Entry Systems Modeling (ESM) Project

Game Changing Development Program | Space Technology Mission Directorate (STMD)

ANTICIPATED BENEFITS

To NASA funded missions:

Deliver two new aerothermal CFD codes to engineering community by December 2013 Deliver 50 W/cm2 flexible TPS to enable HIAD mission infusion Flight relevant validation database allows for reduction in uncertainty and margin, which improves reliability and enables informed trades and downselects

DETAILED DESCRIPTION

Cutting edge customer driven research in two areas: Aerosciences, including the completion and delivery of two new aerothermal CFD codes, a first ever validated shock layer radiation model, and an experimental validationdatabase, at flight-relevant enthalpy, for current and future generations. EDL Materials, including the development and delivery of two new flexible TPS systems to enable HIAD missions, vastly improved ablator modeling capability, and improved polymer resins to enhance or enable future developments in woven, flexible and conformal thermal protection systems.

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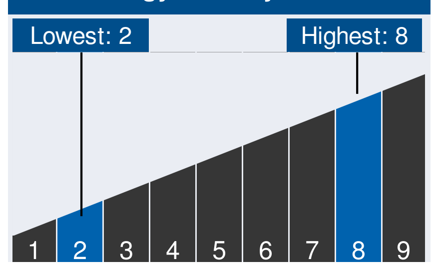
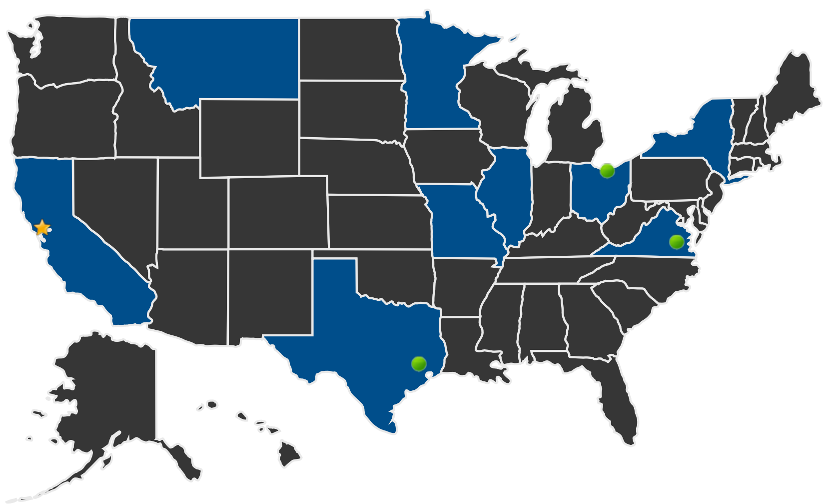
Technology Maturity



U.S. WORK LOCATIONS AND KEY PARTNERS



U.S. States With Work

Lead Center:
Ames Research Center

Supporting Centers:

- Glenn Research Center
- Johnson Space Center
- Langley Research Center

Other Organizations Performing Work:

- CUBRC, Inc.
- Lawrence Berkeley Nation Laboratory
- The Boeing Company
- University of Illinois (Champaign, IL)
- University of Minnesota (Minneapolis, MN)
- University of Southern California

Management Team

Program Executive:
- Lanetra Tate

Program Manager:
- Mary Wusk

Project Manager:
- Michael Wright

Principal Investigator:
- Michelle Munk

Technology Areas

- Entry, Descent, and Landing Systems (TA 9)
- Vehicle Systems (TA 9.4)
- Multi-Disciplinary Coupled Analysis Tools (TA 9.4.5.1)
- Coupled Multi-Dimensional Flow/Material Response/Thermal/Structural Analysis (TA 14.3.2.1)
- Shock Radiation Modeling (TA 14.3.2.2)

DETAILS FOR TECHNOLOGY 1

Technology Title

Advanced Ablator Development

Technology Description

This technology is categorized as a material for ground scientific research or analysis

The long-term goal of the Advanced Ablators task involves the development of novel ablative TPS materials for extremely challenging (e.g. high heat load) proposed future missions. Previous development work on conformal ablators resulted in the Conformal 1 ablator that demonstrated superior integrated heat load capability compared to SoA PICA at comparable bulk density, however, surface recession rates were significantly higher due to excessive loss of poorly interlocked fibers. The degree of interlocking will be improved through the use of commercially available needling capability. Establishing a needled felt capability and the development of polymer resins with improved performance compared to phenolic resin also has the potential to benefit woven ablators capability This task has three objectives:

