

BOLT II Roughness Side Flight Results

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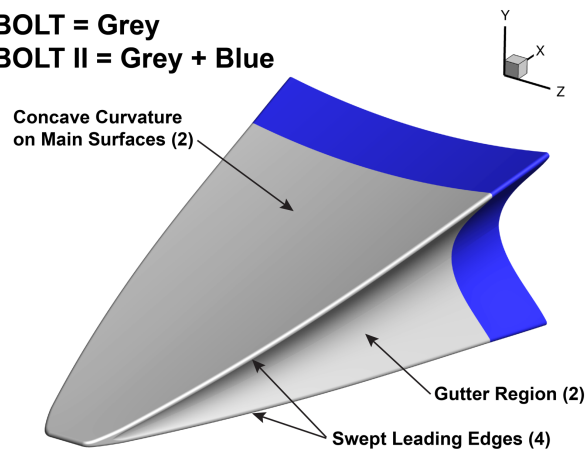
Presentation for SciTech 2023, Jan. 2023

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Introduction

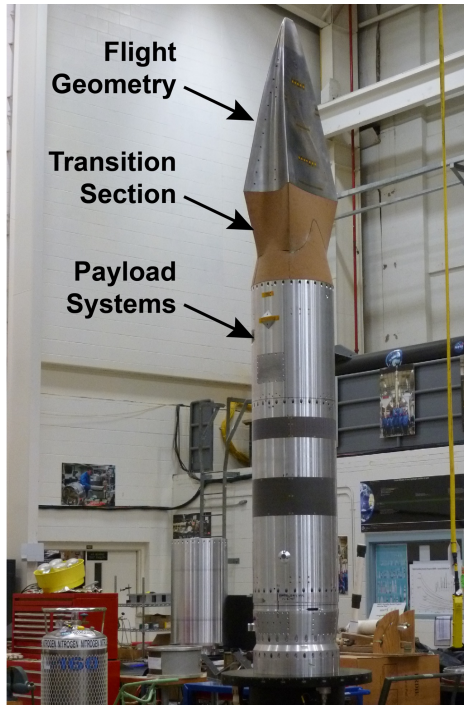
BOLT = Grey

BOLT II = Grey + Blue



- Air Force Office of Scientific Research (AFOSR) primary sponsor of BOLT (for Boundary Layer Transition) sounding rocket flight project as continuation of previous HIFiRE flights (1 & 5)
 - Sounding rockets provide cost-effective flight research tool
 - Study hypersonic BoLT on increasingly complex geometries
 - BOLT shape includes concave surfaces and swept leading edges
- Two missions, two flights:
 - BOLT mission at Esrange, Sweden
 - Johns Hopkins University Applied Physics Laboratory as lead
 - Focus on transition onset measurements
 - Flew June 2021 (staging anomaly)
 - BOLT II mission at Wallops Flight Facility, Virginia
 - Texas A&M and CUBRC provide primary leadership
 - Focus on turbulence measurements
 - Flew March 2022
 - Flight named in memory of Mike Holden
- NASA's support to both BOLT missions provided through the Hypersonic Technologies Project (HTP)

BOLT II Flight



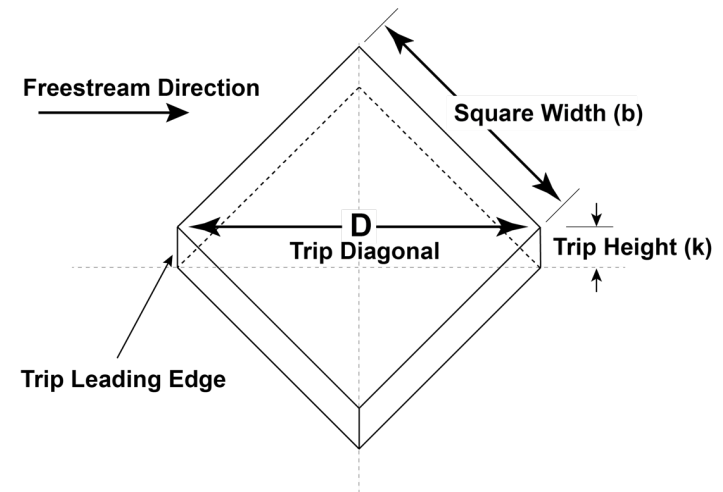
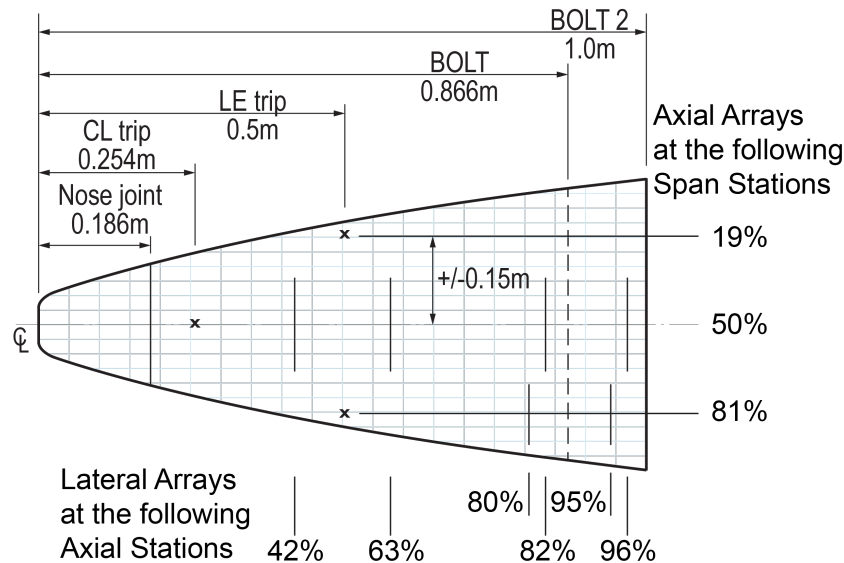
- BOLT II & Fairing built by CUBRC
- DAQ System from AFRL
- Payload sections & telemetry by WFF



