CLEANSAT BB06 – EARLY BREAKUP STRUCTURES

2017-10-25

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AGENDA

1. Introduction
2. Design Options
3. Design Architecture
4. SMA Basic Principals
5. Design trade off
6. Design optimization
7. Shape memory alloy selection
8. Conclusion

INTRODUCTION

- For most of the todays spacecraft operating in Low Earth Orbit, the safe decommissioning or re-entry was not an issue because not obliged to space debris mitigation measures

- Applying the space debris policy, it is a mandatory requirement that - under consideration of a casualty risk - no large object can reach the surface of the earth. This has to be ensured by either active deorbiting or passive and automated structural break-up initiated by the heat from the interaction between the atmospheric plasma and the spacecraft structure.

INTRODUCTION

- One goal that shall be achieved by this approach is that the sandwich panels that represent the exterior surface of the spacecraft shall separate during re-entry in a way that the plasma gets as early as possible in contact with “hot candidates” like the reaction wheels or parts of the propulsion system, such as titanium propellant tanks to facilitate their demise.

- The other objective is the separation of the payload, e.g. optical instruments that tent to outlast the re-entry.

INTRODUCTION

Within this Building Block study, the focus has been placed on thermally triggered **shape memory actuators** that could be **actively activated** at EOL by an electric command or **passively** by the heat generated during the reentry phase.

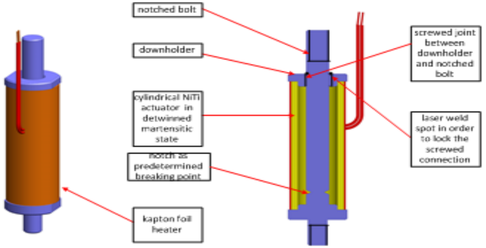
The main requirements of these mechanisms to be developed are:

- a high load capability even at vibration and shock events,
- a long lifetime, since the maximum time duration between manufacturing of the component and actuation is 50 years (10 years on-ground, 15 years on-orbit, 25 years between end of life and re-entry)
- and a very low risk of unwanted actuation during nominal satellite operation.

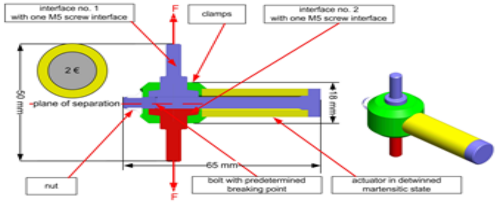
DESIGN OPTIONS

Early Break-up Structures

- **I material closure**
  - concept I/1 bolt with internal actuator
  - concept I/2 bolt with external actuator (two thread interfaces)
  - concept I/3 bolt with external actuator (panel insert interface)
- **II shape connection**
  - concept II/1 Pin Puller Concept
  - concept II/2 clamped interfaces (combined with bracket)
  - concept II/3 clamped interfaces (not combined with bracket)



predetermined breaking point is situated **with-in main load path**



Clamps transmit the axial loads within the **main load path**

DESIGN OPTIONS – ACTIVE VERSUS PASSIVE HEATING

	advantages	disadvantages
active heating concepts	- Actuation by electric command - Separation not depending on the altitude during re-entry	Separation at EOL by electric command. OBC, Power system etc has to be still in operation. - high power demand at EOL - inner sections of satellite are exposed to space before passivation of batteries (OP temp constr.) - high power driver channels needed

DESIGN OPTIONS – ACTIVE VERSUS PASSIVE HEATING

	advantages	disadvantages
passive heating concepts	- No electrical commanding - No cables needed	- Actuation temperature to be adjusted to required separation altitude -Thermal mapping and thermal analysis required

DESIGN OPTIONS – ACTIVE VERSUS PASSIVE HEATING

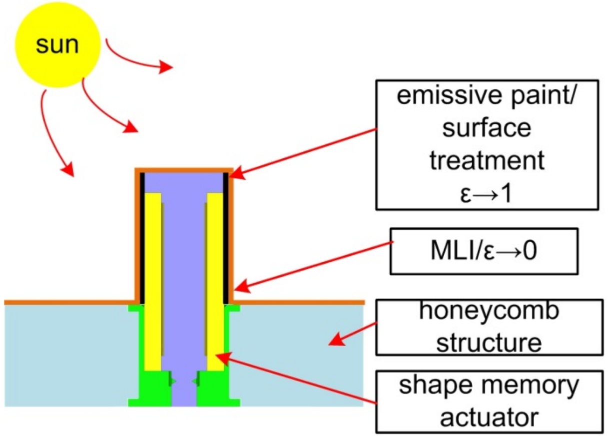
Passive activation to be triggered by re-entry heat:

- maximum non-op temperature should not been exceeded to avoid unwanted actuation,
- Actuator should be heated as fast as possible during re-entry to ensure break-up as early as possible.

DESIGN OPTIONS – ACTIVE VERSUS PASSIVE HEATING

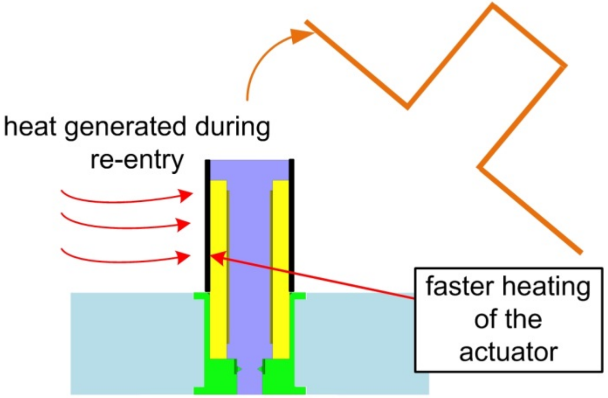
One potential solution for passive activation:

During operation in space



The operation temperature of the mechanism is kept low by an MLI Layer in order to avoid an unwanted actuation of the shape memory actuator

