ABSTRACT

The subsonic unsteady aerodynamic computer programs tend to over pedict the aerodynamics at the wing/control surface interface. In the past when using strip theory aerodynamics to insure that this effect was not critical to the flutter analysis, parameter studies were made using reduced aerodynamics on the control surfaces. To study the effect of using a matrix reduction technique with the MSC/NASTRAN Doublet-Lattice program, an analytical model of the Förschꞏing, Triebstein, and Wagener experimental model was developed. A comparison of the various configurations were made. Additional configurations were analyzed and the effects of the various methods of modeling the wing/control surfaces on the flutter analyses are noted.

NOTATIONS

x, y	$[m]$	Cartesian coordinates, See Figure 3
s	$[m]$	effective half-span, See Figure 3
ℓ	$[m]$	constant model chord parallel to the flow direction
ϕ		sweep angle
ω	$[s^{-1}]$	circular frequency
k		reduced frequency $= \frac{\omega \ell}{2V}$
ℓ_r	$[m]$	constant cord of the control surface parallel to the flow direction
V	$[m s^{-1}]$	flow velocity
q	$[kg\ m^{-1}\ s^{-2}]$	dynamic pressure $= (\rho/2)\,V^2$
ρ	$[kg\ m^{-3}]$	air density
p	$[kg\ m^{-1}\ s^{-2}]$	unsteady pressure amplitude
ΔCp		non-dimensional pressure amplitude $= \frac{p_{lower} - p_{upper}}{q} = \Delta C'p + i\Delta C''p$
$\Delta C'p$		real part of ΔCp
$\Delta C''p$		imaginary part of ΔCp
Aw		angular rotation amplitude of the wing, positive hose-up
Ai.f.		angular rotation amplitude of the inner flap
Ao.f.		angular rotation amplitude of the outer flap
λ		damping

INTRODUCTION

Experience has shown that in most cases where aircraft have encountered flutter problems control surfaces were involved. For this reason it is important that the wing/control surface/tab be accurately modeled when doing flutter analysis on an aircraft. Problems associated with aerodynamic modeling of control surfaces were discussed by Wasserman, Mykytow, and Spielberg[1] as early as 1944 where they suggested reducing the tab aerodynamic coefficients by 30 percent to account for the poor airflow found over control surface tabs. When using strip theory aerodynamics, it is a standard Beech practice to vary the control surface aerodynamic coefficients when doing an aircraft flutter analysis parameter study.

When Beech obtained the MSC/NASTRAN computer program for use in doing in-house flutter analysis one problem was encountered. Strip theory aerodynamics could no longer be used for all flutter analyses since it did not allow for the modeling of the wing/control surface/tab configurations; therefore, it was decided to use Doublet-Lattice aerodynamics when doing some of the in-house flutter studies. Several questions had to be answered at this time.

1) Was it still necessary to include variations in control surface/tab aerodynamics as a parameter in the flutter study when using Doublet-Lattice aerodynamics.
2) Could the control surface/tab aerodynamics be varied with DMAP alters.

3) Would a reduction of control surface/tab aerodynamics in the Doublet-Lattice computer program be a valid procedure.

Comparison of experimental and theoretical lifting pressure distribution on an airfoil with oscillating flap in two dimensional flow by albano and Rodden[2] indicated that the theory would over-predict the pressure. Rowe, Winther, and Redman[3] indicated that considerable variation in results may be obtained when using the Doublet-Lattice program to model wing/control surfaces depending upon the method used in defining the control point distribution, but results would approach asymptotic values provided that either a sufficiently large number of control points were used or by using a smaller number of carefully spaced control points. They also indicated that theoretical and experimental data were in good agreement except for a small area around the wing/control surface hinge-line. In a paper by Rowe, Sebastian, and Redman[4] it was found that the theoretical unsteady hinge moment could vary by as much as 20 percent from experimental results on a wing-aileron-tab configuration. There are at the present time additional studies being carried out to determine methods of modeling and correcting the wing-aileron-tab configurations. Until these results are made available Beech will continue to keep control surface/tab aerodynamics as a parameter in the aircraft flutter study.