1. Development of alternative ablative resins with enhanced thermal properties
2. Development of at least two TPS families utilizing advanced resin systems
    1. Low density, <0.5 g/cm^3, with 500 W/cm^2 peak heating capability.
    2. High density, >0.5 g/cm^3, with 1000 W/cm^2 peak heating capability
3. Computational materials modeling to support the material development tasks

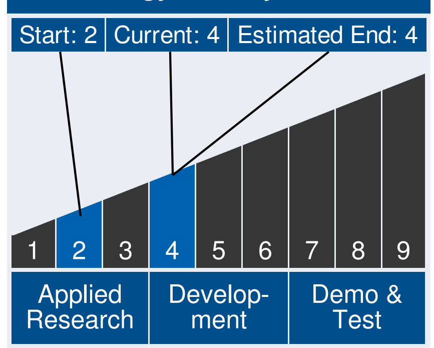
The effort will offer ablative TPS material solutions as well as supporting analysis tools for far-term NASA missions in context with relevant heating environment. This involves maturing

Technology Areas

Primary Technology Area:
Entry, Descent, and Landing Systems (TA 9)
└─ Vehicle Systems (TA 9.4)
  └─ Modeling and Simulation (TA 9.4.5)
    └─ Multi-Disciplinary Coupled Analysis Tools (TA 9.4.5.1)

Additional Technology Areas:
Thermal Management Systems (TA 14)
└─ Thermal Protection Systems (TA 14.3)
  └─ Thermal Protection System Modeling and Simulation (TA 14.3.2)
    └─ Coupled Multi-Dimensional Flow/Material Response/Thermal/Struct Analysis (TA 14.3.2.1)
    └─ Shock Radiation Modeling (TA 14.3.2.2)

Technology Maturity



existing families of resin materials that have demonstrated the potential for improved system performance compared to the current state-of-the-art.

Capabilities Provided

The task will have an experimental element and a modeling element. The efforts under the task will be coordinated with other groups and NASA centers (ARC, GRC, JSC, LaRC).

Experimental element

1. Processing of robust conformable ablative systems through the development of improved methods for interlocking fibrous performs made from carbon, organic systems, and improved char strength polymer impregnation resins.
2. Chemical modification of resin systems to:

- Increase flexibility of the polymer
- Tailor density of conformal TPS

The work outlined in this task allows for the fundamental tailoring of TPS properties for a variety of entry environments while also providing appropriate balance between integrated heat load resistance and ablation recession. Specific ablative resins that will be considered include phenolic and polyimide.

Modeling element

Modeling will focus on improving the processing and properties of ablative composites by building chemically accurate models of crosslinked polymer networks, evaluate their mechanical/thermal properties and develop design strategies to improve strength, toughness, etc. of the resin (additives, etc). Establishment of solvent-resin interaction models will aid TPS infiltration and processing for better control of resin morphology and resulting TPS density. The modeling effort includes two primary activities:

1. Construction of chemical models of cross-linked polymer networks and their resulting thermal/mechanical properties.
2. Chemical modeling of solvent-resin interactions

Potential Applications

- Successfully modifying resins for improved flexibility without substantially reducing ablative properties.

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Potential Applications *(cont.)*

- Processing TPS with tailored densities with the constraint of maintaining in-family performance for medium and high density systems.
- Assessing the effects of fiber chemistry, fiber geometry, and resin decomposition as intrinsic parameters of a multi-scale model.

DETAILS FOR TECHNOLOGY 2

Technology Title

CFD-Ablator Model Coupling

Technology Description

This technology is categorized as complex electronics software for engineering, design, modeling, or analysis

The primary objective of this task will be to strongly couple ablative response models to CFD, and produce an integrated high-fidelity material thermal response simulation system. The goal is to reduce model uncertainty in simulating "ultra" high-enthalpy conditions such as lunar return, sample return or giant planet entries. The effort will enable design of thermal protection systems and provide uncertainty estimates and guidance for margin policy. The tight coupling effort under this task will implement high-fidelity models that will provide guidance and feedback to experimental material scientists for the development of next generation advanced ablative materials. The effort will provide fundamental understanding of material response to high-enthalpy environments and elucidate material property-structure relationships. Codes developed as a part of this task will be considered Class D software when completed.

Capabilities Provided

The CFD code DPLR is currently capable of computing the environment taking into account the effects of gas blowing from an ARM and of providing back estimates of the surface recession and heat load. In FY12, DPLR was loosely coupled to FIAT where the two codes share sequentially required input

Technology Areas

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data. Loosely coupled analyses within DPLR (and similar work with LAURA and Chaleur) demonstrate that flow field modeling with ablation product blowing is a powerful computational strategy that can eliminate reliance on B’ tables.

