Euler angles: Will it tumble?
Torques during de-orbit
Simplified Earth model

Geomagnetic field:

\[ B_N = B_0 \left( \frac{R_E}{R} \right)^3 \cos \delta_M \]

\[ B_E = 0 \]

\[ B_D = 2B_0 \left( \frac{R_E}{R} \right)^3 \sin \delta_M \]

Atmospheric co-rotation:

\[ \beta = -\frac{\dot{\tau}R}{V} \sin i \cos(\chi_0 + nt) \]
Linearized attitude model

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<th>$\ddot{\varphi}$</th>
<th>$\ddot{\theta}$</th>
<th>$\ddot{\psi}$</th>
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Density

Y-dipole = 3 Am²

Density [kg/m³]

Roll angle [rad]

Yaw angle [rad]
Back to reality

Date [dd/mm]

Frequency [mrad/s]

Angle [log10(deg)]

ap

h [km]

03/11 05/11 07/11 09/11

0 2 4 6 8

−4 −2 0

03/11 05/11 07/11 09/11

0 20 40 60

1 1.2 1.4 1.6 1.8 2
Back to reality
- NRLMSISE-00
- SPARTA (G.March)
Inclination

$3 \times 10^{-10} \text{kg/m}^3$
Inclination

$3 \times 10^{-10} \text{kg/m}^3$
Inclination

$3 \times 10^{-10} \text{kg/m}^3$
Conclusions

▶ Significant magnetic torques during de-orbit;
▶ High density required for pitch stability;
▶ Resonance destabilizes attitude.

Recommendations

▶ Include $C_{l\alpha,\beta}$ (roll aerodynamics);
▶ Analytic expressions for aerodynamic coefficients (B. Fritsche);
▶ Verification using simulations.

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Inclination
Inclination

Y dipole = -3 Am²
Inclination

$3 \times 10^{-10} \text{kg/m}^3$
Inclination

$3 \times 10^{-10} \text{kg/m}^3$
Inclination

$3 \times 10^{-10} \text{kg/m}^3$
Control dipole

\[ \mu_x = -\mu_c \cos(2nt) \]