The Space Environment

- Lecture #11 - October 6, 2020
- Course schedule updates
- Planetary environments
- Gravitation
- Electromagnetic radiation
- Atmospheric particles
- Newtonian flow
- Solar wind particles
- Ionizing radiation
- Micrometeoroids/orbital debris
- Spacecraft charging
“Space is big. Really big. You just won't believe how vastly, hugely, mind-bogglingly big it is. I mean, you may think it's a long way down the road to the chemist, but that's just peanuts to space.”

The Earth-Moon System

Note: Earth and Moon are in scale with size of orbits

Photograph of Earth and Moon taken by Mars Odyssey April 19, 2001 from a distance of 3,564,000 km

Earth

Moon

L1

L2

L3

L4

L5

Geostationary Orbit
In The Same Scale...

- Sun
- Mercury
- Venus
- Earth-Moon
- Mars
### Comparison of Basic Characteristics

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Earth</th>
<th>Free Space</th>
<th>Moon</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravitational Acceleration</td>
<td>9.8 m/s² (1 g)</td>
<td>-</td>
<td>1.545 m/s² (.16 g)</td>
<td>3.711 m/s² (.38 g)</td>
</tr>
<tr>
<td>Atmospheric Pressure</td>
<td>101,350 Pa (14.7 psi)</td>
<td>-</td>
<td>-</td>
<td>560 Pa (.081 psi)</td>
</tr>
<tr>
<td>Atmospheric Constituents</td>
<td>78% N₂, 21% O₂</td>
<td>-</td>
<td>-</td>
<td>95% CO₂, 3% N₂</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>120°F -100°F</td>
<td>150°F -60°F</td>
<td>250°F -250°F</td>
<td>80°F -200°F</td>
</tr>
<tr>
<td>Length of Day</td>
<td>24 hr</td>
<td>90 min - Infinite</td>
<td>28 days</td>
<td>24h 37m 22.6s</td>
</tr>
</tbody>
</table>
Lunar Soil Bearing Limits

Lunar Slope Distribution (Apollo 15 data)

The Electromagnetic Spectrum

The Solar Spectrum

Solar Cycle

- Sun is a variable star with 11-year period
- UV output of sun increases thermal energy of upper atmosphere, accelerating atmospheric drag of LEO spacecraft
- Measured as solar flux at 10.7 cm wavelength (="F10.7")

Diurnal Variation of Atmosphere

Atmospheric Density with Altitude

\[ \rho \left( \frac{kg}{m^3} \right) = 3.875 \times 10^{-9} e^{-\frac{h}{59.06}} \]

Newtonian Flow

- Mean free path of particles much larger than spacecraft --> no appreciable interaction of air molecules
- Model vehicle/atmosphere interactions as independent perfectly elastic collisions
Newtonian Analysis

mass flux = (density)(swept area)(velocity)

\[
\frac{dm}{dt} = (\rho)(A \sin(\alpha))(v)
\]
Momentum Transfer

- Momentum perpendicular to wall is reversed at impact
- “Bounce” momentum is transferred to vehicle
- Momentum parallel to wall is unchanged

\[ F = \frac{dm}{dt} \Delta v = \rho v A \sin \alpha (2v \sin \alpha) = 2\rho v^2 A \sin^2 \alpha \]
Lift and Drag

\[ L = F \cos \alpha = 2 \rho V^2 A \sin^2 \alpha \cos \alpha \]

\[ D = F \sin \alpha = 2 \rho V^2 A \sin^3 \alpha \]

\[ c_L = \frac{L}{\frac{1}{2} \rho V^2 A} = 4 \sin^2 \alpha \cos \alpha \]

\[ c_D = \frac{D}{\frac{1}{2} \rho V^2 A} = 4 \sin^3 \alpha \]

\[ \frac{L}{D} = \frac{\cos \alpha}{\sin \alpha} = \cot \alpha \]
Flat Plate Newtonian Aerodynamics

![Graph showing lift, drag, and L/D coefficients vs. angle of attack.]
Example of Newtonian Flow Calcs

Consider a cylinder of length $l$, entering atmosphere transverse to flow

\[ dA = r d\theta dl \]
\[ dm = \rho dA \cos \theta V = \rho V \cos \theta r d\theta dl \]
\[ dF = dm \Delta V = 2\rho V^2 \cos^2 \theta r d\theta dl \]
\[ dD = dF \cos \theta = 2\rho V^2 \cos^3 \theta r d\theta dl \]
\[ dL = dF \sin \theta = 2\rho V^2 \cos \theta \sin \theta r d\theta dl \]
Integration to Find Drag Coefficient

