6th International Conference on Astrodynamics Tools and Techniques (ICATT)

Darmstadt, 14-17 March 2016

[187] Attitude/Orbit Simulation Tools for Drag-augmented Deorbiting - The DGNC Project -

presented in Debris, Safety and Awareness (I)

Outline

- Introduction to the DGNC project for ESA
- Description of the DGNC Simulation Tools : S-MIL and C-MIL
- Validation of the S-MIL
- DGNC project results achieved so far
- Next project’s activities until Final Presentation

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Introduction

- Since some years now, worldwide concern is raising about Sustainable Development of Space, hence about debris limitation in/removal from LEO Protected Region
- Several methods exist to remove debris from the LEO Protected Region:
  - Limit altitude (e.g. to max 550-650 for most typical Area-to-Mass Ratio - AMR)
  - Use drag-augmentation devices (i.e. dragsails/solarsails) or tethers
  - If available, use (remainings of) propulsion for (indirect or) direct re-entry
- For the methods using dragsails/solarsails (DRS/SRS), the question posed to DGNC is:

During deorbit, is it better to continuously optimise the Sat+DRS/SRS attitude wrt aerobraking fluxes (with active attitude control) OR is it better to leave the Sat+DRS/SRS uncontrolled (i.e. tumbling) ?

- To answer this question, the DGNC project had (so far) to:
  - Develop specific simulation tools (i.e. the S-MIL and now the C-MIL)
  - Perform trade-offs relating to ADCS/GNC aspects of Sat+DRS/SRS configurations

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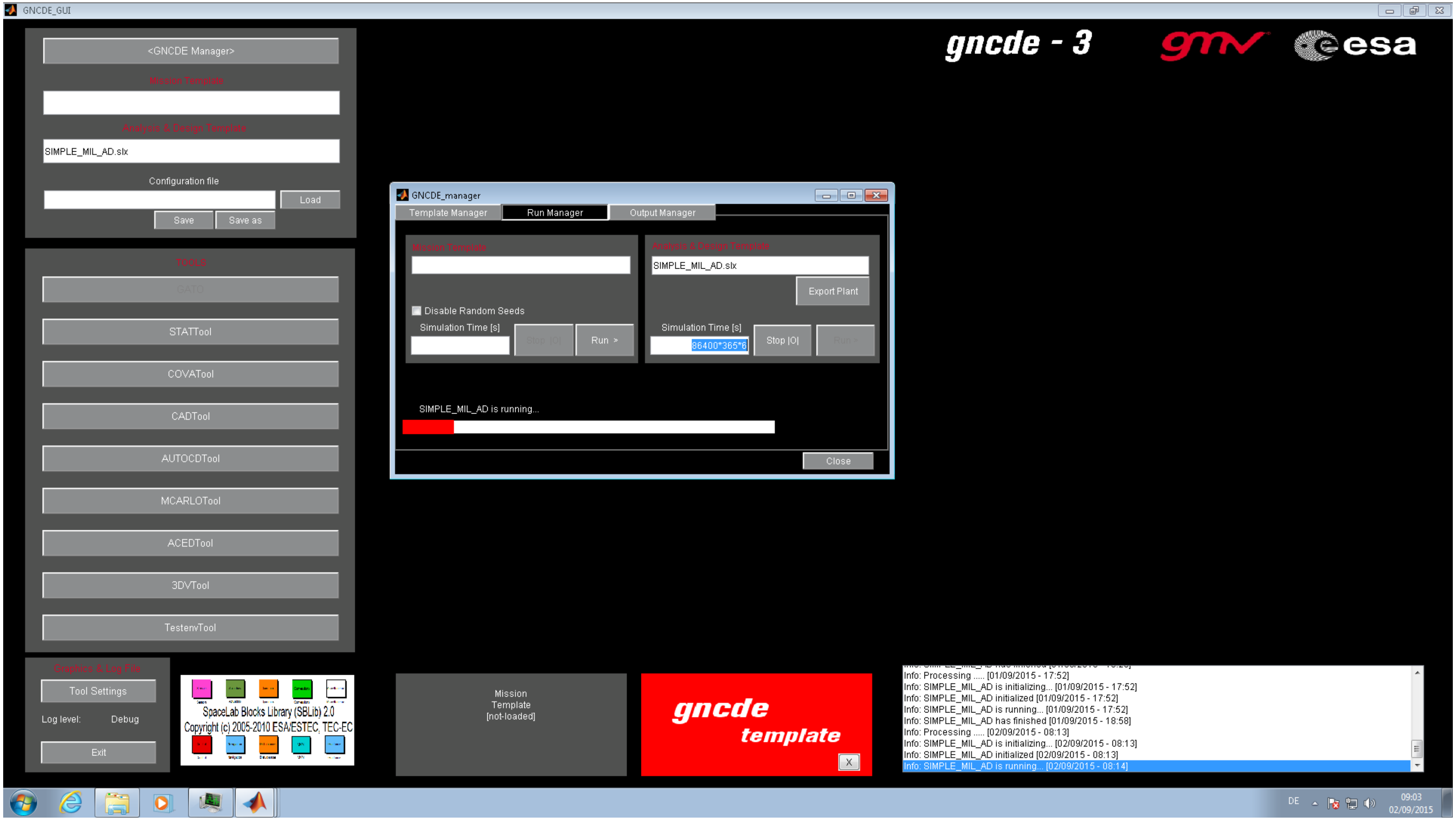
Description of the DGNC Simulation Tools : S-MIL and C-MIL

S-MIL Design (1)



