AeroTechnologies, Inc.
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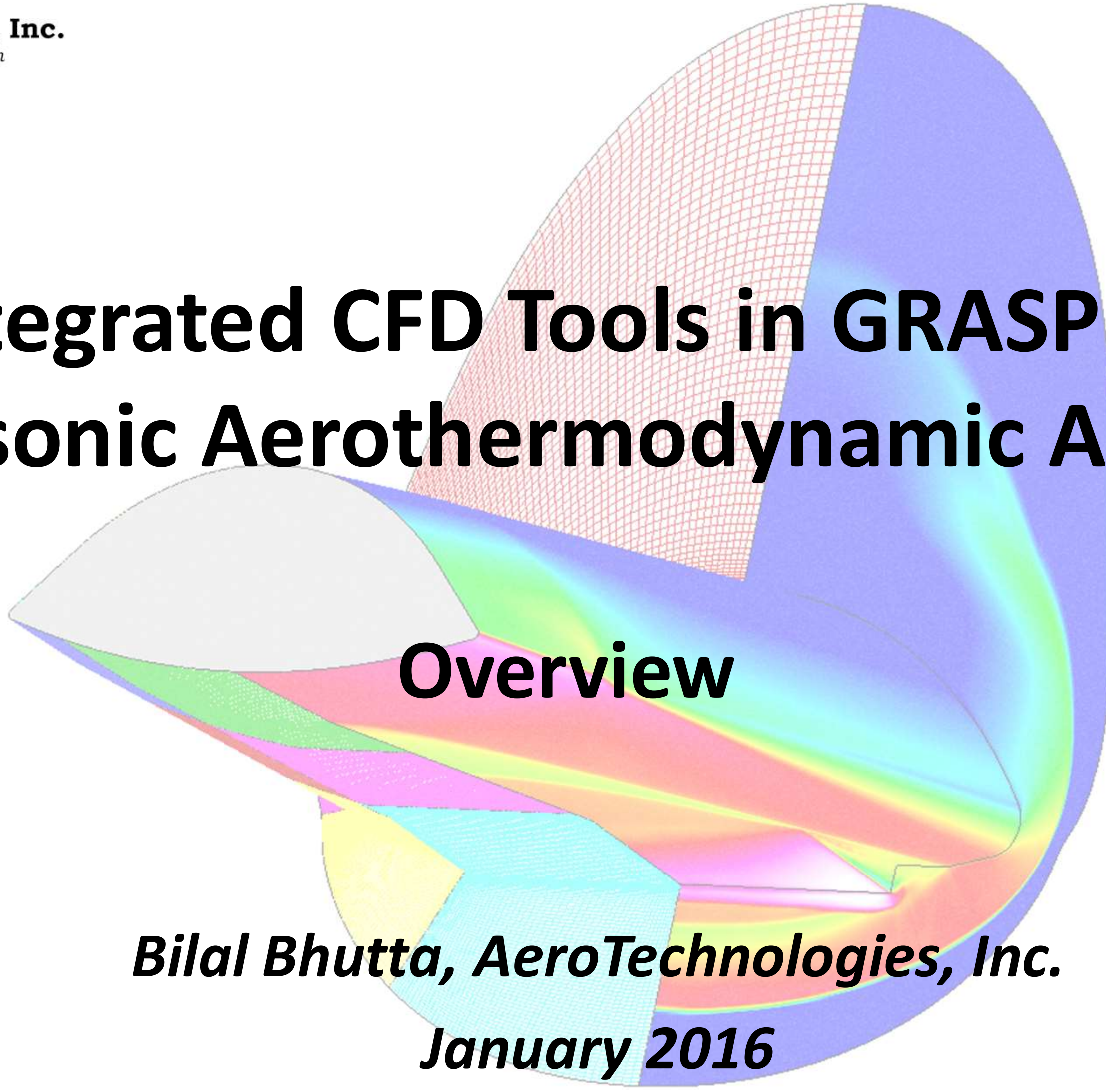

Integrated CFD Tools in GRASP for Hypersonic Aerothermodynamic Analyses

Overview

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Note: We strictly interface with only recognized US entities within the USA

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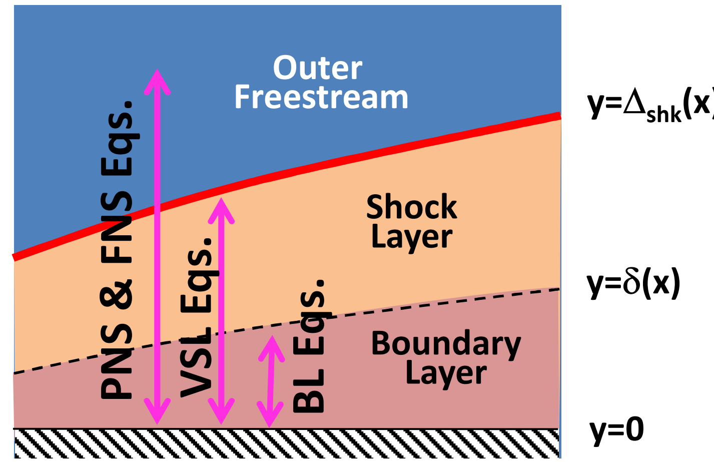
AeroTechnologies Inc Overview

