Shape-Memory Alloy Actuators for Small Satellites

Jerry Fuller
Small Satellite Development & Operations
The Aerospace Corporation

Small Satellite Conference, Logan UT.,
August 5, 2017

Approved for public release. OTR 2017-00893.

Shape-Memory Alloy Actuators for Small Satellites

Philosophy

Small spacecraft often suffer from inadequate design analysis, and testing. In choosing a release mechanism method, pick something you can...

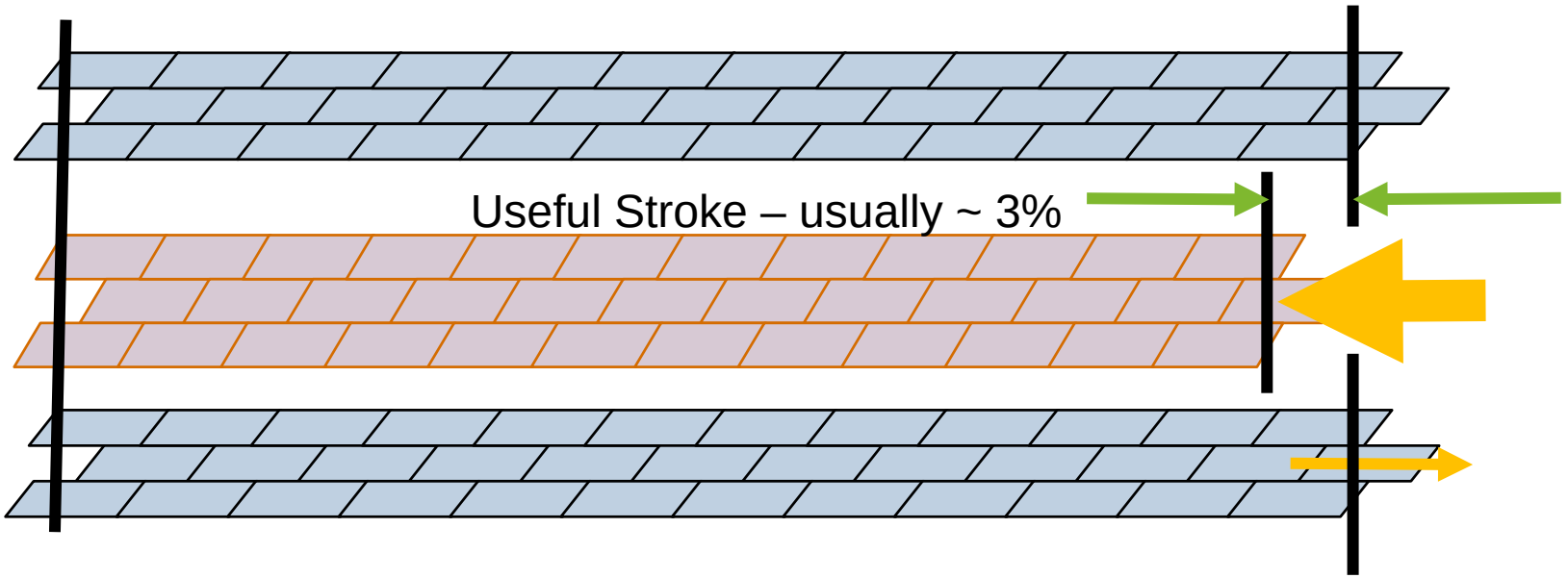
- Test easily and repeatedly
- Test with minimal change to spacecraft configuration
- Measure margin

Shape-Memory Alloy (SMA) Wire Actuators should be considered because they can be built into mechanisms that are easily tested many times.

Shape-Memory Alloy Actuators for Small Satellites

Nitinol SMA Actuator Wire Technology

- Nitinol Actuator Wire – usually about a 50/50 mix of Nickel and Titanium
- Application of heat (usually "I^2R", resistive heating) changes crystal structure and wire length, producing a force. After cooling, a small force will return the wire to its original length
- Actuator wire can be tuned during manufacturing to different transition temperatures, often around 70 to 100 C



Shape-Memory Alloy Actuators for Small Satellites

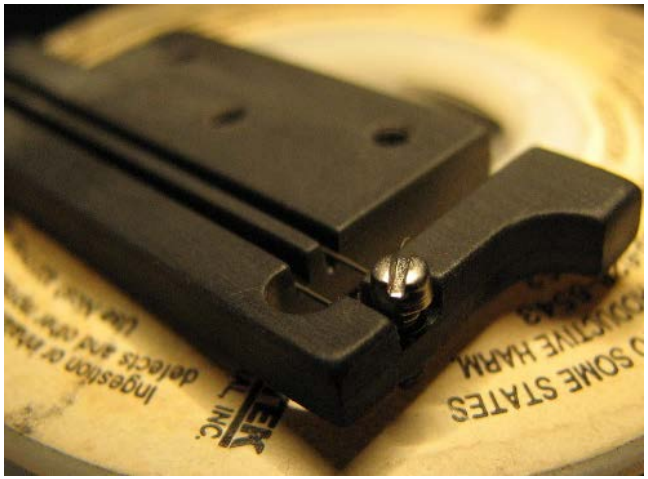
Design Approaches

- Direct-Acting
  - Simple – just pull a blockage out of the way
  - Low Force (given power usually available)
  - A few volts and a few hundred mA

