Apparatus and Method for Low-Temperature Training of Shape Memory Alloys

Adam Swanger[1], James Fesmire[2], Steven Trigwell[3], Tracy Gibson[4], Martha Williams[5] and Othmane Benafan[6]

[1]NASA Kennedy Space Center, Cryogenics Test Laboratory, NE-M5, KSC, FL 32899 USA
[2]NASA Kennedy Space Center, Cryogenics Test Laboratory, UB-R1, KSC, FL 32899 USA
[3]Sierra Lobo ESC, Kennedy Space Center, ESC-850, KSC, FL 32899 USA
[4]Vencore ESC, Kennedy Space Center, ESC-872, KSC, FL 32899 USA
[5]NASA Kennedy Space Center, Exploration Research & Technology, UB-R3, KSC, FL 32899 USA
[6]NASA Glenn Research Center, Cleveland, OH 44135 USA

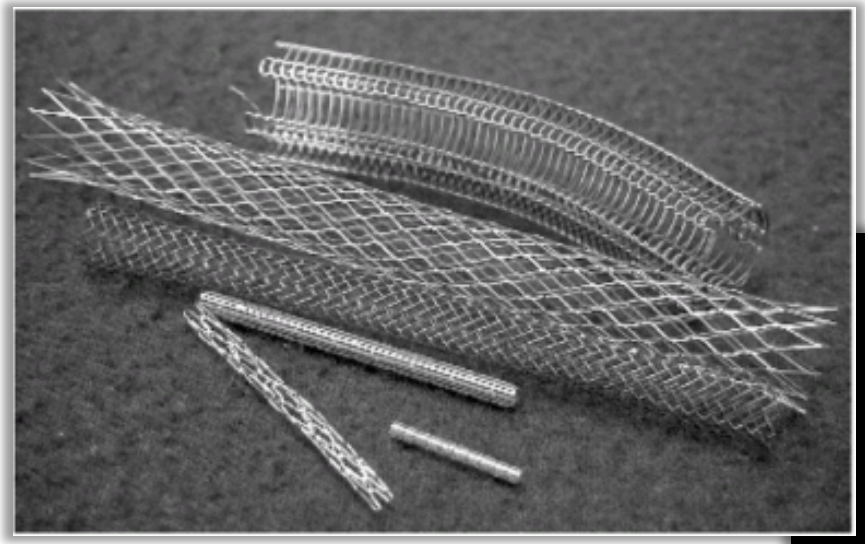
Cryogenic Engineering Conference

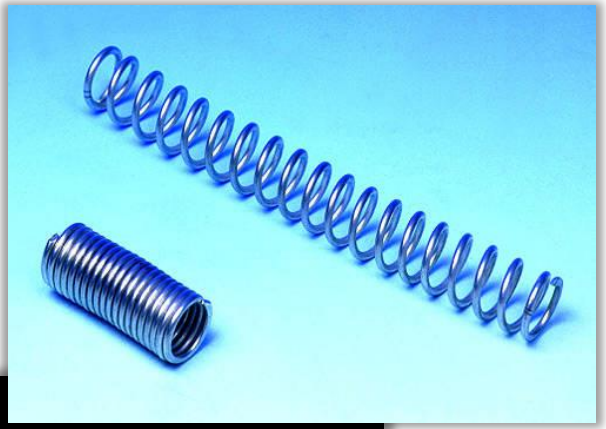
Tucson, Arizona, USA

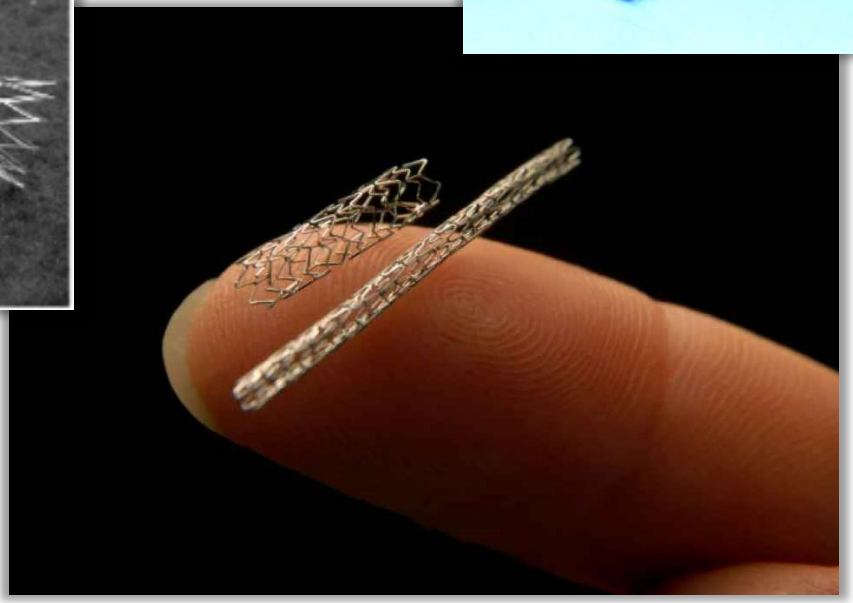
June 29th 2015

Shape Memory Alloy (SMA) 101

