

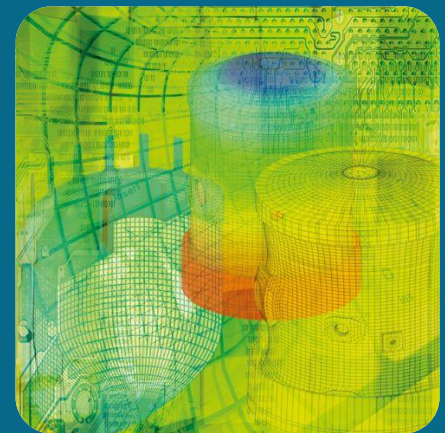
Achievements in Space Flight Dynamics

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Presentation to:



UNIVERSITATEA
DIN
CRAIOVA



14TH OF DECEMBER, 2018



AGENDA

- ➔ Main components of a Flight Dynamics Software (FDS)
- ➔ Orekit open source space dynamics library
- ➔ Neosat FDS application for SpaceBus Neo electric satellites
- ➔ Space debris collision avoidance movie using simulations with Orekit library



MAIN COMPONENTS OF A FLIGHT DYNAMICS SOFTWARE (FDS)

1

➔ What is a Flight Dynamics Software in a Space system?

- › A ground segment operational software used to control a satellite in orbit
 - Determine the orbit (GNSS and/or ground stations measurements)
 - Predict the orbit & orbital events (orbit propagation & detectors)
 - Plan the orbital maneuvers & monitor the propulsion system

➔ When is it used?

- › During all the phases of a satellite lifetime
 - Launch & Early Orbit Phase (beginning of life)
 - Station Keeping (operational phase)
 - Disposal (end of life)

➔ Who uses it?

- › Operators
 - Everyday survey and control of the satellite
 - Occasional help from experts in case of issue or emergency



