Institute of Robotic Systems

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Innovative Locomotion Concept for Long-Range Mission and study of Martian Wind

Windball Locomotion Concept

- **Objectives**
- **Martian Environment**
  - **Wind**
  - **Temperature**
- **Application Scenario**
- **Robotic System**
  - **Motion and Wind interaction**
  - **Thermal actuation**
    - **Shape Memory Alloys, SMA actuation**
- **Conclusion**

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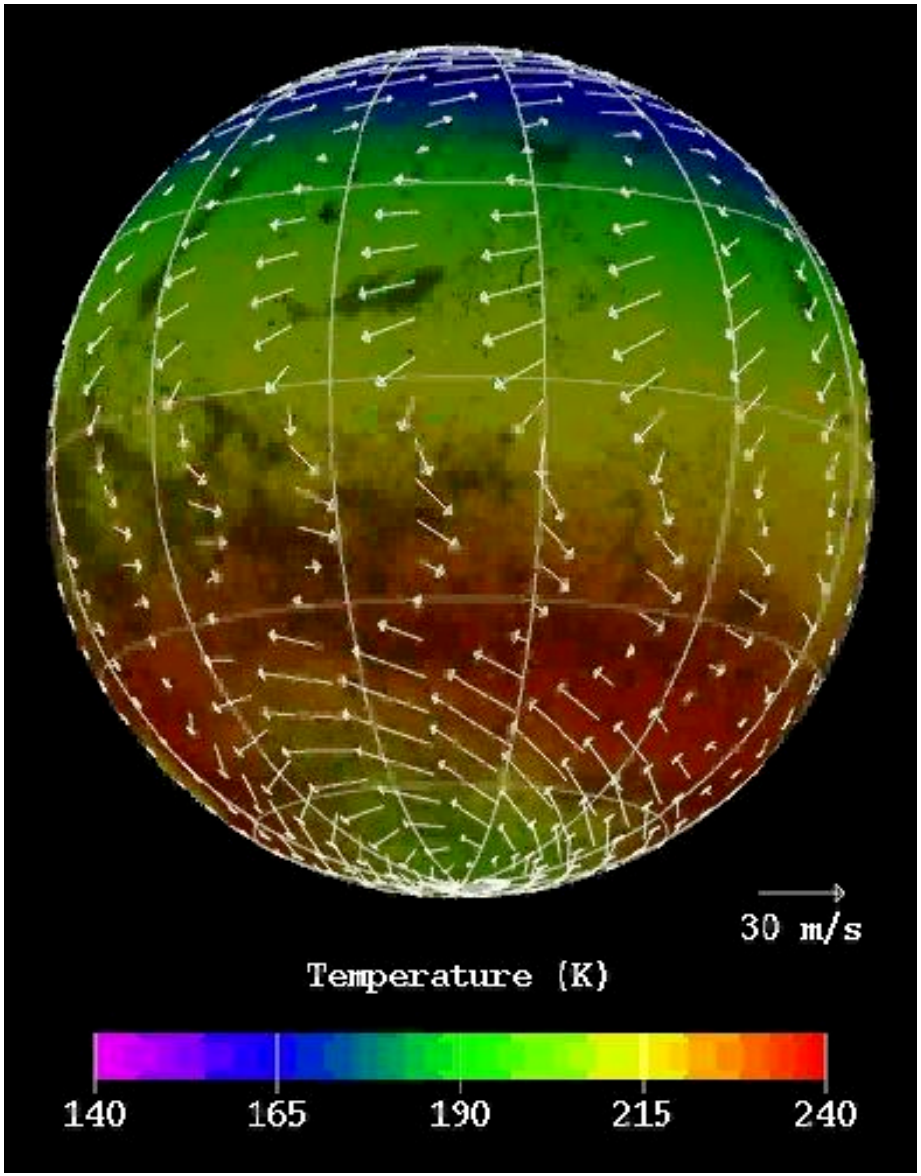
Objectives

- **Increase autonomy of mobile robotic system**
  - ⇨ limited by on board energy storage and production
  - ⇨ limited by on board calculation power
- **Reduce need in energy storage**
  - ⇨ Batteries are massive
  - ⇨ Batteries are sensitive to thermal conditions
- **Reduce need in control for Navigation**
  - ⇨ limit tele-operation from Earth
  - ⇨ limit calculation power for path planning and obstacle avoidance
- **Take the best from the environment**
  - ⇨ Specific system design for specific environment
  - ⇨ Identify most direct mean to use local resources

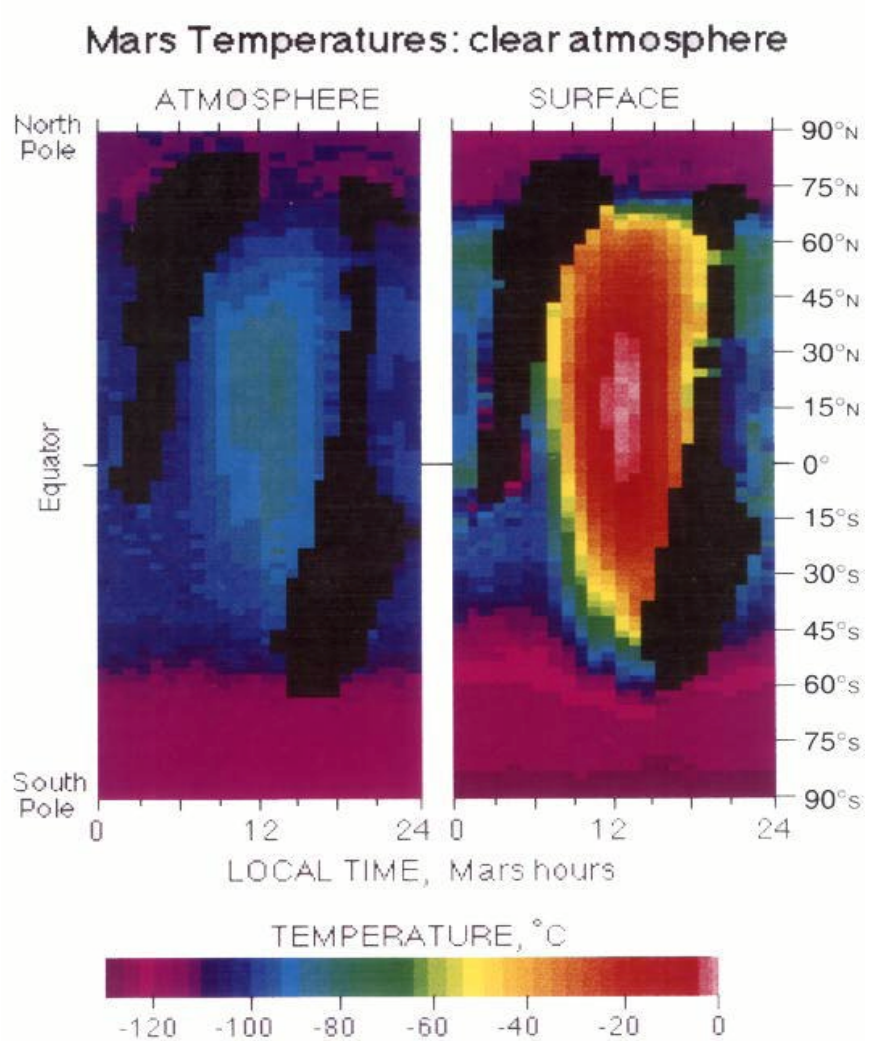
Mars Environment (1)

