Shape Memory Alloy Research and Development at NASA Glenn
Current and Future Progress

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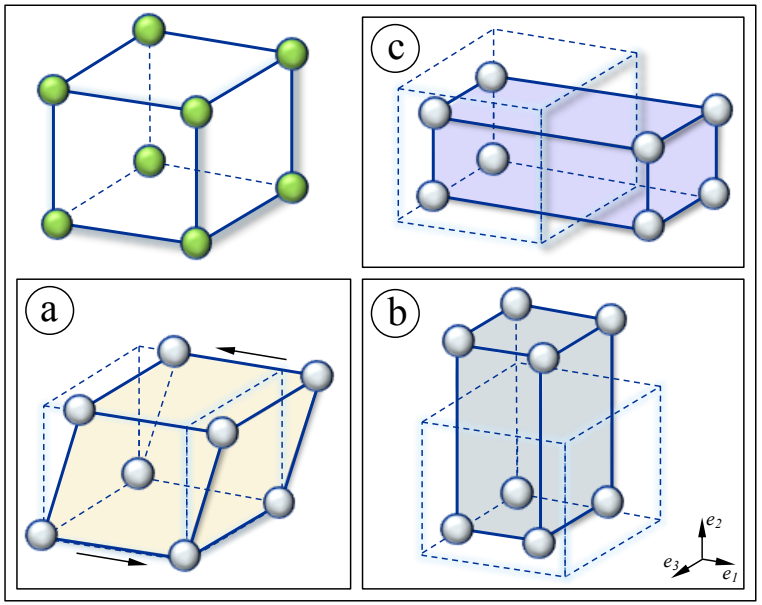
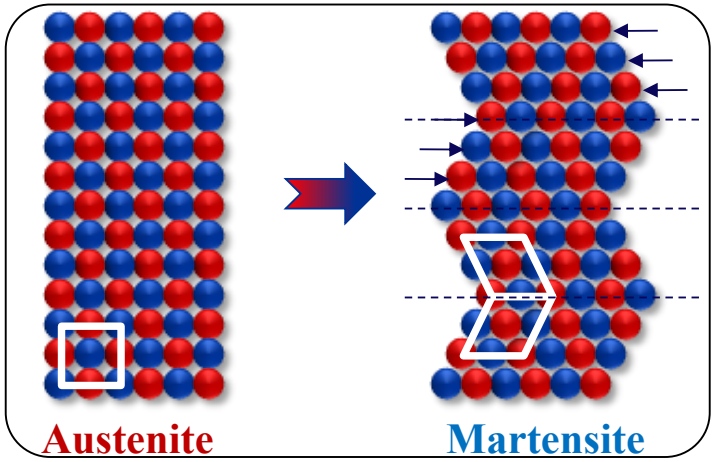
Shape Memory Alloys: An Introduction

- Alloys that have a "memory." These materials have the ability to remember and recover their original shapes with load or temperature.
- SMAs exhibit a solid-to-solid, reversible phase transformation

Variant selection



Simplified 2D



- How?
  1. Bain strain → (lattice deformation)
  2. Lattice invariant shear → (accommodation)