The loosely coupled strategy, however, is unstable under high-enthalpy conditions. During lunar or sample return entries, pyrolysis-gas blowing becomes significant and the carbon at the surface sublimates. We expect a strong influence of the pyrolysis gas products on the flow environment.

In the first year several parallel development paths will be explored in order to reduce overall development risk, with a downselect to the preferred approach expected at the end of year one. This parallel development path is advantageous because it allows us to explore both integration of DPLR with existing ARMs (3dFIAT and CHAR) which have some heritage and validation but may be difficult to tightly couple in a parallel framework, as well as a “green field” approach which allows for the creation of a new design fidelity ARM that is specifically designed to be amenable to CFD integration. At the end of the first year, a down select meeting will determine the path for the second year. Having developed handler software that negotiates between DPLR and an ARM code, the flexibility of the tool will be tested and refined by coupling FUN3D to an ARM code.

The following plan will develop the framework and methods necessary for integration of ablative material response codes with the hypersonic CFD code DPLR. The performance of the new software will be evaluated on representative problems.

- Couple DPLR to various ARM formulations and test performance.
- Develop implicit coupling between DPLR and ARM’s
- Develop an integrated DPLR/ARM code under the same geometry framework.

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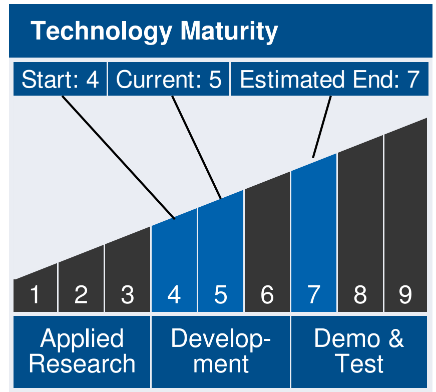

- Simulate arc jet data from various stream conditions, and compare the predictions between implicit and explicit approaches.
- Perform trajectory-based simulation for Stardust Earth Reentry Capsule and MEDLI.
- Couple FUN3D to an ARM formulation and test performance.
- Document results.

Potential Applications

The advancement of computational methods for the analysis of complex multi-physics problems has reached a stage where problems previously considered numerically intensive can now be solved readily with modern computer facilities. The next natural engineering step is to improve analysis fidelity by strongly coupling two or more non-linear solvers. A very important challenge to a strong coupling between the non-linear analysis method for computational fluid dynamics and ablation modeling is the requirement that the solutions for all the physics must be synchronized. A well-posed scheme needs to be established to handle the temporal exchange of information between each solver interface such that compatibility and continuity conditions are met to assure numerical stability.

DETAILS FOR TECHNOLOGY 3

Technology Title

DSMC Development

Technology Description

This technology is categorized as complex electronics software for engineering, design, modeling, or analysis

The primary objective of this Task is to develop a new DSMC code, called Multi-physics Algorithm with Particles (MAP), that takes advantage of modern software engineering techniques, in order to improve computational efficiency and create a development environment amenable to the latest advances in DSMC. The secondary objective is to improve physical models by investigating the extension of the phenomenological electronic energy model to other internal energy modes, updating current molecular models, and introducing radiative transport. These improved models may be implemented into the DAC code as an intermediate step to their inclusion in MAP, depending on requirements from the DSMC user community.

Technology Areas

Primary Technology Area:
Entry, Descent, and Landing Systems (TA 9)
└─ Vehicle Systems (TA 9.4)
  └─ Modeling and Simulation (TA 9.4.5)
    └─ Multi-Disciplinary Coupled Analysis Tools (TA 9.4.5.1)

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MAP will be considered Class E software when completed.

Capabilities Provided

The initial phase of this task will be to improve near-term functionality of DAC by updating the current implementation to include extensions of the Quantum-Kinetic (Q-K) model, as well as an ionized flow capability. For the proposed Q-K model extensions, the same methodology used in the electronic energy relaxation model will be implemented for the rotational and vibrational internal energy modes and compared to measured rates from the literature.

In parallel, a new approach to next-generation DSMC software will be sought by developing a new code (MAP) written in C++. Object-oriented codes written in C++ are likely the most flexible and efficient approach for development of new algorithms and physics modules due to their inherent modularity. However, computational efficiency is an equally critical component of software design that must be considered. Therefore, the approach of this task will be to evaluate the new software with regard to (1) Software design and extensibility, (2) Accuracy of solution, and (3) Efficiency of solution. For each category, comparisons will be made against legacy software (e.g. DAC or DSn(V)) in order to identify the relative merits of each software package.

The final phase of this Task will be to update existing models and incorporate radiative transport. Relevant test problems will be used to quantify performance improvements relative to current practice.