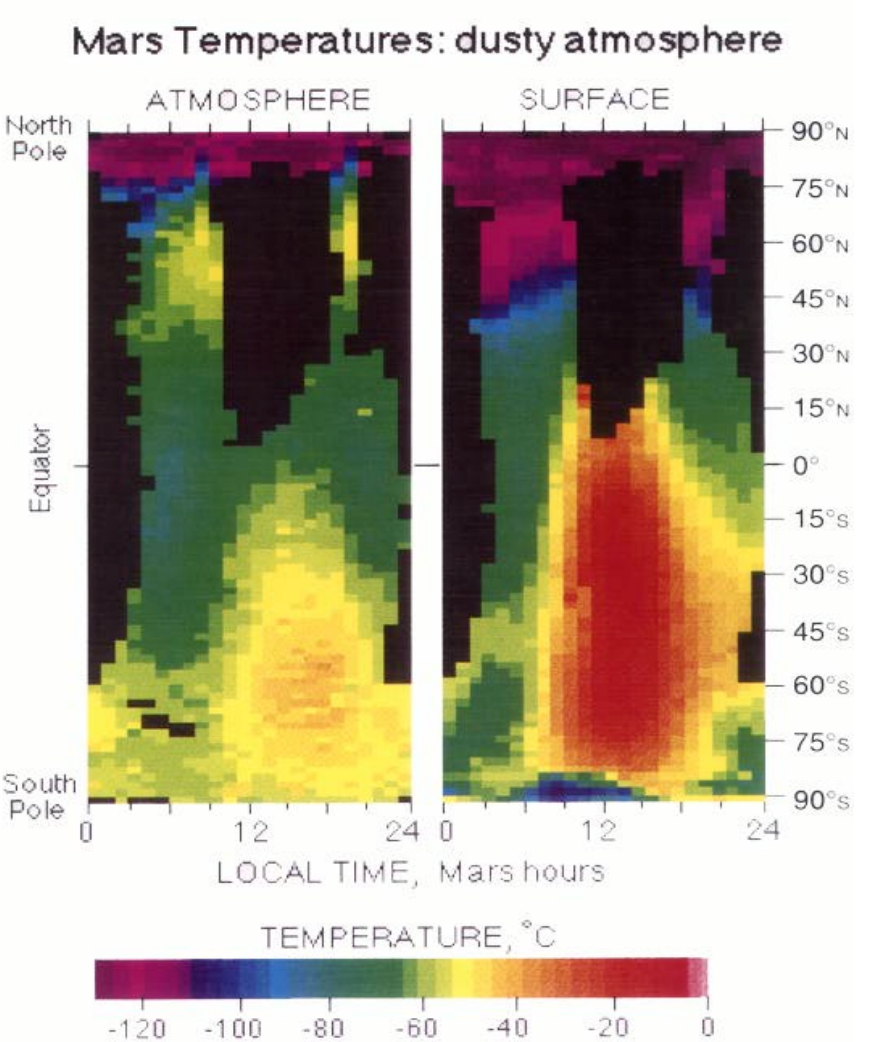


- **Planet**
  - **Mass : 6.42 x 10^{23} (kg)**
  - **Diameter : 6787 (km)**
  - **Mars' distance from the sun varies by 20 %**
- **Atmosphere**
  - **Low density atmosphere ~7 millibars**
  - **95% carbon dioxide, 3% nitrogen, 1.6% argon**
  - **Omnipresent Wind speed average: 1-9 m/s Storms >20 m/s**
  - **At aphelion, south atmosphere, storms travel at >100 m/s**
  - **Pressure wind speed : 10 N/m2 (30m/s)**
- **Temperature**
  - **Surface temperature**
  - **[140; 310] (K)**

Mars Environment (2)