Flight from Wallops Flight Facility on
Eastern Shore of Virginia



Side B Roughness Experiment

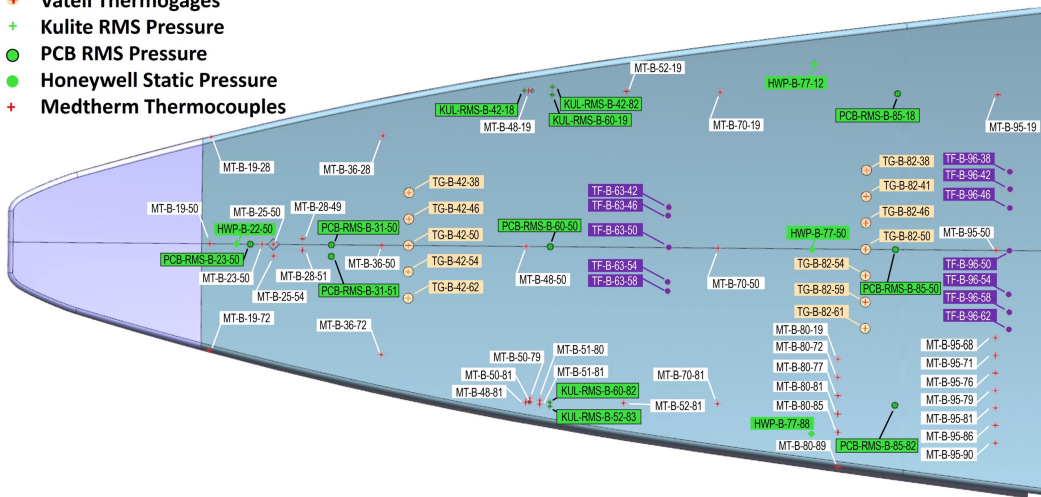


- BOLT geometry provides two independent surfaces
 - Primary side for smooth wall transition & turbulence
 - Secondary side for investigation of roughness effects
- BOLT roughness side designed to study step effects
- BOLT II roughness side designed to investigate discrete tripping

Side B Trips	X (m)	Z (m)	Height (mm)	Width (mm)
CL	0.254	0.000	2.625	7.875
LE19	0.500	0.146	0.903	2.709
LE81	0.500	-0.146	0.903	2.709

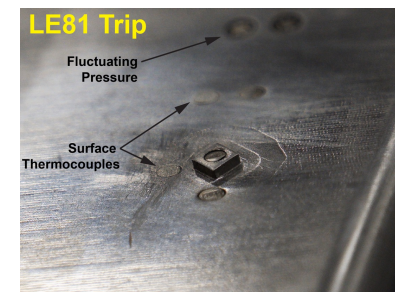
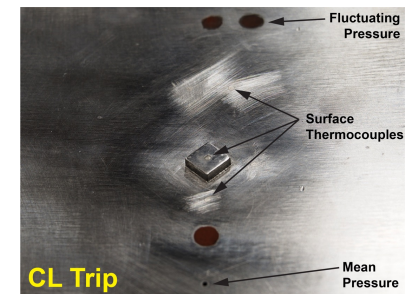
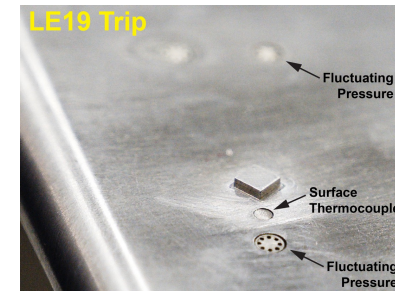
Side B Discussion

- CUBRC Thin-Films
- ✚ Vatell Thermogages
- ✚ Kulite RMS Pressure
- PCB RMS Pressure
- Honeywell Static Pressure
- ✚ Medtherm Thermocouples



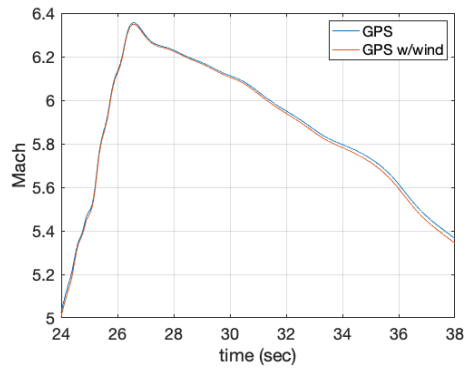
Total # Channels	Type / Designation	Vendor & Model#	Sampling Rate (Hz)	Side B only
192	Thermocouple (MT)	Medtherms Type E Dual TCS-061-EE	400	76
57	Heat Transfer (TG)	Vatell TG-2000	2000	12
50	Thin-Film (TF)	CUBRC custom design	10000	12
39	Mean Pressure (HWP)	Honeywell 19C – 15 psia	400	4
19	Fluctuating Pressure (PCB)	PCB-112B05,	57000	7
5	Fluctuating Pressure (KUL)	Kulite XCE-093-5psid	57000	5
4	High Frequency Pressure	PCB-132B	2500000	0
14	Skin Friction	Ahmico	1000	0
5	Accelerometer	Endevco ±100g	20000	0
11	Internal Payload	Various	400	0

