

Recent BOLT Discrete-Roughness Results from the 20-Inch Mach 6 Air Tunnel

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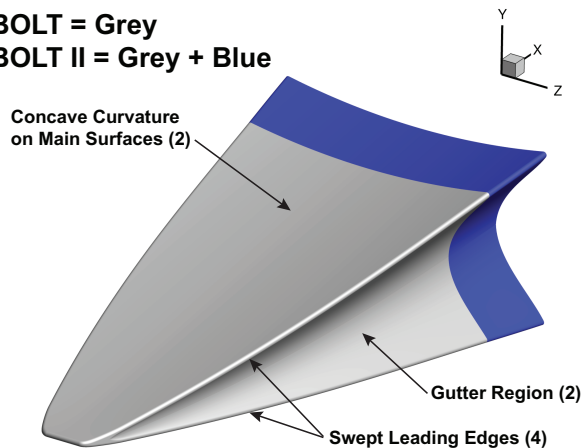
NASA Langley Research Center, Hampton, VA, 23681

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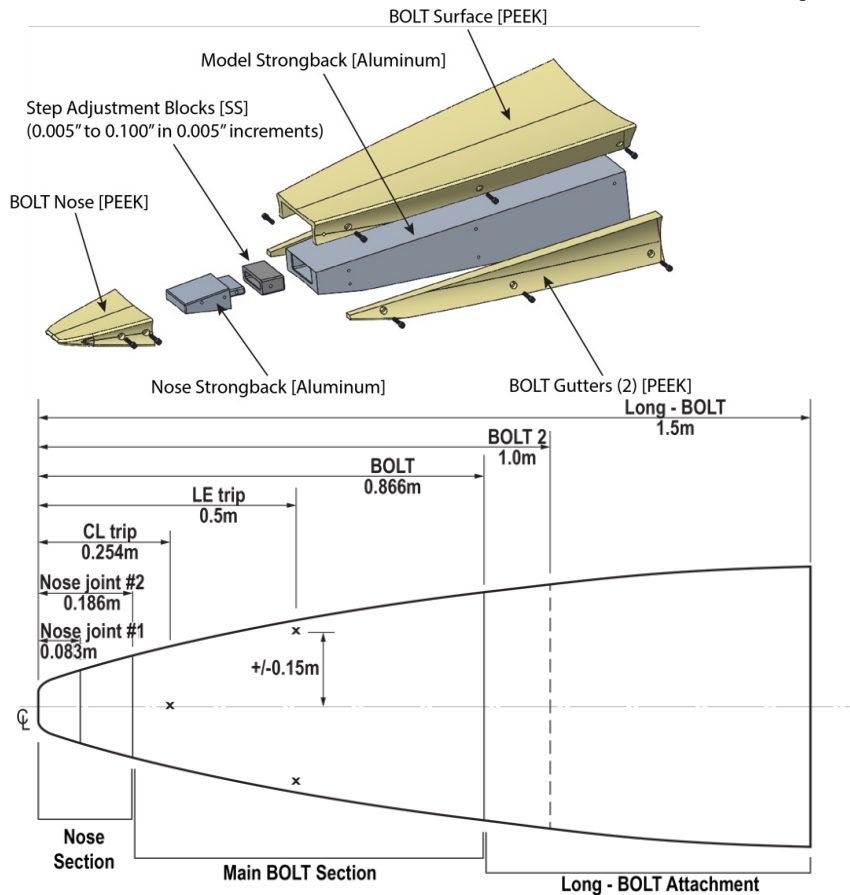
Introduction

BOLT = Grey
BOLT II = Grey + Blue

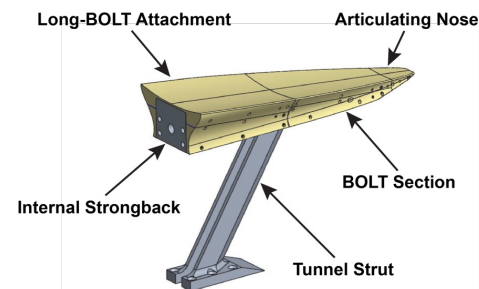


- Air Force Office of Scientific Research (AFOSR) primary sponsor of BOLT (for Boundary Layer Transition) sounding rocket flight project as continuation of previous HIFiRE flights (1 & 5)
 - Sounding rockets provide cost-effective flight research tool
 - Study hypersonic BoLT on increasingly complex 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 Model for Trip Study



