



# Photogrammetry Measurements During a Tanking Test on the Space Shuttle External Tank, ET-137

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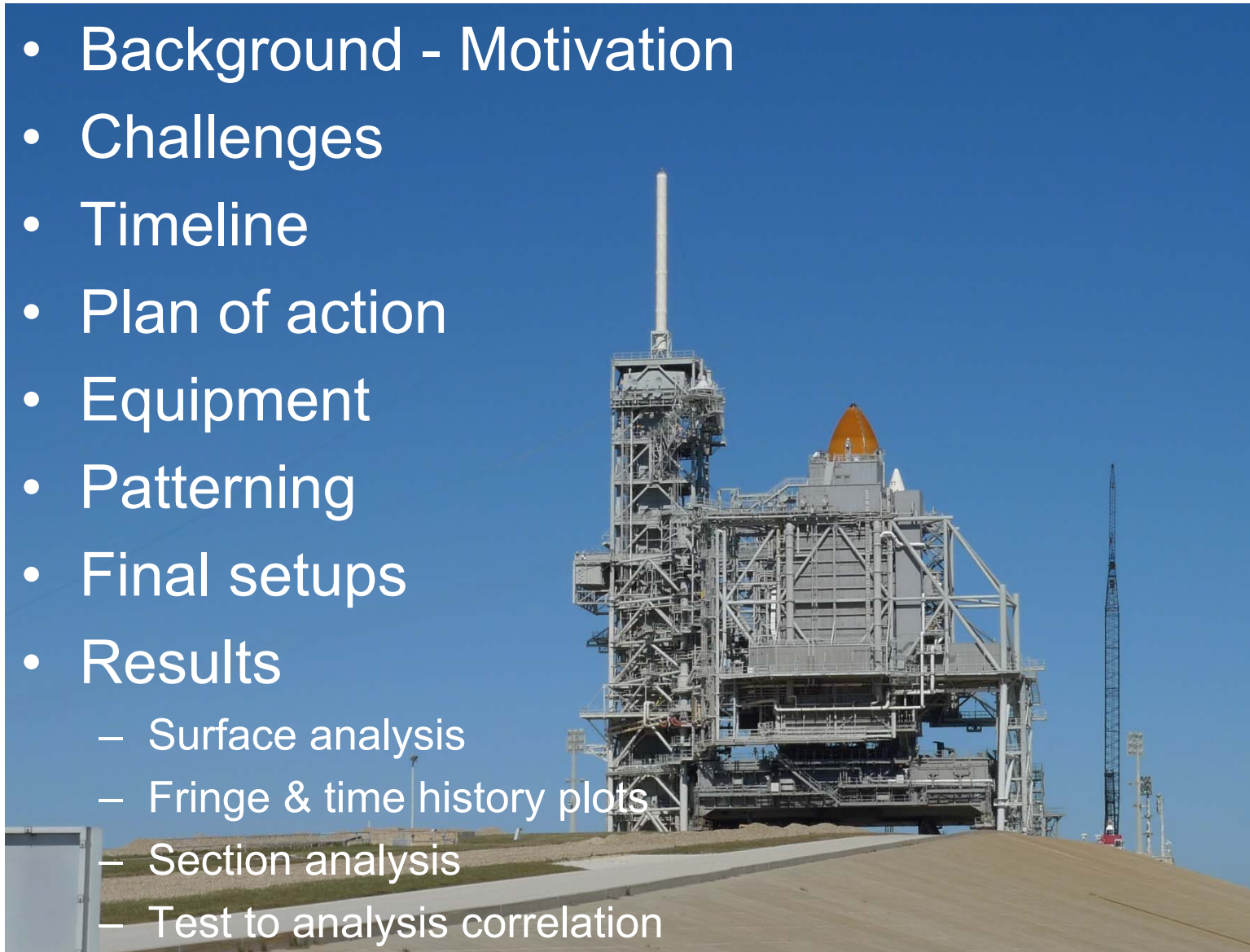
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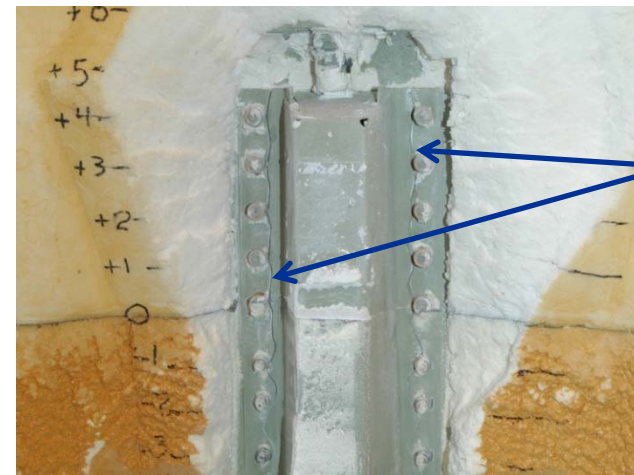
# Outline

- Background - Motivation
- Challenges
- Timeline
- Plan of action
- Equipment
- Patterning
- Final setups
- Results
  - Surface analysis
  - Fringe & time history plots
  - Section analysis
  - Test to analysis correlation





# Background - Motivation



Cracks

- Cracks in TPS insulation found on November 5<sup>th</sup>, 2010, following a scrub related to leaks in the Ground Umbilical Carrier Plate (GUCP)
- Decision was made to use 3-D photogrammetry for root-cause investigation during a tanking test



## Challenges – 3-D photogrammetry has never been attempted at LC-39a on the ET

- 10 days from first walk-down to test day
- Cannot physically contact the vehicle
- Acceptable ways to pattern the vehicle
- Test duration lasts ~8 hours, from sunrise to sunset
  - All equipment has to be ready the night before
- All operations during test will be conducted 3 ½ miles away in Launch Control
- All equipment must be explosion proof (nitrogen purged) and at least 20 feet away
- Doubters and nay-sayers
  - “Science project”



## STS-133 Timeline

September 20<sup>th</sup>, 2010 - Rollout LC-39a

October 14<sup>th</sup>, 2010 – Scrub - OMS vapor leak

November 5<sup>th</sup>, 2010 – Scrub - GUCP leak, first detection of stringer crack

