NASA's Accident Precursor Analysis Process and the International Space Station

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Purpose/Agenda

Purpose:
1. Present an overview of Precursor Analysis being implemented at NASA

2. Present a summary completed Precursor Pilots conducted and future plans

Agenda:
– Background
  » Need for Precursor
  » Definition of a Precursor
– What is Precursor Analysis?
– Pilot Precursor Analysis Summary
– Summary & Conclusion
– Future Work
The Need for Precursor

• CAIB Final Report (October 2003)
  - Section 7.1: “Signals of potential danger, anomalies, and critical information should, in principle, surface in the hazard identification process and be tracked with risk assessments supported by engineering analyses.”

• 2006 ASAP Annual Report in regards to Safety Management
  - “the ASAP found that …the Agency, could better gauge the likelihood of losses by developing leading indicators, rather than continuing to depend on lagging indicators.”

• NPR 8715.3C, “NASA General Safety Program Requirements” (March 2008)
  - 2.5.2.2 System engineers shall:
    » d. Ensure that the system safety models are developed in an iterative process to allow model expansion, model updating, and model integration as the design evolves and operational experience is acquired (Requirement).
    » Note: Relevant leading-indicator (or precursor) events should be documented and evaluated for their impact on the system safety analyses assumptions. Trending of these precursor events should be conducted and contrasted to applicable PMs.

  - 2.5.4.1 Project managers shall ensure that the performance attributes and precursors that are identified as being important indicators of system safety are monitored (Requirement).
Background

• Definition of a “precursor”
  – An indication of a problem with the potential to recur with more severe consequences

• Key Attributes:
  – Observation (IFI, PRACA) indicates some “failure mechanism”
  – Same mechanism could occur again
  – The consequences could be more severe than what has been experienced
Columbia accident was actually preceded by a direct accident precursor, STS-45. Post flight inspection of the right Reinforced Carbon-Carbon leading edge found two gouges.

Corrective Action Taken: Panel Replaced

- This solved the immediate condition, but did not eliminate the mechanism for more dire consequences.
Operational Definition of Precursor

• Historically, precursor analysis has been focused on failures, e.g., at Nuclear Regulatory Commission

• NASA process extends focus to anomalies
  – NASA’s databases contain mostly anomalies (a defect, fault, or other deviation)
  – NASA has a stronger incentive to prevent any failure due to fewer barriers in its space systems

• Operational definition of precursors:
  Anomalies that upon evaluation are determined to indicate a failure mechanism that may pose a significant degree of risk
Background

Examples of Precursors

- A near-miss because of chance or an opportune mitigation
- Faults that without correction can lead to severe outcomes
- Unexpected trend in test or operational data
- Reduced repair/maintenance effectiveness
- Unexpected effects from aging of equipment
- Common causes of faults or deteriorations
What is Precursor Analysis?

- Evaluates IFI (In-Flight Investigation) and PRACA (Problem Reporting and Corrective Action) data to identify unrecognized accident potential or underappreciated vulnerabilities, so they can be addressed/mitigated in a timely manner
  - i.e. looking at your operating data, performance, and experience

- Precursor analysis focuses on aspects of reality that need attention by decision-makers

  - Conditions whose risk potential is not understood in current models (e.g., O-rings, External Tank debris, potential for vessel head to be corroded from the outside)

  - Performance issues whose potential is understood in principle, but whose risk-significance is not
Real World vs. Models

Systems / Operational Practices
- Shuttle
- ISS
- Robotic Missions
- Ground Facilities

Operational Off-Nominal Data
- In-flight Anomalies
- Non-conformance cases
- Failures
- Faults
- Others

Collection and Analysis of Operational Data (e.g. failure, faults) Supports Development of Models, including identification of hazards

Management Decisions and Actions

Modeling / Analysis
- Updating the model based on new hazard analysis and experience

Safety and Performance Model
- Hazard Analysis / Reports
- Engineering Analysis
- Risk / Reliability Models / PRA / and others

Risk-Informed Safety Case
- Performance Allocation
- Implied Resource Allocation
- Performance Commitments Processes
- Input to Risk Management

Risk Information Input

Management Decisions and Actions

Organizational Learning
What is Precursor Analysis?

- **Precursor Analysis**
  - Screens observed anomalies for need to perform evaluation
  - Evaluates and dispositions events into three categories
  - Performs detailed analysis of selected anomalies

- Makes risk analysis more experience-based

“A failure mechanism that is benign when it occurs under one set of circumstances may not be benign under another.”
Pilot Precursor Summaries

- Objective
  - Exercise the Accident Precursor Analysis (APA) Process developed for the ISS

- Two Pilot sessions were held in 2010
- March 2010 - the Electrical Power System (EPS)
- August 2010 – Communications and Tracking (C&T) along with Command and Data Handling (C&DH)
  - 1.5 days dedicated to anomaly review and generalization
  - 1.5 days dedicated to grading of anomalous conditions
  - Constrained focus of session to the respective system anomalies and did not investigate across all ISS systems
Anomaly Review Results

- A caseload of 40 EPS non-conformance records was produced for the working session and all records were reviewed.

