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Paper Session I-B - Prelaunch Processing Scientific Payloads Since Challenger: Lessons Learned Exercise

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PRELAUNCH PROCESSING SCIENTIFIC PAYLOADS SINCE CHALLENGER: LESSONS LEARNED EXERCISE

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INTRODUCTION

The Kennedy Space Center is responsible for processing a large number of payloads for integration and launch with the Space Shuttle. The processing of unclassified Shuttle mission payloads is the responsibility of the KSC Payload Management and Operations Directorate and its NASA-McDonnell Douglas personnel.

Each individual STS mission may involve several payload elements such as deployable satellites, upperstages, free flying platforms, scientific instrument carriers, as well as flight support equipment. As of this writing, 1990 will see the KSC payload processing organizations supporting the launch and/or download of fifteen different payload elements on eight separate STS launches.

The variety of payloads processed and the lack of similarity among successive mission processing flows provides a rich opportunity to utilize the experiences of the past flows to enhance the payload processing team's future operational activities. The payload processing teams have taken this opportunity to engage, therefore, in some effort to retain the corporate knowledge acquired on each of the STS missions, and to attempt to collect that knowledge in an accessible knowledge base. To that end, a "lessons learned" effort forms a part of each of the payload processing operations.

LESSONS LEARNED PROCESS

The organization which is charged with the responsibility for the actual on-line processing of a particular mission's payloads is the "test team". This team is an ad hoc organization composed of KSC NASA and contractor payload processing personnel, orbiter personnel involved in payload-relevant activity, resident members of the payload developer team, quality, safety, security, and other support area representatives. The test team is a forum for discussing status, planning, and concerns regarding the particular STS mission payload processing. It meets at increasingly frequent intervals during the payload prearrival planning and daily during the actual payload processing operations.

Following the mission, the test team members meet to conduct a lessons learned exercise. The overall thrust of this exercise is operational in nature. Forms are provided to the test team members on which problems encountered during the processing operation are outlined and the reporting individual proposes a solution which would preclude the recurrence of the problem on future payload processing flows.

The test team then meets in a special session to review each of these concerns. The actual problem is reviewed, causes identified, actions to preclude recurrence are identified, and the individual lesson learned is incorporated into a database.

MISSIONS SINCE STS-51L

As of the writing date of this paper, there have been seven Space Shuttle launches since the post-51L return to flight. Three of these have been classified Department of Defense flights. This paper deals with the remaining four; STS-26R, STS-29R, STS-30R, and STS-30.

The STS-26R mission, launched on September 29, 1988, payload was the Tracking and Data Relay Satellite TDRS-C and its Inertial Upper Stage (IUS)booster. Total KSC processing time was 137 days.

The next mission, STS-29R, consisted of the TDRS-D satellite and its IUS booster together with the Space Station Heat Pipe Advanced Radiator Element (SHARE). The TDRS-D was at KSC for 104 days and Share for 183 days prior to the March 13, 1989 launch.

The STS-30R mission was a planetary probe and consisted of the Magellan Venus satellite and its IUS booster. The spacecraft was integrated by its developers in an off-line facility and KSC processing began at the Vertical Processing Facility (VPF) on February 15, 1989. Launch was May 4, 1989 after 93 days of KSC payload processing.

The Galileo was powered by two Radioisotope Thermoelectric Generator (RTG) Units. Due to the nature of these units, they had to be installed on the spacecraft after it was installed in the orbiter at the launch pad. This operation required the use of two large specially-built platforms. It was determined that a fit check of these platforms at the pad, together with an installation handling exercise using an RTG simulator would be required. Since this mission would be the first to use RTGs on the Shuttle and the first use of the platforms, this exercise was treated as a separate flow and the lessons learned operation was conducted on this operation separately from STS-34. It is also presented separately in this paper. The actual exercise took place during the period of May 17 - 22, 1989, although planning had preceded the operation for several months.

CATEGORIZATION OF INCIDENTS

The incidents identified in the Lessons Learned process for the above missions have been categorized by their primary characteristic features. These have fallen into three major categories and one minor. The major categories are incidents involving an operational, documentation, or hardware feature. A minor area was software which was noted on only one STS mission's exercise.

Within these categories, the incidents were subcategorized to identify more specific features. These are described and examples given in the following section.

