

Recent Advances Towards an Integrated and Optimized Design of High Lift Actuation Systems

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ABSTRACT

For actuation of high lift surfaces in modern airplanes, complex mechanical shaft transmission systems powered by central drive units are deployed. The design of mechanical actuation systems, which have a major share in the weight of secondary flight controls, is a complex and challenging engineering task. Especially for specification of essential component and system design parameters within the preliminary design phase, engineering skill and experience are of significant importance owing to many uncertainties in component data and boundary conditions. Extensive trade-offs, as well as an evaluation of the system requirements and constraints lead to an iterative and time-consuming design process. Utilizing an integrated design assistance tool, mathematical functions and constraints can be modeled on system and component level and formalized as a constraint satisfaction problem (CSP). Thus, automated consistency checking and pruning of the solution space can be achieved. This approach can be extended to parameter optimization for arbitrary actuation configurations. The methodologies and applied modeling as well as the concept enabling optimization are presented in this paper.

INTRODUCTION

Today's commercial airplanes are equipped with high lift devices providing lift augmentation at low speed during takeoff, approach and landing. State-of-the-art actuation

systems predominantly comprise mechanical transmission shaft systems powered by a central drive unit, as illustrated in Figure 1. The power drive unit (PDU) consists of two redundant drive trains which are coupled by a differential gearbox. A shaft transmission transmits the mechanical power to the drive stations, thus, ensuring synchronous movement of all high lift panels. While operating in extreme environmental conditions, the actuation system has to meet the following basic requirements [9]:

- The system has to be able to hold and move the flap and slat surfaces for all possible air load conditions.
- The panels have to be extended and retracted in a specified amount of time and within a predefined accuracy.
- Malfunctioning, e.g. a power interrupt or a jam, must not damage the system or structure.
- In case of a single mechanical failure in the actuation system, e.g. a mechanical disconnect, asymmetric flap setting resulting in a roll moment that cannot be compensated, must be prevented.

In preliminary design these requirements have to be taken into account, while reliable actuator loads, installation space and component data are not available. Appropriate and established approximations and assumptions have to be made in a first approach in order to define key system parameters. Trade-off studies, basically depending on engineering experience and skill, are thus key elements in preliminary actuation system

design. Although insufficient and uncertain data is available in this development phase, preliminary design has a major impact on the final system specification.

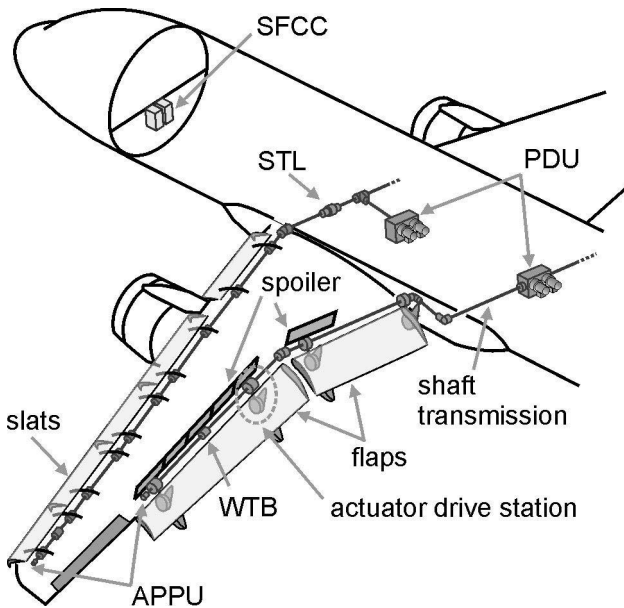


Figure 1: Typical high lift actuation system architecture in commercial airplanes

An integrated, tool-based design assistance is favorable in order to handle system complexity and support iterative design steps. Knowledge-based methods promise benefits in this context with respect to uncertain data processing and computation time. Furthermore, sensitivity studies for specific system architectures can be improved and automated by parameter optimization.