- AeroTechnologies Inc was founded in 1992
  - Small minority owned business
  - Based out of Yorktown, VA.
  - AeroTechnologies, Inc., is a highly focused company, specializing in providing engineering support services for Computational Aero-Thermochemical problems in high-speed flows
  - **We strictly interface with only recognized US entities within the USA**

Hierarchy of Flowfield Formulations



- Governing Equations

$$\frac{\partial \overrightarrow{F_x}}{\partial x} + \frac{\partial \overrightarrow{F_y}}{\partial y} = \left(\frac{M_\infty}{Re_\infty}\right)\left(\frac{\partial \overrightarrow{S_x}}{\partial x} + \frac{\partial \overrightarrow{S_y}}{\partial y}\right)$$

Convective Fluxes   Viscous Fluxes

Increasing Order of Accuracy

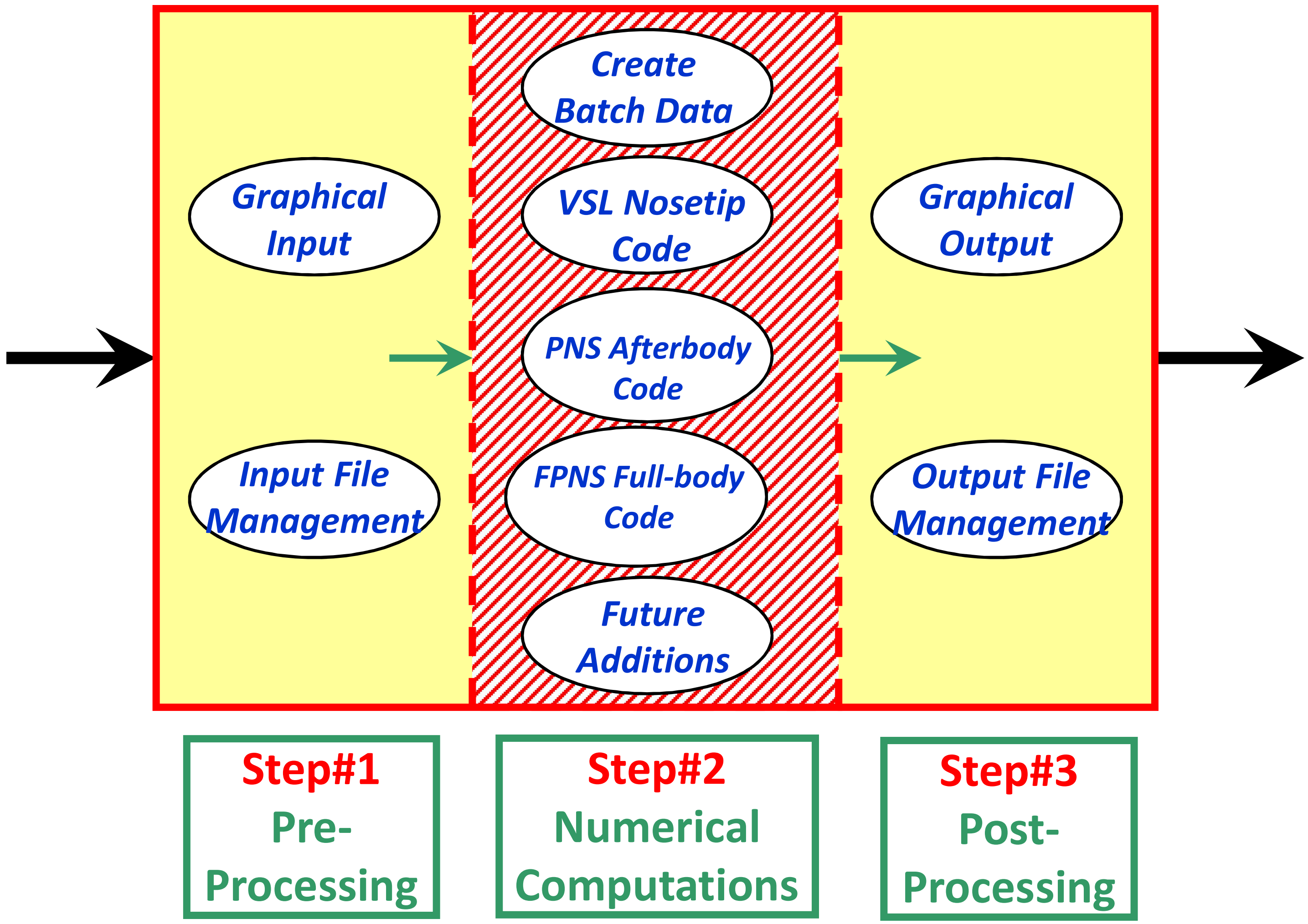
- **Inviscid** Formulation: $\frac{\partial \overrightarrow{S_x}}{\partial x} = \frac{\partial \overrightarrow{S_y}}{\partial y} = 0$
- **Boundary-Layer** (BL) Formulation: $\frac{\partial \overrightarrow{S_x}}{\partial x} = 0,\ \frac{\partial \overrightarrow{S_y}}{\partial y} \neq 0$ for $0 \le y \le \delta$
- **Viscous Shock-Layer** (VSL) Formulation : $\frac{\partial \overrightarrow{S_x}}{\partial x} = 0, \frac{\partial \overrightarrow{S_y}}{\partial y} \neq 0$ for $0 \le y \le \Delta_{shk}$ except for the body-normal momentum equation which is inviscid
- **Parabolized Navier-Stokes** (PNS) Formulation : $\frac{\partial \overrightarrow{S_x}}{\partial x} = 0, \frac{\partial \overrightarrow{S_y}}{\partial y} \neq 0$ for all y>0
- **Full Navier-Stokes** (FNS) Formulation : $\frac{\partial \overrightarrow{S_x}}{\partial x} + \frac{\partial \overrightarrow{S_y}}{\partial y} \neq 0$ for all y>0

