Boundary Layer Transition Flight Experiment Implementation on OV-103

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Boundary Layer Transition Flight Experiment

[4] "The design of hypersonic vehicles today is greatly dependant on the use of CFD. The primary reason for this is the lack of experimental ground test facilities that can simultaneously simulate Mach numbers, Reynolds number, and high temperature levels associated with hypersonic flight"

– John D. Anderson, Jr.

Objective:

To obtain hypersonic aero-thermodynamic data for the purpose of bettering the understanding of flow transition from a laminar to turbulent boundary layer using a known height protuberance.

Targeted Mach number transitions:

- First Flight – Mach 15
- Second Flight – Mach 18
- Third Flight – Mach 19

Boundary Layer Transition Flight Experiment

[1]Four *Hypotheses* are being tested:

- BLT cannot be initiated with a discrete protuberance at hypersonic non-equilibrium conditions
- There is not a ground to flight environment scaling effect on discrete protuberance induced BLT at hypersonic non-equilibrium conditions
- High Mach number / high enthalpy non-laminar heating is not fully turbulent
- High Mach number / high enthalpy heating for turbulent boundary layers and surface catalysis interact and are dependant upon each other

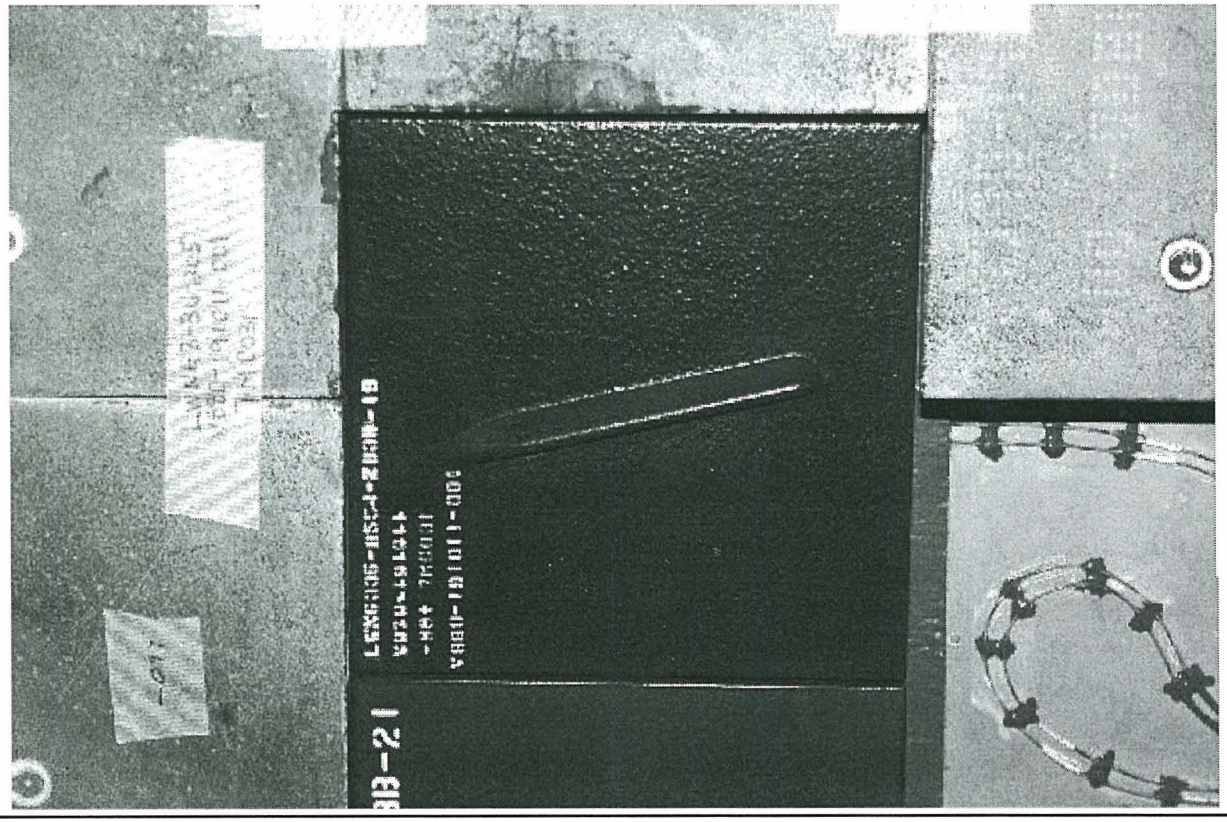
[3] Historical Activities / Parameters

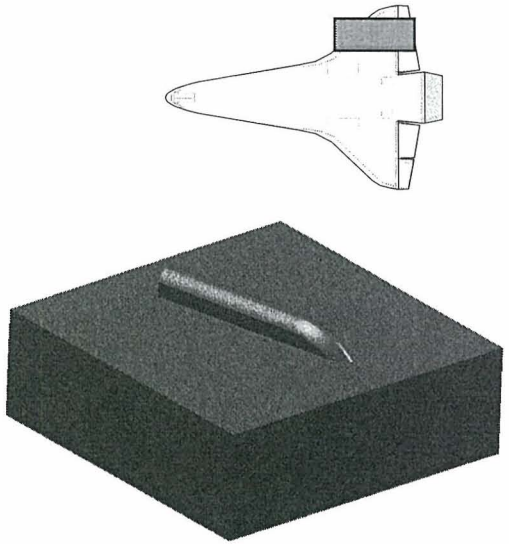
The design team had to account for several parameters:

- Ensure design will meet Space Shuttle safety requirements for nominal ascent, flight, entry, and landing
- Ensure design can be removed during an EVA
- Ensure the peak heat is acceptable for the protuberance, local protuberance tile, tiles downstream, and aluminum skin of the Orbiter is acceptable in an abort case and in worst and nominal entry cases
- Ensure design of supportive hardware meet functional and performance requirements

Project Overview

In order to obtain the flight data, a unique tile had to be installed on the undercarriage of *Discovery* that would have a protuberance of a known geometry that would not change during entry. Thermocouples will need to be installed downstream to obtain temperature data.





System Integration

Groups involved in the implementation of BLT FE at KSC:

- *Thermal Protection System (TPS)*
- *Airframe Structures (STR)*
- *Orbiter Electrical (OEL)*
- *Orbiter Instrumentation (INS)*
- *Optics*

Overview / Responsibilities of TPS

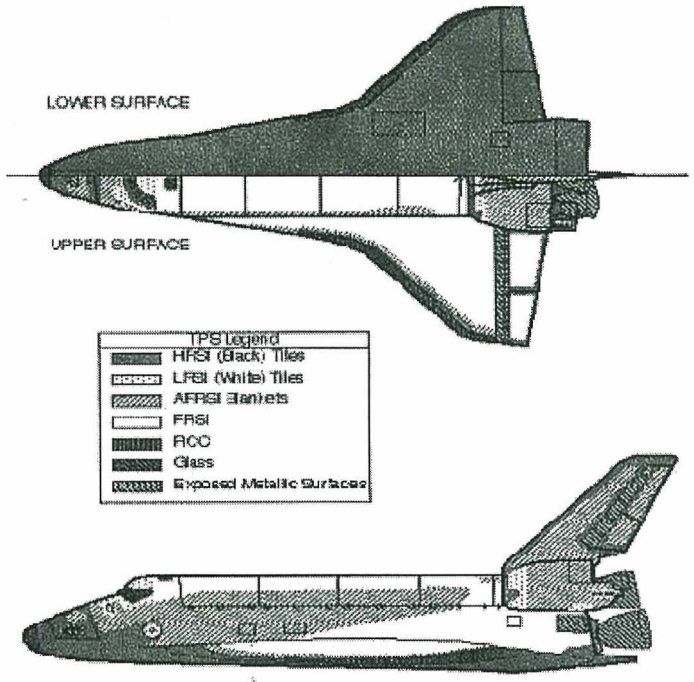


Figure 3 Orbiter TPS Configuration (Approximate Location)

Discovery has approximately 24,000 tiles
-Each has a unique geometry
-Each has unique aero-thermal criteria
-Installation procedures may vary

-Twenty one total tiles removed
-Thirteen had thermocouples installed
-Six acted as cover tiles
-Two / Three changed for thermal reasons
-Sequencing critical to success of FE

