



Orbiter Entry Aerothermodynamic Flight Testing STS-119 and STS-125

June 18, 2009

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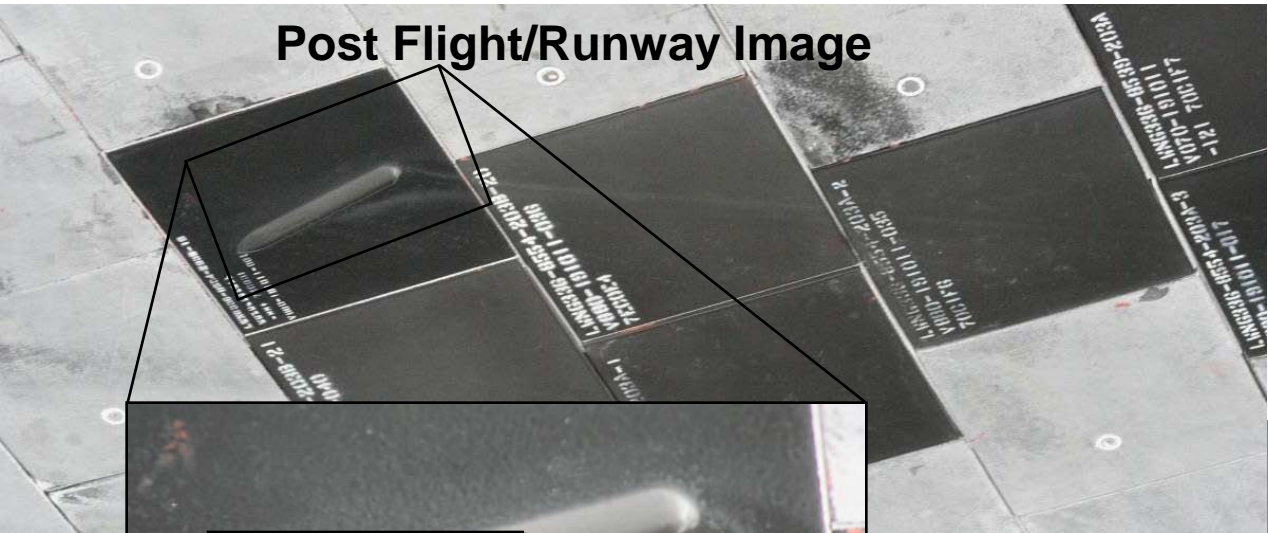
Introduction

- NASA has performed entry flight testing related to boundary layer transition and turbulent heating environments during 2009
- Two projects are involved in implementing the activities and acquiring flight data
 - Orbiter BLT Flight Experiment during STS-119
 - Hypersonic Thermodynamic Infrared Measurements (HYTHIRM) during STS-119 and STS-125
- Orbiter BLT FE has implemented tile surface thermocouples in order to provide in-situ data downstream of a fixed geometry tile protuberance
- HYTHIRM has developed a framework of mission planning and aircraft based telescopic infrared measurements to provide quantitative surface temperature distributions

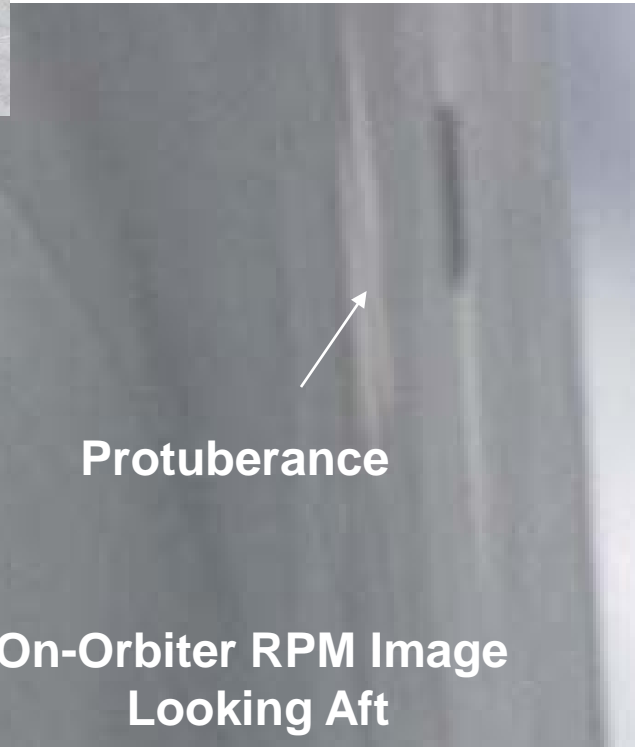
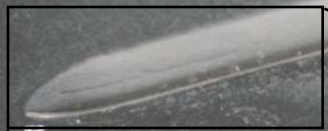
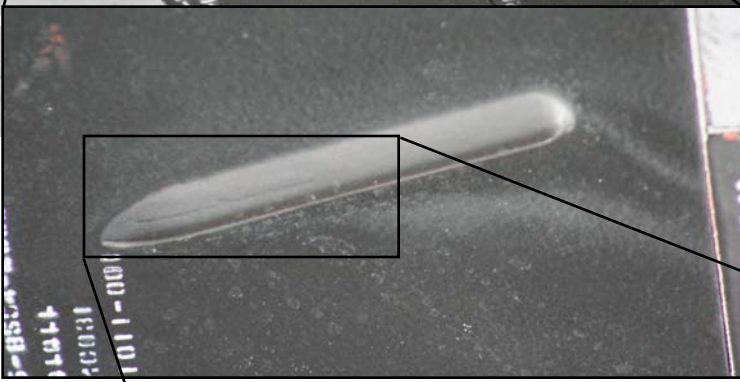




STS-119 Protuberance Imagery



Post Flight/Runway Image



Protuberance

On-Orbiter RPM Image Looking Aft



April 21, 2009



STS-119 BLT FE Summary



- 0.25" Tile Protuberance and Surface TC measurements were implemented on OV-103 prior to STS-119
 - Protuberance height targeted to provide BLT onset near Mach 15
- STS-119 BLT Onset Summary (Based on STS-119 BET trajectory and BLT FE MADS Data)
 - Initial BLT from the 0.25" protuberance at **Mach 15.6** / 969 seconds
 - Initial BLT Onset is very close to RTF V2 BLT tool prediction using BET
 - BLT Tool Predictions: Best Estimate **Mach 15.4** (± 2 -sigma predictions: Mach 18.0- >10.8)
 - Effective BLT at Mach 13.1 / 1045 seconds
 - Protuberance BLT at Mach 7.7 / 1224 seconds
 - Fuselage and Port side BLT near Mach 7.9 / 1217 seconds
 - Starboard wing BLT near Mach 10.5 / 1127 seconds
 - This progression of BLT is consistent with expectations
- Surface Temperature Summary
 - Laminar measurements: ~1600 F (consistent with flight history)
 - Turbulent Wedge region: ~1900 F (lower than predictions, but consistent with STS-28)
 - Vortex Heating region: No RCG melt/flow leads to <2500 F conclusion (lower than predictions)
 - BLT Protuberance Peak: ~2000 F (much lower than predictions)