Late November 2010 – Analysis of stringer cracks

December, 2010

February 24<sup>th</sup> 2011 Launch

March 9<sup>th</sup>, 2011 – Landing KSC

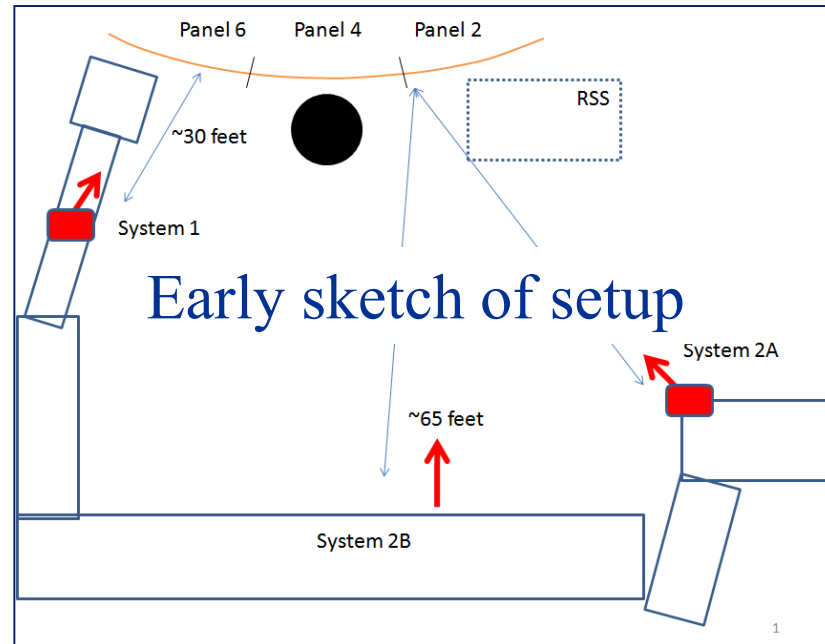
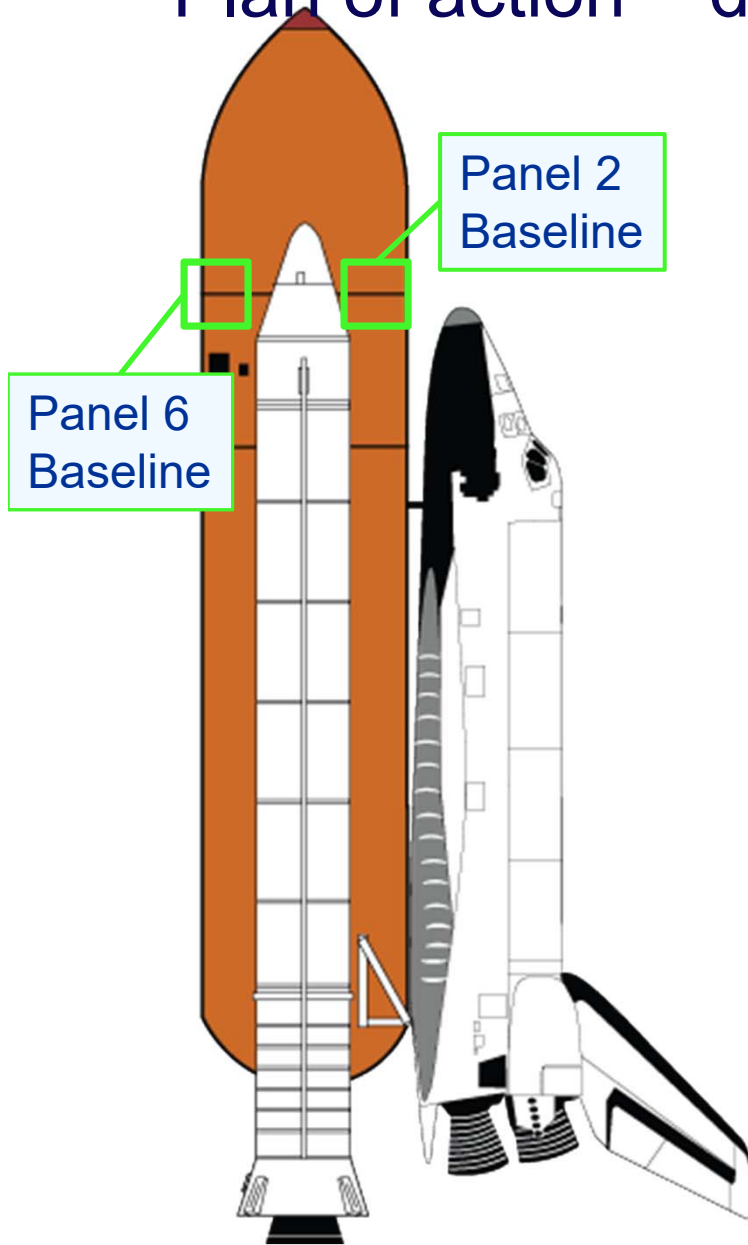
## Timeline

Photogrammetry Team Timeline	
Early Dec	Obtain go-ahead from KSC to conduct investigations into the feasibility of using photogrammetry on STS-133 tanking test to investigate stringer crack formation and propagation
Dec 7 <sup>th</sup>	First walk-down inspection of LC-39a to identify camera locations. After walk-down, order necessary parts
Dec 12 <sup>th</sup>	Arrive back at KSC with necessary equipment ordered, necessary equipment shipped overnight.
Dec 13 <sup>th</sup>	First camera setup in Cape Canaveral Air Force Station (CCAFS) Hangar G. Fabricate necessary parts needed
Dec 14 <sup>th</sup>	Calibrations / camera setup continue in CCAFS Hangar G. Painting of the ET
Dec 15 <sup>th</sup>	Set up cameras on base of LC-39a for further calibrations. Nitrogen purge bags and blankets added
Dec 16 <sup>th</sup>	Hoist camera pairs onto LC-39a Fixed Service Structure / Final calibrations. Establish communications with equipment in Launch Control Center Firing Room 3
Dec 17 <sup>th</sup>	Tanking test
Dec 18 <sup>th</sup>	Tear down and ship all equipment





# Plan of action – developed December 7<sup>th</sup>, 2010



- Two camera views
- Panel 2 (repaired)
  - Mount on FSS/RSS walkway
- Panel 6 (baseline)
  - Mount on GUCP walkway
- Compromises were made for equipment / personnel / due to time constraints



# Equipment

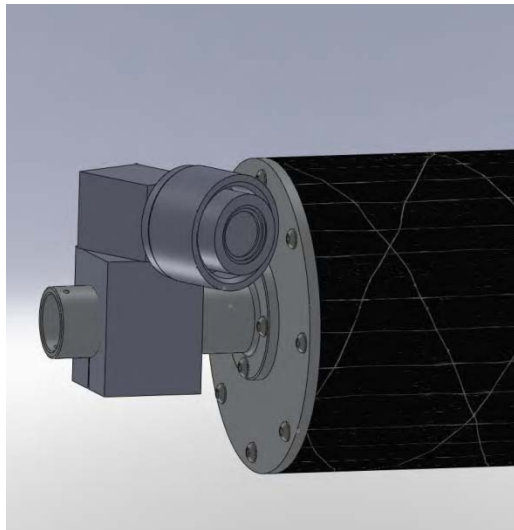
- Photogrammetry systems + extra computers
- Camera beams
  - Panel 2 – 20-ft woven composite
    - Lightweight, low CTE
  - Panel 6 – extruded aluminum
- Cameras
  - Panel 2 – Baumer 5MP
  - Panel 6 – Phantom 10 4MP
- Brackets, mounts, etc
  - KSC/GRC fabricated
- Safety protection
  - Nitrogen rich explosion proof bags
  - Thermal protection blanket
- A big truck