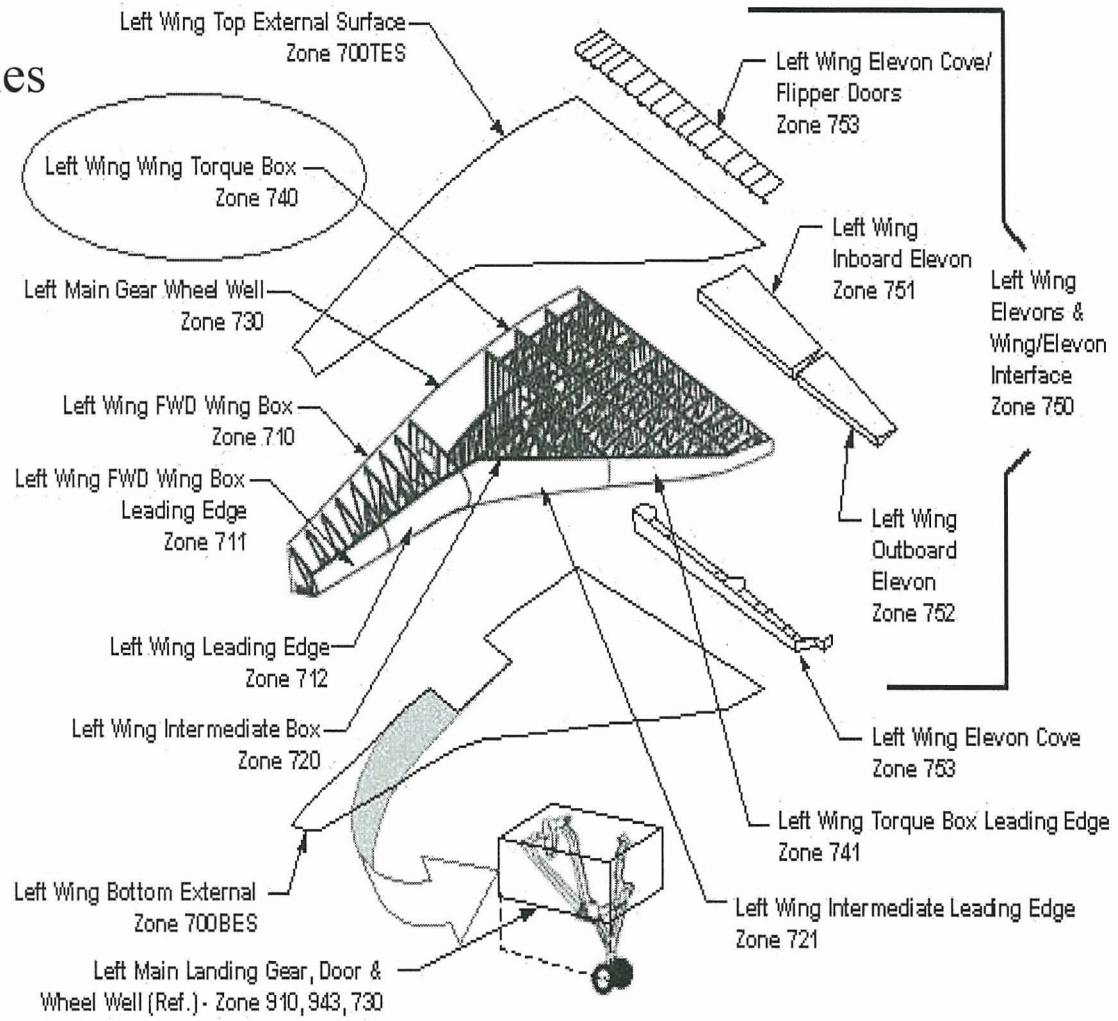
Responsibilities of STR

-Locate and drill penetration holes

-Install grommets

-Install Thermocouple Reference Junction (TRJ)