- Indirect Acting
  - Releases stored energy (spring)
  - Complex motion
  - Higher Forces
  - Lower required currents

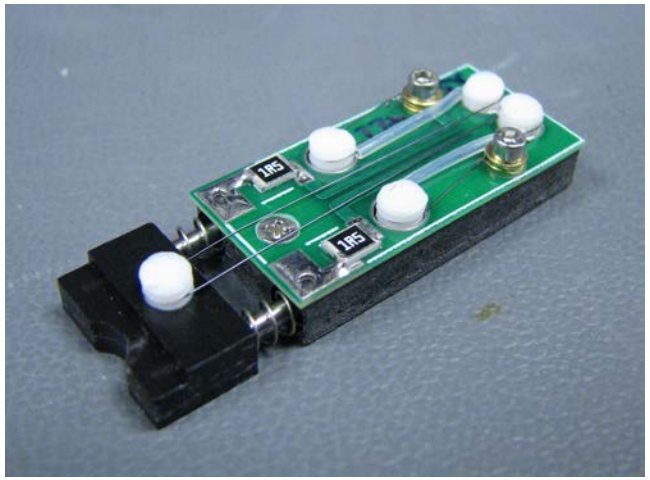
Shape-Memory Alloy Actuators for Small Satellites

AeroCubes 2,3 Balloon Cover Latch Mechanisms



AeroCube 2

- Living Hinge
- SMA Wire doubled back
- Resistance obtained by wire resistivity alone

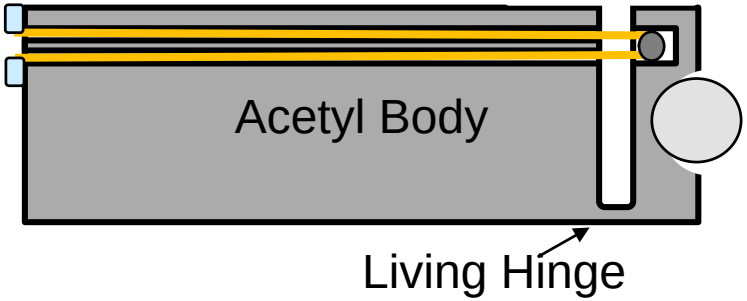


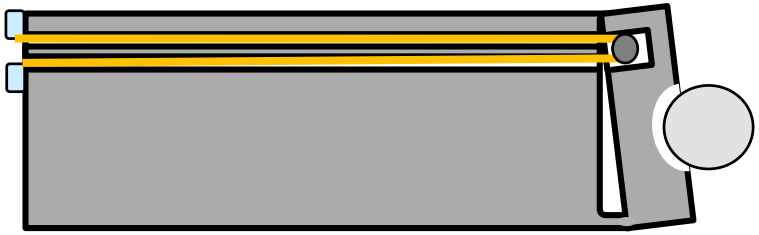
AeroCube 3

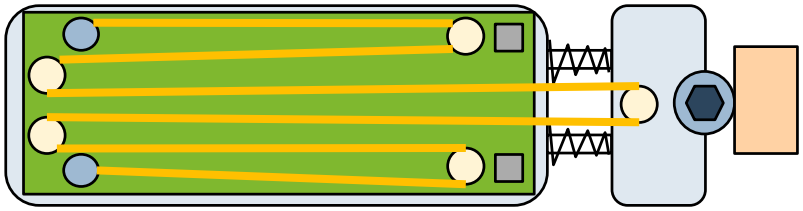
- Sliding assembly
- Serpentine SMA Wire path
- PTFE guides
- Resistance by wire length + circuit card-mounted chip resistors

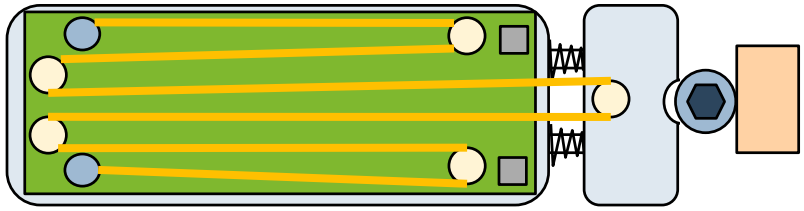
Shape-Memory Alloy Actuators for Small Satellites

