

**Kennedy Space Center (KSC)**  
**Exploration Ground Systems (EGS)**  
*(Formerly Ground Systems Development & Operations)*

**Evolution of KSC EGS Post Space Shuttle -  
Success Factors and Lessons Learned**

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# Executive Summary

In October 2017, the Human Exploration and Operations Mission Directorate (HEOMD) Knowledge Capture & Transfer (KCT) team conducted video interviews with element managers in the Exploration Ground Systems (EGS) Program Office at Kennedy Space Center (KSC). The immediate goal was to capture a point-in-time profile of challenges, solutions, and lessons learned derived from EGS element development activity from the end of the Space Shuttle Program (SSP) to the present time. The ultimate objective is to transfer this knowledge to other program and project managers and participants across NASA to enhance effectiveness and efficiencies in implementing their activities.

This report summarizes key observations from the interviews and is complemented by nine video interviews located on the [“Knowledge @ NASA” YouTube Channel](#). This activity represents a collaboration between HEOMD, the Exploration Systems Division (ESD) Strategic Communications Office, the Agency Chief Knowledge Officer (CKO), and the KSC-based EGS Program Office.

Interviews were conducted with element managers from the following projects:

- Vertical Assembly Building (VAB)
- Crawler-Transporter (CT)
- Logistics
- Launch Equipment Test Facility (LETF)
- Launch Control Center (LCC)
- Landing and Recovery
- Launch Pad 39B
- Thermal Protection System Facility (TPSF)
- Mobile Launcher (ML)

## **Key Management Success Factors:**

- **Co-location:** Several managers identified co-location of the civil servant and contractor teams as critical in addressing communication issues that impeded progress. Co-location enabled frequent face-to-face communication—facilitating rapid resolution of technical issues and promoting collaboration.
- **Communication:** Managers in every case emphasized the importance of communicating and enabling communication vertically and horizontally within the project team. All modalities of communication were recognized as important—especially face-to-face.
- **People:** The interviewees universally cited the outstanding skill, dedication, and excellence of their workforce and the need for managers to nurture, support, train, and enable their staff. Also discussed was the need for managers to recognize and consider employees’ family/life issues and obligations.
- **Organization:** Streamlining their organization structure and work processes was discussed as an important consideration in effectively accomplishing their mission.
- **Procurement:** Several managers cited the importance of exploring innovative procurement approaches to address the unique challenges of rapidly changing requirements and evolving

needs. The use of Undefined Contract Changes (UCA) was cited as an important tool in maintaining schedules.

- Design Considerations: Design-related success factors included: (1) maintaining as much margin as possible as a means to address future requirement changes, (2) learning from test failures (design, test, redesign), and (3) employment of modeling and simulation technology.
- Real-time Problem Solving: “Brute Force” is the term employed in the ML project as a way to address intractable problems by assembling stakeholders on-site, face-to-face to engage in real-time, hands-on problem resolution.
- Peer Review / Lessons Learned: Seeking a fresh perspective on a design or proposed operation was identified as an important management practice (as well as reviewing lessons learned and selectively engaging knowledgeable and experienced retirees) to assist in planning or conducting reviews.
- Schedule Risk Awareness: Risk management was cited most often in the context of schedule management. Identifying potential threats to the critical path was a universal concern and served as a driver for other management elements (e.g., procurement, organizational streamlining, co-location).

#### **Significant Implementation Challenges:**

- Parallel Development: the imperative to move forward while monitoring evolving requirements, making assumptions, and sometimes the need to re-do work.
- Technical Integration: managing multiple (40-plus in the case of ML) project elements and multiple contractor teams—ensuring flow-down of requirements and implementation of requirement changes as well as managing interfaces.
- Safety and Hazards Management: ensuring all safety risks are identified and effectively controlled and/or mitigated.
- Working with Heritage Hardware: finding 50-year-old, as-built drawings and addressing parts obsolescence.
- Schedule Management: planning and maintaining schedule in a high-change traffic environment.

Each of the nine interview chapters concludes with a first-person message from the interviewee to students (in all levels of school) addressing Science, Technology, Engineering, and Mathematics (STEM), and sharing their enthusiasm for working at NASA and the excitement and privilege of working within the EGS organization to prepare KSC for the 21<sup>st</sup> century.

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## Part I. Introduction

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- Crawler-Transporter (CT)
- Logistics
- Launch Equipment Test Facility (LETF)
- Launch Control Center (LCC)
- Launch & Recovery
- Launch Pad 39B
- Thermal Protection System Facility (TPSF)
- Mobile Launcher (ML)

## **Preparatory and On-Site Activities**

Preparatory telephone interviews were conducted with each participant during mid to late September 2017. Discussions addressed goals, objectives, and a preliminary interview outline which participants were asked to tailor in advance of the on-site video sessions. After a delay and rescheduling associated with Hurricane Irma, the KCT team arrived on-site October 9<sup>th</sup>. Interviews were conducted on the afternoon of October 10<sup>th</sup> and all day on October 11<sup>th</sup> and 12<sup>th</sup>. A demonstration with video capture was conducted at the Thermal Protection System Facility (TPSF) on October 13<sup>th</sup>.

- Tuesday: Vehicle Assembly Building, Crawler-Transporter, Logistics
- Wednesday: Launch Equipment Test Facility, Launch Control Center, Launch & Recovery, Launch Pad 39B, Thermal Protection System Facility, Mobile Launcher
- Thursday: TPSF Demonstrations

## **Organization of Report: Themes and Framework**

This report is organized by EGS element. Within each element chapter the following format is employed:

1. Element Functions and Interfaces
2. Renovations and New Features
3. Design, Development, Test & Evaluation (DDT&E) Challenges / Solutions
4. Project Management Success Factors
5. Thoughts for NASA's Next Generation (STEM-related message presented in first-person narrative)

## **Additional Resources**

**KSC EGS Web-based Module:** This report has companion video content deployed on the NASA YouTube Channel: <https://www.youtube.com/knowledgenasa>

## Part II. Lessons Learned

### **(I) VAB: *This Old House***

(based on a video interview with Jose Perez-Morales)

#### **1. Element Functions and Interfaces**

The iconic Vehicle Assembly Building, or VAB, is one of the most visible landmarks at KSC. The VAB is 525 feet tall and is one of the largest buildings in the world by volume. The VAB is divided into four high bays linked by a transfer aisle.

The VAB is where the launch vehicle and spacecraft are stacked atop the ML support structure, integrated, and prepared for rollout to the launch pad on the CT.



*Figure 1: Vehicle Assembly Building at Kennedy Space Center*

An overarching objective of EGS has been to do more of the integration and preparation work inside the VAB as opposed to on Pad 39B exposed to environmental elements. It is noteworthy that this is a return to the approach employed during the Apollo program. The shift in approach will enable completion of most integration activities in the protected VAB environment and allow the management team to select the right weather for rollout and final integration on the pad.

