



Issues in Shuttle System Instrumentation

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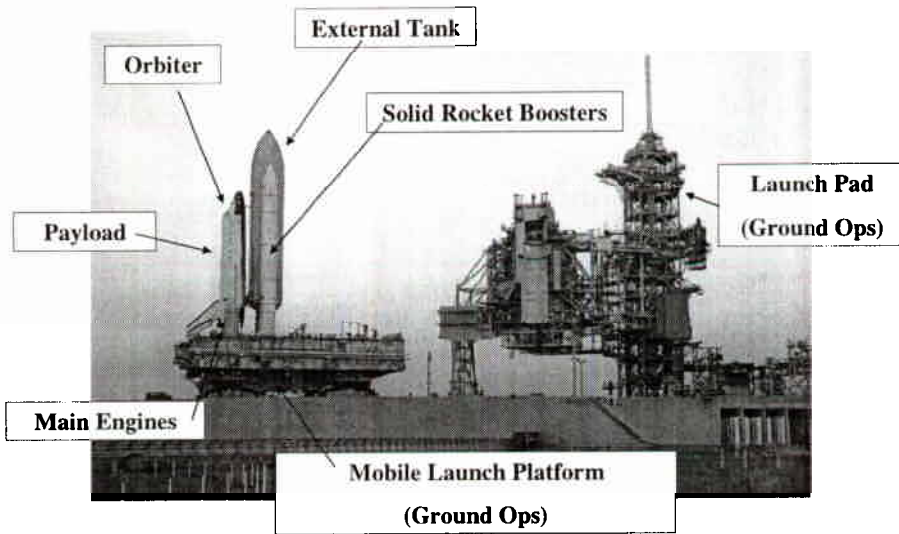
Purpose

- 1. Customer's perspective on Space Shuttle Return-To-Flight (RTF) Instrumentation.**
- 2. Focus on the difficult instrumentation issues.**
- 3. Enable a discussion of new technologies (I.e. – NANO/MEMS/Small Tech) that could enhance Shuttle instrumentation posture.**

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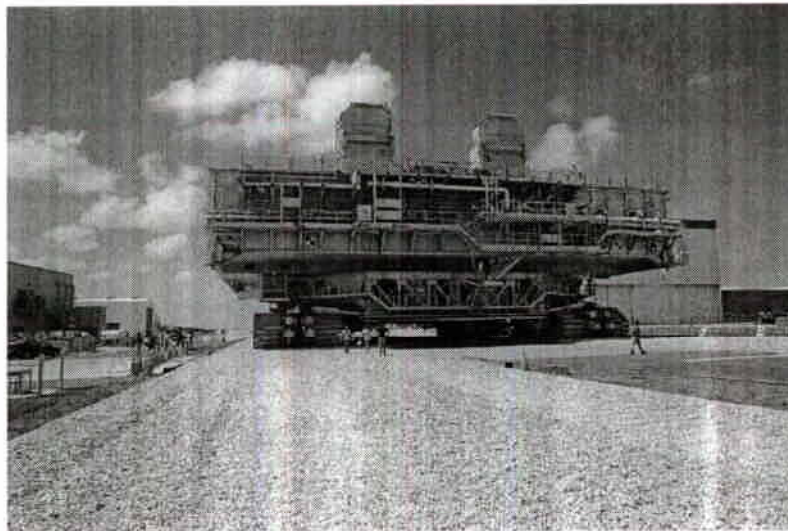
Shuttle System Overview - Hardware



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Ground Capabilities & Constraints



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Ground Capabilities & Constraints

1. T-0 Umbilical

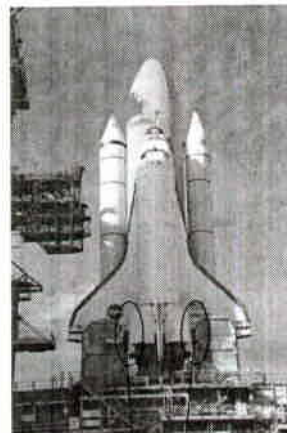
- Allows vehicle instruments to be monitored and recorded prior to launch.
- Retracts during launch.

