Integrated Defense Systems
Huntington Beach

Preparation and Support of a Tap Test on the Leading Edge Surfaces of the Space Shuttle

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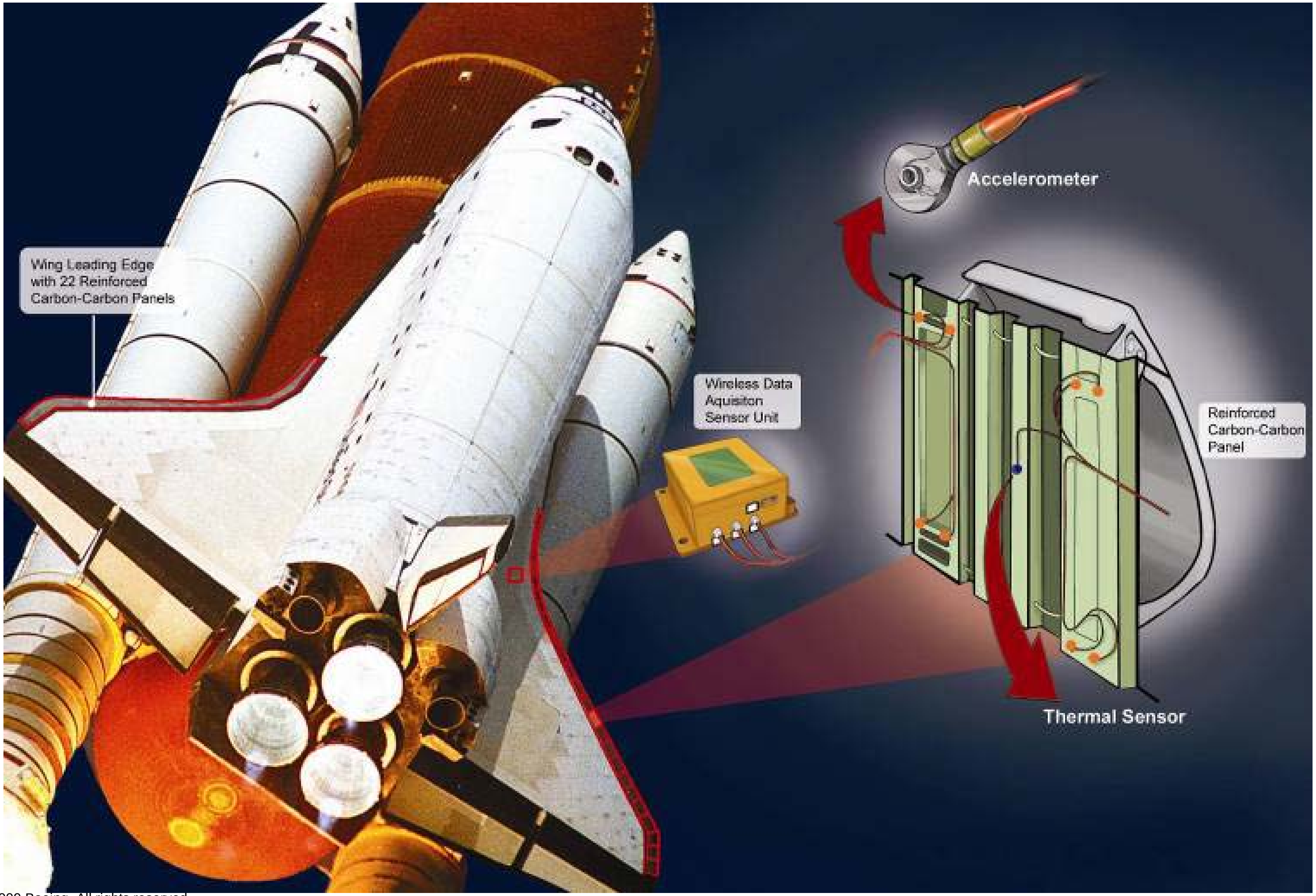
Space Shuttle Discovery heading to Space

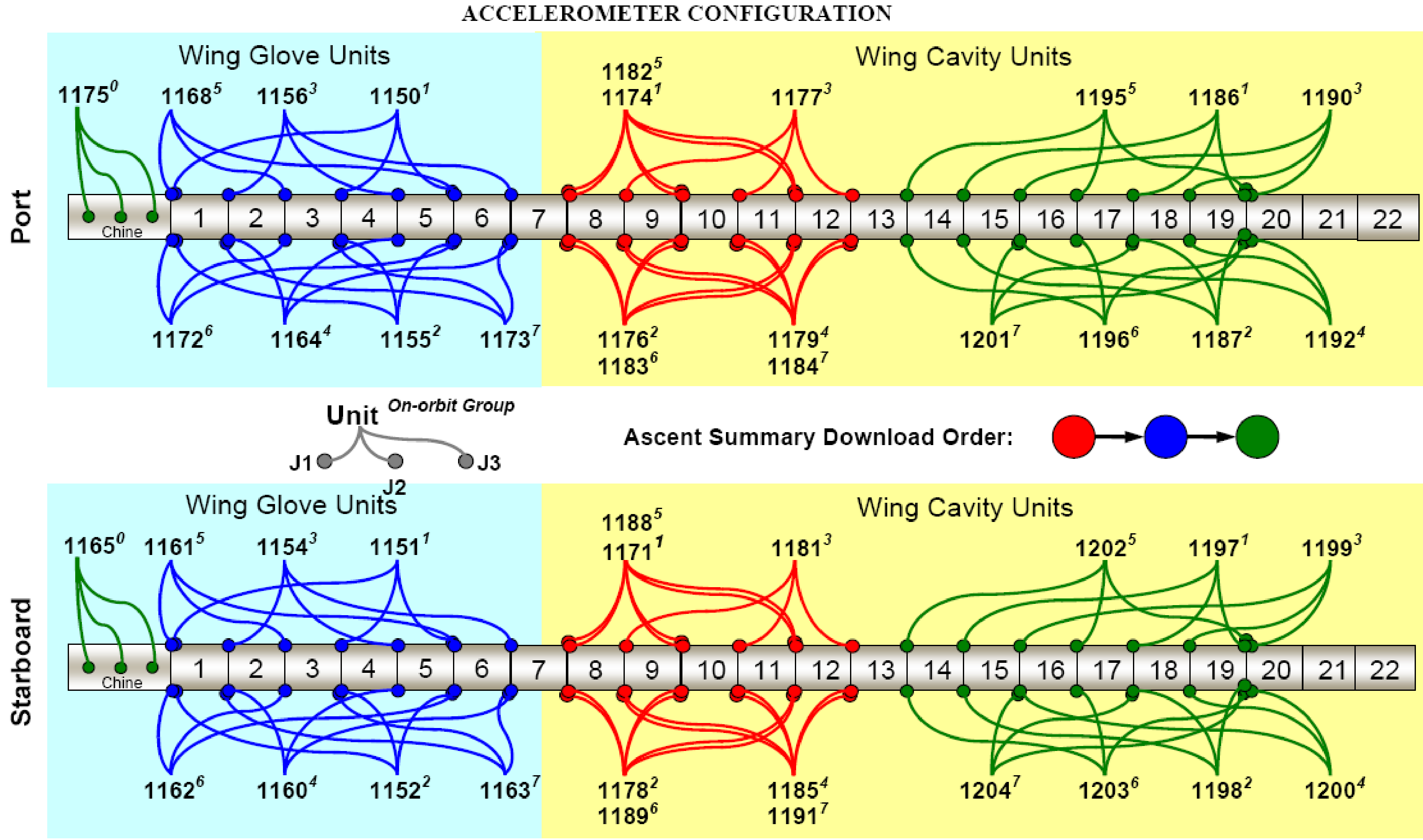
Presentation Outline

- **Background – description of the Wing Leading Edge Impact Detection System (WLEIDS) flight system**
- **Purpose and approach for improving the WLEIDS system performance**
- **Strategy for the test project**
- **Phase 1 : develop a safe and predictable thumper**
- **Phase 2 : demonstrate thumper performance on the Single Panel Leading Edge Test Article (SPLETA)**
- **Phase 3 : set up a system under the OV-105 orbiter and tap the wings**
- **Conclusion : Results**

Wing Leading Edge Impact Detection System



Impact Sensor System Configuration



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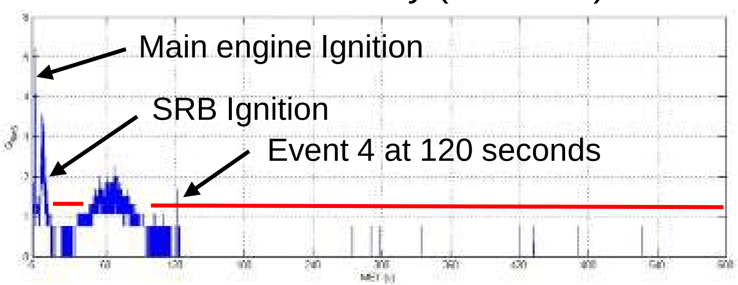
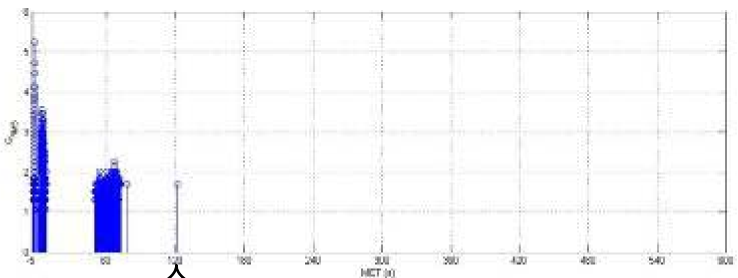
Impact Detection System Data Processing

Grms Time History (STS-114)



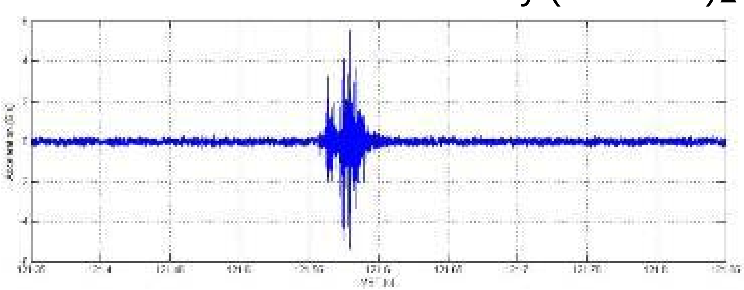
- **Raw data reduced using 256 point RMS windows with 50% overlap**
- **Over 90,000 total points for 10 minutes**
- **Less than 1% of data from time history, but still too large to download**

Grms Summary File (STS-114)



- **Grms value at times of the 2,048 top peaks on all three channels connected to a sensor unit (above red line)**
- **Summarizes top 1% of data from full Grms Time History making it reasonable to download (2-4 minutes per file)**

Half Second G Time History (STS-114)



- **Recovers all raw data points from the half second centered around a point of interest**
- **Check for bad data**
- **Evaluate impact signal criteria in raw data**

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View of Wing Leading Edge and Tiles

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Lift of Discovery in the Vertical Assembly Building

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Post-flight Report of WLEIDS Performance

- **13 spikes (possible events) were identified in the WLEIDS data during the mission, STS-114**
- **Review of downloaded ½ sec time histories surrounding the "events," established that 11 spikes were "non-impacts"**
  - Only 2 spikes were identified as likely events
- **However, no other data sources corroborated these 2 events**
  - Video during mission
  - On-orbit inspection
  - Post-flight inspection
- **Orbiter wing was quieter than estimated**
  - enabling the impact sensor system to detect lower amplitude transients (impact signatures)

Shuttle Program Interest to Improve the System

- **Significant amount mission time was spent inspecting the vehicle while on orbit**
- **WLEIDS demonstrated its capability to sense potential impacts events**
- **It was proposed that the WLEIDS could focus the time-consuming inspections to smaller areas; thus, reduce the inspection time**
- **However, the WLEIDS data analysts needed more confidence in their tools before they would take on this added responsibility**
  - Very limited amount of empirical data existed to establish evaluation criteria
  - Engineering lack the dynamic models to produce analytical data
  - Impacts by different sized foam and ice particles at different locations across the wing was believed to cause different responses on the sensors
- **Program needed to build and validate dynamic models of the leading edge components and wing to generate enough data to establish the evaluation criteria**