38 MT's
(F/B)

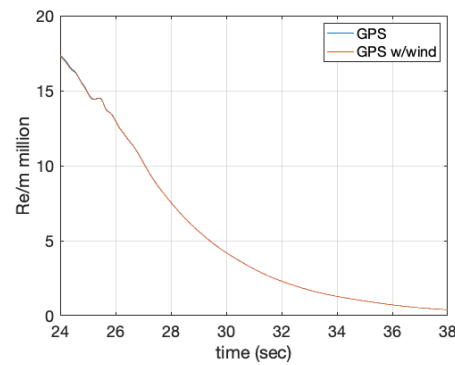


BOLT II Flight Trajectory

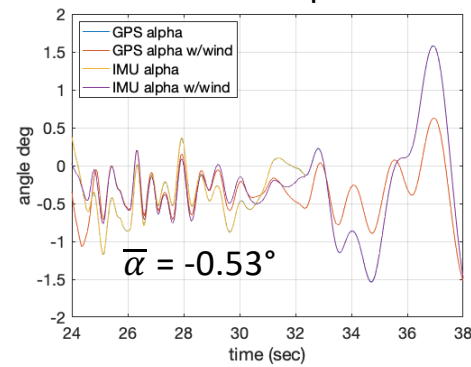
Ascent Mach



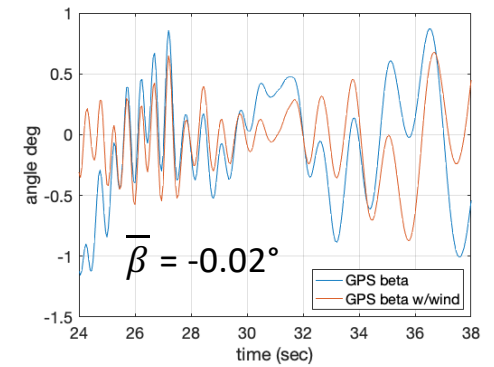
Ascent Re



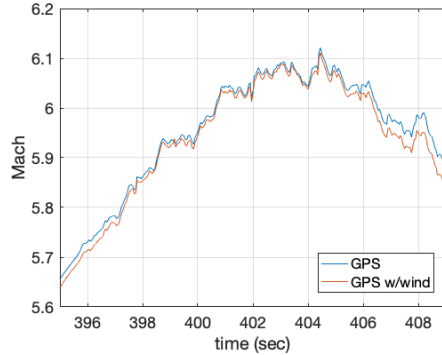
Ascent Alpha



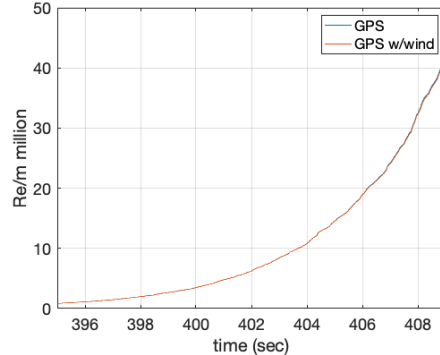
Ascent Beta



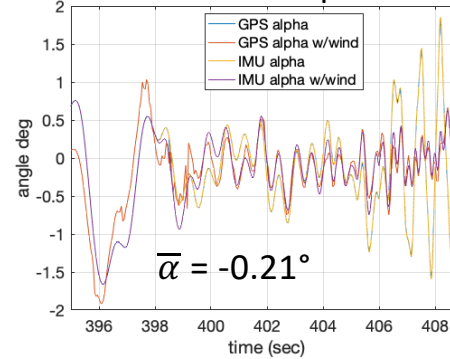
Descent Mach



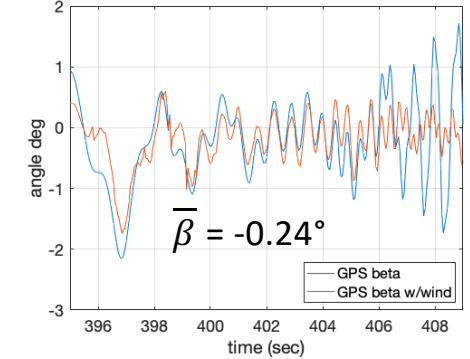
Descent Re



Descent Alpha



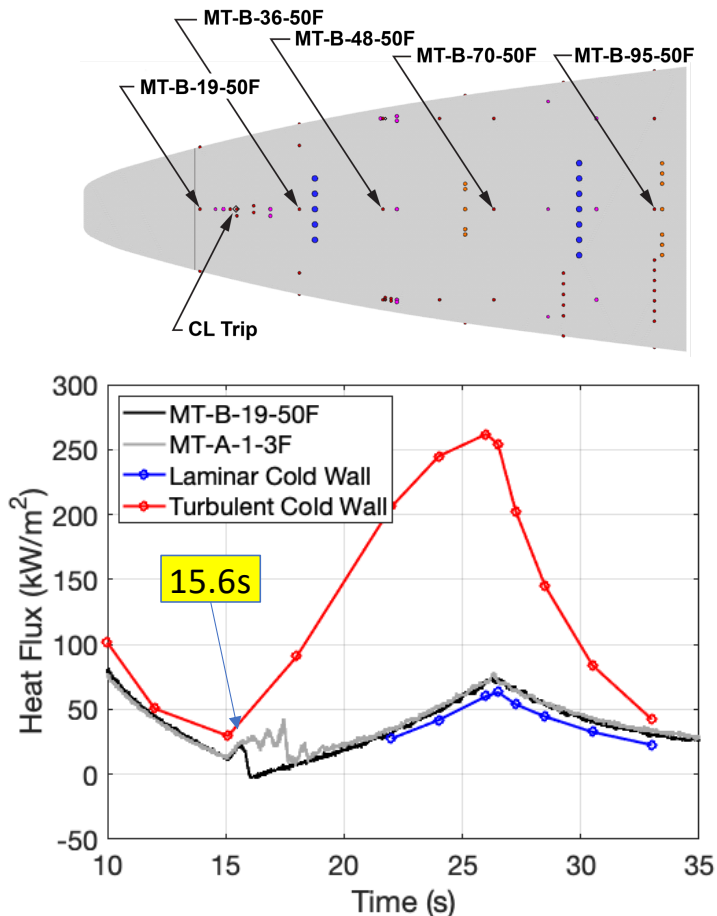
