ANALYSIS OF HISTORICAL INTERNATIONAL SPACE STATION PROBLEM REPORTS FOR INSIGHTS INTO SPACECRAFT INTEGRATED ACCEPTANCE TESTING EFFECTIVENESS

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ABSTRACT

This paper presents the methodology used to collect International Space Station (ISS) hardware failure data to be provided to a NASA study. The objective of this collection task was to assemble historical data that could be used in evaluating the value of integrated system level environmental acceptance testing for NASA's Orion spacecraft. The primary data sources were the ISS Problem Reporting and Corrective Action system and Maintenance Data Collection system. The information retrieval process proceeded through an automated data processing phase followed by a manual phase of close analysis of individual reports. The steps in this process are detailed, and the criteria for evaluating the relevance of a given problem report are described.

KEY WORDS: integration & test, acceptance test, environmental test, system level test, problem reporting

INTRODUCTION

The International Space Station (ISS) Problem Reporting and Corrective Action (PRACA) system is used for reporting, processing and tracking space station hardware problems and their resolutions. This system provides a rich source of historical space system engineering information and knowledge. It contains reports of anomalous incidents from all phases of station development and operations, and it is mined by engineers as they design the next generation of exploration spacecraft. The problem with finding lessons learned in the PRACA system is that it was designed specifically for anomaly tracking and with little support for novel information retrieval tasks.

This paper describes a methodology for finding problem reports of a particular theme in the ISS PRACA system. We sought reports that might provide insight into the value of system level acceptance testing. We carried out this activity to collect historical data for a study evaluating the utility of this type of testing for NASA's Orion spacecraft. Orion is NASA's planned spacecraft for future human exploration space missions. The integrated Orion system consists of a partially reusable crew module, the service module and the launch abort system. The ISS PRACA system was included in this study because it has some functional similarity to Orion. In particular, it is a complex space system designed for manned missions.

Broadly, finding relevant reports translates into searching for ISS hardware problems that are similar to problems that Orion might experience during acceptance testing or early in its lifetime. Since system level testing is expensive, the failures identified should be on mission critical hardware and should be of a type that can only be exposed through system level environmental testing.

An initial idea for retrieving relevant reports was to search the PRACA system for failures induced during system level environmental acceptance testing of ISS elements. The ISS element level of assembly was chosen since it was perceived to be roughly equivalent in complexity to the integrated Orion spacecraft. This seemed a straightforward task since PRACA reports have fields to specify assembly level and activity during the time of failure. It was expected that a simple query on these fields should suffice.

Previously, in a pilot study, we examined the efficacy of using keyword search on text fields along with filtering through selection on drop down lists to retrieve PRACA reports. None of the retrieval schemes we developed proved satisfactory. The PRACA system supports limited trending analysis on pre-determined fields such as failure mode. Information that might be useful for other types of analysis and information retrieval is largely contained in the free text narrative fields which are difficult to mine using standard database queries. Further, the PRACA system is used to report a wide range anomaly types making it even more difficult to construct effective queries.

Instead of searching the PRACA system database directly, our solution was to use data from another reporting system, the ISS Maintenance and Data Collection (MDC) system, to locate interesting failure reports. Because of the type of data in the MDC, it was easier in this system to winnow down the data set to a size that could be searched manually.

After finding interesting reports in the MDC system, we cross-referenced these reports with PRACA reports. Our information retrieval process resulted in a set of 24 reports. The failures in the reports were distributed among 9 different ISS systems.

In this paper, we describe our search and retrieval methodology. The results we provided to the study included supplementary information about each failure in addition to the PRACA reports. The research conducted to obtain this additional information is also briefly described here. The actual assessment of the results as they pertained to the acceptance testing study is beyond the scope of this paper.

DATA SOURCES AND METHODOLOGY

Our data sources were the PRACA and MDC systems. The PRACA system is used for reporting, processing and tracking space station hardware problems. The system is used through all phases of development and test on the ground as well as on-orbit. The types of problems reported are wide ranging. The problem might be anything from an anomaly requiring no action, to a crew or mission threatening failure. The PRACA system is valuable because the documentation is comprehensive. Among other things, the reports capture hardware assembly level—e.g. component, LRU (line replaceable unit), subsystem, etc.,— the activity when the problem occurred, failure mode and often an extensive description of the problem, its investigation and, often, its root cause.

The PRACA database can be accessed and searched via a web interface. The interface allows keyword search on most of the free text fields, such as problem title and problem description. For categorical fields, such as failure mode or activity when the failure occurred, the interface employs dropdown menus to facilitate creating queries. For our work, we used the web interface and a spreadsheet containing a downloaded copy of the database.

