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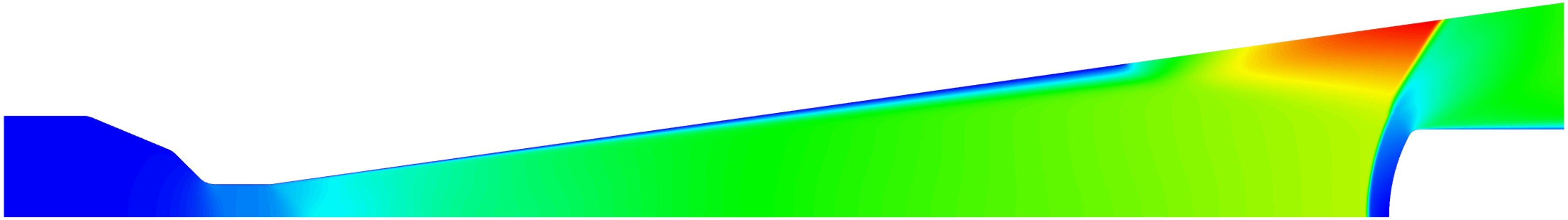

Development of ablation modeling capabilities at Sandia National Laboratories

7th Ablation Workshop, 6-7 October 2016, Tucson, AZ

Derek Dinzl, Justin Smith, David Kuntz,
Micah Howard, Ross Wagnild

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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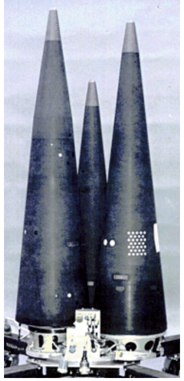
Outline

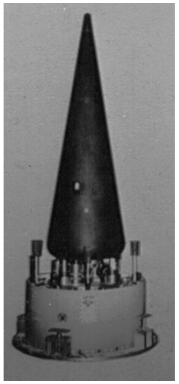
- History of RV Development at Sandia
- Modeling Tools at Sandia
  - Aerothermal Codes
  - Material Thermal Respose Codes
  - Integrated Codes
- Development of SPARC
  - Development Goals
  - Preliminary Results
- Summary

MaST recovery vehicle

Development of RVs at Sandia

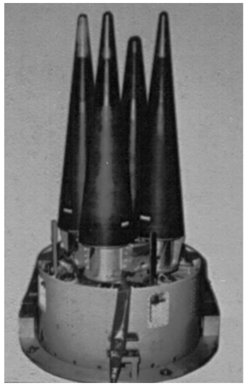
- Sandia has strong historical roots in hypersonic reentry problems
- Flown more than 100 instrumented RVs since 1968
- Continued support and interest in the advancement of understanding of entry phenomena