Potential Applications

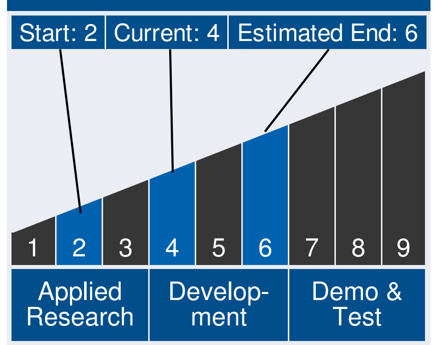
The primary challenge to this task will be extension of the Q-K model to other internal energy modes. While early indications suggest that this approach can be successful, it is not known *a priori* whether the attempted extension of the model will work appropriately outside of the electronic energy mode for which it was developed.

Technology Areas *(cont.)*

Additional Technology Areas:

Thermal Management Systems (TA 14)
- Thermal Protection Systems (TA 14.3)
  - Thermal Protection System Modeling and Simulation (TA 14.3.2)
    - Coupled Multi-Dimensional Flow/Material Response/Thermal/Struct Analysis (TA 14.3.2.1)
    - Shock Radiation Modeling (TA 14.3.2.2)

Technology Maturity



A secondary challenge of this task will be getting the newly developed code sufficiently developed in the short time frame such that it can be reasonably compared with DAC and DS(n)V. Execution speed is also a concern and needs to be addressed by comparing to DAC.

DETAILS FOR TECHNOLOGY 4

Technology Title

Flexible Thermal Protection Materials

Technology Description

This technology is categorized as a material for ground scientific research or analysis

This task is focused on developing advanced flexible insulator materials and fabrication concepts for flexible thermal protection heatshields through the design of materials and conducting property testing, high-temperature wind tunnel testing, and through various studies and analyses. NASA is pursuing a heat shield design technology that is a modular, multilayered insulation system consisting of a refractory textile outer layer designed to accommodate peak heating that is layered over insulators designed to manage integrated heat loads such that the gas barrier temperature remains below its performance limit. Additional effort will be given to the further development of a thermal response model and its thermal-physical characterization requirements for the materials and constituents used in the construction of high performance insulators.

Capabilities Provided

Candidate insulator systems shall encompass both inorganic and organic systems that cover the spectrum from passive non-decomposing insulators, to actively-decomposing that offer the benefit of transpiration cooling. Manufacturing techniques that address improved pack-ability and handling resiliency will be included as part of the technology development activity. Proposed techniques such as scrim backing, needling, sizing, and bonding will be included in the trade study. Thermal testing at LCAT will be used to provide relative performance metrics

Technology Areas

Primary Technology Area:
Entry, Descent, and Landing Systems (TA 9)
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  └ Modeling and Simulation (TA 9.4.5)
    └ Multi-Disciplinary Coupled Analysis Tools (TA 9.4.5.1)

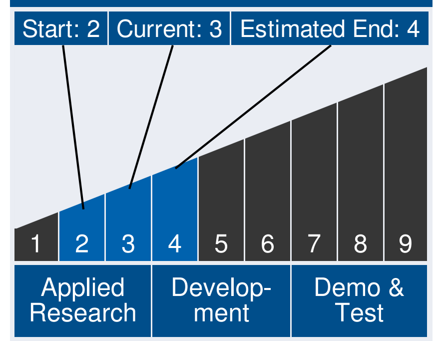
Additional Technology Areas:
Thermal Management Systems (TA 14)
└ Thermal Protection Systems (TA 14.3)
  └ Thermal Protection System Modeling and Simulation (TA 14.3.2)
    └ Coupled Multi-Dimensional Flow/Material Response/Thermal/Struct Analysis (TA 14.3.2.1)
    └ Shock Radiation Modeling (TA 14.3.2.2)

between various concepts and absolute performance metrics against the design goal of 75 W/cm^2. Thermal-physical property testing of candidate materials will also be conducted to support the development of a high-fidelity thermal model that can be used to predict the performance. These predictions will be used to screen potential materials prior to a down select of the more promising technologies.

Potential Applications

- Establishing soft-goods technology that will enable single-use survivability of a flexible heat shield capable of handling a peak heat flux of 75 W/cm^2.
- Identifying fabrication concepts that enable higher performance materials to be used in a flexible TPS.
- Establish material properties at relevant conditions (vendor provided material properties are, in general, invalid at atmospheric entry velocities and altitudes).
- Develop high-fidelity TPS models capable of accurately predicting thermal performance of multilayer systems.

