



Preliminary Analysis of Boundary-Layer Instabilities over HIFiRE-1 Cone

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Progress report provided to Roger Kimmel, AFRL,
for HIFiRE-1 Program Review, Oct. 12, 2010



Outline

- Flow configurations
- Analysis codes
- Results for smooth cone surface ($t = 21.5$ s)
 - $AOA = 0$
 - $AOA = 1$ deg: windward and leeward planes of symmetry
- Effect of Steps
- Transitional Region
- Summary



Flow Conditions

Ascent, $t = 21.5$ sec, $h = 18.8$ km

- Transition moves off the cone
- $0 < \text{AOA} < 1$ deg
- $M=5.0$, $\text{Re}_L = 12.24$ million, $T=216.65$ K

(Based on earlier estimate by Kimmel and Adamczak, "HIFiRE-1 Overview and Preliminary Results," AFOSR/NASA Hypersonic Review, Destin, FL, 7/28/10)

- $\text{AOA} = 0$ deg
- $\text{AOA} = 1$ deg



Analysis Codes

A. Mean Flow Computation

- Viscous Upwind Algorithm for Complex Flow Analysis (VULCAN)
2nd order. <http://vulcan-cfd.larc.nasa.gov/index.html>
- Baseline grid along streamwise and wall-normal directions:
577 X 513

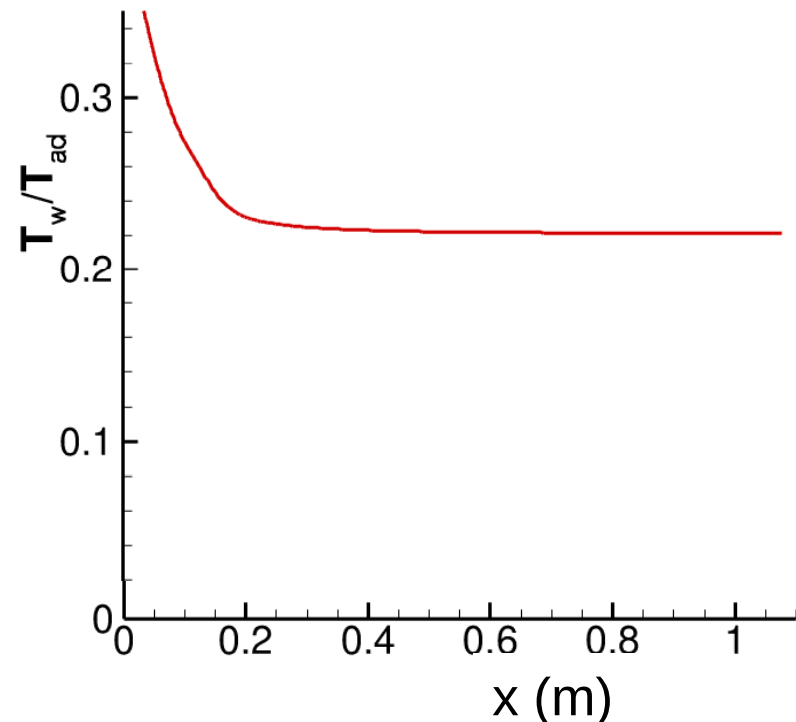
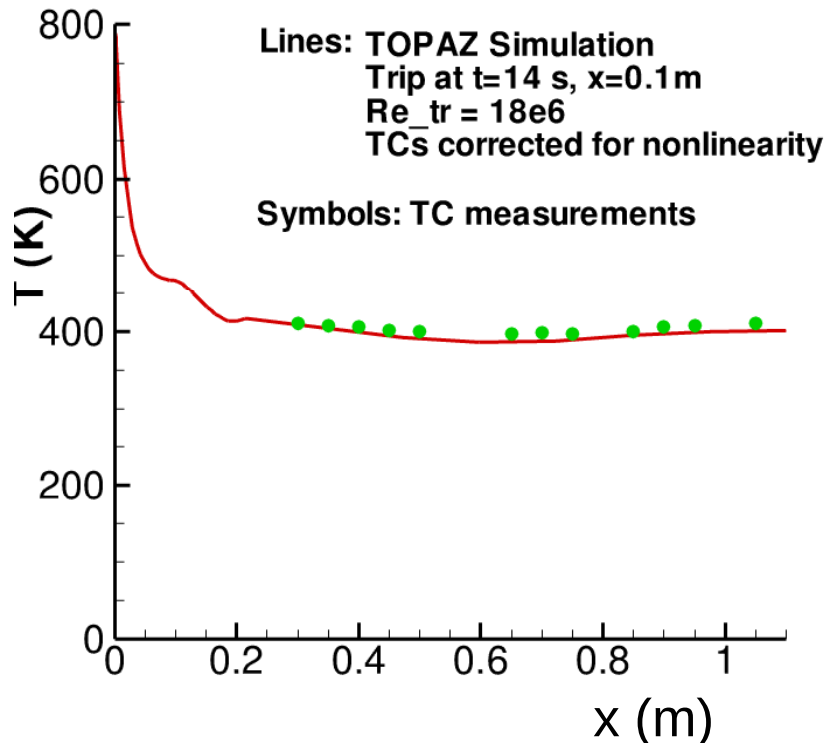
B. Instability Analysis