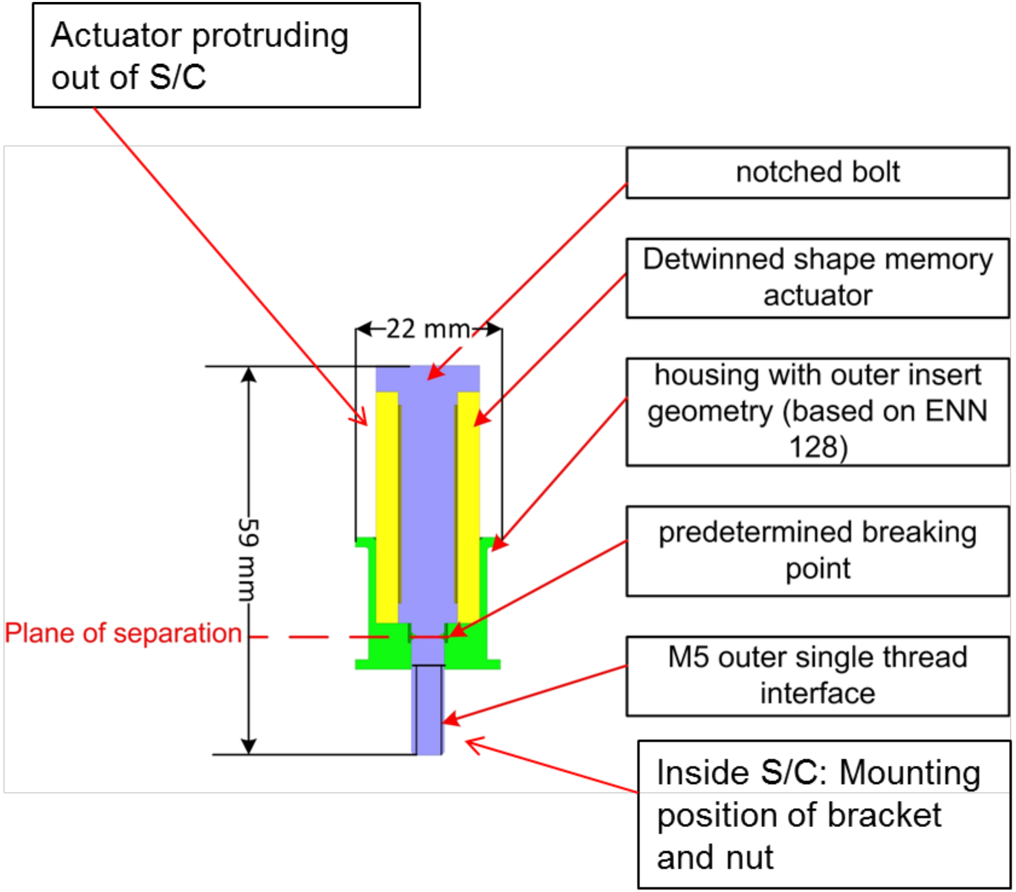
During re-entry phase



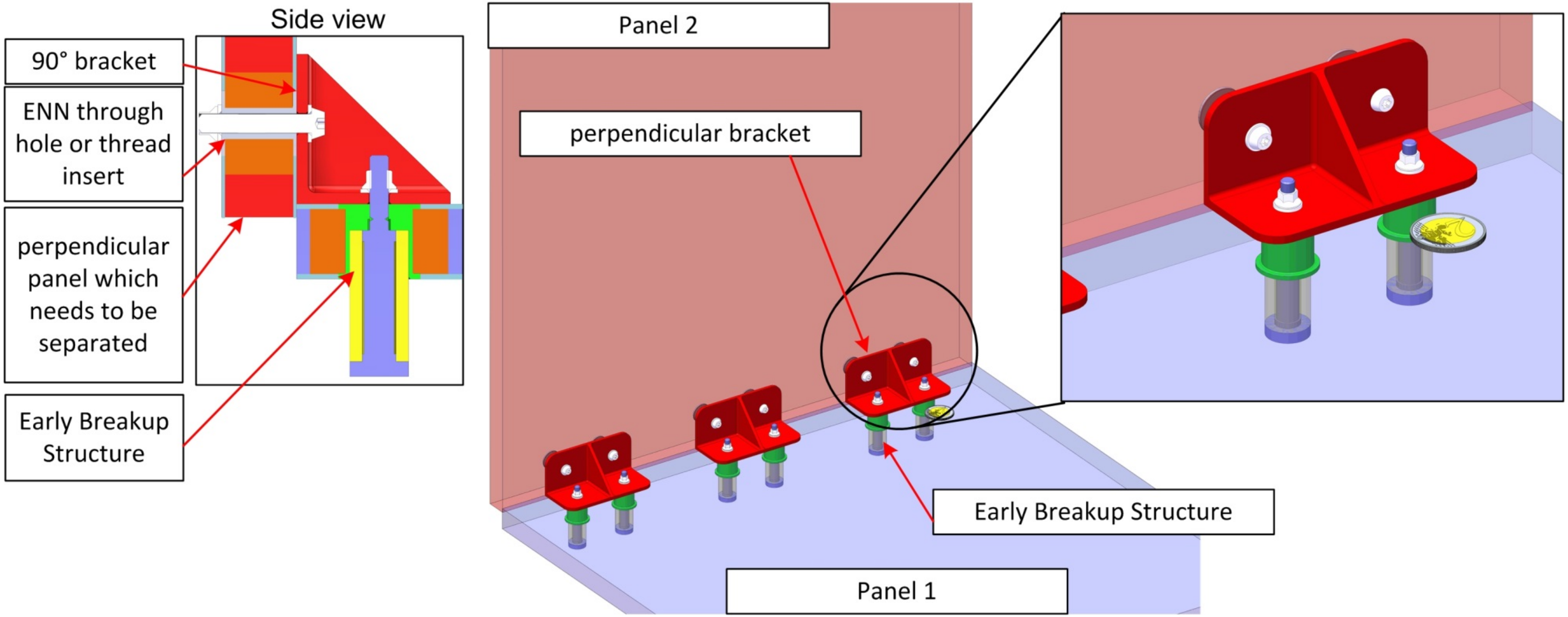
When the re-entry occurs the MLI layer is expected to get detached from the mechanism and the panel surface. Therefore the actuator is directly exposed to the heat flux.
To support the heat absorbtion into the thermal shape memory actuator surface treatments or emissive paints can be used.

DESIGN ARCHITECTURE

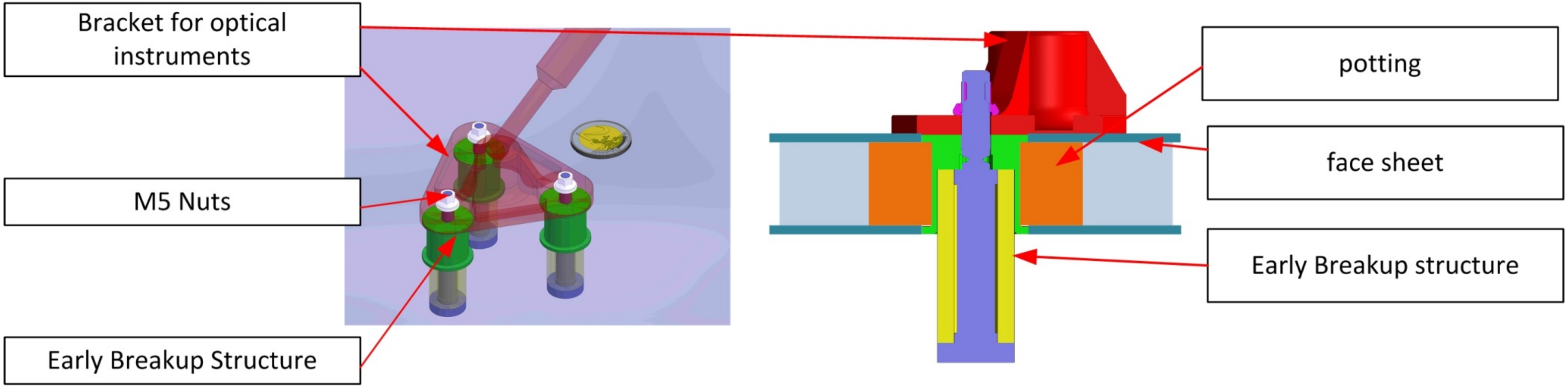
- low complexity of pieceparts
- actuator directly exposed to plasma
- directly integrated in honeycomb insert
- predetermined breaking point directly situated within main load path