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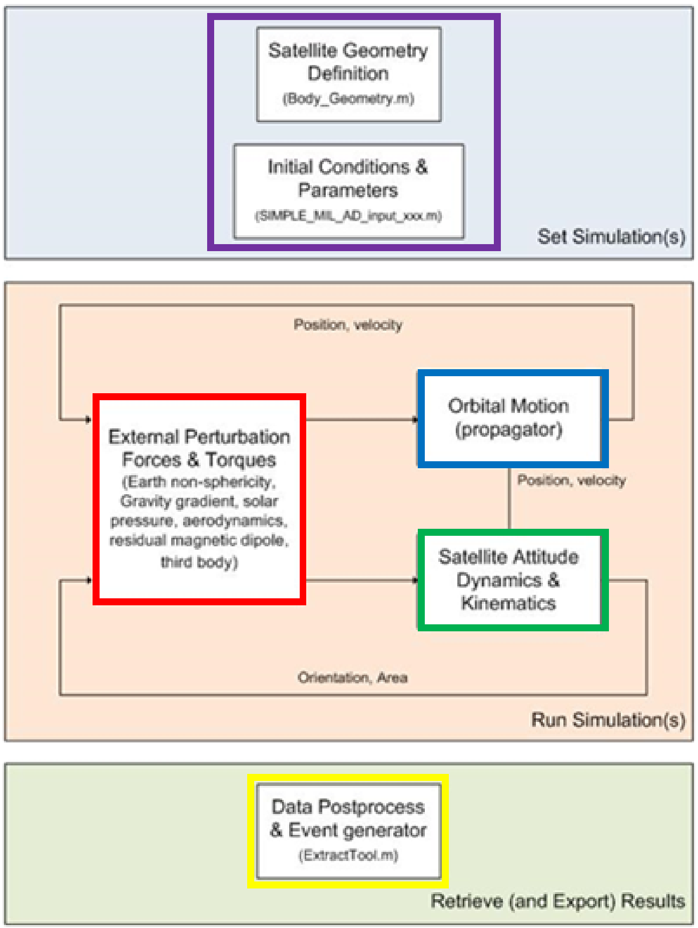
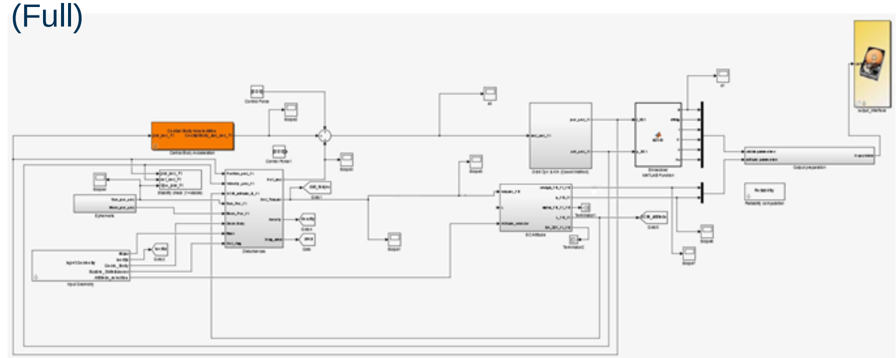
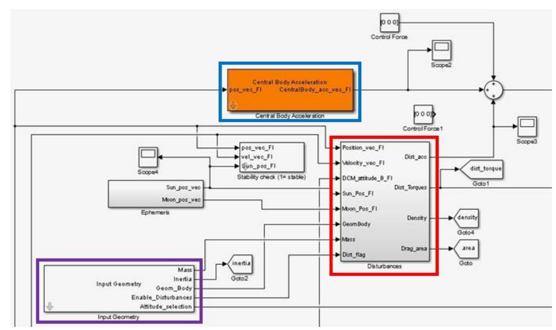
S-MIL Block Diagram



S-MIL implementation in GNCDE

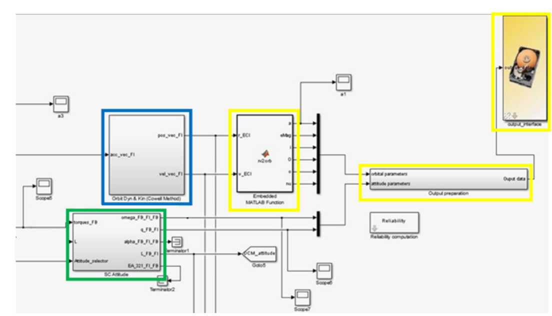
(Full)





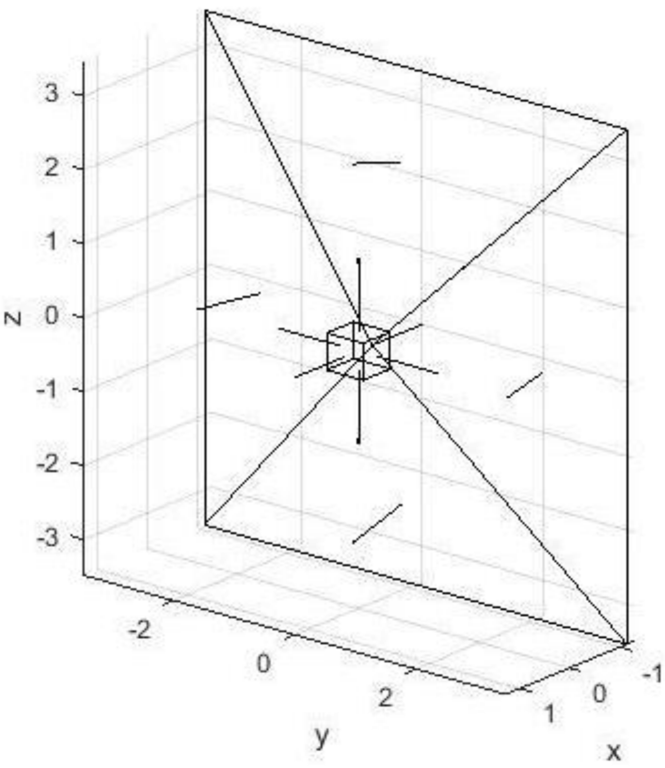
S-MIL implementation in GNCDE (Zoom 1)

S-MIL implementation in GNCDE (Zoom 2)



Inputs to simulation (init_file)

