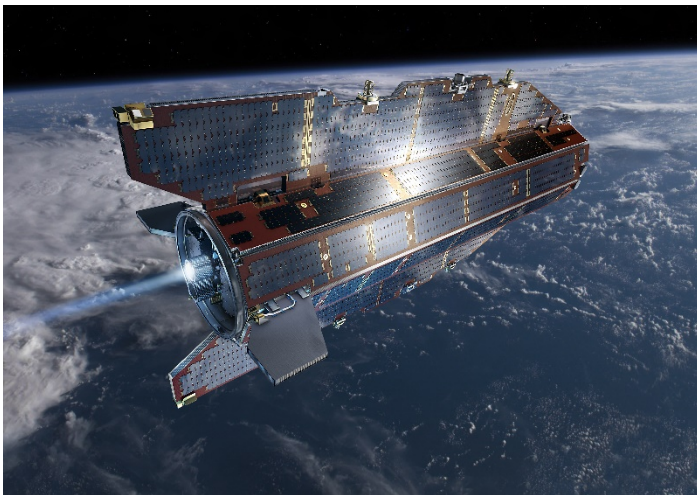

Benchmarking re-entry prediction uncertainties: GOCE Re-Entry Prediction Uncertainty Analysis

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Partners (other entities in the consortium)

SpaceDyS s.r.l (http://www.spacedys.com/index.php/en/)
Belstead Research Ltd (http://belstead.com/)

Funder and total project value (not just the fraction that comes to Strathclyde):

ESA – European Space Operation Centre (ESOC, http://www.esa.int/About_Us/ESOC)
Total value: 150keuro

Motivations and objectives:

During the three week decay period between the end-of-mission and the atmospheric re-entry of the ESA Gravity field and steady-state Ocean Circulation Explorer (GOCE) vehicle, the orbital data collection through a vast set of on board sensors resulted in a very rich set of data. The aim of the project was “to exploit the rich telemetry data set of GOCE to the fullest on the topic of re-entry predictions and extract lessons beyond the re-entry of GOCE itself”, by means of any theoretical and computational methods helping to predict the orbit evolution of the object in space expected to impact on ground due to loss of altitude due to orbit perturbations. In particular, the knowledge of the position and attitude of the GOCE vehicle during this period, letting to understanding the aerodynamics of the vehicle and behaviour of the atmosphere, could provide new insight into the uncertain processes affecting the prediction of decay evolution and re-entry timing.

Key achievements:

The research group at the Aerospace Centre of Excellence focused the efforts on the treatment of the involved uncertainties.

Multivariate sensitivity analyses, as well as uncertainty propagation (UP) analyses were performed, considering uncertainties on initial conditions (position, velocity, attitude and attitude rates), and atmospheric and shape parameters, such as a “density multiplier” that represents both the multiplicative uncertainties on the Cd and on the modelled density, the logarithmic geomagnetic index, Kp, and the solar flux index, F10.7.

Different intrusive methods, based on Tchebycheff as well as Taylor interpolation[2], and non-intrusive approaches, such as the High dimensional Model Representation (HDMR)[1] based method and the approach based on based on Tchebycheff polynomial interpolation[3,4] have been used to perform UP and multivariate sensitivity analyses. Monte Carlo sampling has been as well as a reference method and to demonstrate the efficiency of the other proposed approaches (Figure 1).

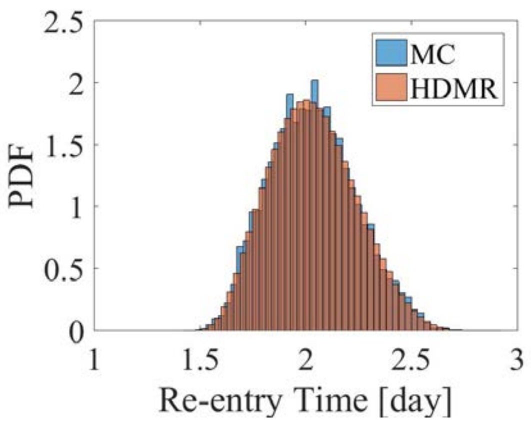

Figure 1- MC vs HDMR based approach

Two different uncertainty quantification/characterisation approaches have been also proposed and tested during the project. The same interpolation techniques used for non-expensive and non-intrusive UP, allowed the development of two methods based on direct optimisation approaches: Boundary Set Approach (BSA) and the Inverse Uncertainty Quantification (IUQ).