#### **2. Renovations and New Features**

Renovations in work are focused on High Bay 3 to enable and support the assembly and processing of the Space Launch System (SLS) vehicle on top of the ML. The VAB team completed a three-year project installing 20 new work platforms and conducted verification testing prior to the planned ML arrival at High Bay 3 in May 2018. The 20 new state-of-the-art platforms can be reconfigured for any launch vehicle, not only the SLS. Each platform not only can be moved up or down 10 feet, but also has an insert that can be modified to conform to any vehicle shape. Each platform provides a host of “commodities” and support functionality, including electrical power and pneumatics (GN2, Helium, and compressed air).

### 3. DDT&E Lessons Learned / Challenges and Solutions

**Unanticipated Flexing:** One of the biggest surprises the project encountered was the inability to install the first platform because of misalignment of mounting hardware. The platforms were designed with holes drilled to match corresponding holes on the supporting VAB structure. The four pins that should have fit perfectly were problematic, taking hours to finally insert. What was the problem? A dynamic structural response model revealed that while suspended by the crane lowering it into position, the platform was flexing—up to two degrees. This flex or rotation was enough to create a critical misalignment. Solution: the team installed two, 70-foot stiffener beams under each platform, eliminating the dynamic flex in the platform. Subsequent platforms were successfully installed in under 10 minutes.



Figure 2: Platforms at VAB

**Design for Fabrication:** “Design is fine, but how are you going to fabricate that design?” Perez-Morales noted the ongoing challenges associated with implementing designs that did not consider the difficulties involved in fabrication. Program and project managers should consider *design for manufacturability*, or DFM, as an important consideration in overall design tradeoffs.

### 4. Project Management Success Factors

**Co-location:** One of the first actions undertaken by Perez-Morales when he moved over from Pad 39B project to become VAB element manager was to consolidate the workforce. He moved employees—previously scattered in various locations with some far away from the work taking place—into a central location near the VAB and close to the prime construction contractor. Perez-Morales remarked, “That alone solved a lot of the issues we had.” The improved face-to-face interaction solved most of communication issues and facilitated rapid resolution of issues that previously might have lingered unresolved for weeks.

**People:** Perez-Morales commented, “I have the most qualified team of people working for me.” He further noted, “If you surround yourself with the right people with the right attitude—no matter what the challenge, you will be successful.”

**Design Considerations:** During the design process, it is critical [important] to consider challenges to fabrication of the design.



**Broad Perspective:** To be successful, project managers need to maintain a broad perspective. “Understand the environment, see the big picture, and don’t drown in the details,” said Perez-Morales.

## **5. Thoughts for NASA’s Next Generation (STEM-related message)**

At NASA, every job or project is a challenging one. You work with some of the most qualified and amazing people in the space industry, working on things that are out of this world. If you are interested in the space program, get involved with the various NASA programs because we will need all kinds of professionals in the future. Stay in school and obtain a higher education.

## (II) Launch Pad 39B: *Towers on the Hill*

(based on a video interview with Regina Spellman)

### 1. Element Functions and Interfaces

The EGS Pad 39B element is overseeing upgrades to Launch Pad 39B and other supporting facilities to support NASA's deep-space missions, SLS, and Orion as well as the transition to a multi-user spaceport. The Pad 39B element provides not only the structural foundation, but all the supporting systems to supply the ML and the vehicle. As shown in the adjacent photo three lightning protection system (LPS) towers have been constructed, each



Figure 3: Launch Pad 39B at KSC

reaching 600 feet. This design will protect any vehicle that can leave the VAB. Pad B provides up to 900,000 gallons of both LH2 and LO2, enough to support multiple SLS launch attempts. The complex perimeter is approximately two miles. The water tower supporting the ignition over-pressure sound suppression system holds 400,000 gallons of water and empties in less than 30 seconds. Pad 39B manager Regina Spellman characterizes the pad as an “RV park.” She remarked, “We provide all the facility systems, commodities, instrumentation, communications. If the Mobile Launcher can’t carry it, we provide it.”

Also of note, the pad isn’t sitting on a hill. It is a man-made structure built up from the ground approximately 50 feet. Underneath the surface are catacombs and rooms packed with wire bundles, instrumentation, and mechanical systems.

### 2. Renovations and New Features

Spellman summarized, “Since taking over Pad 39B from the SSP we have renovated, repaired, replaced, or removed almost every system out there.” Pad modification began in 2007 while the space shuttle was still flying off Pad 39A. Work continued through the Constellation Program, pausing to enable launch support for the Ares I-X test flight.

In implementing the “clean pad” concept, some of the first systems removed were the venerable space shuttle fixed and rotating service structures that provided support for month-long processing campaigns prior to launch. The clean pad concept emphasizes minimizing the time on the pad with the lion’s share of processing carried out in the VAB or other facilities.

Spellman described the work on Pad 39B as a jar with a number of big rocks (major tasks) and the gaps filled with innumerable smaller rocks (smaller tasks). The big rocks included the following:

- 600-foot lightning protection towers, sized for any vehicle that could roll out from the VAB
- Cables everywhere—over 300 miles of copper cable removed and replaced with fiber optic
- Flame deflector
- Flame trench
- Environmental control system (HVAC on steroids)
- Air, GN2 purge
- New communication system
- Replacement of water system piping in the pad perimeter
- Installation of new ignition overpressure/sound suppression bypass valves at the valve complex

### **3. DDT&E Lessons Learned / Challenges – Solutions**

**Parallel Development:** One of the biggest challenges encountered was the need to work in parallel with the SLS launch vehicle development. The parallel schedules require constant cross-program communication to ensure the vehicle design changes and evolutions can be accommodated by designs of the supporting Pad 39B infrastructure. In some cases, it is and has been necessary to make assumptions based on the best available information and past experience. In some cases, rework may be necessary. While parallel development may not be the most efficient approach, it can be successfully implemented with constant communication and conservative assumptions when necessary to keep work moving forward.

**Task Phasing:** A unique challenge for the pad work was the constraint of having to do projects in serial fashion due to their physical size. “It’s been like putting large rocks in a jar. You can only do one at a time, and you fill all the gaps with the little rocks,” she said. The challenge was to phase large construction jobs in the right sequence while getting all the smaller jobs done in parallel.

### **4. Project Management Success Factors**

Spellman eloquently focused on the importance of people in the process and the art of successfully managing people. *“The technical challenges aren’t your biggest problem. Those are the fun ones,” she said. “It’s the people challenges that you have to work hard at. You can never communicate enough, and don’t forget—people are human.”*

Specific workforce issues include:

**Communication:** Effective communication is critical for successful projects. Communication is often a potential failure mode when people begin to rely on one-way communication (e.g., I sent you an email ...?). What is needed is affirmation in communication—either face-to-face or over the telephone.

**Human Needs:** Sensitivity to individual feelings and emotions and recognition that workers have lives outside of work is an important concept for successful managers.