BLT FE Protuberance and TCs

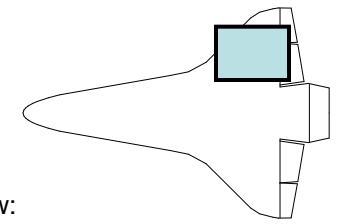
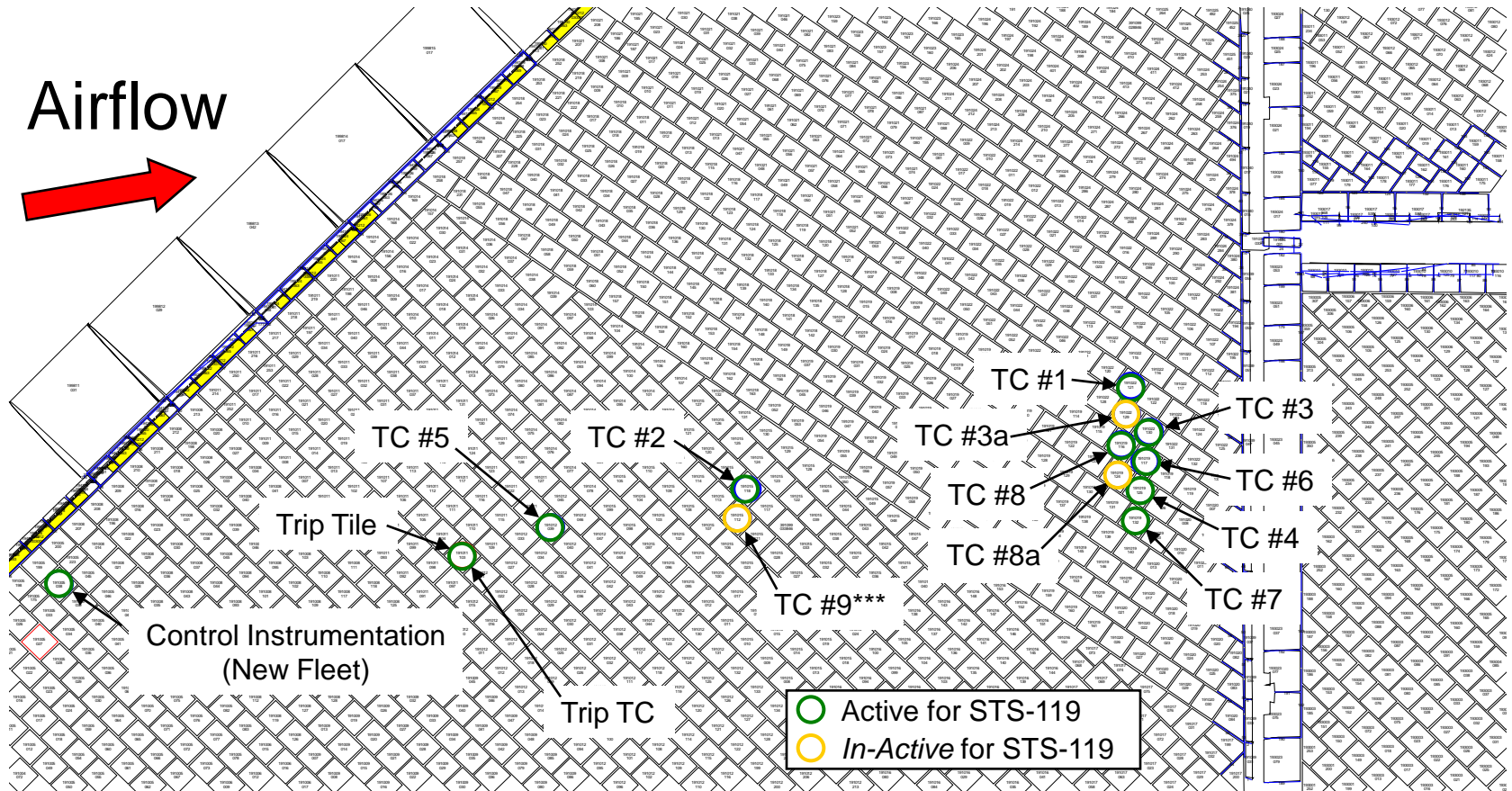
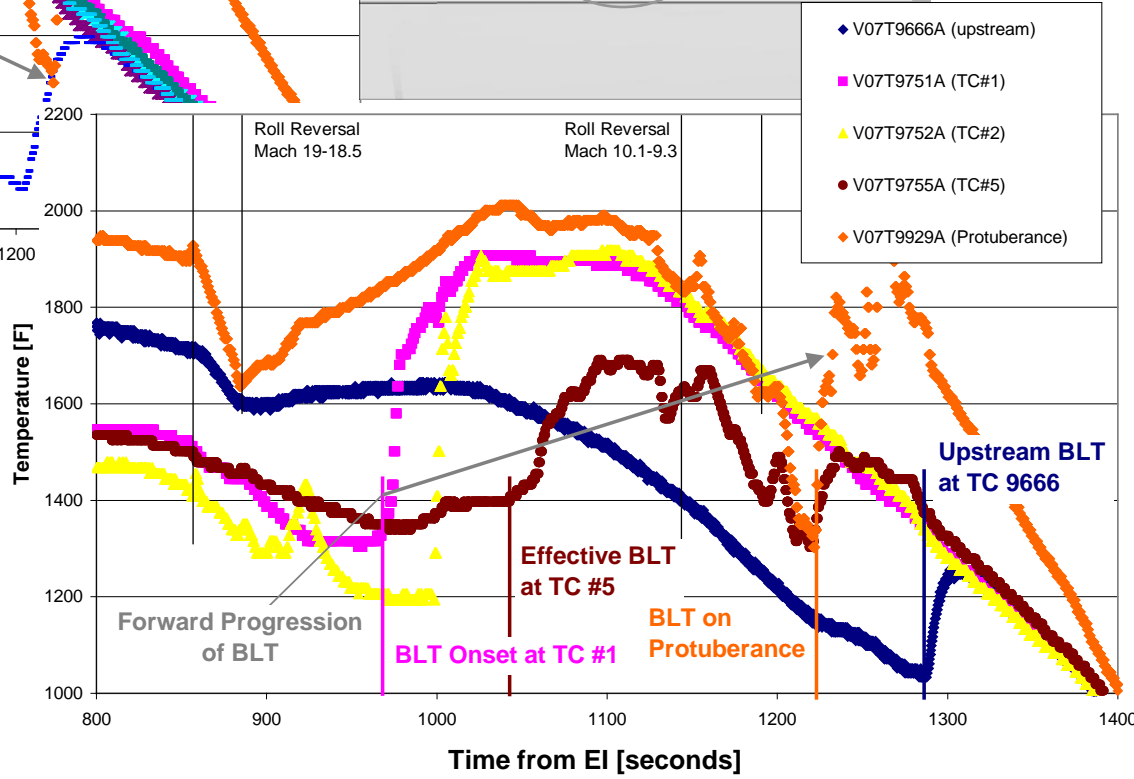
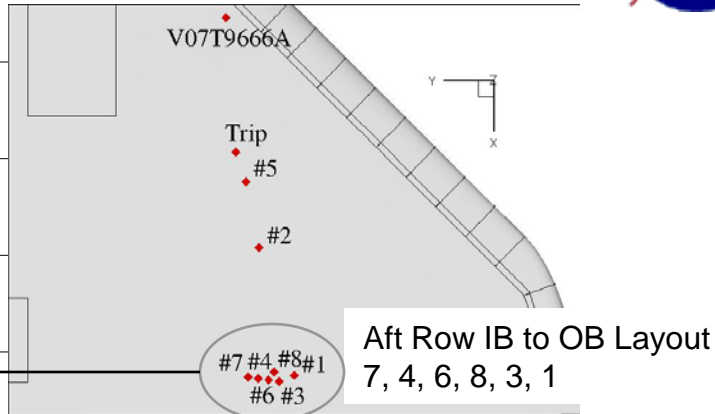
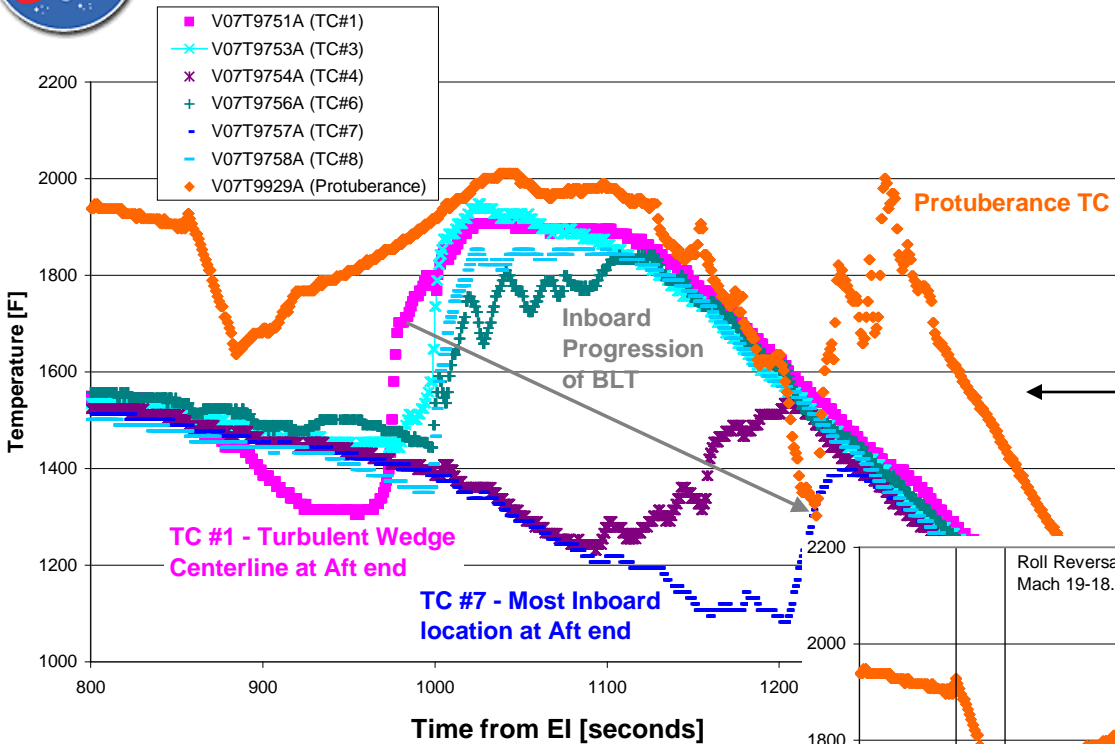


Diagram view:
Looking up at the lower surface of the orbiter.