2. Launch Complex Instrumentation

- Instruments needed for assessment of Launch Commit Criteria (LCC).
- Salt-air and launch environments are issues.

3. Drag-On instrumentation

- Instrumentation can be added as needed to the vehicle for non-flight use.
- The current Roll-out Fatigue Testing is a primary example.

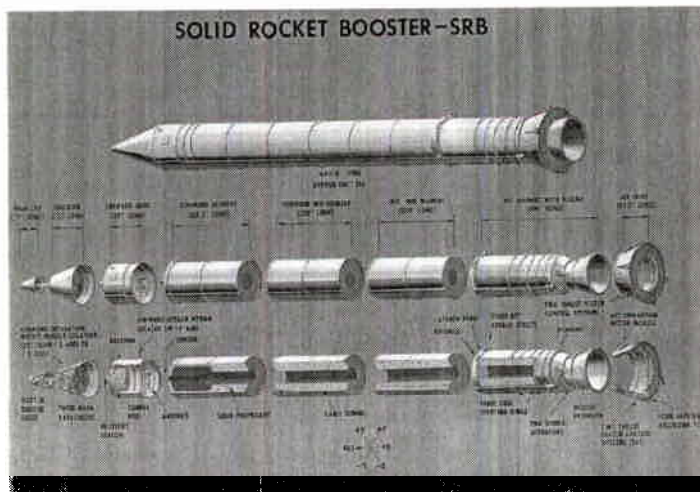


T-0 Umbilicals

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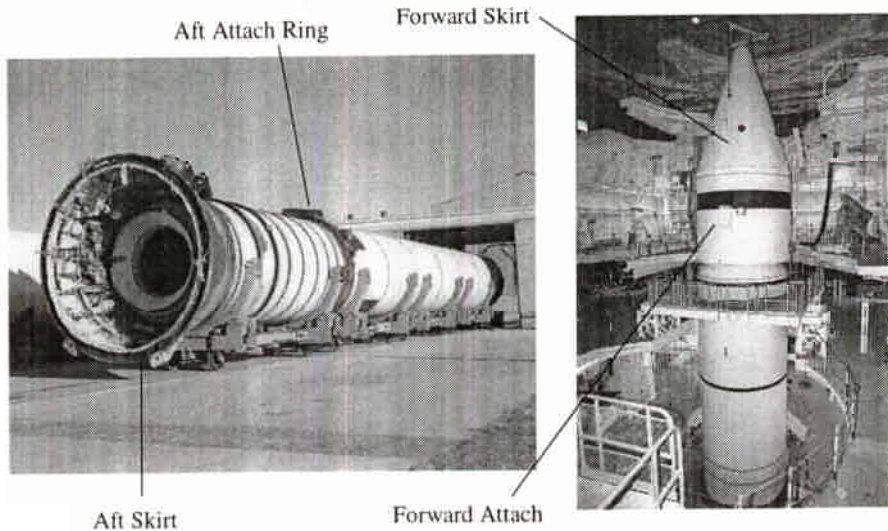
SRB Capabilities & Constraints



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SRB Capabilities & Constraints



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SRB Capabilities & Constraints

1. On-board recording is available (1st Stage Only).

- Chamber pressures and accelerations are recorded.
- Recording capability may be expanded.

2. Systems must survive difficult environments.

- Launch – acoustics, heat, overpressure.
- Recovery – water impact and immersion.