## Equipment - Rapid Fabrication

- 20-ft composite beam ordered Wednesday (Dec 8<sup>th</sup>) from external vendor, shipped to KSC Saturday (Dec 11<sup>th</sup>)

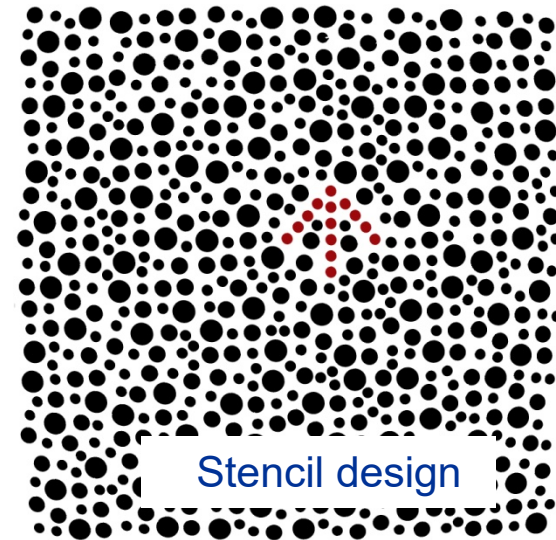
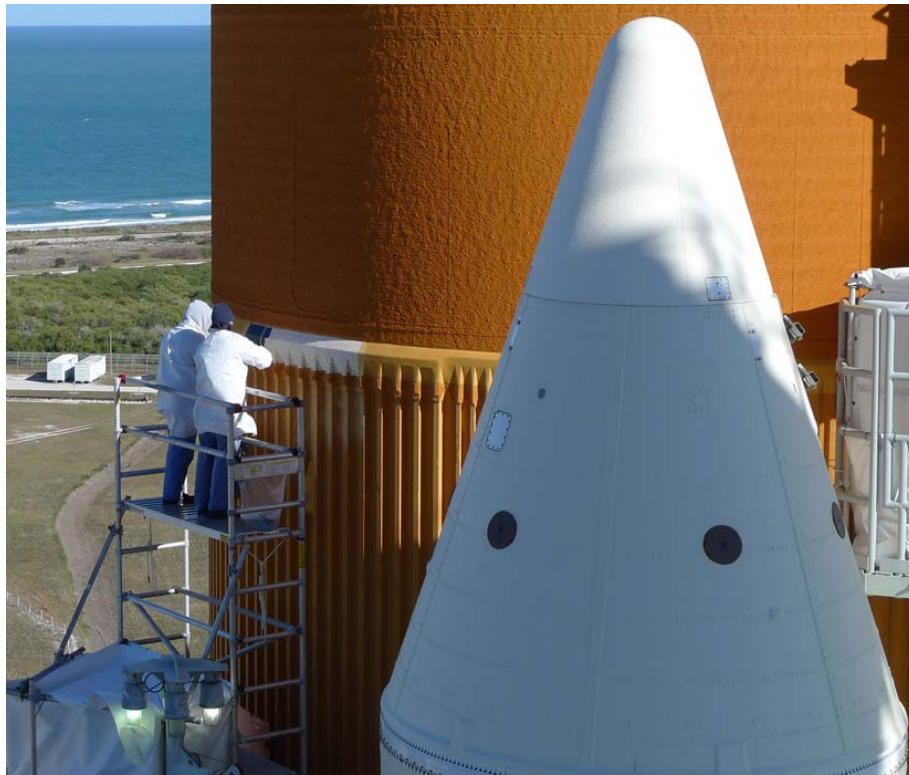


- Brackets in-house designed Thursday (Dec 9<sup>th</sup>), fabricated Friday/Saturday (Dec 10/11<sup>th</sup>) at GRC, hand carried to KSC Monday (Dec 13<sup>th</sup>) morning





# Patterning the External Tank



- Black epoxy paint - nominal 3/8<sup>th</sup>-in. dot size
  - Stenciled onto LOX flange/ intertank
  - Quasi-random stencil used



# Calibrations

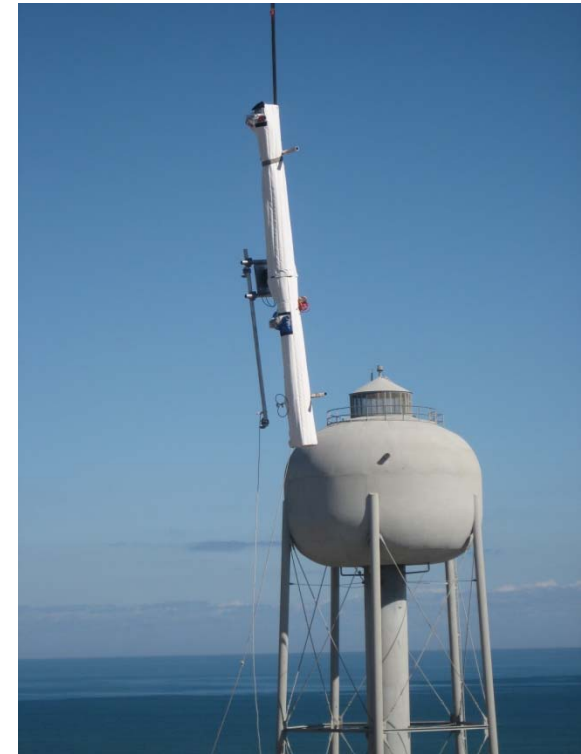


- Much of the functional and checkout tests were completed in the CCAFS Hangar G
- Final calibrations for both camera pairs were at the base of LC-39a
- Calibrated volumes were approximately 2m