Microstructure

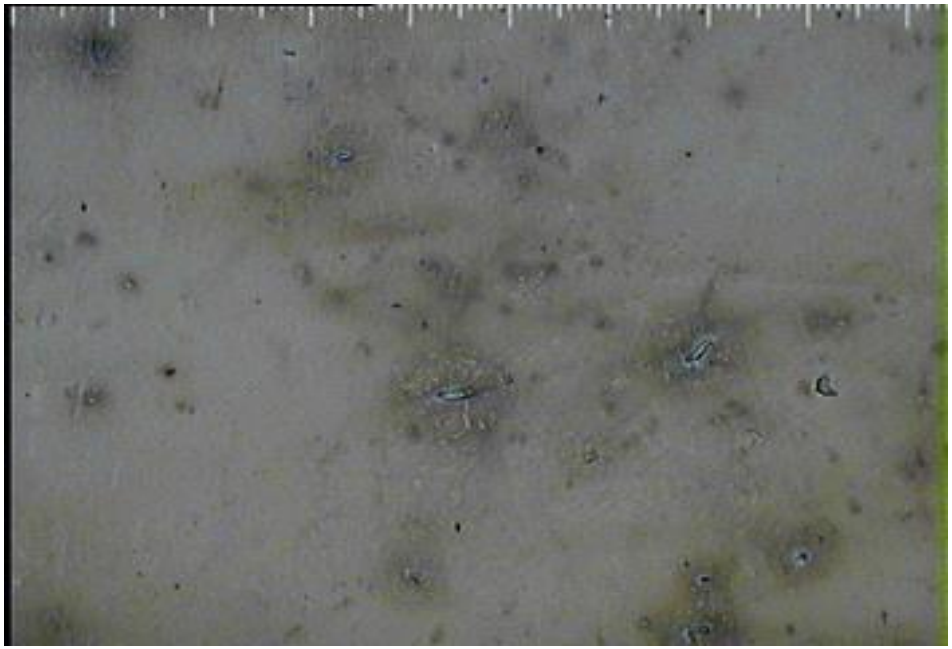
Courtesy of A. Garg

Shape Memory Alloys: An Introduction

Macroscopic

Courtesy of UCF

Microscopic

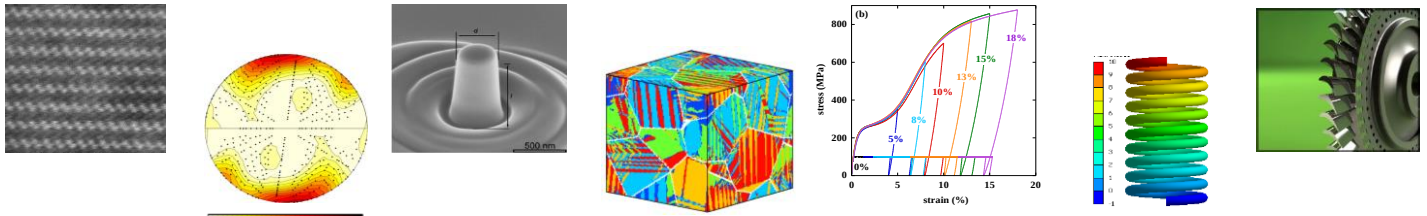


Courtesy of NWU

- 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)

- Functionality: Tension (e.g., wires, springs), compression (e.g., rods, springs), bending (e.g., beams, plates), torsion (e.g., rods, tubes, and springs)

