CONSORTIUM FOR THE ADVANCEMENT OF SHAPE MEMORY ALLOY RESEARCH AND TECHNOLOGY

CASMART

Government Academia Industry

CASMART 6th STUDENT DESIGN CHALLENGE

Fall 2023 – Spring 2024

*To be presented at SMST 2024

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 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, University of Toledo, Iowa State University, University of Birmingham, Georgia Tech., University of Houston.

Industry: ATI, Boeing, Dynalloy, GM, Johnson-Matthey, Telezygology, GE, Rolls Royce, Fort Wayne Metals. Shape Change Technologies, LLC, Smarter Alloys, Kinitics Automation,

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 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?

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. The processing working group meets the 4th 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 and/or SMST conferences.

CASMART Contact Information:

For general CASMART inquiries or issues, you can contact the organization's point of contact or any of the Technical Chairs listed below.

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Design Challenge Contact Information:

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

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THE CHALLENGE

The *6th CASMART Student Design Challenge* is intended for undergraduate and/or graduate students curious of 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, 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: A. Design challenge and B. Business model development.

A. Design challenge: Each team can choose their project from either of 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.

B. Both aspects of the design challenge 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

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. 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 2023
Q&A with student mentors	Fall 2023
Reviews	End of semester 1 TBD
Q&A for teams & mentors	Beginning of semester 2
Final report	April 2024
Present at SMST 2024 conference*	Monday-Friday, May 6-10 (Cascais, Portugal)

** 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 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/smst-2024/

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 for 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 demonstrates the basic functions of the design.
- A project report (not to exceed 50 pages including all figures and appendices).
    - The report shall resemble a journal article –template will be provided.
- A 15-minute (20 including Q&A) oral presentation.
- If approved by organization:
    - Abstract and full-length paper to be submitted to SMST 2024
    - Conference presentation

Resources:

- Budget: Teams are responsible for developing a cost matrix consisting of reoccurring and non-reoccurring costs for the research and development, to be included in the business plan. Teams are encouraged to use school resources such as test equipment, processing tools, machine shops, 3D printers, software, etc. For final prototyping, teams shall construct a bill of material (BOM) not to exceed $250. 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. In addition, two student mentors from SMST will be available to provide guidance.
- Implementation plan: Participants shall start and complete this work in the timeframe specified herein but is estimated to be around 1-2 semesters (Fall 2023 and/or Spring 2024) from acceptance to delivery of hardware/material.
- 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 06 – 10, 2024 in Cascais, Portugal.
- Each team shall consist of no more than 5 student members and no more than 2 faculty advisors (or grad-, post docs).

Design challenges

Each challenge has two aspects, and students should choose from the following options:

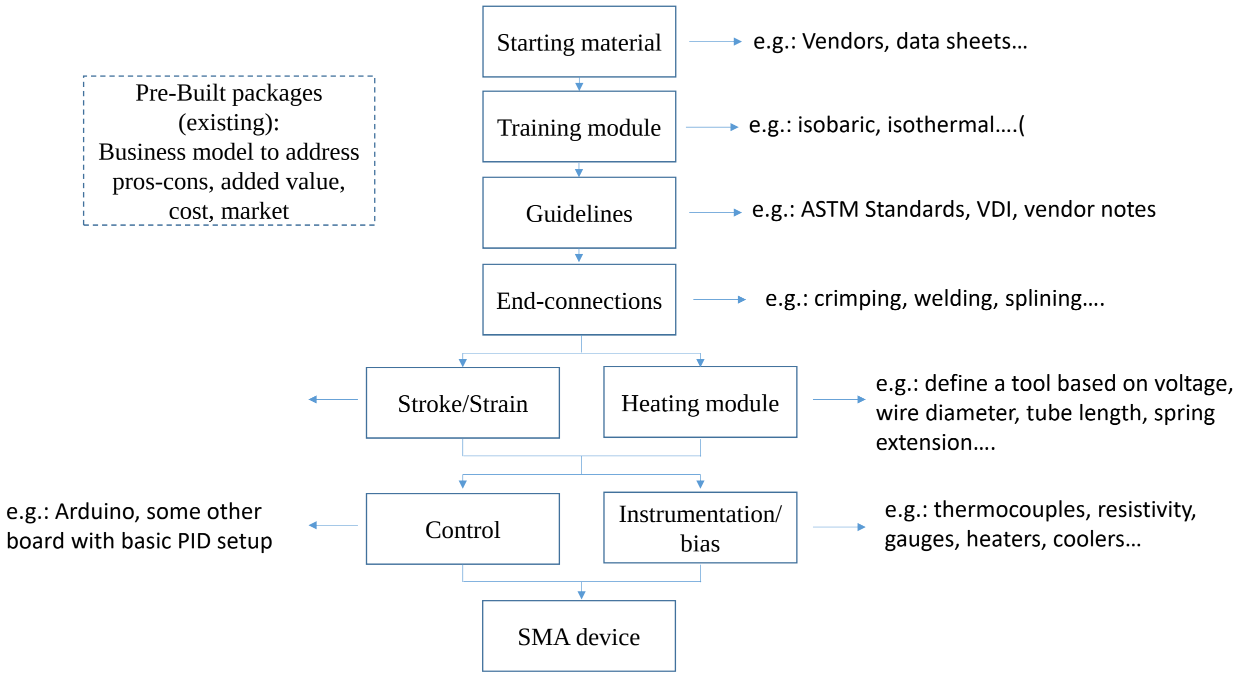
- **Design "with" the material + business model**
- **Design "the" material + business model**

