Assuring that Lessons Learned Critical to Mission Success Get Used

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***Abstract*— NASA has an established process for documenting and disseminating lessons learned from spaceflight missions and related activities. However, independent assessments of the NASA lessons learned process conducted in 2002, 2003, and 2011 have concluded that NASA programs and projects are failing to heed and apply these lessons learned. JPL recently completed implementation of a three-pronged approach to assure that NASA lessons learned get used by JPL spaceflight projects:**

1. ***Targeted Distribution*. Newly published entries in the NASA lessons learned repository are reviewed and forwarded to the JPL technical discipline expert best suited to take preventive action.**

2. ***Project Self-Assesssment*. The JPL project assigns a coordinator to review NASA lessons learned and assign each one to a JPL subject matter expert. The expert then determines its applicability to the project, assesses the potential project impact of non-compliance, evaluates the current compliance status of the project, and proposes a course of action.**

3. ***Lessons Learned Infusion*. By cross-referencing NASA lessons learned to specific paragraphs in JPL's two mandatory core engineering standards, JPL has infused lessons learned into JPL procedures and training such that the institution need not rely on the appropriate person applying a lesson at the proper point in the project lifecycle.**

These steps have added a closed-loop to the recommendations in the lessons learned, and they assure that the recommendations are fully considered by JPL spaceflight projects.

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1. INTRODUCTION

NASA is charged with pursuing chiefly those space missions that are novel and pose a risk of failure higher than may be acceptable to industry. The mishaps that may proceed from these technically complex endeavors may threaten the safety of employees and the survival of billion dollar spacecraft, and they are highly visible to the public. Hence, it behooves NASA to prefer making new mistakes and employ a rigorous process to avoid repeating old ones. NASA must assure a timely and appropriate response to known risks, despite schedule pressures and a surfeit of information competing for the attention of spaceflight project engineers.

A formal lessons learned process is a hallmark of a mature engineering organization, and it can provide an effective countermeasure to avoidable risk. A "lesson learned" differs from other guidance such as a "best practice" in that it is based on a documented incident that may be relevant to the organization, and offers conclusions and recommendations that are practical and can reasonably be implemented within the organizational context. The U.S. military is very effective in using lessons learned, both from history and from yesterday (e.g., after-action reports), to alert personnel to what can go very wrong. Literature provides a wealth of aphorisms recognizing the fallacy of ignoring the lessons of the past.

> "Those who cannot remember the past are condemned to repeat it." -George Santayana
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> "Fools say that they learn by experience, I prefer to profit by others' experience." -Otto von Bismarck
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> "An expert is someone who knows some of the worst mistakes that can be made in his subject, and how to avoid them." -Werner Karl Heisenberg
>
> "Why - I learnt what one ought not to do, and that is always something." -The Duke of Wellington describing the failed Dutch campaign of 1794.

For 15 years, NASA has implemented a formal lessons learned process that has produced useful and searchable information on key success factors for space missions. NASA personnel and the general public have access to more than 1800 lessons learned in the NASA lessons learned repository [1]; they include "positive" lessons on successes as well as lessons on mishaps. The process is led by NASA Headquarters, but lessons learned collection and sharing is

[1] 978-1-4577-0557-1/12/$26.00 ©2012 IEEE
[2] IEEEAC paper #1177, Version 1, Updated 2011:12:09

primarily the responsibility of the NASA Centers—the organizations that perform mission engineering and operations work. Some minimum standards for the Center lesson learned programs were established by NASA in 2005 by NASA Procedural Requirement (NPR) 7120.6, *The NASA Lessons Learned Process*.