**Thoughtful Resolution of Conflicts:** It is not unusual for well-motivated team members to differ on the approach to solving a problem. Conflicts need to be resolved with considerate evaluation of differing opinions and a decision made based on whatever is best for the project.

**Workforce Direction:** People need direction. The lack of decisions on key issues is divisive and degrades morale and, ultimately, teamwork. Unresolved or lingering issues soon become critical path items on the integrated schedule.

**People Make Mistakes:** People are people—and people make mistakes. What is important is how you handle those mistakes when you are the manager. Spellman said questions to ask are: “How can we recover? How we can avoid future mistakes like this? How can our process be improved to mitigate a reoccurrence? What are the lessons learned? Who do we need to share these lessons learned with?”

## **5. Thoughts for NASA’s Next Generation (STEM-related message)**

At NASA, we are creating history. We are making a legacy for future generations. We also get to work on very unique and challenging problems every day. Believe in yourself. We don’t say, “The sky’s the limit at NASA,” because there are no limits for us, and there’s no limit for you, either.

### (III) Crawler Transporter: *“Still crawling after all these years”*

(based on a video interview with John Giles)

#### 1. Element Functions and Interfaces

The CT will carry NASA’s SLS and Orion spacecraft to Launch Pad 39B for launch on Exploration Mission-1. The crawler-transporters were constructed in the mid-1960s to move the Apollo Saturn V rockets that took American astronauts to the moon, Skylab and Apollo-Soyuz Test Project. Through three decades of space shuttle flights, the crawlers served in the same role until the final space shuttle mission in 2011.

Crawler transporters are designed to lift the mobile launchers with launch vehicles mounted atop, then move the entire integrated stack from the VAB to the launch pad. The crawler transporter, designed in the early 1960s, weighs over 6 million pounds, is as large as a major league infield (90 feet by 90 feet), and has more than 400 shoes, each one weighing over a ton.



Figure 4: Crawler Transporter

The CT, described by John Giles as “a hands-on piece of equipment,” is an engineering marvel requiring support from multiple disciplines, including structural, electrical, and mechanical. The CT has an interesting design heritage with elements derived from heavy mining equipment and diesel-electric locomotives. The prime mover power source is an American Locomotive Company (Alco) V16, 2750 HP diesel electric generator that powers the CT 16 traction motors. While 53 years old, the engine is still considered “low mileage” with the odometer at only 2,100 miles. Electrical power (alternating current) is provided to the CT, mobile launcher, Mini Portable Purge Units (MPPU) and launch vehicle by a new twin turbo-charged Cummins diesel engine.

The optimum operational scenario is a roll to the pad in the early morning hours (avoiding inclement weather) cruising at a top speed of 0.8 – 0.9 mph. The six-to-seven-hour trip is carefully managed by a team of 20 engineers and technicians who are continually monitoring performance metrics (level, strain, pressure, weight, lubrication levels, temperatures, and vibration) as well as pre-programmed redlines and alerts.

#### 2. Renovations and New Features

The heaviest SLS rollout weight, including the mobile launcher, is estimated to be about 18 million pounds. That compares to the Apollo Saturn V and space shuttle rollout weight of approximately 12.3 million pounds. The challenge has been to analyze and redesign the entire

load path from the crawlerway river rocks to the drive train to the support “trucks” to handle the net increase of 6 million pounds. Major changes include:

- New bearings (each weighing one ton)
- New jacking equalization and leveling (JEL) hydraulic cylinders
- New rebuilt gearboxes
- New engine (Cummins replacing the previous White diesel)
- New brakes
- New shear webs (adding structural steel inside each truck)

In addition, evaluations are underway to assess the capability of the crawlerway to ensure the river stone top layer and supporting layers of rock and limestone can bear the increased load. A final area under evaluation is the capability of the Cummins generator to provide increased power output for ground support equipment serving the ML and SLS during the roll to the pad.

### **3. DDT&E Lessons Learned / Challenges - Solutions**

**Design Drawings:** The CT design drawings were created by engineers using mechanical pencils and velum over 50 years ago. The CT team worked with engineers at Ames Research Center (ARC) to carefully review and update the drawings as necessary to reflect the as-built configuration. ARC provided the principal structural analysis support for the modifications based on the updated design documents.

**Crane –Workflow Modeling:** The KSC weather environment has always posed risks to schedule. Outside work is subject to severe weather, high winds, rain, and corrosion of unpainted ferrous materials. Not surprisingly, the CT project was motivated to perform the work in the VAB avoiding complications of bad weather. The CT project involves very heavy components that require one crane—and often two—to perform necessary lifts. The question was, “Will the VAB cranes (permanent and mobile) be able to perform the complex maneuvers required to implement the modifications?” Boeing’s Design Visualization team’s VAB crane and lifting device computer simulation model was enlisted to assess the feasibility of CT refurbishment in the VAB. The model demonstrated that all of the moves and lifts could be accomplished and the plan went forward successfully.

**3D Printing to the Rescue:** The CT has miles of piping and tubing that interfaces with valves. The installation of these systems was being set back because of delays in the manufacturing and delivery of the specialized valves. The CT project avoided this schedule bottleneck by using KSC’s 3D printing capability to create highly accurate plastic models of the actual valves, including threads, to enable work crews to move forward with installation of piping while waiting for the real valves to arrive.

**Measurements and Grease:** How did KSC maintain the CT so well for 50 years? First: “Pump grease everywhere.” Second: “We measure everything we can,” including temperatures, pressures, vibrations on every motor and pump, and power consumed, and also maximize the use of photography. The CT maintainability story is noteworthy indeed.

#### **4. Project Management Success Factors**

**Amazing Team:** The importance of teamwork and the stability of the team composition was highlighted as a very real success factor in the implementation of CT upgrades. It was noted that the same team served from beginning to the end and that corporate knowledge was maintained and accomplished by pairing older, more experienced workers with younger engineers in hands-on implementation of critical functions. In addition, the on-site CT team was augmented by the design engineers at ARC and reach back to a cadre of retired CT experts who had spent careers working with the CT.

**Communication:** Giles, the CT project manager, is “on the floor every day” communicating with work teams, observing progress, and discussing issues. This level of engagement is deemed a critical ingredient in fostering teamwork.

**Overdesign:** One way to accommodate anticipated design changes is to overdesign. This option is not always available, especially in weight critical systems (launch vehicle or spacecraft) but is certainly a viable option for ground support equipment and ground support infrastructure.

#### **5. Thoughts for NASA’s Next Generation (STEM-related message)**

Beyond the more obvious need to take classes in math, science, or engineering, Giles noted the importance of continuous learning as a mental framework, with suggestions to follow your interests and “keep on learning.”