OPERATIONAL CATEGORY

Support Required: Incidents displaying this feature were characterized by the absence or inadequacy of support for some operational activity. Example: Parts required to support an STS-26R orbiter-payload interface link check were not kitted and available for pickup one day prior to the test.

Coordination: The lack of coordination between organizations was a feature of over one quarter of the incidents identified. Example: Payload personnel were not notified of a constraint which prevented starting the above STS-26R payload-orbiter interface link test until just prior to beginning the planned checks.

Planning/Scheduling: Inadequate planning for an operation or conflicting scheduling was noted in these incidents. Example Periodic recertifications of STS-34 IUS initiator components at a vendor site revealed concerns with possible major impacts to the operation due to lack of access to the components following spacecraft-booster integration. Had the certification checks been scheduled earlier the preintegration access would have been available.

Inter-Organizational: Incidents identified in this subcategory involved some inter-organizational aspect. Example: During IUS testing on STS-34 the IUS took unexpected telemetry hits when the orbiter updated its GMT.

Intra-Organizational: Incidents also, in some cases, featured intra-organizational aspects. Example: The payload processing organization material support group was not advised of an STS-26R documented requirement to provide a backup static gun to support pad operations

DOCUMENTATION CATEGORY

Operational Documents: Documents involved were primarily operational in nature, rather than test or requirement documents. Example: During STS-34 the J-hooks required to support flight hardware at the Vertical Processing Facility were not available for installation per schedule as they had not been called out in the correct document.

Test Documents: This subcategorization involved documents used for test activities. Example For the checkout of an STS-26R payload-orbiter interface some copies of the test document had revision numbers on all pages while other copies had them only on the revised pages; leading to confusion as to what was the latest document revision.

Requirement Documents: These incidents involved documentation of requirements. Example: On STS-26R the cognizant requirements document did not include intercommunication system channels for the support of mechanical handling operations.

Incorrect/Incomplete: Incidents in this subcategories involved documentation with errors or with incomplete sections. These were not noted in reviews and were noted only when they caused an impact to the activities they controlled. Example: For the STS-26R Mission Sequence Test an unexpected ordnance test set timer event failure was reported. It was discovered that this could occur at any time and future editions of the document were annotated to indicate possible recurrence.

Not Available: These incidents featured documentation which was not available or present when required to support an activity. Example: Patching configurations in support of an STS-26R test were done incorrectly and the quality control inspector on station did not have a copy of the relevant document.

Improper Use: The use of documentation to control activities requires a standardized approach to the use of documentation for specific types of tasks. In some instances this approach was not followed. Example: During integrated testing on STS-26R the problem report paperwork used for trouble shooting was allowed to control portions of the operation, rather than using the controlling document. This leads to "nested" problem reports of unrelated problems on one report with a lack of trouble shooting and operational accountability.

Requirement Unclear: In some cases, although the writer probably understood what he meant, the document's ultimate user did not. Example: During STS-26R pad operations confusion existed over the requirement for hands-on activity to cease when humidity levels fell below a given level.

HARDWARE CATEGORY

Flight Hardware: In several cases the incidents involved actual flight hardware. Example: During the STS-30R countdown the Magellan spacecraft command receiver locked up on S band commands meant for the orbiter when the uplink went from low power (2 kw) to high power (10 kw) mode. Since Galileo used the same receiver this was a concern on both STS-30R and STS-34.

Ground Support Equipment (GSE): For those incidents involving hardware, the majority involved difficulties with equipment which was required to support the prelaunch processing but which was not flight equipment itself. Example:The Magellan spacecraft power cables were not compatible with KSC facilities and adapter cables had to be developed to support Magellan operations.

Facilities: In addition to flight and GSE hardware, in several incidents the facility in which the operation was being carried out had an impact due to failures or inadequacies of its systems. Example: During the STS-34 operations at the VPF an elevator door transformer overheated and produced a noticeable odor. As the Galileo was loaded with hypergolic fuels at the time any unidentified odor required evacuating the building and evaluations by environmental health sniff checks prior to resuming operations.

Hardware Found to be Damaged: Some hardware elements were found to be damaged when they were received for use. Example: During the RTG Simulated installation exercise the platform which had been developed to support the operation was noted as having severe bends on stair treads, indicative of the metal having local yielding.