SYSTEM DESIGN AND DEVELOPMENT

High lift actuation systems consist of three major subsystems. These are the power drive unit, the mechanical shaft transmission including drive station actuators and the monitoring and control unit. For system monitoring and failure detection, the slat flap control computer (SFCC) is fed by position sensor units at both wing tips (Asymmetry Position Pickup Unit, APPU) and the PDU output (Feedback Position Pickup Unit, FPPU). In the process of optimizing the system weight, the mechanical elements of the transmission system are of particular importance.

Figure 2 exemplifies the interrelations between drive unit, monitoring system and shaft transmission in the design process. Furthermore, some characteristic design parameters and their determination depending on these subsystems are illustrated in order to emphasize interdependency.

Starting the design process for a specific system architecture, the drive station gear reduction has to be determined first. Depending on the actuator gear ratio and temperature-sensitive friction losses the operating

torques of the transmission system and, thus, the required drive torque of the PDU can be determined. Furthermore, the nominal transmission speed is a function of the actuator gear ratio, specified stroke and requested extension time. Taking load-dependent speed deviations of the PDU into account, a monitoring threshold for overspeed detection due to system malfunctioning can be defined. Furthermore, the minimum threshold for detection of a mechanical disconnect depends on the static transmission twist between power drive unit and wing tip. Mechanical backlash as well as a torsional deflection due to component loads and stiffness add to a nominal discrepancy between APPU and FPPU signals, thus, defining the lower limit for failure detection.

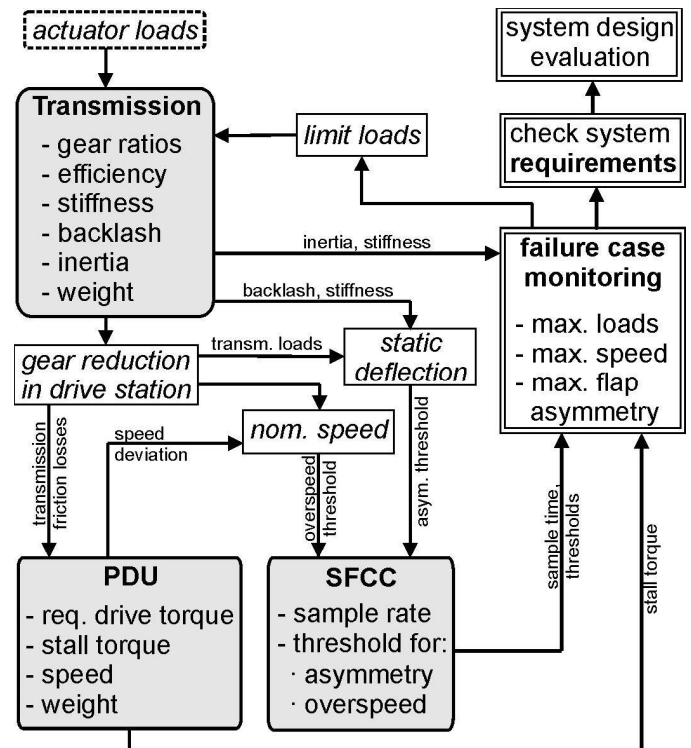


Figure 2: Characteristic design parameters and interrelations between major subsystems

The previous aspects emphasize the influence of the shaft transmission and its components on the design of power drive unit and system monitoring. The design of mechanical components is mainly driven by their limit load and assumed speed, respectively. Inertia loads that can exceed the operating loads by far result from failure cases. In consequence, a detailed analysis of relevant failure scenarios is necessary. In case of jamming, the PDU will induce its maximum drive torque into the actuation system. Torque limiters (TL) in the actuator drive stations then offer overload protection for the downstream system and structure. Most actuation systems apply additional system torque limiters (STL) in order to reduce the maximum loads in the shaft transmission.

Another failure scenario is a mechanical disconnect in the shaft transmission system. In this case, uncontrollable flap movement must be prevented. Mainly two different solutions are applied: The installation of no-backs or wing tip brakes. No-backs are usually installed in all actuator drive stations. In case of a mechanical disconnect, these passive elements hold the disconnected subsystem in place. While this characteristic eases failure detection, the additional elements induce substantial friction losses.

