Influence factor analysis of space debris lifetime estimation for low and near circular orbits

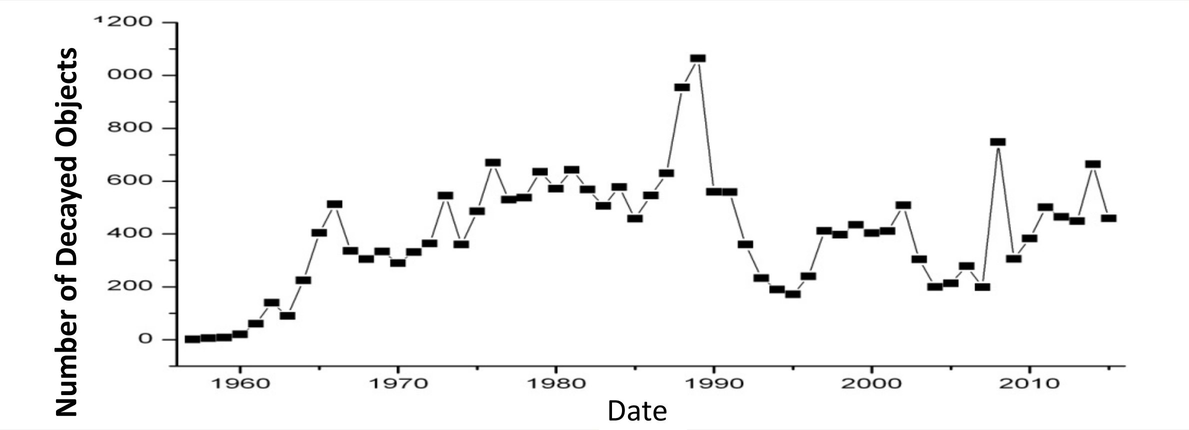
Zhang Yao, Liu Jing, Li Dawei
National Astronomical Observatories of China

Outlines

- Background
- Influence Factors Analysis
- Result Validation
- Conclusion

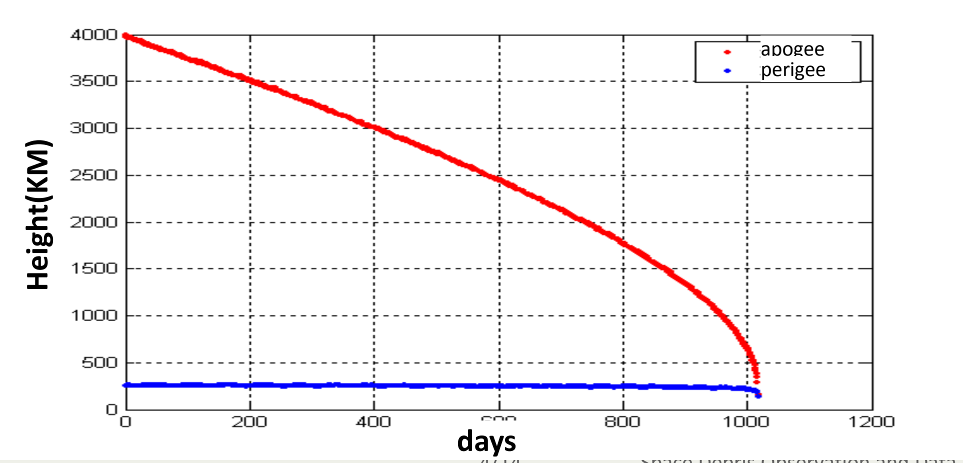
Background

- Every year hundreds of space objects decayed and re-entry to dense atmosphere.
- Some large objects may not burnout and may hit on earth.



Background

- Space objects decay include 2 stages
  - **From current state to 120km height(focus)**
  - From 120km height to the end
  - Lifetime estimation must be fast



Influence Factors Analysis

- Acceleration due to atmosphere drag

$$\vec{a}_{drag} = -\frac{1}{2}\frac{C_D A}{m}\rho v_{rel}^2 \frac{\vec{v}_{rel}}{\left|\vec{v}_{rel}\right|}$$

- Equations for the effects of drag

$$\frac{da}{dt} = -\frac{a^2 C_D A_1 \rho v^3}{\mu}$$

$$\frac{de}{dt} = -(e + \cos\theta) C_D A \rho v$$

Main factors:
(1)Atmosphere density
(2)Area to mass ratio
(3)Coefficient of drag

- Use perigee as threshold to stop the estimation

Atmosphere density

- **Density is decided by**
  - Atmosphere model
  - Geographic position and space weather
- **Model of atmosphere selection**

