EXECUTIVE SUMMARY

EMOTE

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Code:	EMOTE-GMV-ES
Version:	1.0
Date:	20/11/2019
Internal code:	GMV 24605/19 V1/19

DOCUMENT STATUS SHEET

Version	Date	Pages	Changes
1.0	20/11/2019	12	First version for FR

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LIST OF TABLES AND FIGURES

No se encuentran elementos de tabla de ilustraciones.

1. INTRODUCTION

1.1. PURPOSE

The Executive Summary Report shall concisely summarise the findings of the contract.

1.2. SCOPE

This document summarises the main outcomes of the project activities.

1.3. DEFINITIONS AND ACRONYMS

1.3.1. ACRONYMS

Acronyms used in this document and needing a definition are included in the following table:

Table 1-1 Acronyms

Acronym	Definition
ECOM	Enhanced CODE Orbit Model
E-OSPF	Enhanced Orbit and Clock Processing Facility
ESA	European Space Agency
FFP	First Fix Position
FOC	Full Operational Capability
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GST	Galileo System Time
IGS	International GNSS Service
IOV	In Orbit Validation
MGEX	Multi-GNSS Experiment from the IGS
NAPEOS	ESA/ESOC software "Navigation Package for Earth Observation Satellites"
PCO	Phase Centre Offset
PCV	Phase Centre Variation
RINEX	Receiver Independent Exchange format for GNSS data
RMS	Root Mean Square
RTC	Real-time clock
SLR	Satellite Laser Ranging
SRP	Solar Radiation Pressure
TBD	To be determined/done
TC	Test Case
ToW	Time of week
TTFF	Time to First Fix
UCL	University College London

2. REFERENCES

2.1. APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.x]:

Table 2-1 Applicable Documents

Ref.	Title	Code	Version	Date
[AD.1]	ORBIT /SRP Modelling for Long Term Prediction	ESA AO/1-8118/14/NL/LF	1.0	24/09/2014
[AD.2]	Orbit / SRP Modelling for Long Term Predictions	GMV 12416/14 V1/14	1.0	21/11/2014
[AD.3]	CCN 1 to Contract 4000114030		1.0	12/12/2018

2.2. REFERENCE DOCUMENTS

The following documents, although not part of this document, amplify or clarify its contents. Reference documents are those not applicable and referenced within this document. They are referenced in this document in the form [RD.x]:

Table 2-2 Reference Documents

Ref.	Title	Code	Version	Date
[RD.1]	Supporting Analyses for S/C Dynamics and for System Level Activities (Annex 2 to GAL-AN-ASTD-SS-R-0001) & Annex	GAL-AN-ASTD-SS-R-0024	2.2	30/09/2010
[RD.2]	Satellite Mechanical ICD for FMs	GAL-ICD-ASTD-SA-R-0018	6.5	31/05/2012
[RD.3]	Satellite Thermal ICD for FM	GAL-ICD-ASTD-SA-R-0020	4.1	30/03/2012
[RD.4]	SSUM – Volume 6 Thermal	GAL-MAN-ASTD-SA-R-0008	2	11/06/2012
[RD.5]	Reduction of EIRP for GSAT-010x IOV Satellites, expected impact onto System and Users	GAL-MEM-ESA-SYST-TB-14-02 1- 2d1	N/A	20/01/2015
[RD.6]	Description of RTMM for Launcher Thermal Analysis & Annex	GAL-TN-ASTD-SA-Z-0255	3.1	19/03/2012
[RD.7]	Galileo IOV Satellite Metadata	GAL-TN-ESA-SYST-X-2153	1	31/03/2014
[RD.8]	AOCS Full Performance Test Report (extraction RD25)	GS-AOCS-OHB-TR-0048	1	27/03/2014
[RD.9]	GSS Simulation Campaign Test Report (extraction RD24)	GS-AOCS-OHB-TR-0079	6	11/07/2014
[RD.10]	Satellite Mechanical ICD	GS-SAT-OHB-ICD-0003	4	03/09/2011
[RD.11]	DI-19: Satellite Design Data and Satellite Models (extraction RD04)	GS-SAT-OHB-TN-0099	12	13/03/2015
[RD.12]	Thermal ICD (extraction RD03 & Annex)	GS-THE-OHB-ICD-0010	12	24/02/2015
[RD.13]	RGTMM Description (RD05 & Annex)	GS-THE-OHB-TN-0110	10	04/03/2015
[RD.14]	Galileo Satellites - Effect of Thermal Dissipation Imbalance on Precise Orbit Determination	ESA-DTEN-NG-MEMO/0012112	TBD	TBD
[RD.15]	Modelling radiation forces on the Galileo IOV and FOC spacecraft	UCL-EMOTE-ESTEC-May17	1	08/08/2017
[RD.16]	Space product assurance: Measurements of thermo-optical properties of thermal control materials	ECSS-Q-ST-70-09C	2	31/07/2008
[RD.17]	ESATAN-TMS Workbench Reference Manual	N/A	TBD	TBD
[RD.18]	Antenna thrust effect in Galileo satellites	N/A	N/A	05/07/2016
[RD.19]	EMOTE-TN1	EMOTE-UCL-D1	1.0	12/11/2015
[RD.20]	EMOTE-TN2 Design Model Implementation	EMOTE-POSITIM-D2	2.0	20/11/2019
[RD.21]	EMOTE-TN3 Design Model Validation	EMOTE-POSITIM-D3	2.0	20/11/2019