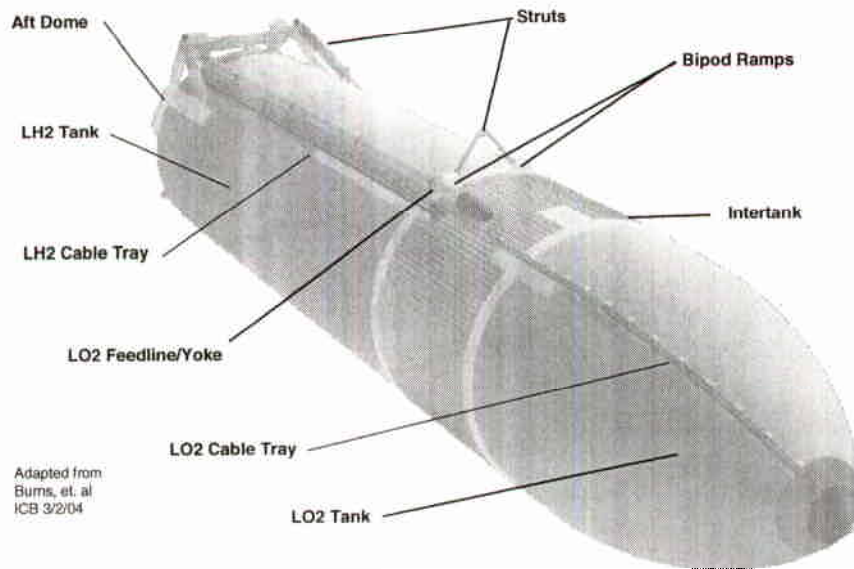
3. Must be electrically benign.

- Solid Rocket Boosters are always loaded.
- Hydrazine powered APUs and Booster Separation Motors are also on-board.

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ET Capabilities & Constraints



ET Capabilities & Constraints

1. The system is not recovered.

- Historically the Orbiter has recorded the data.
- Telemetry is typically used now for cameras.

2. The environment is dangerous.

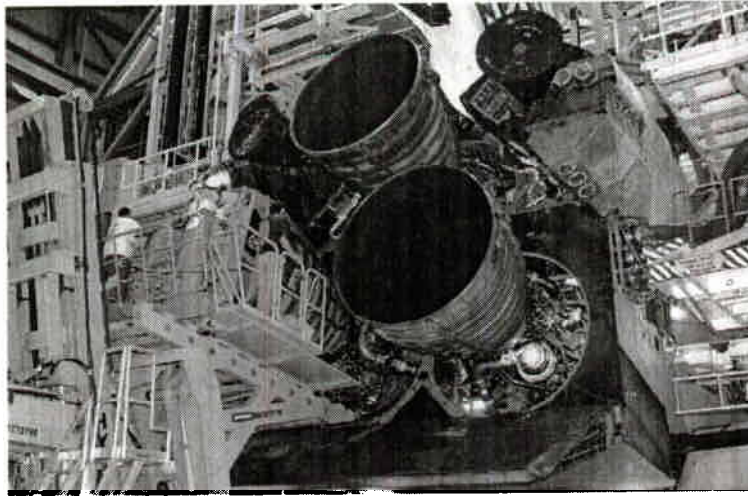
- Cryogenic temperatures and aerodynamic heating.
- Hydrogen gas is potentially present.

3. Potential debris generation must be reduced.

- Any external instrumentation must not become a debris source.
- The local foam insulation must not be weakened and released.



MPS Capabilities & Constraints



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MPS Capabilities & Constraints

1. The engines are already instrumented.

- The Orbiter records and transmits the data.
- Most sensors are for engine performance.

2. The environment is dangerous.

- Cryogenic temperatures and combustion-induced heating.
- Hydrogen and Oxygen gas are potentially present.

3. The environment is highly dynamic.

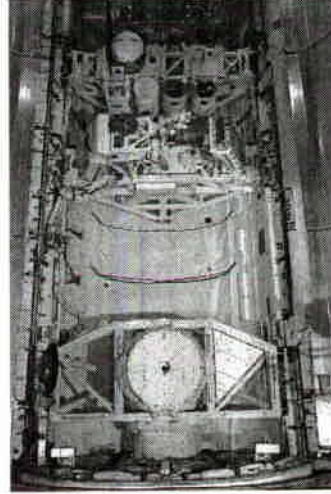
- Acoustics, dynamics, and thermal shocks are all issues.
- The resulting environment is highly complex.



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Cargo Integration Capabilities & Constraints



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Cargo Integration Capabilities & Constraints

1. The system is always changing.

- Payloads change from flight-to-flight and can interact significantly.
- The dynamic environment and response are therefore variable.

