The Thermal Design Evolution of the Phoenix Robotic Arm

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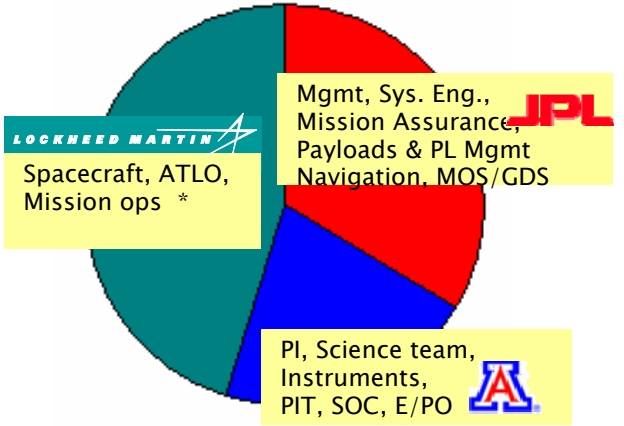
Outline

- Phoenix Mission Description
- RA Mechanical Configuration
- RA Landed Thermal Environment
- RA Thermal Design Challenges
- Warm-up Heater Sizing
- Maximum Actuator Power Dissipation Sizing
- Failed-On Warm-Up Heater Accommodation
- Conclusions

Phoenix Overview

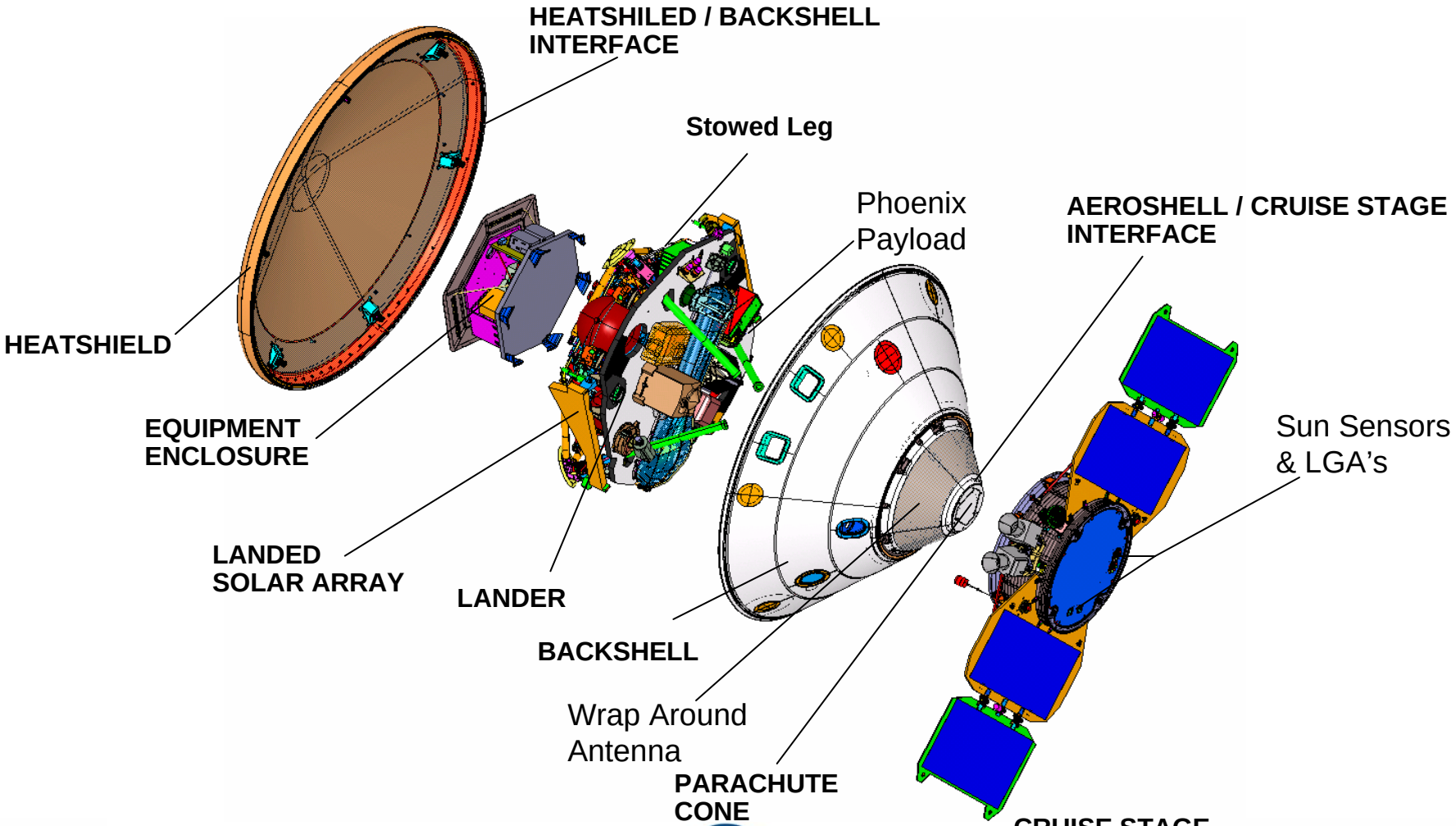
What is Phoenix?