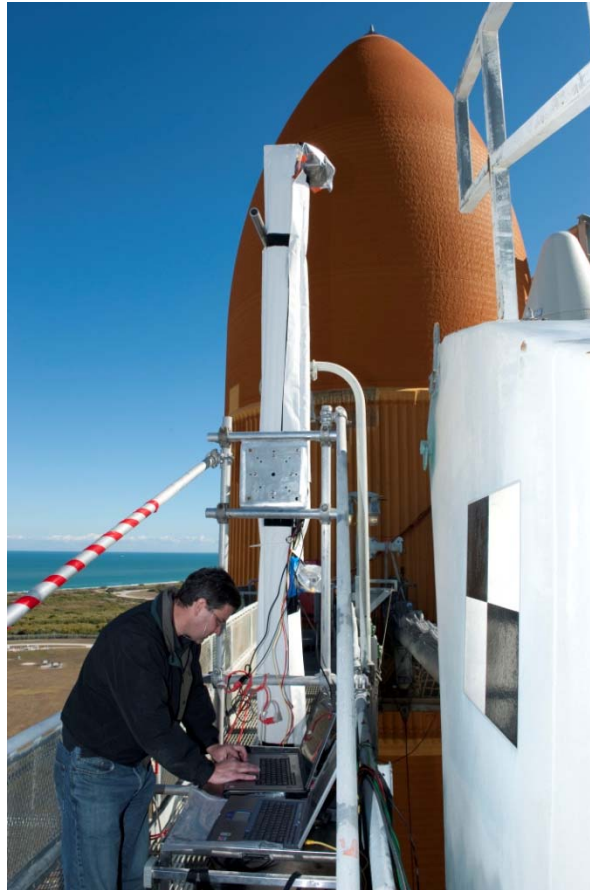
## Moving camera bars to final position



- Camera bars were calibrated before lift
- Care was taken to gently lift the calibrated camera bars to their final location on the FSS