Research and Understanding of Shape Memory Alloys

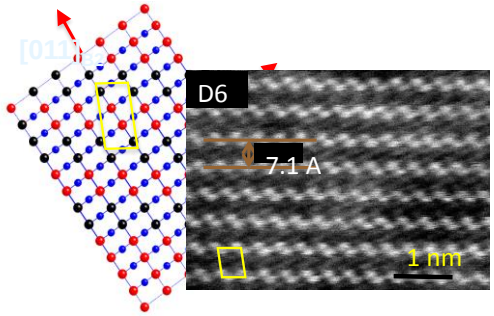


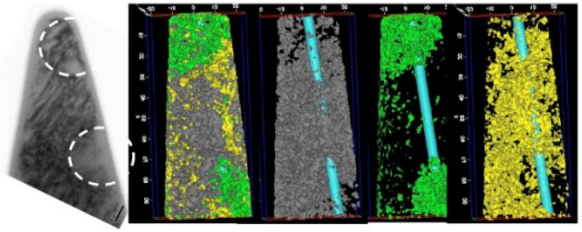
1. Applied Research

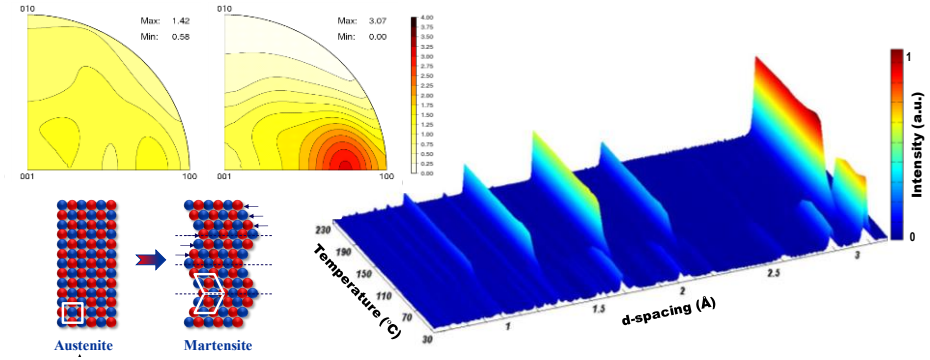
2. Alloy Processing & Development

3. Testing and Modeling

4. Applications







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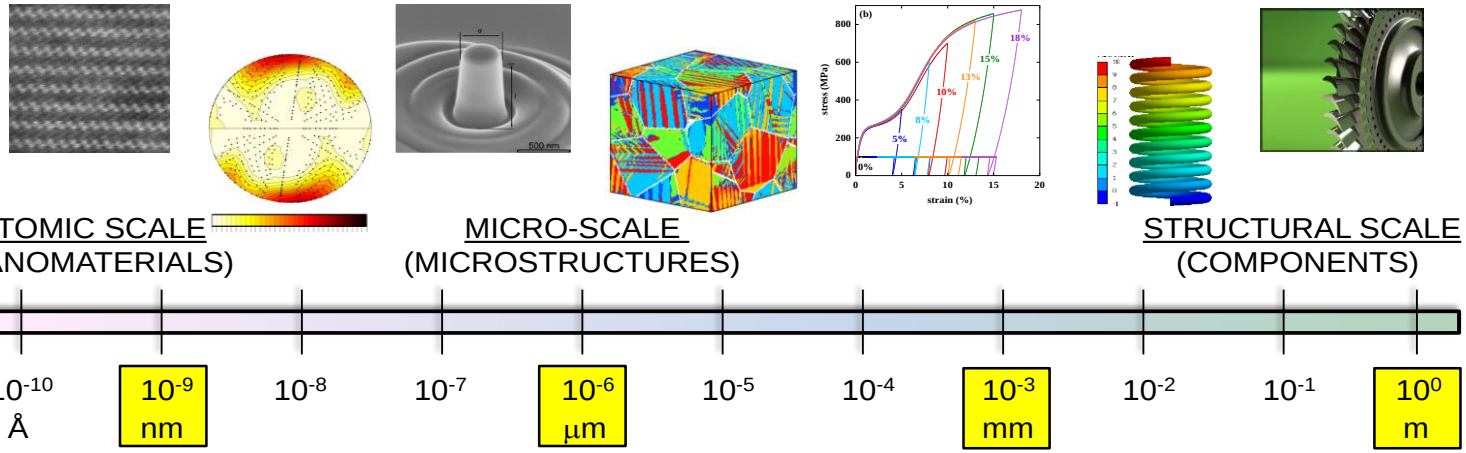

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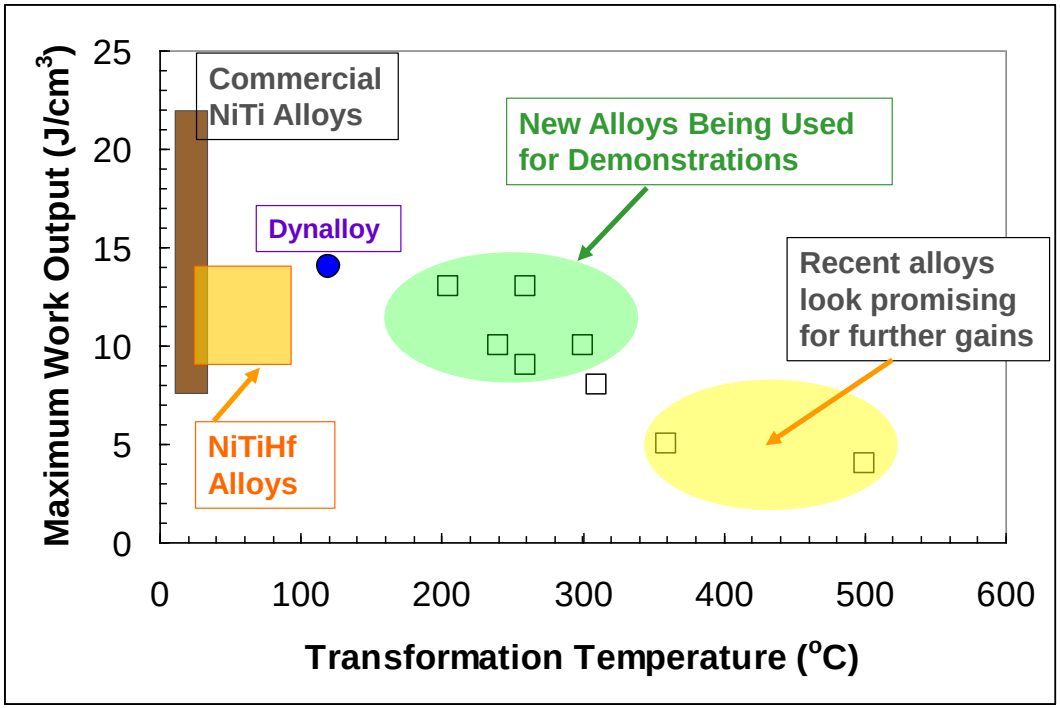
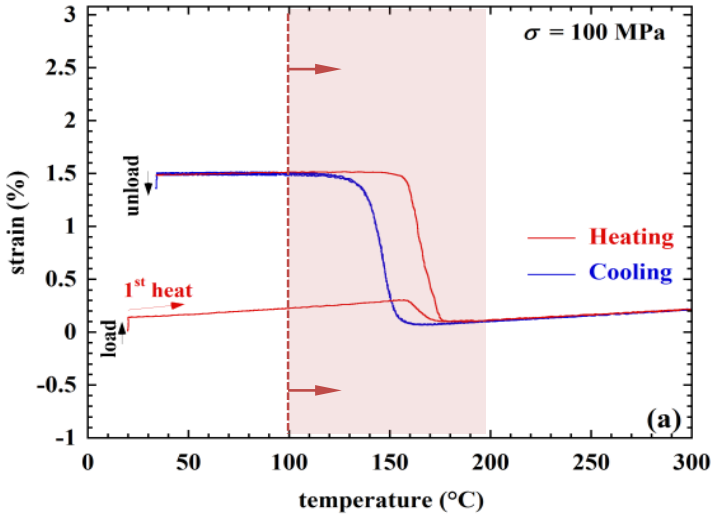