Hardware Damaged by Use: In some cases, the hardware elements were damaged by their use. Example: Following a stress corrosion modification the J-hooks which would support the STS-34 payload in the test stand were proofloaded, during which activity the adjustment mechanism of the J-hooks was deformed.

Modification Required: In a number of incidents hardware elements were found to be undamaged but to require some modification for their effective usage. Example On STS-29R following cleaning, leak checks, and certification of the TDRS propellant facility fill line, there was no way to verify blanket pressure in the line without a modification to add a pressure gauge in the line.

SOFTWARE CATEGORY

Incorrect Software: Some software was found to require modification. Example: Starting dates for operations on STS-26R were found to be inconsistent between the payload integrated control schedule and the open-items status reporting mechanism. A software change was found to be necessary to eliminate this source of confusion.

Incorrect Usage: In one case the software's correct usage was not fully understood by the test personnel. Example: During STS-26R testing an unexpected payload data interleaver decom-fail message was received although other indications did not support the fact of a failure. Later understanding lead to documentation annotation to explain the cause and note it as not being a problem.

CATEGORIZATION OF RECOMMENDATIONS

The evaluation of the Lessons Learned incidents by the mission test team involved recommendation for the future. The objective of these was the avoidance of future repetitions of the same type of incident. These recommendations could be characterized by certain basic approaches or features. These are described as a factor of the relevant incident category for which they were developed and examples given as follows.

OPERATIONAL CATEGORY

Admonitory: Recommendations for the future having this characteristic were primarily in the forms of warnings and cautionary statements. The recommendations state, in effect, "this was an error and the action required is to be aware of it and not to repeat the error". The action is educational rather than calling for a specific activity. Example: During the STS-30 processing a backlog of trouble shooting problem reports built up requiring a large amount of time to clear the documentation and process paper resulting in a request for systems engineers to complete and clear their paperwork in a more timely manner.

Modify Documentation: Recommendations of this type dealt with incidents in which the documentation process as such was not the causative factor, however by modifying the relevant documentation the operation could be enhanced. Example: During the RTG simulation the developer's GSE was prechecked by KSC quality before going to the launch pad. This minimized potential impacts to the operation at the pad and was incorporated into the document for future simulations and actual RTG installations.

Modify Operation By modifying the operational approach the causative factor in these cases could be prevented. Example: Personnel performing nonintegrated tasks at the pad on STS-26R did not notify the payload pad leader of their presence, activities, or problems leading to operational confusion. The recommended action was for the payload pad leader to be designated as the main point of contact so as to have a coordinated payload operation at all times.

Modify Support: In these instances, modifying the character of the support was recommended. Example: During the RTG simulation malfunctioning communications boxes delayed portions of the activity such that the operational support was modified to include portable contingency communications boxes as well as a preoperational check of those present.

Establish Study Effort: Incidents characterized by this type of recommendation were such that the optimal course of approach was not immediately apparent. Therefore, it was considered prudent to convene a group of personnel to study the situation and to determine that approach. Example: During STS-26R it was found that photographic support was uncoordinated, in conflict with various organizations, and of poor quality. It was determined that a working group was required so that the relevant organizations could coordinate this activity and establish operating relations.

DOCUMENTATION CATEGORY

Revise the Document: Such incidents required modification to the cognizant documentation, its distribution, or its application. Example: Some tests, such as orbiter-interface, mission sequence, or end-to-end, are performed on successive mission flows. Since the document authors tend to clone documents from past flows they have to be cautioned to remove inapplicable mission-specific items which may be inadvertently included.

Revise Document Review Effort: This approach involved the education of offsite personnel in the method and effort required in the review process. Example: The personnel on STS-34 did not always fully understand the significance of test and operations document reviews and did not always support them with the necessary individuals such that the review process had to be modified at a late date to obtain fully reviewed documents.

HARDWARE CATEGORY

Modify Hardware: The relevant hardware required specific modification to preclude future incidents. Example: On STS-34 a pad hoist leaked oil on the spacecraft sunshade and the hoist was modified with a diaper arrangement to preclude a recurrence.

Repair Hardware: The damaged hardware required repair. Examples: On STS-30R and -34 VPF facility systems broke down and required repair before the operations could be resumed.

