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

Data Mining in Aeronautics Science and Exploration Systems Conference

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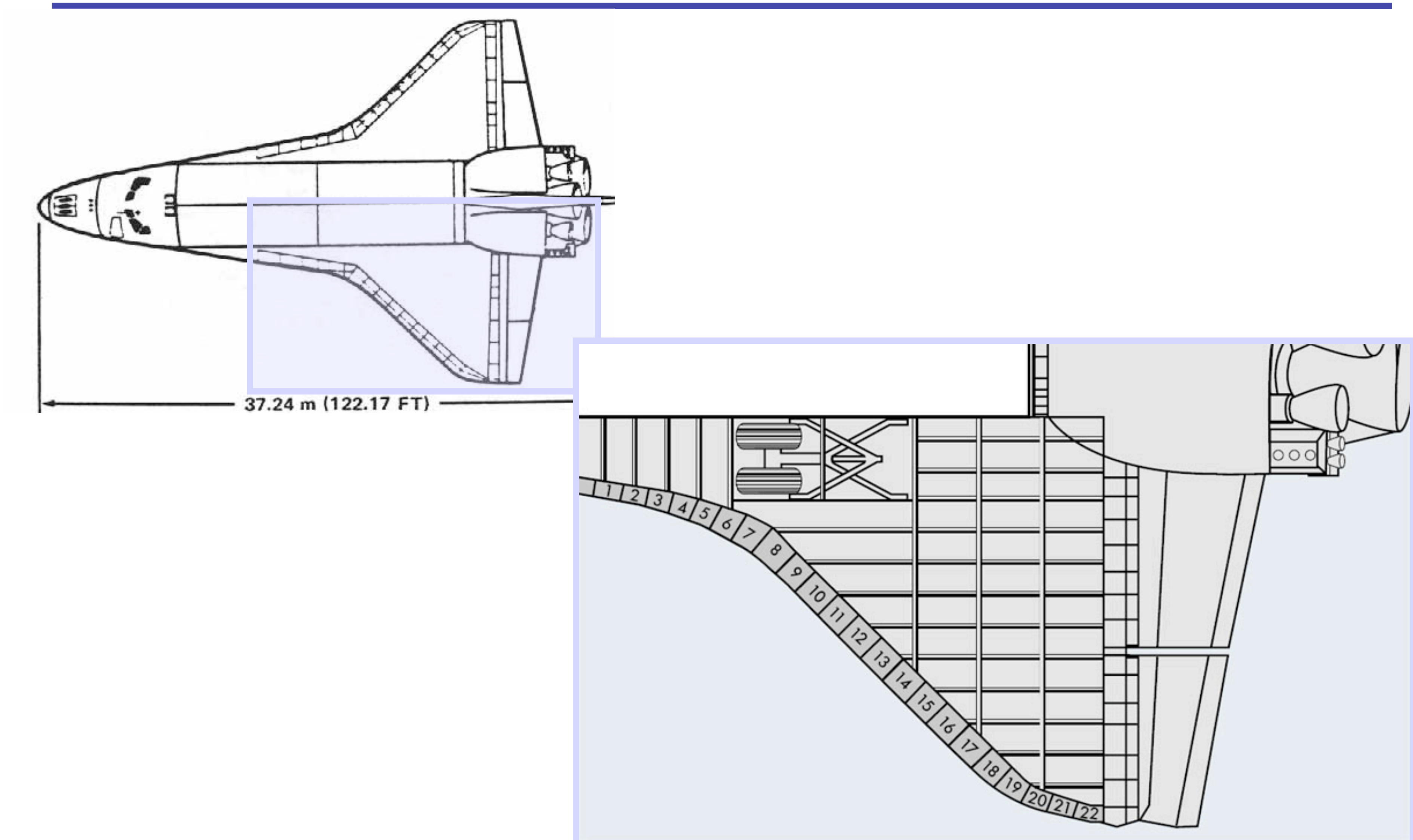
Talk Outline

