDO guidelines for assessing risks was read and understood, and then further knowledge of the risks and the recommended solution for each risk was obtained. Each risk was assessed based on the GSDO guidelines for each category: personnel safety, environmental safety, recovery cost, and schedule impact to name a few. Each risk is given a score for each category (unless the category is not applicable to the risk), and the most severe score is recorded for that risk, however all risks are recorded and shown along with the thinking that led to the score. This is done because the risk assessment is, to some degree, a subjective measure so a clearly outlined justification is needed for each risk. Due to the nature of the presentation, background information and pictures associated with each risk were also included so the audience had a clear understanding of the problem, the location, and the solutions that should be implemented. One example of a risk in this presentation is some deterioration in the support for the intake plenums that feed air from outside to the blowers. Over time, some bolts likely vibrated out, which allowed the plenum to begin to pull away from the wall. After thinking of potential worst-case scenarios involving a failure in this plenum, scores are given based on guidelines for the consequence and likelihood of this event actually occurring. In this particular case, the solution is simple, but this remains a risk being carried through the construction contract, and had to be documented as such. Upon presenting this assessment to the GSDO program project managers at the Launchpad, feedback was given and incorporated. Future work includes taking measurements of the risks to begin the analyses and redesign required for mitigating the risks sufficiently.

Additional Learning Opportunities

The learning began during orientation, when interns were taken on a guided tour of KSC to see some of the ongoing research and become familiar with some of the center's many facilities, including some of the labs and the room in which the scientists who design experiments for space can observe and communicate with astronauts on the ISS. Later in the term, a presentation was attended on Swarmie, which explores the idea of sending a swarm of robots to explore Mars or the moon, gaining information and potentially even gathering resources. This involves a great deal of research and experimentation with building robots that can handle the terrain with minimal supervision and input, while also considering the optimal means for these robots to communicate something like the location of resources to other robots, and back to NASA.

In addition to the structured learning opportunities provided by the education office, there were opportunities to learn about some of the ECS facilities around the center. The first and most frequently visited ECS facility was the Launchpad ECS room, and there was an early opportunity to tour the room and gain an understanding of the system and its operation. That understanding was gradually honed throughout the term, through additional visits and through work with the model of the system. Once the proper facility access had been obtained, there was also a brief tour of some of the more significant VAB ECS equipment like the MPPUs outside and the flexible duct that will eventually be installed.

III. Conclusion

The author, with assistance from his mentor, was able to make steady strides to correct portions of the Launchpad model that were either inaccurate or incomplete. As minor changes are made to the equipment to accommodate construction, the same changes can quickly be made to analysis design models. Much was accomplished outside the domain of these analysis models as well, as these were simply the focus of the internship rather than the sole task.

IV. Acknowledgements

The author would like to thank his mentor, Drew Gillespie, for allowing him to participate in a project as exciting project like the Launchpad refurbishment. The author would also like to thank his supervisor, Zoë Sampson, for her support and patience throughout the term, especially in the preparation phase, as the process would not have been nearly as smooth without her. Thank you to the KSC Education Office for their assistance with housing and directions, and for preparing an interesting and informative orientation, as well as other events throughout the term.

V. References

[1]No author, "ASME Code for Pressure Piping, B31," *American Society of Mechanical Engineers*, Jan. 2017, pp. 1–562.

[2]"SCFM (Standard CFM) vs. ACFM (Actual CFM)," *pdblowers, Inc.* Available: http://www.pdblowers.com/t6-scfm-standard-cfm-vs-acfm-actual-cfm.php.