AIRBUS

DEFENCE AND SPACE

Project

ORBIT/SRP MODELLING FOR LONG-TERM PREDICTION

Title

EXECUTIVE SUMMARY REPORT

Abstract

This report is the study's Executive Summary. It concisely summarise the findings of the contract.

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Applicable documents

Reference documents

[1] Orbit/SRP Modelling for Long-Term prediction: Final report, EAA.TN.000114824, v1.0, 02/09/2019

Change log

- V0

Acronyms

FOC	Full Operation Capabilities
GNSS	Global Navigation Satellite System
HIL	Hardware In-the-Loop
IGS	International GNSS Service
CODE	Center for Orbit Determination in Europe
SA	Solar Array
SRP	Solar Radiation Pressure
TTFF	Time To First Fix

1 STUDY OBJECTIVES

SRP Modelling is one of the main contributors to the residual orbit estimation error. IGS currently uses the ECOM2 empirical SRP model. The purpose of this study is to derive improved models for Galileo in order to improve precise orbit determination of Galileo satellites both at short term and for long term propagation. To achieve this goal, detailed analysis of estimation results has been performed to identify modelling weaknesses and fine tune the proposed deterministic Galileo SRP model. A new ECOM1S model has been implemented together with the derived deterministic model leading to a significant performance with respect to ECOM2 model. Finally some investigation have been performed on the potential benefit of taking advantage of the high stability of the Galileo atomic clocks opening opportunities to further improve the performances.

2 GNSS PRECISE ORBIT DETERMINATION

AIUB CODE software used in the frame of the study is one of the main software packages with precise orbit determination capability from GNSS measurements. Achieving the few cen-timeters level orbit determination requires an accurate orbit models. The orbit evolution is subject to gravitational and non-gravitational forces. Gravitational forces can be modelled to a very high accuracy level. Non-gravitational forces are much less predictable and radiation pressure on the solar arrays is the most important.

The most successful used SRP model is the ECOM and ECOM2 models. The main idea is that this force can be expressed in a frame linked to the solar array frame called DYB, with D along the Sun pressure direction, Y along the solar array axis and B completing the frame. It is composed of 9 coefficients that are estimated everyday by AIUB software with the orbit parameters.

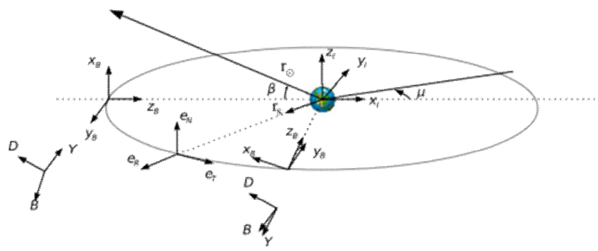


Figure 1: ECOM2 DYB frame

The ECOM2 model equations are:

$$D = D_0 + D_{2S} sin2\mu + D_{2C} cos2\mu + D_{4S} sin4\mu + D_{4C} cos4\mu$$
$$Y = Y_0$$
$$B = B_0 + B_{1S} sin\mu + B_{1C} cos\mu$$

This model reveals deficiency at low Sun elevation and “stochastic pulses” are added at midday to solve the problem. However, they do not correspond to real physical phenomenon and only provide additional degree of freedom to cope with residual non-modelled forces.

This model has good performance over one day but is not good enough for long-term propagation because ECOM2 parameters are not stable with time.

3 PROPOSED MODELS

It is clear that a deterministic model only is not sufficient. The proposed SRP model consists therefore to combine a deterministic model with an empirical model. The deterministic model takes care of the variations with the Sun elevation angle and the empirical model satellite specific corrections.

Two main tracks have been followed to derive a deterministic model:

- Derive a Box-Wing model from available Galileo satellite characteristics.
- Compute a detailed model based on a 3D geometric model of the spacecraft.

3.1 Box-Wing model derivation

Given the detailed satellite geometry, a first box-wing model was derived. A simplified prediction model was setup to predict the ECOM2 parameters from the model. This simplified model allows computing the predicted ECOM2 parameters as function of β and compare with the estimated ones. The small discrepancies have been empirically cancelled by tuning the box-wing coefficients.

3.2 SYSTEMA model derivation

Systema is a software package allowing performing accurate Solar radiation force estimation based on a 3D model. A 3D model of Galileo FOC was used and a look-up table of the induced force computed. No tuning against ECOM2 observation was performed.

