PhD in Modeling and Control of Space Systems
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PhD: Enhancement on structure/control interactions and experimental validation of closed-loop kinematic chains on Space structures in presence of parametric uncertainties

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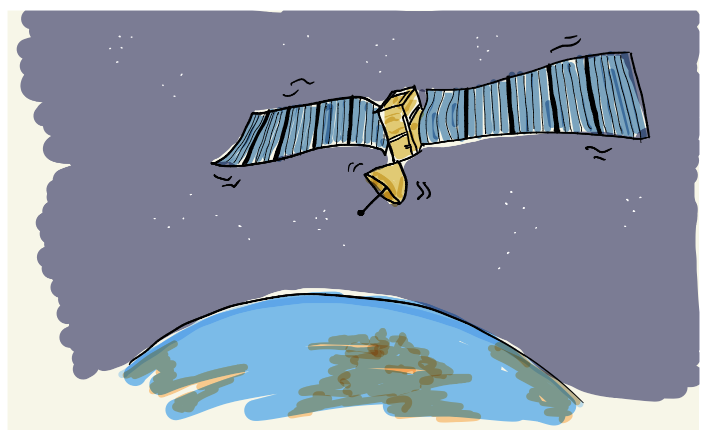
Background



The impact of control/structure interactions has been highlighted by several research studies in the 90's. Belvin et al. [1] considered the application of passive and active payload mounts for attenuation of pointing jitter of the EOS AM-1 spacecraft. O'Brien et al. [2] showed the problem of the isolation of a spaceborne interferometer. Miller et al. [3] modeled the impact of the broadband and narrowband disturbance of the flywheel and bearing imperfections on the pointing performance of the Space Interferometry Mission (SIM). The widespread technique to numerically model complex industrial flexible dynamic systems is the Finite Element Method (FEM). However, while it is necessary to finely characterize the system behavior with all its uncertainties, the complexity of the plant (i.e. number of states and uncertainty occurrences) has to be kept small in order to make this plant exploitable for control synthesis and practical implementation. FEM models strictly used for structure assessment [4], characterized by thousands of degrees-of-freedom (DOFs), cannot be directly exploited for control synthesis and analysis and need to be properly reduced [3]. Moreover, a classic nominal FEM model-based controller [5] suffers from a lack of uncertainty characterization and its validation implies time consuming Monte Carlo's simulations, that can skip rare but critical worst-case configurations. The possibility to take into account parametric variations in a model fully compatible with the standard robust analysis and control tools opens new insights to design and prototype spacecraft architectures while taking into account all the subsystems (structure modelling, control, optics, mechanism disturbances). In this spirit the Two-Input Two-Output Ports (TITOP) approach, firstly proposed by Alazard et al. [6] and further extended by Chebbi et al. [7] and Sanfedino et al. [8], offers the opportunity to assemble several flexible sub-structures by keeping the analytical dependency of the overall model on the constitutive mechanical parameters and reducing this dependency to the minimal number of occurrences. This multi-body approach has been conceived in order to perfectly fit with the Linear Fractional Transformation (LFT) theory developed in the robust control framework [9]. It is in fact possible to include any kind of uncertain and varying parameters with a minimum number of occurrences and recover the dynamic (forces and torques) and kinematic (linear and angular accelerations, speeds, displacements) quantities at the connection nodes of each body. In this way, a huge family of possible plants can be incorporated in a unique LFT model that informs the control synthesis algorithm of all possible uncertain and varying parameters. All substructure models derived for simple (i.e. beams and plates) or complex (FEM models of 3D industrial bodies) geometries and mechanisms have been integrated in a MATLAB/Simulink environment using the Satellite Dynamics Toolbox (SDT), a collection of ready-to-use blocks that allows rapid prototyping of complex multi-body systems for space applications [10][11]. The resulting spacecraft model is then ready for robust control synthesis and robust stability and performance assessment by using the MATLAB routines available in the Robust Control Toolbox [12]. Thanks to the TITOP formalism Perez et al. [13] showed how to perform a simultaneous ACS/structure co-design of a large flexible spacecraft, Sanfedino et al. [14] designed a robust estimation filter for on-orbit micro-vibrations characterization of a SADM, Finozzi et al. [15] designed an optimal truss-structure, actively controlled by PMAs for a high accuracy pointing antenna.