## (IV) Launch Control Center: “We launch rockets...”

(based on a video interview with Steve Cox)

### 1. Element Functions and Interfaces

"We launch rockets ... That's what we're preparing to do here," summarized Steve Cox, element manager for the EGS LCC, in a recent interview. The LCC is comprised of four firing rooms. Firing Room 1, also called the Young-Crippen Firing Room, has been completely renovated and will serve as NASA's firing room for launches of the SLS and Orion spacecraft on exploration missions beginning in 2017. Firing Room 2 (FR2) serves as the principal command



and control software verification and validation facility. FR2 will also provide customers flexibility for checkout, training, launch and post-launch evaluation needs. Firing Room 3 has been configured as a development area for Launch Control System software development applications, and models and simulations. FR3 also contains the Customer Avionics Interface Development and Analysis (CAIDA) emulator of Orion's flight software and hardware. CAIDA will be used to support EGS Orion testing and development. Firing Room 4 serves as a highly reconfigurable, multi-user facility with the capability of supporting other NASA customers, other government customers, or commercial launch providers. Each room can be configured as needed to meet a user's particular requirements. Customers would bring in their own systems and equipment. FR4 is divided into four smaller control rooms designed to support smaller missions that may only require 25 to 30 people for a test. As customers' needs grow and they get closer to launch, adjoining rooms can be opened to accommodate an increased crew size of 50 to 100.

### 2. Renovations and New Features

Beneath the carpeted, raised floors of the LCC, the team found “50 years of wiring”—sedimentary layers (sometimes 18-inches thick) corresponding to programs reaching back to the Apollo era. The team removed over 100, 4-foot-by-4-foot pallet bins full of cut wiring and old equipment. They also removed outdated plumbing and electrical service wiring and fixtures as well as anything identified and documented in drawings as “not to print.” Once cabling was removed the base concrete floor was resealed, and the team was prepared to rebuild from the concrete up. New, raised floors were installed. Fiber optic cabling was installed, vastly



increasing bandwidth while using a fraction of the available space. Windows and doors in the LCC were replaced and shutters were removed. Old wiring was also removed from the maze of distribution pipes running from the basement of the LCC to other processing and launch facilities (e.g., VAB, Pad 39B, OPF) and replaced with fiber optic cabling. New energy-efficient LED lighting was added throughout the firing room. New sound-absorbing ceiling tiles were installed to provide privacy and reduce noise levels. The only elements that remain in FR-1 are the shuttle and Apollo launch plaques on the Firing Room walls.

### 3. DDT&E Lessons Learned / Challenges – Solutions

**Historical Recordation:** One challenge confronting the team was an initiative to preserve historic Firing Room 2 as a monument to the Apollo program. The team worked with historic preservation officials to forge a compromise. Certain artifacts (plaques and launch readiness status board) were left in place and an extensive video documentation effort was undertaken to digitally preserve the room prior to the initiation of renovation activities. For more information on the renovations to the LCC and how it was preserved, click on this link:

<https://environmental.ksc.nasa.gov/EnvironmentalPlanning/CulturalResources/LCC>

### 4. Project Management Success Factors

**Four-Way Teeter-Totter:** Imagine a four-way teeter totter balancing on a post. The project manager lives at that junction and is challenged to maintain a balance between the four arms: (1) design/build activities, (2) operational requirements, (3) resources, including budget, people, and equipment, and (4) schedule. The manager is making risk-balancing decisions that respond to external forces—principally changes in requirements. The interplay between the changing operational requirements and the design/build team is most critical and warrants constant communication. The

classic project management failure mode is “requirements creep,” simply absorbing requirement changes without increases in budget and schedule. The four-way teeter totter reinforces proactive management action to balance the risk between the various domains— absorbing schedule hits or re-baselining, pushing back on certain requirements, finding alternative designs, or going after more resources.

**Innovation:** Give smart young people the freedom to solve problems within the given resources, budget and schedule. What they lack is experience. The key to innovation and maintaining



*Figure 5: The Four-Way Teeter-Totter balances requirements, costs, schedules, and technical performance*

motivation is to blend old and new to create teams comprised of younger and more energetic hires with older and more experienced employees.

**Critical Path Emphasis:** A key approach for balancing the four-way teeter totter discussed above is to keep an eye on what's on the critical path. Put another way, actively managing the critical path reduces project risk and leads to overall program success.

**Peer Review:** Whenever possible bring in a fresh set of eyes to evaluate designs or planning products, and embrace independent evaluation.

**Fun:** As a manager, make sure everyone is having fun! If the team is having fun, you will get their best efforts. If they like what they are doing and you can't make them go home—they will do great things for you.

## **5. Thoughts for NASA's Next Generation (STEM-related message)**

The most important tool is yourself. Invest in yourself. Find something you are interested in and learn all about it. When you go to work, speak up. Don't sit back. Have an opinion.

## (V) Mobile Launcher: The 400-Foot Cradle

(based on a video interview with Cliff Lanham)

### 1. Element Functions and Interfaces

The ML is the tower-like structure that serves as a cradle for the launch vehicle during stacking at the VAB, transport to Pad 39B, and launch. The ML weighs 10.5 million pounds and is 400 feet tall with 662 steps required to climb from the deck to the top.

The ML is also host to multiple deployable T-0 umbilical arms that are attached to the launch vehicle during processing in the VAB. At the moment of launch (T-zero), the umbilicals are disconnected and retracted. The umbilicals are designed to provide the services and commodities necessary for safe and efficient stacking and integration of the SLS and Orion, including pneumatics, electrical power, communications, and environmental control purges. After stacking, test, and checkout (leak checks, data checks, and electrical checks) in the VAB, the ML and launch vehicle travel atop the crawler transporter to Pad 39B for final tests, checkout, and launch.



Figure 6: Mobile Launcher

### 2. Renovations and New Feature

The ML was originally built for the Constellation Program Ares I launch vehicle, a “single stick” design that required only a single, central flame hole for the rocket exhaust. The much larger SLS requires the central, core stage flame hole, but also flanking flame holes for the twin solid rocket boosters. This required a major modification effort during which 750 tons of steel were removed and over 1,000 tons added.

Another major effort was undertaken to install the ground support equipment (GSE) necessary to assemble, process, and launch the SLS rocket and Orion spacecraft. The scope of work included the installation of mechanical,

#### ML Familiarization

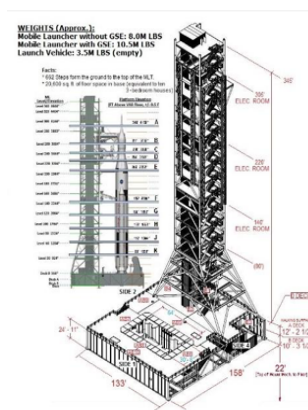


Figure 7: Mobile Launcher Design

#### Mobile Launcher (ML):

The Mobile Launcher is a launch structure which provides for the assembly, test/checkout, service/fueling, Vehicle Stabilization and transport to the Pad, Crew access and launch of future Launch Vehicles and Spacecraft

