CONSORTIUM FOR THE ADVANCEMENT OF SHAPE MEMORY ALLOY RESEARCH AND TECHNOLOGY

CASMART

Government Academia Industry

# CASMART STUDENT DESIGN CHALLENGE

## Spring 2015

## *What is CASMART?*

The Consortium for the Advancement of Shape Memory Alloy Research and Technology (CASMART) was established to promote the growth and adoption of shape memory alloy (SMA) actuation technologies by achieving new understanding of the materials, fostering dissemination of technical knowledge, and facilitating application of that knowledge. The consortium was initiated in 2007 by Boeing, NASA Glenn, NASA Langley and Texas A&M, where since more than 16 other organizations have joined to advance the state of the art for SMA technology through a synergy of academic, industry and government expertise.

## *Who is CASMART?*

CASMART members currently consist of:

*Academia*: Texas A&M, Michigan State, Northwestern University, North Carolina State University, University of Central Florida, University of Saarland, University of North Texas, Colorado School of Mines.

*Industry*: ATI Wah Chang, Boeing, Dynalloy, GM, Johnson-Matthey, Telezygology, Rolls Royce, Fort Wayne Metals.

*Government*: NASA Glenn Research Center, NASA Langley Research Center, Sandia National Laboratories.

## *Why CASMART?*

CASMART thrives to share applied research supporting SMA actuator applications, including material development, tools, processes, and system-level development. Provide a forum for exchange of ideas and strengthen collaborations. Promote SMA actuator technology within field and influence professional societies and research. Propose grand challenges that push state of the art. Promote commercialization.

## *When is CASMART?*

CASMART general technical meeting takes place bimonthly on the 2$^{nd}$ Friday from 11:00 to 12:30 EST. The design working group meets the 3$^{rd}$ Friday of each month from 11:00 to 12:00 EST. CASMART face-to-face meeting typically takes place in SMASIS conference in September

## *CASMART Contact Information:*

For general CASMART inquiries or issues, you can contact the organization lead or any of the Chairs listed below.


### *Othmane Benafan, Chair*

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### *Darren Hartl, Vice-Chair*

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### *THE CHALLENGE*

The *1st CASMART Student Design Challenge* is designed for undergraduate and/or graduate students working with CASMART faculty advisors to consider innovative approaches to designing tools and hardware using shape memory alloy (SMA) technology. Students will have the opportunity to showcase their creativity by applying engineering theories and methods they've learned, using engineering design principles, and leveraging CASMART members experience to address SMA design challenges in the automotive, aeronautics and space industry. The following imperatives shall be satisfied:

1. Construct and employ first-order engineering models for SMA parametric evaluation using CASMART supplied initial tools (e.g., excel spreadsheets, formulas, methods, etc.).

2. Design a user-friendly graphical interface in a way that will enhance the design process and final parametric selection.

3. Design an innovative device (see list below) that employs SMAs with the opportunity to develop new ideas toward this goal, and to pursue intellectual growth in areas of SMA design.

4. Industry/government interaction….

### *SCIENCE AND TECHNOLOGY*

Shape memory alloys (SMAs) are a unique group of materials that have the ability to change their properties, structures and functions in response to thermal, mechanical and/or magnetic stimuli. This ability is a product of a solid-to-solid, martensitic phase transformation between a high temperature, high symmetry austenite phase (generally cubic) and a lower temperature, low symmetry martensite phase (e.g., monoclinic, tetragonal or orthorhombic). Unlike diffusional solid state transformations which require atomic migration over relatively long distances, this martensitic transformation is diffusionless and occurs in a cooperative movement of atoms (generally less than the interatomic distances) that rearrange into a new crystal structure. Through this cooperative movement, atoms maintain a relationship, called lattice correspondence, between the parent austenite phase and the martensite phase lattices. In a crystallographic context, when SMAs transform from austenite to martensite, they do so through mainly a two-step process consisting of a lattice deformation (Bain strain) and a lattice invariant shear (accommodation mechanism). The Bain strain (after Edgar C. Bain [3]) refers to the lattice-distortive strains resulting from the atomic movements and shuffles needed to transform one Bravais lattice into another. The lattice invariant shear refers to the mechanisms that accommodate the shape change due to atomic shear such as irreversible slip or reversible twining, where the latter is the dominant process in SMAs.

Consequences of this phase transformation are two useful behaviors known as the shape memory effect (temperature-induced phase transformation) and superelasticity (stress-induced phase transformation). Both behaviors have been widely exploited in a range of applications including automotive, aerospace, biomedical and industrial applications.