- Phoenix will be the next NASA Mars landed mission
- Phoenix utilizes the terminated MSP'01 lander, improved through Return To Flight upgrades
- Phoenix will fly many of the lost MPL (Mars 98) payloads and some from MSP'01
- Phoenix utilizes a powered descent system unlike MPF and MER
  - More scalable
  - Provides soft landing capabilities
  - More precise placement on the surface
- Key Partners
  - The University of Arizona provides the PI, Peter Smith, and several instruments as well as the PIT and SOC
  - JPL provides Project Management, Systems Engineering, MOS/GDS, as well as the RA and MECA instruments
  - Lockheed Martin provides the Flight System and Operations support
  - Instruments are supported as well through contributions from all over the world

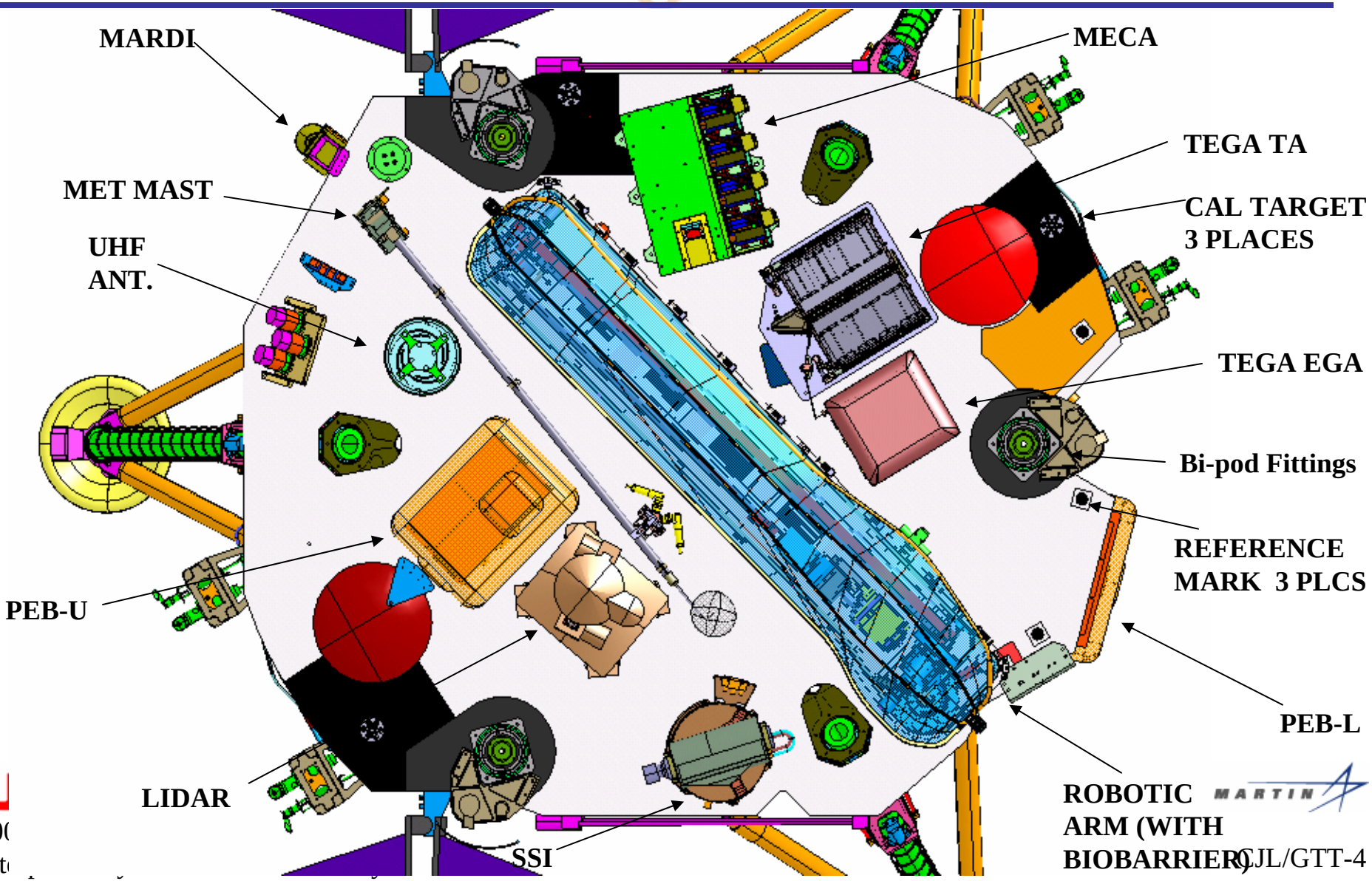


- CSA/MDR/Optech
  - Provides MET station and optical Lidar
- Max Planck Institute for Aeronomy (MPAe)
  - Provides RA camera ('01) and calibration
- University of Neuchatel/Swiss Federal Institute of Technology
  - Provides Atomic Force microscope for MECA ('01)
- University of Copenhagen
  - Provides magnets for MECA and SSI cal target