The next step was to determine how to correct the control surface/tab aerodynamics. A matrix method recommended by Bill Rodden was implemented by a set of DMAP instructions and have been released as a note by MSC. These procedures were first used in conjunction with one of the example problems given in Reference 5. The aerodynamic model is shown in Figure 1, with the results of reducing the aerodynamics on the control surface shown in Figure 2. For this particular example a reduction in the control surfaces aerodynamics raised the flutter speed. To determine if this procedure would be valid and to investigate various modeling techniques, an analytical model of the experimental model presented by Försching, Triebstein, and Wagener[6] was developed. The model they used is shown in Figure 3 and the aerodynamic model used in this study is shown in Figure 4. A flutter study of their model was done by developing a flutter model in which the critical mode was the same as one of the mode shapes presented in their paper. In this manner it was possible to use their experimental pressure distribution with the analytical flutter model.

ANALYTICAL/EXPERIMENTAL PRESSURE STUDY

The methods used to obtain the analytical pressure distributions were similar to those used in Demonstration Problem No. 13, MSC Aeroelastic Supplement, Reference 7. Multipoint Constraints[8] were used along with DMAP alters to obtain the proper modal scaling, phase relationships, and pressure coefficients instead of forces. Three of the seven configurations given in Reference 6 were generated analytically. The results of the first comparison are shown in

Figures 5 and 6. For each comparison mode only the real part of the pressure coefficient has been plotted; results obtained for the imaginary part of the pressure coefficient show the same trends as the real part. The results are similar to results shown by Rowe[3,4], Tijdeman[9] and Darras[10] which indicate that the largest variations in the pressure distribution occur near the discontinuities. As shown by the plots, the actual pressure coefficients are not as large as theory predicts even though the trends are correct. Tijdeman[9] stated that the differences are of the same order as for pressure distribution over wings without control surfaces. If this fact is true then one could use the corrections for one mode on a different mode under similar conditions: Mach number, frequency, etc.. Pressure distributions were calculated for two additional configurations; Figures 7 and 8 show the comparisons of these pressure distributions. Results from Figures 6 through 8 indicate that modal amplitude may play an additional role in matching analytical to experimental results other than that of normalization. Limited results obtained so far indicated that the magnitude and type of corrections needed for the modal configurations presented in Figures 6-8 would vary. These variations seem to correlate with the mode shape being used in the analysis. As an aid in studying the variations in experimental and analytical data various plots of the span-wise pressure distribution are shown for the first modal configuration, Figures 9 and 10. Figures 6, 9 and 10 were used to determine a set of corrections to be used in the flutter analysis.

FLUTTER STUDY

A flutter model was developed of the wing/outboard flap configuration; the same configuration which was used in the first analytical/experimental pressure distribution comparison, Figure 6, The flutter model was developed such that the critical mode was the same and flutter occurred under similar conditions: Mach number, frequency, etc.. The damping/frequency vs velocity plots are shown in Figure 11 for the flutter analysis of this model. Next the analytical pressure distribution was modified by use of DMAP alter to match the experimental pressure distribution and the flutter analysis was repeated. The damping/frequency vs velocity plots for the second flutter analysis are shown in Figure 12. Comparison of the two flutter analyses indicated that with corrected aerodynamics the wing torsion mode shows a region of instability while the flap flutter instability occurs at a higher velocity. The uncorrected model yielded conservative results as far as the flutter velocity was concerned, but it failed to show the wing torsion instability. Figures 13 and 14 show the results of reducing the flap aerodynamics by a set percentage, 20 and 40 percent. As shown by Figure 13, reducing the flap aerodynamics by 20 percent yielded results with the correct trends that are conservative.

CONCLUSION

Results from this study indicate that:

1) Variations in control surface/tab aerodynamics should remain a parameter in the flutter study.
2) The control surface/tab aerodynamics could be reduced using DMAP alters.

3) For the model used in this study, the reduction of the control surface aerodynamics was a valid procedure.

There is still a need to investigate the other mode shapes given in Reference 6 and their effect on the wing/control surface flutter results. Since this study only looked at the wing/control surface problem, there is a continuing need to investigate the wing/control surface/tab flutter problem.