- Simulation step size [s],
- Flag for Drag/Solar surface computation [0=constant, 1=geometry based],
- Value of the constant exposed Drag/Solar area
- Value of drag coefficient for the constant exposed Drag/Solar area
- Centre of pressure position for the constant exposed Drag/Solar area
- Magnetic Residual Dipole Magnitude and Direction
- Number of zonal and tesseral terms for the non-sphericity
- Satellite mass and inertia
- **Satellite Main Body Geometry** (to be imported from Body_Geometry.m output)
- Disturbances flags (1=enable)
- **Attitude selection (0=Tumbling, 1=Fixed orientation)**
- Initial Simulation Date
- Initial Orbital Parameters [rp ra i RAAN omega nu]
- Initial tilting angles of the satellite, order roll, pitch, yaw [deg]
- Initial angular velocities of the satellite [deg/s]



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Outputs

FIRST OUTPUT FILE (1OF) AS GENERATED BY THE GNC MIL

For each processing step, a column is created in the first output file with the following information:

- 1. Simulation Time in seconds
- 2. Simulation Date in MJD format
- 3. Reliability
- 4. Six orbital parameters locating the satellite
- 5. quaternions defining the satellite attitude wrt ECI reference frame
- 6. Angular velocities of the satellite
- 7. Aerodynamic force vector
- 8. Solar radiation pressure force vector
- 9. External torques (total) acting on the satellite
- 10. Estimated Cross Area (with respect to velocity vector)
- 11. Stability associated index (1=yes/0=no)

SECOND OUTPUT FILE (2OF) AS POST-PROCESSED

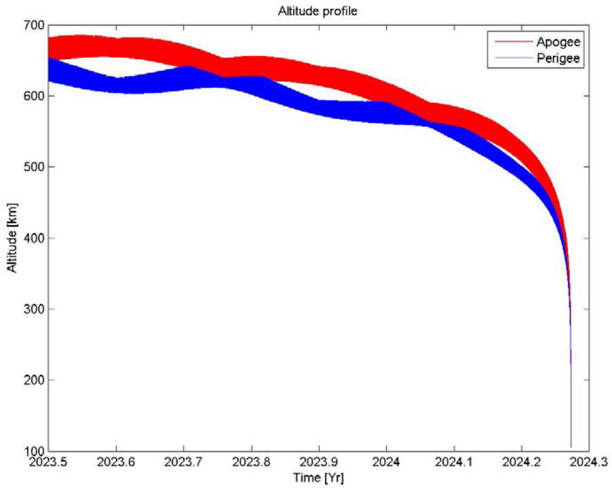
Identified events:

- (T) Start (T0) and Stop (Tend) of Deorbit
- (A) Time when perigee altitude crosses for the first time the next lower altitude (defined by multiples of 50 km).
- (R) Time where the Reliability is closest to a 1 decimal fixed value (e.g. 0.9, 0.8, 0.7 …).
- (S) Time where the stability index changes (e.g. satellite becomes stable/unstable)
- (DI) Time where the satellite rotational acceleration is maximum
- (DE) Time where the external disturbance torques are maximum
- (DC) Time where the module of the aerodynamic and solar radiation pressure forces are comparable

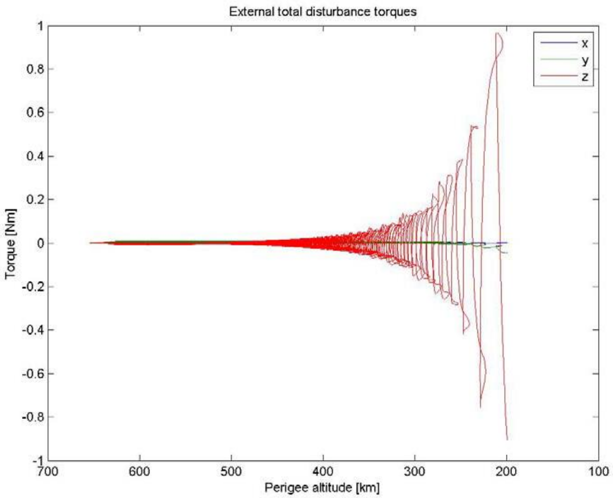
This output file is compatible with commercial spreadsheet tools

Outputs (graphics)

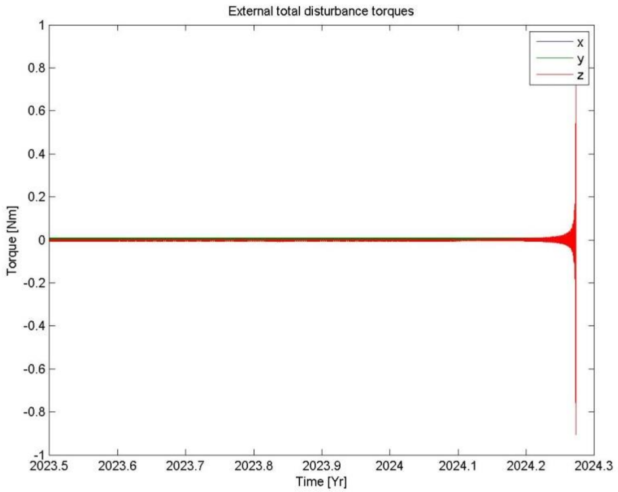
Altitudes vs Time



Torques vs P. Altitude



Torques vs Time



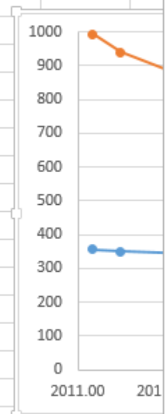
Torques variate with several orders of magnitudes ! …

… Yes, but only during the final (small) portion of time

Output (2OF)

