Jet Propulsion Laboratory
California Institute of Technology

Technical Challenges In Building and Testing Complex Interplanetary Spacecraft Systems: From Inception to Launch

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California Institute of Technology
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Introduction

- One of NASA's chief goals is to understand the origin and evolution of our solar system's planets.

- To achieve this goal, JPL launches complex robotic machines such as spacecraft and rovers to provide the knowledge we need to understand the origin of our own solar system and the planetary systems being discovered around other stars.

Introduction

- In designing, building and testing these complex interplanetary spacecraft and landers, we must keep in mind that:
  - Must endure the rigor of the launch campaign process,
  - Must exist in harsh space environments,
  - Must maintain lifespans between five to 20 years and beyond, and continue to operate sensitive science instruments with absolute mission success,
  - **Every detail matters, from the design workstation to the instrument check out process while in the launch complex.**

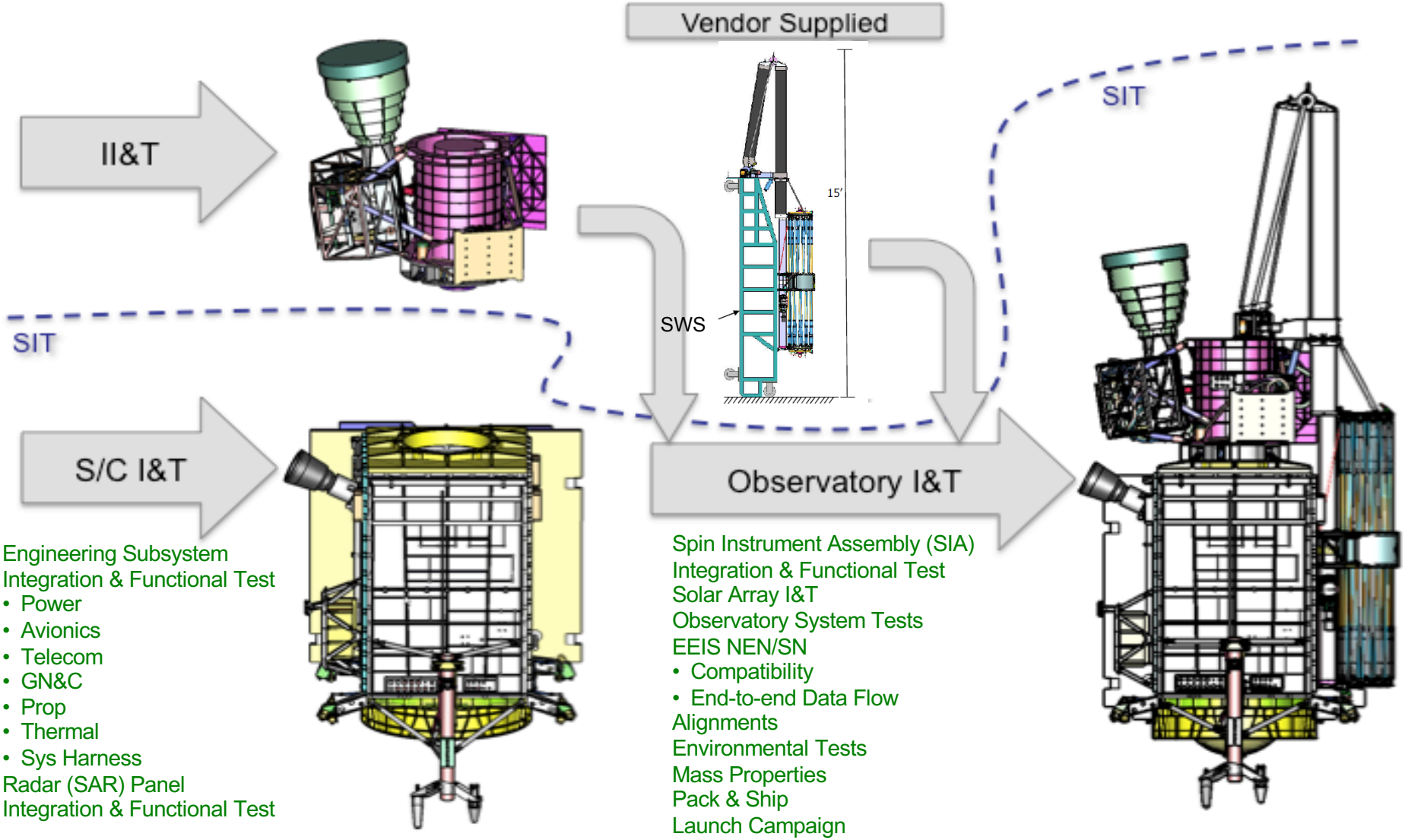
Integration and Test

- A key phase in in this overall cycle is integration and testing (I&T) of each component, each circuit interface and each system prior to sending the spacecraft to the launch site.
- These details are integral throughout the build and testing process that take place in a spacecraft assembly facility clean room as well as in environmental testing facilities.

I&T Approach

- Before the start of integration and test phase, all work flow will have been clearly defined and documented
- Integration plans will have been sufficiently mature for the near-term system integration, and future plans and resources exist for a timely delivery of the remainder
- Test plans will have been sufficiently mature for the near-term testing activities and future plans and resources exist for timely delivery of the remainder
- Integration and test procedures, support equipment and facilities will be ready to execute the integration and test program presented
- The staffing plan is appropriate and personnel have received appropriate training
- Open issues and work remaining are understood and a plan is in place to complete them

System Verification Flow



Spacecraft I&T General Flow

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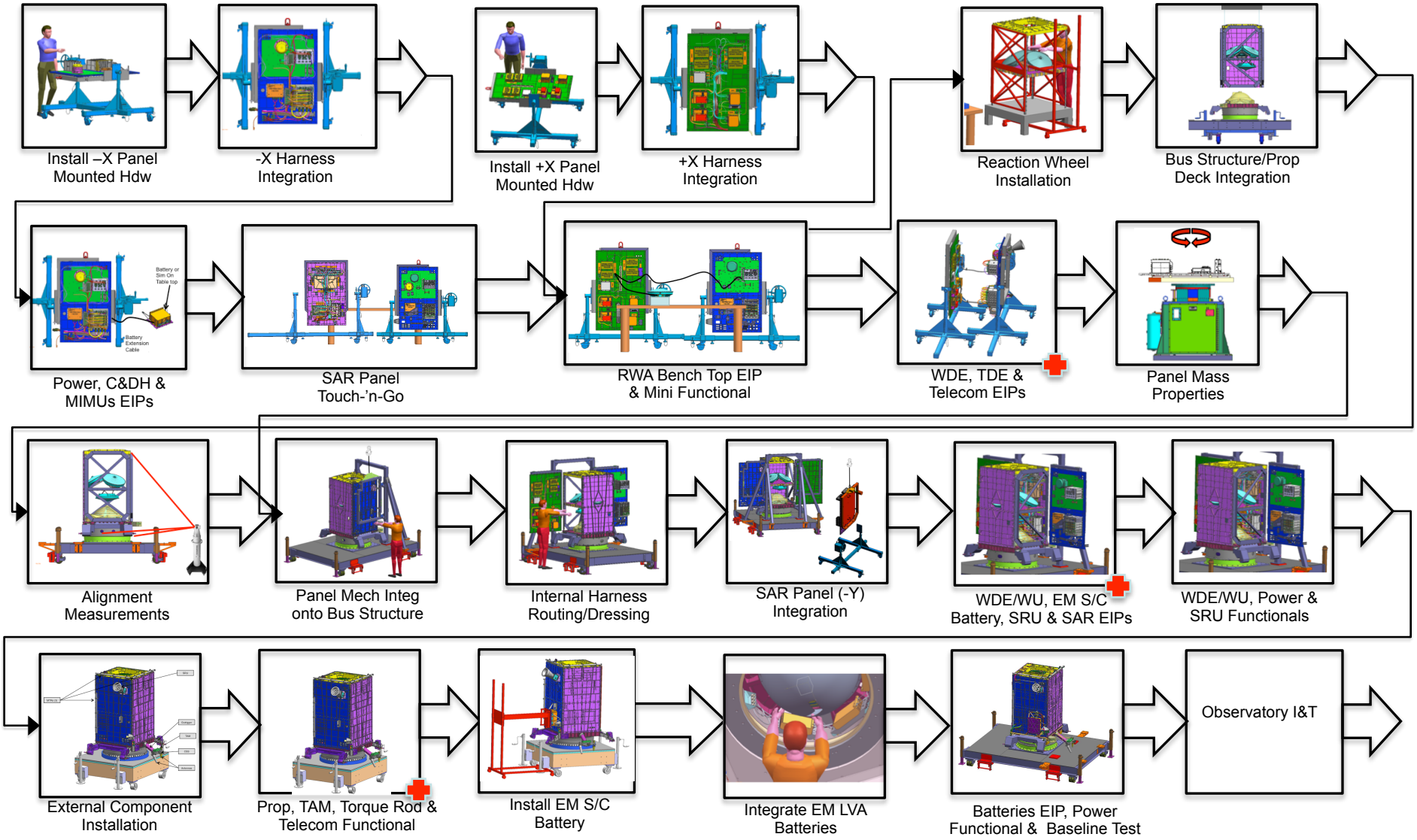
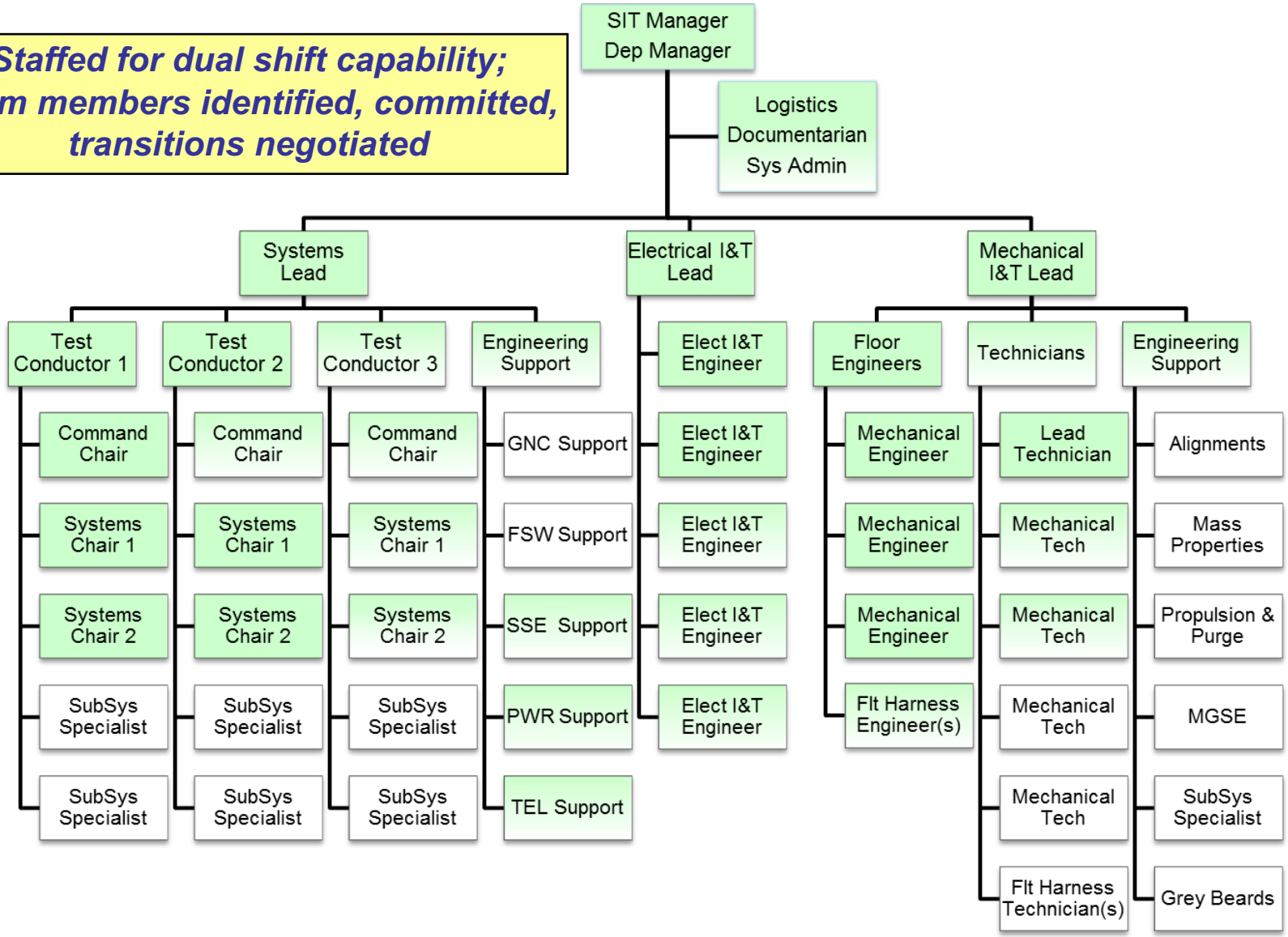
✚ denotes a baseline test

EIP denotes an electrical integration test



Sys I&T Org Chart

Staffed for dual shift capability; Team members identified, committed, transitions negotiated



