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Investigation of Aerodynamic Design Issues with Regions of Separated Flow

by

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Abstract

Existing aerodynamic design methods have generally concentrated on the optimization of airfoil or wing shapes to produce a minimum drag while satisfying some basic constraints such as lift, pitching moment or thickness. Since the minimization of drag almost always precludes the existence of separated flow, the evaluation and validation of these design methods for their robustness and accuracy when separated flow is present has not been aggressively pursued. However, two new applications for these design tools may be expected to include separated flow and the issues of aerodynamic design with this feature must be addressed.

The first application of the aerodynamic design tools is the design of airfoils or wings to provide an optimal performance over a wide range of flight conditions (multi-point design). While the definition of "optimal performance" in the multi-point setting is currently being hashed out, it is recognized that given a wide enough range of flight conditions, it will not be possible to ensure a minimum drag constraint at all conditions, and in fact some amount of separated flow (presumably small) may have to be allowed at the more demanding flight conditions. Thus a multi-point design method must be tolerant of the existance of separated flow and may include some controls upon its extent.

The second application is in the design of wings with extended high speed buffet boundaries of their flight envelopes. Buffet occurs on a wing when regions of flow separation have grown to the extent that their time varying pressures induce possible destructive effects upon the wing structure or adversely effect either the aircraft controlability or the passenger comfort. A conservative approach to the expansion of the buffet flight boundary is to simply expand the flight envelope of non-separated flow under the assumption that buffet will also thus be alleviated. However, having the ability to design a wing with separated flow and thus to control the location, extent and severity of the separated flow regions may allow aircraft manufacturers to gain an advantage in the early design stages of an aircraft, when configuration changes are relatively inexpensive to make.

The goal of my summer research at NASA Langley Research Center (LaRC) was twofold: first, to investigate a particular airfoil design problem observed under conditions of strong shock induced flow separation on the upper surface of an airfoil at transonic conditions; and second, to suggest and investigate design methodologies for the prediction (or detection) and control of flow separation. The context of both investigations was to use an existing 2-D Navier-Stokes[1] flow solver and the constrained direct/iterative surface curvature (CDISC)[2-3] design algorithm developed at LaRC. As a lead in to the primary tasks, it was necessary to gain a familiarity with both the design method and the computational analysis and to perform the FORTRAN coding needed to couple them together.

The airfoil design problem of interest had been observed by Yu and Campbell[4] using the same flow solver with an unconstrained version of the design algorithm called simply DISC[2]. The problem occurred when attempted to design an airfoil to a given pressure distribution obtained from a known airfoil geometry and at a flight condition where a significant amount of shock induced separation was present. Thus, this design attempt was a test to see if the known geometry could be regenerated from its pressure distribution by the design method. The resulting designed surface closely matched the target surface except for an additional hump on the new surface in the region of the shock and separated flow. Yu hypothesized that this feature was an attempt by the design algorithm to enclose the separation flow recirculation within the airfoil surface and that this new surface geometry was a permissible (although not desirable) alternate solution to the inverse design problem. Further, Yu suggested that the CDISC design concept which uses linear assumptions to relate changes in

streamline curvature to changes in desired pressure or pressure gradients may not be used in regions where the flow streamlines do not follow the surface shape, i.e. separated flow regions.

While this explanation seems physically plausible and may be a contributing factor to the observed phenomena, the current investigation indicates that a more likely explanation for the surface hump feature was a more common problem; that of using localized surface irregularities to force a particular shock location. In the current investigation, the hump feature obtained by Yu could be recreated only sporadically and appears to be sensitive to small changes in target pressure distribution . In particular, the hump feature only appeared when small differences between target and design shock locations and/or shock pressure gradients resulted in large surface curvature changes of opposite sign to be applied by the design method. Thus, the design method attempts to locally distort the airfoil surface to control the position and features of the shock. Differing methods were tried which alleviated the sensitivity of the design method to exactly match either pressures or pressure gradients in the shock jump. All of these changes reduced or removed the hump feature while still yielding good agreement between desired and target pressures. The conclusion is that the enclosure of separation regions is general behavior and further, since the conditions considered were more severe than those of Yu, the CDISC design algorithms do not have an observed problem in separated flow regions.

The next task of developing design methods which include separated flow constraints began with considering the simplest problem of specifing fully attached flow as a design constraint. A logic flow chart was developed and from it was identified specific topics which need to be addressed. The first of these is the efficient prediction of profile or shock induced separation from only a pressure profile, and inversely, the specification of a pressure profile to avoid separation. For the case of profile separation, the methods of Stratford[5,6] for incompressible flow are generally believed to be adequate although some "tuning" of parameters may be necessary to match specific situations. Keith et al.[7] have suggested a compressibility modification to Stratford's separation criteria. However, the Stratford separation criteria predicts separation in almost all shock/boundary layer interactions, even those for which experiment or analysis do not show separation. A number of modifications to the basic method have been made to improve the correlation to analysis. As present, no single method has worked in all situations, but it seems likely that one of the modifications could be selected and internally adjusted during an analysis to provide good agreement.

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