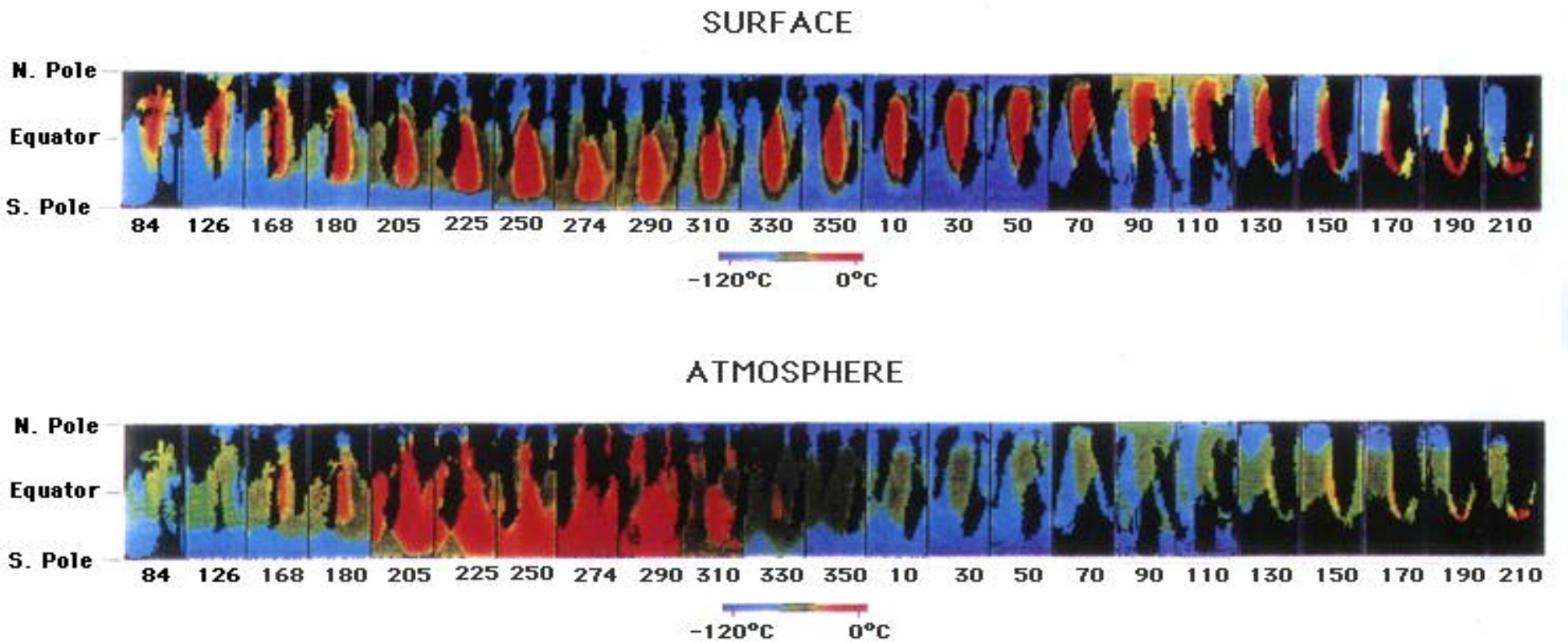
- **Daily Martian Temperature cycle**





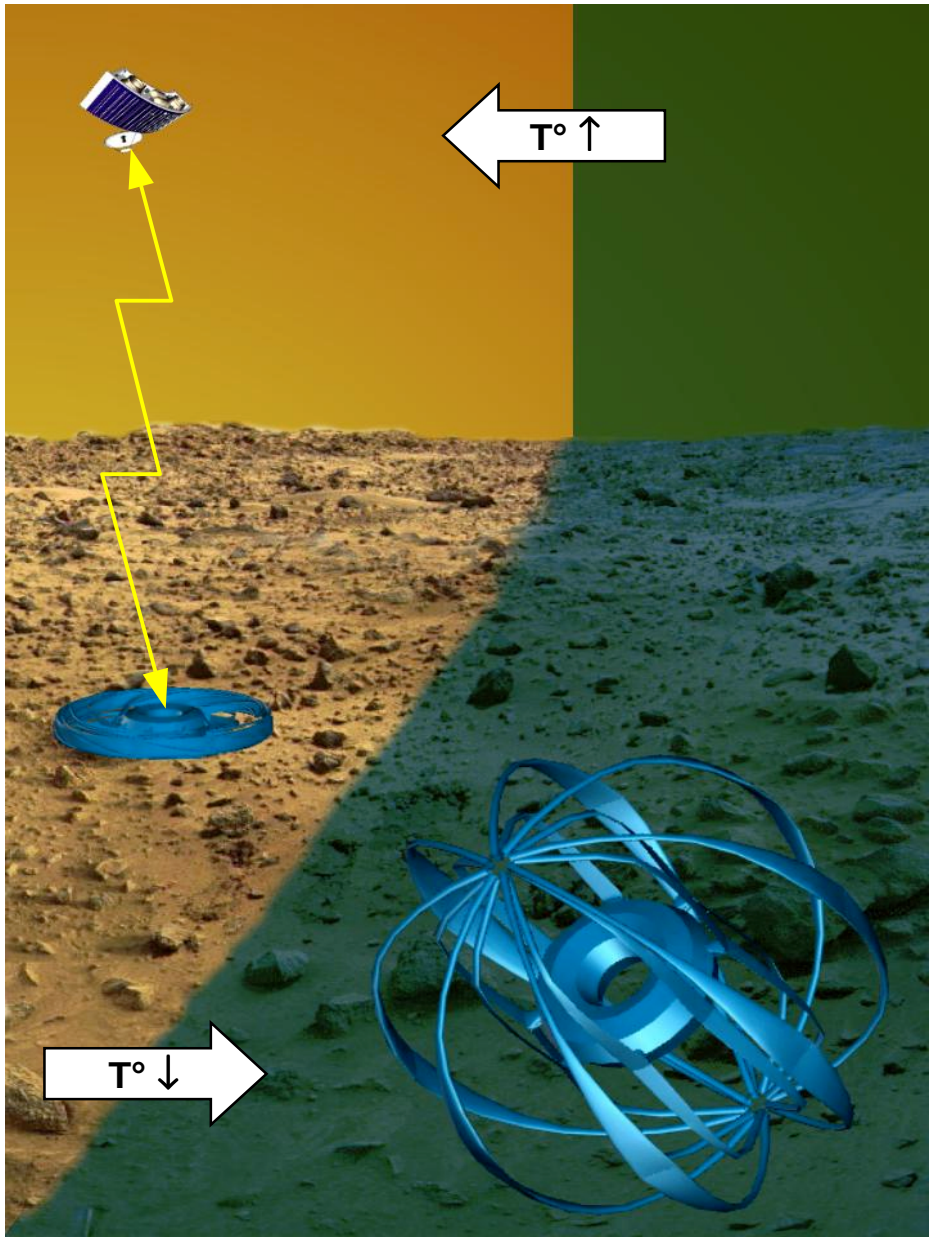
Mars Environment (3)

