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Elastic Multibody Models of Transport Aircraft High-Lift Mechanisms

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In development of transport aircraft high-lift systems, the application of commercial simulation tools is widely used. This paper provides a short overview of parametric modeling of the mechanisms of the high-lift system of a transport aircraft as an elastic multibody system. Elastic mechanical components are modeled by means of the method of finite elements. The high-lift mechanisms comprise the leading-edge devices (droop nose, slats) and the trailing-edge devices (flaps). After giving some details of the theoretical background of elastic multibody systems, the specific models of the high-lift mechanisms are described. Simulation results of representative parameter studies demonstrate the application of the model. Some failure cases are also investigated in addition to an operating load case.

Nomenclature

$\mathbf{D}$	=	deformation tensor
F	=	force
$\mathbf{F}$	=	load vector
$\mathbf{f}$	=	modal load vector
$\mathbf{G}$	=	constraint matrix
$\mathbf{g}$	=	residuals of implicit constraints
$\mathbf{K}$	=	stiffness matrix
$\mathbf{M}$	=	mass matrix
$\mathbf{N}$	=	modal matrix
$\mathbf{q}$	=	modal coordinates
$\bar{\mathbf{q}}$	=	eigenvector
$\mathbf{q}^*$	=	Craig–Bampton coordinates
$\mathbf{r}$	=	position vector
$\mathbf{u}$	=	physical displacement vector
$\mathbf{v}$	=	velocity vector
$\boldsymbol{\gamma}$	=	Euler angles
$\boldsymbol{\varepsilon}$	=	strain vector
λ	=	eigenvalue
$\boldsymbol{\lambda}$	=	reaction force coordinates
$\boldsymbol{\sigma}$	=	stress vector
$\boldsymbol{\Phi}$	=	modal matrix
$\boldsymbol{\omega}$	=	angular velocity vector

I. Introduction

ONGOING aircraft developments in the fields of aerodynamics, structures, and engines had led to continuously increasing aircraft cruise speeds until the end of the 1960s. However, the takeoff/landing speed has not increased in the same ratio because of runway length limitations and landing gear and tire loading capacity restrictions. As a consequence, the aircraft speed ratio between cruise and takeoff/landing has increased from about two to three in modern transport aircraft.

This necessitates a variation of the lift coefficient to provide sufficient lift for takeoff and landing at lower speeds. Aircraft lift coefficient is varied by increasing wing area and wing curvature by the use of so-called high-lift systems. These systems typically comprise of movable devices, at the wing's leading edge (slats and droop nose) and the wing's trailing edge (flaps), that are spatially guided by mechanisms, as shown in Fig. 1.

In cruise configuration, high-lift devices blend into the main wing in order to minimize drag (Fig. 2). In takeoff/landing conditions, the wing area and curvature are increased by extending the flaps and slats. Additional information about high-lift systems and the different types used for commercial aircraft are found in [1–4].

High-lift design is a multidisciplinary process affecting overall wing design. As a result of aerodynamic predesign, the aerodynamic layout of the high-lift devices and their takeoff/landing settings are specified, and preliminary airloads are calculated. In the subsequent system development phase, the high-lift guidance and drive mechanisms are defined. In parallel, high-lift structures (i.e., flaps, slats, and support structure) are developed. Afterward, the high-lift design concept is analyzed and evaluated with respect to weight, costs, complexity, and maintainability. Several iterations may be necessary to find the optimum design solution.

The predevelopment phase is strongly supported by simulation, whereby the modeling approach depends on the specific design topic. In the field of aerodynamics, computational fluid dynamic techniques are used. Detailed structure development is based on static finite element (FE) analysis. Furthermore, the dynamics of the high-lift mechanisms have to be taken into account. For this purpose, the multibody model approach is well suited as it describes the large rigid-body motions of the mechanisms. A model with a low degree-of-freedom (DOF) number is obtained that is suitable for dynamic evaluation.

This paper describes multibody modeling of high-lift mechanisms of transport aircraft using the multibody simulation environment software MSC.Adams; however, other multibody simulation environments could be used as well. Highly stiff components (i.e., tension struts) are modeled as rigid bodies. Bodies subjected to larger deflections, like flaps, slats, or lever arms, are modeled as linear-elastic bodies that are integrated into the multibody model. Altogether, a hybrid model is obtained that couples large rigid-body motions with small flexible-body deformations. It is suitable for the

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