#### Dimensions (L x W x H):

- Approximate ML Base Size : 133' x 158' x ~25'
- Approximate ML Tower Size : 40' x 40' x 345'
- Approximate ML Weight (w/ GSE): 10.5M lbs
- Approximate ML w/ GSE, CT & Vehicle Weight: >21M lbs
- Approximate Launch Vehicle Weight (no fuel) : 3.5M lbs

electrical, and fluid subsystems. The effort included installation of more than 800 mechanical, fluid, and electrical panels; about 300,000-plus feet of cabling; and miles of tubing and piping. As discussed above the ML has been outfitted with multiple umbilical arms, each a highly complex project managed by a dedicated project team and manager. The list of umbilicals in development for the SLS/Orion space system include:

- Crew access arm
- Orion service module umbilical (260-foot level)
- Interim cryogenic propulsion stage (ICPS) umbilical
- Core stage forward skirt umbilical
- Vehicle stabilizer (260-foot level)
- Core stage inter-tank umbilical
- Tail service mast umbilicals for liquid hydrogen and liquid oxygen fueling (on the deck)

### **3. DDT&E Lessons Learned / Challenges – Solutions**

**Requirements Flow-down & Technical Integration:** Probably the biggest challenge (ongoing) is the technical integration of over 40 individual project teams. The challenge is further complicated by the need to coordinate and communicate across three separate design contracts: subsystem design, structural design, and GSE design and installation.

The mitigation approach has included co-location with construction contractors, daily meetings, and the establishment of a technical integrator on every project team.

**Changing Requirements:** As Cliff Lanham noted, “Proceeding with an incomplete design into construction...creates significant change traffic.” Change is inevitable in a complex project with so many sub-projects, ongoing umbilical testing in the LETF, multiple design contractors, and the parallel development of SLS and Orion. Most of these requirement changes require contract changes. Standard contract change processes proved too cumbersome to support the work environment. The mitigation approach has been to work with contract officials to employ a procurement process called undefinitized contract action, or UCA. This process has accelerated the project’s ability to meet the landscape of changing requirements.

**Overly Tight Construction Specifications:** Designers need to recognize that they are designing for steel construction with construction tolerances. Over specification (0.1 inch where 1 inch would be more appropriate) drives cost and creates delays in reconciling what is really required.

**Single Supplier Specifications:** Designers can also impede the build process by specifying material available from only a single supplier. This drives cost and often involves long lead times that impact schedule.

## 4. Project Management Success Factors

**Co-location:** A key success factor has been co-location with construction contractors that enables real-time problem solving (discussed further below).

**Communication:** Daily meetings, dedicated technical integration managers, and staying plugged in to activities (e.g., LETF umbilical testing) that may lead to requirement changes have contributed to success.

**Relationships:** Maintaining a close-knit team has been a key success factor. This includes both civil servants and contractors. Relationships build the trust necessary to solve problems and keep moving forward.

**Brute Force:** “Brute force” is the phrase employed on the project for real-time problem solving that takes place face-to-face in the field with hardware in hand—typically dealing with structural interferences. The goal is to quickly resolve the issue, make the hardware work, and move forward.

**UCA:** The use of UCA, an “out-of-the-box” procurement technique, was a major assistance in a change-heavy project like ML.

***Note:** The NASA Federal Acquisition Regulation Supplement (1843.7001) defines an Undefined contract action (UCA) as a unilateral or bilateral contract modification, or a delivery/task order in which the final price or estimated cost and fee have not been negotiated and mutually agreed to by NASA and the contractor. For purposes of tracking definitization schedules of UCAs, letter contracts are considered to be UCAs and will be tracked as such by the Program Operations Division within the Office of Procurement. Otherwise, the specific requirements, policies, and procedures for letter contracts are in FAR 16.603 and NFS 1816.603.*

## 5. Thoughts for NASA’s Next Generation (STEM-related message)

We are at the advent of a 30-year journey to Mars. You will inherit this program, and we need you to carry it into the future. Many will tell you, “Study hard, take math and science classes, and go to college.” I agree with that, but I have another recommendation to add to the list. Become a “tinkerer” at home. Take things apart, build stuff, learn about electricity, do science experiments, and participate in a science fair. Something you learn as a “tinkerer” may come back to serve you years in the future.

## (VI) Landing and Recovery: *Welcome Home*

(based on a video interview with Melissa Jones)

### 1. Element Functions and Interfaces

The Landing and Recovery Project is responsible for the recovery, retrieval, and rescue of the Orion spacecraft. Recovery refers to a nominal (planned) recovery of the crewed Orion off the coast of San Diego. The requirement is to be able to open the crew door within two hours after splashdown. Retrieval refers to recovery of an uncrewed capsule at an unplanned landing site. Rescue refers to recovery of the flight crew after an abort in the Atlantic or Indian Ocean.



Figure 8: Spacecraft Recovery Test

The nominal recovery sequence of the Orion will involve landing in the Pacific Ocean off the coast of San Diego; approach of the recovery ship, a U.S. Navy Landing Platform Dock (LPD) Class 17 amphibious ship; and evaluation and safety sweep of the recovery area for debris or toxic chemicals. Over 20 to 30 pieces of debris are jettisoned from the capsule. The debris to be recovered includes the three main parachutes and the forward bay cover.

When astronauts come back from the microgravity environment they experience some form of de-conditioning, which is the effect that space has on their body. The team is currently working on two recovery systems that will allow astronauts to egress the capsule and access medical attention as fast as possible. One will allow recovery in the open water and one will enable recovery in the well deck of the ship.

For open water recovery of the flight crew, a stabilization collar is attached to the capsule and inflated. This serves to make the capsule more stable in the open ocean and also provides a platform for the DoD to stand on while they are removing the crew. The crew is then transported to the ship via small boats or helicopters.

Well deck crew recovery involves the crew staying in the capsule until it is in the recovery cradle in the ship. Once the area is secured the recovery ship makes a close approach to the capsule, and the Navy divers attach the winch and tending lines to the capsule. The capsule is pulled into the flooded well deck and positioned over the cradle. Once the capsule is positioned in the cradle, the stern gate of the ship is closed, and the well deck dried. The methods allow the flexibility for crew egress at several points along the recovery timeline.

Once the ship returns to port in San Diego, the Orion capsule will be secured onto a trailer and outfitted with ride monitoring instrumentation for the trip east. Throughout the recovery process, the team will carefully ensure that the heat shield does not get damaged, enabling a comprehensive post-flight performance evaluation.

Abort retrieval or rescue missions in the Atlantic will involve KSC-based helicopters with a 200-mile range that will deploy divers and render assistance as needed until a crane ship with a hoisting sling arrives. If the landing occurs outside the helicopter range, a C-17 aircraft will be deployed to render assistance prior to the arrival of a crane ship. Abort retrieval or rescue missions in the Indian Ocean (a very low likelihood) will depend on ships of opportunity. Orion is designed to sustain the crew afloat for a minimum of 24 hours.