- Langley Stability and Transition Analysis Codes (LASTRAC)
(Chang 2004)



Temperature Distribution

Surface temperature based on FEM analysis + in-flight TC measurements

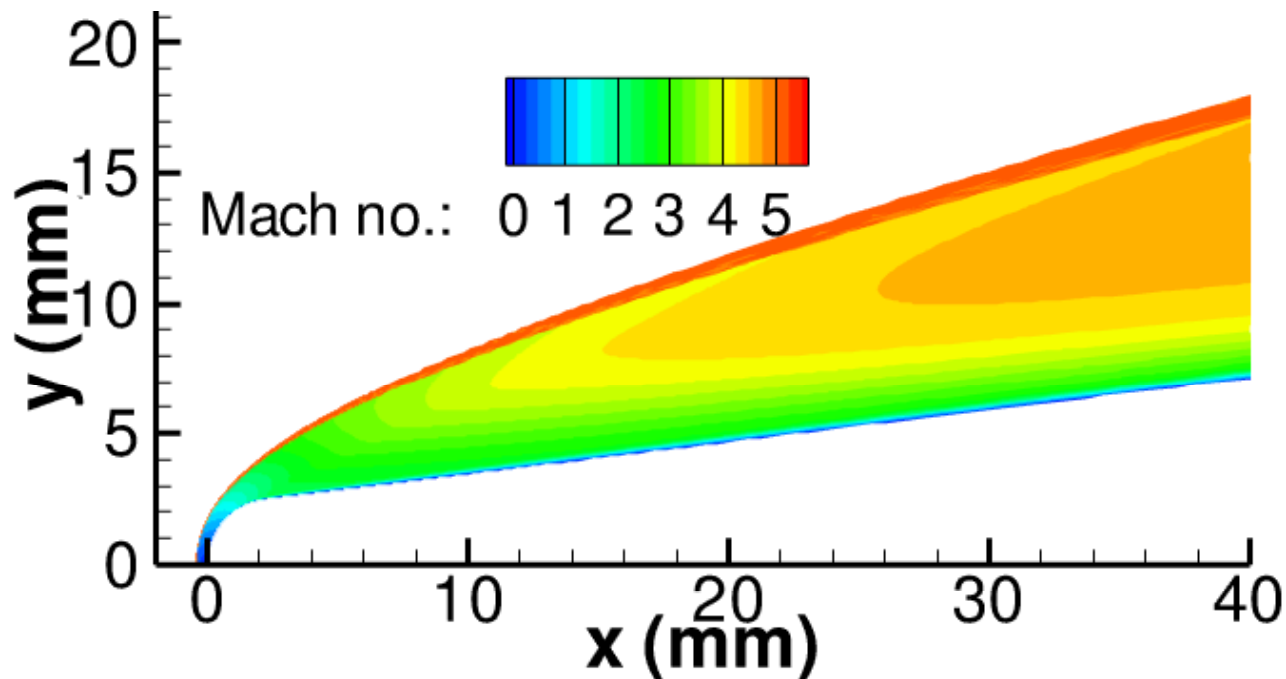


- No temperature measurements over upstream portion of cone surface
⇒ Combine FEM estimates in upstream region with downstream measurements
- $T_w/T_{ad} \approx 0.23$ for $x > 0.2$ m
⇒ First mode waves not a significant player in growth of primary instability