SOFTWARE CATEGORY

Modify Software: The relevant software required modification. Example: On STS-26R a TDRS data drop out occurred due to the program having the wrong configuration and the software was modified to deal with this.

Modify Software Use In one case the correct usage of the software was noted and documentation annotated as described above.

BASIC DATA SET

The tables below provide the basic set of numerical data based upon the above characterizations of the incidents and of the recommendations. These are provided in both numbers of incidents and in the form of percentages.

STS FLIGHT	STS-26R	STS-29R	STS-30R	RTG SIM	STS-34	TOTAL
LESSONS LEARNED EVALUATED PER STS MISSION	116	16	25	37	37	231

TABLE I

Individual Lessons Learned Identified and Evaluated
as a Function of STS Mission

Table I presents the total "lessons learned" identified by the test teams as a function of the individual flows. STS-26R, as the first flight in several years, was characterized by the highest number of incidents. STS-29R was basically a repetition of STS-26R from a payload viewpoint and had the least. The other three processing operations had roughly similar levels of incidents.

STS FLIGHT	STS-26R	STS-29R	STS-30R	RTG SIM	STS-34	TOTAL
INCIDENT CATEGORIES	NUMBER/PERCENTAGE OF INCIDENTS PER MISSION PROCESSING FLOW					
OPERATIONAL						
Support Required	18/15.5	3/18.8	7/28.0	4/10.8	8/21.6	40/17.3
Coordination	32/27.6	4/25.0	6/24.0	5/13.5	15/40.5	62/26.8
Planning/Scheduling	14/12.1	2/12.5	5/20.0	3/8.1	3/8.1	27/11.7
Inter-Organizational	29/25.0	6/37.4	2/8.0	5/13.5	9/24.3	51/22.0
Intra-Organizational	9/ 7.8	-	-	1/ 2.7	2/5.4	12/5.2
DOCUMENTATION						
Operational Document	14/12.1	5/31.3	3/12.0	13/35.1	7/18.9	42/18.2
Test Document	17/14.7	-	3/12.0	-	6/16.2	26/11.3
Requirement Document	14/12.1	1/6.3	1/4.0	1/2.7	2/5.4	19/8.2
Incorrect/Incomplete	28/24.1	6/37.4	5/20.0	13/35.1	7/18.9	59/25.2
Not Available	2/1.7	-	-	-	3/8.1	5/2.2
Improper Use	6/5.2	-	-	-	1/2.7	7/3.0
Requirement Unclear	8/6.9	-	-	1/2.7	-	9/3.9
HARDWARE						
Flight	4/3.4	1/6.3	1/4.0	-	-	6/2.6
GSE	8/6.9	1/6.3	2/8.0	13/35.1	2/5.4	26/11.3
Facility	2/1.7	2/12.5	2/8.0	2/5.4	2/5.4	10/4.3
Hardware Found Damaged	1/1.0	-	-	1/2.7	1/2.7	3/1.3
Hardware Damaged by Use	3/2.6	-	-	-	1/2.7	4/1.7
Modification Required	7/6.0	3/18.8	3/12.0	10/27.0	1/2.7	24/10.4
SOFTWARE						
Incorrect Software	4/3.4	-	-	-	-	4/1.7
Incorrect Usage	1/1.0	-	-	-	-	1/.4

TABLE II

Numbers and Percentages Per Mission Processing Flow of
Lessons Learned Documented as a Function of Incident
Area for Each Mission Flow and the Total

Table II presents the characteristics of the incidents with respect to the individual processing flows for the various categories of incident. In addition to the number format, the data is also presented in a percentage format for each processing flow. It should be noted that some incidents may exhibit two characteristics. An incident may also have inter-organizational aspects as well as coordination aspects. A documentation incident may have operational aspects as well as incomplete aspects. Therefore, the numbers of characteristics should not total to the incident total in Table I nor should the percentages per mission total to 100.

