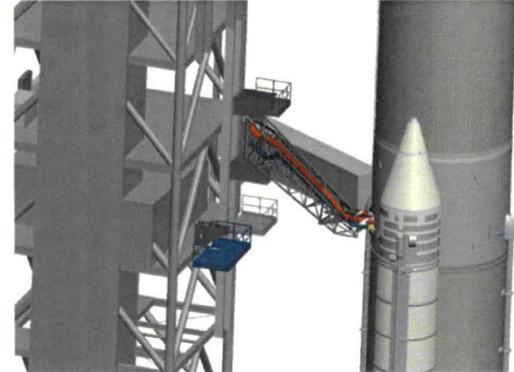
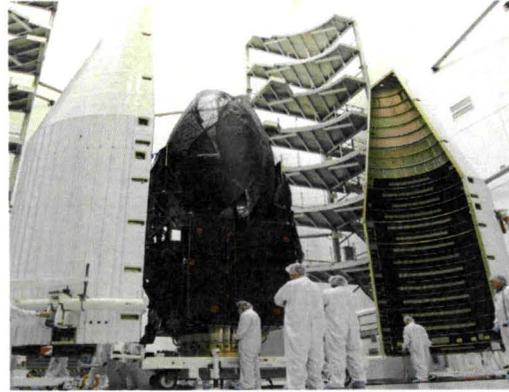
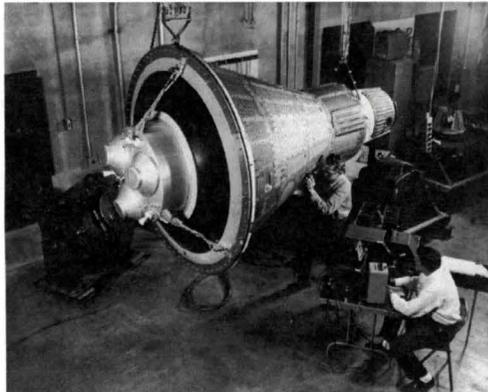


Lessons Learned for Improving Spacecraft Ground Operations



Michael Bell, Gena Henderson, Damon Stambolian
NASA Kennedy Space Center (KSC)
Engineering and Technology Directorate



Lessons Learned is

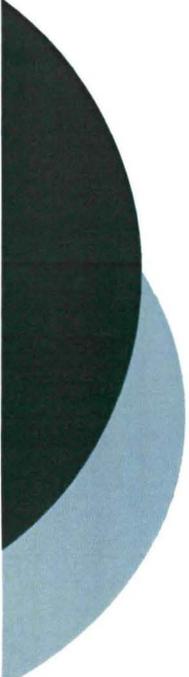
- knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure. Both should be considered excellent sources of lessons learned.

Problem Introduction



Throughout NASA's history (Mercury Program, Gemini Program, Apollo Program, Skylab Program, Space Shuttle Program, International Space Station Program, Constellation Program, SLS and Orion Programs) many lessons have been learned.

- These lessons deal with very complex and unique systems.
- This knowledge needs to be carried over into new programs.
- The lessons learned may not be needed for several years to come.

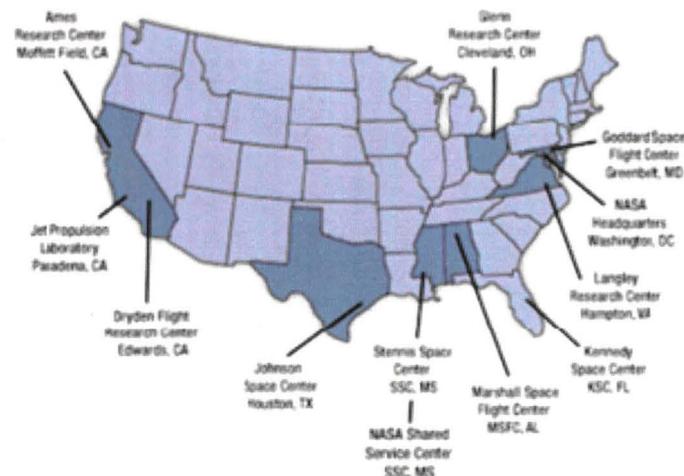


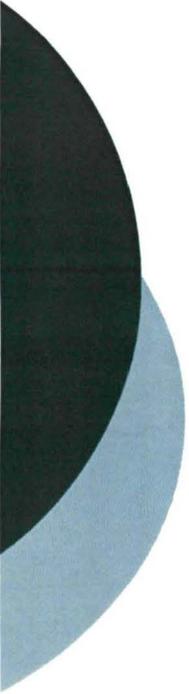
Solution

- NASA policy requires each Program or Project to develop a plan for how they will address Lessons Learned.
- Projects have the flexibility to determine how best to promote and implement lessons learned.
- A large project might budget for a lessons learned position to coordinate elicitation, documentation and archival of the project lessons.

