CONSORTIUM FOR THE ADVANCEMENT OF SHAPE MEMORY ALLOY RESEARCH AND TECHNOLOGY

CASMART

Government Academia Industry

CASMART 3rd STUDENT DESIGN CHALLENGE

Fall 2018 – Spring 2019

*To be presented at SMST 2019

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, Smarter Alloys.

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 take 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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THE CHALLENGE

The *3rd 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, classifying 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/structural strategy from the available SMA forms such as wire, helical spring, plate, 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. In 2017 two new standard test methods for Shape Memory Alloy (SMA) materials and components were released by ASTM International. The standards are available from ASTM as E3097 Standard Test Method for Mechanical Uniaxial Constant Force Thermal Cycling of Shape Memory Alloys (UCFTC) and E3098 Standard Test Method for Mechanical Uniaxial Pre-strain and Thermal Free Recovery of Shape Memory Alloys (UPFR).

TIME REQUIREMENTS

Kick-off and team selection	Summer-Fall 2018
Reviews	End of semester 1 TBD
Final report	End of semester 2 TBD
Present at SMST 2019 conference	Monday-Thursday, May 13-17
	(Konstanz, Germany)

** 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: https://www.asminternational.org/web/smst-2019

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.

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 2019
  - 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 2018 and Spring 2019) from acceptance to delivery of hardware.
- CASMART design tools: 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 13 – 17, 2019 in Konstanz, Germany

❖ Each team shall consist of no more than 5 student members and no more than 2 faculty advisors (or grad-, post docs).

Design challenges

A. Deployment and Orientation Mechanisms For Smallsats (POC: NASA)

B. Compact Deployable Dish with Curvature Correction (POC: UCF)

C. Energy Recovery from Waste Heat (POC: Boeing Company, Shape Change Technologies)

D. SMA Tourniquet (POC: Smarteralloys)

E. An SMA Spinal Curvature Correction Device (POC: Fort Wayne Metals)

A. Deployment and Orientation Mechanisms For Smallsats (POC: NASA)

1. INTRODUCTION

Small spacecraft (SmallSats) represent the majority of the satellite industry, ranging from Mini-satellites (~100 to 500 kg) to Nano-satellites (~1 to 10 kg, e.g., CubeSats) with a record setting over 300 smallsats launched in year 2017. These SmallSats fulfill several objectives from earth observation, communication, deep space exploration and hardware testing. Particularly, Nanosats and Cubesats provide a cost effective means to perform flight testing of new hardware and perform experiments in space. The lower size and cost of SmallSats enable more tolerance of risk in mission planning. However, the small size of these satellites constrains the power that is available on the spacecraft. Often, many redundant solar arrays are attached on many or all sides of the spacecraft, but only one or two may be producing power at any given time. More power can be supplied to the spacecraft using deployable solar arrays, but redundancy is still required and a greater amount of extra weight is added.

CubeSats conform to the design specifications in the CubeSat Design Specification* and come in standard "U" sizes. A 1U CubeSat is a spacecraft with dimensions of 10 cm^3 where a 3U size CubeSat roughly measures 10 cm^2 by 30 cm long. Many of the newer technologies that could be flight tested on Cubesats, such as ion thrusters, require significantly more power. Attitude control systems such as magnetic torquers, moment control gyros, and ion thrusters can be used to provide accurate pointing for fixed solar arrays by orienting the spacecraft, but at the cost of additional electrical power and complexity. In addition, the spacecraft orientation may be dictated by the needs of communications antennas or optical instruments.

In the vacuum of space, incident solar radiation on some surfaces but not on others can generate significant thermal gradients that could be well suited to actuation of a shape memory alloy based sun tracking mount. The thermal gradients present on a satellite in orbit due to illumination and shading of different surfaces could be used to change the material properties, and hence actuate SMA structures to reorient the solar array to maximum efficiency.

Fig. 1: NASA Earth Science Division Operating Missions

Fig. 2: 3U CubeSat with deployable arrays

Successful implementation of a deployment mechanism and a fully **passive** sun tracking mount using SMA actuation would greatly improve the operational capabilities of small satellites including Cubesats and Nanosats with minimal increase in complexity. It is expected that the compact, lightweight mechanisms possible with the use of SMA's allows the overall power system weight to be reduced while increasing available power.

2. SCOPE

The goal of this student challenge is to design and build a deployment and orientation mechanism(s) that conforms to a 3U cubesat weight and footprint. The deployment mechanism will be used to deploy 1 or more solar panels, while the orientation mechanism will be used to orient the panels to maximize power collection. The deployment mechanism will be an active system (feedback controlled), while the orientation mechanism(s) will be a passive system.

