Ascent Summary Data Analysis Tool (ASDAT) for Shuttle Wing Leading Edge Impact Detection

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Talk Outline

• WLE IDS System Overview
• Manual analysis procedure
• Automation Updates:
  – ASDAT heuristic approach to analysis (peak detection & classification)
  – PGrms vs. PGrmsF
  – Refine the ASDAT results with IMS, Orca & C4.5
• Work in progress
Wing Leading Edge Analysis

• Brought about by the Columbia tragedy – Foam impact cracked a panel of the Columbia Shuttle’s wing leading edge during ascent.

• Led to required monitoring of Wing Leading Edges during Shuttle ascent:
  – 132 1-D accelerometers were added behind the spars in the Shuttle wings, including some redundant sensors.
  – 20 KHz sensor data is collected during launch & ascent.
  – Sensor data summary files are downloaded & transmitted to Mission Control.
  – Human analysts pore over the summary files to identify potential impact events.
Space Shuttle Diagram
WLE IDS System Overview
Typical WLE IDS
raw data ascent profile
Summary of Current Approach by JSC WLE MER analysts

• 6+ hours after launch 5 types of summary files are downloaded from the Wing Leading Edge (WLE) accelerometer sensors

• MER analysts view the summary files using a Boeing-developed Matlab tool (IDAT)
  – Visual representation of the summary files
  – Criteria was developed by analysts to help quantitatively categorize peaks that may be impact events
  – Based on initial analysis of summary file(s), raw data is requested when “interesting” peaks are identified

• Within the 24hrs of launch, a list of possible WLE impact locations that may warrant visual inspection is submitted to mission management
WLE IDS
Automation Goal

- Automated detection of possible impact events
- Intended as an analyst tool, not an analyst replacement
  - Identifies possible impacts worthy of further investigation to help focus analyst attention on a subset of the data
Ames’ Ascent Summary Data Analysis Tool (ASDAT)

**Peak Detection & Classification**
- Identifies peaks on each sensor channel
  - Determines a background value for each time window
  - Uses a threshold value appropriate to the summary data type
  - Peaks > background value + threshold = Peak of interest (possible impact)
- Maps peaks to WLE panel locations
  - Distinguish global (full vehicle non-impact) and local events
- Classifies each peak
  - Strong w/ local taper (adjacent lower values, see Fig)
  - Strong
  - Moderate
  - Weak
  - Global

**Collates & sorts results from all summary file types into master list**
- Simultaneous events on nearby sensors can be combined and identified with the sensor with the highest response
- Reports generated for each type of summary file and then cross correlated
ASDAT
Processing Steps FlowChart

Peak Detected? Y

Check for simultaneous peaks on other sensor channels

Global Event? Y

Local Event:
sort & collate

Prioritized Event List

strong
weak

low priority

N

N

N
ASDAT Output
Refined by Other Tools

• ASDAT output list still too long. Need a way to reduce the list to the most relevant items.

• For STS-115 & STS-116, these tools were evaluated:
  – IMS: Anomaly detection method using clustering
  – Orca: Distance-based outlier method
  – C4.5: Decision-tree

• The results from each method were cross-correlated. Results making multiple lists were given higher credibility.
Inductive Monitoring System
Learns how the system typically behaves and tells you if it is behaving differently now.

LEARNING / MODELING

- SYSTEM TO MONITOR
- Archive or Sim. Nominal data
- DATA VECTORS
- NOMINAL OPERATING REGIONS
- MONITORING KNOWLEDGE BASE
- IMS KB

IMS learns nominal system behavior from archived or simulated system data, automatically builds a “model” of nominal operations, and stores it in a knowledge base.

MONITORING

- SYSTEM TO MONITOR
- Real time data or other data to be analyzed
- IMS MONITORING ALGORITHM
- HEALTH PRESENTATION
- IMS KB

IMS real time monitor & display informs users of degree of deviation from nominal performance. Trend analysis can detect conditions that may indicate an incipient failure or required system maintenance.
STS-121 Results

IDAT Results

IMS Identified Points of Interest

69.848, 1031-J3, 139, 1396969, PG, P 19/20L, 5.11
Orca

• Developed by Stephen Bay and Mark Schwabacher under a cooperative agreement between NASA ARC and ISLE