- **Seasonal temperature behavior of Mars**



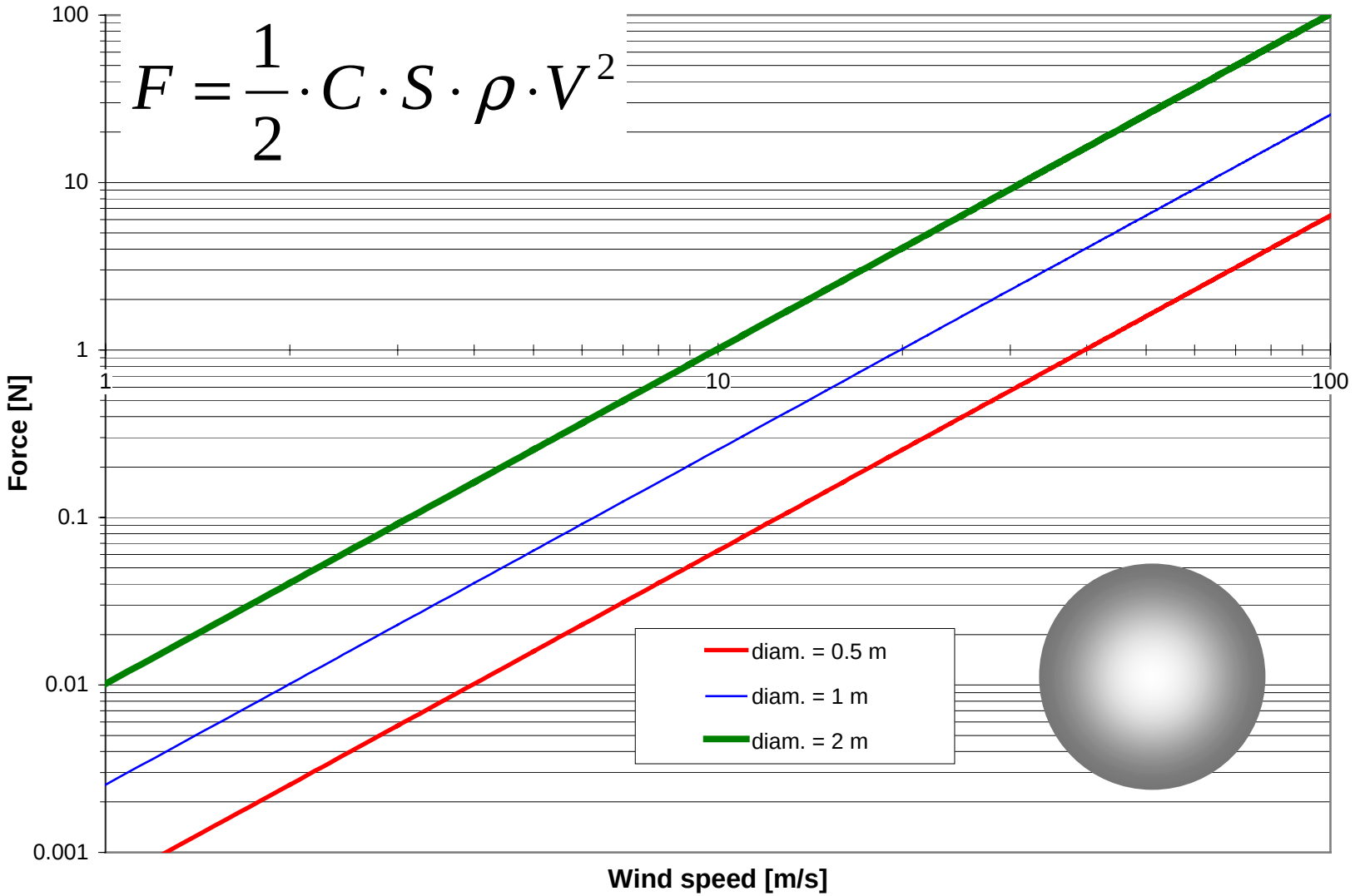
Application Scenario

- **At Night (structure deployed)**
  - spherical morphology
  - max resistance to wind
  - No need of energy
- **During the day (structure not deployed)**
  - Payload in contact with ground
  - energy generation for payload
  - static measurements
  - localization by orbiter

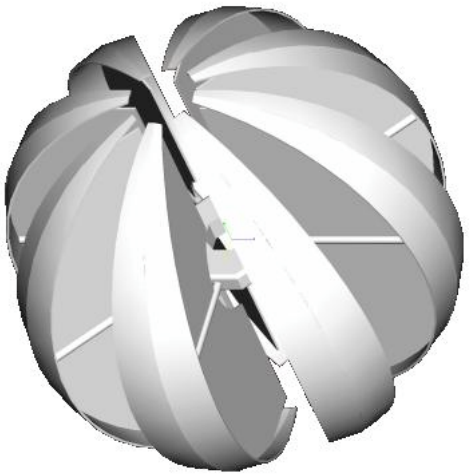


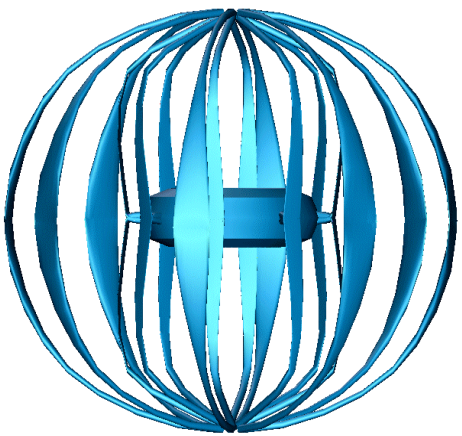
- **Force applied by the Martian wind to the robot**

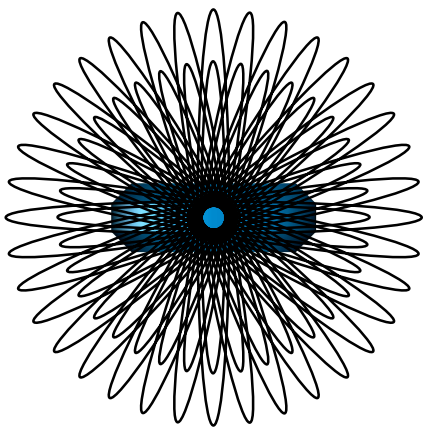
$$F = \frac{1}{2} \cdot C \cdot S \cdot \rho \cdot V^2$$

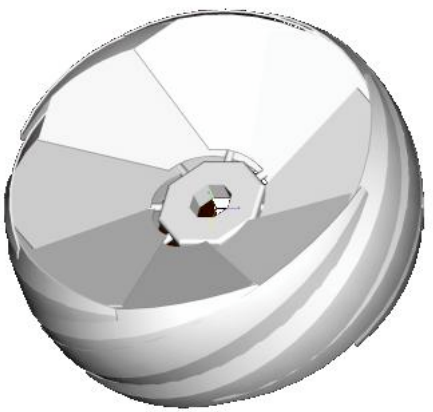


- **Guidelines**
  - Maximal cross section
  - Maximal Cx
  - Minimal Mass
  - Maximal morphological transformation
  - Low fatigue (numerous cycles)
  - Maximal Payload Mass and Volume

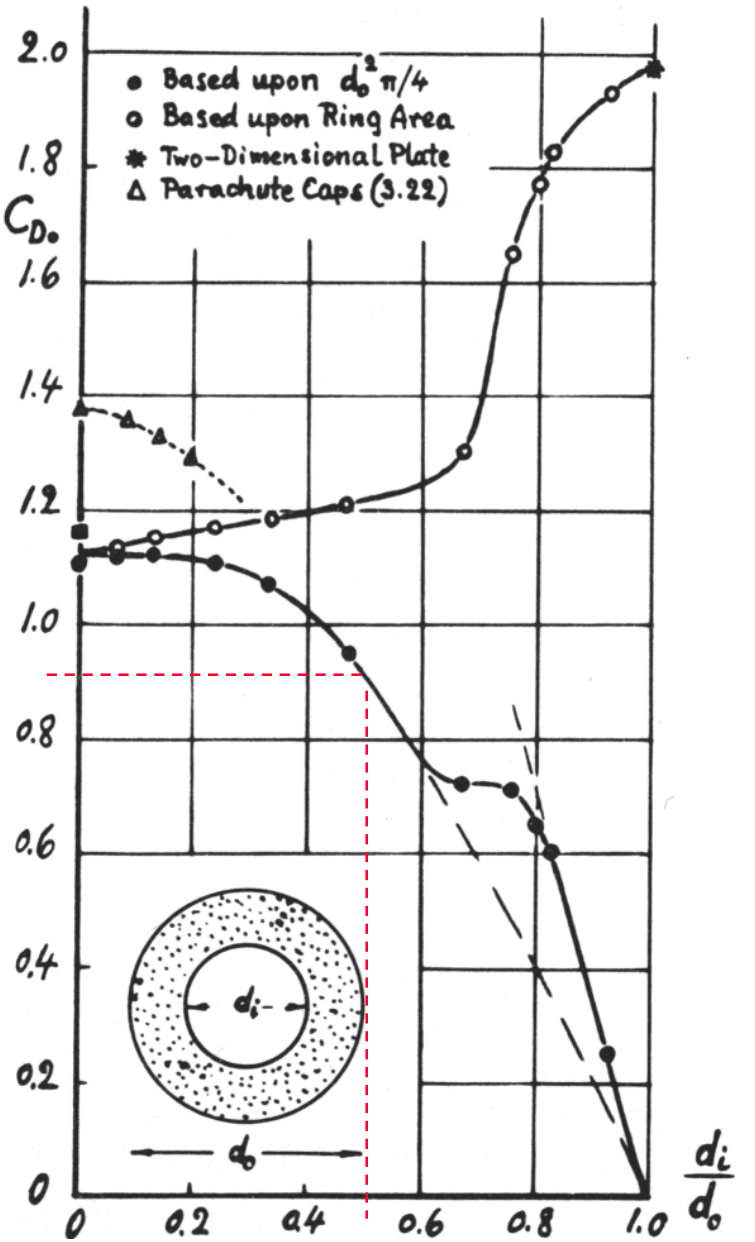








Drag and open structures



(S. F. Hoerner, 1951)