MaST

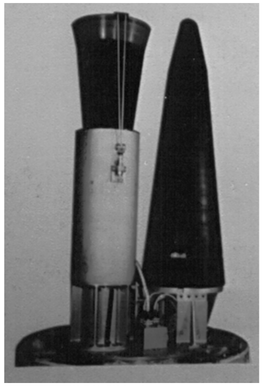

LBRV I


NASA SHARP-B01


GRANITE

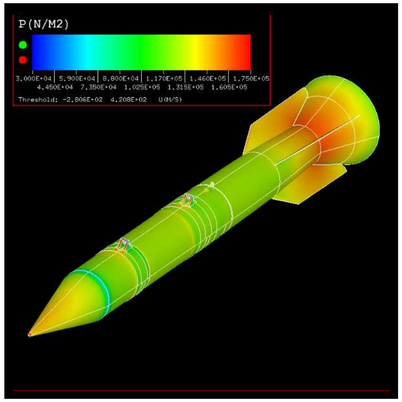

A.N.T. I


SAMAST/MINT

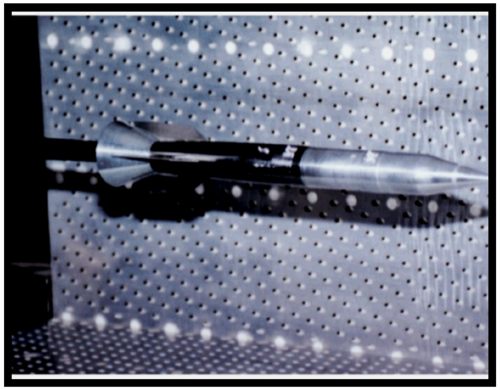

PAS II

A Balanced Approach

Flight Testing



Modeling & Simulation



Ground Testing

Flight Vehicle Analysis

Planetary entry is a complex process encompassing many problems:

- Trajectory
  - Vehicle dynamics
  - Force and moment integration
  - Ballistic/lifting entries
- Aerothermal environment
  - Compressible flow, real gas effects
  - Laminar/turbulent boundary layers
- Material response
  - Decomposing/non-decomposing ablators
  - 3D material properties
- Consequences to substructure/payload
  - Vehicle conduction
  - Thermal contact
  - Enclosure radiation

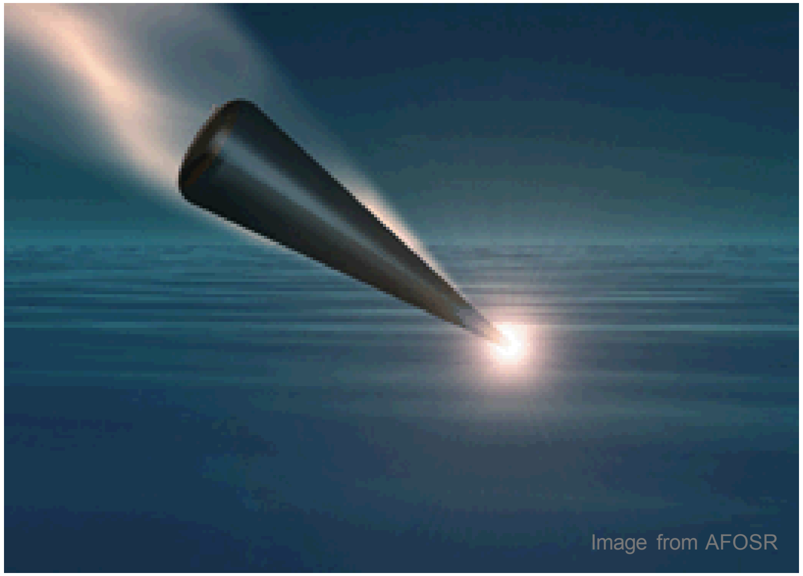
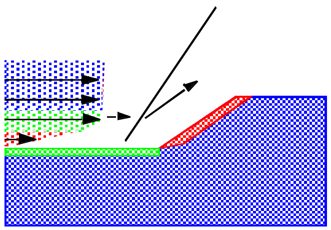


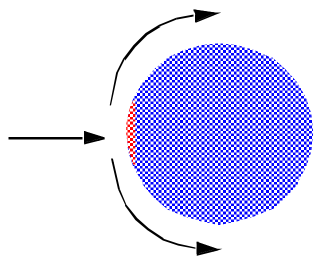
Image from AFOSR

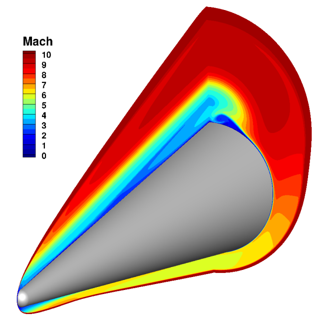
Modeling to Meet the Need

- In addition to the breadth of these problems, there is a spectrum of needs:
  - Complexity of geometry
  - Desired level of accuracy
  - Need for quantities integrated over flight duration
  - Need for parametric sweeps of conditions
  - Balance of computational cost with resources and time