Technology Maturity



DETAILS FOR TECHNOLOGY 5

Technology Title

FUN3D Development

Technology Description

This technology is categorized as complex electronics software for engineering, design, modeling, or analysis

The primary objective of this Task is to develop FUN3D to a capability able to substantially replace LAURA for executing aerothermal environment simulations for vehicles traveling at hypersonic velocities through planetary atmospheres. This transition of codes will bring to bear all of the advantages of unstructured grid technology for aerothermal environment simulations, especially grid adaptation, error estimation, and overset grid capability. Hyp-FUN3D will be considered Class D

Technology Areas

Primary Technology Area:
Entry, Descent, and Landing Systems (TA 9)
└─ Vehicle Systems (TA 9.4)
  └─ Modeling and Simulation (TA 9.4.5)
    └─ Multi-Disciplinary Coupled Analysis Tools (TA 9.4.5.1)

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software when completed, although certain research elements of the code may be Class E.

Capabilities Provided

Certain critical fundamental capabilities that currently reside in LAURA must be reproduced in FUN3D before it is useful as a production tool. The infrastructure of FUN3D is essentially in place to enable this transition. LAURA and FUN3D already share modules associated with gas chemistry, surface boundary conditions, radiation, and turbulence modeling. Still, there are several key tasks that must be accomplished to enable acceptance of FUN3D by current LAURA users. Each of these activities will be addressed as part of this task and they are summarized in the Milestones. Verification and validation of individual components, as well as overall software performance, are key activities to determine successful completion of Hypersonic FUN3D (HYP-FUN3D) and its readiness for production-level release.

Potential Applications

Risk has been mitigated through re-use of modules currently in LAURA where appropriate. Modest challenges associated with conversion of cell-based boundary conditions to node-based in FUN3D and with reformulation of limiters without dependence on structured-grid infrastructure are being addressed. The primary risk to full implementation derives from a continued requirement for high quality, semi-structured (prismatic) grids to achieve acceptable accuracy in simulation of heating in the presence of strong shocks. Offering options in multi-dimensional reconstruction to allow more extensive use of tetrahedral grids and developing options for grid alignment with shocks and/or bow shock fitting are mitigating this risk in HYP-FUN3D. Ultimately, if requirements for initial grid generation quality are not substantially relieved it will be more difficult to convince current users of LAURA and DPLR to switch.

Technology Areas *(cont.)*

Additional Technology Areas:

Thermal Management Systems (TA 14)
- Thermal Protection Systems (TA 14.3)
  - Thermal Protection System Modeling and Simulation (TA 14.3.2)
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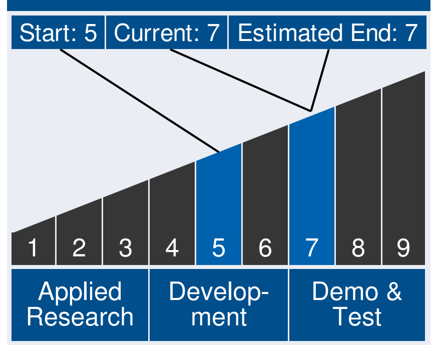
    - Shock Radiation Modeling (TA 14.3.2.2)

Technology Maturity



DETAILS FOR TECHNOLOGY 6

Technology Title

High Enthalpy Aerothermal Database

Technology Description

This technology is categorized as complex electronics software for engineering, design, modeling, or analysis

The objective of the test series is to acquire data relevant to atmospheric entry to Mars. The data will be used, via cooperative agreement, to develop, assess and validate engineering and CFD models employed by NASA for design and analysis of future Mars missions, and to assist the MEDLI team in their analysis of the flight data from the MSL entry.

Capabilities Provided

Using NRA funds, a model will be fabricated replicating the 70-deg sphere-cone forebody shape of MSL. The model will be instrumented with an array of sensors to measure heat flux and pressure, a subset of which will replicate the sensor locations of the MEDLI suite on MSL. In addition, two radiometers will be installed in the stagnation region. One radiometer will be calibrated for measurements in the mid-infrared in order to capture CO_2 radiation in this range. This provides overlap with testing in EAST as part of Task 4.2.1, as well as new model implementation in Task 4.2.4. The second radiometer will be calibrated for measurements in the vacuum ultraviolet in order to capture radiation of the CO 4th positive band. This also provides overlap with the above-mentioned Tasks.

The test matrix will be selected to cover the full range of enthalpies achievable in LENS-XX. To the extent possible, conditions will also be selected to cover the estimated trajectory of MSL.

