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OVERVIEW OF TWO-DIMENSIONAL AIRFOIL RESEARCH AT AMES RESEARCH CENTER

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INTRODUCTION

The five basic elements of the two-dimensional airfoil research program at Ames Research Center are illustrated in figure 1. These elements are experimental, theoretical (including computational), validation, design optimization, and industry interaction. The figure also shows the direction of flow of the information, starting with experimental and theoretical and moving to validation, design optimization, and industry interaction. As in any good program, the information also flows in the reverse direction to provide the needs and guides for the research. The following material treats each area briefly and notes other Ames papers presented at this conference that cover the topics more completely. In other topic areas, recent publications are cited to provide more complete details.

THEORETICAL RESEARCH

The theoretical work can be divided into two major areas: computational aerodynamics computer codes and turbulence modeling.

Computational Codes- The primary work falls into three areas: Navier-Stokes codes, Euler codes, and multielement airfoil codes. Deiwert and Bailey's paper, presented at this conference, reviews the work on time-averaged Navier-Stokes prediction of two-dimensional airfoil aerodynamics at Ames. As analyses tools, these codes are becoming very useful, but they are still too time-consuming (15-30 min on a CDC 7600) to be useful for design work. Some very good results have been obtained with these codes when used for transonic buffet, an area that cannot be predicted by less sophisticated codes.

The paper by Olson provides a good example of work in progress on prediction of complex multielement airfoils at low speeds. Although the technology is sufficiently well advanced to allow determination of optimum slat and flap settings, the codes do not give good absolute values of the aerodynamic characteristics, particularly the drag coefficient.

Finally, J. Steger has developed a time-dependent Euler code that has been modified for easy use with an assortment of airfoil problems by W. Chyu. This code treats pitching and/or plunging airfoils with a time-varying free-stream velocity. In addition, the code can treat a spatially varying upstream boundary condition to allow consideration of a two-dimensional airfoil in a shear flow. This can be considered as an approximation of a rotor blade encountering a wake from a previous blade.

Turbulence Modeling- Turbulence modeling is a crucial area of research for the success of any computational method that attempts to predict viscous drag and/or strongly interacting viscous flows such as separation or shock boundary-layer interaction. A major effort is under way at Ames, primarily under the direction of M. Rubesin. This is a highly complex subject, and I will not deal with it in detail. The simple algebraic turbulence models of the eddy viscosity type do an adequate job for fully attached flows, with more sophisticated one- and two-equation models being required as the viscous interaction becomes more important. However, computational time also increases significantly. The simple eddy viscosity models, however, do not predict drag better than about 5%. This may be sufficient for two-dimensional airfoils since we normally wish only to select good candidate airfoils to use in three-dimensional wing design.

A primary requirement for good turbulence modeling is good experimental data. This is the area where much work needs to be done.

EXPERIMENTAL RESEARCH

For discussion purposes, experimental research is divided into two areas: methodclogy and data base.

Experimental Methodology- This area deals basically with the development of new experimental methods, particularly those that have application in two-dimensional airfoil research. Four new experimental methods are of interest: laser velocimetry, holography, skin friction gages, and an airfoil oscillatory apparatus.

Laser velocimetry is covered in two papers - one from Ames and one sponsored by Ames. These are the papers by Johnson (Ames) and Owens, respectively. Johnson (Ames) shows the high degree of accuracy that has been obtained in both potential and viscous flows with the laser velocimeter. These included very accurate Reynolds shear stress measurements in a shock-induced separation on an airfoil at Mach number 0.8. The Owens paper shows the application of conditional sampling techniques to provide temporal as well as spatial resolution of time periodic flows. The laser velocimeter has reached the stage of a highly accurate research tool. However, at this point it is not a production test device in the sense that a highly trained individual is still required for operation and data interpretation.

The use of holography in two-dimensional testing is also discussed in the paper by Johnson (Ames). Although this technique is much newer than the laser velocimeter, it already shows excellent promise. The potential for completely mapping the density field in a single picture makes for much more rapid data-gathering than the laser velocimeter. Holography has been shown to be very accurate, both by comparison with laser velocimetry data and with surface static pressures. This latter comparison suggests the possibility of testing nonpressure-instrumented models and hence cutting manufacturing costs considerably.