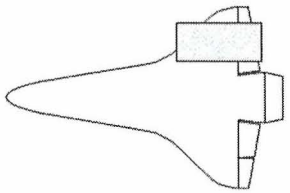
-Install Tempi-labels

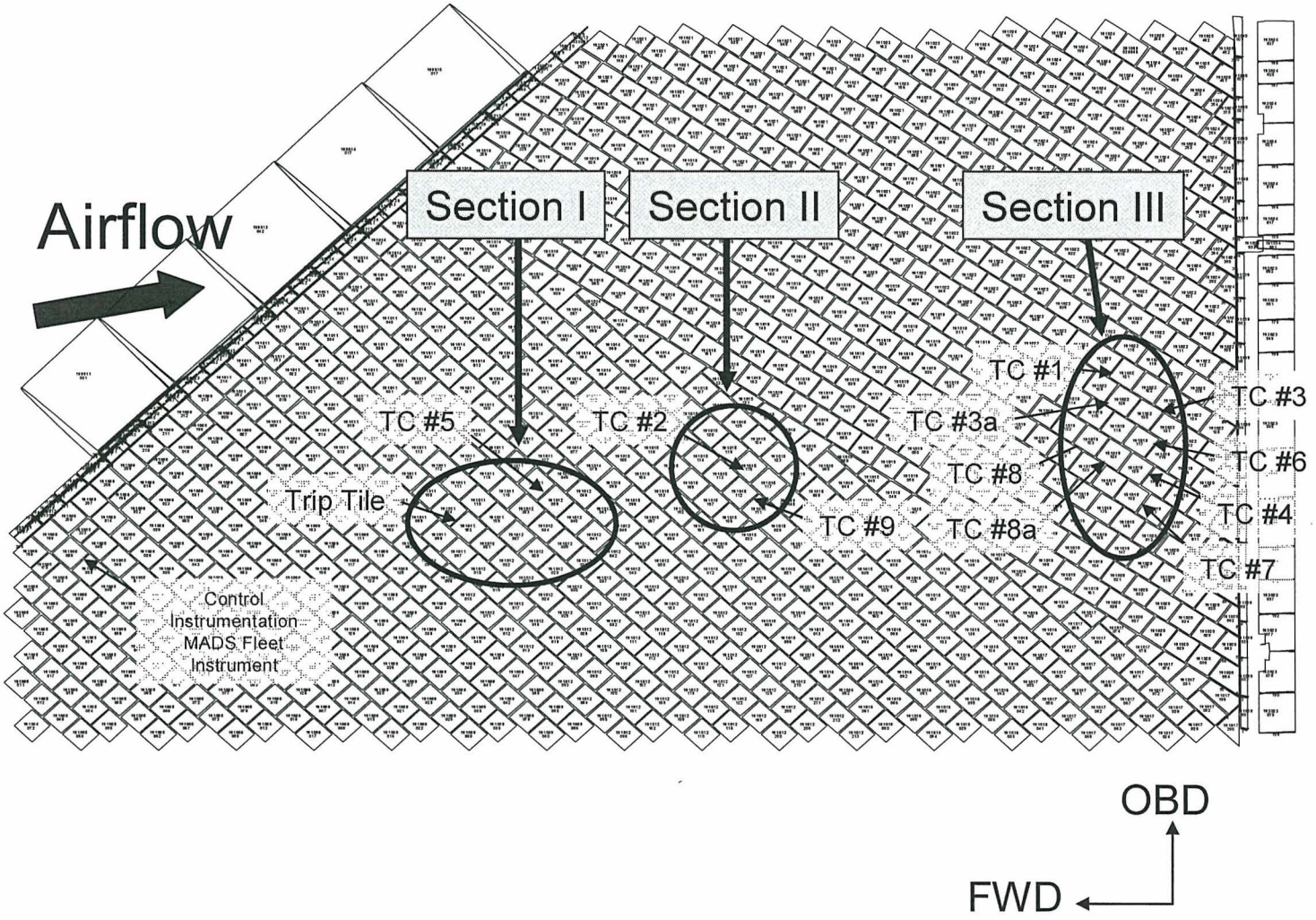


Overview / Responsibilities of OEL / INS / Optics

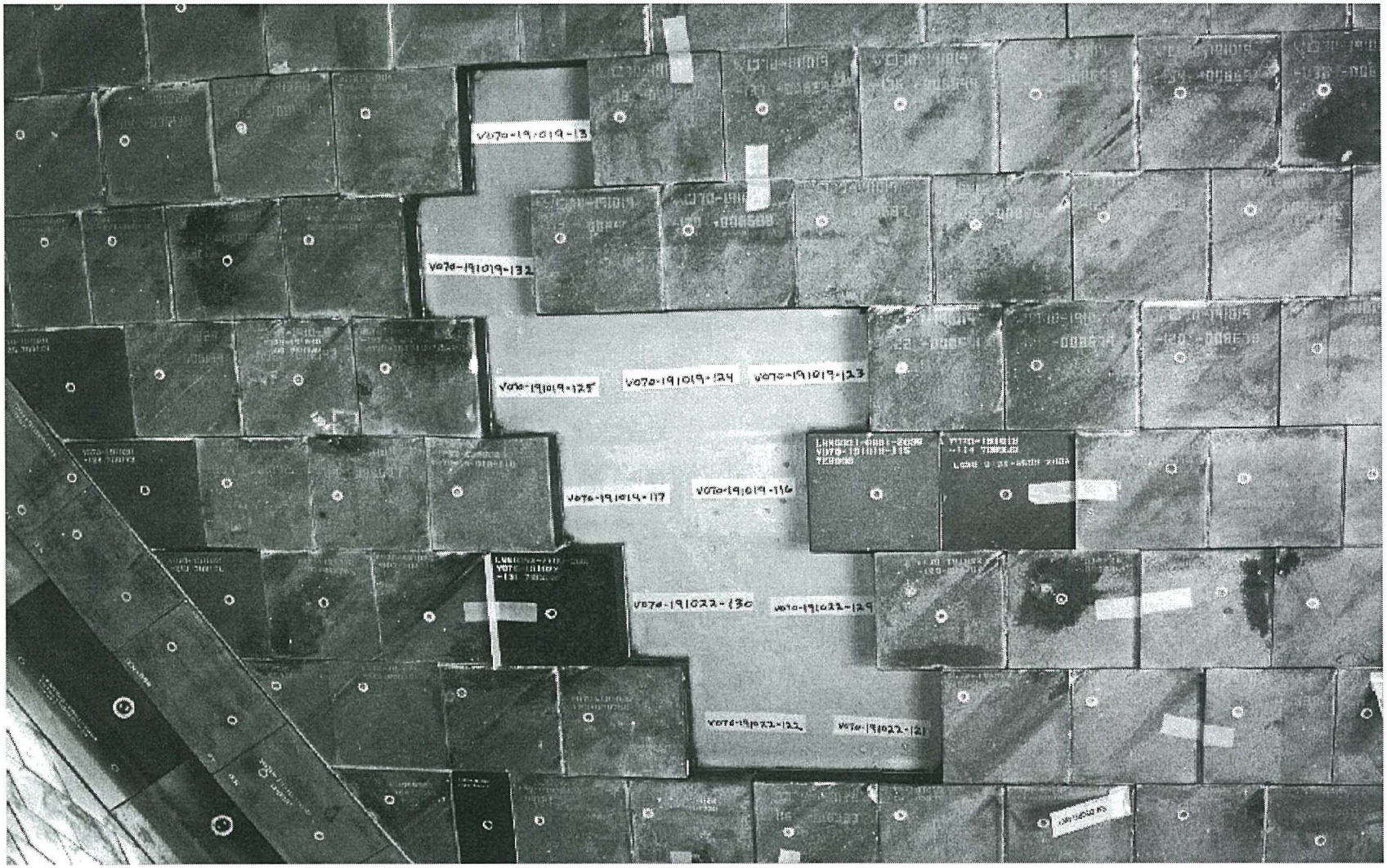
- INS responsible for interfacing tile thermocouples to TRJ and individual channelization / calibration.
- OEL responsible for interfacing the TRJ to the Modular Auxiliary Data System (MADS) – on board recorder
- Optics responsible for obtaining high resolution 3-D images of the pre-flight and post-flight protuberance as well as surrounding tiles. HYTHRM team obtained IR images of *Discovery* on entry.