*CubeSat Design Specification, Revision 13, California Polytechnic State University (February 2014).

3. DESIGN REQUIREMENTS

3.1 Material Design Challenge

For the selected smallsat, the design challenge shall consist of the following:

a. Research and document a list of shape memory alloys with:
   i. Transformation temperatures: The material Af at zero external stress shall be at +120 °C ± 10 °C for both deployment and orientation
   ii. Actuation strain: fully recoverable strains at max operating stress shall be at least 3.5 % strain for actuation

iii. Slopes (A_f-A_s): define method to control the hysteresis span from As to Af (sharp transition or very gradual)
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.
v. Actuation time: complete actuation in < 30 seconds

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 (do not use Hf, Zr, Au, Pt, Pd)
ii. Define methods to tune the transformation temperatures and slopes
iii. Production method: Arc, VIM, VAR, ISM, etc.
iv. Melt Purity: Carbon content should be less than 0.030 wt.%, and Oxygen content should be less than 0.08 wt.%.
v. 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 smallsat hardware challenge shall comply with the following requirements:

a. Perform a search on existing devices (SMA and non-SMA based)
b. Comply to 3U Cubesat specifications
c. The 3U CubeSat shall be 100.0±0.1 mm wide. (X and Y dimensions) and be 340.5±0.3 mm tall. (Z dimensions) when stowed.
d. No space debris shall be created at any point in the mission, pyrotechnics shall not be permitted.
e. Weight: mechanisms shall not exceed 0.5U of <u>usable</u> footprint (payload) and no more than 20% of the gross 3U cubesat weight (<100grams) each for the total mechanism
f. Rigidity: the platform shall handle launch loads (see GSFC-STD-7000A), thermal environment for the selected mission, pressure differential, and gravitational loading. Key aspect is maintaining shape.
g. Achieve deployment angle of equal or greater than 90 degrees from the stowed configuration.
h. Folding panels are allowed.
i. Remote deployment/recovery: The solar panels shall be deployed on-demand, and stowed back to initial position as needed, i.e., the structure shall allow for multiple deployment and recovery (20 cycles/mission) cycles (stow and redo)
j. Orientation mechanism to be fully passive and actuation time shall be within 30 seconds
k. Power requirements: not to exceed 40 Watts. (Battery power onboard the CubeSat)
l. Use NASA-STD-5017 rev A as a guide to design the mechanisms.

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)

B. Compact Deployable Dish with Curvature Correction (POC: UCF)

1. INTRODUCTION

Reliable and effective optical and communications satellites are paramount to our everyday lives. The deployment of these satellites is still cost prohibitive and requires a large percentage of support structure in payload design to create an effective platform. A compact deployable system that could be stowed during launch and deployed when the target orbit is reached could significantly reduce the volume and mass of the payload and lead to a major reduction in the cost per launch of these systems. These deployable systems could be used for satellites ranging from data communication to optical satellites in low earth orbit (LEO), geosynchronous orbit (GEO), or for probes that may need to protect instrumentation over long periods of travel. One of the unique attributes of this concept is the ability to correct the geometry (i.e., curvature) of the dish subsequent to the primary shape memory alloy deployment. This is expected to require a secondary smart material process that allows for fine adjustment of the reflective surface.

Figure 3: Ultralight 1.2 kg/m^2 reflector built by Thales Alenia Space

2. SCOPE

The end goal of this student challenge is to have a deployable shape memory dish that can function as an optical mirror for image capture or data transmission. The Compact Deployable Dish (CDD) will need to operate in environments exposed to thermal radiation and environmental perturbations. The system will need to be able to survive launch conditions and operate with minimal power during deployment, stowing, and regular operation to be competitive with current satellite dish technologies. The system should also weigh significantly less than current systems in order to capitalize on the small foot print of the concept. It is additionally required to have the ability to correct the geometry (i.e., curvature) of the dish subsequent to the primary deployment. This may be accomplished by using a secondary smart material process, either shape memory or another smart material such as a magnetic smart material, that allows for fine adjustment of the geometry of the reflective surface. A challenge is expected to arise while integrating the secondary mechanism that finely corrects the reflective surface geometry with the primary deployment mechanism.

