REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
February 2013

2. REPORT TYPE
Viewgraph

3. DATES COVERED *(From - To)*
February 2013- March 2013

4. TITLE AND SUBTITLE
Computational Analysis of High Enthalpy Effects on 2nd Mode Disturbances

5a. CONTRACT NUMBER
In-House

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
Q0AF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory (AFMC)
AFRL/RQRE
4 Draco Drive.
Edwards AFB CA 93524-7160

8. PERFORMING ORGANIZATION REPORT NO.

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory (AFMC)
AFRL/RQR
5 Pollux Drive
Edwards AFB CA 93524-7048

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-RQ-ED-VG-2013-033

12. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution A: Approved for Public Release; Distribution Unlimited. PA#13110

13. SUPPLEMENTARY NOTES
Viewgraph for the working group meeting on hypersonic transition, College Station, TX, 6-7 March 2013.

14. ABSTRACT
This effort is focused on using linear stability analysis (PSE) and Navier-Stokes solvers to study the effect of non-equilibrium effects, present in high-enthalpy flows, on 2nd mode disturbances and transition. The effort is concentrated on flows over slender cones with air, CO2, and mixtures of those two gases as the test gases.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Ivett Leyva
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	SAR	13	**19b. TELEPHONE NO** *(include area code)*
Unclassified	**Unclassified**	**Unclassified**			661-525-5817

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

Computational Analysis of High Enthalpy Effects on 2nd Mode Disturbances

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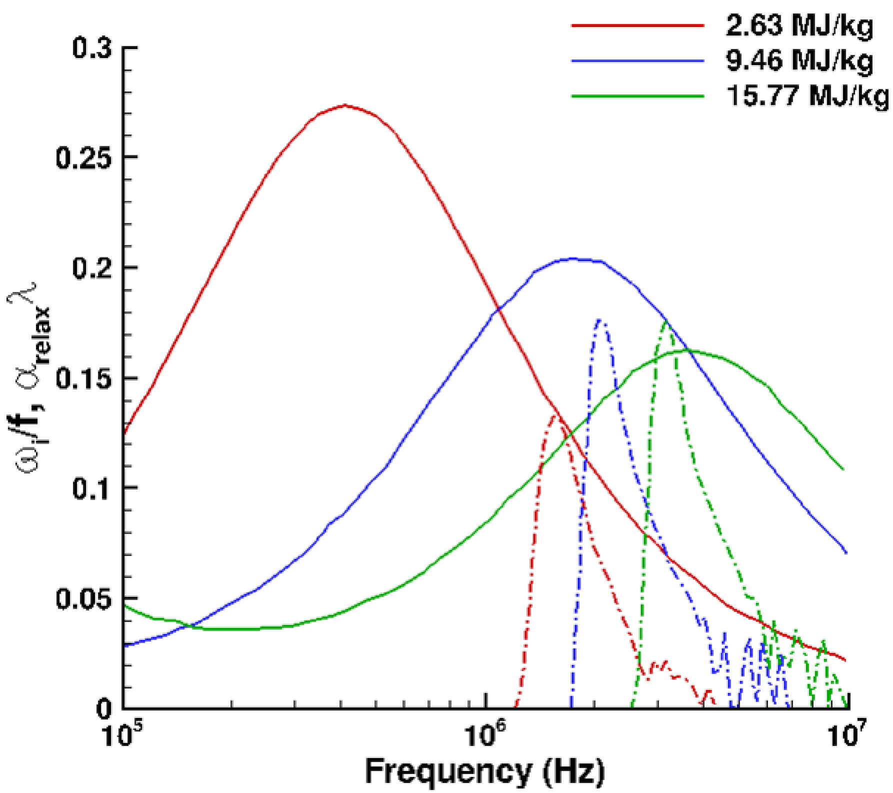
Introduction

- Transition on slender, constant-angle cones
- Fujii and Hornung
  - Investigated acoustic damping in equilibrium mixtures
- Jewell et al.
  - Porous injection of CO_2 into a hypervelocity boundary layer on a sharp cone



Amplification and absorption over a range of frequencies in CO_2

Previous work

- Modeling T5 shock tunnel experiments
  - 5° half-angle sharp cone
  - Smooth and injection inserts
  - Air, N_2, and, CO_2
  - $h_0 \sim 4 - 10.5\ MJ/kg$
  - $P_{res} \sim 30 - 85\ MPa$

