THERMOSPHERE DENSITY
AND UPPER ATMOSPHERIC DRAG ON SATELLITES IN LEO

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SMALL SATELLITE CONFERENCE
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Satellite atmospheric drag

A satellite/object in Low Earth Orbit loses altitude due to interaction with neutral air particles (thermosphere).

Ultimately, it reenters the lower atmosphere.

$$a_{\text{drag}} = \frac{1}{2} C_D \frac{A}{m} v^2$$

Satellite drag acceleration:

- $C_D$ = aerodynamic coefficient (model)
- $\rho$ = thermosphere density (model)
- $m$ = satellite mass
- $A$ = satellite surface perpendicular to speed, or ram area
- $v$ = satellite speed with respect to co-rotating atmosphere (orbit)

Increase lifetime: Orbit raising maneuvers
Satellite atmospheric drag

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Increase lifetime: Orbit raising maneuvers

GRACE-1 Decay Scenario (20-Aug-2009)

CHAMP Orbit Decay Prediction (24-Aug-2009)
Thermosphere density is a function of location:

- Altitude
- Latitude, longitude
- Local solar time
Thermosphere density variability

And date:
• Solar and geomagnetic activity
• Season
Thermosphere density variability

Slow and fast temporal variations:

• Solar cycle (≈11 years)
• Season (6 months & 12 months)
• Active regions (months)
• Solar rotation (≈27 days)
• Corotating Interaction Regions (9 & 13.5 days)
• Solar/geomagnetic storms (hours – days)
• Solar flares (hours)
Thermosphere density variability

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Thermosphere density variability: min-max amplitudes
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- **Solar min without any geomagnetic activity**
- **Solar max without any geomagnetic activity**

- F10.7=240 Ap=1: 72 x bigger
- F10.7=65 Ap=400: 90 x bigger
- F10.7=65 Ap=1: 15 x bigger
Thermosphere density variability: min-max amplitudes

- Solar min without any geomagnetic activity
- Solar max without any geomagnetic activity
- Solar min without any geomagnetic activity
- Solar max and storm

Graph showing density variations with altitude and density in g/cm³.
Thermosphere density variability: impact on LEO

Examples of semi-major axis decay due to a severe geomagnetic storm:
- 7-day arc from 27 Oct – 2 Nov 2003, polar and circular orbit
- spherical satellite, S/m=0.001 & 0.01 m²/kg

<table>
<thead>
<tr>
<th>Altitude (km)</th>
<th>Total Δa (m) S/m 0.001</th>
<th>Total, no storm</th>
<th>Storm Δa (m)</th>
<th>Total Δa (m) S/m 0.01</th>
<th>Total, no storm</th>
<th>Storm Δa (m)</th>
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</thead>
<tbody>
<tr>
<td>250</td>
<td>-14643</td>
<td>-10621</td>
<td>-4022</td>
<td>(reentry)</td>
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<td>-4.8</td>
<td>-5.0</td>
<td>-98.4</td>
<td>-48.4</td>
<td>-50.0</td>
</tr>
</tbody>
</table>

Altitude: Total Δa = Total, no storm + Storm Δa

Radar

3-hourly planetary geomagnetic index ap

Halloween storm

(no storm)
1. Order of magnitude changes in density over a solar cycle for altitudes > 300 km
2. Solar cycle phase (ascending/max/decaying/min) has large impact on satellite lifetime
3. Density increases several 100% during geomagnetic storms within hours
4. Orbit decay can be significant due to a storm, but not dimensioning for lifetime
5. Geomagnetic storms cannot reliably be predicted at the present time

Something to read:
Next Step Space Weather Benchmarks, IDA SCIENCE & TECHNOLOGY POLICY INSTITUTE
https://www.ida.org/

The benchmarks specify nature and intensity of extreme space weather events