Project Timeline

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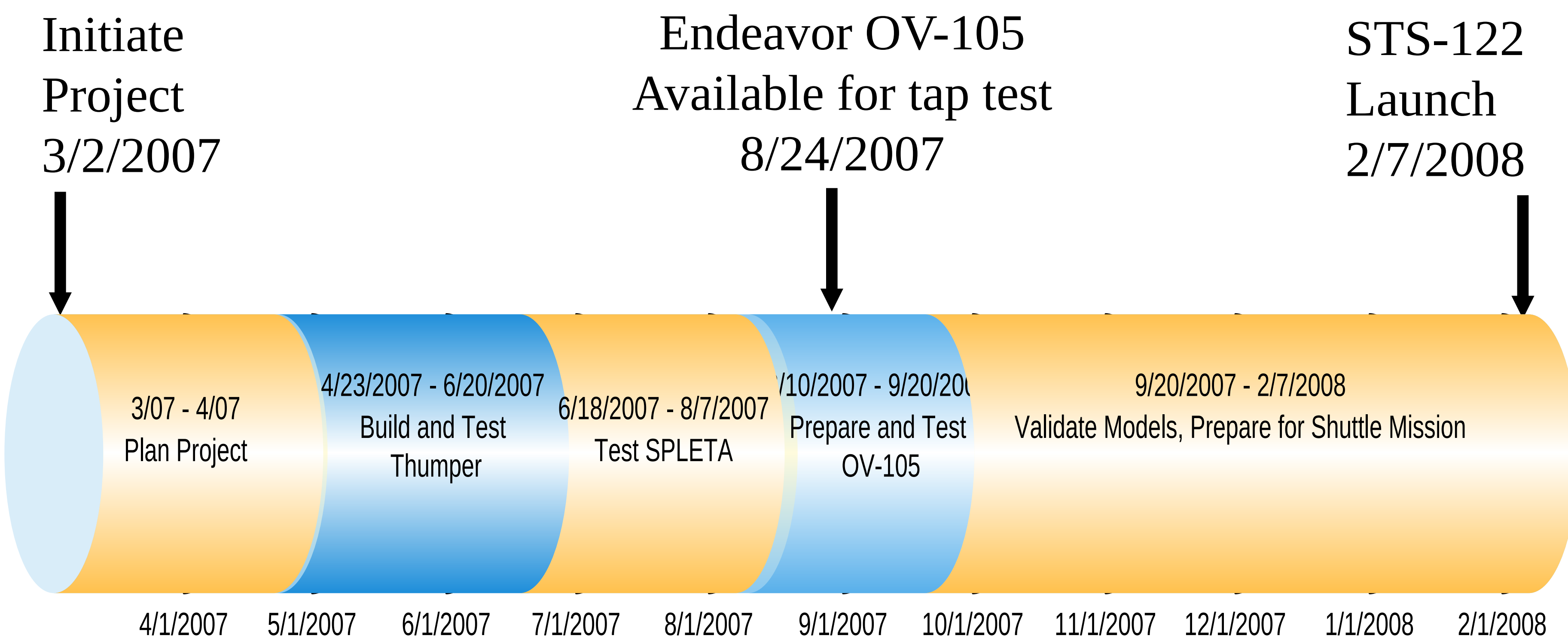

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WLEIDS Upgrade Project Approach

- **Analysis team:**
  - Build high definition models of leading panels 4 thru 18, spar fittings, and front spar and spar caps for one wing
  - Correlate the model with tap test data from the Single Panel Leading Edge Test Article (SPLETA) with panel 16 with spar fittings and a section of the spar panel
  - Correlate vehicle spar model with tap test data obtained by tapping inside the wing cavity in 2005
  - Validate models with tap test data obtained by tapping on the leading edge panels on both wings
  - Use the models to produce response data from simulated ice and foam impacts at several locations across the leadings edge panels
  - Support the next shuttle mission (STS-122)

WLEIDS Upgrade Project Approach

- **Test team:**
  - Develop a reliable thumper (instrumented hammer) **and prove** that it can safely tap the leading edge panels on the orbiter OV-105
  - Demonstrate the hammer performance against a solid thick plate in three orientations (up, down, and side)
  - Install strain gages and accelerometers to the SPLETA and provide solid mounts to hold the test article in two test configurations
  - Prove the tap test will not damage the leading edge panels
  - Develop a method to securely hold the thumper next to the leading edge of OV-105 in the Orbiter Processing Facility (OPF)
  - Set up a 60 channel data system to record signals from the flight sensors
  - Coordinate and support the tap test in the OPF at Kennedy Space Center (KSC)

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Commercial Impact Test Hammer (Thumper)

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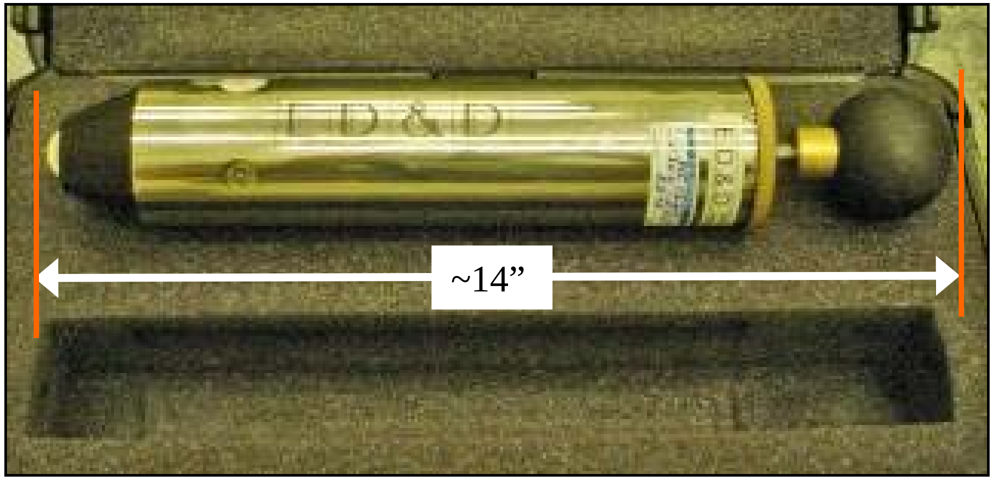
- **NASA Principal Investigator suggested the model F22.50 impact hammer from Educated Design & Development for the tap test**
- **Thumper had adjustable energy levels from .2 to 1.0 Joule**
- **Arm thumper by pulling the black knob until it clicks**
- **Press the cone of the hammer on surface to trigger the release**
- **Thumper produced 4 millisecond pulses – similar to real impact durations for foam and ice**



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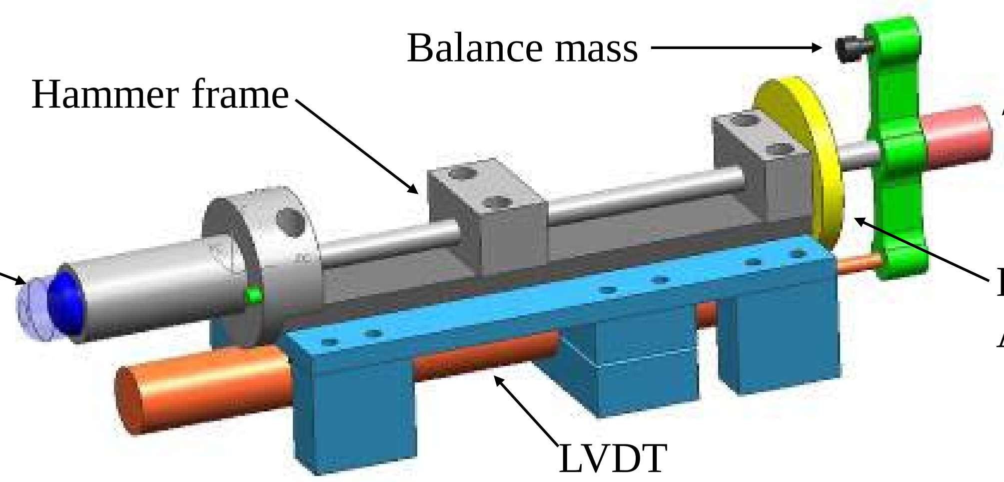
Instrumented Hammer Required

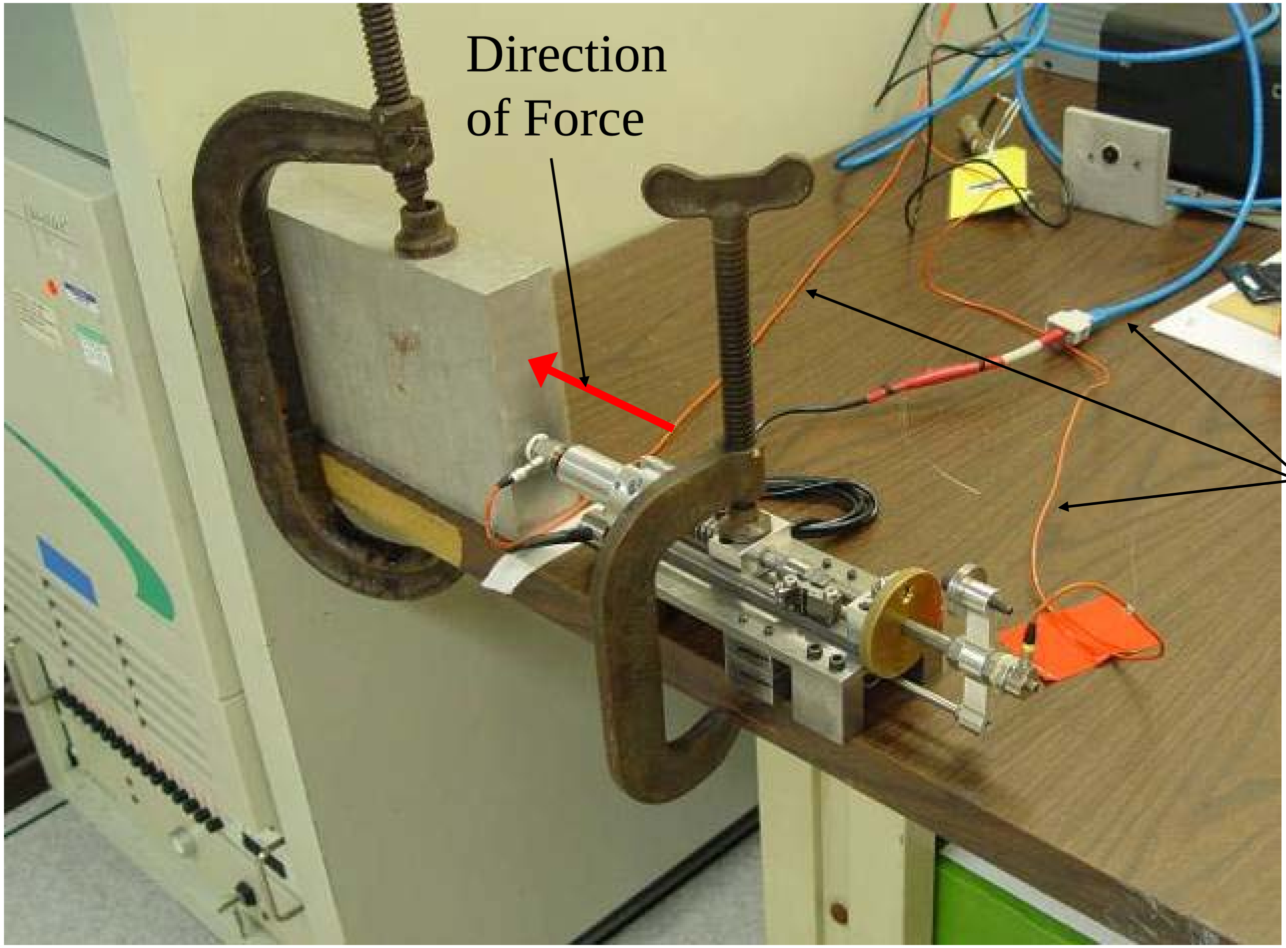
- **The program review technical team at Boeing, United Launch Alliance (ULA), and NASA requested to have the impacts monitored throughout the tap test**
- **Methods:**
  - Install strain gages under the impact sites on the leading edge panels to monitor the stress levels directly
  - Strike the impact sites with an instrumented hammer and compare the impact force to predictions after every tap
- **Instrumented hammer showed most promise**
  - Strain gage installations would require significant labor and presented risk to the surface of the flight panels

