# Platelet based Active Thermal Protection System (ATPS)

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**Thermal Protection Systems (TPS) are a key element of all aerospace applications. We propose the use of platelet manufacturing processes to create large, conformal, and low-cost metallic structures that are cooled by transpiration cooling. If successful, this approach would enable fully redundant and reusable atmospheric reentry TPS configurations. Another application is in high Mach number atmospheric flight for both Reusable Launch Vehicle (RLV) first stage boosters and super/hyper-sonic aircraft. The described Active TPS has many applications in aerospace systems, and very significant safety and operational advantages. It can be paired with ablative type TPS for fail-safe redundancy, and it's inherent reusability enables simplified ground handling and quick vehicle turn-around. The ATPS technology base is well established from air breathing propulsion applications and the physical processes are very well understood. The extension of the film cooling approach to structural TPS for reentry and launch vehicles only requires a moderate investment.**

## Nomenclature

*ATPS* = Active Thermal Protection System
*CRC* = Carbon Reinforced Carbon
*EVA* = Extra Vehicular Activity
*RLV* = Reusable Launch Vehicle
*TPS* = Thermal Protection System
*TRL* = Technology Readiness Level

## I. Introduction

Thermal Protection Systems (TPS) are a key element of all aerospace applications. They are driving design elements of launch and reentry vehicle structures, as well as rocket and air breathing engines. TPS technology can be grouped into three categories: (1) hot structures where the selected material is fully capable to withstand the environment without any permanent change, (2) ablative systems where the structure is cooled by continuously eroding during use, and (3) active systems where a fluid is used to transport the heat-energy away from the structure.

Hot structures are made from advanced materials such as ceramics or advanced composites that can withstand extraordinary temperatures. An example would be the Carbon Reinforced Carbon (CRC) nose cone on the Space Shuttle. While very effective, these materials are difficult to manufacture (expensive), and either brittle (easily damaged) or very dense (heavy).

Ablative systems are generally easier to manufacture (Soviet reentry vehicles successfully used wood as an ablative heat shield). However, by their very nature these materials are not suitable for reusable designs. This makes them more expensive to operate, as they need replacing after each exposure and even their gradual erosion during a single mission will cause deviation from the optimal performance geometry (especially in propulsion applications).

Active cooling systems use some transfer medium (usually a liquid or gas) to transport the heat away from the structure to be protected and dump it somewhere else. These systems can be closed-loop like a heat-pipe or heat-exchanger/radiator combination, or they can be open-loop where the fluid is simply discarded from the system to the environment. An example would by Extra Vehicular Activity (EVA) space suits, which use water evaporation to dump heat to the environment while in use, or combustion chambers that operate with secondary injection of water to cool the structure. Active cooling systems are very effective for reusable systems (only the cooling fluid needs replacing between repeated uses), but have traditionally not been considered for large vehicle structures due to the challenge of integrating them into the design and associated weight penalties.

We propose the use of platelet manufacturing processes to create large, conformal, and low-cost metallic structures that are cooled by water transpiration cooling. If successful, this approach would enable fully redundant and reusable atmospheric reentry thermal protection systems, and high Mach number atmospheric flight for both Reusable Launch Vehicle (RLV) first stage boosters and high-speed aircraft.

## II. Technology Definition

The proposed technology of using transpiration cooling as either primary or secondary structure thermal protection could enable low-cost reusable TPS alternatives for both vehicles and subassemblies. In transpiration cooling, a fluid (gas or liquid) is channeled through openings in the structural skin surface. Transpiration Cooling (also called Film Cooling) can be controlled by selection of the opening size, density of placement, and rate of fluid flow. Both the fluid phase change and its specific heat capacity remove heat from the structure.

Panels can be constructed from a variety of metals, with selection driven by the anticipated environment. Very low-cost applications are possible using readily available aluminum alloys, while high heat-load and/or structure load applications are conceivable using more advanced materials such as titanium.