Variant for low speed winds

- **SoftBall**
  - **Inflatable structure (mass prop. to square of size)**
  - **SoftBall structure is directly used for the landing phase**
  - **Deformation by SMA actuation bringing the poles nearer the center of the sphere**
  - **Payload situated in the center of the sphere**
  - **Same operational cycle**

Shape Memory Alloys

- **Phase transformation without diffusion**
  - **Twinning**
- **Austenite ⇔ Martensite**
  - **under temperature variation**
  - **under applied stress**
- **Mechanical Properties**
  - **Shape Memory Effect**
  - **Super-elasticity**
  - **High damping capacity**

Electrical Resistance

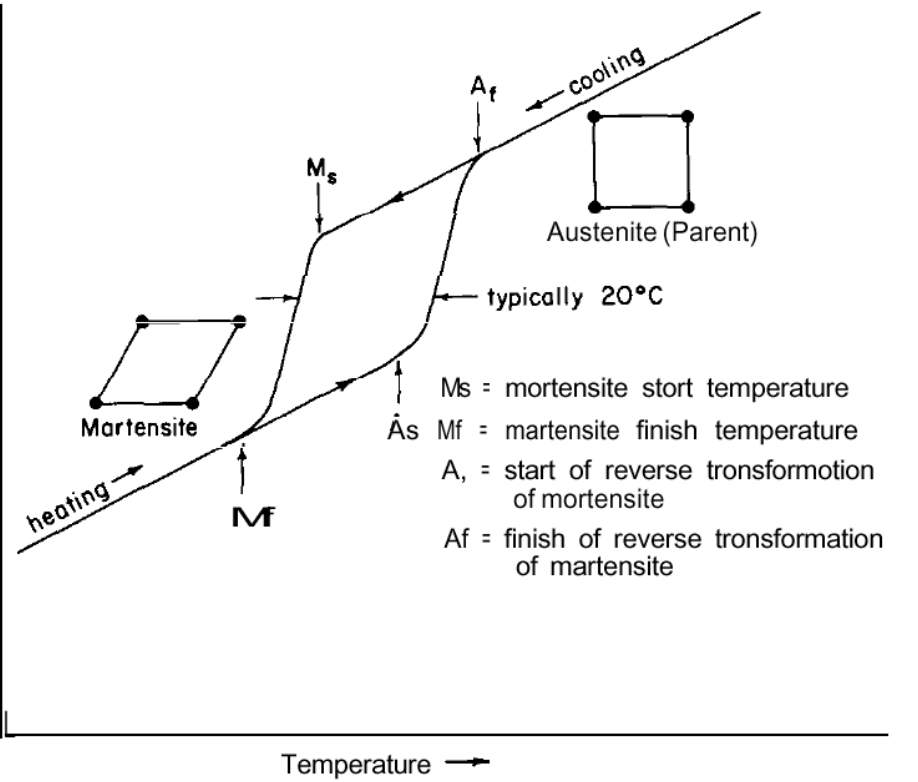
or

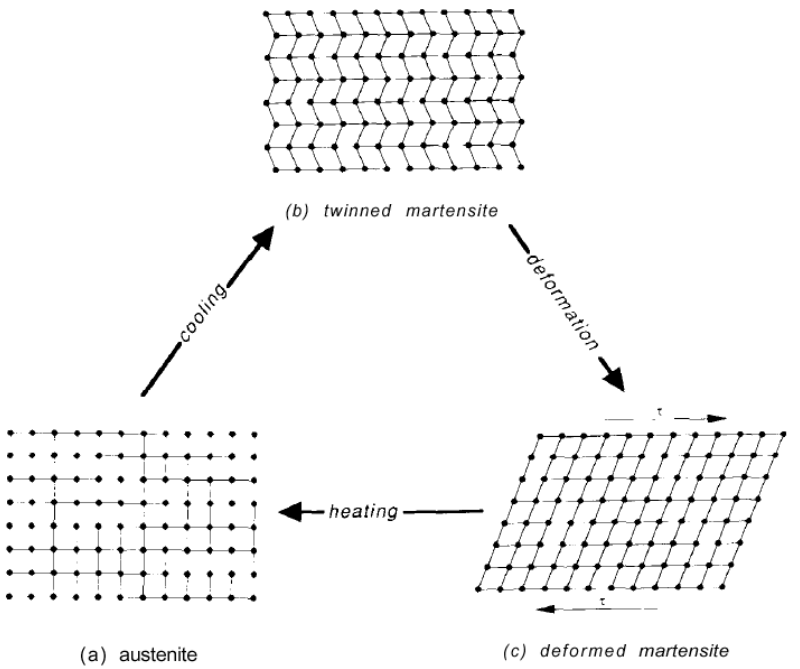
Length Change

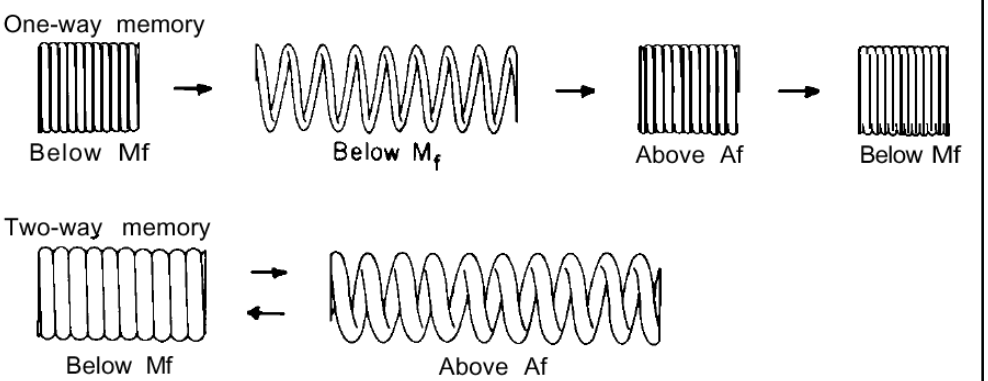
or

Volume Change

etc.