DESIGN ARCHITECTURE

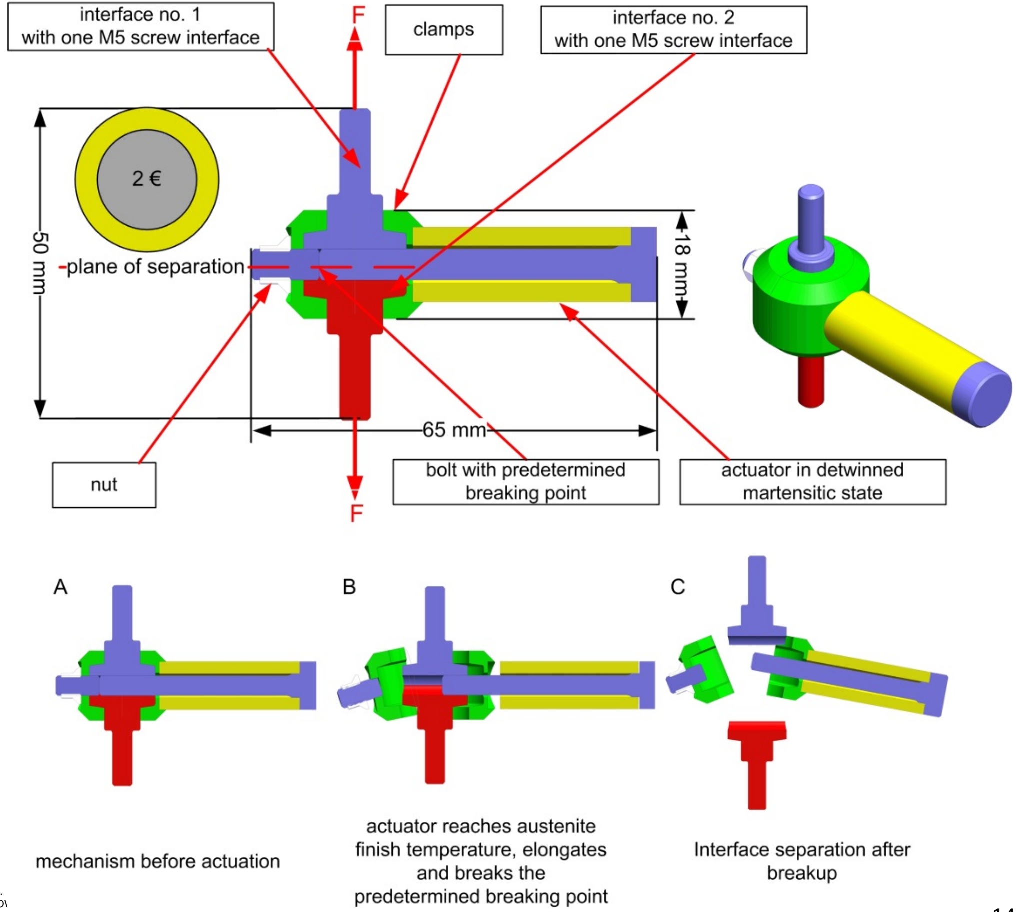


DESIGN ARCHITECTURE

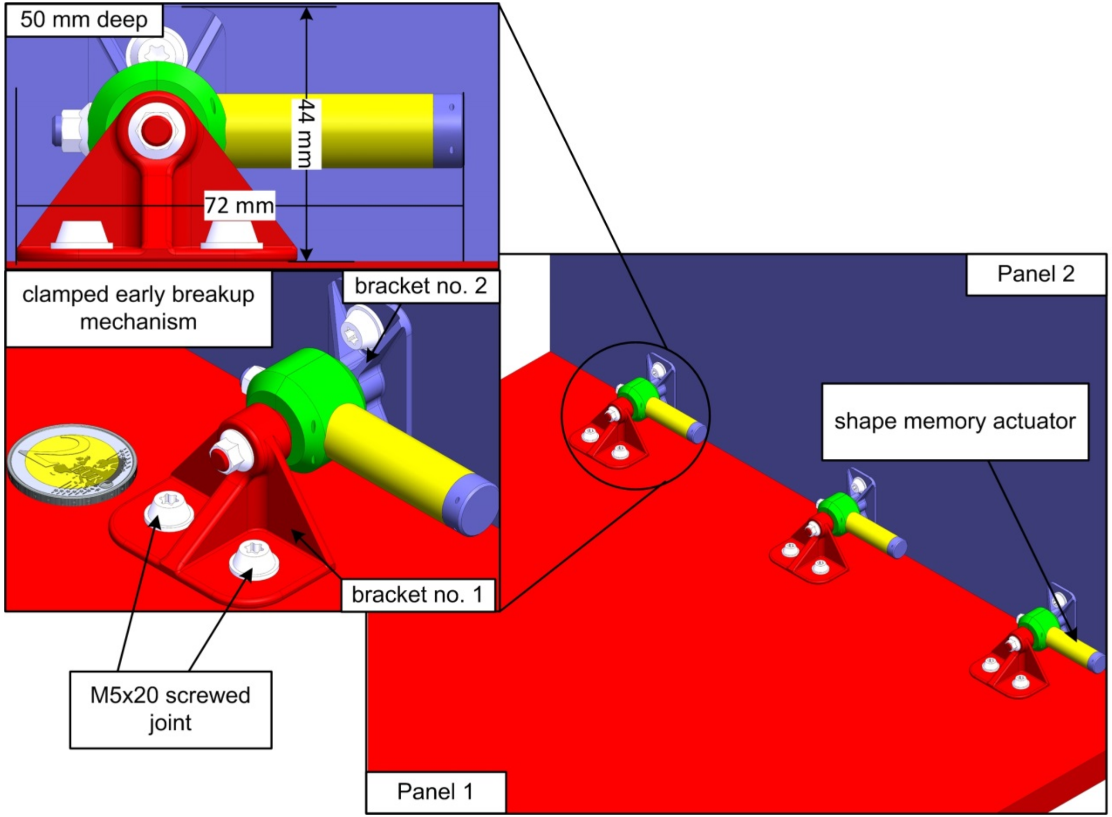


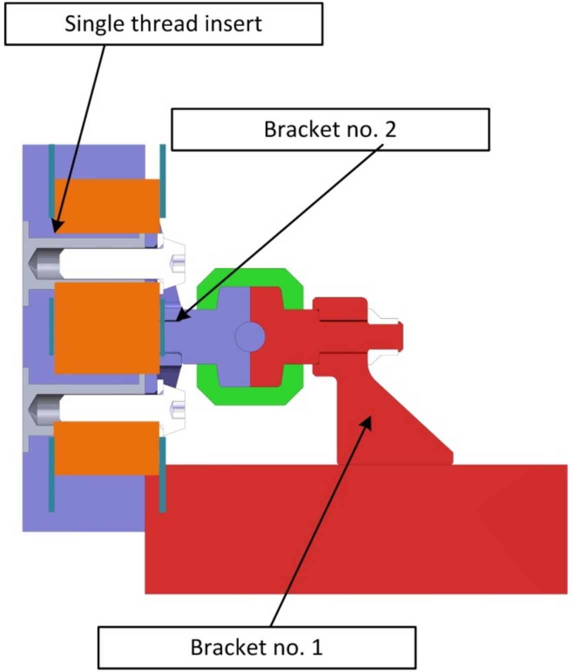
DESIGN ARCHITECTURE

- Notch not in load path
- higher performance (kN/g) at high load supports than baseline concept
