CONSORTIUM FOR THE ADVANCEMENT OF SHAPE MEMORY ALLOY RESEARCH AND TECHNOLOGY

CASMART

Government   Academia   Industry

CASMART 7th STUDENT DESIGN CHALLENGE

Fall 2025 – Spring 2026

*To be presented at SMST 2026

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 37 other organizations have joined to advance 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, Northwestern University, North Carolina State University, University of Central Florida, University of Saarland, University of North Texas, University of Toledo, Iowa State University, University of Birmingham, Georgia Tech., University of Houston. University of Michigan, Worcester Polytechnic Institute, Colorado School of Mines

Industry: ATI, Boeing, Dynalloy, GM, Johnson-Matthey, GE, Rolls Royce, Fort Wayne Metals. Shape Change Technologies LLC, Smarter Alloys, Kinitics Automation, Ingpuls GmbH, Quartus Engineering, Khanjur, Resonetics, Nitinol Technology, Inc., Medical Device Components, SAES, Lear Corporation, Sigma Engineering,

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

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 the 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?

Recurring Virtual Meetings (All Times Eastern):
General Technical Meetings
- When: 2nd Friday of each month
- Time: 11:00 AM – 12:30 PM

Design Working Group
- When: 3rd Friday of each month
- Time: 11:00 AM – 12:00 PM

Processing/Multifunctional Working Group
- When: 4th Friday of each month
- Time: 11:00 AM – 12:00 PM

Modeling Working Group
- When: 4th Thursday of each month
- Time: 9:30 AM – 10:30 AM

Grand Challenges Working Group
- When: 1st Thursday of each month
- Time: 12:00 PM – 1:00 PM

Face-to-Face Meetings

Typically held during the following conferences:

- SMST (Shape Memory and Superelastic Technologies)
- SMASIS (Smart Materials, Adaptive Structures, and Intelligent Systems)

CASMART Contact Information:

For general CASMART inquiries, please contact the organization's primary point of contact or one of the Technical Chairs listed below.

Drew Forbes, Chair

Fort Wayne Metals
9609 Ardmore Avenue
Fort Wayne, IN 46809

Phone: 260.747.4154
Email: drew_forbes@fwmetals.com

Peter Jardine, Vice-Chair

Shape Change Technologies LLC
2985 E. Hillcrest Drive, Suite 108
Thousand Oaks, CA 91362

Phone: 805.497.2549
Email: jardine@shape-change.com

Design Challenge Contact Information:

For general information regarding the guidelines, challenge organization, or any other inquiries:

Othmane Benafan

NASA Glenn Research Center
21000 Brookpark Road
Cleveland, OH 44135

Phone: 216.433.8538
Email: othmane.benafan@nasa.gov

THE CHALLENGE

The *7th CASMART Student Design Challenge* invites undergraduate and graduate students who are interested in innovative approaches to developing new materials and hardware using Shape Memory Alloy (SMA) technology. Participants will have the opportunity to showcase their creativity by applying engineering theories, utilizing design principles, and drawing on the experience of CASMART members to tackle real-world SMA design challenges in the fields of aeronautics, astronautics, medical industry, automotive, energy, electronics, HVAC, and many other fields. To support participants, CASMART organizers have provided multiple example applications (see below), each including a detailed description of the application, its objectives, constraints, and other relevant information.

Each project consists of two elements: A. Design challenge and B. Business model development.

A. Design challenge: Each team can choose their project from the following challenges.

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 state of the 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 tools and hardware with commercially available SMAs. The challenge involves developing an actuating device/structure from the available SMA forms such as wire, helical spring, 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.

   a. *DEMO*nstration Units: under this category, the task consists of designing an SMA device resembling a standalone product such a toy, a medical device, or anything that can be used to explain SMA properties to a non-SMA person. This part of the challenge must be complete, packaged, and scalable product to multiple units.

3. **NEW**!! SMA Constitutive Modeling: Assess models for SMA behavior to be used for model based design analysis of SMA actuation and superelastic devices. Additionally, to contribute to the objectives of the CASMART Grand Challenge on SMA constitutive modeling; namely, to identify a suite of SMA constitutive models with acceptable fidelity for a range of analyses and facilitate their utilization by non-experts in SMA technology.