Design Approaches, Direct-Acting





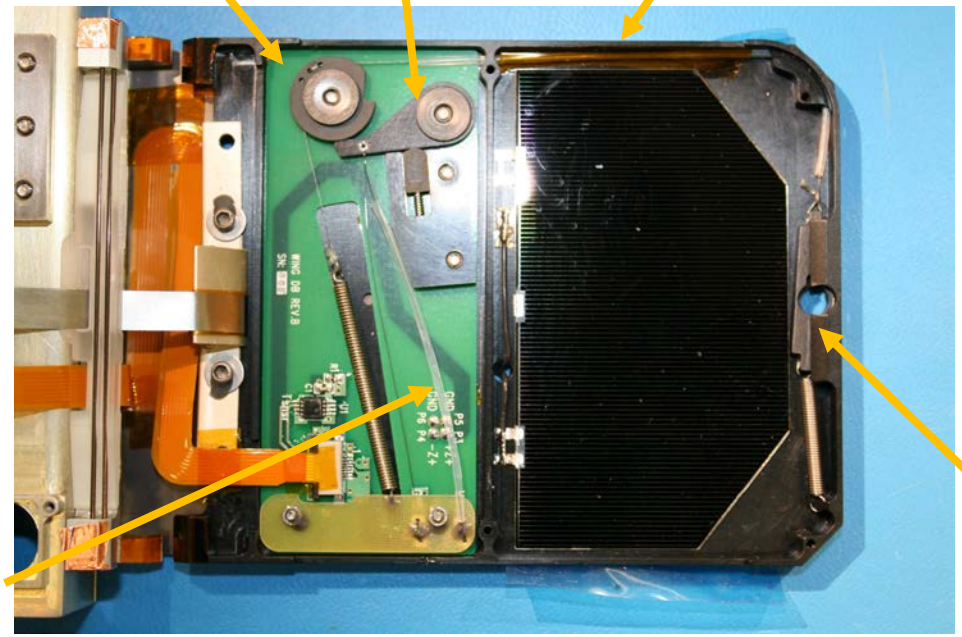




- Increase wire length to increase stroke
- Increase pull force by doubling wire length
  - Or increasing wire diameter (and current)