STS-119 BLT FE TC Data



BLT Mach Numbers Based on BET Trajectory	
BLT Onset (TC#1)	15.60
Onset Behind Trip (TC #5)	13.09
Protuberance BLT (9929)	7.71
Upstream BLT (9666)	6.34





STS-119 BLT FE



Preliminary Observations

- All BLT FE MADS instrumentation performed nominally
- Initial BLT Onset Downstream of the Protuberance occurred at Mach 15.6
 - This is within the RTF BLT V2 1-sigma prediction (BET prediction: Mach 15.4)
- Protuberance Temperature from MADS data is ~2000 F, compared to 2974 F pre-flight prediction and 2810 F BET prediction
 - Laminar Bump Factor Prediction ~7.5, flight bump factor ~2
- Turbulent wedge half-angle of ~7 degrees based on BLT FE TCs
- Starboard ABLT occurred at Mach 10.5 (opposite side of BLT FE)
 - Corroborated by GN&C post-flight assessments, HyThirm IR data and MADS TCs
 - OML geometry that led to STS-119 ABLT is unknown, but region has been isolated to near the STBD side of the nose gear door based on turbulent wedge tool assessments
 - Historical BLT onset is below Mach ~11 due to typical vehicle roughness
 - Does Not include flights with early BLT due to protruding gap fillers or tile damage
- TPS reviewed visually and via OML scan data – No discernible OML change
- All objectives for first flight of the BLT Flight Experiment accomplished
- STS-128 / 0.35" protuberance RTF BLT V2 onset prediction of Mach ~18

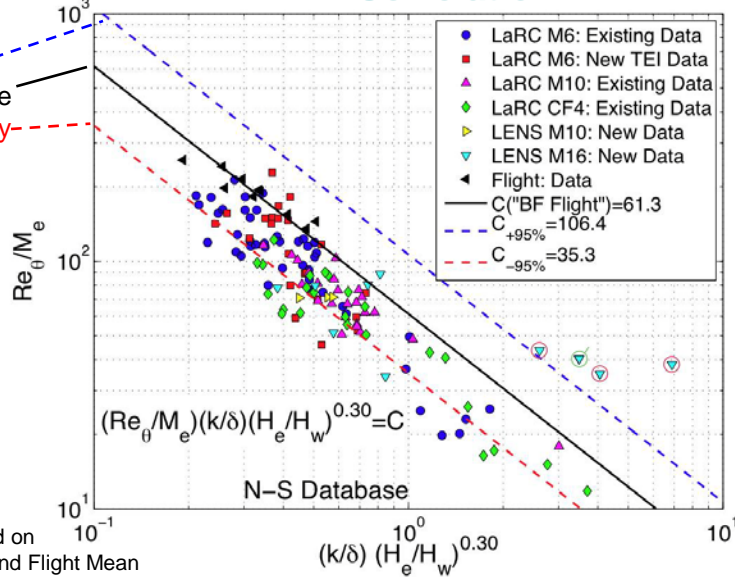




Orbiter Return To Flight BLT Correlation

RTF BLT V2 Correlation

2-sigma late
Best Estimate
2-Sigma early



Correlation based on
WT uncertainty and Flight Mean

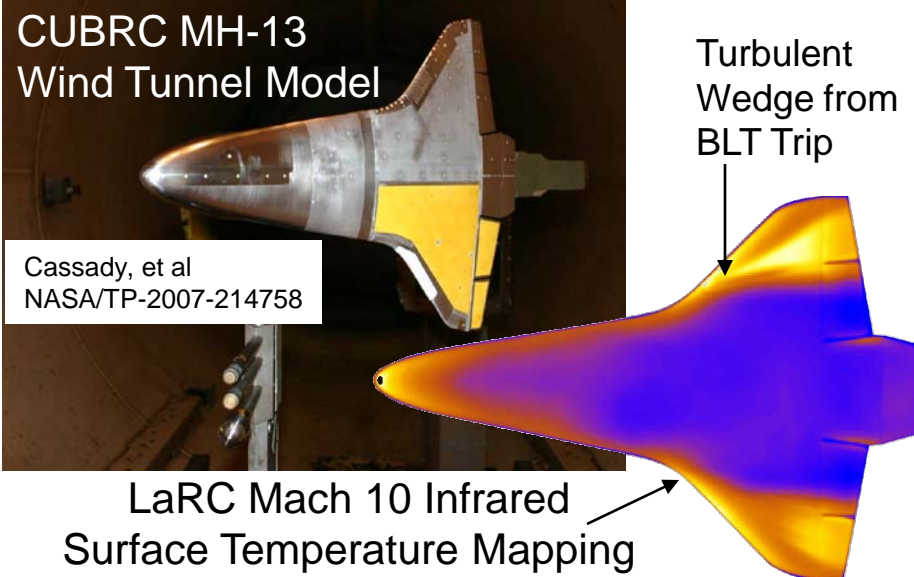
Accuracy of various BLT Engineering Correlations with Orbiter RTF Data

Proposed Correlation	Correlation Equation	Ground-Based			Ground-Based + Flight		
		R	$\Delta C/C$	σ_C/\bar{C}	R	$\Delta C/C$	σ_C/\bar{C}
1	$Re_{\theta}/M_e \times k/\delta = C$	-0.87	1.26	19.9%	-0.88	1.25	21.2%
2	$Re_{\theta}/M_e \times (k/\delta)^* = C$	-0.90	1.08	7.3%	-0.87	1.32	34.9%
3	$Re_{\theta}/M_e \times (k/\delta)(T_e/T_w)^{0.16} = C$	-0.89	1.14	14.5%	-0.89	1.20	23.6%
\Rightarrow 4	$Re_{\theta}/M_e \times (k/\delta)(H_e/H_w)^{0.30} = C$	-0.91	1.04	8.9%	-0.91	1.10	19.9%
5	$\rho_k u_k k / \mu_w = C$	-0.79	2.51	30.9%	-	-	-
\Rightarrow 6	$Re_k^{0.6} \times [Re_{\theta} \cdot (\mu_e/\mu_k)]^{0.4} = C^*$	-0.87	1.09	14.8%	-0.84	1.30	35.0%

* Results are for $n = -0.6$ for all data

Ref: King, R.A., Kegerise, M.A. and Berry, S.A.,
 "Proposed Protuberance Correlations for the Next Generation BLT Tool (vsn 2)",
 EG-SS-07-07, March 30, 2007

CUBRC MH-13 Wind Tunnel Model



Cassady, et al
 NASA/TP-2007-214758

Turbulent
 Wedge from
 BLT Trip

LaRC Mach 10 Infrared
 Surface Temperature Mapping

- Wind tunnel data to support correlation acquired in Langley Mach 6 Air, Mach 10 Air, Mach 6 CF4 and CUBRC Mach 10, 14, 16
- Engineering correlations of this type achieve correlation values of >0.8 on Orbiter configuration
- Better correlations are desired, but this is acceptable for providing engineering assessments and design input



