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Structural Deformation-Based Computational Method for Static Aeroelasticity of High-Aspect-Ratio Wing Model in Pressurized Wind Tunnel

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Abstract. In this study, the structural model of a high-aspect-ratio wing is unknown but its structural deformation is measured at some attack angles in a pressured wind tunnel. To implement the static aeroelastic computation at an arbitrary state, an inversion method is proposed to derive the structural stiffness from the known deformation. The wing is simplified into a single-beam model and its bending and torsional flexibility distributions are respectively expressed as a linear combination of several selected basis functions. The bending deformation can be then expressed as a linear combination of the bending deformations of the models structurally characterized by each basis function, which are gradually evaluated by loading the aerodynamic loads computed at the chosen design state. Based on the measured deformation, the bending stiffness distribution is ultimately fitted by a least square method. The torsional stiffness distribution is solved in the same way. Resultantly, a structural deformation-based computational method for static aeroelasticity of a high-aspect-ratio wing model is achieved by combining the structural stiffness inversion method with a coupled computational fluid dynamics (CFD)-computational structural dynamics (CSD) algorithm. The present method is applied to the design and validation states and the numerical results agree well with the experimental data.

AMS subject classifications: 65Z05

Key words: Static aeroelastic computation, high-aspect-ratio wing, pressurized wind tunnel, CFD-CSD, structural stiffness.

1 Introduction

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Except for special aeroelastic experiment, a wind tunnel model is usually designed with very large structural stiffness to reduce static aeroelastic effect. However, an absolutely rigid structure exists only in theory and static aeroelastic deformation is inevitable for any experimental model. In fact, the wind tunnel measurement in a high Reynolds (Re) number wind-tunnel facility has revealed significant static aeroelastic effect [1]. For common wind tunnel experiment aiming at aerodynamic force measurement, the force change due to static aeroelasticity may be far beyond the maximum allowable error of wind tunnel experimental data. Moreover, high dynamic pressures, along with accompanying deformations, are typically associated with high Re number testing. Static aeroelastic effect is known to alter the aerodynamic characteristics of an experimental model in the opposite trend to increasing Re number and can totally mask true Re number effect [2–4], which must be considered carefully to isolate Re number effect [5–8]. Therefore, static aeroelastic analysis is of particular importance especially for a high-aspect-ratio wing model tested in a pressurized wind tunnel [9].

In the traditional methods for static aeroelastic computations, the linearized potential flow theory or the compressible full-potential equation is used to predict aerodynamic forces. The former cannot deal with shock wave. The latter can simulate weak shock wave but is unsuitable for complex configurations because of the use of a finite difference scheme. With the rapid development of modern CFD techniques based on the nonlinear Euler and Navier-Stokes (N-S) equations, the more accurate coupled CFD-CSD method has become increasingly popular in the field of aeroelasticity [1, 10–12], which is applicable to all-speed flows over complex combinations, including aircraft wind tunnel models.

In the existing CFD-CSD methods for static aeroelastic computations, structural model is one necessary condition, which can be represented by flexibility matrix [10], natural vibration modes [11, 12] or finite element model [13]. With the exception of aeroelastic wind tunnel experiment, structural model is usually unknown and a CFD-CSD method cannot be applied directly. On the other side, static aeroelastic deformation can be measured conveniently in the experiment, which determines the deformed configuration. Therefore, the CFD-based static aeroelastic correction under the experimental condition can be made by simulating the undeformed and deformed configurations comparatively. However, the structural deformation at any other state is still unknown.

For a special static aeroelastic problem, as long as the structure is statically stable, the fluid-structure interaction will converge to a static equilibrium state. Theoretically, any one of aerodynamic loads, structural characteristics and structural deformation is determined by the other two. For example, in a conventional CFD-CSD method, structural deformation is computed based on known aerodynamic loads and structural characteristics. It can be inferred that structural characteristics can be derived from structural deformation and aerodynamic loads in turn. Once structural characteristics are solved, the coupled CFD-CSD computation at an arbitrary state can be done. This idea motivates the present work.

In this study, an inversion method is proposed at first to derive the structural stiffness distribution of a high-aspect-ratio wing from the known aerodynamic loads and