Atmospheric Density Estimation Via Satellite Two Line Element Sets

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Overview

• Introduction
• Procedure/Results
• Application
• Improvements
• Conclusion
Introduction

• Atmospheric density estimates often contain large errors
• Density is difficult to model
• Varies widely over time
• Important in satellite trajectory calculations
Orbit Perturbations

- Two largest perturbations (low Earth orbits)
  - Atmospheric Density
  - Oblateness of Earth
- Drag – difficult to model
- Oblateness – have accurate model
- Third-body effects, solar-radiation pressure, albedo and Earth shine are small effects and only come into play for larger orbits
Atmospheric Drag

\[ a_{\text{drag}} = -\frac{1}{2} \frac{C_D A}{m} \rho v_{\text{rel}}^2 \frac{\bar{v}_{\text{rel}}}{|\bar{v}_{\text{rel}}|} \]

where

- \( a_{\text{drag}} \) is the acceleration due to drag,
- \( C_D \) is the coefficient of drag
  (between 2.0 and 2.1 depending on the satellite),
- \( A \) is the cross-sectional area “normal to the satellite’s velocity vector”,
- \( m \) is the satellite’s mass,
- \( \rho \) is atmospheric density, and
- \( v_{\text{rel}} \) is the velocity relative to the Earth’s atmosphere
Density

- Hardest drag parameter to estimate
- Decreases exponentially with altitude
- Diurnal Variations
- 27-Day Solar Rotation
- 11-Year Solar Sun Spot Cycle
- Seasonal Variations
- Smaller variations  
  - (e.g. rotating atmosphere, winds, magnetic storms and tides)
Current Models of Atmospheric Density

• Standard Atmosphere of 1976
• $F_{10.7}$ solar flux measurement
  – Harris-Priester model
  – Jacchia-Roberts model
• For more accuracy, use real data from satellites to update over time
Importance

• Accurate density is needed for accurate trajectory estimates

• Accurate trajectories are important
  • Navigation
  • Lifetime Estimations
  • Collision Avoidance
Examples

• Skylab
  – Atmospheric density higher than expected
  – Orbit degradation faster than expected
  – Reentered early (1979) before shuttle was finished to provide boost in altitude
Examples

• Iridium 33/Kosmos 2251
  – Satellites’ orbits intersected
  – Iridium 33 was destroyed
  – Kosmos 2251 was already dead
  – Accurate orbit estimates might have prevented this
Research Overview

• Generate improved density model
• Use current satellite orbit parameters
• Extract orbit parameters from Space Command Two Line Element set (TLE’s) database
Process

- Download and extract drag information from Space Command Two Line Elements (1 Jan - 1 Jul 2013)

ISS (ZARYA)
1 25544U 98067A 04236.56031392 .00020137 00000-0 16538-3 0 5135
2 25544 51.6335 341.7760 0007976 126.2523 325.9359 15.70406856328903

- Circled $B^*$ term is the orbit drag parameter

$$B^* = \frac{1}{2} \frac{CD A}{m} \rho R$$

where $R$ is radius of Earth

- Decimal point is implied with an exponent:

$$0.16538 \times 10^{-3}$$
Raw Data Satellite 38710

Raw B* Values for Satellite 38710
Interpolate to Adjust to Noon and Fill in Gaps

Interpolated B* Values for Satellite 38710
Adjusted by Scale Factor to Have an Average Value of 1.0

Scaled B* Values for Satellite 38710
Combine All Models into One

• The process above is done for each satellite
• Each satellite has a similar form but each has noise and measurement errors
• By averaging all the satellite models, noise and error effects are reduced
B* Model with Individual Satellite Data
Can Rescale Model to Fit Individual Satellites

B* Scaled Back to Satellite 38710 Level
Model

• Overall model can be used to study relative variations in the density over time
  – 27-day Solar Cycle
  – Varies by a factor of 3 from minimum to maximum

• Model can be rescaled to individual satellites
  – Reduce noise
  – Remove spurious bad measurements
  – Potential for density prediction
Calculate Actual Density

• Actual density can be calculated from:

\[ \rho = \frac{2B^*}{R} \frac{m}{C_D A} \]

• Multiple satellite could be used to generate a model for all altitudes

• One satellite could be used to calibrate the Standard Atmosphere with a scale factor
Other Applications

- Improved historical density models
- Accurate short term density prediction
- Long term density estimates
- Estimation of satellite parameters such as ballistic coefficient
Improvements

• Use more satellites over a longer range of time
• Throw-out outliers caused by events such as maneuvering satellites or adjusted panels
• Convert the modeled B* terms to equivalent $F_{10.7}$ values
Conclusions

• Space Command TLE’s can be used to generate accurate model of density fluctuations
• Data can reduce noise, remove measurement errors and fill in missing data gaps
• Resulting model can be used in many applications
References

• Oblate Globe - http://en.wikipedia.org/wiki/Figure_of_the_Earth
• Density Graph - http://www.geogrify.net/GEO1/Lectures/EnergyAtmosphere/Atmosphere.html
References (cont.)

Questions?