- higher manufacturing effort
- surface treatment for clamps needed

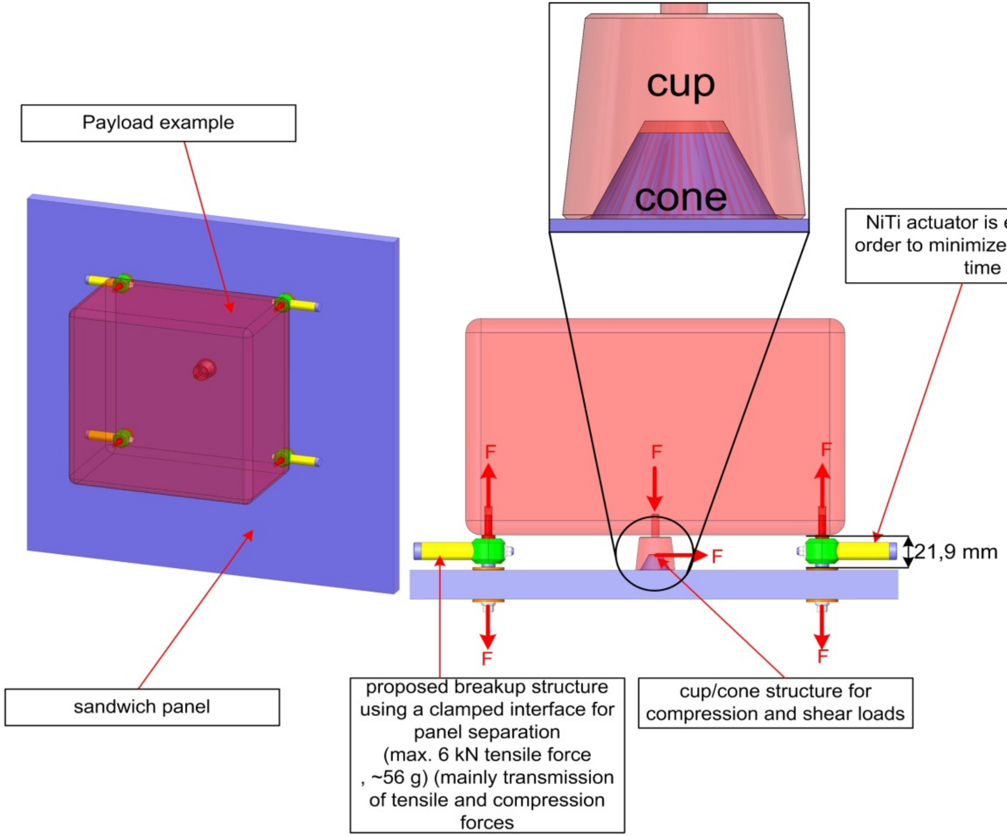


DESIGN ARCHITECTURE





DESIGN ARCHITECTURE



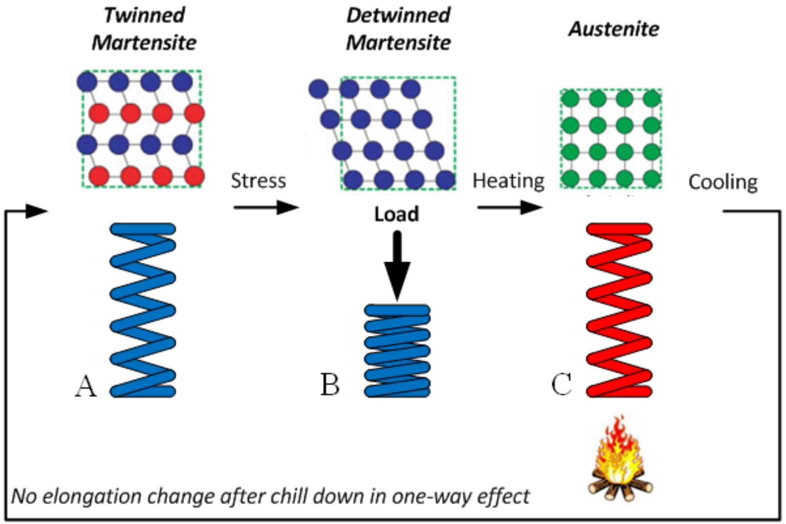
DESIGN TRADE OFF

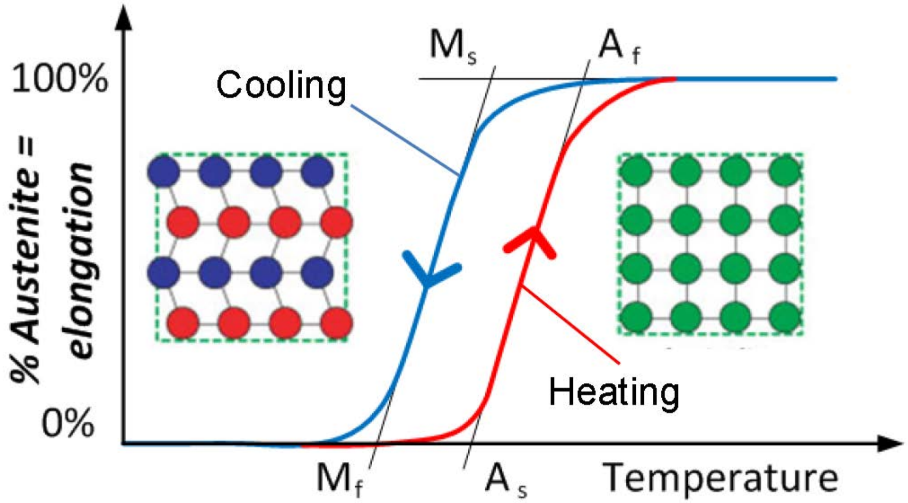
lower manufacturing and development effort