Mean Flow : 0 deg AOA

- $Me \approx 4.5$ over most of cone length
- $r_n = 2.5 \text{ mm} \Rightarrow Re_n \approx 27800$

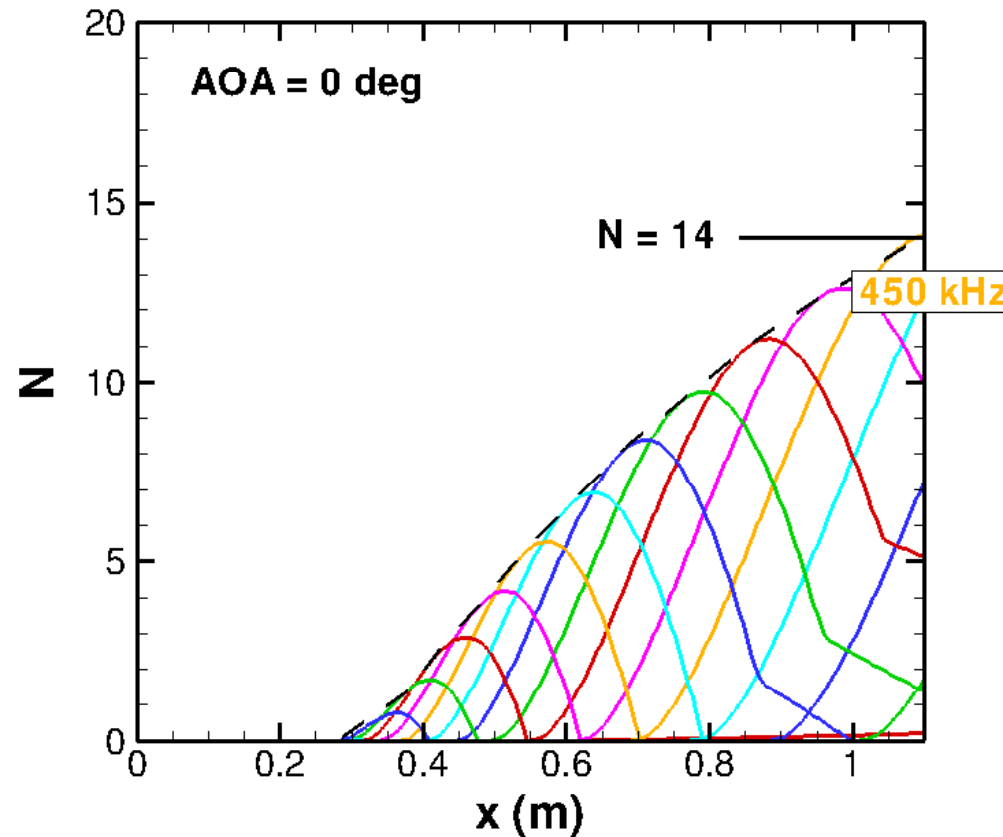


Cold wall $\Rightarrow$ 1st mode waves not a significant player in transition



Second Mode Amplification: 0 deg AOA

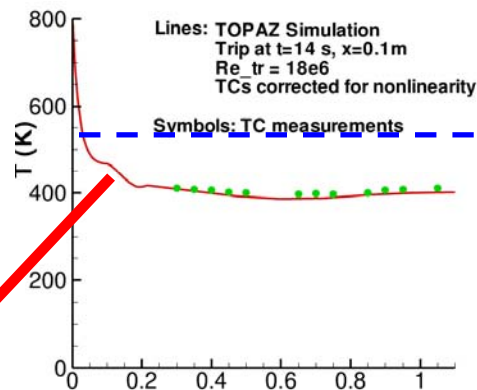
N-factor curves for selected frequencies
using PSE + measured surface temperature