3.3 New empirical Model

By processing ECOM2 estimation without stochastic pulses, it was observed that there is some semi major axis drift at low Sun elevation while the model do not allow for it. Consequently the model does its best to fit the orbit but introduces large error. It was also observed that the D_{1S} coefficient has this capability to compensate semi-major axis drift during eclipse periods.

4 FULL ACCURACY VALIDATION

The new SRP models (deterministic model + ECOM1S) have been compared to the reference one (REF): ECOM2 model without stochastic pulses. The period used to estimate the models was October 2015 – September 2016.

4.1 Short-Term performances

Day Boundary discontinuity consists in comparing the estimated orbit at the same epoch from two consecutive estimations. As the position is expected to be the same, the difference is an indicator of estimation error. The main results are:

- Significant improvement mainly during eclipse thanks to the D_{1S} coefficient. Note that stochastic pulses have been removed in the reference.
- Mean RMS improved w.r.t REF by about 40% for Galileo and 20% for GPS. The main reason for reduced improvement for GPS is that orbit discontinuities at day boundaries is not a good validation method for GPS due to the 12h orbit period where a systematic error at orbital frequency do not induce an orbit discontinuity at day boundary.

- Ray tracing do not perform better than Box Wing. The deterministic model was introduced to improve long-term and not short-term prediction.

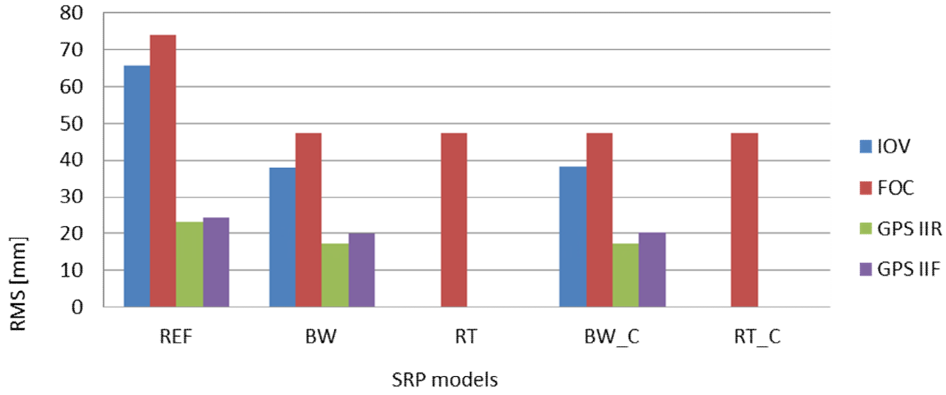
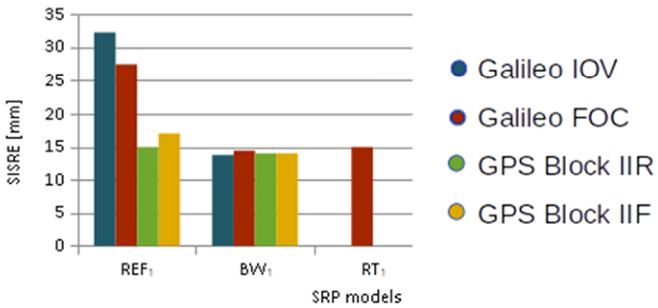


Figure 2: Orbit discontinuity at day boundary SRP models performance

4.2 Long-Term performance

Long term prediction performance has been estimated for prediction over 1day, 7days, 14 days and 31 days. In the following figures, the indices in the model name refer to the number of days used to estimate the prediction model. The performance is estimated using Signal In Space Range Error (SISRE). This metric gives a higher weight in the range direction than in the cross track directions as it is the case for a receiver located on the Earth surface. The main results are:

- Significant improvement is observed thanks to the deterministic model.
- For GPS, improvement is more observed after 7 days (and more) because it has already high short-term performance with the REF model due to its 12h orbit period almost synchronized with the daily estimation period.
- Ray Tracing is slightly worse than Box Wing model. This shows that the adjustment of the bow-wing model parameters (not performed for the ray tracing model) has some positive impact.
- The improvement reduces after 14 days due to the increasing impact of the error in predicting the semi-major axis drift.



