MULTI-DISCIPLINARY DESIGN OPTIMIZATION OF COMPOSITE FIXED WINGS

Budget	State Budget
PNCDI II	Human Resources
Subprogram	Young Research Teams
Project duration	24 months (01/10/2015 - 30/09/2017)
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Contractor	Military Technical Academy
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RESEARCH TEAM

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PROJECT EXECUTIVE SUMMARY

The project’s goal is to develop, implement and validate through experimental results a new multi-disciplinary optimization procedure for the aeroelastic tailoring of composite fixed wings. The research team will address the development of a new composite beam modelling technique to represent the principal load carrying member in the wing. An aeroelastic tool will be developed with the proposed software technology and the effect of composite tailoring on aeroelastic stability and structural characteristics of airplane wings

will be investigated with a formal design optimization procedure. The numerical results will be calibrated and validated through experimental data.

Objectives

1. State-of-the-art of aeroelastic tailoring

The specific objective is the detailed understanding of the fundamentals of aeroelastic tailoring by reviewing the research literature to have a thorough insight of the state-of-the-art of this research field. The activity will concentrate on the status of aeroelastic tailoring with emphasize on the multi-disciplinary optimization techniques in use nowadays. The analytical, numerical and experimental methods and tools used in this research field will be exhaustively analyzed.

2. Structural analysis of tailored composite wings

The research team will concentrate on the development of a structural model for the structural analysis of the principal load carrying member in the wing. The structural analysis of aircraft wings can be performed either through a detailed investigation of the wing sections comprising skins, spars, ribs etc. or using reduced structural models. The detailed analysis based on a full three-dimensional finite element solution is computationally very expensive and requires a large modeling time. Hence, such techniques can be impractical in design optimization or trade-off studies during the conceptual design phase. Therefore, we will use a “box beam” reduced structural model during conceptual wing design. Numerical simulation of box-beams will be run with different combinations of ply stacking and orientation based on the knowledge accumulated in the first activity.

3. Aeroelastic analysis of tailored composite wings

Nowadays two solutions have emerged for the study of aeroelastic phenomena: the monolithic approach which solves simultaneously the coupled structural and fluid equations of motion and the staggered approach which separates the fluid flow from structural movement and solves them one at a time-step. The second method, known as partitioned analysis, has several advantages including the ability to use analysis programs already available and validated for the fluid and the structural fields. Monolithic solvers are generally recognized to be more robust than the segregated solvers however they are believed to be too expensive for use in large-scale problems. The objective is to program a simplified monolithic aeroelastic code to be used in the proposed optimization technology and to use it in conjunction with a segregated solver.

4. Hybrid multidisciplinary optimization procedure for the conceptual design of tailored composite wings

An optimization problem can be associated with several objective functions, constraints and design variables. However, in many existing procedures the problem is formulated with a single objective function subject to several constraints. Such procedures do not allow simultaneous minimization or maximization of more than one objective. The research team will combine individual objective functions to address the multi-objective optimization problem.

5. Design and fabrication methodology of tailored composite wings

To validate the multi-disciplinary optimization analysis method, the project team intends to compare its results to the response of an actual test specimen. Small-scale tailored box beams will be designed and fabricated from filamentary composites for this purpose. Using a structural tailoring technique, the wing box specimens designed will exhibit bend-twist coupling under load. The composite fabrication process that will be used is called Vacuum Assisted Resin Transfer Molding (VARTM). This technique does not require an autoclave, which makes it more flexible in terms of panel size and reduces cost.

6. VALIDATION OF THE SOFTWARE TECHNOLOGY

Since the materials used (fibers, resin) do not have standard mechanical properties, a series of mechanical property tests will be needed to characterize the composite materials. Specimens will be sampled from different areas of the cover panel to determine if the resin density affects the mechanical properties. Using transverse and longitudinal gages, these specimens will be tested. The fabricated small-scale box beams will be instrumented with displacement and strain transducers and will undergo static, vibration and aerodynamic tests. The data obtained will be compared with the results from the multi-disciplinary optimization software tool.

THE WORKING PLAN

WP1. The framework of aeroelastic tailoring			
Start month	1	End month	3
Activities	Background, definition and classification Aeroelastic phenomena of the fixed wing State-of-the-art in aeroelastic tailoring State-of-the-art in multi-disciplinary optimization techniques used in aeroelastic tailoring		
Outcome	A database of standard objective functions, constrains and design variables used in the optimization of the aeroelastic tailoring of the composite wings will be defined and the lessons learned from the existing knowledge will be specified.		
Risks	The examples described in the literature lack enough information to construct a thorough database. Action to minimize the risk: Engineering approach for estimating the data that are not provided.		
WP2. Structural analysis of tailored composite wings			
Start month	3	End month	9
Activities	2.1 Structural techniques used to analyze the composite wings 2.2 Finite element composite box beam model 2.3 Ply stacking and orientation scenarios. Numerical analysis 2.4 Dissemination		
Outcome	A “box beam” reduced structural model based on the Higher-Order Shear Deformation Theory.		
Risks	Failure to implement a finite element composite box beam model. Action to minimize the risk: The involvement in the project team of post-doctorate researchers with experience in composite materials numerical models.		
WP3. Aeroelastic analysis of tailored composite wings			
Start month	6	End month	12
Activities	3.1 Specifications for the working environment 3.2 Fluid-structure interface data transfer 3.3 Grid deformation		
Outcome	Integration of a non-linear unsteady aeroelastic software technology into the “box beam” reduced structural model coupled with the aerodynamic loads		
Risks	Failure to implement the non-linear unsteady aeroelastic software technology. Action to		