SMAP I&T

SMAP I&T

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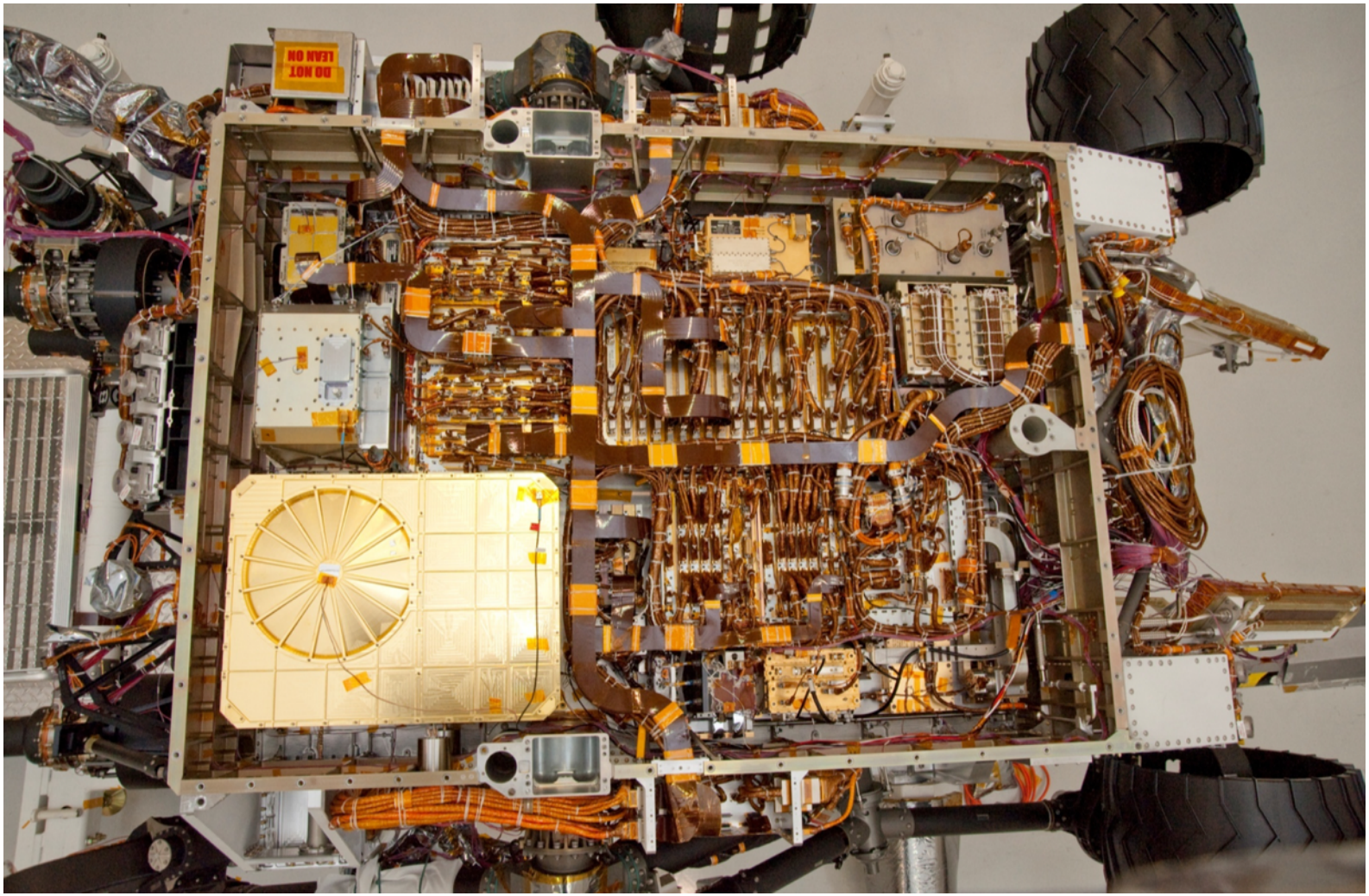
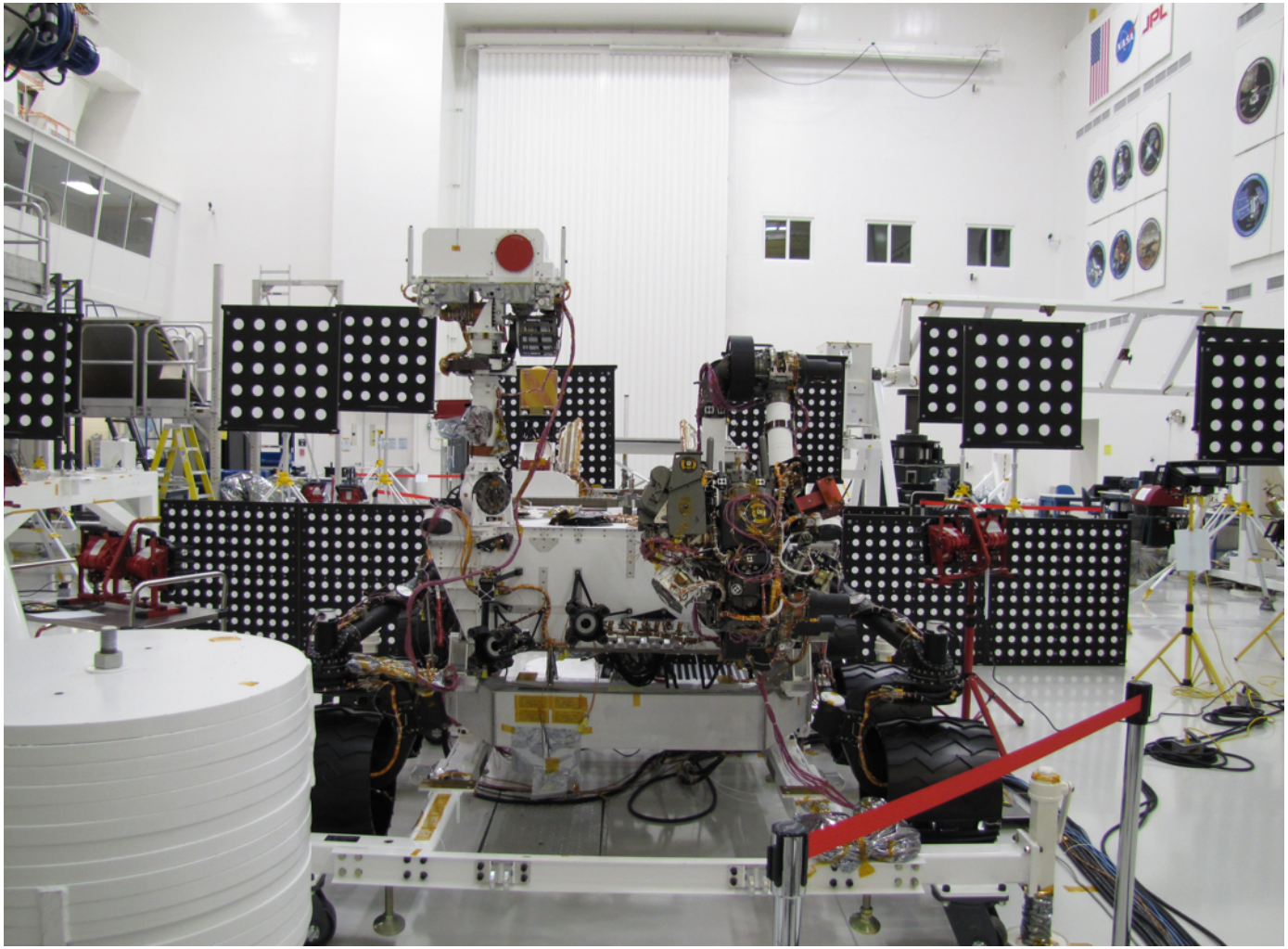
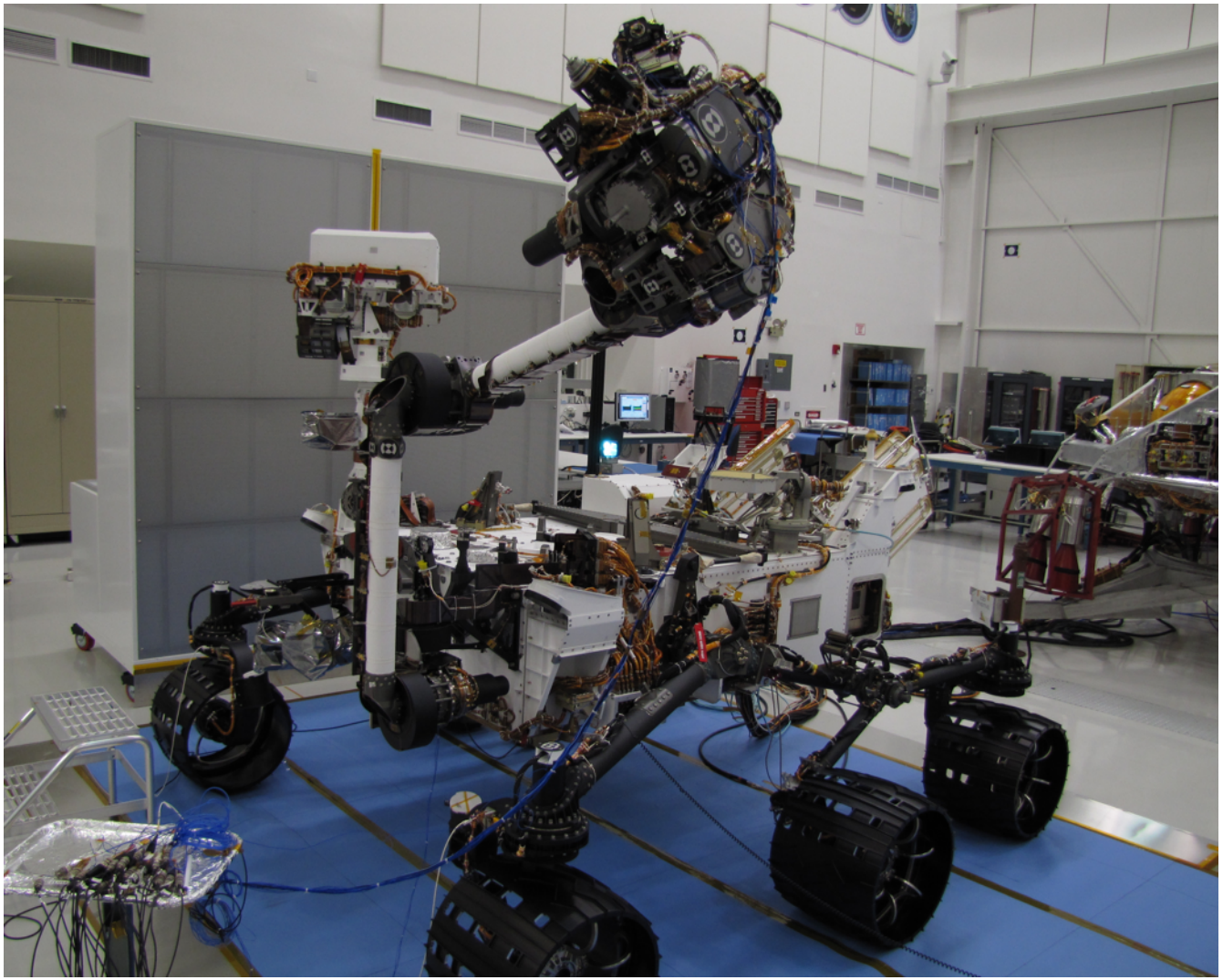
Integration and Test



Mars Science Lab (MSL) Testing



Mars Science Lab (MSL) Testing



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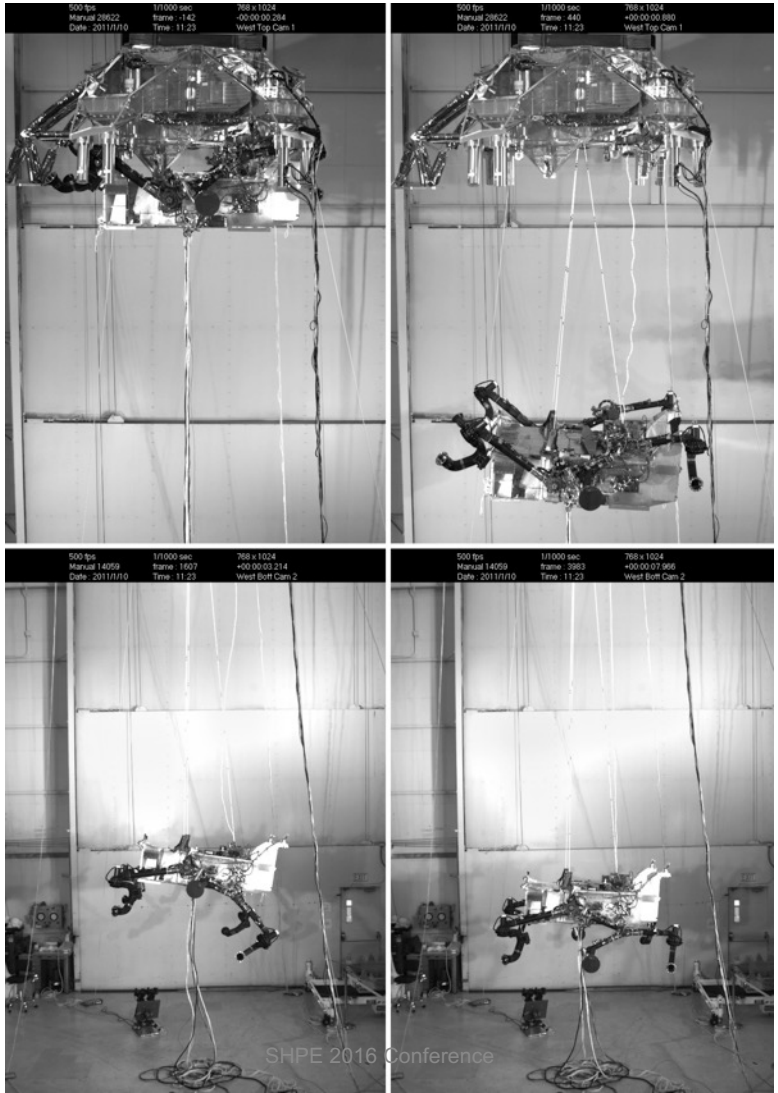
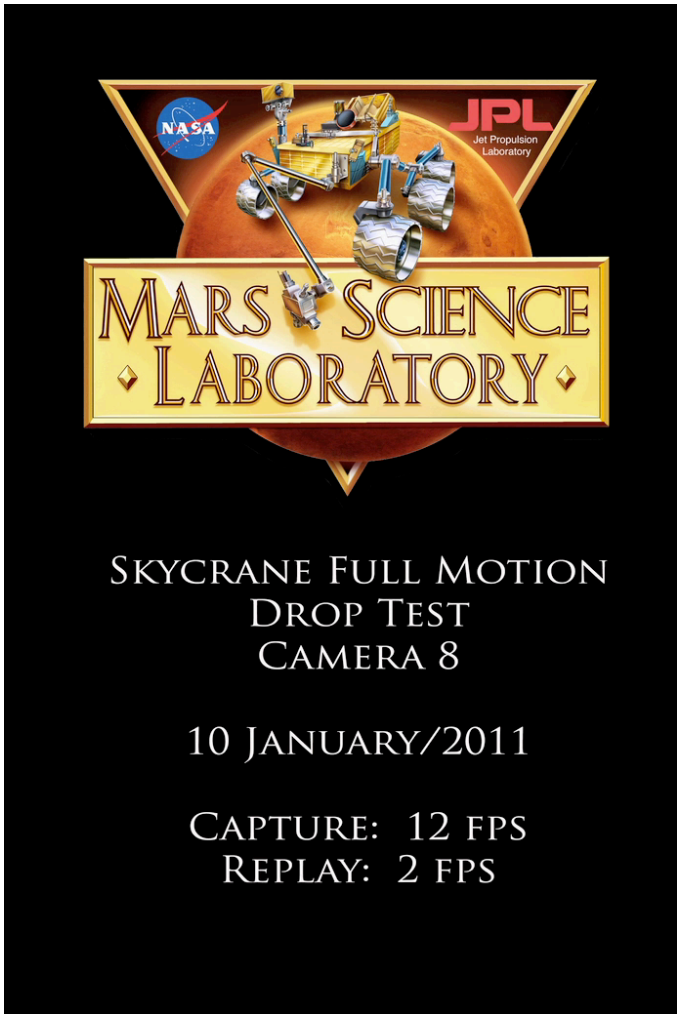
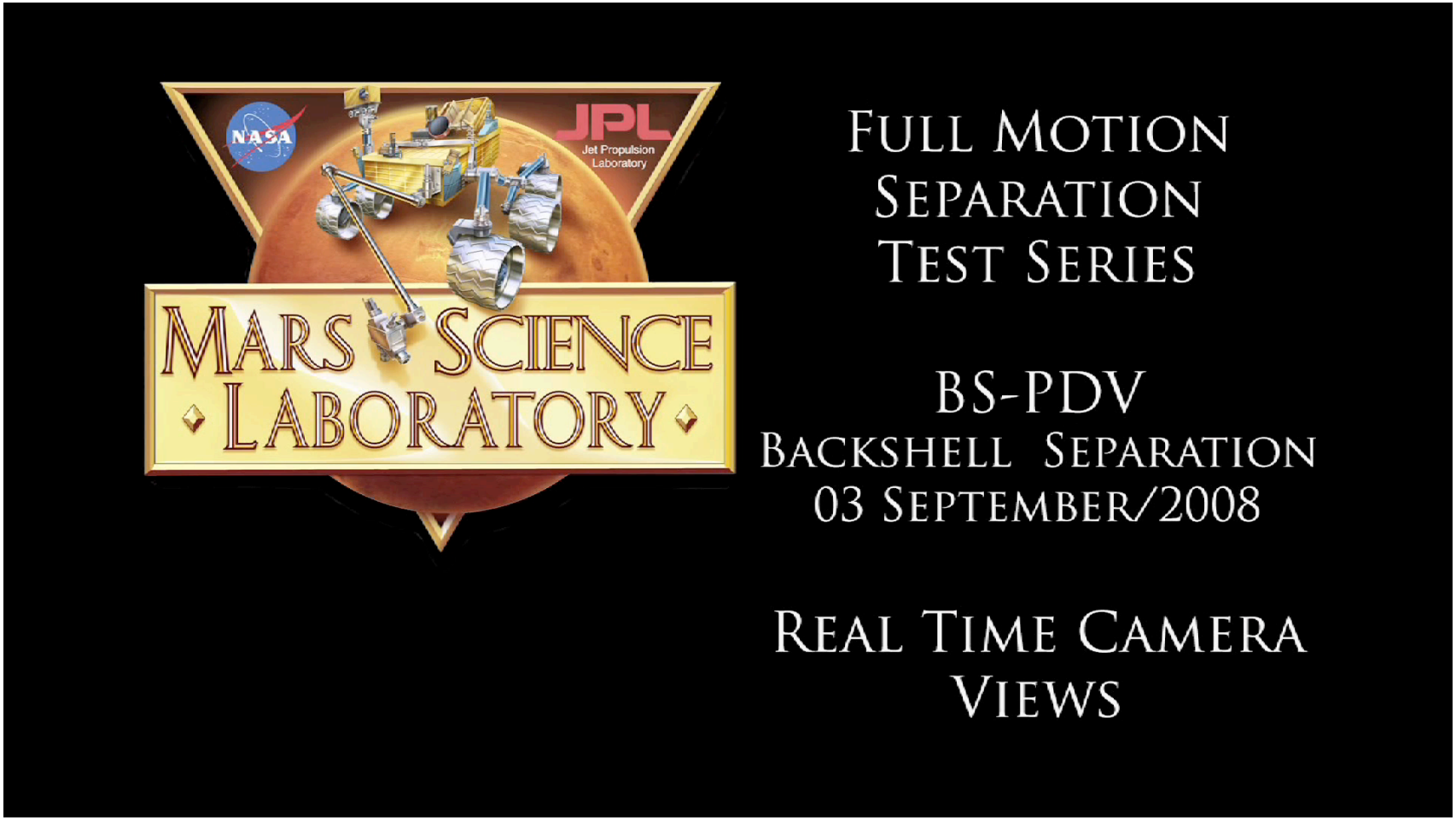