Aerothermal Codes







model fidelity →
computational cost →

HANDI
correlation based methods

- Analytical/empirical relationships for engineering design

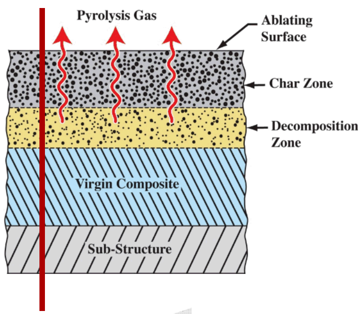
2IT-SANDIAC-HIBLARG
integral boundary layer equations

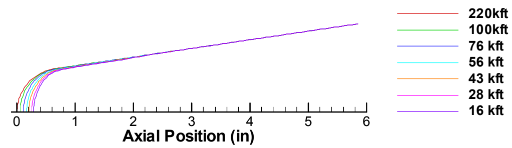
- Inviscid transonic flow over nosetip
- Euler equations for supersonic flow on aftbody

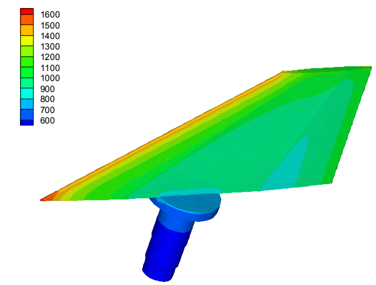
DPLR(NASA) US3D(U of MN)
Navier-Stokes solvers

- Compressible, real gas effects

Material Thermal Response Codes







model fidelity →
computational cost →

Chaleur
CMA(Aerotherm)
1-D models
- In-depth decomposition

ASCC
SMITE
specialized for nosetips

Coyote-ab
Coyote-Q
multidimensional models
- ab: subliming/melting, non-decomposing
- Q: decomposing

Integrated Codes

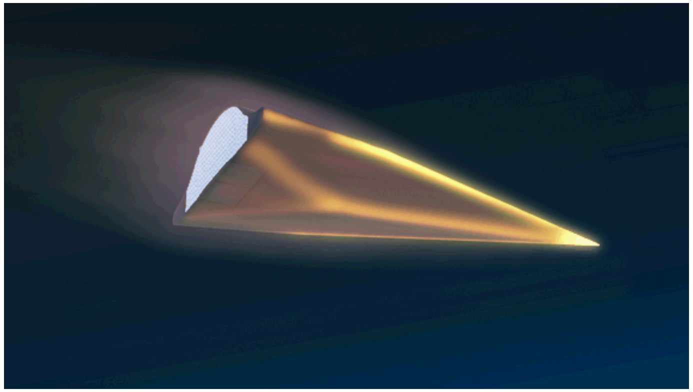
TAOS used to compute trajectories

- Solves Newton’s 2^{nd} Law, 3/6 DOF trajectories

- SABRE
  - TAOS, 2IT-SANDIAC-HIBLARG, CMA
  - Automates reentry analyses
- LAPS
  - TAOS, HANDI, CMA
  - Used for large parametric sweeps of entry conditions
- PIRATE
  - 17 codes
  - Computes RF attenuation on RVs
- ParChaleur
  - US3D aeroheating -> Chaleur

The Future of Ablation Modeling

- These approaches have been very successful for research and design
- However, they uncouple a tightly coupled process
- Next generation vehicles (e.g. boost-glide) will need next generation TPS
- With the increase in computational power and need for greater accuracy, need something better