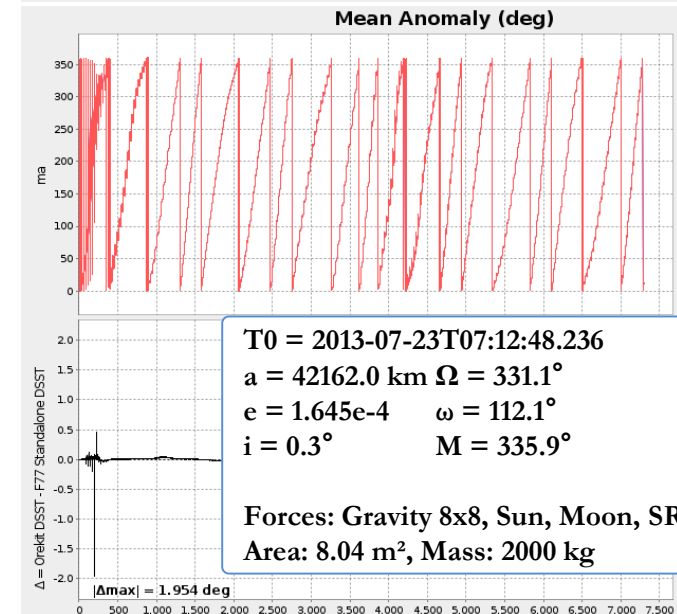
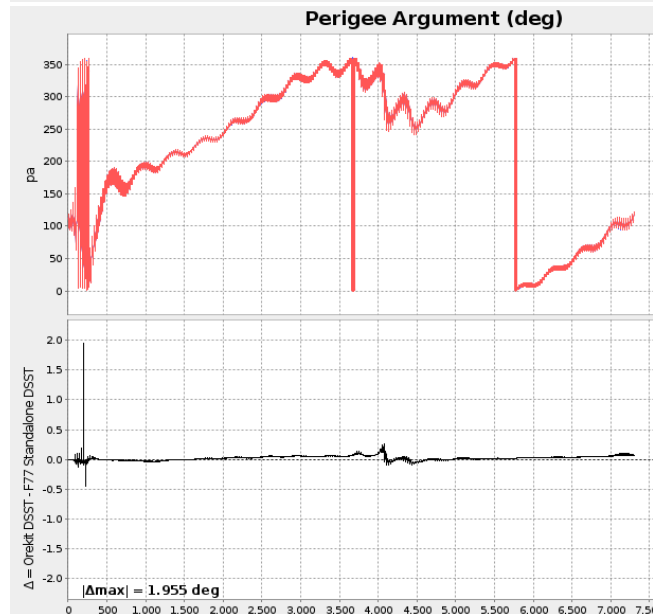
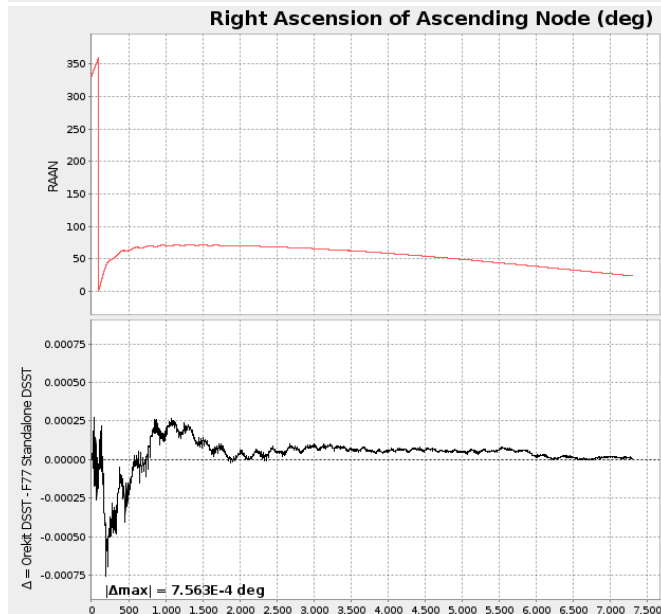
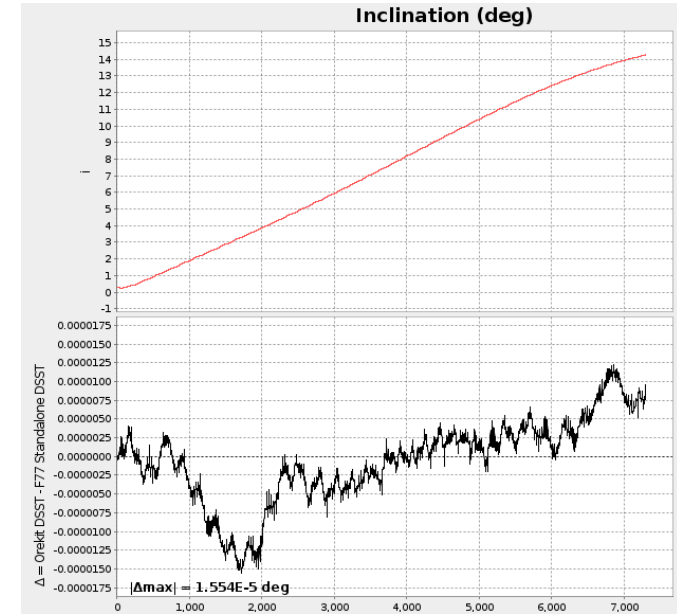
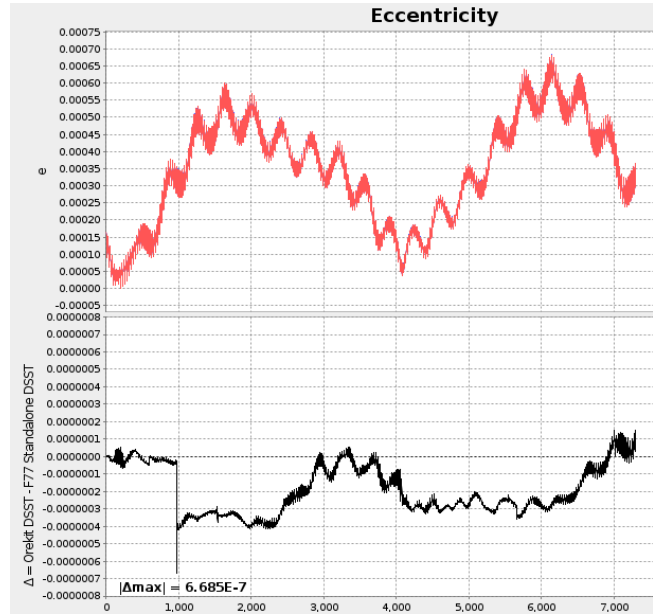
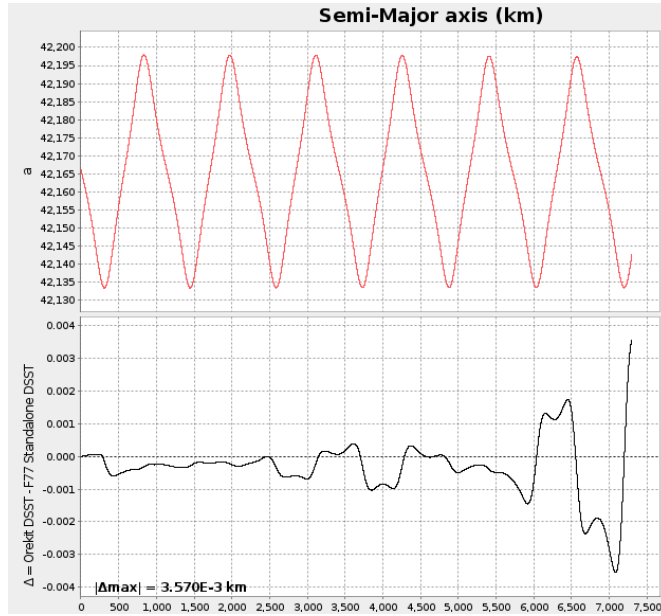
OREKIT OPEN SOURCE SPACE DYNAMICS LIBRARY

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- ➔ Open source space dynamics library that provides accurate and efficient low level components for the development of flight dynamics applications, implemented in Java (<https://www.orekit.org>)
- ➔ Main features:
 - › Propagation
 - Analytical propagation models
 - Numerical propagator with customizable force models (central attraction, gravity models, atmospheric drag, third body attraction, radiation pressure with eclipses, tides, multiple maneuvers)
 - Semi-analytical propagation model (DSST) with customizable force models, implemented by CS ROMANIA and CS SI as ESA project
 - › Maneuvers - Impulse maneuvers, continuous maneuvers
 - › Attitude - Predefined laws such as nadir pointing, yaw compensation, inertial
 - › Spacecraft - Cartesian, elliptical Keplerian, circular and equinoctial parameters, Two-Line Elements and transparent conversion between parameters
 - › Use of Hipparchus (<https://hipparchus.org>), a Java a library of low level, lightweight and self-contained mathematics and statistics components

Orekit DSST – semi-analytical propagator (ESA project)

➔ Validation against Standalone DSST software provided by Paul Cefola (Draper Labs)