Shape-Memory Alloy Actuators for Small Satellites

AeroCube 4 - Indirect-Acting Wing Release, Direct-Acting Drag Device Release

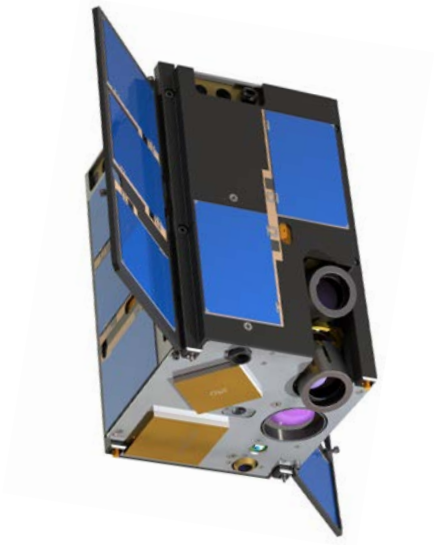


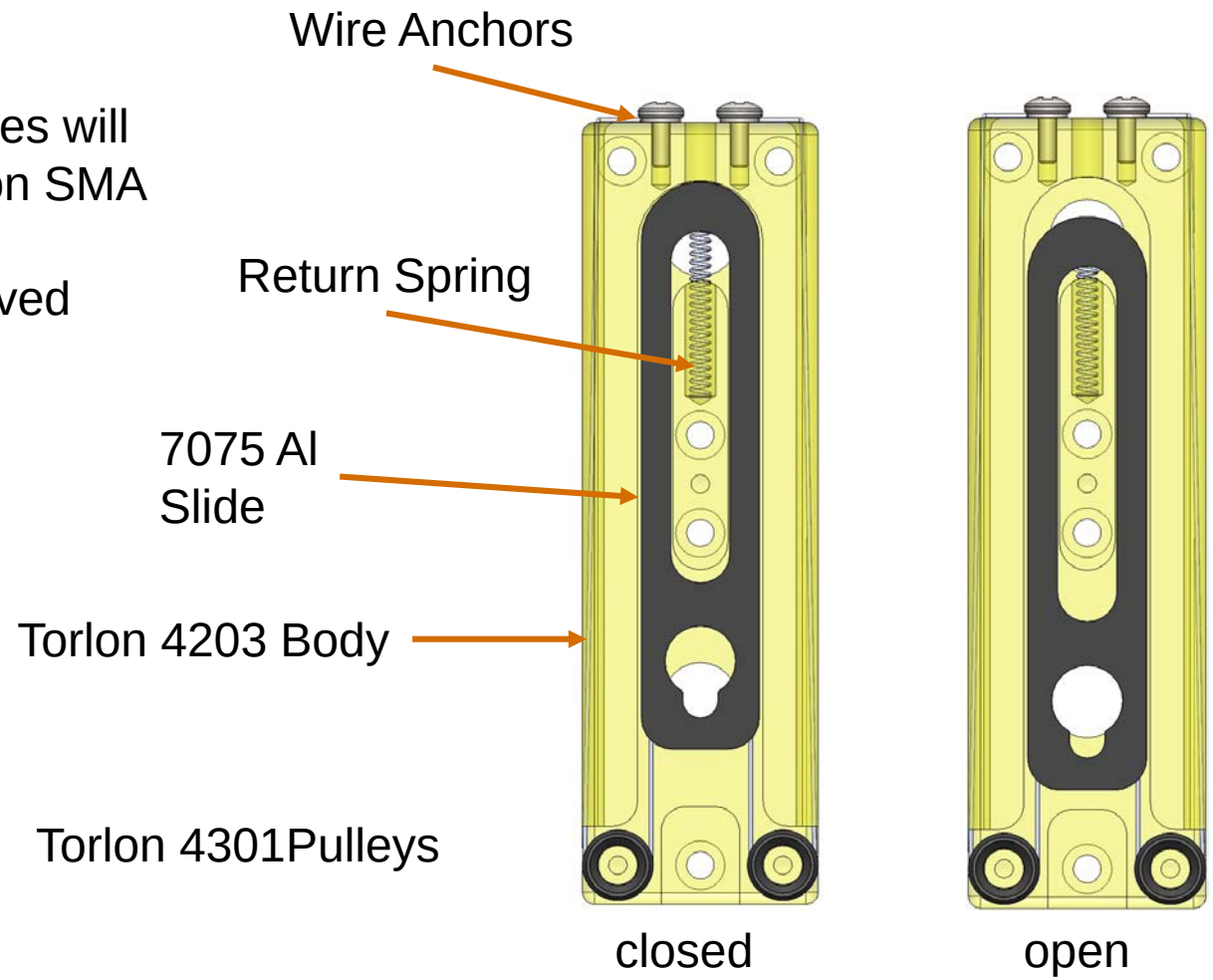
Direct-acting cover latch released AC4's Drag Device

Shape-Memory Alloy Actuators for Small Satellites

Optical Communication and Sensor Demonstration (OCSD) satellite

- Many future satellites will use modular, bolt-on SMA Wire Actuators
- Evolved and improved serpentine path
- Better materials