The NASA lessons learned process defined in NPR 7120.6 was modeled largely on the process established by the NASA/Caltech Jet Propulsion Laboratory (JPL). JPL has long viewed lessons learned as a principal component of an organizational culture committed to continuous improvement, and the Laboratory leadership has consistently supported implementing a formal process. The roots of the JPL process is traceable back to 1978, when JPL first published the Spacecraft Significant Event File as a three-ring binder that was maintained and updated by coordinators from each of the JPL technical divisions. This set of coordinators formed the nucleus of a Lessons Learned Committee (LLC) that began holding weekly meetings in 1984. Today, the JPL LLC still meets weekly, includes representatives from the JPL technical divisions and the mission assurance organizations, is chaired by the JPL Office of the Chief Engineer, and is charged with validating and prioritizing lesson learned candidates, developing and approving draft lessons learned, and assuring that the lessons are shared. Figure 1 illustrates the JPL lessons learned process flow. The JPL lessons learned process is generally recognized as the most mature of the NASA Center processes.

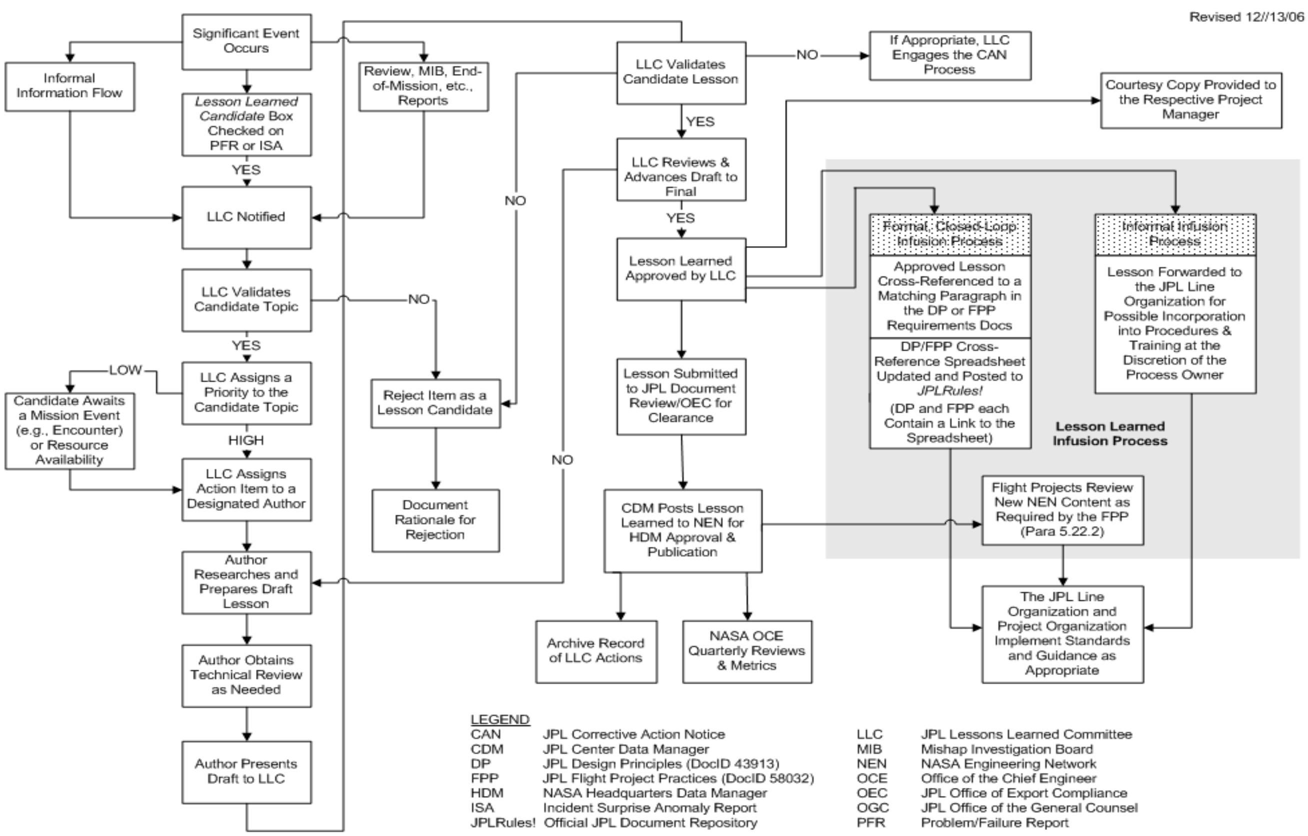

Figure 1 – JPL lessons learned process flow, with the shaded area depicting the lessons learned infusion process