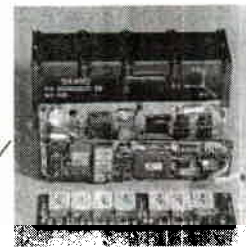
2. There are limited electrical feeds to cross the Orbiter interface.

- The MADS system instruments the longeron on OV-103 & OV-102.
- SAAMD, WB-SAAMD, Micro-TAU, and Wide-Band Micro-TAU are stand-alone units.

3. Time-synchronization is needed.

- Multiple systems make this nearly-impossible today.
- Mix of permanent and stand-alone systems.

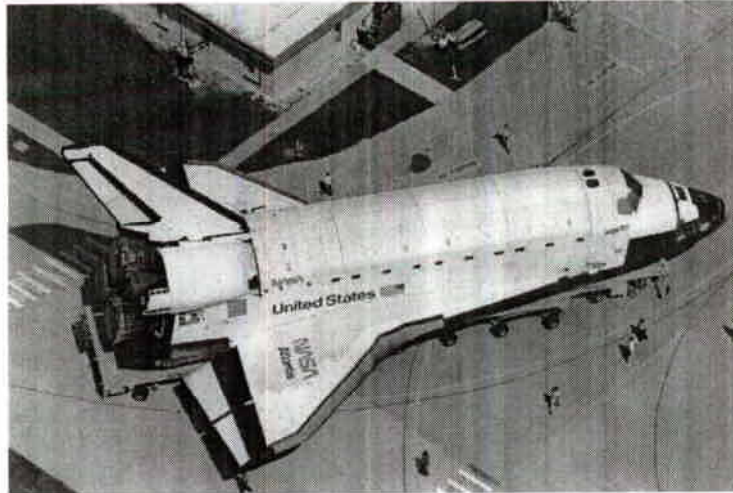
Stand-Alone Acceleration Monitoring Device (SAAMD)



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Orbiter Capabilities & Constraints



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Orbiter Capabilities & Constraints

1. The Orbiters are self-contained systems.

- Each vehicle has power and telemetry.
- Each vehicle has a (Modular Auxiliary Data System) MADS recorder.

2. Sensors are difficult to install.

- Tile replacement and substructure access (nose, tail) is an issue.
- Significant engineering support for installation, wiring, certification.

3. MADS System is difficult to change.

- Specific sensors types/sampling rates.
- Analog recording - no on-orbit play-back.



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Shuttle System Overview - Orbiters

Table of MADS Channels by Orbiter

Sensor Type	Columbia OV-102	Discovery OV-103	Atlantis OV-104	Endeavor OV-105
Pressure	249	64	-	1
Strain	373	27	14	17
Temperature	96	5	22	9
Accel/Vib	22	54	3	18
Other	11	10	-	40
Total (Excluding Other)	740	150	39	45

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Shuttle System Overview – ET,SRB's, MLP

Instrumentation by Element

- **ET** – None
- **SRB's**
 - Low Sample Rate Chamber Pressure
 - Accelerometers
- **MLP** – 5 Microphones



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Shuttle Instrumentation Issue: Number of Requested Sensors

- Original VHMS Request from Loads – 881 Channels
- Original RTF Request from Loads - 383 Channels
- Removing Pre-Approved Channels – 230 Channels
- Program Agreed to Consider – 206
- Maximum That Elements Can Support on STS-114 – 44
- Maximum That Elements Can Support on any of the first six missions – 178
- Possible Solution – Cheap MEMS Sensors

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Instrumentation Issue: Manned Spaceflight Certification

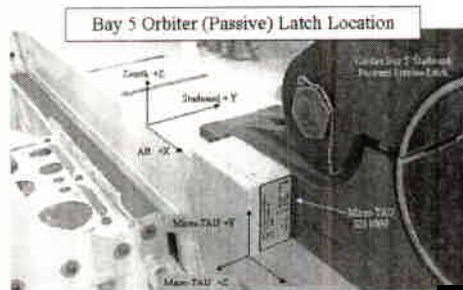
- **Problem – Certification is costly**
 - Environmental testing is required
 - Paper trail for each sensor
 - Materials must be approved
 - Batteries must be approved
 - Acceptance testing is required
 - All other safety issues must be addressed
- **Possible Solution – Lower the size, weight, and power**

