

Achievements in Space Flight Dynamics

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Presentation to:



UNIVERSITATEA DIN CRAIOVA







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DESIGNER, INTEGRATOR, OPERATOR OF MISSION CRITICAL SYSTEMS





- → 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)

Flight Dynamics Software (FDS)



→ 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



About OREKIT library and main features



- Open source space dynamics library that provides accurate and efficient low level components for the development of flight dynamics applications, implemented in Java (<u>https://www.orekit.org</u>)
- ➔ 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 (<u>https://hipparchus.org</u>), a Java a library of low level, lightweight and selfcontained mathematics and statistics components

Orekit DSST - semi-analytical propagator (ESA project)



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



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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









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







NEOSAT FDS FOR SPACEBUS NEO ELECTRICAL GEOSTATIONARY SATELLITES



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Neosat FDS Project (1/2)



- 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 FDS Project (2/2)



- ➔ 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 Flight Dynamics Modules





Neosat FDS Technology Stack





Neosat FDS Example – Orbit Propagation



Orbit 📏 🍈 Propagation			Satellite: Astra 2G 💌 Set
🛃 Inputs Astra 2G	E Load context	Run X Cancel Validate	e Outputs Astra 2G
Select Bulletin Propagator & Force	Models		Data Plots Files
Select Maneuvers			2 Rows / 2 Columns Set Choose Plots to Display
Maneuvers files: A2G_cycle1	1.manplan (from 2018-11-02T01:00:	:00.000 to 2018-11-02T02:43:50.009)	
• Maneuver Plan A2G_cycle	1.manplan Content		True longitude
Propagator Settings			
Extrapolation Step:	5	minutes	239.84 F
Integrator:	Dormand Prince	•	¹ ¹ ² ¹
Propagator Minimum Step:	0.001	seconds 💌	42160,4110
Propagator Maximum Step:	5	minutes	0.48 2018-10-31 18:45 2018-11-01 10:45 2018-11-02 18:45 2018-10-31 18:45 2018-11-01 10:45 2018-11-02 18:45
Propagator position error [m]:	10		True longitude in maneuver True longitude in maneuver Mean Semi-major axis Mean Semi-major axis in maneuver [km]
Force Models			Mean inclination vector (iy vs ix)
Central Body Gravity:	Degree:	8	
	Order:	8	
Third party perturbations:	Consider Sun Gravity:	v	
	Consider Moon Gravity:	v	-0.000130
Radiation pressure:	Consider SRP:	v	0.00233 0.00234 0.00234 0.00235 0.00235 2018-10-31 18:45 2018-11-01 10:45 2018-11-02 02:45 2018-11-02 18:45
			In maneuver
Timestamp	Level	Message	
2018-12-10T16:57:22	INFO	The execution of the process function of the Orbit P	ropagation module has finished
2018-12-10T16:57:01	INFO	Executing the process function of the Orbit Propagatio	in module
Execution Logbook 🔨			

Neosat FDS Example – Orbit Determination



rbit 🔰 💽 Deter	mination (Least-square)									Satellite: A	stra 2G 🔹 🔹	
🛃 Inputs Astra	2G 🗲 Load cor	ntext 🕨 Run	X Cancel	Validate		1 Outputs	s Astra 2G					
Initial Bulletin & Target Da	ate Measurements & Maneuvers Files	s Estimated Parameter	s Estimator Configuration	n		Data Plots	s Files					
Propagator & Force Mode	els					LS Algo	orithm Comp	utation Details				
Orbit determinati	on target date					Final Iteration: 4 Final RMS value	4 e: 0.6101131 2	92218224	Final Ev Final m	valuation: 5 aximum weighted residual: 3.0)717002376914024	
Expected UTC Date:	2016-11-22T00:00:00					Orbital I	Parameters					
Estimated orbit frame:	J2000 Estimated orbit format: Cartesian Position and Velocity 💌					3 Estimated orbit of Estimated Orbit	ated orbit date: 2016-11-22T00:00:00.000 ated Orbit Frame: EME2000		Estimated Orbit Format: Cartesian Position and Velocity			
						Parameter	Estimated	I Value	Accuracy	Initial Value	Difference	
Initial Guess Bull	etin Selection					px [km]	20398.49	521531081	0.0014045296388343273	20308.092068101756	90.403147209052	
						py [km]	36882.02	030800822	0.0009922781618060554	36932.80558507595	-50.78527706772089	
Initial Epoch:	2016-11-21100:00:00	Get Bulleti	n			pz [km]	184.3519	8892882826	0.0005727527533065985	184.957020850595	-0.6050319217667275	
						vx [km/s]	-2.690361	1457960091	1.1315504836771609e-7	-2.693241088441953	0.002879630481862022	
Initial orbital bulletin: A2G_20181031_194500.odp 🔻						vy [km/s]	1.489043	8357337568	1.0642058758831505e-7	1.4828577095563638	0.006186126177392908	
					vz [km/s]	0.032028	78514378139	4.6386695198104214e-8	0.03224709151981897	-0.000218306376037588		
Bulletin File Type : Ephemeris Parameter Value Unit												
Source Frame:	TOD Osculating Keplerian Elements	px 2.105224552	2.1052245523012E4 kn			Propag	gation Paran	ieters				
Source Format:				km		Parameter	E	stimated Value	Accuracy	Initial Value	Difference	
		ру 3.65423933	3637E4			SRP coefficient	t 1.	0561345992494373	0.06703936645190922	2 0.8	0.25613459924943727	
Display frame:	TOD	pz 208.1216613	49 km			 Maneuver Cycle 3 / Maneuver 3 						
Display format:	Cartesian Position and Veloci		0.000740440			Delta V radial [m	m/s] -(.2437649714223415	2 0.00014187681865133	8006 -0.2312673410943945	-0.01249763032794701	
		VX -2.66274211	3			Delta V tangenti	tial [m/s] 0	0480357582890255	0.00002795791588834	7253 0.04557300432517262	0.002462753963852884	
		vy 1.534978768	3	km/s		Delta V normal [[m/s] 0	22579532111574088	0.00013141806896756	097 0.21421898003351275	0.011576341082228131	
Mass:	1161.83 ka	vz 0.02805436		km/s		+ Maneu	uver Cycle 3 /	Maneuver 4				
							Maneuver Cycle 3 / Maneuver 1					
SRP coefficient:	0.8		Reset to Bui	lietin		+ Maneu	uver Cycle 3 /	Maneuver 2				
						Measu	urement para	meters				
			📲 Save	context		Parameter	(Computed Value	Accuracy	Initial Value	Difference	
						Satellite Range	Bias [m]	Not Estimated	Not Estimated	5969	Not Estimated	
stamp	Level	Message										
12-11T10:40:02	INFO	The execution	The execution of the process function of the Orbit Determination Batch Least-Square module has finished									
	INFO	FKH _	a process function of the Orbit D		Dotob I	aget Cauero modulo						