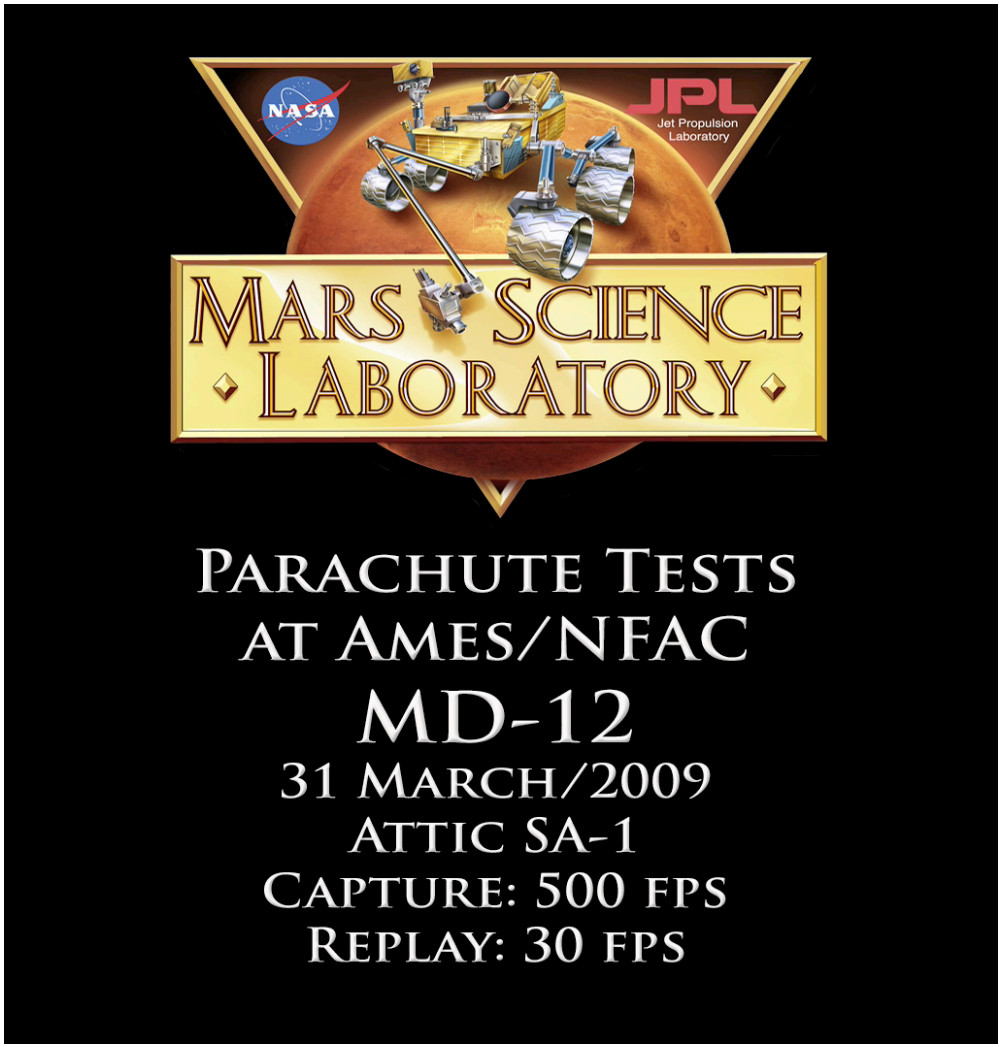
Mars Science Lab (MSL) Testing



Mars Science Lab (MSL) Testing

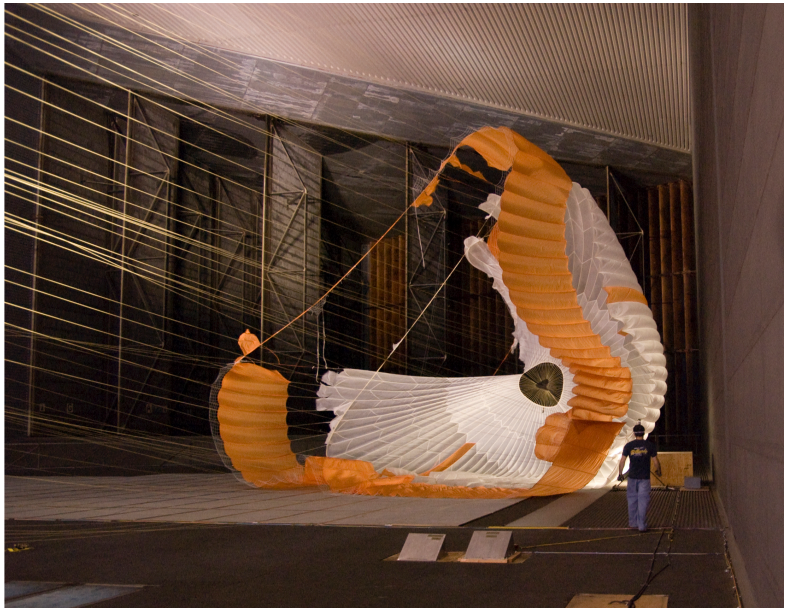


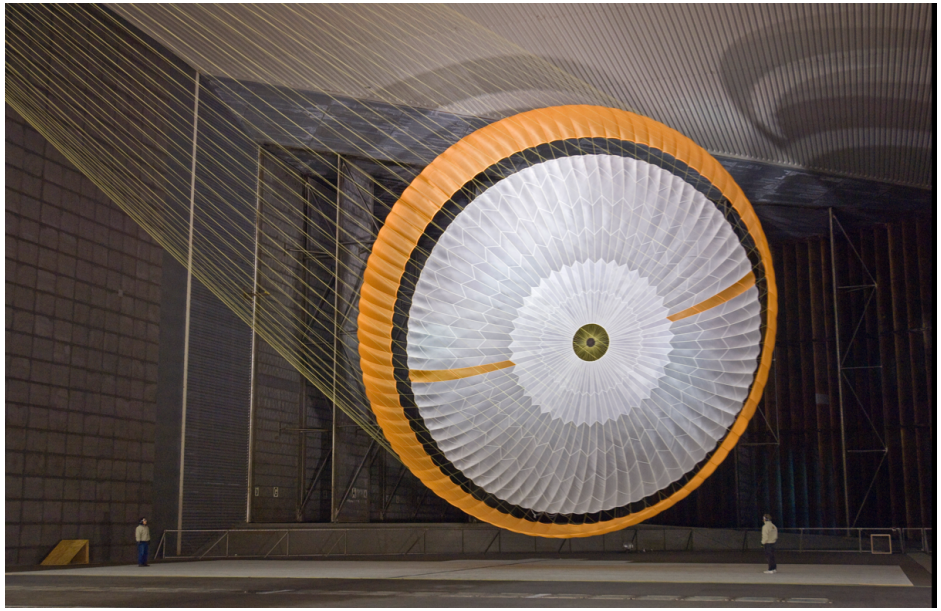
PARACHUTE DEPLOYMENT



Mars Science Lab (MSL) Testing

Constant testing can be the difference between failure and success





Environmental Tests

- The spacecraft environmental testing verification approach is designed around the mission type.
- Testing the mission environments is critical to meeting the mission requirements and the design life of the spacecraft.

Spacecraft Environments that Concern Us:

Concerned with environments throughout the hardware life cycle

- Example: Potential Mars Sample Return – Sample Tubes

  - Identify the environments for:
    - Ground Operations: (Manufacturing, Ground Handling and Test)
    - Launch
    - Cruise
    - Entry Descent and Landing
    - Surface Operations
    - Mars Assent
    - Mars Orbit
    - Possible Earth Return
- Will the environment be a design driver? (3000 g Earth Impact)
- What is the configuration of your hardware at the time it encounters the environment?

Spacecraft Environments that Concern Us

Core Environments for Most Spacecraft Projects

- Dynamics
  - Acoustic Vibration
  - Random Vibration
  - Pyroshock
  - Quasi Static Loads
- Natural Space Environments:
  - Radiation
  - Solid Particles
  - Atomic Oxygen
- Thermal
  - Temperature
  - Pressure (launch pressure decay)
  - Humidity
- EMC:
  - Radiated Emissions
  - Radiated Susceptibility
  - Conducted Emission
  - Conducted Susceptibility
  - Grounding, Bonding

Pass/Fail Criteria

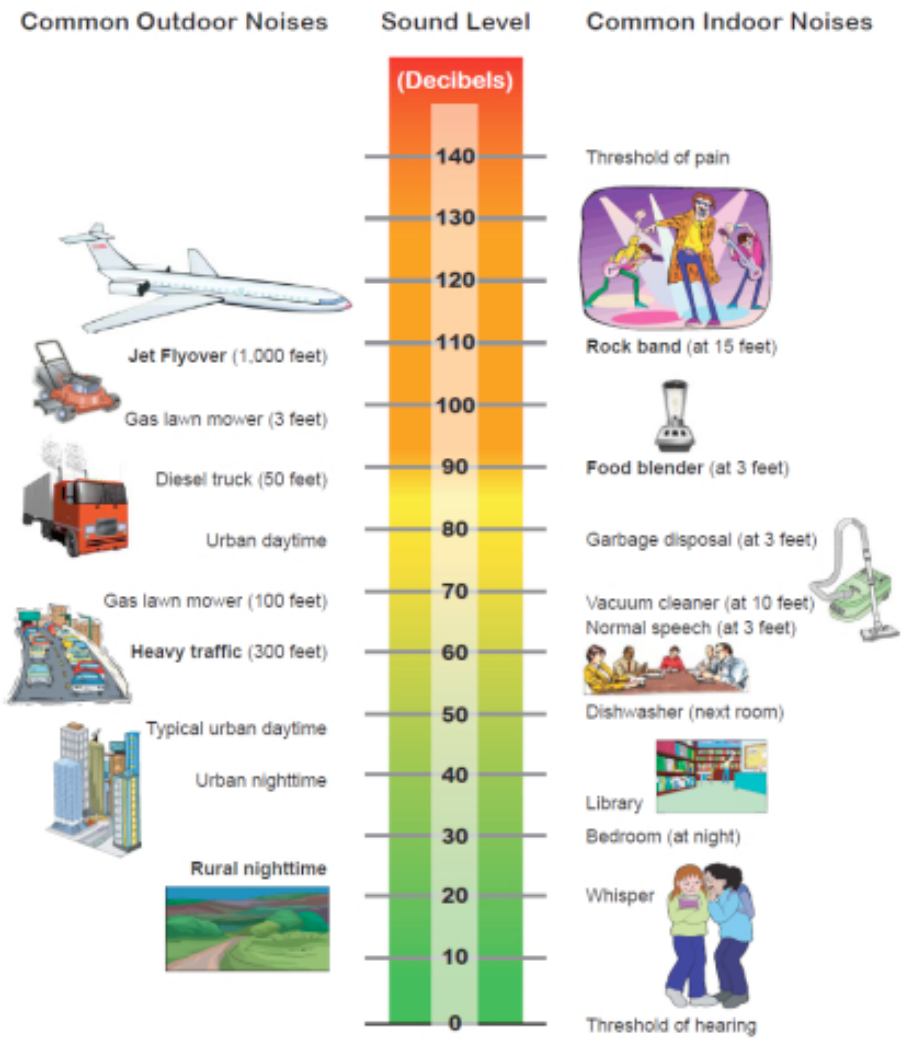
- **Pass:** Test Article performs to specification, with no damage or anomalies during and following formal environmental testing.
- **Fail:** Test Article or flight test equipment ***malfunctions, is physically damaged or exhibits out-of-specification or anomalous performance*** during or following an environmental test.

Typical Dynamic Sources

- Acoustic Noise
  - Rocket Engine Noise
  - Aerodynamic Noise
  - Transmission/Internal Cavity Effects
- Random Vibration
  - Acoustically Excited
  - Base Drive from Launch Vehicle
- Shock (Pyrotechnic)
  - Pyro Separation Devices
- Sine Vibration
  - Booster Transients

Mars Science Lab (MSL) Environmental Testing – Acoustics

- ACOUSTICS TEST
  - Captures High Frequency Excitation generated at launch.