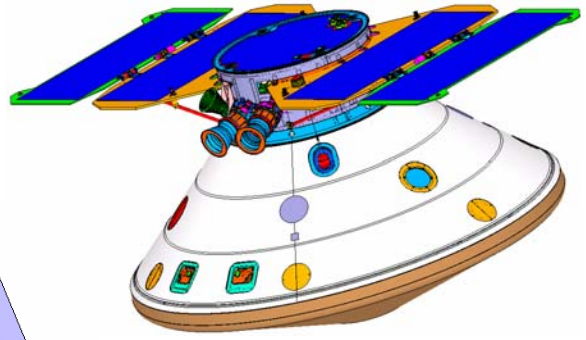
Spacecraft - Exploded View



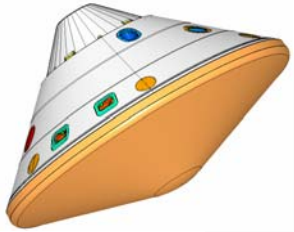
Science Deck Layout



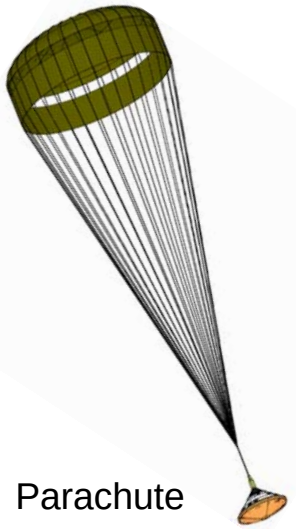
Mission Phase Overview



Cruise

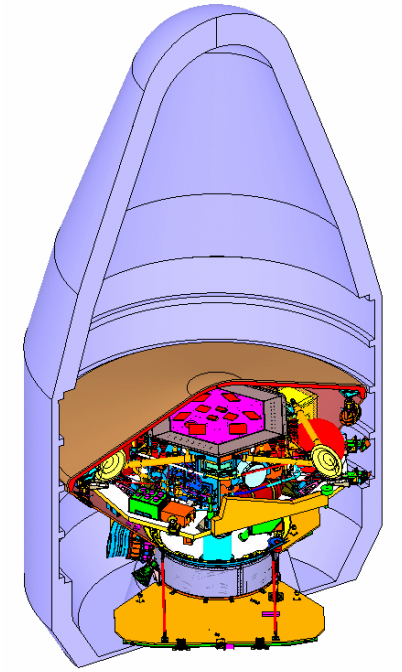


Hypersonic Entry
With Guidance

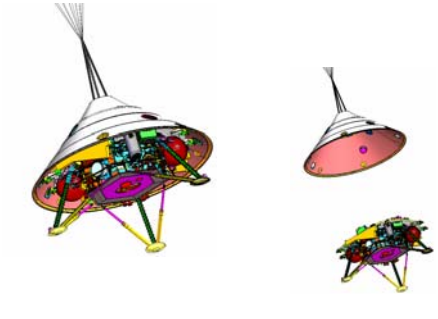


Parachute

Heatshield
Separation



Launch Configuration

