Introduction and Motivation

• Mars Helicopter (aka Ingenuity) is an JPL internally funded Technology Demonstration Mission Concept
• Entirely COTS-based mission concept
• Need to implement adapted radiation hardness assurance (RHA) approaches due to cost limitation and tight schedule
Conceptual Mission Overview

• Proposed Objectives:
  • Design and complete Earth testing of Ingenuity prototype
  • Conduct five test flights on Mars
  • Generate technology performance data
  • Demonstrate traverse planning with future Mars rover missions

Challenges:
• Very thin Martian atmosphere
• Mass allocation of 1.8kg
• Autonomous operation
• Multiple take-off and landings
• Relatively harsh environment
• Limited time scale and budget

DO NO HARM

June 16th, 2020
Pre-decisional information for planning and discussion only.
**Proposed Architecture Overview**

- **BLADES**
  Made of carbon fiber foam core provide lift in the thin Mars atmosphere.

- **SOLAR PANEL**
  A solar panel helps keep the battery charged.

- **ANTENNAS**
  Radio antennas that communicate with Mars 2020.

- **LEGS**
  Ultra-light legs made of carbon fiber tubes to help it land after flight.

- **Power Sub-System**
  Batteries, charging, and power delivery.

- **Sensors, Cameras & Autonomy**
  Sensors that collect data on how fast the helicopter is traveling and in which direction. Flight “vision”.

- **Avionics**
  Its avionics — or "brains" — help the helicopter function and navigate.

*Artist’s illustration of concept architecture

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Radiation Hardness Assurance Overview

Set Survivability Requirements
- Determine TID, DD, and SEE limits and thresholds

Define & Evaluate Radiation Hazard
- Shielded contributions from various environments

Technology Evaluation
- Develop and evaluate parts list
- Analyze/test/analyze
- Determine “tall tent pole” hazards

Peel & Iterate
- Re-evaluate at the system-level
- Attack the next “tent pole”

Replace or Mitigate
- Replace parts that don’t meet requirements if possible
- Mitigate what can’t be replaced


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Mission Concept Environment

CRUISE/APPROACH

• Seven to nine month cruise period
• Standard interplanetary solar minimum galactic cosmic ray (GCR) model
• Nearly all Ingenuity’s electronics powered OFF

ENTRY, DESCENT, & LANDING

EGRESS & OPERATIONS

RHA Phase 1: Cruise

RHA Phase 2: Landed

• Martian surface model
• Goal of at least 10 hours of powered ON operation
Atmosphere will stop nearly all solar energetic particles
Optical shadowing of planet reduces GCR flux in half
Generic atmospheric model is equivalent to 2-3 inches of aluminum
Reduces GCR flux by another factor of 2
Use solar maximum GCR model
Mars Surface Model

Single Event Effects RHA Approach

- No testing (bound the risk through analysis)
- Adopt PETS 3 mission requirements
- Perform board-level proton test
- Adopt our own LET requirements

Given an operational time of 10 hours and the Mars surface radiation model...

- Assumed a worst-case saturated cross-section and used a conservative step function with varying LET$_{TH}$
- Settled on an LET$_{TH}$ requirement of 10 MeV-cm$^2$/mg that yielded a 99.99% success probability against Single-Event Hard Errors (SEHE) for the Martian surface
- Continued use of 37 MeV-cm$^2$/mg for electronics powered on during cruise phase


Test Overview and Results

- 30 devices were screened for single-event latchup (SEL) or gate rupture/burnout (SEGR/SEB)
Failures and Mitigation Approaches

• Devices that failed and could be replaced were
• Two devices exhibited “non-destructive” SEL, but could not be replaced

• Current-limiting mitigation was employed
  • Proposed technique of using an FPGA output pin to power the devices is under consideration
  • Current limiting resistor
Conclusions

• Same RHA approaches, more willingness to accept risk
• Define the environmental threats
  • Would be operating in a fractionally GCR dominated environment nearly devoid of protons
• Set survivability requirements
  • A desired 99.99% probability for success against SEHE
  • Set LET thresholds to 10 or 37 MeV-cm²/mg (depending on mission phase)
• Apply existing data and/or test sensitive components
  • Removed failed devices if possible
• Explore mitigation solutions as required
  • Current limiting of SEL sensitive devices
• Iterate this process beginning with most critical threats
  • Once SEHE is dealt with, fold test observables and literature-based soft-error analysis into the system-level