Thumper Design

- **Accelerometer and LVDT were added to the hammer frame to determine the impact energy and measure plunger position**
- **AC type LVDT with a separate signal conditioner worked well**
- **A dynamic force sensor was added after early demonstration runs to measure the impact force directly**
- **The hammer frame was installed into a thick-walled 4” square steel tube to provide more inertial mass**

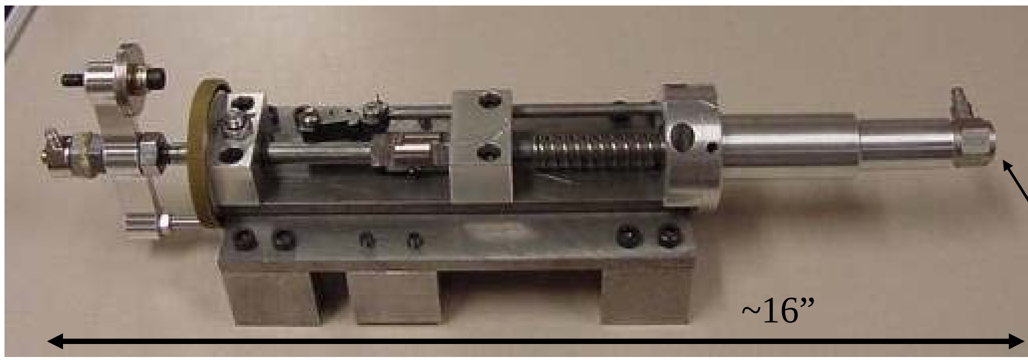


Thumper Checkout Setup



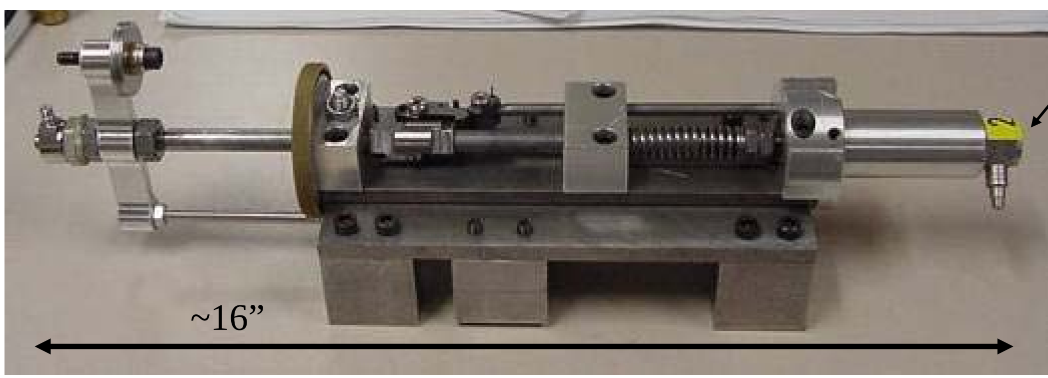
Load Cell, Accel, and LVDT Cables routed to the Data System