## **2. Renovations and New Features**

**Redesign:** The team learned that they had underestimated the loads that hardware such as lines, and crew module (CM) attach points would see during testing and recovery. No one had ever had a capsule in the well deck of a Navy ship. Once the well deck was flooded, the CM started surfing on the top of waves like a surfboard, and the more it moved, the harder it was to control. The hardware was clearly under-designed. With a better understanding of the operational environment, lines and attach hardware were strengthened. The team also deployed instrumentation to monitor the loads during subsequent testing.

**LLAMA:** After the failure, early Lead Design Engineer Jeremy Parr developed an active recovery method called the Line Load Attenuating Mechanism Assembly (LLAMA). The LLAMA design helps the Navy line handlers to safely maintain high tension in the tending lines during recovery of Orion into the well deck of a ship. It also regulates the amount of tension in the lines to ensure equal loading on the vehicle. The LLAMAs are mounted on the ship's T-bits, and the mechanisms provide all tending line control of the crew module once it enters the well deck and until it is secured on the recovery cradle pads. It's unique because it basically acts like a giant fishing reel. It allows sailors to safely pull slack out of the lines while pressure is holding a car braking system at a predetermined pressure. If the force of the line-pulling exceeds the pressure, then the LLAMA allows the line to "pay out" instead of breaking, just like a fishing reel does.

## **3. DDT&E Lessons Learned / Challenges – Solutions**

**Learning from Test Failures:** In 2014, NASA and the Navy conducted an underway recovery test (URT-1) in preparation for the EFT-1 mission. That test exposed some significant issues with the recovery process. First, the 20,000-pound Orion simulator test article was very difficult to control and careened around the well deck in the turbulent standing waves. Several lines snapped due to the jerk loads and sailors manning the ropes suffered rope burns and, in one case, a broken finger. This failure stimulated an extensive trade study to evaluate alternative methods and processes for recovery that ranged from the baseline well deck concept to submarines. In the end, given the host of requirements beyond physical recovery (e.g., medical staff and facilities),



the well deck concept was retained. A total of five additional tests are scheduled prior to the 2019 EM-1 flight. Underway Recovery Test-6 (URT-6) was conducted successfully as a joint NASA/U.S. Navy exercise off the coast of San Diego in January 2018.

**Safety:** The recovery process design has been very mindful of potential safety hazards to the recovery crew as well as the Orion crew. The team has identified principal hazards and is implementing measures to mitigate potential impacts. Hazards include unexpended pyros (used in deploying parachutes), toxic chemicals (ammonia and hydrazine), pressure vessels (high-pressure helium), and RF energy (beacon transmission antenna). Mitigations include powering down the beacon transmitter, deploying sensor systems for toxins in the well deck and on diver vests, and wearing personal protective equipment. Prior to cross-country transport, the Orion helium tank will be depressurized.

**Organizational Complexity:** Another challenge for the landing and recovery team has been the inherent complexity of working with another agency with different management structures. In this case, the U.S. Navy is providing critical support functions and personnel, including weather monitoring, medical, boat drivers, divers, and helicopters. While the support has been stellar and relationships have been the best, there have been challenges communicating during testing.

**Test Planning, Scheduling, and Coordination:** A large ship is required in order to accomplish the integrated testing to verify and validate hardware and recovery processes. Between NASA and DoD, this requires about 600 people. Coordination with Navy and scheduling availability of the ship and crew requires at least 15 months lead time.

#### **4. Project Management Success Factors**

**Teamwork:** Team is number one. The people and teamwork carry the project forward.

**Lessons Learned:** The team leveraged the expertise of retired NASA recovery director (James) Mitt Heflin, who has shared lessons learned from both the shuttle program and Apollo.

**Training:** Extensive training of divers and recovery crews has been ongoing. Training has included Navy personnel working with an Orion test article in the Neutral Buoyancy Laboratory (NBL) at Johnson Space Center (JSC).

**Simulation:** Both testing and design activities are informed by simulation and modeling support.

**Test:** Testing has been the key to finding problems and implementing redesigns and process improvements.

#### **5. Thoughts for NASA's Next Generation (STEM-related message)**

We do things that no one else gets to do. NASA is about more than science and technology. We have accountants, lawyers, doctors—we even have a SWAT team. No one knows what they want to be at 18 [years old]. Try new things. Shadow people. Adults love talking about their work. Do research. My favorite quote: “Aim for the moon because if you should happen to miss, you’ll still be among the stars.”



## **(VII) LETF: *Shake, Rattle, and Roll***

(based on a video interview with Jeremy Parsons)

### **1. Element Functions and Interfaces**

The LETF is where functional tests are conducted for the structural arms and umbilicals that connect SLS and Orion with the mobile launcher. Some of these umbilicals are massive—two stories high and weighing 65,000 pounds. Aptly named, umbilicals are the launch system life lines providing pneumatic and environmental air commodities, electrical power, telemetry, and communications. Several also flow extremely hazardous cryogenics (LH2 and LO2). Besides providing essential services, the arms are also required to be agile and nimble, disconnecting at T-zero (launch ignition) and then retracting or swinging out of the way.



*Figure 9: Umbilical Testing at LETF*

Each umbilical has a primary and secondary disconnect retraction mechanism and is designed with high reliability components. Failure to disconnect or retract would likely result in catastrophic consequences. They must work. Accordingly, the testing in the LETF must be as rigorous as possible.

The unique capability and key function the LETF provides is its ability to simulate the SLS operational launch environment, a notion central to NASA's Test Like You Fly (TLYF) philosophy. The LETF is equipped with two Vehicle Motion Simulators which simulate movements of the SLS on the ML and during the first few seconds of liftoff. They have a full six degrees of freedom. Tests are dramatic and dangerous, requiring great emphasis on safety. Imagine a 45-foot-long, two-story, 65,000-pound structure flowing liquid hydrogen, disconnecting and rotating 90 degrees in 3 seconds while subject to an ignition/liftoff shock and vibration environment.

Any specific test activity is documented in a Test Requirements Document. A given verification campaign will include multiple tests under nominal conditions as well as multiple tests with one or more failure conditions, thus exercising and verifying the fidelity of the backup functionality. In many situations, a test campaign may include 50 to 60 tests in the simulated launch environment. Testing data is extensive, including sensors, video, and photogrammetry that are all used to verify and validate the fidelity of the system being tested.

Beyond SLS and Orion (principal customers), and consistent with the multi-user spaceport concept, the LETF is seeking to support multiple customers and is currently working with SpaceX to host future testing activity.

The LETF has been testing two shifts per day/six days per week/10 hours per shift for the last year. It also has delivered 17 of 21 SLS launch accessories. The LETF is on pace to deliver three of the remaining accessories by spring 2018.

## **2. Renovations and New Features**

Not covered in the video interview

## **3. DDT&E Lessons Learned / Challenges – Solutions**

**Test Non-Conformances:** System-level tests are designed to expose latent defects in design, fabrication, assembly, integration, or operational procedures. The LETF certainly exposed a wide range of issues in every test, logging over 80 nonconformances per test campaign. The results served to identify quality control and subsystem/component testing inadequacies in the development of each test article.