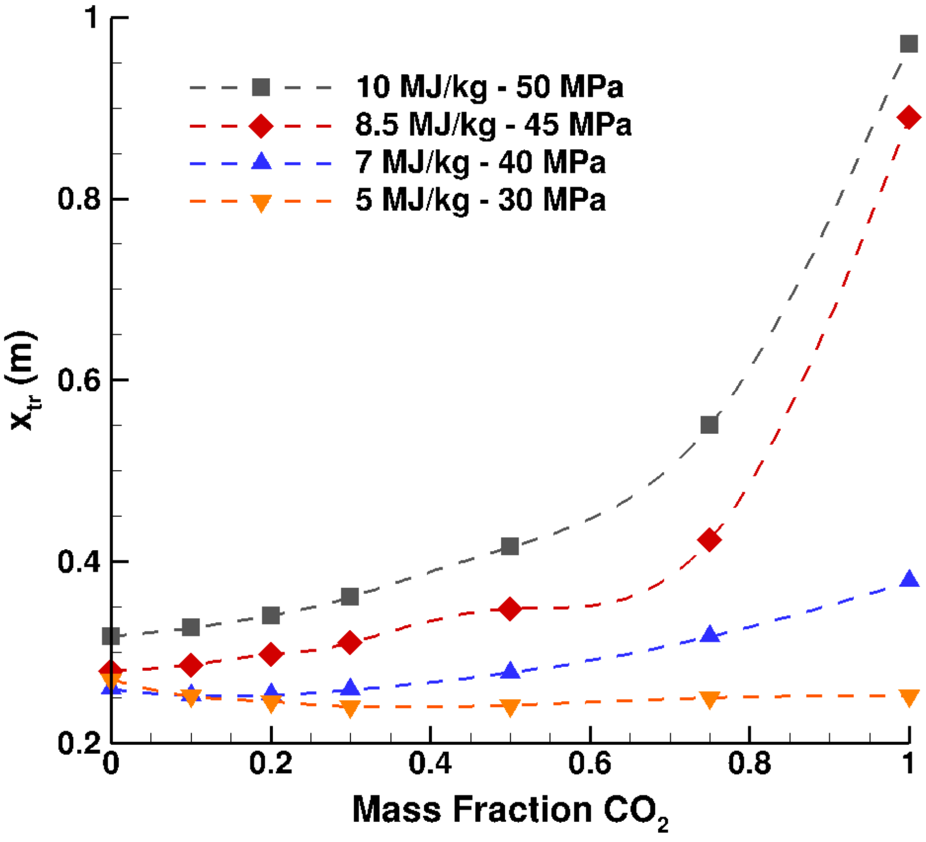
Test cone used in T5 tunnel experiments

Computational Tools

- Tunnel Flow
  - Nozzle Code + STABL CFD solver
    - 2D and axi-symmetric, reacting Navier-Stokes
    - Second-order accurate fluxes
    - High-pressure, excluded-volume equation of state
  - US3D
    - Solves 3D, reacting Navier-Stokes Equations
    - Inviscid fluxes are formulated for low dissipation
    - Viscous fluxes are second-order accurate
    - Implicit time advancement up to second-order accurate
    - High-pressure, excluded-volume equation of state
- Stability Analysis
  - PSE-Chem
    - Solves the axi-symmetric linear PSE
    - Includes finite-rate chemistry and T-V energy exchange

Current Efforts:

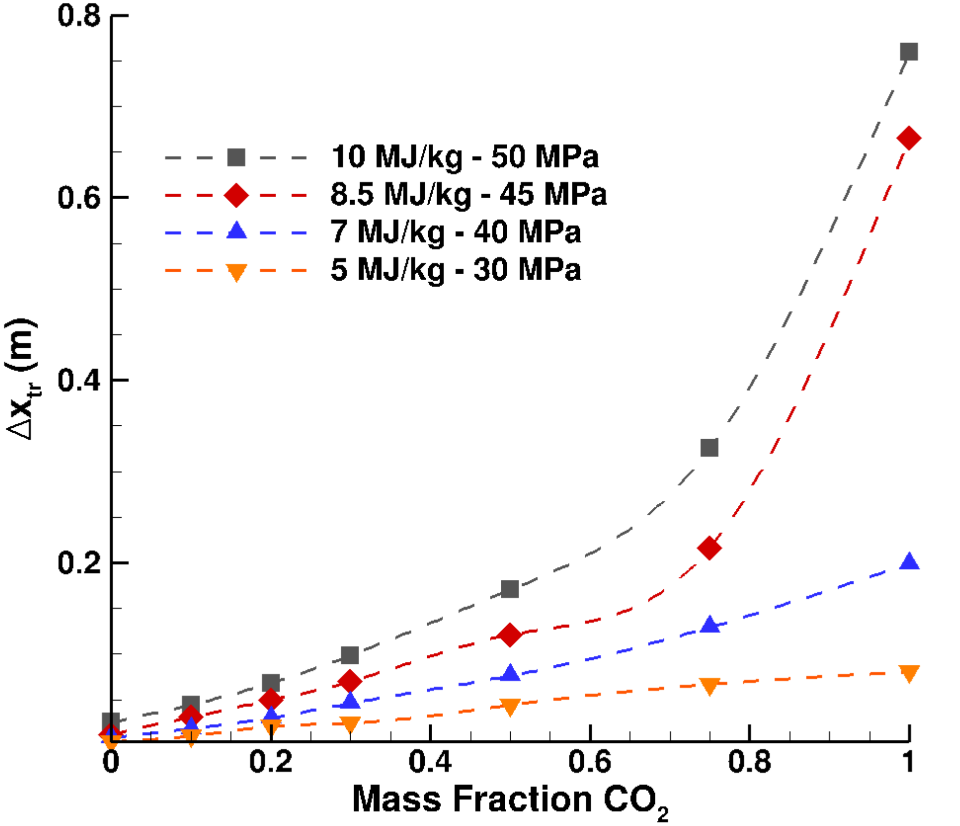
- Freestream Mixtures
  - Air + CO_2
- Prediction Goals
  - Large transition delay in T5
  - Ensure effective application of damping
    - "Freezing" vibration in PSE stability analysis



Predicted transition of T5 experiments using N = 5

Current Efforts:

- Freestream Mixtures
  - Air + CO_2
- Prediction Goals
  - Large transition delay in T5
  - Ensure effective application of damping
    - "Freezing" vibration in PSE stability analysis



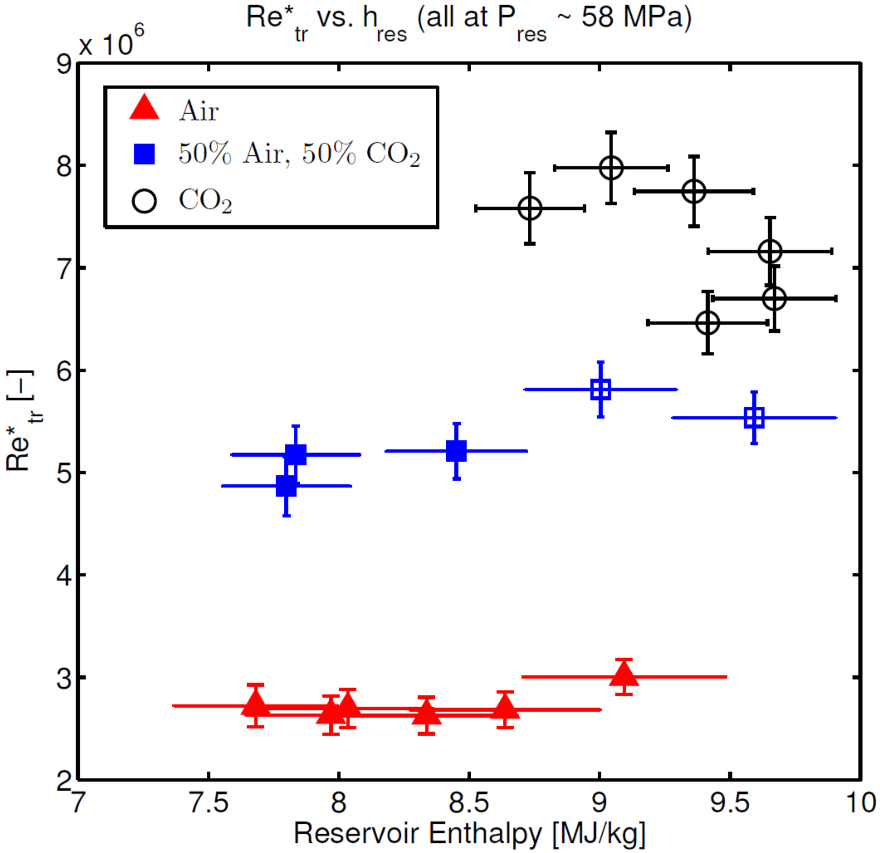
Change in transition location due to vibrational damping

Current Efforts

- Experiments
  - Measured clear distinction in Re^*_{tr}
  - Observed transition delay

$$\frac{T^*}{T_e} = \frac{1}{2} + \frac{\gamma - 1}{2}\frac{\sqrt{\mathrm{Pr}}}{6}M_e^2 + \frac{1}{2}\frac{T_w}{T_e}$$