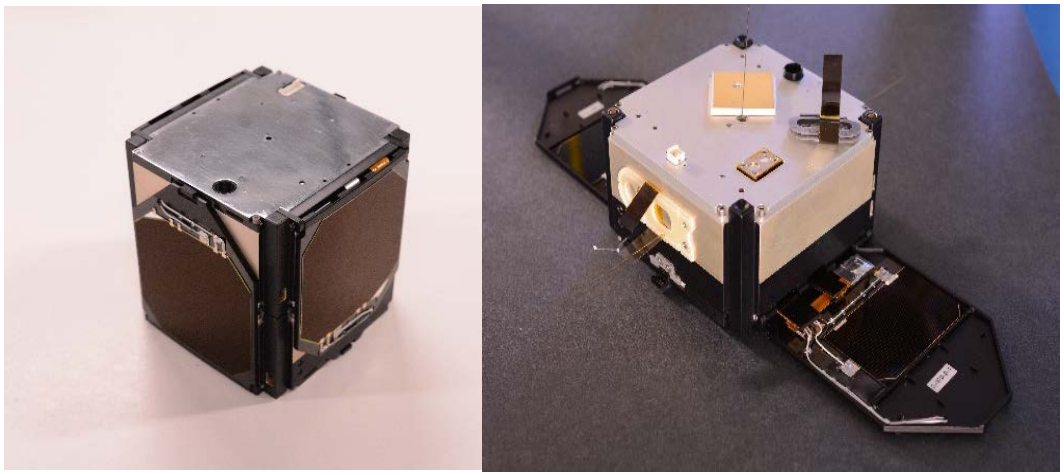


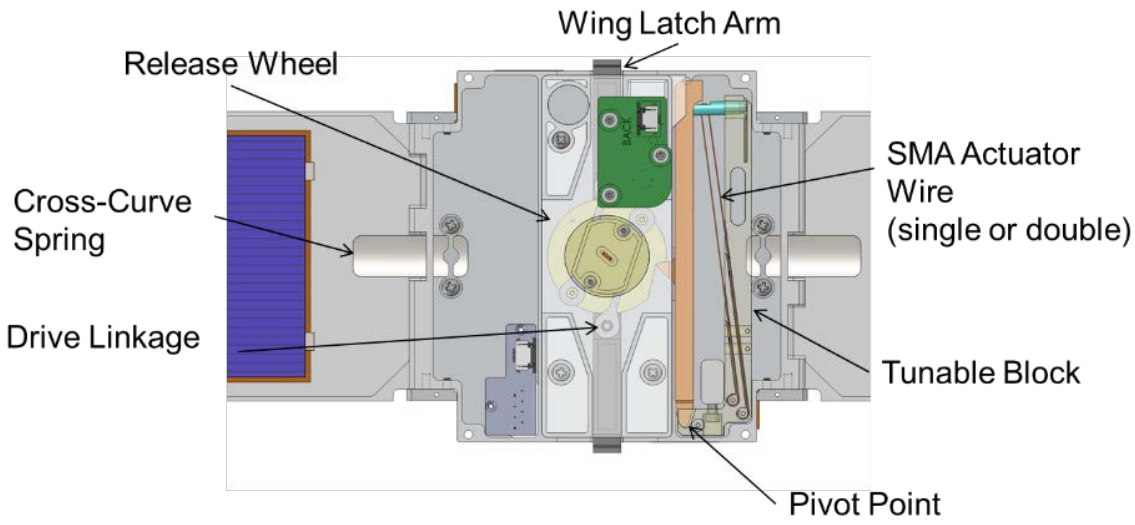


Shape-Memory Alloy Actuators for Small Satellites

AeroCube 6 – Indirect Actuation complex deployment

- SMA Wire restrained a clock spring
- Rotating element simultaneously deployed wings and separated satellites
- Qualification model tested with 80 consecutive deployments



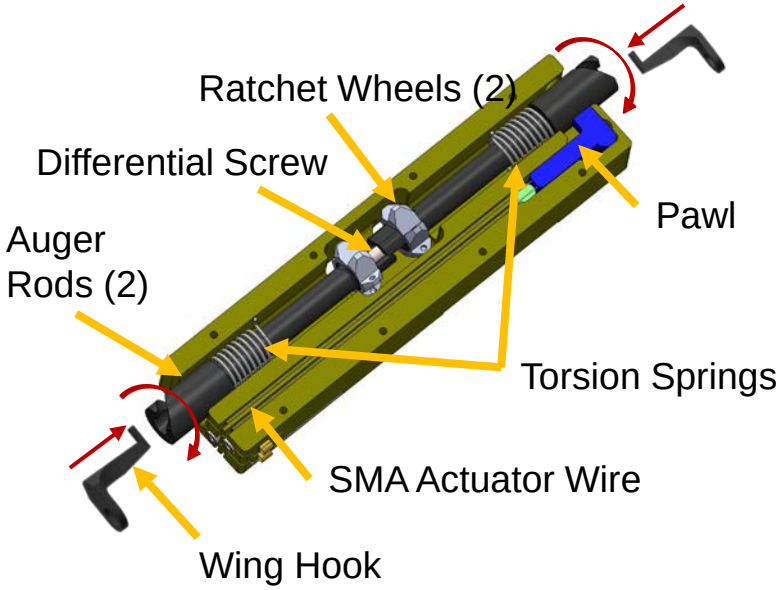


Shape-Memory Alloy Actuators for Small Satellites

ISARA– Indirect Actuation complex deployment

- SMA Wire restrained a torsion spring mechanism to release a complex reflectarray antenna
- Qualification model tested with 80 consecutive deployments
- Reset time was less than 1 minute

- Problems later emerged with SMA wire damage during vacuum testing as a result of overheating
- Resolution: Temperature was controlled more thoroughly by pulsing current to wire



Shape-Memory Alloy Actuators for Small Satellites

GOTCHAs

- Wire Overheating in Vacuum
  - Pulsing, PWM, External Resistor,
- Force Margin - Walking Wounded
  - Plan to measure and show margin
  - Watch for change in margin over repeated tests
  - Measure SMA Wire resistance before and after tests
- SMA-to-Conductor Interface
  - Screw terminal connection best if possible
  - Multiple passes of SMA wire through crimps
- Hard Stops
  - Avoid energizing the wire while at the end of travel
  - Can “Re-train” the SMA
  - Solder flux causes embrittlement
  - Separate mechanical from electrical connection
  - Consider mechanical crimp connection

Shape-Memory Alloy Actuators for Small Satellites

Conclusions

- Shape Memory Wire Actuators can be a great alternative to Meltwires/ Burnwires
- Watch out for design “gotchas”
  - Test thoroughly in vacuum
  - Measure SMA Wire resistance before and after tests
  - Show force margin after vacuum testing

Shape-Memory Alloy Actuators for Small Satellites

Acknowledgements

- United States Air Force Space & Missile System Center Advanced Systems and Development Directorate (SMC/AD)