GRASP Overview

- <u>**G**</u>eneral <u>**R**</u>eentry <u>**A**</u>erothermodynamic <u>**S**</u>imulation <u>**P**</u>ackage (GRASP) is a CFD packaged designed and administered by AeroTechnologies Inc
  - Competitively priced compared to other CFD tools available on the market
  - Designed to run without the need for High Performance Computing (HPC) resources
  - Specially Optimized for high speed (Hypersonic) environments
  - Extensively Validated against CFD codes, Wind Tunnel Testing, and Flight Data

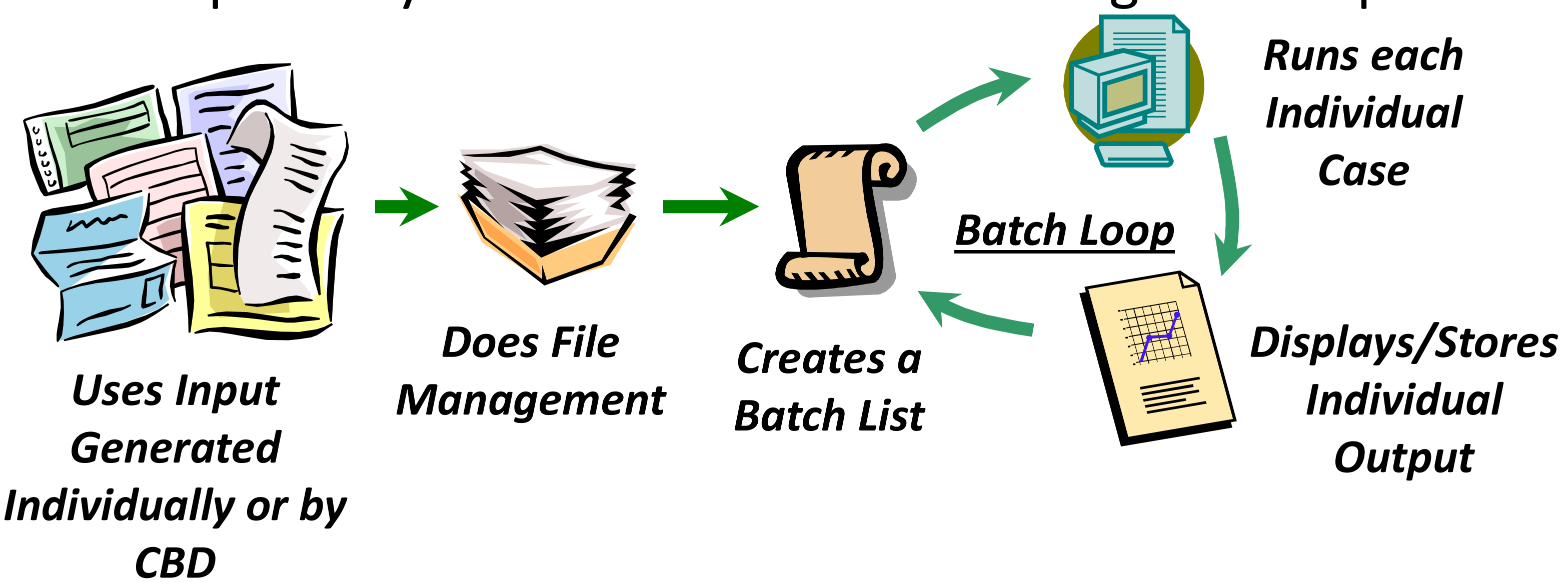
GRASP Overview

- General Reentry Aerothermodynamic Simulation Package (GRASP) consists of a three-step solution approach



GRASP Overview (Concluded)

- Simulates a batch-execution environment (Batch Loop) using
  - Aerothermal codes designed for single-case executions
  - A Batch-List File containing a list of cases to run
  - Input files for each case created individually or
  - A number of individual input files and a corresponding Batch-List File created using the Create-Batch-Data (CBD) Code
  - Transparently does all needed file-management operations



CFD Tool Highlights

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Baseline Integrated CFD Tools