SMAs provide new solutions and alternatives for the development of advanced engineering structures for aeronautic, automotive, space, bio-medical and other applications. SMA-based technologies can integrate sensing, control and actuation functions in a single entity, which significantly reduces design complexities and most importantly reduces total weight and size of the total system. In addition, SMAs provide many other advantages such as high power/weight and stroke length/weight ratios, smooth movement, and clean, frictionless, spark-free operation. Designing and engineering with SMAs, however, requires a new approach and design paradigm. Testing, modeling and processing methodologies of shape memory alloys need to consider the dynamic responses due to changing external and internal stimuli. As a result, new design methodologies and standards are needed to engineer high performance and reliable SMA components. To date, only six ASTM standards exist (ASTM F2004-05, F2005-05, F2063-05, F2082-06, F2516-07 and F2633-07) that focus on superelastic behavior. Additional standards and methodologies to efficiently and accurately design with SMAs.

## *TIME REQUIREMENTS*

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|---|---|
| Registration (Free) | Open Monday, December 1 |
| Kick-off and team selection | January |
| System Requirement Review (SRR) | Friday, February 13 |
| Preliminary Design Review (PDR) | Friday, March 13 |
| Submit abstracts to SMASIS* | Friday, March 20 |
| Operational Readiness Review (ORR) | Friday, April 10 |
| Submit final full length paper* | Friday, May 22 |
| Present at SMASIS conference | Monday-Wednesday, September 21-23 |

** Need approval from University mentor*

***REGISTRATION:***

Registration forms must be completed starting Monday, December 1. Only one registration form is required per team. Each team must designate a student primary contact (project manager) for reporting purposes, and a team name for the project.

***Teams and Roles***

- The registration form requires each team member to provide (use provided form):
    1. Full name
    2. Team member role and responsibilities
    3. Current institution/college/department
    4. Degree program
    5. Expected graduation date
    6. Email address
- Each team shall consist of 3 to 5 members from CASMART member institutions

***SPONSORSHIP:***

Teams are encouraged to seek sponsors to support their design effort. The role of the sponsor(s) may be to provide in-kind labor for the design effort and/or future construction and donation of materials.

CASMART members will provide in-kind support through mentorship, materials and/or equipment needed to accomplish the design.

Conference attendance: Teams are encouraged to seek funding from the university and/or external entities to attend and present at the conference venue. Conference information can be found here: http://www.asmeconferences.org/smasis2015/. In the event that no member(s) can attend the conference, A CASMART representative from that institution can present on behalf of the team(s).

Teams are encouraged to explore design plans within a limited budget to be established by the member organization (depending on availability of funds)

***AWARDS:***

Each team will have:

1. The opportunity to interact and establish contacts with SMA experts in industry, academia and government.
2. The opportunity to present their work at a professional conference.
3. Winning team(s) will be awarded with a CASMART award plaque and/or certificate(s) in recognition of their achievements and design innovation.

## *SMA DESIGN CHALLENGES*

*Guidelines to the listed design opportunities are to be defined by the student team(s) and the CASMART point of contact organizing each design challenge.*

### ***Challenge Deliverables***

- A working model that models the basic functions of the design.
- A project report (not to exceed 50 pages including all figures and appendices).
- A 15-minute (20 including Q&A) oral presentation.
- If approved by organization :
  - Abstract and full length paper to be submitted to SMASIS 2015
  - Conference presentation

### **Constraints**

- Each team will have a budget constraint of $200 for project development and final model build. Donated smart materials do not count against this budget.
- The project must be completed in the Spring 2015 Semester. Additional work on the report and presentation may be done after, but the design and model should be frozen at each university's finals week.
- Shape memory alloys should be used in the final prototype.
- Only engineering models may be used for SMA component calculations – no Finite Elements or other simulations.

### ***Design challenges***

1. **Deployable Solar Array**

   Most spacecrafts, rovers and satellites flown to date are powered by deployable solar arrays that consist of deployment, positioning and assembly mechanisms. NASA has an enormous interest in High-fidelity, functioning, innovative structures and materials technologies and capabilities for the next generation of lightweight solar arrays mechanism. Designs that offer flexibility and minimize structural mass and packaging volume while maximizing deployment reliability, deployed stiffness, deployed strength, and longevity of

the mission. The mass savings in some of these arrays come from solar array supporting structures and deployment mechanism. The goal of this design challenge is to construct a small scale deployment device made of shape memory alloy with the following requirements:

a. Deploy upon request when the spacecraft reaches desired orbit. This component needs to consist of a retaining devices, hinges and any other necessary hardware to retain the panels close and deploy when needed.
b. The hinge mechanism shall remain structurally intact and able to support the simulated solar array mass throughout the entire mission without any signs of detrimental operation of the hinge such as those that could cause binding, jamming, or seizing.
c. Positioning mechanism(s) shall aid in orienting the solar panels to the optimum sun and or albedo angles.
d. The prototype shall be scalable to multiple solar panels and capable of deploying multiple systems simultaneously.
e. Specifications such as size, weight, angles, power, etc. will be provided upon project start date.