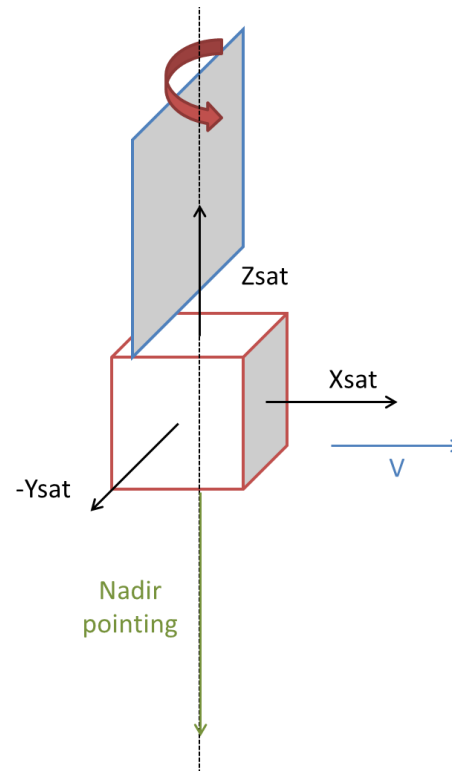


T0 = 2013-07-23T07:12:48.236
 $a = 42162.0 \text{ km}$ $\Omega = 331.1^\circ$
 $e = 1.645\text{e-}4$ $\omega = 112.1^\circ$
 $i = 0.3^\circ$ $M = 335.9^\circ$

Forces: Gravity 8x8, Sun, Moon, SRP
 Area: 8.04 m², Mass: 2000 kg

Orekit DSST – handling of periodic attitudes

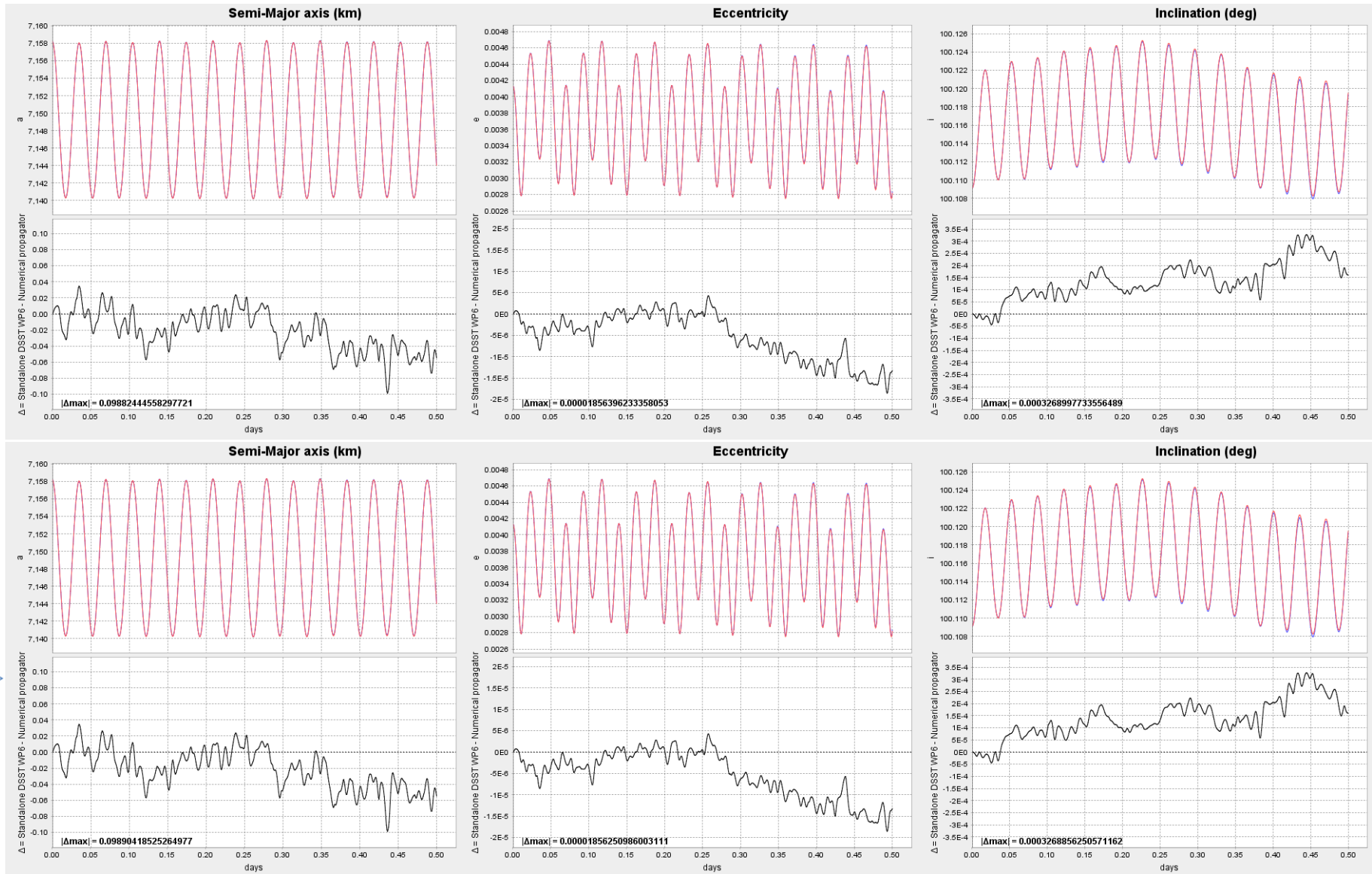
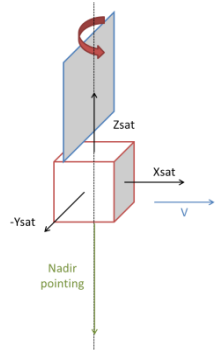
- ➔ Validation strategy for attitude handling – implement DSST attitude modelling and use of Orekit's numerical propagator as a reference
- ➔ Various cases of spacecraft shape, surface, and attitude law
- ➔ Example: observation satellite
 - › Box + Solar arrays: Mass: 1000 kg
 - › Box: 1.0 x 1.0 x 1.0 m
 - › Solar arrays: 5 m²
 - › Attitude law: Nadir Pointing