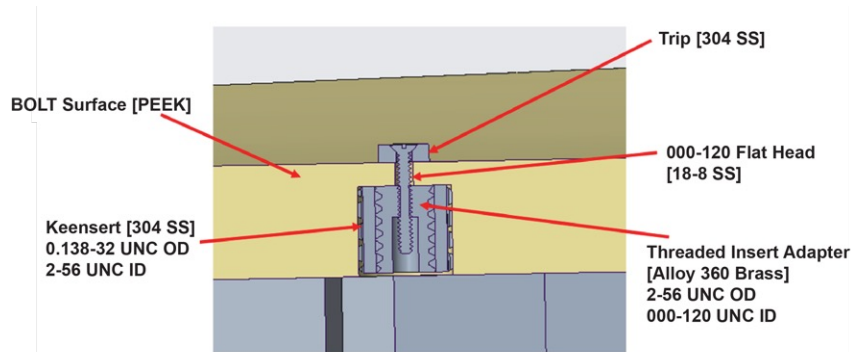
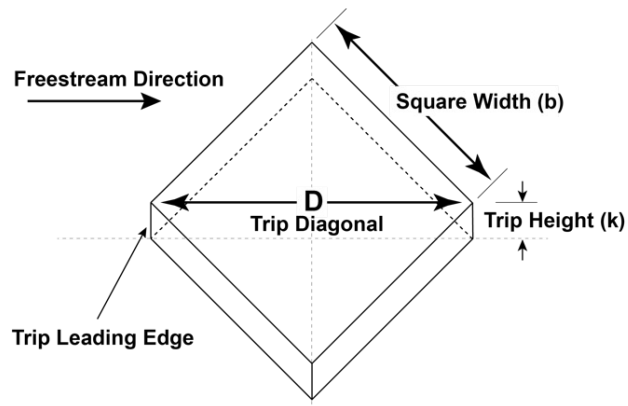
- BOLT flight geometry provides two independent surfaces
 - Primary side for smooth wall transition & turbulence
 - Secondary side for investigation of roughness effects
- BOLT roughness side designed to study step effects
- BOLT II roughness side designed to investigate discrete tripping



Half scale model designed for looking at step effects repurposed for trip study

Feature (length from nose or CL)	Applicability	Full-scale length (m)	Full-scale length (in)	Model-scale length (m)	Model-scale length (in)
Joint step #1	BOLT only	0.083	3.27	0.042	1.64
Joint step #2	BOLT & BOLT 2	0.186	7.32	0.093	3.66
CL trip	BOLT 2 only	0.254	10.0	0.127	5.0
LE trips	BOLT 2 only	0.5/±0.15	19.7/±5.9	0.250/±0.075	9.85/±2.95
BOLT step length	BOLT only	0.866	34.1	0.433	17.05
BOLT 2 length	BOLT 2 only	1.0	39.4	0.500	19.7
Long-BOLT length	Model only	1.5	59.1	0.750	29.5

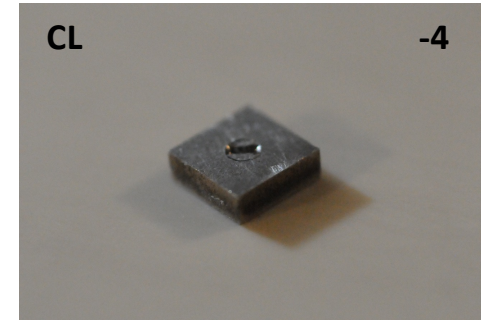
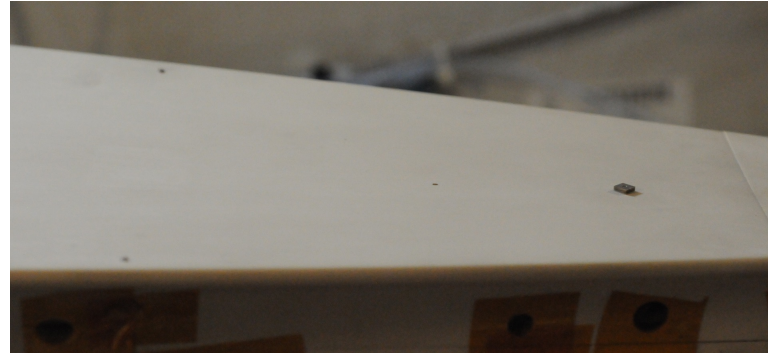
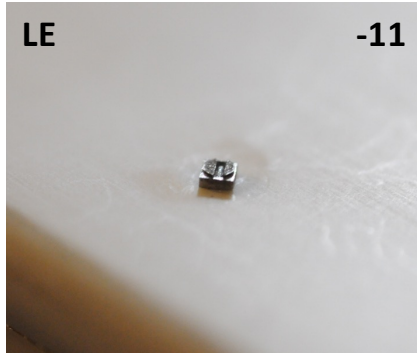
Model Trip Details