Development of Shape Memory Alloys:

NiTi –Based HTSMAs

NiTiHf



Processing and Workability of HTSMAs

NiTiPt

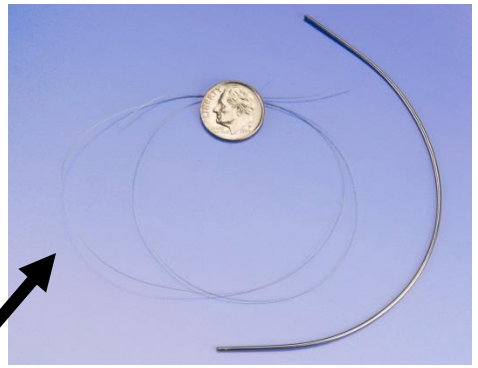
Induction Melt + Homogenization

Extrusion

Multiple-Pass Extrusion

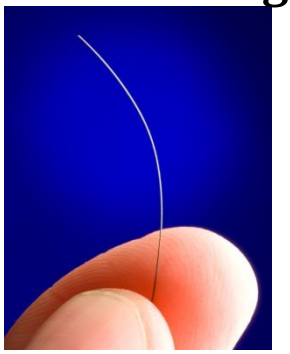
60 mil NiTi-20Pt rod

Wire Grinding



44 & 5 mil NiTiPt

Wire Drawing

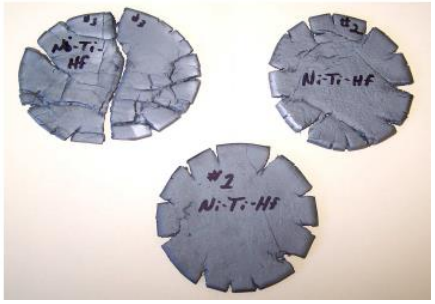


5 mil NiTiPt wire

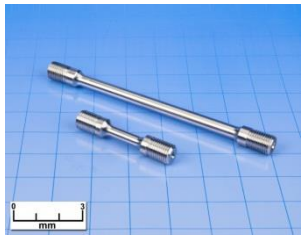
Processing and Workability of HTSMAs

NiTiHf

Successful hot rolled button (C. Wojcik 2008)

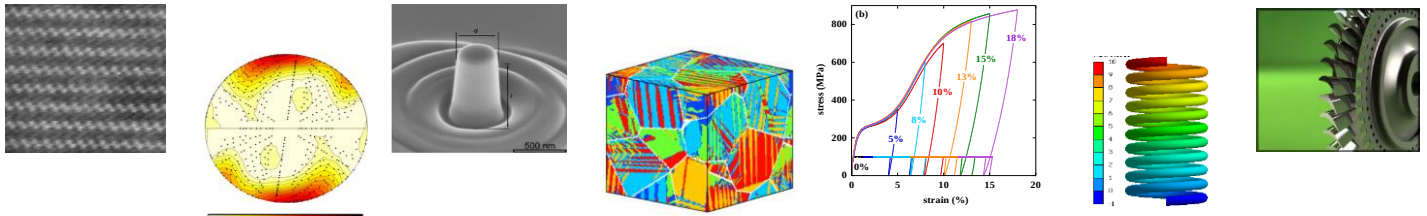


High temperature extrusion proved to be problematic (C. Wojcik 2008)



Successful hot extrusion (rods and tubes)