- The Baseline GRASP (Ver. 1.5x2) includes

- **<u>VSL Nose Code</u>**
  - ➢ Axisymmetric Viscous Shock-Layer (VSL) solver for spherically-blunt nosetips
  - ➢ Embedded inviscid solver for bow-shock-shape prediction
  - ➢ 3-D flowfield rotation for angle-of-attack effects
  - ➢ Fast and efficient prediction of spherically-blunt nosetip flowfields

- **<u>PNS Afterbody Code</u>**
  - ➢ 3-D Parabolized Navier-Stokes (PNS) solver for conical and 3-D RV shapes
  - ➢ Fully-Implicit formulation with bow-shock fitting
  - ➢ Fast and efficient prediction of 3-D afterbody flowfields
  - ➢ Perfect-Gas and Equilibrium-Air gas models
  - ➢ Laminar and turbulent flows

Baseline Integrated CFD Tools (Cont'd)

- **<u>FPNS Full-body Code</u>**
  - ➢ 3-D Full Navier-Stokes (FNS) solver for the nosetip region
  - ➢ 3-D Parabolized Navier-Stokes (PNS) solver for afterbody region
  - ➢ Fully-Implicit formulation with bow-shock capturing
  - ➢ Fast and efficient prediction of 3-D afterbody flowfields
  - ➢ Perfect-Gas, Equilibrium-Air, and Nonequilibrium-Air, Nonequilibrium Carbon/Carbon-Phenolic in Air (C/CP-Air) gas models
  - ➢ Laminar and turbulent Flows

- **<u>CBD (Create-Batch-Data) Code</u>**
  - ➢ Uses a simple, master input
  - ➢ Creates individual VSL/PNS input files and associated Batch List File for a user-specified set of
    - ✓ Various combinations of freestream conditions along a trajectory
    - ✓ 1962, 1976, and Day-of-Flight atmospheric conditions

Advanced CFD Tools

- Baseline GRASP 1.5x2 can be easily upgraded to include the following advanced hypersonic flowfield simulation tools
-
- **<u>Nonequilibrium FPNS Code for Plasma Predictions</u>**
  - ➢ Axisymmetric/3-D Nonequilibrium FPNS Code includes a Full Navier-Stokes (FNS) solver for the nosetip region
  - ➢ Axisymmetric/3-D Nonequilibrium FPNS Code includes a Parabolized Navier-Stokes (PNS) solver for the afterbody region
  - ➢ For simulations of Carbon and Carbon-Phenolic (CP) heatshields with alkaline impurities
  - ➢ Fast and efficient prediction of 3-D afterbody flowfields
  - ➢ Perfect-Gas, Equilibrium-Air, and Nonequilibrium-Air, Nonequilibrium C/CP-Air gas models
  - ➢ Laminar and turbulent flow simulations with specialized algebraic and K-ω turbulence models

Advanced CFD Tools (Cont'd)

- **<u>Multi-Block FNS code for Complex 3D Nose-to-Far-Wake Flowfield Simulations</u>**
  - Axisymmetric/3-D Nonequilibrium Full Navier-Stokes (FNS) solver for forebody and wake regions
  - Decomposes a large flowfield problem into multiple smaller flowfield blocks
  - Block solutions done simultaneously (in parallel) on multiple cores of a modern Many-Core PC Workstation (such as a 16 core dual CPU PC)
  - Perfect-Gas, Equilibrium-Air, and Nonequilibrium-Air, Nonequilibrium C/CP-Air gas models
  - Laminar and turbulent flow simulations with specialized algebraic and K-ω turbulence models

Computational Requirements

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Computational Time Requirements

- GRASP is designed to run on as little as a single core with 4 gb of RAM
  - Typical RV solution time is <1 hr
- Multicore processor computers allow for running multiple instances of GRASP on the same machine
  - Batching techniques allow for processing of large databases

