winds through a time-space conversion. The glide slope wind profiles provide three components of wind as a function of altitude (or position along glide slope). The Stanford Research Institute performed work for the FAA to develop wind fields consisting of a set of wind profiles located along the vertical plane containing the glide slope. These two-dimensional wind fields provide three components of wind as a function of altitude and distance to touchdown. The wind field data sources include accident reconstructions, wind tower data, and meteorological models.[6]

Hazardous meteorological situations tend to be localized and quite time variable. Three-dimensional wind data with time variation are required for adequate training in storm avoidance and storm penetration training in conjunction with weather radar presentations. Only the recent development of multiple Doppler radar analyses has made the acquisition of three-dimensional wind data possible. Unfortunately, such analyses have been limited to studying the most severe thunderstorms, the type a pilot would avoid at all costs. The innocuous little thunderstorm with a hidden downburst has in the past received little attention from meteorological researchers. Such storms are short-lived and very localized, requiring a large commitment of equipment and manpower. The National Severe Storm Laboratory in Norman, Okla., has recorded many such storms but more research is required.

The Joint Airport Weather Studies (JAWS) Project to be supported by NASA, NSF, and FAA is designed to study thunderstorms down to the Earth's surface with a resolution previously unobtainable in convective storms. Field data has been collected during the spring and summer of 1982 in the vicinity of the Stapleton Airport in Denver, Colo. The JAWS Project has the stated specific objective to collect vastly improved two- and three-dimensional thunderstorm wind shear data for utilization in manned flight simulators for training airline pilots.[7]

Speculations and Future Requirements

In addition to the stated requirements of the FAA Advanced Simulation Program, both military and commercial simulator customers are desiring better training for hazardous flight and ground conditions due to weather. The FAA requirements specify weather representations for the approach and landing phase of flight at and below 2000 ft altitude and within 10 miles of the airport. Mesoscale storms and downbursts, gust fronts, and heavy precipitation will need to be modeled along with the runway contamination resulting from the snow, ice, or rain present. Precipitation rates are needed in cloud and below cloud for the simulation of the aerodynamic effects of heavy precipitation resulting in drag and lift effects due to airfoil roughening.[8]

Radar information is becoming increasingly important as more training is required in pilot routing of aircraft and hazardous weather avoidance procedures. Weather radar simulation will probably require greater vertical resolution in radar data than is presently given by meteorological radars.

Simulators may begin to be used as a test bed for meteorological models of thunderstorms which have caused aircraft incidents. The meteorological conditions have been well modeled if simulator pilots fly a flight path similar to that taken by the original aircraft. Simulators may also be used to test wind shear detection systems in the cockpit.

Conclusions

Meteorological inputs for flight simulators have become more complex as more realistic and varied simulations are required. The sophistication of the weather modeling is limited by real-time computational requirements. The use of approved simulators for FAA certification checks requires a degree of weather variability to be modeled. Turbulence models for simulation need to include the pitching, rolling, and yawing moments experienced while flying through atmospheric turbulence. Turbulence scale lengths, rms values, and gust cross correlations need to be chosen to closely match the atmospheric conditions being modeled. Three-dimensional wind data with time variation are required to adequately simulate wind shear conditions around thunderstorms for training in storm avoidance and penetration. Weather radar information is becoming more important to simulation as more training is required in pilot routing and hazardous weather avoidance. An integrated simulation is required to be consistent with real world situations. As weather simulations become more complex, more emphasis must be placed upon internal meteorological logic than burdening the instructor. In short, the importance of meteorological simulation for purposes of flight crew training has now gained wide recognition, but much work needs to be done before this field of simulation gains the sophistication already achieved in other areas of simulation.

References

[1] Handberg, G.O., "Meteorological Inputs to Advanced Simulators," *Proceedings: Fifth Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems,* Tullahoma, Tenn., March-April 1981, pp. 21-25.

[2] "Advanced Simulation, Final Rule," Federal Aviation Administration, U.S. Department of Transportation, 14 CFR, Pts. 61 and 121, June 30, 1980.

[3] Reeves, P.M., Joppa, R.G., and Ganzer, V.M. "A Non-Gaussian Model of Continuous Atmospheric Turbulence for Use in Aircraft Design," NASA CR-2639, 1976.

[4] Houbolt, J.C., "Survey on Effects of Surface Winds on Aircraft Design and Operation and Recommendations for Needed Wind Research," NASA CR-2360, Dec. 1973.

[5] Etkin, B., "Turbulent Wind and Its Effect on Flight," *Journal of Aircraft,* Vol. 18, May 1981, pp. 327-345.