3. HARDWARE DESIGN CHALLENGE REQUIREMENTS

The CDD will have the following requirements:

a. Stowed: The stowed configuration shall have overall dimensions of Y x Y x Y, to meet payload requirements of the host satellite including launch conditions.
b. Deployed: The deployed configuration must be parabolic/hyperbolic with a clear ocular focus for image/data capture with a maximum error from ideal of $\lambda/8$.
c. Weight: The weight is to be less than 2.0 kg/m^2 as to exceed the performance of many antennae and reduce the overall cost of flight.
d. Impact: The dish will not be required to survive impact whilst deployed, but should be able to be easily stow and return to a protected environment.
e. Power requirements: Deployment and stowing should use under 1 KW of power, environmental power sources like the sun can be used for coarse manipulation of dish surface and to reduce subsystem power consumption.
f. Vibration: The deployed Dish is required to handle minor vibration perturbations with minimal loss in focus/signal.
g. Other Considerations: Scaled sizes for sub scale and macro scale may change requirements for material selections, as well as the wavelengths of light the system can effectively capture.

4. APPLICABLE DOCUMENTS AND DEFINITIONS

a. *Modern Optical Engineering,* Warren J. Smith, Chapter 11: A quantitative procedure for quantifying image quality.
b. GSFC-STD-7000A: General Environmental Verification Standard

C. Energy Recovery from Waste Heat (POC Boeing Company, Shape Change Technologies)

1. INTRODUCTION

When the Shape Memory Effect (SME) alloy Nitinol is cycled from its cooler martensitic shape to its warmer austenitic shape, its work energy density is quite high, approximately 20 MJ/m3, which makes it a promising material for converting waste heat into other froms of energy. The primary challenge in realizing this is optimizing heat transfer between the media and Nitinol element. Two shapes that have been investigated are Nitinol open-celled foams and assemblies of Nitinol wires that are bonded. Of the two, the wire assemblies are much more mature and allow for mixing various wires of differing transformation temperatures, that increases the Carnot and thermal efficiencies of the wire ensembles.

To make available a device to convert waste heat to useful power; non-trivial fluidic, mechanical and electrical engineering designs and implementations are needed. Fluidic concepts are required to apply hot and cold fluid streams (air, water, hydraulics) to the wire or foam Nitinol elements to maximize the energy conversion efficiency of the device, i.e., how to get fluids to cycle through these hot reservoirs as quickly and reliably as possible, with minimal fluid/thermal wastage. Nitinol torque tubes respond by twisting, whereas the Nitinol wire assemblies respond by contracting, consequently mechanical engineering will also be required to convert this oscillatory motion into a rotary motion so that an alternator could be attached, allowing for waste heat to be converted to useful electrical power

Application areas for these devices are in aircraft, utilizing engine exhaust and ambient air flow, geothermal applications, industrial heat exchangers etc. using water or oil thermal reservoirs. These can be broken down into two scenarios, energy harvesting of waste hot air/exhaust gases, such as in jet aircraft or automobiles, or energy harvesting of waste hot water, such as in industrial processes, geothermal energy, etc. We assume that the waste heat is approximately 250 oC for waste exhaust gases, and 95 oC for waste water/fluids, and take ambient air or water for the cooling media.

Each scenario has its own challenges: Exhaust gases have poor thermal transfer but systems are easier to design to. Waste water is a much denser media so although the heat transfer is much faster, the systems are, as a whole, more complex to design.

Customers for each system can vary, hot exhaust application for automotive applications, where the system must be simple and inexpensive, or remote power application, where the customer will pay significantly more for available power. Domestic energy conversion applications are typically priced at $1/W whereas remote power applications are much higher. Generating power from aircraft jet engine air flow can be used to power wireless sensors or reduce the system requirements of actuation systems such Environmental Control System valves.

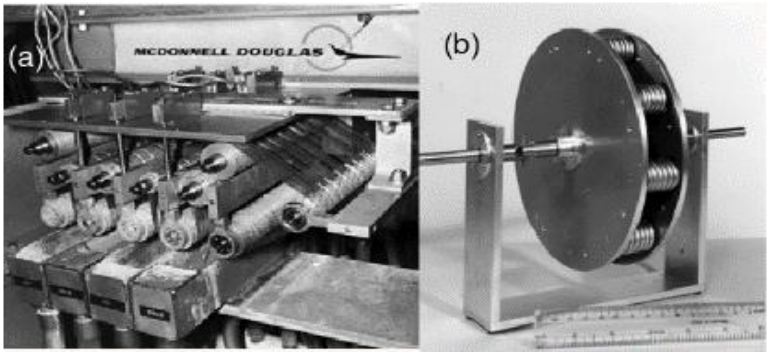
Waste heat sources from both small scale but numerous agricultural and commercial sources, as well as large scale wate heat from Combined Heat and Power and Geothermal sources. Aircraft waste heat to power applications is an example of a remote power application.

