

Lessons Learned for Improving Spacecraft Ground Operations

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Abstract—NASA has a unique history in processing the Space Shuttle fleet for launches. Some of this experience has been captured in the NASA Lessons Learned Information System (LLIS). This tool provides a convenient way for design engineers to review lessons from the past to prevent problems from reoccurring and incorporate positive lessons in new designs. At the Kennedy Space Center, the LLIS is being used to design ground support equipment for the next generation of launch and crewed vehicles. This paper describes the LLIS process and offers some examples.

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1. INTRODUCTION

Throughout NASA's programs (the Mercury Program, Gemini Program, Apollo Program, Skylab Program, Space Shuttle Program, International Space Station Program), many lessons were learned, and this knowledge was carried over into new programs. These lessons dealt with very complex and unique systems, and the lessons learned may not be needed for several years to come.

In the Space Shuttle Program, many ground-processing lessons were learned and were mainly included in the processing documentation. Now KSC is beginning the design phase of a new program. These designs can benefit from the expertise of experienced Space Shuttle systems operators through the Lessons Learned Information System (LLIS). The LLIS is an efficient and effective means to retrieve lessons and utilize them to improve the new designs.

2. WHY WE SHARE LESSONS

Knowledge sharing is an everyday human activity. Lessons are naturally shared during peer reviews and other business processes to provide insights and make others aware of innovations. An engineer's curiosity to discover new things makes it enjoyable to learn more about one's area of expertise. Herbert Rice, NASA Aerospace Engineer with over 44 years at KSC [1], says that, for the future of NASA, "The important thing to remember is to remain flexible. Outside forces are constantly changing, and the only way we survive is to change along with them. Apply the lessons you've learned from the past, but always look at new requirements with a fresh perspective."

At the Kennedy Space Center (KSC), storytelling takes place between employees, which can lead to the improvement of system designs; sometimes these stories are told in the hallway, at the water cooler, in cubicles, in meetings, or through mentoring. Seniority or grade does not trump anyone's voice at KSC. Contributions are welcomed from the Chief Engineer, the newly hired intern, or an employee who worked during the Apollo era. All views are explored at KSC. Eventually, these stories are recorded into the LLIS or formal Kennedy Engineering Academy presentations (see Figure 1).



Figure-1 Tony Pego, Project Manager, Shares Lessons Learned During a Kennedy Engineering Academy Presentation

3. THE LESSONS LEARNED PROCESS

The lessons learned process is performed across all NASA Centers and includes the contractor community. Figure-2 shows the geographic spread of the Agency locations. The Office of The Chief Engineer at NASA Headquarters in

Washington D.C., is the overall process owner, and field locations manage the local implementation.

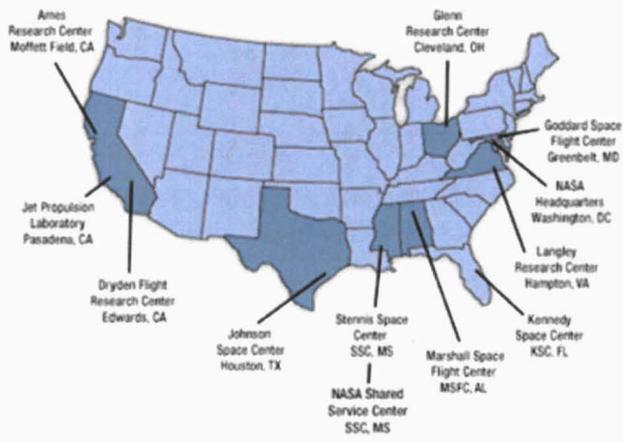


Figure-2 NASA Centers

The lessons learned life cycle, as shown in Figure3, involves sources such as engineering design teams; mishap reports; organizations involved in research, science, operations, administration, procurement, management, safety, maintenance, training, flight or ground-based systems, facilities, medicine, and the many ground processing activities that were part of the Space Shuttle missions. Lessons can be elicited by using facilitated pause-and-learn (PaL) sessions. Key decision points and design schedules are potential LLIS entry points. A PaL session can explore many issues. As the PaL is being performed, the team should try to focus on five questions: What did we intend to do? What worked well and why? What didn't work well and why? What did we learn from this? What should we

change? These questions and others are used to extract the root causes and contributing factors of the lessons, and then the lessons are submitted for expert peer review for possible inclusion into LLIS. This process is accomplished in various ways across the NASA Centers.

New projects use the system to determine which lessons might impact their project design. As part of the entrance criteria during design reviews, the LLIS is reviewed for any applicable data that may influence the design. Any lessons learned *during the design of that system* are also submitted to the LLIS. This is required by the Technical Review Process document, KDP-P-2713 [2,3].

A successful knowledge-sharing workshop allows all team members to contribute ideas, and discipline leads often "distill" the input down to a few major points for action (see Figure 4).