Close-up of Finalized Thumper Design



Fully Extended

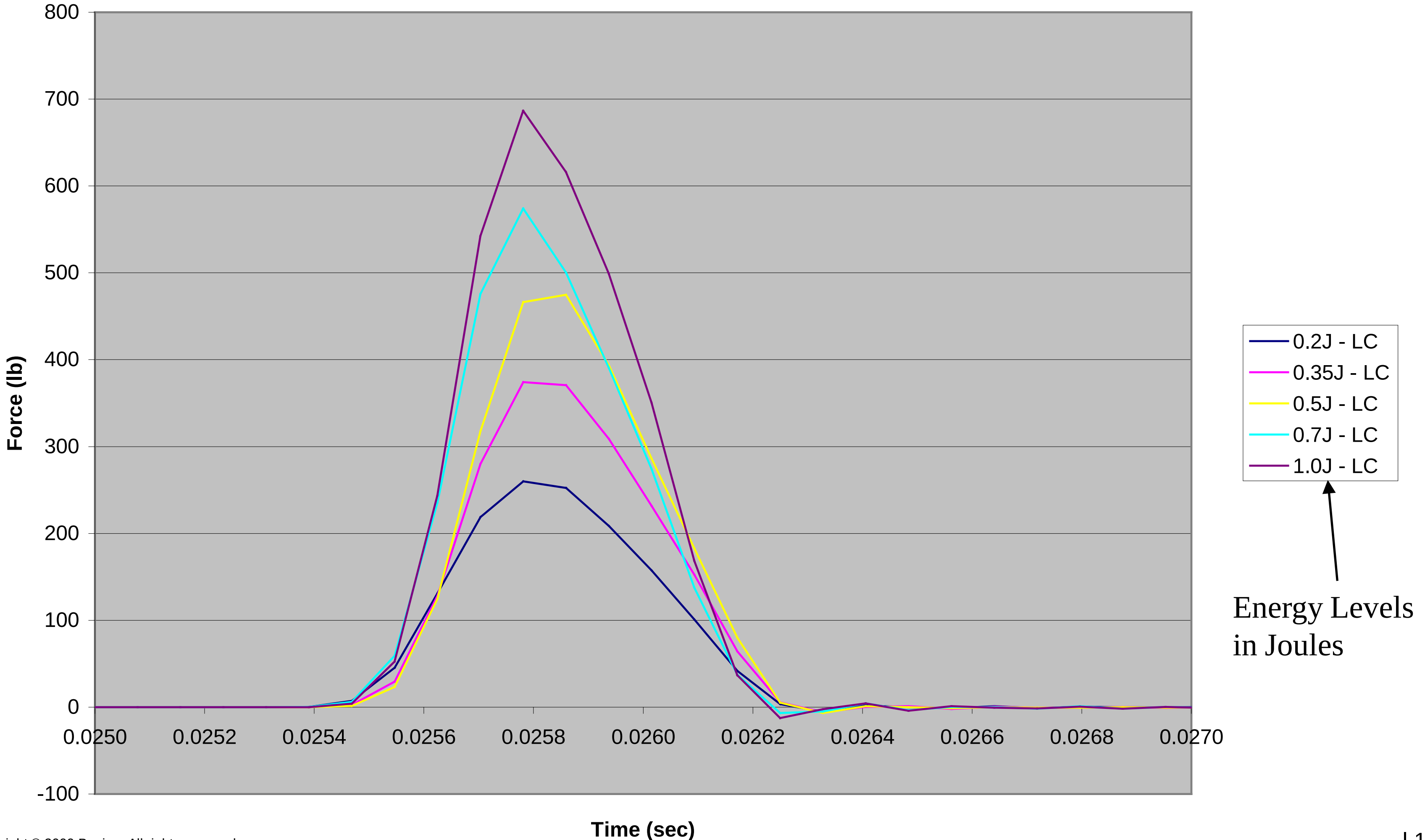
Impact Tip not shown



Fully retracted at Setting 5

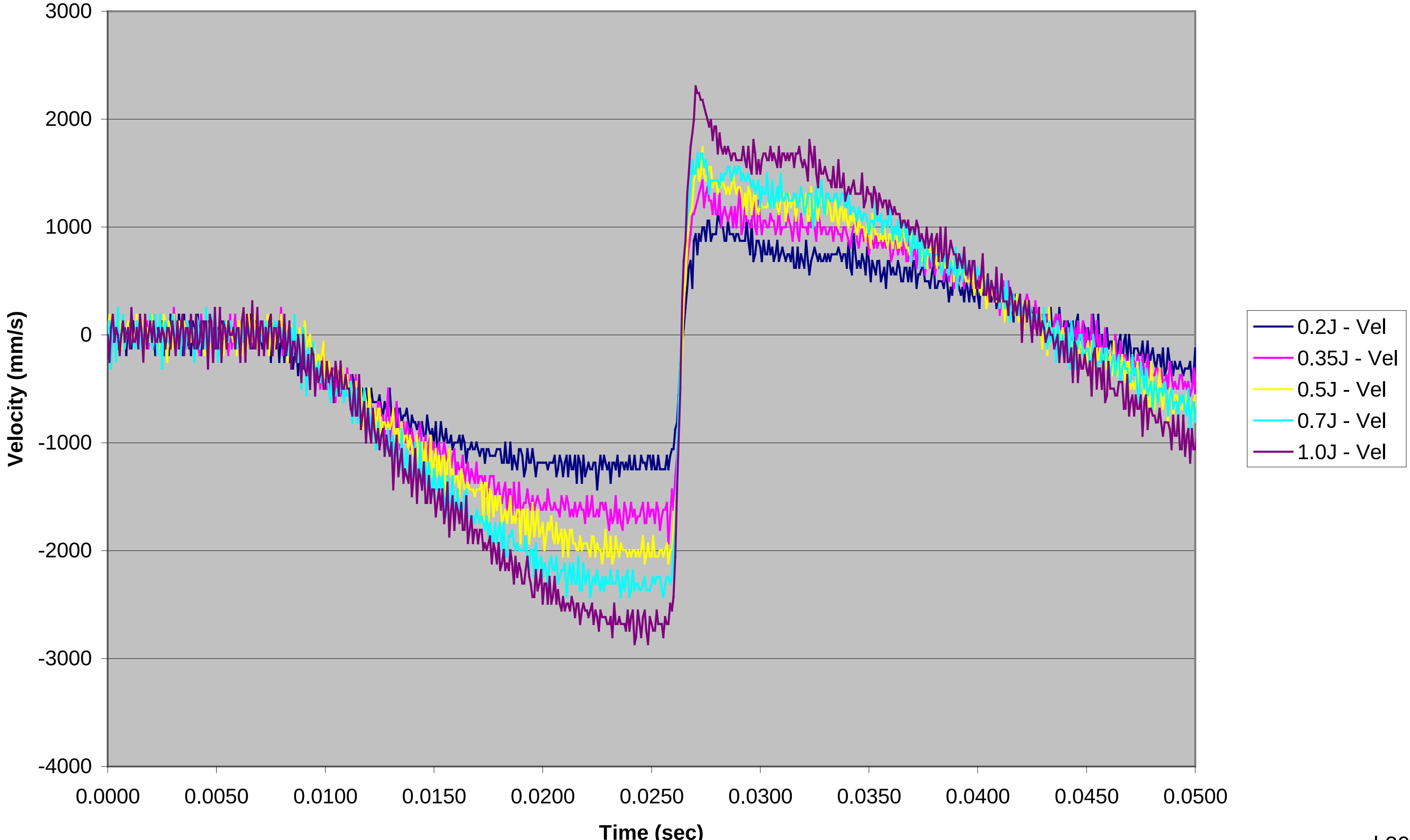
Thumper Impact Force against Al Block

Load Cell Data

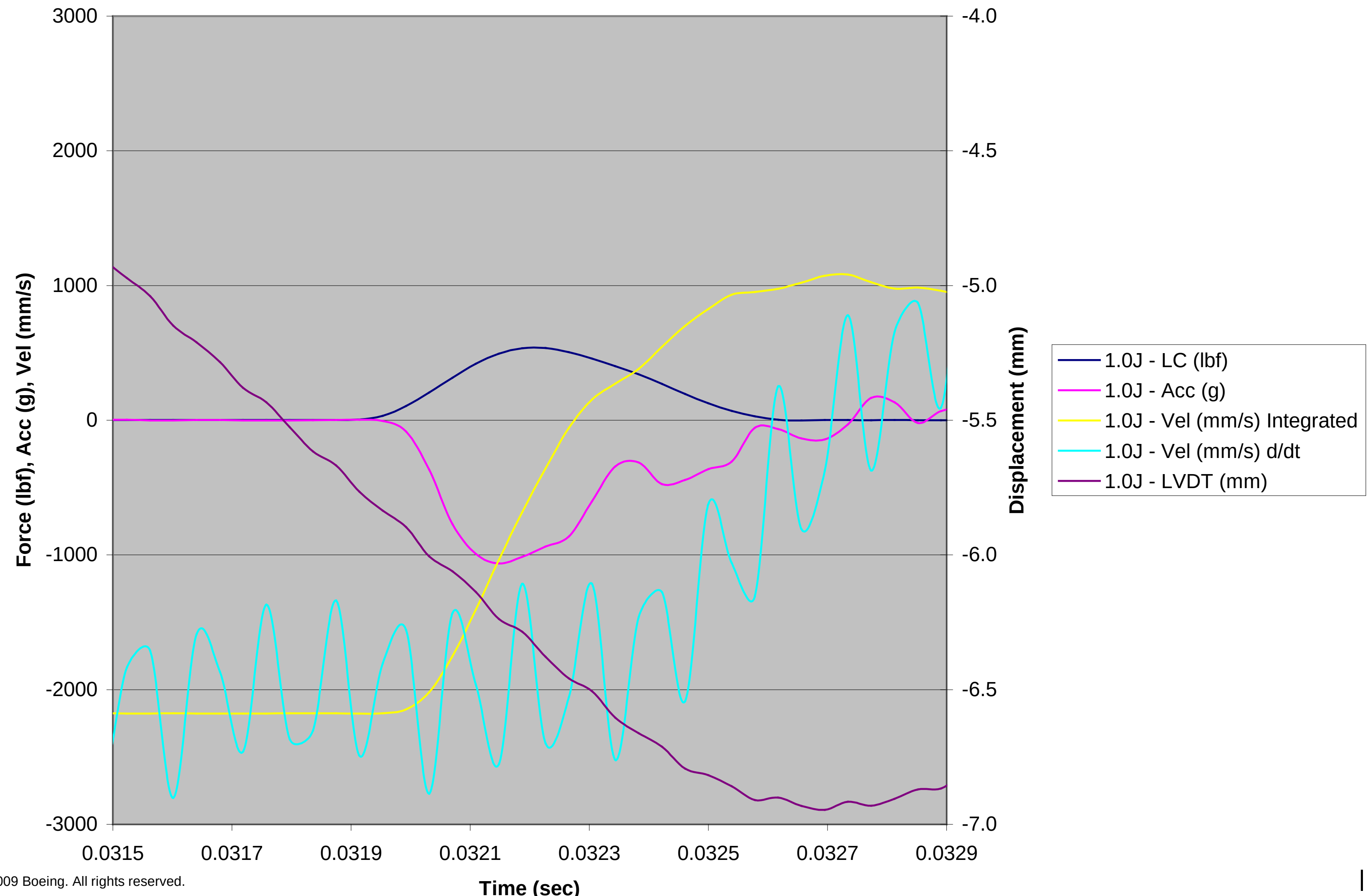


Thumper Piston Velocity (d/dt)

Thumper Velocity Data



Thumper Response with DC type LVDT



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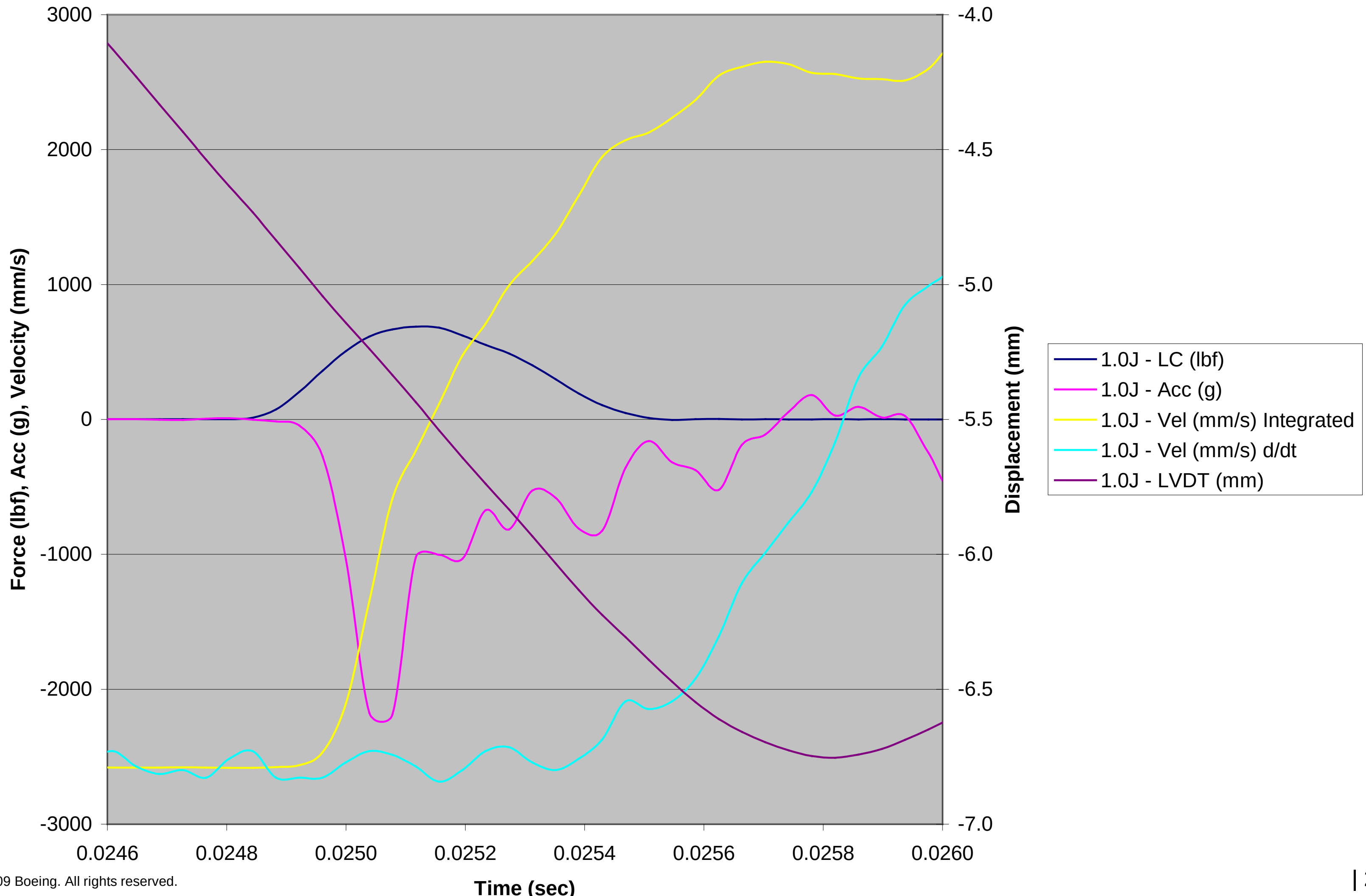
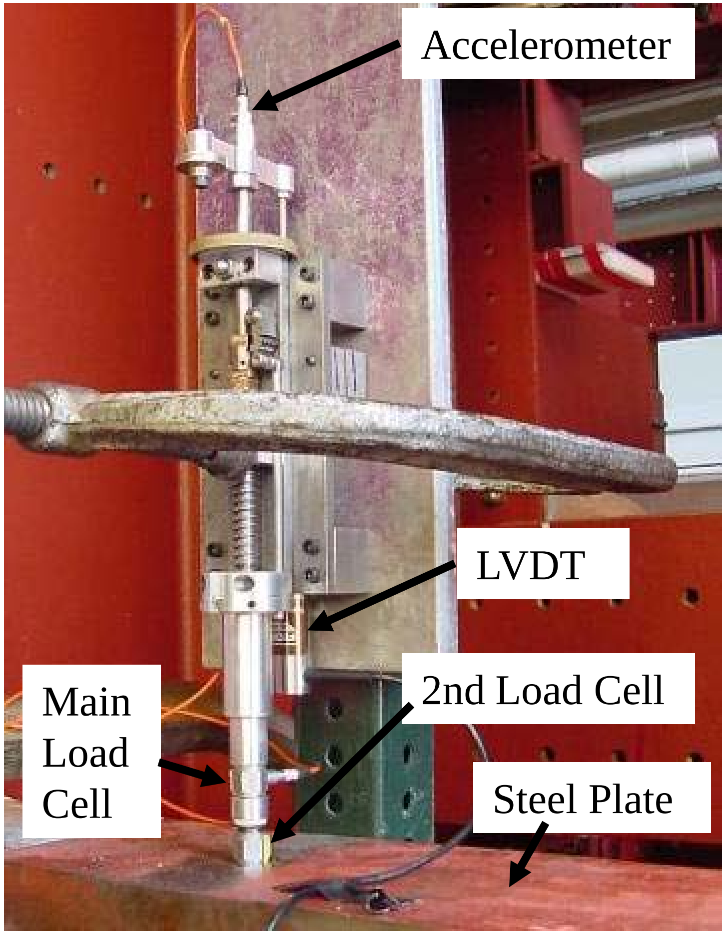
Thumper Response with AC type LVDT



Thumper Characterization Test



Test Setup for Downward Orientation

- **Thumper actuated in three different setups – downward, upward, and sideward orientations**
- **Orientation did change the impact energy as a function of gravity**
- **Characterized all energy levels against a second load cell mounted to a large thick steel plate**
- **The pair of load cell outputs matched very well.**
- **The LVDT provided exact stroke range and impact velocity**
- **The accelerometer was used as a backup trigger signal and to calculate the velocity profile after impact**