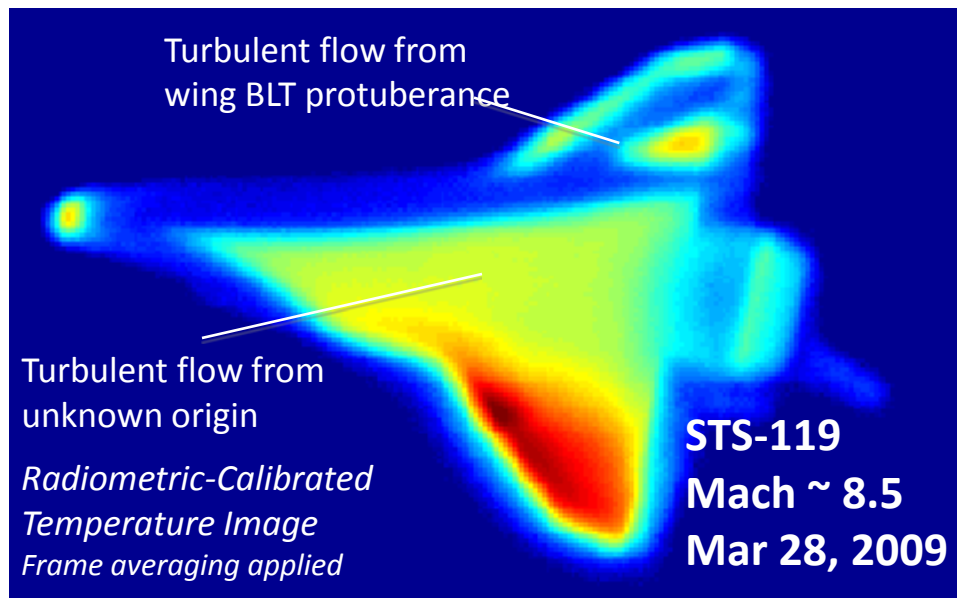
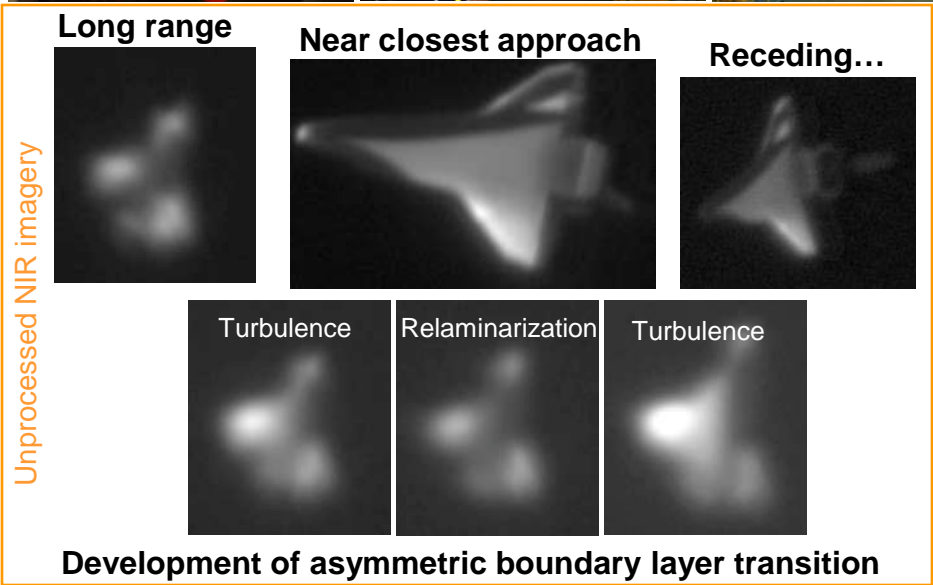
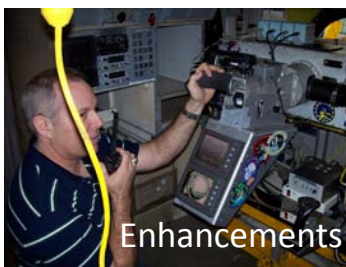
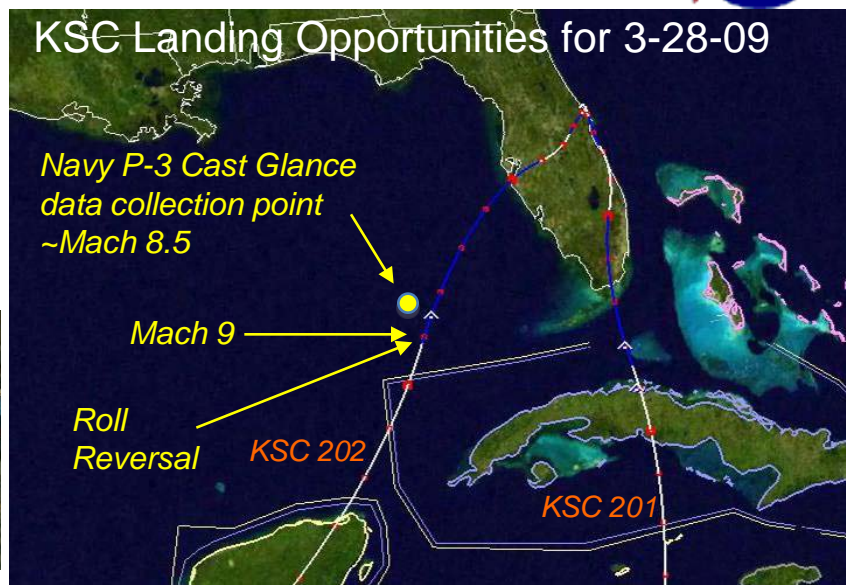


HYTHIRM STS-119

Hypersonic Thermodynamic Infrared Measurements



STS-119 success criteria: To obtain spatially resolved infrared imagery during a flight experiment that will provide a quantified surface temperature map of the Shuttle during hypersonic re-entry





HYTHIRM STS-125

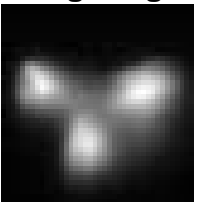
Hypersonic Thermodynamic Infrared Measurements



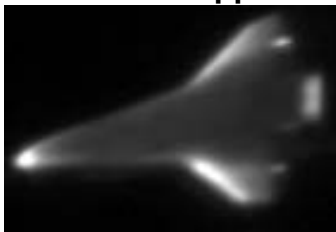
STS-125 success criteria: To obtain spatially resolved infrared imagery that will provide a quantified surface temperature map of the Shuttle during a high Mach hypersonic re-entry



Long range



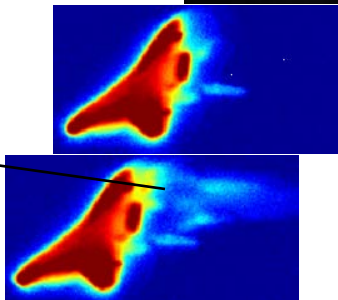
Near closest approach



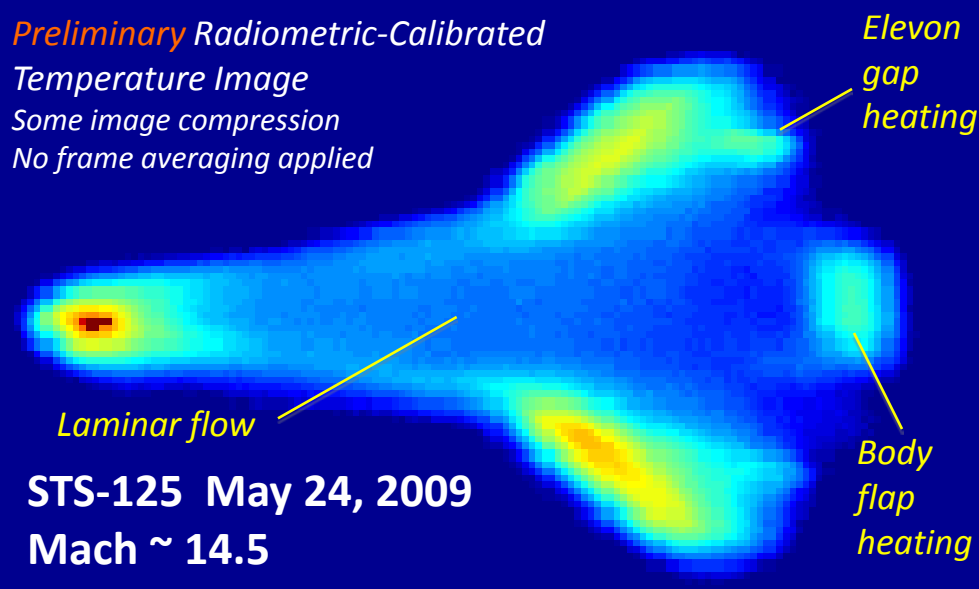
Receding...



RCS plume or plasma trail?