Figure-4 Knowledge Sharing Workshop Brainstorming and Distilling

4. HOW LESSONS LEARNED ARE SHARED

Lessons learned committees are a key element in ensuring Centerwide commitment, product quality, and effective implementation. Each lessons learned committee member:

- Promotes the use of lessons learned during technical reviews and throughout the



Figure-3 Lessons Learned Life Cycle

program/project life cycle.

- Coordinates reviews of approved lessons learned for export control, patent, legal, and public affairs clearance.
- Coordinates the transfer of the lessons learned recommendations to the Center's corrective action system(s) when appropriate.

Lesson recommendations are assessed for potential changes to policy, procedures, guidelines, technical standards, training tools, education curricula, etc., and infused back into the system via existing corrective action systems. Each LLIS entry is in a format specifically designed for learning. They contain an abstract, description of the driving event, summary of the key lesson learned, recommendations, and the evidence of recurrence. Any documents or links supporting the lesson are attached. Figure-5 is an example of the LLIS entry components.

Lesson Learned Components

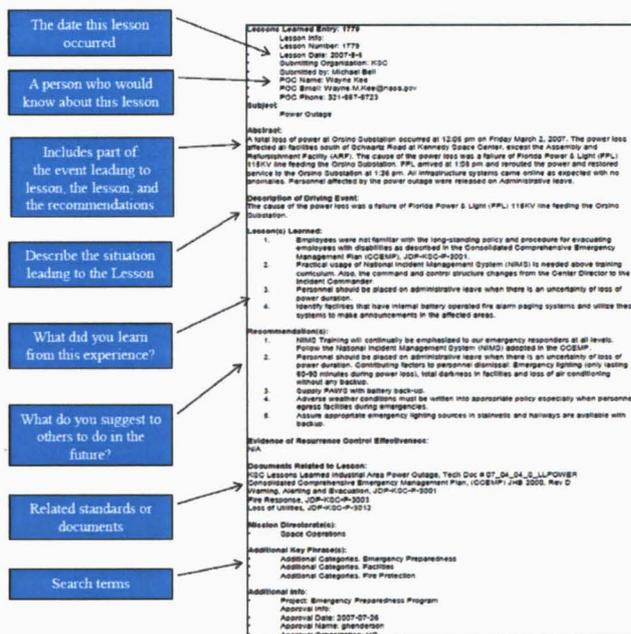


Figure-5 Lessons Learned Format

As these lessons learned are created, Kennedy Engineering Academy Forums are held to disseminate the results to a wide audience. At the end of a high-level program, lessons learned reports, such as the Ares Project Office Knowledge Management Report and the Constellation Program Lessons Learned Executive Summary volumes I and II, are included in the LLIS to be maintained by the Agency (see Figure 6).

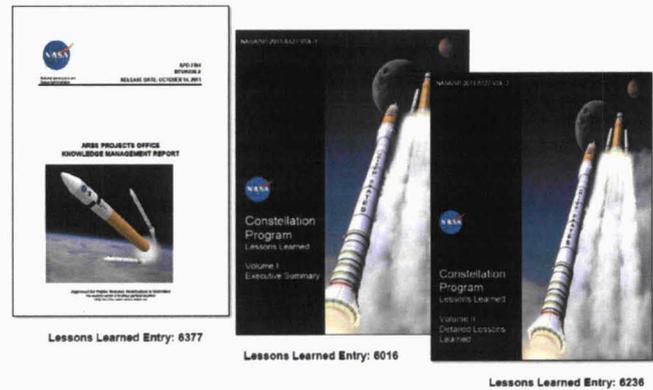


Figure-6 High-Level Lessons Learned Reports

As the Space Shuttle Program was ending, lessons learned were recorded in a video format, using interviews to bring out more context and background information. In addition, visual and audio aids contribute to the learning process. The videos are included as part of the lessons learned entry (see Figure 7 for several examples of the LLIS entries with video interviews).

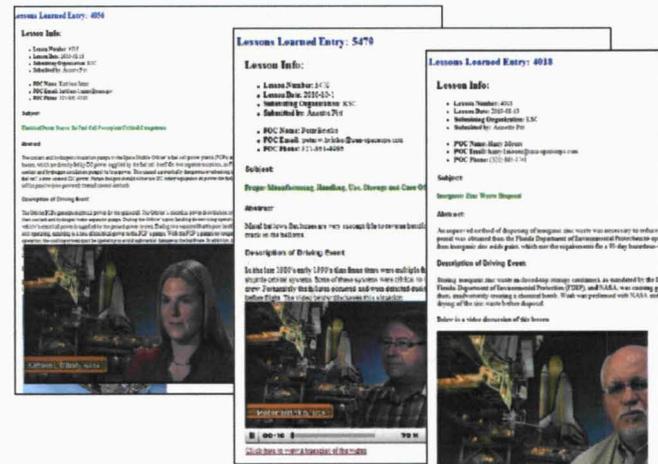


Figure-7 Video Lessons Learned

5. EXAMPLES OF LESSONS LEARNED

“Hits” on the internal LLIS website in the NASA Engineering Network have doubled every year for the last 3 years. In 2012, approximately 6,000 searches of the lessons learned page took place each month. The developers of KSC ground subsystems follow the design process and have researched the LLIS database for lessons applicable to these subsystems. Searching a database used to be a time-consuming activity requiring great skill and creativity. However, a 2012 study conducted by the Pew Research Center found that more than half of search users (56%) say

they are "very" confident in their search abilities, while only 6% say they are "not at all" confident [4].