The requirements for an LLC and for sharing lessons learned are both enshrined in NPR 7120.6. However, the actual use of the information by engineers, managers, astronauts, and safety personnel in spacecraft design, development, and operation is difficult to assess or to assure. The available metrics on lessons learned effectiveness are of limited value: if a single user visit to a lessons learned repository provided information that saved a mission, it may outweigh the previous one thousand "hits" on the website. A 2002 report by the U.S. General Accounting Office (GAO) [2] concluded that NASA lessons learned are not being heeded and applied by NASA programs and projects, and the 2003 Columbia Accident Investigation Board Report [3] reported that "design engineers and mission assurance personnel use [the NASA Lesson Learned Information System] only on an *ad hoc* basis, thereby limiting its utility." Initial informal feedback from a 2011 audit of the NASA lessons learned process by the NASA Office of the Inspector General indicated that most NASA Centers have not successfully implemented the NPR 7120.6 requirement for lessons learned infusion into NASA procedures and training. [4]

2. METHODOLOGY

If lessons learned are only being used on an *ad hoc* basis, then it behooves NASA to assure that the information is applied systematically. There are precedents for successfully mandating the use of technical guidance by NASA projects. For example, technical standards issued by government and industry are commonly imposed on project design and implementation processes, and the projects and contractors complete a compliance matrix that responds to each "shall" statement in the standard.

However, because lessons learned examine a specific incident and document conclusions that are intended to be widely applicable, "shall" and "must" language is not appropriate. Instead NASA lessons learned offer mere recommendations that a project may review for their technical merit and use only as appropriate. Since lessons learned are a source of advice rather than requirements, and reading is an essentially solitary activity that is self-controlled, the material must compete with the plethora of information sources and other project activities competing for the target audience. Even for a horse known to be thirsty, "You can bring the horse to water [and you can also assure the water is of high quality], but you can't make it drink."

So how can we assure that the horse will partake from our pool? JPL has implemented a three-pronged approach to assuring that lesson learned get used by spaceflight projects in the development and operation of spacecraft systems and support equipment.

Targeted Distribution of Lessons Learned

The NASA Lesson Learned Information System (LLIS) has a subscription feature that allows users to subscribe to all newly published lessons learned, or a subset that contains pre-selected keywords. The JPL LLC Chair presently subscribes to receive a notification of all lessons learned submitted by all of the NASA Centers. When a notification is received and the lesson appears relevant to JPL, the Chair forwards a link to the appropriate JPL subject matter expert for review. This personalized outreach to a targeted individual— "Here is something you specifically need to know"-- is very effective. Were the Chair to be less selective, for example forwarding a NASA Kennedy Space Center lesson on saltwater corrosion of launch facilities to a JPL engineer, this process would become less effective.

The JPL LLC Chair also performs a periodic e-mailing of summaries of recent JPL lessons learned to the JPL Mission Assurance Managers (MAMs) and Project System Engineers (PSEs). Because a MAM and a PSE are assigned to each JPL project in an oversight role, they are well positioned to assess the project impact of each lesson and recommend any needed action.

Project Self-Assessment of LLIS "Compliance"

A second approach employed by JPL to assure that NASA lessons learned get used provides objective evidence of project application of lessons learned recommendations. A 2002 NASA program/project management requirements document required review of lessons learned, and "At each major milestone, the Program/Project manager shall report the extent to which he or she applied the lessons learned." [5] Subsequent revisions of the NASA document have omitted this NASA requirement, but major JPL flight projects have continued the practice.

The JPL practice derives from project-specific risk management measures rather than from any sort of mandated JPL-wide Category A requirement. As a result, the methodology used is somewhat inconsistent between JPL spaceflight projects:

- The Kepler project was probably the most ambitious. During an early project phase, the MAM assessed the entire contents of the LLIS (which then held 1100 lessons learned) for Kepler-relevant guidance, tasked the system contractor to duplicate the exercise, and then Kepler repeated the review during Phase D.