lower resistance of the design towards applied forces

Classification	Name	Dimensions / mass impact (20 %)			Manufacturing/ procurement (25%)				Development effort (25 %)				Functionality/Loads (30 %)								
													Resistance of design towards…								
		Mass	Dimensions	*Result*	Complexity of manufacturing	# parts to be procured	# parts to be manufactured	*Result*	Does ASL have experience with key Component level	Does ASL have experience with the Actuator level	Jigs&Tools level	*Result*	blocking	bending	tensile	Compre…	Torsion	System…	Is the a… ed to the S/C enviAct… ntry plasma		*…sult*
weighting		15	5		8,3	8,3	8,3		8,3	8,3	8,3		4	4	4	4	4	5	5		
material closure	I/1 bolt with internal actuator	1	1	1	3	1	1	1,7	2	2	1	1,7	1	3	3	3	3	4	6	3,40	2,1
	I/2 bolt with external actuator	2	2	2	1	1	1	1,0	2	2	1	1,7	1	3	3	3	3	3	1	2,40	1,8
	I/3 bolt with external actuator and insert interface	2	2	2	1	1	1	1,0	2	2	1	1,7	1	3	3	3	3	2	1	2,23	1,7
shape connection	II/1 pin Puller Concept	4	1	3,25	3	2	3	2,2	3	3	4	3,3	6	1	1	1	1	3	1	2,27	2,7
	II/2 clamped interface with integrated bracket	6	2	5	4	2	4	2,8	3	2	3	2,7	3	1	1	1	1	3	3	2,20	3,0
	II/3 clamped interface without integrated bracket	1	6	2,25	3	2	4	2,5	3	2	3	2,7	3	1	1	1	1	2	1	1,70	2,3

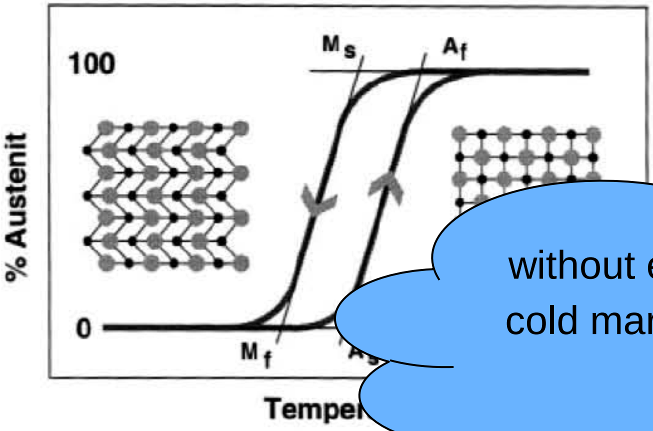
INTRODUCTION INTO SHAPE MEMORY ALLOY METALLURGY (3)





See:
Duerig: Engineering Aspects of Shape Memory Alloys, 1990

INTRODUCTION INTO SHAPE MEMORY ALLOY METALLURGY (2)



<u>Characteristical Temperatures</u>

As : Austenit Start

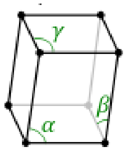
Af : Austenit Finish →body centered cubic

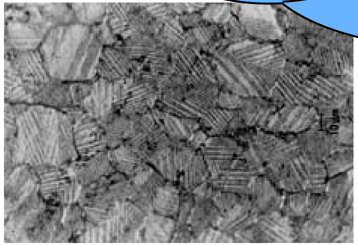
noclinic

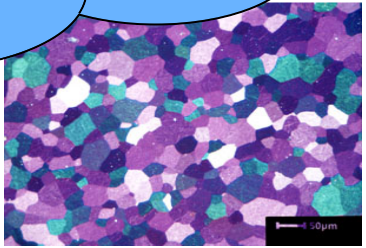
pendant)

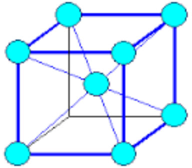
Belastung

without external load / Deformation in cold martensite, no shape change will occur during heating









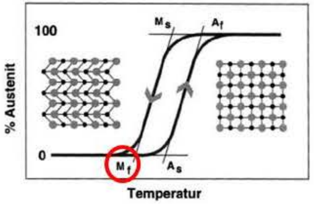
monoclinic

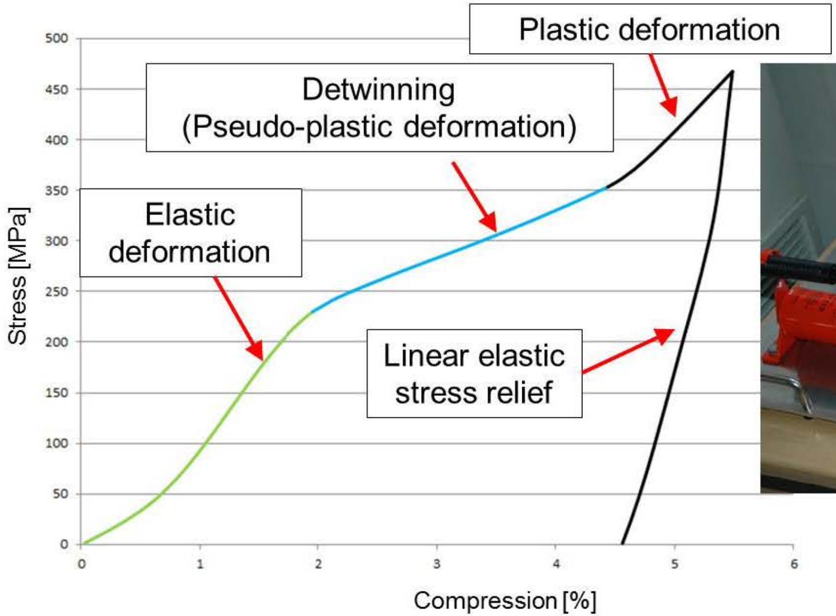
body centered cubic

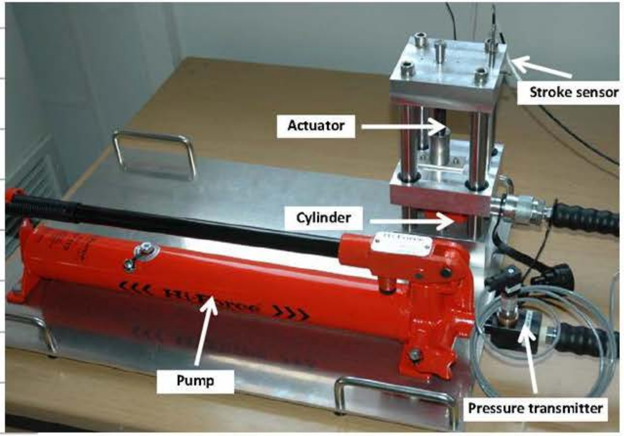
See:
Platinum Metals Rev., 2003, 47, (4), 142: Platinum Alloys for Shape Memory Applications