- Shape Memory Alloy's "remember" their shape after being deformed, and return to it when subjected to heating or cooling.
- Solid phase changes: Austenite & Martensite
- Can have 1-way or 2-way shape memory effect.







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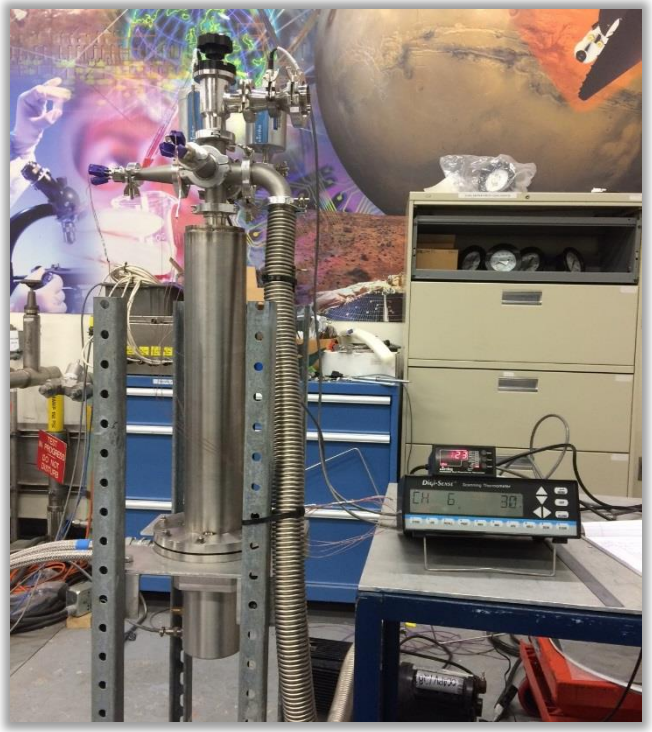
INTRODUCTION

- **Cryogenic thermal management systems employing Shape Memory Alloys (SMA) to transport heat from undesirable to desirable regions, or vice versa.**
  - **Passively Active: moving parts that respond to temperature**
  - **Engineered Systems: tuned to operate at particular temperatures**
  - **Applications for ground and space storage, ISRU, habitats, space suits, etc.**

- **Low temperature two-way shape memory actuation was the goal!**

Apparatus for Low-Temperature Training of Materials (ALTM)

- Compression Actuator
- Vacuum Chamber
- G-M Cryocooler
- Temperature & Pressure Measurement
- Two-Way Actuation Verification



