Why Environments & Effects Studies?

- Space environments are complex.
- Complexity of spacecraft systems is increasing.
- Design accommodation must be realistic.
  » Need minimum impact on performance
  » Maintain balance between cost vs. risk
- Environmental problems can be limited at low cost relative to spacecraft cost.

Goal
Use Applied Science Research to Enable Technology Infusion into Space Programs
Performance Predictions

Simulated conditions → Actual conditions

Accuracy of performance prediction is dependent on fidelity of protocols and models.

Design margins can drive requirements that preclude use of newer technologies.

Natural Environments

- Atmospheric Density & Composition
- Plasma
- Radiation Environment
- Electromagnetic Radiation
- Meteoroid & Orbital Debris
- Thermal Environment
- Geomagnetic Field
- Gravitational Field
Environmental Hazards

- Low Earth Orbits (LEO)
  - Low Inclination
  - Polar
- Middle Earth Orbits (MEO)
- Geostationary (GEO)
- Interplanetary
- Jovian

Meteoroid/Orbital Debris

- Meteoroids
  - Primarily remnants of comet orbits
  - Several times a year Earth intersects a comet orbit
  - Asteroid belt - Sporadic particles on a daily basis
- Debris
  - Operational payloads, Spent rockets stages, Fragments of rockets and satellites, Other hardware and ejecta
  - USAF Space Command tracks over 7,000 > 10 cm objects in LEO
  - Tens of thousands smaller objects
The Threat

- Damage and decompression threat
- Hypervelocity impacts from larger particles
- Surface erosion from collisions with smaller objects
  » Surface effects on thermal, electrical, and optical properties
- Risk Factors
  » Duration, vehicle size and design, solar cycle, orbit altitude, and inclination
  » Threat is highly directional

Spacecraft Effects
Neutral Thermosphere

- Definition
  - Atmospheric Density, Density Variations, Atmospheric Composition (AO), Winds
- Neutral atmospheric constituents
  - 90 – 600 km
- Neutral gas particles
  - Lower - Atomic oxygen (AO)
  - Higher - Hydrogen & Helium
- Altitude variations due to temperature
  - Solar cycle effects due to absorption of solar extreme ultraviolet radiation (EUV)
  - Proxy measurement with 10.7-cm radio flux (F10.7)

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Spacecraft Effects

- Spacecraft drag
  - Density of neutral gas
  - Altitude decay & torques
- Materials degradation - Erosion
  - Thermal, mechanical, optical properties
  - AO (200 – 400 km), Solar cycle dependent
  - Effects aggravated by micrometeoroid impacts, sputtering, UV exposure, contamination
- Spacecraft glow
  - Optical emissions generated by excitation of metastable molecules
  - Surface acts as catalyst – material dependent

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Plasma Environment

- Energy < 100 keV - No radiation effects
- Ionized gas where electron and ion densities are approximately equal
- Sources
  - Ionosphere
    - Electrically charged portion of the atmosphere
    - Low energy (eV)/High Density
  - Geomagnetic substorm activity
    - High energy (keV)/Low density
  - Solar Wind
    - Sun's corona
    - Seen at > 10 Billion km from the Sun
- Dramatic variation with altitude, latitude, magnetic field strength, and solar activity

Plasma Interactions – Ionosphere

- Supersonic spacecraft motion through background ions in the plasma
- Solar array coupling to plasma
  - Current drain on solar arrays
- Contamination
  - Dense pressure of atmosphere in LEO
  - Modification of ambient atmosphere by outgassing
- Generation and emission of plasma waves
- Polar regions - High level of charging
  - Exposure to auroral electrons, esp. if current collection occurs in ion-depleted wake zones
**Plasma Interactions - Storms**

- Induced charge on surface
  - Disrupt operation of electrically biased instruments
- Missions affected
  - LEO - Polar orbits
  - Geosynchronous orbits are generally a greater concern
- Effects
  - Biasing of instrument readings
  - Arcing - upsets to electronics, increased current collection, reattraction of contaminants, ion sputtering which leads to acceleration of erosion of materials

**Conditions for Charging**

- Large differential
- Large fraction of total flux
- Darkness
- Large spacecraft
Charging in GEO

- Strong local time effects
- Solar storm effects
- Experience base is in LEO & GEO
  » MEO?
  » Auroral regions?

The Radiation Environment

Nikkei Science, Inc. of Japan, by K. Endo
**Electron Environment Dynamics**

April 2001 Storm

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**Radiation Effects**

- Total Ionizing Dose – Degradation
  - Materials
  - Electronics
- Total Non-ionizing Dose – Degradation
  - Solar Cells
  - Optocouplers
  - Optical lens
- Single Event Effects – Single Particle Strikes
  - Destructive – SEL, SEGR, SEB
  - Non-destructive – SEU, SET, SEFI, MBU
- Degradation of surface materials
- Deep Dielectric Charging
Seastar - COTS DRAM Technology

Single Event Upsets: January 1 - December 25, 1999 - 705 km

Definition of Contamination

An unwanted material or substance that causes degradation in the desired function of an instrument or flight hardware
**Systems Affected**

- Optical components - lenses
- Thermal control - external paints & blankets
- Guidance - baffles
- Any sensitive surfaces
  - Exposed to all environments!

**Contamination - Pulling It Together**

- Micrometeoroids and debris
  - Surface erosion from collisions with smaller objects
  - Surface effects on thermal, electrical, and optical properties
- Neutral thermosphere
  - Materials degradation - Erosion
    - Thermal, mechanical, optical properties
    - AO (GEO = 400 km), Solar cycle dependent
    - Effects aggravated by micrometeoroid impacts, sputtering, UV exposure, contamination
- Spacecraft glow
  - Optical emissions generated by excitation of metastable molecules
  - Surface acts as catalyst - material dependent
- Plasma - Ions
  - Contamination
    - Dense pressure of atmosphere in LEO
    - Modification of ambient atmosphere by outgassing
- Plasma - Storms
  - Reacceleration of contaminants, ion sputtering which leads to acceleration of erosion of materials
- Non-ionizing and ionizing dose
  - Degradation of surface materials & optical lenses
Contamination Processes

• Particulates and gases
  » Outgassing, engine firings, plume impingement, material processes

• Effects
  » Charging
  » Glow
  » False signals on optical detectors
  » Surface erosion

Complexity Increased by Material Processes

• Atomic Erosion
  » Infrared Radiation
  » Particle Radiation
  » Ultraviolet Radiation
  » Thermal Vacuum Outgassing
Mission Phases for Contamination

- An Issue at All Mission Phases
  » Construction & Assembly
  » Ground Handling & Transportation
  » Launch
  » Orbital Insertion
  » Early Outgassing
  » Long Term Exposure
  » Recovery

Contamination Risk?

Thermal control surfaces?
H < 1000 km?
Instrument calibration?

Solar UV?
Baffle design?

Earth albedo UV?
Lens design?

UV instruments?
Detector design?

IR instruments?
Mirror design?

Spacecraft lifetime?
Cooled detector systems?
Common Issues

- Many unknowns in space environments & the interaction mechanisms
  » Model development & validation lags behind technology changes.
  » Unknowns result in large design margins
    - Higher accommodation/mitigation overheads
    - Can preclude use of newer technologies
- Must be addressed in all design phases
  » Use a systems approach.
  » Begin early - “Pay now or pay more later”
- Ground tests cannot duplicate the space environment
  » Synergistic effects
  » Enhanced low dose rates