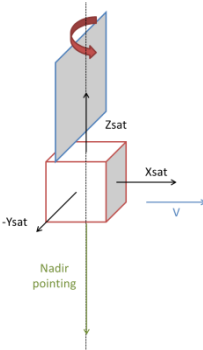
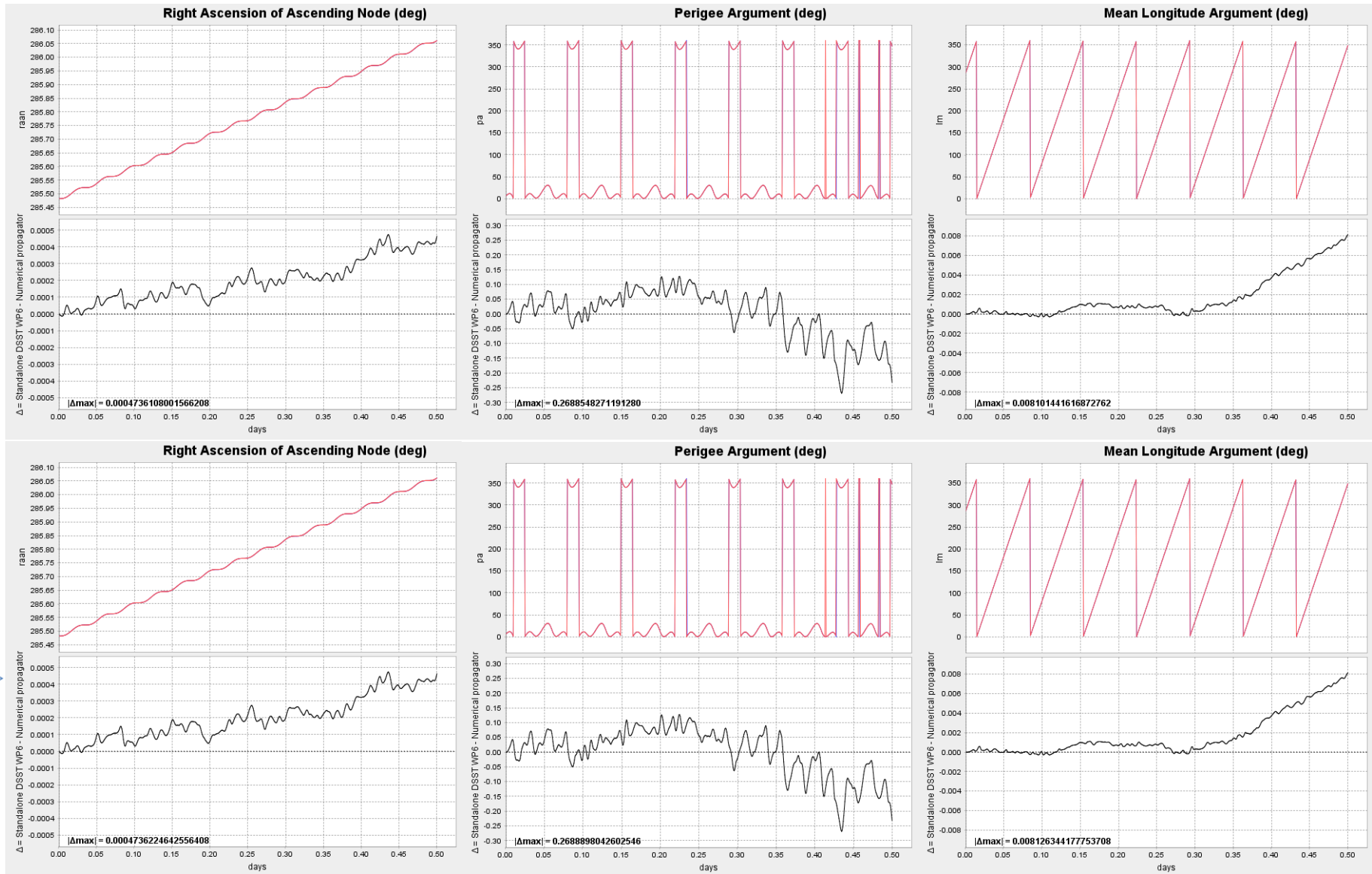
T0 = 2013-07-23T06:46:23.312
 a = 7149.2 km $\Omega = 285.5^\circ$
 e = 3.652e-3 $\omega = 6.4^\circ$
 i = 100.1° M = 353.8°
 apogee alt. = 797.2 km
 perigee alt. = 745.0 km

Forces: Gravity **50x50**, Drag, **Sun**, **Moon**

Orekit DSST – handling attitudes of an observation satellite (1/2)



Orekit DSST – handling attitudes of an observation satellite (2/2)





NEOSAT FDS FOR SPACEBUS NEO ELECTRICAL GEOSTATIONARY SATELLITES

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- ➔ Neosat - part of ESA's Advanced Research in Telecommunications Systems (ARTES) program
- ➔ Context and Challenges
 - › Development of an infrastructure for the integration with Satellite Control Center (SCC) system
 - › Combining FDS modules with Electrical station keeping, Relocation maneuvers, De-orbitation maneuvers and Maneuver reconstruction modules
- ➔ SpaceBus Neo electrical geostationary telecommunication satellites
 - › Payload capacity: up to 2000 kg, in the range of 20kW
 - › Mass at launch: from 3 to 6 tons



➔ Neosat project objective:

- › Implementation of a Flight Dynamics Software (FDS) set of modules designed to perform the orbital control of a geostationary satellite during On Orbit Control (OOC), relocation and deorbitation phases

➔ Neosat project organization:

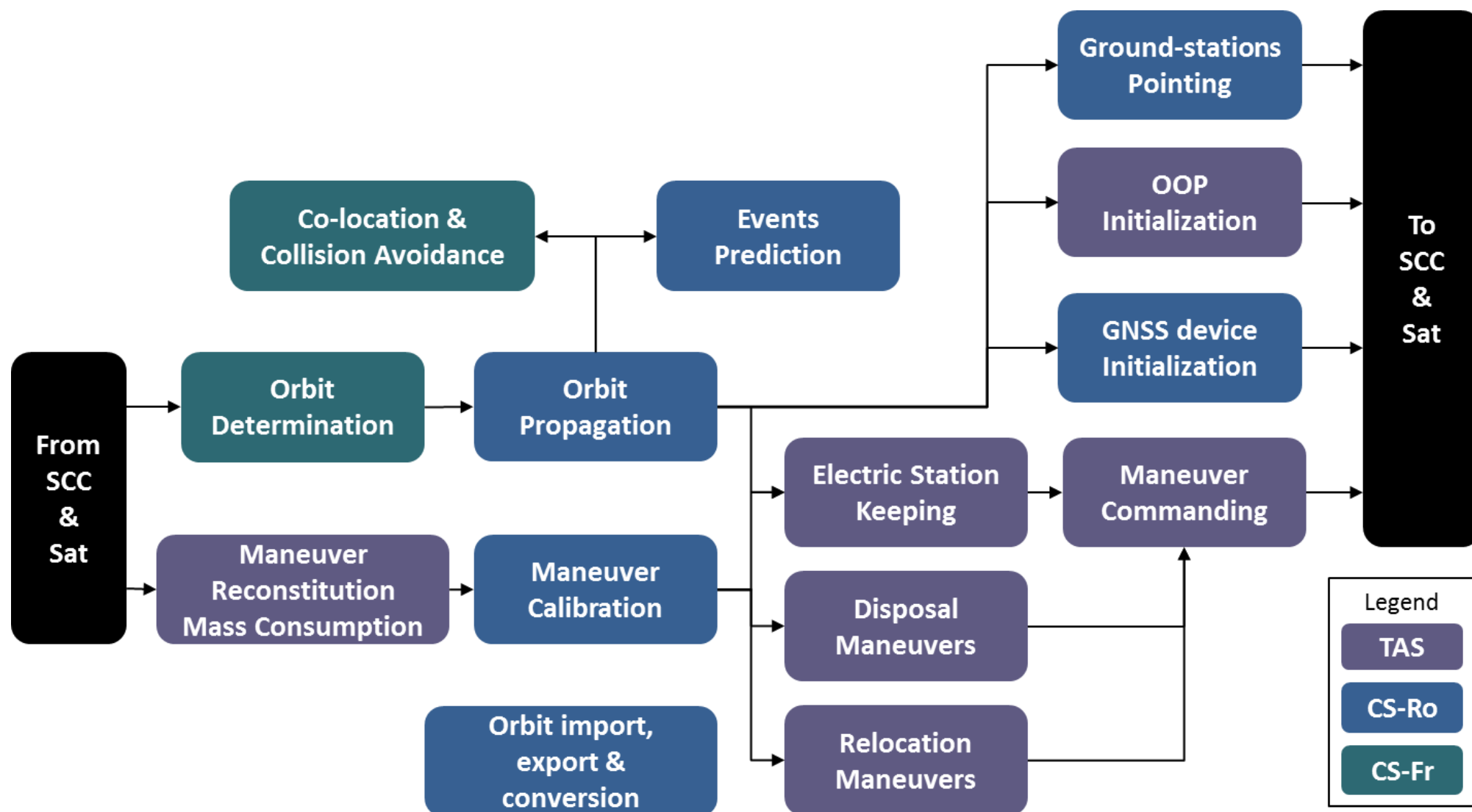
- › ESA – Head of Neosat Program, final customer
- › Thales Alenia Space (TAS) – designer and integrator of SpaceBus Neo, customer of Neosat FDS
- › CS ROMANIA – Prime Contractor of TAS, in charge with FDS management, design, development and validation
- › CS France – Sub-contractor, provides expertise in flight dynamics