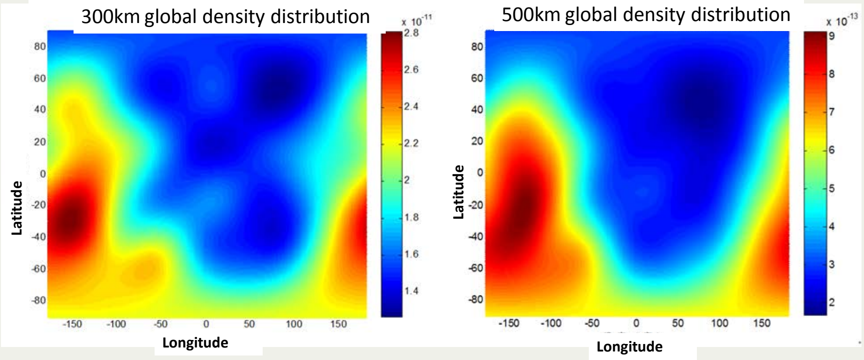
Model	Characteristic	Range(km)	Relative runtime
CIRA-72	Semi-theoretical technique	25--500	1
Jacchia-Robert	Popular model in military operations	70--2500	14
NRLMEIS-00	Base on air-glow temperatures and incoherent radar scatter, high accuracy	0--2000	200

- **Chose NRLMEIS-00 model**

Atmosphere density

- Different height and position have different atmosphere density

Global atmosphere density distribution in different height



- Inclination and RAAN perturbation must be compute

Atmosphere density

- **Space weather is considered**
  - Lifetime span may be months or years, space weather may change a lot.
  - Solar flux variation use the textbook from http://celestrak.com

Area to mass ratio(AMR)

- The secular changes of semi-major axis are used to estimate the AMR:

$$\Delta a = (\frac{da}{dt})_{\text{average-atmosphere}} * \Delta t + (\frac{da}{dt})_{\text{average-radiation}} * \Delta t = (\alpha A_1 + \beta A_2)\Delta t$$

- supposing that N pieces of orbit data can be used in the estimation, so N-1 equations can be established.

$$\Delta a_i = (\alpha_i A_1 + \beta_i A_2)\Delta t_i, i = 1, 2 \cdots N-1$$

- Least square method is used to solve the equations

Coefficient of drag

- Coefficient of drag change a lot when re-entry to dense atmosphere, but we focus on stage 1 that Coefficient of drag can be considered as constant 2.2.

Equation of lifetime estimation

- Equation of lifetime estimation

$$
\begin{cases}
\dfrac{\mathrm{da}}{\mathrm{dt}} = -\dfrac{a^2 C_D A_1 \rho v^3}{\mu} \\[2ex]
\dfrac{de}{dt} = -(e+\cos\theta) C_D A \rho v \\[2ex]
\dfrac{di}{dt} = 0 \\[2ex]
\dfrac{d\Omega}{dt} = -\dfrac{3nR_e^2 J_2}{2p^2}\cos(i)
\end{cases}
\Longrightarrow
\begin{cases}
\left.\dfrac{da}{dt}\right|_{ave} = -\dfrac{\sigma}{\pi\mu\sqrt{1-e^2}}\displaystyle\int_0^{2\pi} r^2 v^3 \rho d\theta \\[2ex]
\left.\dfrac{de}{dt}\right|_{ave} = -\dfrac{\sigma}{\pi a^2\sqrt{1-e^2}}\displaystyle\int_0^{2\pi} r^2 v \rho (e+\cos\theta) d\theta
\end{cases}
$$

- Runge-kutta (4 order) integrator are used
- Fix the semi-major axis change in each integrate step Δa, the time of step is conpute by $\Delta t = \Delta a / \Delta a_{ave}$

Result Validation

- Select 5 space objects that already decayed, their information are as flows

Number	Name	Semi-major axis(km)	Eccentricity	Re-entry time
28642	DART	6769.817	0.00930	2016-05-07
26481	JB 3A	6742.627	0.00043	2016-03-11
32765	C/NOFS	6820.914	0.01247	2015-11-28
25064	ETS 7	6757.679	0.00053	2015-11-13
13818	Cosmos 1441	6785.577	0.00020	2014-11-8

- Lifetime estimation result:

Number	Estimate AMR（M^2/kg）	Estimation start epoch	Estimate re-entry epoch	error
28642	0.00518	2015-05-01	2016-06-15	38 days,6%
26481	0.00310	2015-01-01	2016-01-16	53 days， 11%
32765	0.01174	2015-01-07	2015-12-2	4 days,8%
25064	0.00565	2015-01-01	2015-10-15	44 days， 15%
13818	0.00558	2013-11-02	2014-11-07	1 days， 1%

Conclusion

- The factors that influence the lifetime of space object are analyzed;
- Lifetime estimation model are established and validated;
- We can change Δa to accelerate or reduce the time consuming in lifetime estimation.

Thank You!

yaozh@bao.ac.cn