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3. Rowe, W.S., Winther, B.A., and Redman, M.C., "Unsteady Subsonic Aerodynamic Loadings Caused by Control Surface Motions", Journal of Aircraft, Volume 11, No. 1, January 1974

4. Rowe, W.S., Sebastian, J.D., and Redman, M.C., "Recent Developments in Predicting Unsteady Airloads Caused y Control Surface Motions", Journal of Aircraft, Volume 13, No. 12, December 1976

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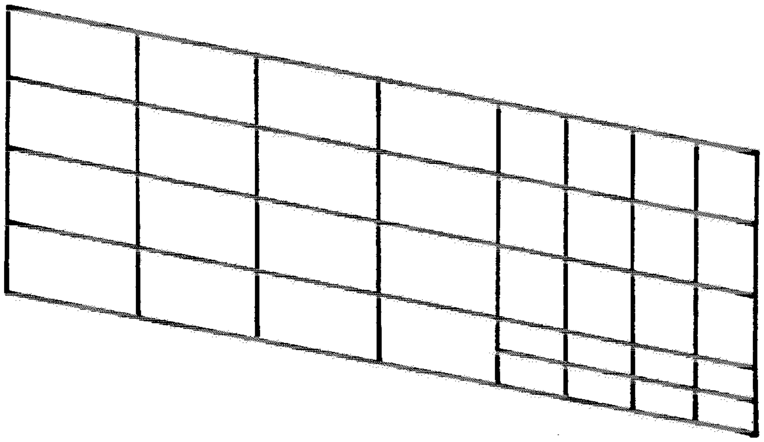
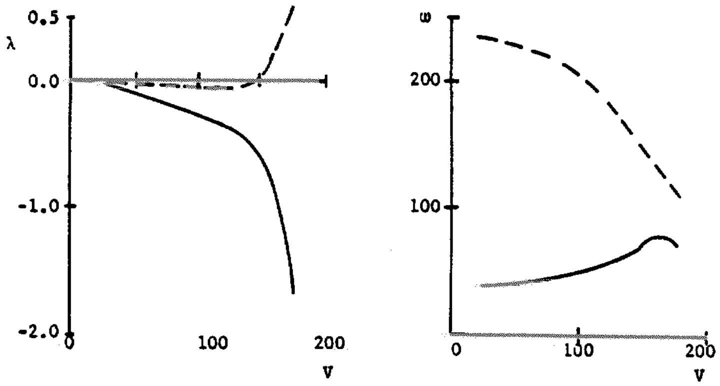
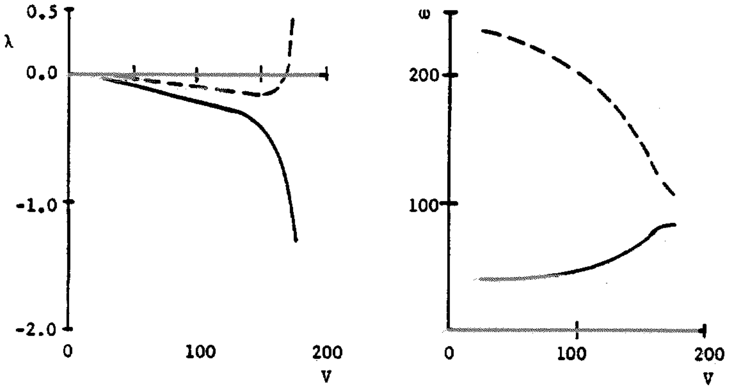
FIGURE 1