**Schedule Issues:** The other major impact of test nonconformances was on the LETF master schedule. While statistical scheduling models consider weather delays and the need to address nonconformances, the baseline schedule did not incorporate these and only addressed them as a potential risk. This has led to consistent schedule slips that can be accounted for, but are not always understood at higher levels. In addition, the magnitude of nonconformances taken was not anticipated.

The disposition of each nonconformance took days and, in some cases, weeks. The challenge was how to shrink the nonconformance disposition response time. The solution was to establish a daily face-to-face meeting with the chief engineers for each subsystem or project team to discuss, negotiate as appropriate, and resolve each nonconformance.

**Hazardous Operations:** It took two months to certify the LETF for hazardous operations. During this time period a detailed system safety hazards analysis was performed identifying hazards, failure modes, and potential control and mitigation strategies. The mitigation and control measures implemented included extensive cryogenic safety training, implementation of an upgraded fire suppression system, modification of all electrical outlets, and development of emergency egress procedures. In addition, the prime support contractor was required to provide training and certification of all personnel involved in cryogenic operations. Finally, a former space shuttle cryogenic expert was placed on the LETF management team.

### **Other Programmatic Challenges:**

**Manufacturing delays:** Issues with IDIQ vendor performance

**Staffing:** Personnel with the appropriate skills for testing and design were limited. This caused the need to work longer shifts versus and weeks versus just being able to add personnel.

**Contract transition:** The loss of critical skills and expertise during a major contract transition had a huge impact on schedule and technical risk.

#### **4. Project Management Success Factors**

**Risk Awareness:** Ensure schedule risks are identified and managed.

**Decision Making:** Streamline decision making.

**Team Composition:** Establish a strong team composed of operations-minded individuals.

**Skilled Craftsmen:** Welders and machinists with amazing skills and precision.

**Delegation:** Empower project managers over individual test elements.

**Technology:** Photogrammetry, 3D printing to support testing fit check, 3D modeling, simulation modeling.

#### **5. Thoughts for NASA's Next Generation (STEM-related message)**

If you love space we have people of all sorts and backgrounds working on these projects. We have welders, machinists, engineers, designers, artists, programmers, public affairs, administrators, financial analysts, etc., all to make projects of this size come to together.

## (VIII) TPSF: “*Tiles ‘R Us*”

(based on a video interview with Karim Courey)

### 1. Element Functions and Interfaces

The TPSF manufactures thermal protection systems (TPS) and thermal control systems (TCS) that protect spacecraft on orbit and during reentry. This includes both tile and soft-goods, such as thermal blankets and gap fillers. The facility also manufactures ground support equipment (GSE) as needed. The TPSF is currently supporting both government and commercial customers.



Figure 10: Thermal Protection System Facility (TPSF)

The TPSF provides the widest range of TPS and TCS manufacturing and repair capabilities ever to exist within a single facility. This capability began at KSC in 1979 to provide real-time support to Space Shuttle Orbiter processing and is currently providing manufacturing services to NASA’s Orion program and commercial customers.

Lessons learned and manufacturing improvements learned from 30 years of Space Shuttle Orbiter tile production have been incorporated into the manufacturing of TPS for the Orion spacecraft and commercial customers.

The TPSF manufactures all of the tiles surrounding the Orion capsule. The facility has also added the capability to machine the Orion ablative heat shield, an element provided by an outside vendor. In addition, the facility provides waterproofing of the tiles as well as heat cleaning of various other thermal barriers employed on the vehicle.

It is important to note that thermal protection engineering, design, and test functions are distributed across three NASA Centers – KSC, JSC and ARC. ARC performs the research and development for TPS as well as Arc jet testing, JSC performs thermal analysis and radiant testing while KSC develops TPS manufacturing processes and performs the large-scale TPS manufacturing. The TPSF is a government-owned facility that is contractor-operated under a Test and Operations Support Contract (TOSC).

### 2. Renovations and New Features

**Upgraded Fabrication Capability:** Moved from manual fabrication using gun stock machines, molds, and “sand to fit and paint to match” processes to automated manufacturing using CAD

models and 5-axis milling machines. These improvements significantly reduced the manufacturing time while increasing product quality and decreasing cost.

**Manufacturing of new leading-edge materials:** Improvements in tile ceramics from early pure silica-based to Alumina Enhanced Thermal Barrier (AETB) include increased strength of the tiles, dimensional stability, and thermal performance. The only disadvantage of AETB is the higher steady state thermal conductivity. The tile needs to be thicker and thus heavier than a pure silica-based tile to provide that same level of insulation.

**Coatings:** Improvements have been made in coatings capability to resist micro-meteor debris damage. The TPSF has evolved coating techniques that integrate the coating into the tile structure more effectively, creating a less brittle barrier to particle impact.

### **3. DDT&E Lessons Learned / Challenges – Solutions**

**Material Obsolescence:** There is no “Tiles ‘R Us” supply store for aerospace grade TPS materials. Many of Tier 1 suppliers in the U.S. are no longer supplying the technical ceramics market. As a result, the TPSF has developed an in-house capability to manufacture the materials when alternate sources are not available. In addition, TPSF has developed alternate manufacturing methods that eliminate the need for obsolete materials. This includes manufacturing billets and coatings for tile production, as well as Strain Isolation Pads (SIP) and Felt Reusable Surface Insulation (FRSI).

### **4. Project Management Success Factors**

**Innovative Contracting:** In order to implement the multi-user spaceport model, multiple contracting mechanisms were developed to support commercial and government customers. Some of these contract types allow the customer to work directly with the NASA contractor to facilitate quicker turnaround.

**Workforce:** The TPSF has an experienced contractor workforce with decades of SSP experience, providing deep knowledge and expertise.

**Second Shift:** To address increased demand with commercial customers, the TPSF has added a second shift to meet peaks in production.

**New Ways of Manufacturing:** As discussed above, the TPSF has gleaned increased efficiency, moving away from gunstock machines to using CAD systems with 5-axis milling machines.

**Cross-training:** The TPSF has implemented cross-training to enable existing staff to more effectively support an integrated schedule with overlapping demands of multiple customers.

### **5. Thoughts for NASA’s Next Generation (STEM-related message)**

Engineering combines analytical and creative thought, science, and art to produce products to make life better on earth and beyond. Do what you love, be passionate about what you do, take pride in your work, and you will be successful!

## (IX) Logistics: *Space Depot*

(based on a video interview with Victor Alvarez)

### 1. Element Functions and Interfaces

EGS Program Logistics is responsible for ensuring that the ground systems being developed to support SLS and Orion Processing are logistically supportable.

EGS Program Logistics support is what is known as high-variation/low-volume logistics. This means that only a few of one item are procured at a given time, but that requirements exist to procure many different items. This type of support is common to very complex systems, such as ones used for unique operations like launching rockets. Program Logistics can be divided into two main branches: Logistics Engineering and Logistics Operations.



