Processing TLEs to facilitate re-entry prediction of spent rocket bodies from GTO

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Re-entry prediction

Knowledge of the present

MODEL

Prediction of the future

Altitude

Now

Reality

Prediction

Time
How to improve TLE-based predictions
How to improve TLE-based predictions

TLEs

TLE filtering

Find corrected TLEs
Find outliers in mean motion
Find outliers in perigee radius
Find outliers in inclination
Find negative B*

Filtered TLEs

Initial BC guess

Compute new BC estimate

Compute $\Delta \text{obs}$ by propagation using BC estimate

$\Delta \text{obs}$ equals $\Delta \text{est}$?

Yes

Compute $\Delta \text{est}$ from TLEs

$\Delta \text{est}$

Generate pseudo-observations

Compute initial state

Pseudo-observations

Initial state guess

BC estimate

Fixed Jacobian?

Yes

Compute Jacobian a priori

Compute state estimate using batch least-squares

State estimate

Final BC estimate

No

Compute state estimate using batch least-squares

Re-entry computation

Propagate until re-entry

Re-entry date

AAS 2016, Napa, CA
Problems with TLEs
Problems with TLEs
Addressing problems with TLEs

1. Corrected TLEs
2. Time gaps
3. Outliers in mean motion and events that physically change the object
4. Outliers in eccentricity and $B^*$ – need to estimate the ballistic coefficient
5. Outliers in inclination – need orbit determination to converge
Corrections

Before 2011

After 2011
Corrections

Before 2011

After 2011
Time gaps
Mean motion outliers

- Mean motion at the epoch of last TLE in the sliding window, $n_{\text{R2D}}(t_{i+1})$
- Residual, $\Delta_A$
- Predicted change, $\Delta_P$
- Last TLE in the sliding window, $i$

Graph:
- Mean motion
- Outliers
- Sequence endpoints

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Mean motion outliers

- Predicted change, $\Delta P$
- Residual, $\Delta_A$
- Last TLE in the sliding window, $i$
- Mean motion at the epoch of last TLE in the sliding window, $n_{RAG}(t_{i+1})$

Graph showing mean motion (rad sec$^{-1}$) vs TLE epoch (year) with data points for mean motion, outliers, and sequence endpoints.
Events – change BC and SRPC

The diagram illustrates a trend over epochs with mean motion shown on the y-axis and TLE epoch (year) on the x-axis. The trend line is fitted with regression polynomials, and events are indicated by specific markers. Notably, there is a difference in values, $\Delta_{i+2}$, which is less than the absolute tolerance, indicating a consistent trend. Additionally, there are outliers marked with crosses, and sequence endpoints are identified with green circles.

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Mean motion filter tuning
Mean motion filter tuning

13025 filter performance for different regression orders

1st 3rd 5th

Sum of all false positives (false outliers)
Outliers in n, e, i, and $B^*$
Outliers in $n$

![Graph showing semi-major axis (km) vs. epoch from 2011.9 to 2012.6 with outliers indicated.]
Outliers in $e$
Outliers in $i$
Outliers in $B^*$
Re-entry prediction error

Relative error: $\delta \tau = \frac{\Delta \tau}{\tau_A}$
Effects of filtering on prediction accuracy

![Graph showing the effects of filtering on prediction accuracy.]
When we filter too many TLEs
When we filter too many TLEs

![Graph showing the relationship between semi-major axis (km) and epoch from 1998.48 to 1998.53. The semi-major axis decreases as the epoch progresses.](image-url)
When we DO NOT filter TLEs
Importance of filtering
Conclusions and recommendations

• Filtering of the TLEs is key to get good predictions, however it isn’t always necessary

• Filter in all orbital elements you’re using

• Be wary that the TLEs change with time (2011, 2013...)

• Outliers => robust statistics
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Changes in TLE generation process
Why do we care

**Large objects – many R/Bs**
We don’t know the re-entry epoch too well

24 hours lead time.
We don’t know the re-entry epoch too well

48 hours lead time.
We don’t know the re-entry epoch too well.

74 hours lead time.