Validation Examples

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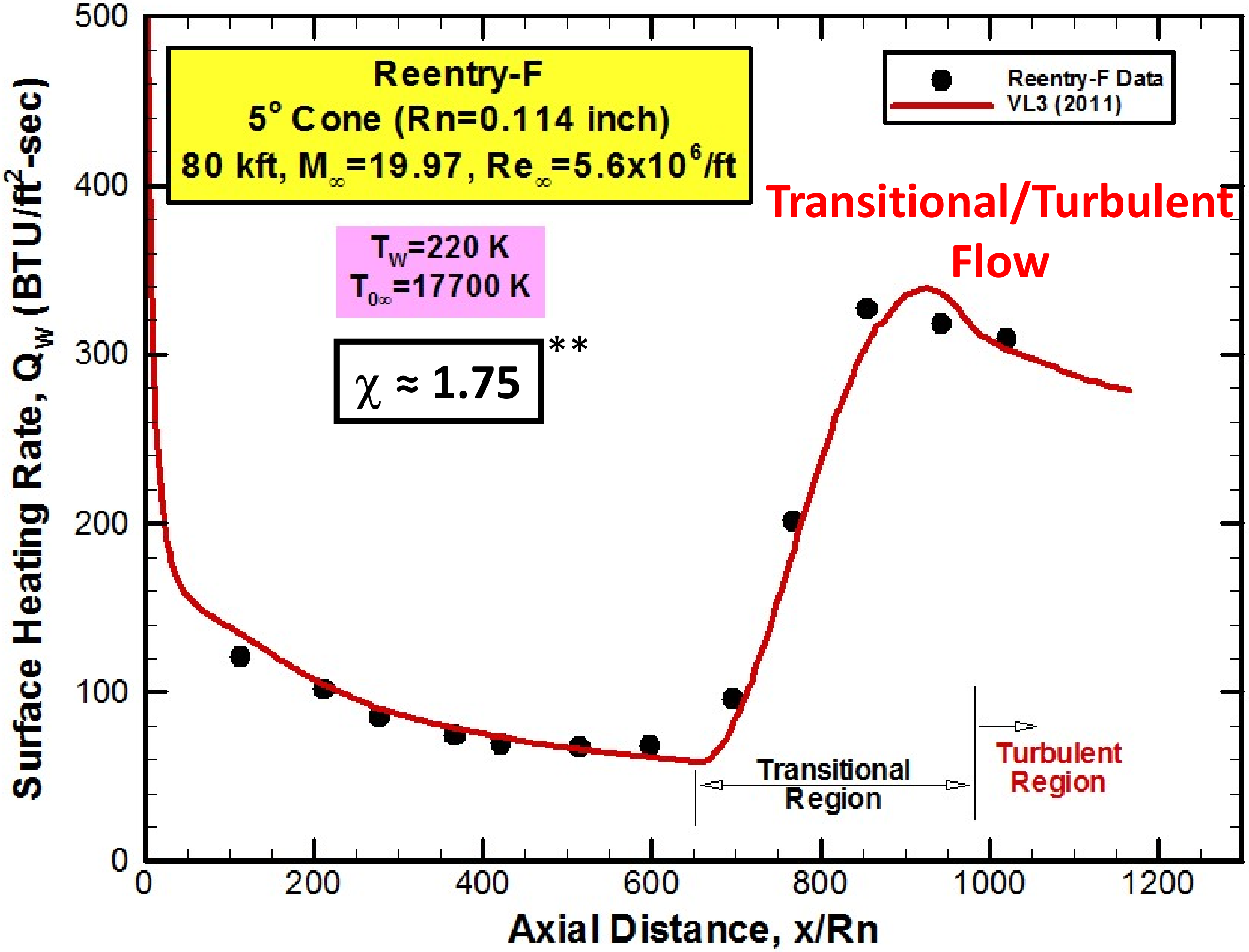
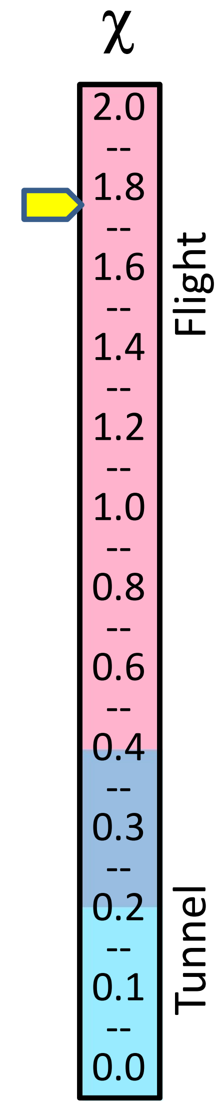
80-KFT REENTRY-F

