Multi-disciplinary flight control design technologies for space applications

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DLR has developed a large number of methods and tools for flight dynamics modelling and flight control law design that have found application in the civil and military aircraft industry. These methods and tools address issues like multi-disciplinary model integration, uncertainty modelling, flight control law clearance, multi-objective optimisation, and nonlinear, fault tolerant and robust controller synthesis. These are issues that also play an important role in the design and clearance of space control applications. Therefore, this presentation will give an overview of control design technologies successfully employed and thoroughly proven in many flight control and space robotics applications. The needs for future developments will be also discussed.

Object-oriented modelling – Object-oriented modelling (OOM) was developed for implementation of multi-disciplinary system models. The methodology allows for graphical construction and integration of model components from various disciplines, based on the common language base Modelica. As compared with block-diagram methods, OOM implements physical model and interconnection equations, rather than differential equations and signal flows, allowing the physical structure of the system to be retained in its implementation. DLR is extensively using OOM for development of complex multi-disciplinary flight dynamics models. For example, a component library has been developed that provides complete functionality for a re-entry vehicle modelling. Using a new flexible bodies Modelica-based library developed in DLR, complex flexible aircraft and spacecraft models can be easily developed for simulation and control design purposes.

Nonlinear flight control law design – Inversion-based control techniques like Nonlinear Dynamic Inversion (NDI) allow for straightforward design of nonlinear flight control laws by inclusion of nonlinear model equations. Considerable design time is saved since manual scheduling of control law gains is avoided. DLR has developed techniques that allow NDI control laws to be automatically derived from object-oriented model implementations. This allows for very fast design updates in the case the vehicle's geometry is modified, or when improved model data become available. The methodology has been successfully applied for autoland design and manual control of a thrust-vectored high-performance aircraft. Handling of robustness, implementation issues, as well as space control applications of interest will be addressed.

Periodic control techniques – Attitude control of LEO satellites using magneto torquers represents a class of challenging periodic control problems with a relatively large period. The solution of the stabilization problem for the attitude control has been addressed recently in both continuous- and discrete-time using periodic output feedback control techniques. The tuning of controller parameters requires appropriate tools to handle periodic control systems. Such tools have been recently developed in DLR and used to solve several attitude control problems with parameterised periodic control laws.

Fault tolerant control design – In aircraft and space applications, fault tolerant control law design is becoming more and more important in order to improve safety, especially in face of unforeseen failures. DLR is developing model-based methods, and reliable software tools for both fault tolerant control law synthesis, as well as fault monitoring. These unique tools can be immediately employed to address challenging fault monitoring and control law reconfiguration problems for space applications.

Multi-objective optimisation-based robust control law synthesis – Flight control laws have to satisfy a large number of multi-disciplinary performance criteria and constraints. Multi-objective optimisation is used for automatic tuning and compromising of control law synthesis parameters with respect to all criteria and constraints at hand. Based on this methodology DLR has developed a tool called MOPS (Multi-Objective Parameter Synthesis), which is used extensively in industry to tune control laws for robots, cars, and aircraft. As an example, with the help of multi-disciplinary flexible aircraft models, primary flight control laws are designed while directly taking flutter and structural loading constraints into account. Robust tuning is achieved by considering multiple model parameter cases simultaneously in the optimisation, or by directly including robustness measures as criteria. The methodology has matured and is expected to considerably reduce design times in complex control applications.

Control law robustness assessment - Robustness assessment with respect to model uncertainties, varying operational parameters, etc. is a crucial aspect of the control design process. The main problem hereby is that the number of parameters may be very large, prohibiting the use of grid-based parameter studies. For this reason, DLR has developed methodologies for closed-loop system analysis based on anti-optimisation, as well as methods based on Linear Fractional Transformations (LFTs). The first method has been successfully applied to the robustness analysis of a spacecraft attitude control system as well as to the clearance of civil and military aircraft control laws. LFT-based methods can be seen as powerful complementary techniques to assess robustness. However, they require the system model to be made available in the form of an LFT. Therefore, methods and tools have been (and are being) developed that perform this task automatically, starting from a parametric state space model, or even a nonlinear object-oriented model implementation.