AERODYNAMIC DESIGN OF AEROFOILS AND WINGS USING A CONSTRAINED OPTIMISATION METHOD

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Abstract

A design method for aerofoils and wings which couples CFD and numerical optimisation codes is described. The method handles multiple design points and practical constraints on aircraft geometry. Three applications are described. An Euler CFD code has been used to investigate dual-point transonic/supersonic aerofoil design. To define a drag trade-off curve, the thickness distribution and camber have been designed for minimum supersonic drag with transonic drag constrained to a series of values. A viscous-coupled CFD code has been used to design a wind-tunnel strut guard, with severe geometric constraints, to maintain attached flow. A multi-block Euler CFD code has been used for the dual-point design of a delta-wing/body combination. 46 variables including the twist, camber and thickness at four wing sections have been optimised to produce minimum drag for a range of weighted combinations of the drag at transonic and supersonic design points, and give a drag trade-off curve. A drag reduction of 29% relative to the datum case has been obtained. Design of the upper and lower wing surfaces reduce drag by up to 20% relative to camber design alone. The designs obtained indicate real aerodynamic improvements.

Introduction

In the quest to reduce the cycle time for the aerodynamic design of aircraft shapes two approaches to automating the process have generally been adopted.

The first approach, inverse design, requires the specification of a target pressure distribution. An algorithm is used to define a change in the aerofoil ordinate at a point from the difference in pressure from the target value at that point. For each flow analysis a new aerofoil can thus be obtained, and rapid convergence to the aerofoil shape corresponding to the target pressure distribution can be achieved. Initial work by Davies(1) and Tranen(2) on aerofoil design was followed by the development of many related methods for aerofoil(3) and wing design. Inverse methods for wing design were developed by applying the aerofoil methods to streamwise sections on the wing(4). The difficulty of defining the best pressure distribution to use in inverse design to meet an aerofoil or wing design point has been overcome(5) by using a procedure to determine an optimum target pressure distribution. A further problem with inverse design methods is the difficulty of satisfying a set of constraints on aerodynamic and geometric parameters. The DISC method developed by Campbell(6) has been extended to include constraints of this nature. For practical aerodynamic design it is necessary to consider multi-point design. With inverse methods there is a basic difficulty in defining a pressure distribution to provide a suitable compromise between, for example, subsonic and supersonic design points. The DISC method has been used for dual-point design with some success.

The second approach, optimisation design, utilises a numerical optimisation procedure to control the geometric variables that determine the shape of the aerofoil or wing, in conjunction with a flow analysis code that enables an objective function such as drag to be evaluated. This approach has the potential to overcome all the problems with inverse methods noted above; there is no need to limit the type of pressure distribution, virtually any number of constraints can be included, and multi-point design is straightforward. This general capability of optimisation design methods has not been fully exploited because of the large magnitude of the computing task for these methods, relative to that required for inverse design methods. The increase in computation time is due to the less direct coupling between the flow analysis and geometry modification elements in optimisation design methods. A separate flow analysis is required for each variable perturbation used in the search for an optimum solution. Several strategies have been adopted to reduce the magnitude of the resulting computational task.

Firstly, to reduce the number of design variables, the aerofoil or wing shape to be optimised is specified by other means than point data. Base functions(7,8,9) and aerofoil libraries(10) have been employed, with the design variables defining the optimum proportion of each base shape or aerofoil. This approach tends to restrict the range of shapes that can be considered.

Secondly, to minimise the number of flow solutions required, there has been continuing research to produce more efficient numerical optimisation

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