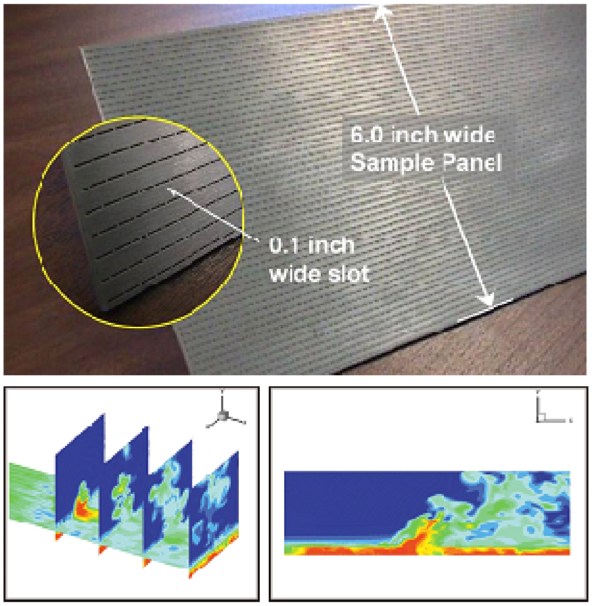

Figure 1: Active TPS prototype aluminum panel.

### A. Key Feature & Benefits

Active (water-cooled) TPS technology is both environmentally benign (non-toxic) and low-cost. The reduced materials cost enables both lower initial system cost as well as lower maintenance & repair costs throughout the systems operation. Operations are simplified with reduced maintenance work (no replacing of ablative elements) and safety is significantly enhanced through the option of non-destructive testing during system maintenance. Vehicles can be serviced faster for quick turn-around and operational responsiveness.

Maybe most importantly, the Active TPS concept has very significant safety advantages. Not only can the system be tested and monitored for effective operation both during maintenance and in flight, but it can be combined with a second (ablative) TPS layer for fully redundant fail-safe atmospheric reentry designs. Other advantages are in system robustness, even after prolonged exposure to space or other harsh environments.

For RLV applications, the ATPS technology can be applied to targeted areas such as joints, aerodynamic leading edges, or sensitive mechanisms (landing gear doors). This would enable higher staging Mach numbers for fully reusable first stage booster concepts. Through tailoring of the system characteristics such as material selection, fluid selection, and size / density of orifice openings on the panel, the technology is adaptable to a variety of applications.

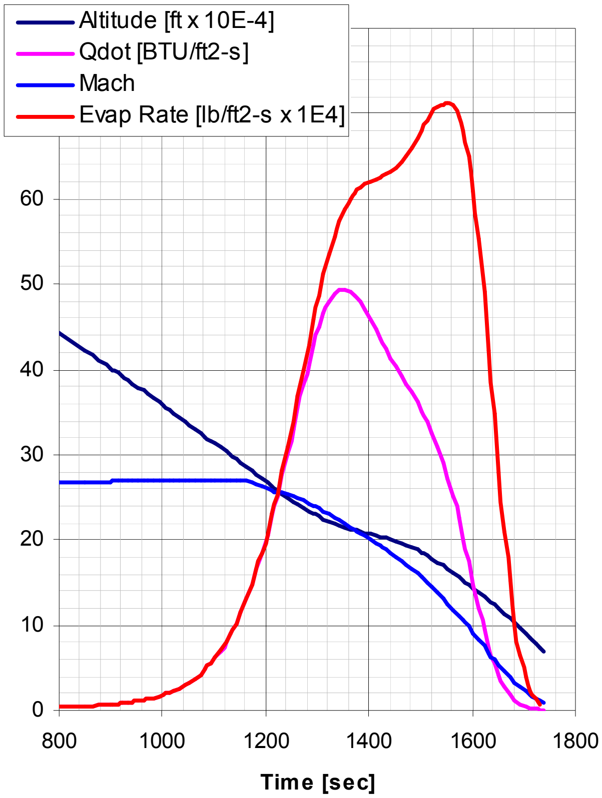

Figure 2: Typical orbit reentry profile using ATPS.