# Panel 6 Final Setup

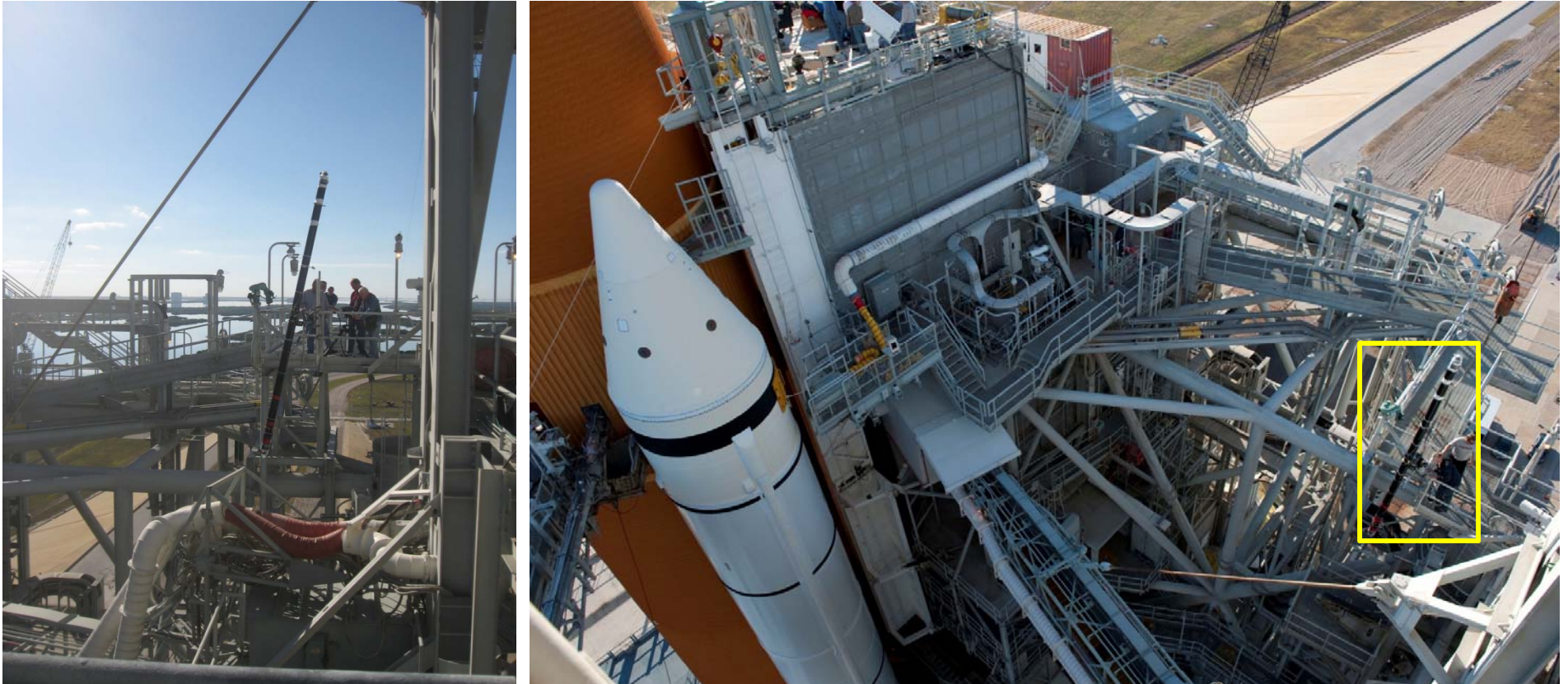


- GUCP walkway
- Phantom 10 cameras spaced ~6' apart





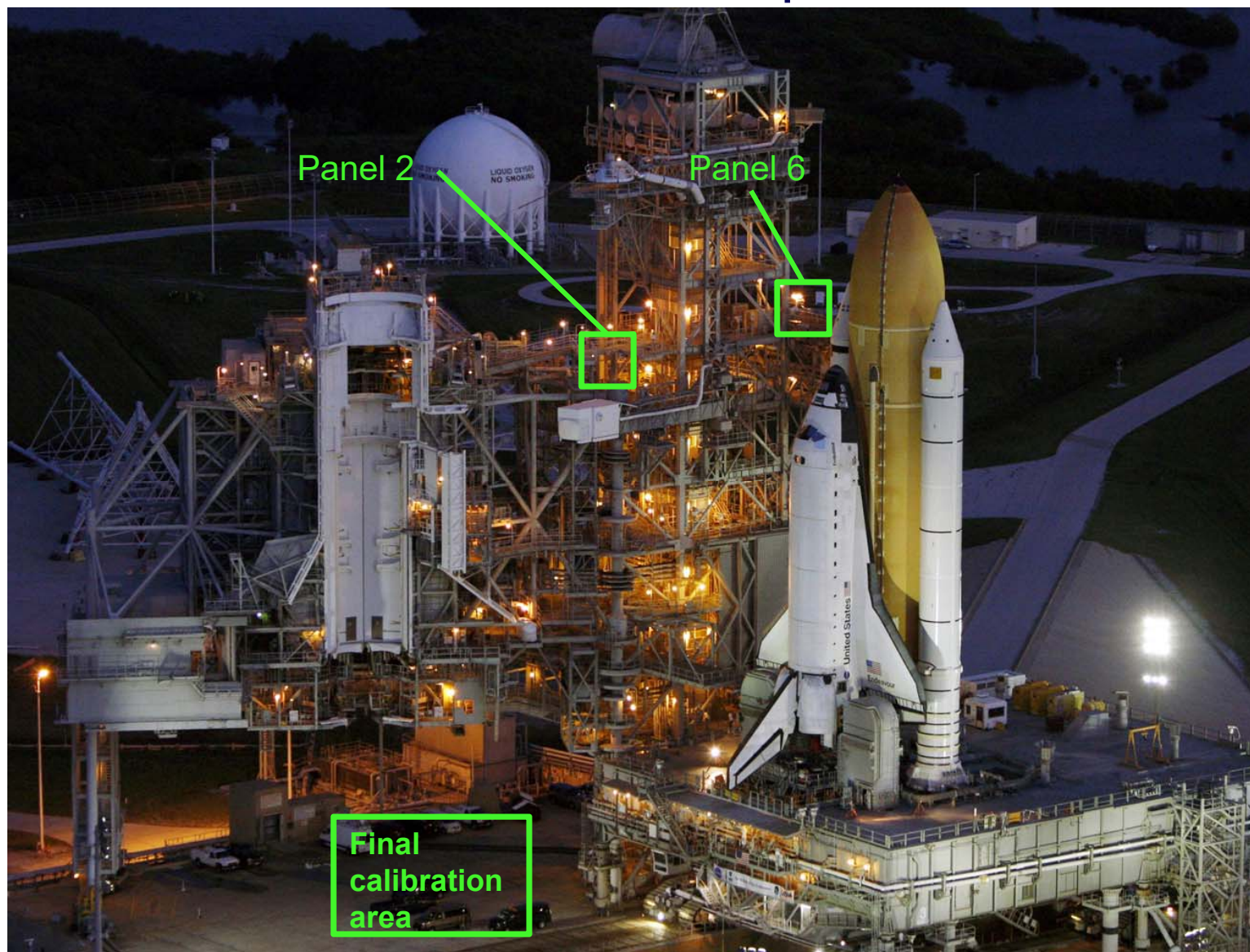
## Panel 2 Final Setup



- Only suitable location - walkway between the RSS and FSS
- Approximately 60 ft away from Panel 2

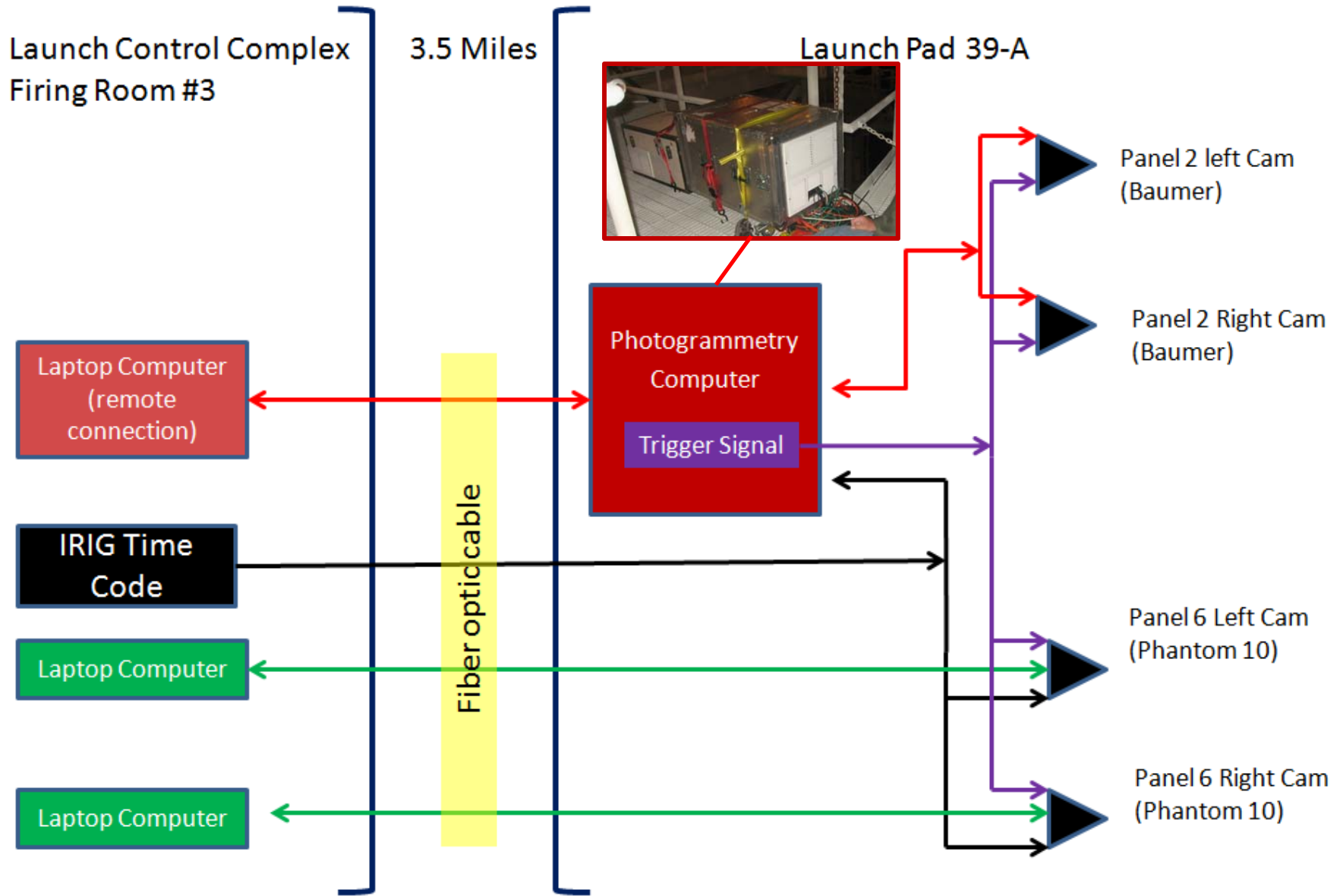


# Illustration of both setups – LC-39a





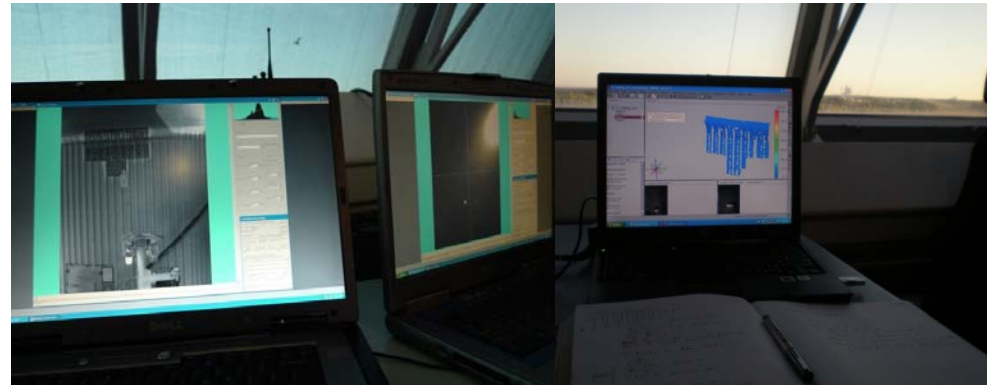
# Final Setup Schematic





## December 17<sup>th</sup>, 2010 –Launch Control Center

- Situated in Firing Room 3 next to Ice/Debris team
- Strictly monitor data collection / fix minor issues as needed