- 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

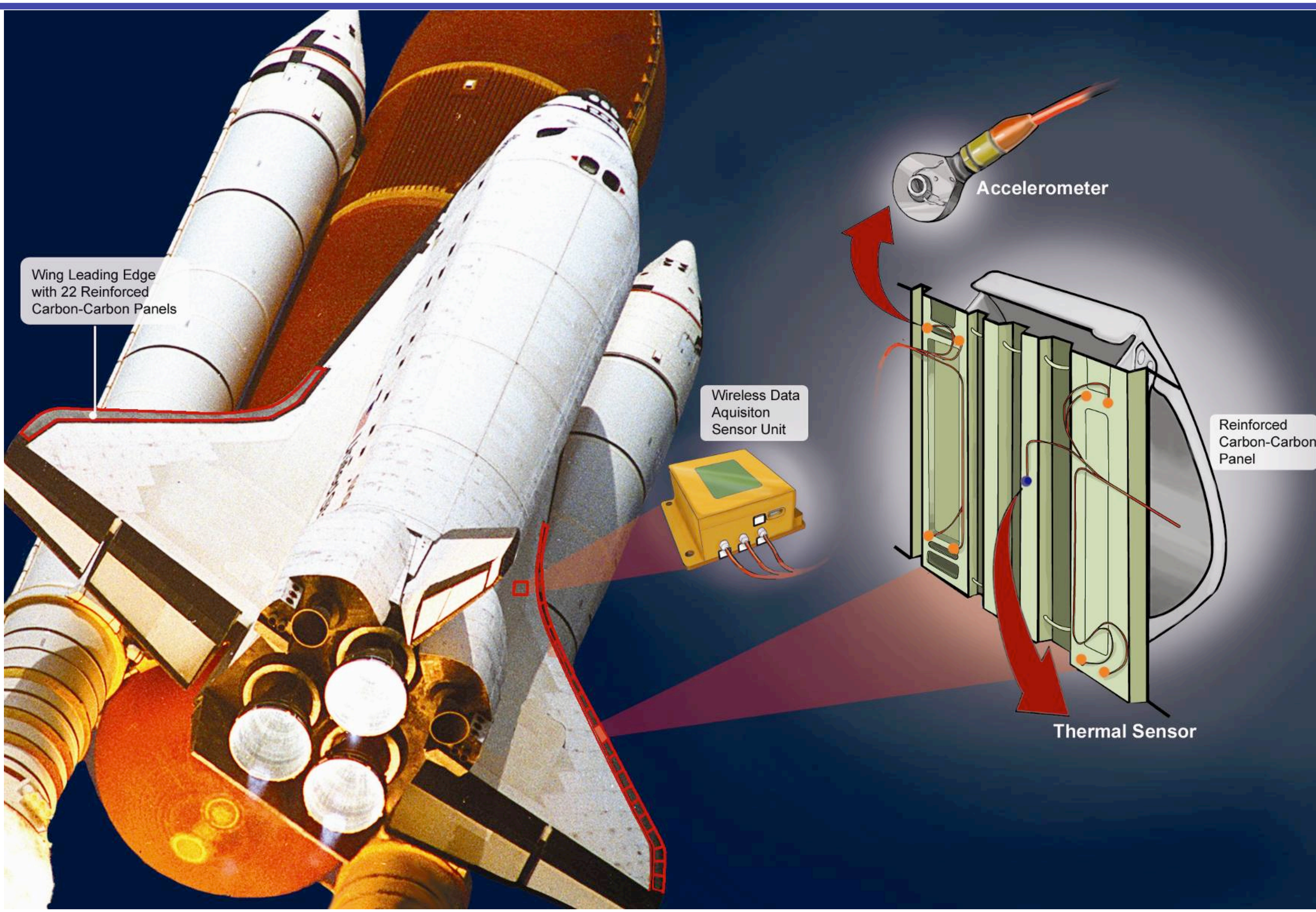
Wing Leading Edge Analysis

- 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.