- Many records, however, were screened out from further APA evaluation.

![Pie chart showing Anomaly Review Results]

- 17 Records
- 11 Records
- Anomaly Fully Reviewed
- Redundant Anomalous Condition
- Discovered During Acceptance Testing
- Not An Anomaly
- Insufficient Information to continue APA evaluation
- Records pursued for APA evaluation
- Screened out from further APA evaluation
Generalization Results

- Of the 28 Anomalies which were fully reviewed, 15 Generalized Potential Failures (GPFs) were created
  - Total of 33 anomalous conditions (both observed and postulated)

![Bar chart showing the number of anomalous conditions per anomalous event report.](chart.png)
Example Walk-Through Diagram of an ISS Anomaly

**Observed Anomaly**
Ungrounded Connectors on Jumper W3301P1. Jumper were designed without a grounded backshell; original cables needed grounded backshell. Design flaw exists in some IVA and EVA cases.

**Failure Mechanism**
Design Flaw

**Component Type**
Jumper Cables with Ungrounded Backshell

**Observed Anomaly**
Failure Condition of Concern: possibility for electric shock to a crew member (>32V, 3A) during nominal activities

Not recommended for further evaluation

**GPF #1**
Failure Condition of Concern: possibility for electric shock to a crew member (>32V, 3A) during IVA maintenance

Recommended for further evaluation

**Failure Condition Index**
Graded unexpected that a ungrounded jumper cable could cause electric shock to a crew member during IVA maintenance

**Conditional Consequence Index**
Graded probable that electric shock to crew could cause loss of crew

**GPF #2**
Failure Condition of Concern: possibility for molten metal generation to occur during EVA

Recommended for further evaluation

**Failure Condition Index**
Graded unlikely that a ungrounded jumper cable could cause molten metal generation during EVA

**Conditional Consequence Index**
Graded probable that generation of molten metal on EVA could cause loss of crew

**Evaluation & Grading**

**Recommended Further Action**
- None
- Risk Modeling
- Observation & Trending

**Anomaly Review & Generalization**
Not recommended for further evaluation

**Recommended Further Action**
None
Grading Results (cont)

- All Anomalous Conditions Recommended for Evaluation

- Risk Modeling Threshold
- Observation & Trending Threshold

Potential Problem Index

Anomalous Condition #

- Consequence Outside of EPS System & System Expertise of Session
Results Summary

process completed for 40 anomalies over ~3 days

- 40 Anomalies
- 28 Evaluated
- 15 GPFs
- 28 Anomalies
- 15 recommended for grading
  - 3 recommended for Risk Modeling
  - 3 recommended for Observation & Trending
  - 9 deemed low risk requiring no further analysis
  - 3 had consequences outside of the evaluated system and the expertise of the session

- Insufficient information/Acceptance Test/Non-Anomaly Records
- Of those 40 records, 28 anomalies were not screened from further evaluation

- Generalization

- Grading
Results of Screening Criteria

• 1 screen identified
  – Screen out records recorded during acceptance testing
  – Requires search in the “detected during field” for “acceptance” or “ATP”
  – Only applies to PRACA reports

• Other areas for potential screens did not return results
  – Both “open” and “closed” records had sufficient information to complete generalization
  – The type of report (IFI or PRACA) did not reflect any non-applicability to the APA process
  – Records recorded both “on-orbit” as well as at NASA or contractor facilities were found sufficient to generate GPFs
Summary & Conclusion

- Accident Precursor Analysis (APA) has been used by other govt agencies with positive results (e.g., NRC)
- Intended to be applied outside the normal problem resolution cycle
- Establishes a foundation for experience-based analysis and trending of actual events from ISS, and Exploration technology demonstrators, and testing to help build more reliable and safer systems.
- Timely implementation provides the possibility of completely avoiding these events
• Successfully demonstrated that Precursor Analysis is implementable on the ISS

• Both PRACA and IFI records were evaluated, and both provided valid risk information to support the process

• ISS experts noted that the Precursor exercise gave them a different perspective on the anomalies reviewed
Future Work

- Future Work
  - Have made the Precursor Analysis part of the Fiscal Year 2011 baseline work plan
Back-up
NASA APA Process

Anomalies

Screening and Dispositioning

Screen

Dispositioning
Grade the potential impacts to safety

Generalization
Apply the mechanism to different circumstances

Analysis
Risk Modeling

Results

Findings
Complete results, reconciling the model with reality

No Further Action

Observation & Trending
Well-Known Precursors

**Anomalies**

- Challenger:
  - O-ring blow-by
  - Debris impacts on thermal protection system

- Columbia:
  - Frequent Containment Air Filter Replacements

- Davis-Besse NPP:
  - Other Observed Anomalies

**Potential) Failures**

- Severe Burn-through, ET containment compromised, Loss of Shuttle
- Severe RCC Impact, Loss of Shuttle on re-entry
- Significant Vessel Head Erosion
- Large Loss of Coolant Accident

How do we focus on risk-significant anomalies?