	minimize the risk: Adequate simplification of models without losing basic physics		
WP4. Hybrid multidisciplinary optimization procedure for the conceptual design of tailored composite wings			
Start month	15	End month	18
Activities	4.1 Objective function, Constraints, Design Criteria 4.2 Hybrid multidisciplinary optimization procedure 4.3 Numerical simulations of tailored composite wing 4.4 Dissemination		
Outcome	Hybrid multidisciplinary optimization procedure for the conceptual design of tailored composite wings		
Risks	Failure to implement the hybrid multidisciplinary optimization procedure. Action to minimize the risk: different approaches for the optimization procedure; different approaches from team.		
WP5. Design and fabrication methodology of reduced model tailored composite wings			
Start month	12	End month	18
Activities	5.1 Design of reduced model tailored composite wings 5.2 Fabrication of reduced model tailored composite wings 5.3 Dissemination		
Outcome	Small-scale box beams specimens with different ply stacking and orientations		
Risks	Failure to fabricate the composite box beams. Action to minimize the risk: The involvement in the project team of post-doctorate researchers with proven experience in composite materials.		
WP6. Validation of the software technology through static, vibration and aerodynamic tests			
Start month	15	End month	24
Activities	6.1 Static and vibration tests 6.2 Aerodynamic tests 6.3 Validation of the software technology 6.4 Dissemination		
Outcome	Validated multidisciplinary optimization technology for aeroelastic tailoring		
Risks	Failure to perform experimental tests. Action to minimize the risk: The involvement in the project team of post-doctorate researchers with proven experimental experience. Failure to validate the proposed software technology. Action to minimize the risk: Periodic meetings with the team for the evaluation of specific activities and the early identification of possible problems; critical design review meetings.		

CURRENT STATE OF RESEARCH

According to the Working Plan, at the end of 2016 the research team has completed the first three objectives of the project: the state-of-the-art of aeroelastic tailoring, the structural analysis of tailored composite wings and the aeroelastic analysis of tailored composite wings.

In the first phase of the project, the research team has reviewed the background and the state-of-the-art in fixed wing aeroelasticity methods and has compiled a technical report on static and dynamic aeroelastic effects. The team focused on analytical and numerical methods used to model the flutter phenomena, detailing both frequency and time domain methods. The fundamentals of composite materials were also presented in the same report, progressing from theoretical aspects to fabrication technologies and analytical methods used to model the laminated composites. Since the aeroelastic tailoring is by definition a multidisciplinary optimization problem, the research team has also reviewed the state-of-the-art on optimization techniques.

On the second phase of the project the research team has developed a numerical model for the structural analysis of the principal load carrying composite member in the wing and a binary aeroelastic model of the wing.

The reduced box beam structural model has been programmed in C++ based on Vasiliev's theory of beams. Two codes were written, one code that reduces the 3D structural problem of the principal load carrying member of the wing to a 2D analysis of its cross section and then to a 1D analysis of an Euler-Bernoulli beam, and a second code that can compute/optimize the angle of the plies in the upper and lower panels of the box beam under axial strain constraints.

The first C++ program, AEROTAIL_STRUCTURAL, computes the stiffness and the flexibility matrices of the composite box beam and can predict the bend – twist behavior of the 3D wing. The code has been evaluated and validated with experimental data available in the relevant published literature and with a finite element model based on Reissner-Mindlin theory of plates (Timoshenko beams).

The second C++ program, AEROTAIL_OPTIM, is an extension of the first one and can compute the optimum angle ply for maximum bend-twist coupling behavior of the wing. The program can be extended with multiple constraints, currently having implemented a limit on the axial strain of fibers in the panels.

The binary aeroelastic model has been written also in C++. The program, AEROTAIL_AERODINAMIC, simplifies the aeroelastic problem by limiting the wing deformation to the spanwise bend and twist. The aeroelastic equations of this binary model are reduced to a system of homogenous differential equations with constant coefficients whose stability can be analyzed by monitoring the coefficients of the system's characteristic equation. The code can also compute the divergence speed, the flutter speed and the flutter frequency according to the angle ply of the upper and lower panels of the wing.

On the third phase of the project, the three codes will be improved and extended with the aim of being integrated into an aeroelastic optimization platform of composite fixed wings. This platform will be evaluated and validated with experimental data from static, dynamic and aerodynamic tests that will be undertaken by the research team on its own fabricated composite box-beams.

DISSEMINATION

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Mihaila-Andres, Mihai, Larco, Ciprian, Rosu, Paul-Virgil, Rotaru, Constantin, *Aeroelastic Tailoring of Composite Aircraft Wings*, 14th International Conference of Numerical Analysis and Applied Mathematics (ICNAAM 2016), Rhodes, Greece, 2016,

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