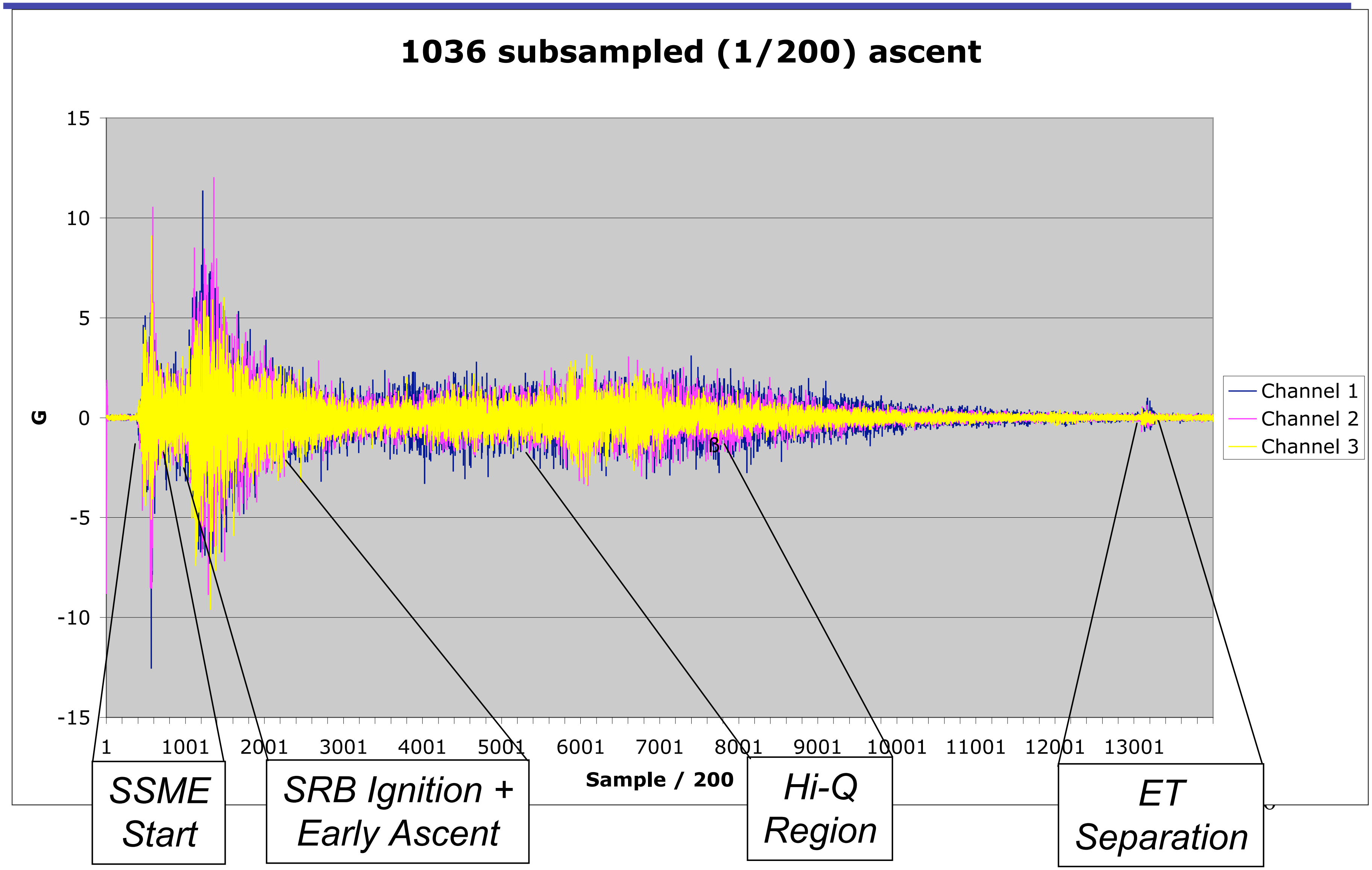
Space Shuttle Diagram



WLE IDS System Overview

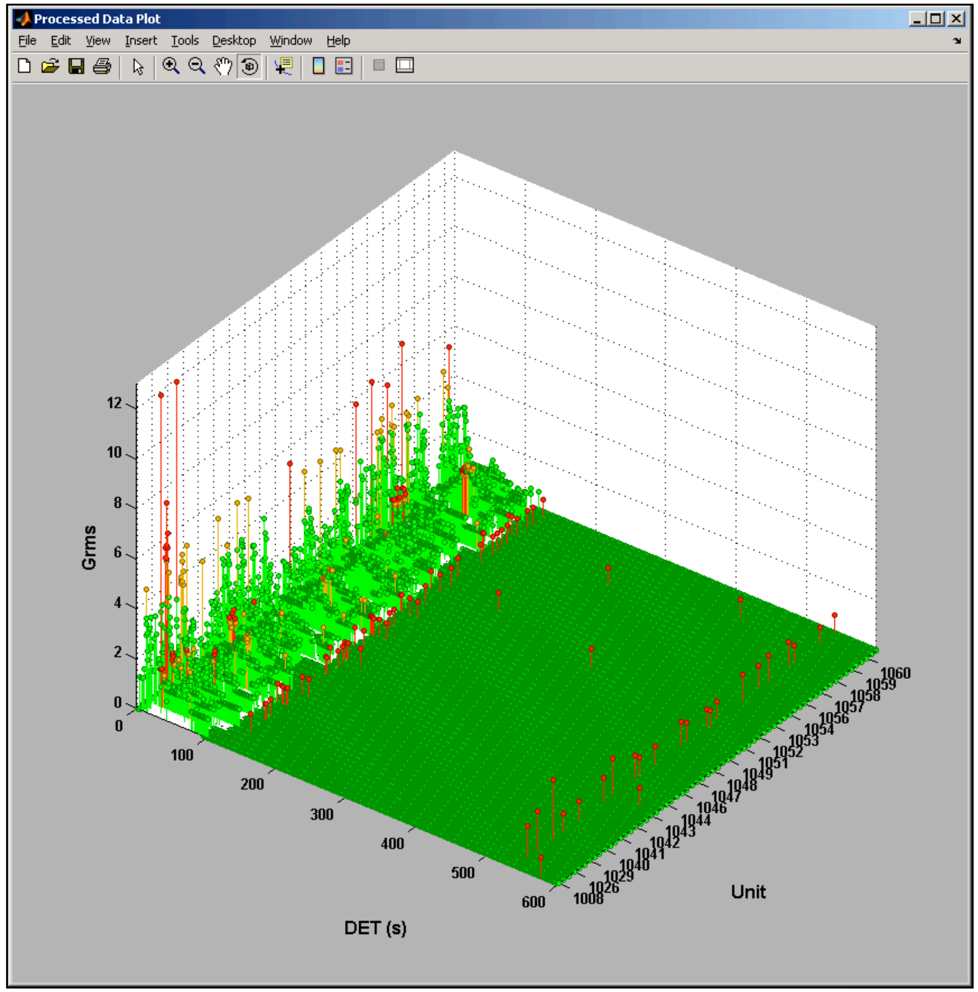


Typical WLE IDS raw data ascent profile



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



Screenshot of summary data display in the Impact Data Analysis Tool (IDAT)

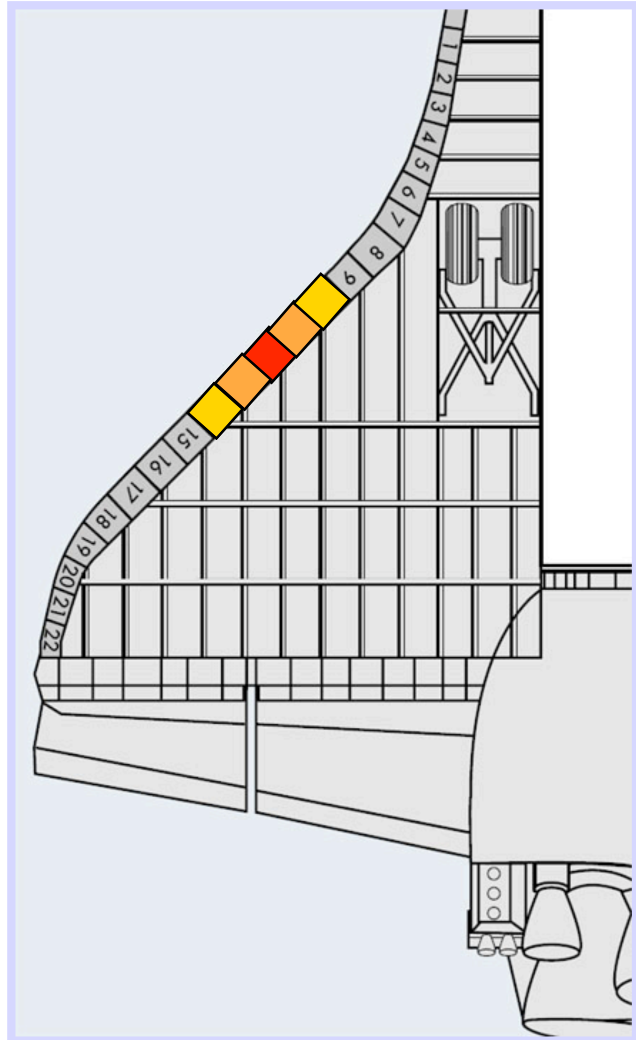
WLE IDS Automation Goal

- 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)