Figure 11: Program Logistics Building

**Logistics Engineering:** Initially, Logistics Engineering evaluates the ground systems being designed and developed to understand what kind of logistics support is required:

- What spare parts and material will a system need, and how many?
- What kind of training will the operators need?
- How many need to be procured now vs. later?

If the system being designed and developed requires a large logistics footprint or relies on many obsolete parts, then the engineering organization will request a redesign if possible. Once the system is built and operating, Logistics Engineering reviews the ongoing logistical needs of the systems. Typical questions asked include:

- Are more parts and material being procured than expected?
- Are there parts and material that are going obsolete?
- Are there ways Logistics can assist operations and engineering in order to reduce or optimize the logistics supportability footprint of a system?

**Logistics Operations:** The second branch is Logistics Operations. This is the “day-to-day” logistics support that organizations outside of Logistics are more familiar with. Responsibilities include:

- Getting parts and material in inventory staged to support operations requirements.
- Moving parts and material around (from inventory to the customer who needs it).

- Operating the Logistics Warehouse, which is the “hub” of where most parts and materials first come into the center for EGS. Activities include packaging, handling, storage and transportation (PHS&T).
- Operating the Material Service Centers, which serve as staging areas throughout KSC to position parts and materials closer to where they will be needed and function as “service desks” where customers can go to pick up what they need.
- Storing and staging parts and material to support flight systems for SLS or Orion as those programs identify needs.

## **2. Renovations and New Features:**

**Moving to More Analytical Management Approach:** There was never a requirement during past programs to track which parts and materials went to specific end items. The way logistics supported was simply to evaluate what operations and engineering was asking for and how often they asked for it, and then just make sure that material was stocked to support. The downside of this is that it does not allow for any analysis as to why material is being requested or what material is no longer needed. Therefore, the amount of logistics optimization that can be accomplished is limited. Logistics is working to correct that approach, moving to a more analytical, statistically based management model.

## **3. DDT&E Lessons Learned / Challenges – Solutions**

**Old and New:** EGS systems consist of a mix of heritage/existing systems and newly developed systems. For the newly developed systems, the challenge has been trying to keep up to date with all of the design changes occurring. Because these new systems often require frequent redesigns, it has been difficult in many cases to ensure a proper evaluation is done of these changes to identify impacts to supportability. For existing systems, EGS Logistics is doing “heritage assessments,” which entail evaluating the systems as they currently exist to try and identify spare parts that are now obsolete. Many of these systems have been around since Apollo, and performing these types of assessments can become a very involved process.

**Budget Limitations:** Similar to other parts of EGS, logistics is always encountering funding limitations. Because there are a lot of new systems coming online that require spares, this entails trying to find a smart way of prioritizing what can be procured and when, given that the program cannot afford to procure everything all at once.

**Disconnected Development & Operations:** Initially, EGS divided the logistics for development from the logistics that would be required to support the systems once they become operational. As part of this structure, it was assumed that the groups responsible for development would develop some sort of logistics plan to procure what they needed and also include an initial inlay of spare parts and material for a smooth transition to operations without logistics-related interruptions. As it turned out, that process did not occur. Each subsystem bought just what they thought they would need to finish their development.

#### **4. Project Management Success Factors**

- Do not separate Logistics Development from Logistics Operations. They are coupled and are not done efficiently if decoupled.
- Material procurement during development should be done in an integrated and planned method. It should not be segmented and performed by each subsystem or by site.
- There needs to be flexibility in material procurements. It cannot be limited to procuring material only on released drawings. There has to be a mechanism that allows for procurement of material that may not ever make it to a drawing because the system is in development.
- Development has higher uses of bench stock and material compared to operations, and that should be accounted for in planning.
- Tracking failure rates during initial development helps refine future projections for materials needs.

#### **5. Thoughts for NASA's Next Generation (STEM-related message)**

I love working at NASA because it embodies discovery and exploration. Just about every kid growing up, I think, dreams at one time about being an adventurer or explorer, discovering new or never-before-seen things. That's what makes working at NASA a dream job, because this Agency strives to make those dreams a reality.

Logistics is a cross between engineering and business. It involves analyzing what the system engineers are building, and figuring out how you can support it in the most economical way possible for the entire life cycle of those systems. For this you have to have an understanding of why parts fail the way they do and what it takes to set up a supply chain. That starts with the vendor who makes and sells the part, to the distributor, to the costs of buying it and storing it. Along the way, you also have to understand how long it takes to get the material and parts from the time it is ordered to the time it is available for use. The type of knowledge required to be able to do all of this involves engineering, business, and statistics.



## Appendix A: Acronyms

AETB:	Alumina Enhanced Thermal Barrier
ARC:	Ames Research Center
CAIDA:	Customer Avionics Development and Analysis
CT:	Crawler Transporter
CY:	Calendar Year
DDT&E:	Design Development Test and Evaluation
DFM:	Design for Manufacturing
EGS:	Exploration Ground Systems
ESD:	Exploration Systems Division
FR:	Firing Room
FRSI:	Felt Reusable Surface Insulation
GN2:	Gaseous Nitrogen
GSDO:	Ground Systems Development and Operations
GSE:	Ground Support Equipment
HB:	High Bay
HEOMD:	Human Exploration Operations Mission Directorate
HVAC:	Heating Ventilating and Air Conditioning
JEL:	Jacking Equalization and Leveling
JSC:	Johnson Space Center
KCT:	Knowledge Capture and Transfer
KSC:	Kennedy Space Center
LCC:	Launch Control Center
LETf:	Launch Equipment Test Facility
LH2:	Liquid Hydrogen
LO2:	Liquid Oxygen
LPS:	Lightening Protection System
ML:	Mobile Launcher
NBL	Neutral Buoyancy Laboratory
OCE:	Office of the Chief Engineer
OPA:	Office of Public Affairs
OPF	Orbiter Processing Facility
RV:	Recreational Vehicle
SIP:	Strain Isolation Pads
SLS:	Space Launch System
SSP:	Space Shuttle Program
STEM:	Science Technology Engineering and Math

TCS: Thermal Control Systems  
 TPS: Thermal Protection Systems  
 TPSF: Thermal Protection System Facility  
 UCA: Undefined Contract Actions  
 VAB: Vertical Assembly Building

## Appendix B: Interviewees

Project SME	Area	Title
Jeremy Parsons	LETF	Chief Systems Engineering and Integration Division
Regina Spellman	Pad 39 B	Launch Pad Senior Project Manager
Melissa Jones	Landing & Recovery	Landing and Recovery Director
Karim Courey	TPSF	Mission Operations Integration Engineer
Jose Perez-Morales	VAB	VAB Element Senior Project Manager
Victor Alvarez	Logistics	Logistics Acquisition Lead
Cliff Lanham	Mobile Launcher	Mobile Launcher Element Senior Project Manager
Steve Cox – retired	LCC	Launch Control Center Operations Manager
John Giles	Crawler	Crawler Transporter Project Manager