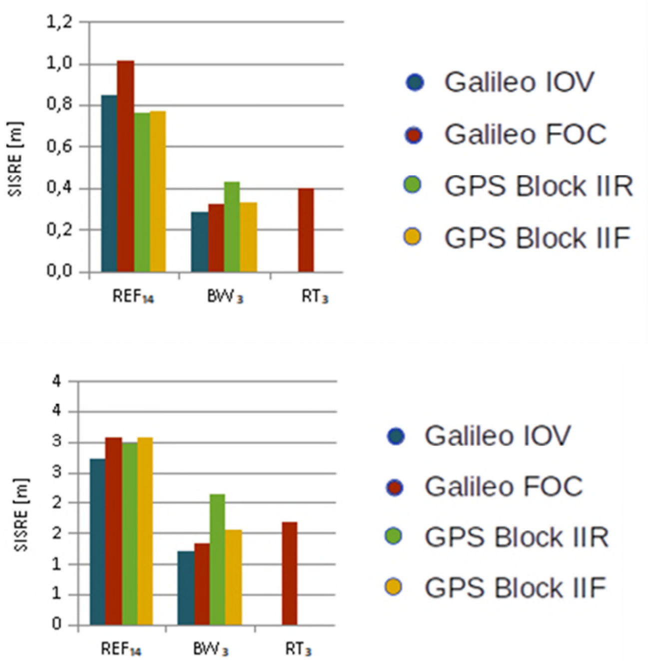


Figure 3: SISRE after 1, 7 and 14 day of propagation

5 ADVANTAGE OF GALILEO HIGH CLOCK STABILITY

This paragraph presents some investigation to take advantage of the high stability of Galileo clocks that were not taken into account in the first part.

5.1 Linear Clock Drift Model

A linear clock drift model was introduced and the ECOM1S parameters estimated over a one year period. The estimation with and without clock model have been compared. This estimation was performed without box-wing model and only for short term performance and for Galileo only. Performance was estimated using Laser Ranging residuals. An improvement of 15% for IOV and 10% for FOC has been obtained.

However, it was expected that the introduction of the clock drift model should increase the measurement weight in the range direction. Yet, the estimation does match with this prediction model but with the one in which the measurement is almost “blind” in the range direction. A better understanding of the equivalent measurement model is mandatory to further improve the performance.

5.2 Processing of clock corrections

Processing of clock correction estimation provided by standard IGS processing was also performed. The objective is to identify if systematic error can be detected. It is assumed that when clock bias are removed in pre-processing and assuming that the clock stability is high, clock correction harmonics at orbital frequency harmonics are likely due to range errors.

A systematic error of 0.3 ns (+/- 9 cm) can be observed at low Sun elevation.

6 ORBIT DISSEMINATION

To achieve the accuracy required in a GNSS receiver:

- 4 SRP coefficients (D_0, Y_0, B_0, D_{1S}) and 6 orbit parameters as correction from classical broadcast ones need to be transmitted to the receiver for each satellite. 7 bits per parameters can be considered. The other coefficients can be stored.
- Considering a pure numerical integration, a typical value of 0.6s is required to propagate the orbit of 4 spacecraft over one week.

7 FIELD TESTS

First, a receiver simulator was used to assess the performances. Second, tests on a real receiver have been performed in ESTEC housing ESA facility. The main test results are:

- In bi-constellation mode and Galileo mono-constellation mode, without clock prediction, the precision on each axis is about 1m after less than 7 days of propagation, both during simulations and field tests.
- With clock prediction, the uncertainty on the position is dominated by clock-induced errors.
- In terms of TTFF performances, the Fine-Time, Fine-Position results are consistent with receiver's Hot Start performances, with a median TTFF below 2s. The Coarse-Time performances are within expectations in Galileo-only mode (about 6s of median TTFF), and slightly higher than expected in bi-constellation configuration (about 8s of median TTFF).

8 CONCLUSION

The study shows that introduction of a deterministic model together with the improved ECOM1S stochastic model significantly improves the performances thanks to:

- The introduction of a boxwing model "tuned" to match observations.
- The introduction of the D_{1S} coefficient.

Processing of the clocks shows that some improvement can be expected by taking into account this additional observation and could potentially solve the observability problem. However, the orbit estimation process is complex and a deeper characterization is required to better understand the relation between the model and the observations (including the clock) in order to be in a position to revert this relation and fine tune the model on the basis of the observation to remove any systematic error.

While some systematic error is probably still present in the orbit determination and will be removed by further analysis, it is likely that we are now close to the point where the platform instability (attitude and thermal) will dominate the performance. Future platforms shall include requirements to ensure that precise orbit determination to the required user level is possible.