Europa Clipper Lander Solid Propulsion Retro Motor

THE VALUE OF PERFORMANCE.

NORTHROP GRUMMAN

AIAA Propulsion & Energy Forum

August 20, 2019

Stephen Palopoli, Ph.D., Jonathan Katz, David McGrath

Europa

- NASA is studying a mission concept that would investigate signs of life on Jupiter's icy moon Europa.
  - Europa is thought to contain a moon-spanning ocean of salty water that might permit life to make its way onto the icy surface.
  - The Europa Lander would land a laboratory on the icy crust to investigate the surface and seek out signs of life.

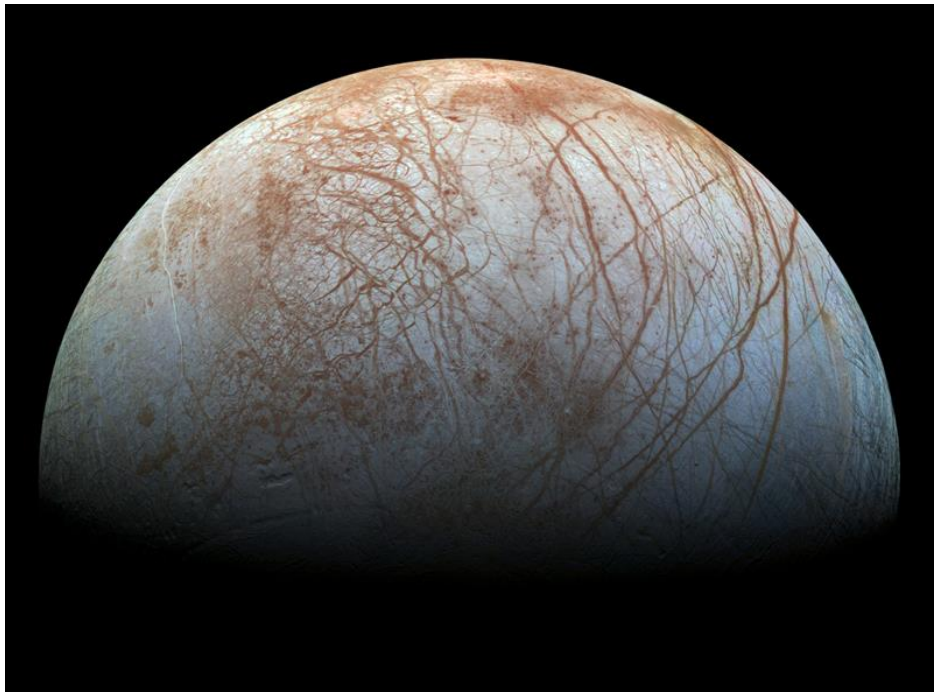


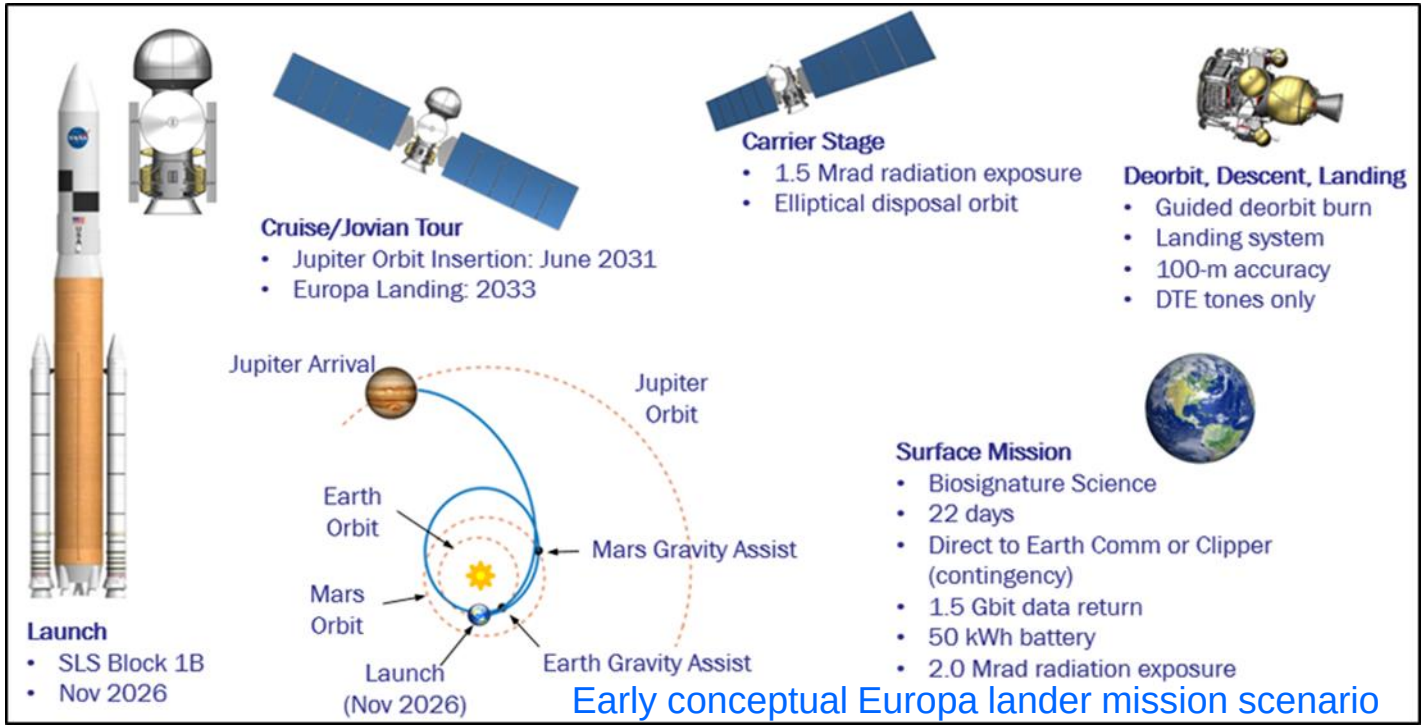