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SMA Specimens

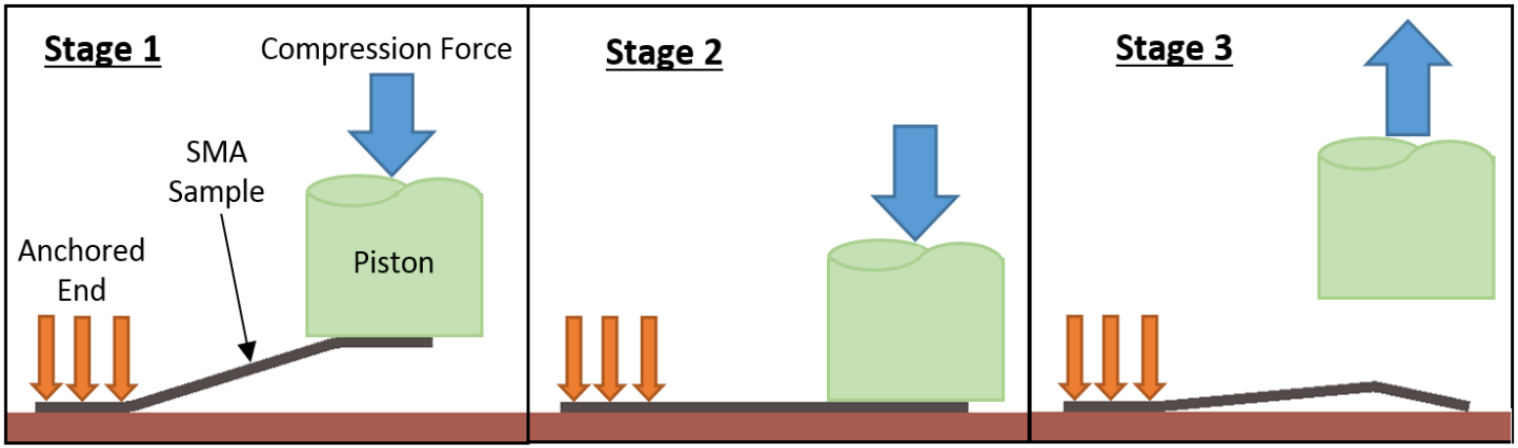
- **Two-way memory is ingrained by high temp annealing followed by rounds of deformation below the martensitic transformation temp.**
  - Transformation temps are a function of alloy constituents, and the composition ratios.
- **Large knowledge gap regarding low-temperature SMA's**
  - High-temp SMA's (>300 K) have been studied extensively.
  - A lot of low-temp SMA work has been done over-seas (i.e. China & Russia), but few studies have been done at cryogenic temperatures.
  - Overall difficulty in achieving low-temperature two-way shape memory.

- **ALTM specimens were 40mm x 10 mm x 1 mm thick rectangles, with a 10 mm out-of-plane S-bend.**
- **Alloys were thought to have a transformation temperature below 77 K.**
- **NiTi alloys with addition of Fe, Cr and Co**

Training Methodology

- **To achieve two-way actuation S-shaped samples were subjected to the following process:**
  1. High-temp annealing in the s-shape ← **Multiple Rounds**
  2. Cool-down to cryo temperatures in the ALTM while in the s-shape
  3. Compression until completely flat while at cryo temperature
  4. Controlled warm-up unloaded.

