Engineering Notes

ENGINEERING NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes cannot exceed 6 manuscript pages and 3 figures; a page of text may be substituted for a figure and vice versa. After informal review by the editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

OPSGER: Computer Code for Multiconstraint Wing Optimization

S. C. Gupta*
Institute of Armament Technology, Pune, India

Nomenclature

$a_{i,j}$	= influence of jth panel on ith control point
A	= panel elemental area
b	= semispan
c	= local chord length
C_D	= induced drag coefficient
C_L	= lift coefficient
ΔC_p	= pressure-difference coefficient
D	= induced drag
L	= lift
M	= Mach number
M_x	= pitching moment
M_y	= wing root-bending moment
N	= total number of panels
U	= freestream velocity
x,y,z	= Cartesian coordinates
XC	= distance of panel control point from y axis
YC	= distance of panel control point from x axis
ZX	= panel chordwise slopes
α	= angle of attack
Γ	= vorticity distribution before optimization
γ	= vorticity distribution after optimization
ρ	= freestream density

Subscript

$1, 2, \ldots, N$	= panel number

Introduction

USING an advanced mathematical model, we develop a code named OPSGER for the aerodynamic optimization. It can handle linearized flows. Several combinations of constraints can be specified. The code is useful for advanced aerodynamic application to aircraft design. It is applied to a delta wing of low-aspect ratio and the results are reported here.

Mathematical Modeling

The Cartesian coordinate system is shown in Fig. 1. Constant pressure[1] panel-type singularities are used to simulate lift effects. Half of the wing is divided into panels. Downwash due to each panel is collected at each control point to form a matrix of influence coefficients. Control points are selected at 95% of the local panel chord. For a given shape of wing profile, panel slopes are calculated. The influence of the other half of the wing is created through imaging.

The expressions for unoptimized lift, drag, and moments are

$$
\begin{aligned}
L &= (A_1\Gamma_1 + A_2\Gamma_2 + \cdots + A_N\Gamma_N)\rho U \\
D &= [(A_1\Gamma_1 (\alpha - ZX_1) + \cdots + A_N\Gamma_N (\alpha - ZX_N)]\rho U \\
M_x &= (A_1\Gamma_1\, XC_1 + \cdots + A_N\Gamma_N\, XC_N)\rho U \\
M_y &= (A_1\Gamma_1\, YC_1 + \cdots + A_N\Gamma_N\, YC_N)\rho U
\end{aligned}
\tag{1}
$$

Drag after optimization is expressed as

$$
\begin{aligned}
D^* = \rho U[&(a_{1,1}\gamma_1 + \cdots + a_{1,N}\gamma_N)\gamma_1 A_1 \\
&+ (a_{2,1}\gamma_1 + \cdots + a_{2,N}\gamma_N)\gamma_2 A_2 \\
&+ \cdots \\
&+ (a_{N,1}\gamma_1 + \cdots + a_{N,N}\gamma_N)\gamma_N A_N]
\end{aligned}
\tag{2}
$$

The objective function (F) to be minimized is written as[2]

$$F = D + \lambda_1 (L - \bar{L}) + \lambda_2 (M_x - \bar{M}_x) + \lambda_3 (M_y - \bar{M}_y) \tag{3}$$

where λ_1, λ_2, λ_3 are Lagrange multipliers. The overbar indicates constraint quantities.

The minimum drag condition is applied

$$
\begin{aligned}
\frac{\partial F}{\partial \nu_K} &= 0, \quad \text{for} \quad k = 1, 2, \ldots, N \\
\frac{\partial F}{\partial \lambda_\ell} &= 0, \quad \ell = 1, 2, 3
\end{aligned}
\tag{4}
$$

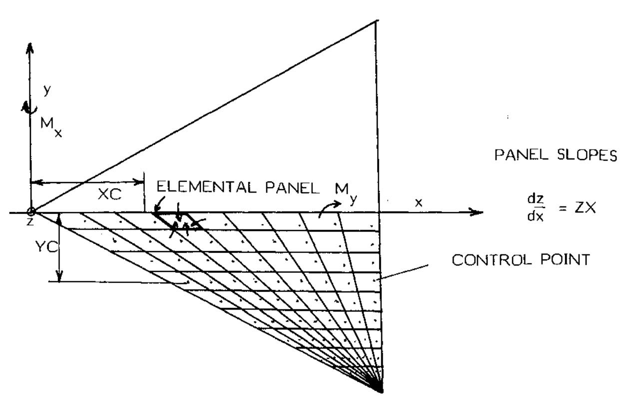

Fig. 1 Cartesian coordinate system.