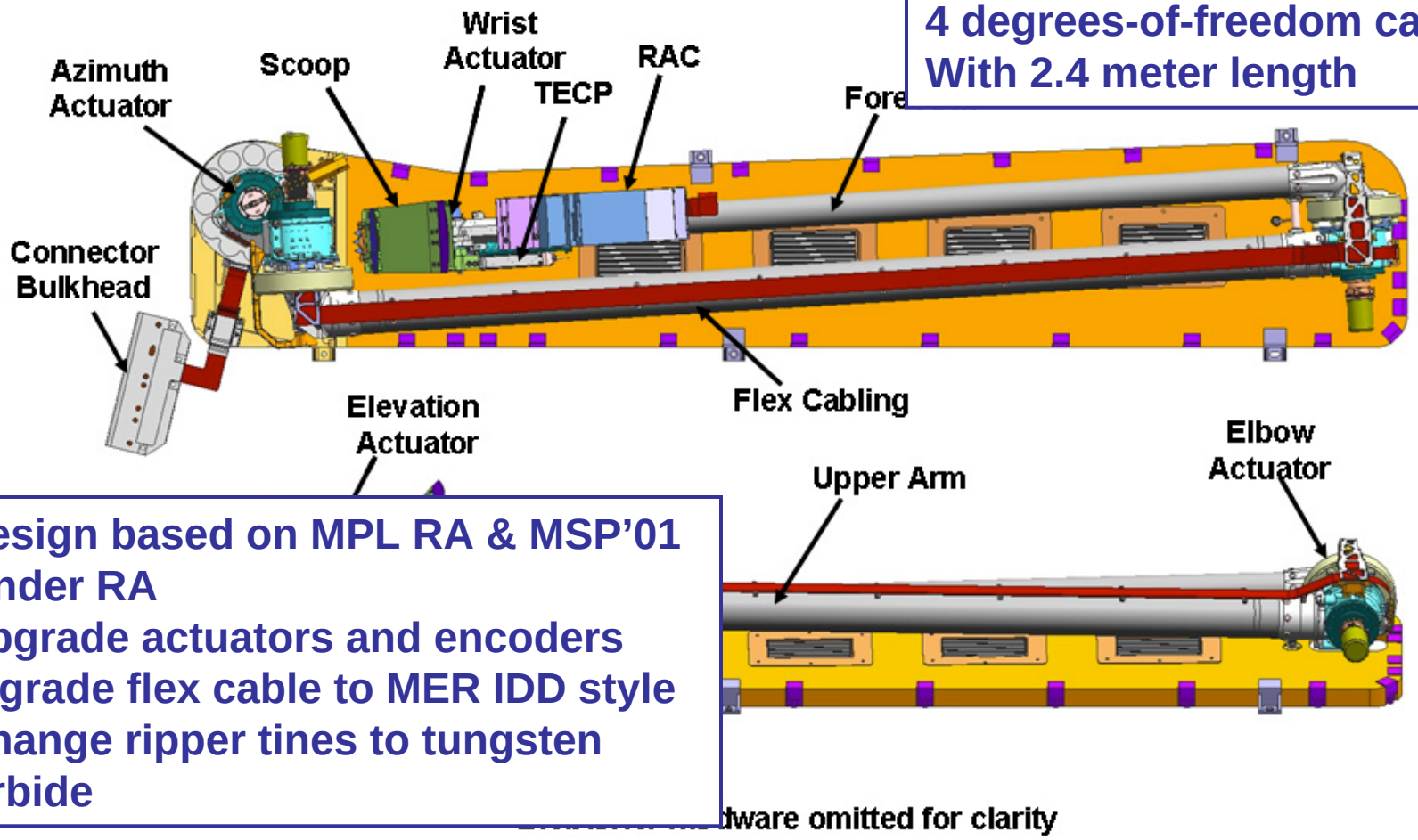


Terminal Descent and Landing

Lander with Deployments

RA Mechanical Configuration

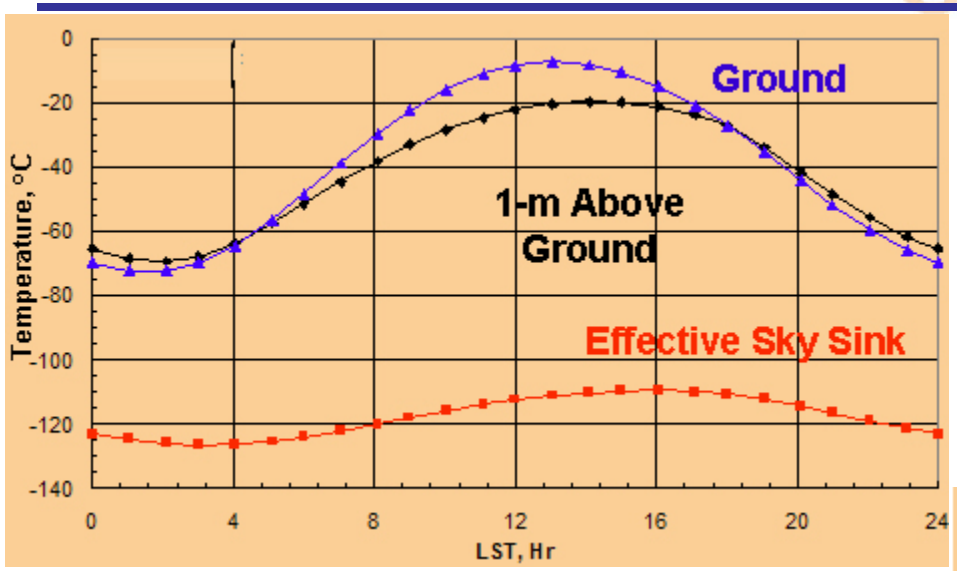
4 degrees-of-freedom capability
With 2.4 meter length



- **Design based on MPL RA & MSP'01 Lander RA**
- **Upgrade actuators and encoders**
  Upgrade flex cable to MER IDD style
- **Change ripper tines to tungsten carbide**