B. All aspects of the design challenge (excludes constitutive modeling) shall include a business model. This includes:
- Business/mission model canvas
- Value propositions
- Customer development and customer discovery

- Potential customer interviews
- Venture capital (VC) and Pitch idea

Note: for the modeling challenge, instead of submitting a traditional business model, participants shall complete an Impact Canvas that clearly identifies who would benefit from their model and in what way. The canvas should also highlight which organizations, businesses, or sectors would benefit most from the model.

SCIENCE AND TECHNOLOGY

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 the 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, 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.

As a result of this phase transformation, two useful behaviors are exhibited 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.

SMAs provide new solutions and alternatives for the development of advanced engineering structures for aeronautic, automotive, space, biomedical, and other applications. SMA-based technologies can integrate sensing, control, and actuation functions in a single entity, which significantly reduces design complexities. Moreover, the coupling of such functions can significantly reduce the 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 SMAs 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. Two new standard test methods for Shape Memory Alloy (SMA) materials and components were released by ASTM International in 2017. 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).

TIMELINE

Kick-off and team selection	Summer-Fall 2025
Q&A with student mentors	Fall 2025
Reviews	End of semester 1
Q&A for teams & mentors	Beginning of semester 2
Final report	April 2026
Present at SMST 2026 conference*	Thursday, May 7
	(La Jolla, CA)

Need approval from university mentor(s)

REGISTRATION:

Each team must designate a primary student 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. Email address
- Each team shall consist of no more than 5 student members and no more than 2 faculty advisors.

Team Name:
University
Topic:
CASMART POC:

	Name	**Email**	**Role**	**Degree**
1	Student 1			
2	Student 2			
3	…			
4	…			
5	….			
	Mentor 1			
	Professor			

SPONSORSHIP:

Teams are encouraged to seek sponsorship to support their design efforts. Sponsors may contribute through in-kind support such as labor for design development, materials donation, or assistance with future construction.

CASMART member organizations will also provide in-kind support through mentorship, materials, and/or access to equipment essential for completing the design project.

Conference Attendance: Teams are encouraged to pursue funding from their university or external sources to attend and present their work at the conference venue. Information about the upcoming conference can be found here: SMST 2026 Conference

Budget Considerations: Design plans should be developed within a limited budget, which will be established by the participating member organization, depending on available resources and funding.

AWARDS:

Each team will have the opportunity to:

- **Engage with SMA Experts:**
  Connect and collaborate with professionals from industry, academia, and government who specialize in Shape Memory Alloy (SMA) technology.
- **Present at a Professional Conference:**
  Showcase their design and research at a recognized technical conference.
- **Publish in a Technical Journal:**
  Be considered for publication in a technical journal through a special-issue collaboration between the SMST Conference organizers and the Shape Memory and Superelasticity journal.
- **Earn Recognition:**
  Compete for the CASMART Student Design Challenge Award, with winning team(s) receiving an official plaque and/or certificate(s) in recognition of their innovation and achievement.

DELIVERABLES:

Participating teams are expected to submit the following:

- **Working Prototype or Demonstration Model (Working Computational Model for the Modeling challenge)**
  A proven material or functional model that illustrates the core concepts and capabilities of the proposed design. For the case of the modeling design challenge, a working predictive model is required.

- **Project Report**:
  A comprehensive report detailing the design process, analysis, and results. Maximum length: 50 pages (including figures and appendices). Format: Journal-article style (template will be provided)

- **Oral Presentation**
  A fireside presentation to introduce team and key aspect of project (5 minutes), to be delivered at the conference venue.

- **Poster**
  A technical poster to be presented to the audience during the design challenge session.

RESOURCES:

- **Budget**: Each team is responsible for developing a cost matrix outlining recurring and non-recurring expenses related to research and development. This matrix should be included in the business plan. Teams are encouraged to utilize university resources such as testing equipment, machine shops, 3D printers, processing tools, and software. For final prototyping, teams must prepare a Bill of Materials (BOM) that does not exceed $250. Donated SMA 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.

- **Mentorship**: Each team will be assigned a CASMART Point of Contact (POC) to provide mentorship, technical clarification, and project feedback throughout the research and development phase.

- **Implementation plan**: Projects are expected to begin and conclude within the designated timeframe, estimated to be 1–2 academic semesters (e.g., Fall 2025 and/or Spring 2026), starting from the date of acceptance to delivery of final materials or hardware.

- **CASMART design tools**: A set of CASMART-developed design tools (e.g., wire, spring, and tube models) will be made available and explained by CASMART representatives.

- **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 04 – 8, 2026 in La Jolla, CA.