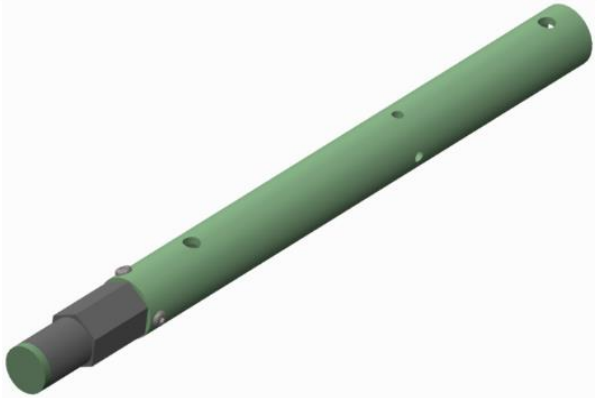
  } **Multiple Rounds**

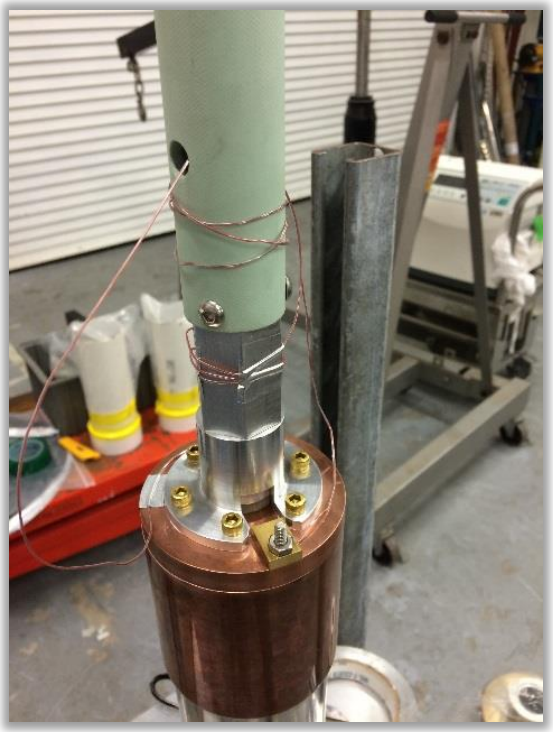


Simplified SMA Training Sequence

ALTM Design Challenges & Solutions

- **Cool SMA sample below LN_2 temp (77 K) without using a different cryogen due to safety & cost constraints.**
  - **Utilize a 20 W @ 20 K G-M cryocooler (Cryomech A230)**
  - **Required use of a vacuum chamber**
- **Compress SMA sample flat at cryogenic temperature without introducing excessive heat.**
  - **Low conductivity G10 piston, aluminum head, G10 face**
  - **Aluminum guide on cold-head to thermalize piston face**
- **Vacuum chamber had only one 40 mm port.**
  - **Only interface for piston, instrumentation, and vacuum pump**
  - **G10 tube was used as both the piston body and feed-through.**



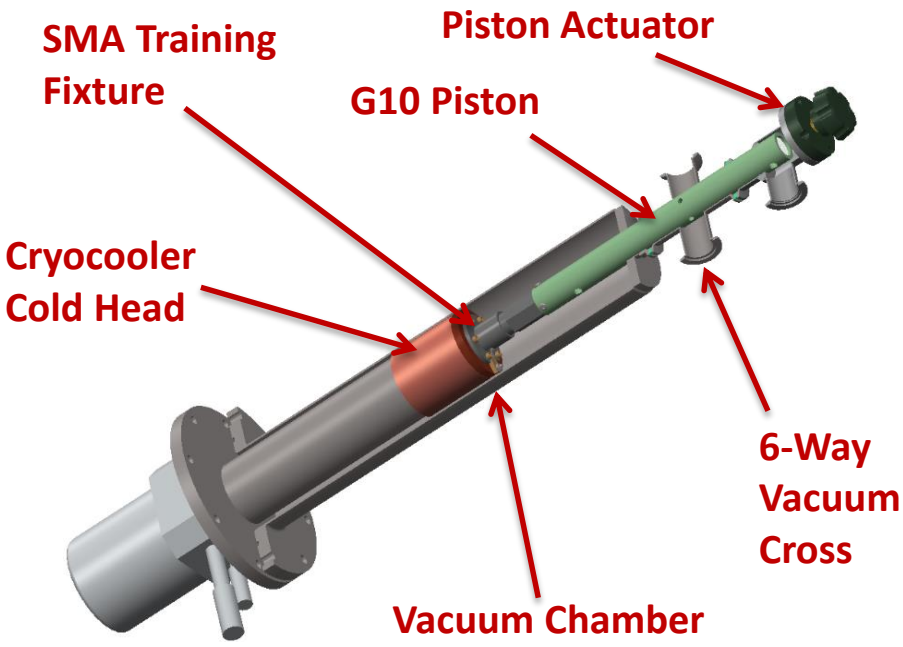


SMA Training Fixture

- **Copper base with aluminum piston guide.**
  - Positions piston and **thermalizes assembly**.
  - Creates a “cold box” around the SMA sample.
- **Sample anchored at one end by a brass block; other end centered in the guide.**
  - Affords **good thermal conductivity** between the cold-head and SMA sample.
- **Strategically located stainless steel pin to prevent copper galling during compression.**