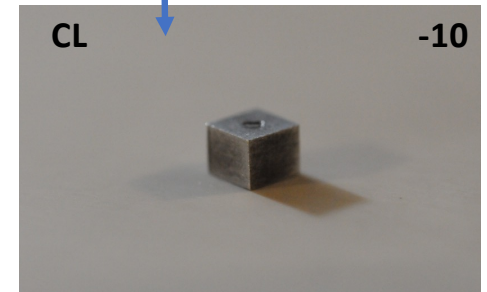
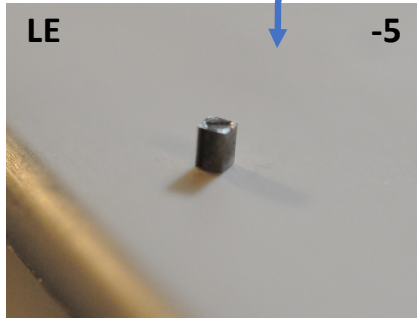
PART NUMBER	Trip Height (k) (in)	Trip Width (b) (in)	Notes
300931-1	0.026	0.052	LE, nominal +1
300931-2	0.026	0.156	CL, nominal -1
300931-3	0.052	0.052	LE, nominal +2
300931-4	0.052	0.156	CL, nominal
300931-5	0.076	0.052	LE, nominal +3
300931-6	0.076	0.156	CL, nominal +1
300931-7	0.100	0.052	LE, nominal +4
300931-8	0.100	0.156	CL, nominal +2
300931-9	0.124	0.052	LE, nominal +5
300931-10	0.124	0.156	CL, nominal +3
300931-11	0.018	0.052	LE, nominal

Trip Configs	CL Part #	Measured Height (in)	LE Part #	Measured Height (in)
1 (flight scale)	-4	0.052	-11	0.021
2 (+1 bigger)	-6	0.076	-1	0.031
3 (+2 bigger)	-8	0.100	-3	0.052
4 (+3 bigger)	-10	0.124	-5	0.077

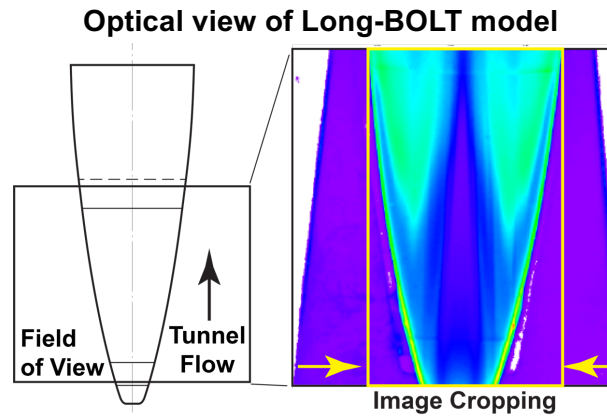
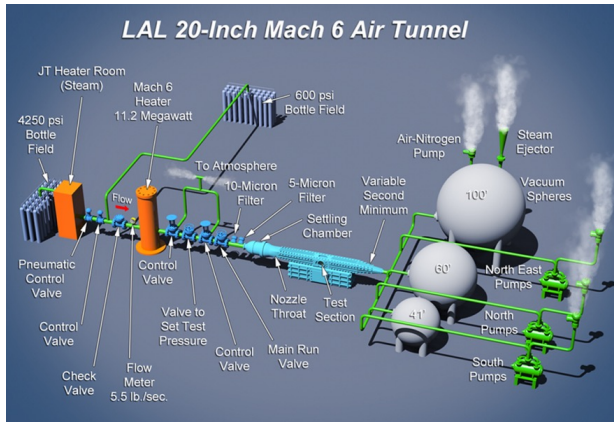
Photos of Trips



