**Context and Motivations**

In the last decade the European Space Agency (ESA) and NASA made an effort to join their experience to tackle the micro-vibration problem in a more systematic way than before as witnessed in [1]. This collaboration is fed by the growing need of tighter pointing performance for both future observation and Science missions than in the past.

Micro-vibrations are defined in [2] as small amplitude vibrations, corresponding typically to micro or nano radians in pointing performance, due to the propagation of internal disturbance sources (reaction wheels, cryocoolers, solar array drive mechanism, antenna trim motors, etc.) to the optical payload through the spacecraft flexible structure. These vibrations can span from few Hz up to few hundred Hz.

According to the requirements, the instruments and the structural architecture of the mission the main source of perturbation impacting the final pointing budget can be different as well as the critical frequency bandwidth. This problem offers a clear benchmark of multi-disciplinary nature: structure, control and system engineering are involved in order to limit the most the propagation of the internal disturbance and the amplification of the natural modes of the spacecraft structure. This is why it is crucial to develop rigorous methodology to model and predict...
worst-case scenario to avoid mission requirement degradation as done in the recent works [3, 4] in preliminary design phase.

The first time in history the problem of micro-vibrations rised is probably with the Hubble mission, when an unexpected level of jitter was observed on flight data. Further studies revealed the cause of the anomalous perturbation in the solar array flexible mode that was thermically excited by the transition to/from eclipse [5]. The attitude control was redesigned in order to take into account this phenomenon [6].

The biggest difficulty in preventing this kind of accidents is to obtain high fidelity models before flying by comparing analytical and numerical Finite Element (FEM) models with identification experiments on ground environment and in presence of gravity. The Solar Dynamics Observatory (SDO) represents an example of this difficult task [7]. The on-ground test of disturbance to payload line-of-sight assessment was not performed for the reasons already evocated. A deep on-orbit jitter analysis was driven and revealed the performance limitations to impose to the reaction wheel assembly and the high gain antenna (HGA) stepper motors in order to mitigate the induced micro-vibrations.

An important achievement was reached by NASA and ESA for the Solar and Heliospheric Observatory (SOHO) mission. A soft cable system was used to suspend the entire spacecraft in order to reproduce the free-free condition in Space above some Hz [8]. A set of 40 fine accelerometers were used to measure the micro-vibrations induced by all the possible internal sources. However an on-board test campaign was always needed in order to assess the on-ground predictions and explain the unavoidable mismatches. What is extremely difficult to capture in on-ground tests is the effective dynamic coupling effect among the different spacecraft bodies and the actual damping of the various structural modes [1]. What is more is that generally the dynamical characteristics tend to evolve during the mission lifecycle by shifting natural frequencies and by varying the modal amplitudes.

The common approach to make jitter predictions is to use FEM models and simplify the analysis to particular nodes of the mesh and avoid to deal with unaffordable large models of thousands of states. Nonetheless this task results very tough if we imagine that a different FEM model has to be provided for a different reaction wheel speed or a different angular configuration of a solar pannel driven by a Solar Array Drive Mechanism (SADM). Linear Fractional Transformation (LFT) and structured singular values framework [9] represent nowadays robust and powerful tools to tackle this difficult task in an alternative way. They reduce the analysis time and can detect worst-case scenario without relaying on classical non-global time-consuming simulation-based approaches like Monte Carlo campaigns.

As stated in [1] for BepiColombo mission a Monte Carlo campaign was discarded for jitter analysis since a different FEM model should have been considered for any combination of HGA and Solar Array (SA) angular configurations. The adopted approach was then to extract a confidence interval by extracting data from only seven scenarios. This method was not able to provide any worst-case scenario for the HGA and SA configurations together with the worst-case mechanism/wheel speeds. One of the goals of this research activity will be to fill this gap in order to make possible these preliminary analyses even with large-scale systems.

