Abstract:

The complexity of Rotorcraft design and need for collaboration between disciplines demands innovative design techniques [5,6]. An evolving Rotorcraft design methodology has been developed at Georgia Tech that brings various disciplines together to one platform and allows for the integration of various conceptual and preliminary design tools. This methodology is divided into product development and process development categories where both the categories are progressed simultaneously towards a new design. The product development cycle starts with the requirements analysis, which through a Conceptual Design Iteration Loop, leads into baseline model(s) selection, where upgrade targets are identified. Vehicle sizing and performance analysis is performed based on the selected baseline(s). This sizing and performance analysis is based on classical Fuel Ratio (RF) balance method and an in house vehicle sizing, synthesis and performance tool called Georgia Tech Preliminary Design Program (GTPDP).

Figure 1: Rotorcraft Preliminary Design (PD) and PLM Methodology
Based on the first sizing estimates obtained from the GTPDP, vehicle engineering geometry/analysis is performed where a design tool like CATIA® is used to generate a three dimensional depiction of the initial preliminary design. This depiction’s geometry and weights & balance are used to generate air loads and trim states through a flight dynamics computer program, such as FlightLab®. Following this stage, static structural analysis, multi-body, non-linear dynamic analysis, linear and non-linear structural and stability and control analyses are performed as shown in Figure 1. The information obtained from these analyses can then be used to perform Aerodynamic performance analysis, propulsion and noise/vibration characteristics analyses. After the first iteration, a more mature design is available and this refined information is used to perform an improved design analysis using GTPDP and RF method. The product development loop is repeated several times using collaborative optimization as discussed in more detail below. The process development cycle deals with the manufacturing, assembly, support processes, vehicle operation safety processes and FAA certifications. These items directly affect the design and are connected with the product development cycle via a virtual product data management tool, which also affects the preliminary vehicle configuration geometry. After process development items have been incorporated in the design, reliability and cost analyses can be performed. This information directly affects the product development cycle. After several iterations of the product and process development cycles, a final helicopter proposal can be generated that gives the detailed results of the conceptual and preliminary design.

Rotorcraft design is a multidisciplinary problem. Depending on the level of detail, it can be composed to a large number of variables and conflicting requirements. The design of any aircraft includes, among other disciplines, aerodynamics, structures, propulsion, avionics and control [1,2,3,4]. All these disciplines have evolved over a long period of time [7,8,9]. Each one of these disciplines has their own variables, constraints and requirements. Collaborative Optimization (CO) is being used in this research in conjunction with Georgia Tech preliminary design methodology to bring various disciplines involved in Rotorcraft design together to one platform where the system level designer has control over all the disciplines as shown in Figure 2. In this scenario, the independent disciplines coordinate with the system level designer. This removes the conflict of interest among disciplines and retains existing disciplinary design tools. When CO is implemented, a system level objective function is defined. The local variables and local constraints are kept at the local level giving freedom to the sub-level experts. Instead of optimizing individual disciplines, one system level objective function is optimized. So ideally, one optimizer can be used to solve a large problem. This technique parallelizes all the disciplines. All the disciplinary experts can work independent of each other. They coordinate with the system level expert. This removes any mutual dependency. CO keeps the disciplinary experts at the discipline level. The disciplinary requirements may be different for different designs.

To demonstrate this concept, Rotorcraft Aerodynamics and Stability and Control codes are integrated on a common platform called Model Center® as shown in Figure 3. A new overall evaluation criterion is defined that involves metrics from both Aerodynamics and Stability and Control. Model Center® gives the designer the freedom to integrate and run
a variety of programs and codes. Two simple codes are generated for Stability and Control and Aerodynamics.

The Stability and Control code is developed in Matlab®. The code calculates trim solution using the simplified propulsive trim equations. AH-1G cobra helicopter data is used for this purpose. An Aerodynamic analysis code is developed using MS Excel®. The excel code calculates the lift and drag coefficients using the Blade Element and Momentum (BEM) theory. Few other parameters such as power coefficient and figure of Merit can also be calculated using this code. The Stability and Control code calculates trim angles that are used as input for the Aerodynamic code. The Aerodynamics code estimates the thrust and power requirements that are then used as inputs for the Stability
and Control. This iterative process is coordinated by using Overall Evaluation Criteria (OEC). The OEC is then optimized at the system level using one optimizer. The results obtained satisfy the requirements of both disciplines and yields an optimized feasible design.

Component plug-ins of Matlab® and MS Excel® codes are used. The input and output variables and their reference locations are defined in the plug-ins. These variables are combined in the OEC script function where the Overall Evaluation Criteria is defined. This OEC is then optimized using a built in Sequential Quadratic Programming (SQP) optimizer. Information is passed between the two disciplines and the optimizer iterates until an optimum solution is obtained.

Figure 3: A simple example where Aerodynamic and Stability and Control disciplines are integrated and an OEC is defined and optimized
This simple example demonstrates that model center can be used to integrate different types of software and allows the flow of information between them. For future work, all the disciplines in the product development loop of the Georgia Tech Preliminary design methodology will be integrated using a similar platform. This will include the information flow between high fidelity tools and integration of GTPDP with other commercially available software for conceptual and preliminary design studies.

References:

8. X. Gu, and J.E. Renaud, “Decision based Collaborative Optimization”, 8th ASCE Specialty conference on probability mechanics and structural reliability