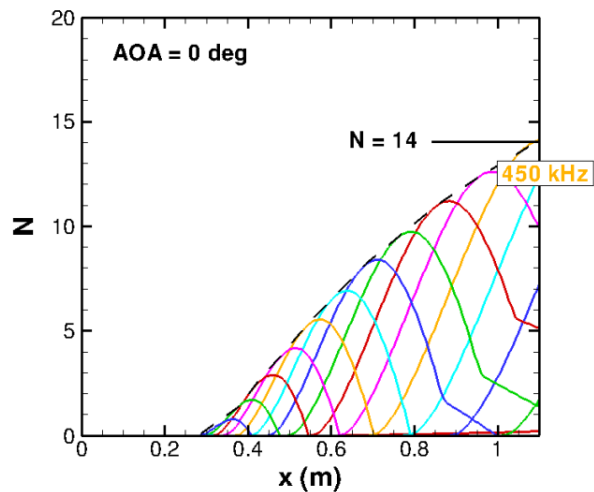
- Approximately linear increase in N over $x = 0.3 \rightarrow 1.1$ m
- Wavelength of most amplified 2nd mode disturbances = $O(3\text{mm})$



Second Mode Amplification: Effect of Surface Temperature

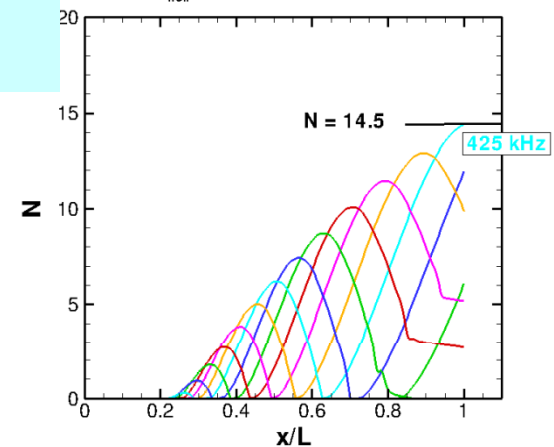


PSE, Measured T_{wall}



Effect of uncertainties in
measured surface
temperature expected to
be small
($\Delta N(x=L)/\Delta T_w < 0.005 \text{ K}^{-1}$)