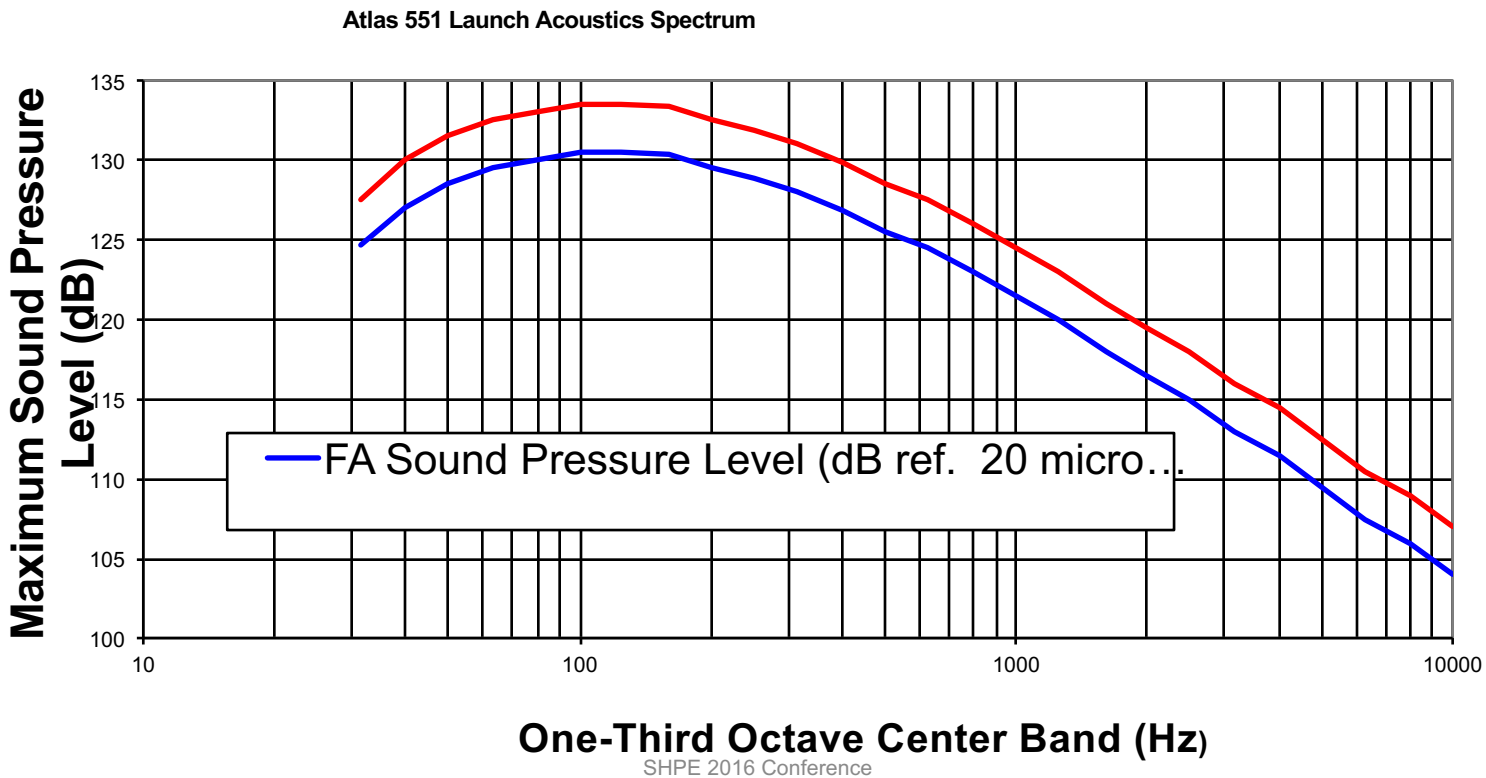


How Dynamic Requirements are Generated

Acoustic Environment:

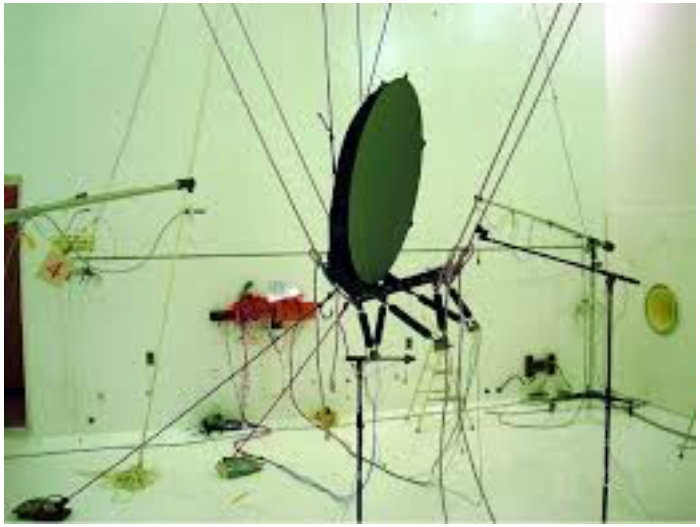
The acoustic environments comes directly from the Launch Vehicle Payload Users Guide

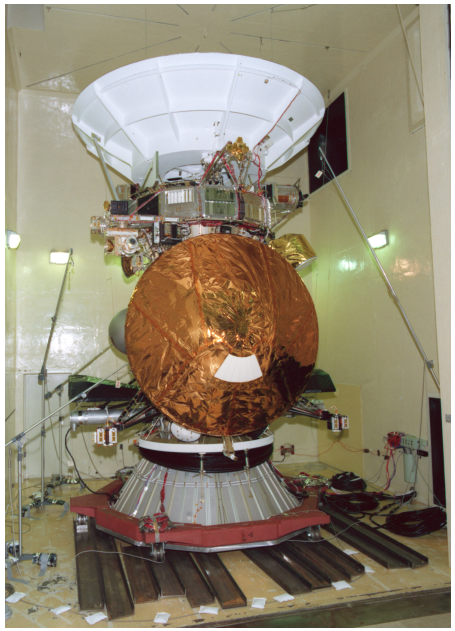
This applies for both Assembly and System level testing.



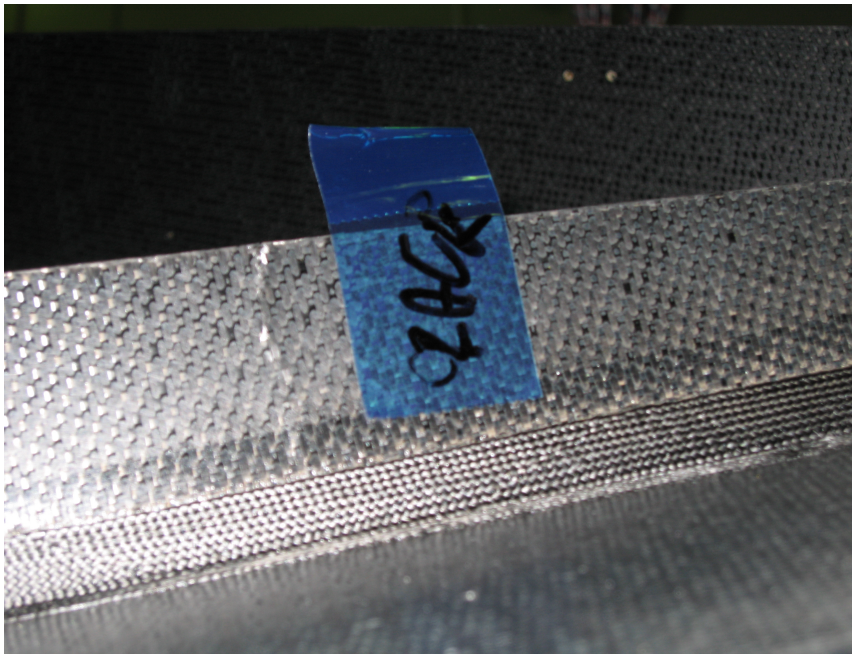
Typical Environmental Testing - Dynamics

Acoustics Testing





Crack in Aquarius Antenna After Acoustic Test



Mars Science Lab (MSL) Environmental Tests - Acoustics

MSL Undergoing Acoustic Testing Inside Test Chamber

Loud Speakers

Microphones To Measure Acoustic Levels

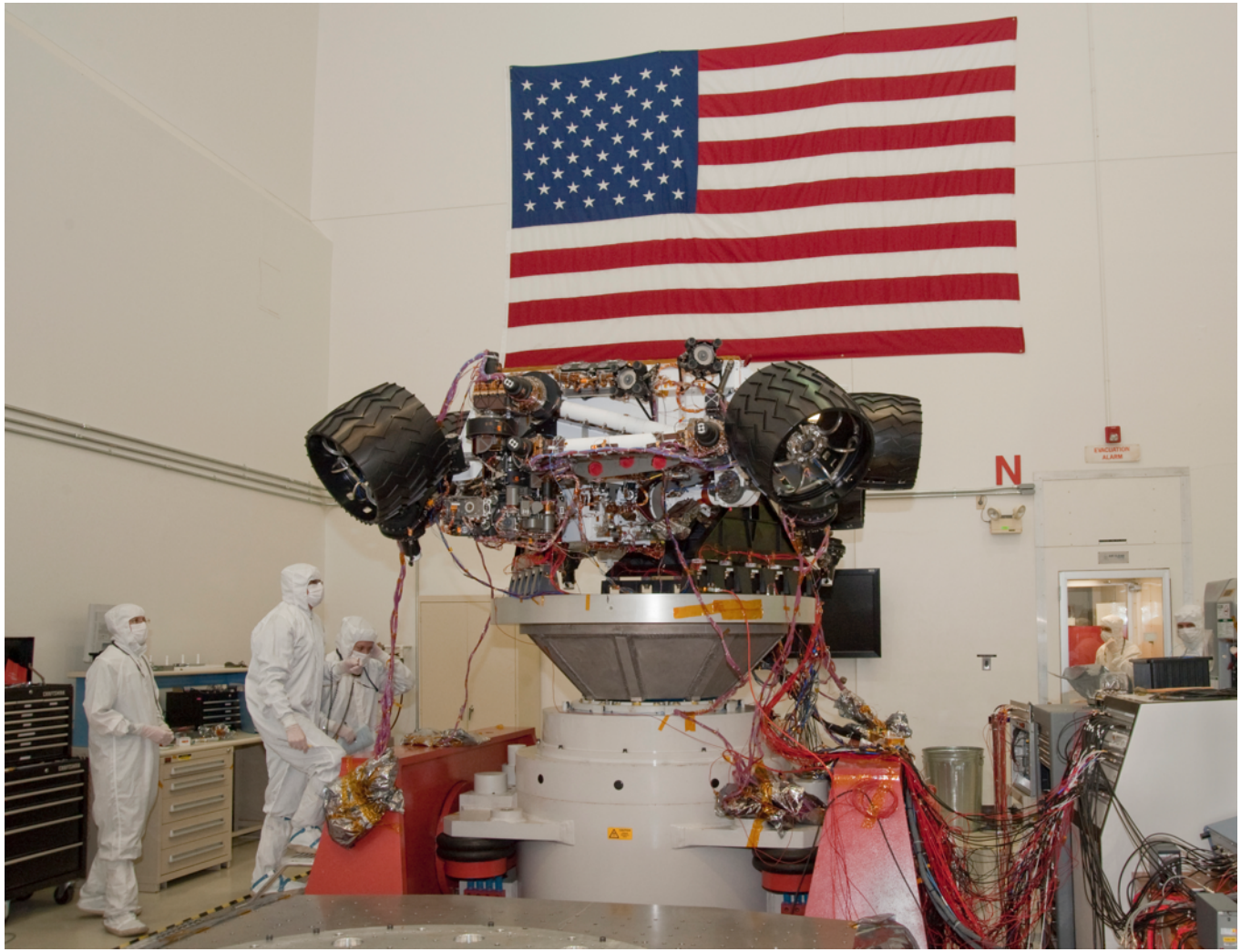
Mars Science Lab (MSL)
Environmental Testing – Random Vibration

- RANDOM VIBRATION TEST
  - Captures Low Frequency Excitation coming from LV Interface and is a workmanship test for all secondary hardware.

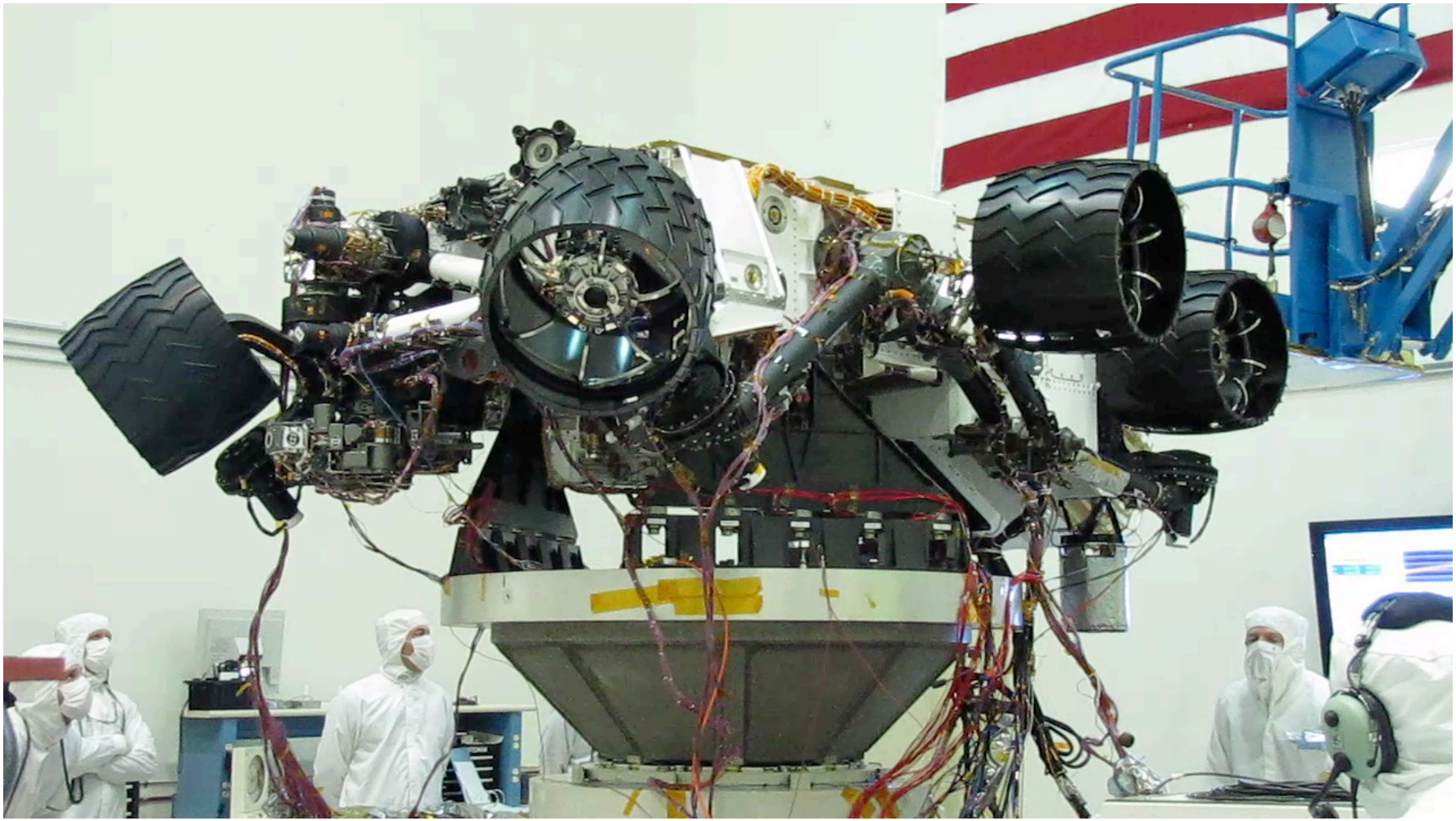
Typical Environmental Testing - Dynamics