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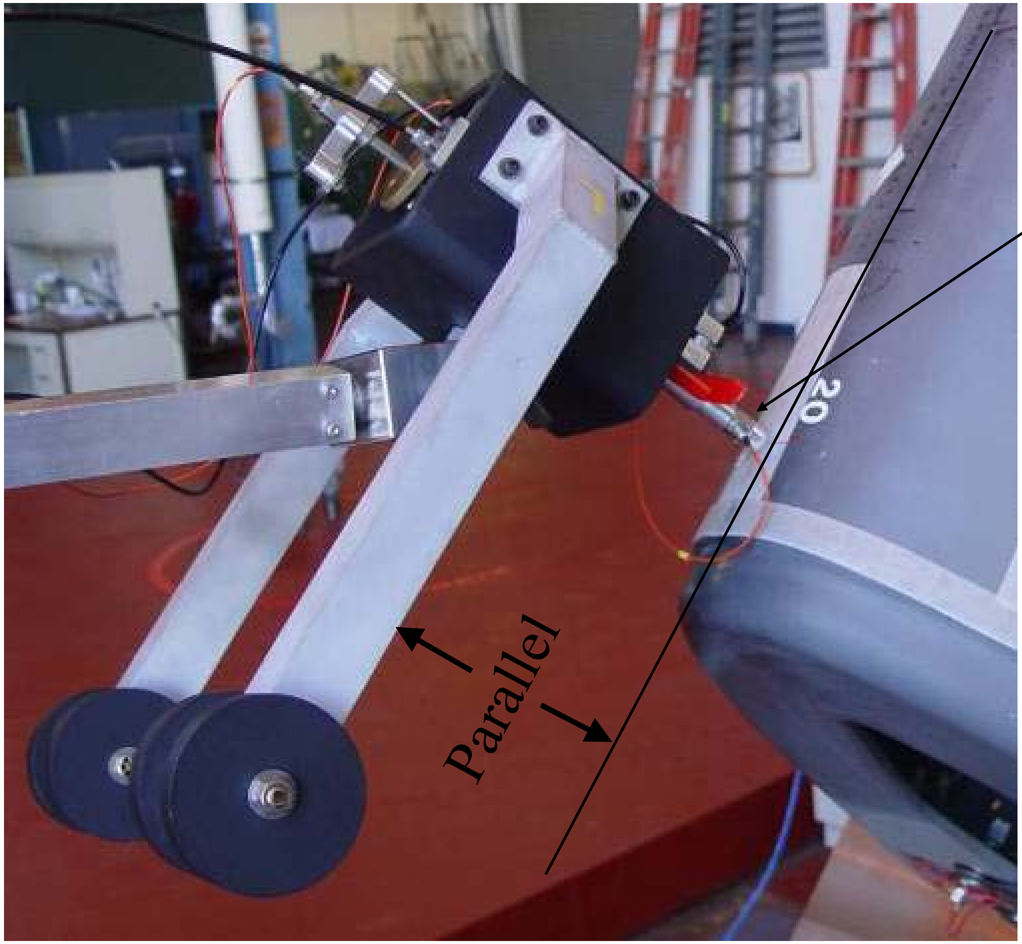
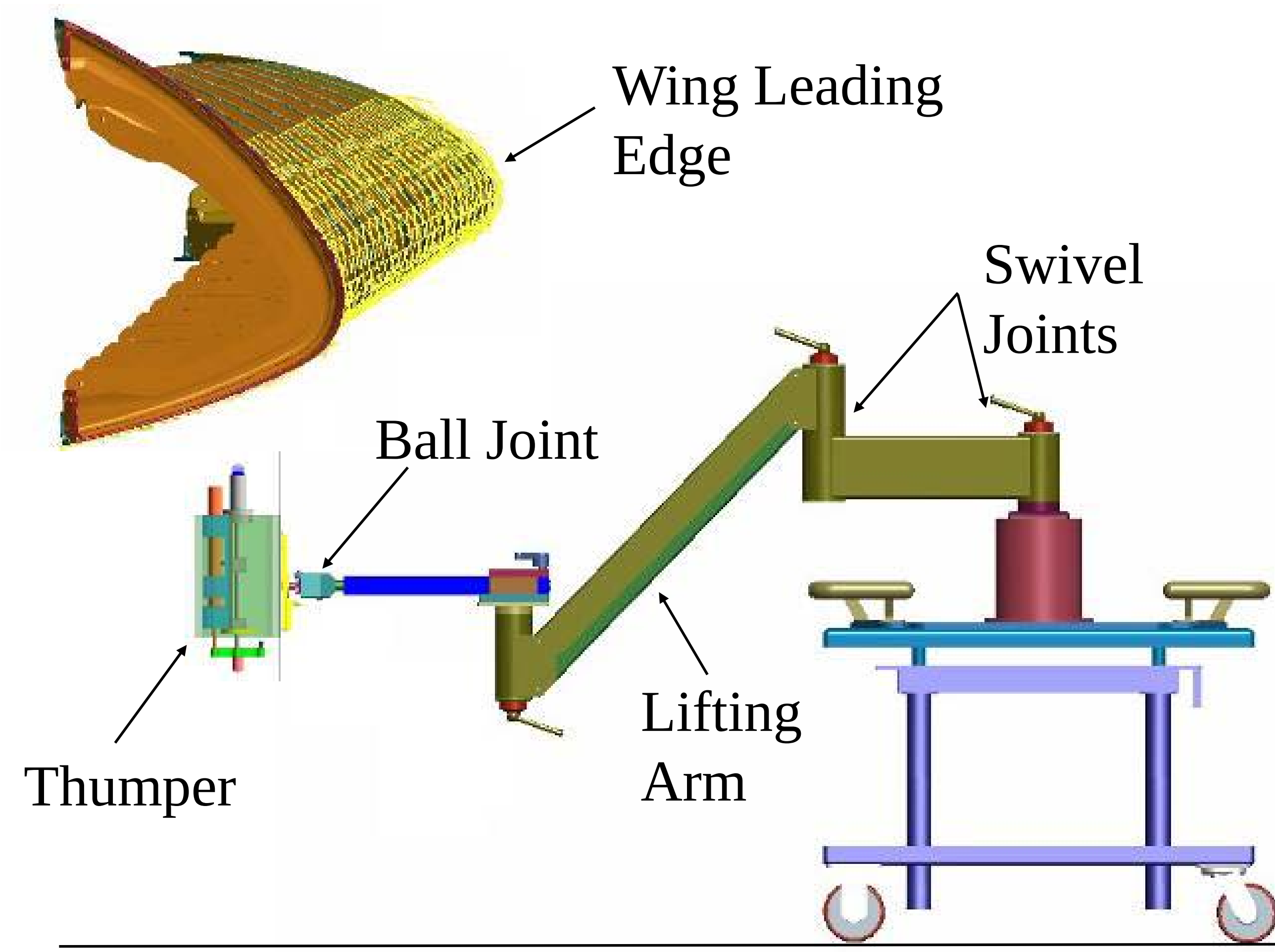
Final Thumper Configuration



Required to strike normal to the local surface

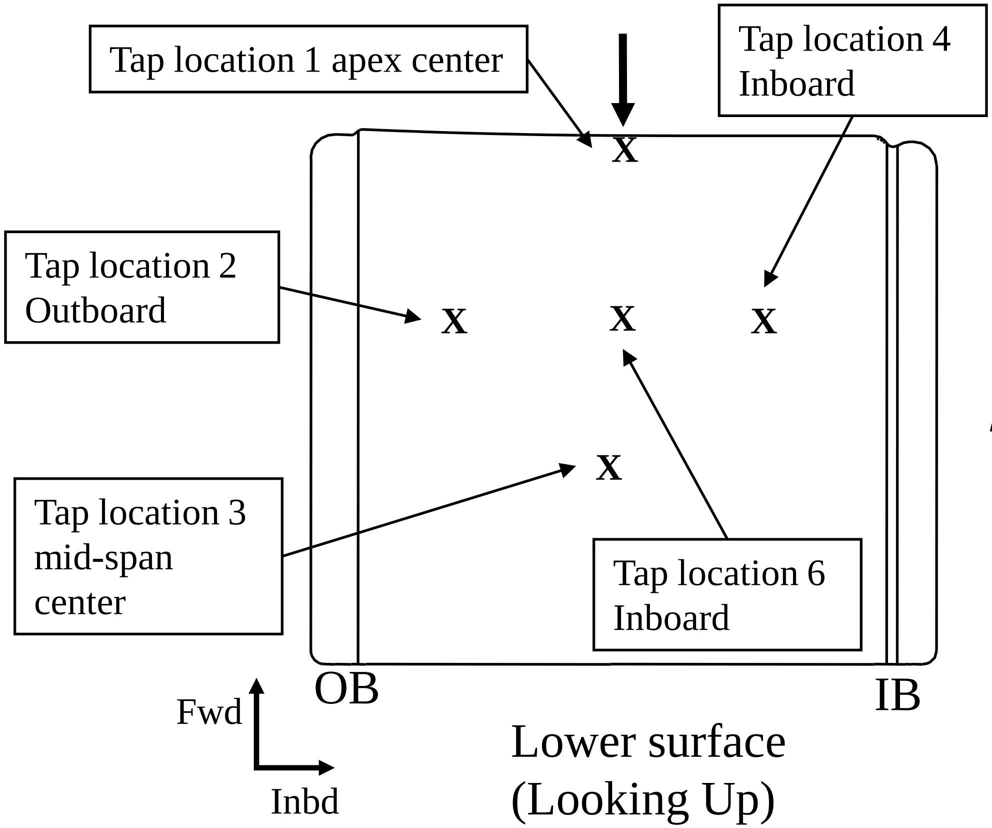
Thumper in position on the SPLETA

Thermography Cart Available to Hold the Thumper in the OPF



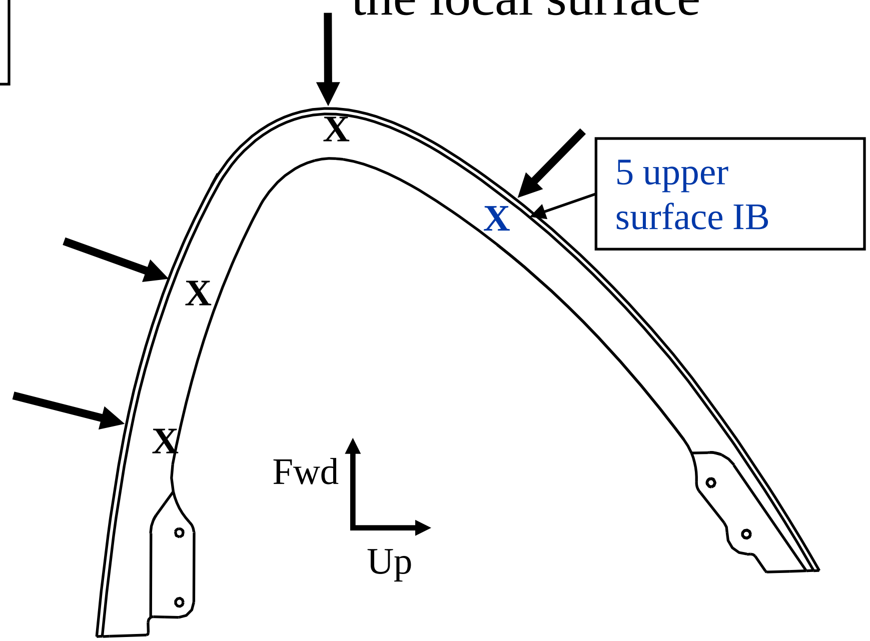
Thermography Cart

Tap Locations on the Leading Edge Panel



Lower surface (Looking Up)

Vectors are normal to the local surface



Side view (Looking Outboard)

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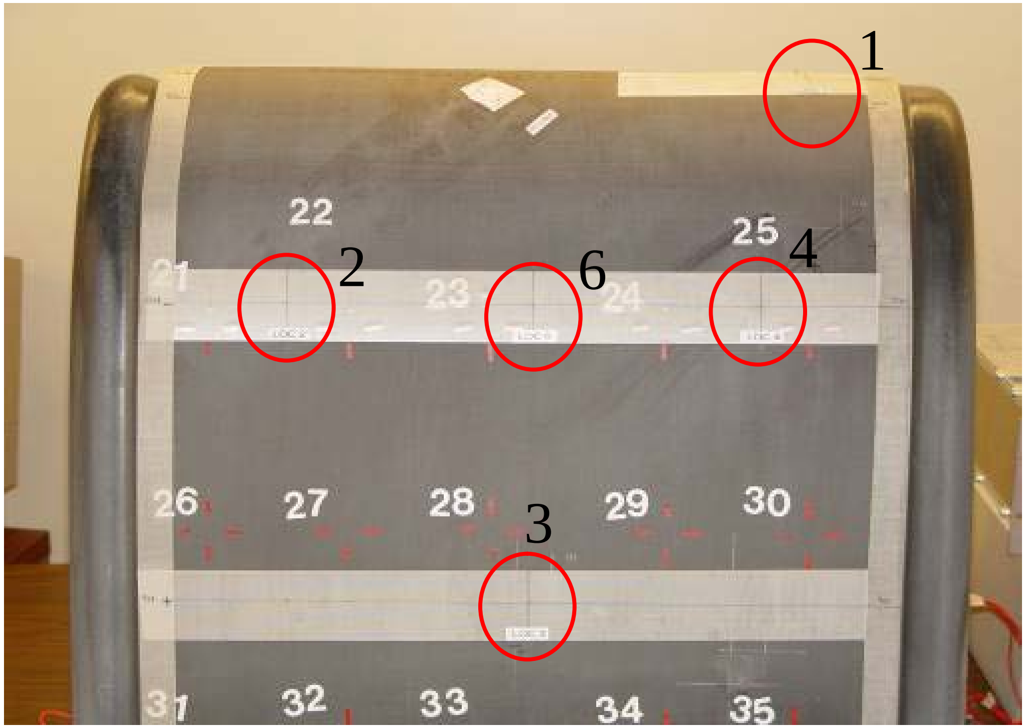
Tap Locations – 4 lower, 1 apex, 1 upper



