Robustness Analysis Methods in Parameter Space for System Design and Control Clearance

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A general problem that arises during the design phase of an aerospace system and when verifying the control performance and stability robustness is to assess vehicle compliance with a set of mission requirements, with the uncertainty ranging in given subsets. In many cases, especially during early stages of a design process, it can be also useful to estimate the uncertainty ranges which still satisfy a requirement, so to identify design critical parameters (which have smaller ranges) and to optimally plan the detailed design activities and the uncertainty refinement process in order to obtain, at the end of manufacturing process, uncertainty ranges that still allow requirements compliance.

State-of-the art robustness analysis techniques mainly exploit the possibility of describing the nonlinear system dynamics applying the small perturbation theory around pre-defined stationary equilibrium points. Indeed, given the unsteady nature of the re-entry trajectory, the extended range of flight regimes, the large uncertainty and disturbances ranges, the vehicle trajectory can be poorly represented assuming trimmed stationary flight or quasi-steady manoeuvres, which calls for different approaches. Presently, when analysing a re-entry mission, only Montecarlo based simulations are used with the drawback to not get useful information for vehicle or control system design refinement and or modification, but giving only a global assessment of the system compliance to a requirement, assuming pre-defined statistic characterization of the uncertain parameters (which are not always available).

In the presentation some advanced robustness analysis methods are described which allows to cope with the above identified limitations giving a direct information on the regions in the parameter space where the system does not satisfy the requested property, thus being also applicable to the vehicle early design phase when identifying the critical parameters, their value and their allowable uncertainty range. This allow to drive subsequent design phases for obtaining a closed loop system that better satisfy the mission requirements.

Analysis techniques are presented aimed at efficiently quantifying the admissible ranges of uncertainties in which relevant system properties are still guaranteed. For what concerns aerospace vehicles, this methodologies cope with properties like trimmability, manoeuvrability and stability for non-linear uncertain open-loop systems. Moreover, a novel method based on practical stability concept is described, which can deal with robust stability analysis for vehicles flying on time-varying trajectories. Finally, a technique based on a probabilistic, MonteCarlo based approach, is presented which identifies the range of uncertainties that still satisfy a pre-defined system requirement with a ‘high degree of confidence’ (i.e. in a probabilistic sense) and a reduced computational burden, polynomial increasing with the dimension of the uncertainty parameter space.