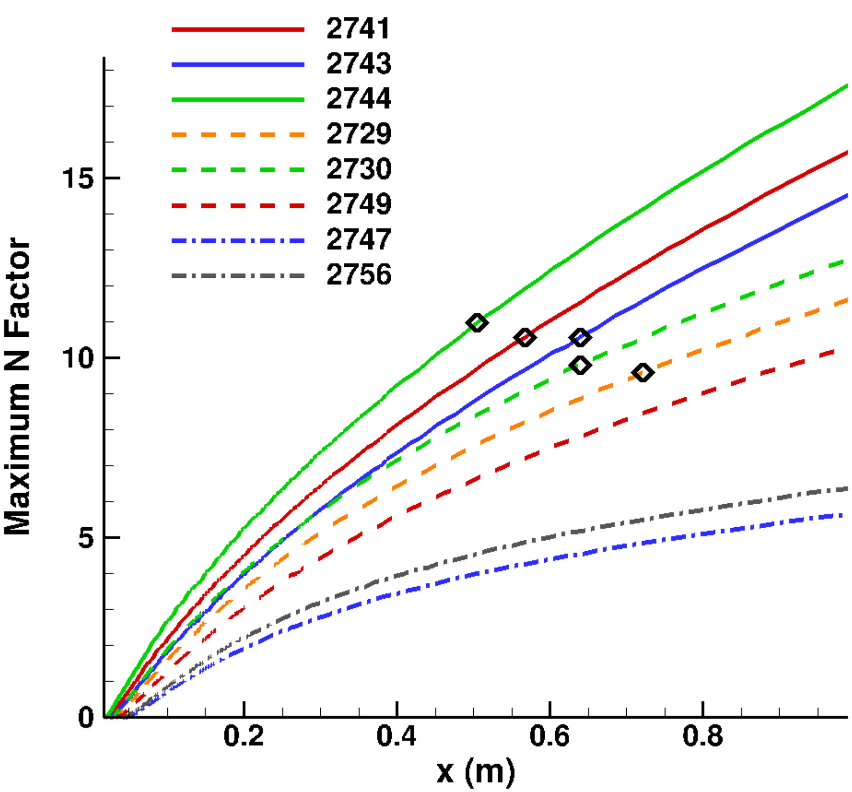
$$\mathrm{Re}^*_{tr} = \frac{\rho^* u_e x_{tr}}{\mu^*}$$



Transition Reynolds number from experiments

Current Efforts

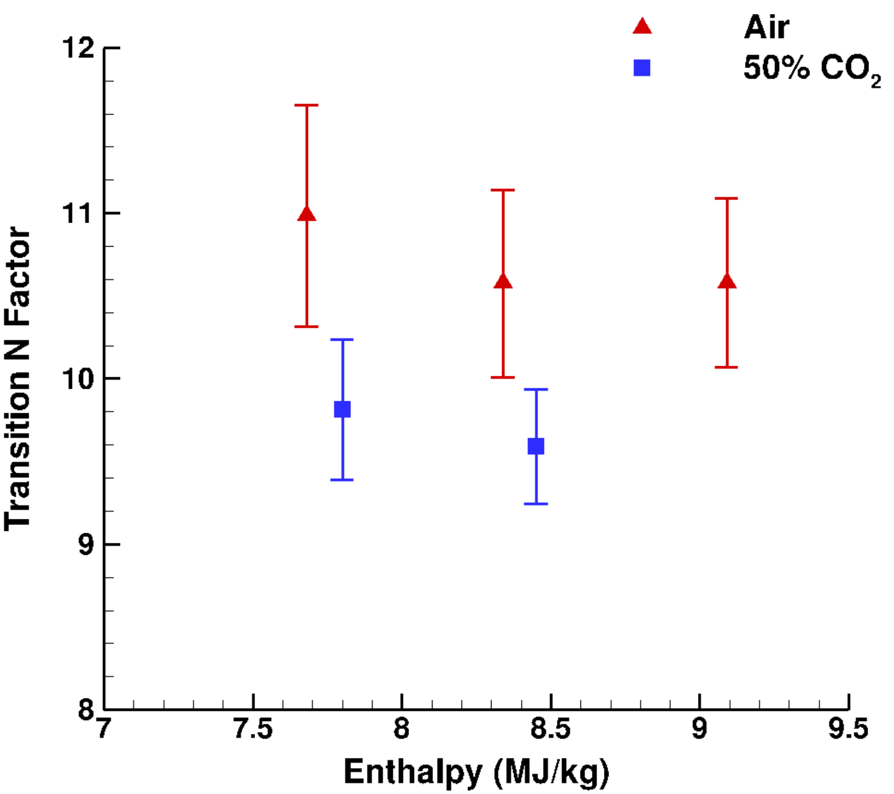
- Computational Analysis
  - Decrease in amplificatior with increase of CO_2
  - Consistent $N_{tr} \sim 10$
    - Range of freestream compositions
    - Range of Enthalpy