Received Oct. 20, 1987; revision received Jan. 7, 1988.

*Squadron Leader, Technical Staff Officer, Faculty of Guided Missiles.

The following matrix for optimization is generated

$$\begin{bmatrix} 2A_1a_{1,1}\gamma_1 \; (A_1a_{1,2}+A_2a_{2,1})\gamma_2 & \cdots & (A_1a_{1,N}+A_Na_{N,1})\gamma_N & \lambda_1A_1 & \lambda_2A_1XC_1 & \lambda_3A_1YC_1 \\ (A_2a_{2,1}+A_1a_{1,2})\gamma_1 & \cdots & (A_2a_{2,N}+A_Na_{N,2})\gamma_N & \lambda_1A_2 & \lambda_2A_2XC_2 & \lambda_3A_2YC_2 \\ (A_Na_{N,1}+A_1a_{1,N})\gamma_1 & \cdots & 2A_Na_{N,N}\gamma_N & \lambda_1A_N & \lambda_2A_NXC_N & \lambda_3A_NYC_N \\ A_1\gamma_1 & \cdots & A_N\gamma_N & 0 & 0 & 0 \\ A_1XC_1\gamma_1 & \cdots & A_NXC_N\gamma_N & 0 & 0 & 0 \\ A_1Y_1\gamma_1 & \cdots & A_NYC_N\gamma_N & 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \bar{L} \\ \bar{M}_x \\ \bar{M}_y \end{bmatrix} \tag{5}$$

The matrix is solved for the unknown values of γ (optimal vortex strength) and new values of the surface slopes computed through Neumann's boundary conditions of flow tangency. The perturbation velocities and pressure field are computed subsequently.

OPSGER: Capabilities and Validation

OPSGER is developed for minimizing drag for a given set of conditions. In designing the OPSGER computer program system, maximum versatility is kept in mind. The program can handle two categories of an optimization problem. In one, the surface slopes of the configuration are specified and the optimal profile worked out. In another, the loading is specified and the program calculates the surface slopes and then optimizes the camber. Wings of arbitrary planform can be handled.

Optimization is done subject to constraints. There are five constraints available in the code, namely, $(\bar{L}, \bar{M}_x, \bar{M}_y)$, $(\bar{L}, \bar{M}_x)$, $(\bar{L}, \bar{M}_y)$, $(\bar{L})$, $(\bar{M}_x, \bar{M}_y)$.

Subsonic and supersonic flow at low angles of attack can be handled. The code is conditioned to handle mixed flows, so long as shock waves are not present. Mixed flow conditions occur mainly for subsonic flows. For this, local Mach numbers are first calculated without considering the region of influence. Subsequently, the region of influence is redefined considering Mach waves and cones. The optimization matrix fails to converge in the presence of shock waves. The program is written in Fortran-IV.

Wake interrogation is feasible through OPSGER. The wake points are specified, and the nature of the wake behind an optimal profile can be studied.

OPSGER subroutines fall into three categories: equation preparation programs, matrix solutions, and gross characteristics estimation programs. Matrices without diagonal discontinuities are solved with the Gauss-Seidel technique. The optimization matrix has diagonal discontinuities (zero in the last few rows). The Gauss-Seidel technique diverges when inverting such matrices. The Gauss-Jordan numerical technique is used for the solution of the optimization matrix.

Results and Discussion

No data are available to validate OPSGER for such a variety of constraints. As an alternative, the optimal-profile camber generated through OPSGER has been fed into the WINGER code of Ref. 4. The drag levels from OPSGER and WINGER are the same. For the lift-alone constraint, some data are available in Refs. 2 and 3 for supersonic flows. The overall drag levels achieved through OPSGER are similar; however, no pressure-distribution data are available.

The code is applied to a flat-plate delta wing of 2.5 aspect ratio. Results for the lift-alone constraint are shown in Table 1. Drag reduction as high as 67% is feasible in the incompressible flow regime. Improvement in aerodynamic efficiency through optimization deteriorates with increasing compressibility. Relief in wing root-bending moment is prominent in the subsonic region.