The LLIS process

- The lessons learned process crosses all NASA Centers and includes the contractor community.
- 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.



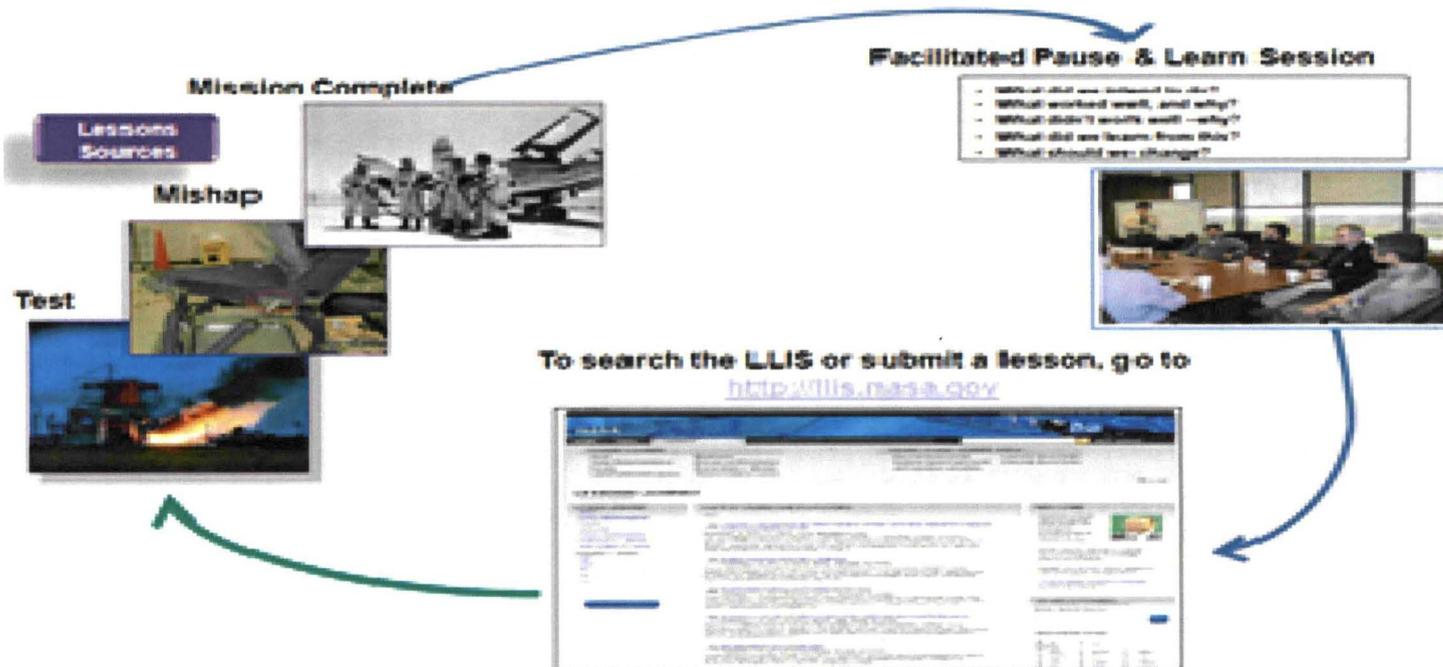


Solution

- One tool used to transfer knowledge between program and projects is the Lessons Learned Information System (LLIS).
- Most lessons come from NASA in partnership with support contractors.
- A search for lessons that might impact a new design is often performed by a contractor team member.
- Knowledge is not found with only one person, one project team, or one organization. Sometimes, another project team, or person, knows something that can help your project or your task.