SMA DESIGN CHALLENGES

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

Design challenges

Each challenge has two aspects (Design + business/impact canvas), and students should choose from the following options:

- **Design "with" the material + business model**
- **Design "the" material + business model**
- **SMA Constitutive Modeling + impact canvas**

A. DESIGN "WITH" THE MATERIAL

A1. SMA Actuator Development Design Tool

The challenge consists of designing, building, and demonstrating a set of design tools and hardware based on SMA technology. The challenge consists of:

1. Design sub-tools: Build a set of design modules (Figure A1) that address key technological gaps associated with SMA actuators and devices. Each individual module shall be designed in MATLAB or similar packages.
2. Design tool: Combine all design modules into an organized and logical tool. The use of graphical user interfaces in MATLAB, or a similar web-based model is required.
3. Apply the tool to designing a device such as an actuator, thermal engine, medical device, etc. to evaluate the validity of the tools. The hardware shall provide all metrics for a successful actuator design (including actuation requirements, expected material training requirements, etc.) and be based on (1) wire, (2) spring (3) torque tube, or (4) sheet. The choice of a device shall be based on the business model (see business section).
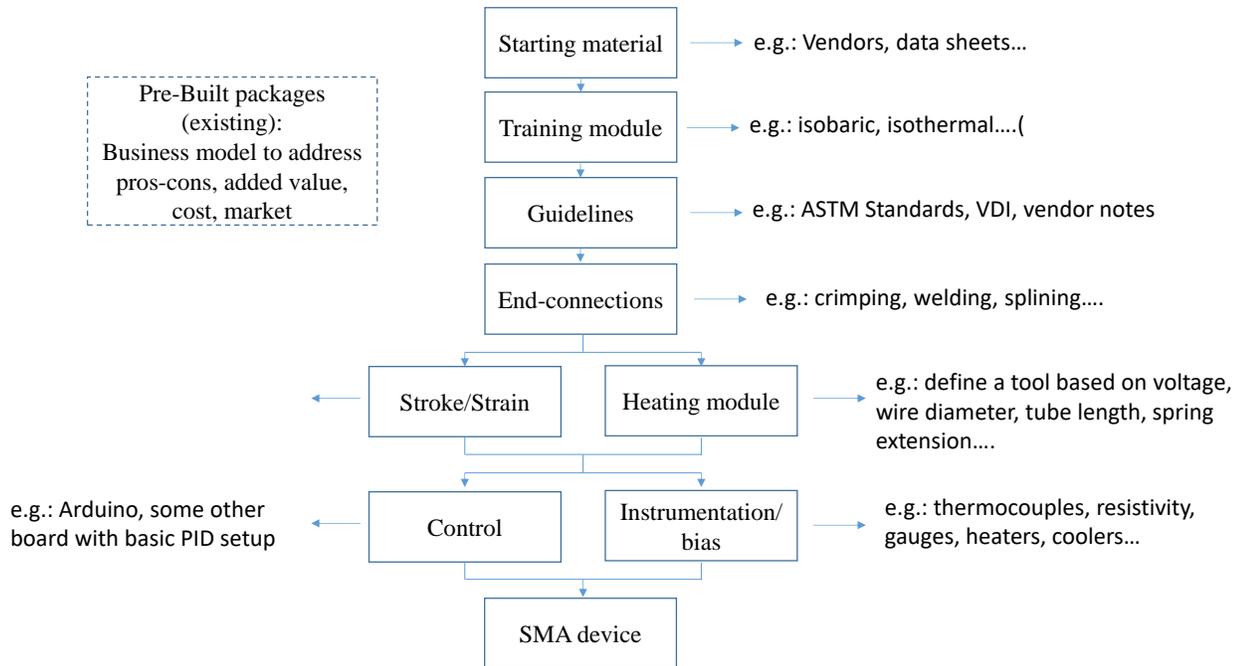
Figure A1: A flow chart showing an example of several modules required for designing an SMA actuator/device. (Not inclusive or generalized).