Moreover, an innovative approach to treat the empirical accelerations has been proposed, based on polynomial expansions in the state variables. The method has been tested and further developed to consider uncertainties in the initial conditions, leading to a statistical characterization of the coefficients and representation of the possible trajectories.

Additional work has been done to see if and in what extent it is possible to predict the atmospheric drag from a set of measurements at previous time steps. Results obtained by using a Kriging based approach indicate that a reasonable prediction is possible and relatively straight forward for high altitude conditions, i.e., >= 200km .

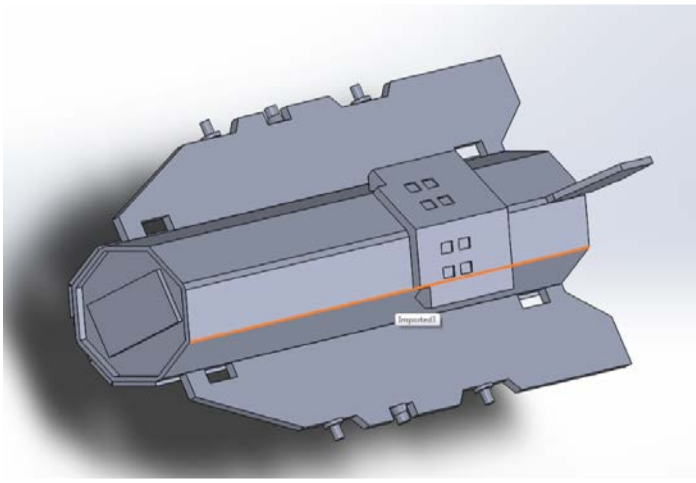

Figure 2 - CAD model of GOCE

Finally, the results of aerodynamic analysis and sensitivity to geometry features are presented. The quantification of the CD as a function of the side slip angle and with some geometrical features as parameters, has been carried out by means of a high fidelity, Direct Simulation Monte Carlo (DSMC), code and a low fidelity, raytracer code. The work has been performed to better characterise the uncertainty on the aerodynamic performance and suggest an additional source of uncertainties for future work, if uncertainties as function of the attitude can be considered and modelled.

Resources (e.g. links to external pages, key publications, final reports, data sets, software, etc.)

1. Kubicek, M., Minisci, E., Cisternino, M., High dimensional sensitivity analysis using surrogate modeling and High Dimensional Model Representation, International Journal for Uncertainty Quantification, 5(5), pp 393–414, 2015. http://www.dl.begellhouse.com/journals/52034eb04b657aea,6e80c1d03916a3a4,5b0e09ca442f8edd.html
2. Riccardi A., Vasile M. and Tardioli C., An intrusive approach to uncertainty propagation in orbital mechanics based on Tchebycheff polynomial algebra, Proceedings of the AAS/AIAA Astrodynamics Specialist Conference, Vail, Colorado, August 2015
3. Ortega C., Riccardi A., Vasile M., Tardioli C., SMART-UQ: Uncertainty Quantification Toolobx for Generalised Intrusive and Non intrusive Polynomial Algebra, Proceedings of the 6th International Conference on Astrodynamics Tools and Techniques, Darmstadt, Germany, March 2016. https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&ved=0ahUKEwjC2_bBiJLTAhWIAcAKHXjUCdMQFggpMAI&url=https%3A%2F%2Findico.esa.int%2Findico%2Fevent%2F111%2Fsession%2F27%2Fcontribution%2F137%2Fmaterial%2Fpaper%2F0.pdf&usg=AFQjCNFFDGAWZRwERTBIVTZR18PKcYgsAQ&sig2=F30L3eahc3n4hPFjSAbUzg&cad=rja
4. SMART-UQ, Uncertainty Quantification Toolbox https://github.com/strath-ace/smart-uq