Descent Beta



Negative α = Side B leeward

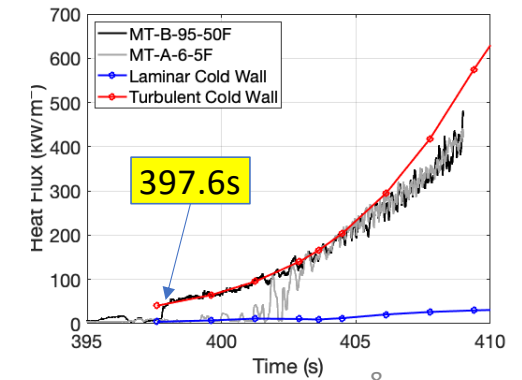
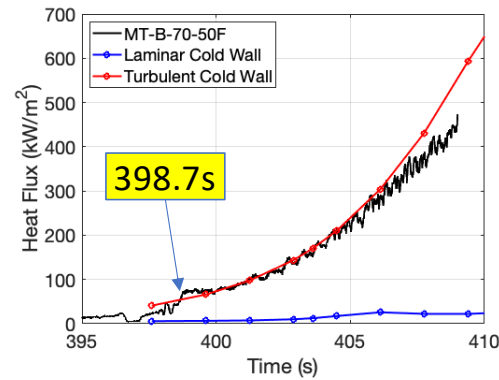
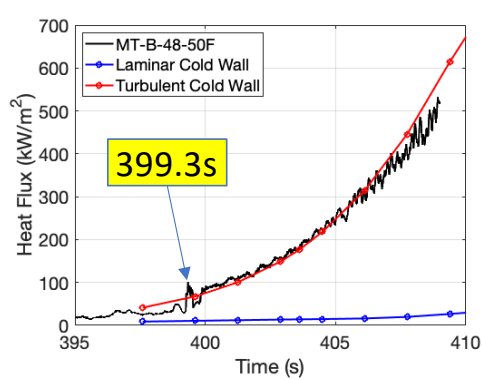
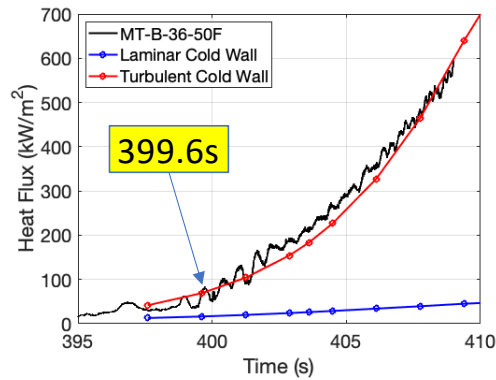
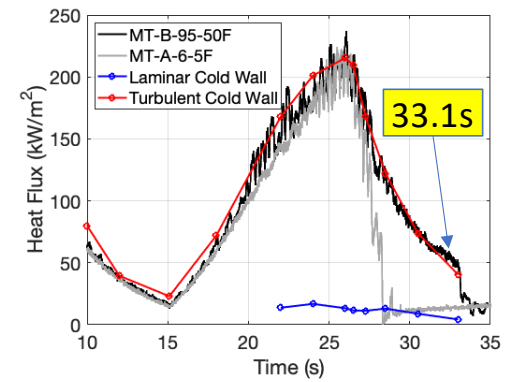
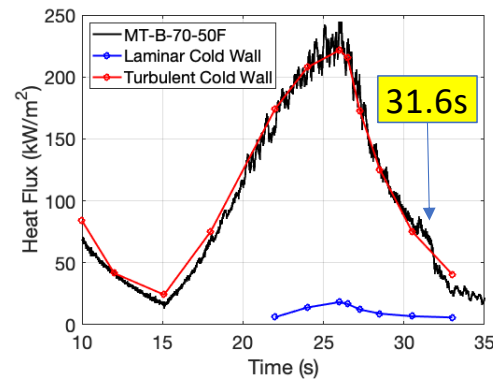
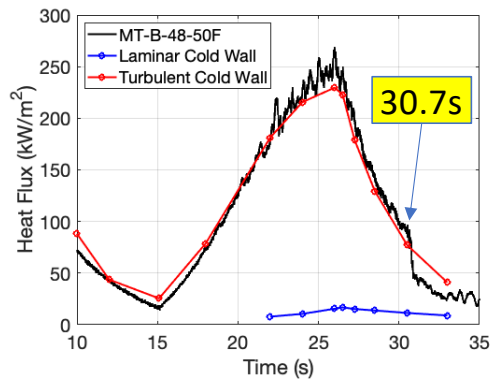
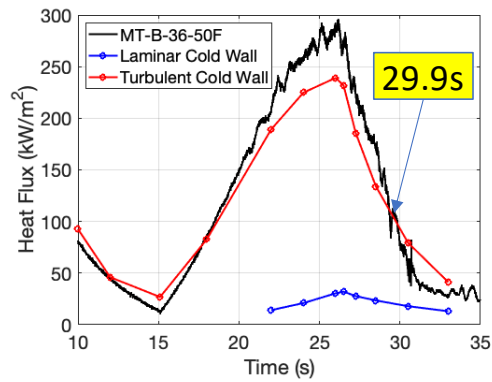
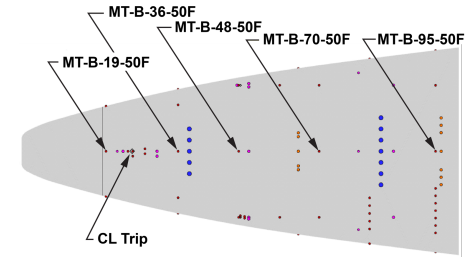
Negative β = Nose to port