Artist's rendering of HTV-2

Enter SPARC

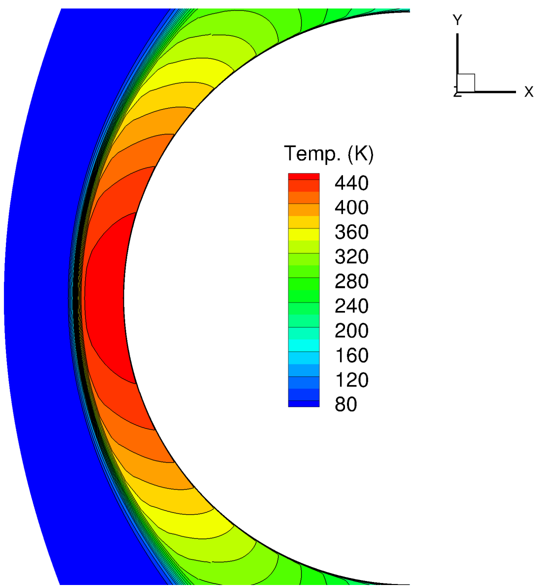
- Aero-ablation code under development at Sandia
  - Solve the coupled problem from surface to centerline
- Designed for use on next generation heterogeneous architectures
- Scalability, performance portability
- Modular, object oriented design
- Fully couples a compressible, reacting Navier-Stokes solver with a three-dimensional material thermal response solver
  - Thermochemical nonequilibrium
  - Decomposing and non-decomposing ablators
  - Allows surface recession, mesh motion

SPARC Continued

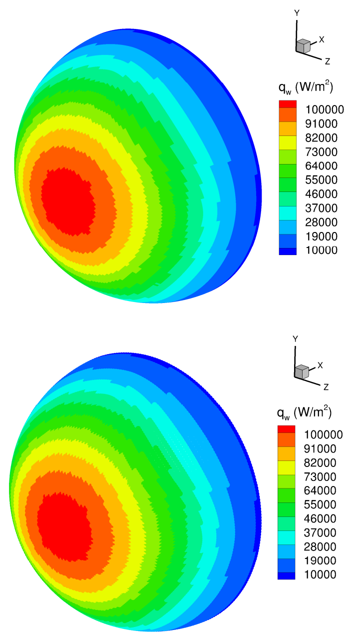
- Both structured and unstructured finite volume implementations for fluid solver, plans for hybrid meshes
- Being coupled to Sierra Aria for solving substructure conduction
- Plans to couple to trajectory code TAOS
- Plans for capabilities to model melting/subliming ablators

