

# Static Aeroelastic Analysis for Generic Configuration Wing

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## Abstract

A STATIC aeroelastic analysis capability that calculates flexible air loads for generic configuration wings was developed. It was made possible by integrating a finite element structural analysis code (MSC/NASTRAN) and a panel code of aerodynamic analysis based on linear potential flow theory. The framework already built in MSC/NASTRAN was used, and the aerodynamic influence coefficient matrix was computed externally and inserted in the NASTRAN by means of a DMAP program. It was shown that deformation and flexible air loads of an oblique wing configuration including asymmetric wings can be calculated reliably by this code both in subsonic and supersonic speeds.

## Contents

Static aeroelasticity is a problem involving the response of a flexible structure to aerodynamic loading. The analysis of static aeroelasticity involves the calculation of static response, including loads and stresses in the structure. MSC/NASTRAN<sup>1</sup> uses an aerodynamic influence coefficient matrix generated based on the doublet-lattice method<sup>2</sup> to calculate aerodynamic quantities in subsonic flow.

The doublet-lattice method in the NASTRAN program does not have a capability of supersonic aerodynamic analysis. The Mach box method<sup>3</sup> installed in NASTRAN can be used to estimate aerodynamic forces in supersonic flow. However, this method is applicable only to the symmetric configuration in NASTRAN. The other option for supersonic aerodynamics is the piston theory,<sup>4</sup> which is valid in the range of Mach numbers from about 2.5 to 7.0. Therefore, an alternative aerodynamic code, Wing3D, was used to calculate the aerodynamic properties in the low supersonic range. In the subsonic range, the results obtained by Wing3D agree well with those obtained by the doublet-lattice method.

The Wing3D computer code has been developed by Carmichael and modified to include thickness effects and second-order pressure rules in the design mode by Kroo at NASA Ames Research Center. This code has been developed based upon the theories of Ref. 5. The Wing3D computer code is used to compute a linear potential flow about a thin wing.

The structural response equation can be given as<sup>6</sup>

$$[K]\{u_g\} = \{F_0\} \quad (1)$$

where the system stiffness matrix  $[K]$  is defined as

$$[K] = [K_s] - [K_a] \quad (2)$$

Here,  $[K_s]$  is the structural stiffness matrix, and  $[K_a]$  is defined as

$$[K_a] = q[G_{kg}]^T[S_{kj}][A_{ij}]^{-1}[D_{jk}][G_{kg}] \quad (3)$$

Here,  $[G_{kg}]$  is the interpolation matrix,  $[S_{kj}]$  the force transformation matrix from  $j$  set to  $k$  set, and  $[D_{jk}]$  the displacement transformation matrix from  $k$  set to  $j$  set. We can obtain the aeroelastic response from Eq. (1). Here, aerody-

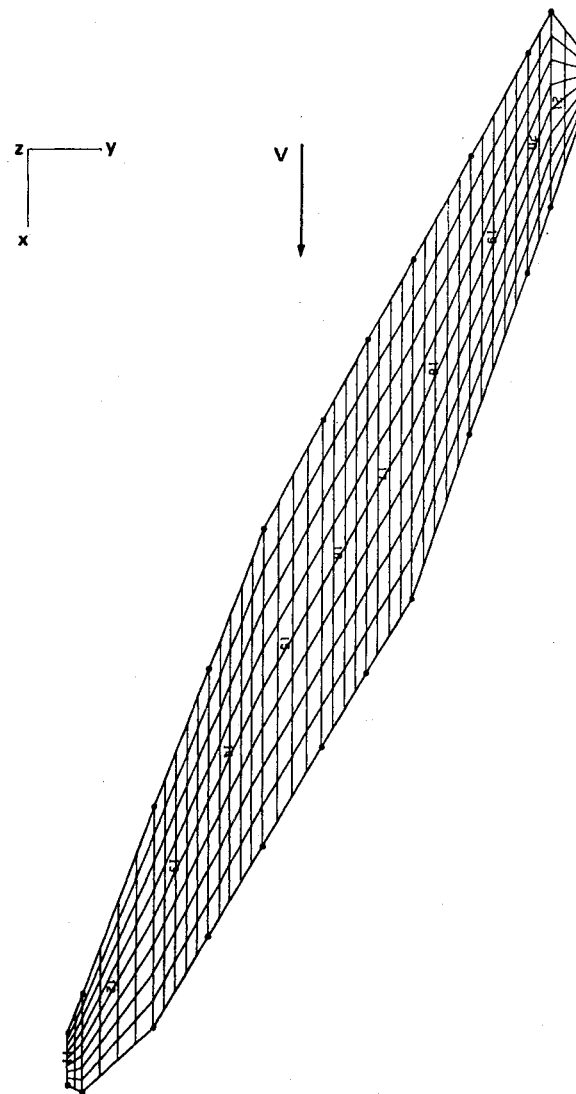


Fig. 1 Aerodynamic grid for 250-ft² oblique wing.