Boundary Layer Transition Flight Experiment
STS-119 OV-103 FLT-36 Layout

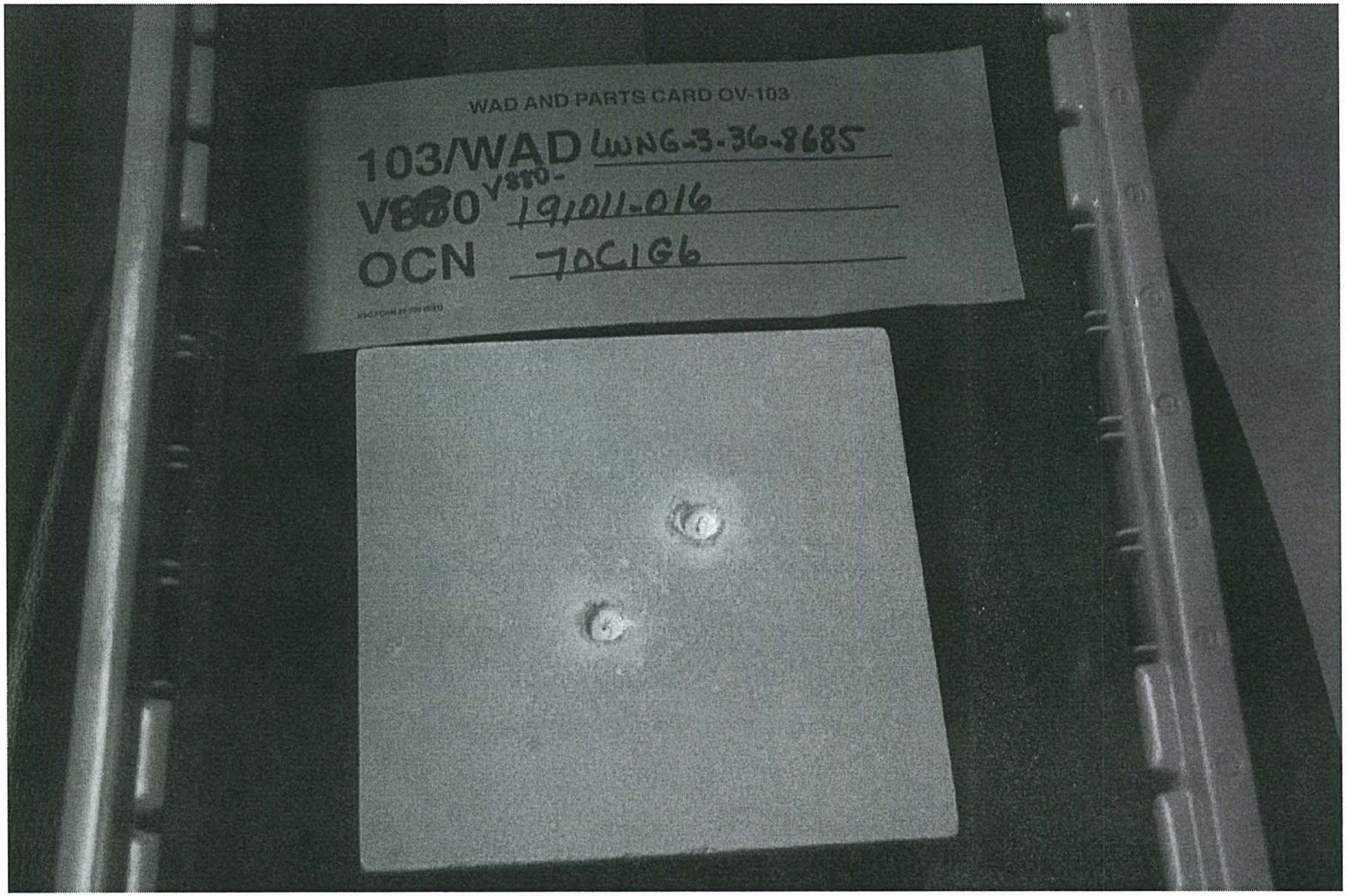




Tile Removals / Processing Discussion



TPS Processing Discussion



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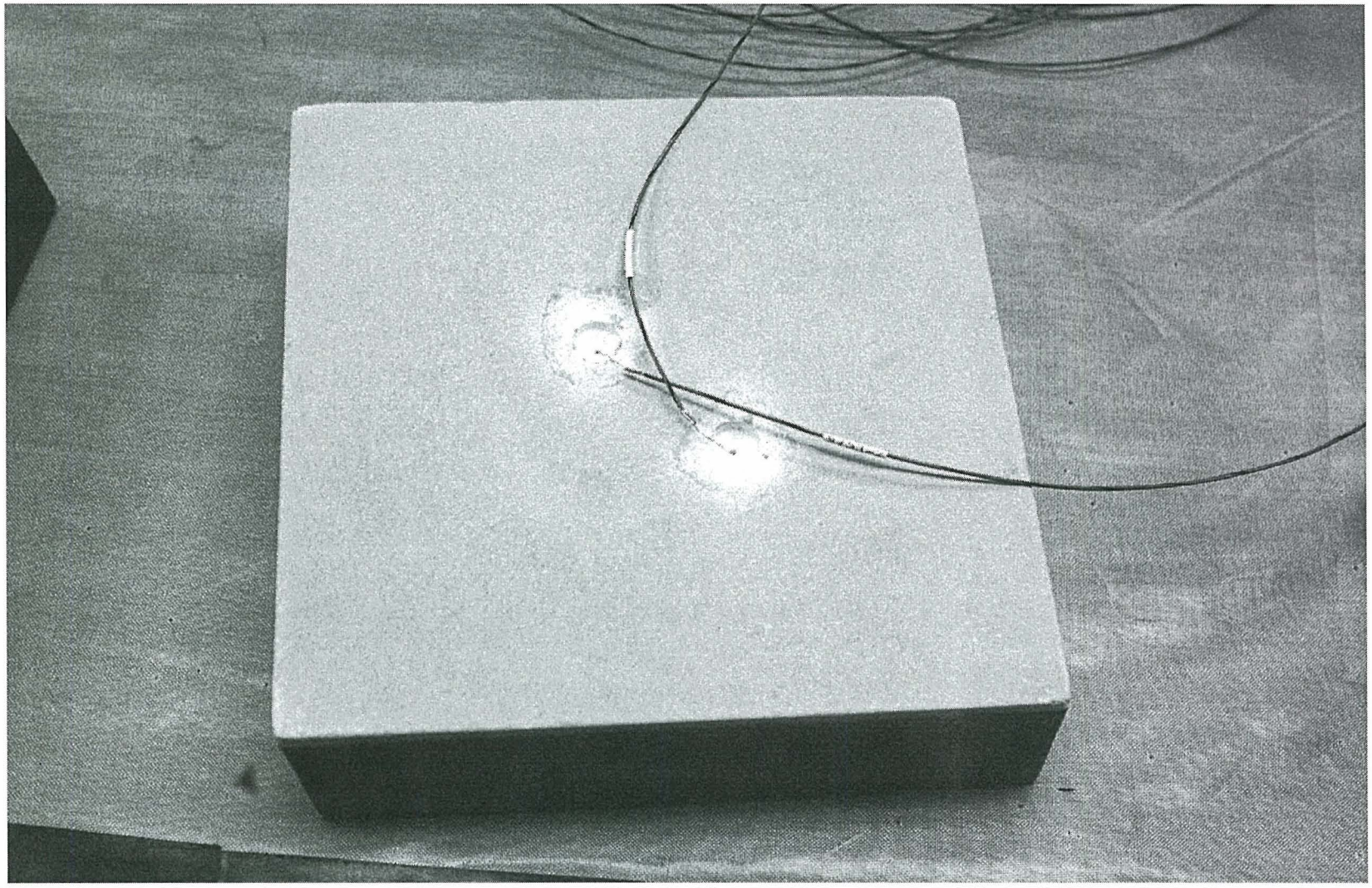