| **Requirements** | **Specifications** |
|---|---|
| Safe | The design should meet 99% or better reliability. This success rate should be documented for a samples size of at least 100 consecutive operations of the final model. |
| Form | The full-size design should be compact and lightweight in order to be integrated at the hinge line and or other accessible locations. |
| SMA design | SMA shall be used for deployment (e.g., superelastic SMA), release mechanism (e.g., SMA springs), and positioning system (e.g., torque tubes) |
| Scalability | The design should be scalable to multiple panels |
| Durable | The device should be service-free for a year. Deployment can occur multiple times per orbit. A minimum of 2 cycles per orbit can take place. |
| Cost-Effective | While each team has a $200 budget, one metric for judging final designs is cost effectiveness. Every dollar required should be justified. |

Requirement for prototype: The final model should maintain the requirements set forth upon project start date.

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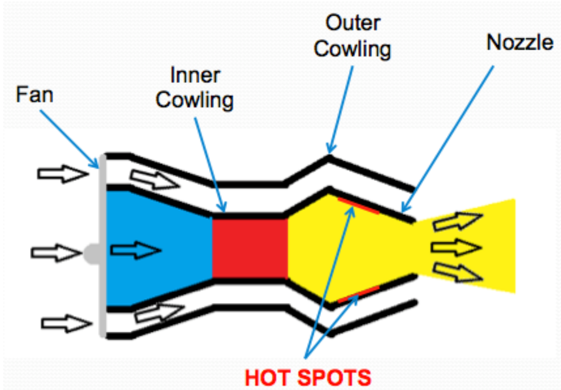
## 2. Passive Turbine Inner Cowling Vent




A jet engine development cycle can take ten or more years. In the design process, care is taken to design the jet engine geometry to be as efficient as possible. However, sometimes when the engine is built "hot spots" arise in the nozzle (exhaust) of the engine due to unanticipated, non-ideal operating conditions. These hot spots are not a permanent state, but rather occur only in extreme conditions. Still, when they do form, they can cause harm to the engine. The current solution to alleviate these hot spots without complete redesign and manufacture of the nozzle is to put holes in the inner cowling where the hot spots occur. These holes solve the problem, but also make the engine less efficient, as the mixing of the airstreams through the inner and outer cowlings was not the original intent of the design.

SMAs can provide a unique solution, as their shape change can be triggered by a change in temperature. In this project, Boeing and Dynalloy challenged the students to design a vent for hot spots that would automatically open in cases of extreme temperatures, but remain normally closed to preserve the efficiency of the engine at all other times. In response, the students developed Naturally Cool. In their prototype, the cooling hatch is normally closed. When the core gets too hot, an SMA wire changes shape and causes the slots to open, allowing cool air from the outer cowling into the nozzle. Once cooled, the SMA becomes deformable (similar to bendable eyeglass frames) and a spring element stretches the SMA and returns the vent to its closed position, restoring the efficiency of the turbine core

| **Requirements** | **Specifications** |
|---|---|
| Safe | The design should meet 99% or better reliability. This success rate should be documented for a samples size of at least 100 consecutive operations of the final model. |
| Lightweight | The full-size design should add no more than half a pound of weight to a GE-90 engine. The weight of the model should be scaled appropriately. |
| In-plane | The design should not alter the airflow through the turbine when closed. |
| Durable | The device should be service-free for a year. Each plane may fly 2 routes per day, and the over-temperature protection may be needed up to 5 times per |

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|---|---|
| | route. |
| Cost-Effective | While each team has a $150 budget, one metric for judging final designs is cost effectiveness. Every dollar required should be justified. |

Requirement for Model:

The final model should maintain proper aspect ratios of the GE-90 turbine. The largest dimension of the model may not exceed 3 ft.

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3. **<u>Deployable and stowable helical turbine</u>**

Deployable and stowable helical wind (or solar) turbines for harvesting energy from winds and storms. This vision (and figure) was generated by a team of NU undergraduate students through a design project advised by Stebner (Brinson's PhD student allocated to the proposed work).