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Instrumentation Issue: Integration Engineering

- **Problem – Integrating a sensor on the Shuttle is costly**
 - Attach hardware must be designed and built
 - Wiring runs must be designed and built
 - Drawings must be produced
 - Installation must be planned in the flow
 - Maintenance must be planned and performed



- **Possible Solution – Small wireless systems**
 - Already flying wireless units on the Shuttle
 - Already flying units small enough for adhesive mounting



Instrumentation Issue: Large Dynamic Range Needed

- **Problem – The Shuttle sees a wide range of excitation**
 - Launch, Hi-Q, and Staging have extremely high loading
 - Input fades to a lower value before ET separation
 - Some very telling events produce minimal change in a signal
- **Possible Solution – MEMS-based sensors**
 - MEMS-based sensors can have an extremely high dynamic range
 - Ultra-small size keeps the sensor resonances very high



Instrumentation Issue: Time Synchronization Needed

- **Problem – Multiple sensor systems cannot be synchronized**
 - Looking for validation of system level models
 - Looking for system-level response
 - Looking for system-level anomalies
 - Looking for system-level forcing functions
 - System-level means that time synchronization is important
- **Possible Solution – Is there one?**
 - There is no near-term solution
 - An advanced Vehicle Health Monitoring System might be capable

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Instrumentation Issue: Obtaining SRB Chamber Pressures

- **Problem – Internal chamber pressures are difficult to obtain**
 - Need chamber pressures at more than one location
 - The SRB's dominate everything during first stage flight
 - Environment is extremely harsh
 - No desire to create additional holes in case
- **Is there a solution?**



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Instrumentation Issue: Recording ET Data

- **Problem – The ET has no data recorder**
 - The ET is expendable
 - The ET has no power source
 - The ET has a couple of antenna, but they are dedicated to video
- **Near Term Solution – Record the data on the SRB's**
 - Additional recorders can be flown on the SRB's
 - The SRB's are recovered
 - Limited data and recording time
- **Long Term Solution – Provide the ET a stand-alone system**
 - A data system from an Atlas rocket can be used
 - Must be man-rated and certified
 - Will take up to two years to certify and implement



Atlas V

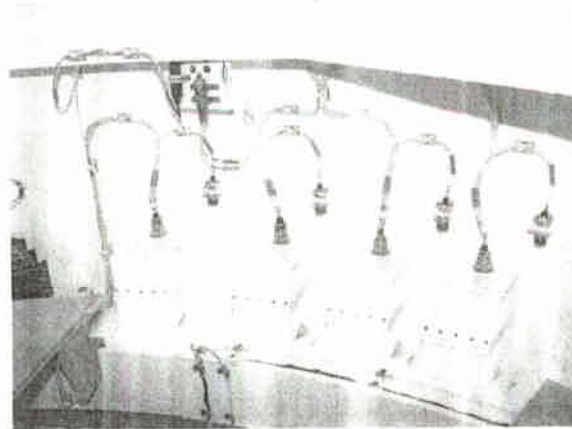
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Instrumentation Issue: Recording ET Data



Range Safety Cable
Between SRB & ET



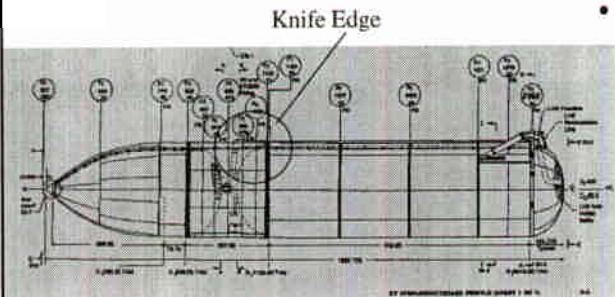
EDAS Recorders in the SRB

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Instrumentation Issue: Internal ET Sensors Needed in Small Area