Code-to-Code Comparison

SPARC vs. US3D
Mach 5 flow over sphere
Coarse grid

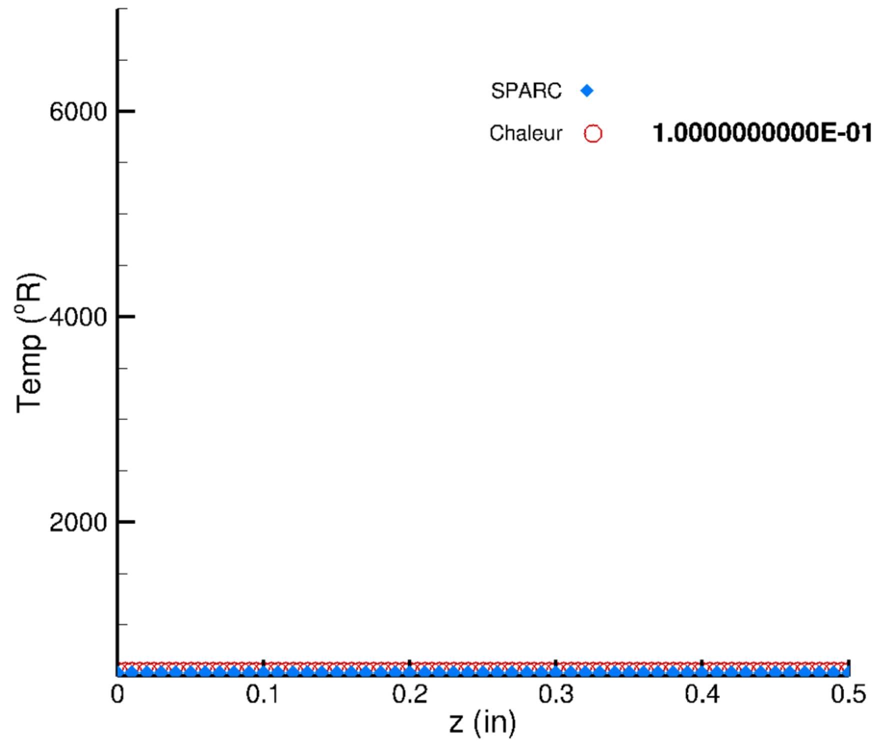


Slice of flowfield
Lines: US3D
Contours: SPARC



Surface heat flux
Top: US3D
Bottom: SPARC

SPARC vs. Chaleur
1-D carbon-carbon ablation



Performance

For a generic RV problem with roughly 4 M cells:

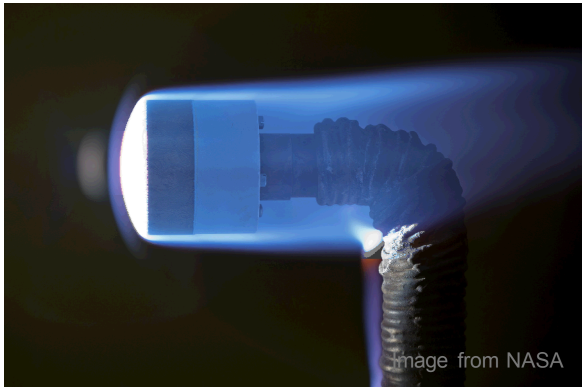
- 1000 iterations on 32 cores
- Codes were run as similarly as possible

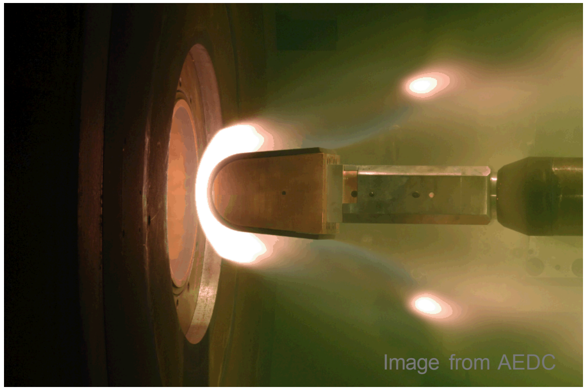
Code	Assembly (min)	Solve (min)	Total (min)	Relative to SPARC
SPARC Structured	6.72	10.60	17.73	1.0x
US3D	N/A	N/A	27.11	1.53x
SPARC Unstructured	15.77	10.50	32.57	1.84x
DPLR	N/A	N/A	38.20	2.15x
Sierra Aero	21.25	16.37	41.17	2.33x

- Plans for further optimization

Simulation of AHF

- Demonstrate SPARC for a common problem
  - Simulate Iso-Q geometry in NASA Ames AHF 20 MW Arcjet
  - Use conditions prescribed by Prabhu et al.[1]
  - Modeling assumptions:
    - 6-species (N2, O2, NO, N, O, Ar) gas model
    - Park T-T_v model for thermal non-equilibrium
    - Fully catalytic wall BC (293 K)