Via collaborative agreement, NASA will provide pre and post flight CFD analysis, guidance on instrumentation placement and

Technology Areas

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Entry, Descent, and Landing Systems (TA 9)
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    - Multi-Disciplinary Coupled Analysis Tools (TA 9.4.5.1)

Additional Technology Areas:
Thermal Management Systems (TA 14)
- Thermal Protection Systems (TA 14.3)
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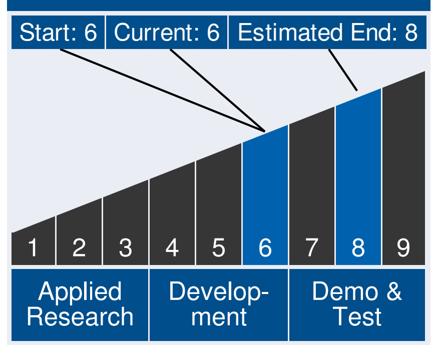
    - Shock Radiation Modeling (TA 14.3.2.2)

Technology Maturity



test matrix priorities, and will consult regularly with CUBRC staff before, during and after the runs.

A potential second source of high-enthalpy CO_2 testing has been identified with the High Enthalpy Tunnel (HET) at University of Illinois. An exploratory test series will be conducted in FY14 to determine the usable operating envelope and whether future investments are warranted to expand capability.

Potential Applications

Tunnel availability poses the largest schedule risk. The CUBRC facilities have numerous customers who compete for precedence should any disruption to the nominal schedule occur. Additional risk arises from the possibility of low-quality tunnel runs. If such events occur, it may not be possible to reschedule additional runs to cover the lost test time. Also, the LENS-XX facility is new to operation, and its performance has not been fully validated in CO_2 (validation of the facility for CO_2 is one of the objectives of the NRA). Finally, available instrumentation is limited. Should any instrumentation be lost due to freestream particles from the diaphragm rupture, it will not be possible to replace the instrumentation.

DETAILS FOR TECHNOLOGY 7

Technology Title

High Fidelity Ablator Response Model

Technology Description

This technology is categorized as complex electronics software for engineering, design, modeling, or analysis

The objective of this task is to develop a high-fidelity ablation material response model for phenolic-based porous ablation materials that will reduce model uncertainty in simulated “ultra” high-enthalpy conditions such as lunar return, sample return or giant planet entries. The effort will enable a new design approach for thermal protection systems by guiding margin policy decisions through reduced uncertainty estimates in performance. An additional benefit of high-fidelity models will be through an improved fundamental insight to performance as feedback to experimental material scientists, which will serve to improve the development of the next generation advanced ablative materials. Overall, the effort will provide a fundamental

Technology Areas

Primary Technology Area:
Entry, Descent, and Landing Systems (TA 9)
└─ Vehicle Systems (TA 9.4)
  └─ Modeling and Simulation (TA 9.4.5)
    └─ Multi-Disciplinary Coupled Analysis Tools (TA 9.4.5.1)

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understanding of material response to high-enthalpy thermal environments, elucidate material property-structure relationships, and provide recommendations for new materials and structures with enhanced application specific properties.

The stretch goal of this task is to have a computational tool with sufficient fidelity that it has *predictive* capability of the performance of new materials in this class. In this scenario the development of *tailored* ablator families, guided by computational analysis and with performance verified rather than validated with arc jet testing, becomes possible. Codes developed as a part of this task will be considered Class E software when completed.

Capabilities Provided

This task will be accomplished via a cooperative agreement with the University of California Santa Cruz and their co-investigators, who were awarded a NASA Research Announcement by the Fundamental Aeronautics Program and currently funded by the STMD/Space Technology Research Grants Program.

Phenolic-based porous ablators are mass efficient; however, the fact that such systems are porous highlights the importance of in-depth response modeling with a high-fidelity approach that incorporates the flow and chemistry within the material. Specifically, the following modeling aspects will be considered: properties of resin decomposition, in-depth chemical reactions and reaction rates, subsurface gas advection, and thermal-mechanical properties of char formation and erosion. The task is compromised of an experimental element, a modeling element and a code development element. Although porous phenolic-based ablators are relatively simple binary-constituent composite materials, the majority of existing data is on material system response and little information exists regarding the details of decomposition chemistry needed for a higher fidelity model. The experimental effort will focus on gathering the microstructural and chemical decomposition data needed within the model. The modeling effort will develop phenomenological

Technology Areas *(cont.)*

Additional Technology Areas:

Thermal Management Systems (TA 14)
- Thermal Protection Systems (TA 14.3)
  - Thermal Protection System Modeling and Simulation (TA 14.3.2)
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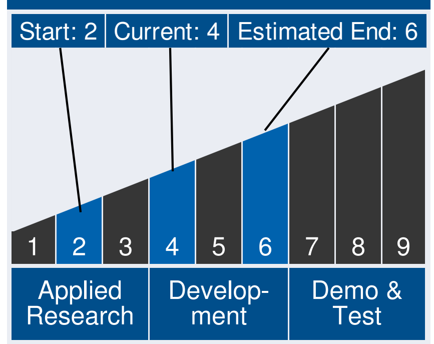
Technology Maturity



computation models for resin pyrolysis, finite rate chemistry, and gas advection of the pyrolysis products. The code development effort will focus on the Pyrolysis and Ablation Toolkit for OpenFOAM (PATO) code as the high-fidelity platform to test and compare the new physical models.