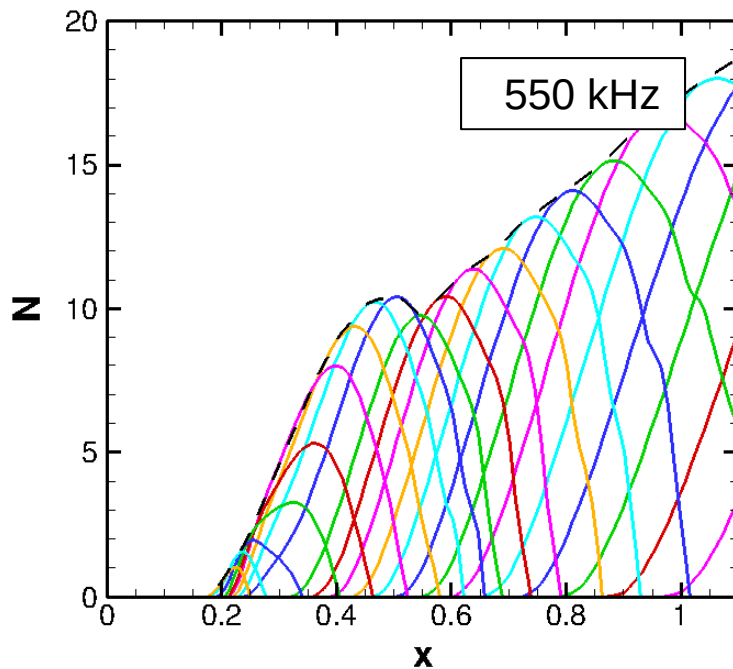
PSE, $T_{wall} = 550 \text{ K}$



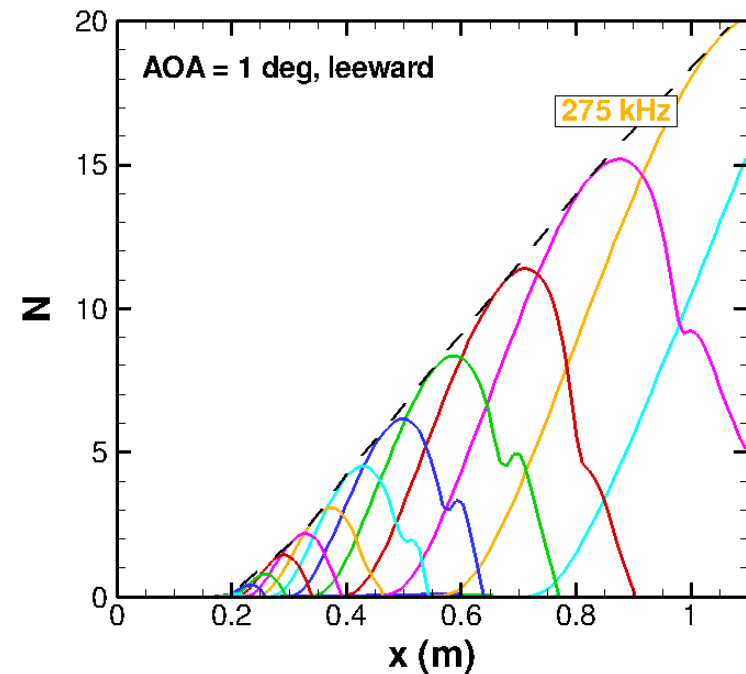


Second Mode Amplification: 1 deg AOA (Coarse grid 3D mean flow computation)

Windward



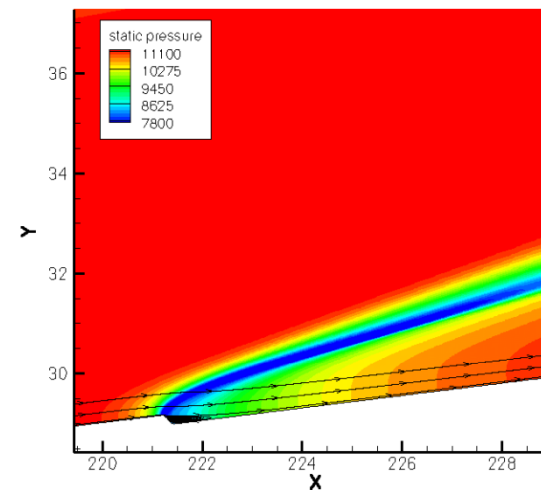
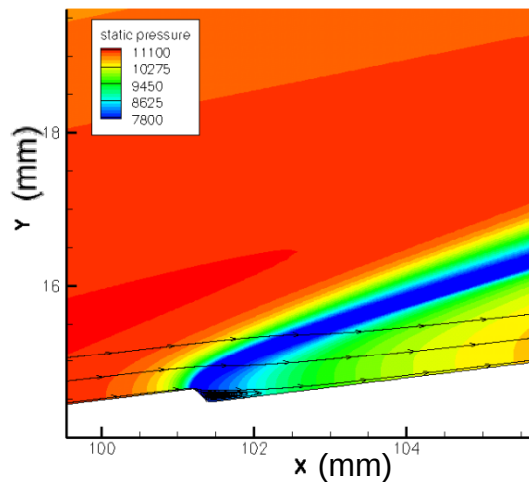
Leeward



- Max N-factors along both windward and leeward meridians are significantly larger than that at AOA=0 ($\Delta N \approx 5-6$)
 - Need to verify coarse grid predictions via mean flow computation over refined grid
- Factor of 2 range in frequency of most amplified second mode disturbance along windward and leeward rays