2. DESIGN REQUIREMENTS

2.1 Design *THE* material: Given your chosen fluid media, design an actuator system that best captures and releases thermal energy, so as to optimize the useful mechanical power that can obtained. This will require knowledge of flow rates and heat transfer coefficients, as well as means to increase the surface area to volume ratio, to optimize heat transfer. Wire, tube and ribbon will have differing strategies as to how to optimize heat transfer.

2.2 Design *WITH* the material: The hot media flow is typically moving in a stream, and so one strategy is how to capture the most energy in the flow as possible. Thus the macroscopic architecture of the SMA material is also important. In addition to the SMA architecture, connection from the SMA to the apparatus is non-trivial in order to transfer significant forces. Other variables that need to be considered are how to move the SMA material between the hot and cold reservoirs or vice versa, i.e., can the flow be manipulated through valving, or is it easier to translate the SMA element.

Using either a hot air or hot water source, design and build a representative sub-element of a larger system that could be used to measure the efficiency of your embodiment. There is a considerable need for a team here, thermal engineering for heat transfer, mechanical engineering for containing forces, fluid engineering to direct flow and electrical engineering to monitor and measure the effectiveness of the device, and SMA material and component design. In addition, consider balance of plant costs , i.e., the cost of the total system as well as the most efficient use of the SMA elements and their respective costs. If the end customer is willing to pay more, such as in remote power applications, then justify your costs.



Two examples of heat engines: (a) uses Nitinol wire to extract 5KW of power from waste heat. (b) uses a swashplate design and helical spring design to generate 3W of power.

Services:

Boeing: mentoring and material

SCT: mentoring, material, including SMA Torque tubes, bonding services

D. SMA Tourniquet (Smarteralloys)

1. INTRODUCTION

Exsanguination continues to be the leading cause of death in active military zones and disaster areas. Tourniquets are life-saving devices designed to stop the outflow of blood and provide time for transportation to a medical facility where emergency care can be administered to treat life-threatening conditions. Tourniquets are designed to provide compressive forces above the wound; the forces must be sufficient to stop arterial bleeding to be effective. Furthermore, tourniquets must be easy and quick to place in a high-stress situation. To ensure mobility in emergency situations, the design must light, compact with simplicity and ruggedness being a necessity. It is critical that a tourniquet be adaptable for variation in limb size and capable of being deployed using a single arm if needed. However, the efficacy of these devices can be limited due to current design limitations.

Figure 4

2. ISSUES WITH CURRENT TOURNIQUETS

1) Complexity: existing devices can be difficult to place and operate correctly using a single arm
2) Operation: in many situations, the device is not adjusted properly to apply correct compressive forces
3) Form factor: the windlass, rachet and/or bladder design are often bulky and not compact for lightweight travel

3. SCOPE

The goal of this project is for the student team to develop a tourniquet system that utilizes shape memory alloys to apply the correct compressive forces to stop arterial bleeding. The device should be compact and lightweight while also being rugged and durable. The mechanical design should be an improvement on state-of-the-art devices in terms of single-handed operation and ability to apply the correct compressive forces.

4. MATERIAL DESIGN CHALLENGE

i. Given the chosen mechanical design, design a material that ensures activation at temperatures down to zero degrees Celsius (0°C).
ii. Cost: NiTi-based or other cheaper alternatives are sought (do not use Hf, Zr, Au, Pt, Pd)
iii. Material Strain: the material must have sufficient recoverable strain to satisfy the mechanical design requirements.
iv. Hysteresis: Hysteresis may be used to its advantage in the mechanical design. Provide stress-transformation temperature graphs to ensure the stability of the material design for varying temperatures and stresses.
v. Actuation cycle life: This is a one-time use device however it should be able to withstand various external forces while in use on the body.
vi. Actuation time: Due to the requirements to arrest blood loss, actuation time should be considered within the overall mechanical design to ensure timely application.
vii. Validation: The proposed material is to be validated using a variety of experimental methods such as DSC, Tensile Data, SEM, etc.

5. HARDWARE DESIGN CHALLENGE

i. Review existing tourniquet designs.
ii. Design a tourniquet that is at least 20mm wide contact area for peripheral applications and at least long enough to meet 99th percentile leg size at the maximum circumference.
iii. The design should be able to be placed and activated with single-handed operation to either arms or legs, with placement 25 to 50 mm above the wound site, or directly on the wound site for junction applications.
iv. Pressure needed: 30kPa to 60kPa for circumferential applications, or 150 N for direct applications, device should be self-regulating to ensure correct and constant pressure
v. Design may be passively or actively activated, with the possibility of a manual backup in case of device failure
vi. Overall application and activation time should be less than 1 minute

E. Medical: An SMA spinal curvature correction device

a. Challenge sponsor: Fort Wayne Metals
b. Corporate advisors: Brandon Liechty, Jeremy Schaffer

1. KEY OBJECTIVE

i. The student team is to design an externally worn superelastic brace that works similar to orthodontic hardware with the following performance outputs:
   i. not losing tension as quickly over time while providing effective expected therapy as compared to current polymer-based designs
   ii. achieving therapeutic settings more user independent by leveraging plateau behavior
   iii. results in fewer trips to the doctor to get refitted for a new brace or have the current one adjusted
   iv. Note that such a design is worn as an alternative to invasive spinal correction surgery with titanium or cobalt-chromium hardware as shown in Fig. 5, or as compared to less effective conventionally worn devices as in Fig. 6.