### B. Technology History

Transpiration or Film Cooling is routinely used in propulsion applications throughout the aerospace industry (rockets, jets) and also in the automotive industry (internal combustion engines). The TPS material commonly used for reentry vehicles known as SIRCA (Silicone Impregnated Reusable Ceramic Ablator) uses a film cooling mechanism (however it is ablative and not reusable). Given the scale of current film cooling applications in propulsion, there is currently a gap in the expertise regarding the production of large sections of ATPS panels. We have identified platelet technology as a promising technique for this purpose, and a prototype was successfully constructed for use with water/steam as the working fluid. The platelet process (Figure 4) is well understood and can be performed with various metals including copper, titanium, nickel steel, and aluminum. The process is suitable for the production of combustion chambers and nozzles for rocket engines and thrusters, as well as large structural plate elements for vehicle skin TPS.

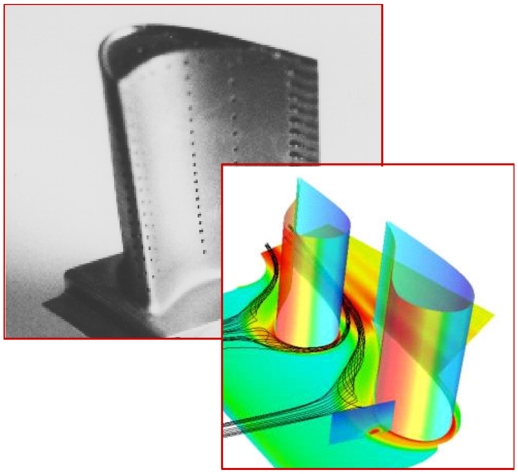

**Figure 3: Film cooled jet turbine blades.**

## III. Program Goals

At present, the Technology Readiness Level (TRL) of the proposed application is at TRL 3: a prototype has been manufactured and its basic function has been verified in a laboratory environment. The goal is to advance to TRL 6: a system demonstration in a relevant environment, while retiring the risks of manufacturing, integration, operability, and performance.

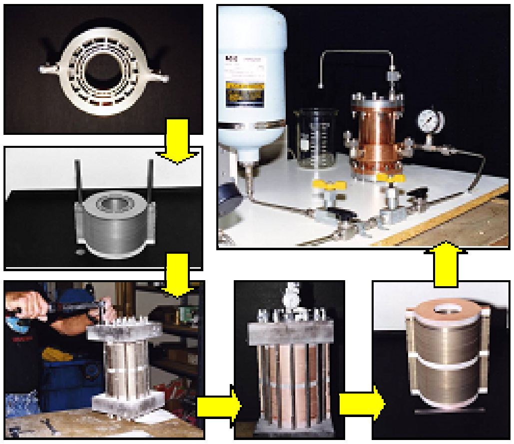

**Figure 4: Platelet manufacture of a cylindrical heat-exchanger element using copper.**

The technology maturation roadmap (Figure 5) includes mitigation targets in the area of manufacturing such as the ability to create conformal panels and complex geometries, as would be needed to accommodate nose cones, aerodynamic leading edges, and vehicle walls. This includes a demonstration of robust cross-connects between panel segments, and a firm foundation of manufacturing cost to meet the low-cost objective.

In the area of operability, the system will be investigated for potential failure modes such as clogged pores, which may become an issue in ground handling or touchdown of reusable vehicles on a runway. Panel performance degradation due to impact damage and/or punctures will also be investigated. This addresses the system's ability to survive prolonged exposure to the space environment (MMOD) or bird-strike on aircraft during operation.

Integration risks to be retired are possible interaction of the outgassing during active cooling with the aerodynamic properties of the structure being protected. The integration of ATPS with secondary ablative solutions for fail-safe redundancy will also be investigated.

Performance concerns are in the flow-rates required to achieve specified heat mitigation parameters, and the impact of panel geometry on the flow of the working fluid throughout the panel passages. The program will include rapid prototyping and testing to validate predictions generated by CFD and thermal analysis models, allowing for higher confidence when extrapolating to fully integrated application scenarios.