[6] Dieudonne, J.E., "Comments on a Proposed Standard Wind Hazard Environment and Its Use in Real-Time Aircraft Simulators," AIAA Paper 79-0324, Jan. 1979.

[7] Wilson, J., McCarthy, J., Carbone, R., and Fujita, T.T., "Doppler Weather Radar Applications to Terminal and Enroute Air Traffic Control," *Electro/81 Professional Program Session Record,* April 1981.

[8] Luers, J.K. and Haines, P.A., "The Effect of Heavy Rain on Wind-shear Attributed Accidents," AIAA Paper 82-0213, Jan. 1981.

Aerodynamic Characteristics of a Slotted vs Smooth-Skin Supercritical Wing Model

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Background

FOR more than 20 years, engineers have considered high-speed flutter model testing to be necessary for final verification that an aircraft is free from flutter. The complex effects of transonic aerodynamics on flutter appear to be even more important with the advent of the supercritical airfoil designs. Recent model tests indicate conflicting results concerning the severity of the compressibility effects of supercritical airfoils on flutter speed.[1,2]

Even though high-speed models have been tested for many years using sectionalized model construction, concern has increased over the possibility that the unevenness and gaps between the sections created interference with the formation of shock waves and other aerodynamic characteristics.

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Smooth-skin models have not only been very expensive and time-consuming to build, they have in most cases been unsatisfactory in 1) meeting stiffness and mass properties, 2) duplicating additional models, 3) determining mass and stiffness properties, and 4) varying mass and stiffness or changing the surface twist.

If a sectionalized model could be used early in the development program, when it is necessary to study many parameters such as mass, stiffness, store locations, and control surface configurations, the important flutter conditions could be identified with confidence. After a search of the available literature disclosed no data that would help to answer the question of smooth-skin vs sectionalized models, an investigative test was conducted.[3]

Outline of Slotted-Wing Test

The test model (Fig. 1) was a cantilevered, semispan, rigid wing with a 19-in.-long supercritical airfoil with a 28-deg sweep of the leading edge, an aspect ratio of about 8.3, and an airfoil thickness ratio of 11%.

The airstream chordwise slots were cut at wing stations 9.41, 11.41, and 16.9 (Fig. 1). The slots were cut as deep as possible while still maintaining model strength and not cutting the pressure tubes. The slots were nominally 0.125 in. deep, and the leading and trailing edges were cut through approximately ¾ in. from their respective edges. The gaps were approximately 0.05 in. wide (Fig. 2).

Five slot configurations were tested to simulate the various conditions that were considered important in comparing a sectionalized model with a smooth-skin model. The first slot configuration had open slots; the second configuration had slots filled with soft foam rubber, smoothed with the model surface, to represent the design typically used with sectionalized models to minimize airflow through the gap, yet adding minimum damping or stiffness; the third and fourth configurations had fences in the slots which were respectively 1/8 and 1/16 in. above the wing surface to typify the steps that result when the flexible model oscillates; and the fifth configuration had slots filled and sanded smooth with the surface. Each of the five slot configurations was tested at four Mach numbers: 0.67, 0.8, 0.875, and 0.95; and at five angles of attack: −2, −1, −0, +1, and +2 deg at each Mach number.

The model was tested in the Lockheed-Georgia Company Compressible Flow Facility (CFF), a blowdown tunnel with a test section 20 in. wide by 28 in. high and 6 ft long. The tunnel has variable porosity walls with a Mach range of from 0.2 to 1.2, a Reynolds number variation of 1×10^6 to 50×10^6/ft, a run time of 15 to 20 s, and a data acquisition time of from 10 to 15 s. The run time for this test was 15 s with a data acquisition time of 10 s, and the Reynolds number was 4×10^6. The model was mounted on the tunnel five-component strain-gage balance. The model had 35 pressure ports distributed chordwise (19 upper surface and 16 lower surface) at the inboard slotted section centerline, and 35

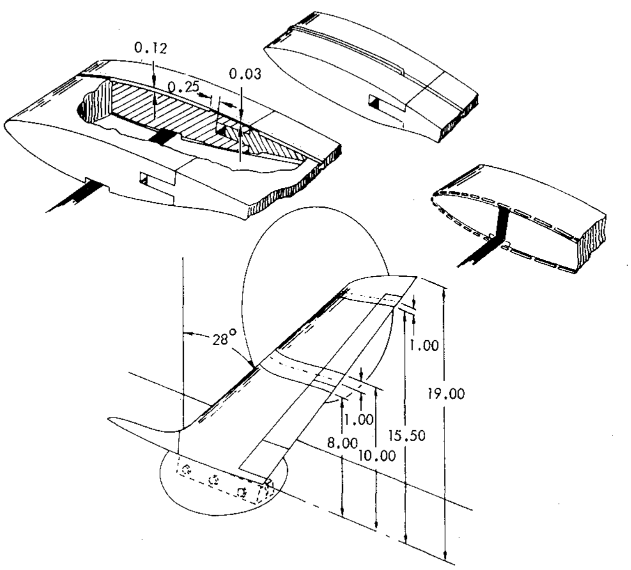

Fig. 1 Test model.