	A	B	C	F	G	H	I	J	K	L	M	N	
1	Cod	Code	Key event	Time after T0 (years)	Time (YYYY.Dec)	R (-)	a (km	e (-)	hp (kn	ha (km	i (deg	RAAN (d	Per
2	1	To	Start of deorbit	0.0000	2011.0865	1	7052.588	0.045194	355.85	993.32	99.457	0	
3	5	DI	Maximum rotational acceleration	0.0212	2011.1077	0.993323	7046.881	0.043295	363.79	973.98	99.47267	9.044913	
4	2	A	Crossing perigee altitude 350 km	0.1625	2011.2489	0.950019	7022.848	0.041964	350.14	939.55	99.5402	69.42928	
5	6	DEF	Maximum disturbance accelerations: 1.273e-07 m/s2	1.6063	2012.6927	0.602364	6918.617	0.026843	354.90	726.33	99.43868	342.7127	
6	7	DC	Similar aerodynamic and solar pressure	2.4465	2013.5329	0.462069	6833.373	0.016916	339.78	570.97	99.48749	8.677904	
7	2	A	Crossing perigee altitude 300 km	2.8569	2013.9433	0.405941	6731.525	0.007931	300.14	406.91	99.43655	205.8055	
8	2	A	Crossing perigee altitude 250 km	2.9341	2014.0205	0.396167	6668.311	0.006028	250.11	330.51	99.40049	244.5134	
9	6	DET	Maximum disturbance torque: 181.9933 µNm	2.9573	2014.0437	0.393284	6617.653	0.004594	209.25	270.05	99.38843	256.4806	
10	1	Tend	End of deorbit	2.9577	2014.0441	0.393229	6602.875	0.003748	200.13	249.62	99.39321	256.7216	
11	2	A	Crossing perigee altitude 200 km	2.9577	2014.0441	0.393229	6602.875	0.003748	200.13	249.62	99.39321	256.7216	
12	2	A	Crossing perigee altitude 150 km	2.9621	2014.0485	0.392686	6542.669	0.002226	150.11	179.23	99.39266	259.0627	

	C	G	K	L
16	Start of deorbit	2011.0865	355.85	993.32
17	Crossing perigee altitude 350 km	2011.2489	350.14	939.55
18	Crossing perigee altitude 300 km	2013.9433	300.14	406.91
19	Crossing perigee altitude 250 km	2014.0205	250.11	330.51
20	Crossing perigee altitude 200 km	2014.0441	200.13	249.62
21	Crossing perigee altitude 150 km	2014.0485	150.11	179.23



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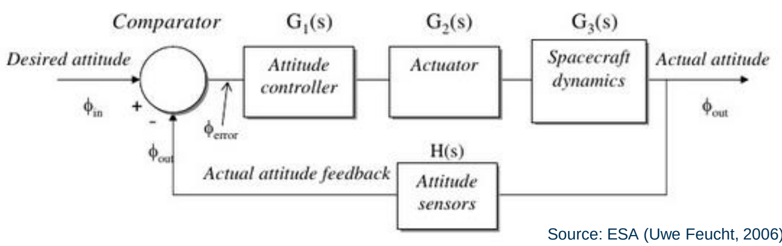
Two complementary tools:

- The S(imple)-MIL is to be used first, to simulate the whole deorbit and to identify (+ quantify) key events,
- The C(omplex)-MIL will implement conventional and non-conventional ADCS sensors and actuators models, together with their relative control loops to support the design of the ADCS/GNC subsystem necessary for active attitude control during deorbit,
- The C-MIL is to be run only for several orbits, identified previously as key events
- Such (iterative) usage of C-MIL will ultimately identify the ADCS/GNC subsystem required for the complete deorbiting

Code	Key event	Time after T0 (years)
To	Start of deorbit	0.0000
DI	Maximum rotational acceleration	0.0212
A	Crossing perigee altitude 350 km	0.1625
DEF	Maximum disturbance accelerations: 1.273e-07 m/s2	1.6063
DC	Similar aerodynamic and solar pressure	2.4465
A	Crossing perigee altitude 300 km	2.8569
A	Crossing perigee altitude 250 km	2.9341
DET	Maximum disturbance torque: 181.9933 µNm	2.9573
Tend	End of deorbit	2.9577
A	Crossing perigee altitude 200 km	2.9577
A	Crossing perigee altitude 150 km	2.9621



Source: ESA (Uwe Feucht, 2006)

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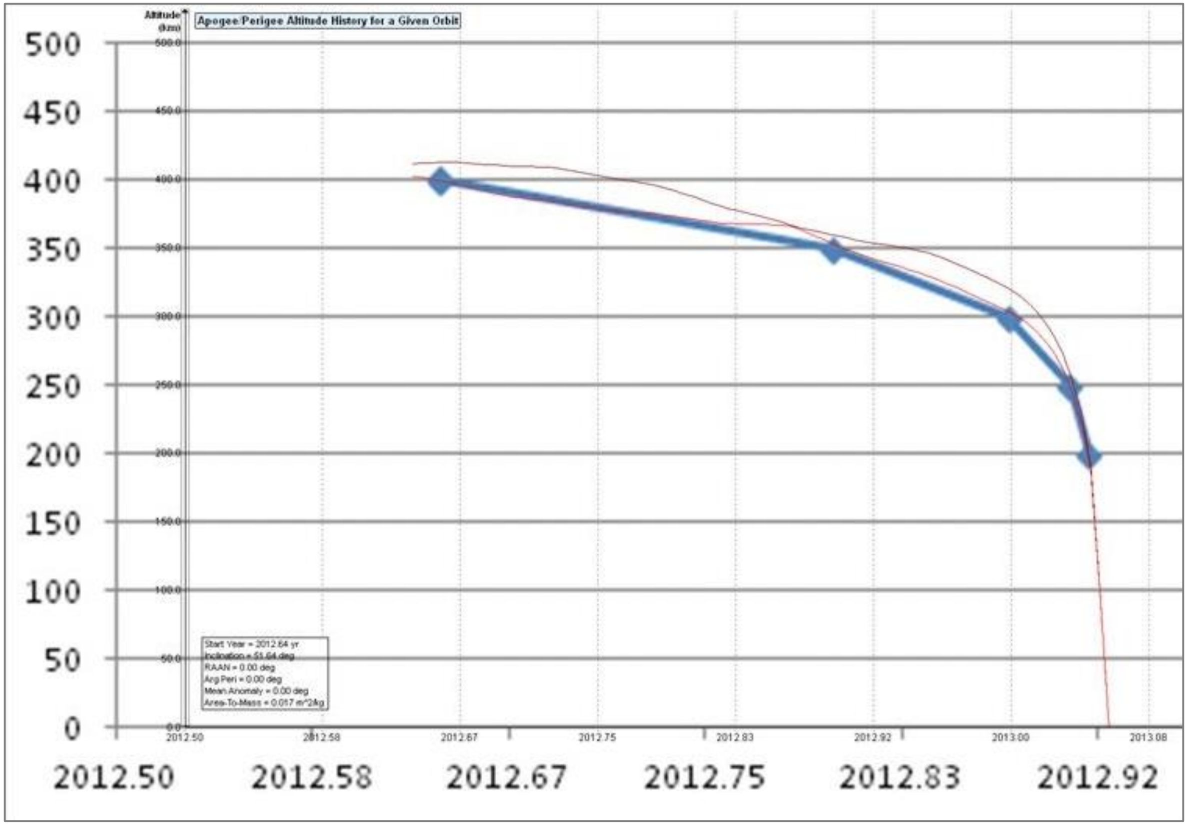
Validation of the S-MIL