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4 (+3 bigger)	-10	0.124	-5	0.077



20" Mach 6 Tunnel Details



Capabilities:

- $M_\infty = 6$
- $Re_\infty = 0.5$ to $8 \times 10^6/\text{ft}$
- $P_0 = 30$ to 500 psia
- $T_0 = 410$ to 500°F
- Test gas, air, $\gamma_\infty = 1.4$

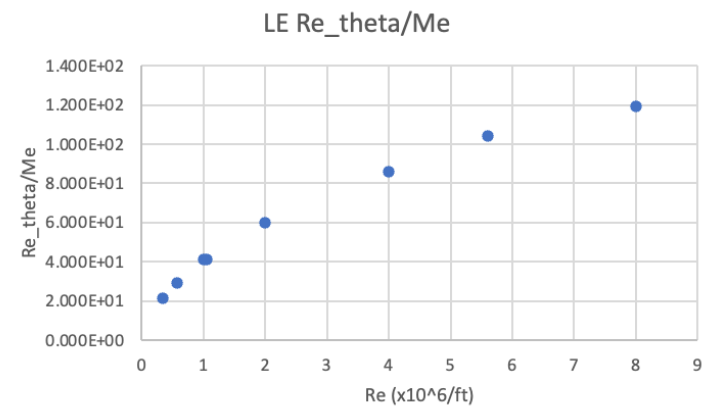
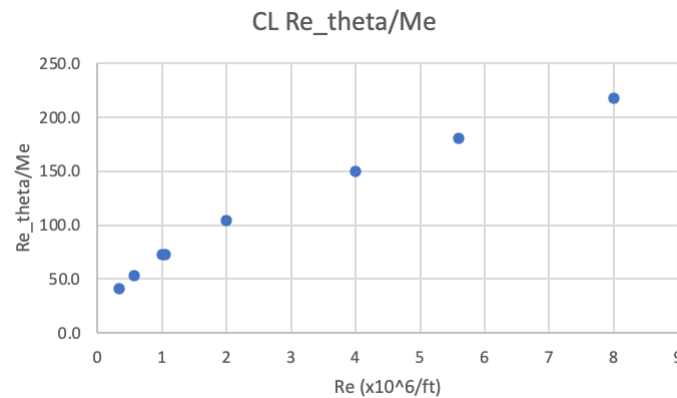
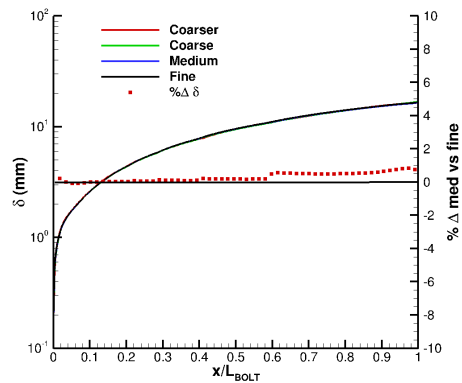
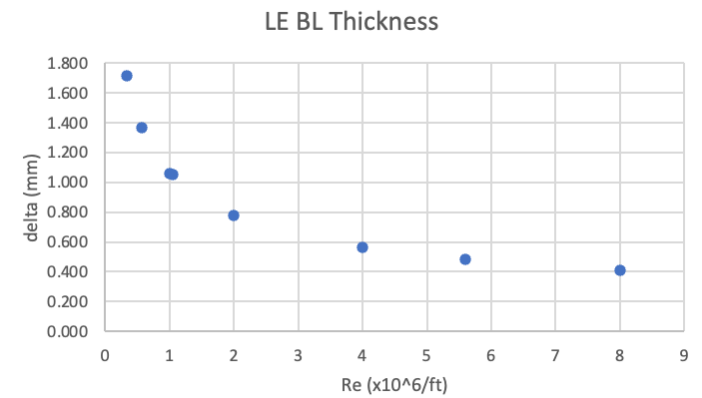
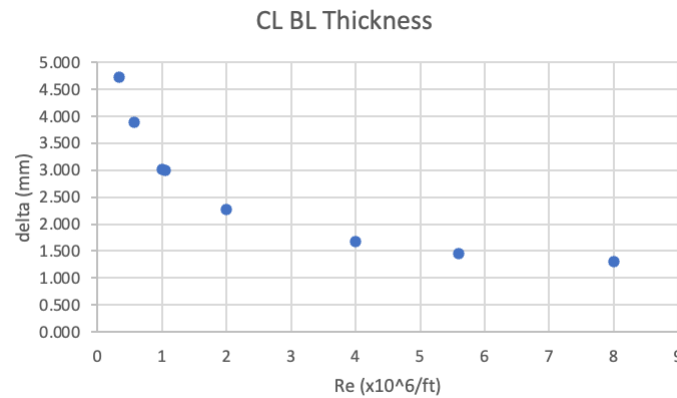
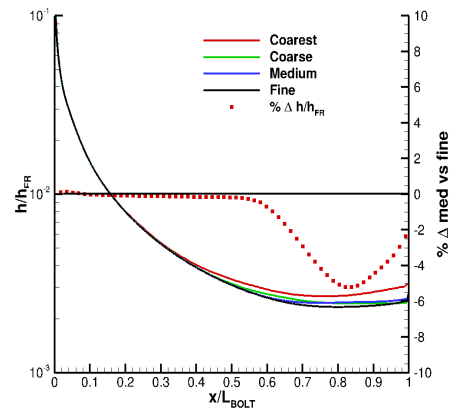