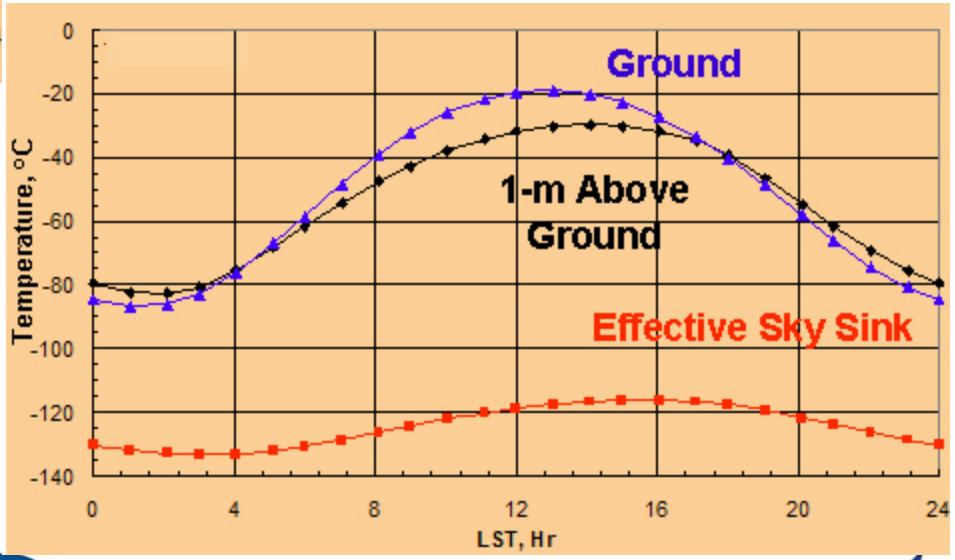
dware omitted for clarity

RA Landed Thermal Environment

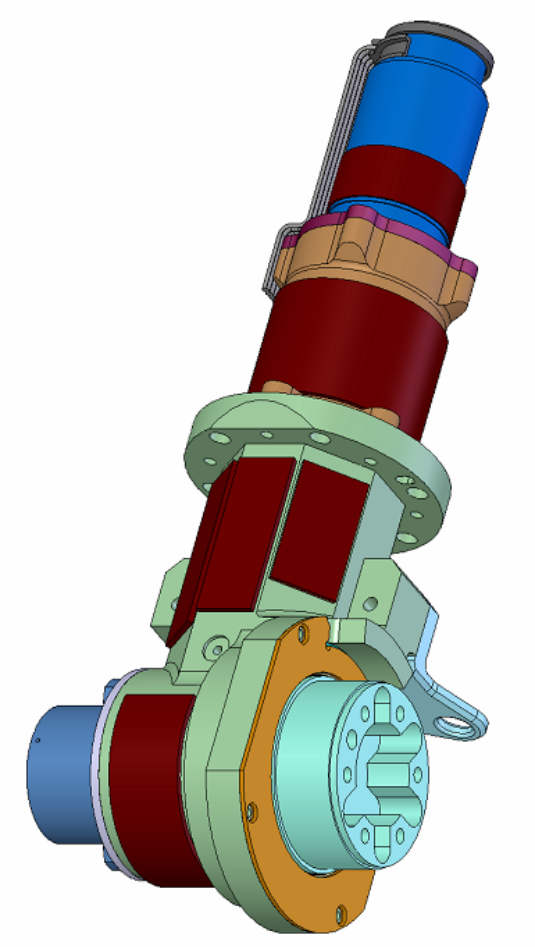


Hot Case:
- $L_s = 110.7^o$
- Opacity = 0.2
- Latitude = 70°N

Cold Case:
- $L_s = 73.3^o$
- Opacity = 0.2
- Latitude = 70°N



RA Thermal Design Approach

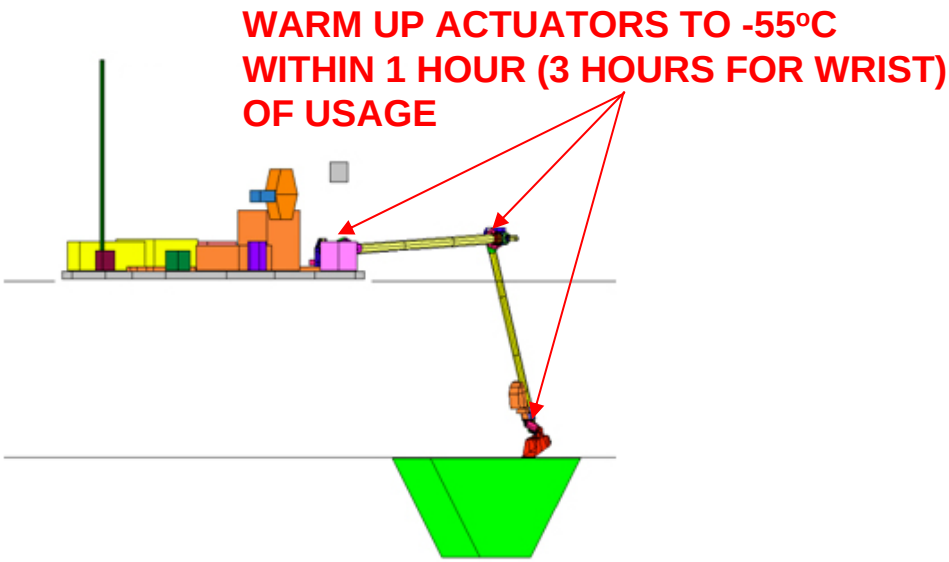


- Film heaters located on motor, gearbox, and output to warm-up actuator for early morning operation
- No insulation to prevent entanglement
- “As-manufactured” surface finishes

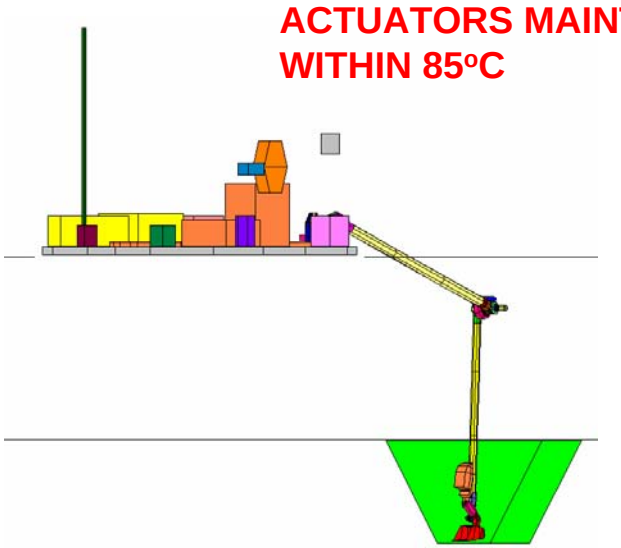
RA Thermal Design Challenge (Driving Requirements) 1/2