Lower Surface of the SPLETA Panel

Upper Surface of the SPLETA Panel

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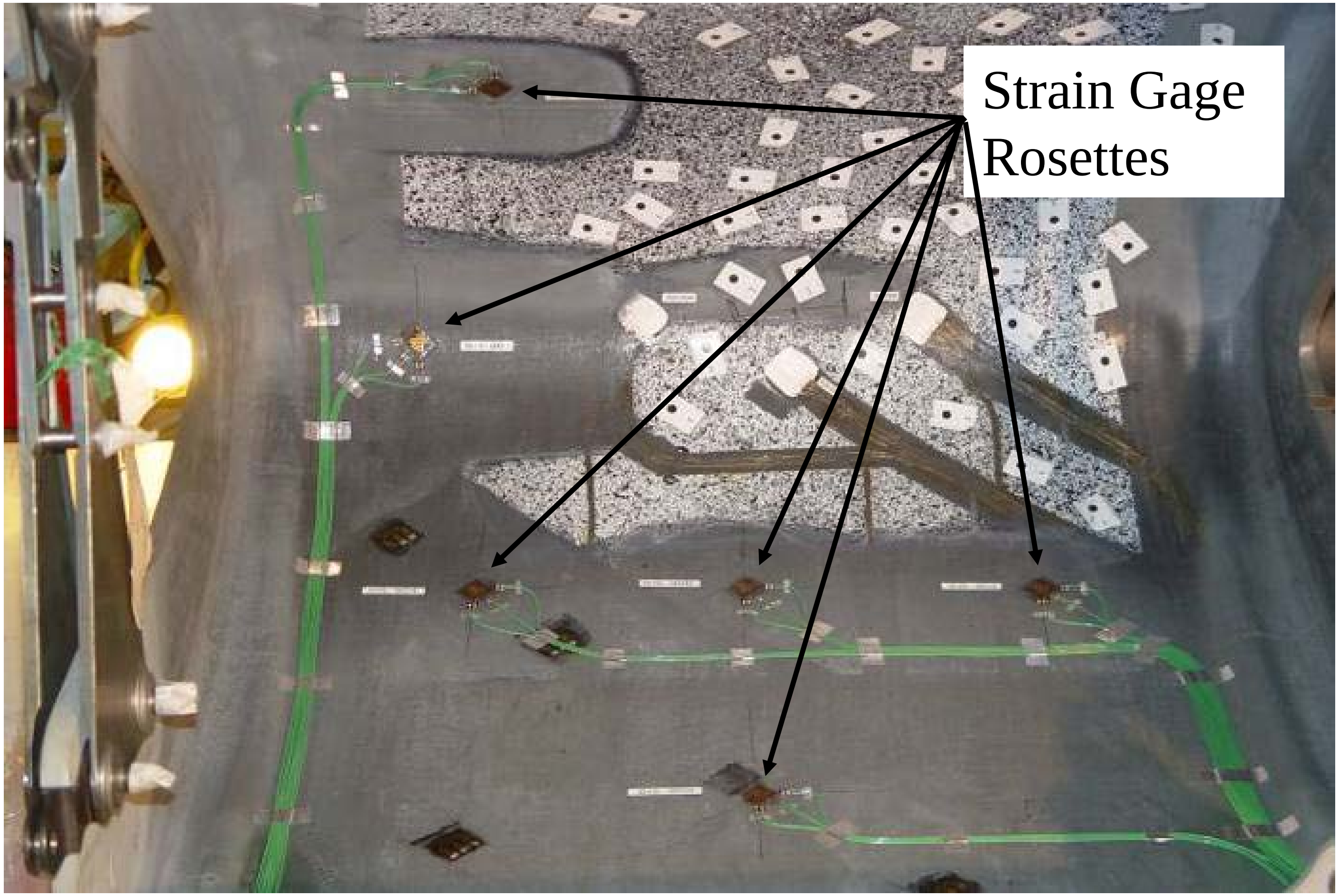
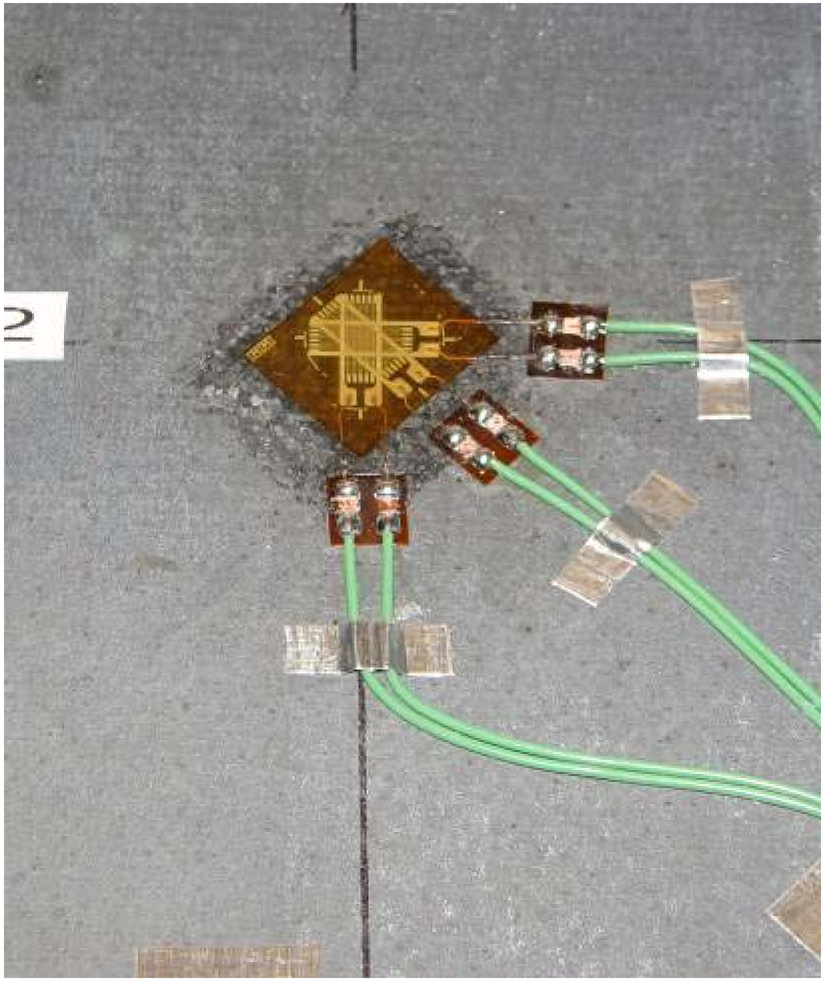
Strain Gages under the Impact Points



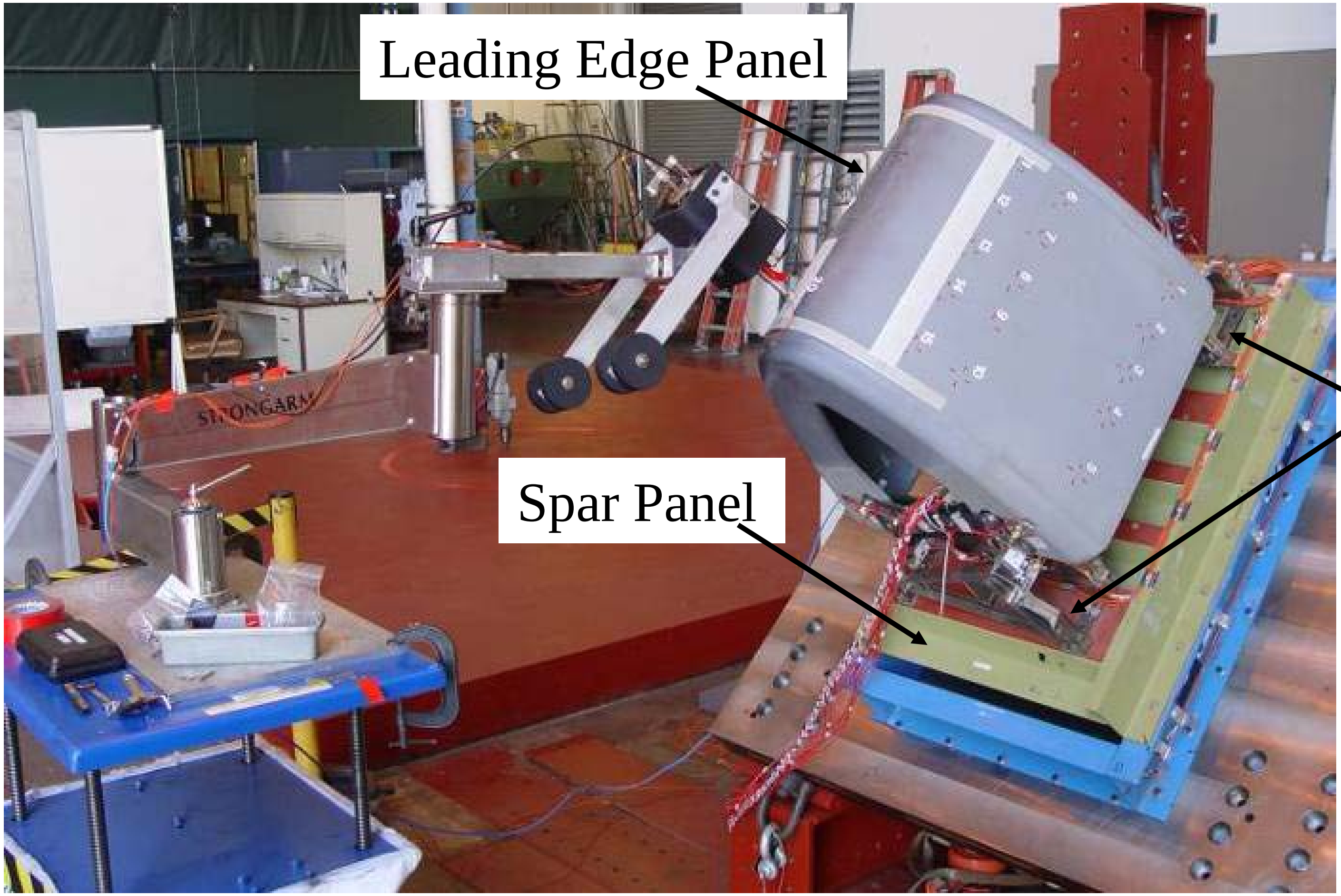
Strain Gages installed on the SPELTA for Thumper Validation

Strain Gage Installation



- **Stacked Rosette**
  - WK-06_250WR-350
- **Cement**
  - EPY-150
  - Heat cure
- **Surface Prep**
  - Abraded with diamond coated strip
  - Alcohol clean
- **Leadwires**
  - 30 AWG to base of panel
  - 26 AWG to signal conditioners