Table 1 Influence of aerodynamic optimization on a flat-plate delta wing, aspect ratio = 2.5, $\alpha = 4$ deg, lift-alone constraint considered

M	C_L	C_D	C_D[a]	Drag reduction, %	M_x/M_x[a]	M_y/M_y[a]
0.5	0.22	0.0153	0.005	67	0.86	0.87
0.75	0.24	0.017	0.007	58	0.86	0.878
1.25	0.28	0.02	0.013	35	1.02	0.95

[a]Indicates optimized values.

Table 2 Comparison of drag levels

M	M^2C_D (drag level) Flat-plate	Optimal-plate
0.5	0.00382	0.00125
0.75	0.00956	0.00393
1.25	0.0312	0.0203

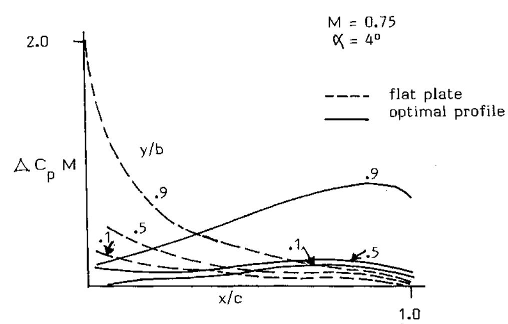

Fig. 2a Subsonic pressure distribution.

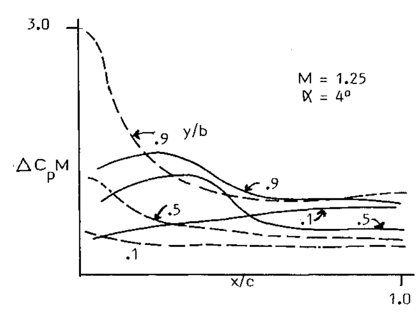

Fig. 2b Supersonic pressure distribution.

Induced drag levels are shown in Table 2. The optimization benefit deteriorates with increasing Mach number; however, the overall benefits are larger because the drag levels are much higher in supersonic flow.

Subsonic and supersonic chordwise pressure distribution are shown in Fig. 2. Figure 2a shows a large drop in leading-edge pressures as a result of optimization. Optimization results in evenly distributed chordwise loading and the adverse pressure gradient shifts further rearward, delaying flow separation. The local load distribution toward the wing tips is reduced by optimization, decreasing the root-bending moment. In supersonic flow, some drop in leading-edge pressure is observed as a result of optimization (Fig. 2b); however, peak loading and the start of the adverse pressure gradient remain close to the leading edge. Reduction in local load distribution toward wing tips due to optimization is marginal because of the conical nature of the flow.

Conclusions

The computer code OPSGER is useful for the aerodynamic optimization of arbitrary wing planforms. OPSGER features analysis and optimization in the presence of several constraints, and can be applied to wake studies.

Acknowledgments

The author expresses his gratitude to Air Vice Marshal (Retired) H. N. Krishnamurthy for his kind encouragement in pursuing this work and permission to use the computer facilities at the Aeronautical Development Establishment. The author is also indebted to Dr. E. Bhagiratharao, Dean and Director of the Institute of Armament Technology, for encouragement and permission to publish this work.

References

[1]Woodward, F. A., "An Impoved Method for the Aerodynamic Analysis of Wing-Body-Tail Configurations in Subsonic and Supersonic Flow," NASA CR-2228, Part 1, May 1973.

[2]Woodward, F. A., Tinoco, E.N., and Larsen, J.W., "Analysis and Design of Supersonic Wing-Body Combinations, Including Flow Properties in the Rear Field, Part 1, Theory and Application," NASA CR-73106, Aug. 1967.

[3]Yoshihara, H., Kainer, J., and Strand, T., "On Optimum Thin Lifting Surfaces at Supersonic Speeds," *Journal of Aerospace Sciences,* Vol. 25, Aug. 1958, pp. 473–479.