Preliminary Radiometric-Calibrated Temperature Image
Some image compression
No frame averaging applied





Back-up

June 18, 2009



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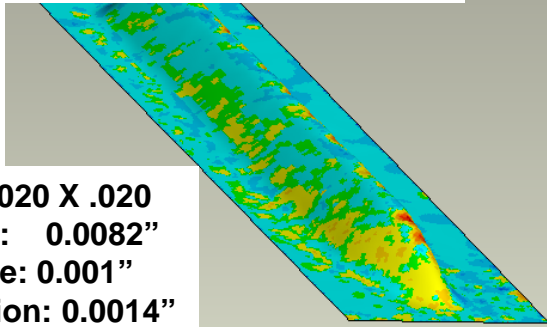
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STS-119 OML Scans



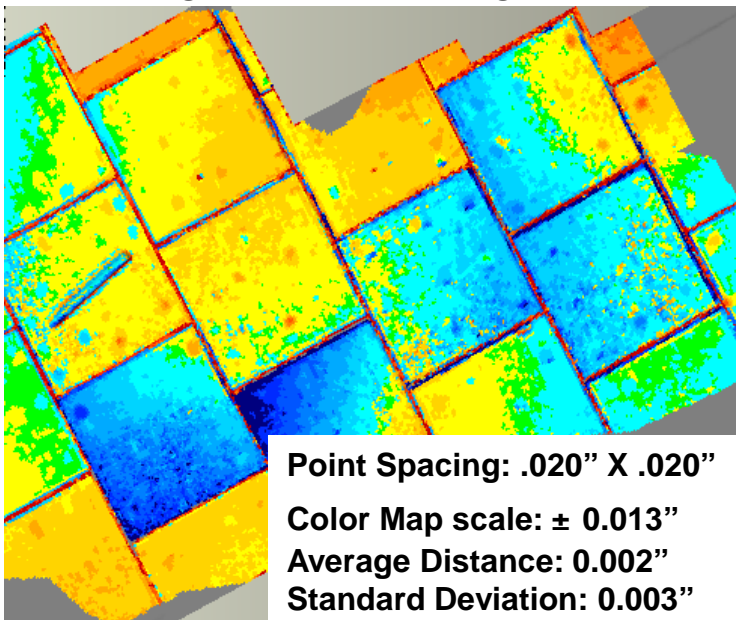
Optigo Pre/Post Flight Delta



Point Spacing: .020 X .020
Color Map scale: 0.0082"
Average distance: 0.001"
Standard deviation: 0.0014"

- Pre-flight OML Scans performed
 - Metris Laser/Radar, Optigo and Z-scanner
- Post flight OML Scans Performed to establish geometry change during flight
 - Metris Laser/Radar and Optigo
- Delta Geometry Assessment Accuracy
 - 0.001" -> 0.005" Depending on Resolution
- No Discernible Geometry change

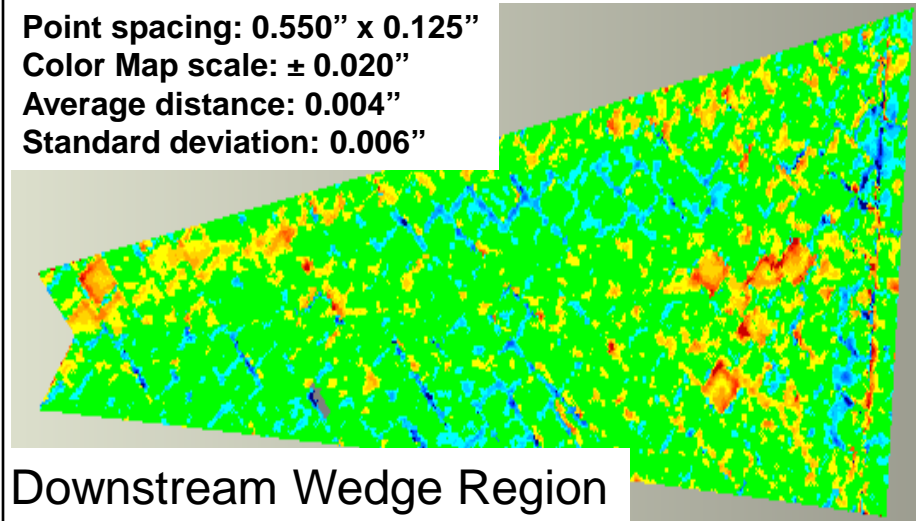
Optigo Pre/Post Flight Delta



Point Spacing: .020" X .020"
Color Map scale: ± 0.013"
Average Distance: 0.002"
Standard Deviation: 0.003"

Metris Laser/Radar Pre/Post Flight Delta

Point spacing: 0.550" x 0.125"
Color Map scale: ± 0.020"
Average distance: 0.004"
Standard deviation: 0.006"