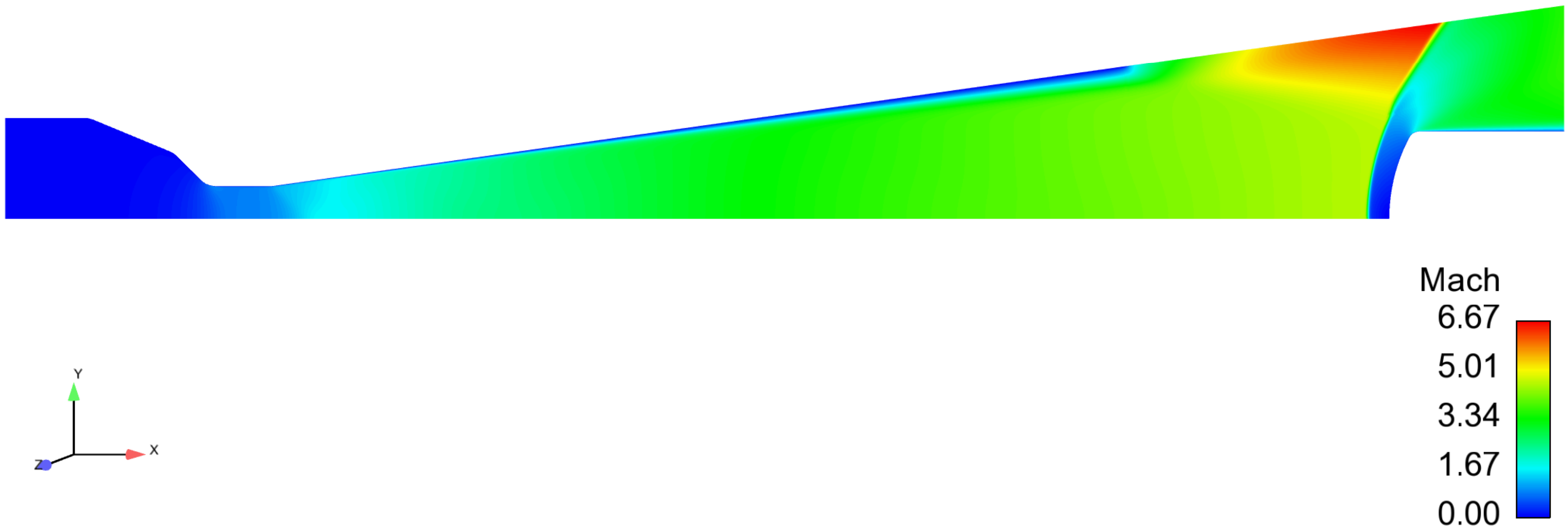




1. Prabhu, D., et al., "CFD Analysis Framework for Arc-Heated Flowfields, I: Stagnation Testing in Arc-Jets at NASA ARC", *Proceedings of the 41st AIAA Thermophysics Conference*, 22-25 June 2009, San Antonio, TX

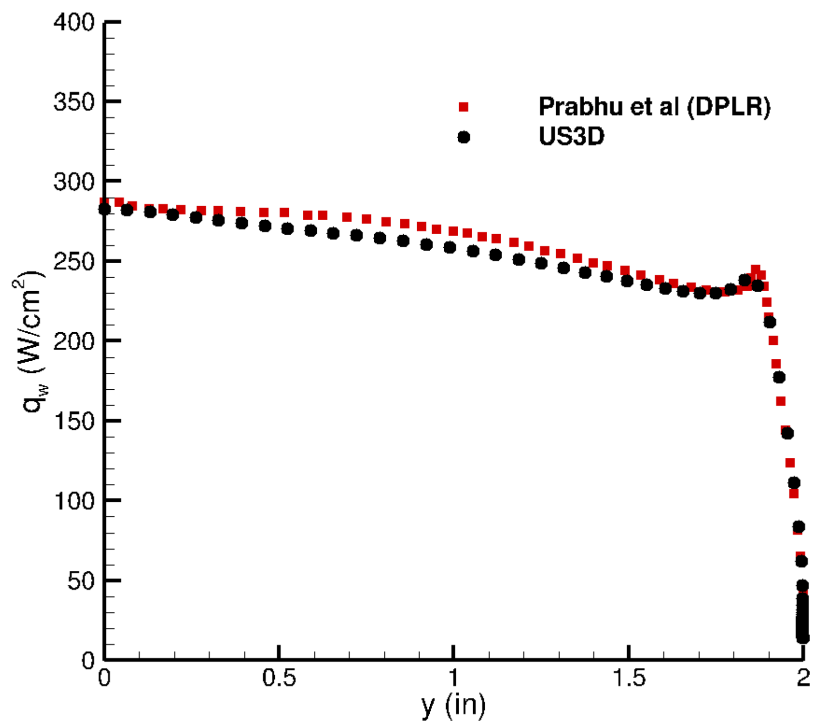
Flow Domain

- Simple, 70K cell axisymmetric grid
- Subsonic inflow is expanded through straight nozzle
- h_0 is 11.38 MJ/kg