Very-High Total-Temperature Flight Conditions

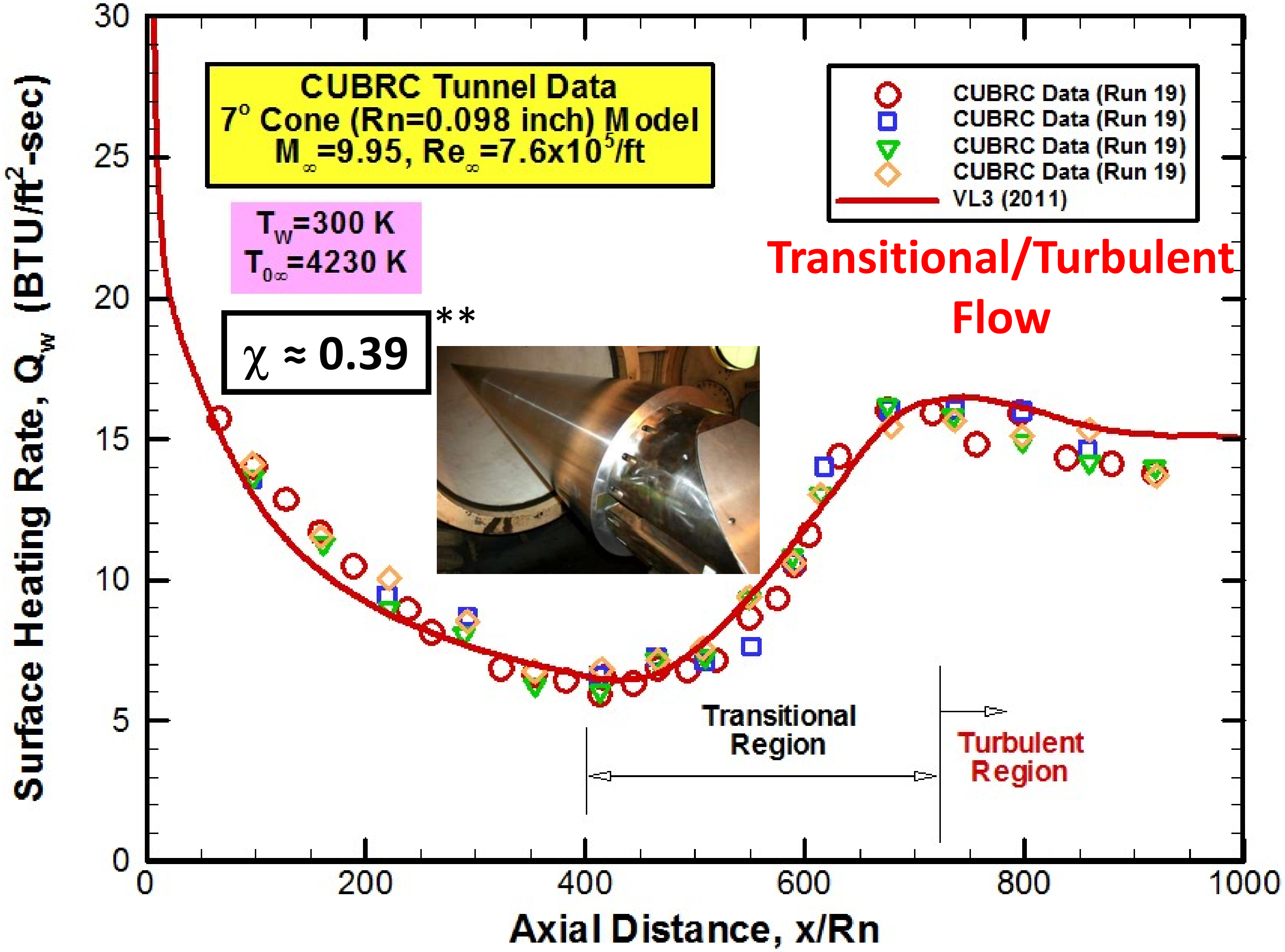


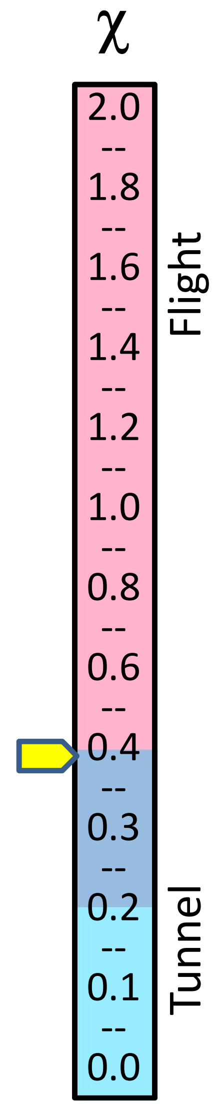


** $\chi = [T_{0\infty}(K) - T_w(K)]/10^4$

CUBRC 7° CONE

Moderate Total-Temperature Wind-Tunnel Conditions

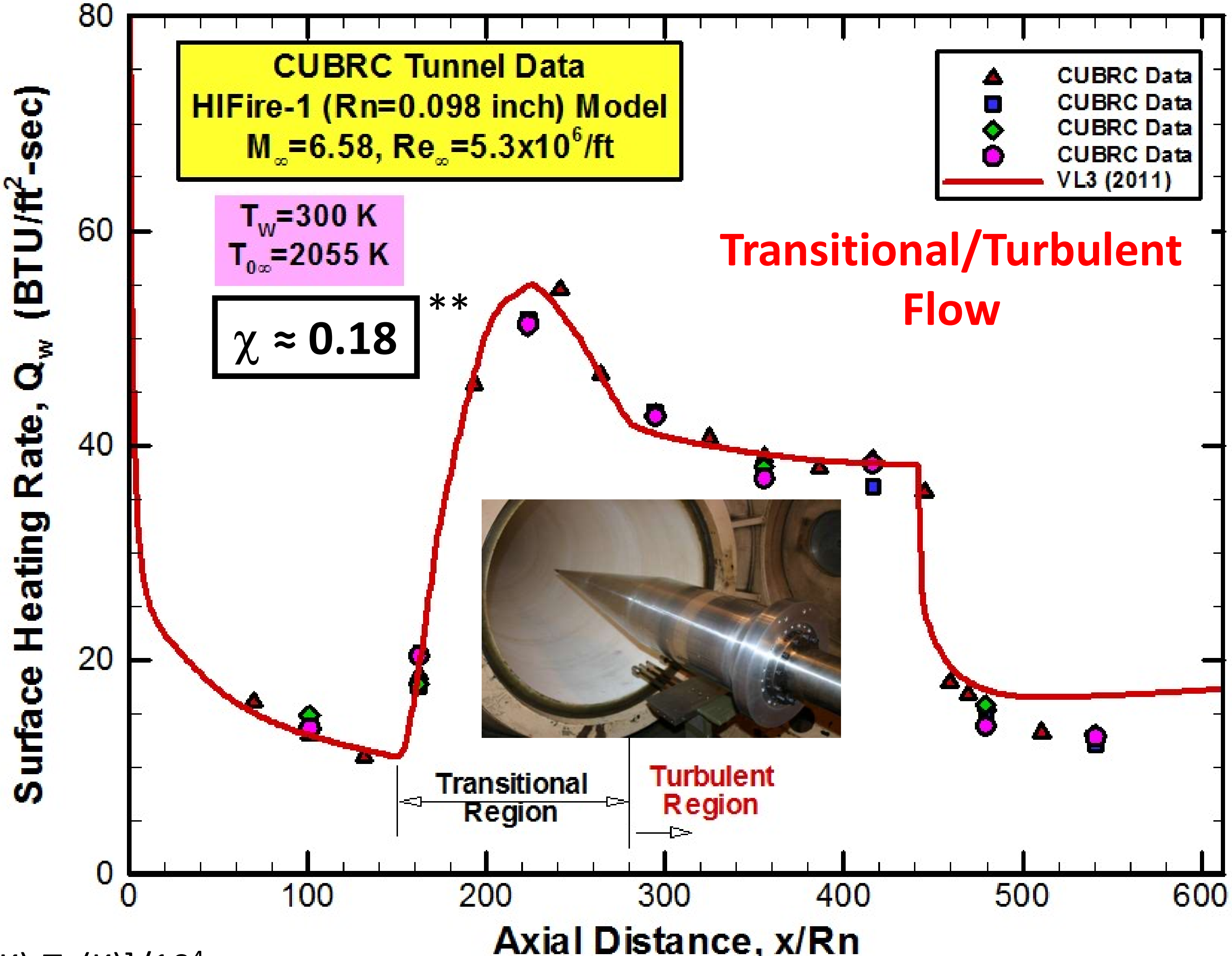


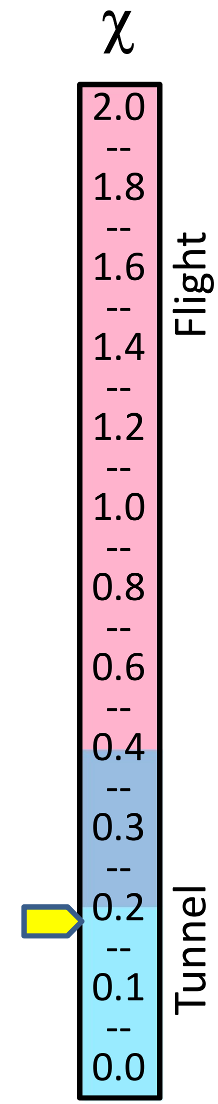


** $\chi=[T_{0\infty}(K)-T_w(K)]/10^4$

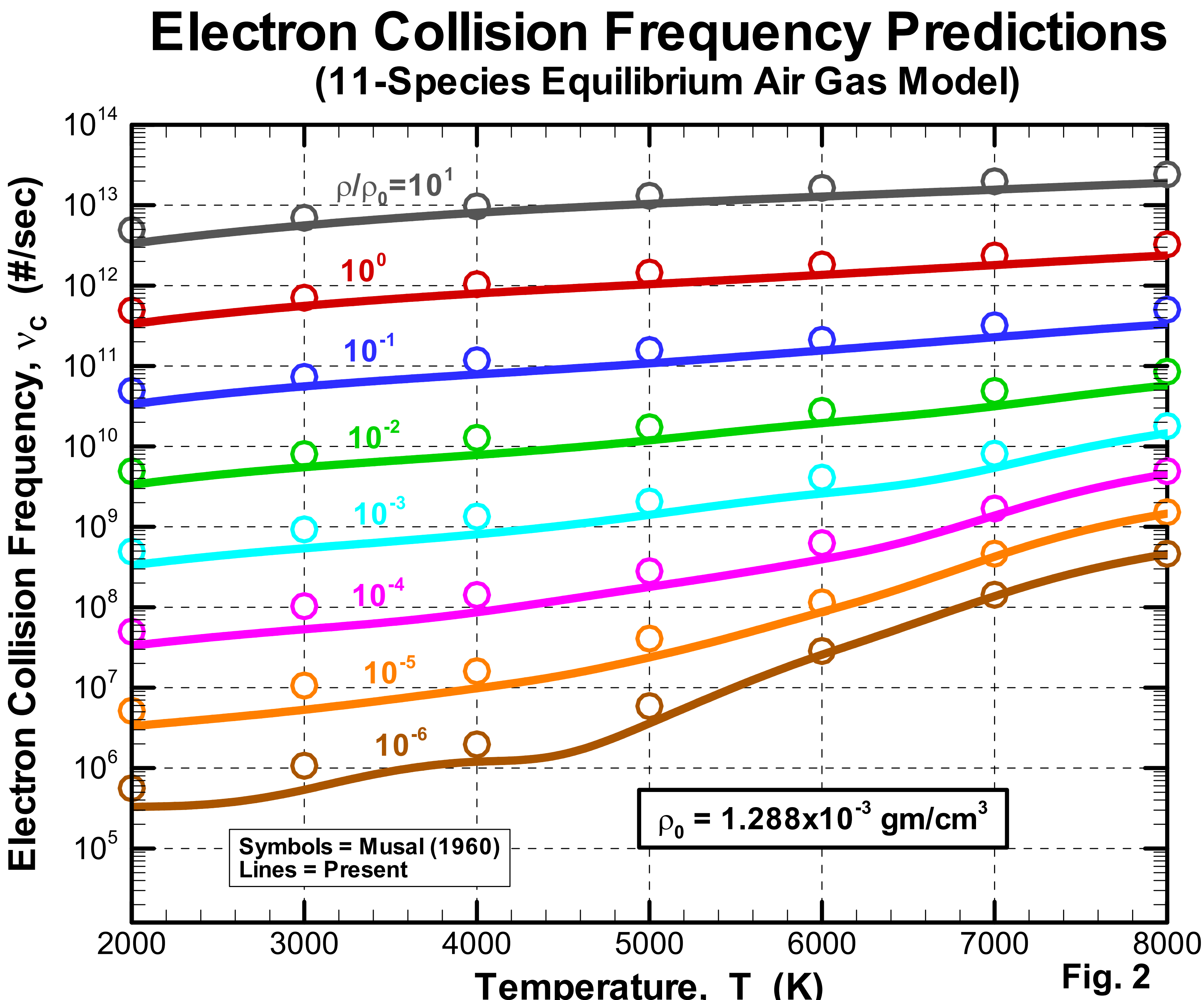
CUBRC HIFIRE-1 7° CONE-CYLINDER

Low Total-Temperature Wind-Tunnel Conditions





** $\chi = [T_{0\infty}(K) - T_w(K)]/10^4$



~~Fig-006a~~
Plasma: 9-3-2003

Sample PNS Input

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PNS Input for 12° Sphere-Cone at M_∞=10 and Alt=0kft

Grid Size
Gas Model
Skip-Print Controls
X-flow Grid Type
Nose Radius, Step Size & Convergence
Freestream Conditions
Pitch-Plane Symm.
Turbulence
Geometry
Thermal Printout Locations
Wall Temperature
X-Flow Grid Distrib.
Expanded Print
Step-size & Convergence Table
Ref. Length & Area

Sys12deg_m10h000ta00p0.pin - Notepad

File Edit Format View Help

```
M=10, Alt=  0 kft, AoA= 0.0 deg, Trb. <-- Sys12deg_m10h000ta00p0
    1                    KMAX