Vibration Testing

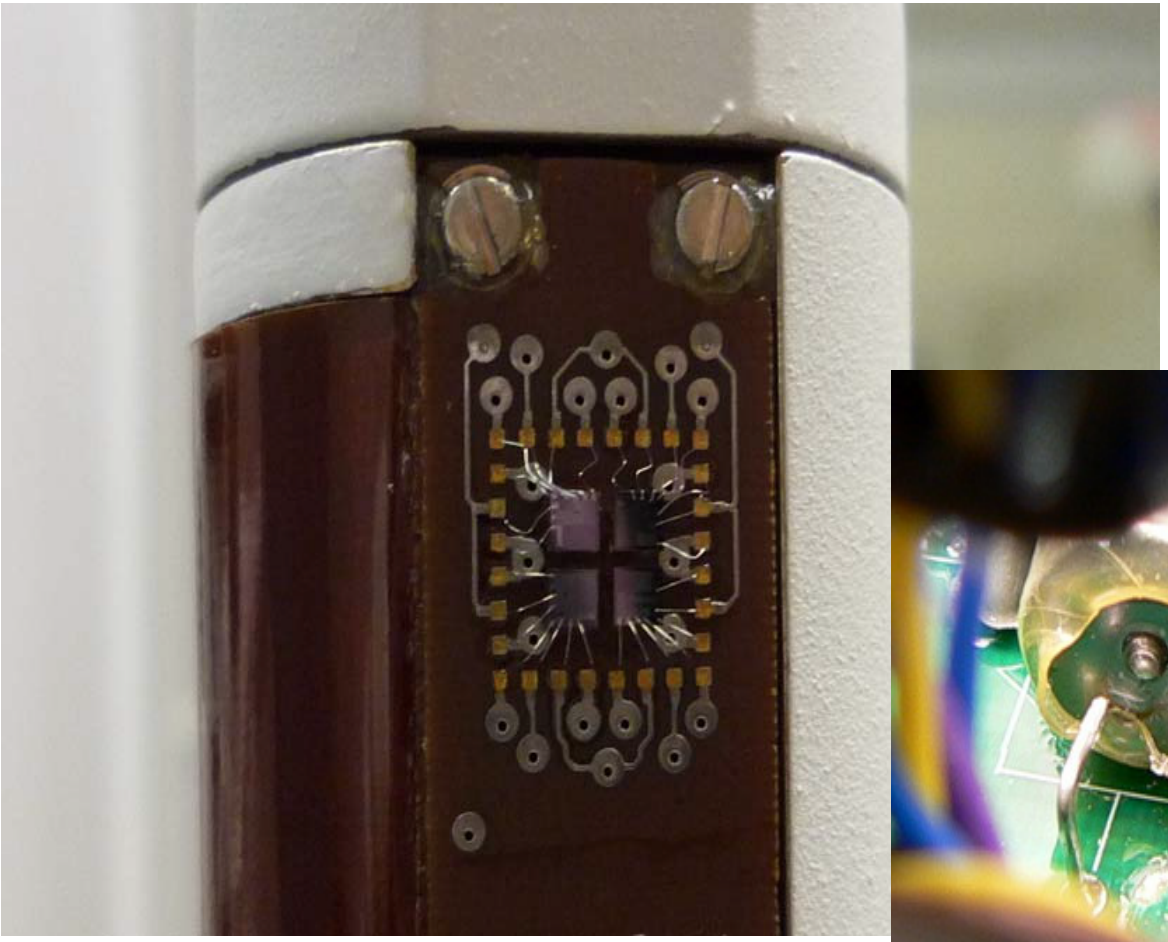
Mars Science Lab (MSL) Environmental Tests - Vibration

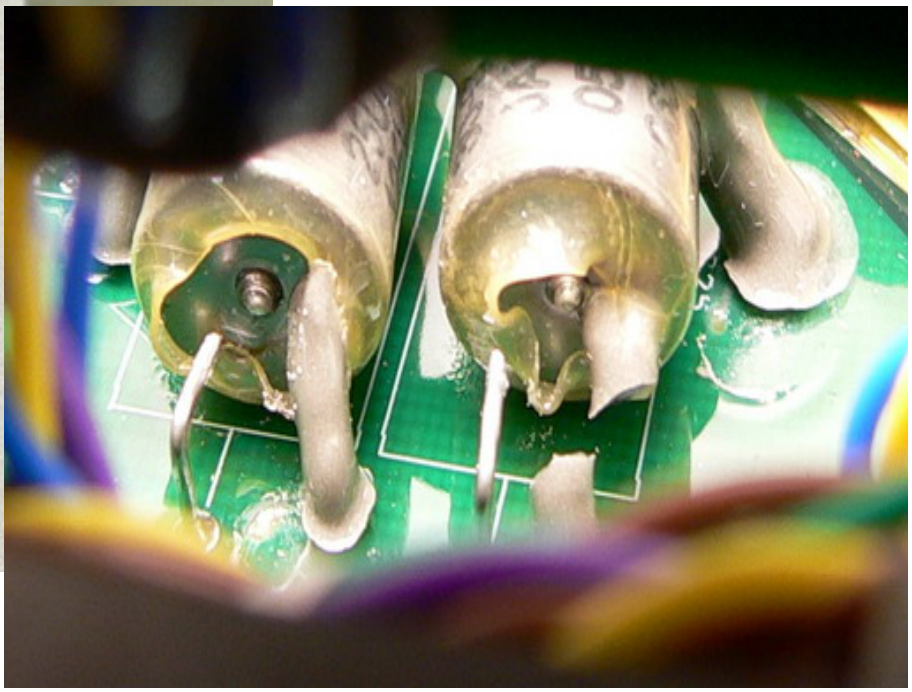


Mars Science Lab (MSL) Environmental Tests - Vibration



MSL REMS Wire Bond and MEDLI Capacitor Failures after Random Vibration

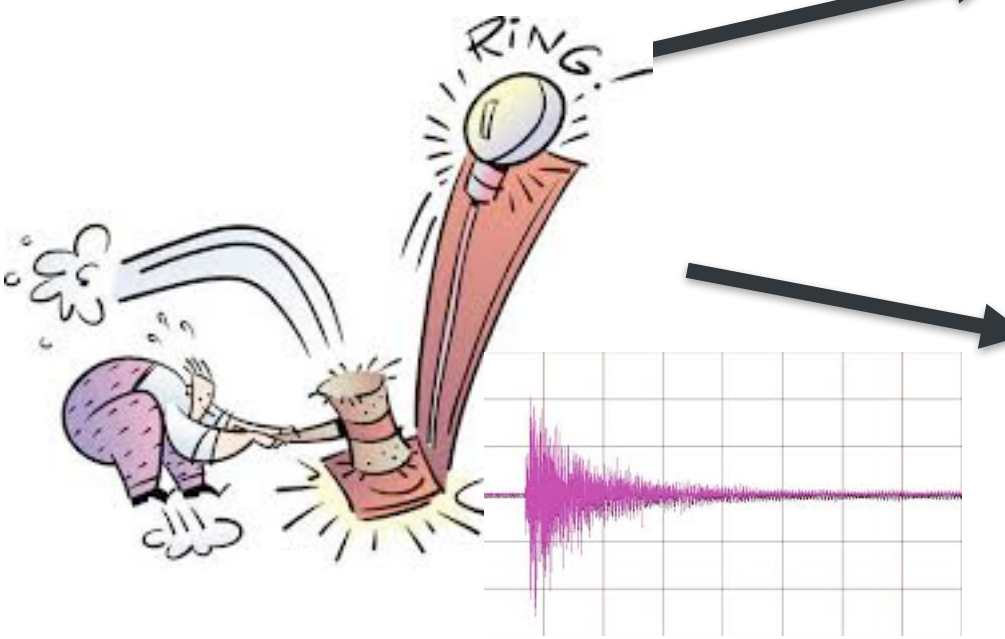


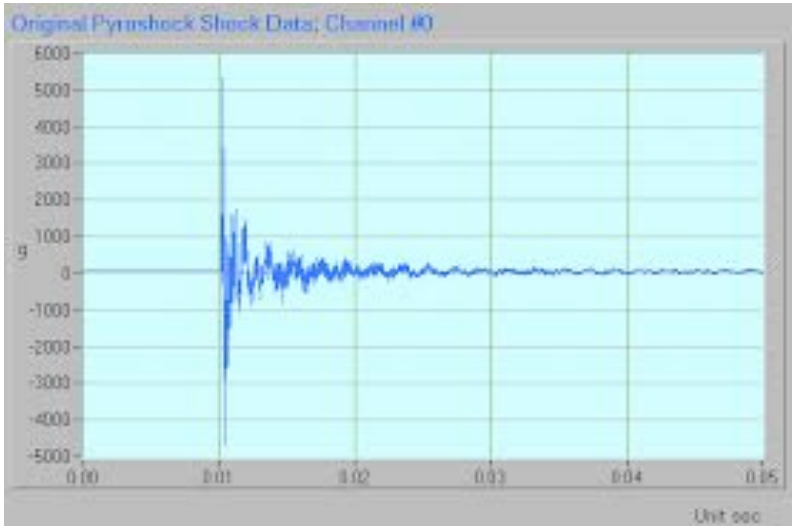


Mars Science Lab (MSL) Environmental Testing – Pyro Shock

Shock Testing

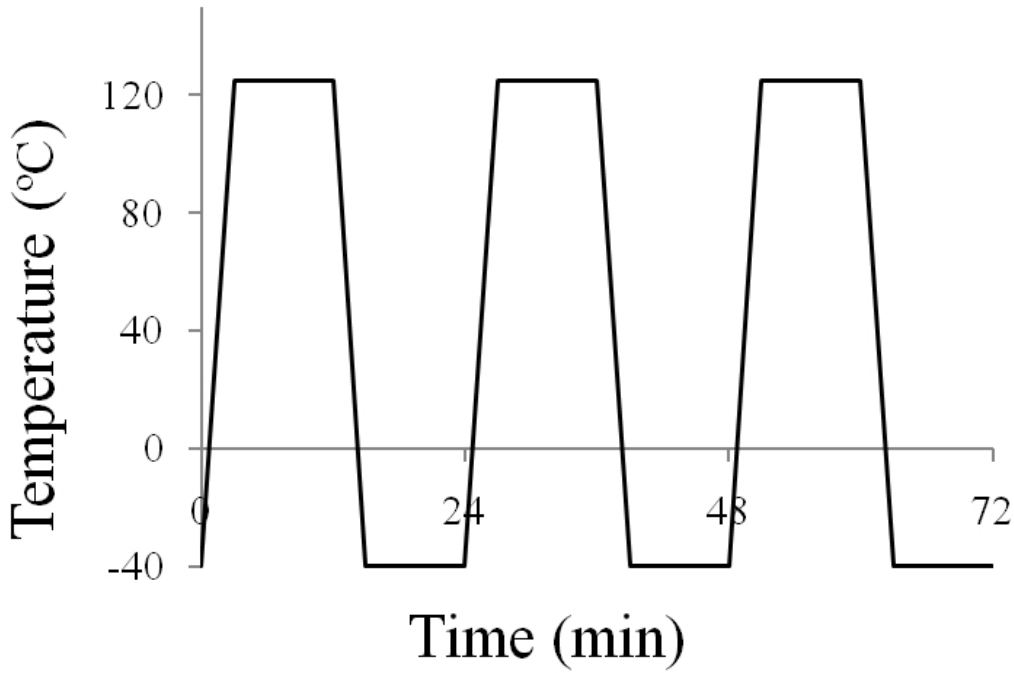
- PYROSHOCK TEST
  - Captures shock from LV release & all pyro firings.
  - Also demonstrates first motion of all separations.





Thermal Testing

- SOLAR THERMAL VACUUM (STV) TEST
  - Verify Thermal Model with Thermal Balance Testing
  - Verify Full System Functionality in a Hot state and a Cold state.



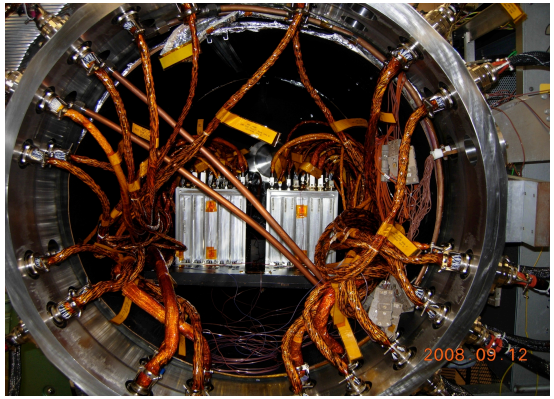
Typical Environmental Testing - Thermal

Freezer

Cold Temp Testing

Oven

Hot Temp Testing



Temperature Table (Example)

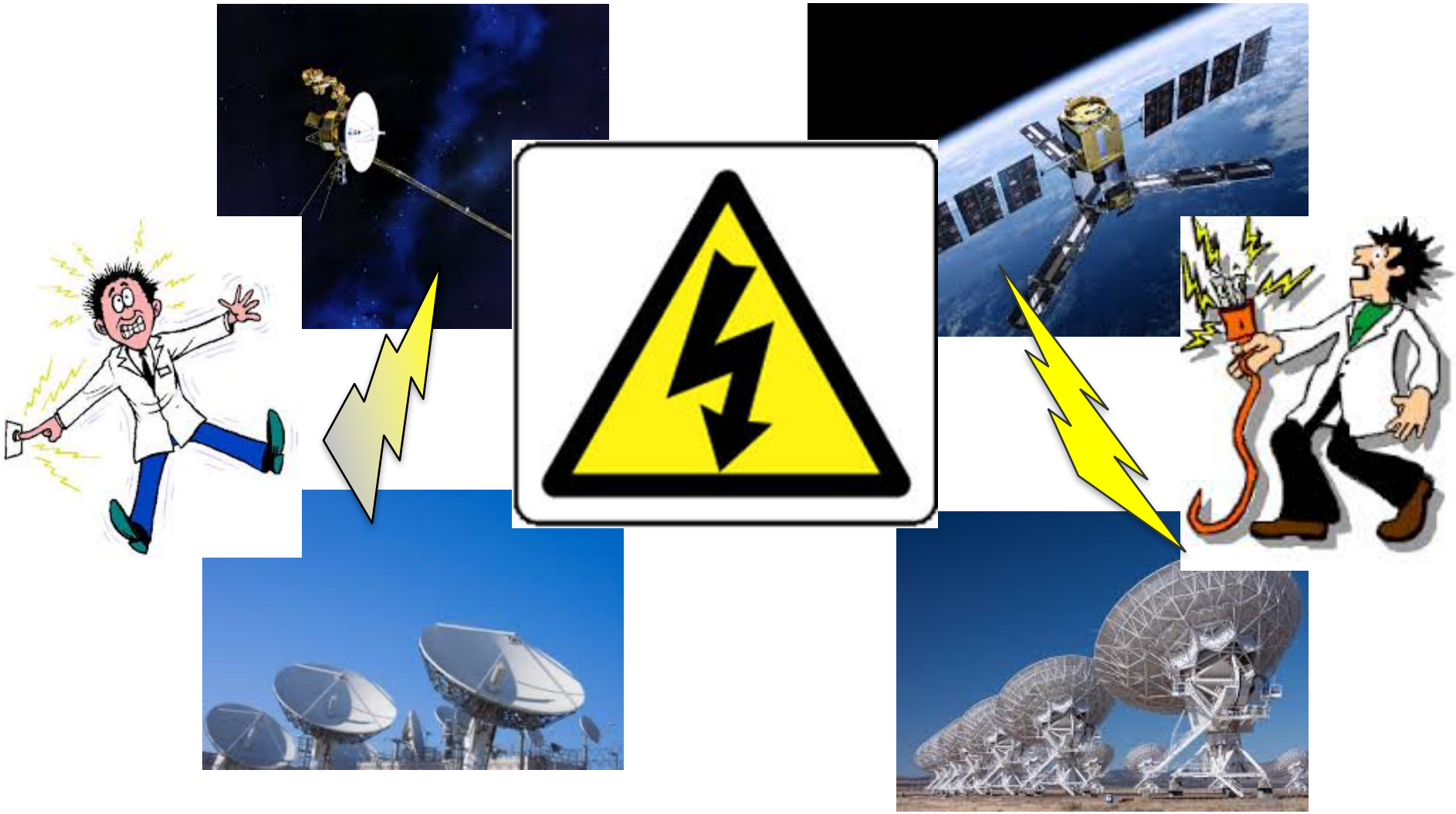
Assembly Name	Allowable Flight OP	Allowable Flight Non-Op	Flight Acceptance OP	Flight Acceptance Non-Op	Qual/PF OP	Qual/PF, Non-O
Avionics Assembly	-20C / +50C	-30C / +50C	-25C / +55C	-35C / +55C	-35C / +70C	-45C / +70C
Science Instrument	0C / +35C	-20C / +35C	-5C / +40C	-25C / +40C	-15C / +55C	-35C / +55