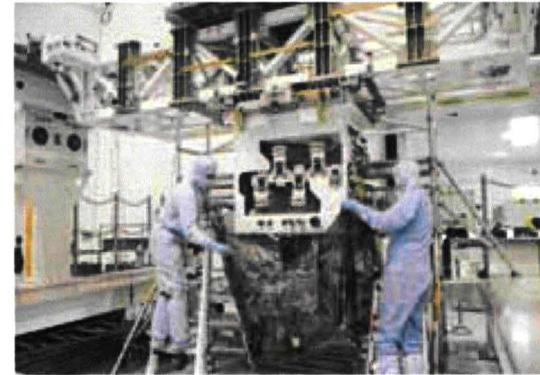
The LLIS process – Life Cycle

The lessons learned life cycle involves sources such as engineering design teams, mishap reports, research, science, operations, administration, procurement, management, safety, maintenance, training, flight or ground-based systems, facilities, medicine, etc.



The LLIS process – Gathering

- Key decision points and design milestones are potential lessons learned points.
- 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.

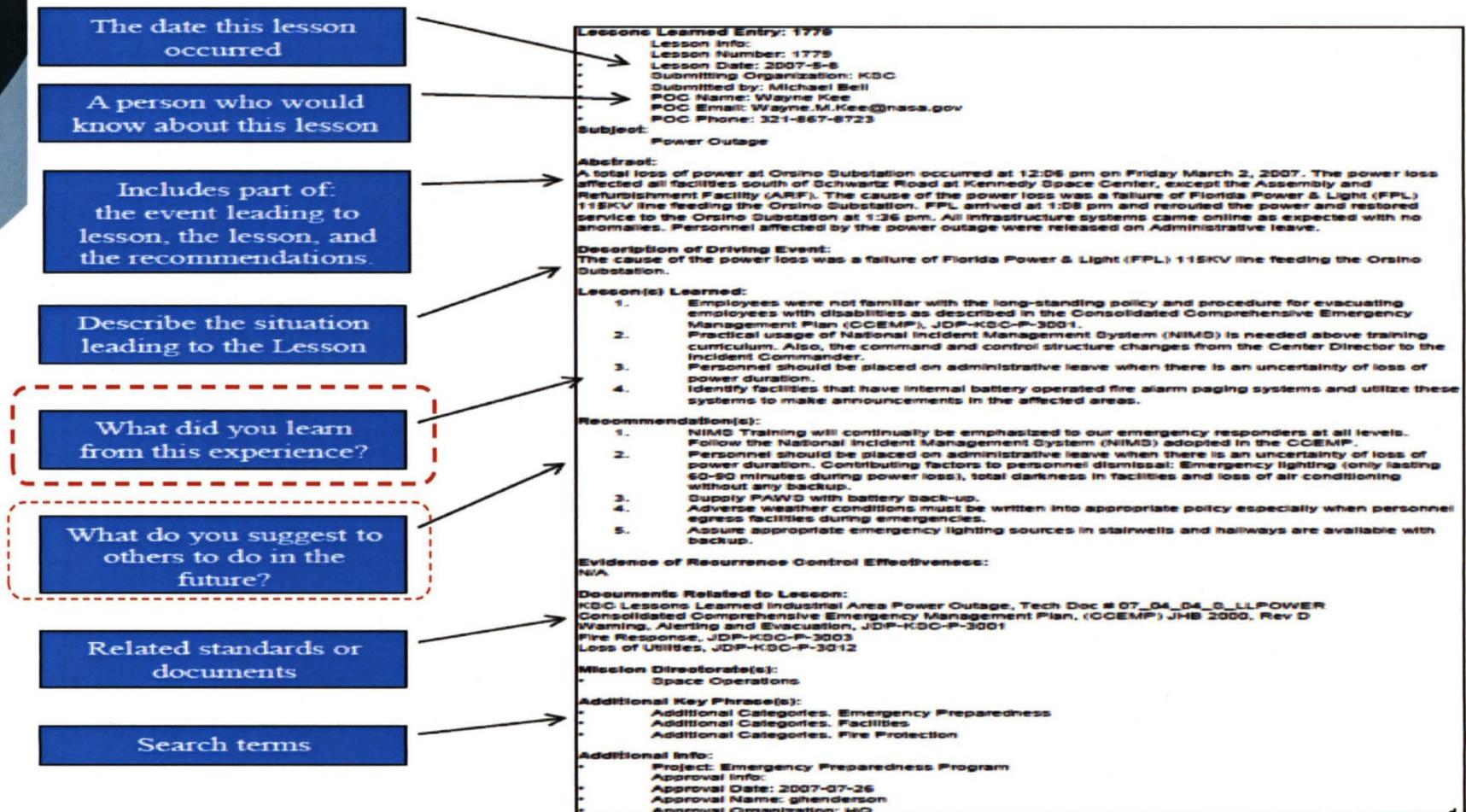


The LLIS process – Gathering

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.