A. DESIGN "WITH" THE MATERIAL (TOOLS AND HARDWARE CATEGORY)

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).



4.

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 "A" (design with the materials), 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 Mf 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 As to Af (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. Elasto-caloric materials for near room temperature cooling applications– Research and document a list of elastocaloric alloys with:

2. Transformation temperature: The material A_f at zero external stress shall be <10 °C.
3. Transformation latent heat: >8 J/g (higher latent heat is preferred)
4. Critical stresses required to induce phase transformation <400 MPa (lower critical stress is preferred).
5. Thermal hysteresis: <25 °C
6. Thermal conductivity > 18 W/m-K (no less than nitinol)
7. 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.
8. No restriction in alloy synthesis method. It could be thin film, powder additive manufacturing, mechanical alloying, or arc/induction method.

9. The final deliverable is a composition with desired latent heat and critical stress, no requirement on material's form.
10. 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.).

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).

Business Model

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 start-up business or a graduate-proposal.

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 member. 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.**

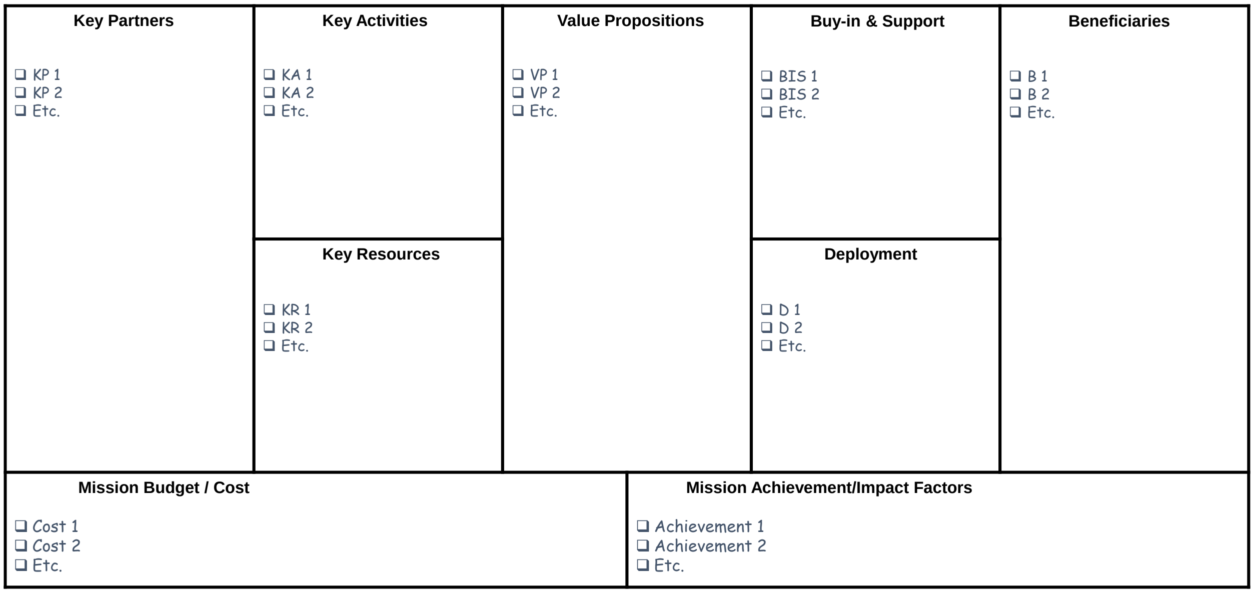


Figure C1: An example model canvas

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/
- F*ort 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

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[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)

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

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