Mars Science Lab (MSL) Environmental Tests Thermal Vacuum

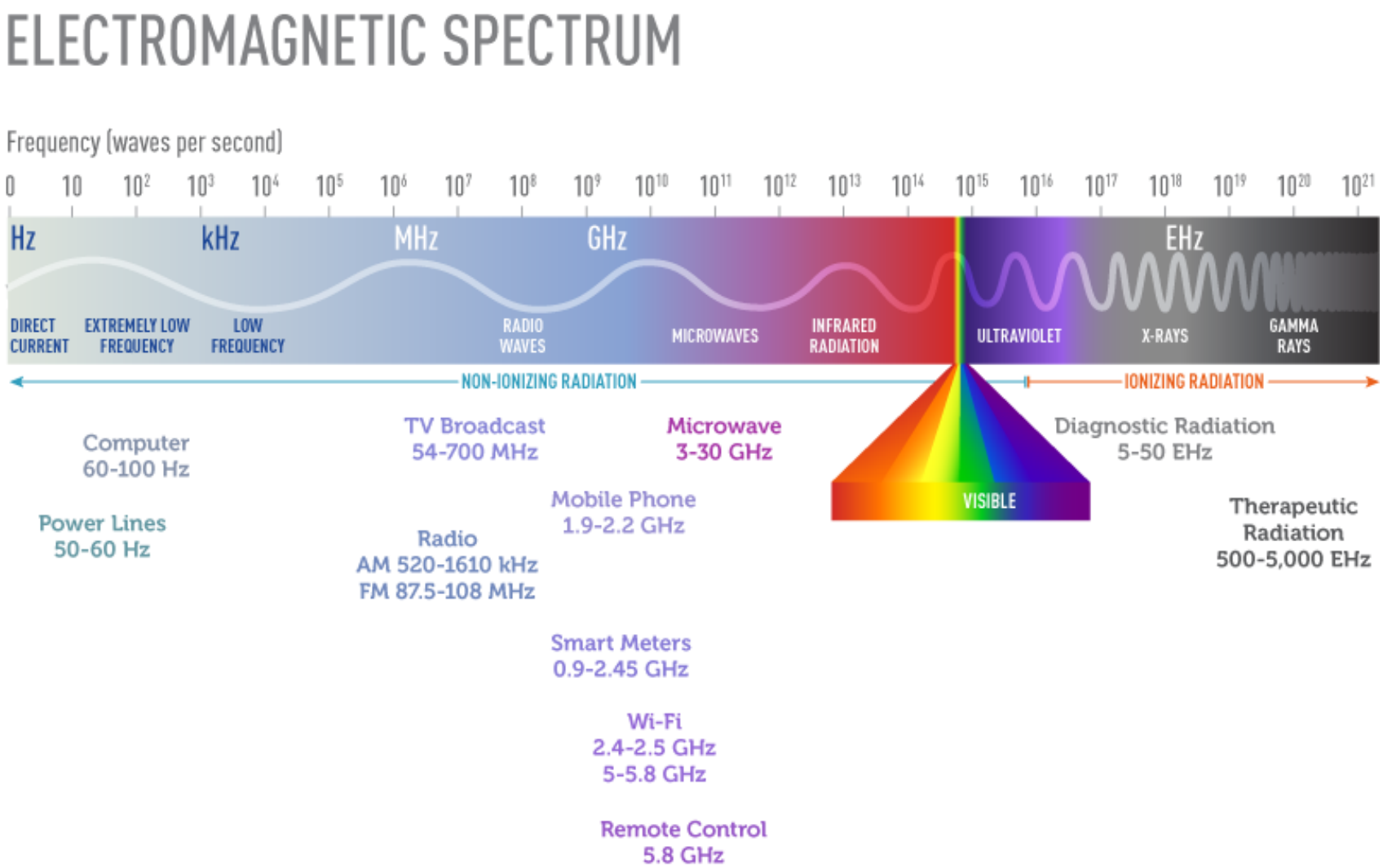
Mars Science Lab (MSL)
Environmental Tests - Thermal Vacuum

Rover Curiosity Inside Thermal Vacuum Chamber Prior To Testing

Mars Science Lab (MSL) Environmental Testing - EMI/EMC



Mars Science Lab (MSL) Environmental Testing - EMI/EMC



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Environmental Testing - Electromagnetics

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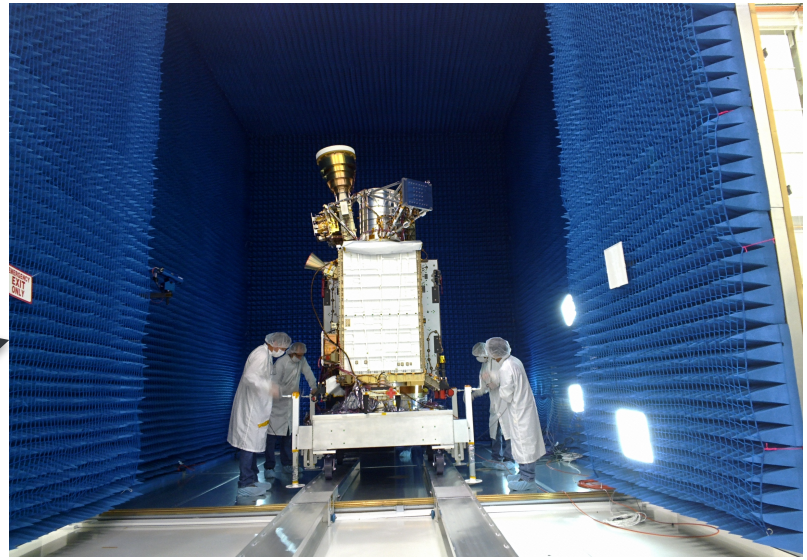
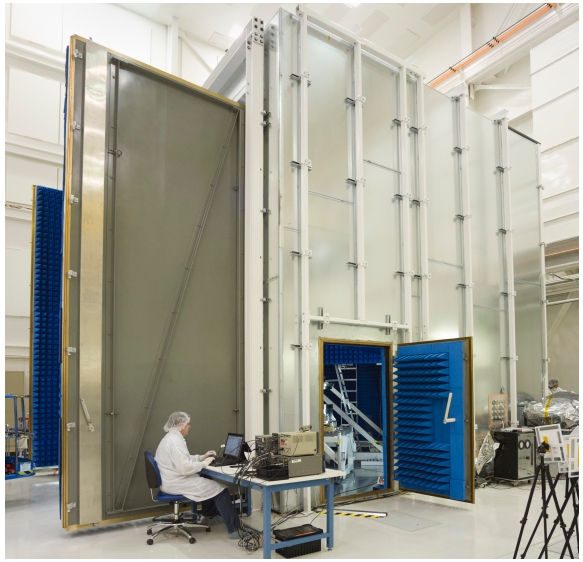
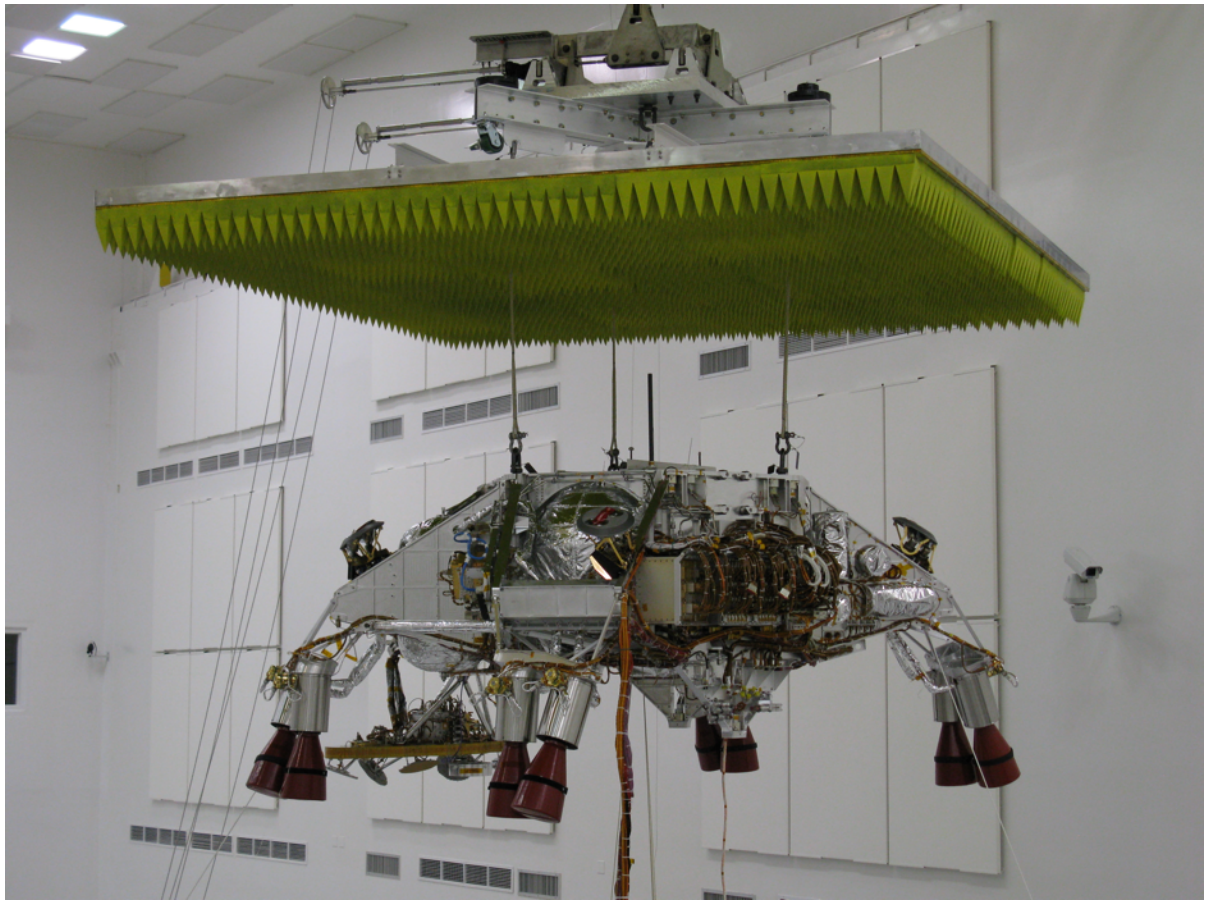
Microwave (RF)
Exposure Testing





Mars Science Lab (MSL)
Environmental Tests - Electromagnetic Compatibility



Mars Science Lab (MSL)
Environmental Tests - Electromagnetic Compatibility

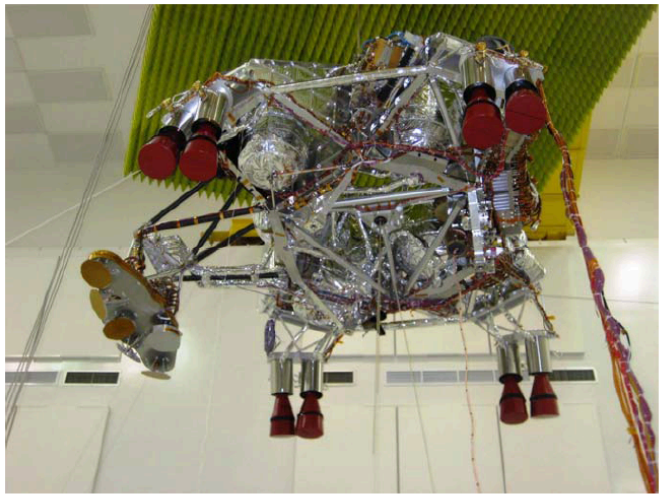


Figure 25, EDL Skycrane at testing position (TDS about 18 ft up)

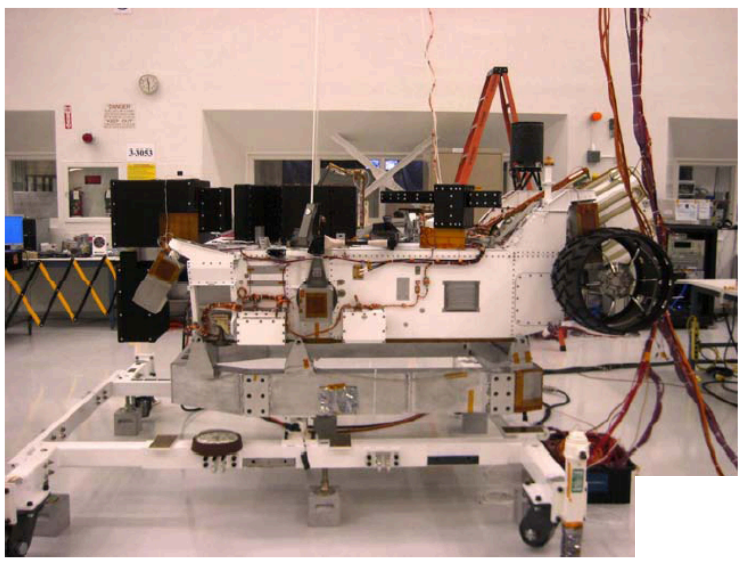
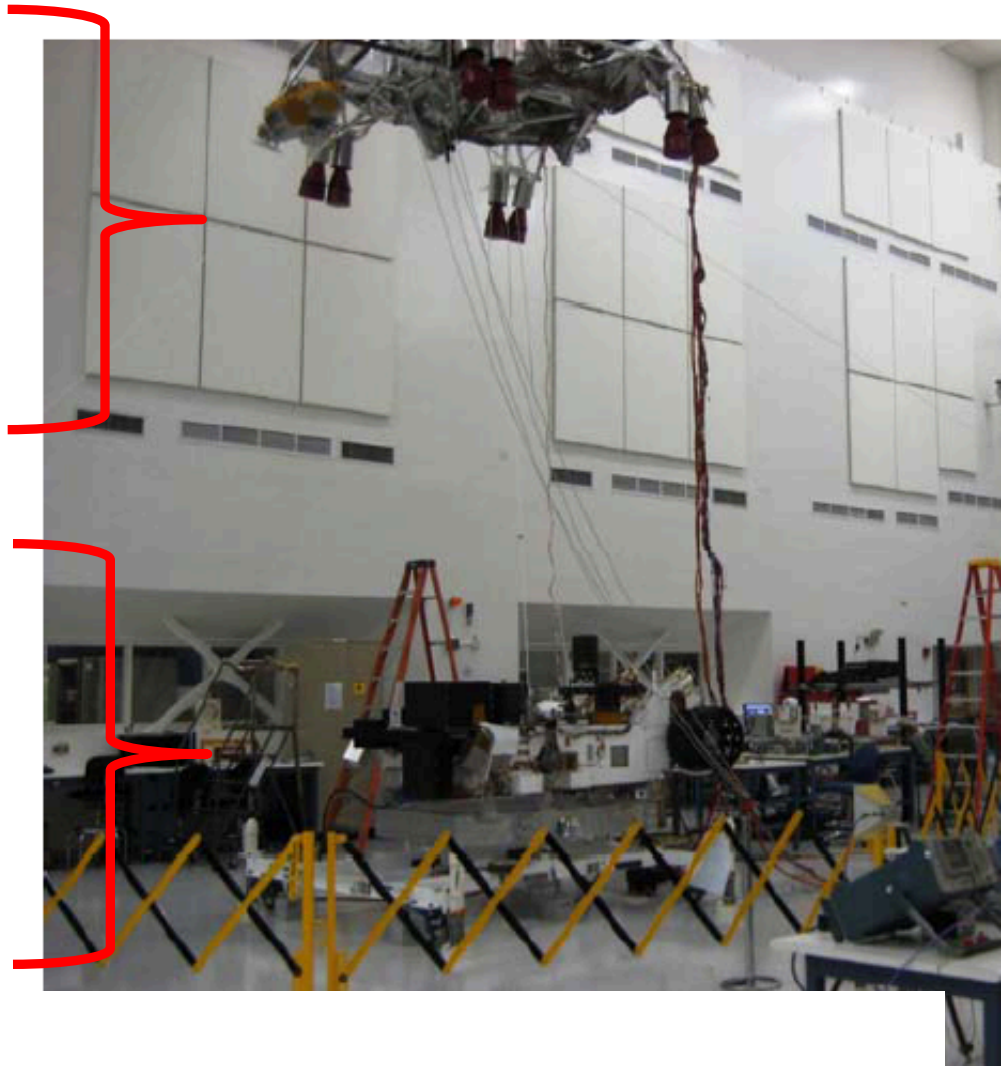