- **Problem – The LH2 Tank/Intertank Ring Is a Tight Fit**
 - The forward Orbiter attach is on the Lowest Intertank Ring
 - This ring comes to a knife edge at the Liquid Hydrogen dome
 - An internal stiffener further crowds the area
 - Cryogenic temperatures exist
 - Acceleration, vibration
 - Sensors can be mounted before assembly if they are small enough



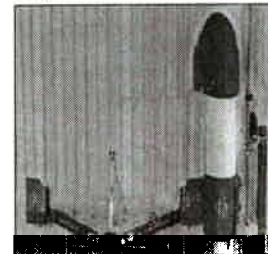
- **Possible Solution:**
MEMS-size sensors
 - Allows internal monitoring
 - Avoids skin panel effects



Instrumentation Issue: External ET Sensors can be a Debris Hazard

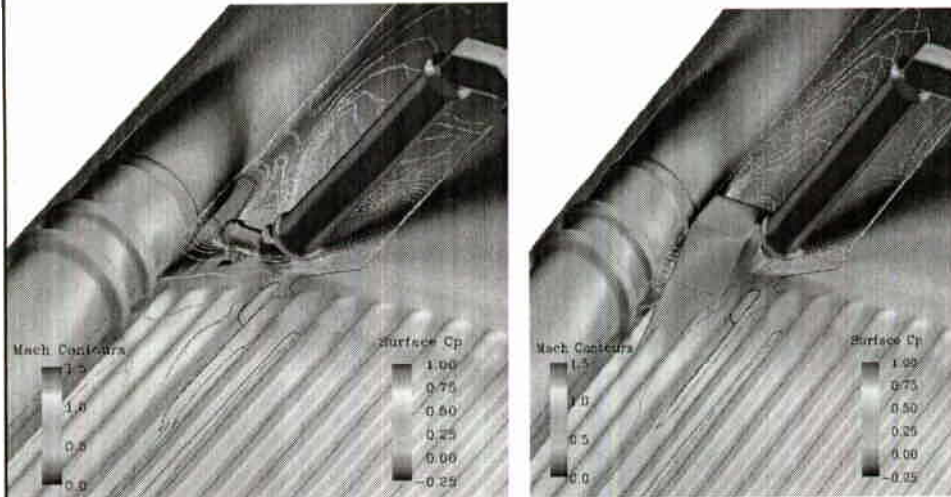
- **Problem – Several ET Sensors must be mounted externally**
 - Up to six ET's are covered in TPS* (Foam)
 - External sensors will require removing and replacing large sections
 - External sensors will also be a debris hazard
 - Later ET's have bare skin
 - Bare-Skin applications will see cryogenic temperatures
 - The ET experiences significant cryo-shrinkage
 - Pressure, microphone, vibration, temperature, strain
- **Possible Solution – MEMS-size sensors**
 - Keep the size below the debris danger level
 - Smart Dust Concepts

* TPS – Thermal Protection System





Instrumentation Issue: ET LOX Feedline Bracket

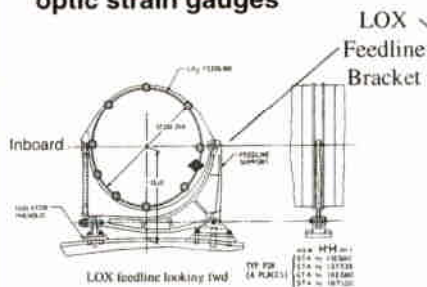


Instrumentation Issue: ET LOX Feedline Bracket

- **Problem – The ET LOX Feedline Bracket is a challenge**
 - Aero Loads on the ET LOX Feedline will increase
 - Validate CFD* with pressure or strain
 - Mounting strain gauges on the bracket is difficult
 - Pressure sensors require degrading TPS integrity

*CFD: Computational Fluid Dynamics

- **Possible Solutions – MEMS-size pressure sensors or fiber-optic strain gauges**