<u>**Peak Detection & Classification**</u>

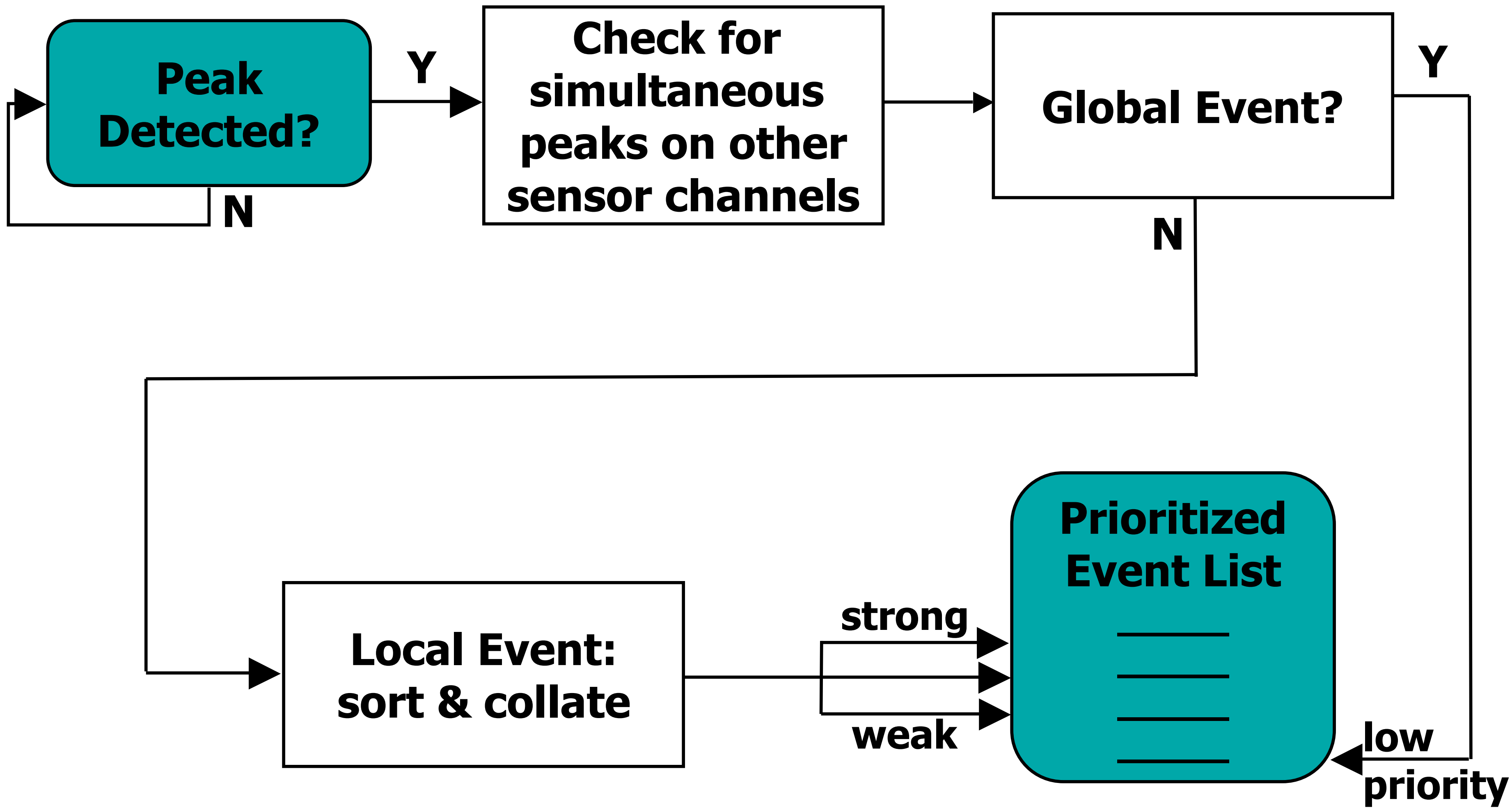
- Identifies peaks on each sensor channel
  - Determines a background value for each time window
  - Uses a threshold value appropriate to the summary data type
  - Peaks > background value + threshold = Peak of interest (possible impact)
- Maps peaks to WLE panel locations
  - Distinguish global (full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



<u>**Collates & sorts results from all summary file types into master list**</u>

- 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



ASDAT Output
Refined by Other Tools

- ASDAT output list still <u>too</u> long. Need a way to reduce the list to the most relevant items.

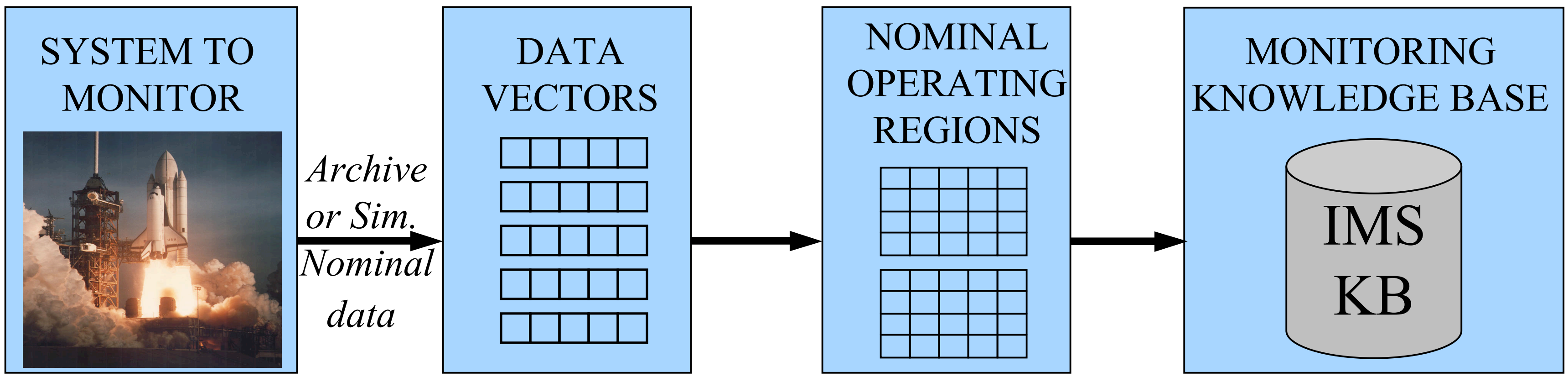
- For STS-115 & STS-116, these tools were evaluated:
  - **IMS**: Anomaly detection method using clustering
  - **Orca**: Distance-based outlier method
  - **C4.5**: Decision-tree

- The results from each method were cross-correlated. Results making multiple lists were given higher credibility.