Image Credit: NASA/JPL-Caltech/SETI Institute

Image Credit: NASA/JPL-Caltech

The Europa Lander Mission

NORTHROP GRUMMAN

- The spacecraft and descent stage will experience extreme environments during transit and around the Jovian system
  - Cold interplanetary cruise at 0°C from Earth to the Jovian system
  - Exposure to high-energy electrons in the Europa-Jovian system
- Planetary protection may require dry heat microbial reduction (DHMR) of the descent stage solid rocket motor prior to spacecraft integration



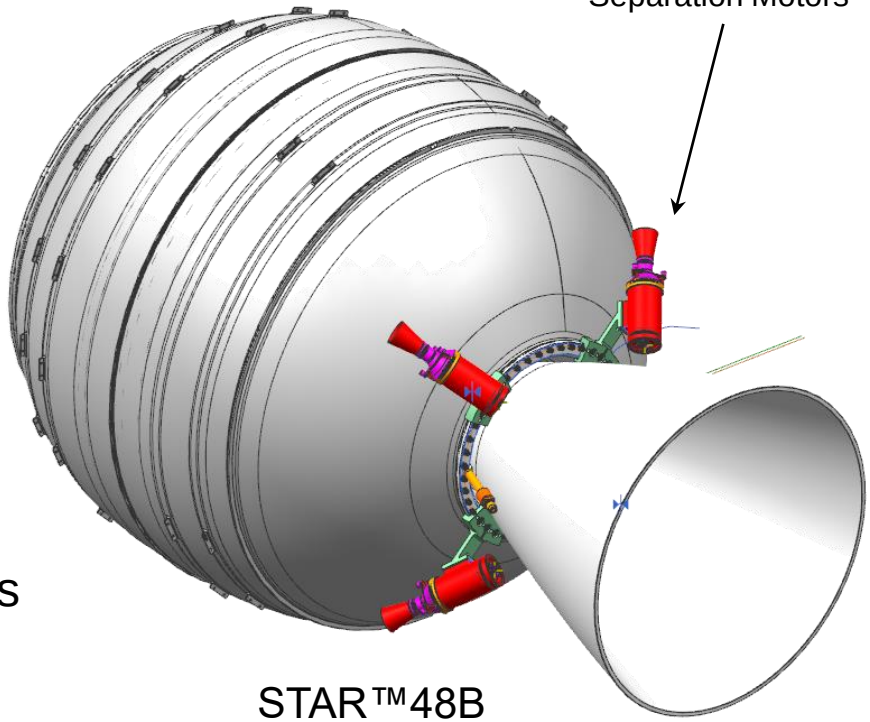
Early conceptual Europa lander mission scenario