- The Mars Exploration Rover (MER) project assessment was also comprehensive, though the project elected to restrict their scope to JPL and NASA Goddard Space Flight Center (GSFC) lessons learned. The product was a matrix of 364 lessons learned that documented in detail the project compliance status. For example, where a GSFC lesson learned cautioned against thruster plume impingement upon the spacecraft structure [6], the lesson learned was forwarded to a specialist who determined that the project was compliant. The entry read, "High fidelity tests of closed loop attitude control operations have been performed in both ATLO and testbeds."

- The Juno project took a different tack. Though they clearly stated their intention to periodically review and address lessons learned, they selected five lessons learned for special attention throughout the project as perceived project risks [7]:

    1. Mars Global Surveyor Loss of Contact lesson learned
    2. Mars Odyssey High Efficiency Power Supply (HEPS) failure
    3. Mars Reconnaissance Orbiter (MRO) computer side swap anomaly
    4. MRO waveguide transfer switch failure
    5. Failure of the MRO Small Deep Space Transponder Ka exciter

- The flagship Mars Science Laboratory (MSL) project is clearly phasing their lessons learned application activities to major project milestones. The MSL project plan states, "The project and the subsystems shall review NASA Lessons Learned [http://llis.nasa.gov]

- Failure Lessons Learned and report on these issues at design reviews.” [8]

For self-assessments where the project reviews a significant number of lessons learned, the project manager typically appoints a project coordinator to categorize the lessons by technical discipline and assign each category to a subject matter expert. The expert then reviews each lesson in the set, determines whether it is applicable to the project, assesses the potential project impact of non-compliance, evaluates the current compliance status of the project, and proposes a course of action to achieve compliance. This assessment by the expert should be done early in the project when it is most cost effective to implement the lesson learned recommendations. Because the lesson applicability is often not known early in the project, prior to detailed design decisions, the project self-assessment should be iterated at major project milestones. When the project has taken preventative or corrective action, the project has provided a closed-loop response to the lesson learned.

These project self-assessments are fairly labor-intensive— more so as the contents of the LLIS grows-- and the practice is viewed as possibly impractical for smaller projects. It is not clear that the disparity between the scope of these assessments is undesirable, so long as the scope is consistent with the projects’ risk management strategy. Of course, the term “compliance” is somewhat misleading, since lessons learned are intended as merely cautionary recommendations to be considered by a project: there are no “shall” statements in lessons learned against which to assess compliance.

Infusion of Lessons Learned into Center Business Practices

Because the above two approaches cannot assure that the appropriate individual reads and applies a key lesson learned at the appropriate point in the project life cycle, JPL perceived a need to achieve a closed-loop to the lesson learned recommendations. In responding to the 2002 GAO findings, the selected methodology is to formally infuse lessons learned into the JPL standards and processes by which project work is done. Along with the requirement for each NASA Center to have an LLC, this requirement for Center *lessons learned infusion* became a key element of NPR 7120.6.

Early attempts to implement an infusion process at JPL were unsuccessful due to the scope and complexity of incorporating lessons learned into JPL processes. Lessons learned were categorized to match the organizational units in the JPL line organization. For example, LLIS content related to spacecraft propulsion were forwarded to the manager of the propulsion engineering section for incorporation into propulsion engineering procedures and training that apply to all JPL projects. To track the action item to completion, a JPL Corrective Action Notice (CAN) was issued against the section manager. There were several problems with this initial approach:

- There are thousands of JPL procedures and work instructions to which lesson learned recommendations could potentially apply.

- The section managers were perplexed by the request to incorporate recommendations (i.e., advisory statements) into what were essentially requirements documents.

- The section managers were chagrined at receiving a CAN, with its negative connotations, as a result of what were in some cases “positive” lessons learned that reported the section doing something correctly.