A2. SMA Demo Units (Product-like)

SMAs are best perceived when demonstrated and displayed. This part of the challenge consists of building an SMA widget that can be used to demonstrate the power of SMAs. Similar to a toy, a laboratory demo, a twisting wing, and a medical device, or anything that can be used to explain SMA properties to a non-SMA person. Unlike Challenge "A1" (SMA Actuator Development Design Tool), this one requires a finished product with packaging, instructions, just like a product you would buy from a store. Design of tools such as Figure A1 is encouraged but not required. The DEMO challenge consists of the following options:

SMA Stent Model:

- Build a stent, table-top demonstration model (stents will be provided or purchased).
- Research how stents work, the current state-of-the-art, FDA guidelines, standards, etc.
- Identify the SMA stent market, usage, failure modes, and propose a better solution.
- The demo shall provide the basic functions of SMA stents and how they work once deployed into the human body.
- The demo shall be interactive, simple to use, transportable, and self-contained.
- The demo shall be high quality, resembling a finished product that can be purchased.

Magnetic SMA Model:

- Build a magnetic SMA (M-SMA) model to demonstrate the fast actuation response.

- Research how magnetic SMAs work, the current state-of-the-art current employments in product if any, standards etc.
- Identify the M-SMA market, usage, failure modes, etc.
- The demo shall provide the basic functions of magnetic SMAs and how they work.
- The demo shall be interactive, simple to use, transportable, and self-contained.
- The demo shall be made in high quality, resembling a finished product that can be purchased.

Orthodontics SMA Model:

- Build an Orthodontics SMA model to demonstrate the superelastic response.
- Research how Orthodontics SMAs work, the current state-of-the-art, current employments in product, FDA regulations, standards etc.
- Identify the Orthodontics SMAs market, usage, failure modes, etc.
- The demo shall provide the basic functions of Orthodontics SMAs and how they work.
- The demo shall be interactive, simple to use, transportable, and self-contained.
- The demo shall be made in high quality, resembling a finished product that can be purchased.

Other

- Following the same model as above, students can propose other demonstrable devices that are justified by the business model.

B. DESIGN "THE" MATERIAL (MATERIALS CATEGORY)

The Material challenge consists of designing and producing novel materials by recourse to experimentation, machine learning, theoretical approaches, and other means.

B1. High Temperature Shape Memory Alloys (HTSMAs)

Research and document a list of shape memory alloys with:

a. Transformation temperatures: The material M_f at zero external stress shall be at +100 °C ± 10 °C.
b. Actuation strain: Fully recoverable strains at max operating stress shall be at least 3.0 % strain for actuation.
c. Functional stresses between 100-300 MPa.
d. Slopes (A_f-A_s): Define a method to control the hysteresis span from A_s to A_f (sharp transition or very gradual), and obtain a hysteresis of no more than 25 °C.

e. 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.

f. Consideration for actuation time.

g. Cost: The alloy shall be comprised of a total cost not to exceed a binary NiTi. No use of precious metals. Hf and Zr are allowed in quantities of no more than 5 at.% total.

h. Alloy shall be produced using conventional methods such as Arc, VIM, VAR, ISM, AM, etc.

i. Melt Purity: Carbon content should be less than 0.030 wt.%, and Oxygen content should be less than 0.08 wt.%.

j. Material shall be processable to a useful form such as rod, plate wire, tube, etc.

k. 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.).

l. Students shall build a preliminary phase diagram of the final alloy selected.

B2. Elastocaloric materials

For near room temperature cooling applications, research and document a list of elastocaloric alloys with:

a. Transformation temperature: The material A_f at zero external stress shall be <10 °C.

b. Transformation latent heat: >8 J/g (higher latent heat is preferred).

c. Critical stresses required to induce phase transformation <400 MPa (lower critical stress is preferred).

d. Thermal hysteresis: <25 °C.

e. Thermal conductivity: >18 W/m-K (no less than nitinol).

f. Cost: The alloy shall be comprised of a total cost not to exceed a binary NiTi. No use of precious metals. Hf and Zr are allowed in quantities of no more than 5 at.% total.

g. No restriction in alloy synthesis method. It could be thin film, powder additive manufacturing, mechanical alloying, or arc/induction method.

h. The final deliverable is a composition with desired latent heat and critical stress, no requirement on material's form.

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

B3. Strain Glass Alloys (SGAs)

Research and document a list of strain glass alloys with:

a. Transformation temperatures: The material M_f at zero external stress shall be in a range of -100 °C to 100 °C, with the ideal target being 25 °C ± 10 °C.

b. Actuation strain: Fully recoverable strains at max operating stress shall be at least 3.0 % strain for actuation.

c. Functional stresses between 100-300 MPa.

d. 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.
e. Actuation time: Complete actuation in < 30 seconds.
f. Cost: Comparable to conventional NiTi-based SMAs.
g. Alloy shall be produced using conventional methods such Arc, VIM, VAR, ISM, AM, etc.
h. Material shall be processable to a useful form such as rod, plate wire, tube, etc.
i. 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.).