De-Orbit/Deceleration Motor Design

Requirements and Constraints

- Modified propellant grain to target required deceleration delta velocity over a wide temperature range
- Propellant offload based on successful Low-Density Supersonic Decelerator (LDSD) design (20% offload)
- Incorporated and confirmed a 1.4 factor of safety for all components while considering extreme temperature and radiation environments
- Incorporated separation system to remove the deorbit stage from the Descent Vehicle
- Planetary protection concept and processes being incorporated to limit the risk of contaminating Europa with Earth-based microbes

Credit: NASA/JPL-Caltech



STAR™48B
Deceleration Motor
15% offload from standard STAR™48B

Propellant DHMR, Radiation and Combined DHMR + Radiation Exposure Testing

NORTHROP GRUMMAN

- Samples of propellant were treated to DHMR at 125°C for 442 hours
- Samples were exposed to high-energy electron radiation at NASA MSFC at cumulative doses of 3 and 6 Mrad
  - Limited samples exposed to DHMR + 3 Mrad combined environment
  - A 6 Mrad exposure is up to four (4) times the expected mission radiation exposure
  - The titanium motor case will provide some shielding from radiation
  - A large radiation dose is predicted along the external 1-2 cm depth of the motor encompassing the case insulation and propellant-liner-insulator bondline
  - The bulk propellant and bore will experience negligible radiation
- The samples evaluated included:
  - Individual JANNAF Class B milled tensile dog bones, propellant-liner-insulation panels, 0.25” diameter strands and 0.25 kg test motor grains
  - Testing included visual, dimensional and weight change; differential thermal analysis (DTA), hazard sensitivity, mechanical property, bondline strength, burning rate in strands and test motors, optical and scanning electron microscopy

Selected representative results are reported in this presentation

Comparison of Control and 6 Mrad Tensile Samples

Control **6 Mrad**

- No statistically significant weight, dimensional, density or visual changes observed due to DHMR and/or radiation exposure
- Impact, friction and ESD (spark) threshold ignition level energies are equivalent or higher after DHMR and/or irradiation

Radiation Effect on Propellant Exotherm Temperature (DTA)

Control

6 Mrad

- Propellant exotherm temperature is correlated with ammonium perchlorate (AP) decomposition
  - AP decomposition is a complex process involving crystallographic phase transition; low temperature induction, acceleration and deceleration regimes; and final high temperature decomposition
  - The Control propellant exotherm is near 331°C following the phase transition and the deceleration/arrest low temperature AP decomposition regime
  - Exposure to radiation advances the propellant (and AP) decomposition to near 243°C coincident with the AP orthorhombic-to-cubic phase transition
  - This observation is consistent with open literature studies dating to the 1960s on the effect of radiolysis on ammonium perchlorate

Radiation does not adversely impact the thermal stability of the propellant. Our internal requirement is an exotherm temperature of ≥ 200°C for all manufacturing, handling and flight applications with a large margin of safety.

