Multifunctional Hypersonic Components and Structures

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ABSTRACT

This article describes a Johns Hopkins University Applied Physics Laboratory (APL) strategic independent research and development project exploring multifunctional hypersonic components and structures. The project was envisioned to develop transformational materials technologies and expertise that could be applied to relevant hypersonic vehicle programs supported at APL.

As part of a strategic independent research and development project during fiscal years (FY) 2015–2017, an APL team investigated multifunctional hypersonic components and structures. Their goal was to develop transformational materials technologies and expertise that could then be applied to the Lab's relevant hypersonic vehicle programs. In scoping the 3-year effort, the team identified the following areas of concentration to support the needed hypersonic materials science and technology and engineering:

- Develop overarching materials design, analysis, and manufacturing methodologies for materials and structures optimized for weapons systems.
- Acquire and customize state-of-the-art coatings processing and test and evaluation capabilities.
- Develop high-temperature joining methods for mechanically integrating dissimilar materials, such as joining refractory metals to ceramics, or carbon–carbon to insulation.
- Establish core competency in electro-optical/infrared and radio frequency transparent ceramics for terminal seekers, which are on a critical path to weapon realization.
- Integrate active cooling strategies to negate aerothermal and ablation effects (e.g., apply heat pipes for cooling primary structures and electro-optical/infrared windows).
- Develop leap-ahead electrical power generation through use of thermoelectric materials and devices that take advantage of the inherently large thermal gradients in hypersonic flight.

By identifying these technical goals for materials, subsystems, and fully integrated vehicles, the team was able to narrow its focus to the one of the most challenging areas for these vehicles—the vehicle leading edge and control surface leading edges. They developed a plan to establish core competencies and demonstrate subject-matter expertise, positioning APL to provide not only technical approaches but also crucial insight into understanding material behavior and resulting performance of materials the community is considering for these applications.

From a technical perspective, development and application of multifunctional materials for leading-edge challenges became the focus of development efforts for the project. The many critical dimensions of material multifunctionality are illustrated in Figure 1. The team leveraged past experience in the performance of relevant materials, the interaction of these materials, and the ability to tailor their properties and performance to achieve the desired characteristics. The plan in Figure 2 illustrates the progression from refining and building the team's core expertise and establishing high-temperature material processing, measurement, and test capabilities in FY2015; to focusing on materials optimization, manufacturing science, detailed measurements, and modeling in FY2016; to conducting relevant demonstrations on prototype hardware in FY2017.

A number of key accomplishments illustrate the achievements of this effort. The team

- successfully established unique test capabilities, including high-velocity oxygen-fueled (HVOF) testing of materials up to ~2,300°C in real air under representative flow conditions, and high temperature spectral emissivity measurement up to 1,200°C;
- developed multiple novel manufacturing techniques for key materials, independently, in concert with commercial vendors and through research and development efforts with the Johns Hopkins University Whiting School of Engineering;

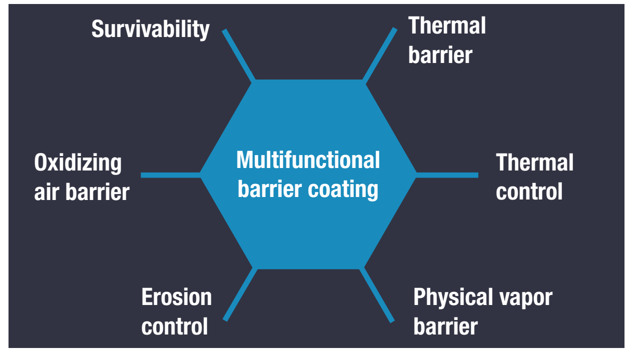

Figure 1. Multidimensional hypersonic material challenges. Many dimensions influence the development of a multifunctional thermal barrier coating to protect hypersonic systems. Tailored materials provide a balance of these attributes best meeting the operational requirements. Survivable coatings must withstand peak heat loads and extreme thermal gradients and must control erosion by being resistant to the impact of atmospheric particulate. The coating thermally protects the underlying structure by creating a thermal barrier and providing thermal control by rejecting as much energy as possible. A physical vapor barrier isolates the underlying surfaces from reacting with the external coating itself when at extreme temperatures, and, further, an oxygen diffusion barrier prevents subsurface reactions with atmospheric oxygen.