While lessons learned infusion efforts bogged down, a new development at JPL offered an opportunity. Two JPL documents that were originally written as guidance, the *Design Principles* [9] and the *Flight Project Practices* [10], became core standards against which each JPL project was audited for compliance. Basically, the *Design Principles* (DP) document lists the minimum set of design requirements for all spaceflight systems, while the *Flight Project Practices* (FPP) covers the mission engineering activities other than design engineering (e.g., testing, problem reporting, system safety, quality assurance, etc.) Reviewing this comprehensive list of “things JPL projects should always do,” it is apparent that the lesson learned recommendations are written perhaps one level of detail lower, such that they provide historical examples that reinforce the DP and FPP content. Hence, lessons learned infusion into the DP and FPP provides two benefits: (1) just two documents provide closed loop infusion of lessons learned and (2) cross-referencing lessons learned to the DP and FPP paragraphs provides additional rationale for the requirements in these core standards. Because the DP and FPP paragraphs are terse statements that provide little background information, JPL projects and system contractors can benefit from the concrete example provided by the cross-referenced lessons learned.

A spreadsheet cross-referencing each lesson learned to one or more specific paragraphs in the DP and/or the FPP was prepared last year by the JPL Chief Engineer’s Office.

Lessons learned published in the LLIS by other NASA Centers, as well as by JPL, were reviewed last year for inclusion in the spreadsheet. To further validate the cross-references, the JPL Chief Engineer directed the JPL Engineering Board (JEB) to vet them. The JEB validation was completed this year, and the spreadsheet was linked to the DP and FPP documents. An update of the DP and the FPP is being prepared that will insert hot links to the cross-referenced lessons learned at the end of each paragraph, instead of in the separate spreadsheet.

3. KEY FINDINGS & RECOMMENDATIONS

Outcome of Conducting “Targeted Distribution”

The procedure in which the JPL LLC Chair reviews newly published lessons learned and brings relevant items to the attention of the appropriate JPL subject matter expert is a efficient dissemination method. It requires little effort if the Chair also maintains a list of JPL subject matter experts, and the personalized aspect of the communication increases the likelihood that the recipient will read the lesson and act upon it. Anecdotal evidence of the effectiveness of targeted distribution includes some inter-Center requests for additional information that were prompted by the initial lesson dissemination.

The downside to this lesson sharing technique is that:

- Unless it is forwarded further, the lesson reaches only a single individual in the JPL line organization, and it does not assure formal compliance assessment by the JPL project organizations. This is somewhat ameliorated by the periodic distribution of lesson summaries to the MAMs and PSEs.

- The lesson reaches the attention of the subject matter expert at an arbitrary time—shortly after the lesson is published—instead of at a key project decision point when the information would be most useful.

Outcome of Conducting "Project Self-Assessment"

Project assessment of (1) the relevance of the LLIS contents to the project, and (2) the status of project compliance with the lessons learned recommendations, provides objective evidence that a project has systematically applied lessons learned. When a project performs this self-assessment, an independent auditor cannot reasonably claim that the NASA lessons learned repository is not being used by the project.

To be effective, however, the project review of the LLIS must be conducted iteratively. If the topic of a lesson learned involves a particular design implementation, a project in a pre-design phase may be unable to judge its applicability and must revisit the lesson at a later project milestone when the system design is better defined. Or, if a lesson learned is known to be applicable, it may still be too early to assess the project's response to the recommendation. The need to repeat the exercise at major project milestones requires a high level of project commitment to lesson learning, and there is little evidence that the other NASA Centers ever implemented the requirement in the 2002 NPG.[5]

Even if the project performs a comprehensive assessment at each major milestone, there remains a risk that the appropriate individual will not be alerted to the lesson learned at the proper point in time to avert repetition of a mishap. The assessment matrix is a project document that is not necessarily tied to NASA Center level procedures or training. Also, as stated earlier, smaller projects may lack the resources to perform comprehensive and iterative self-assessments. Smaller projects and Class D/E projects may view this assessment as "hosing them down" with information.