Lesson Learned Components





The LLIS process – Review Process

- The goal for review of a new lessons learned entry is to enhance the learning potential from the experience described in the entry.
- The reviewers work with the submitter to provide feedback so the description of the situation is clear and ask technical questions so the write up is accurate.
- The committee reviews the lesson so it has a meaning that can be understood even by those outside of NASA.

The LLIS process – Review Process

- It is important to provide good situational context information to be able to understand how the lesson could be applied in the future.
- The review team assists the lessons submitter in capturing pertinent details such as;
 - size and magnitude of the project
 - type of project
 - how the team discovered the situation



How Lessons Learned are Shared

Kennedy Engineering Academy Forums are held to disseminate the results to a wide audience.



How Lessons Learned are Shared

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.

Lessons Learned Entry: 4417

Lesson Info:

- Lesson Number: 4417
- Lesson Date: 2010-08-31
- Submitting Organization: KSC
- Submitted by: Annette Pitt
- POC Name: Albert K. Curry
- POC Email: albert.k.curry@hqs.nasa.gov
- POC Phone: 321-861-4582

Subject:
Shuttle Orbiter Airlock Hatch Failure Caused by Loose Screw On STS-89 Presented Two

Abstract:
During the Space Shuttle STS-89 mission, the two planned Extravehicular Activities (EVA) were on plan. This incident the plan to evaluate the EVA task that would be used for the construction and

Description of Driving Event:
The Space Shuttle mission STS-89 was launched on October 30, 1996. The mission plan for two of the International Space Station (ISS) hardware, when the airlocks attempted to open the mission managers had to attempt the EVA since they did not want to risk damage to the hatch or mission. Troubleshooting revealed that the outer airlock hatch actuator assembly was faulty. A new and checked assembly. Troubleshooting on the hatch revealed that one of the two Number 140 bolts lodged between a planetary gear and the ring gear within the actuator gearbox. Furthermore, the seal also found that the planetary gear used with the assembly was a non-holding type when the planetary drawing did not specify a torque value for these fasteners. To resolve this issue, all actuator drawing was also updated to specify a torque on the fasteners and to verify locking torque during

Below is a video discussion of the lesson.



Albert K. Curry, Boeing

Lessons Learned Entry: 3697

Lesson Info:

- Lesson Number: 3697
- Lesson Date: 2010-07-20
- Submitting Organization: KSC
- Submitted by: Maria Antonova Pitt
- POC Name: David Andrews
- POC Email: david.andrews@nasa.gov
- POC Phone: 321-861-3113

Subject:
EMC Contamination Control Cartridges Were Installed Backward

Abstract:
During storage and functional check-out of the Extravehicular Activity Unit (EVA) it was found that the two Contamination Control Cartridges (CCC) were installed backward. This condition forced the removal of EMU 2 from the flight. The CCCs might have caused the EMU 2 vent loop or the electrical damage might be that no relevant electrical damage had occurred. The CCCs were then used and was updated to be more specific in the installation process. This CCC review is

Description of Driving Event:
During the performance of COMY1105.002 (EMU 2) operations, a significant and troubleshooting and data retrieval, it was found that the Orbiter airlock power to be located with water. This condition forced the removal of EMU 2 from the flight. The CCCs might have caused the EMU 2 vent loop or the electrical damage might be that no relevant electrical damage had occurred. The CCCs were then used and was updated to be more specific in the installation process. This CCC review is

Description of Driving Event:
A review of the KSC installation procedure and SC installation drawing reveals "was installed" on both the EMU 2. Obviously, these would steps were not paid to be installed on the wrong side of the CCC, which would then lead to similar to the points on the left top, which would only allow a one-way installation. The new design. This problem was presented to the Shuttle Operational Action Group (SOAG) to the installation procedure and to the SC drawing, as well as a Creative user of slipping up the thermal cover for covering the PLAS and CCC. The added CCC resistance and should be built with the back of the PLAS was the key to close all subsequent Shuttle flights.