Determination of Transition Onset

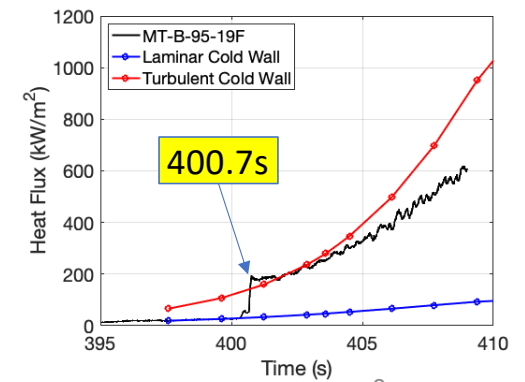
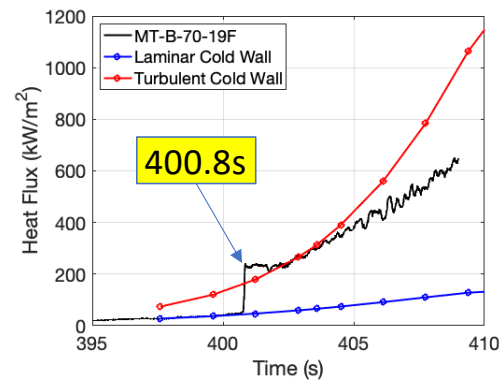
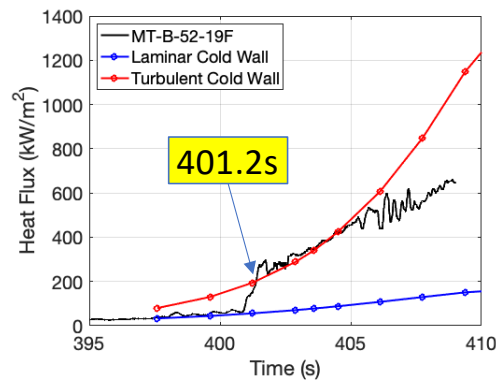
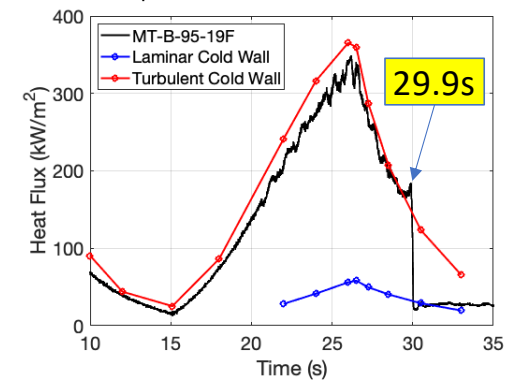
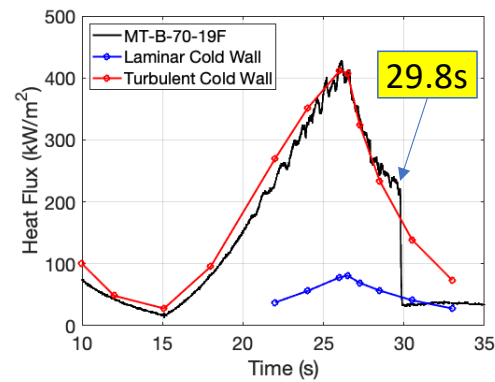
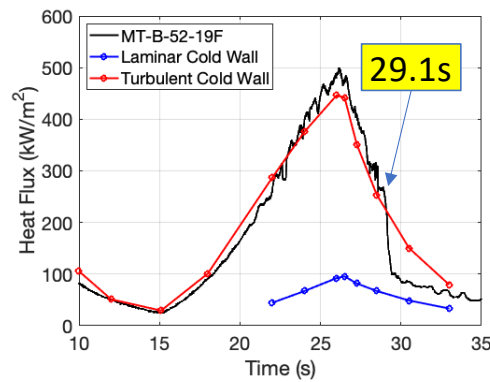
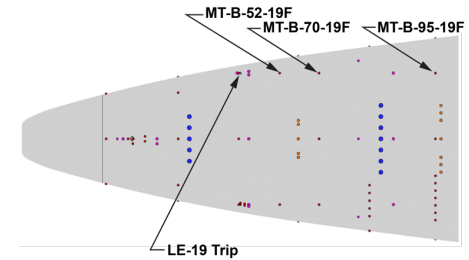


- Conversion of thermocouple temperature data to surface heating using method of Cook-Felderman
- Comparison of measured heating to computational results based on database of solutions using the flight trajectory and nominal flight alpha/beta
 - See Wheaton & Dufrene (AIAA SciTech 23)
- Some thermocouple locations have corresponding sensors on opposite side of vehicle, useful for assessing alpha/beta effects
- Transition onset determined from the point of deviation from the fully turbulent predictions