ALTM Integration

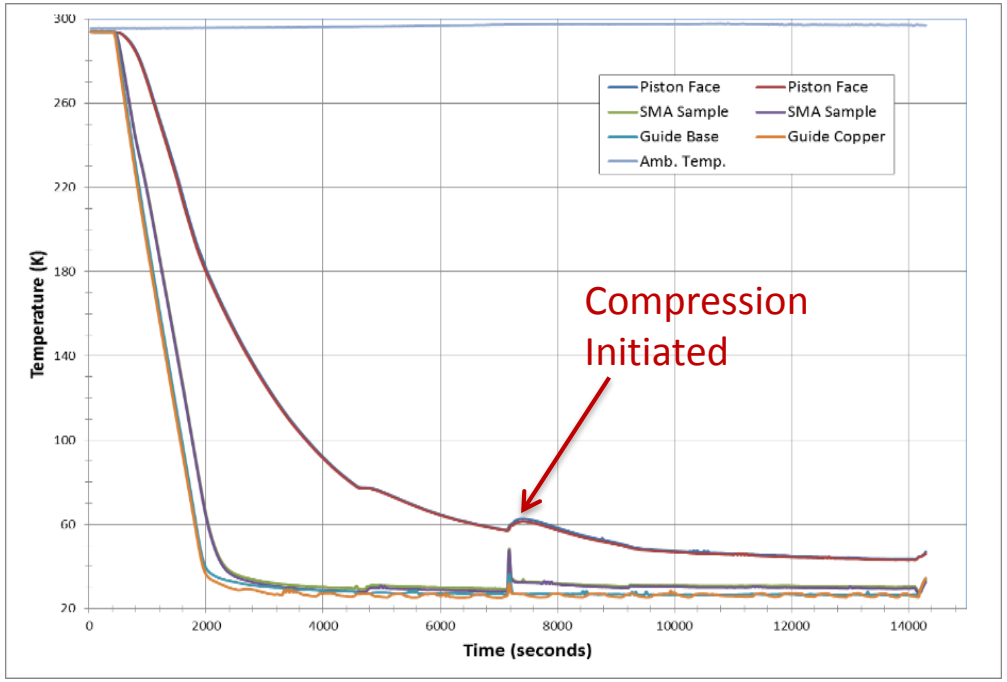
- Compression was applied by a 40 mm vacuum angle valve mated to the piston warm-end by a **magnetic coupling**.
- 6-way vacuum cross was employed for vacuum pump and instrumentation interfaces.



ALTM Operation

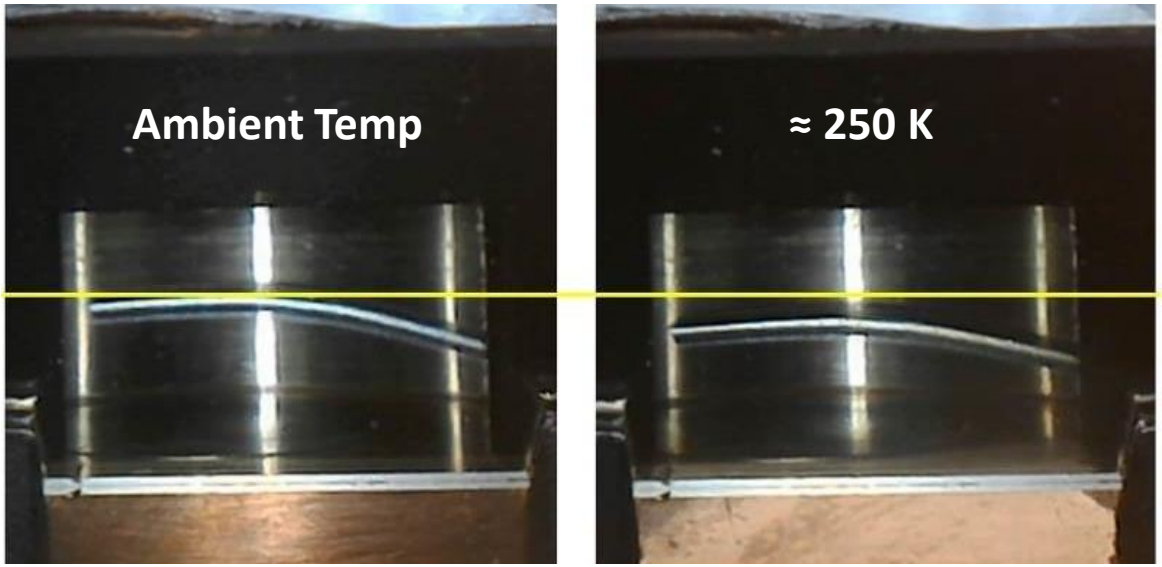
- **6 type-E thermocouples were used during SMA training with the ALTM**
  - 2 on the copper cold-head
  - 2 on the SMA specimen
  - 2 in the G10 piston face