Description

In the last ten years the department Conception et Conduite des Véhicules Aéronautiques et Spatiaux (DCAS) of the Institut Supérieur de l’Aéronautique et de l’Espace (ISAE-SUPAERO, Toulouse, France) works on the development of minimal (in terms of mechanical parameter occurrences) LFT models under several contracts (ESA, ONERA, Airbus DS, Thales Alenia Space). The developed framework is a multi-body approach called Two-Input Two-Output Ports (TITOP) [10, 11, 12, 13, 14] that is able to connect several flexible sub-structures through some dynamical ports by keeping the uncertain nature of the plant and condensing all the possible configurations (variation of the mechanical properties, variation of mechanical configurations like solar array rotation angle, variation of reaction wheel speed, etc.) in a unique LFT model. This model is then ready for robust control synthesis and robust stability and performance assessment [4, 15, 16] by using the available ©MATLAB routines of the Robust Control Toolbox [17].

All the models derived in TITOP approach have been systematically implemented in the last release of the Satellite Dynamics Toolbox (SDT) [18, 19], which allows the user to easily build the model of a flexible spacecraft with several appendages by assembling elemental ©SIMULINK customized blocks.

Thanks to this toolbox even complex structures built with FEM software (like ©PATRAN/NASTRAN) can be assembled in a ©SIMULINK environment by directly extracting their dynamical information from FEM dynamical
analysis thanks of a dedicated interface with ©MATLAB [20, 14].

The goal of this research activity is to enhance the features of the tool in order to make it generic for a end-to-end structure/control co-design activity. Nowadays Space industries relies on several software programs in order to drive this kind of activity. This brings to lack of physical understanding, lack of mastering modeling and analysis/verification tasks in the same formalism, increase of computational time due to several iterations and data exchanges among different tools. The tool has to deal with all the tasks depicted in Fig. 1. Many of these blocks have already been implemented in the past. From the abundant literature targeted on these topics, the PhD activity will consist in filling the following gaps:

T1 Development and validation of the corresponding fully parametric non-linear models in TITOP formalism of the existing SDT linear models by tacking into account large deformations and dynamical non-linear terms (centrifugal and Coriolis accelerations)

T2 Development of a customized linearization function that take into account all parametric/non-parametric uncertainties of the model and provide a correct uncertain LFT dynamical system even in presence of distributed forces/torques as gravity

T3 Development of system order reduction algorithms in order to provide LFT linear models for control synthesis and linear worst/case analysis with a limited number of states

T4 Development and validation of truss structure TITOP model

T5 Development of the algorithm of the multi-objective control/structure optimization process [21] which meet the mission requirements

The PhD work has finally an experimental task:

T6 The process described in Fig. 1 has to be validated on an experimental test bench. The co-design of a flexible structure actively controlled by a set of actuators will be performed. Robust control techniques will be used in order to synthesize the active controller as in [16] (see Fig. 2).
Candidate Profile

We are looking for self-motivated team-player candidates that match the following profile:

- A Master’s degree in Aerospace Engineering, Control Systems, Robotics, or Dynamic Systems-related disciplines with excellent grades
- Excellent knowledge in dynamic systems
- Good knowledge in FEM modeling and analysis with Patran/Nastran
- Numerical simulation and programming skills in Matlab/Simulink
- Excellent oral and written communication skills
- English language mastery (writing and presenting) is mandatory

Conditions of employment

A full-time employment for three years, including:

- An intermediate evaluation after one year
- To support you during your Ph.D. and to prepare you for the rest of your career, you will have access to personal development opportunities from the EDSYS doctoral school and mandatory coursework
- A gross monthly salary and benefits in accordance to the ISAE-SUPAERO standard
- Possibility of a visiting scholar period abroad with one of our international partners
- A rich, diverse, and stimulating research group

Candidates are expected to start around October 2021.

Application

All applications should be compressed (.zip, 5MB max.) and submitted by email to the addresses below, including:

- Cover letter including a statement of purpose and previous experiences
- Detailed curriculum vitae
- Course grades transcripts
- A scientific writing sample (Master thesis, seminar paper, or equivalent)
- Contact information of two references

Applications will be received until June 15-th, 2021. Interviews will be held shortly thereafter.

For more information regarding this position, please contact:

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References