➔ Contributions of CS ROMANIA

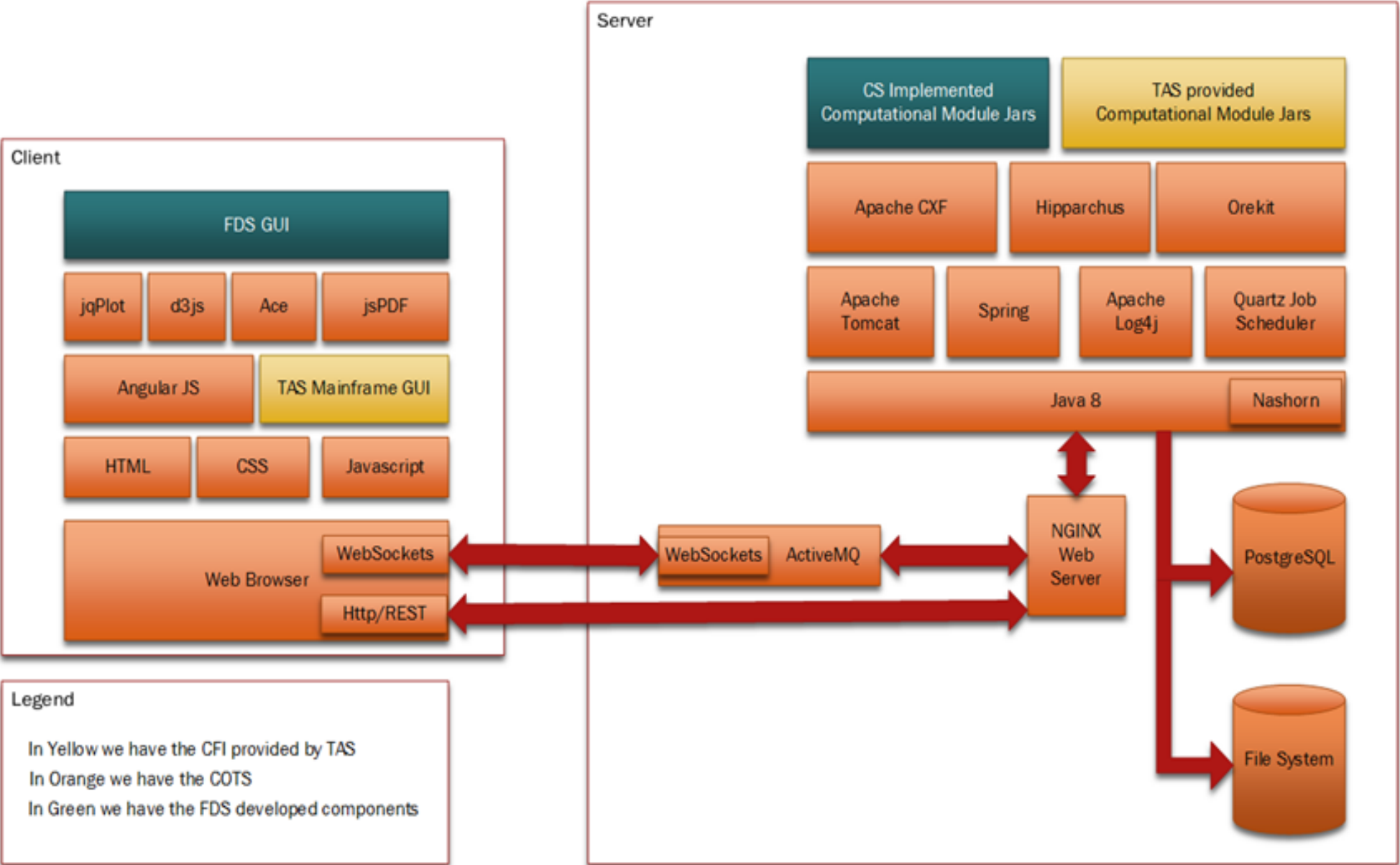
- › Implementation of FDS modules:
 - Orbit propagation including maneuvers,
 - Orbital events prediction (including interferences computation),
 - Ground antenna pointing,
 - Orbit import, conversions and export,
 - GNSS receiver initialization,
 - Software infrastructure for integration with SCC

➔ Client Benefits

- › High precision Flight Dynamics Software modules
- › Integration with Satellite Control Center
- › Use of Orekit open-source space dynamics library



Neosat FDS Technology Stack



Neosat FDS Example – Orbit Propagation

Orbit >  Propagation

Satellite: Astra 2G Set

Inputs Astra 2G

Load context

Run

Cancel

Validate

Select Bulletin

Propagator & Force Models

Select Maneuvers

Maneuvers files:

☒ A2G_cycle1.manplan (from 2018-11-02T01:00:00.000 to 2018-11-02T02:43:50.009)

+

Maneuver Plan A2G_cycle1.manplan Content

Propagator Settings

Extrapolation Step:

5

minutes

Integrator:

Dormand Prince

Propagator Minimum Step:

0.001

seconds

Propagator Maximum Step:

5

minutes

Propagator position error [m]:

10

Force Models

Central Body Gravity:

Degree:

8

Order:

8

Third party perturbations:

Consider Sun Gravity:

☒

Consider Moon Gravity:

☒

Radiation pressure:

Consider SRP:

☒

Outputs Astra 2G

Data

Plots

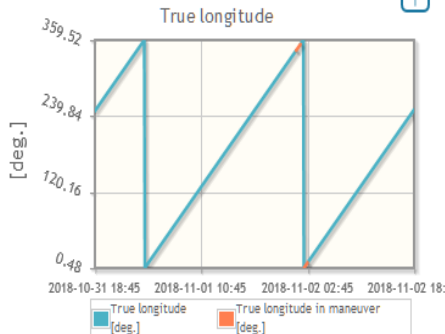
Files

2 Rows / 2 Columns

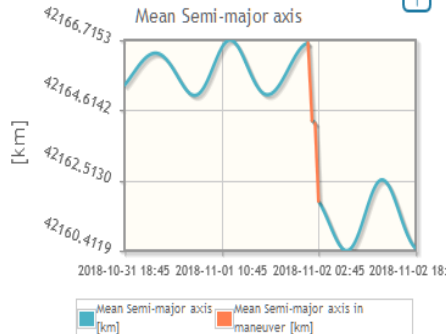
Set

Choose Plots to Display

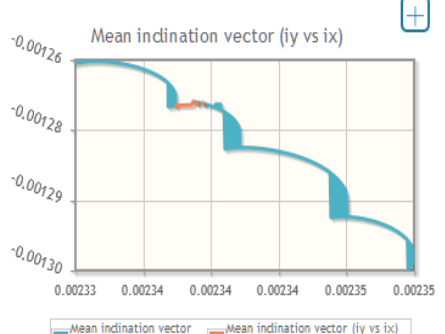
True longitude



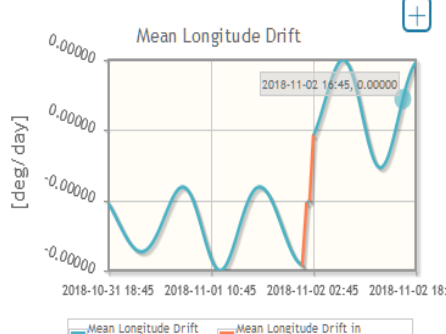
Mean Semi-major axis



Mean inclination vector (iy vs ix)