The design process for 11 KSC subsystems in various stages of the design cycle were sampled for this paper. For 8 of the systems, between 1 and 41 different search terms were used to search the LLIS, with a median number of 9 different search terms used. These searches resulted in 4 to 270 "hits." A lessons learned entry may present the solution to a design challenge or may provide more questions for the design team to resolve. The lessons they review may also provoke curiosity along new lines of thought. The team must review these search results and decide how to apply the information. Table 1 lists 5 typical projects and shows how often the development teams have applied the recommendations they found by using the LLIS.

Project Name	Search Results Returned	Results Utilized	% Results Utilized
Mobile Launcher Cryogenic Systems Design LH2 System	18	18	100%
Mobile Launcher Cryogenic Systems Design LO2 System	52	14	27%
Tail Service Mast Umbilical (TSMU), Mobile Launcher Element	4	4	100%
Offline Processing Integration High Pressure Gas Servicing	270	39	14%
Mobile Launcher, Breathing Air System	90	38	42%

Table 1. Lessons Learned Used in Ground Subsystems

A report for each of these subsystems was generated based on an analysis of the applicable entries in the LLIS. To illustrate this, the Vehicle Support Post Launch Mount for the Mobile Launcher project report and the Tail Service Mast Umbilical for the Mobile Launcher project report are examined.

The Vehicle Support Post (VSP) team focused on gathering all relevant information for better planning and improving the design and implementation of the VSP subsystem while preventing or minimizing risks to the VSP project. A search of the database returned Lessons Learned Entry 0588, Solid Rocket Booster (SRB) Holddown Post Incident. This lesson concerned an expensive piece of ground support equipment hardware that slid off a forklift while it was being moved up a slight ramp at the Launch Equipment Test Facility (see Figure 8). The team used this lesson to improve shipping/handling pallets and containers to provide adequate restraint of the VSP.



Figure-8 Launch Equipment Test Facility

The Tail Service Mast Umbilical (TSMU) team focused on four lesson areas: personnel access, leakage, pyrotechnic release mechanism, and carrier-plate manual mate. The lessons below were returned in a search of the LLIS;

- Lessons Learned 0171 – Tail Service Mast (TSM)
- Lessons Learned 0107 – LH2 (liquid hydrogen) Leakage at the 8" T-0 Flexhose QD (quick disconnect)/Interface
- Lessons Learned 0188 – T-0 Umbilical Carrier Plate
- Lessons Learned from Space Launch System (SLS) Project Team – T-0 Umbilical Carrier Plate Manual Mate

The lessons were evaluated by the design team for applicability. Their actions are listed below.

1. The SLS TSMU should focus on designing personnel access and safety limits which meet Occupational Safety and Health Administration (OSHA) requirements.
2. The SLS TSMU Project team will coordinate with the Hazardous Gas (HazGas) Subsystems project team to determine an efficient configuration of HazGas sensors to minimize risks.
3. The SLS TSMU project team has eliminated the pyrotechnic release mechanism from the Space Shuttle TSMs, and is currently planning to use a new release mechanism with each mission.
4. The SLS TSMU project team will use mechanical positioning mechanisms with controlled adjustments to perform the mating of the ground umbilical carrier assembly (GUCA) to the vehicle (Figure 9).



Figure-9 Umbilical and Plate

6. SUMMARY

Throughout the history of NASA, many one-of-a-kind events and circumstances that have occurred that are worthy of recording for future use. Some of these lessons have been captured, but many potential lessons are still waiting to be documented and made available through the LLIS. And lessons are being learned every day as current projects progress towards their objectives. The lessons learned team has a great responsibility to collect and disseminate these lessons so that they are shared with future generations of space systems designers.

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BIOGRAPHIES



Michael Bell, Ph.D., serves as program manager of NASA's Lessons Learned program and was recently appointed the Chief Knowledge Officer of John F. Kennedy Space Center.



Gena Henderson, Ph.D., serves as a chief within the Systems Engineering and Integration Division of the Engineering and Technology Directorate at John F. Kennedy Space Center. She has held many leadership and management positions, and has established many game-changing new tools and programs during her career at NASA. Tools established or refined via her expertise include the KSC Human Factors Engineering processes and tools and the NASA LLIS web interface and database.



Damon Stambolian is completing a Ph.D. in Industrial Engineering at the University of Miami's Biomechanics Laboratory. Prior to his current position in the KSC Engineering and Technology Directorate, he worked in the Constellation Ground Operations Project office, the Space Station Program, the Orbiter Space Plane Program, and the Space Shuttle Program at KSC. Within these programs, he was involved with systems engineering, lessons learned, and human factors-related process improvements for ground processing operations, i.e., the assembly, maintenance, inspection of flight hardware.