Effect of Steps at Material Discontinuities

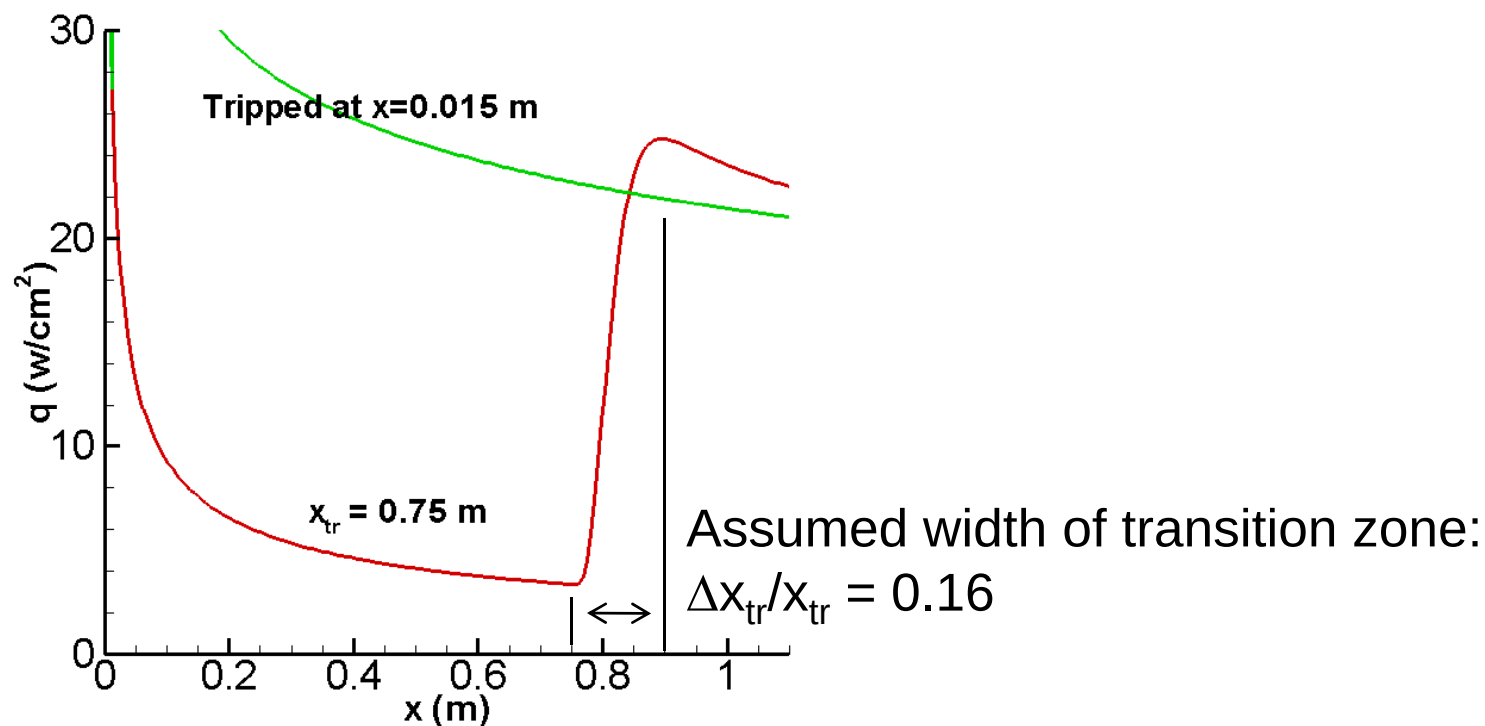


- Both steps are within subcritical region to 2nd mode growth
- $k < 0.2 \text{ mm} \Rightarrow k/\delta < 0.2, Re_k < 2225$
- Magnitude of reversed flow is small ($u/U < 0.03$)
 $\Rightarrow$ Assuming no absolute instability within the recirculation zone, expect **no major effect on transition due to steps**
- Preliminary analysis $\Rightarrow$ flow within recirculation zone supports instability modes near $f = 500\text{kHz}$



Transition Zone

- Length of transition region impacted by facility environment
 - Quiet tunnel measurements indicate shorter transition region than data from conventional facilities
- HIFiRE-1 data expected to provide useful information for modeling of transition zone





Summary

- Ascent, $t=21.5s$
 - 2nd mode N-factor over cone length = 14 → 19
- AOA uncertainty, albeit small, could have significant impact on correlating N factor
- Effects of uncertainty in T_{wall} distribution less significant than those of AOA uncertainty
- Effect of steps not likely to be important
- Follow-on analysis:
 - Additional trajectory locations (ascent, re-entry)
 - Overall correlation uncertainty
 - Nonlinear computations + numerical simulations