The developed high-fidelity model will be used to guide the development of a next generation engineering design tool, which will incorporate modern software engineering practices (including parallel operation). PATO will be used to conduct sensitivity studies on real heatshield design problems in order to determine the relative importance of the “new” physical models to overall design thickness and margin predictions. Those that have significant influence will be then ported to the design tool.

Potential Applications

The focus on porous ablators recognizes that these materials are composite systems are intrinsically multi-scale materials. Microscopic effects of the fibers, resin and interfaces as well as large scale effects related to the composite architecture are all important in determining material properties and response to high-enthalpy environments.

DETAILS FOR TECHNOLOGY 8

Technology Title

HyperRad Development

Technology Description

This technology is categorized as complex electronics software for engineering, design, modeling, or analysis

The primary objective of this task is to enhance HyperRad so that it is usable for entry flows containing significant regions of non-equilibrium conditions. This enhancement will bring HyperRad to a point at which it will be suitable for release as a production tool for entry aerothermodynamic analysis of flows containing non-equilibrium regions by the end of FY14. HyperRad will be considered Class E software when completed.

Capabilities Provided

In addition, the Agency lacks a radiative heat code that can be fully coupled to general CFD codes. Existing coupling efforts

Technology Areas

Primary Technology Area:
Entry, Descent, and Landing Systems (TA 9)
└─ Vehicle Systems (TA 9.4)
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assume one-dimensional radiation transport, which can introduce significant errors away from the stagnation region of blunt bodies. HyperRad provides this functionality and can be linked to any grid-based CFD code, structured or unstructured, providing full three-dimensional radiative transfer throughout the computational domain. As a result, any body shape, including multiple and maneuvering bodies, can be accommodated.

Potential Applications

The current release of HyperRad is only applicable to flows in thermochemical equilibrium. The radiation from non-equilibrium gases is significantly different from that in equilibrium. Since many entry trajectories have portions during which radiative heating is significant but in which the flow is not in equilibrium, it is incumbent to generalize the physical modeling to treat non-equilibrium conditions. The existing quasi steady-state (QSS) non-equilibrium model in NEQAIR and HARA has not been updated in many years and contains a number of ad hoc modeling assumptions. It was also designed for and tested in only a narrow range of entry conditions that were deemed relevant and accessible in the time period in which it was developed.

Technology Areas *(cont.)*

Additional Technology Areas:

Thermal Management Systems (TA 14)
- Thermal Protection Systems (TA 14.3)
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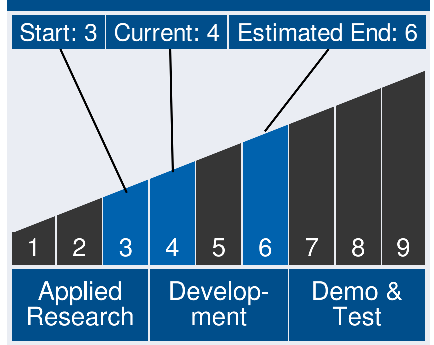
Technology Maturity



DETAILS FOR TECHNOLOGY 9

Technology Title

M-SAPE Development

Technology Description

This technology is categorized as complex electronics software for engineering, design, modeling, or analysis

The primary objective of this task is to develop and integrate models of highly-promising mid-TRL technologies for M-SAPE.

Complementary tasks will add atmospheric and alternate vehicle geometry models to support trade space analysis for interplanetary science probes. Overall, the proposed work will provide a comprehensive SA tool for EDL that will greatly facilitate technology development as well as mission infusion for science mission probes. M-SAPE will be considered Class D software when completed.

Capabilities Provided

Five additional capabilities for M-SAPE have been identified: 1) develop a parametric trajectory model, 2) add Uranus, Saturn, and Venus models (trajectory & aerothermal), 3) parametric parachute model, 4) advanced woven-TPS concepts, 5) update M-SAPE & add additional cone angles, 6) additional probe shapes (e.g., Apollo), 7) Hypersonic Inflatable Aerodynamic Decelerator (HIAD) with flexible TPS, and 8) Adaptable, Deployable Entry Placement Technology (ADEPT). Woven-TPS, HIADs and ADEPT are considered highly-promising mid-TRL technologies that are currently being developed for future missions. For each additional capability, appropriate models will be developed and integrated with M-SAPE. The new capabilities will be verified with existing results.