Deorbited missions

- Validation of the S-MIL was performed as agreed with 7 real test cases of already deorbited missions
- Validation consisted of both quantitative (QN) and qualitative (QL) comparisons wrt real/effective (TLE) and DAS-simulated deorbit data
- *Both QN (see table here aside) and QL (see next slides) comparisons confirmed the validity hence the suitability of the S-MIL tool for subsequent usage in DGNC*

Satellite	S-MIL (yrs)	S-MIL/Real	DAS/Real
SFERA	0.2766	1.05	1.58
Ande-Castor	0.2314	0.22	0.88
INVADER	0.3642	0.71	1.01
Dove-1	0.0176	1.20	1.85
Navid	0.1111	0.70	0.90
GEO-IK2	2.9621	1.21	1.38
NanoSail-D2	0.4006	0.61	1.00
Min		**0.22**	**0.88**
Average		**0.82**	**1.19**
Average* (excl. Min and Max)		**0.86**	**1.13**
Max		**1.21**	**1.85**

Graphical comparisons



Similar altitude profiles between S-MIL and DAS

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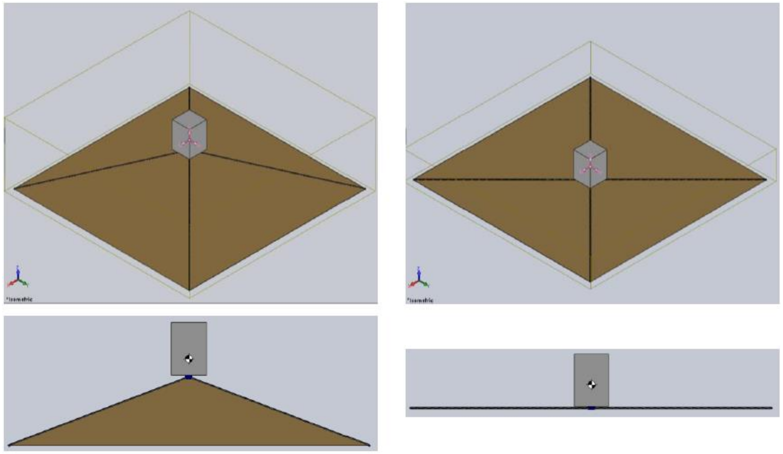
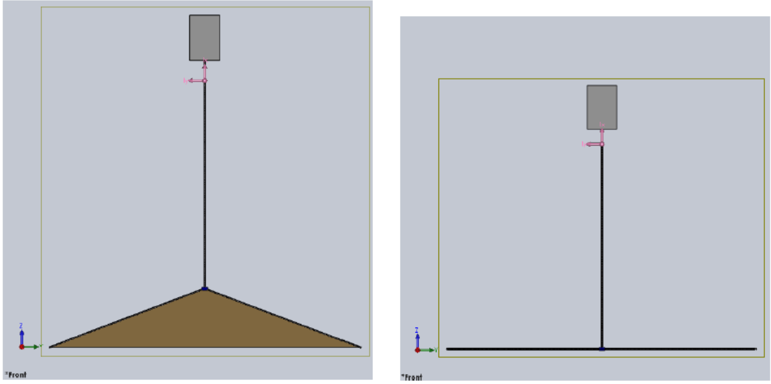
DGNC project results achieved so far and next project’s activities until Final Presentation

Sat+DRS/SRS alternatives

- Trade-offs for Best DRS/SRS configuration (GNC point of view)
  - 4 DRS/SRS configurations defined (ARROW, FLAT, ARROW OFFSET, FLAT OFFSET)
  - 6 DRS/SRS Pyramidal angle defined (0, 15, 30, 45 deg) + (5, 10)
  - 4 DRS/SRS Boom length defined (3.54, 5, 10, 15m)
  - 2 Attitude modes simulated (Fixed, Tumbling)



Isometric and front views of Arrow (left) and Flat (right) DRS/SRS



Front views of Arrow Offset (left) and Flat Offset (right) DRS/SRS

Weight sets

- Trade-offs for Best DRS/SRS configuration (GNC point of view)
  - Three sets of weights have been used, as part of the sensitivity analysis:
    - Balanced : 30/25/40%
    - GNC – TorqueComponents : 20/20/60% (0% for Modulus)
    - GNC – TorqueModulus : 20/20/60% (40% for Modulus)
- Confirmed conclusions:
  - *“Avoid Offset DRS/SRS Configurations”*
  - *“Better Flat than Arrow shaped”*
  - *“Optimise Boom Length”*

	Description	Weight
1D-Val. Funct-01	Sail S/S Mass	0.15
1D-Val. Funct-02	Nb of Booms	0.15
1D-Val. Funct-03	DAS Deorbit Duration	0.10
1D-Val. Funct-04	S-MIL Deorbit Duration	0.15
1D-Val. Funct-05	Global Stability	0.20
1D-Val. Funct-06	Abs Avg Torque (X : roll)	0.05
1D-Val. Funct-07	Abs Avg Torque (Y : pitch)	0.10
1D-Val. Funct-08	Abs Avg Torque (Z : yaw)	0.10