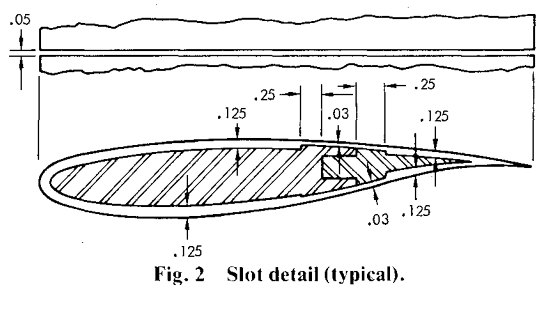

Fig. 2 Slot detail (typical).

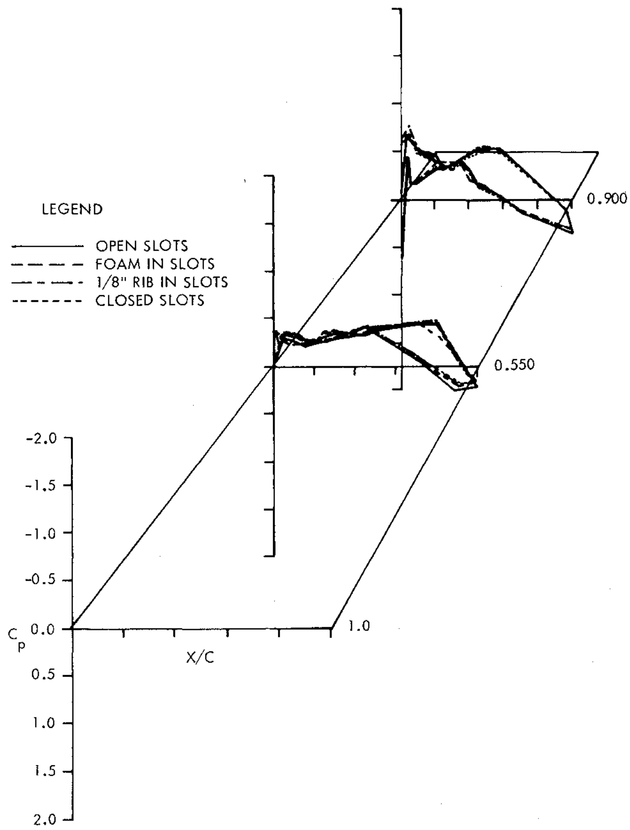

Fig. 3 Pressure distribution overlay at Mach number 0.95; angle of attack, +2 deg.

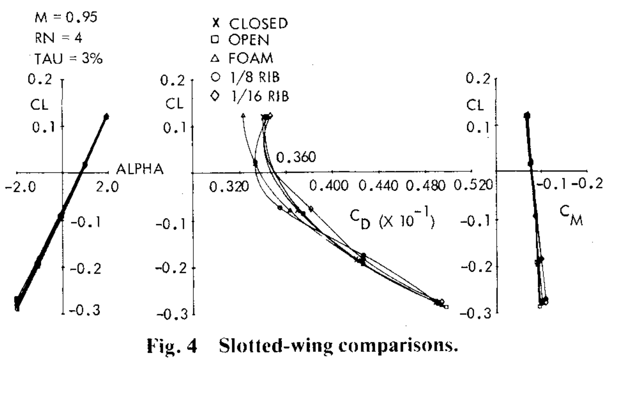

Fig. 4 Slotted-wing comparisons.

pressure ports (18 upper and 17 lower) at the outboard section. Data were recorded at each Mach number and angle-of-attack combination for each model configuration.

Test Results

The comparative pressure plots made of all model configurations at each Mach number and angle of attack are overlays so nearly identical that any slight difference can be attributed to run repeatability or small differences in Mach number. A pressure plot of the more interesting run comparison is shown in Fig. 3 at Mach number 0.95 for +2-deg angle of attack. In this figure, a comparison overlay is shown which illustrates that, at a Mach number of 0.95 for all slot configurations, all the parameters for each model configuration are nearly identical. Figure 4 is an overlay plot of C_L, C_D, and C_M vs the angle of attack for all model configurations at 0.95 Mach number. Direct overlays have been made for all the other Mach number conditions with similar results.