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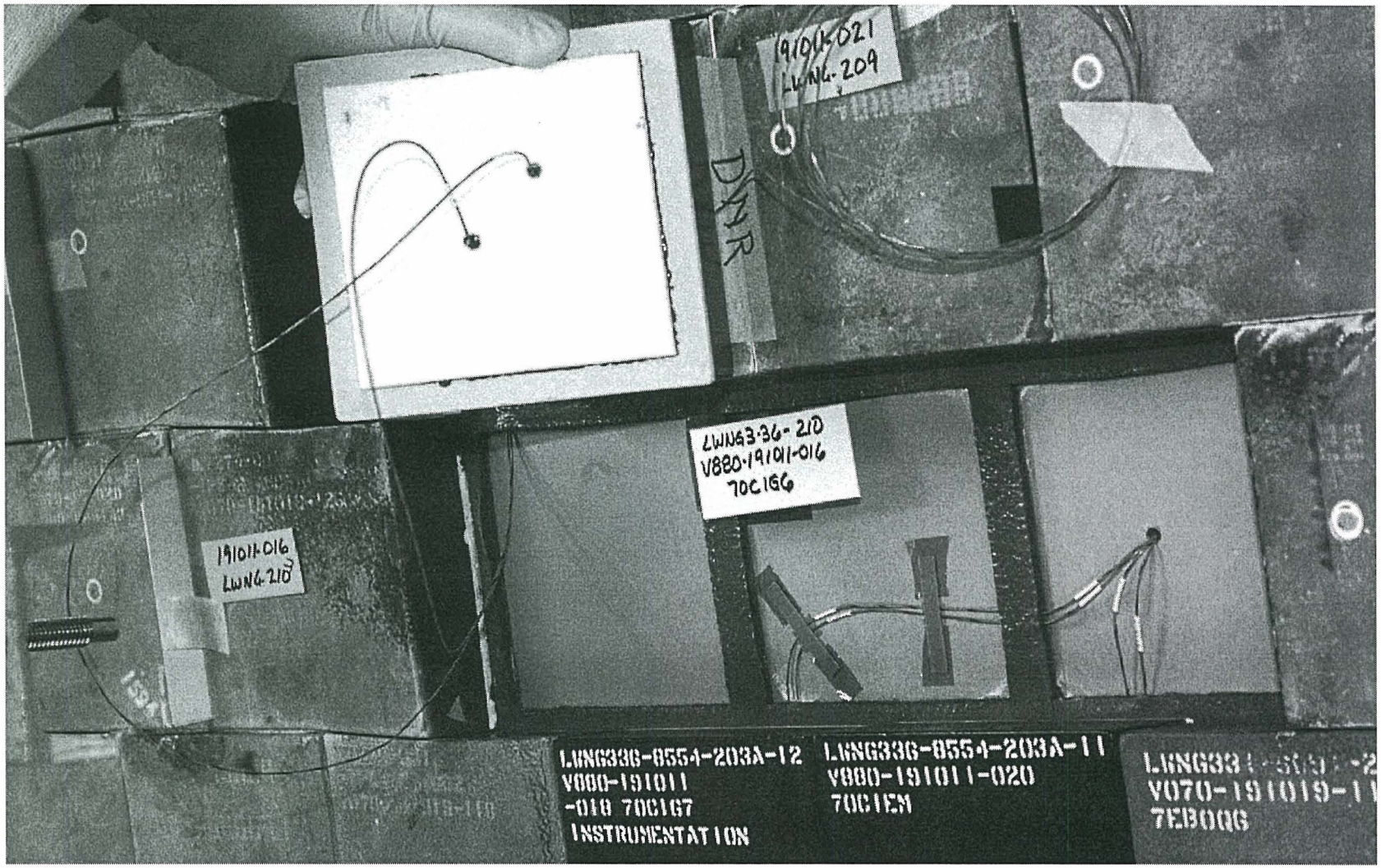
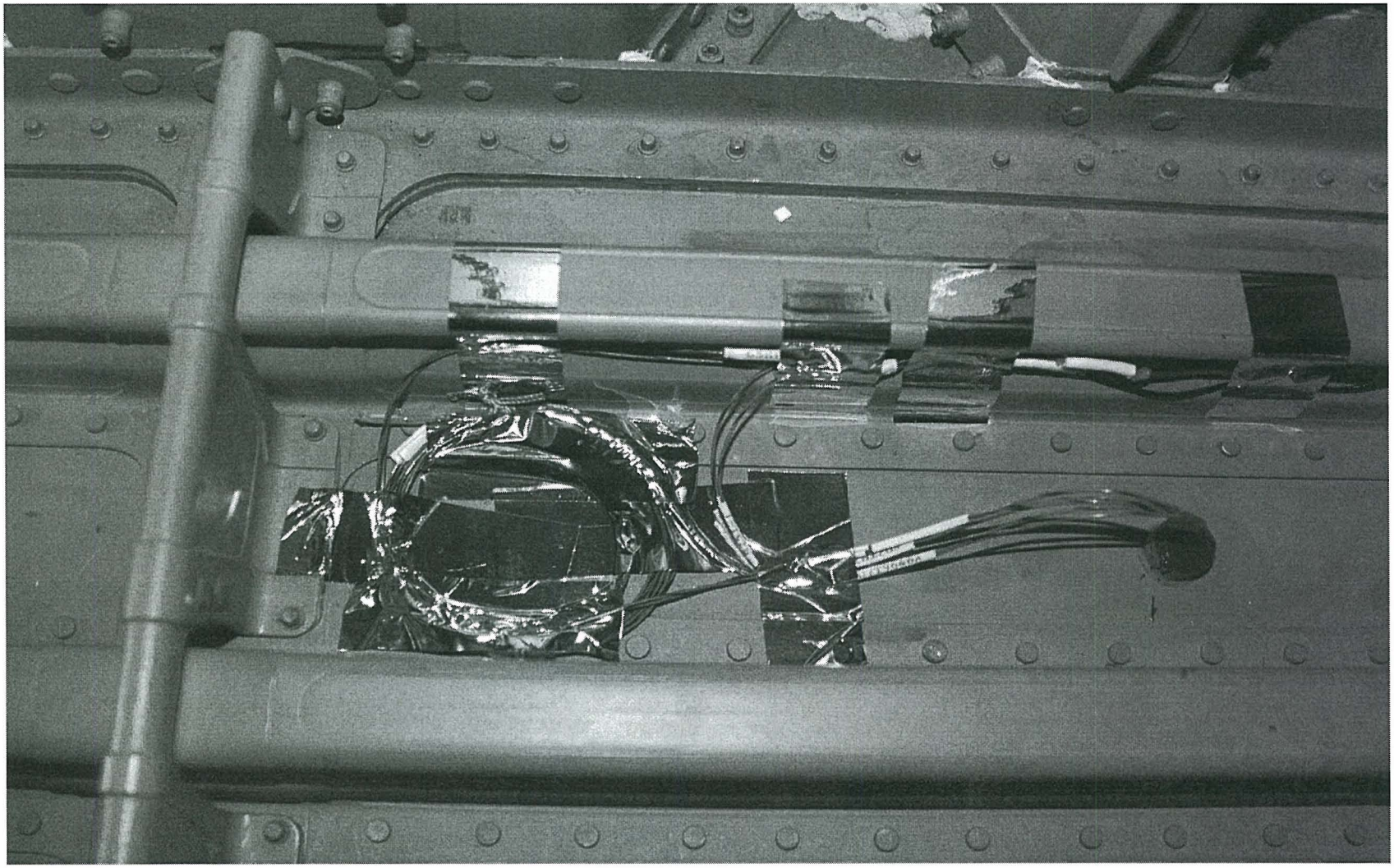
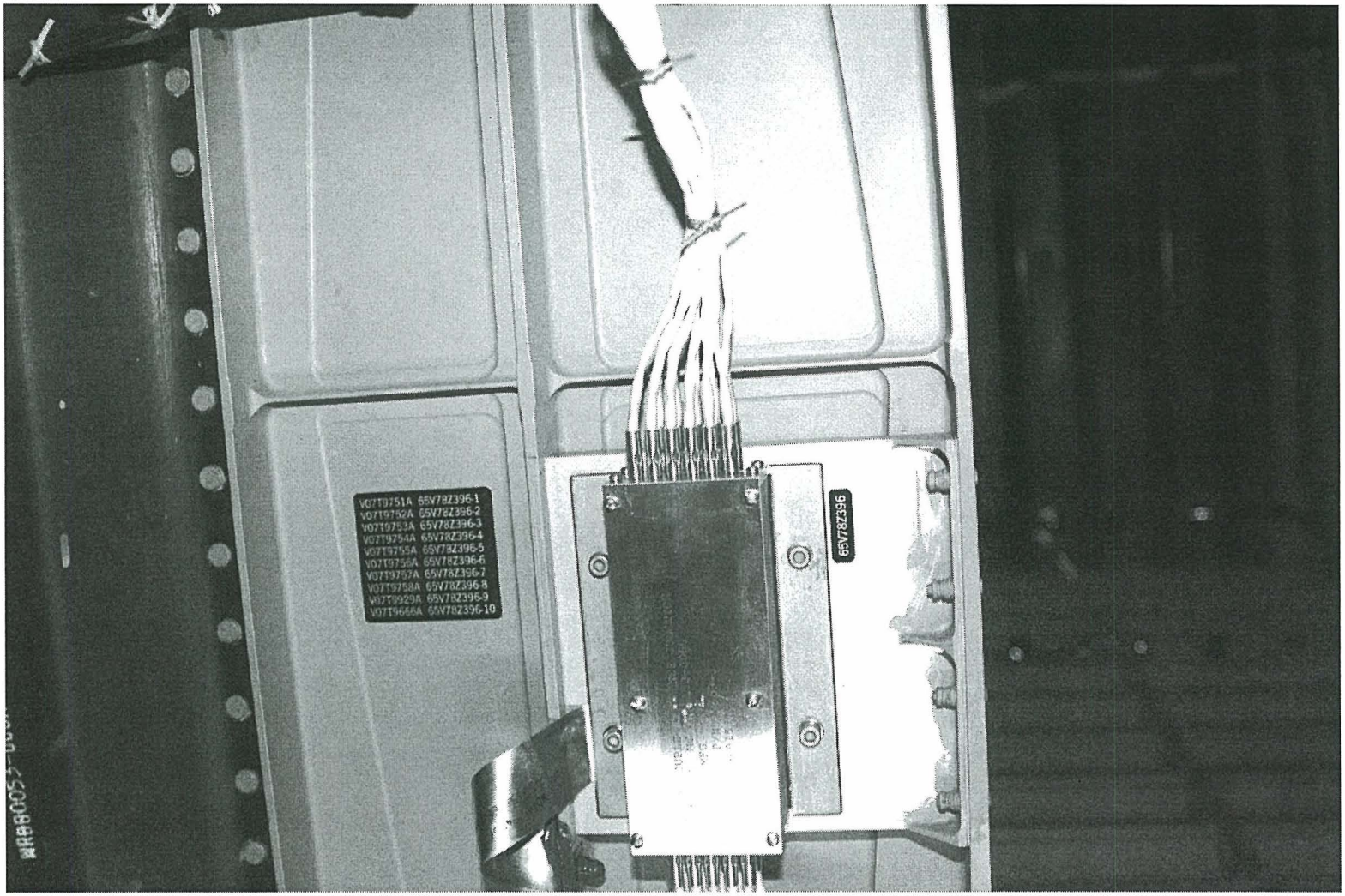