- Richard Welle
- Brian Hardy
- David Hinkley
- Alex August-Schmidt, Geoff Maul, Jacqueline Tardif, Sean Hutchinson

Shape-Memory Alloy Actuators for Small Satellites Support Information

Jerry Fuller

Small Satellite Conference, Logan Ut.,
August 5, 2017

Shape-Memory Alloy Actuators for Small Satellites

Types of Actuators

Reset-able Shape Memory Actuators (SMAs) should be considered for small spacecraft applications, especially CubeSats, where ease of testing is important

- One-time Use (usually)
- Test many times (in some cases, over 100)
- Minimal Change to Tested Configuration (just re-stow deployable)
- Simple direct-acting mechanisms OR
- Complex mechanisms with complex or returning motion

Shape-Memory Alloy Actuators for Small Satellites

SMA Wire Actuators on AeroCube CubeSats

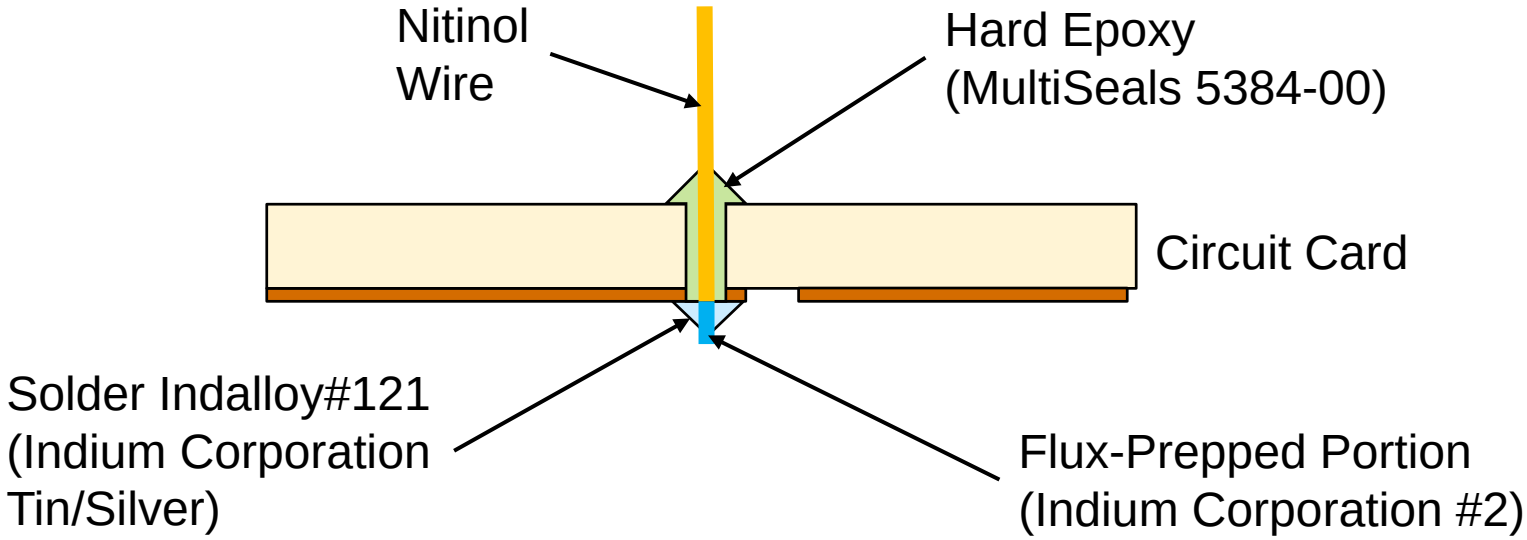
Spacecraft	SMA Wire Actuator	Type	
AeroCube 2	Drag Balloon Release	Direct	
AeroCube 3	Drag Balloon Release	Direct	
AeroCube 4	Wing Release	Direct	
AeroCube 4	Drag Device Deployment	Direct	
AeroCube 6	Wing Release & 1-U to 1/2 U separation	Indirect	
OCSD	Wing Release	Direct	
OCSD	Star Camera Sun Shade Release	Indirect	
ISARA	Simultaneous Wing Release	Direct	

Shape-Memory Alloy Actuators for Small Satellites

Electrical Connection – Solder Joint

- Dynalloy recommends crimp mechanical connections
- Nitinol can be successfully soldered BUT
  - Beware of embrittlement from aggressive fluxes
  - Wash immediately and thoroughly
  - We recommend separating mechanical from electrical engagement

