

An Efficient Finite Differences Method for the Computation of Compressible, Subsonic, Unsteady Flows past Airfoils and Panels

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Abstract

A finite differences scheme is proposed in this work to compute in the time domain the compressible, subsonic, unsteady flow past an aerodynamic airfoil using the linearized potential theory. It improves and extends the original method proposed in this journal by Hariharan, Ping and Scott [1] by considering: (i) a non-uniform mesh, (ii) an implicit time integration algorithm, (iii) a vectorized implementation and (iv) the **coupled airfoil dynamics and fluid dynamic loads**. First, we have formulated the method for cases in which the airfoil motion is given. The scheme has been tested on well known problems in unsteady aerodynamics —such as the response to a sudden change of the angle of attack and to a harmonic motion of the airfoil— and has been proved to be more accurate and efficient than other finite differences and vortex-lattice methods found in the literature. Secondly, we have coupled our method to the equations governing the airfoil dynamics in order to numerically solve problems where the airfoil motion is unknown *a priori* as happens, for example, in the cases of the flutter and the divergence of a typical section of a wing or of a flexible panel. Apparently, this is the first self-consistent and easy-to-implement numerical analysis in the time domain of the compressible, linearized coupled dynamics of the (generally flexible) airfoil-fluid system carried out in the literature. The results for the particular case of a rigid airfoil show excellent agreement with those reported by other authors, whereas those obtained for the case of a cantilevered flexible airfoil in compressible flow seem to be original or, at least, not well-known.

Keywords: airfoil-fluid dynamics, compressible subsonic flow, convected wave equation, flutter, linearized potential flow, unsteady aerodynamics

1. Introduction

The interest for unsteady, aerodynamic flows has increased in the recent years due to its many applications. For example, in aeronautics [2–5] it is of primordial importance to know the extra loads over an aeroplane that suddenly changes its angle of attack, enters in a gust or goes into a turbulence zone. In addition, many aeroelastic problems can appear such as the divergence and the flutter of wings or other aerodynamic surfaces. Flutter phenomena can also appear in fields other than aeronautics, e.g., in the vocal chords [6] when snoring, in some artificial heart valves [4] and in tall bridges and buildings [7] —a well known case being the failure of the Tacoma Bridge.

Usually, many of those phenomena (such as snoring and wing flutter) are modelled using the strip assumption [4], i.e., the corresponding entity (the vocal cords or the wing) is divided into cross sections that are studied as if they were subject to a two-dimensional flow. For that purpose, the linearized potential theory for flows past airfoils was developed around 1940. This theory yields simple equations whose physical meaning is very clear. However, the procedures developed for their analytical resolution [2, 4, 8–10] were

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