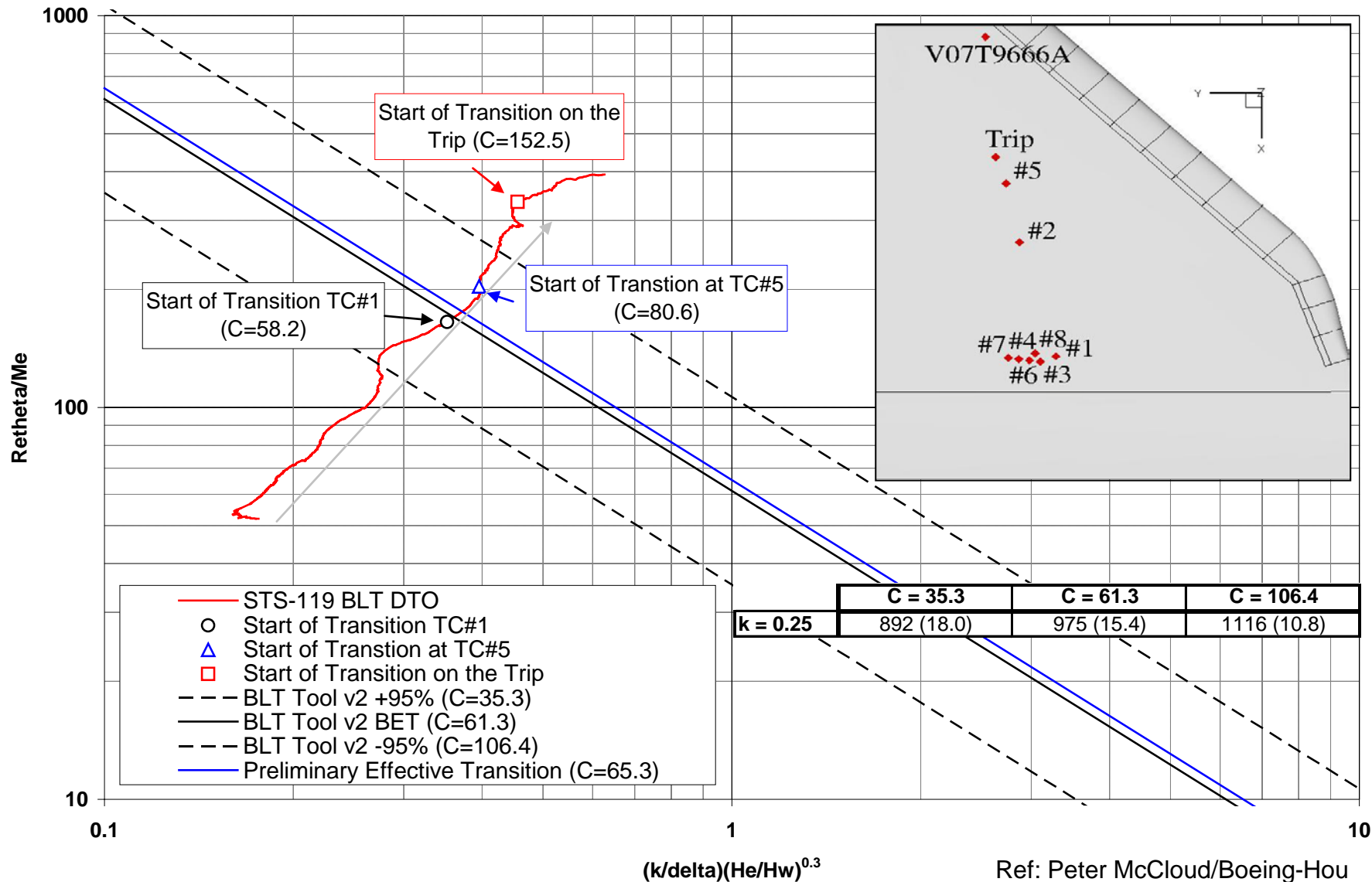


Downstream Wedge Region





STS-119 RTF BLT V2 Correlation

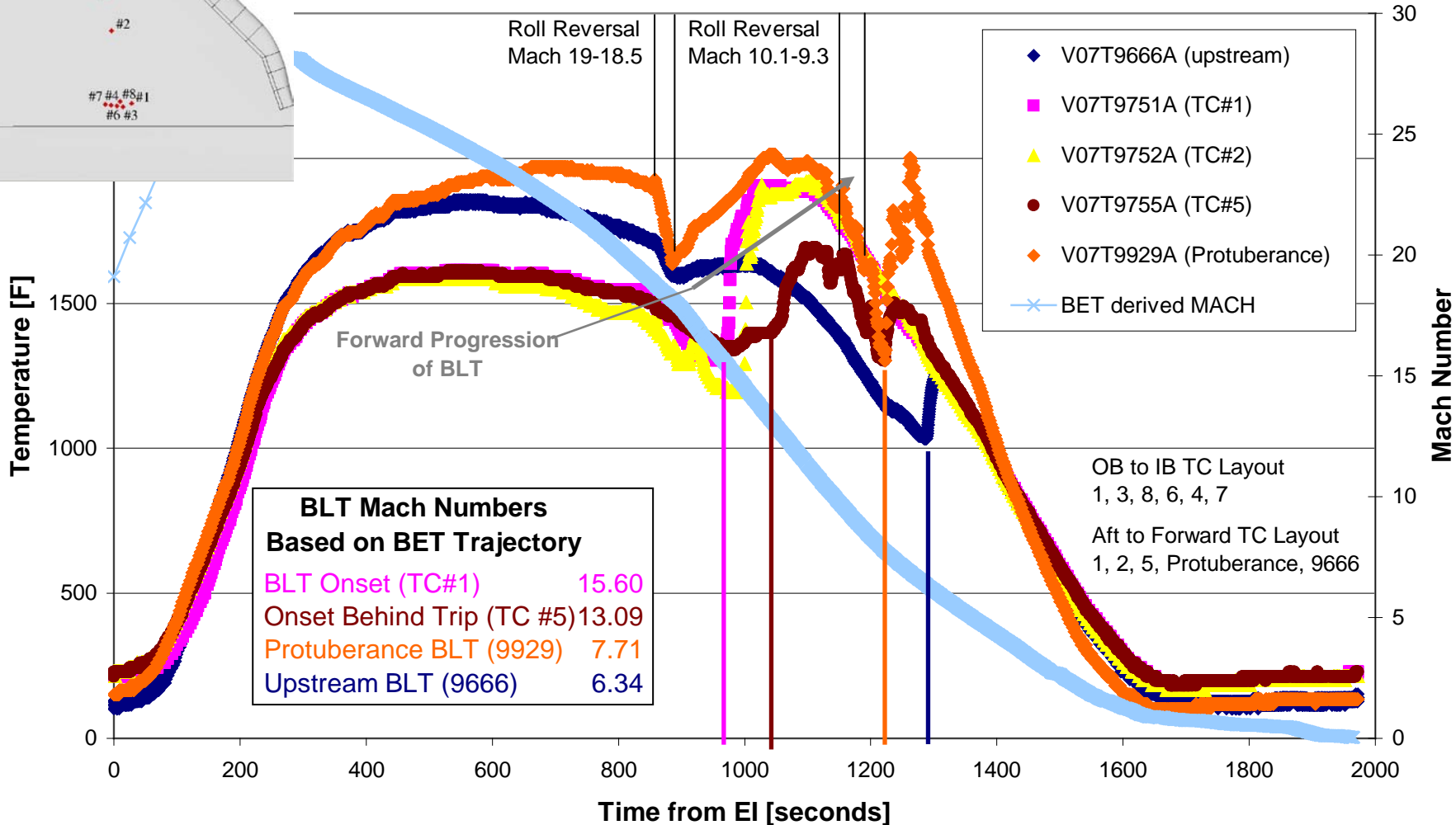
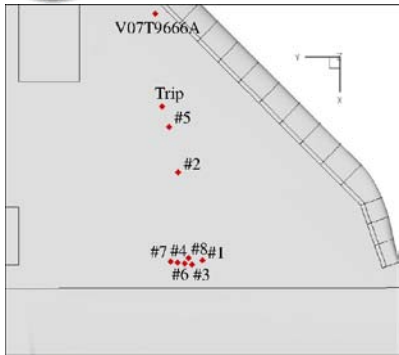


Ref: Peter McCloud/Boeing-Hou



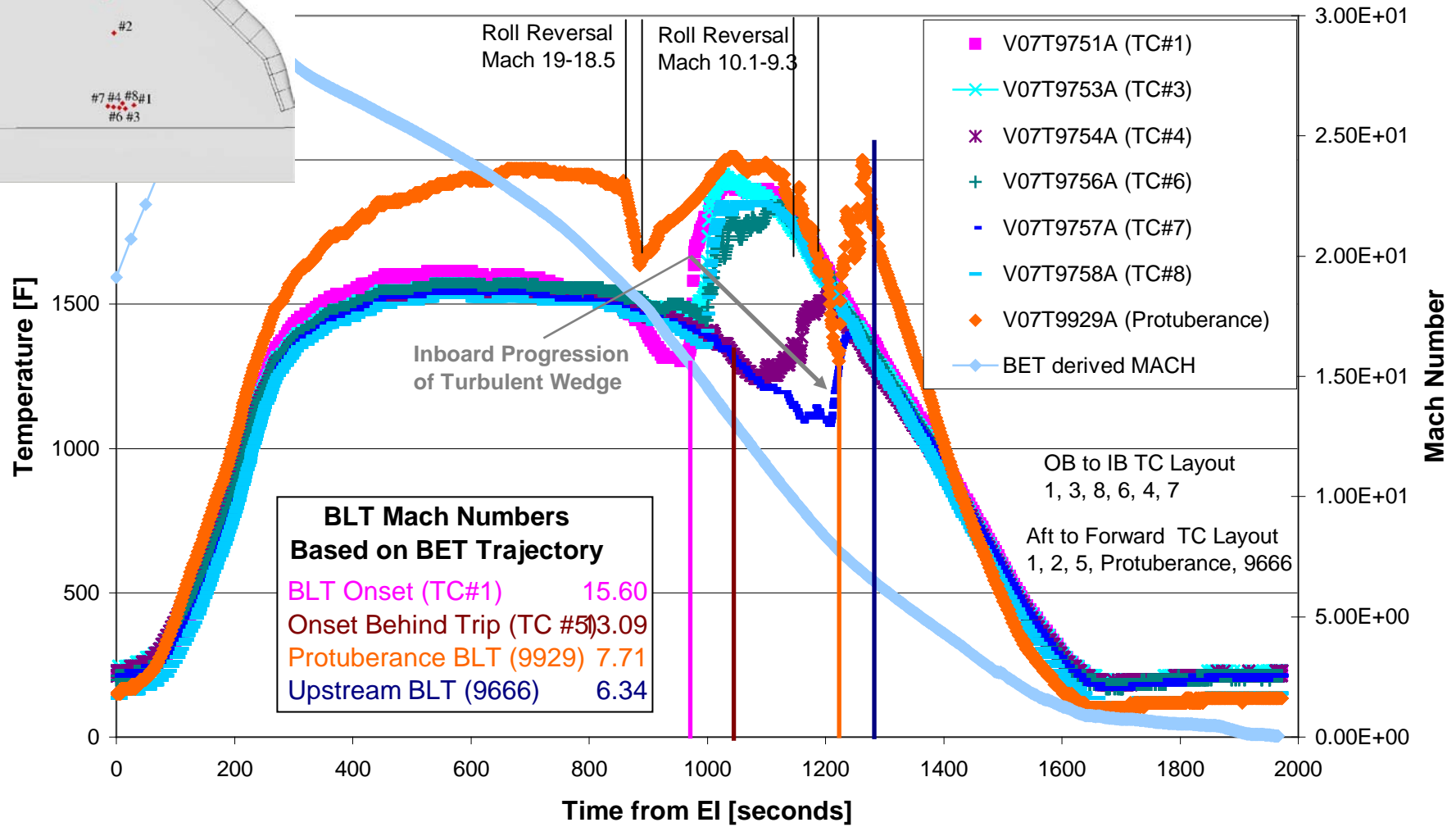
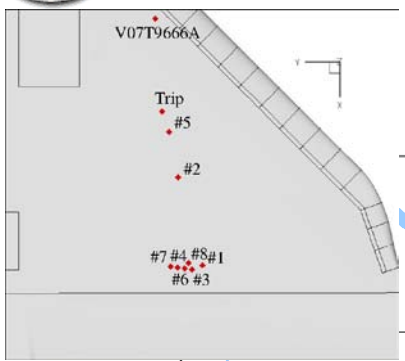