The MDC system is used by logistics and maintenance engineering groups to track all ISS program maintenance activities. We used the MDC data because it was easer to find actual hardware failures in this system than in the PRACA system. In addition, many MDC reports reference PRACA reports; a PRACA reported anomaly resulting in unscheduled corrective maintenance will be appear in an MDC report. This made it possible to search through the MDC reports to indirectly find PRACA reports of interest. For searching through the MDC data, we used a local copy of the data stored in a spreadsheet.

Recall that our overall goal was to find reports that would provide insight into the value of integrated system level environmental acceptance testing. For our purposes, this translates into retrieving reports of ISS hardware failures that are similar to failures that Orion might experience and that can be perceived through this type of acceptance testing. Further, the problems should be of a serious nature: failures that threaten the crew or mission or failures on critical hardware. Note that not all failures on critical hardware result in severe consequences. For instance, a switch indicator may fail on a valve position. However, for given instances, it may be possible to detect valve function based on temperatures and pressures.

As is often the case with databases, the MDC contained entries with empty fields, and fields were filled out inconsistently. Data cleansing was required before we could sort or filter through the database. Our data cleansing and preprocessing mainly consisted of eliminating any entries with no PRACA reference, and processing the values in the operating-time field so they would have uniform time units.

Both the PRACA database and MDC database contain thousands of entries, making purely manual search unfeasible. Our retrieval strategy was to do a coarse filtering of irrelevant MDC reports using automated means to the extent possible. This would be followed by a finer-grained manual filtering to determine true relevance. The following types of reports were filtered from the initial MDC data set:

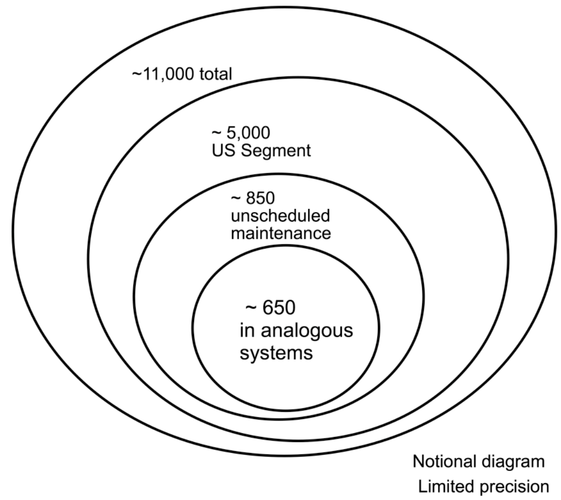

Figure 1. Coarse filtering of reports in the MDC database.
(notional only)

- Failures in the Russian segment,
- Inspection activities
- Preventative and planned maintenance
- Failures in a system that had no analogue on the Orion spacecraft
- Multiple reports for the same problem
- Failures on non-critical hardware
- Time to failure later than 180 days

After applying these filters, the dataset consisted of failures on the U.S. segment that resulted in unscheduled maintenance, occurred on systems that have an Orion analogue and occurred within the first 180 days of operating time.

The rationale for the first six filters is straightforward. We filter preventative and planned maintenance because we were looking for failures that resulted in unplanned corrective maintenance. Inspection activities also do not result from failures. We needed to account for multiple reports since a single problem may generate multiple reports. (For example, if a corrective action spanned several days, a new report might be submitted for each day.) Failures on non-critical hardware are eliminated since the presence of these failures does not justify the cost of system level environmental acceptance testing. Finally, Orion is not susceptible to failures on a system that it lacks. The last filter regarding time to failure has a more complex rational that will be discussed in the next section.

Four of the filters could be performed through automated means and were used to carry out a coarse first filtering pass. These filters were for failures on the Russian segment, scheduled maintenance, preventative maintenance and failures on hardware on non-analogous systems. This coarse filtering removed the greater part of the reports from consideration, and left approximately 650 reports on 9 different subsystems. Figure 1 is a notional view of the first pass of coarse filtering. Human judgment was required to apply the rest of the filters. The details of executing these filters are discussed in the next section.

Once all the failure incidents that could be eliminated using the MDC information were removed, the remaining reports were used to retrieve the associated PRACA reports. These PRACA reports contained more detailed information describing the incident, and, among other things, its root cause (typically) and resolution. In a final detailed manual filtering pass, engineering judgment was used to select the truly relevant failures. This selection process incorporated expert knowledge and reasoning beyond that used in the preceding filtering passes.

DISCUSSION

One direction we pursued was to retrieve reports of ISS element level environmental acceptance test failures on hardware similar to Orion hardware. Our assumption was that if a failure occurs on ISS hardware that is sufficiently similar to Orion hardware, then Orion might be susceptible to the same failure. We developed two criteria to judge if the ISS hardware was sufficiently similar: the hardware is at an assembly level roughly equivalent to the integrated Orion system, and the hardware was part of a subsystem that has an Orion analogue.