SMA: NiTi properties

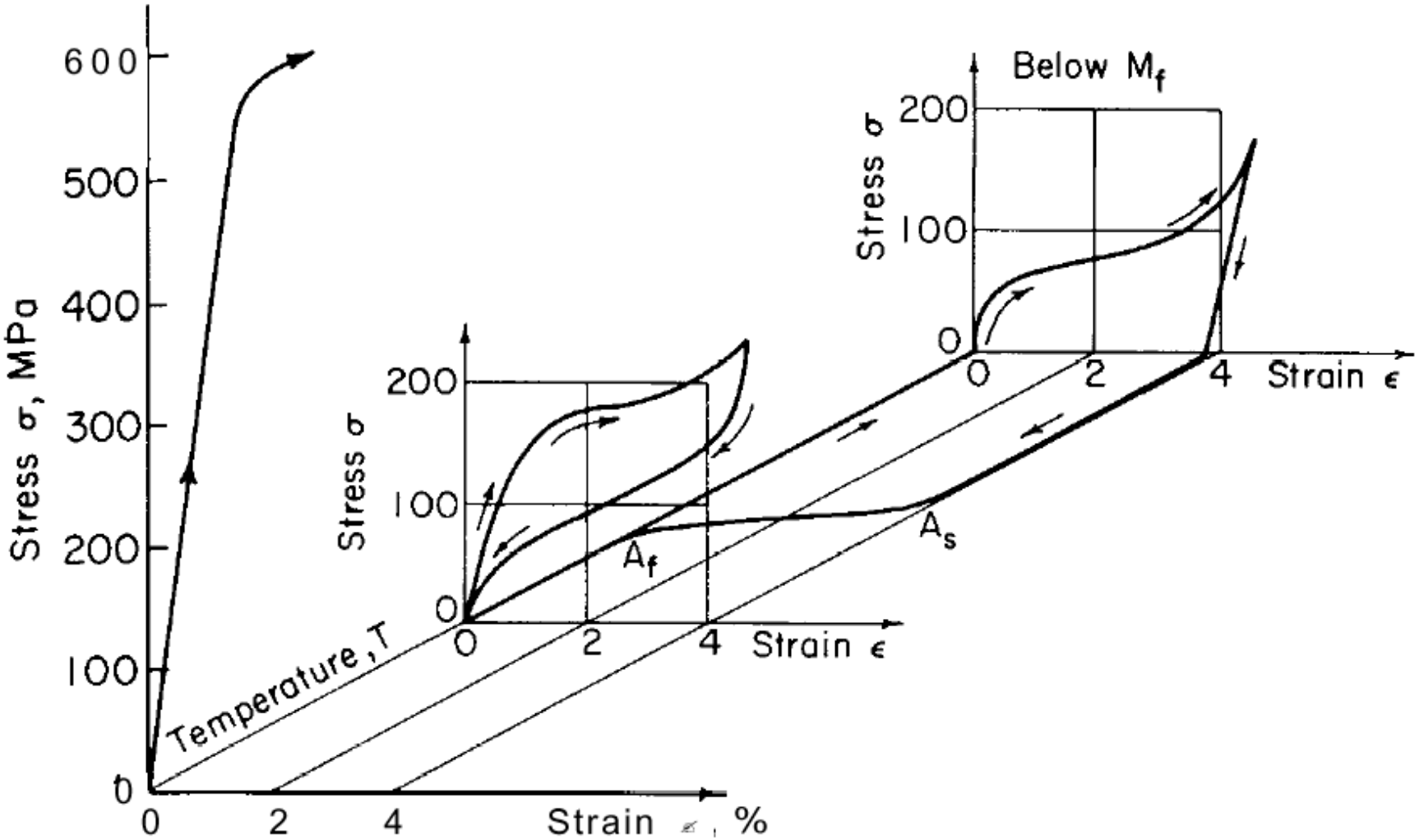
	Austenite	Martensite
⇨ Young's Modulus	~ 83 Gpa	~ 28 to 41 GPa
⇨ Yield Strength	195 to 690 Mpa	70 to 140 Mpa
⇨ Resistivity	~ 100 μΩcm	~ 70 μΩcm
⇨ Thermal Conductivity	18 °C W/cm	8.5 °C W/cm

- ⇨ Melting Temperature : 1300 °C
- ⇨ Density : 6.45 g/cm^3
- ⇨ Corrosion Resistance : similar to 300 series stainless steel or titanium alloys

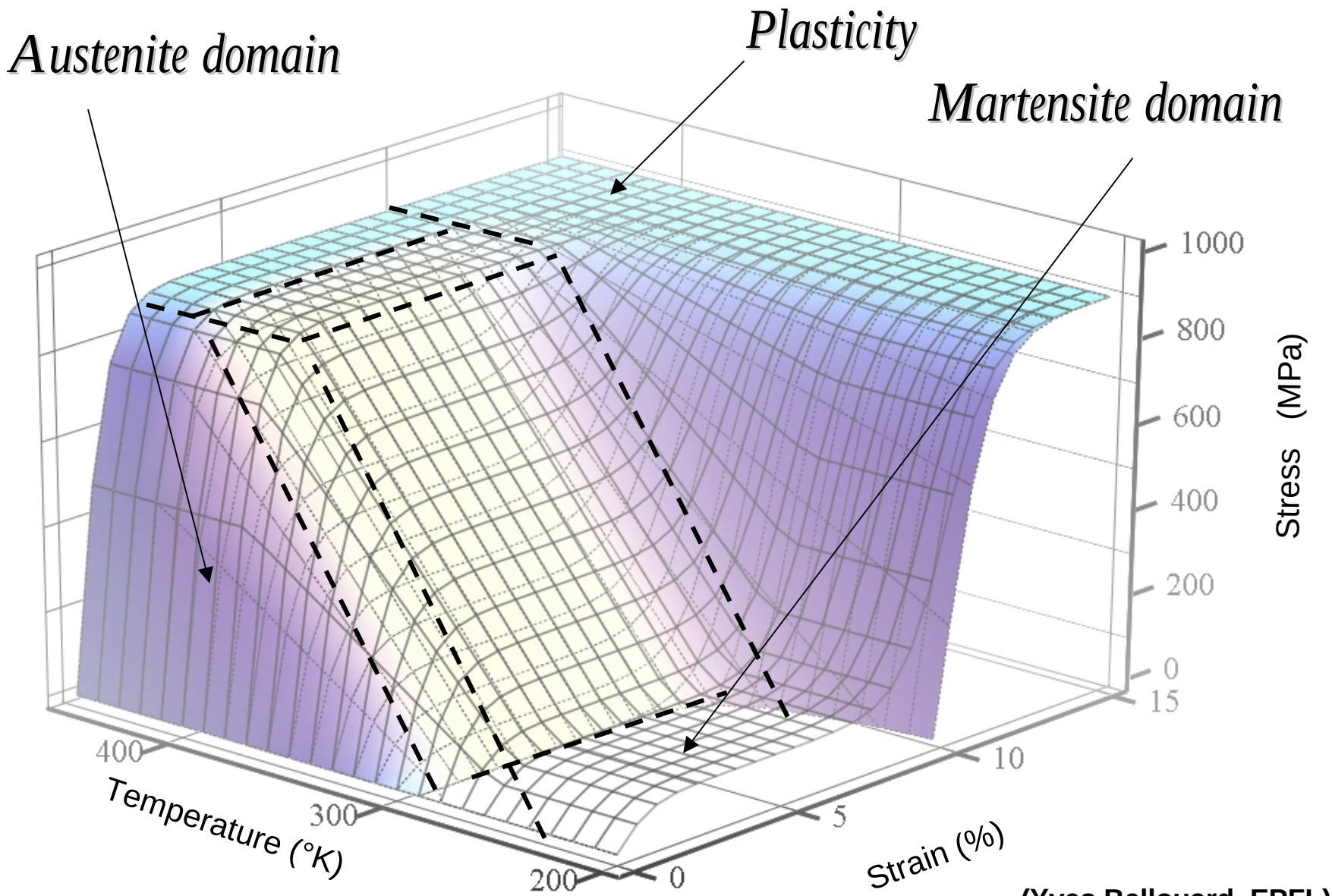
- ⇨ Transformation Temperatures range: [-200 ; 110] °C
- ⇨ Shape Memory Strain: 8.5% maximum