INTRODUCTION INTO SHAPE MEMORY ALLOY METALLURGY (4)

Preparation of actuators







See:
CLEAN-ASLLAM-TN-0008

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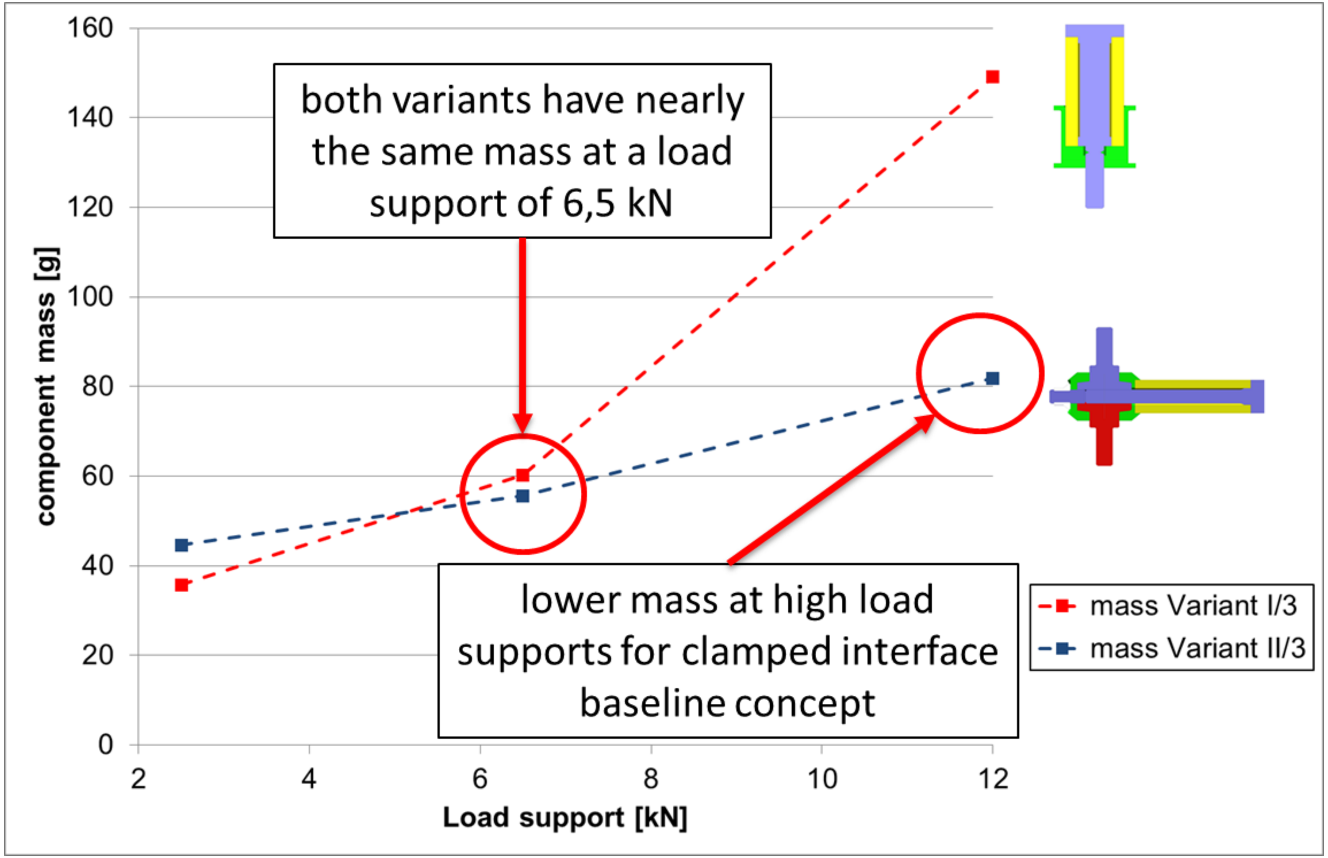
DESIGN OPTIMIZATION