Inductive Monitoring System

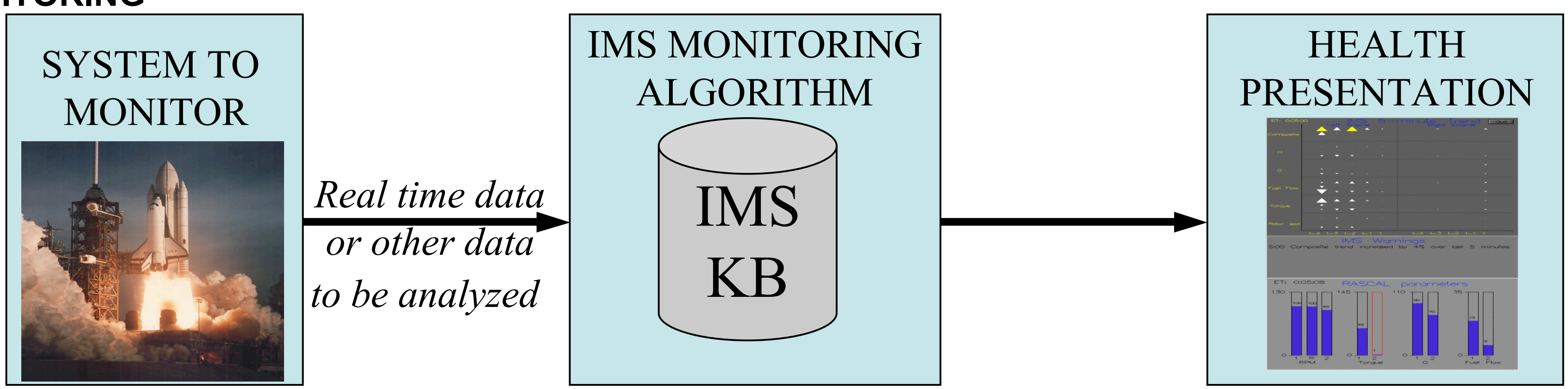
Learns how the system typically behaves
and tells you if it is behaving differently now

LEARNING / MODELING



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.

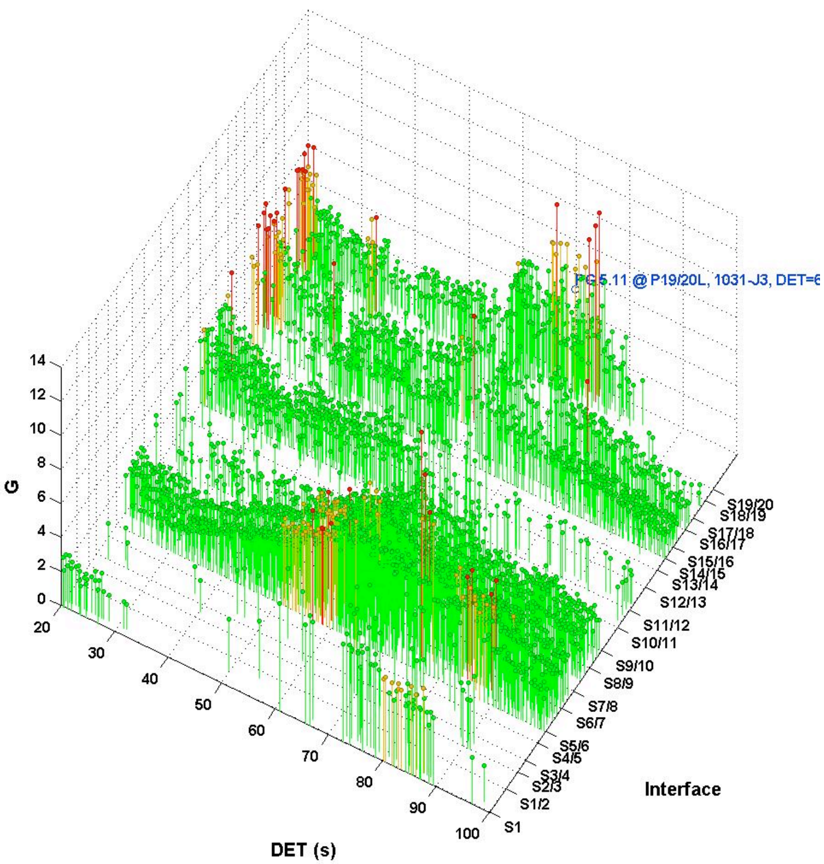
MONITORING



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.