Mean Longitude Drift



Timestamp	Level	Message
2018-12-10T16:57:22	INFO	The execution of the process function of the Orbit Propagation module has finished
2018-12-10T16:57:01	INFO	Executing the process function of the Orbit Propagation module

Execution Logbook 

Neosat FDS Example – Orbit Determination

Orbit > **Determination (Least-square)**
Satellite: Astra 2G Set

Inputs Astra 2G

Load context

Run

Cancel

Validate

Initial Bulletin & Target Date

Measurements & Maneuvers Files

Estimated Parameters

Estimator Configuration

Propagator & Force Models

Orbit determination target date

Expected UTC Date: 2016-11-22T00:00:00

Estimated orbit frame: J2000

Estimated orbit format: Cartesian Position and Velocity

Initial Guess Bulletin Selection

Initial Epoch: 2016-11-21T00:00:00

Get Bulletin

Initial orbital bulletin: A2G_20181031_194500.odp

Bulletin File Type : Ephemeris

Source Frame: TOD

Source Format: Osculating Keplerian Elements

Display frame: TOD

Display format: Cartesian Position and Velocity

Mass: 1161.83 kg

SRP coefficient: 0.8

Parameter Value

Unit

px 2.1052245523012E4 km

py 3.6542393333637E4 km

pz 208.121661349 km

vx -2.662742113 km/s

vy 1.534978768 km/s

vz 0.028054361 km/s

Reset to Bulletin

Save context

Outputs Astra 2G

Data

Plots

Files

LS Algorithm Computation Details

Final Iteration: 4

Final Evaluation: 5

Final RMS value: 0.6101131292218224

Final maximum weighted residual: 3.0717002376914024

Orbital Parameters

Estimated orbit date: 2016-11-22T00:00:00.000

Estimated Orbit Frame: EME2000

Estimated Orbit Format: Cartesian Position and Velocity

Parameter	Estimated Value	Accuracy	Initial Value	Difference
px [km]	20398.49521531081	0.0014045296388343273	20308.092068101756	90.403147209052
py [km]	36882.02030800822	0.0009922781618060554	36932.80558507595	-50.78527706772089
pz [km]	184.35198892882826	0.0005727527533065985	184.957020850595	-0.6050319217667275
vx [km/s]	-2.690361457960091	1.1315504836771609e-7	-2.693241088441953	0.0028796304818620227
vy [km/s]	1.4890438357337568	1.0642058758831505e-7	1.4828577095563638	0.006186126177392908
vz [km/s]	0.03202878514378139	4.6386695198104214e-8	0.03224709151981897	-0.00021830637603758874

Propagation Parameters

Parameter	Estimated Value	Accuracy	Initial Value	Difference
SRP coefficient	1.0561345992494373	0.06703936645190922	0.8	0.25613459924943727

Maneuver Cycle 3 / Maneuver 3

Delta V radial [m/s]

-0.24376497142234152

0.00014187681865133006

-0.2312673410943945

-0.012497630327947012

Delta V tangential [m/s]

0.0480357582890255

0.000027957915888347253

0.04557300432517262

0.0024627539638528845

Delta V normal [m/s]