B4. High Entropy Shape Memory Alloys (HESMAs)

High Entropy Shape Memory Alloys (HESMAs) combine the unique properties of **High Entropy Alloys (HEAs)** with the **shape memory effect (SME)** seen in traditional Shape Memory Alloys (SMAs). These alloys typically consist of five or more principal elements in near-equiatomic ratios, resulting in high configurational entropy and often simple solid solution phases, along with **martensitic phase transformation** for shape memory behavior. While the typical HEA definition is fairly strict, the minimum number of elements will be limited to four or more principal elements with compositional ranges from 5 to 50 at.% each for HESMAs.

1. NiTi-based HESMAs

- Example: **NiTiCoFeCrMn**
  - o NiTi is a well-known conventional SMA.
  - o Adding Co, Fe, Cr introduces high entropy characteristics.
  - o Maintains shape memory effect while improving mechanical strength and thermal stability.

2. TiZrHfNi-based HESMAs

- Example: **TiZrHfNi**
  - o Exhibits both high-temperature shape memory behavior and high-entropy characteristics.
  - o Suitable for applications requiring high-temperature performance.

3. CoNiFeMnAl-based HESMAs

- This system can act both as a high entropy alloy and exhibit **martensitic transformation**, leading to shape memory effects.
- Can also show multifunctional properties like magnetism (magnetic shape memory effect).

4. Fe-based HESMAs

- Example: **FeMnCoCrNi with additions like Al or Cu**
  - o Offers high ductility and strength.
  - o Can be tuned to exhibit martensitic transformation for shape memory effect.

5. Cu-based HESMAs

- Example: **Cu-Al-Ni-Mn-Co**
  - Cu-based SMAs are relatively cheaper and more machinable.
  - High entropy elements help stabilize the structure and enhance functional properties.

The goal of this category is to design novel shape memory alloys that fall under the high entropy alloy class, as described above. The key design requirements include:

- **Martensitic transformation and shape memory effect**
- **Excellent thermal and mechanical stability across cycles**
- **No use of precious metals; total Hf and Zr content limited to 5 at.% total**
- **Cost must not exceed that of binary NiTi**
- **Fabrication must use conventional techniques** (e.g., Arc, VIM, VAR, ISM, AM, etc.)
- **Processable into functional forms** (rod, wire, plate, tube, etc.)
- **Characterization of thermal, structural, and mechanical properties is required**

Proposed Alloy and Concept

Based on these requirements and findings from relevant literature, we are currently focusing on the following alloy design:

Proposed Composition: (e.g., $Ni_{40}Ti_{20}Fe_{10}Co_{10}Cr_{10}Mn_{10}$ at.%)
Key Features:
– Shape memory behavior via B2 ↔ B19' transformation
– Recoverable strain of ~4-5%
– Functional stress around ~200 MPa
– Hysteresis span ~20-22 °C
– Cost-effective (no precious metals) and compatible with standard processing routes

EXAMPLE

Design a **cost-effective High Entropy Shape Memory Alloy (HESMA)** that:

Property	Target	Designed Alloy
Transformation Behavior	Martensitic + SME	B2 ↔ B19' (Ti-Ni base)
Actuation Strain	≥ 3%	~4–5%
Functional Stress	100-300 MPa	~180–250 MPa
Hysteresis Width (Af–As)	≤ 25 °C	~20–22 °C
Cost	≤ Binary NiTi	No precious metals
Hf/Zr Content	≤ 5 at.%	None added
Process	Conventional (Arc, VIM, VAR, etc.)	Arc melting + hot working
Purity	C < 0.03 wt.%, O < 0.08 wt.%	Achievable
Form	Rod, wire, plate, tube	Wire & rod planned

Property	Target	Designed Alloy
Stability	Good under cycling	Multi-phase, refined grains

6. Alloy Composition (Proposed High Entropy SMA)

e.g., $Ni_{40}Ti_{20}Fe_{10}Co_{10}Cr_{10}Mn_{10}$ at.%

- **Base system**: NiTi, known for shape memory and martensitic transformation.
- **High entropy additions**: Fe, Co, Cr, Mn enhance strength, control hysteresis, and increase entropy.
- **No expensive elements** like Pt, Pd, or Au.
- **No more than 6 elements** → near equiatomic design with dominant NiTi.