Conclusions

The test results show very conclusively that sectionalized flutter model design is not aerodynamically inaccurate when testing in the transonic speed range. This information can give the flutter engineer confidence that sufficiently accurate data can be obtained from other than a smooth-skin model. It also gives the test engineer a quicker and easier method of testing a larger variety of model parameters early in the aircraft design phase. Sectionalized model tests should be considered as a useful tool for extensive parametric studies at transonic speeds.

References

[1] Farmer, M.G. and Hanson, P.H., "Comparison of Supercritical and Conventional Wing Flutter Characteristics," *Proceedings of the AIAA/ASME/SAE 17th Structures, Structural Dynamics and Materials Conference*, King of Prussia, Pa., 1976, pp. 608-614.

[2] Houwink, R., Kraan, A.N., and Zwaan, R.I., "A Wind-Tunnel Study of the Flutter Characteristics of a Supercritical Wing," *Proceedings of AIAA/ASME/ASCE/AHS 22nd Structures, Structural Dynamics and Materials Conference*, Atlanta, Ga., April 1981, pp. 748-754.

[3] Grosser, W.F., "A Wind-Tunnel Study of the Aerodynamic Characteristics of a Slotted Versus Smooth-Skin Supercritical Wing," *Proceedings of the AIAA/ASME/ASCE/AHS 23rd Structures, Structural Dynamics and Materials Conference*, New Orleans, La., May 1982, pp. 84-94.

A New Approach to Optimization for Aerodynamic Applications

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Nomenclature

E = objective function
M = Mach number
P = vector of design parameters
R = residual
x = coordinate in the undisturbed flow direction
y = vertical coordinate in the upward direction
ϵ = small positive number determining convergence
ρ = density
ϕ = perturbation velocity potential

Subscripts and Superscripts

c = corrected value
F = free air condition
R = residual
T = tunnel condition
∞ = undisturbed condition
0 = minimum value
$(\ )^*$ = optimum value

Introduction

OPTIMIZATION problems arise in different aerodynamic applications, and their solutions attempt to determine the vector of design parameters, $\boldsymbol{P}$, that minimizes the objective function $E(\boldsymbol{P};\phi)$, where ϕ is the solution of the potential flow equation. For example, in airfoil design problems[1] $\boldsymbol{P}$ contains different shape functions for the airfoil surface, and E is the drag or negative lift. Wind tunnel wall interference is another example where the above optimization problem arises. There $\boldsymbol{P}$ may be chosen as a single design parameter (scalar) equal to the freestream Mach number.[2] The objective function E is chosen to be a measure of the Mach number differences on the model surface in the tunnel and in free air.

The optimization problem under consideration may be stated as follows: Find $\boldsymbol{P}$ such that

$$\min_{P} E(\boldsymbol{P};\phi) \tag{1}$$

with ϕ satisfying the equation

$$\nabla \cdot [\rho \nabla (x+\phi)] = 0$$

or the approximation

$$D(\phi;\boldsymbol{P}) = 0 \tag{2a}$$

subject to the boundary condition

$$B(\phi;\boldsymbol{P}) = 0 \tag{2b}$$

Currently available procedures[1,3] for solving the above minimization problem are time-consuming. Their high cost prevents their regular use in design problems. These procedures are inner-outer iterative procedures. In such procedures, each outer iteration results in a new iterative solution for $\boldsymbol{P}$ by using an optimization scheme (e.g., the steepest descent method or the conjugate gradient method). However, each outer iteration requires that the objective function be estimated, and, therefore, that a solution for Eq. (2a) be obtained (e.g., by line relaxation) using the new value for $\boldsymbol{P}$. Consequently, Eq. (2a) must be solved many times before the optimum $\boldsymbol{P}$ value is found, resulting in the high cost of calculation.

In this Note, a new and efficient approach to solving problems (1) and (2) is presented. This approach eliminates the need for an inner-outer iterative procedure, and requires that the boundary value problem (2) be solved only once. The approach is tested on a single design parameter problem.

Formulation

Present procedures for solving problems (1) and (2) use an optimization scheme to determine a sequence of successive approximations, $\boldsymbol{P}_m$, where $m=1,2,\ldots$, which converge to the optimum value $\boldsymbol{P}^*$. This is the outer iterative process. Within the mth outer iteration, the boundary value problem (2) is solved by making a number of iterative sweeps (inner iterations). The inner iterative sweeps update the value of ϕ, giving the successively improved approximations ϕ_m^n, where

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