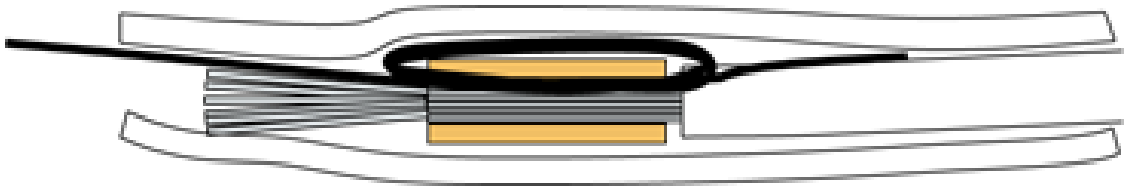
Example below – technique developed for mounting .015” Nitinol antennas

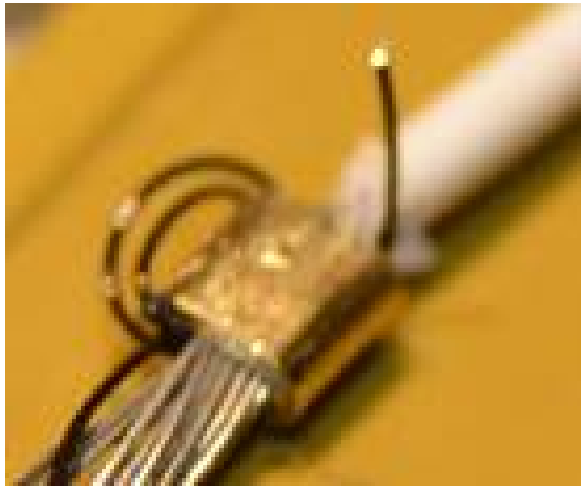


Shape-Memory Alloy Actuators for Small Satellites

Electrical Connection – Crimp Joint

- Multiple loops through the crimp may be needed for to assure good contact
- Soft brass crimp
- strain relief by heatshrink