Research and Understanding of Shape Memory Alloys



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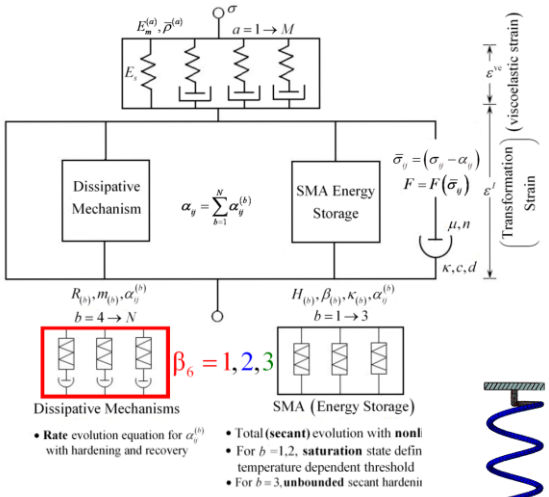
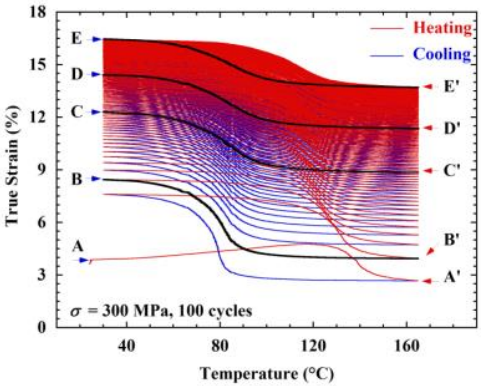
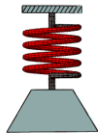


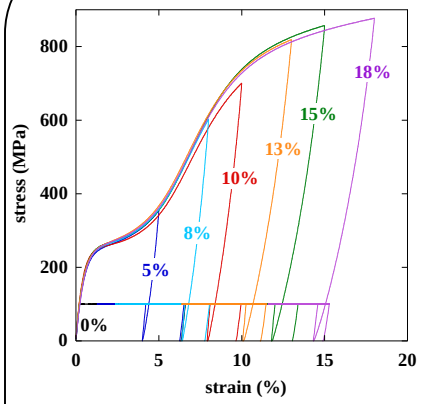




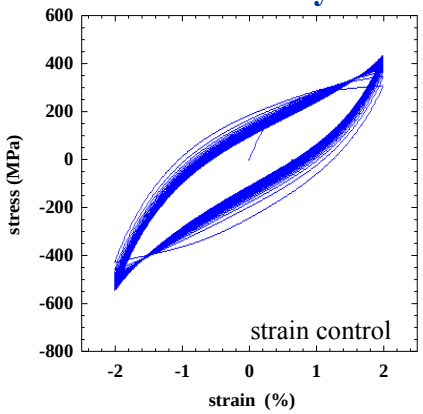
Thermomechanical Testing

Uniaxial (tension/compression)

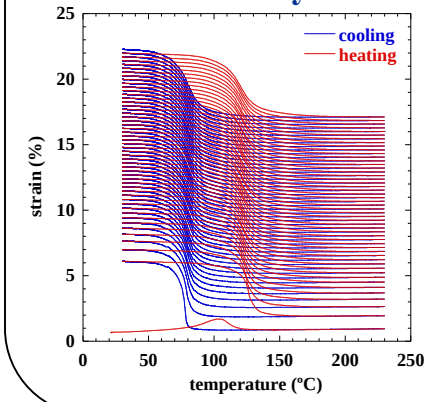
Isothermal monotonic



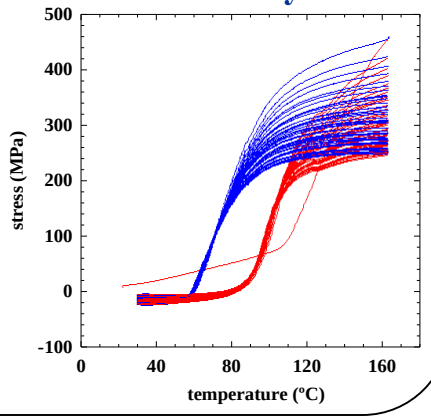
Isothermal cyclic



Isobaric cyclic



Isostrain cyclic



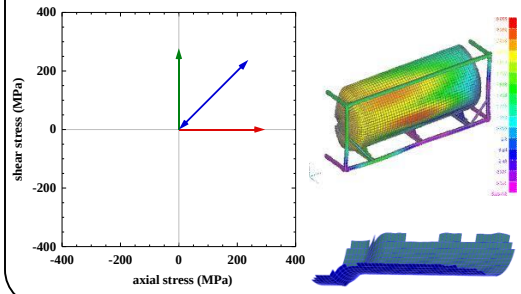
Durability

- *New frames for durability testing are underway*
  - Durability analysis of sample and components
  - Generate data for existing materials