STS FLIGHT	STS-26R	STS-29R	STS-30R	RTG SIM	STS-34	TOTAL
<u>INCIDENT CATEGORY</u> <u>RECOMMENDED ACTIONS</u>	<u>NUMBER/PERCENTAGE OF RECOMMENDED ACTIONS PER MISSION PROCESSING FLOW</u>					
<u>OPERATIONAL</u>						
Admonitory	63/54.3	9/56.3	13/52.0	6/16.2	23/62.2	114/49.4
Modify Documentation	9/7.8	-	1/4.0	2/5.4	3/8.1	15/6.5
Modify Operation	20/17.2	4/25.0	11/44.0	5/13.5	14/37.8	54/23.4
Modify Support	2/1.7	-	1/4.0	1/2.7	1/2.7	5/2.2
Establish Study Effort	11/9.5	-	-	7/18.9	1/2.7	19/8.2
<u>DOCUMENTATION</u>						
Revise Document	27/23.3	5/31.3	4/16.0	13/35.1	5/13.5	55/23.8
Revise Review Effort	1/1.0	-	1/4.0	-	1/2.7	2/.9
<u>HARDWARE</u>						
Modify Hardware	27/6.0	3/18.8	4/16.0	11/29.7	1/2.7	26/11.3
Repair Hardware	1/5.2	-	-	1/2.7	1/2.7	6/3.5
<u>SOFTWARE</u>						
Modify Software	4/3.4	-	-	-	-	4/1.7
Revise Software Use	1/1.0	-	-	-	-	1/.4

TABLE III

Numbers and Percentages Per Mission Processing Flow of Recommended Actions as a Function of Incident Category

Table III provides the numerical and percentage data for the recommended actions for each of the STS missions discussed. As with the incidents themselves, the recommended actions are categorized in the same three major and one minor (software) areas. Also, more than one characteristic may apply to a specific incident's recommendation such that the numerical total per mission should not necessarily equal the incident total in Table I nor should the percentages total 100 per mission.

OBSERVATIONS

Consistently, the major area flagged by the lessons learned process appears to be that of coordination, which was a concern in approximately one quarter of the lessons learned incidents. Also, the inter-organizational aspect is a far more prevalent factor than inter-organizational. Incomplete or incorrect documentation is also a major area of concern. Together with coordination concerns, these two areas accounted for over half of the incidents.

Although they do not form a large number of incidents, it is noted that facility systems failures occurred on each mission with two failures on each of the missions.

In the recommended actions area it is noteworthy that approximately half involved admonitory measures. This would involve warnings, cautions, or requests to "be advised" of the threats in a number of situations. A concern with such types of remedial activities is that they are basically heuristic in nature and it is difficult to track the results. Also difficult to track are the study effort recommendations. No mechanism is set up to track these two types of recommendations to determine if they were, or are, being followed.

Revisions to documents were flagged in almost a third of the incidents noted. As with recommendations to fix something damaged, this type of action is basically an after-the-fact approach rather than preventative.

The lessons learned exercise appears to reinforce the idea that operational payload processing is primarily an area where individuals' experiences on the job and past exposure to operations determine how successful they may be in the future. To that end, the formal lessons learned process has great potential in educating personnel in the subject of payload operations.

The lessons learned process at present, however, suffers from its being a non-structured and non-rigorous program. The participation of the test team members may be enthusiastic or it may not. The main objective of the test team is to process a given mission payload and the lessons learned exercise may be considered only ancillary. The test team itself is subject to individualistic factors and to demands on its time such that the lessons learned process may receive much emphasis or little. Also, having completed the gathering of lessons learned, the compilation into a data base is often of low priority. In addition, little effort to analyze the cumulative lessons may be present. on.

It must also be noted that test team personnel are not knowledgeable in operations analysis nor statistical research. It may be presumptuous to expect them to be as enthusiastic or as effective as professional analysts of operational activity might be.

RECOMMENDATIONS

The lessons learned process has the potential of being an extremely effective educational tool in payload processing operations. The emphasis on individual experience which may be passed on through this process and the scarcity of any organized training in operations as such, make it a valuable tool if it is utilized. At present it does not appear to be utilized - rather it is one more task for the test teams to complete. A major causative factor in this is simply the lack of contractor or NASA personnel resources to carry out effective data collection and analysis.

The potential benefits of an effective, consistent, and organized evaluation of these experiences, however, suggest that a vigorous prosecution of the concept may pay dividends far in excess of the cost. This is true especially if trained researchers and analysts are involved. It is therefore suggested that a professional operations research entity be used in conjunction with the test teams to structure, conduct, analyze, and provide the results of the payload processing lessons learned program in the future.