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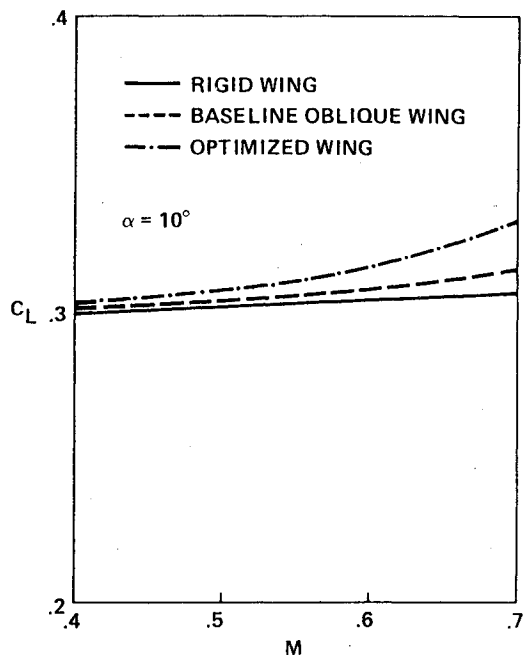


Fig. 2 Lift coefficient vs Mach number ( $\alpha = 10$  deg).

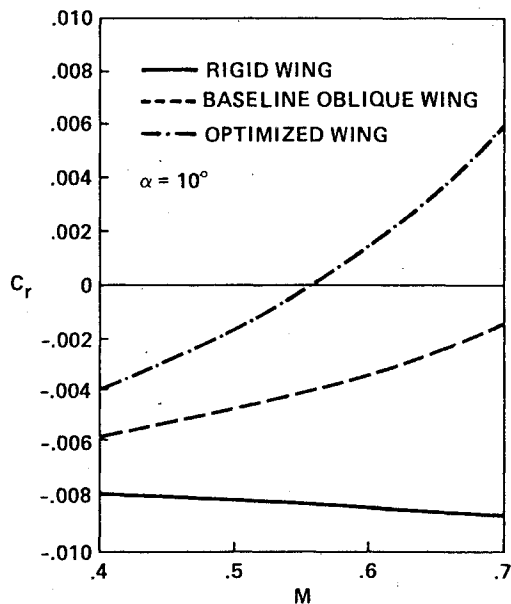


Fig. 3 Rolling moment coefficient vs Mach number ( $\alpha = 10$  deg).

dynamic influence coefficients are calculated from the Wing3D program.

### Discussion of Results

In this section, we will discuss the full-scale 250-ft<sup>2</sup> oblique wing. Also, we will examine a rigid oblique wing and flexible-

optimized wing to show the wing flexibility effect. The aerodynamic elements are given in Fig. 1. The analyzed structural shape is three dimensional. For the aerodynamic analysis, zero-thickness panels are used. The thickness ratio of the airfoil at the centerline is 14% and linearly decreases to 12% at the 85% semispan station. The sweep angle of the wing is 65 deg.

The comparison between the doublet-lattice method and the Wing3D program results is obtained. The total lift is almost the same between the two methods (0.4% difference); however, the maximum deflection has more difference (5.5%). The rolling moment coefficient has some difference but these values are relatively small.

The rigid-wing results were obtained by increasing the Young's modulus  $E$  and the shear modulus  $G$  by 100 times. An optimized wing, which is the most flexible, was analyzed to show that it can withstand the composite thickness for a 4-g maneuvering condition.

Figure 2 shows the lift coefficient vs the Mach number in the subsonic region. The angle of attack is 10 deg and the sea level conditions are used for the computations. The optimized (flexible) wing has the biggest lift. The flexibility effects increase with the increase of Mach number for both the baseline oblique wing and the optimized wing. When the Mach number is 0.7, the lift coefficient of the optimized wing is 7.8% higher than that of the rigid wing and the coefficient of the baseline oblique wing is 5.4% higher than that of the rigid wing.

Figure 3 shows the rolling moment coefficient vs the Mach number. The angle of attack is 10 deg. Substantial differences in the rolling moment caused by wing flexibility are observed. For the rigid wing, the rolling moments are almost constant but they tend to decrease slightly with the increase of Mach number. For this rigid wing, the effective angle of attack is strongly affected by the upwash. The upwash of the left-side wing (swept-back wing) is larger than that of the right-side wing (swept-forward wing). This effect results in the negative rolling moment for the rigid wing. The most significant effect of the wing flexibility on the rolling moment is observed for the optimized wing. The sign of the rolling moment of the optimized wing (the most flexible wing) changes from negative to positive at a Mach number of 0.57.

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