  101                    LMAX
    1                    IGAS
 0001                    IDSPLY    (I5)
   10                    JPRT
    1                    KPRT
    1                    LPRT
 0001                    IGRID     (I5)
 0050                    MAXITR    (I5)
       0.0419948         RNOSE
 45.0000000E+00          XEND      (F15.0)
 1.00000000E-02          DXMIN     (F15.0)
 2.50000000E-01          DXMAX     (F15.0)
 5.00000000E+00          ERRDX     (F15.0)
 5.00000000E-02          ERFLW     (F15.0)
 1.00000000E+00          OMGMAX    (F15.0)
     -10.0000000         FSMACH
       0.0000000         ALTKFT
     515.4585434         TINF
    2105.5218649         PINF
       0.0000000         ALPHA
       0.0000000         BETA
    1                    IPER
    1                    ITRANS
       0.0000000         XTRANS
-0099 1.0000000 200.00000 0  NNCONE (I5)
 0002
0.7920883090000 0 0 0 0 0 0 0 0 0 1 1 1
200.0000000000 0.9781476000000 0.21255656200 0 0 0 0 0 0 0 0 0 0.7920883090000
 0009                   NPRNT    (I5)
 0000002.000000 nny
 0000010.000000 nny
 0000020.000000 nny
 0000040.000000 nny
 0000060.000000 nny