7. Processing Method

Step	Process
Melting	Arc melting (Ti-gettered Ar), 4× remelt for homogeneity
Homogenization	950 °C for 12 hours in vacuum furnace
Hot working	Hot forging/hot rolling into rods, wires
Solution treatment	950 °C followed by water quenching
Aging (optional)	400-500 °C for 1-2 hours to refine precipitates and hysteresis

8. Expected Properties

Property	Estimated Value
Transformation Temp (A_f)	~70-90 °C (tunable by aging)
Actuation Strain	~4-5%
Functional Stress	~200 MPa
Hysteresis Width	~20-22 °C
Cycle Life	10^4-10^5 cycles (multi-phase stabilized)
Phase Stability	FCC/BCC matrix + martensite at low temp
Processability	Good - arc melting + rolling confirmed in literature

9. Characterization Plan

Method	Purpose
DSC (Differential Scanning Calorimetry)	Determine M_s, M_f, A_s, A_f, latent heat
SEM + EDS	Microstructure, phase boundaries, elemental mapping
XRD	Confirm B2/B19' + any secondary precipitates
Optical Microscopy	Grain structure + defect analysis
Tensile / Thermomechanical Testing	Actuation strain, stress plateau
Fatigue Cycling (DMA or custom rig)	Functional stability

Method	Purpose
Chemical Analysis (ICP or OES)	Confirm elemental ratios and purity

10. Preliminary Phase Diagram Plan

- Use **CALPHAD modeling** or Thermo-Calc with TCHEA databases.
- Focus on B2 ↔ B19' transformation.
- Evaluate solid solution stability and suppression of brittle intermetallics.
- Phase boundaries around 600–1200 °C expected.

11. Cost & Practicality

- No precious metals → low cost
- Common elements (Ni, Ti, Fe, Co, Cr, Mn)
- Arc melting compatible
- No need for exotic processing routes
- Similar to binary NiTi in overall cost

The students are encouraged to use a Machine Learning approach to find a new material that meets the material design requirements. Some useful resources include:

1) Introductory machine learning principles and open-source Python programming: https://colab.research.google.com/github/jakevdp/PythonDataScienceHandbook/blob/master/notebooks/Index.ipynb#scrollTo=ohIBQ5_n3cjq
2) Example machine learning algorithms for different problems: https://scikit-learn.org/stable/auto_examples/index.html#examples

NEW: Student groups are allowed to design the material or design with the material using modeling tools (e.g., FEA, DFT, thermodynamics).

C. SMA CONSTITUTIVE MODELING

- **Purpose**
  Assess models for SMA behavior to be used for model based design analysis of SMA Actuation and Superelastic devices. Additionally, to contribute to the objectives of the CASMART Grand Challenge on SMA Constitutive Modeling; namely, to identify a suite of SMA constitutive models with acceptable fidelity for a range of analyses and facilitate their utilization by non-experts in SMA technology.

- **Target**
  Open to CASMART members and non-members for participation as an individual or a team. Team members can change in the course of the competition, e.g., between semesters 1 and 2.

- **Approach**
  CASMART defines a set of 3-4 benchmark systems of varying dimensionality/stress state for the SMA component involved, e.g., wire, helical spring, torque tube, sheet/film product forms. CASMART provides all system information necessary to perform a prediction for each benchmark system.

SEMESTER 1

- Teams survey the SMA constitutive models in use and in the literature and choose or develop a model that is well suited to modeling one or more of the benchmark systems.
- Milestone 1 (date TBD): Teams implement the selected model(s) to make a prediction(s) of the performance for one or more of the benchmark systems using the information provided by CASMART.
- Milestone 2 (date TBD): CASMART provides the measured performance to the teams, the teams assess discrepancies between their prediction(s) and the measurement(s), and the teams refine their predictions by physics-based parameter corrections, inclusion of higher order effects, etc.
- Milestone 3 (date TBD): Teams submit a report to CASMART that documents their SMA constitutive model survey effort and model selection rationale, detailed walk-through of initial modeling effort(s) and comparison with measurement(s), discrepancy analysis/parameter or model refinement/refined comparison(s), and initial assessment of their chosen constitutive model for advancement toward improved out-of-the-box accuracy and usability.

