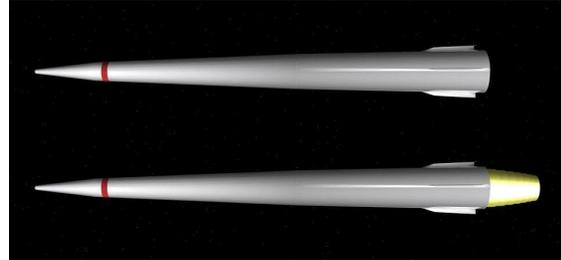


Morphing High Temperature Shape Memory Alloy Actuators for Hypersonic Projectiles

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PROBLEM STATEMENT

Sea-level launched hypersonic rounds will undergo immense aero-thermal heating throughout flight. Care must be taken to design control actuators and surfaces that will not only survive high temperatures, but also maintain their performance. The extreme nature of each flight configuration demands innovative airframe and actuator design to ensure survivability, and ultimately the desired lethality at strike. In the development of the hypersonic projectile control actuation systems, size, weight, and power consumption are major concerns. An electronically-controlled actuator system developed with Shape Memory Alloys (SMAs) can provide the necessary performance while operating within the size, weight, and power limitations of the projectile. The thermal and structural survivability of actuators and control surfaces are being tested under the Midé program. In addition Midé is investigating other uses of SMAs, for the hypersonic projectile including, morphing deployable boat-tailing and multi-thrust point concepts for drag and parasitic mass reduction.

WHO CAN BENEFIT?

The technology is being developed to be applied in high speed projectiles. Many of these programs are being developed over a long time period and will only be operational within the next ten to fifteen years.

Boeing and Draper Laboratories are two of the major primes that are involved in the development of high speed projectiles. There are also many programs and concepts for new cruise missiles within the U.S. defense industry. Some of these programs are active weapons programs, while others are in the early phases of experimental demonstrations and investigations.

Smart Memory Alloys (SMA's), the material used by Midé in the design of the actuators, are being used in numerous commercial aerospace applications. A more robust, high response actuation system can greatly enhance the current state of the art systems. SMA actuators can also

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be used in the development of higher response robotic structures. Another application area is the medical field. Research has gone into the development of surgical tools of SMA's such as bone plates or the repair of highly fractured bones. SMA may also be used in thermally activated venting safety systems for rocket motors.

BASELINE TECHNOLOGY

The baseline design platform for these actuators is a hypersonic round, which will operate in a harsh thermal environment due to aero-thermal heating at high Mach numbers. The expected operating temperatures is up to 720 K for internal components, and considerably higher at the leading edges of the control surfaces. The scope of the program involves aerodynamic control surface actuators; smooth body morphing multi-thrust points concepts, and a deployable boat-tail effort. In this thermal environment, the control surface actuators must be able to deflect to the required angular stroke and maintain a high bandwidth operation.

The baseline projectile is a 3' long slender conical body. The control surface baseline concept incorporates aft body planar fins, actuated by center hub fin shafts that are driven by a motor and gear set. This is certainly just concept level, and no actuator scheme has currently been built or tested. Limitations of this design are concerns of the survivability of the gear set at high launch loads and the availability of a motor that can perform at the elevated temperatures and launch loads. The baseline projectile does not incorporate smooth body morphing multi-thrust points or a deployable boat-tail, and thus the concept development in these areas will be evaluated by comparing their drag, structural survivability, and weight to that of the baseline projectile itself.

TECHNOLOGY DESCRIPTION

The main objective of the Phase II STTR is to optimize the structural aerodynamic and aero-thermal performance of a hypersonic airframe and its control architecture. These goals are being met with Midé developing drag reduction and control mechanisms focusing on smart materials, while Colorado University employs in-house optimization software that models aero-thermal performance.

Goals of decreasing aero-thermal heating at high Mach numbers and increasing range by reducing the drag of the projectile are being met by developing coupled aero-thermal/structural heating analysis tools, and a smart material deployable boat-tail to reduce base-drag. Also, Midé is looking at developing adaptable thrust points, which will either retract from flow at launch, or quickly dissipate in the high-thermal environment.

In addition aero-servo systems are being developed for flight control under extreme thermal flight conditions. Currently, Midé is evaluating candidate actuators, control surfaces, and materials, and focusing on novel actuators and smart materials.

Primarily, Midé is investigating SMAs for use with retractable thrust points, pop-out boat-tails and morphable control surfaces. The benefits of using SMAs for these applications are:

- Reduced part count by limiting motors and gears
- Lower actuator mass by utilizing the high power density of SMA

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- The potential to morph portions of control surface or body geometries for improved aerodynamic performance.
- High strain characteristics of SMA may allow components to be wrapped around or intricately packaged within the body

SMA is capable of these benefits, due to changes that occur in its crystalline structure in different temperature ranges. With specific heat-treatments SMA can be programmed to return to a certain shape when the material's temperature exceeds a certain transition threshold. In its soft martensite phase, the alloy can be deformed and strained into many shapes with low applied stress. When the material's temperature is raised above its transition point, the material reverts to its pre-memorized state, capable of performing considerable work while morphing into shape. The transformation is a key component to making SMA a very high energy density actuator material. The large thermal excursions seen in high speed projectiles provide a perfect opportunity to exploit SMA as a thermally activated actuator. Figure 1, shows the amazing capability of SMA, as it transforms from a wrapped up configuration into rigid boat-tail type geometry.



Figure 1: SMA actuation demonstration.

Left: SMA sheet in its soft Martensite state rolled up and attached to a boat-tail mold at one point.
 Center: SMA sheet as it is being heated and returning to its memorized truncated conical shape.
 Right: Rigid SMA sheet in its memorized Austenite shape wrapped around the conical mold.

Features	Advantages	Benefits
Multi thrust points.	Distribute launch loads over entire surface of projectile.	Creates smooth aerodynamic surface.
Actuators for control surface fins.	Actuators can survive thermal loads.	Reduced part count.
Deployable boat-tail.	Reduce launch mass.	Reduce drag. Allows for increased stability. Reduced mass / weight.

CURRENT STATE OF DEVELOPMENT

Midé is currently reducing SMA boat-tail deployment concepts, and creating sizing requirements with aerodynamic modeling. A projectile is said to have a boat-tail when the diameter at the end

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of the projectile reaches its largest point near the rear, with a gradually declining diameter until the end of the bullet. The boat-tail shape reduces drag on the projectile. In addition, control surfaces and actuator materials are being reviewed for use in high speed projectiles. Some of the control system candidates currently being reviewed are: deployed grid fins and high temperature piezo-ceramic materials for actuator control. Aerodynamic simulation models are being developed and will be used to perform trades to optimize designs and down-select between options. The design effort will focus on ensuring that the entire system will meet all requirements, such as desired CEP, minimized drag, and ideal thermal management. System components will continue to be fabricated and tested at room temperature in order to demonstrate functionality of the control architecture, retractable thrust rings, and boat-tail deployment mechanisms. Continued tests will help validate the boat-tail components are functioning as expected, before moving on to high-temperature prototype testing and modeling.

Colorado University is pursuing analysis of a transient coupled aero-thermal model of the projectile geometry. Current development efforts are focusing on the implementation of the Q* ablation model into the Finite Element code.

The Phase II work will continue with sensitivity analysis modules that will be developed for evaluating the gradients of the transient aero-thermal-structural response with respect to changes in geometry and material parameters. In addition an optimization of the effects of thermal protections systems, in particular ablative coatings, and thermo-elastic/plastic material behavior will be investigated.

The expected Technology Readiness Level on the completion of Phase II is TRL4, moving on to TRL5-6 during option phases. Midé in an associated effort has built a wind-tunnel model of the baseline projectile geometry for the Navy. Building from that effort Midé may move on to develop our own concepts to be integrated into the next set of wind-tunnel and thermal testing. Midé is looking to work with prime contractors that are involved in the development of high speed projectiles.

REFERENCES

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ABOUT THE COMPANY

Midé Technology Corporation is headquartered in close proximity to the nation's premier high-technology research and development areas of Cambridge and Boston, Massachusetts. Founded in 1989 by Dr. Marthinus van Schoor, a Ph.D. graduate of the Massachusetts Institute of

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Technology's (MIT) Department of Aeronautics and Astronautics, the company has, over the years, established a high-powered team of practical experts.

Midé is an innovative technology-driven company that develops, produces and markets high performance products such as piezoelectric transducers and actuators, and other smart material based solutions, power amplifiers and system identification software; primarily for the U.S. Government as well as the aerospace, automotive and manufacturing industries. Our innovative people, systems approach, and customer focus provides us with the ability to conceptualize, design and deliver these high performance, intelligent systems and services tailored to our clients' needs.

Midé's Core Competencies include mechanical design, integration and testing; Digital / Analog electronics and controls; Smart Materials Systems; structural analysis and structural dynamics; Aeroelasticity and Aero-acoustics. We strive to grow our value through transitioning of technologies to products and the licensing of intellectual property.

We have a strong patent base and have been awarded 13 U.S. Patents in the fields of piezoelectric ignition; electroactive ceramics; HydroGel technologies; and measurement of stress. Midé has a proven track record in system approach and integration using our expert material knowledge. We have an excellent track record with our customers and receive numerous follow-up contracts. We regularly enter into partnership agreements with our customers.

Following are a few commercial highlights accomplished by Midé Technology Corporation:

- 12 Positive Pressure Relief Valves are flying on the international space station.
- Piezoelectric valves are manufactured by Midé and sold to various international OEMs and research facilities.
- **SBIR Transition Success:** Advanced production Hydrogel Bulkhead Shaft Seals have been installed on DDG 102 (USS Sampson). Midé Bulkhead Shaft Seal has been selected for forward fit and retrofit install for DDG class 51, and is in development of seals for several other ship classes including both LCS variants.
- Midé has spun off two high tech companies.
- Midé manufactures and sells an energy harvester product named the Volture™