Advancing the orbit model for Galileo satellites during eclipse seasons

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Motivation

- Poor (Galileo) orbit modelling during eclipse seasons using Empirical CODE Orbit Model (ECOM2; Arnold et. al., 2015):
  - elevated orbit misclosures at day boundaries;
  - artifacts in SLR residuals at low $\beta$ angles;
  - elevated RMS of linear clock fits during eclipses.

[Graphs and plots showing orbit data and residuals]
Possible reasons

- Incorrect modelling of satellite attitude (nominal instead of the “true”).
  - Corrected thanks to the metadata of Galileo IOV and FOC satellites published by GSA.
- Insufficient SRP model parameterization.
  - More demanding to the modelling due to low satellite weight, but reasonably solved by ECOM2.
- Thermal effects are not fully absorbed (e.g., during eclipse seasons).
  - All empirical (SRP) parameters are switched off in eclipses.
Galileo Satellites

- From the metadata\(^*\) published by GSA:
  - thermal radiators on \(+X, +Y, -Y, -Z\) (FOC only) faces of the satellite body;
  - Galileo satellite mass \(~700\) kg.

\(^*\) https://www.gsc-europa.eu/support-to-developers/galileo-satellite-metadata
Simulations of +X radiator effects

Along-track component

TR-induced acceleration

Braking
\( \Delta u = 90^\circ \)

\( \Delta u = 180^\circ \) Midnight turn

\( \Delta u = 270^\circ \)

Noon turn \( \Delta u = 0^\circ \)

Acceleration

\( \beta = 0^\circ \)

\( \beta = 5^\circ \)

\( \beta = 10^\circ \)

\( \beta = 15^\circ \)

\( \beta = 20^\circ \)

\( \beta = 30^\circ \)

\( \beta = 40^\circ \)

\( \beta = 50^\circ \)

\( \beta = 60^\circ \)

\( \beta = 70^\circ \)

\( \beta = 80^\circ \)
Additional terms in ECOM2 (D1S)

To be accounted by ECOM2:

- for low $\beta$ angles requires a once-per-rev sine term in $D$,
- for high $\beta$ angles a constant term in $D$ is sufficient.

Actions taken:

- introduced D1S for $|\beta|<12^\circ$ for Galileo satellites,
- reprocessed the data from one eclipse season for Galileo.
Results: Orbit Misclosures

- Orbit misclosures for E11 during eclipse phase in Dec 2015 – Jan 2016:
Results: Orbit Misclosures

- Orbit misclosures for E26 during eclipse phase in Dec 2015 – Jan 2016:
Results: Orbit Misclosures

- Orbit misclosures for E30 during eclipse phase in Jan – Feb 2016:

![Graph showing orbit misclosures](image-url)
Results: SLR Residuals

Summary on the SLR residuals:

- the pattern is left unchanged (shrinking at orbit noon and expansion at orbit midnight);
- the scatter of the SLR residuals is reduced during eclipse phases in Dec 2015 – Feb 2016:

<table>
<thead>
<tr>
<th></th>
<th>ECOM2</th>
<th>ECOM2+D1S</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOV</td>
<td>(-12.7 \pm 57.3)</td>
<td>(-16.7 \pm 53.8)</td>
</tr>
<tr>
<td>FOC</td>
<td>(-9.7 \pm 49.0)</td>
<td>(-11.5 \pm 46.7)</td>
</tr>
<tr>
<td>IOV+FOC</td>
<td>(-10.6 \pm 52.3)</td>
<td>(-13.4 \pm 49.6)</td>
</tr>
</tbody>
</table>

All values are in [mm]
Results: Satellite Clocks

- RMS of the linear clock fit for E11 in Dec 2015 – Feb 2016:
Results: Satellite Clocks

- RMS of the linear clock fit for E30 in Dec 2015 – Feb 2016:

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Results: Satellite Clocks

- Estimated satellite clocks (extreme case):

E11 clock on 02 Jan 2016
Conclusion

- The recently published Galileo metadata shed light on how to model shadow crossings of the satellites, e.g.,
  - attitude control,
  - complete antenna correction models,
  - surface properties.

- Details on the internal temperature management of the satellites are appreciated.

- The unaccounted thermal effects may significantly deteriorate the estimated orbit.

- Addition of once-per-rev sine term in $D$ to ECOM2 during eclipses significantly improves orbit modelling of Galileo satellites (should be added only for small $\beta$ angles).