GENERAL BACKGROUND ON SHAPE MEMORY ALLOYS

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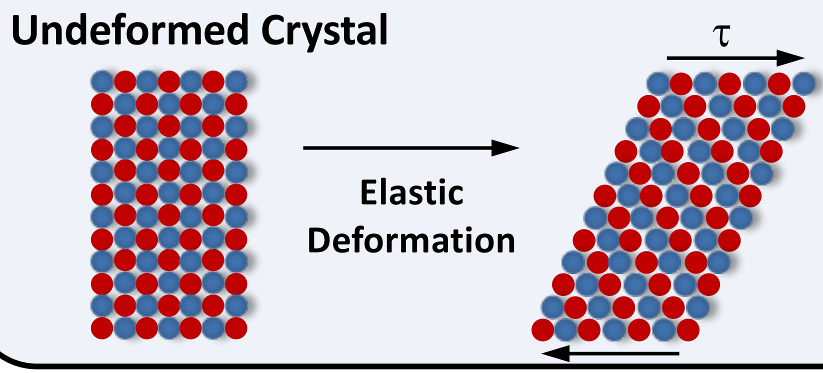
Shape Memory Alloys (SMAs): An Introduction

- ✓ Metal alloys that have a “memory.”
- ✓ These materials have the ability to remember and recover their original shapes against significant externally applied loads.
- ✓ SMAs exhibit a solid-to-solid, reversible phase transformation that can be induced by the application of force or temperature.
- ✓ NiTi most common alloy – highest work output/energy density.

Basic Differences between Conventional Metals and Shape Memory Alloys (SMA)

Conventional Material Deformation

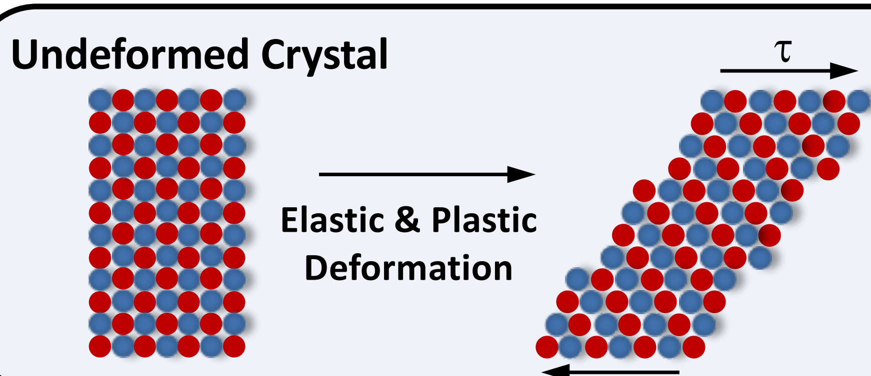
❑ Require imposed forces/stresses only generate ***ELASTIC*** deformation.



Elastic deformations

✓ Distort the material lattice through bond stretch.
✓ Deformations are ***REVERSIBLE***.

❑ If imposed forces/stresses create deformations that can't be accommodated by ***ELASTIC*** distortion of lattice – ***PLASTIC*** deformation (bond breakage).



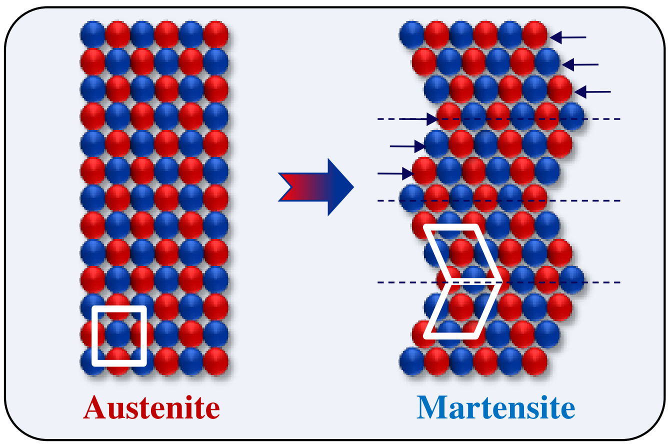
Inelastic deformations - Plasticity

✓ Distort the material lattice through microstructural rearrangement (metallic materials - slip).
✓ Deformations are ***IRREVERSIBLE***.
✓ Can only dissipate energy.

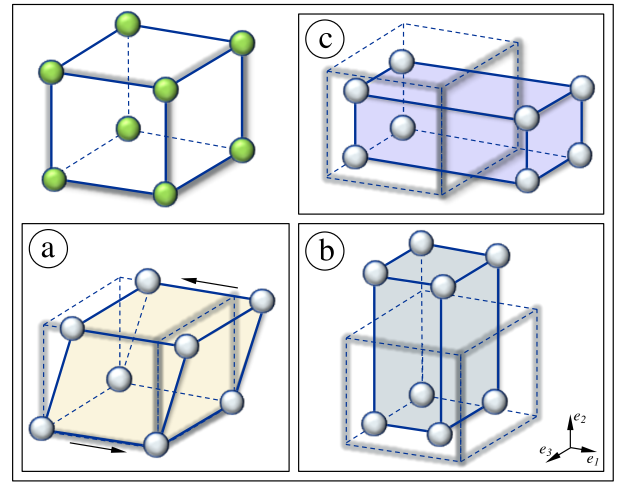
Shape Memory Alloys: An Introduction

- Don't accommodate deformations through elastic bond stretch.
- SMAs exhibit a solid-to-solid, reversible phase transformation.
- Transformation capable of storing ***over 30x*** the deformation that can be done in an ***elastic*** bond stretch.

Simplified 2D



Variant selection



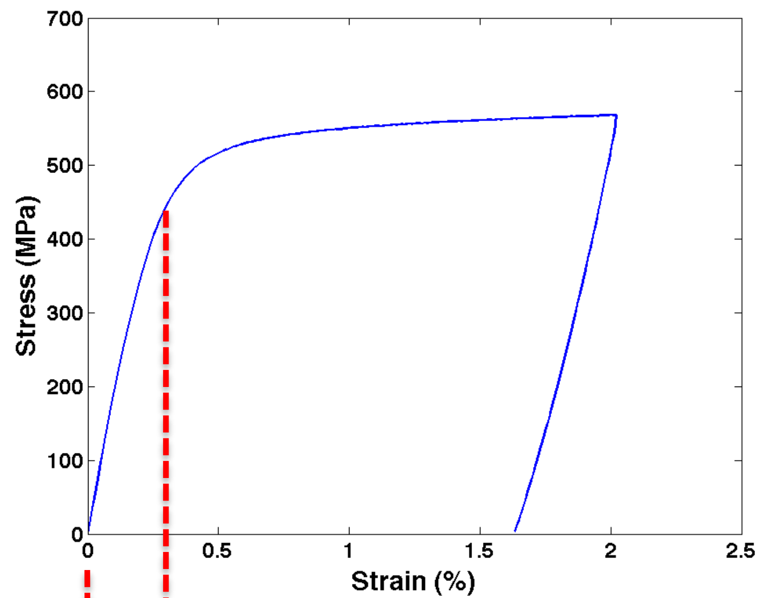
Microstructure

Courtesy of A. Garg

- **How?**
  - ✓ Bain strain → (lattice deformation)
  - ✓ Lattice invariant shear → (accommodation)
  - ✓ ***Inelastic*** deformation (transient twinning) → ***REVERSIBLE***

Mechanical Component Design Constructs

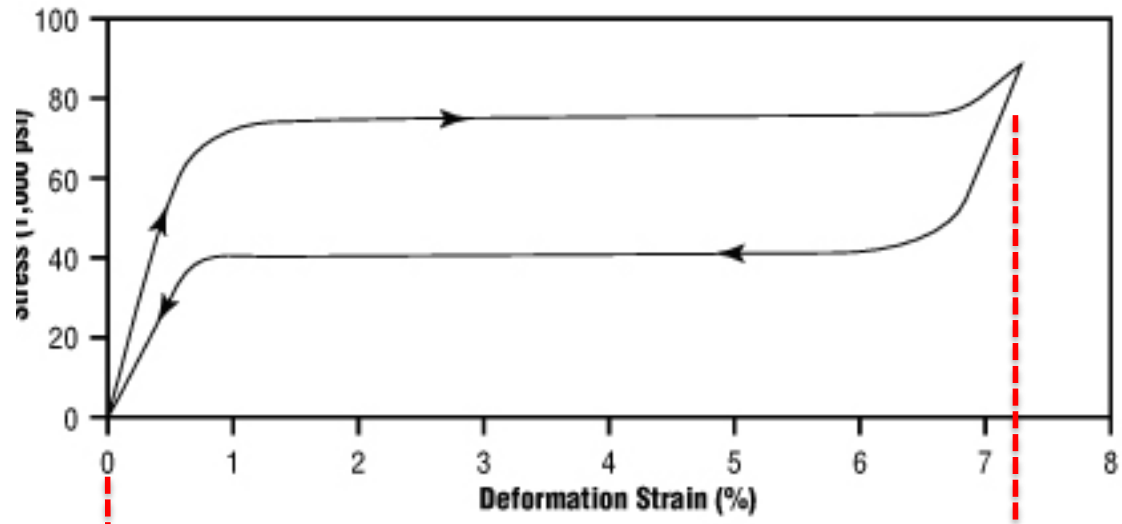
Conventional Design



0.3 % Reversible Strain

Design so that component remains ***elastic***

SMA Design



7 - 8 % Reversible Inelastic Strain

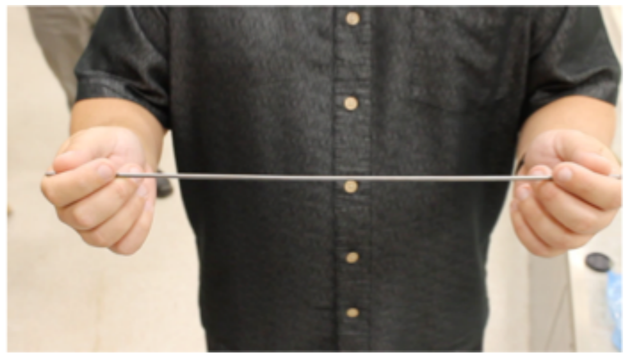
Design so that component takes advantage of ***inelastic***

Shape Memory Alloys (SMAs) allow for > 10 times the strain to be accommodated in the component, allowing designs that could never be contemplated with conventional materials

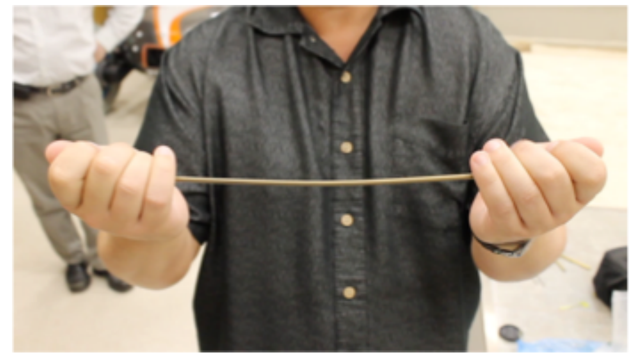
Practical Example of Difference between Conventional Material and Shape Memory Alloys

Brass
Plastic Buckling & Fracture

Stainless Steel
Plastic Deformation



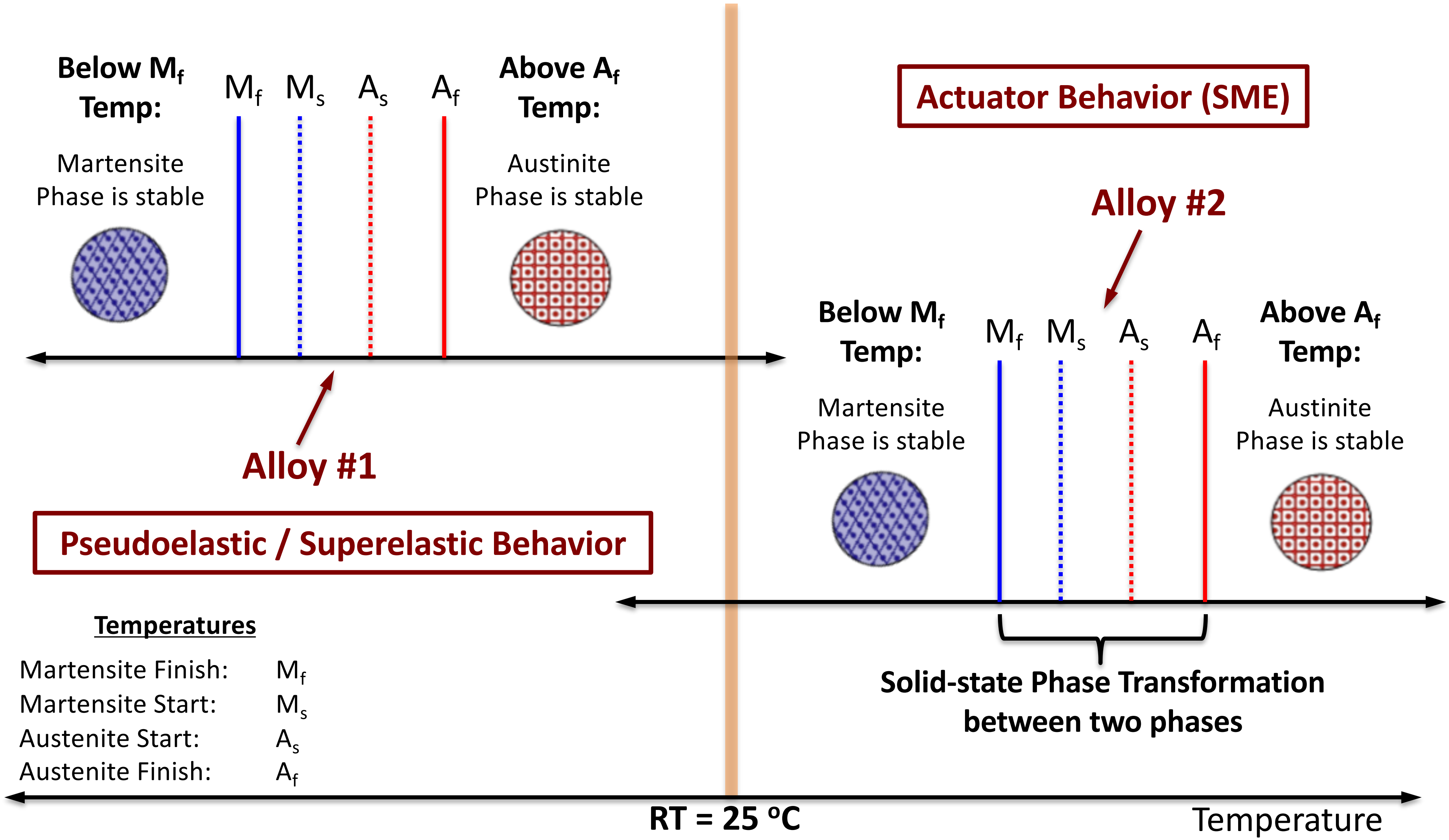
Shape Memory Alloy
Reversible Pseudoelasticity



The reversible, solid-state phase transformation that occurs in Shape Memory Alloys (SMAs) is capable of storing ***over 30x*** the deformation that can be done in a material required to accommodate the deformation solely through ***elastic*** bond stretch.

Different Modes of Operation When Using Shape Memory Alloys (SMA)

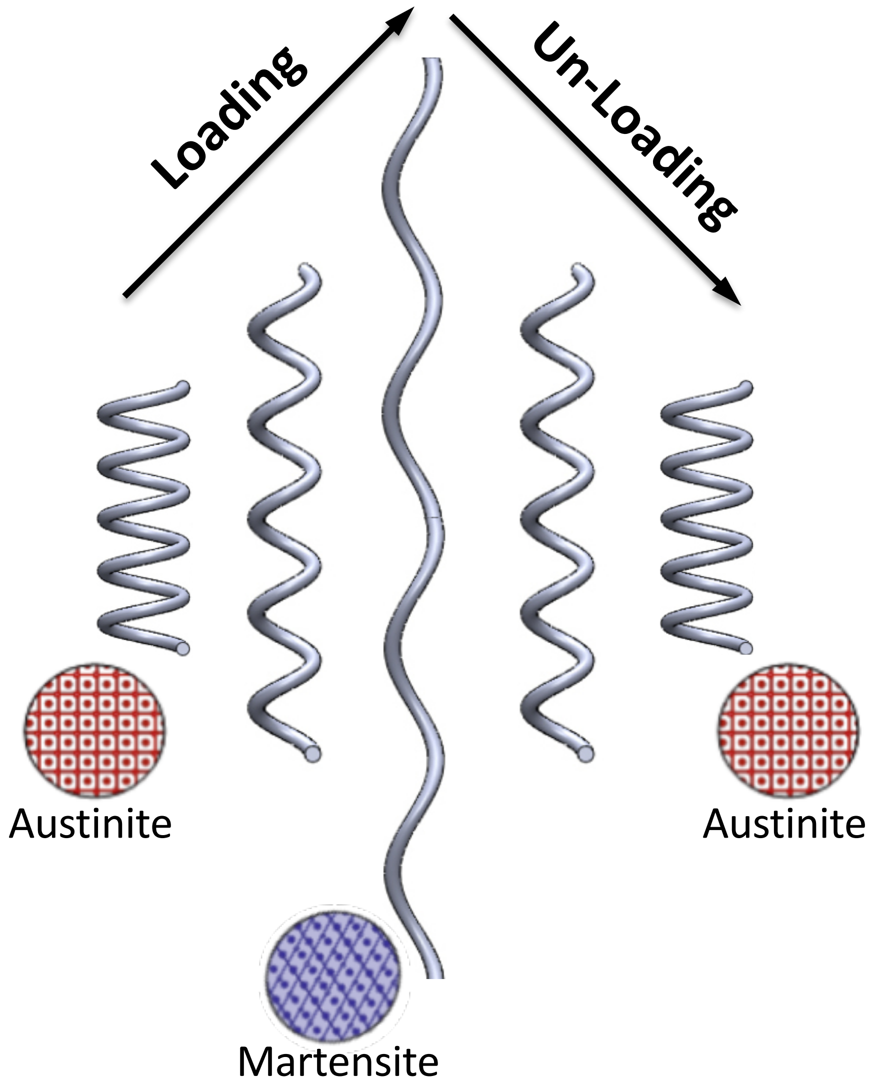
Alloy Chemistry Alters Temperature at Which Phase Transformation Happens



Examples of Shape Memory Alloys in Action

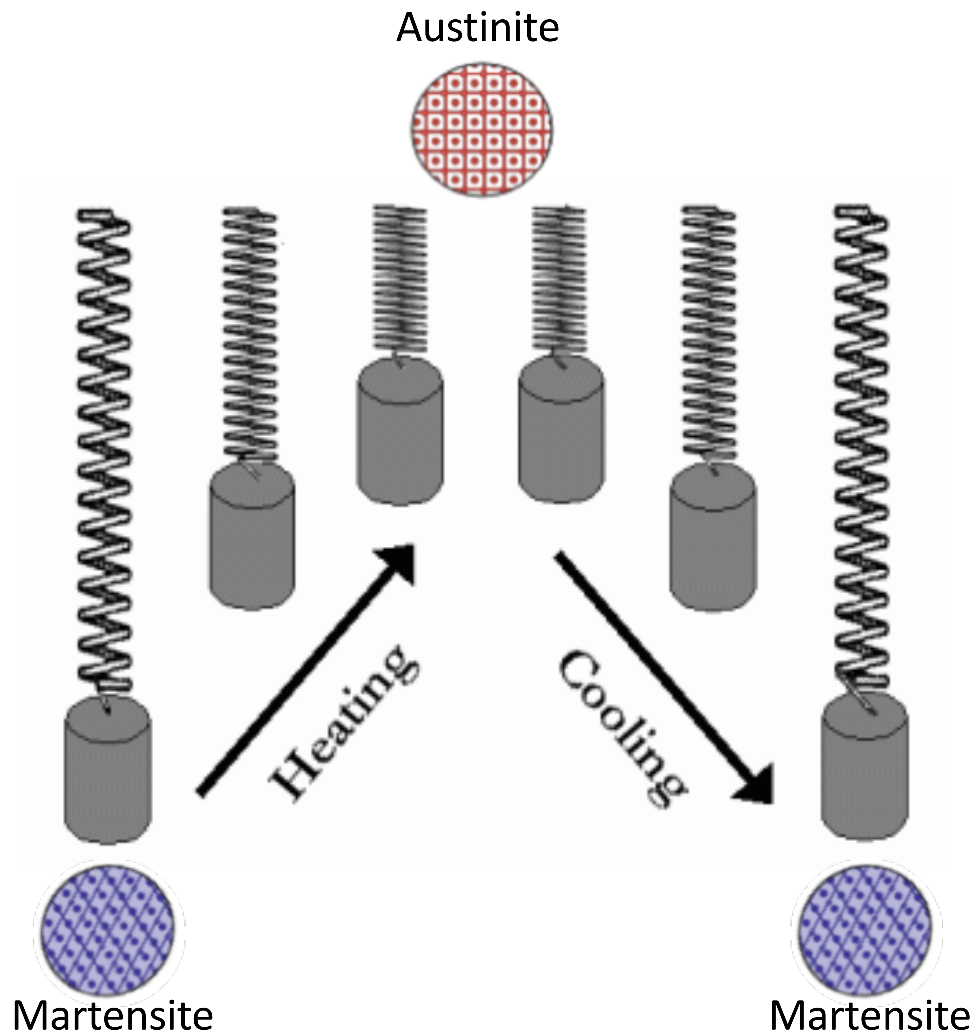
Mechanically Induced Transformation

(Pseudoelastic / Superelastic Behavior)



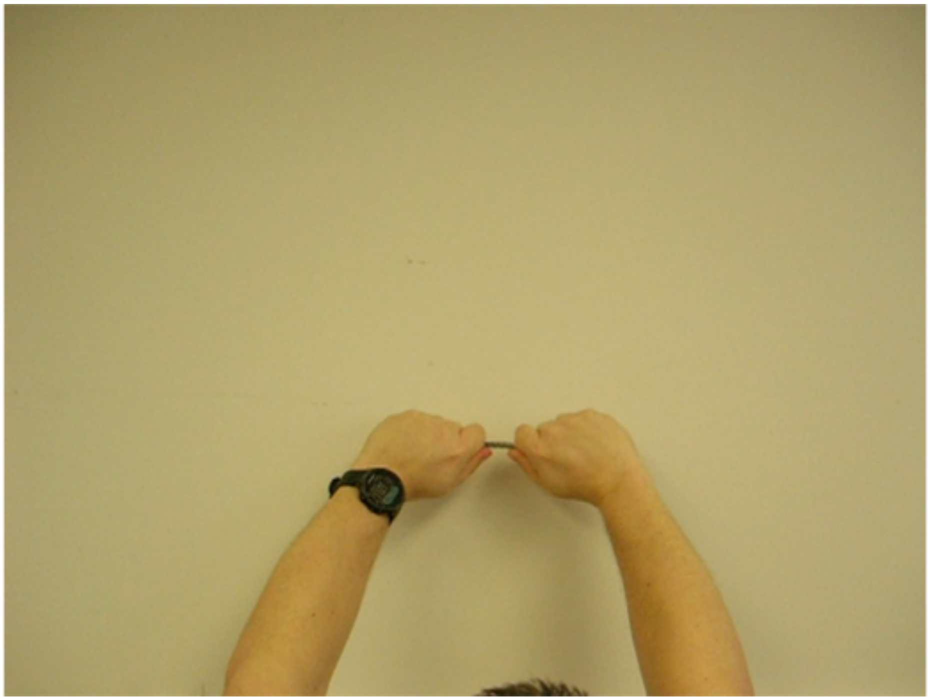
Thermally Induced Transformation

Actuator Behavior (SME)



Examples of the Two Transformation Types

Mechanically Induced Transformation



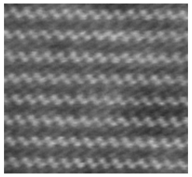
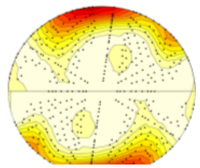
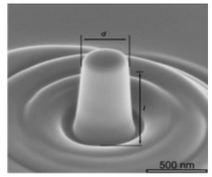
Thermally Induced Transformation

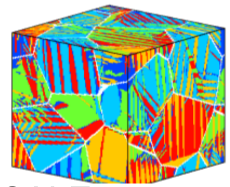
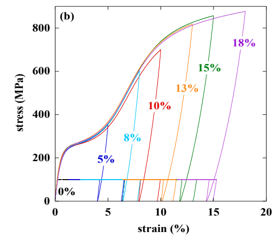
Courtesy of UCF

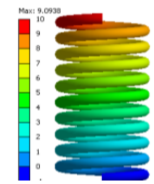
- SMA actuators can generate motion in one dimension (wire form), two dimensions (bending of a bar) or even motion in a more complex three dimensions(springs, honeycombs, panels)
- Functionality: Tension (e.g., wires, springs), compression (e.g., rods, springs), bending (e.g., beams, plates), torsion (e.g., rods, tubes, and springs)

Work Being Conducted by
Shape Memory Alloy (SMA) Team at GRC

Research Driven Approach to Product Development

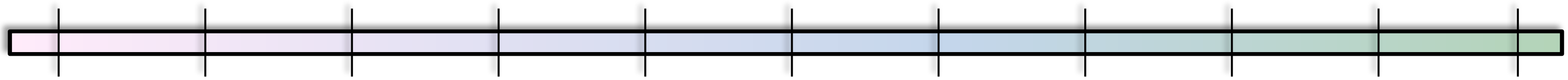



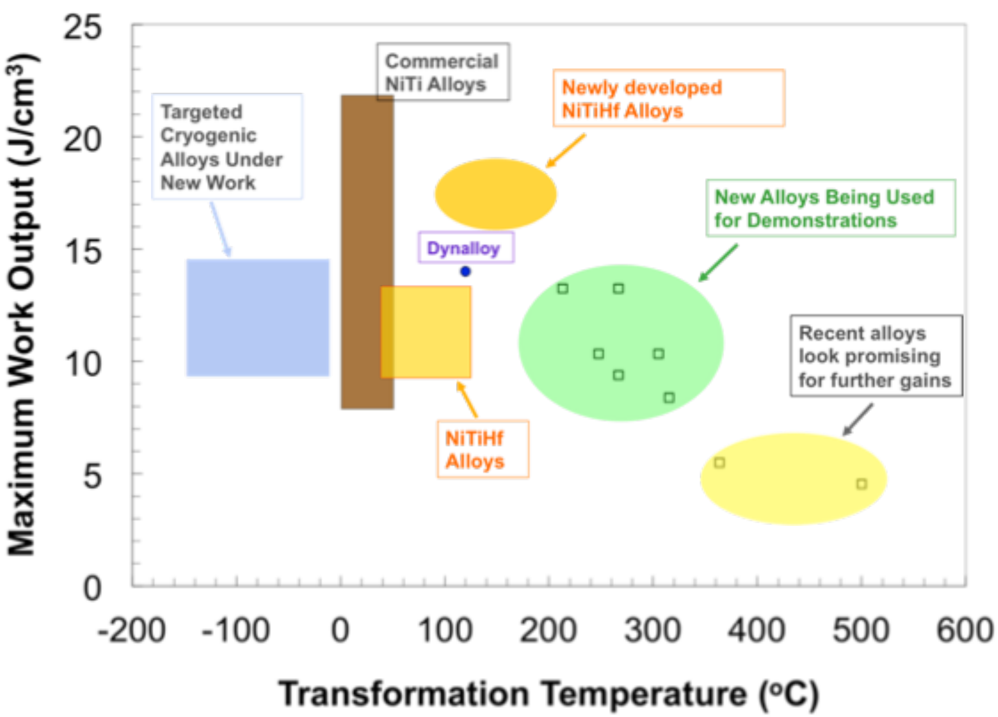



ATOMIC SCALE
(NANOMATERIALS)

MICRO-SCALE
(MICROSTRUCTURES)

STRUCTURAL SCALE
(COMPONENTS)





- **WIDEN TEMPERATURE** range over which they can be used.
- Improving **WORK** capability.
- Create materials that have **BETTER STABILITY (REPEATABLE PERFORMANCE)**.
- **BETTER WEAR** and **CORROSION RESITANCE**.
- **HIGHER DURABILITY** and **LONGER LIFE**.

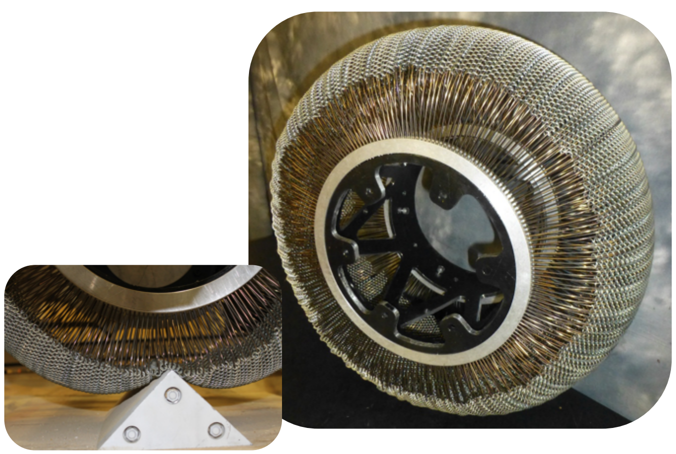
Examples of NASA Applications Using Shape Memory Alloys (SMA)

Shape Memory Alloy (SMA) Non-Pneumatic Tires

- Utilization of **Nickel-titanium (NiTi)**, *"psuedoelastic"* Shape Memory Alloy (SMA).
- Compliant tire technology:
  - ✓ Carry significant load
  - ✓ Envelop obstacles without permanent deformation or damage
- Two types of construction currently available:
  - ✓ Spring Tire
  - ✓ Radially Stiffened Tire
    - Can carry much higher loads than coiled designs
    - More easily scalable for changes in load and tire size requirements

Generation 1 – 890 N (~200 lbf.)

Generation 2 – 2200 N (~500 lbf.)



Generation 3 – 8900 N (~2000 lbf.)

Shape Memory Alloy (SMA) Non-Pneumatic Tires

Generation 1 – Spring Tire

Generation 3 – Radially-Stiffened Tire

Non-pneumatic tire designs have the potential to open the door to thinking about wheel and brake assemblies in a way never before possible.

Wing-tip actuation using SMAs (Ground test)

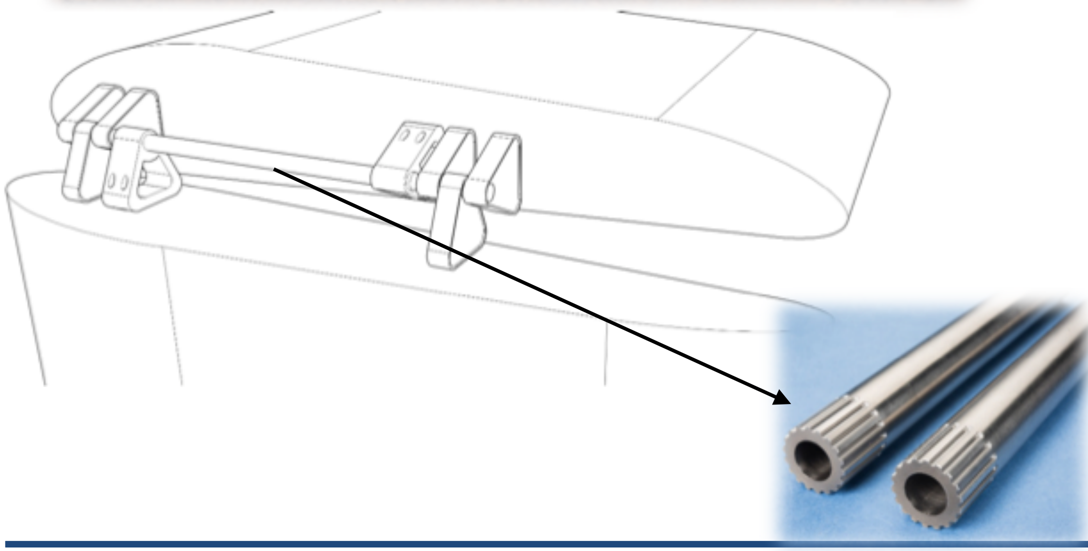
Wings at 0°

Wings up +75°

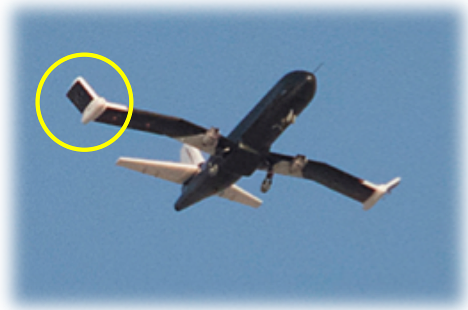
Wings down -75°

Wing-tip actuation using SMAs (Flight test)

https://www.youtube.com/watch?v=9y1kkG2_QpE



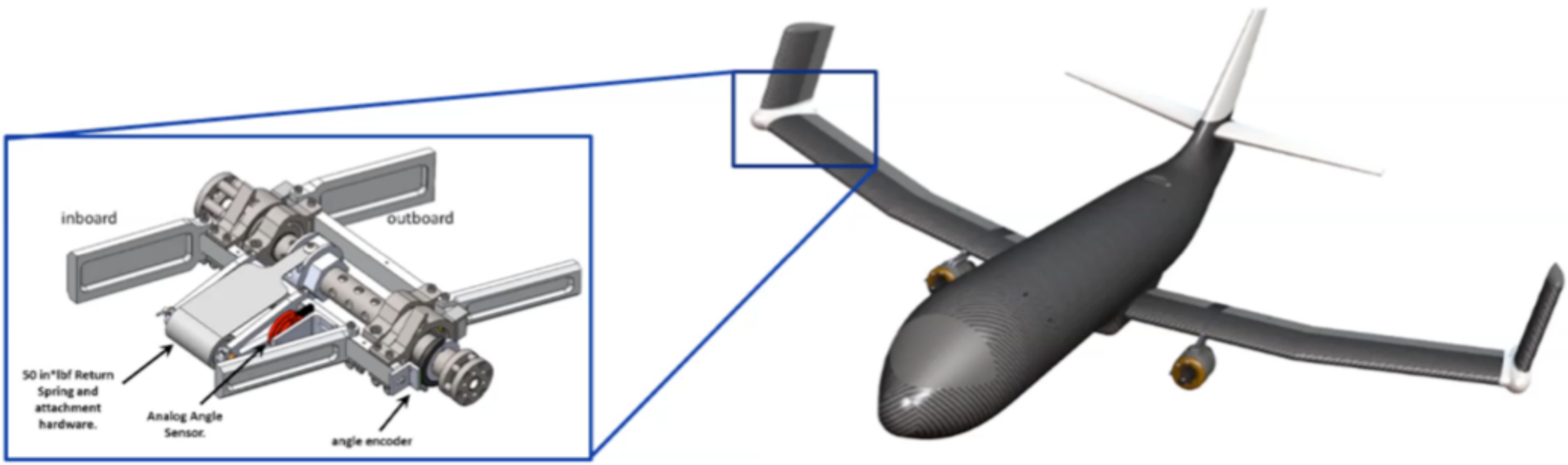
Wings at
0°



Wings up
+75°

Wings down
-75°

Wing-tip actuation using SMAs (Close-up Demo)



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PTERA Test Aircraft Specs:

- Manufacturer: AREA-I
- 180 lb GVW, 40lb payload
- 11.3ft span
- 144 kts max airspeed
- Twin JetCat P220
- Research instrumentation


Questions?
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