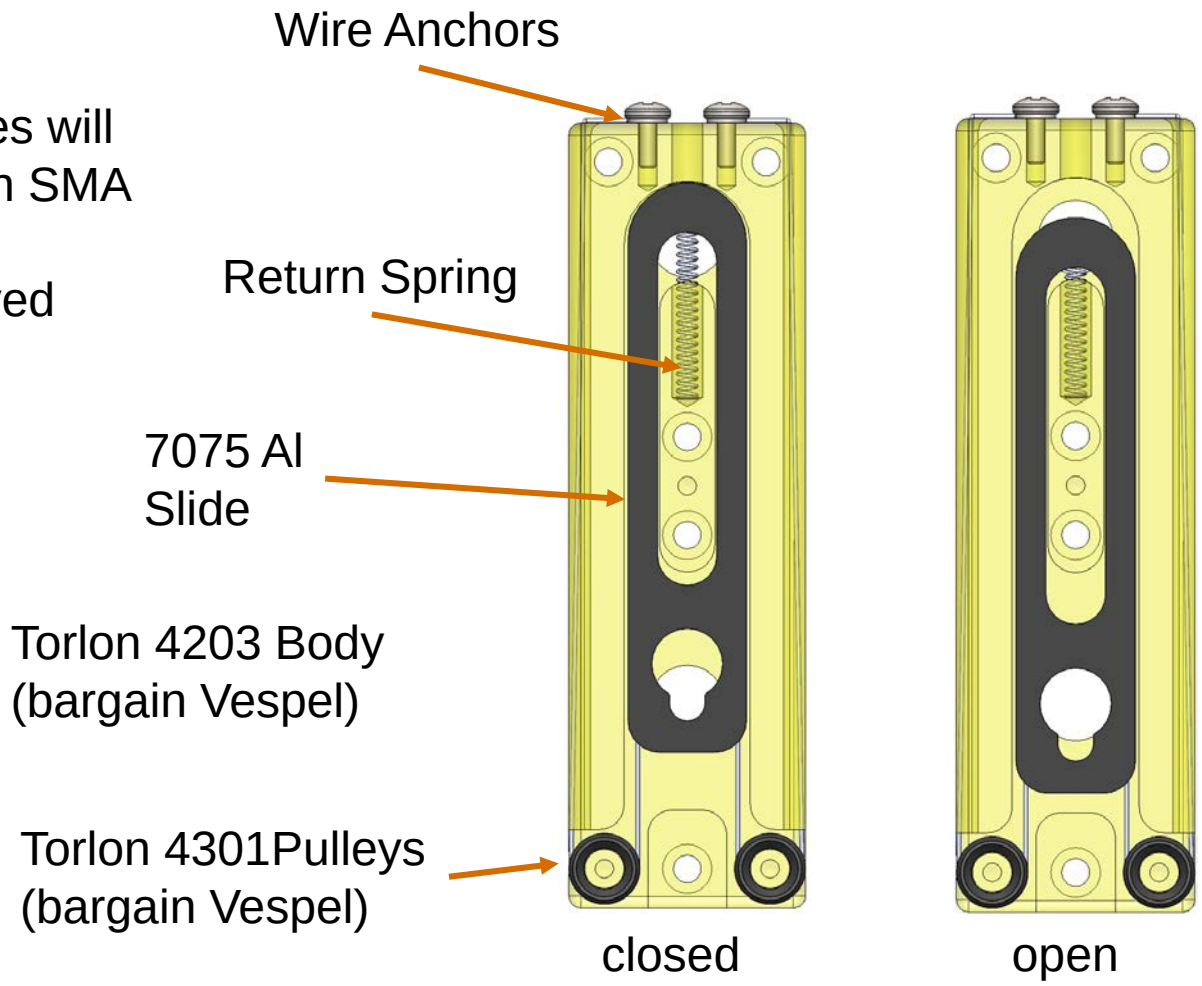




Shape-Memory Alloy Actuators for Small Satellites

OCSD (and more)

- Many future satellites will use modular, bolt-on SMA Wire Actuators
- Evolved and improved serpentine path
- Better materials



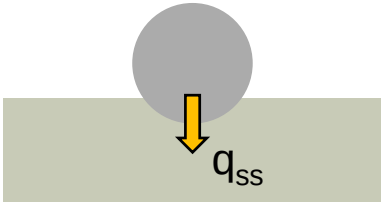
Shape-Memory Alloy Actuators for Small Satellites

Operation (and Testing) in Vacuum

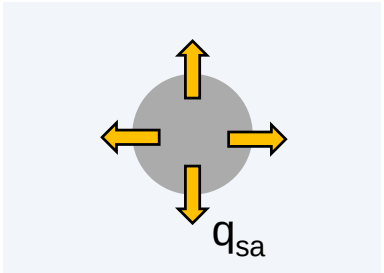
- Wire temperature balances resistive heating with heat dissipation
  - *Solid-solid conduction (atmosphere or vacuum)*
    - Partially limited by surface area of contact
  - *Solid-air conduction/convection (atmosphere only)*
  - *Solid-vacuum – radiation only (vacuum only)*
- Very approximately (depending on conditions):

$$q_{ss} \cong 10 \times q_{sa} \cong 10 \times q_{sv}$$

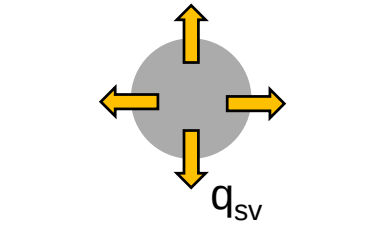
- With solid contact, q_{ss} is approximately the same whether tested on the ground or operated in space
- Without solid contact, q_{sa} is what you will test in air on the ground while q_{sv} is what you get in space
  - *For the same power input, the vacuum case will be substantially hotter than the air case, possibly damaging the wire through overheating*



solid



air



vacuum

Shape-Memory Alloy Actuators for Small Satellites

Materials and Resources

Material	Use
Aluminum, 6061 T6	Structure, retained member, linkage
Aluminum, 7075, Hard-Anodized	Sliding Latch – interface to retained member
Brass, Alloy #260/270	Crimps (Nitinol-to-Leadwere)
Stainless Steel	Fasteners, retaining interface, retained member (bolt)
Stainless Steel	Bias spring, extension spring, clock spring (energy storage)
Nitinol (superelastic)	Cantilever bias spring, Antenna Element
Dynalloy Inc. Flexinol® SMA Actuator Wire	Actuation force
polyamide-imide (Torlon™ 4203)	Structure, sliding members
polyamide-imide (Torlon™ 4301)	Sliding members (low-friction)
Teflon™	Wire post guides, insulating tubing
Acetyl Copolymer (Delrin™)	Structures
Polyimide tape (Kapton™)	Insulation, Hinges
Polyimide tube (Kapton™)	Insulation
NyTek 1200 CF® Nylon™(printed)	Sliding linkage
Somos® WaterShed XC 11122 (printed)	Guides fixed components, prototypes

Shape-Memory Alloy Actuators for Small Satellites

SMA Wire vs Meltwire vs Motors

	Meltwire/Burnwire	SMA Wire Actuator	Motors
Ease of Testing	Re-string each time	Very easy	Very Easy
Break Configuration	Considerable	Minimal	Minimal
Modular	Not usually done – but a good idea	easily modularized	Can be
Cost	Low	Low	higher
Design Time	Low	Medium	high
Reusable mechanisms	Very difficult	Difficult	Easy
Mass and Volume	Very low	Very low	Moderate
Residual Magnetism	Zero	Zero	Depends on motor and shielding

Shape-Memory Alloy Actuators for Small Satellites

If you must use Meltwires, consider modular, bolt on assemblies

Modularizing Meltwire (or SMA) Actuators:

- Allow testing at component level
- Allow testing *en masse*
- Give confidence through statistics
- Minimize change to configuration during system testing
- Minimize time to “reset” after actuation test
- Make system testing much more convenient and less expensive