STR Discussion



STR Discussion: TRJ Installation



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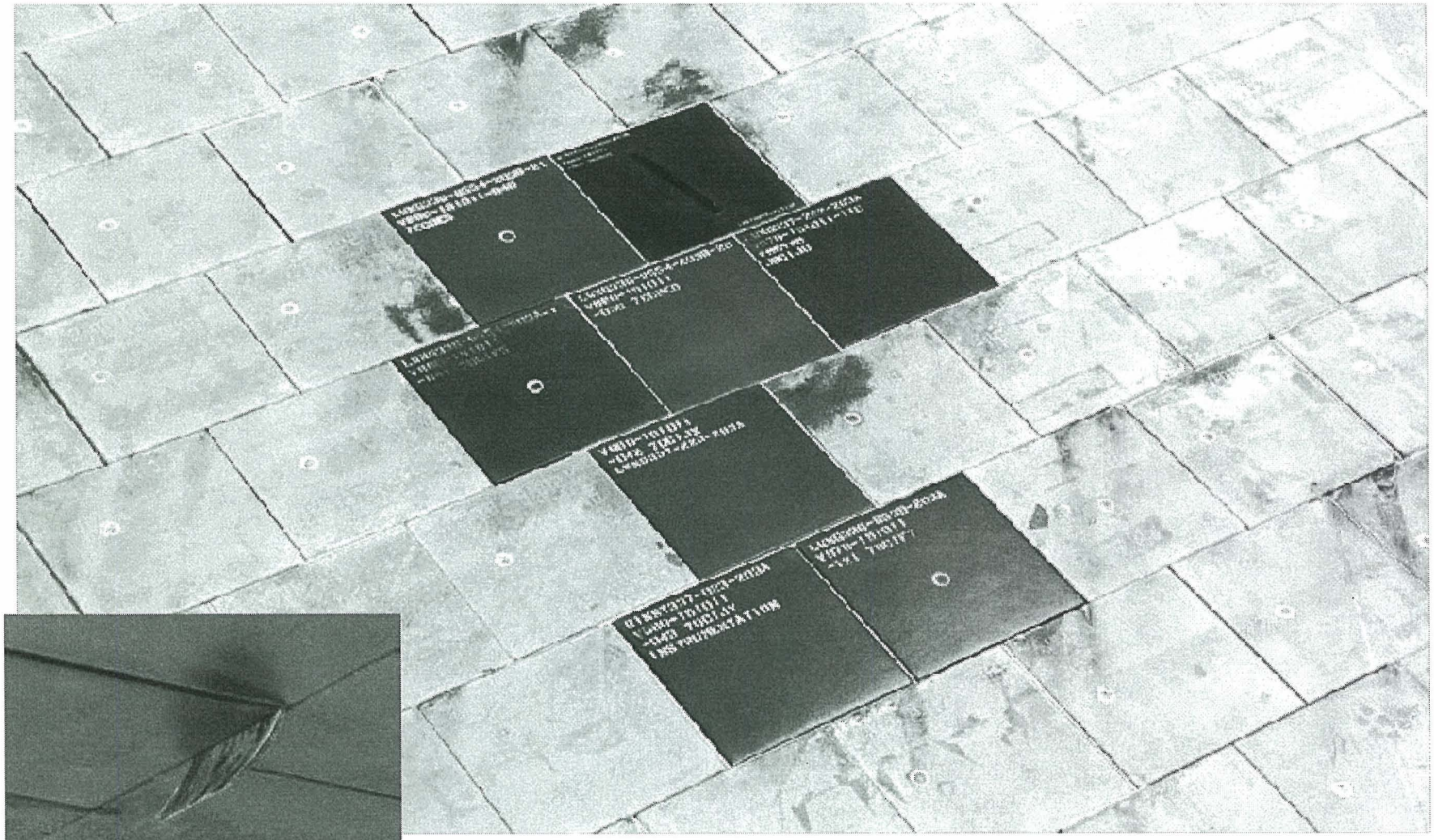

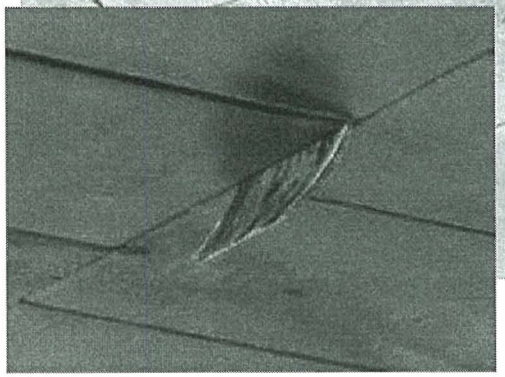

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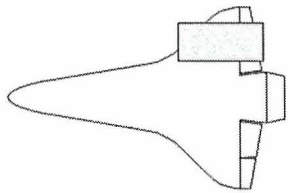
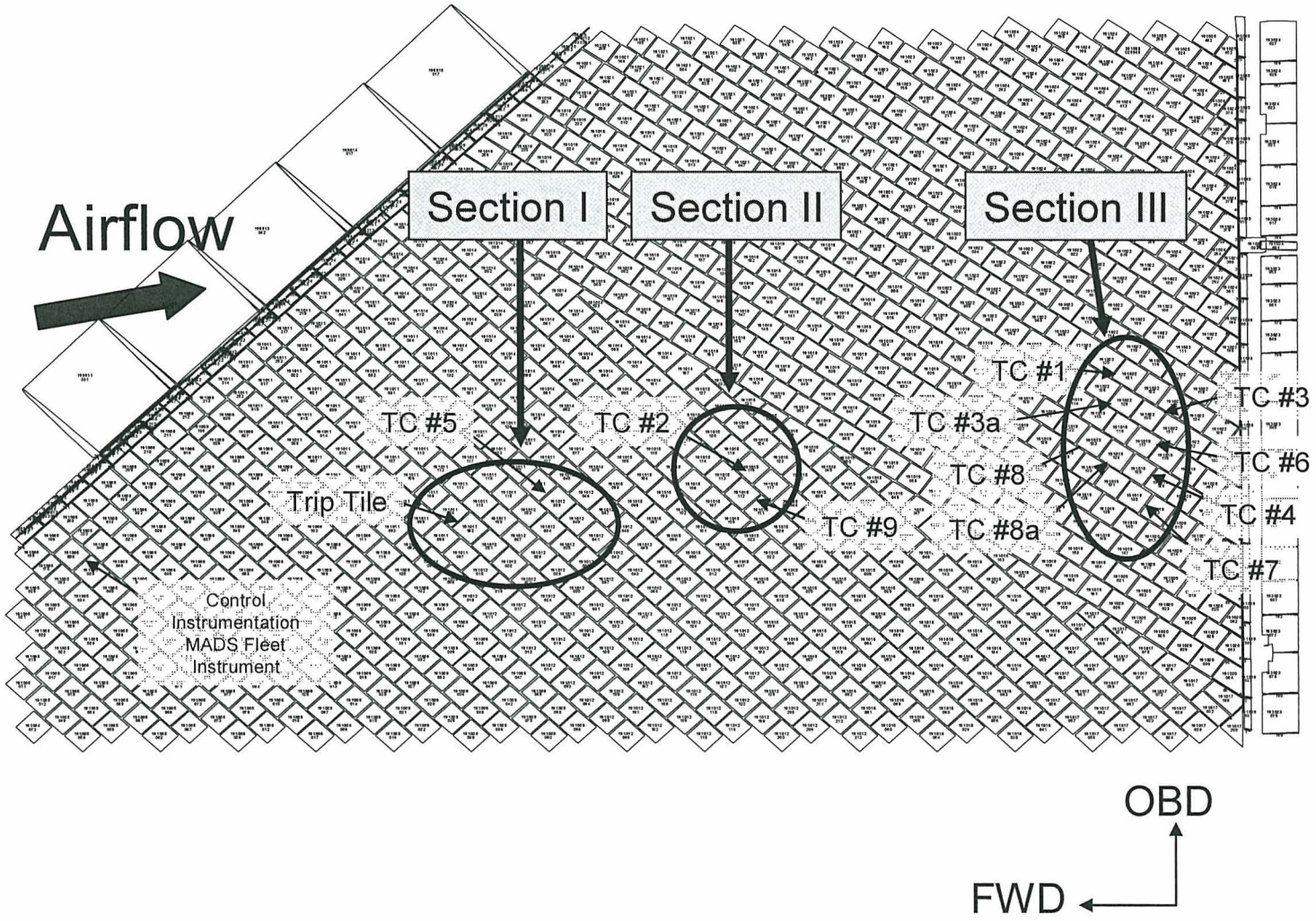
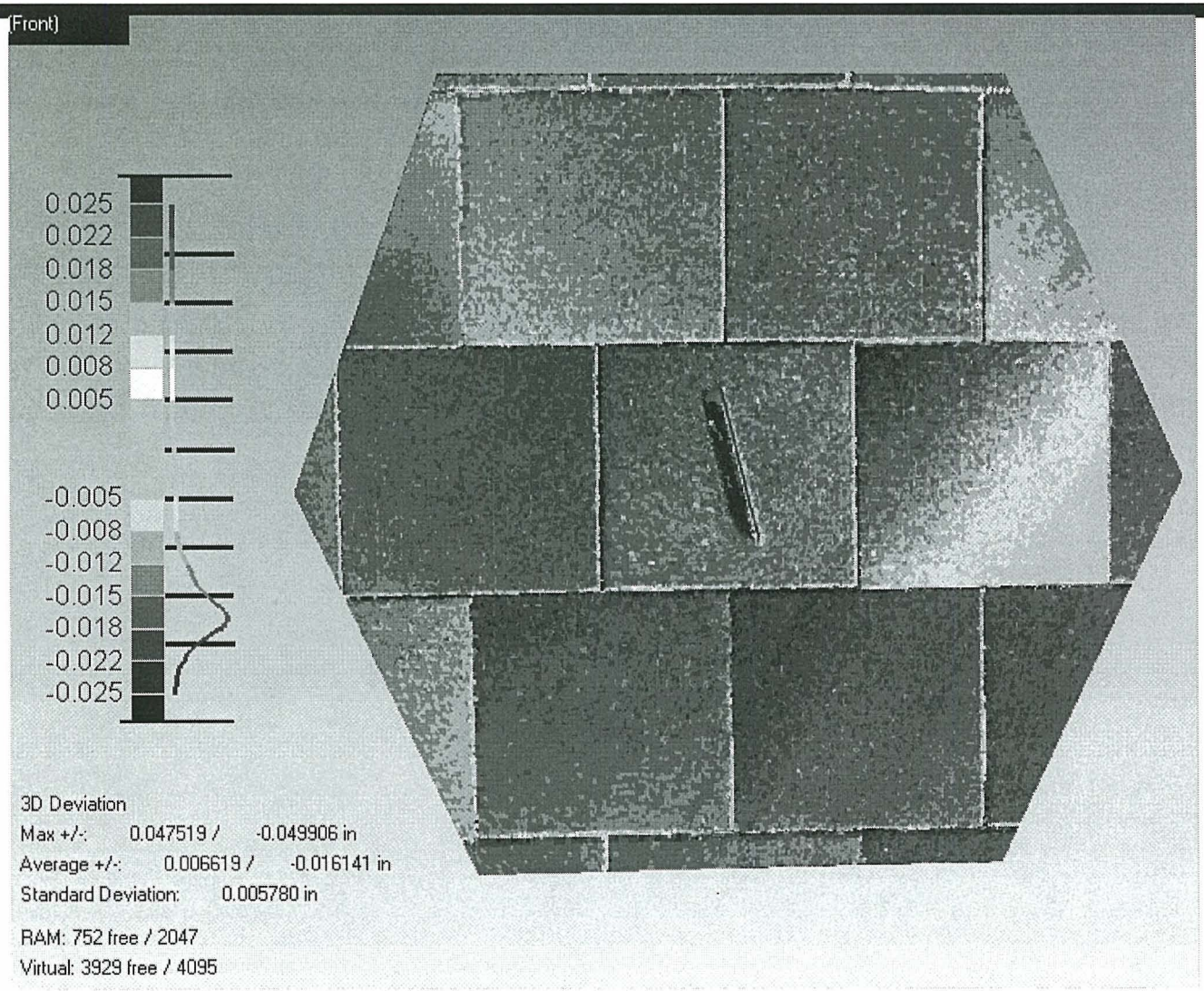