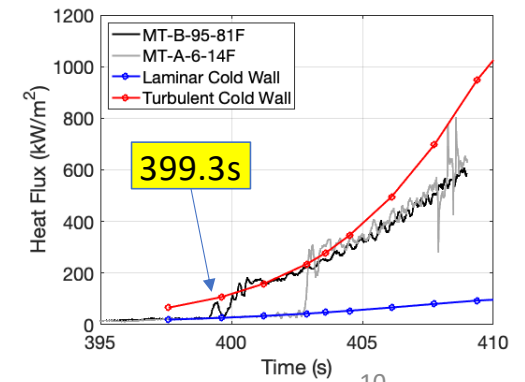
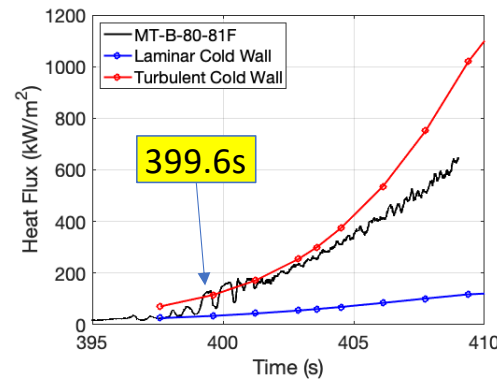
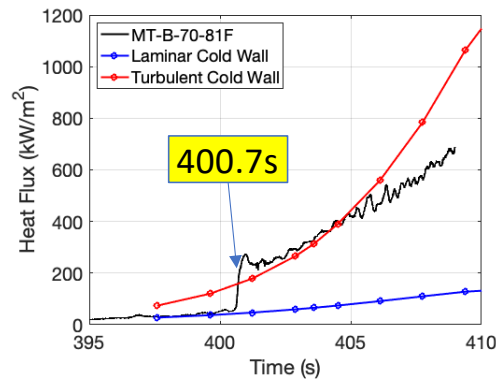
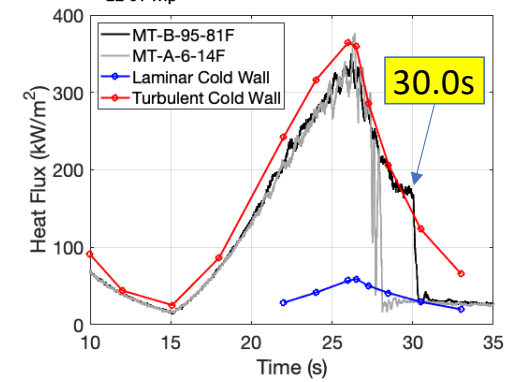
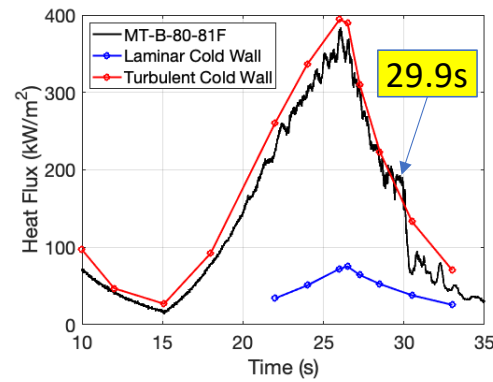
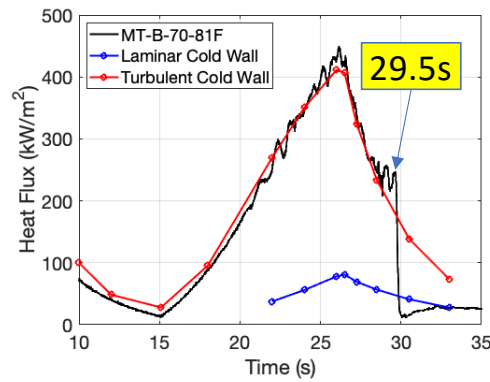
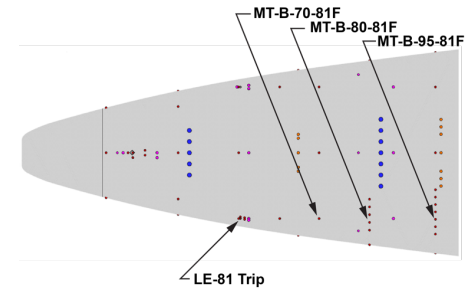
CL Trip – Axial Array



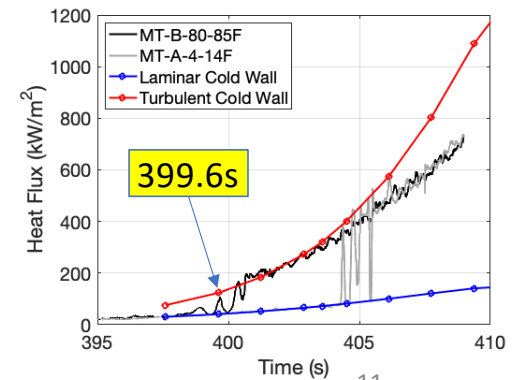
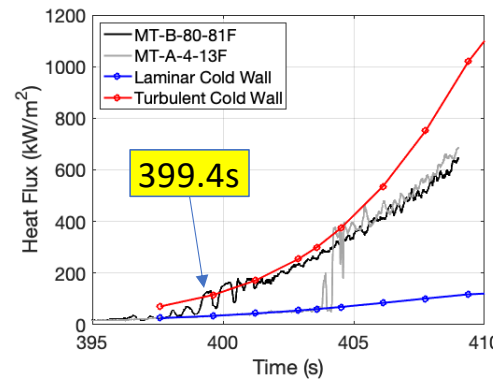
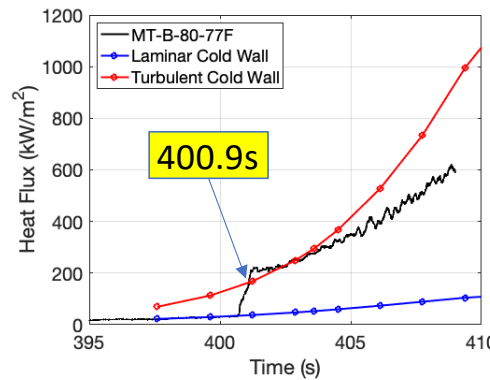
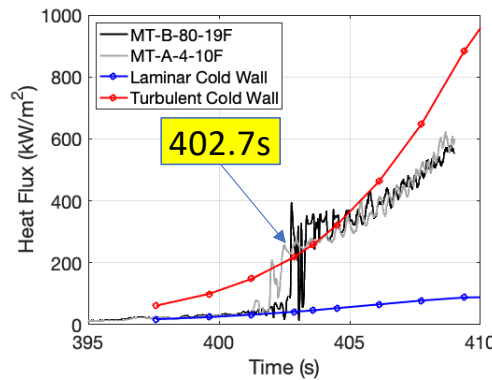
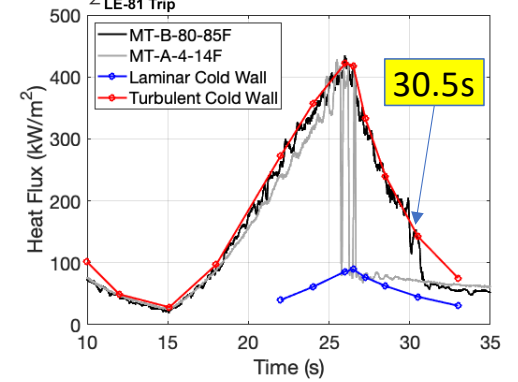
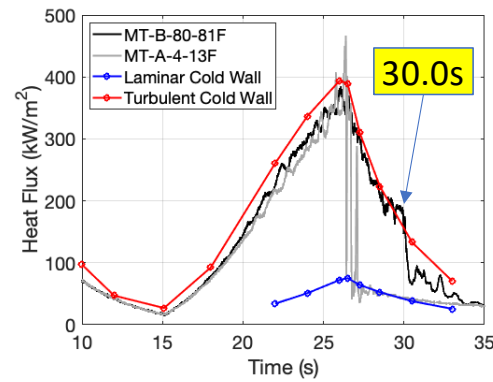
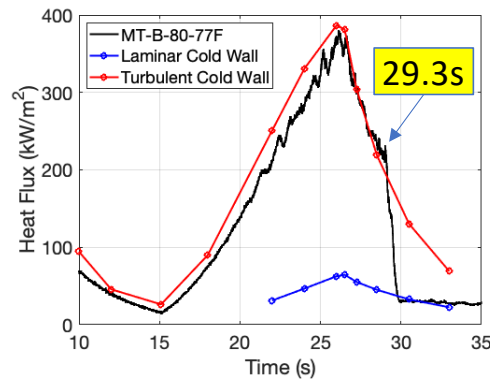
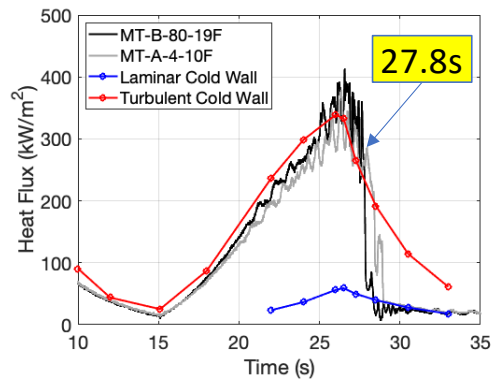
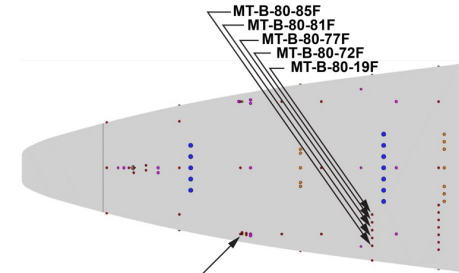
LE19 Trip – Axial Array