Summary of Tensile and Bondline Effects

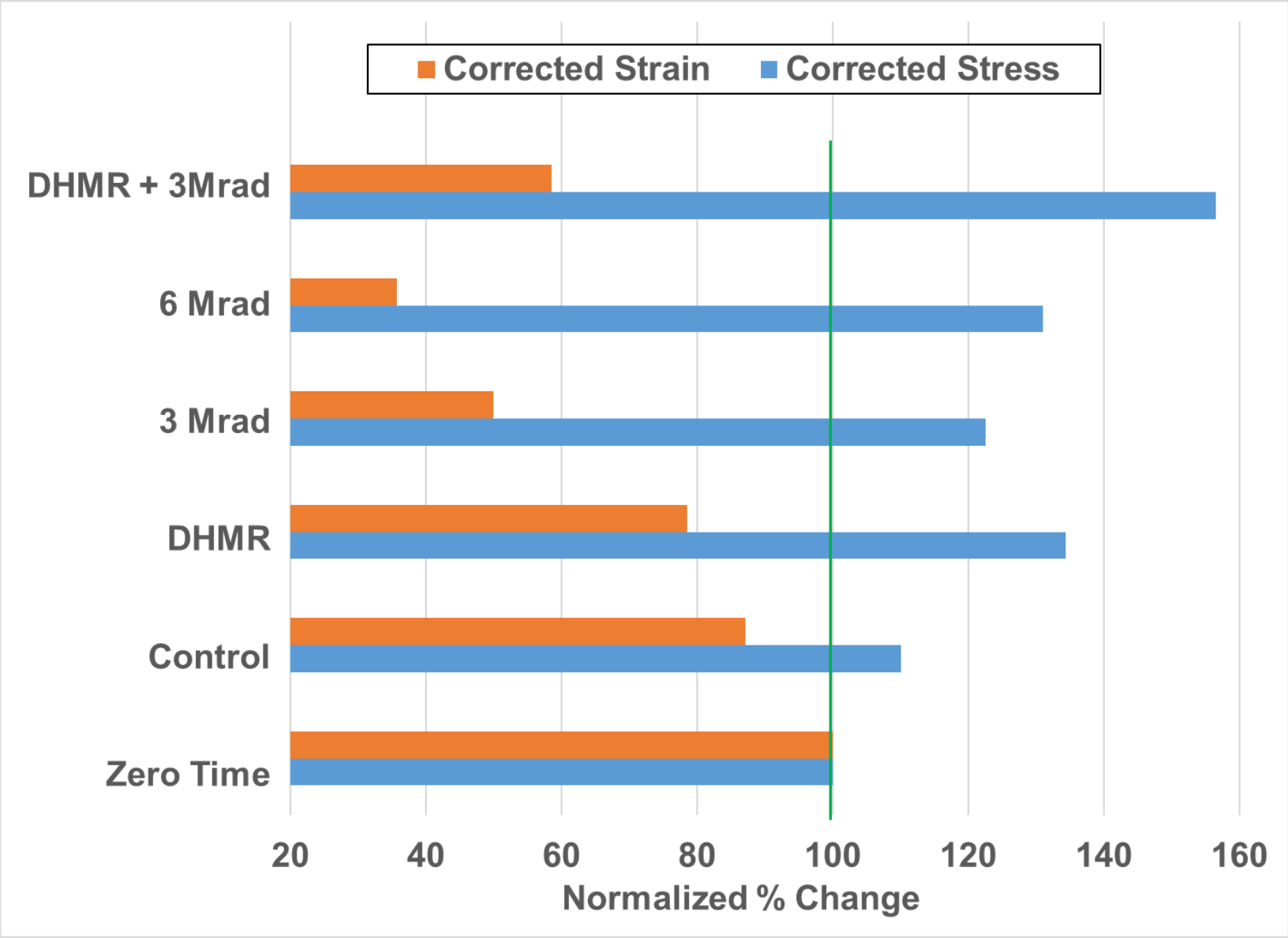
NORTHROP GRUMMAN

- DHMR treatment increases stress and decreases elongation (strain)
  - DHMR effectively is accelerated thermal aging (hardening) of the propellant
  - The mechanism is oxidative cross-linking across polybutadiene polymer chains
  - The increase in stress with DHMR duration is logarithmic
- High-energy electron radiation exposure increases stress and decreases strain
  - Radiation induced hardening occurs by an analogous cross-linking process
  - The increase in stress with radiation dose is logarithmic
  - The effects of DHMR + Radiation do not appear to be additive and follow a combined logarithmic stress increase
- The propellant-liner-insulation bondline is not adversely affected by DHMR, radiation or DHMR + Radiation
  - Bondline strengths generally increase after DHMR and/or radiation exposure
  - All failure modes were 100% cohesive-in-the-propellant as desired

Motor bondline and bulk propellant tensile properties will survive expected Europa mission radiation exposure with margin