NASA projects that have assessed their compliance with the growing compendium of NASA lessons learned should be commended on their dedication to risk avoidance. Feedback indicates that the JPL projects identified above have found the review quite worthwhile in assuring that they do not have to relearn the mistakes of their predecessors. However, such formal and iterative project review of the LLIS contents is not, and should not be, a blanket NASA requirement. Like any other engineering process, it should be implemented where it makes sense in terms of the project risk strategy and project resources.

Outcome of Lessons Learned Infusion

With the infusion of lessons learned into JPL standards and processes, JPL no longer need rely on the appropriate person reading a key lesson learned at the specific point in time needed to effect project decision making. The JPL DP and FPP documents are recognized by the JPL projects (and by NASA Headquarters) as a stand-alone set of core JPL standards, and their comprehensive provisions adequately cover the range of topics found in NASA lessons learned. JPL projects complete a DP Compliance Matrix in which they record their state of compliance or non-compliance with the DP requirements, and the Compliance Matrix is attached to the Project Implementation Plan. [11] Even if a project requests a waiver to a DP requirement, the waiver preparation and evaluation process assures that the waiver preparer will have reviewed the associated lesson(s) learned. (A side-benefit is that the cross-referenced lesson(s) learned inform the waiver process.) Hence, the lessons learned infusion process achieves a closed loop.

There are some loose ends to the infusion process because newly published lesson learned may not yet have been cross-referenced and vetted. To close this process escape, Paragraph 5.22.2 of the projects' guiding rules [9] requires projects to "review lessons learned that are yet to be incorporated into the institutional standards and processes by which the work is done, and take appropriate action in responding to the relevant experience(s)."

The objective of the above three practices is merely to assure that lessons learned knowledge is not ignored. Programs and projects are only called upon to consider the lesson learned recommendations; the program/project manager may have sound justification for deciding not to implement a recommendation.

4. PLANS FOR FUTURE WORK

Other NASA Centers are reportedly preparing core engineering standards similar to the JPL DP and FPP. NASA Marshall Space Flight Center is preparing a "Red Book," and NASA Glenn Research Center is preparing a "GRC Processes, Policies, and Procedures" document. NASA Goddard Space Flight Center has an established "Gold Book." This documentation may prove helpful to these NASA Centers' infusion efforts.

The plan to add lesson learned links to the next version of the DP and FPP has spurred JPL interest in also cross-referencing and listing waivers that have been requested to each DP and FPP requirement. When projects complete their DP and FPP compliance matrices, they can review the rationale used by previous projects. The JPL Office of the Chief Engineer is very open to granting waivers to these requirements that make sense, and providing this information to projects will facilitate the process and help screen out waiver requests that are ill considered or inconsistent with the mission class.

5. CONCLUSIONS

NASA has struggled to respond to independent assessors' criticism of its lessons learned dissemination efforts. All three components of JPL's three-pronged approach to this problem have now been implemented by JPL, and together they provide a comprehensive solution to the persistent problem of assuring that lesson learned get used by spaceflight projects. The Targeted Distribution method is direct and simple to implement, though it is not closed-loop as the subject matter expert may take action or non-action after being informed of the lesson learned. The Project Self-Assessments are closed-loop for the project, but are not closed-loop for the institution, although similar projects may build on the previous work. They are quite rigorous, though the scope of the self-assessments (i.e., number of lessons reviewed and how often the review has been iterated) has varied between JPL projects. Lessons learned Infusion is effective because it is a closed-loop process that is linked to established institutional processes: it does not rely on "hosing down" individuals or projects with information.

The infusion methodology serves as a Center baseline practice because it provides "use-of-lessons assurance" at the institutional level. It best answers independent evaluators like the GAO because it is a closed-loop process and it provides objective evidence of an institution-wide response—not just a project response. It is when a JPL project provides its compliance matrix against the paragraphs in the *JPL Design Principles* and *JPL Flight Project Practices* standards that we have convincing evidence that the project has reviewed the lessons learned cross-referenced to the paragraphs. From an institutional viewpoint, Targeted Distribution and Project Self-Assessment are *ad hoc* measures that provide additional assurance of lessons learned use.

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BIOGRAPHY

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