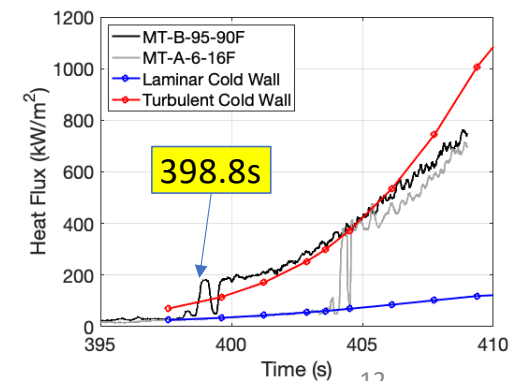
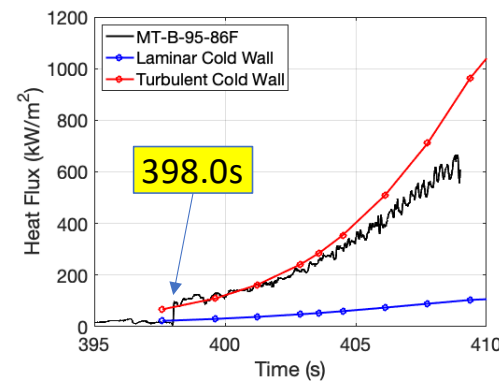
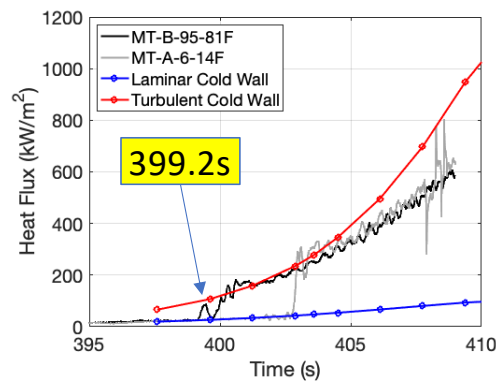
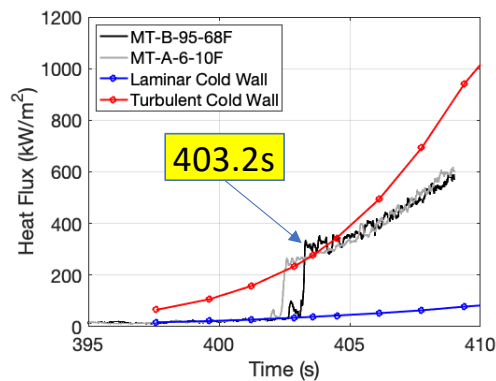
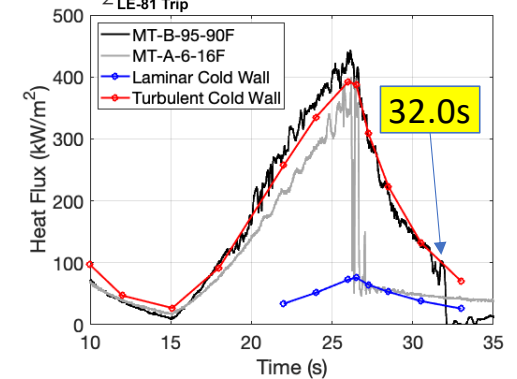
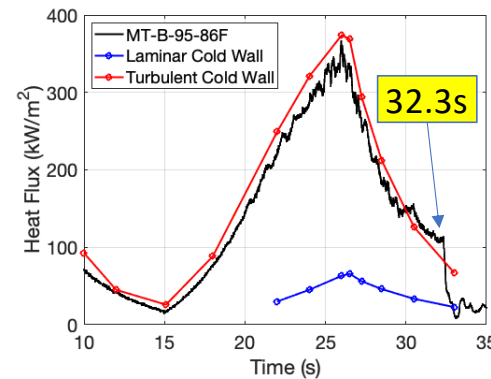
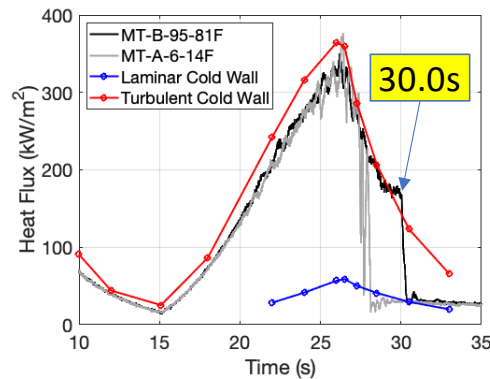
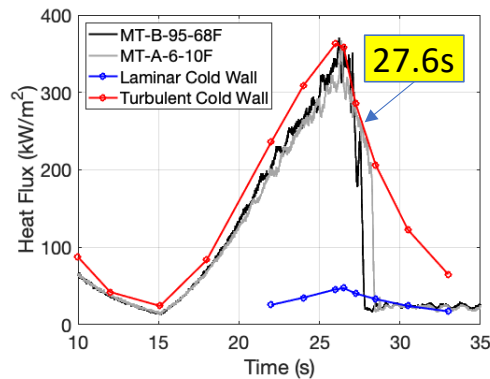
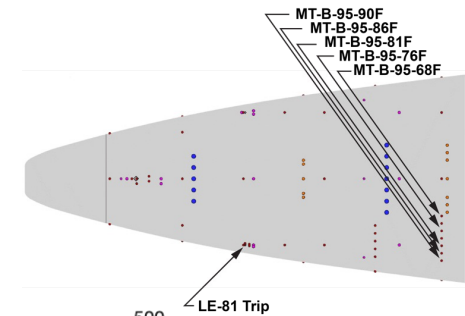
LE81 Trip – Axial Array