Phoenix

Daytime: Enable early morning operation



Daytime: Enable 3.5 hours of operation

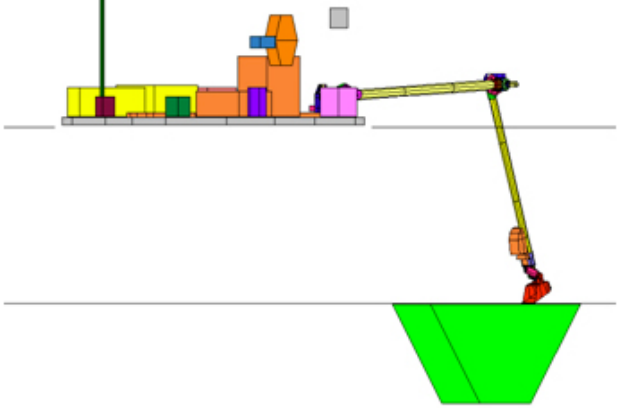


RA Thermal Design Challenge (Driving Requirements) 2/2

Phoenix

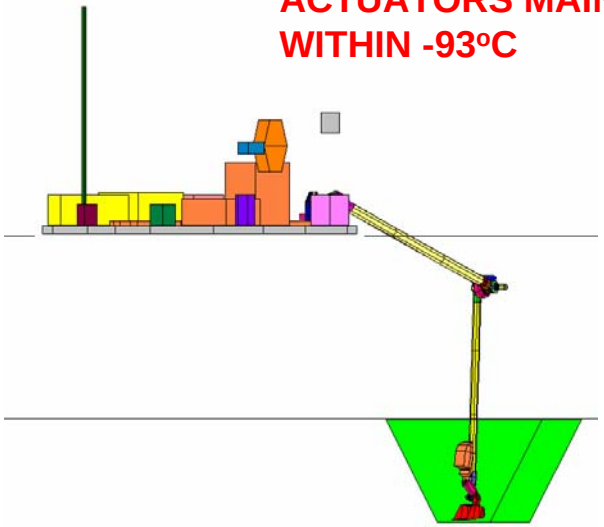
Daytime – Fault Condition: Tolerate a stuck-on actuator heater