- **Cold end was wrapped with 10 layers of Cryolam MLI**
- **SMA sample and piston face were allowed to thermalize prior to compression**



Verification of SMA Two-Way Actuation

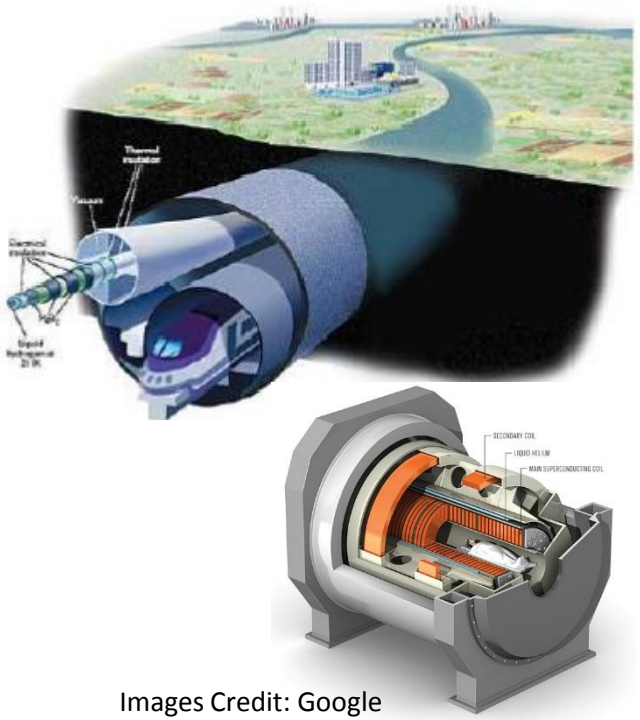
- **Visual verification was most definitive method**
  - Inexpensive USB-style camera with integrated LED lighting.
  - Due to spatial constraints the unit was vertically mounded, with a 45° mirror.
  - Wires penetrated the vacuum chamber via an 8-pin feed-through.



Camera worked in high vacuum, down to temperatures of 30 K!

Conclusion

- The Apparatus for Low-Temperature Training of Materials (ALTM) was used to successfully train various SMA samples at **temperatures as low as 30 K**.
- Utilization of a USB camera inside the vacuum chamber proved highly successful, and **verified two-way shape memory effect** in several cases.
- Integrating all the hardware through one 40 mm vacuum port was successful, albeit complicated to execute. **More ports would be preferable.**
- Motivation for the new ALTM was aimed at SMA training, but the expectation is that its **capability is extendable to a wide variety of other materials and situations** where exercising specimens at cryogenic temperatures is needed.



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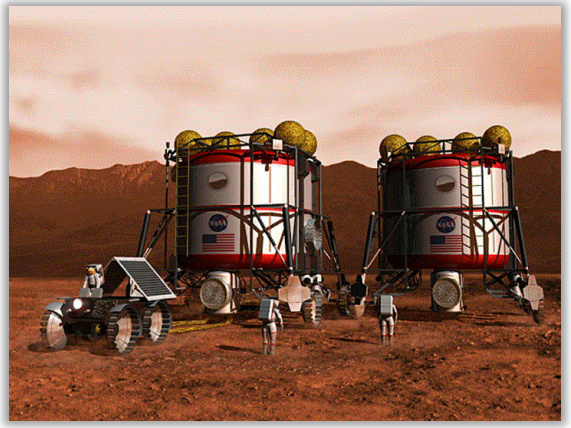