 0000080.000000 nny
 0000100.000000 nny
 0000120.000000 nny
 0000140.000000 nny
 0005                    NTWLL    (0:ADIAB., >1:SPEC. TEMP)
     0.00000000  3000.00000000
     1.60000000  3000.00000000
     2.00000000  3000.00000000
    54.50000000  3000.00000000
   265.00000000  3000.00000000
 0001                    IXBDY    (I5)
 0000                    MXBDY    (I5)
EXTE
-0002                    IEXPRT   (I5)
 2.50000000E-01          DXBAR   (F15.0)
 0000                    ICON     (I5)
 2.50000000E+01          ERRITR   (F15.0)
 0000                    NTTB     (I5)
 0003                    NDXMX    (I5)
 0040.0000 0000.5000 0000.5000 0000.1000
 0050.0000 0000.5000 0000.5000 0000.1000
 0257.0000 0000.5000 0000.5000 0000.1000
 1.59953403E+03                          REFARA (I5)
 1.50393906E+02 9.00859498E+01     REFLNG,XMREF (2I5)
 0000                    NSMZ3    (I5)
 0.00000000E+00          EPSCRX   (F15.0)
 0002 0002               IDIFZ2   (2I5)
```

X, ΔX_{max}, ω_{RHS}, DXBAR

In this example the 12° sphere-cone shape is described using 12-coefficient piece-wise curvefit option

OPTIONAL EXTENDED INPUT SECTION

Thank you