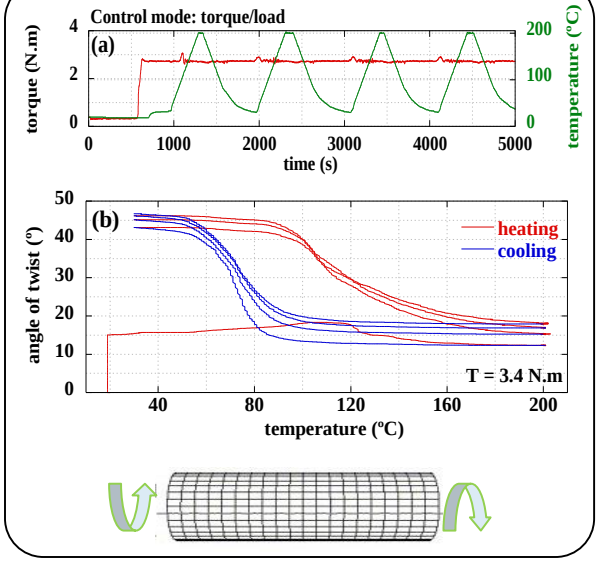
Geometries

Multiaxial

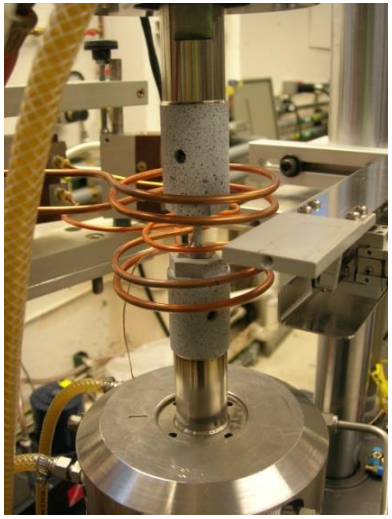
- Proportional/non-proportional loading
- 3D strain measurement
- Torque/force/twist/displacement control capability



Torsion



Hot grip testing



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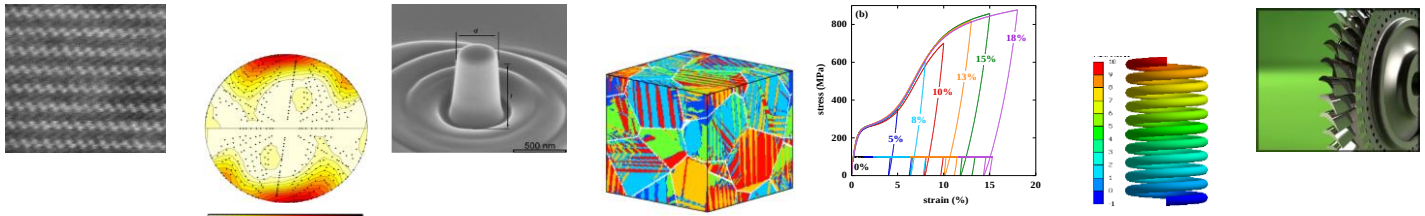

ATOMIC SCALE (NANOMATERIALS) | MICRO-SCALE (MICROSTRUCTURES) | STRUCTURAL SCALE (COMPONENTS)

10^{-10} Å	10^{-9} nm	10^{-8}	10^{-7}	10^{-6} µm	10^{-5}	10^{-4}	10^{-3} mm	10^{-2}	10^{-1}	10^{0} m

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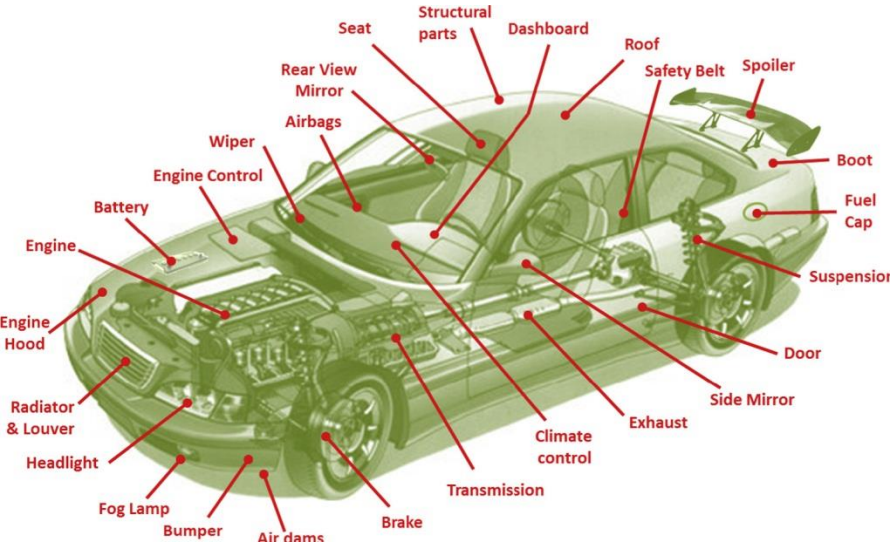
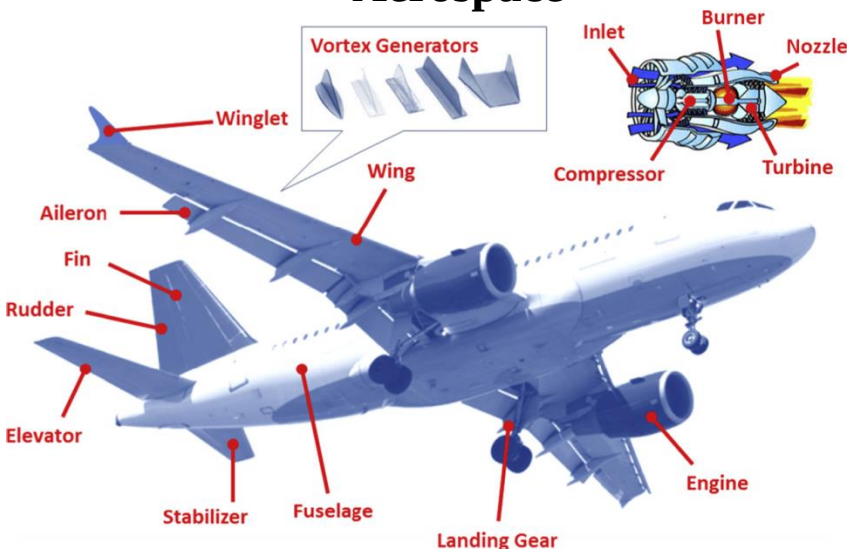
SMA Existing and Potential Applications