A new experimental apparatus that provides new data for unsteady aerodynamics has been developed. This new two-dimensional airfoil oscillating apparatus for the Ames 11-Ft Transonic Tunnel is reported in a paper by Davis and Malcolm at this conference. The test apparatus allows for a wide range of test conditions: reduced frequencies to 0.35; Mach numbers from 0.4 to 1.2; Reynolds numbers to 12 million; center of rotation from plus infinity to minus infinity (pure plunge to oscillation about any point on or off the airfoil); static angles of attack to 16°; and pitching amplitude of ±2°. The apparatus has automated real-time data acquisition, first harmonic analysis, and display capability provided by a dedicated minicomputer. The apparatus is operational and has already greatly expanded the data base in this area.

A significant amount of work is going on at Ames to develop simple and accurate skin friction gages. Two types are under development: the "buried" wire gage and a very small floating element mounted on a crystal gage. The "buried" wire gage development is nearly complete and has been reported by Murthy and Rose (ref. 1). This gage is similar in principle to most heated wire or film skin friction gages but differs in construction. The heated wire, after being soldered to the leads, is pulled snuggly to the surface of a plastic button (leads pass through holes in the button). A drop of solvent is placed on the surface around the wire, bringing the substrate (button) material into suspension. When the solvent evaporates, a smooth, very thin coat is deposited over the wire. Gages constructed in this manner are inexpensive, simple to use, repeatable, and fairly accurate.

The floating element gage is nearing the point of first test. The basic idea is similar to all floating element gages. The major difference is that the crystal mount (the deflecting beam) is very rigid, allowing movement of only a few millionths of an inch. This requires a special sensing method. The technique used here is a surface acoustic wave detection method — the surface acoustic wave speed being linearly proportional to the stress in the beam surfaces caused by deflection of the beam. This device is much more expensive that a "buried" wire gage but has the potential for much higher accuracy and does not require in-place calibration.

Data Base- The data base work covers three primary areas: steady, unsteady, and turbulence. Data base information is seldom isolated from some other activity because it is normally acquired to validate a theory or develop a better understanding on which a more complete theory can be developed. This is particularly true of the two-dimensional airfoil research at Ames. Examples of steady data base can be found in the papers by Lores, Burdges, Shrewsbury, and Hicks, and by Johnson (Vought) and Hicks. Examples of unsteady data can be found in the paper by Davis and Malcolm and for turbulence in the paper by Johnson (Ames).

VALIDATION

Validation is the step whereby theory and experiment are brought together for comparison. It can be used both to validate the theory or point out errors in the experiment. This is a continual area of activity that is never really finished. I would like to describe briefly one example in the area of wind-tunnel wall interference. Much has been said about the need for a good set of interference-free wind-tunnel data on an airfoil at transonic speed. In an attempt to assess wall interference in the 2 by 2 ft transonic wind tunnel at Ames (this is a slotted test section facility), some interesting points have been discovered. This discovery results from a more complete comparison of experiment and theory. The experiment was with an NACA 64A010 airfoil. Both pressure distribution and flow fields were measured (the latter with the laser velocimeter). Computations were made with a small disturbance transonic code under conditions for which the theory would be expected to be valid.

First, calculations were made at the set angle of attack. At this condition, the lift and pressure distribution were missed badly, but the flow angle measurement (one chord height above the model) was predicted very well upstream and over the leading edge but deviated downstream of the leading edge. A second calculation was performed at an angle of attack that resulted in the correct lift coefficient. At this condition, the pressure distribution, while not exact, was realistic; however, the stream angle was not correct anywhere although the agreement improved in the downstream portion of the flow. This suggests that the classical angle-of-attack correction method used for transonic wall effect is not valid in general.

DESIGN OPTIMIZATION

The application of numerical optimization procedures — with existing airfoil computational methods — to the problem of airfoil design has been actively researched at Ames. Work has been under way in three different areas: transonic airfoils, low-speed improved $C_{L_{max}}$ airfoils, and rotor airfoils. There are two papers on transonic airfoil designs that are the result of cooperative programs with industry. These are the papers by Lores (Lockheed-Georgia) et al., and Johnson (Vought) and Hicks. These two papers illustrate the power, as well as the limitations, of this method of design.

In the area of low-speed airfoils designed to improve $C_{L_{max}}$, there has been considerable success. A recent leading edge modification (30% of upper surface) of an NACA 63_2215 resulted in a 20% improvement in $C_{L_{max}}$ at landing conditions. Other cases have also been designed and tested. A design methodology has evolved and been verified, and a handbook of leading edge modifications (theoretically defined) for the most widely used NACA airfoils is underway.