SEMESTER 2

- Teams perform a thorough analysis of their chosen constitutive model for improved accuracy and usability based upon the semester 1 effort. Parameter or model refinement for improved accuracy might include:
  - User guidance on estimation of required parameters not readily deduced from the CASMART provided data.
  - Inclusion of effects like evolutionary behavior, tension-compression asymmetry, plasticity, etc.

- Teams formulate an approach for improving the out-of-the-box accuracy and usability of their chosen constitutive model, take action to implement improvements to the model source code, and demonstrate improvements via return to initial comparison with the benchmark systems(s) using only the CASMART provided information.
- Milestone 4 (date TBD): Teams submit a final revised report to CASMART that documents the detailed analysis of their chosen constitutive model for accuracy and usability, recommended model improvements/how they would be implemented and used, and any actions that the team was able to take to demonstrate advancement in model accuracy and usability.
- Teams present their results at a mutually agreed time/place (e.g., SMST or SMASIS Conference) and CASMART presents awards in conjunction with the CASMART Student Design Competition.

CASMART will form a committee that will manage distribution of system information necessary to make benchmark system performance predictions, distribution of measured performance data for the refined prediction, and judging of the modeling efforts via the two semester reports and the final presentation. Ranking will be based upon weighting of factors including initial prediction-measurement comparison(s), refined comparison(s), breadth (dimensionality/stress states) of modeling effort undertaken, and thoroughness/thoughtfulness/progress toward improved out-of-the-box model accuracy and usability.

CASMART mentoring will be made available to the extent possible throughout the competition.

Benchmark Systems
The pre-defined benchmark systems students can choose from are listed below. A minimum of one benchmark system is required for this challenge, however the ability of the model to predict additional system behaviors will result in a better final score at the competition.

C1. Wire
This benchmark will require the modeling of a straight SMA wire. SMA wires are one of the most used SMA geometries due to their simplicity and linear actuation/superelastic response.
- Inputs:
    - Loading direction: tension
    - Test data provided: uniaxial constant-force-thermal-cycling (UCFTC) based on ASTM E3097.
    - DSC data
- Output:
    - Predict the superelastic response of the material at $A_f+20°C$, $A_f+40°C$, and $A_f+60°C$ (see ASTM F2516 for more information on superelastic testing).

C2. Spring
- Inputs:
    - Loading direction: tension

- o Test data provided: uniaxial constant-force-thermal-cycling (UCFTC) based on ASTM E3097.
  - o DSC data
- Output:
  - o Predict the superelastic response of the material at $A_f+20°C$, $A_f+40°C$, and $A_f+60°C$ (see ASTM F2516 for more information on superelastic testing).

C3. Machined Helical Spring

- Inputs:
  - o Loading direction: tension
  - o Test data provided: dog-bone sample with data for the following
    - UCFTC based on ASTM E3097
    - UPFR based on ASTM E3098
    - Superelastic based on (F2516)
    - DSC data
    - Model geometry
- Output:
  - o Model based on the machined spring geometry that predicts at least one of the following:
    - UCFTC response
    - Superelastic response
    - Blocking force

C4. Torque Tube for Vortex Generator

- Inputs:
  - o Loading direction: torsion
  - o Test data provided:
    - Superelastic (F2516)
    - Constant torsion thermal cycling (CTTC) based on E3414
    - Torsional blocking force
  - o Aero-load
  - o Necessary device geometry
- Outputs
  - o Model that predicts the temperature-deflection response with an applied aero-load

C5. Rod for Shape Memory Alloy Rock Splitter (SMARS) Device

- Inputs:
  - o Loading direction: tension OR compression
  - o Test data provided:
    - UCFTC (E3097)
    - Blocking force
    - Data for rock to crack
- Output:

- o Model that predicts the stress-strain, stress-temperature, and stress-time response for a SMARS device breaking a rock.

C6. Strip for Adaptive Chevron

- Inputs:
  - o Loading direction: bending
- Output:
  - o Model predicting the in-use case of Actuation

D. BUSINESS MODEL (Excludes Modeling)

All challenges shall include a business model. The hardware and material challenges shall be based upon a sound business model. After the completion of this project, the goal is for students to transition the idea into a <u>start-up business</u> or a <u>graduate-proposal</u>.