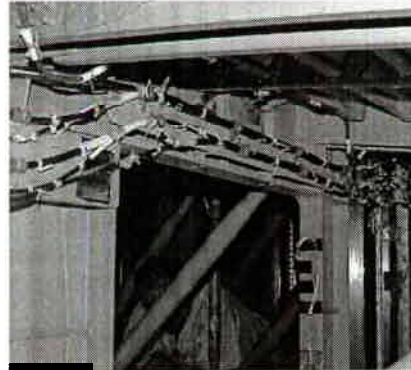




Instrumentation Issue: Orbiter Wiring

- **Problem – Wiring the Orbiter is difficult**
 - OV-103 has some wiring in place
 - OV-104 & OV-105 have little wiring in place
- **Possible Solution – Wireless sensor systems**

Wiring in OV-102
Wing Box



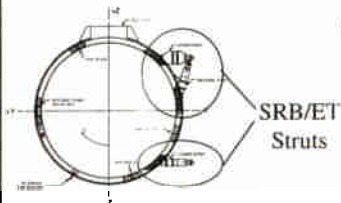
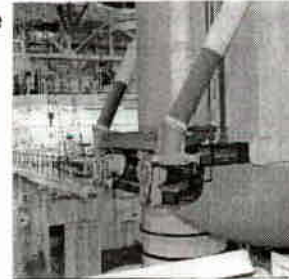
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Instrumentation Issue: Strut Strain Gauge Calibration

Aft ET/Orb
Struts

- **Problem – Strain gauges on attach struts require calibration**
 - SRB-ET struts can be performed by the vendor
 - SRB-ET struts do not have major TPS concerns
 - Orbiter-ET struts have to be performed on the vehicle
 - The calibration frame may be unavailable
 - TPS-covered struts are an issue
- **Possible Solution – Fiber Optic Sensor systems**
 - May not help calibration issue
 - May help installation and recording issue



Fwd. ET/Orb
Bipod Struts

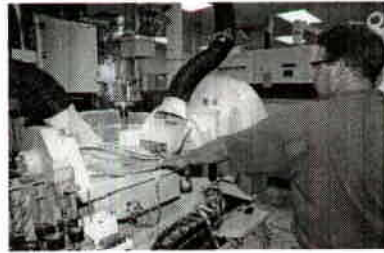
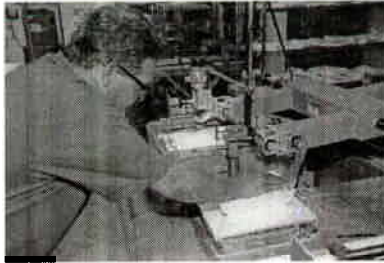


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Instrumentation Issue: Orbiter TPS Change-Out

- **Problem – Some Sensors require special Orbiter tiles**
 - Pressure, temperature, and microphones on external surfaces
 - Significant engineering and installation
- **Possible Solution – Small sacrificial sensors, smart dust**



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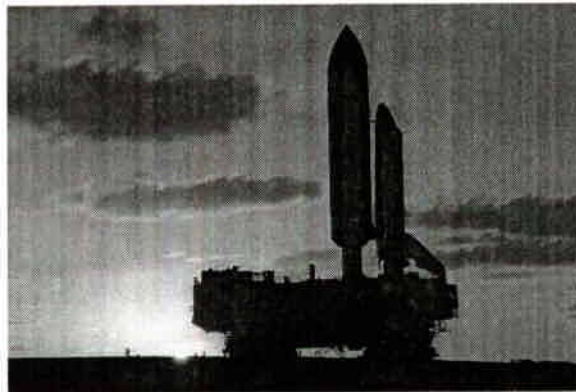


Issues Summary

- **Issues:**
 - Number of Sensors
 - Certification
 - Integration Engineering
 - Dynamic Range
 - Time Synchronization
 - SRB Chamber Pressures
 - No ET Recorder
 - Internal ET Sensors in a Small Area
 - External ET Debris Hazard
 - ET LOX Feedline Bracket
 - Orbiter Wiring
 - Orbiter TPS Change-Out
 - Strut Strain Gauge Calibration



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Conclusions

1. Instrumenting the Shuttle system will be a challenge.
2. New Technologies Should be considered where appropriate.
3. Wireless Sensors, Smart Dust, Fiber-Optic Strain Gauges, MEMS-based sensors are possible technologies.