Long-BOLT model in 20" Mach 6



FLIR SC6701sls LWIR camera with a 50mm lens

LAURA Computations

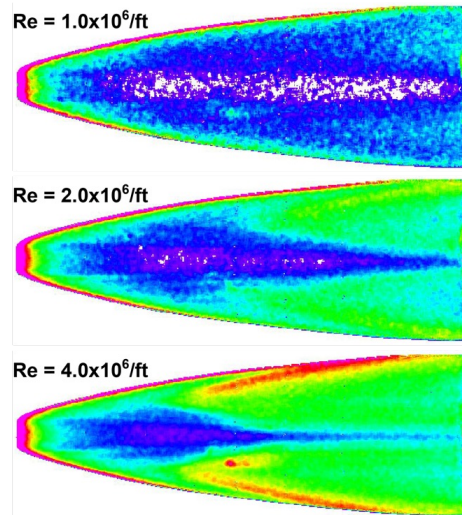


LAURA is a finite-volume, shock-capturing, structured-grid, computational fluid dynamics (CFD) tool

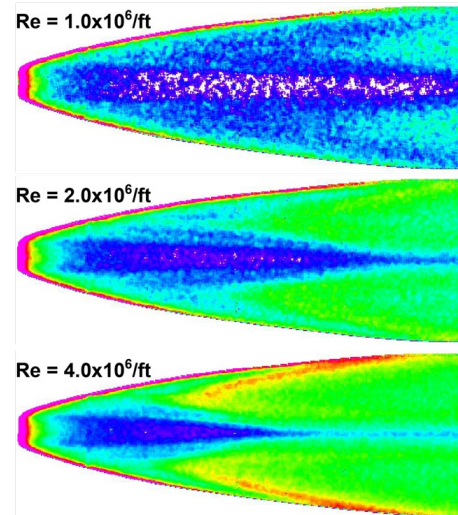
Initial Phosphor Study



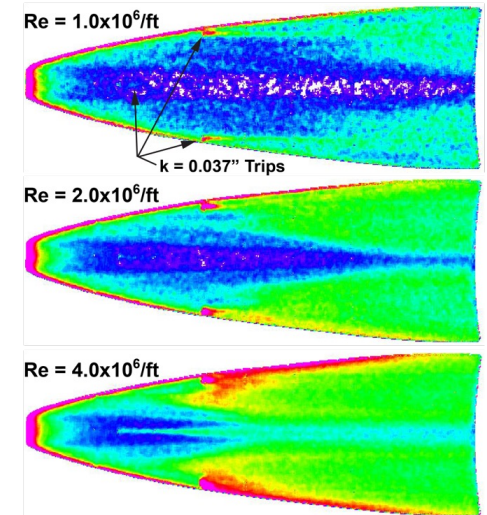
Smooth Model



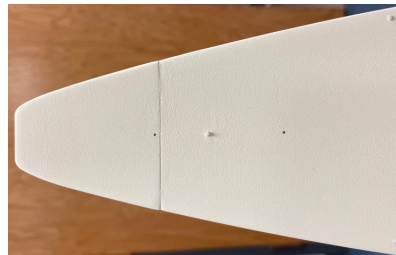
Step Model



0.037" trips



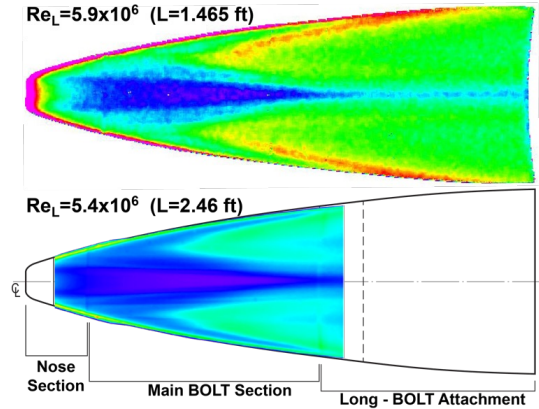
- Long-BOLT Model 30% Scale
- Two built (w/ & w/o nose-step)
- Trips using standard stick-on type



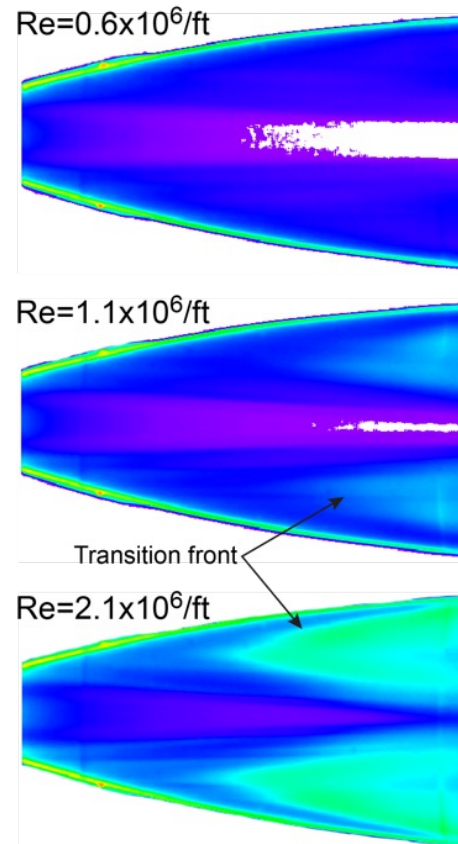
- Unable to determine incipient transition due to interference from natural transition lobes