The rotor airfoil section work is unique in that these sections require multipoint designs. The retreating blade (shock-induced stall at $M = 0.4$ and 0.5) and advancing blade transonic effects must be considered. A recent three-point design has been tested and found satisfactory although not the best possible. This area of multipoint design will continue to receive greater attention.

INDUSTRY INTERACTION

Industry interaction is not an area of research but rather a mode of operation that is essential to good applied research. The two papers described in the foregoing section regarding transonic airfoil design optimization (Lores et al., and Johnson (Vought) and Hicks) are examples of this industry interaction. The importance of the two-way nature of this interaction is crucial to the foregoing work. NASA gets direct input of industry's needs as well as active evaluation of the validity of the research it is conducting. Industry gets the fastest possible transfer of new technology, often long before complete publication or documentation is available. This is a continuing area of activity with a shift towards interacting for complete three-dimensional wing design problems.

CONCLUDING REMARKS

In conclusion, the two-dimensional airfoil aerodynamics research at Ames Research Center has been briefly described. Although in many respects it is a small program, the contributions are substantial.

REFERENCE

1. Murthy, V. S.; and Rose, W. C.: Buried Wire Gages for Wall Shear Stress Measurements, AIAA Paper 78-798. San Diego, Calif., April 19-21, 1978.

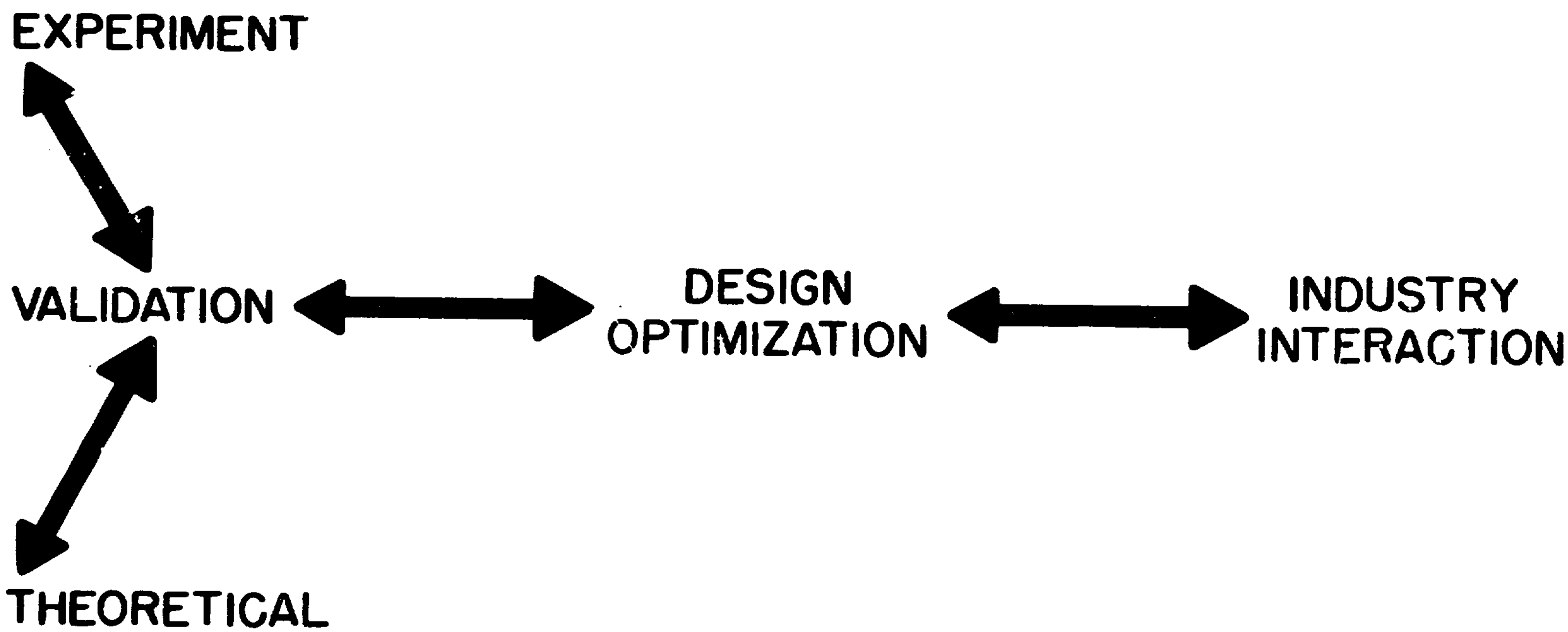

Figure 1.- Two-dimensional airfoil research at Ames Research Center.