- ⇨ NiTi 49/51 at.% Ni
  - Temp range transformation [-50 ; 110] °C
  - Transformation Hysteresis 30 °C
  - Shape Memory Strain for several cycles ~ 4%

Shape Memory Effect

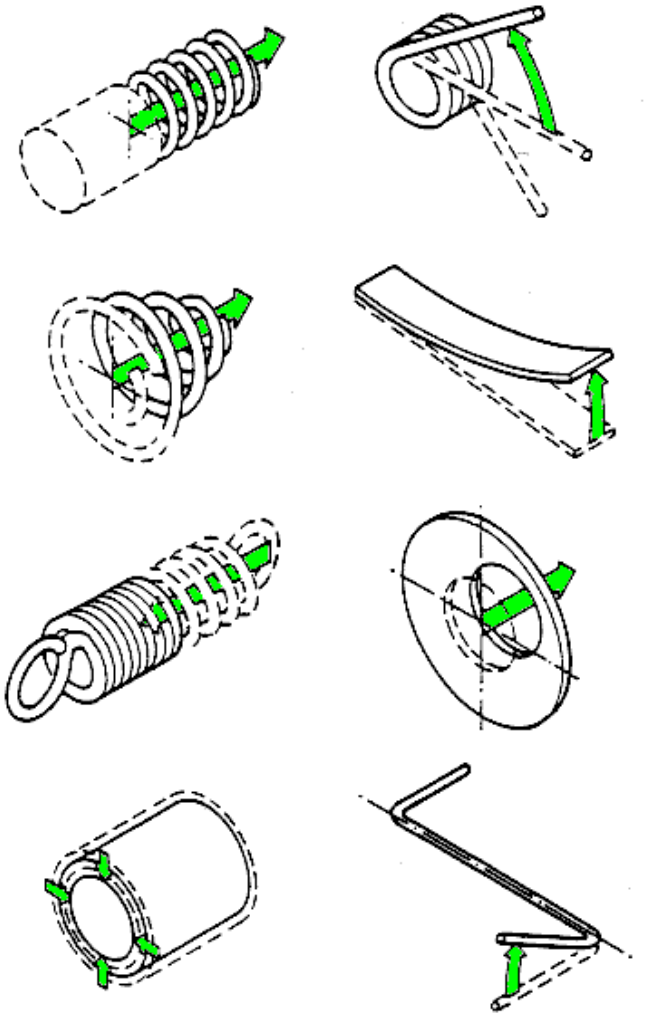


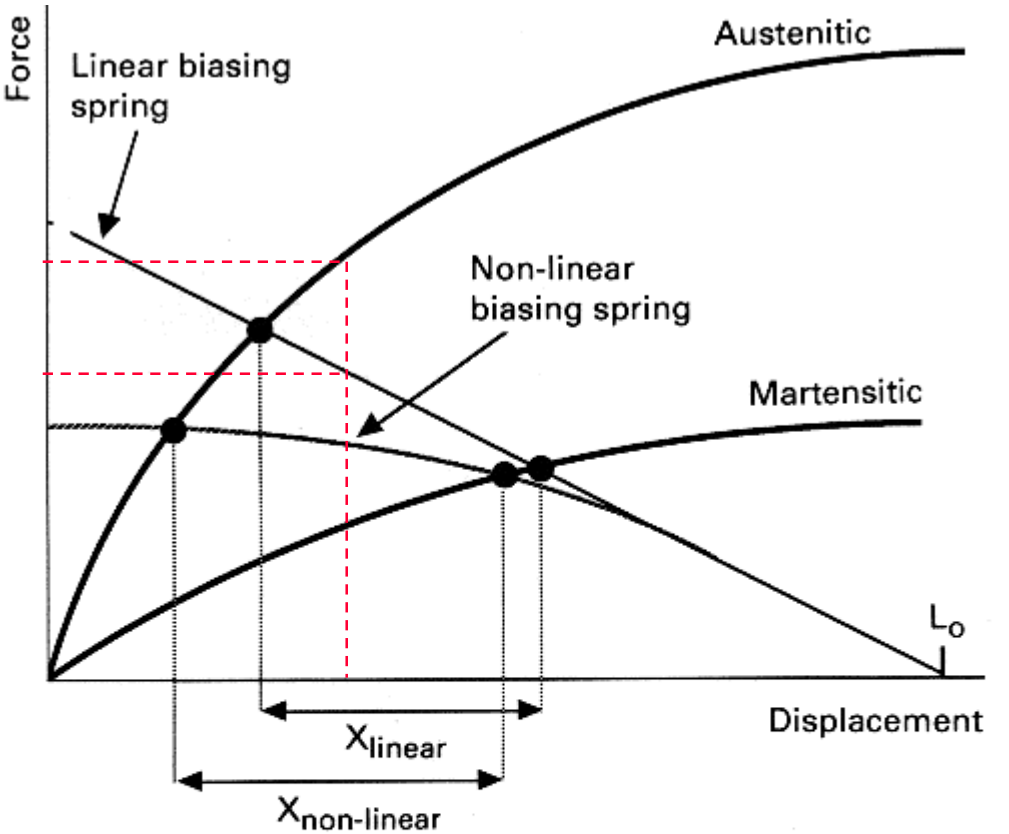
Shape Memory Effect

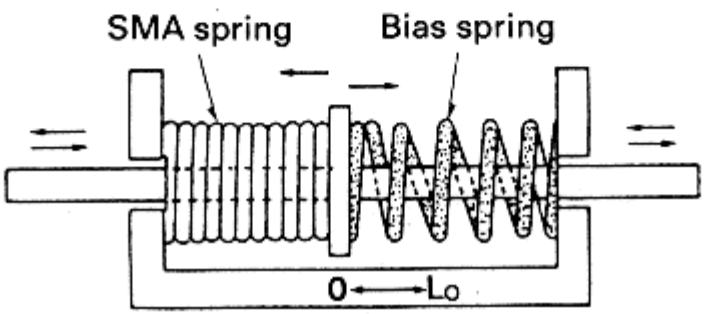


(Yves Bellouard, EPFL)

