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 $\rightarrow$ 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

Spacecraft Effects

- 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
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)

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
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

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
  - Surface effects on thermal, electrical, and optical properties
- Neutral thermosphere
  - Spacecraft glow
  - Optical emissions generated by excitation of metastable molecules
- Plasma - ionosphere
  - Contamination
  - Dense pressure of atmosphere in LEO
  - Modification of ambient atmosphere by outgassing
- Plasma - storms
  - Reattraction 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