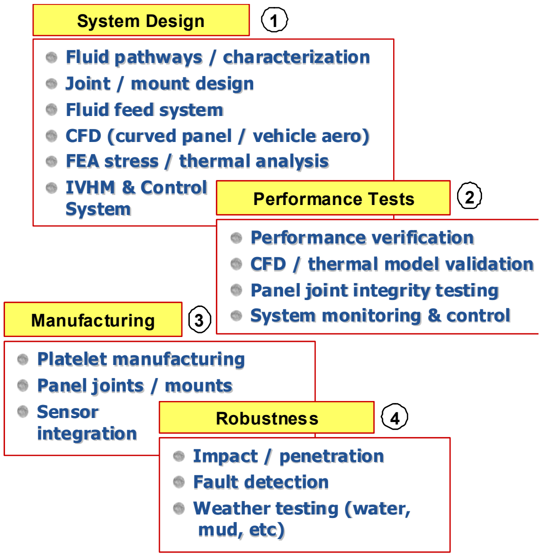

**Figure 5: Technology maturation road map.**

# IV. Test Program

Various heat sources are readily available to enable a rapid prototyping program as outlined in the previous section. We have extensive experience in the setup of test facilities that allow for testing in progressively more challenging operating regimes from ground handling and operations all the way to high Mach number flight and atmospheric reentry.

## A. Jet Exhaust Testing

Panel testing using the exhaust of a turbojet engine provides an inexpensive method for the validation of analytical models in a relevant environment. Stream conditions of up to Mach 3 and 2000 K are achievable. We have previously operated this type of facility (Figure 6); typical test article configurations can measure up to 3 feet in diameter. Test objectives for this approach include:

- Internal flow / thermal model verification
- Structural integrity of individual panels and joints
- Cooling performance verification (low Mach)
- Panel joint integrity testing (low Mach)
- System monitoring & control system shake down

**Figure 6: Outdoor jet test facility at Mojave CA.**

## B. Arc Jet Exhaust Testing

Higher flow temperatures are achievable using the exhaust from a plasma arc discharge. Small test objects can be tested inexpensively using commercially available plasma torches (Figure 7). Larger panel configurations (up to 10 feet) can be tested at the NASA Ames Arc Jet Facility. The facility has a proven capability of reproducing atmospheric reentry environmental conditions (Apollo, Space Shuttle, X-33, X-34, etc) and a test rate of up to 500 tests per year. Both conical and flat panel type geometries can be accommodated, with gas flow reaching 4500 K and speeds in excess of Mach 6. Test objectives for this approach include:

- Thermal model verification
- Structural integrity of individual panels and panel joints
- Cooling performance verification (high Mach)
- Panel joint integrity testing (high Mach)
- System fault detection / tolerance

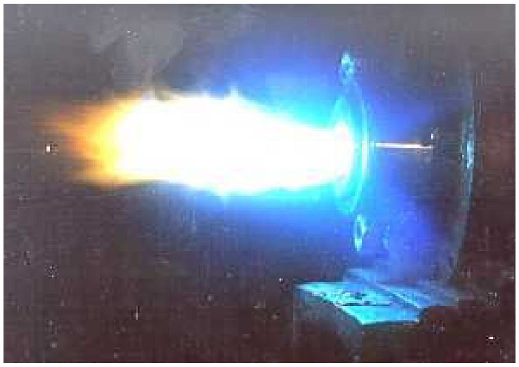

**Figure 7: Exhaust plume of a commercially available industrial plasma torch.**

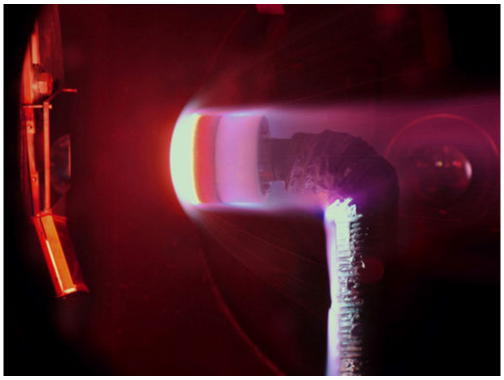

**Figure 8: Conical test article in the NASA Ames arc jet facility.**

# V. Summary

This paper discusses the use of platelet manufacturing for the development of film cooled aerospace thermal protection systems. Active TPS has many applications in aerospace systems, and very significant safety and operational advantages. It can be paired with ablative type TPS for fail-safe redundancy, and its inherent reusability enables simplified ground handling and quick vehicle turn-around. The ATPS technology base is well established from air breathing propulsion applications and the physical processes are very well understood. The extension of the film cooling approach to structural TPS for reentry and launch vehicles only requires a moderate investment.