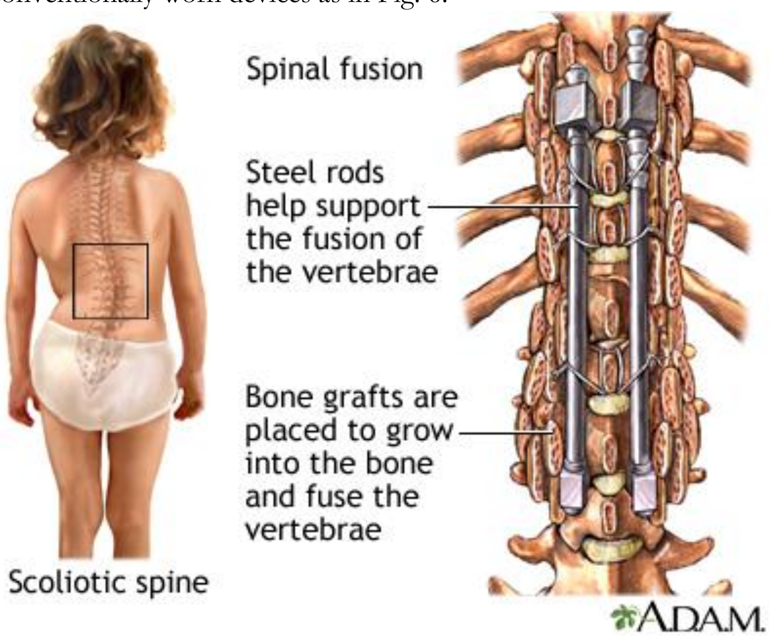


Figure 5 – The student-designed external brace is an alternative to the invasive rods shown above.

2. QUALITATIVE DESIGN CONSIDERATIONS

i. Could use superelastic wire knit fabrics and/or SMA-incorporated textiles (e.g. Dr. Julianna Abel's work at U. Minnesota)
ii. Would most likely target adolescent idiopathic scoliosis with a similar approach to a non-rigid dynamic brace like the SpineCor

3. DESIGN REQUIREMENTS

i. Utilizes any Ni-rich superelastic binary or ternary nitinol grade, e.g. FWM NiTi#1, #2, #3, #9, #4, according to student-determined force and temperature parameters. Example nitinol grades:

Alloy	Ingot A_s	Typical A_f post heat setting @ 500°C for 5 min
Niti #1	-35°C to -10°C	+15°C
Niti #2 *0.2 to 0.3 Wt% Cr*	-45°C to -15°C	+5°C
Niti #3 *1.0 to 2.0 Wt% Co*	-95°C to -50°C	-15°C
Niti #4	-10°C to +10°C	+22°C
Niti #5	≥ 85°C	+85°C
Niti #6	+35°C to +85°C	+60°C
Niti #8	+10°C to +35°C	+30°C
Niti# 9	≤ -35°C	0°C

ii. Easy to apply
   a. Therapeutic tension and/or loading (appropriate geometry and material transformation temperature)
   b. User-specific fit/sizing for comfort and as a starting point to apply therapeutic loads
   c. Positioning so that load contact sites align well with anatomical requirements

iii. Comfortable (student tested)

iv. Effective and appropriate forces as per literature review (to be completed by student team)

v. Cost effective (to be defined upon market analysis by student team, recommend including practitioner interviews)

vi. Style / non-encumbering

Fig. 6 – An example of a stylish, non-Shape Memory Alloy-based, back brace by Gensingen.

4. RESOURCES:

i. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4973373/
ii. https://www.sauk.org.uk/types-of-scoliosis/types-of-scoliosis
iii. https://www.sauk.org.uk/scoliosis-treatment/bracing
iv. http://www.spinecor.com/ForPatients/ScoliosisTreatments.aspx
v. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3675353/
vi. https://www.treatingscoliosis.com/blog/scoliosis-braces-children-teenagers-adults/

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

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[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.

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

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3rd 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: