CONSORTIUM FOR THE ADVANCEMENT OF SHAPE MEMORY ALLOY RESEARCH AND TECHNOLOGY

CASMART

Government Academia Industry

CASMART 2nd STUDENT DESIGN CHALLENGE

Fall 2016 – Spring 2017

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, whereupon 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. Shape Change Technologies, LLC.

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

Why CASMART?

CASMART strives to share applied research supporting SMA actuator applications including material development, tools, processes, and system-level development through the following means.

- Providing a forum for exchange of ideas and strengthening collaborations
- Promoting SMA actuator technology within the field and influencing professional societies and research
- Proposing grand challenges that push state of the art
- Promoting commercialization

When is CASMART?

CASMART general technical meetings takes place bimonthly on the 2nd Friday from 11:00 AM to 12:30 PM Eastern. The design working group meets the 3rd Friday of each month from 11:00 AM to 12:00 PM Eastern. CASMART face-to-face meetings typically take place in conjunction with the 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.

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A NOTE FROM SHAPE MEMORY AND SUPERELASTIC TECHNOLOGIES (SMST)

Welcome to the ASM International Organization on Shape Memory and Superelastic Technologies (SMST). We are a volunteer-led professional society that serves to promote networking, education, and dissemination of knowledge amongst inventors, entrepreneurs, scientists, engineers, and academics working with materials that exhibit shape memory behaviors.

While some aspects of these materials are quite simple, such as the idea of putting together equal parts nickel and titanium atoms to make a metal compound, the underlying physical behaviors of these materials and their responses to different environments are often complex. At the core of SMST is a group of experienced professionals from industry and academia dedicated to furthering understanding of these complexities, preserving knowledge from past lessons learned, and most importantly training the future leaders, innovators, and doers for the field.

Thus, the distinguishing characteristic of SMST is a focus on serving the industry of shape – memory technologies. This industry is largely centered upon nickel-titanium shape memory alloys (Nitinol) and their derivatives. We are also experiencing exciting growth in novel technologies emerging from new materials such as shape memory polymers and nickel-free shape memory alloys.

SMST POSTER FAIR

New Format for the 2017 SMST Poster Fair! This year, we will transform the poster fair into an "inverse career fair", where people looking for new opportunities in SMST technologies market themselves to the SMST community. This includes people looking for sales/R&D/Engineering jobs in industry as well as students looking for post-docs or graduate research assistantships in academia. Anyone interested in marketing themselves to the SMST community in this manner, please apply for a poster slot. Then, bring a poster that highlights your skills and/or achievements for the SMST community to display, plus a 1-2 page resume' to pass out to people interested in following up with you.

THE CHALLENGE

The *2nd CASMART Student Design Challenge* is intended for undergraduate and/or graduate students to consider innovative approaches to developing new materials 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 aeronautics, astronautics and medical industry. Multiple application examples are provided (see below) by CASMART organizers of the challenge. Each example includes a description of the application, the objective(s), constraints, etc.

Each project consists of two elements:

1. Design *THE* material: Consists of designing a new shape memory alloy to match specific requirements as outlined in the project description. This involves researching prior art, classify properties, and finally suggesting and making the material formulation. Students will have the opportunity to engage and collaborate with industry and/or government members of CASMART to share ideas and experience.

2. Design *WITH* the material: Consists of designing SMA hardware with commercially available SMAs, but with a transition path using the newly developed SMA above. The challenge involves developing an actuation/structurally strategy from the available SMA forms such as wire, helical spring, plate and torque tube, and others. Students will have the opportunity to develop new ideas toward this goal, and to pursue intellectual growth in areas of SMA design.

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 mainly through 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 twinning, 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 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 are needed.

TIME REQUIREMENTS

Kick-off and team selection	Friday, September 2nd (Fall 2016)
	Friday, January 13th (Spring 2017)
Present at SMST 2017 conference	Monday-Thursday, May 15-19

** Need approval from University mentor(s)*

REGISTRATION:

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 no more than 5 student members and no more than 2 faculty advisors).

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.asminternational.org/web/smst2017/home .

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. The potential for publishing their work in a technical journal via a special-issue arrangement between the SMST Conference organizers and the Shape Memory and Superelasticity journal.

4. 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.

Design challenge 1: ***Expandable Habitat and Deployable Platforms***

Design challenge 2: ***Design of a wire-based body temperature actuator for distal medical tissue manipulation***

Challenge Deliverables

- A proven material or 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 SMST 2017
  - Conference presentation

Resources:

- Budget: Each team will have a budget constraint of $250 for project development and final prototyping. Donated smart materials do not count against this budget.
- Shape Memory Material: Shape memory alloys (e.g., wires, rods, tubes) will be donated and/or supplied by supporting CASMART organizations.
- Alloy processing: support for this effort will be provided by supporting CASMART organizations.
- Mentorship: each project will have a CASMART point of contact (POC) to provide mentorship, clarification and review throughout the R&D phase and project completion.
- Implementation plan: Participants shall start and complete this work in the time frame specified herein but is estimated to be around 2 semesters (Fall 2016 and Spring 2017) from acceptance to delivery of hardware.
- CASMART tool: a set of CASMART developed design tools (wire, springs, tubes) will be provided and explained by supporting CASMART organizations.
- Travel: Each group or a group representative is required to attend The International Conference on Shape Memory and Superelastic Technologies (SMST) to be held May 15 – 19, 2017 in Paradise Point in San Diego, California, USA.

- Each team shall consist of no more than 5 student members and no more than 2 faculty advisors).

Design challenges

Expandable Habitat and Deployable Platforms

1. INTRODUCTION

NASA’s journey to deep space exploration will soon consist of manned missions to asteroids, Mars and other objects of the solar system. Part of these missions include new technologies for life support, detection, human health and habitat systems that are necessary for human spaceflight beyond low-Earth orbit (LEO). In support of these mission, development of expandable habitat is required to support long term human space travel in the harsh space environment. Such habitat can be for crew quarters, greenhouse, spacecraft cabins, storage modules, in-space facilities, passenger compartment, or many other functionalities. Over the years, many inflatable habitat technologies have been developed, and just recently flown to the International Space Station (Figs. 1 and 2). The habitat needs capitalize on volumetric efficiency and structural rigidity, but at the same time be lightweight and compact for launch purposes. The habitat should also provide means of deployment and recovery as needed throughout the mission.

Fig. 1: William Gerstenmaier, NASA’s associate administrator for human exploration and operations, left, and Jason Crusan, director of NASA's Advanced Exploration Systems, take a closer look at the packed Bigelow Expandable Activity Module (BEAM) at Bigelow Aerospace's Las Vegas facility before it launches on the eighth SpaceX resupply mission to the International Space Station. Credits: NASA

Fig. 2: The BEAM module will be attached to the rear port of the space station’s Node 3. After installation, the BEAM expands to roughly 13-feet-long and 10.5 feet in diameter. Credits: Bigelow Aerospace, LLC

Most of the inflatable habitat, however, suffer from dimensional stability and rigidity. Adding structural members such as metallic trusses or linkages adds rigidity but presents new challenge such as weights, and difficulty in deployments. The challenge is: can expandable habitats be built with flexible and rigid materials while maintaining small and lightweight footprint? Can expandable habitats be built with non-pressurized components? Can the structure be deployed, recovered and redeployed throughout the mission?

2. SCOPE

The goal of this student challenge is to design and build an expandable habitat for a fictional mission to Mars using shape memory alloy technology. The mission is called "NAP" and is planned for a total duration of 4 years that includes the flight to Mars, orbiting multiple times and travel back to planet Earth. The Four astronauts aboard the spacecraft will require private dormitories with enough space for an average 6 feet tall person weighting approx. 180 lbs. The dorms are the expandable habitats that needs to be deployed by the astronauts as needed, and re-stowed once not in use.

3. DESIGN REQUIREMENTS

3.1 Material Design Challenge

The shape memory material for the Expandable Habitat shall consist of superelastic, shape memory effect, or a combination thereof. For the selected mission, the design challenge shall consist of the following:

a. Research and document a list of cold shape memory alloys that
    i. Transformation temperatures: The material Af at zero external stress shall be at -150 °C ± 10 °C. Document the Temperature-stress shifts.
    ii. Actuation/superelastic strain: fully recoverable strains at max operating stress shall be at least 3.5 % strain for actuation and recoverable superelastic.
    iii. Hysteresis: material shall be classified as a narrow (~20 °C) and wide (~50 °C) hysteresis span. At a minimum, a method shall be outlined to produce the desired hysteresis.
    iv. Stress plateau at above Af equal or better than NiTi binary alloys (no less that 200 MP{a over the operating range of the intended application)
    v. Actuation cycles (stability): an inherent thermal and dimensional stability is required. Composition control, strengthening methods, grain size control, multi-phases (R-phase, B19') and processing techniques shall be employed.
b. Propose a candidate alloy to be made to validate the findings.
c. Students shall address the following:

   i. Cost: No precious metals shall be used. NiTi-based or other cheaper alternatives are sought.
   ii. Production method: Arc, VIM, VAR, ISM, Etc.
   iii. Melt Purity: Carbon content should be less than 0.030 wt.%, and Oxygen content should be less than 0.08 wt.%.
   iv. Alloy form: material shall be processable to a useful form such as rod, plate wire, tube, etc.

d. Characterization: students shall perform some basic characterization of the alloy to determine, microstructures, thermal response, mechanism strength or a combination thereof (SEM, optical, DSC, chemistry, thermomechanical testing, etc.).

3.2 Hardware Design Challenge

The Expandable Habitat shall comply with the following requirements:

a. Stowed configuration: the structure shall fit within a 1' x 1' x 0.3' bounding box. This should allow it to fit within the launch payload geometry constraints
b. Deployed configuration: Once deployed, the structure shall expand to within 7' x 4'x 4' to accommodate a crew a member for example (rest area)
c. Weight: the entire structure shall not weight more than 2 lbs (minimize weight)
d. Rigidity: the platform shall handle launch loads (see GSFC-STD-7000A), thermal environment for the selected mission, pressure differential, gravitational loading. Key aspect is maintaining shape.
e. Debris impact: The structure shall resist any impact from debris, meteorites, or other foreign objects. Define impact load (need velocity)
f. Radiation shielding: The outer shell (e.g., fabric) shall provide radiation shielding and possibly a view port to space (as needed)
g. Remote deployment/recovery: The structure shall be deployed on-demand, and stowed back to initial position as needed, i.e., the structure shall allow for multiple deployment and recovery (10 cycles/mission) cycles
h. Power requirements: not to exceed 150 Watts. Goal is to minimize power consumption
i. Other consideration: folding methods, fabric connection to maintain sealing, access point, fail-safe, volumetric expansion, scale-up or down-size options, oxygen/nitrogen valves, interfaces (e.g., fabrics to SMAs), non-pressurized concept.
j. Trade-space: maximize habitable space (deployed), reduce launch weight/volume, increase structural rigidity, flexibility vs rigidity, deploy/redeploy methods, insulation (MLI, Aerogels...), expansion factors (e.g., vertical vs. volumetric), and other factors.

4. APPLICABLE DOCUMENTS AND DEFINITIONS

The following documents are applicable to this work:

a. NASA Roadmaps (http://www.nasa.gov/offices/oct/home/roadmaps/index.html)
    i. TA 12: Materials, Structures, Mechanical Systems, and Manufacturing
    ii. TA 6 Human Health, Life Support, and Habitation Systems
    iii. TA 7 Human Exploration Destination Systems
b. NASA-STD-6016: Standard Materials and Processes Requirements for Spacecraft
c. NASA-STD-5017: Design and Development Requirements for Mechanisms
d. GSFC-STD-7000A: General Environmental Verification Standard (GEVS)

Design of a wire-based body temperature actuator for distal medical tissue manipulation

5. INTRODUCTION

Since the 1980's, the development of laparoscopic surgical techniques have significantly reduced the prevalence of more invasive interventions including vascular, orthopedic and gastric surgical procedures[1]. Such procedures are enabled by slender, mechanically effective instruments that are inserted through small apertures into the body combined with simple digital cameras, fiber cameras, and/or high resolution medical fluoroscopic and magnetic-resonance-based imaging. Several types of tools have been developed and refined, for example, including tissues snares for polyp removal (Fig. 1, left) and graspers for general tissue manipulation (Fig. 1, right).

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[1] SPANER, SHELLEY JANE, and GARTH LOREN WARNOCK. "A brief history of endoscopy, laparoscopy, and laparoscopic surgery." Journal of Laparoendoscopic & Advanced Surgical Techniques 7.6 (1997): 369-373.

Fig. 1 – (left) Example Boston Scientific polypectomy snare with 13 mm loop width, order no M00561821; (right) Example Ethicon 5 mm laparoscopic tissue grasper (5DSG).

Laparoscopic tools use wires, cables, rods and linkages to directly transfer force from physician's hand movement to patient. All tools enter through a port that can range from 2 mm ("microlaparoscopy"), 3.5 mm ("minilaparoscopy") up 12 mm diameter ("laparoscopy"). The 2 mm entry port is the least invasive, and somewhat limited in utility due to rather ineffective instruments in terms of force transmission capability[2]. The design challenge is: Can shape memory alloy design be used to enable a compact, distal motor to drive a laparoscopic SMA Tissue Grasper? Can this active tip be designed for delivery within the 2 mm trocar? Can the actuator system achieve thermal operation without exceeding the safe temperature limits of bodily tissue? Can this tip be used in the future to reach more distal patient lesions, with less invasiveness, and improved ergonomics[3]?

6. SCOPE

The goal of this student challenge is to design and build a laparoscopic SMA Tissue Grasper for a fictional microlaparoscopic surgery. The objective is to enter through a 2 mm trocar where a thin gage instrument will be inserted and driven to a fictional lesion requiring 2N of compression force. At this point, the grasper tip will be deployed and used to grasp a 6 mm^2

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[2] Pini, Giovannalberto, et al. "Minilaparoscopy, needlescopy and microlaparoscopy: decreasing invasiveness, maintaining the standard laparoscopic approach." Arch Esp Urol 65.3 (2012): 366-83.

[3] Berguer, Ramon. "Surgical technology and the ergonomics of laparoscopic instruments." Surgical endoscopy 12.5 (1998): 458-462.

lesion with at least 2N of force. The grasper should be capable of sustaining this force during instrument withdrawal, release of the force to drop the tissue, and repetition of this process for at least 10 complete cycles.

7. DESIGN REQUIREMENTS

3.3 Material Design Challenge

The materials for the SMA Tissue Grasper shall utilize the shape memory effect for actuation as well as conventional materials and/or a combination thereof for necessary structure and spring bias. For the selected procedure, the design challenge shall comprise:

e. Research and document a list of body-temperature-capable shape memory alloys with:
    i. Transformation temperatures: The material's active Af (that is, in final form, at operating grasping stress) shall be 30 < T < 42°C. Document the Temperature-stress shifts, and assume a maximum material element operating stress of 500 MPa at full grip.
    ii. Actuation/superelastic strain: fully recoverable strains at max operating stress shall be at least 3.5 % strain for actuation and recoverable superelastic.
    iii. Hysteresis: thermal hysteresis throughout the operating stress range, that is from fully closed (austenite) to fully open (martensite) shall be designed to maintain a safe instrument temperature of 15 < T < 42°C. A method shall be outlined to produce the desired hysteresis.
    iv. Actuation cycles (stability): an inherent thermal and dimensional stability is required. Composition control, strengthening methods, grain size control, multi-phases (R-phase, B19'), and processing techniques shall be employed to achieve reversible gripping at a maximum material stress of 500 MPa for at least 10 complete cycles without diminished performance (loss of stroke or load).

f. Propose a candidate alloy to be made to validate the findings.

g. Students shall address the following:
    v. Cost: No precious metals shall be used. NiTi-based or other cheaper alternatives are sought.
    vi. Production method: Arc, VIM, VAR, ISM, Etc.
    vii. Melt Purity: Carbon content should be less than 0.030 wt.%, and Oxygen content should be less than 0.08 wt.%.
    viii. Alloy form: material shall be processable to a useful form such as rod, plate wire, tube, etc. A thin, commercially-available binary NiTi wire alloy is suggested.

h. Characterization: students shall perform some basic characterization of the alloy to determine, microstructures, thermal response, mechanism strength or a combination thereof (SEM, optical, DSC, chemistry, thermomechanical testing, etc.).

3.4 Hardware Design Challenge

The SMA Tissue Grasper shall comply with the following requirements:

a. Minimally invasive: the tip structure shall fit through a 2 mm inside diameter rigid stainless trocar. This should allow it to fit within a typical microlaparoscopic introducer.
b. Operating geometry: Once activated, the tip shall be capable of grasping 6 mm^2 of tissue area with an opening of greater than 3 mm.
c. Operating force: The instrument should be capable of grasping tissue and applying a force of 2-3N.
d. Rigidity: the instrument tip could be added as a tip to a rigid slender instrument, for example to reduce physician fatigue and increase force capability, or to a slender and flexible body more similar to an endoscope.
e. Energization: The instrument can be operable by suitable OR heat sources including low level DC power, cooled or heated saline. The method of energizing the grasper should be easily accomplished using "typical" sources.
f. Power requirements: not to exceed 20 Watts. Goal is to minimize power consumption and the potential of undesirable energy release to the anatomy.
g. Other considerations: consideration of how to scale grip force, provision of haptic feedback to the clinician, fatigue life of actuator component and support structure, biocompatibility, general pros and cons compared to conventional laparoscopy including a comparison of force capability compared to a similarly sized conventional microlaparoscopic instrument.

OTHER USEFUL RESOURCES

- *Dynalloy: http://www.dynalloy.com/*
- *NDC: http://www.nitinol.com/*
- *Johnson Matthey: http://jmmedical.com/resources/251/Nitinol-Shape-Setting.html*
- *TU-Berlin: 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.

CASMART STUDENT DESIGN CHALLENGE: Registration form

Team Name:

College/University:

Address:

City: **State:** **ZIP:**

Team Info

Student Name 1:
Email:
Phone (opt):
Role:
Degree program
Expected graduation date

Student Name 2:
Email:
Phone (opt):
Role:
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