Automotive

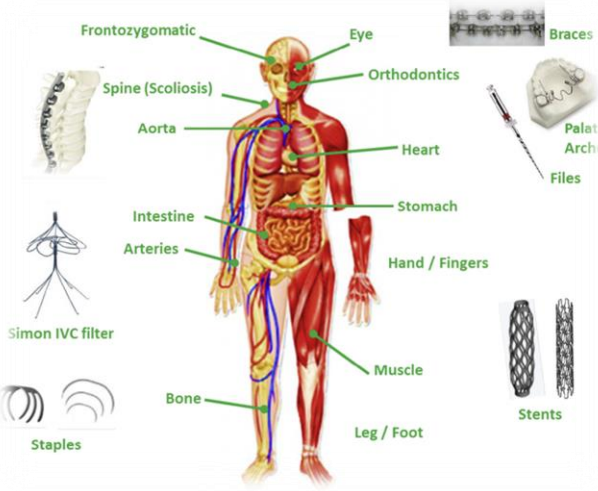


Aerospace



Robotics

Biomedical

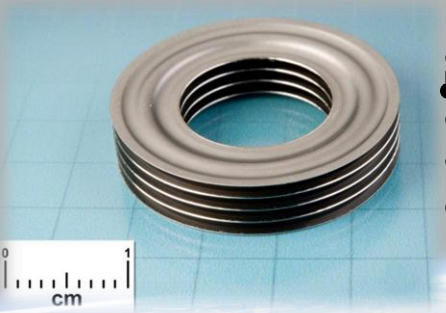


Space
Home goods
Energy harvesting
Toys

Source: J. Mohd Jani et al. / Materials and Design 56 (2014) 1078–1113

Shape Memory Alloy Applications

Space

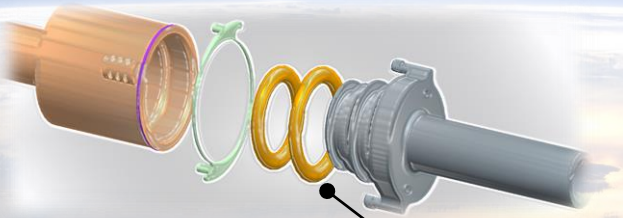


SMA Bellows

- Dynamic sealing
- Fluid handling
- Flexibility (structure alignment)

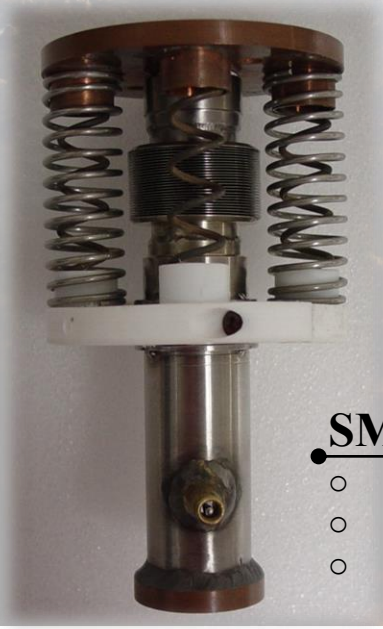
SMA Spring Tire

- Superelastic technology
- Lunar rovers
- Terrestrial tires



SMA Docking Coupling

- Cryogenic transfer coupling
- Orbital propellant depots
- Propellant handling/protection