In contrast, shaft brakes at the wing tip reduce the system efficiency only slightly. They represent active elements that have to be activated in failure cases in order to stop and hold a disconnected subsystem. Until the failure is detected and the brakes are applied, aerodynamic loads acting on the flap panels and consequently on the actuators will accelerate the disconnected part of the transmission system leading to high failure speeds. In consequence, inertia loads due to high speed gradients occur after brake activation. These peak loads are basically influenced by the transmission system's inertia and torsional stiffness.

The maximum transmission loads consequently arise from failure cases whereas PDU and SFCC failure detection thresholds have an important influence. After all, the limit loads defining the torsional strength of the mechanical components have to take these failure loads into account. In consequence, the limit loads sizing the particular components predominantly determine the transmission weight. Total system weight, taking also the power drive unit into account, however, is a major criterion for system evaluation. All in all, actuation system design is a complex engineering task with numerous interrelations.

DEVELOPMENT PROCESS

The development process of aircraft systems can be divided into the following constituents presented in Figure 3 [2]:

- Before any system can be designed, its requirements have to be specified. Some of the requirements for high lift actuation systems have been introduced previously.
- The design task starts with the conceptual or preliminary design phase. It is characterized by analysis and evaluation of different system concepts and trade-off studies. The preliminary design ends with a decision for a specific configuration (design freeze) and an appropriate system specification.
- In the detail design phase, the system design and analysis continues. Component layout is fixed in detail and manufacturing and integration drawings are created.
- In the manufacturing process first prototypes are produced that can be used for testing on component

and finally on system level, thus, enabling system and component certification respectively.

Owing to concurrent engineering, the design phases overlap. This results in a reduction of the overall time required for the development process [2]. Figure 3 also indicates the availability of system data. Although major decisions are made in the preliminary design phase, only little information is available to support these decisions. Furthermore, mistakes or unjustified assumptions made in the preliminary design phase may cause difficulties in meeting the requirements. If the need for fundamental changes is revealed in the detail design phase, or worse, during prototype testing, the consequences are costly.

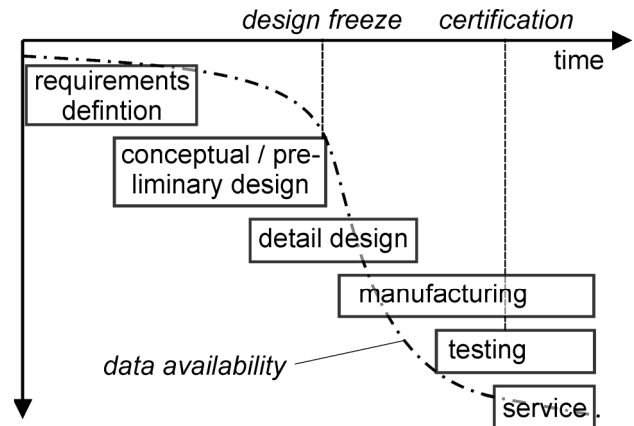


Figure 3: Phases in aircraft systems design

After freezing and specifying the preferred concept, components can be designed in detail. In consequence, more and more reliable component data become available. In order to further support the development process, modeling and simulation then allows for system performance evaluation and prediction of critical operation and failure scenarios.

This work focuses on the preliminary design phase which is a complex and challenging task of utmost importance. It is mainly characterized by extensive trade-off studies based on incomplete, uncertain and changing information. In early design stages, even actuator loads, which are inputs for designing the actuation system, might change, while the installation space is only roughly known. The presented aspects of actuation system design and analysis outline the influence of component characteristics, like e.g. stiffness or backlash, on the overall system design, which, in turn, specifies component requirements. Thus, reliable empirical functions based on statistic component data sets are needed to compensate missing component data. Sensitivity studies aiming at an optimization for specific concepts require an iterative evaluation of the functional interrelations between the actuation system and its components. This is a complex and time-consuming task favoring a tool based approach, which is introduced in the following.