Research Questions

The definition of parametric uncertainties affecting the dynamic model is crucial in preliminary design phase in order to design robust control laws which cope both with stability and performance requirements. However, LFT system description is exploitable when an affine dependency on physical parameters is available. This is the case of the majority of multi-body systems on open-loop or tree-like kinematic chains. In case of closed-loop kinematic chains, as Stewart platforms or on-orbit assembled chaser/target spacecrafts [16], trigonometric dependency from joint angles does not allow to find an exact generalized LFT problem formulation. One of the objectives of this thesis is to investigate this kind of systems in order to provide a minimal approximated LFT representation. The interest of studying these systems becomes more and more important with the advent of the next generation on-orbit assembling missions.

The second objective of this PhD work will be to demonstrate the applicability of the proposed approach to complex industrial benchmarks, where high complex FEM models are available to describe the dynamics of large flexible appendages. In particular uncertainties related to mis-knowledge of material properties, like Young Modulus, Poisson's ratio and density and to geometrical dimensions, translate into uncertainties on the mass properties, natural modes frequencies, modal shapes and modal participation factors. The limitation existing in nowadays robust control synthesis and analysis algorithms is provided by the number of parametric repetitions. Automatic generation of a minimal generation of parametric uncertainties given a FEM model will be thus investigated. Experimental validations of all developed models and robust control synthesis will be finally put in place in order to develop digital twins for real-time implementation. The PhD student will have the opportunity to work in the laboratory PASTAVIBES (PlAteforme de STabilisation Active de VIBrations d'Engins Spatiaux), recently developed by the DCAS group in ISAE-SUPAERO (Fig. 1).

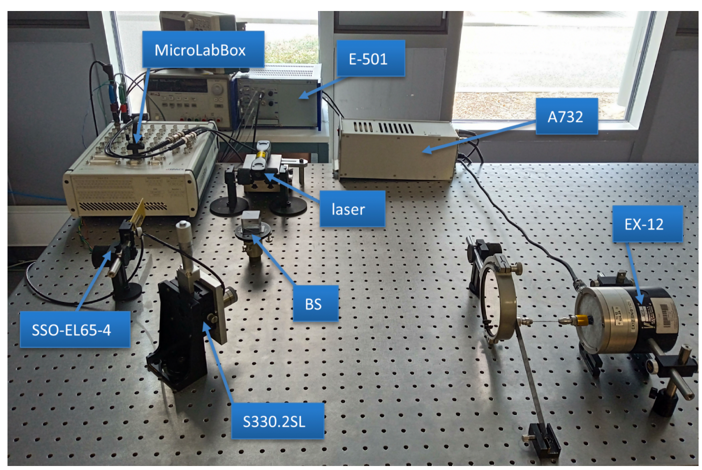


Figure 1: PASTAVIBES Laboratory

Candidate Profile

Students from engineering schools and top universities, with a good knowledge in dynamics modeling, control theory, linear algebra, aerospace systems and Matlab/Simulink software, as well as a very good English level.

Fundings

This PhD is a ISAE/CNES Co-funded PhD initiative (https://cnes.fr/fr/theses-post-doctorats).

Conditions of employment

A full-time employment for three years, including:

- A gross monthly salary and benefits in accordance to the ISAE-SUPAERO standard
- Receiving institutions: ISAE-SUPAERO (Toulouse, France), *Department of Aerospace Vehicles Design and Control* (DCAS), CNES

Candidates are expected to start around October 2023.

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
- Contact information of two references

Applications will be received until **March 16-th, 2023**. Interviews will be held shortly thereafter.

Note that an application has to be also submitted on the CNES platform when the offer will be published. A recommendation letter of your Master's director will be needed as well.

For more information regarding this position, please contact:

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