SPLETA in 45 Degree Test Configuration



Setup 1: SPLETA Setup Duplicates High Energy Impact Test Configuration

SPLETA OPF Test Configuration

Thumper

Steel Plate

Spar Panel

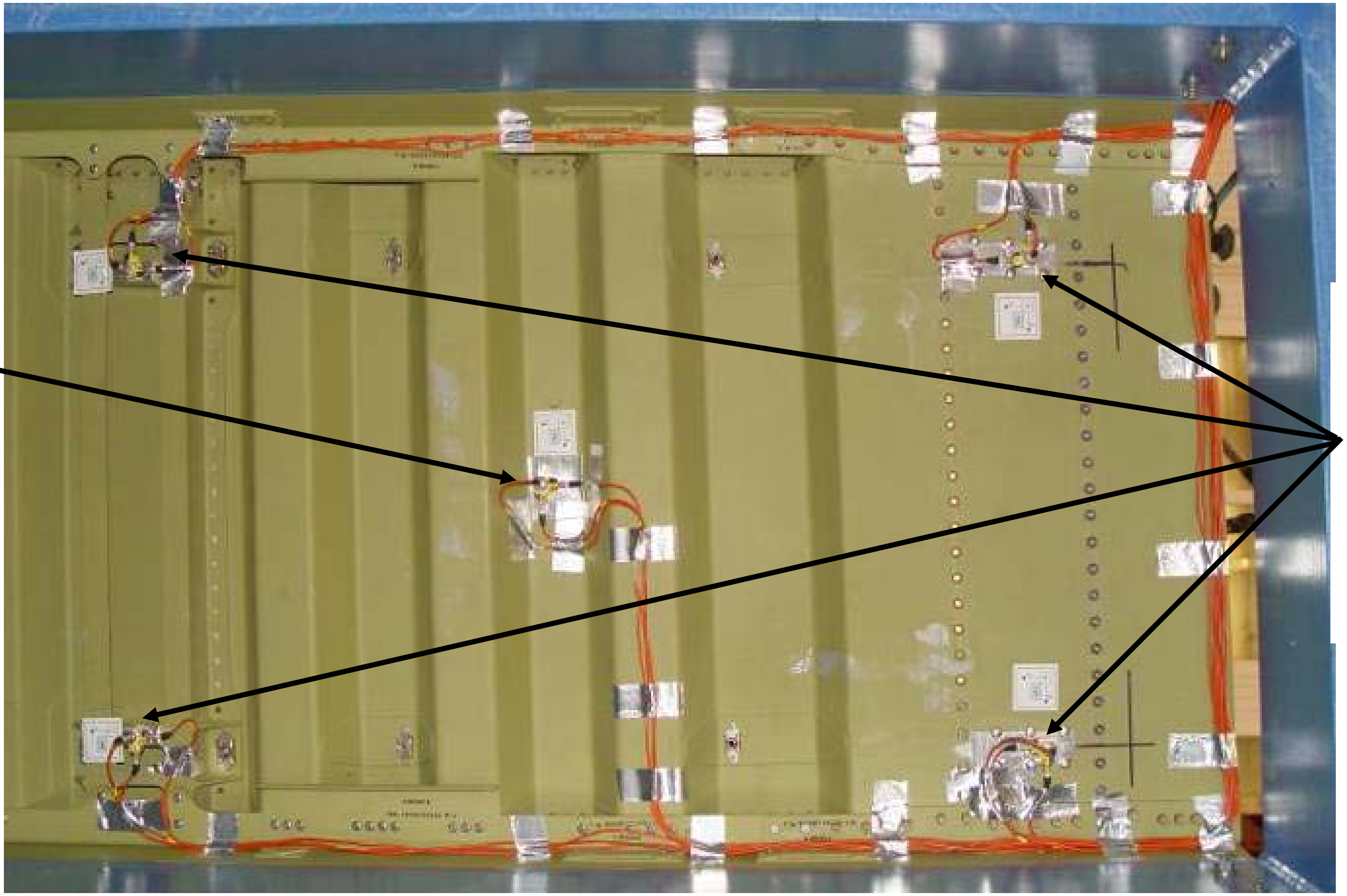
Spar Fitting

Leading Edge Panel

Setup 2: SPLETA set up in a Lateral Configuration

Close-up of Accelerometers Mounted behind the Spar

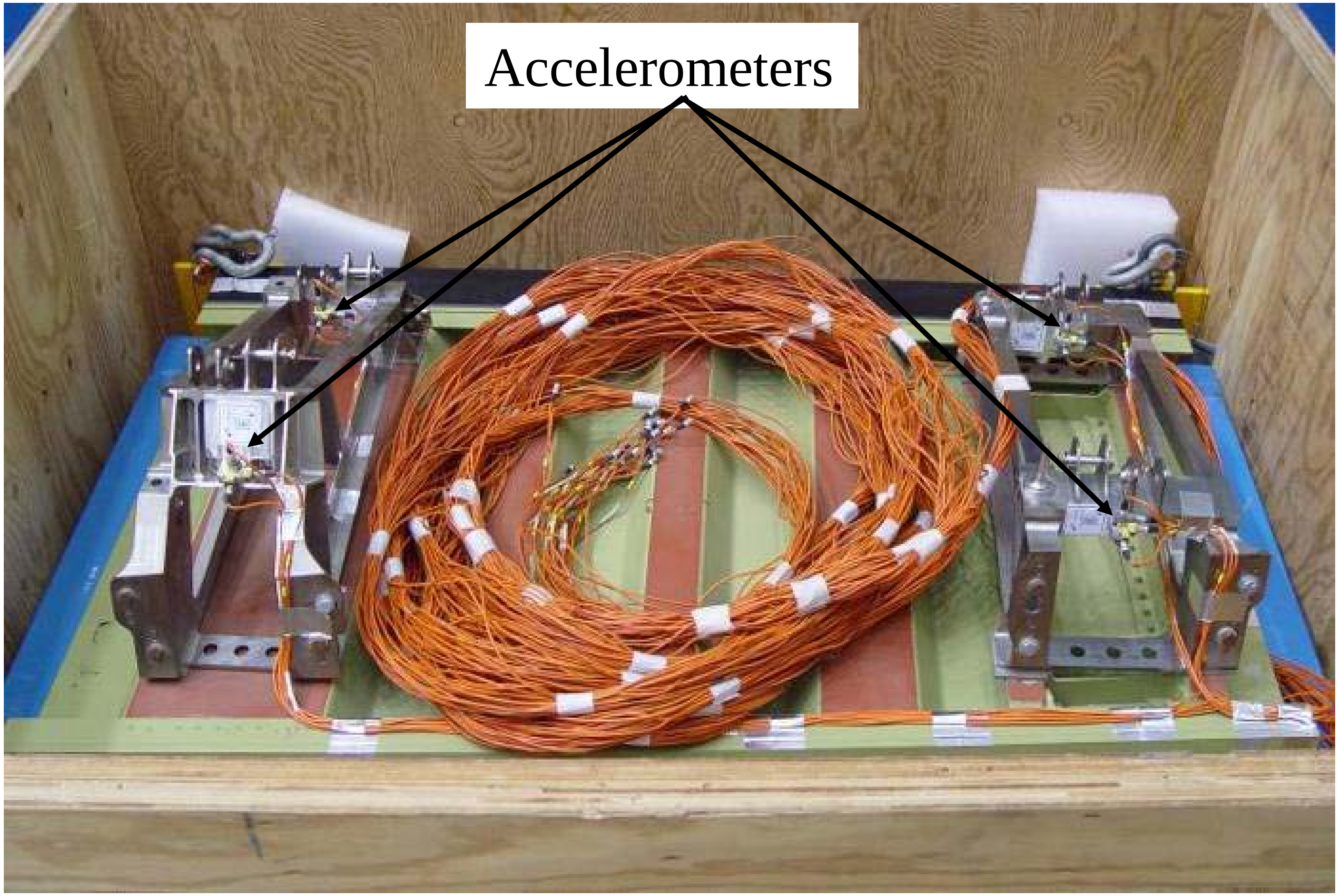
Accel in the middle of the spar panel



Accels Behind the Spar Fittings

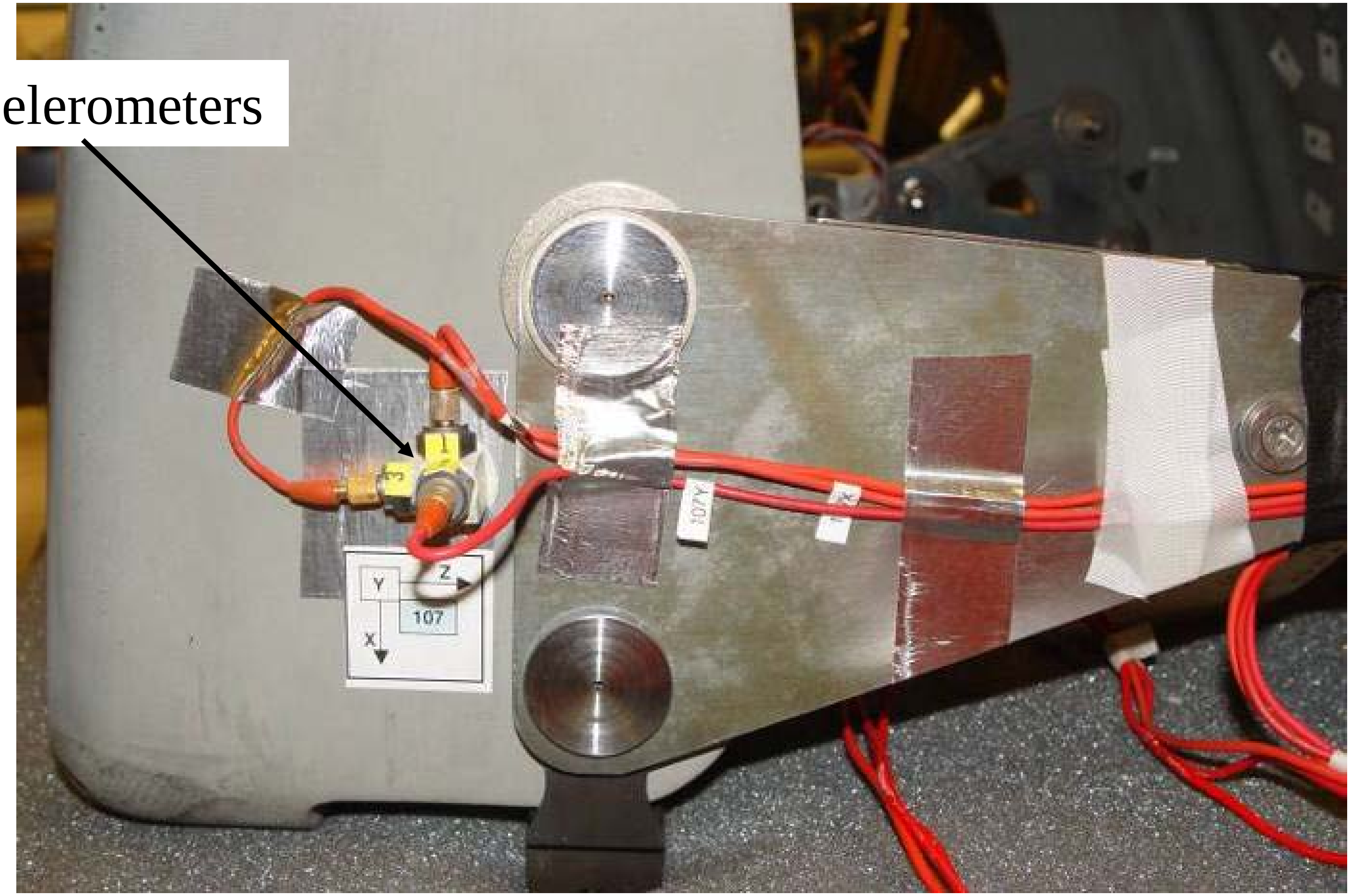
SPLETA: Underside of the Spar Panel

Close-up of Accelerometers Mounted on the Spar Fittings



SPLETA: Front side of the Spar Panel

Close-up of Accelerometers Mounted at a Corner of the Leading Edge Panel



SPLETA: Corner of the Leading Edge Panel

SPLETA Test Results

- **Test results met requirements:**
  - Found only small differences in sensor output between SwRI and OPF configurations (as expected)
  - Accelerometer outputs correlated well with the leading edge panel and SPLETA dynamic models
  - Strain gages correlated with predicted levels for all ranges of the thumper power
- **Met the success criteria**
  - Post test NDE did not identify damage to the surface of the panel – validated thumper is safe to use on the orbiter

Tap Test Operations

- **Tap at 5 targets on each of 8 panels on both port and starboard wings**
- **Tap each target 2 times – a third time, if required, for a consistent taps**
- **Use the LVDT to control the free-travel (no spring engagement) dimension**
- **Connect 44 sensors from each wing to the data system (one wing at a time) using Microdot barrels and cables**
- **Coordinate support between groups to achieve a safe and efficient tap test**

Thumper installed on Thermography Cart

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View of Port Wing Leading Edge Panels