Click this link to see the video transcript

Recommendation(s):
Lesson(s) Learned:

Lessons Learned Entry: 3676

Lesson Info:

- Lesson Number: 3676
- Lesson Date: 2010-09-26
- Submitting Organization: KSC
- Submitted by: Annette Pitt
- POC Name: Christopher Saly
- POC Email: christopher.saly@nasa.gov
- POC Phone: 321-861-3787

Subject:
Communication and Tracking (C&T) Status

Abstract:
Testing the Space Shuttle Orbiter Radio Frequency Antenna System by using a C&T Station can contain all of the external Radio Frequency (RF) antennas that Data Relay Satellite (DRS) System, Ground Stations - Identical Launch Air Station provides identically radio flight hardware

Description of Driving Event:
Early in the Space Shuttle Program's Orbiter ground support processing, RF testing, problems resulted in the removal and replacement of replacement Line Box have been installed or replaced. The C&T Station also provides a third and flow the MSLA ground station to the orbiter.

Lesson(s) Learned:
Initial testing of RF antennas should be performed both at its element level and at that intermediate with flight hardware. To ensure responsibility of test data, a correct which increases the potential for damage to both test equipment and flight hardware



Christopher Saly, NASA

Click this link to see the video transcript

Recommendation(s):
Lesson(s) Learned:

Lessons Learned Entry: 4656

Lesson Info:

- Lesson Number: 4656
- Lesson Date: 2010-08-04
- Submitting Organization: KSC
- Submitted by: Annette Pitt
- POC Name: Karlene Ison
- POC Email: karlene_ison@nasa.gov
- POC Phone: 321-861-3300

Subject:
Electrical Power Source for Fuel Cell Powerplant Critical Component

Abstract:
The oxidizer and hydrogen circulation pumps in the Space Shuttle Orbiter's fuel cell powerplants (FCPs) houses, which are directly fed by DC power supplied by the fuel cell itself. On two separate occasions, an oxidizer and hydrogen circulation pump in the fuel cell itself failed. This caused a potential danger to the fuel cell's own internal DC power. Power design should either use DC entry equipment to be the fuel cell powerplant's internal current methods

Description of Driving Event:
The Orbiter FCPs generate electrical power for the spacecraft. The Orbiter's electrical power distribution to the main oxidizer and hydrogen power systems pumps. During the Orbiter's port landing the working powerplant's electrical power is supplied by the ground power system. During two separate Shuttle power plant test operations, resulting in a loss of electrical power to the FCP's pumps. With the FCP's pumps on long operation, the cooling system can be operating or avoid potential damage to the hardware in addition,



Karlene Ison, NASA

Lessons Learned Entry: 5479

Lesson Info:

- Lesson Number: 5479
- Lesson Date: 2010-10-1
- Submitting Organization: KSC
- Submitted by: Annette Pitt
- POC Name: Peter Brinko
- POC Email: peter.w.brinko@nasa.gov
- POC Phone: 321-861-4096

Subject:
Proper Manufacturing, Handling, Use, Storage and Care Of

Abstract:
Metal bellows fan boxes are very susceptible to reverse bending crack in the bellows.

Description of Driving Event:
In the late 1980's early 1990's time frame there were multiple shuttle orbiter systems. Some of these systems were critical to the crew. Fortunately the failures occurred and were detected during before flight. The video below discusses this situation.



Peter Brinko, USA

Click here to view a transcript of the video

Lessons Learned Entry: 4018

Lesson Info:

- Lesson Number: 4018
- Lesson Date: 2010-08-13
- Submitting Organization: KSC
- Submitted by: Annette Pitt
- POC Name: Harry Isaacson
- POC Email: harry.isaacson@nasa.gov
- POC Phone: (321) 861-1741

Subject:
Inorganic Zinc Waste Disposal

Abstract:
An improved method of disposing of inorganic zinc waste was necessary to reduce a permit was obtained from the Florida Department of Environmental Protection to open inorganic zinc oxide paint, which met the requirements for a 90-day hazardous-waste

Description of Driving Event:
Storing inorganic zinc waste in closed-top storage containers, as mandated by the Florida Department of Environmental Protection (FDEP), and NASA, was causing gas from, inadvertently creating a chemical bomb. Work was performed with NASA and drying of the zinc waste before disposal.