Potential Applications

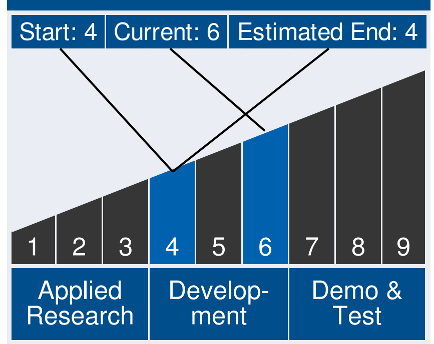
Implementation of each additional capability includes three major activities: model development, model integration, and model testing and verification. M-SAPE has gone through several enhancements for sample return applications, and as a result a set of robust techniques have been developed to minimize the risk. The risk is primarily in the model development phase, where it may be difficult to develop a single parametric model that would applicable over a wide range of applications. In the past this problem has been resolved by developing multiple models that are valid in different range of applications. This could have an impact on the task completion schedule.

Technology Areas

Primary Technology Area:
Entry, Descent, and Landing Systems (TA 9)
└ Vehicle Systems (TA 9.4)
  └ Modeling and Simulation (TA 9.4.5)
    └ Multi-Disciplinary Coupled Analysis Tools (TA 9.4.5.1)

Additional Technology Areas:
Thermal Management Systems (TA 14)
└ Thermal Protection Systems (TA 14.3)
  └ Thermal Protection System Modeling and Simulation (TA 14.3.2)
    └ Coupled Multi-Dimensional Flow/Material Response/Thermal/Struct Analysis (TA 14.3.2.1)
    └ Shock Radiation Modeling (TA 14.3.2.2)

Technology Maturity



DETAILS FOR TECHNOLOGY 10

Technology Title

US3D Development

Technology Description

This technology is categorized as complex electronics software for engineering, design, modeling, or analysis

The primary objective of this task is to advance development of the US3D CFD code such that it is suitable for release as a production tool for NASA entry aerothermodynamics analysis by mid-FY14. US3D will be considered Class D software when completed.

Capabilities Provided

The effort is undertaken collaboratively between NASA and the inventors of US3D at the University of Minnesota. NASA is requesting enhancements to the current version of the code to make it amenable for solution of the types of problems currently solved using DPLR. Staff members at the University and NASA collaboratively share responsibility for code implementation. As completed, enhancements are validated by comparison to DPLR and to available experimental datasets. NASA bears primary responsibility for the code validation effort.

In order to qualify as a production-ready aerothermodynamics CFD code, the team has developed a set of required additional capability for US3D, as detailed in the Milestones for this task. The activities were selected to address capability gaps and to validate US3D solutions against accepted DPLR benchmarks.

Potential Applications

The primary risk to successful completion of this task is the dependence on a timely technology transfer from the University of Minnesota in terms that are amenable to the Government. The US3D code has been developed primarily at the University of Minnesota, with support from NASA and the Air Force Office

Technology Areas

Primary Technology Area:
Entry, Descent, and Landing Systems (TA 9)
- Vehicle Systems (TA 9.4)
  - Modeling and Simulation (TA 9.4.5)
    - Multi-Disciplinary Coupled Analysis Tools (TA 9.4.5.1)

Additional Technology Areas:
Thermal Management Systems (TA 14)
- Thermal Protection Systems (TA 14.3)
  - Thermal Protection System Modeling and Simulation (TA 14.3.2)
    - Coupled Multi-Dimensional Flow/Material Response/Thermal/Struct Analysis (TA 14.3.2.1)
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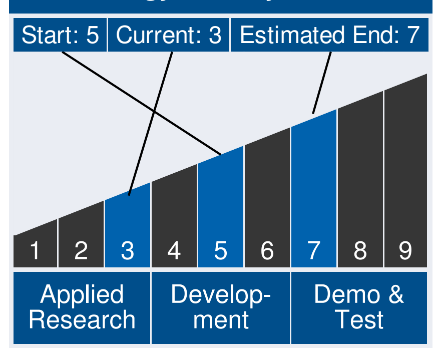
Technology Maturity



of Scientific Research. Both NASA and the primary developer at the University are interested in seeing this transfer occur, but there are legal hurdles that must be overcome. The HEDL project is in the process of managing those legal hurdles in order to ensure that they do not stand in the way of successful task completion.