Ref.	Title	Code	Version	Date
[RD.22]	EMOTE-TN4 Field tests	EMOTE-GMV-D3	2.0	27/06/2018
[RD.23]	EMOTE-TN5 Conclusions and recommendations	EMOTE-GMV-D5	1.0	20/11/2019
[RD.24]	EMOTE-TN6 Algorithm detailed processing model	EMOTE-UCL-D6	1.0	20/11/2019
[RD.25]	Frank van Diggelen, 'A-GPS: Assisted GPS, GNSS, and SBAS'	-	-	-

3. OBJECTIVES OF THE PROJECT

The principal objectives of this activity were threefold:

- Develop a revolutionary set of force models dealing comprehensively with those forces induced by electro-magnetic radiation either incident on, or emitted by, the Galileo satellites. These can be split into 3, namely:
  - GEN1: Model derived from the reduced geometric and thermal mathematical models (RGTMM), provided to UCL in ESARAD/ESATAN format, which was converted to UCL spacecraft modelling format.
  - GEN2: Evolution motivated by inconsistencies identified when cross-referencing values of surface material properties given in the RGTMM against values included in the Thermal ICD's and other documents (e.g the material properties of the radiators, black MLI, etc.).
  - GEN3: Model evolution to be undertaken under EMOTE's CCN1, to account for the following effects:
    - MLI processing
    - Retro reflector array modelling
    - NAVANT thermal signature modelling
    - Bus Component Thermal Dissipation
    - Treatment of the SLI covering the NAVANT
- Apply these force models in the process of orbit determination and prediction of the Galileo satellites, assessing their performances by means of different metrics.
- Study the impact of this new prediction capability on mass market user positioning in a series of experiments.

4. OVERVIEW OF THE ACTIVITIES

This section provides a brief overview of each activity performed during this project. Accounting for the model definition, implementation and validation, and its subsequent testing at user level.

4.1. MODEL DEFINITION

The activity related to the definition of the new SRP models, accounted for:

- Reviewing of available literature on photon force modelling and orbit prediction/ephemeris extension methods. Collation of space vehicle structural, materials properties, attitude and ancillary data provided by ESA as inputs to the project.
- Selection of appropriate modelling and model computation methods. Definition of approach for ephemeris extension/orbit prediction, including design of POD environment (software selection) and estimation strategy.
- Definition of high accuracy, high resolution force models for Galileo IOV and FOC vehicles

4.2. MODEL IMPLEMENTATION

The activity related to the implementation of the new SRP models, accounted for:

- Definition of the test scenarios. Gathering of test data and all corresponding metadata.
- Implementation of high accuracy, high resolution force models for Galileo IOV and FOC vehicles, to be gathered within grid files.
- Design and implementation of the algorithms of the selected models both within NAPEOS and the E-OSPF.
- Definition, design and implementation of the interfaces to the outputs (grid files) of the UCL models
- Review of selected techniques, in particular regarding complexity, error budget, and sensitivity assessment of dependence of input parameters.

4.3. MODEL VALIDATION

The validation activities carried out throughout the project, comprised:

- Execution of the validation tests.
- Evaluation of the obtained results.
- Iteratively, where needed, improve/correct software implementation and rerun all tests.

4.4. FIELD-TESTS

The filed test activities comprised the final demonstration of selected techniques during field tests with standard mass-market receivers and real-time measurements to validate the gain with respect to current techniques. These activities took advantage of the record and replay equipment made available by ESA at ESTEC.

The filed test activities focused on:

- TTFF Analysis
- Accuracy Analysis

4.5. MAIN ACHIEVEMENTS

Although this project addressed different topics, the following deserve a special mention:

- The consortium, including ESA, have built a significant body of new knowledge and experience in the Galileo Project.

- Each successive generation of developed SRP models has tried new ideas, and systematically improved the orbit results.
- GEN3 models achieved SLR results of 6.5 mm +/- 18 mm over two years of orbits for the FOC spacecraft.
- The UCL model has the best accuracy for the 14 day prediction using the GALILEO constellation.

5. CONCLUSIONS

Over the scope of this project the Consortium has managed to continuously increase its understanding of the Galileo satellites. Not in the least thanks to the persistent efforts of ESA's Technical Officer. Thanks to this increased understanding it was managed to step for step improve the derived models.

The final model is the UCL 3rd generation model enhanced with a special thermal model for the navigation antenna (NAVNAT). This final model outperforms all the evaluated SRP models for most of the analysed evaluated criteria.

Although this model gives the best overall results, there are still some relatively large uncertainties and imperfections which are:

- Temperature difference between the radiators on the Y sides. This constant part of this will be captured by the Y0 parameter of the ECOM but it should then also be "always on", currently this force is turned off during the satellite eclipse.
- Amount of radiation being emitted by the radiator on the –Z side. This may very well be a rather significant force judging by the significant scale issue of the box-wing model for the FOC satellites.
- Energy equilibrium of the navigation antenna. The simple model of the NAVANT did clearly bring an improvement. There are, however, some clear deficits in our simple model and we have to better understand what happens with the NAVANT temperature.

The next steps should be to further enhance our understanding of the thermal household of the Galileo satellites and with that improve our current model even further. Both the role of the radiators on the satellite as well as the reradiation of the MLI and SLI are important aspects to investigate. In principle it is necessary to completely understand the steady state of the energy flow through the satellites resulting from the electrical current as well as from solar and terrestrial radiation.

All these unknows lead, in particular, to an uncertainty in the scale of the orbit and the periodic forces along the Z-axis of the satellite body fixed frame (radial direction). For future work the high stability of the Galileo clocks and the presence of excellent SLR tracking data will be very helpful to identify improvements in the derived models.

END OF DOCUMENT