Weights used for the “Balanced” MOVA

	Description	Weight
1D-Val. Funct-01	Sail S/S Mass	0.10
1D-Val. Funct-02	Nb of Booms	0.10
1D-Val. Funct-03	DAS Deorbit Duration	0.05
1D-Val. Funct-04	S-MIL Deorbit Duration	0.15
1D-Val. Funct-05	Global Stability	0.05
1D-Val. Funct-06	Abs Avg Torque (X : roll)	0.05
1D-Val. Funct-07	Abs Avg Torque (Y : pitch)	0.25
1D-Val. Funct-08	Abs Avg Torque (Z : yaw)	0.25

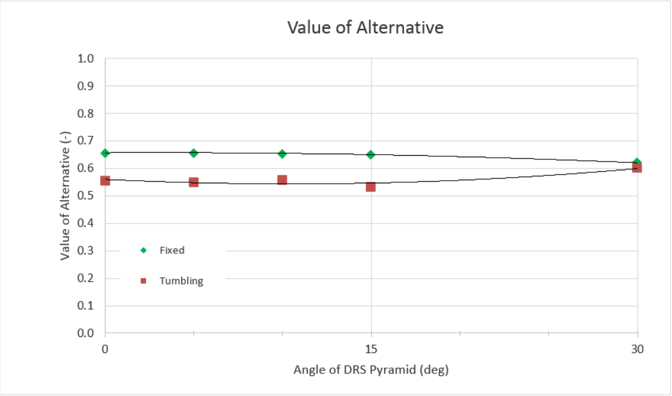
Weights used for the “GNC – T. Components” MOVA

	Description	Weight
1D-Val. Funct-01	Sail S/S Mass	0.10
1D-Val. Funct-02	Nb of Booms	0.10
1D-Val. Funct-03	DAS Deorbit Duration	0.05
1D-Val. Funct-04	S-MIL Deorbit Duration	0.15
1D-Val. Funct-05	Global Stability	0.05
1D-Val. Funct-06	Abs Avg Torque (X : roll)	0.05
1D-Val. Funct-07	Abs Avg Torque (Y : pitch)	0.05
1D-Val. Funct-08	Abs Avg Torque (Z : yaw)	0.05
1D-Val. Funct-09	Module Avg Torque	0.40

Weights used for “GNC – T. Modulus” MOVA

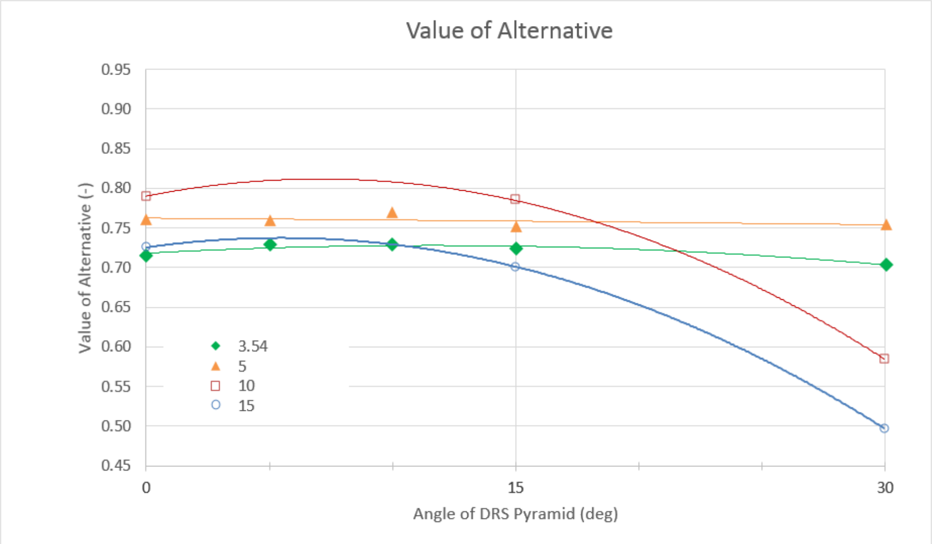
« Better Flat than Arrow »

Min/max ranges for 3.54 and 5m boom lengths:

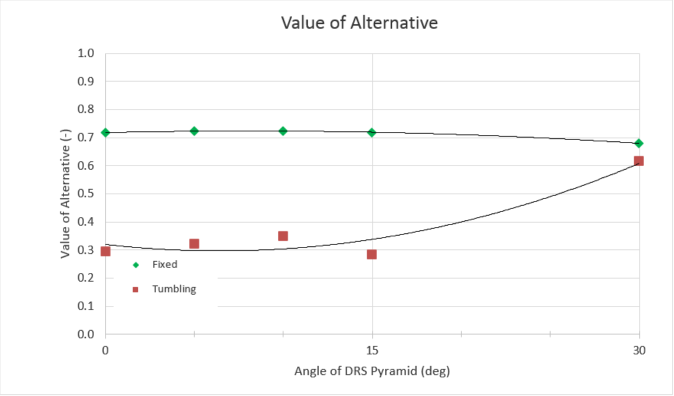


Value of alternative when limiting the MOVAs to small boom configurations and ranges – here for 3.54 m (BALANCED)

Min/max ranges for all boom lengths:
(Value is average of Fixed and Tumbling)



