Technology Investments in the NASA Entry Systems Modeling Project

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The Entry Systems Modeling Project

- Formed in 2013 within Space Technology Mission Directorate’s Game Changing Development Program
- Grew out of prior pursuits funded by Fundamental Aeronautics Hypersonics Project and Entry, Descent, and Landing Technology Development Project

The primary objective of the ESM Project is to develop enabling technologies and tools for hypersonic entry system design and development.

**Aerosciences**
- Flight mechanics,
- CFD, vehicle dynamics,
- parachute dynamics,
- turbulence

**Shock Layer Radiation**
- Chemical kinetics,
- spectral properties

**Model Validation**
- Turbulent heating,
- transition, shock interaction, etc.

**Thermal Protection Materials**
- Fibrous ablators, flexibles, woven,
- micro-to-macroscale modeling

**EDL Systems**
- Early-phase design, concepts, sub-system proof-of-concept
### The Entry Systems Modeling Project

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### Model Validation
- High enthalpy CO2 database
- Heating due to distributed roughness
- Shock wave/turbulent boundary layer interaction

### EDL Systems
- Exo-Brake for small payload return
- M-SAPE
Next-Generation CFD Software

- **US3D (in partnership with University of Minnesota)**
  - Unstructured, High-accuracy, Adaptive Mesh Refinement, Fluid-Structure Interaction
- **Hypersonic FUN3D**
  - Added thermochemical non-equilibrium
  - Walsh Functions for resolving
- **Multiphysics Algorithm with Particles (MAP)**
  - New DSMC code provides independent path for innovation

High-order resolution of unsteady flows

New platform for DSMC model development and applications

Automated adaption to flow features

Walsh function numerical scheme for feature detection and reconstruction
Entry Vehicle Dynamics

- **Magnetic Suspension Wind Tunnel**
  - Refurbished subsonic tunnel, magnetic balance, and electronic positioning system at Langley
  - New supersonic test section for Glenn 225 cm² tunnel

- **Free-flight CFD**
  - Desktop ballistic range
  - Provide detailed predictions of vehicle dynamics and driving physics
  - Application on several NASA projects
Parachute Fluid-Structure Interaction

- *eddy* CFD solver
  - Fully-coupled fluid-structure model
  - Intended for high risk applications
- **Space Technology Research Grants**
  - Focused on inflation problem: Self-contact, canopy and line stress
  - Stochastic deployment models

Micro-CT imaging of parachute fabric
Shock Layer Radiation

- **Electric Arc Shock Tube (EAST)**
  - 4” aluminum (High Velocity) and 24” steel (Low Density)
  - Uncertainty reduction for air from 200% to 17%
  - Informed detailed radiation margin policy for Orion
  - Next Up: Mars, Venus, Outer Planets…

- **Theoretical Chemistry**
- **NEQAIR and HARA**
  - Workhorse radiation tools for design applications
  - Orion, Mars 2020, InSight, OSIRIS-REx, industry
EDL Model Validation

- **High enthalpy CO\textsubscript{2} database**
  - Expansion tunnels shown to provide cleaner data
  - Quantified turbulent heating uncertainty

- **Heating augmentation due to distributed roughness**
  - Extensive datasets on sand-grain roughness from wind tunnel and ballistic range

- **Shock wave/Turbulent boundary layer interactions**

Global surface heating from wind tunnel (left) and ballistic range (right)

Blunt body heating in CO\textsubscript{2} environment at CUBRC LENS-XX

Turbulent heating in CO\textsubscript{2}
Thermal Protection Materials

- **Flexible TPS**
  - Established two 75 W/cm² layups, tested successfully up to 100 W/cm²

- **Convective Heating Improvement for Emergency Fire Shelters (CHIEFS)**
  - Applying entry technology to protect firefighters

Left: Commercial manufacture of CHIEFS fire shelter

Right: Interior images of shelter tests show dramatic improvement over currently deployed USFS shelter
TPS Modeling: Micro to Macro-scale

• Micro-CT and Material Characterization
  ▪ Detailed 3-D imaging
  ▪ Porous Media Analysis (PuMA)

• Engineering and Design
  ▪ Pyrolysis and Ablation Toolbox in OpenFOAM (PATO)
  ▪ Icarus

Micro-CT imaging of materials enables highly accurate characterization of material properties
DSMC (with SPARTA) simulation of FiberForm

SpaceTech-REDDI-2017 NNH17ZOA001N
http://tinyurl.com/NASA-17ESI

Improved micro-scale model for carbon/phenolic material (from article submitted to Carbon)
Future Directions

• **Focused research in four elements (chosen from feedback by missions on their needs)**
  - Predictive Materials Modeling
  - Shock Layer Kinetics and Radiation
  - Computational and Experimental Aerosciences
  - Guidance, Navigation and Control

• **Deliver new capabilities that have advocacy and mission impact**

• **Continue tight collaboration with NASA programs, other government agencies, academia, and international partners**

• **New “integrated systems analysis” role**
  - Impact assessment of capabilities proposed and under development
  - Uncertainty quantification via comparison to flight data
  - Mission infusion; demonstrating value to mission managers
Questions?