New IR Study

Comparison of phosphor to IR

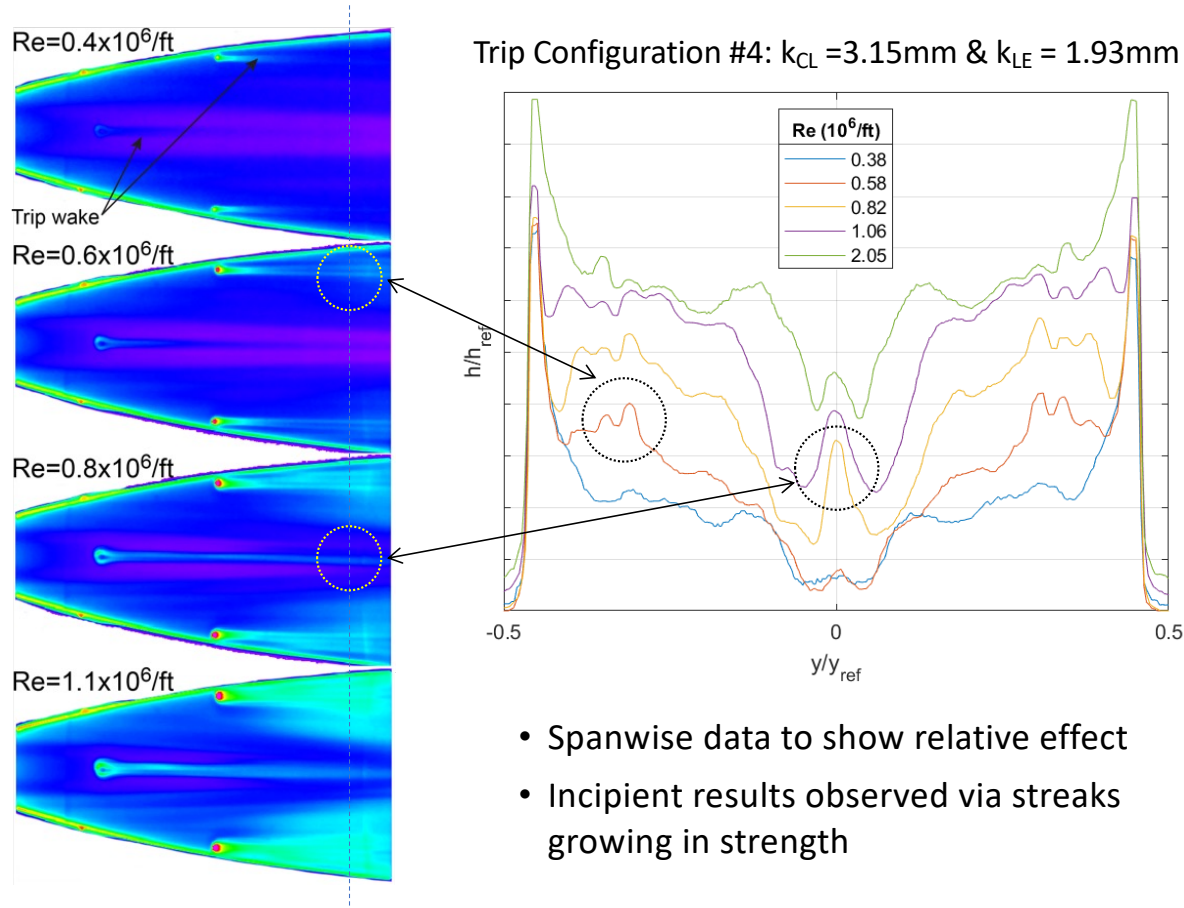


- Most of BOLT2 length in view
- Qualitatively similar results between both studies



- IR test technique still under development, thus only qualitative for now
- Some pre-run temperatures slightly higher than during run, resulting in negative heat transfer in low heating (center region)
- Use of larger scale (50%) model resulted in higher Re_L than previous study
- Step insert used for this study provided smallest RF step available ($\sim 0.0045''$)

Incipient Trips



From the computed BL properties:

- CL trip incipient between $Re=0.6$ & 0.8
 $\delta = 3.68\text{mm} \rightarrow k/\delta = 0.86$
 $Re_\theta/M_e = 59.1$
- LE trips incipient at $Re=0.6$
 $\delta = 1.37\text{mm} \rightarrow k/\delta = 1.43$
 $Re_\theta/M_e = 29.3$
- Shuttle correlation suggests that:
 $(Re_\theta/M_e) \times (k/\delta) = C$
 Based on N-S codes $C=41.6$
- Above BOLT results provides
 $C=46 \pm 12\%$

Concluding Remarks

- Wind tunnel study conducted to develop tripping database applicable for comparisons to BOLT II roughness flight experiment
- Roughness elements studied same as used for flight, the diamond configuration
 - Trip locations same but heights increased for testing at lower Reynolds numbers, to minimize interference from natural transition process
 - Preliminary (phosphor) data had shown that taller trips were required
- Primary test technique was IR thermography, which is still under development at LaRC, thus results shown are only qualitative
- Tallest trips were successful in providing incipient transition results, but further testing still required to strengthen database
- Supplemental testing in quiet facility might help to remove interference from the natural transition fronts observed during testing in conventional facility