LE81 Trip – Spanwise Array #1

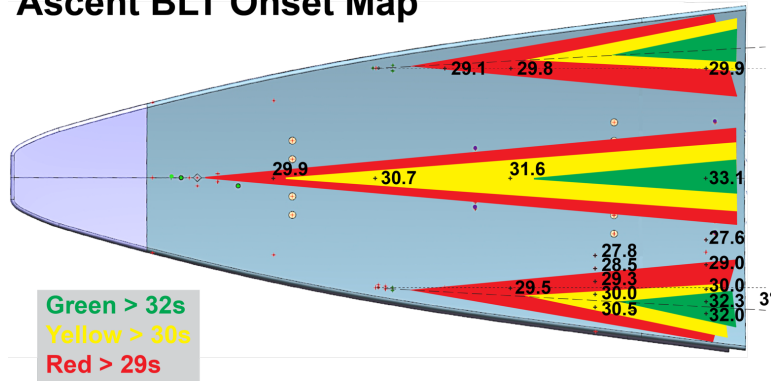


LE81 Trip – Spanwise Array #2

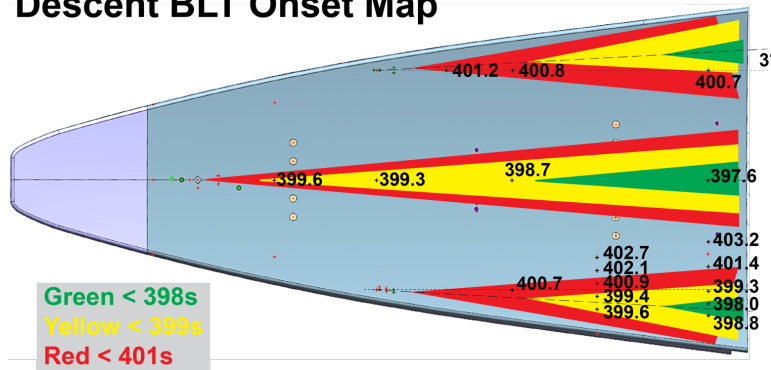


Preliminary Trip Performance based on TC Data

Ascent BLT Onset Map



Descent BLT Onset Map



- TC data suggests that trips performed as expected
 - Designed for all three to trip at same time
 - Current assessment of transition onset shows consistent results, with some allowance for spatial coverage and accuracy of selecting onset
- Disturbance path behind LE trips appear to track outboard of sensor layout by roughly 3 degrees
- During ascent
 - Incipient trips @ $t=32s \rightarrow M_\infty = 6.0$ & $Re_L = 2.1$ million
 - Effective trips @ $t=29s \rightarrow M_\infty = 6.2$ & $Re_L = 5.4$ million
- During descent
 - Incipient trips @ $t=398s \rightarrow M_\infty = 5.8$ & $Re_L = 1.7$ million
 - Effective trips @ $t=401s \rightarrow M_\infty = 6.1$ & $Re_L = 4.3$ million

Summary Remarks

- A preliminary assessment of the BOLT II roughness side results was provided focused only on the thermocouple data
- BOLT II roughness experiment designed to study discrete roughness elements (trips) based on the diamond shape
- Three trip locations selected for flight experiment based on sensor allocations
 - And sized to trip at same time during flight
- Based on current analysis of thermocouple data only, the three trips did trip as expected and at nearly the same point during the trajectory, although not at matching conditions during ascent and descent
- Further analysis, including the additional sets of sensors is ongoing