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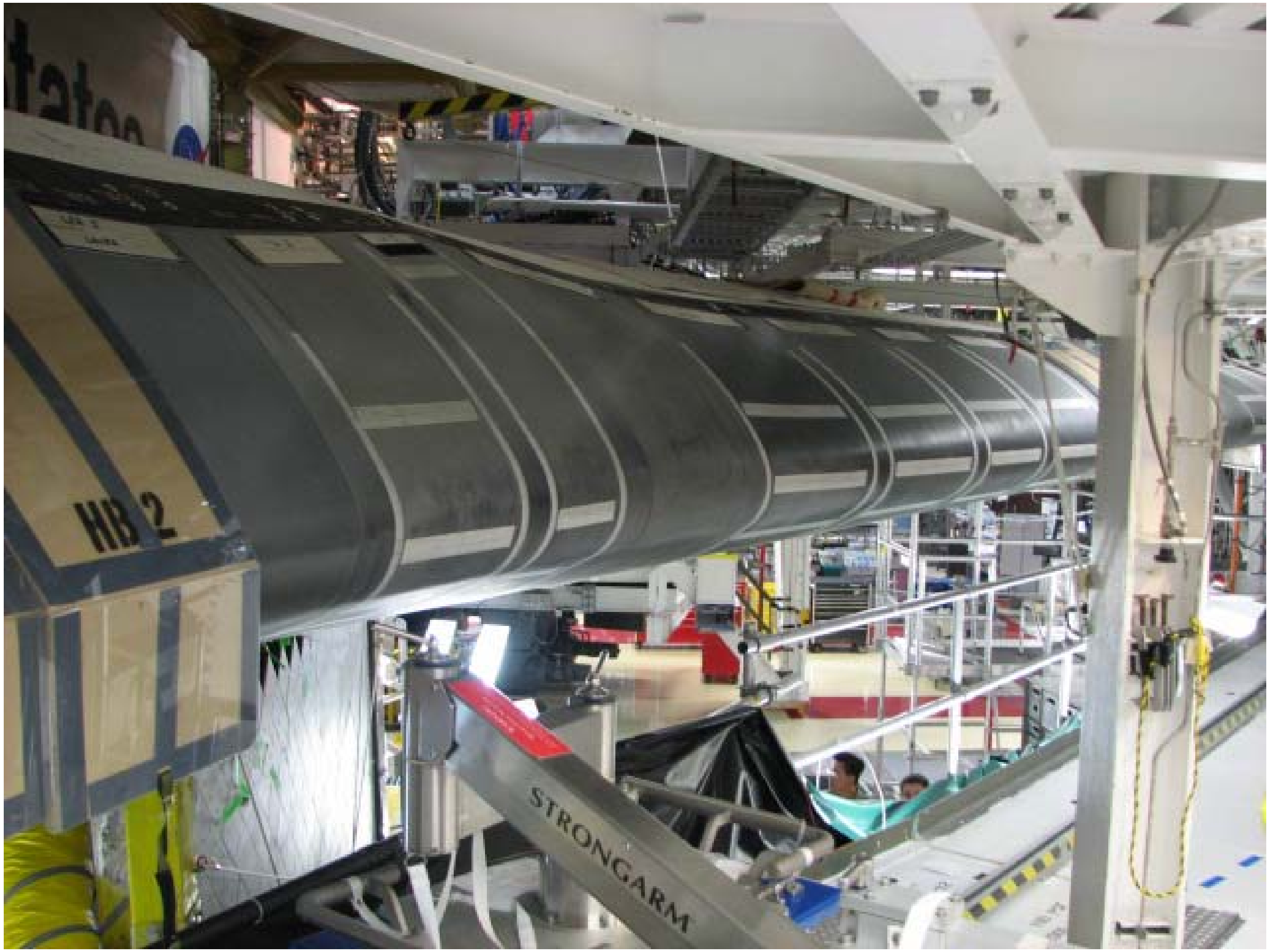

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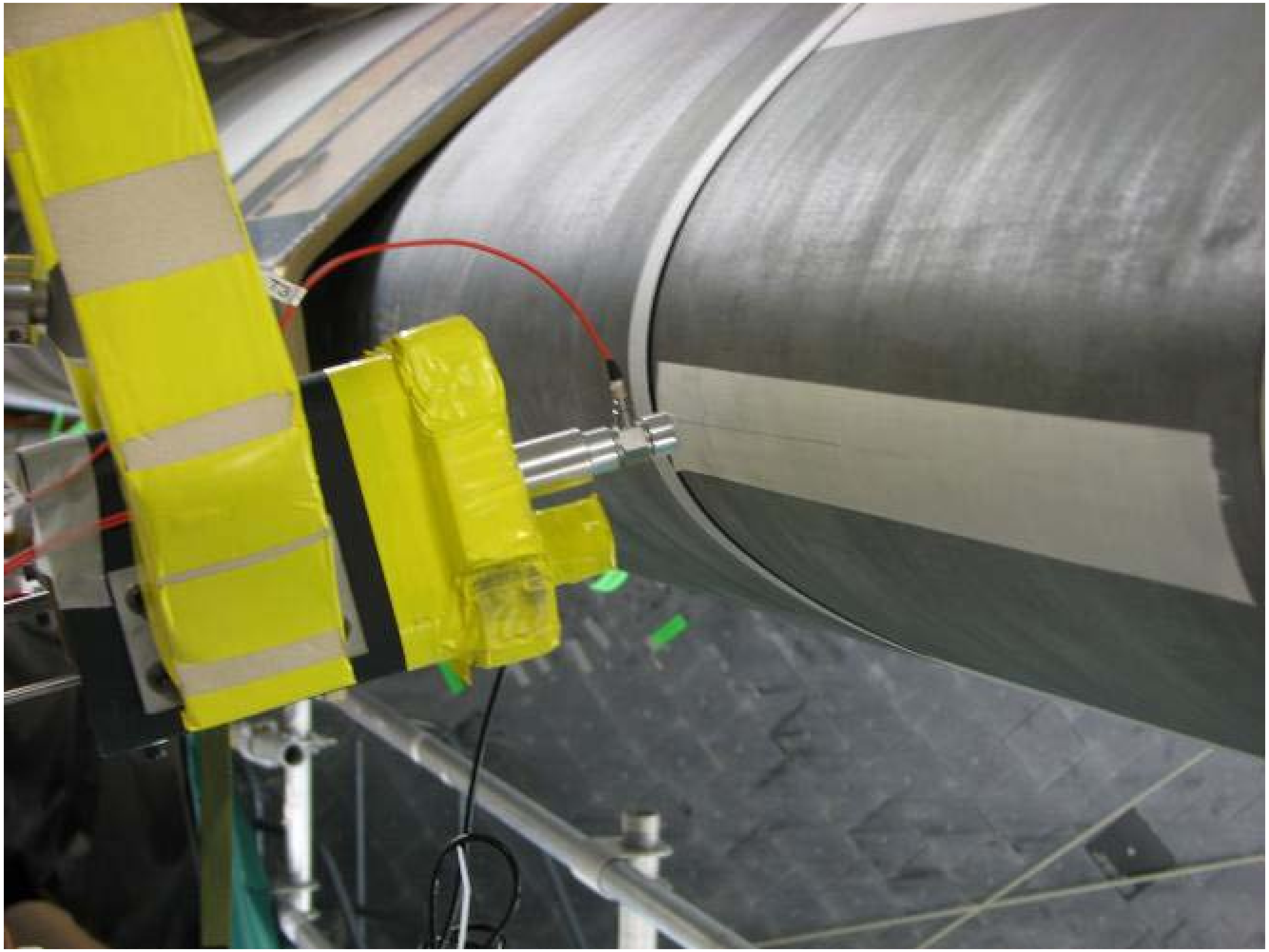
Thumper being aligned to Target

Thumper in Position for another Tap



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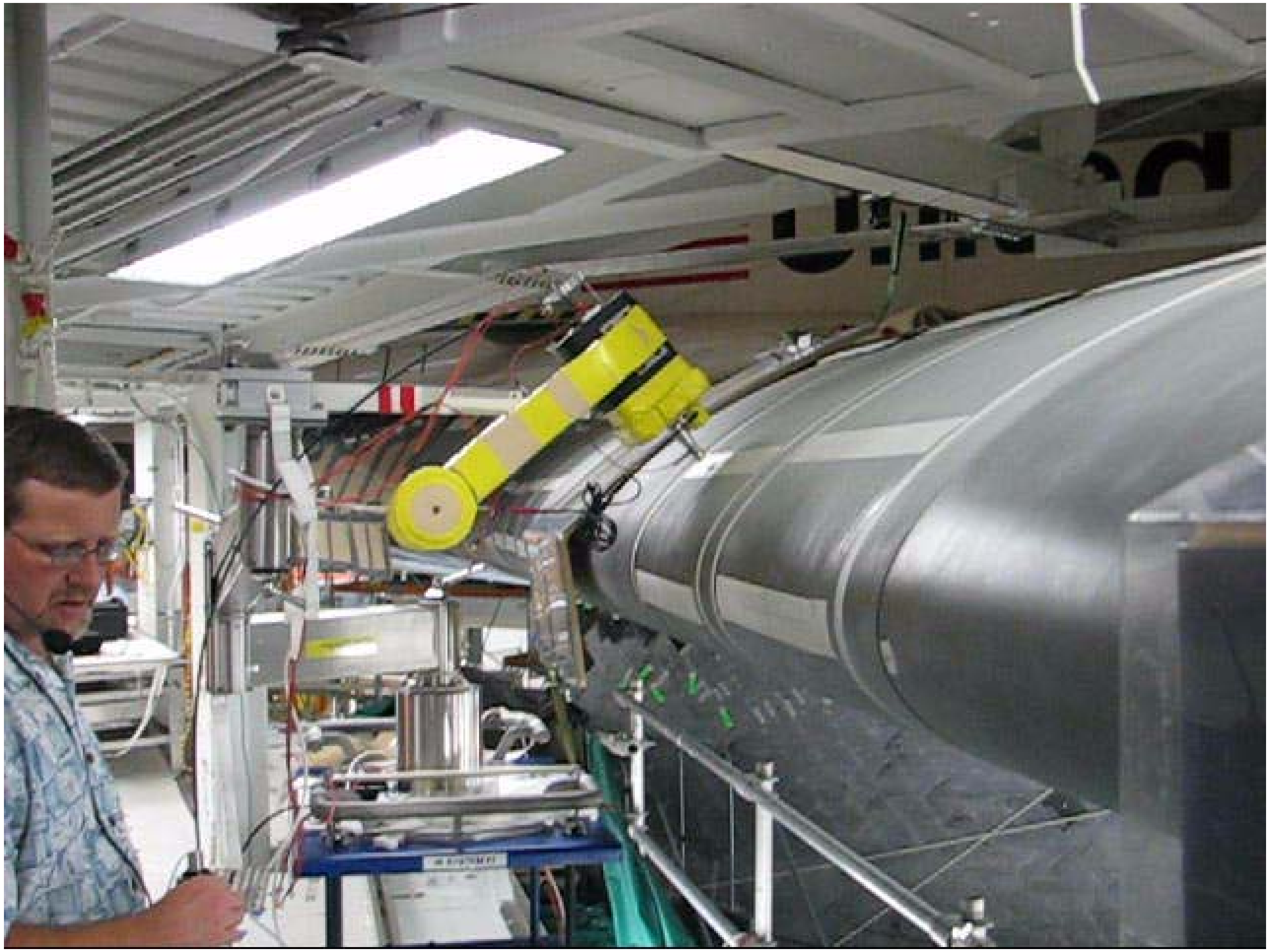
Video of a Tap



The Under-side of the Space Shuttle

TEAM MEMBERS:

KSC Ground Ops

KSC NDE

USA Project Office

Jacobs Sverdrup - ECSG

Boeing Huntington Beach

Tap Test Results

- **Tap Test was successful**
  - Thumper performed very consistently
  - LVDT proved handy for targeting
  - Test team worked well together - Boeing Huntington Beach Test Team, KSC Ground Operations, and USA Nondestructive Evaluation Groups
  - Data proved very useful for validation of the Dynamic Models
- **Successful Shuttle Mission support**
  - Customer expressed extreme satisfaction in WLEIDS upgrade task
  - Based on the upgrade methods and tools using the correlated models, out of 50 previously reported ascent indications, 43 could be eliminated as cases of concern