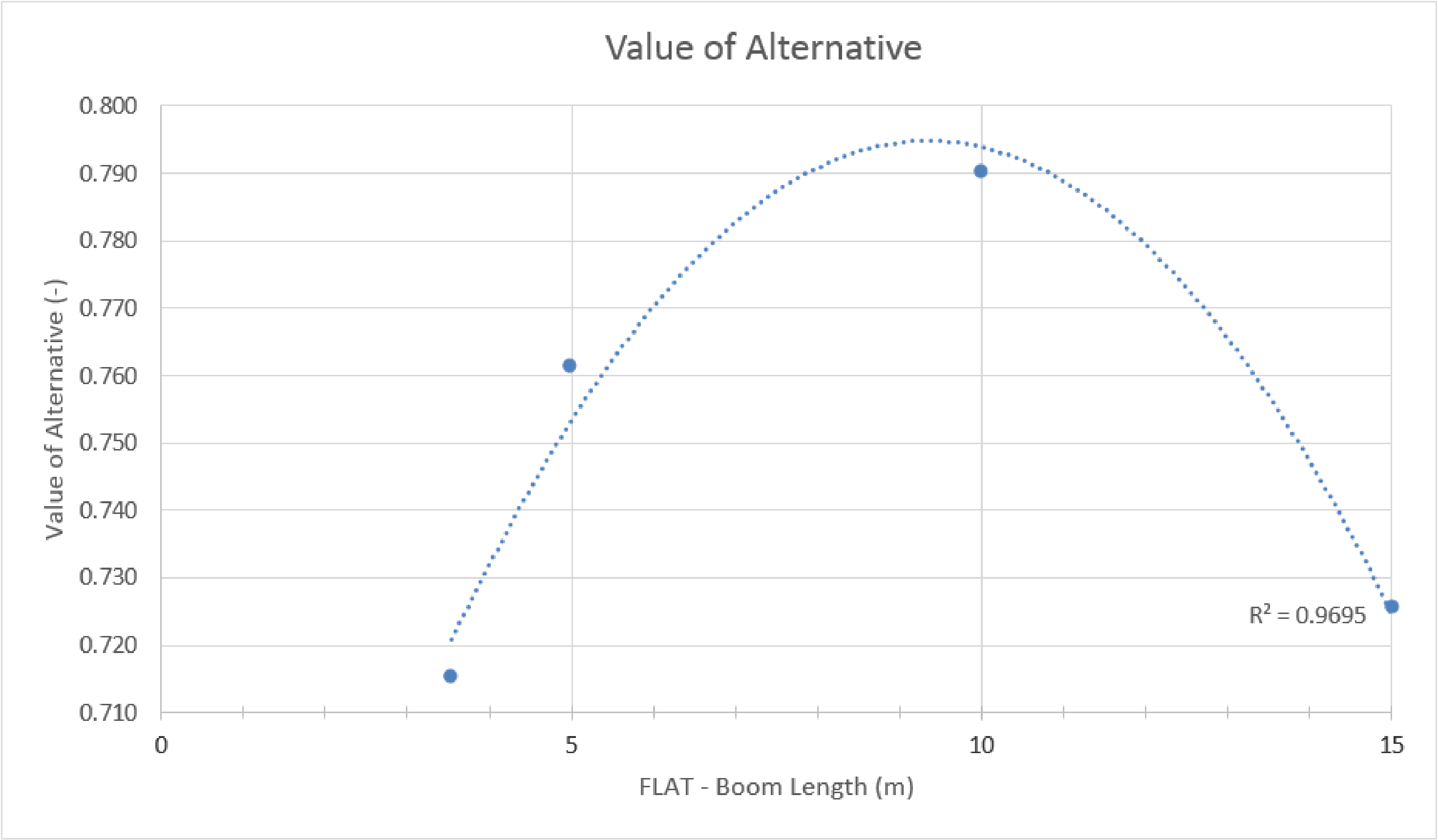
Value of alternative is either almost constant or decreases with increasing DRS/SRS pyramidal angle (BALANCED)



Value of alternative when limiting the MOVAs to small boom configurations and ranges – here for 3.54 m (GNC MODULUS)

Only when <u>focusing on GNC (Torques)</u>, value <u>for Tumbling cases with small booms</u> increases for DRS/SRS angles > 10 deg

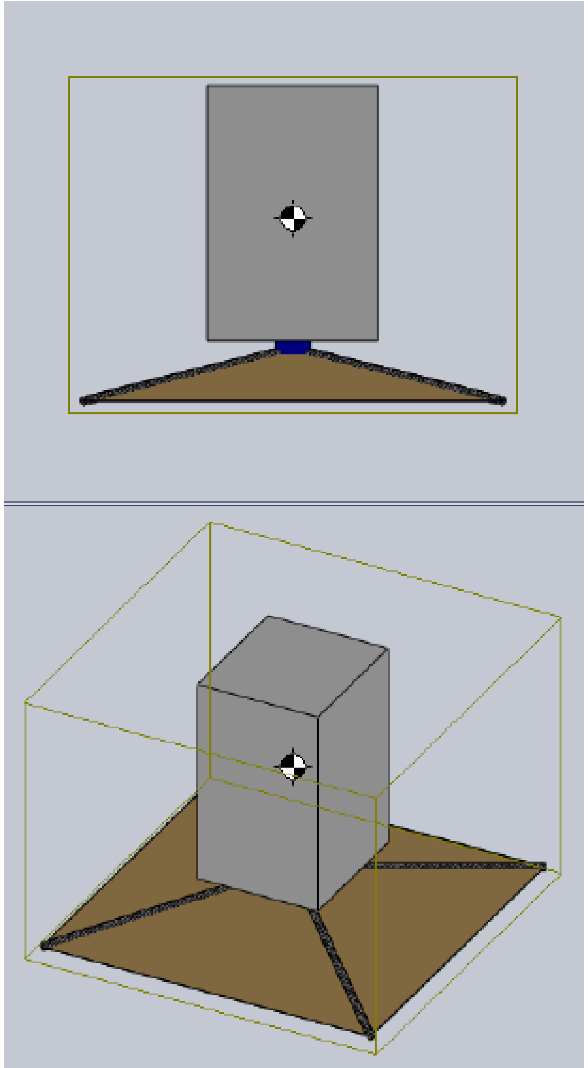
« Optimise Boom Length »



Value of alternative (here for FLAT) with increasing boom length (BALANCED)

« Nominal Case »