Computed max N factor for various T5 experiments

Current Efforts

- Computational Analysis
  - Decrease in amplification with increase of CO_2
  - Consistent N_{tr} ~ 10
    - Range of freestream compositions
    - Range of Enthalpy



Computed transition N factor* for various T5 experiments

*Error Bars indicate $\pm 4\ cm$.

Future Interests

- Apply this computational method to other high-enthalpy facilities
  - Do we see the same trends?
    - Gain confidence in modeling tools
    - Opportunity to improve modeling deficiencies
- Open to other high-enthalpy transition research

Questions/Comments?

- Referenced Papers:

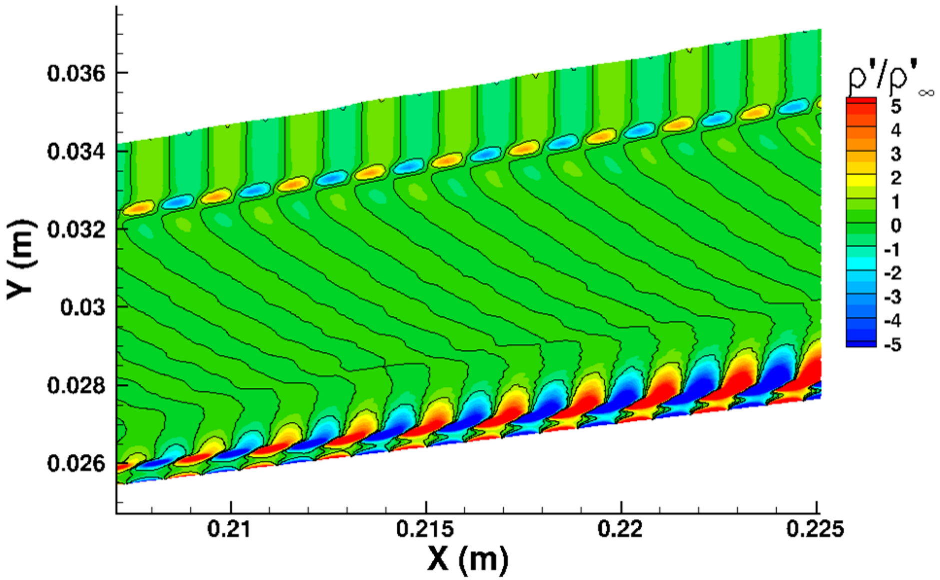
  – Fujii, K. and Hornung, H.G. “Experimental Investigation of High-Enthalpy Effects on Attachment-Line Boundary-Layer Transition”. AIAA Journal. Vol. 41, No. 7, July 2003.
  – J. Jewell, I. A. Leyva, N. Parziale, and J. E. Shepherd. “Effect of gas injection on transition in hypervelocity boundary layers.” In Proceedings of the 28th International Symposium on Shock Waves, University of Manchester, July 17-22, 2011, 2011.
  – Jewell, J. S., Wagnild, R. M., Leyva, I. A., Candler, G. V., and Shepherd, J. E., “Transition Within a Hypervelocity Boundary Layer on a 5-Degree Half-Angle Cone in Air/CO_2 Mixtures”, AIAA Paper 2013-0523, January 2013

- Acknowledgements

- Mr. Nick Parziale, Mr. Bahram Valiferdowsi Prof. Hans Hornung
- Experimental portion -> Air Force Office of Scientific Research under award number FA9550-10-1-0491 and the NASA/AFOSR National Center for Hypersonic Research.
- Computational work -> Air Force Office of Scientific Research grant FA9550-10-1-0352.
- Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.

Vibrational Relaxation Effects on Acoustic Disturbances

- Geometry
  - 7° half-angle sharp cone
  - Nose radius $12.5\ \mu m$
  - Length $0.5\ m$
- Conditions
  - $h_0 = 4.6\ MJ/kg$
  - $Re = 2.6 * 10^7\ 1/m$
  - $Mach = 12.58$



Contours of density disturbance for the $1.4\ MHz$, slow wave case