Below is a video discussion of this lesson.



Harry Isaacson, NASA



Lessons Use – Systems Engineering

- As part of the entrance criteria for design reviews, projects query the lessons learned information system to determine which lessons might impact their project design.
- A lessons learned search may spark additional questions to be researched or investigated
- Past lessons learned submitters may be contacted or consulted on the new design.
- The LLIS can serve as an expert locator or knowledge matching engine



Examples of Lessons Learned

The design process for 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 (median of 9 different search terms used)
- These searches resulted in 4 to 270 "hits."
- The team must review these search results and decide how to apply the information.

Examples of Lessons Learned

- The following table 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 LH ₂ System	18	18	100%
Mobile Launcher Cryogenic Systems Design LO ₂ 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%

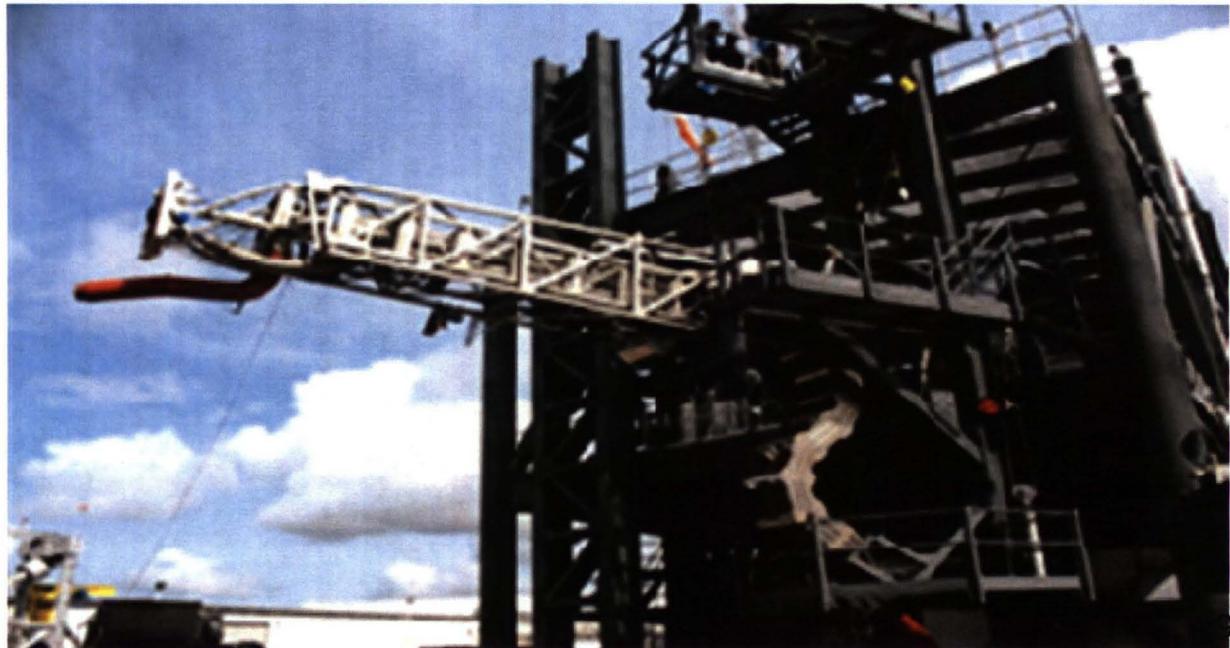


Vehicle Support Post (VSP) team

- 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.
- The team used this lesson to improve shipping/handling pallets and containers to provide adequate restraint of the VSP.