- Main characteristics:
  - Sat+DRS/SRS : 1000 kg
  - DRS/SRS : Arrow, 3.54m booms, 10 deg
  - Deorbit from 650 km after mid 2021
- Sat (alone) deorbit : close to 50 years
- Sat+DRS/SRS deorbit:
  - Active ADCS/GNC : 11.5 years
  - No Attitude control : 14.8 years
- Propulsion alternative (chemical):
  - Remainings (indirect) : 5.0 kg to 25 years orbit (650x595 km)
  - Direct re-entry : 82.5 kg to burn in few days



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Before Summer 2016 …

1. Design and modelisation of the ADCS/GNC subsystem (and its FDIR) architecture required for the active attitude control of Sat+DRS/SRS during deorbit,

2. Upgrade of the S-MIL into the C-MIL and verification of the proposed ADCS/GNC architecture with this C-MIL tool,

3. Compilation of the project synthesis and the final recommendations with respect to best GNC solution for satellite (debris) deorbiting thanks to Dragsails.

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Brief presentation of LuxSpace, an OHB Company

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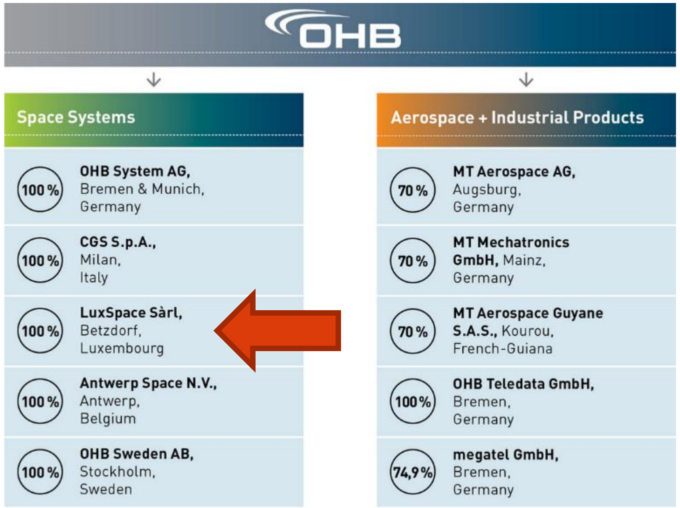
OHB : the European company for Space Technology & Security, Telematics and Satellite Services

Brief portrait

- Domiciled in Bremen, OHB SE is Germany’s first listed aerospace and technology company.
- With over 30 years of experience in high technology, the Group is ideally positioned as one of the leading independent forces in the European aerospace and aeronautics industry.
- OHB SE currently relies on the skills and the high motivation of (about) 2.000 Employees.



More on : www.ohb.de

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LuxSpace

Brief portrait

- Founded in November 2004
- Business activities started in January 2006
- 100% owned by OHB
- Offices located in at Betzdorf, Luxembourg
- ISO 9001:2008 certified since 2008
- 40 staff from 12 different countries

More on : www.luxspace.lu

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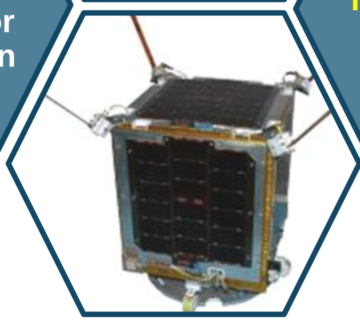
Our activities focus on Hardware, Software, Studies and Data-Services
... for and/or from Space

Software and Simulators

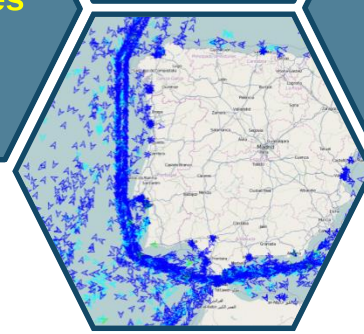
Space System & Subsystem

Telemetry, Telecommand & Ranging Subsystems for Communication Satellites



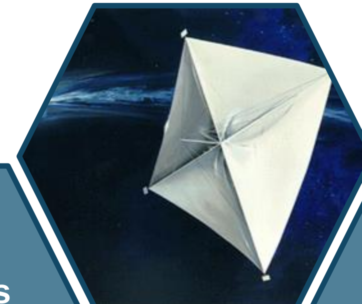
Microsatellites

Applications and Services



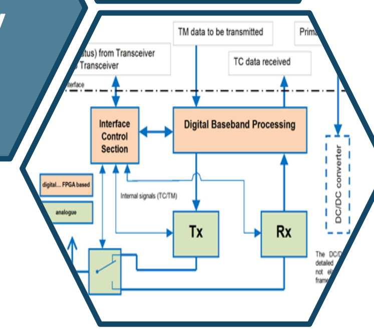
Sails

„Made in Luxembourg"

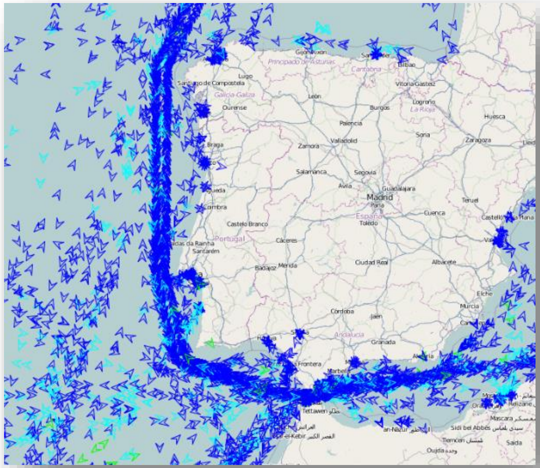


Space Technology

Studies & Consultancy



Our most relevant projects



TT&R Subsystems for SGEO

- **HAG-1**
- **EDRS-C**

Launched Microsats

- **VesselSat 1** (since Nov. 2011)
- **VesselSat 2** (since Jan. 2012)

Spaceborne Data Collection

- **AIS** (also for NATO)
- **ADS-B** (Phase 0 for SES TechCom)