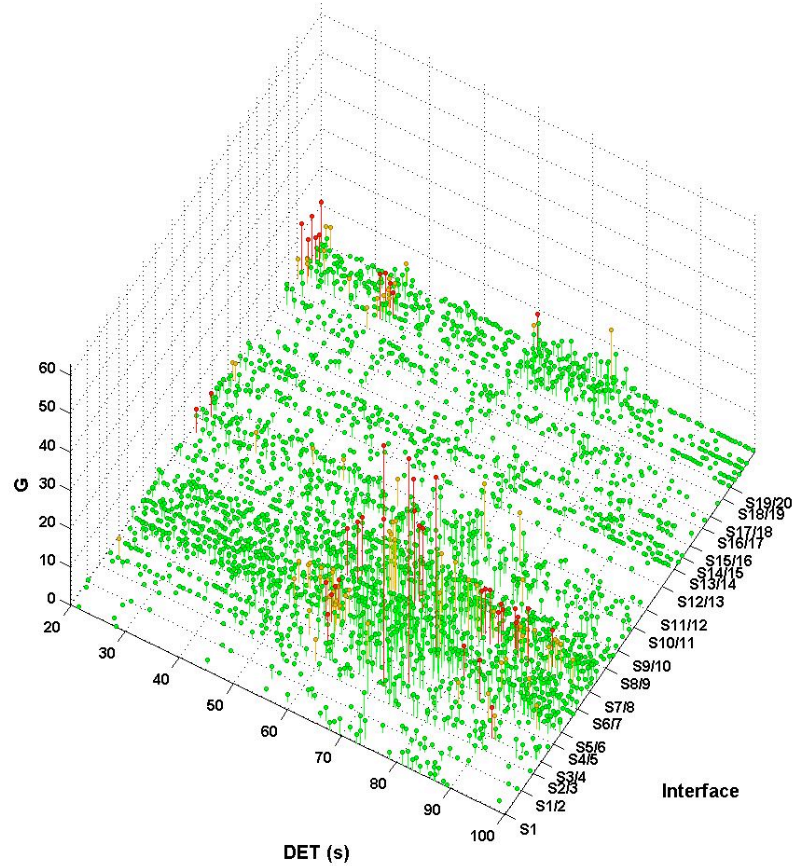
STS-121 Results

IDAT Results



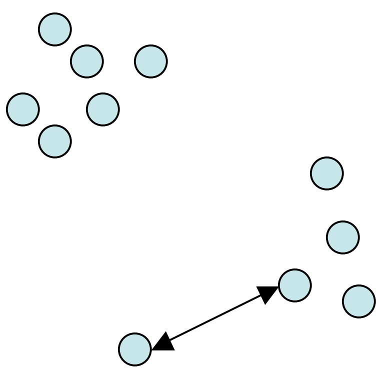
69.848, 1031-J3, 139, 1396969, PG , P 19/20L, 5.11

IMS Identified Points of Interest



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.

STS-115 & STS-116 Results (More Tools)

- 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 PG PGRMS PGRMSF TGRMS & TGRMSF summary files
- Analyze local and global characteristics in small time windows (to account for DET offset) and classify each peak

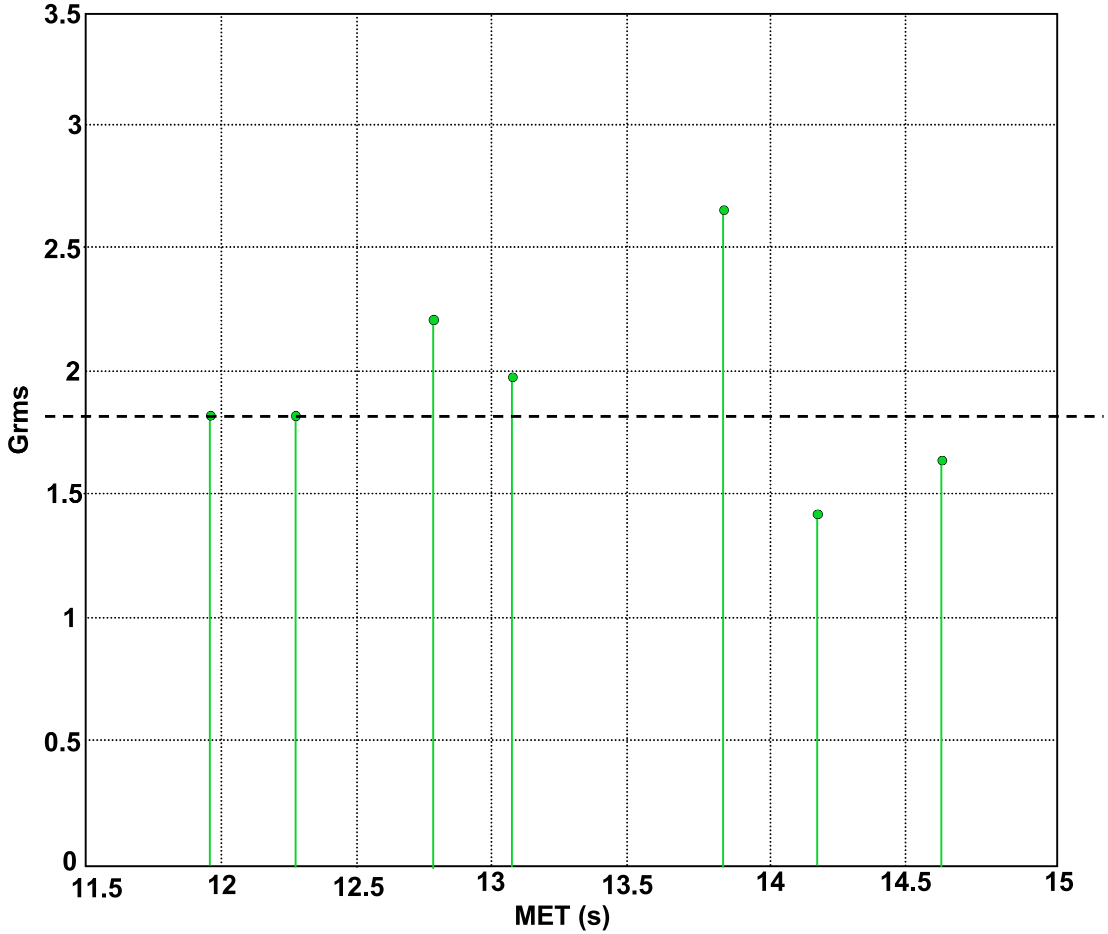
- Classes are:

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

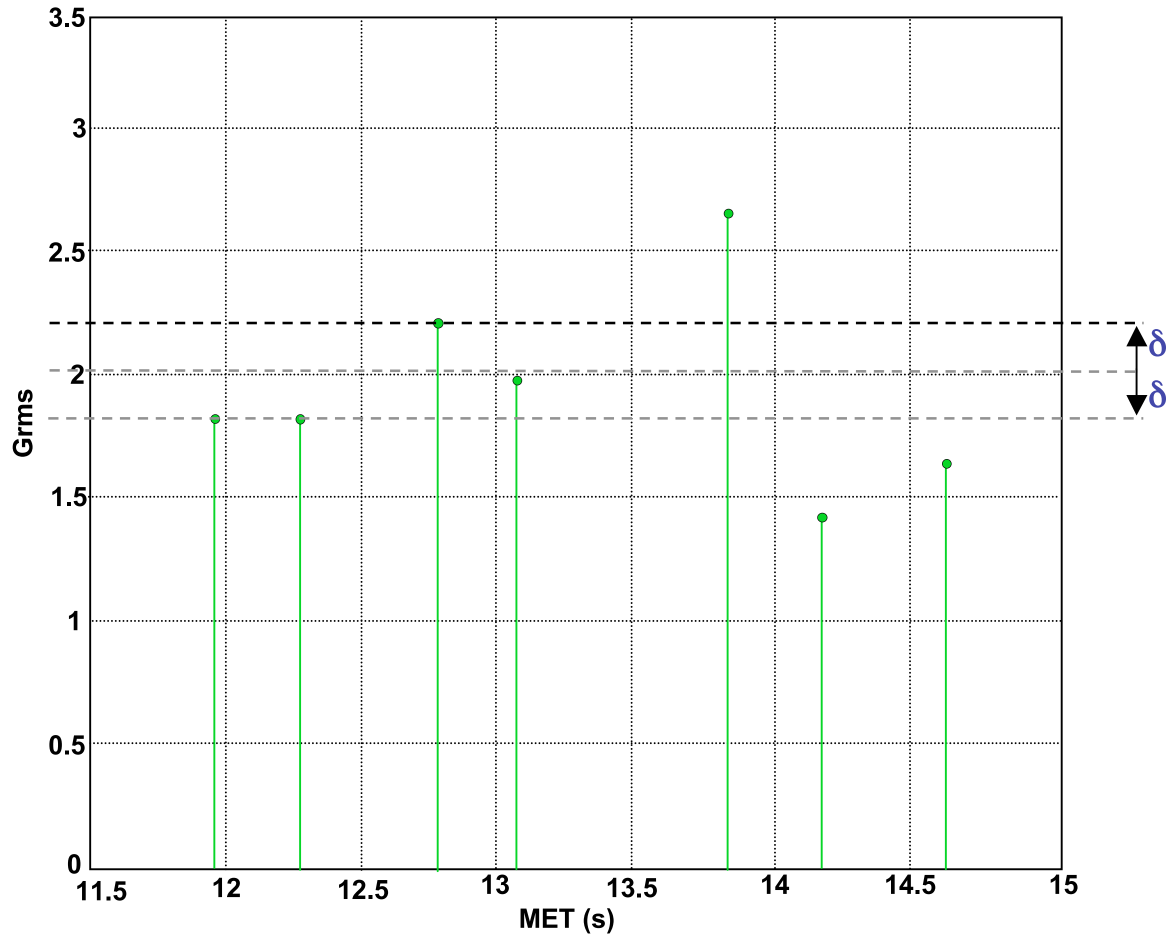
ASDAT Summary File Peak Detection Overview

Draw a background line at Grms value with min. of N data points in time window above that level



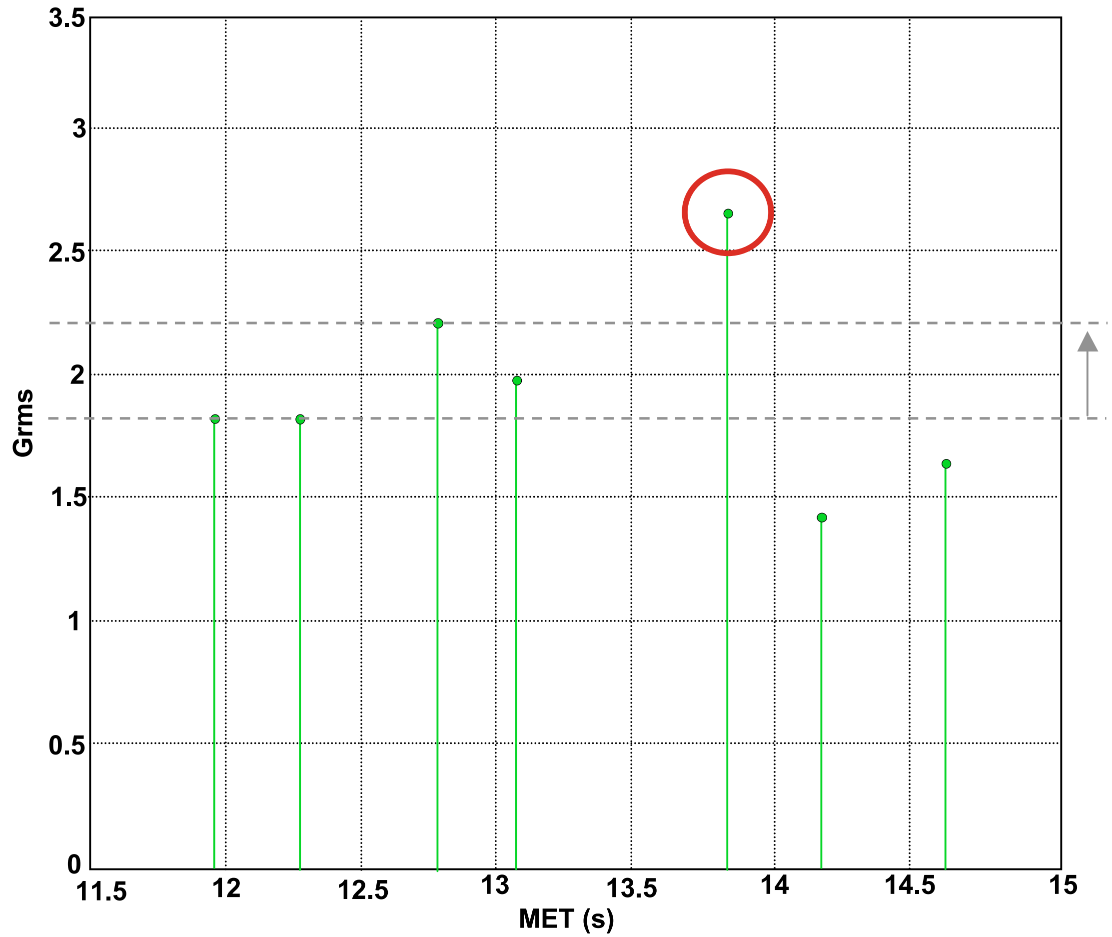
ASDAT
Summary File Peak Detection Overview