Comparison of heat flux

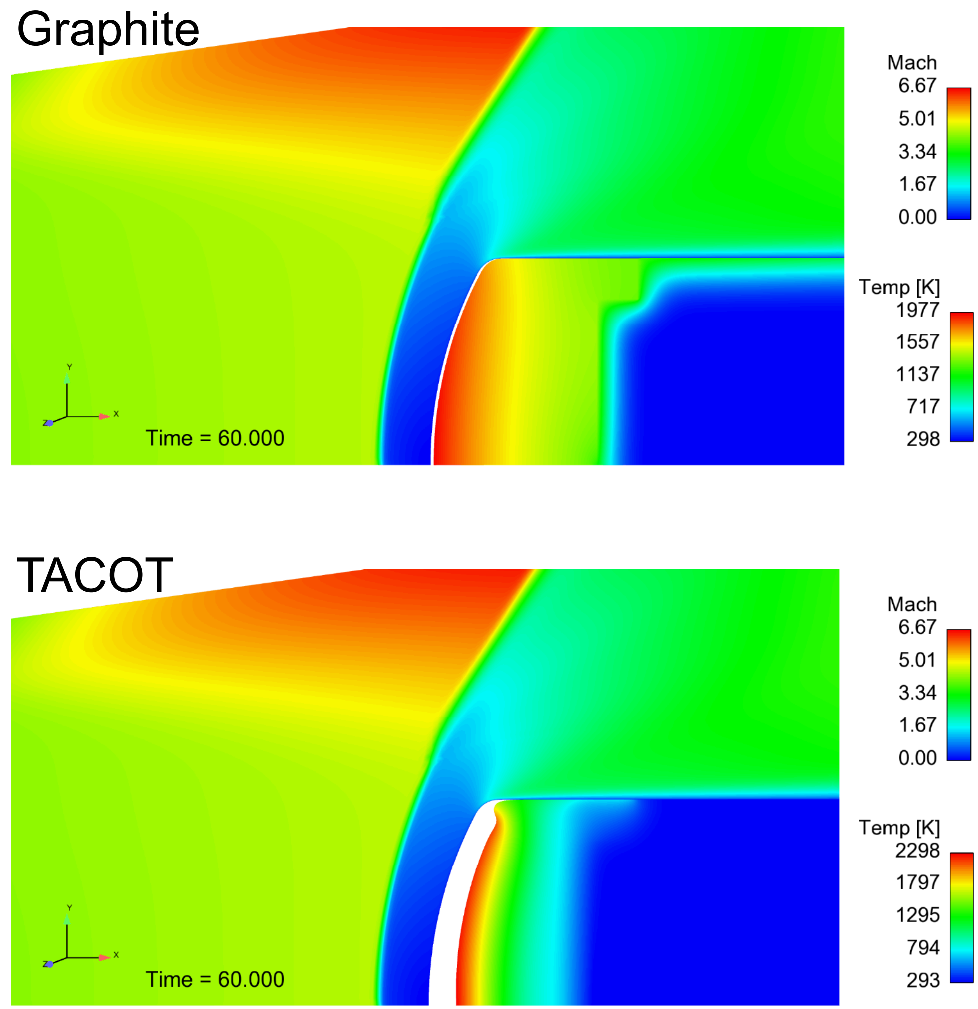
- Previous work using US3D did not use a catalytic wall
- US3D and DPLR show good agreement when including catalytic BC
- (placeholder for line about agreement of SPARC)