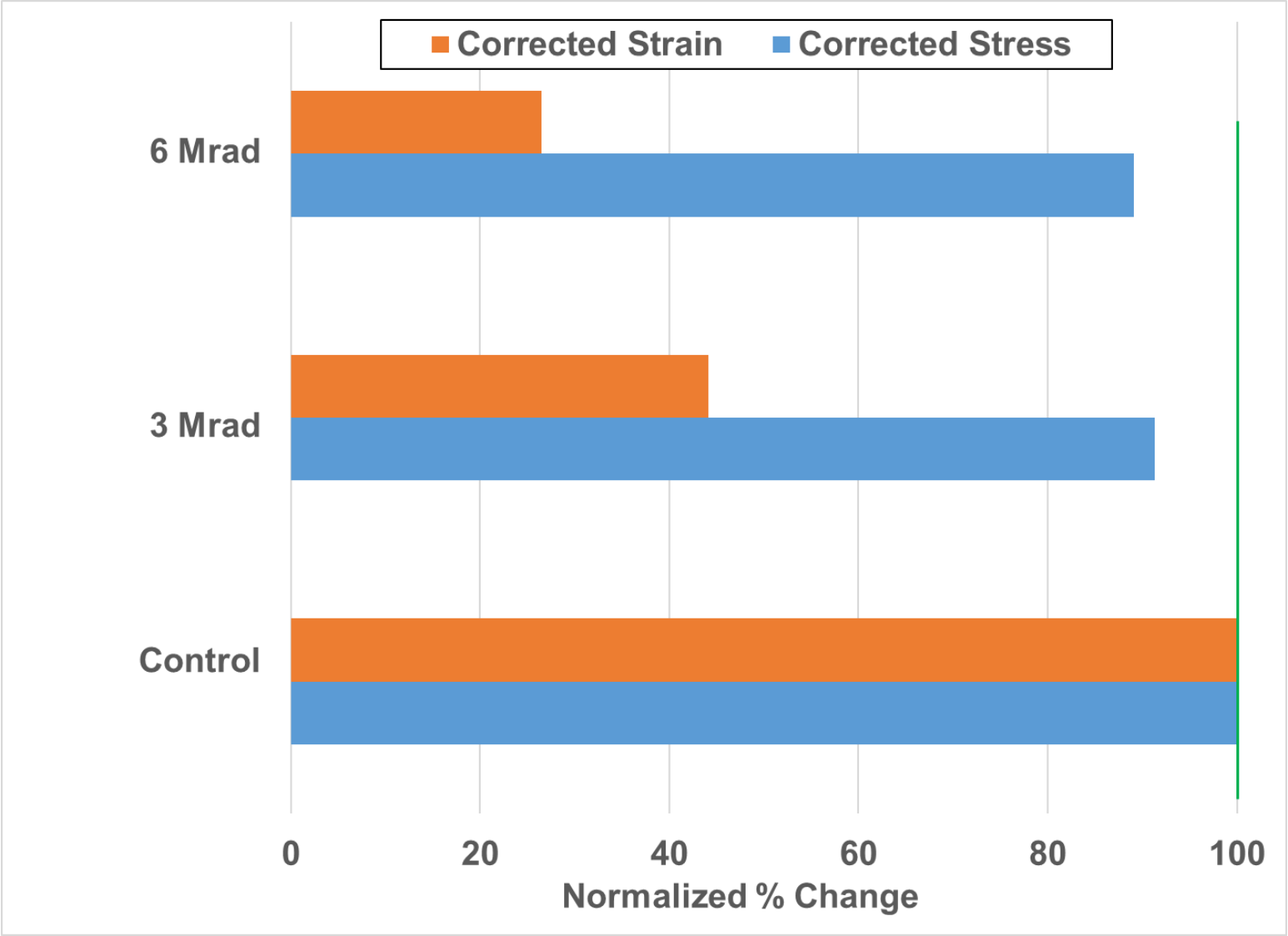
Effect on Propellant Stress and Strain

Class B Tensile Samples, 25°C, 0.0128 cm/cm/s

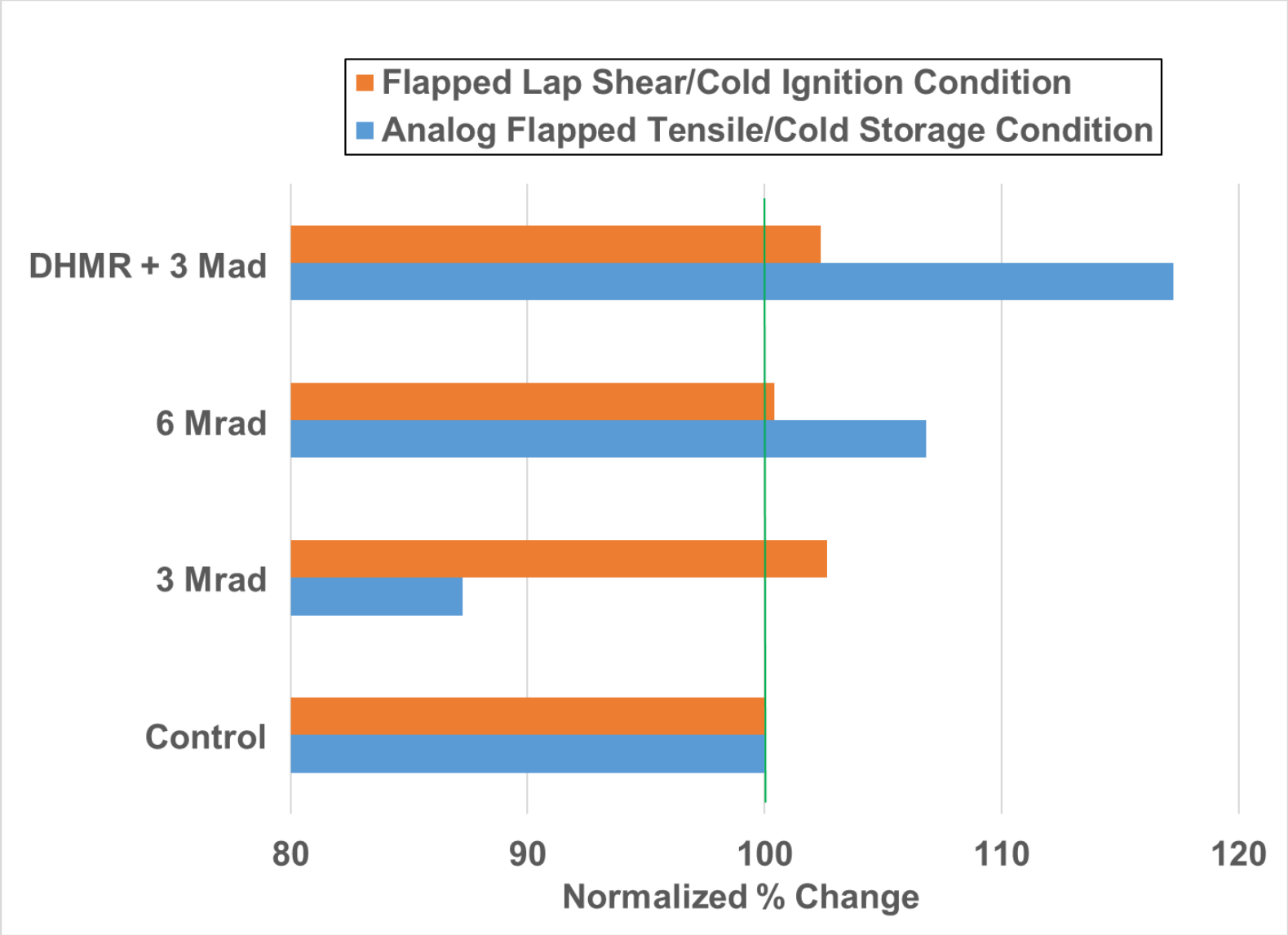


Effect of Radiation on Cold Stress and Strain

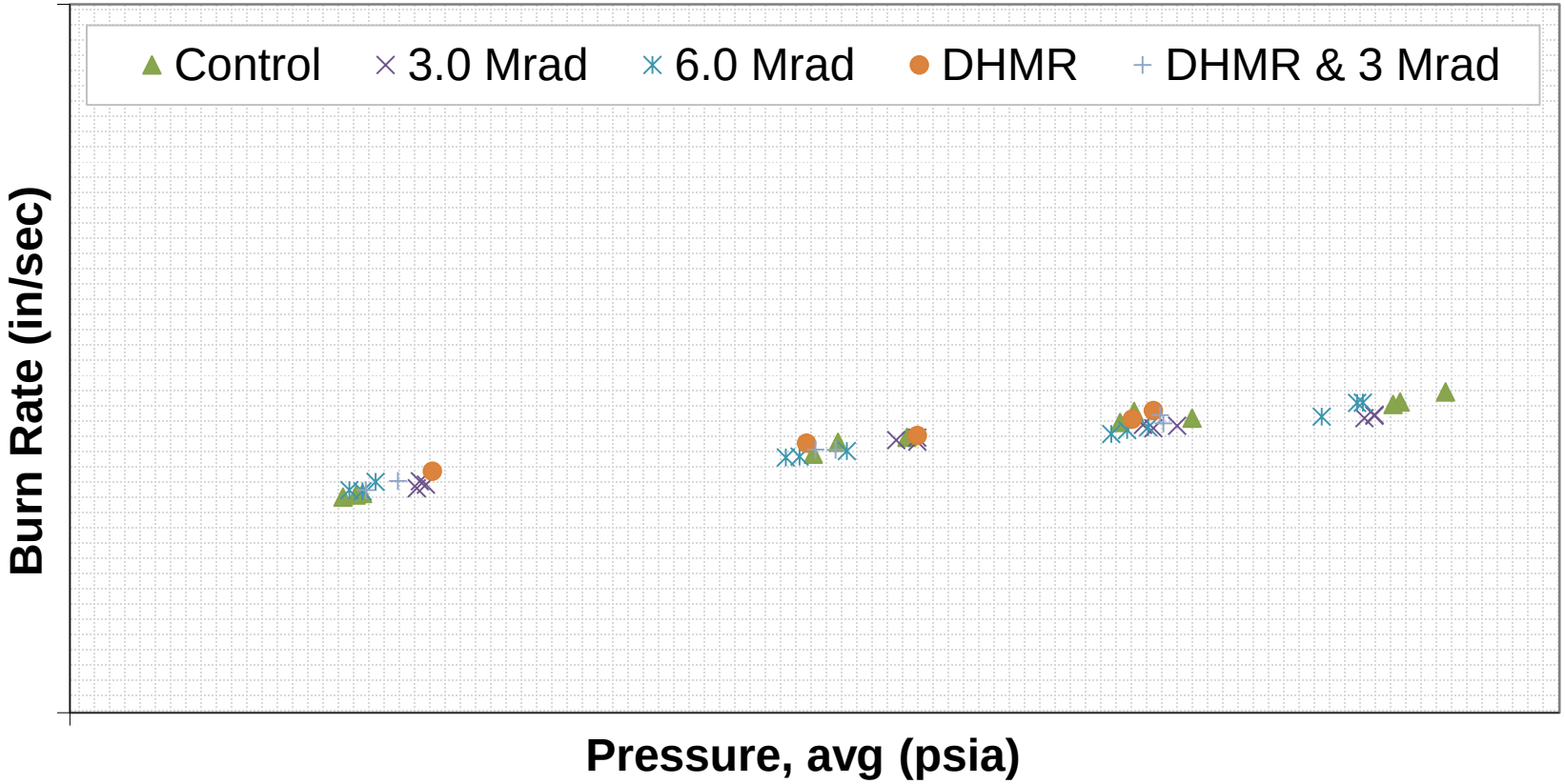
Cold, High-Rate Loading Ignition Condition



Propellant-Liner-Insulation Bondline Strength
Desired Cohesive-in-Propellant Failure Mode Observed



Effect of DHMR and/or Radiation on Propellant Burning Rate



There is no significant effect due to DHMR and/or radiation on propellant burning rate in end-burning test motors – possible slight decrease in burn rate at intermediate pressures

Future Work and Conclusions

NORTHROP GRUMMAN

- Additional bondline radiation exposure testing is in progress for Control, 3 Mrad and 6 Mrad dosages as a function of radiation exposure temperature

- It is unlikely that DHMR of the STAR™ motor will be used for planetary protection because of the accelerated aging strain penalty
  - Motor operation will sterilize all internal materials and components, except possibly the insulation and case inside wall; however, these regions will see the higher radiation dose and potentially effective microbial reduction
  - Pre-propellant cast, motor case assembly operations will be modified to control microbial contamination
  - Multiple redundant motor ignition systems will insure successful ignition and extreme heat sterilization
  - Common methods for external surface microbial reduction will be used at the spacecraft level

An off-loaded STAR™48 motor will survive the interplanetary cruise and Jovian radiation environment, and successfully function as part of the Europa Lander Descent Stage

This work was sponsored and conducted under contract to NASA Marshall Space Flight Center, Europa Solid Motor Breaking Stage Characterization

THE VALUE OF PERFORMANCE.

NORTHROP GRUMMAN