AERODYNAMIC MODEL USED IN DMAP STUDY





a) STANDARD DOUBLET-LATTICE AERODYNAMICS



b) REDUCED DOUBLET-LATTICE AERODYNAMICS

FIGURE 2

EXAMPLE OF USING DMAP ALTER TO REDUCE
AERODYNAMICS ON CONTROL SURFACES

PROFILE NACA 0012

$S = 0.88$ m $\quad l = 0.6$ m

$S_r = 0.41$ m $\quad l_r = 0.18$ m

$\phi = 25°$

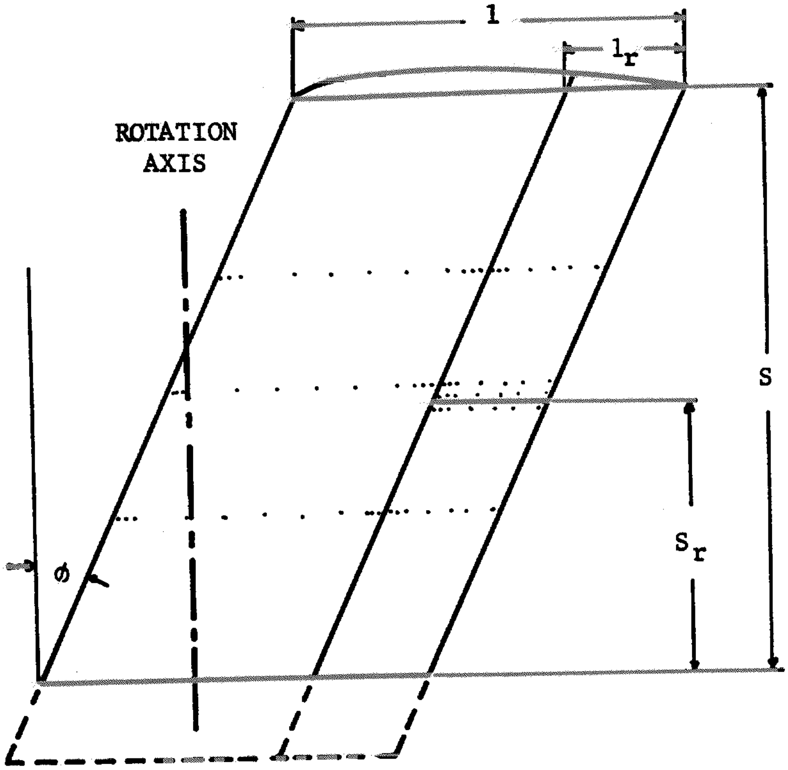


FIGURE 3