Time (EST)	Image #	Event
7:19:38	0	Test begin
7:38:27	112	L02 slow fill
7:53:50	202	L02 5% sensor wet
8:12:34	313	Eq.time - stringer crack
9:52:25	900	L02 fast fill end
2:18:35	1245	L02 prepress begin
2:24:44	1306	L02 preress end
2:51:49	1465	L02 drain begin
4:21:05	1607	L02 5% sensor dry
4:51:31	1637	Test end







# Field of views



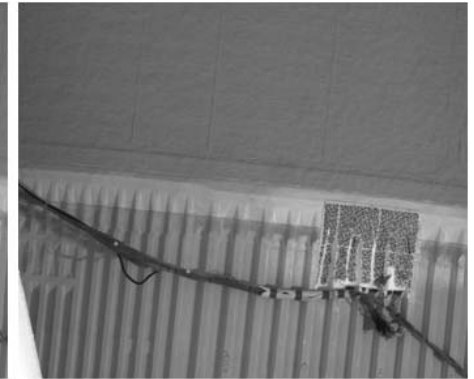
Left Camera



Right Camera



Left Camera

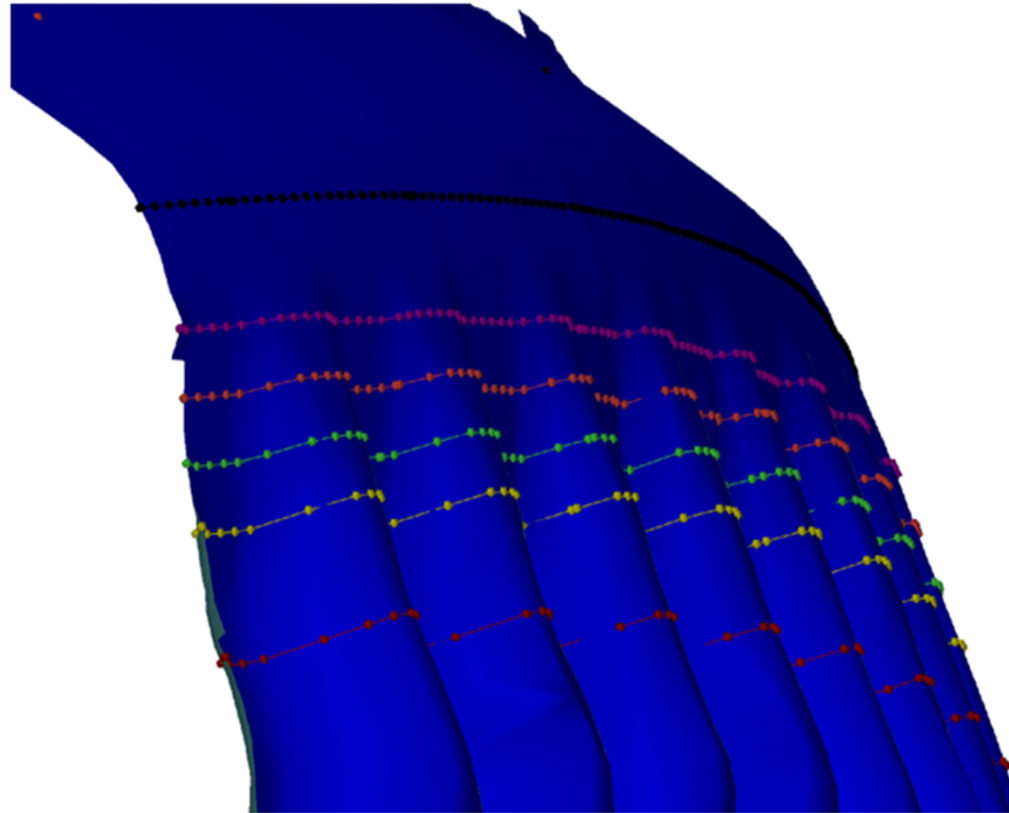


Right Camera

- Cameras image re-exposed due to changing sun conditions
  - Upper left of Left cam Panel 6
- Dot pattern coverage severely reduced from the original camera field of view due to flight safety concerns