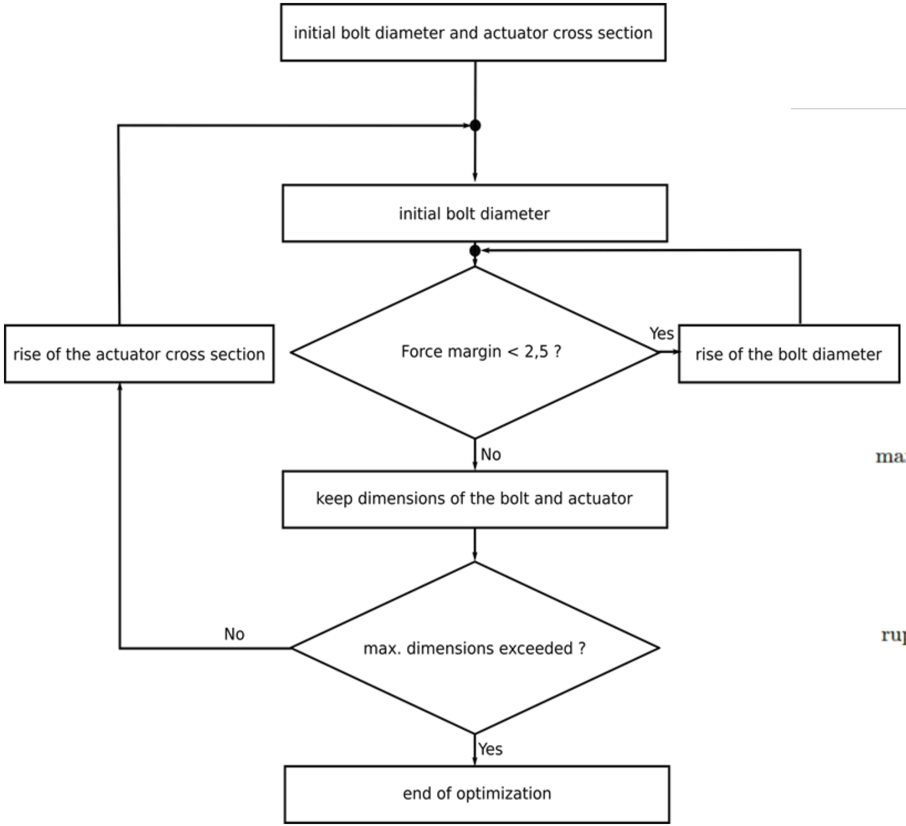
DESIGN OPTIMIZATION

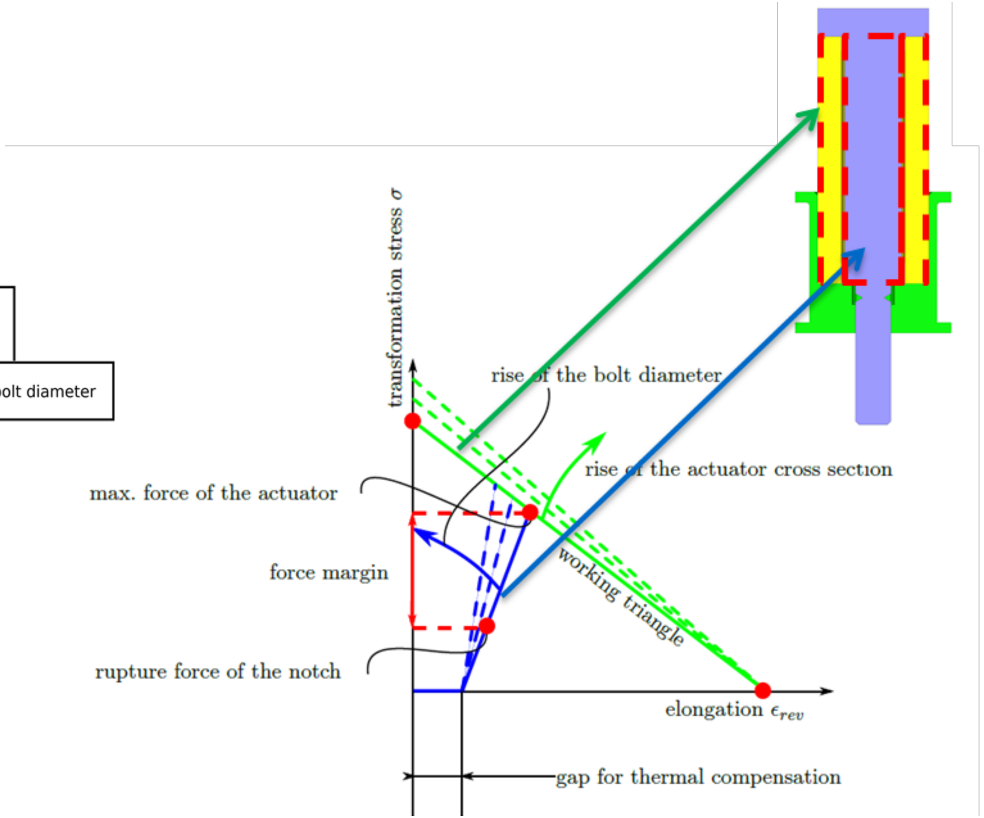
Main factors, which determine the maximum force margin of the actuator:

- diameter of the bolt, which has the highest impact on the deflection of the mechanism
- cross section of the actuator, which raises the maximum transformation force.

→ Iteration is required for design optimization!

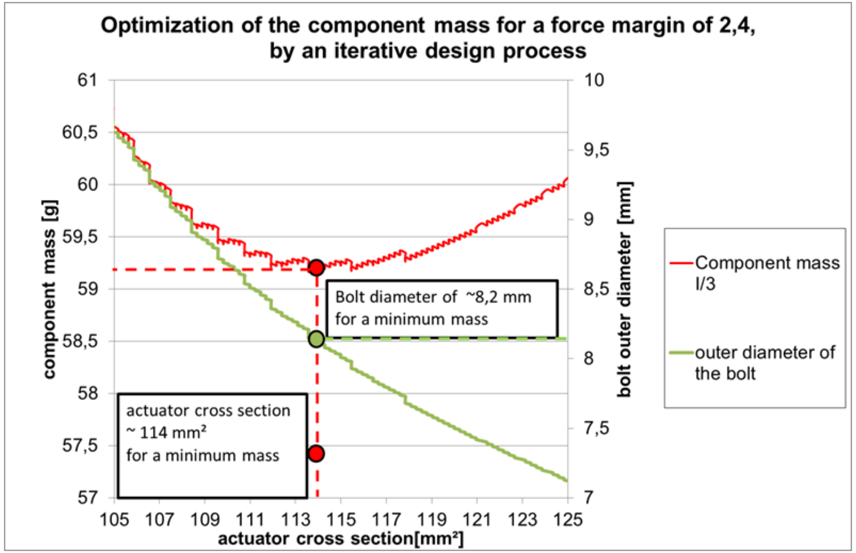
DESIGN OPTIMIZATION

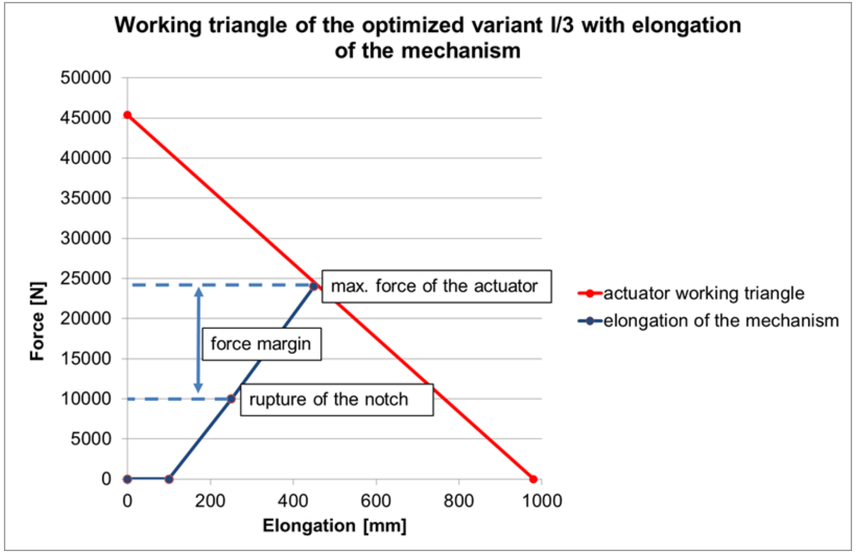




DESIGN OPTIMIZATION

Minimum mass of the component can be achieved at a certain ratio between bolt diameter and actuator cross section