EXPERIMENTAL MODEL USED TO OBTAIN OSCILLATORY PRESSURE COEFFICIENTS

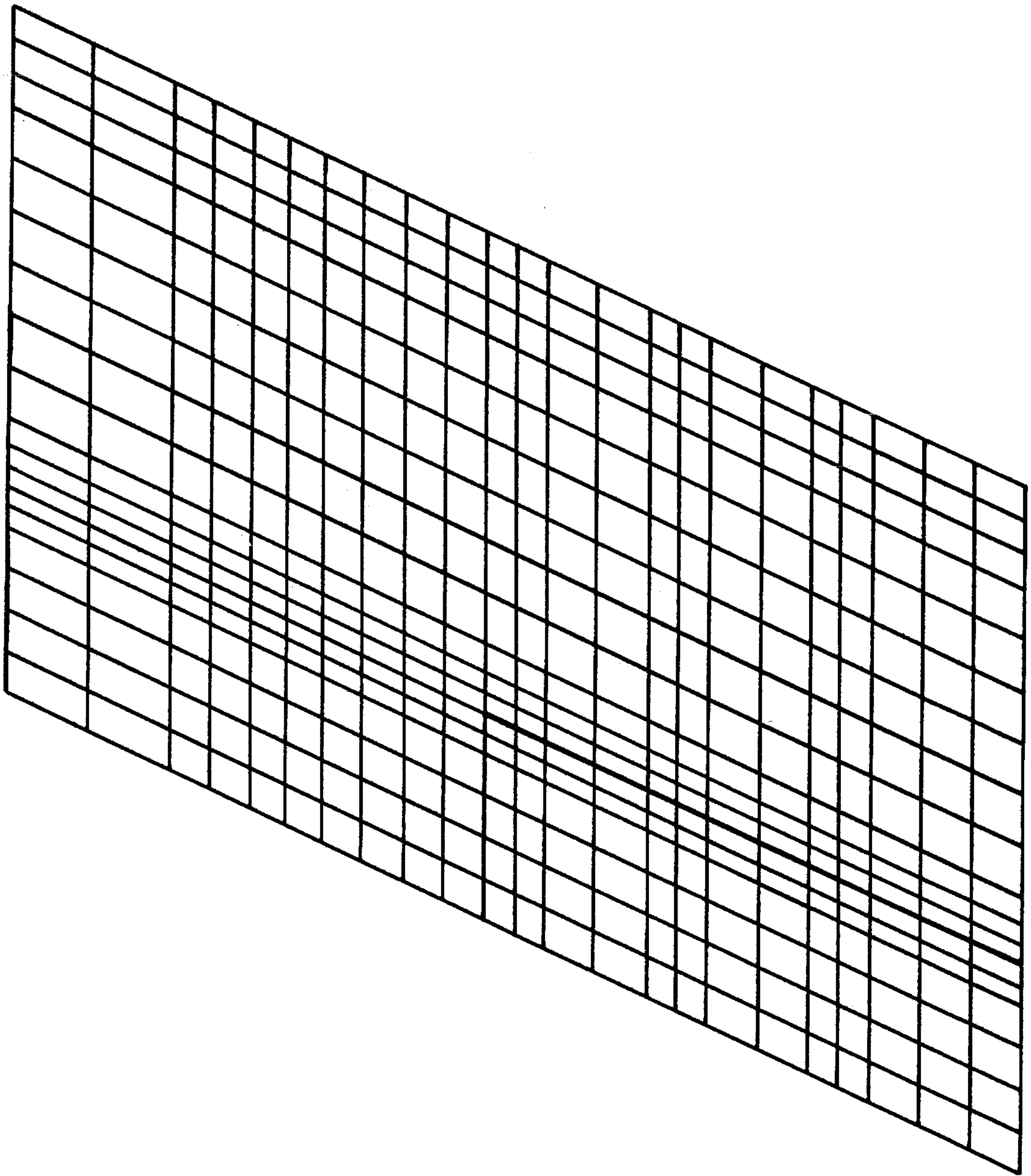


FIGURE 4

DOUBLET-LATTICE AERODYNAMIC MODEL USED
IN PRESSURE AND FLUTTER STUDY

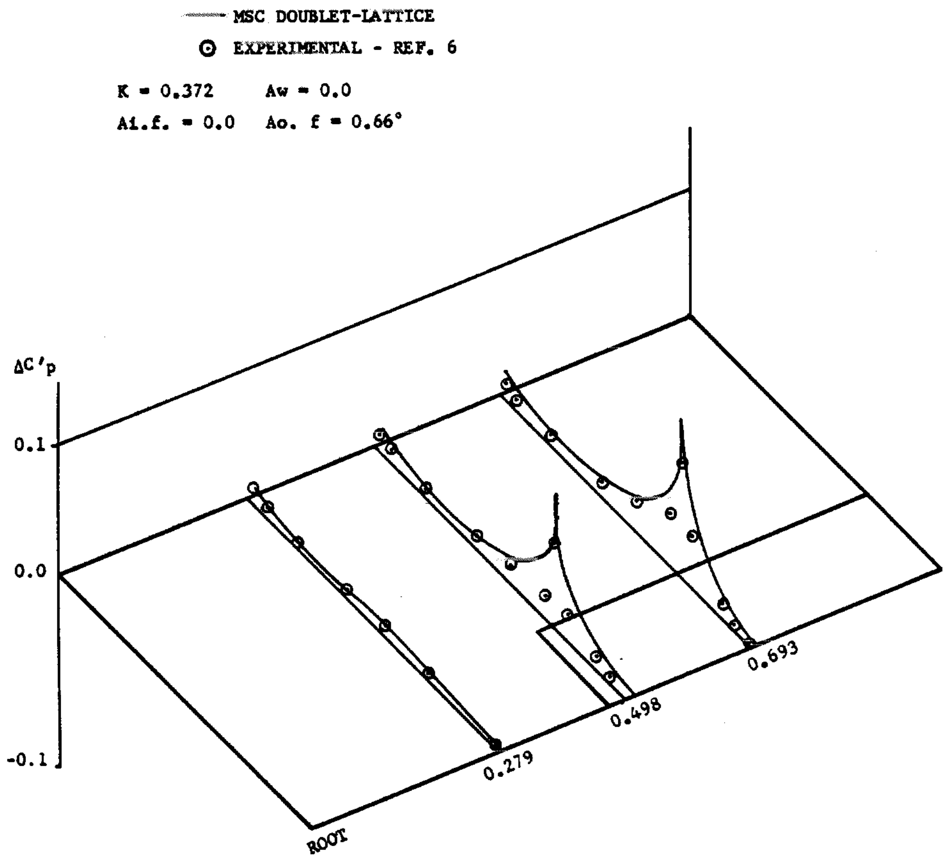