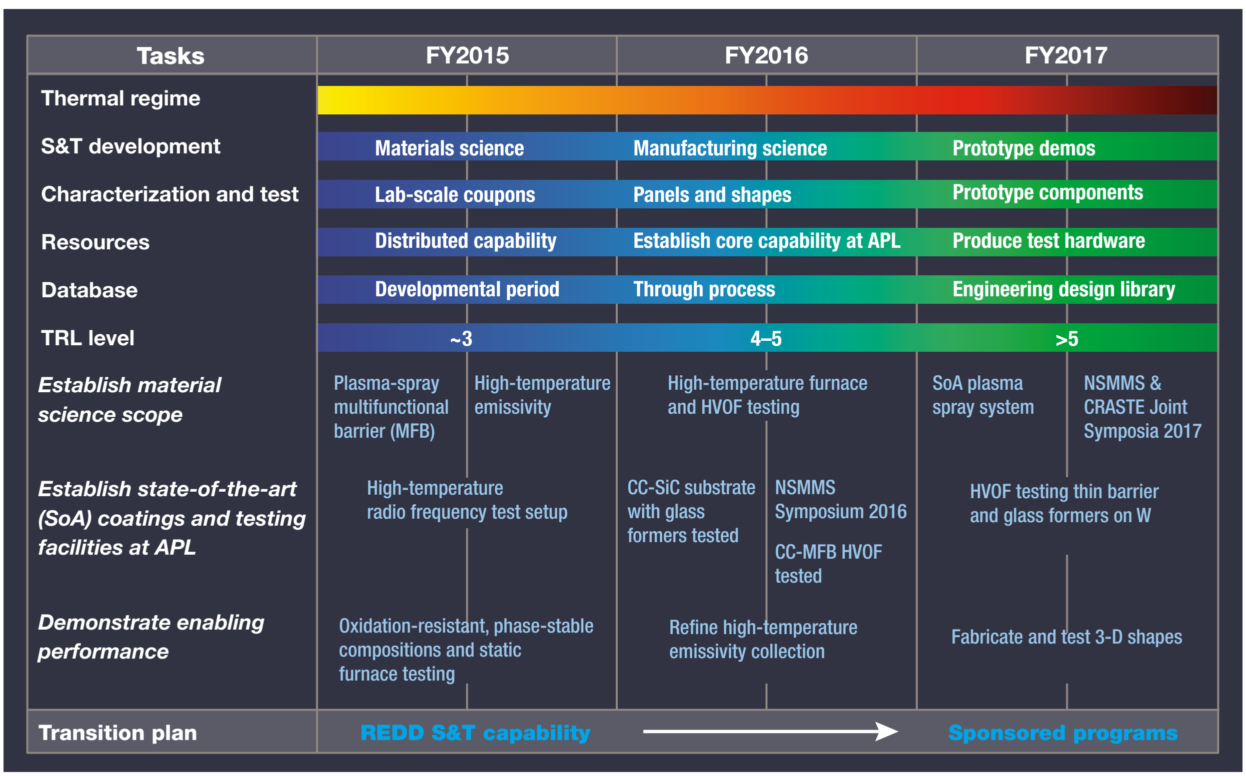

Figure 2. The 3-year research and development plan. The plan illustrates the progression in capabilities, improvement in performance, and increase in technology readiness level of multifunctional material technologies and approaches. The lower part of the plan provides snapshots of materials' test and demonstration, illustrating not only the desired performance levels but also capabilities needed for future engagements. CC-MFB, carbon-carbon composite, multifunctional barrier; CC-SiC, carbon-carbon, silicon-carbide composite; CRASTE, Commercial and Government Responsive Access to Space Technology Exchange; NSMMS, National Space & Missile Materials Symposium; S&T, science and technology; TRL, technology readiness level.

- established commercial and government relationships to enable key demonstration activities; and
- demonstrated thermal protection of relevant substrates in pertinent test environments, such as depicted in Figure 3. The NASA Langley Research Center, contracted to provide a representative environment via the Hypersonic Materials Environmental Test System (HyMETS) arcjet wind tunnel facility, provided test services supporting the technology readiness level 5 assessment as part of this research and development effort.

Not only did this project achieve unique capabilities, but it also laid the groundwork for follow-on engagements to mature technology related to the demanding material challenges associated with hypersonic flight. The APL materials team continues to develop materials solutions and explore transitioning materials technologies to specific vehicle programs led by APL and its government sponsors. In the future, these materials, whose development originated during this strategic independent research and development project, could be enabling capabilities for hypersonic leading-edge survivability.

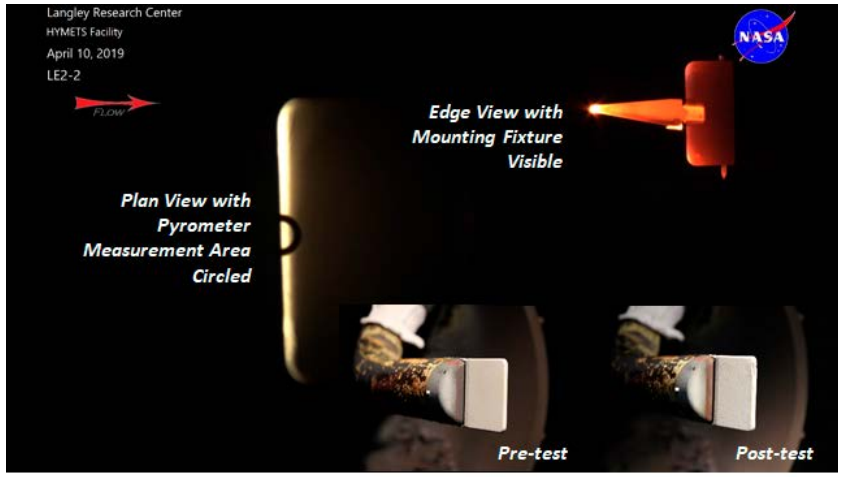

Figure 3. Testing at NASA Langley Research Center's Hypersonic Materials Environmental Test System (HyMETS) arcjet wind tunnel facility. The HyMETS facility creates representative conditions for hypersonic flight, and the testing supported the technology readiness level 5 assessment.

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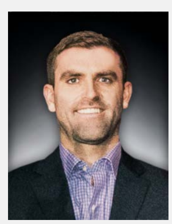

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