1. Business/Mission Model Canvas: How your business creates, delivers, and captures value for the SMA community? Here you need to generate a model and address:

    - *Customer segments*: Who are your most important customers? What are their archetypes? What job do they want you to get done for them? Explore both medical and non-medical SMAs. Are these customers already satisfied with existing SMA companies/products?
    - *Value Propositions*: What customer problems are you helping to solve? What customer needs are you satisfying? You can start with CASMART members.
    - *Channels*: Through which channels (sales, distribution, support) do your customers want to be reached? You can target SMST audience, exhibits, CASMART members. This also includes customer relationships (How will you get, keep, and grow customers?)
    - *Revenue stream*: How will you make money? What is the revenue model? What are pricing tactics? Consider SMA raw material cost upfront. Build a cost structure
    - Key partners: Who are your key partners? Who are your key suppliers? What are you getting from them and giving to them?
    - Key activities and resources: Manufacturing? Software development? Personal concierge service? Etc.
    - Key resources: What key resources do you require? Financial? Physical? Intellectual property? Human resources?
    - **REMEMBER: MORE STARTUPS FAIL FROM A LACK OF CUSTOMERS THAN FROM PRODUCT / TECH FAILURE.**

Key Partners	Key Activities	Value Propositions	Buy-in & Support	Beneficiaries
❑ KP 1 ❑ KP 2 ❑ Etc.	❑ KA 1 ❑ KA 2 ❑ Etc.	❑ VP 1 ❑ VP 2 ❑ Etc.	❑ BIS 1 ❑ BIS 2 ❑ Etc.	❑ B 1 ❑ B 2 ❑ Etc.
	Key Resources ❑ KR 1 ❑ KR 2 ❑ Etc.		**Deployment** ❑ D 1 ❑ D 2 ❑ Etc.	

Mission Budget / Cost	Mission Achievement/Impact Factors
❑ Cost 1 ❑ Cost 2 ❑ Etc.	❑ Achievement 1 ❑ Achievement 2 ❑ Etc.

Figure D1: An example model canvas.

2. Value Propositions: While the business canvas helps you create value for your business, now it is time to create value for **YOUR CUSTOMERS**
   - Identify customer problems ad needs: focus on customer pains, desired gains, and jobs.
   - Trade out gains and pains; is your product addressing essential gains or extreme pains?
   - What is your customer profile?

3. Customer development and customer discovery
   - It is important for YOU to talk to the customers, "Get out of the building!"
   - Focus on customer behavior to reveal underlying motivations: Attitudes, Needs, & Goals
   - Conquer the 3 common fears: Fear that their idea is embarrassingly bad. Fear that their ego will become tarnished. Fear that they don't possess innate wisdom.
   - Interaction with early adopters focused on the problem to understand past behavior and urgency

4. Potential customer interviews
   - Think…. conversation first
   - Remember…. there is great genius in simplicity
   - Perspective…. the value proposition

5. VC and Pitch idea

- Entrepreneurs complain they can't find investment—and investors say there aren't enough investable opportunities.
- Gain self-awareness about your level of investment-readiness.
- Understanding level of demonstration maturity/worthiness.

RESOURCES

- *CASMART website:* http://www.casmart.org/
- *Dynalloy:* http://www.dynalloy.com/
- *Fort Wayne Metals:* https://www.fwmetals.com/materials/nitinol/shape-memory-nitinol/
- *ATI:*https://www.atimetals.com/specialtyalloysandcomponents/Pages/products-materials.aspx
- *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] *Gantz F, Stroud H, Fuller JC, Adams K, Caltagirone PE, Ozcan H, Karaman I, Hartl DJ, Stebner AP, Trehern W, Turner T, Wheeler RW, Young ML, Benafan O. (2022), Aerospace, Energy Recovery, and Medical Applications: Shape Memory Alloy Case Studies for CASMART 3rd Student Design Challenge. Shape Memory and Superelasticity 8.2, pp. 150-167 (2022)*

[2] *Caltagirone PE, Wheeler RW, Benafan O, Bigelow G, Karaman I, Calkins FT, Kuntz ML, Leal PB, Nicholson DE, Ozcan H, Stebner AP. (2021), Shape Memory Alloy-Enabled Expandable Space Habitat—Case Studies for Second CASMART Student Design Challenge. Shape Memory and Superelasticity. 7, pp. 280–303 (2021)*

[3] *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.*

[4] *R. Wheeler., O. Benafan, F. T. Calkins, X. Gao, Z. Ghanbari, G. Hommer, D. Lagoudas et al. "Engineering design tools for shape memory alloy actuators: CASMART collaborative best practices and case studies." Journal of Intelligent Material Systems and Structures 30, no. 18-19 (2019): 2808-2830.*

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

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

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

[8] *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.*