SMA rock splitters

SMA Thermal Switch

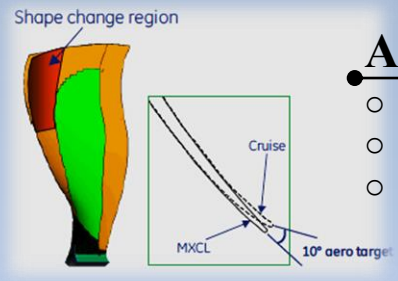
- Thermal management
- Clean & spark-free operation
- Passive or active control

SMA Bearings

- Corrosion resistant
- Non-galling properties
- High yield

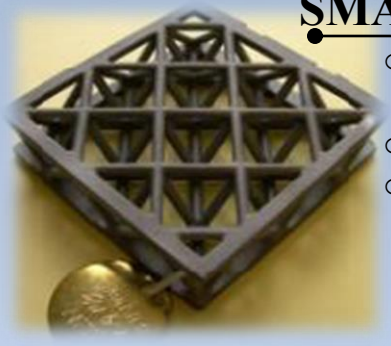
Shape Memory Alloy Applications

Aeronautics



Adaptive Fan Blade

- Embedded SMA actuators
- Aerodynamic efficiency
- Specific fuel consumption reduction

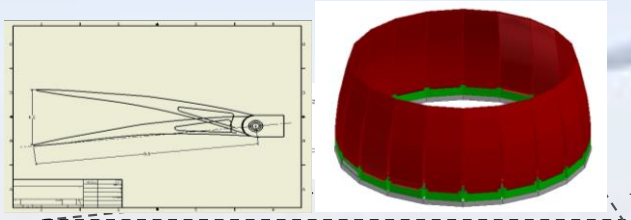


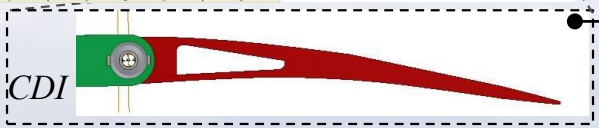
SMA Cellular Structures

- Airframe and engine components
- Morphing airfoils
- Light weight trusses

The Mars Atmosphere and Volatile EvolutioN (MAVEN) mission.

- SMA Pinpullers (From *TiNi Aerospace*) were used to secure and release deployables





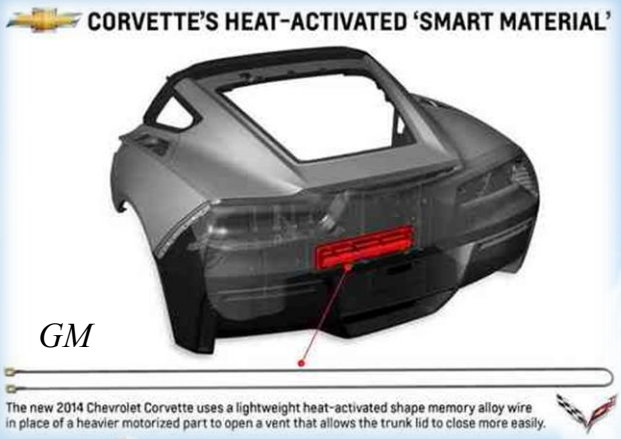
Variable Area Nozzle

- High bypass turbofan
- SMA torque tubes provide flap rotation
- Engine noise reduction

Shape Memory Alloy Applications
Non-Aerospace Potential

Oil and Gas Industry
- SmartRAM™ actuators (*LMP*)
- SMA couplings (Aerofit Inc)
- Deep-water valves/shut off valves
- Self-torquing fasteners

Other Applications
- Home appliances
- Electronics
- Transportation
- Air conditioners



Cleveland Clinic

Medical Industry
- Surgical tools
- Stents and implants
- Glasses frames

Automotive Industry
- Louvers
- Quiet actuators
- Door handle

Development of Shape Memory Alloys: Challenges

High transformation temperatures
- Above 100 °C
- Good work output
- Thermal stability

Durability
- Loading history
- Functional fatigue
- Structural fatigue

Challenges in
microstructures
↓
Micromechanics
↓
Design
↓
Applications

Modeling
- Micromechanics
- Phenomenological
- Evolutions/transients

Workability/Processing
- Ductility
- Composition control
- Heat treatment
- Large scale

Dimensional stability
- Cyclic stability
- Stress-strain relationship

Deign Tools
- Testing standards
- Design handbooks
- Database

SMA Team at NASA GRC

- Santo Padula II
- Ron Noebe
- Glen Bigelow
- Anita Garg
- Darrell Gaydosh
- Timothy Halsmer
- Othmane Benafan
- (Branch Chiefs: Joyce Dever, Bob Carter)