Surface heat flux vs distance from stagnation point

Previous Work

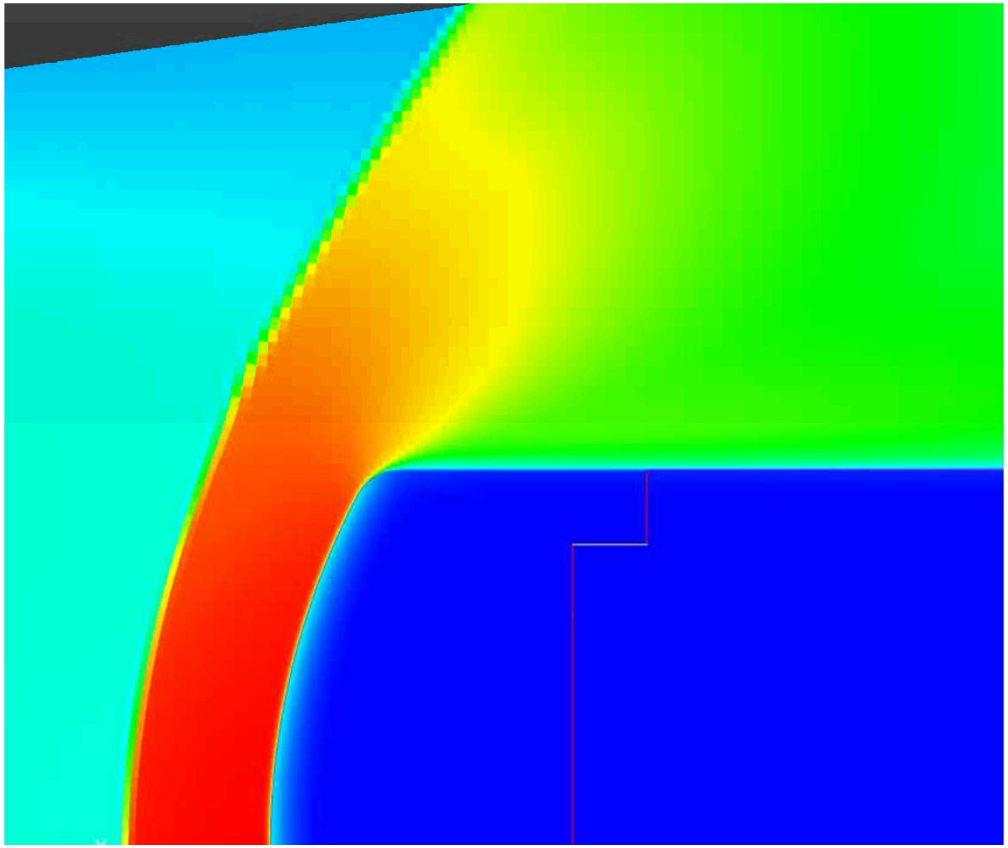
- Simulation of AHF Iso-Q by Howard and Blackwell[1]
- Surface heat flux passed from US3D to inform SPARC material response
- Recession of TACOT demonstrates need for passing shape change back to flow solver



1. Howard, M., Blackwell, B.,"A Multi-Dimensional Finite Element Based Solver for Decomposing and Non-Decomposing Thermal Protection Systems", *45th AIAA Thermophysics Conference*, 2015

A Coupled Problem

- Preliminary demonstration of coupled aerothermal/ ablation with shape change of the Iso-Q
- TACOT (no blowing)
- Results in reasonable shape change which one way transfer could not predict



Summary

- Sandia has a complete array of tools for modeling reentry environments:
  - Trajectory
  - Aerothermal environment
  - Material thermal response
  - Substructure conduction
- A new aero-ablation code, SPARC, is being developed to tightly couple these phenomena, to tackle the future's most challenging ablation problems

Thank you!