NON-OP ACTUATORS MAINTAINED WITHIN 110°C



Nighttime: Tolerate overnight environment

ACTUATORS MAINTAINED WITHIN -93°C



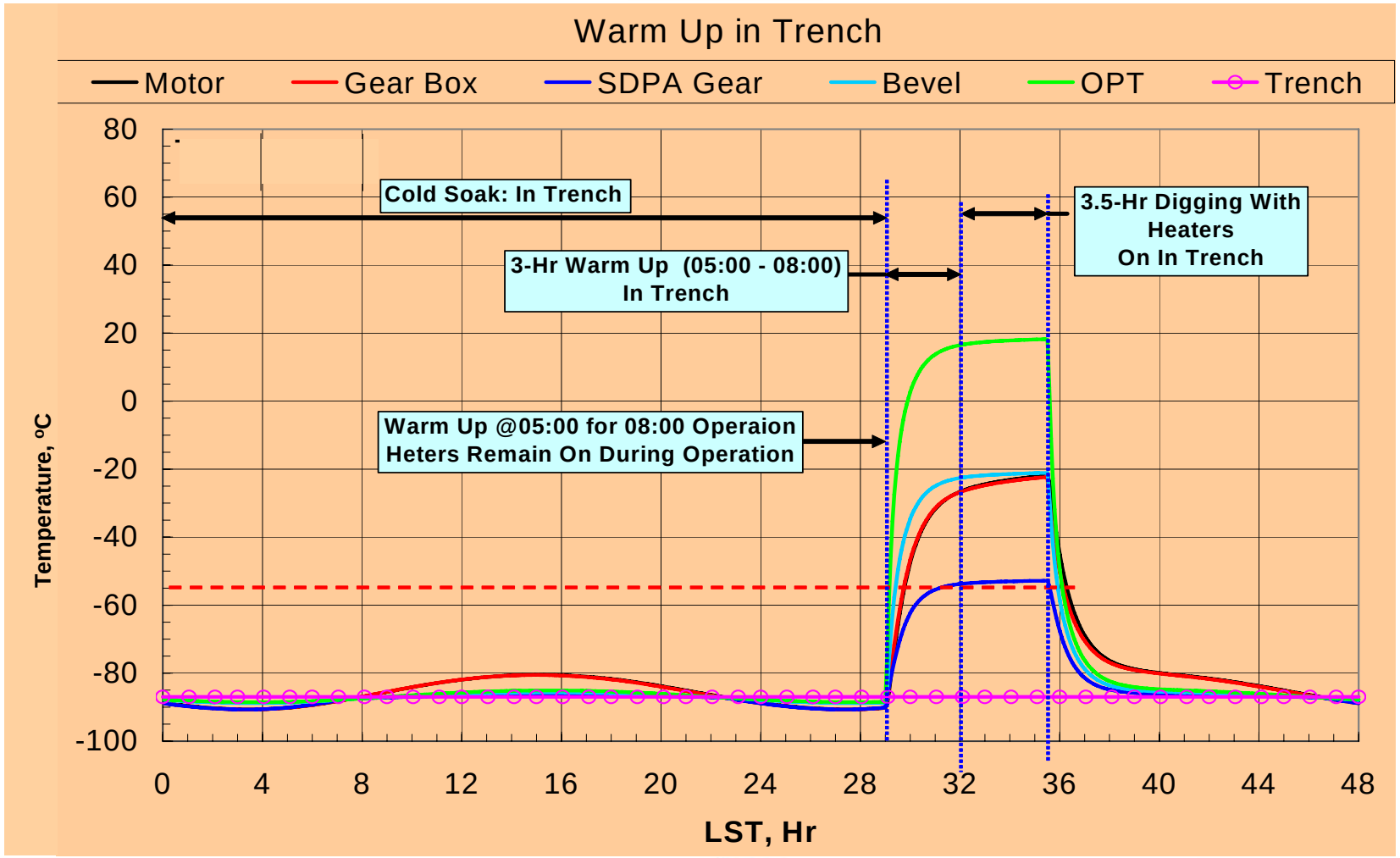
Warm-up Heater Sizing

Heater Location	Azimuth	Elevation	Elbow	Wrist
Motor	0.5	0.3		
Gearbox	0.0	0.3		
House-1	0.8	1.3		9.1
House-2	0.8		1.0	
House-3				6.3
Total	2.0	1.8	1.0	15.3

Total Warm-up Heater Power is 20.1 W

Heater power sized to warm actuators to -55°C in 1 hour (3 hours for the wrist) prior to early morning actuator use

Warm-up Heater Sizing
Wrist Actuator



Maximum Actuator Power Dissipation

Actuator	Max Allowable Motor Power Dissipation, W
Azimuth	4.4
Elevation	5.2
Elbow	3.6
Wrist	5.3

Actuator power sized to maintain temperature below 85°C during 3.5 hours of operation

Failed-on Warm-up Heaters

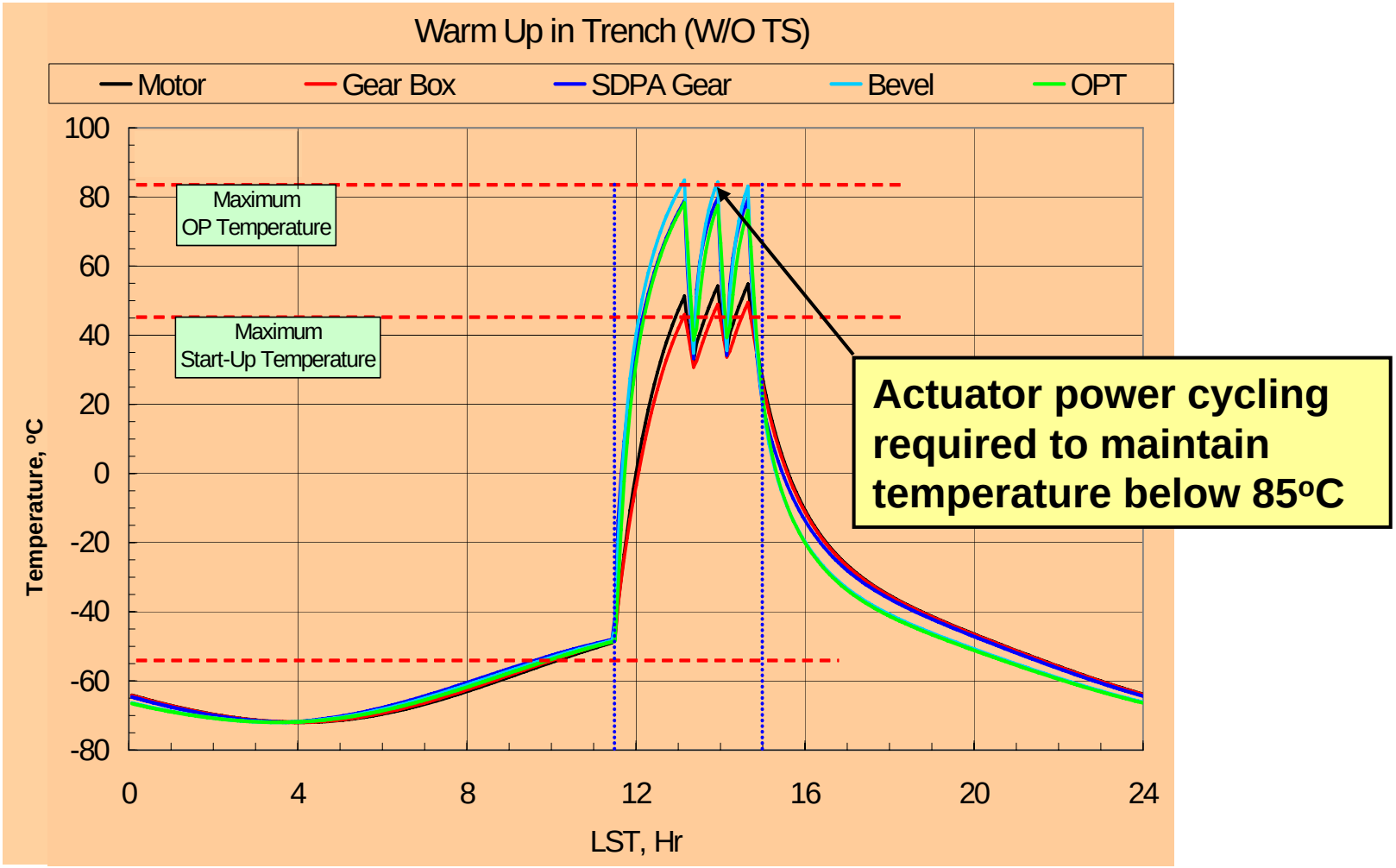
Wrist Actuator Component	Maximum Temperature, °C
Motor	69
Gearbox	70
SDPA	109
Bevel	119
OPT	113