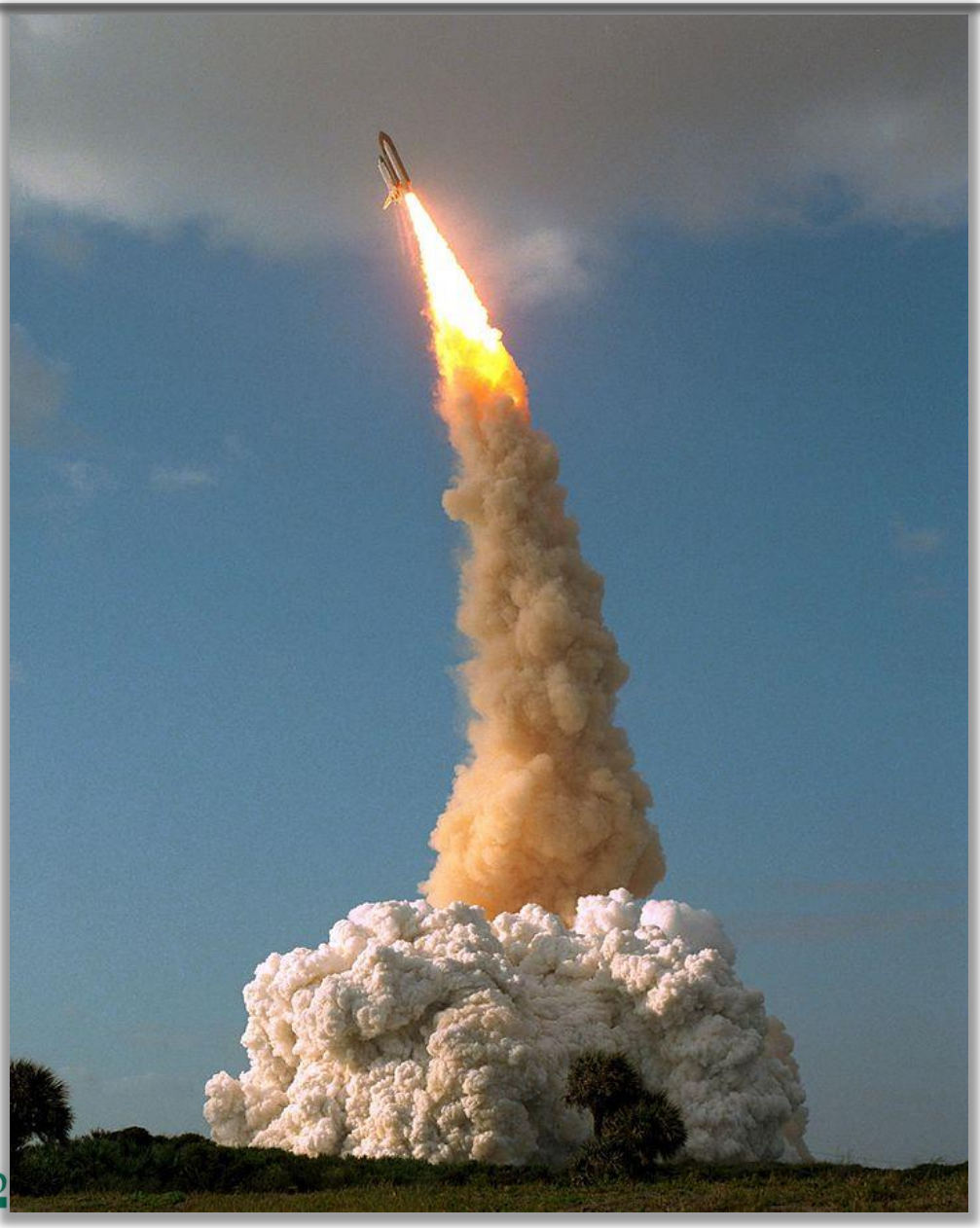

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