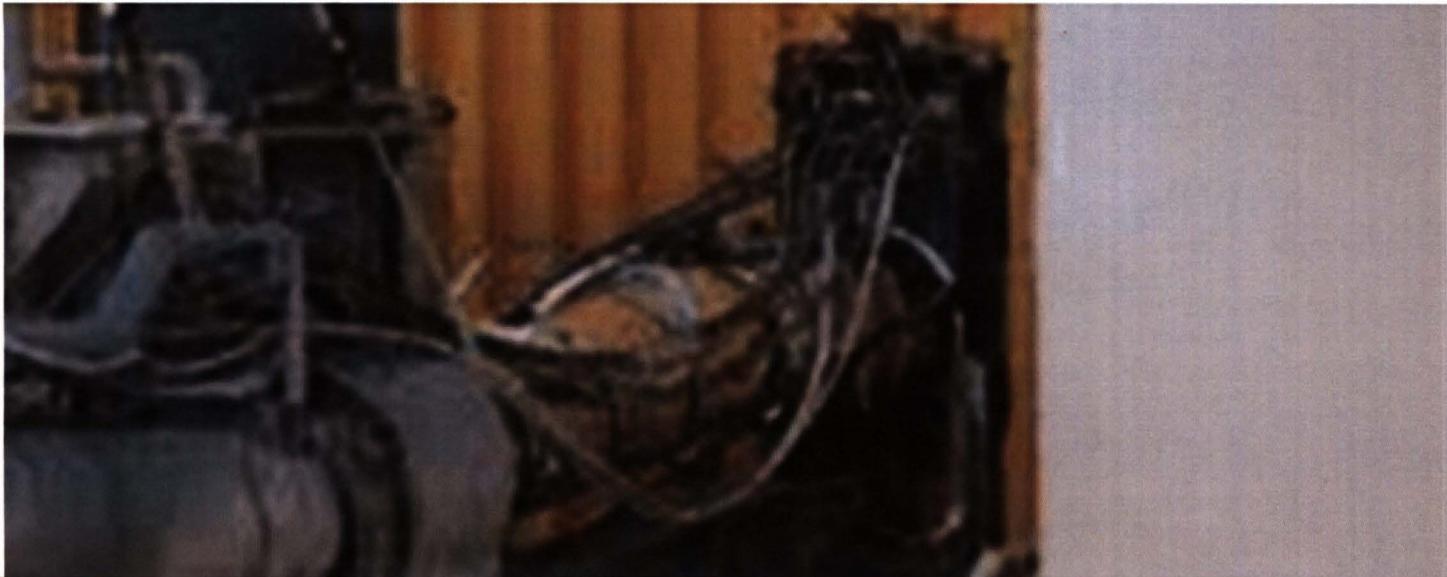
Vehicle Support Post (VSP)

- 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



Tail Service Mast Umbilical (TSMU) team

- The lessons were evaluated by the design team for applicability.

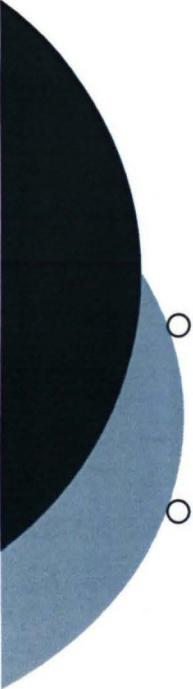


Project Name	Search Results Returned	Results Utilized	% Results Utilized
Tail Service Mast Umbilical (TSMU), Mobile Launcher Element	4	4	100%