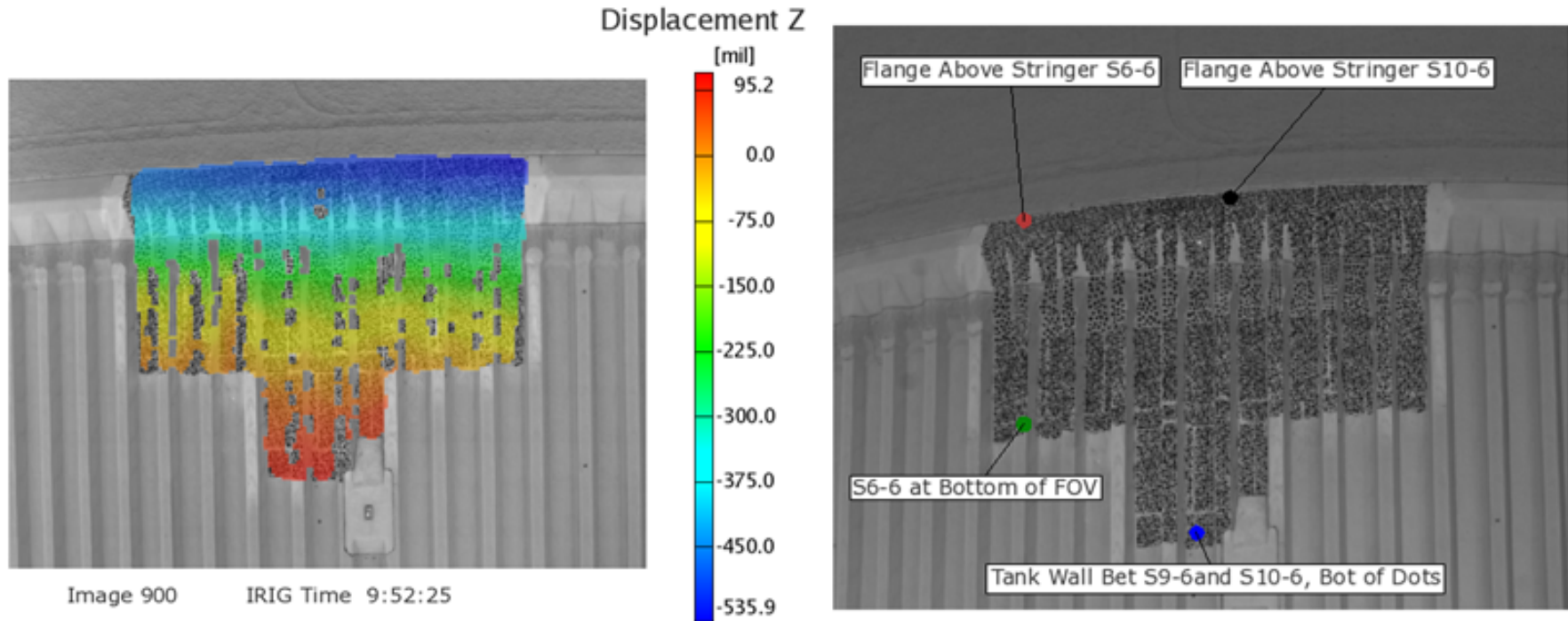


## Results – Surface Analysis



- Qualitative first check at the data
- Determine overall “shape” of tank

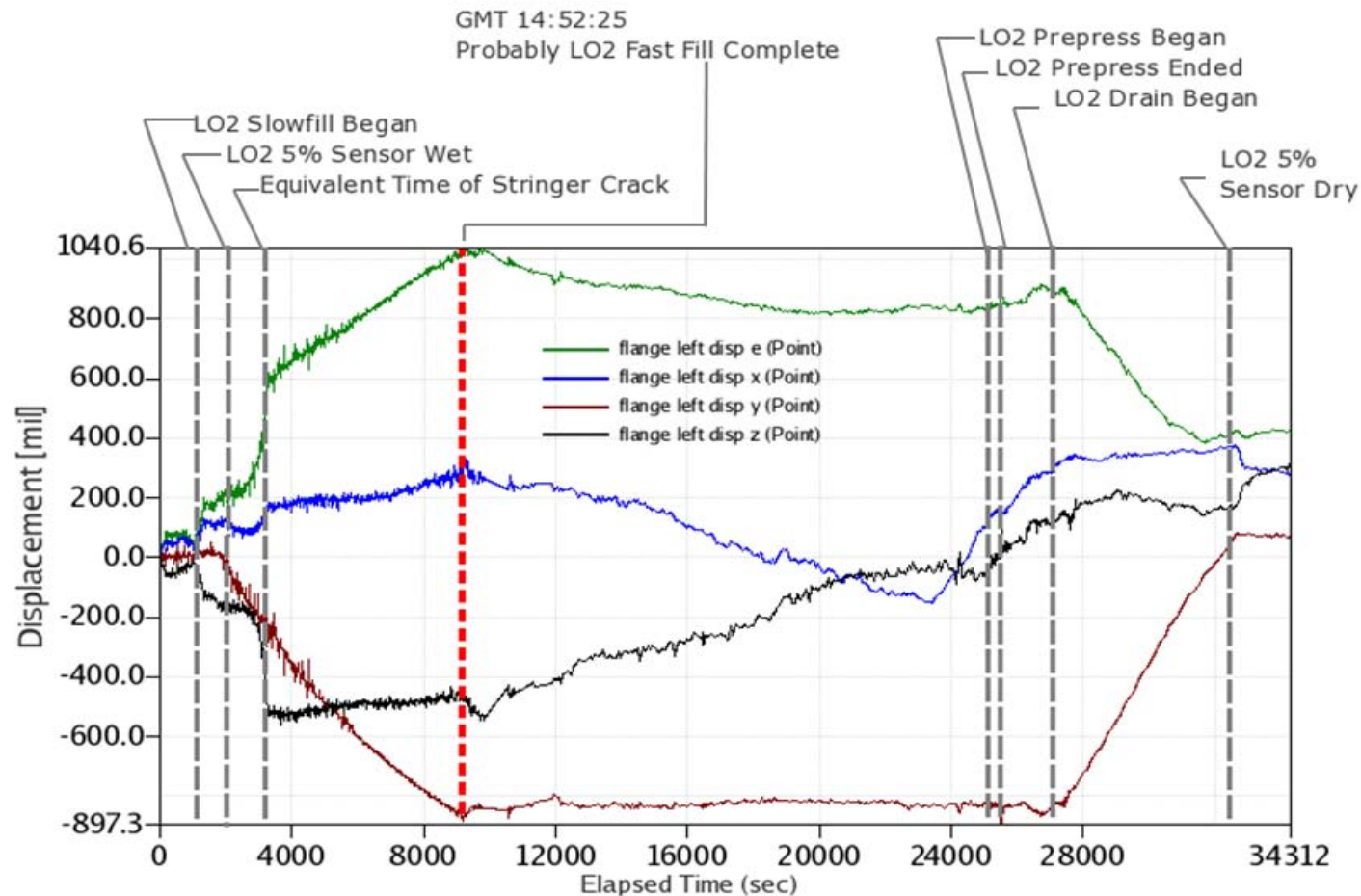
# Results – Fringe plots and point extraction locations



- Fringe plots show inward contraction of the L02 tank above the flange
- Fringe analysis also used to pick points for time history data extraction