FIGURE 5
IN-PHASE CHORDWISE PRESSURE DISTRIBUTIONS

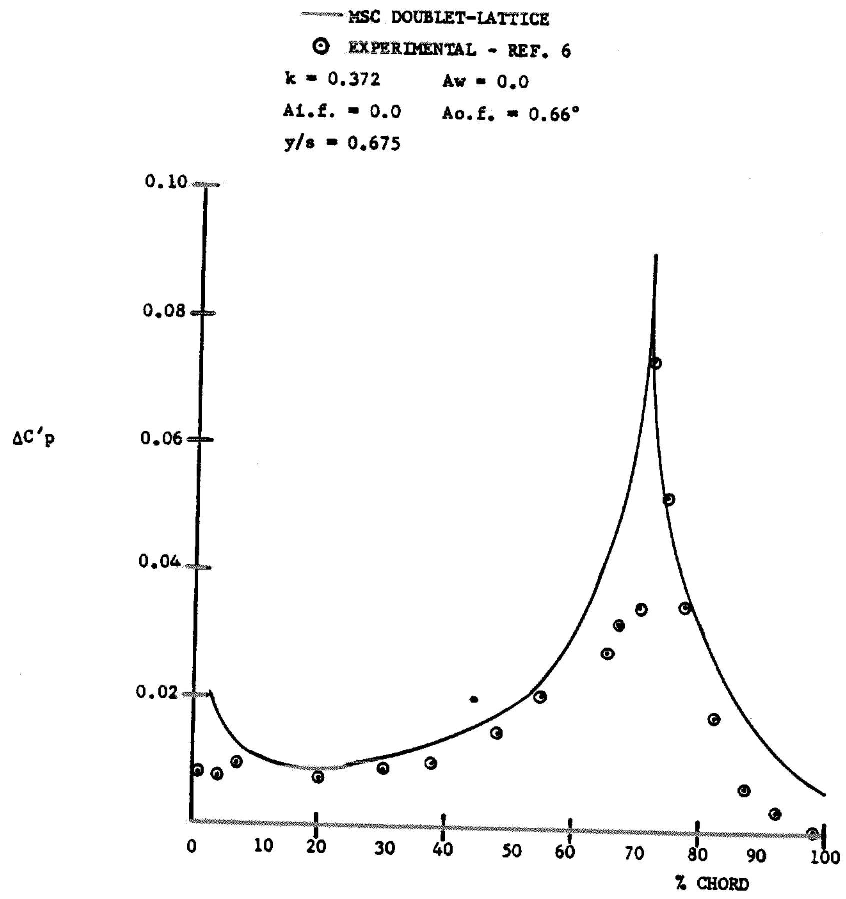


FIGURE 6

IN-PHASE PRESSURE DISTRIBUTION

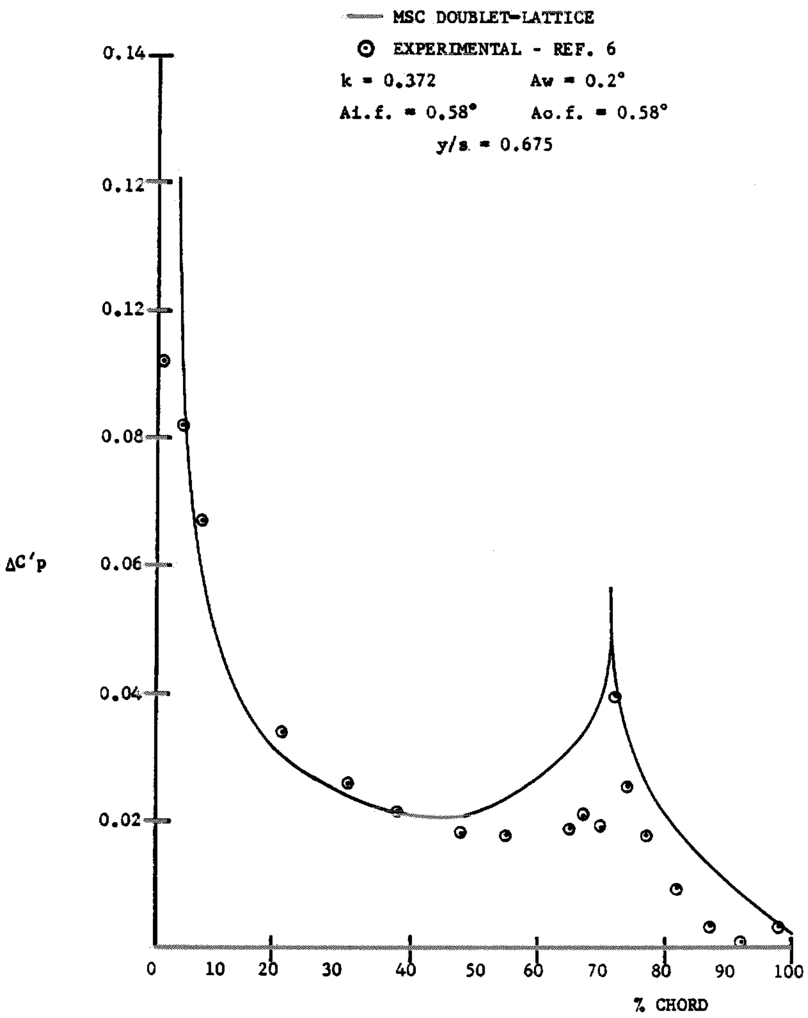