STS-119 BLT FE TC Data



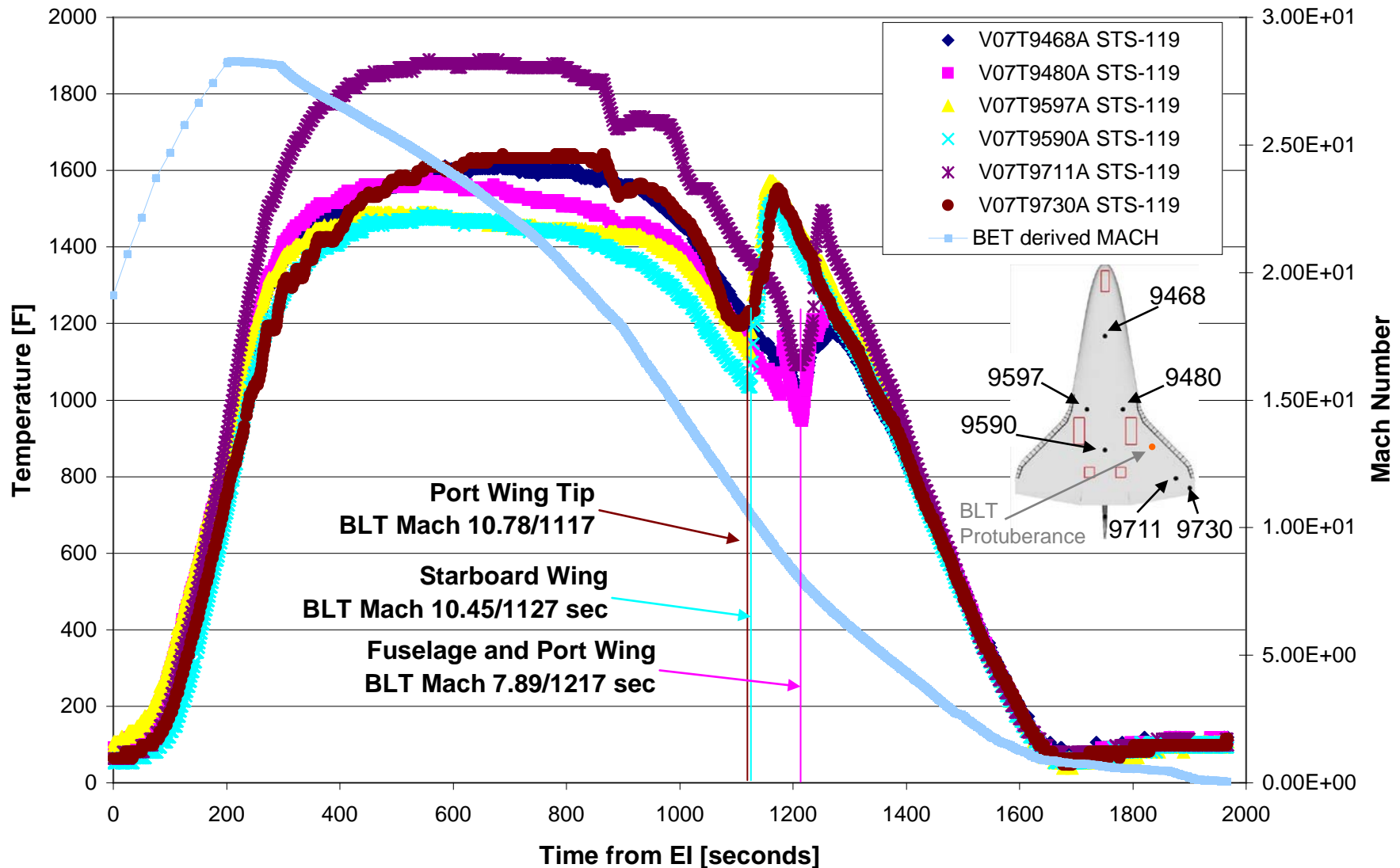


STS-119 BLT FE TC Data



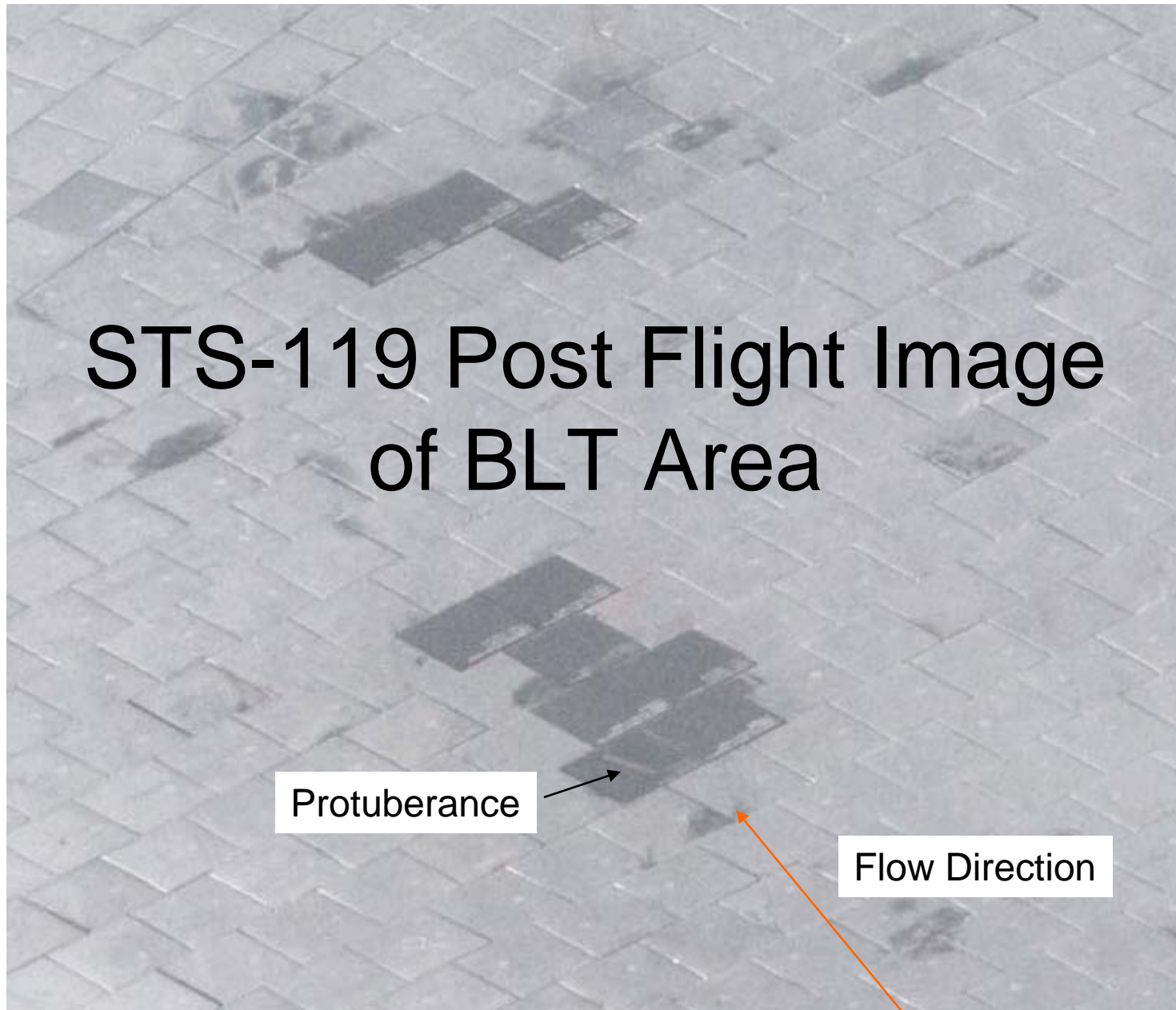


STS-119 Windward MADS TCs





STS-119 Post Flight Image of BLT Area



Protuberance

Flow Direction





STS-119 Post Flight Image of Aft BLT Area



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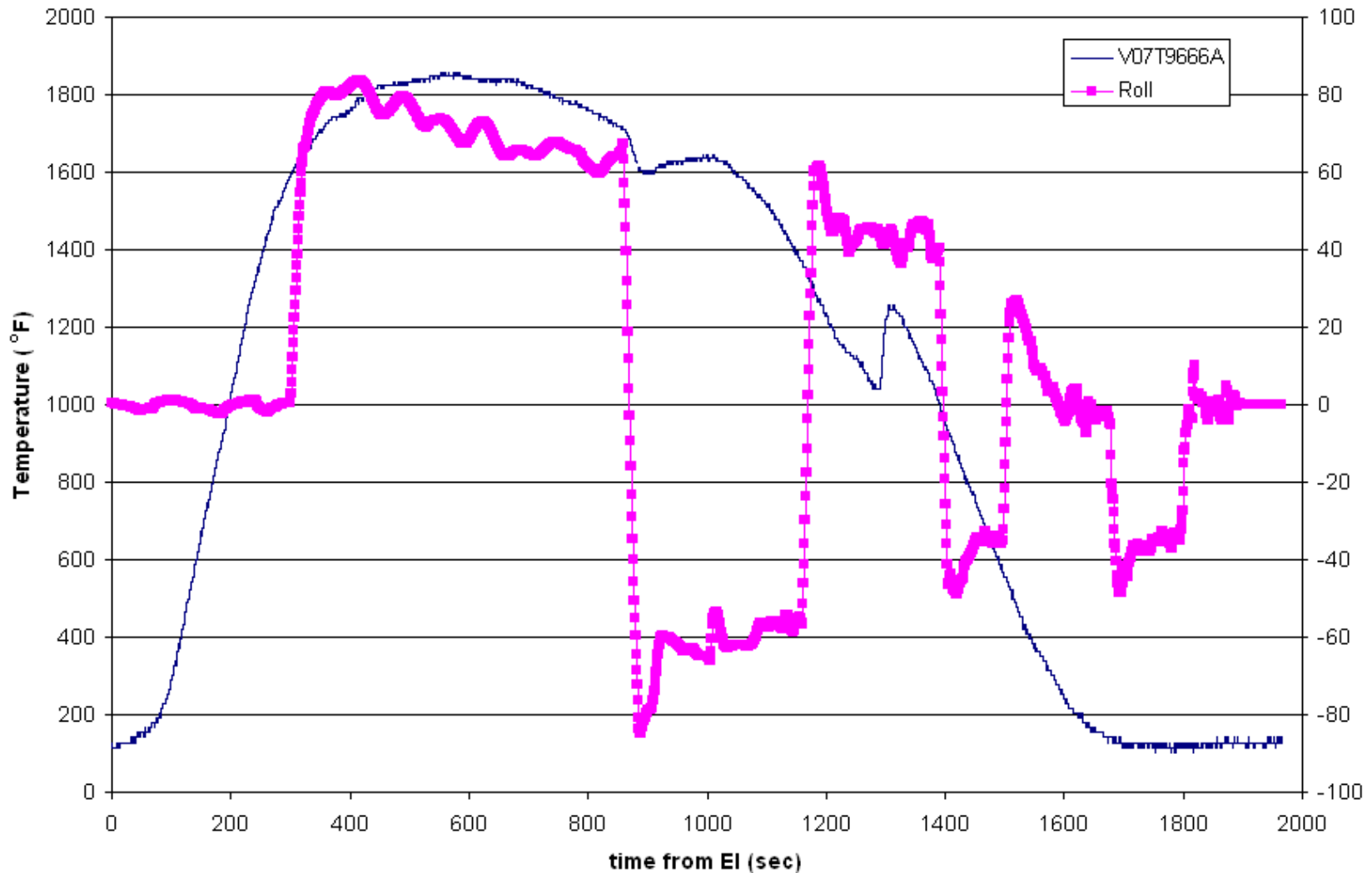
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STS-119 Roll versus Time from EI



STS-119 MADS Temperature



Time from EI Estimated from EOM Trajectory and MADS Nav Data
 charles.h.campbell@nasa.gov 19

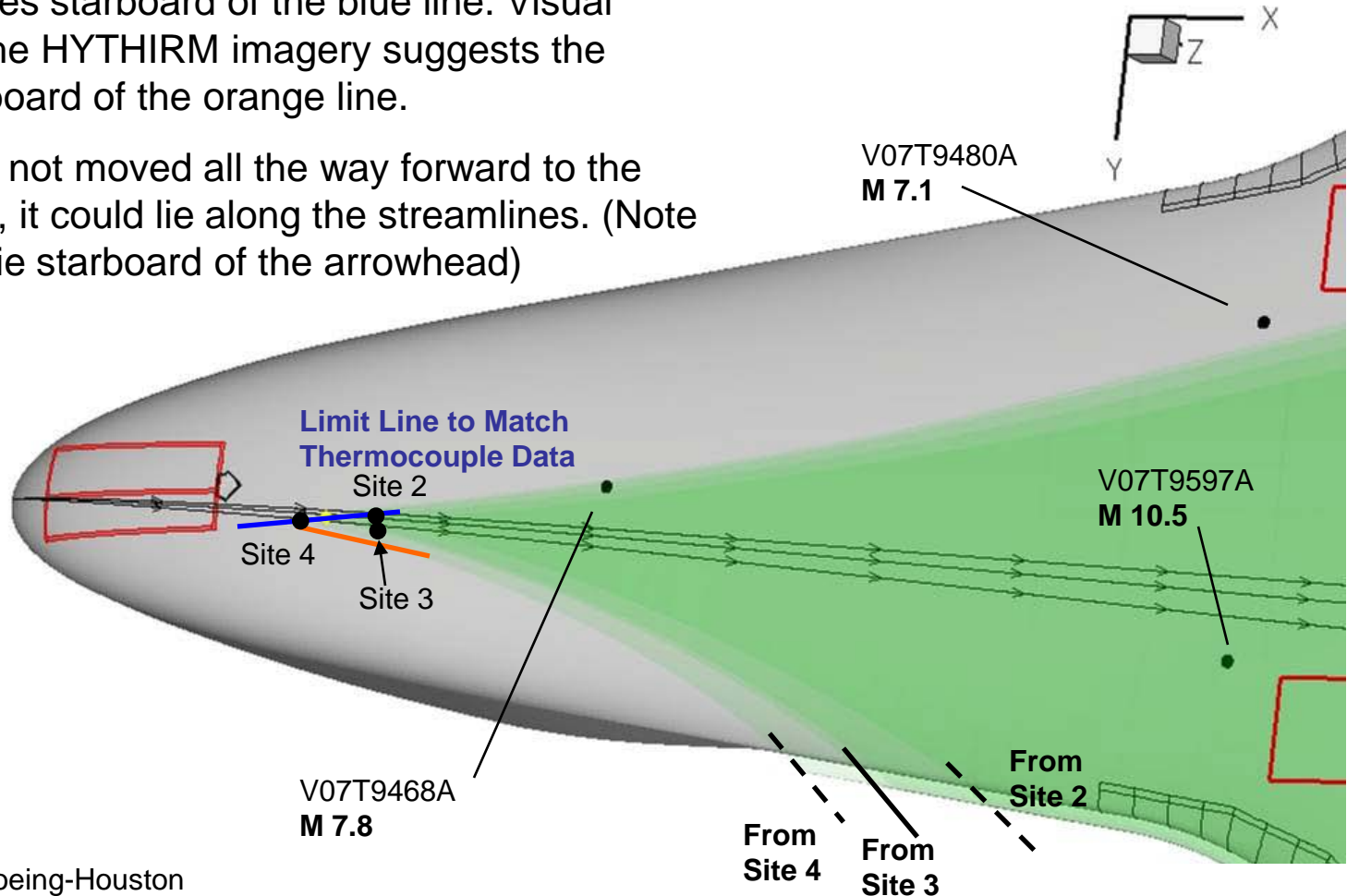




STS-119 Starboard ABLT Wedge Assessment

If the wedge starts at the source, MADS data suggests that the source lies starboard of the blue line. Visual Comparison of the HYTHIRM imagery suggests the damages lies inboard of the orange line.

If the wedge has not moved all the way forward to the transition source, it could lie along the streamlines. (Note the streamlines lie starboard of the arrowhead)



Peter McCloud / Boeing-Houston





STS-128 BLT FE Instrumentation Recommendation

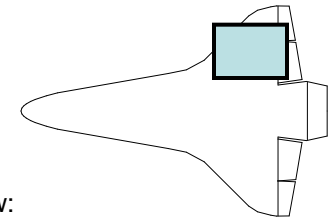


Diagram view:
Looking up at the lower surface of the orbiter.