## Results – Time history analysis

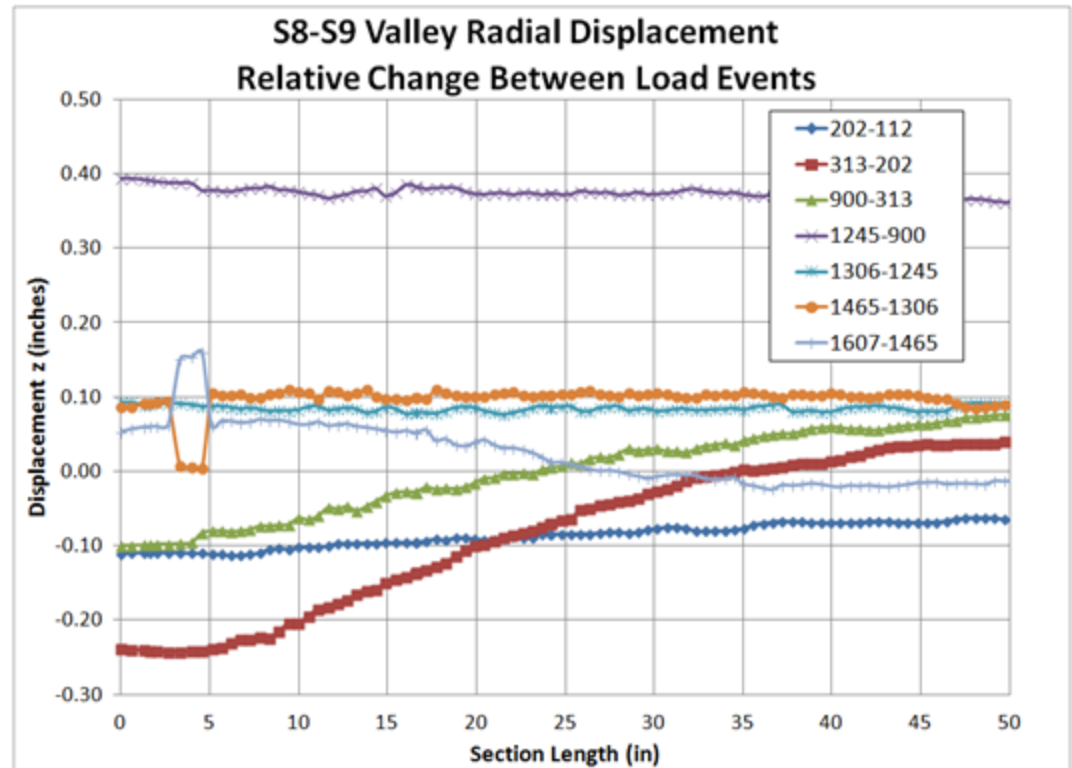
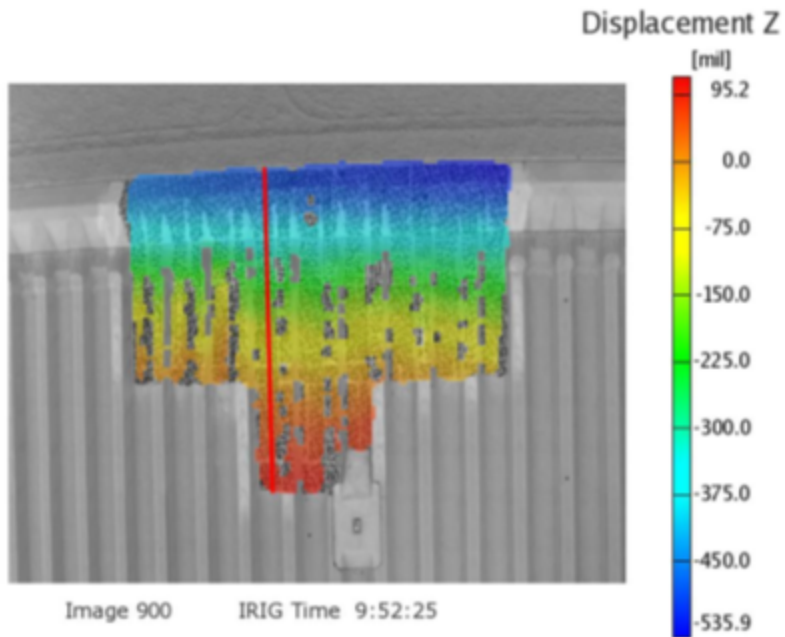


- Large amounts of negative displacement suggests that the ET is sagging due to the propellant being loaded
- Significant event times are highly noticeable





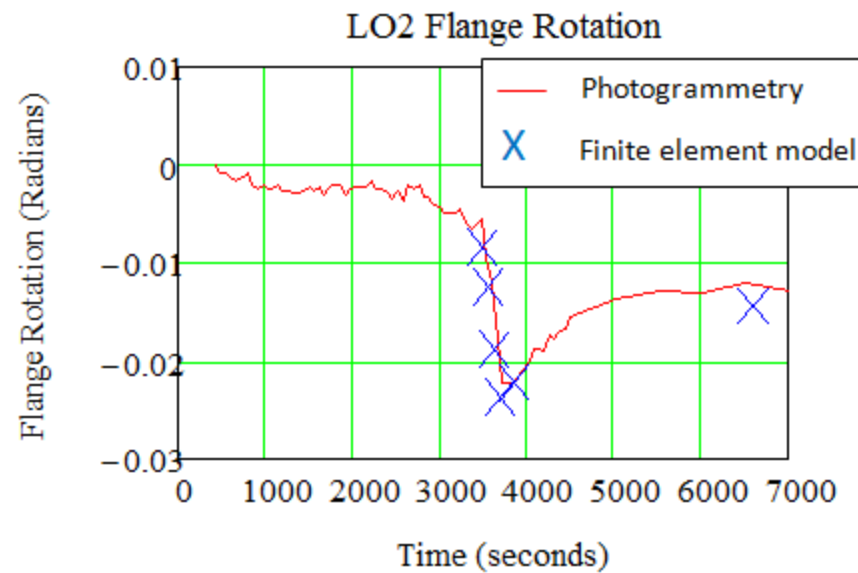
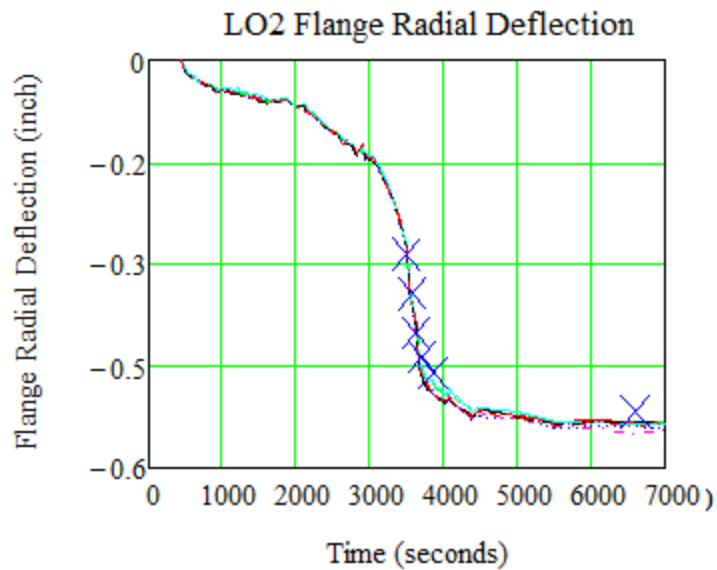
# Results – Section line analysis



- Plots as a function of position
- Plot shows time differences of data as a function of position
- The “flatness” of the line shows rigid body motion
- Large amount of ET deformation up through filling (image 900) indicated by large slopes in lines



# Results – LOX flange rotation, test to analysis



- Flange deflection and rotation are compared throughout the time history
- Shows excellent agreement and has been used to validate ET FEMs
- A complete analysis has been completed by MSFC



# Summary

- The photogrammetry team successfully collected data from a ET tanking test to support the ET stringer crack investigation
  - Success –
    - Working quickly
    - Shipping/ordering/fabricating all materials
    - Setting up and calibrating both camera pairs
    - Hoisting the camera pairs to the 215-ft level of LC-39a
    - Remotely acquiring data over the course of 8+ hours
- Data provided significant insight into ET behavior
- Data was used to validate ET FEMs





# Acknowledgements

- **Primary Liaison** - Wulf Eckruth
- **KSC Management** – Mike Payne, Jack Strieter
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