Integrate from \( \theta = -\frac{\pi}{2} \to \frac{\pi}{2} \)

\[
D = \int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} \int_0^\ell dD = 2\rho V^2 r \int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} \int_0^\ell \cos^3 \theta d\theta d\ell
\]

\[
= 2\rho V^2 r \ell \int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} \cos^3 \theta d\theta = \frac{4}{3} \rho V^2 r \ell
\]

By definition, \( D = \frac{1}{2} \rho V^2 A c_D \) and, for a cylinder \( A = 2r \ell \)

\[
\rho V^2 r \ell c_D = \frac{4}{3} \rho V^2 r \ell \implies c_D = \frac{4}{3}
\]
Orbit Decay from Atmospheric Drag

Makeup $\Delta V$ Due To Atmospheric Drag

Atmospheric Constituents at Altitude


Fig. 2.3. (a) Relative concentrations of atmospheric constituents during periods of minimum solar activity. (b) Relative concentrations of atmospheric constituents during periods of maximum solar activity. (Adapted from U.S. Standard Atmosphere, 1976.)
Atomic Oxygen Erosion Rates

- Annual surface erosion at solar max
- Orbital altitude 500 km

<table>
<thead>
<tr>
<th>Material</th>
<th>Erosion Rate (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>.22</td>
</tr>
<tr>
<td>Chemglaze Z302</td>
<td>.079</td>
</tr>
<tr>
<td>Mylar</td>
<td>.071</td>
</tr>
<tr>
<td>Kapton</td>
<td>.061</td>
</tr>
<tr>
<td>Epoxy</td>
<td>.048</td>
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<tr>
<td>Carbon</td>
<td>.020</td>
</tr>
<tr>
<td>Teflon</td>
<td>.00064</td>
</tr>
<tr>
<td>Aluminum</td>
<td>.0000076</td>
</tr>
</tbody>
</table>
The Earth’s Magnetic Field

The Van Allen Radiation Belts

Cross-section of Van Allen Radiation Belts

Electron Flux in Low Earth Orbit

The Origin of a Class X1 Solar Flare
Heavy Ion Flux

Background

Ref: Neville J. Barter, ed., TRW Space Data, TRW Space and Electronics Group, 1999

Solar Flare
Radiation Dose vs. Orbital Altitude

300 mil (7.6 mm) Al shielding

Ref: Neville J. Barter, ed., TRW Space Data, TRW Space and Electronics Group, 1999
Trackable Objects On-orbit
Micrometeoroids and Orbital Debris

Flux (Number greater than size indicated per square meter year)

1995, 500 km S = 97
28.5 degree inclination

Diameter (cm)

Orbital Debris
Meteoroid
Space Station module - cylindrical, 15’ diam. X 43’ long

\[ \text{Area} = \pi ld + 2\frac{\pi d^2}{4} \]

Surface area=221 m\(^2\)

Flux value for one hit in 20 years

\[ \text{Flux} = \frac{1 \text{ hit}}{(221 \text{ m}^2)(20 \text{ yrs})} \]

Flux=2.26x10\(^{-4}\) hits/m\(^2\)-yr (3mm)

For 0.1 hits/20 years, allowable flux= 2.26x10\(^{-5}\) hits/m\(^2\)-yr (9 mm)
Damage from MMOD Impacts

The Space Environment

ENAE 483/788D - Principles of Space Systems Design
Long Duration Exposure Facility (LDEF)

- Passive experiment to test long-term effects of space exposure
- 57 experiments in 86 trays
- Deployed April, 1984
Surprising Results from LDEF

- Presence of C-60 ("buckyballs") on impact site
- Much higher incidence of MMOD impacts on trailing surfaces than expected
- Local thermal hot spots did surprising levels of damage to blankets and coatings
- Thermal blankets are effective barriers to smaller high velocity impacting particles
- Anomalies are typically due to design and workmanship, rather than materials effects
Typical MMOD Penetration from LDEF
Spacecraft Charging

References

- Neville J. Barter, ed., TRW Space Data TRW Space and Electronics Group, 1999