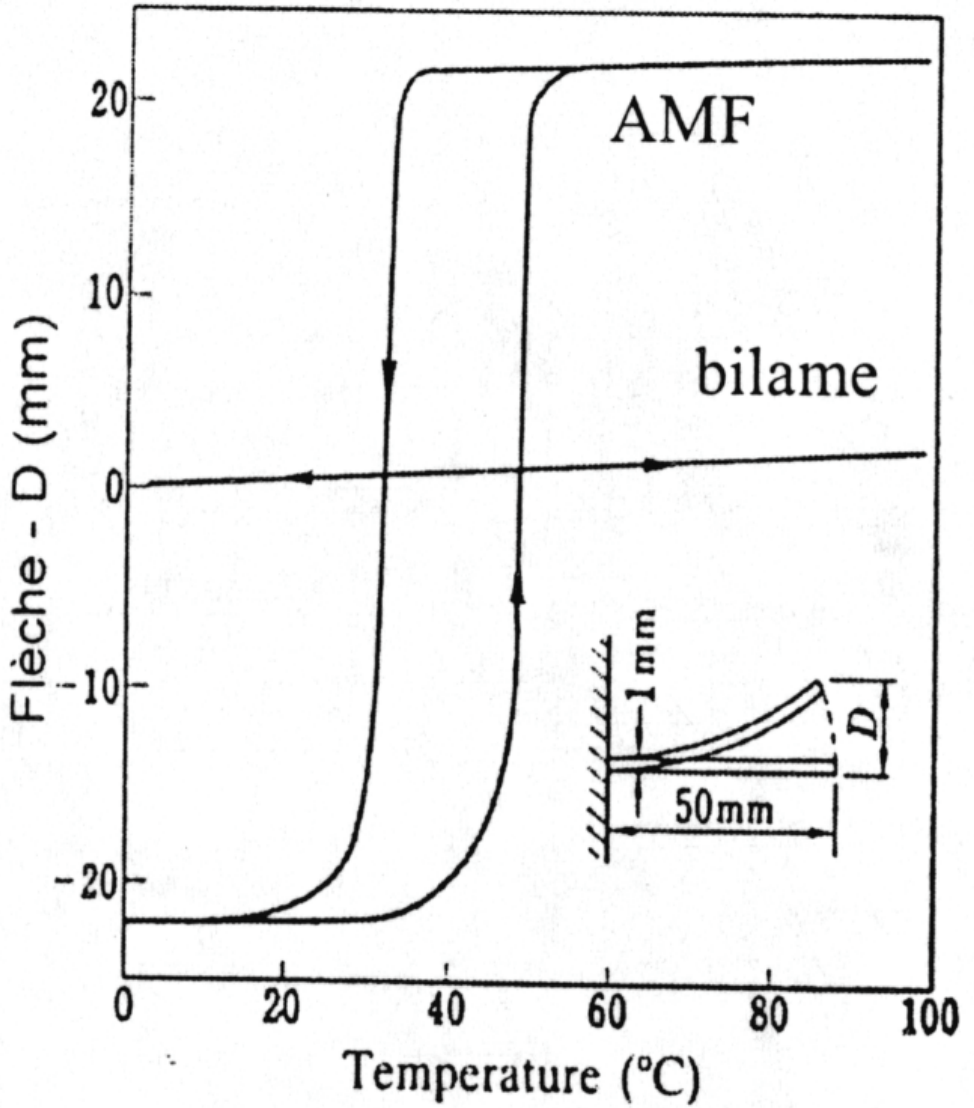
SMA Actuation





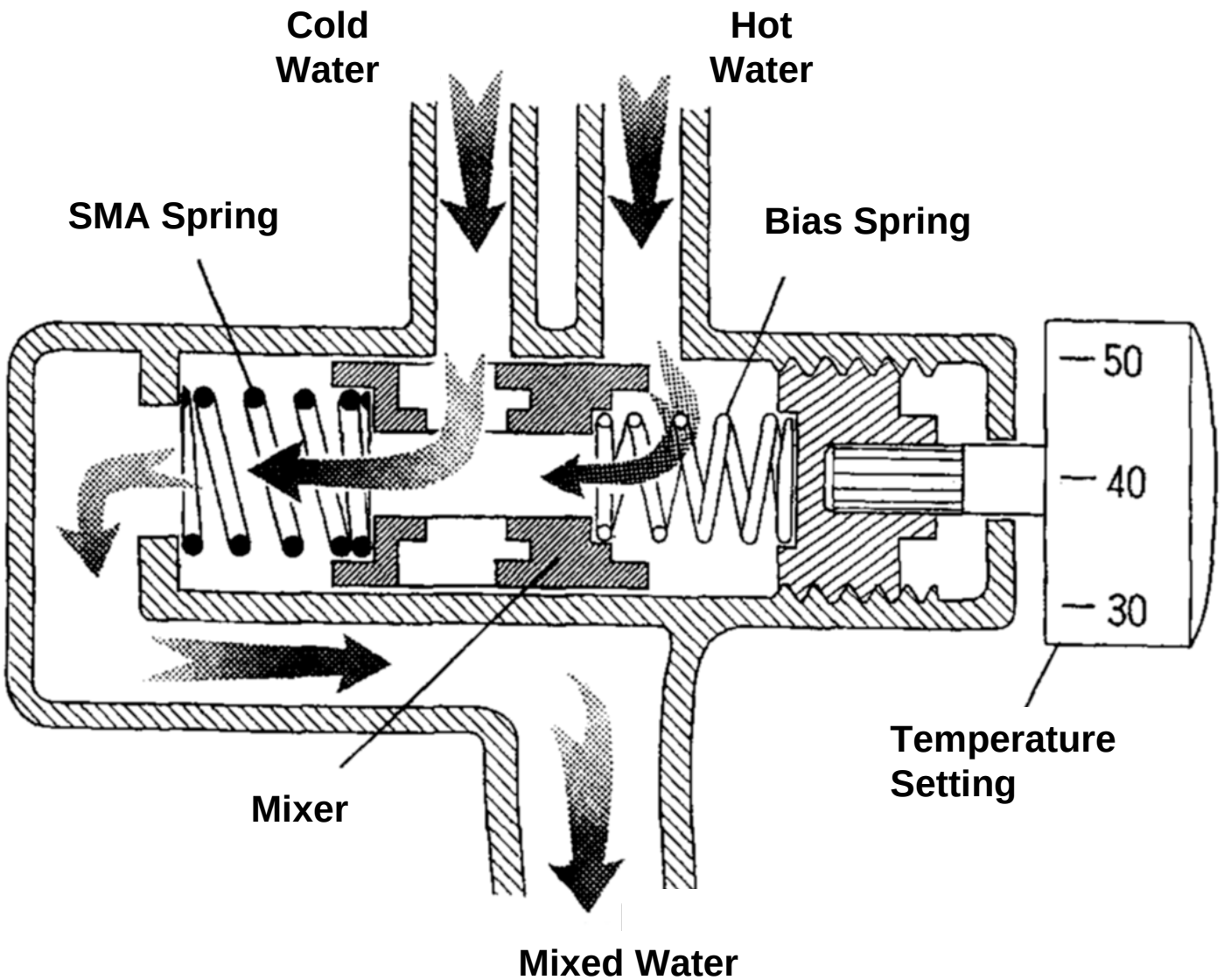


SMA versus bimorph actuation



(I. Okhata) TOTO Ltd.

SMA: Close Loop Control



(I. Okhata) TOTO Ltd.

Conclusion

- **Technology demonstration**
  - ⇨ Exploitation of Martian wind and storms for mobility
  - ⇨ Generation of mechanical energy with Martian temperature cycles
  - ⇨ Innovative locomotion concept
- **Scientific interest**
  - ⇨ Study wind and/or storms effects at the surface
  - ⇨ Very long range (time) exploration
- **SMA actuation**
  - ⇨ compatible with space environment (orbit or planetary surface)
  - ⇨ allows high reliability system
  - ⇨ allows purely mechanical close loop control
  - ⇨ applicable in every space application with thermal variation