• An unsupervised anomaly detection algorithm
  – Uses a nearest-neighbor approach
  – Uses average distance to nearest points in data as anomaly measure

• Uses a novel pruning rule to run in nearly linear time

• Has also been used to find anomalies in historical SSME data, ISS CMG data, aviation safety & security data, and Earth science data

• Generic C++ code
**STS-121 Results**

**ASDAT Results:**
- ASDAT found ~91% of the interesting events that made it onto the initial WLE MER analysts log.
  - Of the events missed by ASDAT only 1 was above the 1 Grms minimum threshold.
- All possible impact events reported in the WLE IDS Post Ascent In-Flight Report made the ASDAT log as either a Moderate event or higher.
- ASDAT analysis found 4 additional peaks which we identified as potentially interesting (all above 1 Grms).
  - The JSC WLE MER team requested raw accelerometer data download for all four events. Their conclusion:
    - 2 noisy backgrounds;
    - 1 early triggered event.
    - 1 aeroacoustic transient.
  - None of the four peaks were categorized as impacts by the WLE MER team.

**Results from other Ames tools:**
- The Inductive Monitoring System (IMS) was used to compare the STS-121 WLE summary data to STS-114 WLE summary data (used as a baseline)
- Orca was used to search for outliers in the STS-121 WLE summary data.

  *IMS & Orca found all events reported in the WLE IDS Post Ascent In-Flight Report.*
The IMS tool compared the STS-115 WLE summary data to baseline data collected during the STS-114 & STS-121 missions.

Orca was used to search for outliers (unusual points) within the STS-115 data itself.

Both methods identified the significant events selected by MER analysts as points of interest and show promise for helping to confirm and refine ASDAT results on future missions.

In addition, ASDAT results were classified with a decision tree built from analyst results from the last two missions.
  - Automatically constructed using the C4.5 software package
  - Used to identify events in the STS-115 ascent data that closely matched events the analysts identified as interesting on previous flights.
  - The C4.5 classification identified 80% of the significant STS-115 events.

Based on expert suggestion we automatically compared the ASDAT PGrms & PGrmsF outputs to each other with the intention of identifying the peaks that remained post-filtering. Much less successful than expected.

*IMS & Orca performed well on both STS-115 & STS-116*
Concluding Remarks

• Treating the Shuttle wing impact identification problem as an anomaly problem, thus using anomaly detection tools & techniques to identify possible impacts, shows promise.

• The learning techniques were more successful than one would have thought.
  – Even with few flights to train on.
  – Apparently WLE IDS data are fairly consistent across Shuttle flights and between orbiters.

• Eventual goal is to automatically combine the techniques we evaluated (the good ones anyway) and rank AOIs based on the aggregate support of multiple analysis methods.
Questions?

Thank you.
Backup Slides
Peak Detection / Classification

• Automatically find peaks on each sensor channel in PGRMS, PGRMSF, TGRMS, & TGRMSF summary files
• Analyze local and global characteristics in small time windows (to account for DET offset) and classify each peak

• Classes are:
  T - Strong w/ taper  Peaks on 2 adjacent interfaces that taper w/ distance
  S - Strong         Peaks on 2 adjacent interfaces without taper
  M - Moderate       Peaks on 2 local sensors
  W - Weak           Peak on one sensor only
  G - Global         Peaks more than 6 interfaces

• Collate results from all summary file types into master list
Draw a background line at $G_{\text{rms}}$ value with min. of $N$ data points in time window above that level.
ASDAT
Summary File Peak Detection Overview

Slide line up above data points within a background threshold delta
Points remaining above the line are considered peaks
IMS analysis of normalized WLEIDS data collected from the STS-114 mission has produced characterizations of patterns expected during quiescence and periods of known vehicle activity.

Downlinked data samples from future missions can be compared to these patterns for correlation to expected nominal conditions.

IMS identified deviations from expected nominal conditions may indicate possible impact events and prompt further investigation.
### Collated Output Sample

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<th>PG</th>
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<td>1239.590000 T 3 P 9</td>
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</tbody>
</table>
IMS WLE IDS response to LO₂ and LH₂ feedline disconnects vs. background signal

WLEIDS Unit 1036 STS-114 Ascent
Samples 10549493 - 10559493

Graph showing IMS WLE IDS response to LO₂ and LH₂ feedline disconnects vs. background signal.