Scope of Upper Atmosphere Density Variations During the Entire Space Age - as Determined From Satellite Drag Measurements

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Background

Drag from the thermosphere is the most important alterer of orbits for all low earth orbit (LEO) satellites. It affects the accuracy of position predictions and satellite lifetime. We now have available a long-term series estimating this drag, which includes terms from the NORAD catalog.

- ‘n dot’ \( n \) or ‘Bstar’ \( B^* \)

This drag can vary by a factor of 10 or more during a solar cycle.
Thermospheric Neutral Models

CIRA atmosphere
Jacchia 1971 – the gold standard
NRLMSIS 2000 – the most thoroughly researched
Others – somewhat local preference
All are in error by 10-15%
  This is mean error under most conditions
  can be worse under solar storm conditions
Use $F_{10.7}$, $A_p$ solar proxies
Much emphasis on determining chemical composition, but this is not relevant to drag uses
Newest development Bowman 2008
  Ideally uses better Mg II, $D_{st}$
  performs better under disturbed conditions
All perform more poorly for predictions
What is B*?

Bstar is the acceleration defined in the SGP4 analytic orbit theory

We should have \( B^* = C_D \rho_0 A/2m \)

\( C_D \) is usually 2.2, \( A/m \) is the area-to-mass ratio of the object

\( \rho_0 \) is the mean atmospheric density over the fit span……

As defined by a crude model (basically 1/\( \text{alt}^4 \))

Is readily available for the entire database of NORAD elsets
Demonstration of Atmospheric Variability

During a Day

- 8x variation

Over a Year

- 10x variation
- 10x variation
- 10x variation
Predicted and Observed One-Day Median Drag Delays for LEO Objects

Observational data for 9/20/2012
F10.7 = 117
Ap = 9
B* for a sample of 100 active payloads
**B** for satellite catalog

\[ \sim C_d A/M \]

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<th>Object Type</th>
<th>Average</th>
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Bstar Distribution, #63

# 63
Alt = 416 km
I = 50
Correlation Coefficients

F107, Bstar = 0.62
Rho, Bstar = 0.66
F10.7, MSIS = 0.87
Ap, Bstar = 0.11
Bstar for #60, #63 = 0.85
Correlation between objects

Atmospheric drag does correlate between objects. The degree of correlation depends on the similarity of the orbits.

**Solar Activity**

- **High**
- **Medium**
- **Low**

Grace 1 vs Grace 2 @460 km

Aqua vs Aura @760 km

Close Approach of PSLV debris to ISS, 10/12

Rho = 0.80

Mango vs Tango @760 km
Noted Solar Storms

The Space Age Storm 8/2/1972
The Quebec Blackout Storm 3/13/1989
The Bastille Day Storm 7/15/2001
The Halloween Storm 10/29/2003
The Boxing Day Storm 12/26/2011

The most famous of all – the Carrington event – late August 1859
Future Drag Environment

Current solar cycle looks to be significantly less active than past several
The Future

Are we entering a period of lower solar activity? Possibly another Maunder Minimum?

Consequences
- Longer satellite life = more debris
- Better orbit predictions
- Better astronaut safety
Conclusions

Bstar in the readily available TLEs derived from SGP4 theory is a very useful measure of the thermosphere not perfect

The thermosphere density varies tremendously, but mean value can be obtained

Bstar, and thus drag, varies by a factor of at least 10 over the solar cycle

Mean densities, and thus drag, for objects with similar orbits are highly correlated

Affects collision predictions

This solar cycle seems to be less active than the previous 3

Will this trend continue?