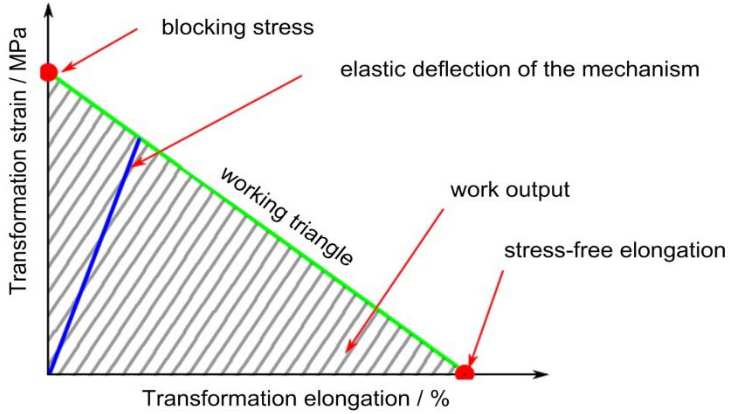
SHAPE MEMORY ALLOY SELECTION

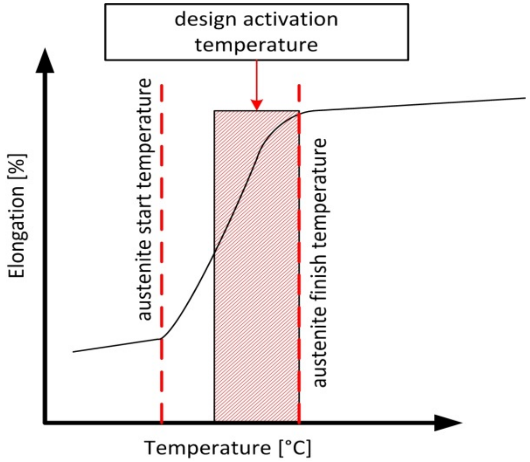
actuator design parameters:

- maximum elongation of actuator (ϵ_{max}) without external load applied,
- maximum transformation strain of actuator ($\sigma_{trans\ max}$),
- work output (which is $W=\epsilon_{max} \cdot \sigma_{trans\ max}$)

further criteria for the alloy selection:

- Actuation temperatures 120 °C ... 200 °C
- Manufacturing constraints (formability, turning/milling performance, forging properties)
- raw material cost
- long term thermal cycle stability





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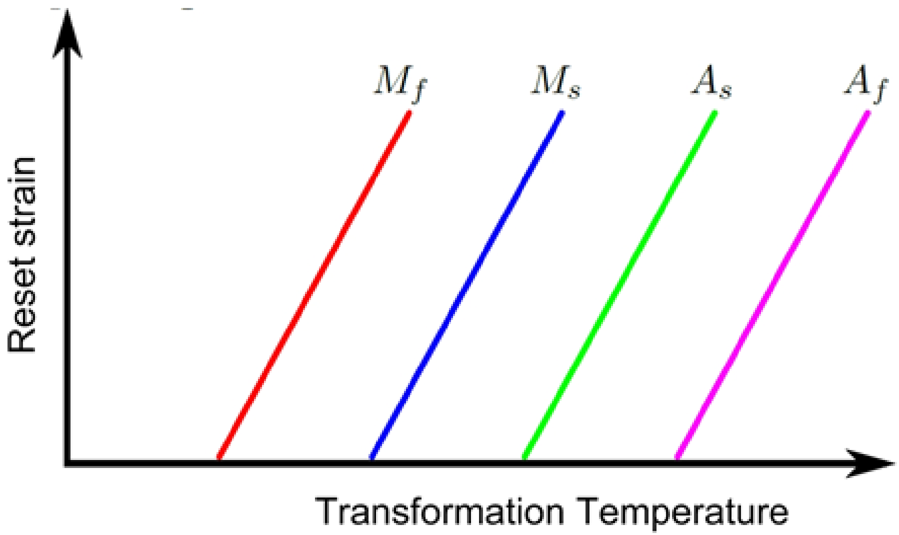
SHAPE MEMORY ALLOY SELECTION

The easiest option is to use the influence of a higher detwinning ("reset") strains, which leads to a rise in the transformation temperatures, following the Clausius Clapeyron relation



$$\frac{d\sigma}{dT} = const.$$

SHAPE MEMORY ALLOY SELECTION

Adaptation of the alloy: Most commercially available SMA are binary NiTi alloy using a nickel content of nealy 50 %

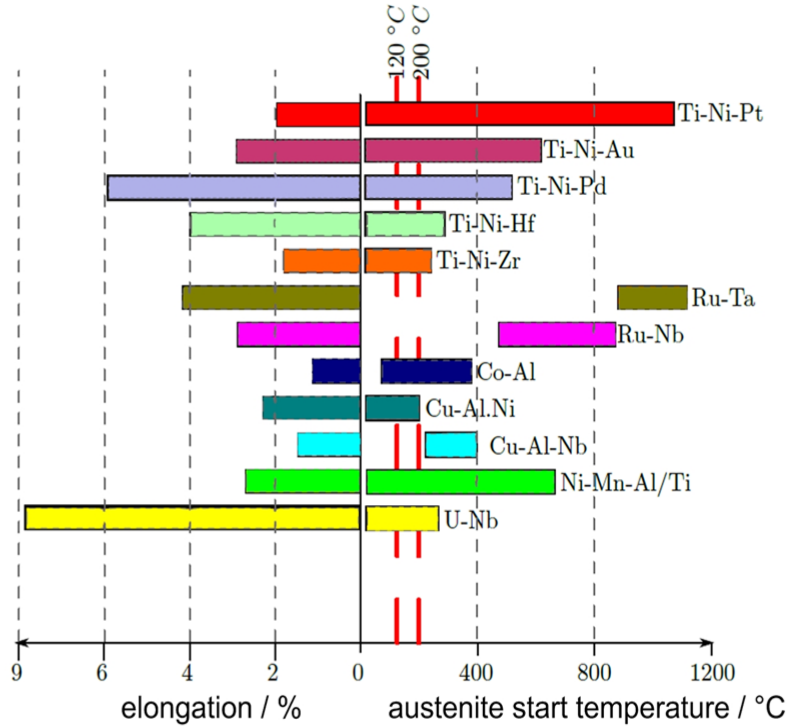
- **Adaptation of phase transformation temperature by adjusting nickel content.**
- **As lower the nickel content the higher is the phase transformation temperature up to nickel content of 49 %**
- **Method applicable to transformation temperature of ≈100 °C, which is lower than required actuation temperature (BB06-04: between 120 °C and 200 °C)**

SHAPE MEMORY ALLOY SELECTION

Additional constituents to NiTi System can increase the phase transformation temperatures.

Process associated with drawbacks:

- lowering of long term stability
- limiting recoverable strain
- due to low material cost, high work output and good shape memory effect, hafnium is promising candidate
- Hf alloys suffers from difficult formability



CONCLUSION

- Several possible design concepts were evaluated and a development road map has been worked out for one baseline concept
- One concepts using an integrated and a notched bolt within the main load path is considered to be a feasible approach
- A passive activation using the heat flux during reentry is considered to be the best option
- The baseline for high activation temperatures is marforming of a binary NiTi alloy
- High temperature shape memory alloys were evaluated and foreseen as a backup option, if marforming doesn‘t satisfy the expectations.

Thank you for your Attention