[4]Gupta, S. C., "WINGER: Computer Code for Aerodynamic Coefficient Prediction for 3-D Arbitrary Wing-Body Combination at Subsonic and Supersonic Speeds, Including Wake Interrogation and Indirect Design Capability," Aeronautical Development Establishment, DRDO, India, ADE/TR/84-103, April 1984.

Preliminary Weight Estimation of Conventional and Joined Wings Using Equivalent Beam Models

Prabhat Hajela*
University of Florida, Gainesville, Florida
and
Jahau Lewis Chen†
National Cheng Kung University, Taiwan, Republic of China

Introduction

THE implementation of optimum design methods in automated synthesis programs makes available a significant capability for assessing new concepts in aircraft design. Such methods, however, tend to be computationally demanding, particularly if detailed analysis is used in each participating discipline of this multidisciplinary exercise. This Note outlines an efficient approach to obtaining optimum weight estimates of conventional and joined wing structures and is based on representing the detailed finite-element models of the structure by equivalent beam models. The latter are considered more efficient in an optimization environment, which requires repetitive analysis of several candidate designs.

A joined wing design[1] is obtained by replacing the horizontal tail in a conventional airplane with a forward swept wing that is joined to the front wing at the tip or an intermediate span station (Fig. 1). The resulting truss formed by the front and aft wings has its primary load-carrying plane inclined to the horizontal by an angle determined by the dihedral on the wings. The loads have an in-plane and an out-of-plane component, where the latter tends to concentrate material on the upper surface of the leading edge and the lower surface of the trailing edge of the airfoils. As seen in Fig. 1, the effective beam depth that defines stiffness in bending is dependent on the chord length and the dihedral angle, in contrast to the thickness profile for conventional wings. An optimization study to quantify this potential[2] employed detailed finite-element models in the analysis at a substantial computational cost. To reduce analysis costs, the present approach proposes the use of reduced-order equivalent beam models.

Equivalent Beam Models

The central idea behind this approach was to represent the spanwise distribution of sectional moments of inertia I_{yy} and I_{zz}, the product of inertia I_{yz}, and the torsional constant Q (Fig. 2) for the built-up wing structure on an equivalent beam. The mass per unit length of the wing span M was also introduced to establish a weight relation between the wing and beam models. Before transferring the section properties from the wing to the beam, they must be scaled to account for shear lag effects. If this scaling were not used, the resulting beam structure would be artificially stiff. In this work, the lag factor was obtained by a process of numerically matching the reponse of the built-up wing model to its equivalent beam model for nominal values of the section dimensions. Details of obtaining this scale factor are described in Ref. 3. The beam section to which these five section properties are attributed is shown in Fig. 2. It can be described in terms of five independent wall thicknesses and can accommodate an unsymmetrical material distribution typical of swept conventional and joined wing configurations.

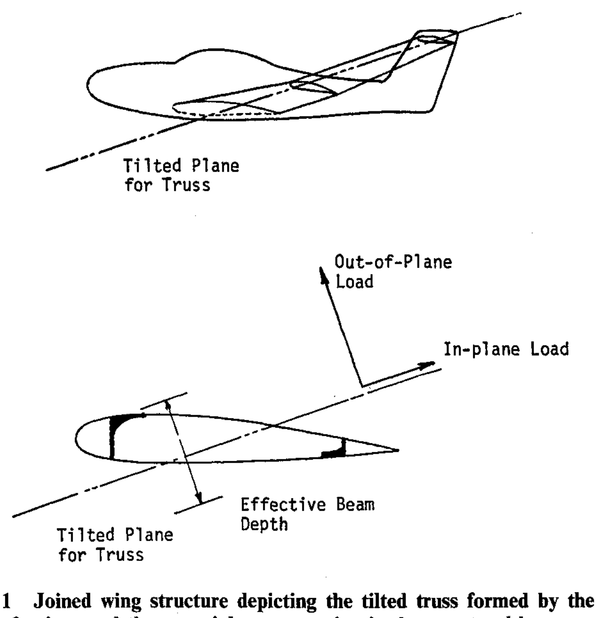

Fig. 1 Joined wing structure depicting the tilted truss formed by the fore-aft wings and the material concentration in the structural box.

Received July 14, 1986; revision received Sept. 23, 1987.

*Associate Professor, Department of Aerospace Engineering, Mechanics and Engineering Science. Member AIAA.

†Associate Professor. Member AIAA.