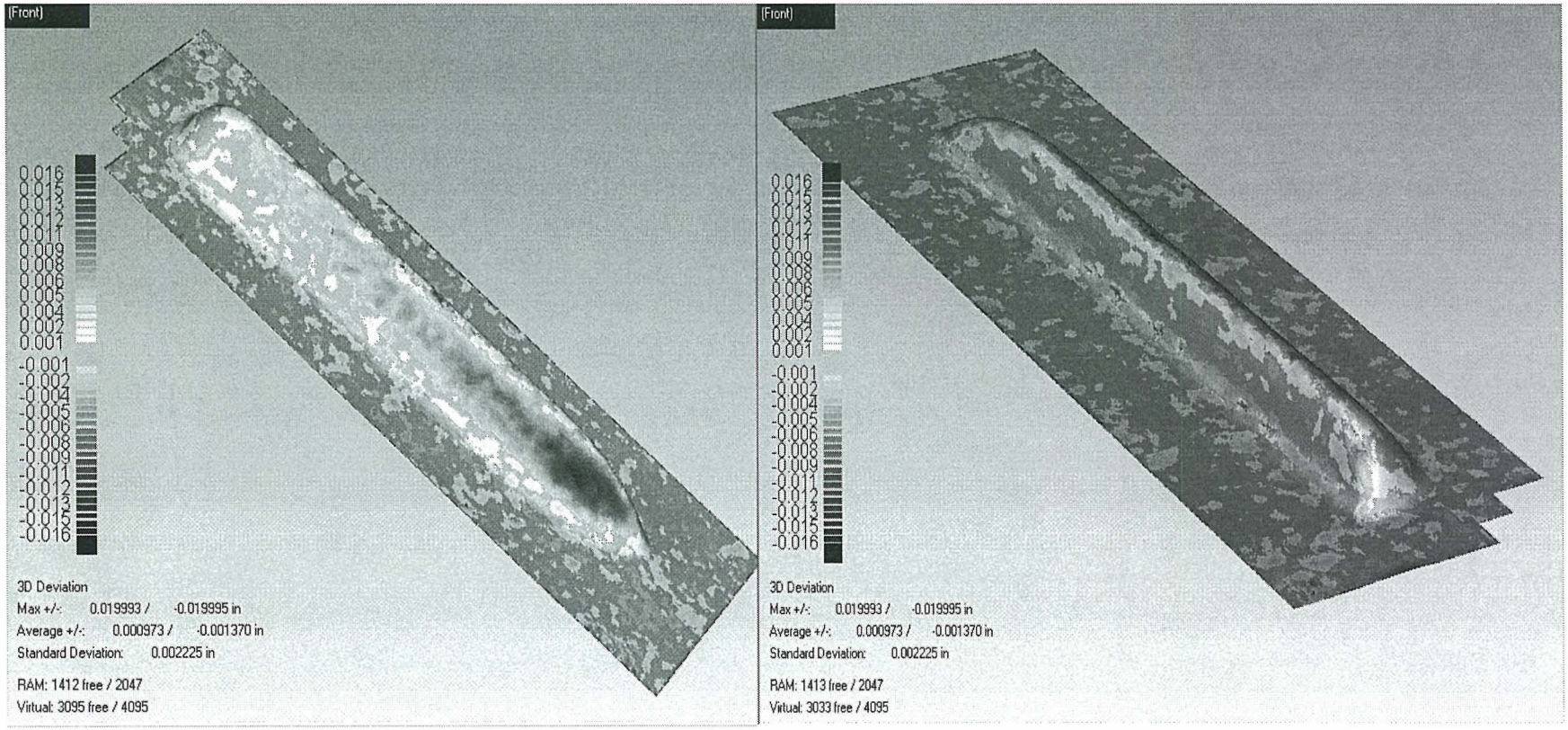


[5] Optics Discussion

Metris post flight scan to pre flight Surface



[5] Optics Discussion



FWD Side

AFT Side

STS-119: First Flight of BLT

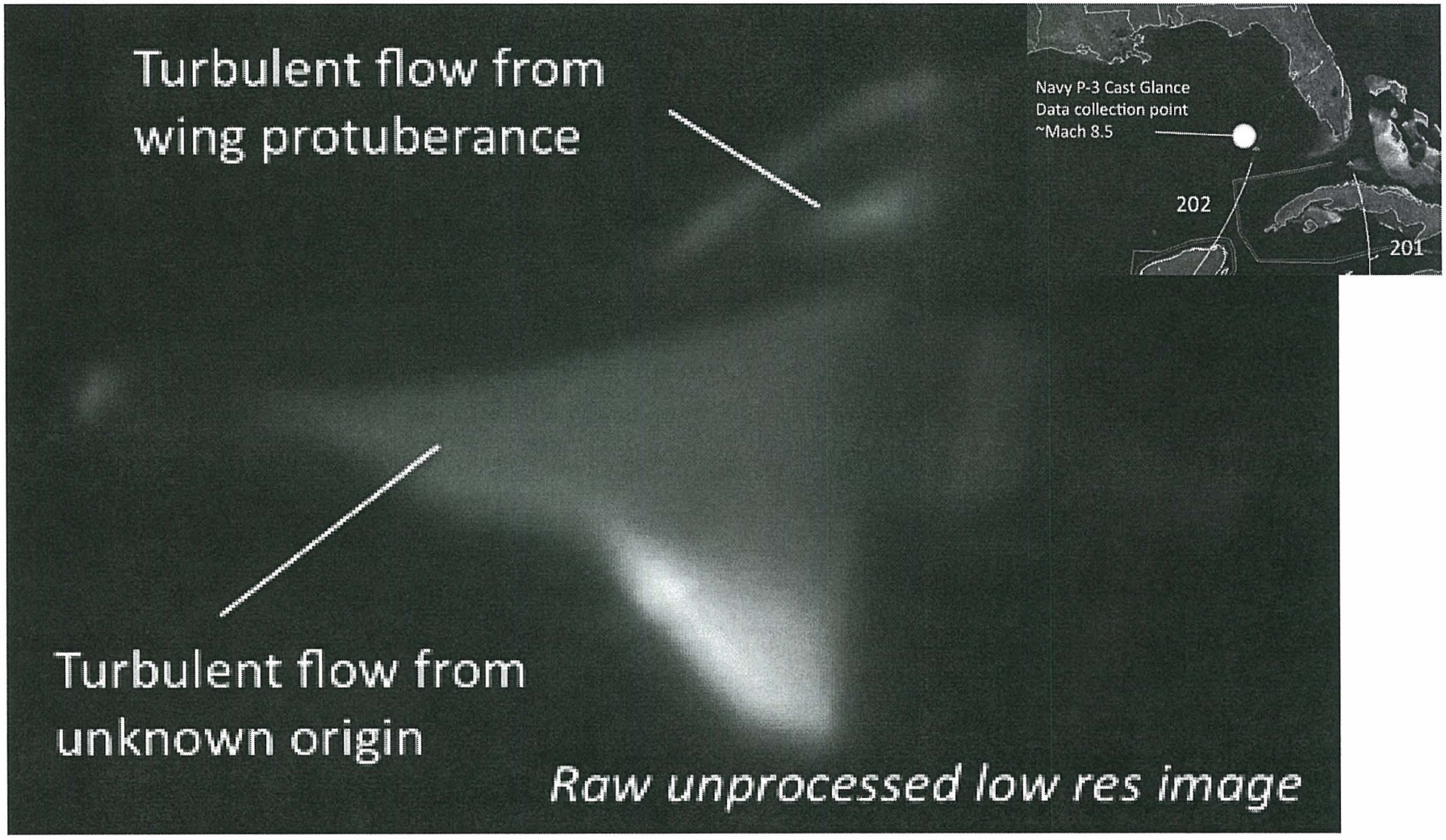
STS-119 launched on 15 March 2009 and had early success. Engineers were able to review data from the MADS, while the mission was ongoing that revealed the MADS recorded ascent heating as expected.

Summary:

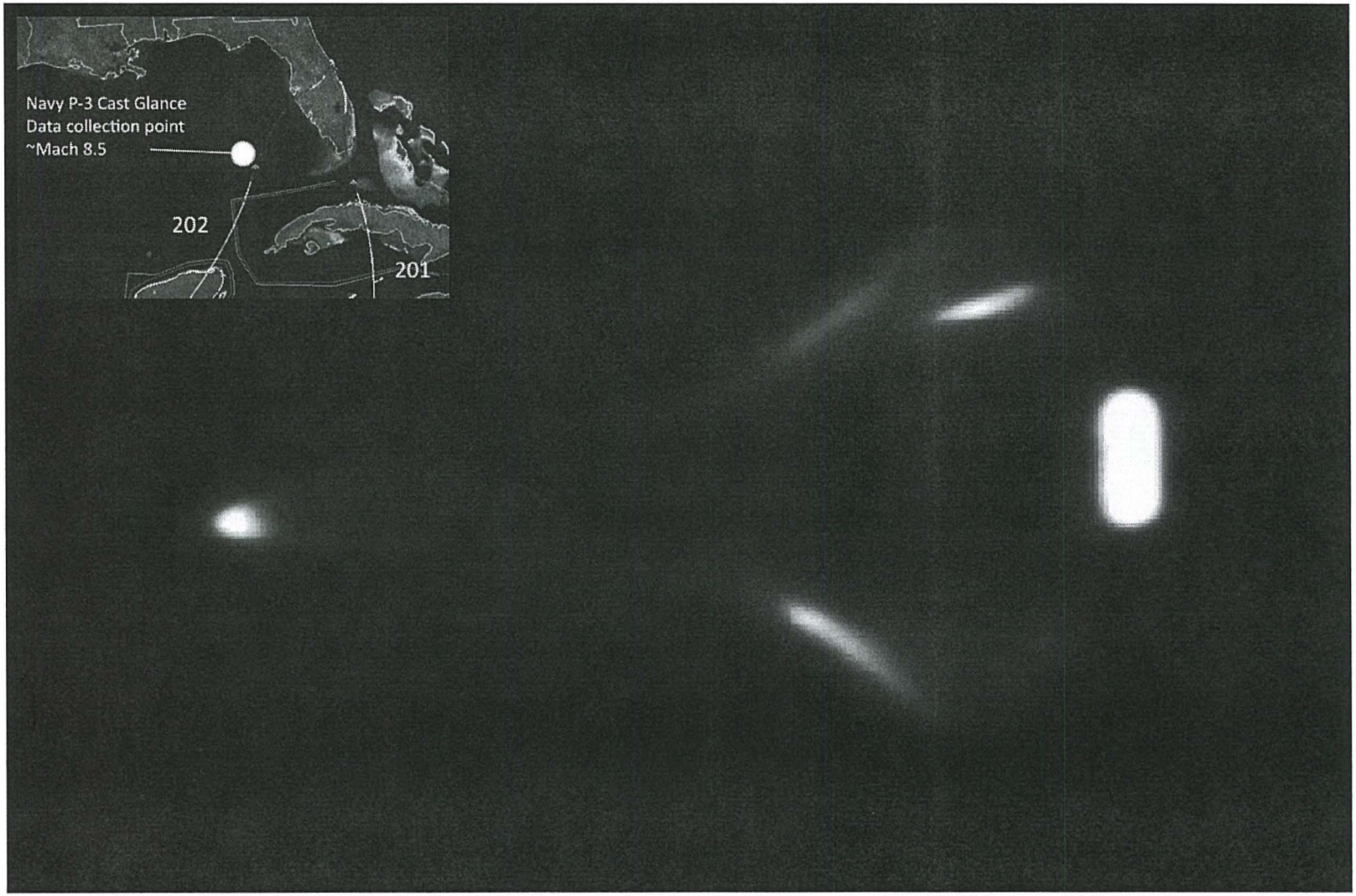
- All ten active thermocouples performed as expected.
- First indication BLT Onset for TC#1 (Most AFT and Outboard) was Mach 15.6 ± 0.1 (969 sec)
- Protuberance TC tripped at Mach 7.71 ± 0.3 (1224 sec)
- BLT Protuberance Peak: ~2000 F (lower than predictions ~ 2900F)
- Comparison of pre and post-flight OPTIGO scans did not show any significant change in protuberance geometry.
- No damage or slumping was identified within the turbulent wedge as a result of the flight experiment

STS-119 Runway Photo

[6] HYTHRM Image



HYTHRM Image



Plan for BLT-2 on STS-128

Preparations

- Expected to fly a protuberance of increased height

- Several changes:
  - Change location of TC # 5 to fit flight observed streamline of max heating.
  - Change several tiles to higher density material due to the projected increase in temperature caused by the taller protuberance
  - Deactivate TC #3 and TC #8 and Activate TC #3a and TC # 8a for better turbulent wedge resolution and to better accommodate the C742 catalytic coating experiment

STS-128: Second Flight of BLT

STS-128 landed at Edwards AFB on 11 SEP 09
Data obtained not as clear cut as STS-119

Summary:

- Several thermocouple had data drop-offs (Protuberance included)
- Attributed to MADS anomaly – sporadic occurrence on fleet
- Asymmetrical BLT occurred on vehicle
- Estimate BLT on protuberance occurred around Mach 18

Plan Forward (STS-131):

- Re-fly same protuberance as STS-128 (0.35 inches)
- Installation on OV-103 is currently in work

Questions

References:

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5. Brad Wilson Pitch to BLT IPT
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