Maximum allowable non-operating limit is 110°C in an event of a heater failure

- **Overheating of actuator components is not readily detected by sensing motor case temperature**
- **Power cycling will be necessary during hot conditions**

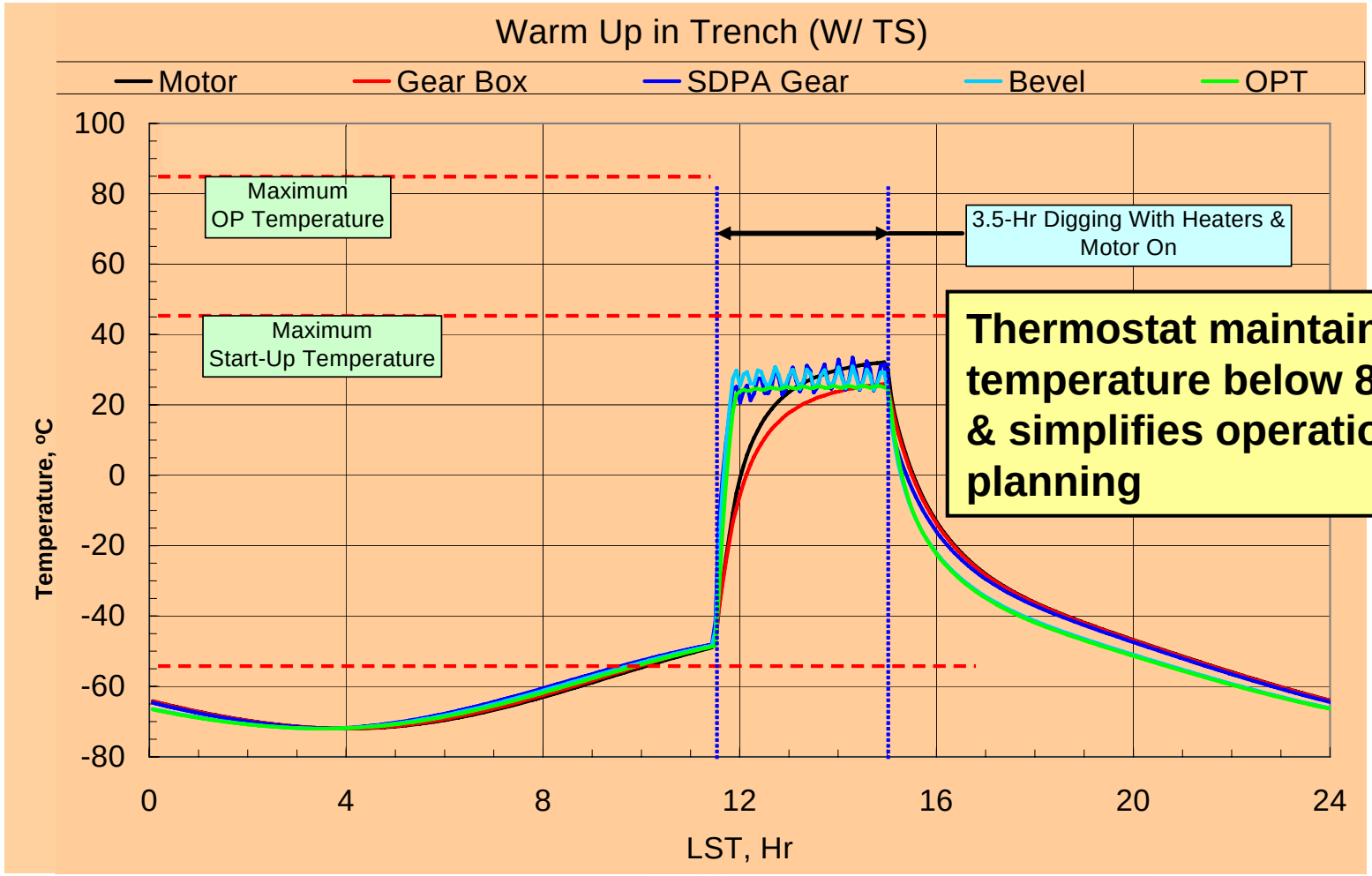
FAILED-ON WARM-UP HEATERS

Wrist Actuator: Hot Case in Trench **WITHOUT** Cut-off Thermostat



FAILED-ON WARM-UP HEATERS

Wrist Actuator: Hot Case in Trench **WITH** Cut-off Thermostat



Conclusions

- An adequate warm-up heater approach was developed using analysis & previous Mars surface experience
- In the worst-cold environment, all the actuators were able to warm to their minimum operating temperature within the required time
- In the worst-hot environment, the maximum continuous actuator power dissipation during normal operations was determined
- A mechanical thermostat provides best means to cope with a failed-on wrist heater & to ease RA operations planning