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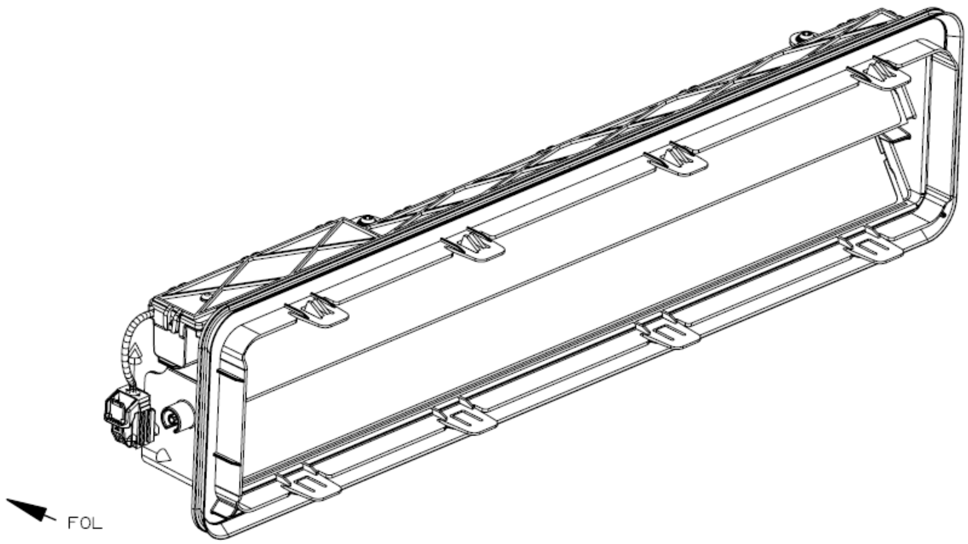
4. **<u>Alternative SMA actuator to drive the Active Hatch Vent (AHV) in 2014 Corvette Stingray</u>**

The current production AHV uses a linear SMA wire actuator to drive the vanes via a gear train. The actuator assembly is slid in from the top left and snapped in to detents on the housing to be secured. This student project seeks an alternative actuator placement to the left side of the vent. A preferred design would be using SMA spring(s) packed in a 1.5"x3"x0.5" envelope. If desired, the students can use the current reset spring inside the current actuator assembly. Alternatively, the complete current actuator assembly could be removed and a new mechanism installed.




Students will be provided two production AHV's. These are functional units for students to get familiar with the desired performance and use as a housing to build the prototypes utilizing their design.

## *DESIGN TOOLS POSSIBILITIES*

*A starting material in spreadsheet form or other forms will be provided once the project commences.*

1. Helical spring spreadsheet
2. Torque tube spreadsheet
3. Plate spreadsheet
4. Wire spreadsheet

## *USEFUL RESOURCES*

All design challenge inquires and issues must be directed to CASMART Challenge Coordinator (from that institution) or to the CASMART general chair.

- *Dynalloy: http://www.dynalloy.com/*
- *NDC: http://www.nitinol.com/*

- *Johnson Matthey: [http://jmmedical.com/resources/251/Nitinol-Shape-Setting.html](http://jmmedical.com/resources/251/Nitinol-Shape-Setting.html)*
- *TU-Berlin: [http://www.smaterial.com/SMA/sma.html](http://www.smaterial.com/SMA/sma.html)*

## *USEFUL REFERENCES*


*[1] Benafan O, Brown J, Calkins FT, Kumar P, Stebner AP, Turner TL, et al. Shape memory alloy actuator design: CASMART collaborative best practices and case studies. Int J Mech Mater Des 2014;10:1-42.*

*[2] Otsuka K, Ren X. Recent developments in the research of shape memory alloys. Intermetallics 1999;7:511-28.*

*[3] Otsuka K, Ren X. Physical metallurgy of Ti–Ni-based shape memory alloys. Progress in Materials Science 2005;50:511-678.*

*[4] Van Humbeeck J. Non-medical applications of shape memory alloys. Materials Science and Engineering A 1999;273-275:134-48.*

*[5] Ma J, Karaman I, Noebe RD. High temperature shape memory alloys. International Materials Reviews 2010;55:257-315.*

*[6] Duerig TW, Pelton AR. TiNi Shape Memory Alloys. In: Boyer R, Welsch G, Collings EW, editors. Materials Properties Handbook - Titanium Alloys: ASM International; 1994. p. 1035-48.*


***<Modelers: please add important and related modeling papers***

| **CASMART STUDENT DESIGN CHALLENGE: Registartion form** | | | |
|---|---|---|---|
| **Team Name:** | | | |
| | | | |
| **College/University:** | | | |
| | | | |
| **Address:** | | | |
| | **City:** | **State:** | **ZIP:** |
| **Team Info** | | | |
| Student Name 1:<br>Email:<br>Phone (opt):<br>Role:<br>Degree program<br>Expected graduation date | | | |
| Student Name 2:<br>Email:<br>Phone (opt):<br>Role:<br>Degree program | | | |

Expected graduation date

Student Name 3:
Email:
Phone (opt):
Role:
Degree program
Expected graduation date

Student Name 4:
Email:
Phone (opt):
Role:
Degree program
Expected graduation date

Student Name 5:
Email:
Phone (opt):
Role:
Degree program
Expected graduation date

Student Name 6:
Email:
Phone (opt):
Role:
Degree program
Expected graduation date