Precursor Analysis for Flight- and Ground-Based Anomaly Risk Significance Determination

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Need for Precursor Analysis

- **CAIB Final Report (October 2003)**
  - Section 6.1: "The Board notes that although there is a process for conducting hazard analyses when the system is designed and a process for re-evaluating them when a design is changed or the component is replaced, no process addresses the need to update a hazard analysis when anomalies occur."
  - 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."
  - Finding 7.4-5: "Risk information and data from hazard analyses are not communicated effectively to the risk assessment and mission assurance processes. The Board could not find adequate application of a process, database, or metric analysis tool that took an integrated, systemic view of the entire Space Shuttle system."

- **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."
“Swiss Cheese” Concept of Precursor Analysis

- Ordinarily, accidents are prevented by a combination of barriers (human and hardware system features to prevent accidents)

- Complete pathway through cheese represents accident
- Precursor conceived as partial pathway through the holes in Swiss cheese
- Precursor analysis then corresponds to learning about existence and size of holes
“Precursor” Definition

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

• Key Attributes:
  – Observation indicates some failure mechanism
  – Same mechanism could occur again
  – The consequences could be more severe than what has been experienced
Anomaliies

Challenger

Severe Burn-through, ET containment compromised, Loss of Shuttle

Columbia

Debris impacts on thermal protection system

Severe RCC Impact, Loss of Shuttle on re-entry

Davis-Besse NPP

Frequent Containment Air Filter Replacements

Significant Vessel Head Erosion

Large Loss of Coolant Accident

Other Observed Anomalies

How do we focus on risk-significant anomalies?
Examples of Types of Precursors

- A near-miss because of chance or an opportune mitigation

- Faults that can become failure conditions without correction

- Unexpected trend in test, operation, or maintenance

- Unexpected effects from aging of equipment

- Common causes of faults or deteriorations
Accident Precursor Analysis

• Establishes a systematic process for evaluation of flight and test anomalies
  – Risk-based evaluation of failure mechanisms
  – Triggered by actual flight/test experience
  – Emphasizes ‘imagination’ through generalization

• Provides insight into safety performance
  – Identifies safety-related system vulnerabilities
  – Indicates trends in safety performance

• Makes safety analysis more experience-based
  – Triggers review/modification of safety models based on analysis findings
    • Completeness of represented failure modes
    • Failure probabilities and influencing factors
Real World vs. Models

- Our Systems
  - Shuttle
  - ISS
  - Robotic Missions
  - Ground Facilities

- Safety and Performance Model
  - PRA
  - Reliability Model
  - Trending Model
  - Accident Precursor Model
  - Others

- Collection and Analysis of Operational Data (e.g. failure, faults)
  - Good Fit? Or Not?

- Results of the Model
  - Predicted System Performance
  - Trends and Temporal Behavior
  - Risk Importance
  - Risk/Failure Significance
  - Determination
  - Others

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

- Updating the Model based on Experience

- Feedback

- Management Decisions and Actions

- Risk Information Input

- APA Allows us to Improve the Fidelity & Accuracy of our Models
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.
NASA APA Process

Anomalies

Screening and Dispositioning

Screen
- Yes
  - Dispositioning
    - Grade the potential impacts to safety
  - Generalization
    - Apply the mechanism to different circumstances
- No

Analysis
- Risk Modeling
  - Quantify the impacts
- Observation & Trending

Results
- Findings
  - Complete results, reconciling the model with reality

No Further Action
Anomaly Dispositioning Model

- Other failure times
- Other systems
- Other locations on the affected system
- Larger fault magnitude
- Anomaly failure mechanism

Mechanism active within subsystem or component
Potential for Failure Conditions of Concern
Potential for Severe Consequences
Problem Potential Index

- Generalization
- GPFs

4
7
9
5
Disposition Pathways

- Anomalies without obvious risk- or reliability implications are removed from consideration using rules-of-thumb.

- Failure mechanisms of screened-in anomalies are determined and generalized.

- Dispositioning is based on:
  - Generalized problem potential
  - Evidence caliber
Probabilistic Analysis

- Parametric Probabilistic Modeling & Risk Significance Assessment
  - Quantify the risk potential for anomalies and GPFs dispositioned for Risk Modeling
  - Provides a rigorous assessment of the quantified risk significance of the failure mechanism acting within the system while also highlighting parametric uncertainties of the accident sequences that should be further investigated

Scenario Development for Events Dispositioned for Risk Modeling

PPM Results

Anomaly Risk Importance & Parameter Vulnerability Analysis
Example Space Shuttle Working Session Results

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Observation & Trending

Rule-Based Screen Out
Closing Remarks

• 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
• Development of NASA APA methodology will continue in 2010