Figure 24, Rover positioned below Skycrane



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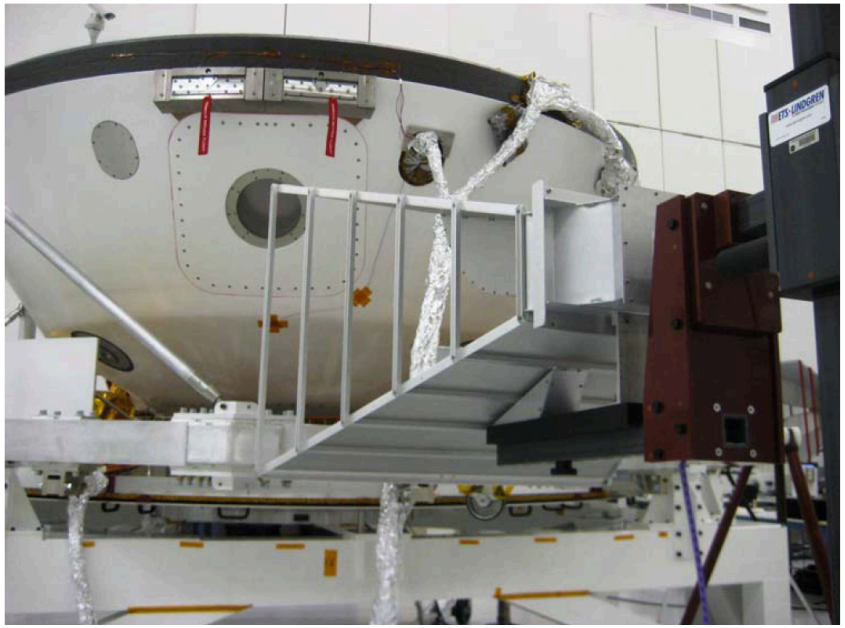
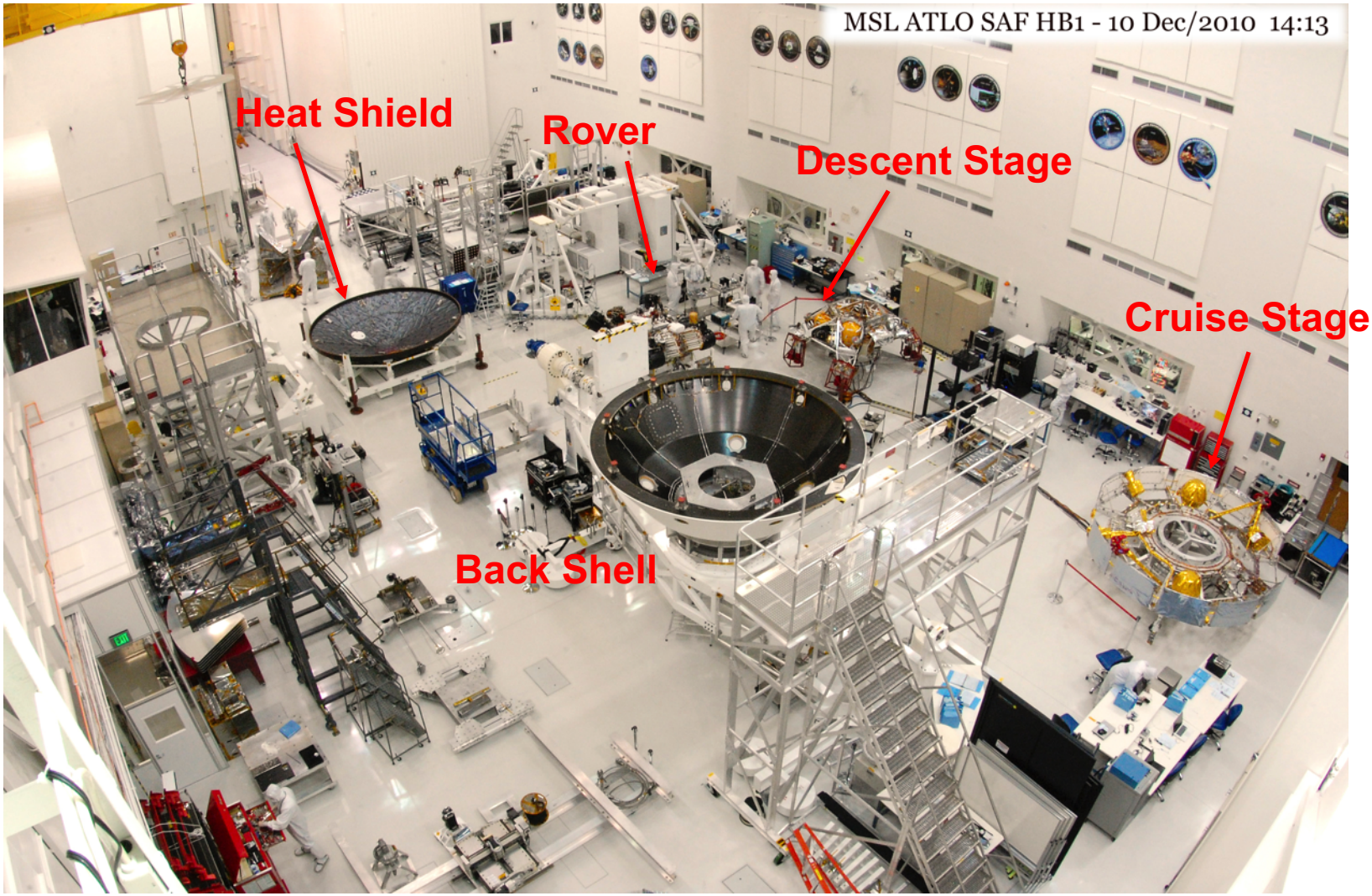
MSL Rover EMC Test

Launch/Cruise System Level EMI/EMC Test



Mars Science Lab (MSL) Final ATLO Phase At JPL



2010

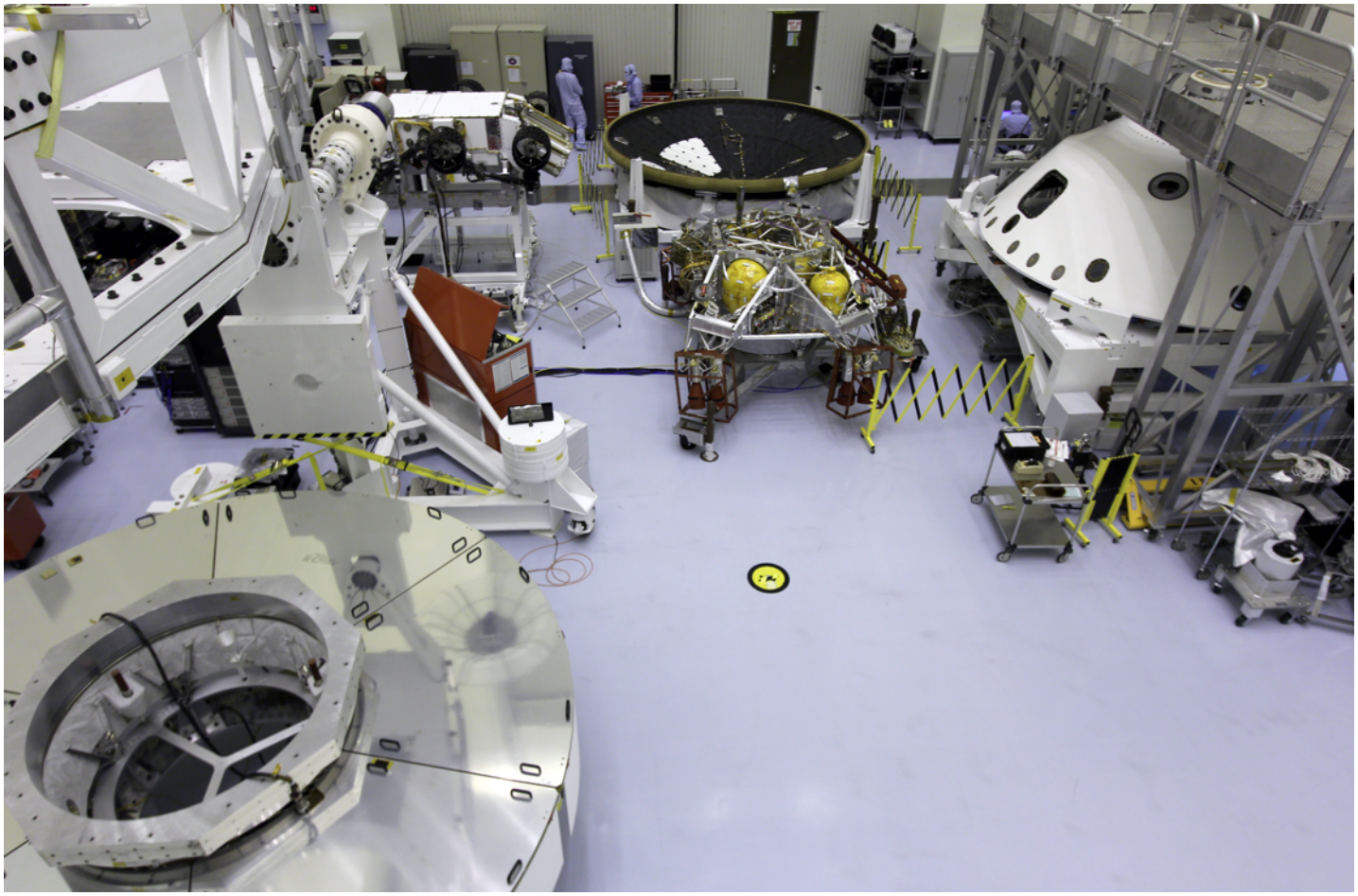
Mars Science Lab (MSL) Shipping To Launch Site

Mars Science Lab (MSL)
Shipping to Launch Site - KSC

Mars Science Lab (MSL)
Shipping To Launch Site - KSC

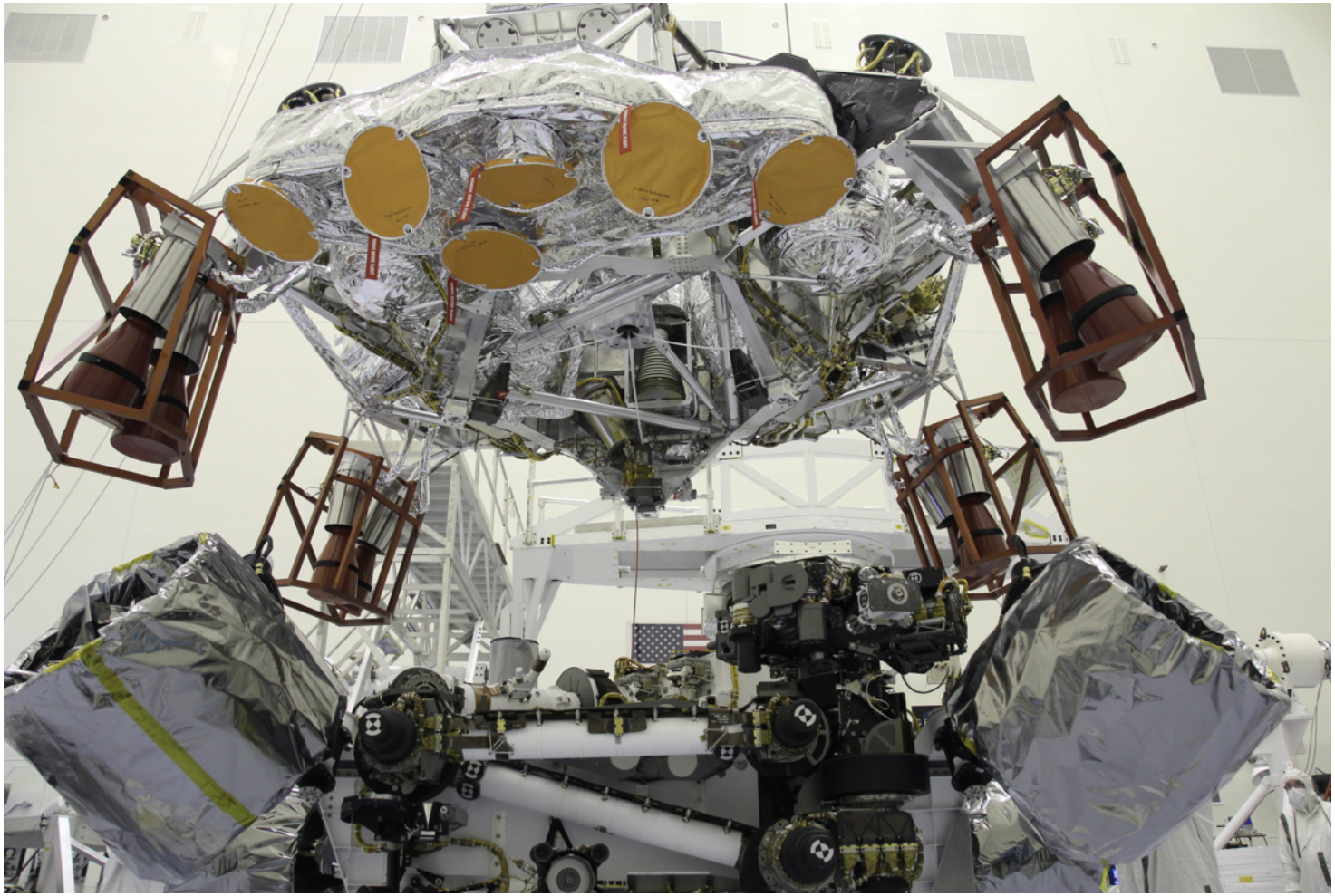
Mars Science Lab (MSL) Launch ATLO - KSC