Neosat FDS Example – Collocation and collision avoidance



ineuver 🔰 👎 C	collocation									Satellite	e: Astra 2G 💌 Se
🛃 Inputs Astra 2	2G 🗲 Lo	ad cont	ext	► Run	X Cancel	✓ Validate		1 Outputs Astra 2G			
DS Satellite Colloca	ted Satellites External Bodie	es Si	urvey Optic	ons Propagato	r & Force Models			Data Plots Files			
Survey interval									Rows / 4 Columns	Set Choose Plots	
Survey start date:	2010-09-20T00:06:00		Survey end	d date:	2010-09-25T00:06:(00					
Orbital Parameters	Maneuvers and Spacecraft Para	ameters					0 0	Longitude drift rate	Mean eccentricity vector $\rho_{, \rho_{0,0}}(ey(t) vs ex(t))$	Tangential relative distance versus time	Relative distance Radial ₅₀₀ vs Normal
Bulletin selection	n							0.0000002	0.00006	500.00	500.00
Initial Epoch:	2010-09-20T00:06:00			Get Bulletin				2000000.0 200000.0 000000.0 000000.0 0 000000.0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.00002 0.00000 0.00000 0.0000	1 _{66.67}	
Initial orbital bulletin:	A2G_20181123_154	414.odp	•					-0,00008 75.05.05.15.20	-0.00002 -0.00004 -0.00006	≚ ^{-166.67}	-500.00
Bulletin File Type :	pe : Ephemeris P		Parameter	arameterValue Unit				[deg.]	-0.00008	-500.00	-500 0 500
Source Frame:	EME2000 Cartesian Position and Veloci	tv	рх	10704.624640348457		km	km	drift degree]	eccentricity	Tvt54C	RvN54C
oodroo i onnac		.,	ру	40784.34441479	316	km					
Display frame:	J2000	•	pz	0		km		Relative distance Normal	Maneuver Efficiency vs	Radial relative distance	Normal relative distance
Display format:	Cartesian Position and Velo	and Veloc 💌 🗸		-2.97387285917	9326	km/s		sys Tangential	8.1053 date	soversus time	500.00
			w	0.7805493294649538		km/s					
Mass	3000	ka	vz.	0		km/s		E ^{'6.67}	5.4156 5	^{166.67}	C 166.67
0000 (finite	0	NY I			Besett	o Rullotin		[⊥] ^{-166.67}	트 ² .7 ₂₅₉	-166.67	∑ -1 _{66.67}
SRP coefficient:	U				Reset in	o Bulletin		-500.00	0.0363	-500	-500
tomp	Level			Maaaaaa				-500 0 500 [km]	2010-09-20 00:11 2010-09-20 09	56 2010-00 2010-06 2010-09-25 0	0:06 2010-09-20 00:06 2010-09-25 00:
2-10T16:48:59	INFO			The execution of	of the process functi	ion of the Collocati	on Surve	y module has finished			
-12-10T16:48:58 INFO			118 maneuver option(s) have been generated (min DV = 0.036286 m/s)								
-12-10T16:48:58 INFO		collision risk at 2010-09-20T10:03:09.265 : 2653.019817 m									
2-10T16:48:58	INFO			A collision avoid	ance plan is general	ted					
2-10T16:48:58	INFO			Collocated sate	lite S4C close appro	bach					
12-10T16:48:58	INFO	_	_	1 warning(s) fou	nd		_				



SPACE DEBRIS COLLISION AVOIDANCE MOVIE USING OREKIT LIBRARY



SPACE DEBRIS MOVIE – TECHNICAL DATA



- 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!



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