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Different fidelity computational models in aeroelastic design of aircraft and WT models

Vasily Chedrik[a,*], Fanil Ishmuratov[a]

[a]*Central Aero-Hydrodynamic Institute (TsAGI), Zhukovsky, Moscow region, Russia, 140180*

Abstract

Using of different fidelity computational models and relations between them in the multidisciplinary design system is considered. A structural design procedure and optimization methods for aeroelastic design of aircraft and wind tunnel models are discussed. An application of the topology-based optimization together with the two-level structural sizing method is considered. Main stages of the approach to synthesis of structural layouts of aircraft components are described. Some numerical examples of analysis and aero-structural optimization of aircraft wings are considered to demonstrate the proposed methods and algorithms. The accuracy, reliability and efficiency of using of the considered structural models at design studies are discussed.

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Keywords: aircraft structure; computational model; aeroelasticity; strength; optimization

1. Introduction

The design of an aircraft structure and its wind tunnel model is very complex problem. This is due to that many operating constraints arising from different technical disciplines, determining the performance of the aircraft, should be taken into account. An increase of requirements to the lift to drag ratio, aeroelasticity characteristics, the stability and the controllability of aircraft causes a necessity of the experimental validation of the static aeroelasticity characteristics on elastically-similar models in a high-speed wind tunnel (WT). When using modern advanced technologies for manufacturing of the models the accuracy of the modeling of the aeroelasticity characteristics depends mainly on the accuracy of a computational model of the aeroelastic wind tunnel model (AWTM) with chosen similarity scales. Therefore, nowadays the development and research of the AWTM computational models of different fidelity

* Corresponding author. Tel.: +7-495-556-4288; fax: +7-495-777-6332.
E-mail address: chedrik@tsagi.ru

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is an urgent and important problem. These models are intended for an aeroelasticity and strength analysis, for the analytical support of the lab and WT tests and for the purposes of design optimization.

In recent years, the multidisciplinary design optimization approach is often used in aircraft design to solve the problem involving a highly large number of design variables and constraints. This process is very time-consuming and, and often in practice, it is necessary to simplify the design problem by using mathematical structural models of different fidelity for different design problems and levels. Structural optimization can be performed by using the structural models both of the global and the local levels. Many technical papers are devoted to the development of the multilevel methods for analysis and optimization (Sobieszczanski-Sobieski et al., 1985; Kirsch, 1975; Rao, 2009; Kuzmina et al., 2005; Chedrik, 2013; Chedrik and Tuktarov, 2015). Two-level approach to structural optimization with stress and panel buckling constraints has been developed in the paper (Chedrik, 2013). There the optimization problem is solved by using different level models in the multidisciplinary design optimization environment. The multilevel approach for structural analysis and optimization with taking into account strength, buckling and aeroelasticity requirements is presented in (Chedrik and Tuktarov, 2015). In this case, the considered models are a global finite element model for stress/aeroelasticity analysis and a local panel model for buckling analysis and optimization.

The purpose of this paper is to present an approach for aeroelastic analysis and optimization based on two-level modeling. Development of agreed mathematical models of different levels is discussed. In this method the sizing problem is to determine the structural sizes that will ensure a minimum weight while satisfying the numerous constraints which are of different types for many load conditions in disciplines such as linear static analysis, normal modes, and static and dynamic aeroelasticity. The responses in the disciplines can be analyzed by programs which use the structural models of different fidelity. In the developed multidisciplinary design system the problems of aeroelasticity and loads are solved by using the discrete-continual model of prescribed forms. The finite element model is used for detailed evaluation of stresses and displacements of a structure. Also, the application of topology optimization for the determination of a reasonable structural layout together with optimization by using the structural models of different level is discussed. Three numerical examples on using of the different fidelity computational models for structural analysis and optimization are presented. We introduce the following notations.

Nomenclature

C	vector of generalized coordinates
F	objective function
G	constraint function
GJ	torsion stiffness
G^0	reduced stiffness matrix
K	global stiffness matrix
M	global mass matrix
M^r	reduced mass matrix
Q^0	vector of generalized forces
R	vector of applied forces
T	torsion moment
U	vector of nodal displacements
X	vector of design variables
f	polynomial term
p, q	integer polynomial powers
t	time
x, y, z	coordinates
u, v, w	displacement components
Π	transformation matrix
α	correction factor
λ	eigenvalue