Kennedy Space Center (KSC), Cape Canaveral, Florida



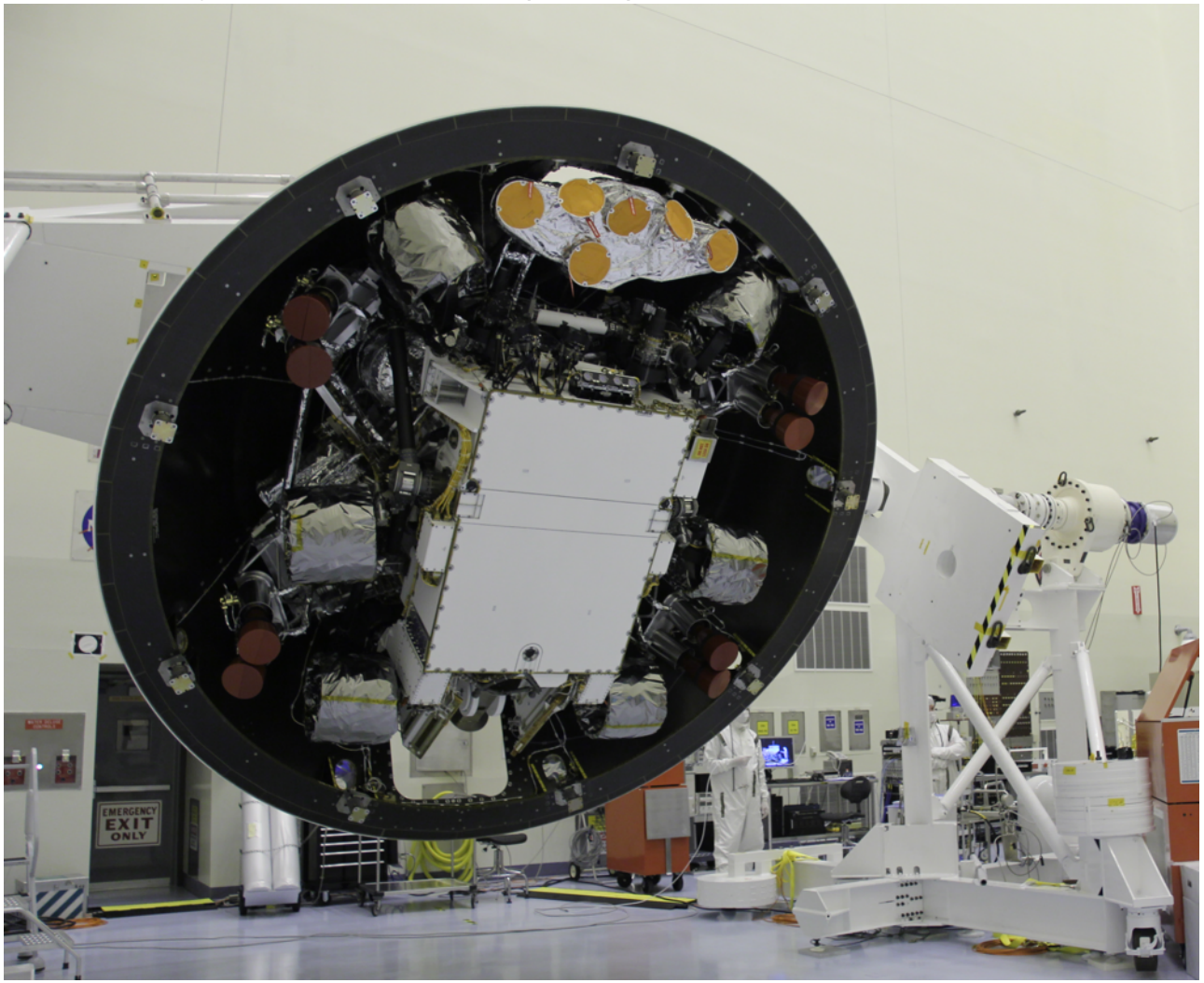
Mars Science Lab (MSL) Launch ATLO

Kennedy Space Center (KSC), Cape Canaveral, Florida



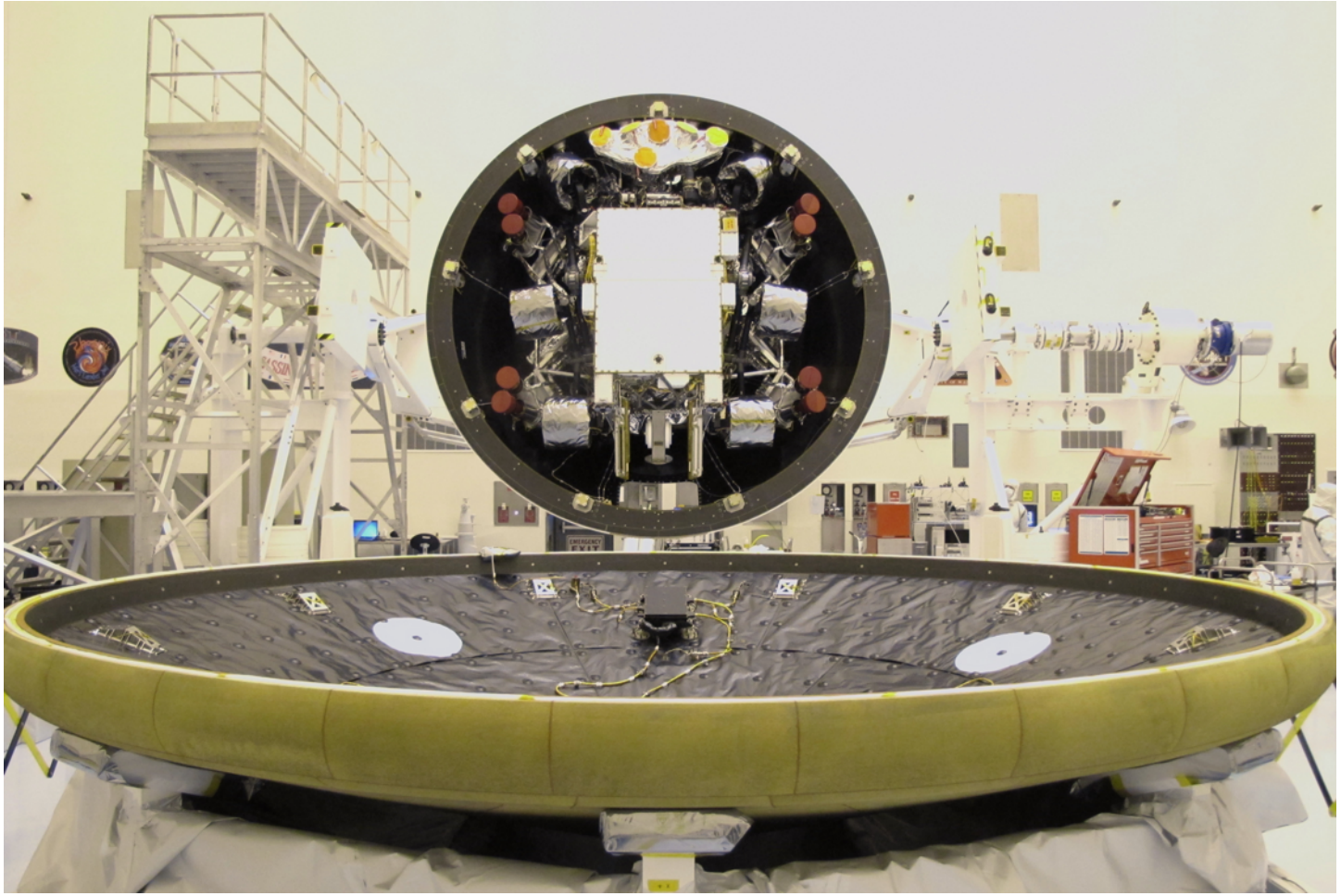
Mars Science Lab (MSL) Launch ATLO

Kennedy Space Center (KSC), Cape Canaveral, Florida



Mars Science Lab (MSL) Launch ATLO

Kennedy Space Center (KSC), Cape Canaveral, Florida



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Mars Science Lab (MSL) Launch ATLO

Kennedy Space Center (KSC), Cape Canaveral, Florida

Payload Fairing

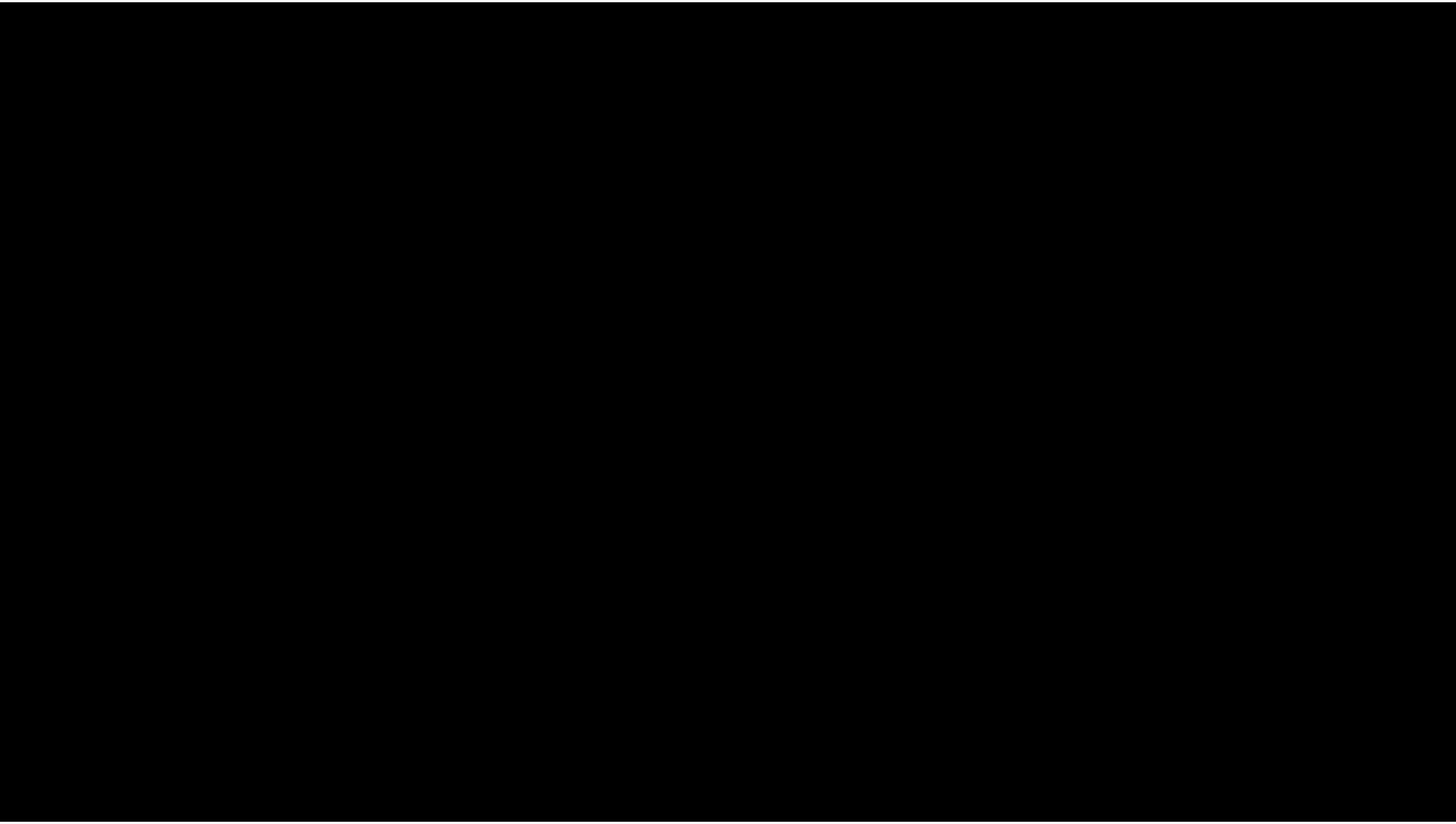
MSL

Mars Science Lab (MSL) Launch ATLO

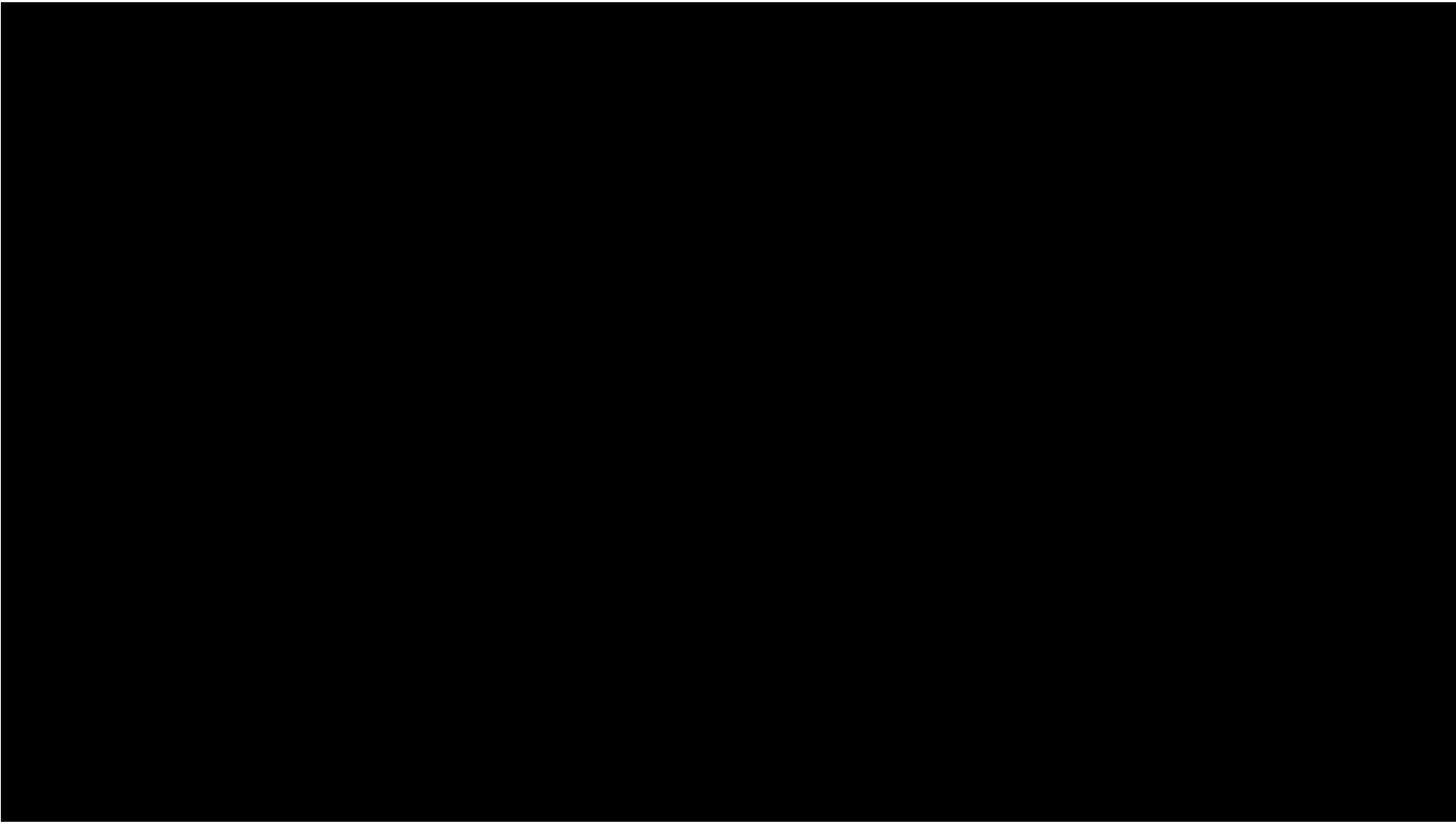
Payload Fairing with MSL inside being hoisted onto the ATLAS V Rocket

Mars Science Lab (MSL) Launch ATLO

Mars Science Lab (MSL) Launch Day



Mars Science Lab (MSL) Landing



Mars Science Lab (MSL) Successful Landing

QUESTIONS?

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Dare Mighty Things!