In the end we softened the first constraint because the only element level environmental acceptance testing in the ISS program, so far, has been acoustical. We were more interested in thermal and vacuum induced failures. Consequently, this assembly level constraint was changed to allow any assembly level above line replaceable unit (LRU) or orbital replaceable unit (ORU).

Another class of applicable reports is on-orbit problems that might have been avoided or mitigated through integrated environmental acceptance testing. It is generally accepted that integrated environmental testing will uncover failures that are induced by the flight environment since this type of testing is meant to submit the integrated article to a flight-like environment. We then infer that if there is no integrated environmental acceptance testing, then any failure that would have been caught during this testing will manifest when the spacecraft is in flight.

Further, these failures are expected to occur soon after the spacecraft goes into flight. It has been shown that for satellites, environmental testing has a significant effect in reducing the rate of early flight failure, implying that that type of acceptance testing does screen out early failures [1]. The study also found that satellite failure rates slowly decrease after 12 months in flight, suggesting that the infant mortality period lasts less than a year.

To screen for infant mortality failures we filtered failures that occurred beyond the first 180 days of an item's on-orbit operation. We start time-to-failure from the time when the item is put into operation since an item may be in flight for a period of time before becoming operational. The 180 day mark was selected after consulting domain experts.

We synthesized a time-to-failure field because the data in the MDC's operating time field had been filled out inconsistently. Operating time is a text field, so a person has to type in the time and its units. Sometimes these were given in hours, sometimes in days, sometimes with no units or units with question marks or an indication that the time was approximated. Other times, the field was blank or filled in with "N/A", "UNK" or "UNKNOWN." When the operating time was ambiguous or missing, we attempted to find out when the item was put into operation by querying ISS system engineers. If we obtained the operation start date, then we could calculate time-to-failure using the failure occurrence date in the MDC report.

We carried out coarse filtering on the cleansed data set by sorting and filtering the entries using a spreadsheet software application. Following coarse filtering, manual inspection of the approximately 650 remaining reports was used to refine the data set further. For this manual process, we and several system and test engineers reviewed the discrepancy descriptions in more detail. In many instances the MDC report contained too little information to ascertain its relevance. These inconclusive reports were removed from consideration. Other reports were eliminated based on engineering judgment.

At this point, we used the remaining MDC reports to retrieve their referenced PRACA reports. PRACA reports often contain extensive descriptions of the failure, the anomaly resolution process and, often, the root cause analysis. Using detailed information in each report and in consultation with subject matter experts, the final set of PRACA reports was assembled.

The final product provided to the study included an analysis of each of the reported failures in addition to the PRACA reports themselves. This analysis required further research to obtain information that could not be derived from the PRACA reports alone. Then the following information was extracted from the problem reports and using the supplementary research:

- a summary of the problem and its root cause,
- the criticality level of the failed hardware,
- the severity of its mission impact,
- the time to failure,
- whether the root cause was attributed to design or workmanship,
- whether or not the corrective action was a repair and replace,
- whether or not the failure is only detectable by system level environmental testing and
- if the preferred environmental test is thermal, vacuum, thermal-vacuum or other.

Root cause attribution is included because acceptance testing is meant to screen for anomalies resulting from workmanship variability as opposed to design flaws. This analysis was based on a recent study of satellite integrated environmental testing efficacy [2].

SUMMARY AND CONCLUSIONS

We presented a methodology for collecting ISS PRACA reports that provide insight into the value of system level integrated environmental acceptance testing for the Orion spacecraft. A pivotal part of the methodology was using the MDC system, a maintenance and logistics incident reporting system, to indirectly find useful PRACA reports. The methodology used automated means to filter out most of the irrelevant reports. Then a more fine-grained search was carried out manually. We consulted with subject matter experts to make the final selection. The value of this methodology is that it was an effective means of finding high quality reports.

A limitation of our methodology is that it does not necessarily find every relevant PRACA report. For one, it only finds problems that were cross-referenced with reports in the MDC system. Further, we found that random human inspection of the data set occasionally found exceptions to the filtering criteria. Although a problem clearly did not pass a particular filter, someone saw other problem characteristics that made it relevant. This implies that the filters were overly general and likely screened a number of applicable failure reports. On the other hand, this limitation is mainly of significance if a statistical analysis is being performed on the aggregate data set.

Our study was largely qualitative and not quantitative in nature. The greater value of our results lay in its detailed content. The PRACA system is a rich source of engineering knowledge and experience, and we have shown a methodology for retrieving historical reports that are applicable to today's engineering efforts.

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BIOGRAPHIES

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