Slide line up above data points within a background threshold delta



ASDAT
Summary File Peak Detection Overview

Points remaining above the line are considered peaks

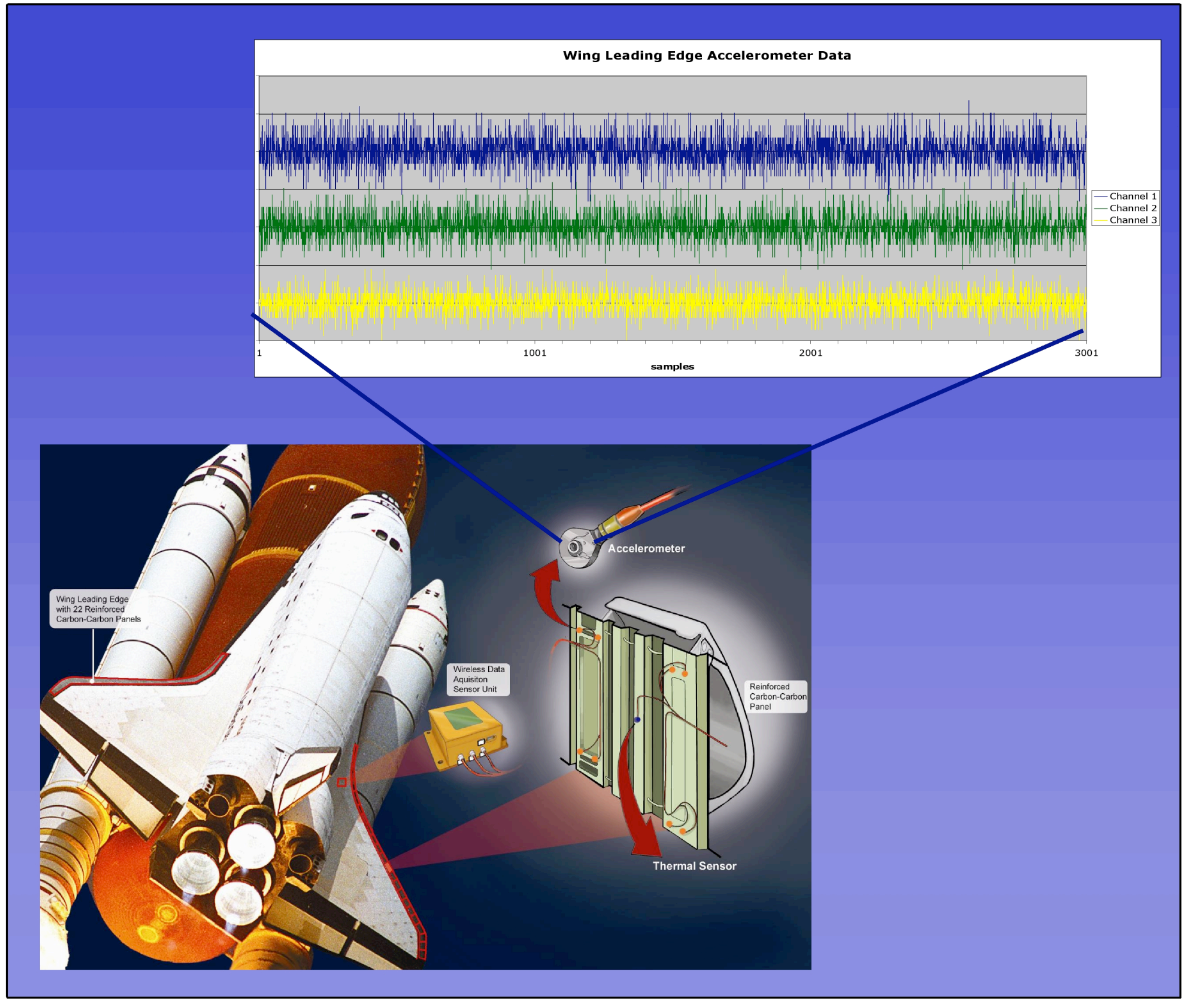


IMS WLE IDS Analysis

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.



ASDAT
Collated Output Sample

TIME	CHANNEL		PG						
117.127800	1020	1	2.304170	1.553274	206.856000	S	3	P	8
117.128300	1032	1	1.620064	0.854046	111.492000	S	3	P	8
117.153100	1009	2	2.239165	2.072012	1239.590000	T	3	P	9
117.153600	1019	2	2.056229	1.949395	1824.695000	T	3	P	9
117.156800	1025	2	3.105069	3.044708	5044.164000	T	3	P	9
117.166200	1027	2	3.304618	3.186227	2691.275000	T	3	P	9
117.178800	1014	1	1.428290	0.751187	110.941000	S	3	P	8
118.195300	1024	2	2.067127	1.189419	135.514000	M	2	P	16
118.221100	1021	2	2.752447	2.034531	283.394000	M	2	P	16
118.453100	1034	3	3.063645	2.360925	335.970000	M	3	P	6
118.461100	1023	3	2.822236	2.007348	246.334000	M	3	P	6
118.461800	1013	3	5.528769	4.686699	556.569000	M	3	P	6
118.579800	1032	1	1.469281	0.704857	92.208000	T	2	P	8
118.603900	1009	1	0.810219	0.616425	318.083000	S	2	P	7
118.608400	1019	1	0.732263	0.604337	472.411000	S	2	P	7
118.610100	1025	1	0.923756	0.895197	3134.553000	S	2	P	7
118.620100	1027	1	0.814994	0.639857	365.347000	S	2	P	7
118.629500	1014	1	1.266674	1.043164	466.719000	T	2	P	8
118.968200	1019	2	0.790056	0.551843	231.659000	M	2	P	9
118.976700	1027	2	0.734852	0.610616	491.497000	M	2	P	9
120.201400	1019	3	1.049971	0.841199	402.927000	W	1	P	11

IMS WLE IDS response to LO_2 and LH_2 feedline disconnects vs. background signal