0.22579532111574088

0.00013141806896756097

0.21421898003351275

0.011576341082228131

Maneuver Cycle 3 / Maneuver 4

Maneuver Cycle 3 / Maneuver 1

Maneuver Cycle 3 / Maneuver 2

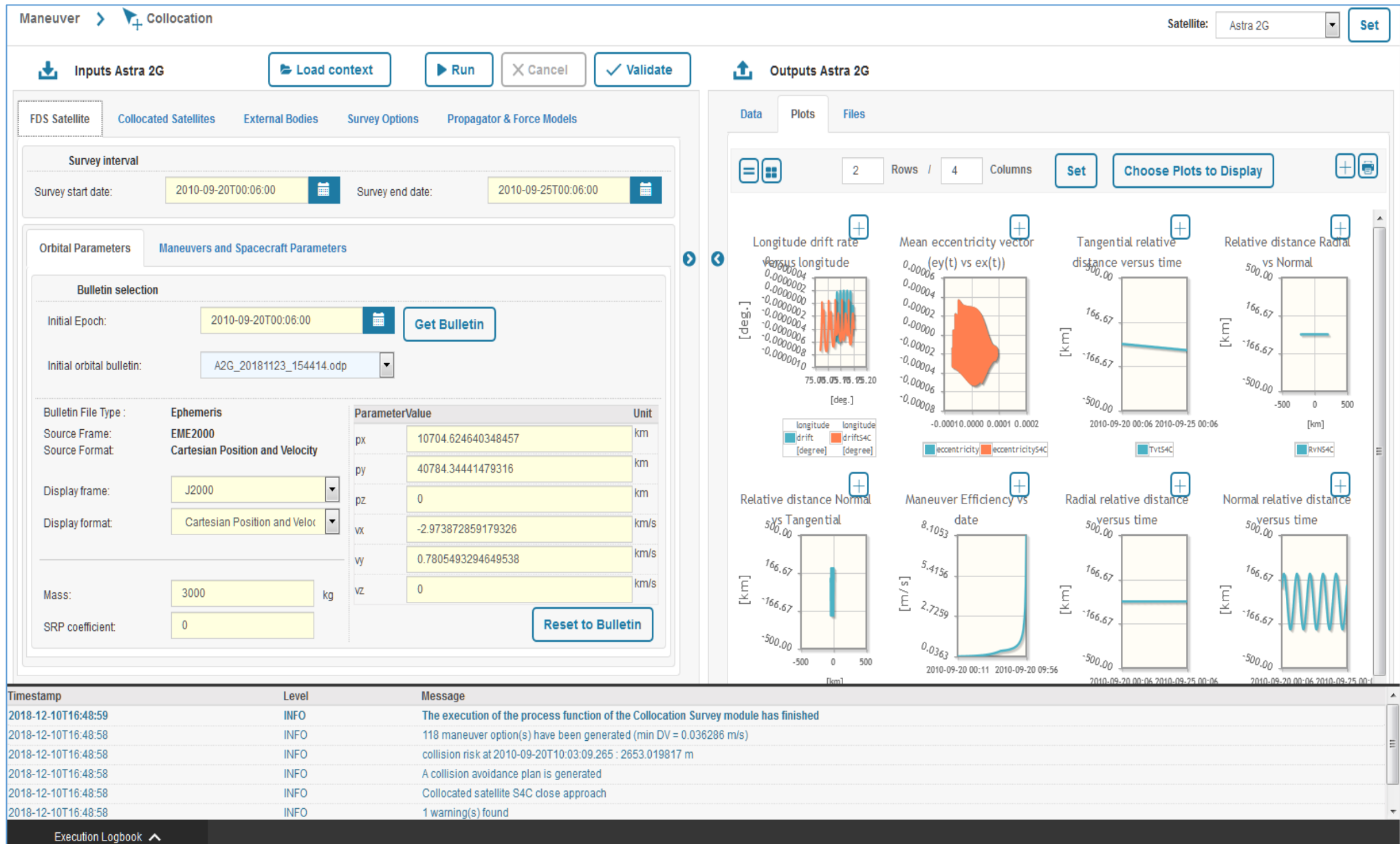
Measurement parameters

Parameter	Computed Value	Accuracy	Initial Value	Difference
Satellite Range Bias [m]	Not Estimated	Not Estimated	5969	Not Estimated

Timestamp	Level	Message
2018-12-11T10:40:02	INFO	The execution of the process function of the Orbit Determination Batch Least-Square module has finished
2018-12-11T10:39:39	INFO	Executing the process function of the Orbit Determination Batch Least-Square module

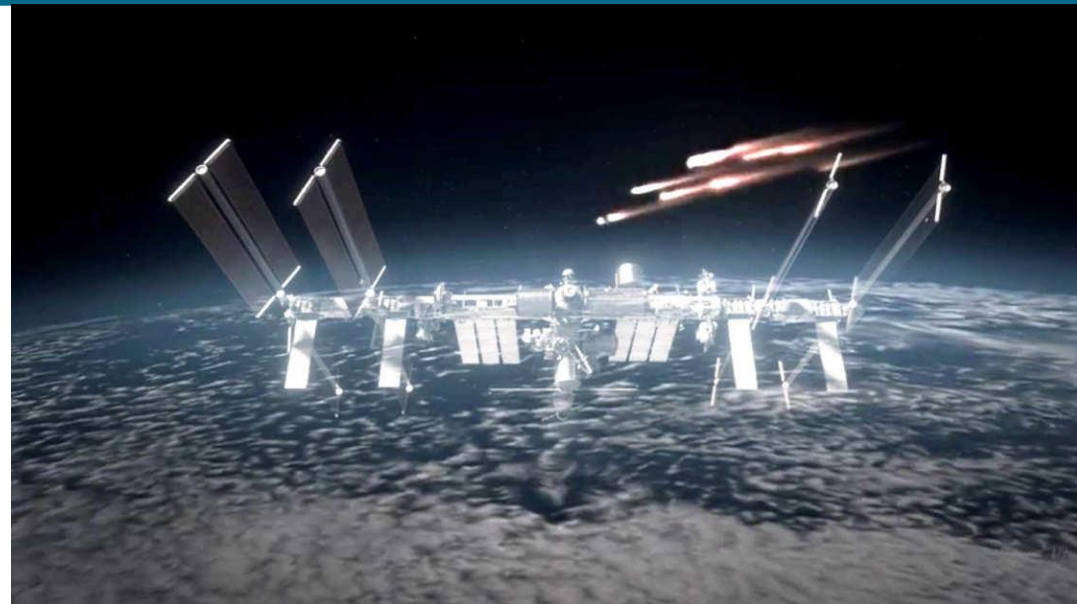
Execution Logbook

Neosat FDS Example – Collocation and collision avoidance



SPACE DEBRIS COLLISION AVOIDANCE MOVIE USING OREKIT LIBRARY

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- ➔ Stereoscopic 3D Space debris movie developed in 2017 for ESA's Space Debris Office by ONiRIXEL with support from CS OREKIT team for Flight Dynamics and Attitude simulation
- ➔ In order to display realistic positions and attitude requested by ESA, physical simulation was required for Earth orbiting objects. This simulation was based on OREKIT, that was directly interfaced with Blender Open-Source 3D animation software, to provide accurately realistic simulations for more than 15 000 objects
- ➔ Attitude is handled using a few predefined modes, depending on the debris category:
 - › Active spacecraft use controlled attitude depending on their orbit
 - › Other objects use tumbling mode with random initial attitude and angular velocity
 - › Solar arrays attitude is also computed with respect to the body attitude to ensure a proper orientation with respect to lighting in the movie scenes
- ➔ Orbit and attitude are propagated using a variable step numerical propagator
- ➔ Very realistic simulation, movie available on the net (YouTube, Google+) in both 2D & 3D

ENJOY THE MOVIE!