Tail Service Mast Umbilical (TSMU) lesson actions are listed below

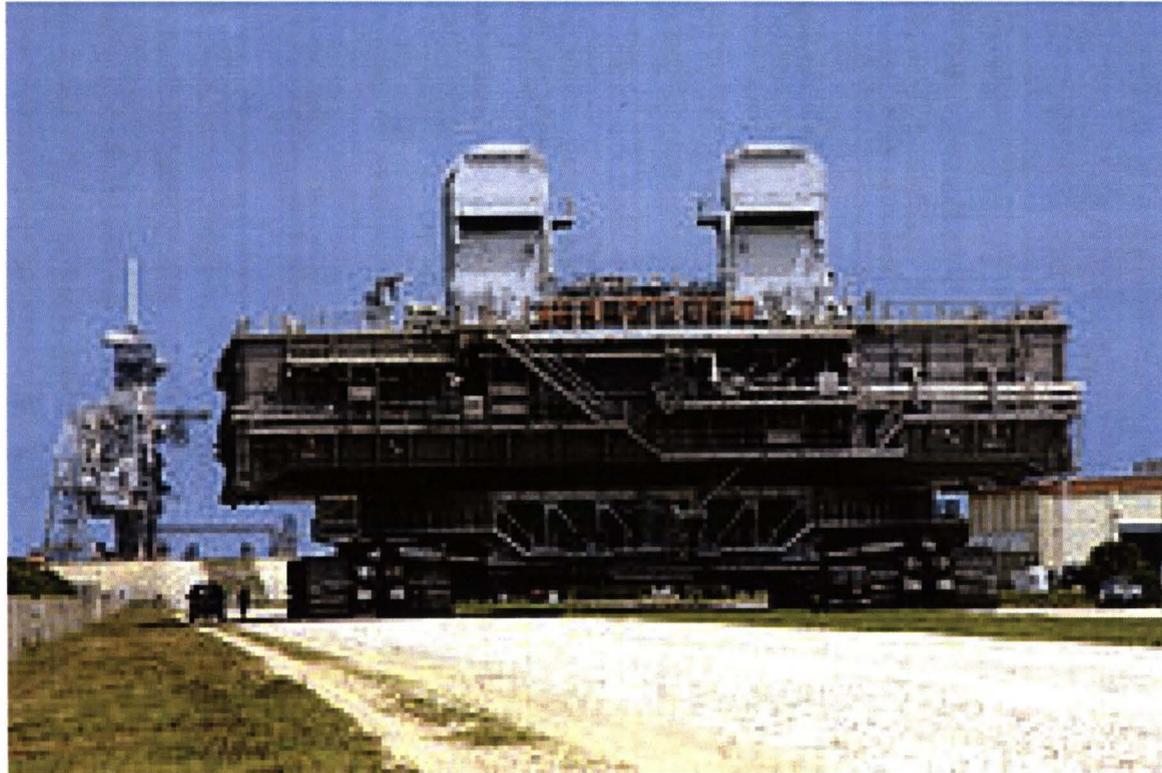
- Focus on designing personnel access and safety limits.
- Coordinate with the Hazardous Gas (HazGas) Subsystems project team to determine an efficient configuration of HazGas sensors to minimize risks.
- Use a new release mechanism that eliminates the safety hazards associated with explosives, and provides a cost savings, by being reusable.
- Use mechanical positioning mechanisms to perform the mating of the ground umbilical.



The Mobile Launcher Cryogenic LO2 Systems

- The design team searched the LLIS and was able to apply 14 relevant recommendations from the 52 items they reviewed, resulting in 27% utilization.
- A sample of recommendations from the lessons are listed below;
 - Minimize leakage by utilizing welded connections, pneumatic systems for controlling cryogenic valves, and purging system for valves flowing LH2 (from Lessons Learned Entry: 0034).
 - Design/install a new leak detector sensor console to accommodate additional leak detectors (from Lessons Learned Entry: 0107).
 - Design and install permanent safe access platforms (from Lessons Learned: 0112).
 - Design a mechanism that will prevent the ET GH2 vent arm from rebounding back into an SRM (from Lessons Learned Entry: 0157).
 - Perform outdoor wind tunnel testing of vent/relief valve to provide data, quantifying leak rates below which the hazard is eliminated (from Lessons Learned Entry 0184).

Mobile Launcher Breathing Air System



Project Name	Search Results Returned	Results Utilized	% Results Utilized
Mobile Launcher Cryogenic Systems Design LO ₂ System	52	14	27%

Summary

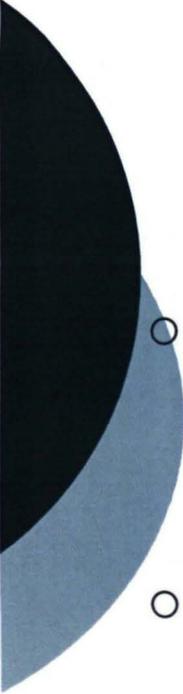


- Knowledge sharing is an everyday activity at the Kennedy Space Center through storytelling, Kennedy Engineering Academy presentations and through searching the Lessons Learned Information system.
- Project teams search the lessons repository to ensure the best possible results are delivered.
- The ideas from the past are not always directly applicable but usually spark new ideas and innovations.

Summary



- Teams have a great responsibility to collect and disseminate these lessons so that they are shared with future generations of space systems designers.
- Leaders should set a goal for themselves to host a set number of lesson learned events each year and do more to promote multiple methods of lessons learned activities.
- High performing employees are expected to share their lessons, however formal knowledge sharing presentation are not the norm for many employees.



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- [4] Kristen Purcell, Joanna Brenner, Lee Rainie. Search Engine Use 2012, Pew Internet & American Life Project, Mar 9, 2012, <http://pewinternet.org/Reports/2012/Search-Engine-Use-2012.aspx> , accessed October 10,2012, .



Acknowledgements

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