FIGURE 7

IN-PHASE PRESSURE DISTRIBUTION

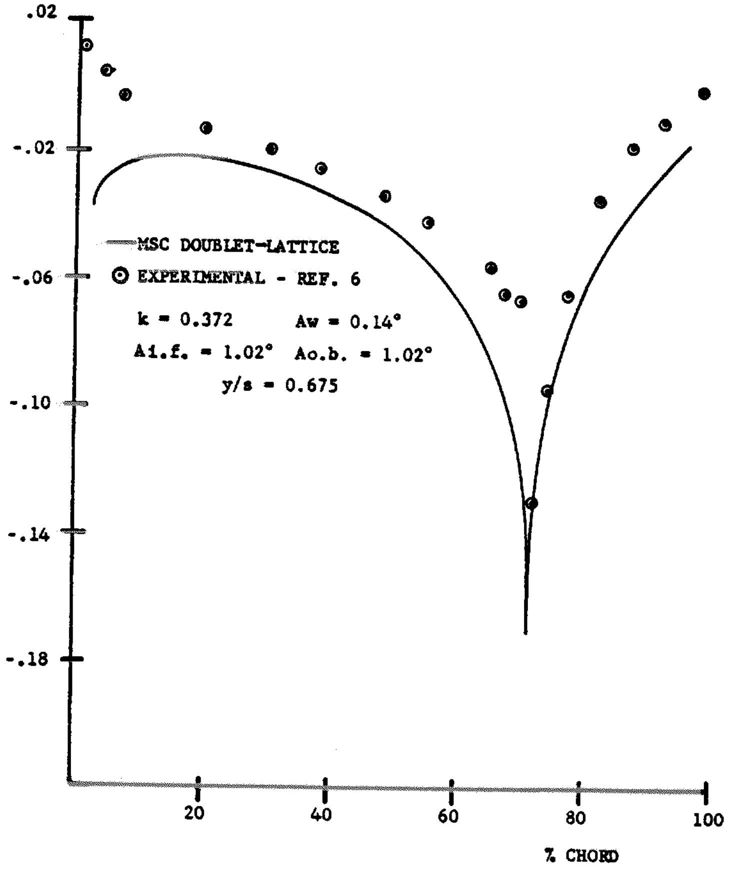


FIGURE 8
IN-PHASE PRESSURE DISTRIBUTION

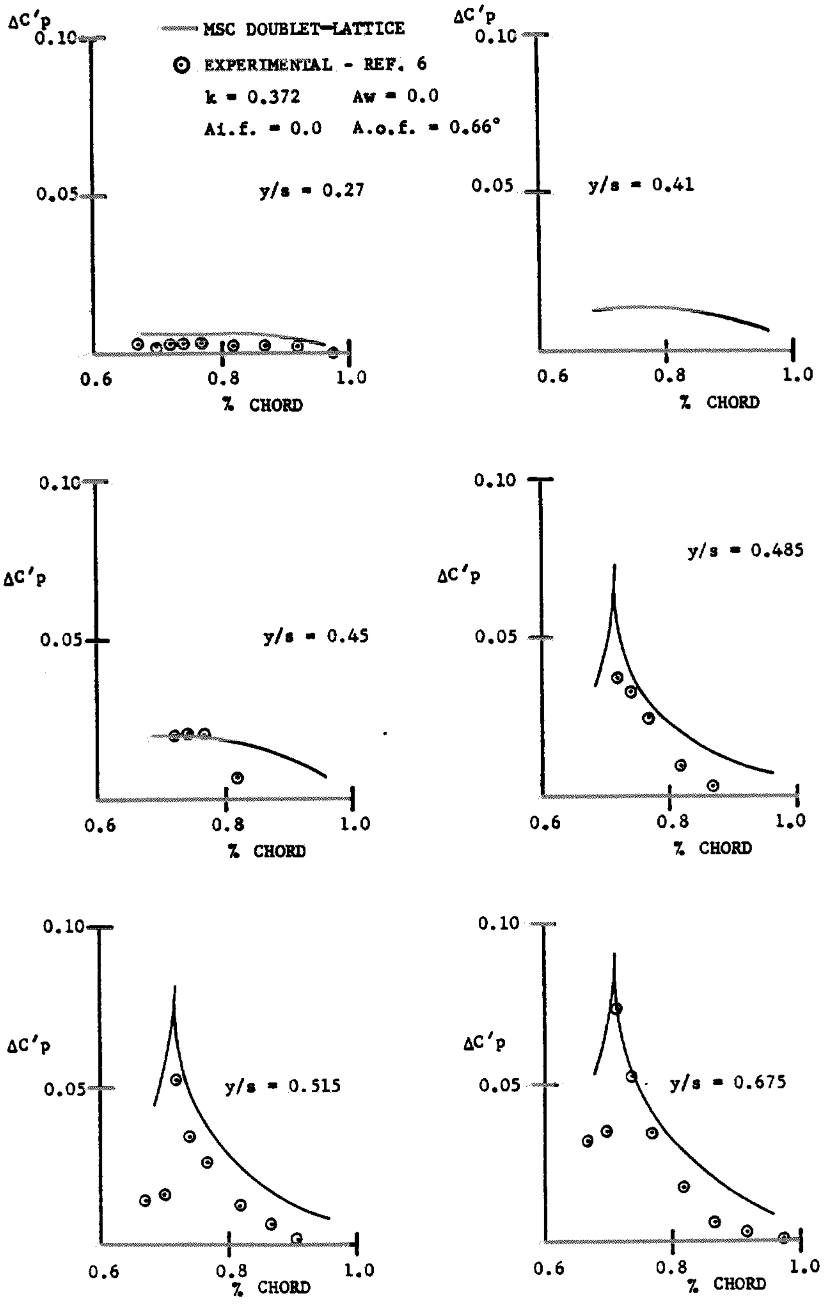


FIGURE 9
IN-PHASE PRESSURE DISTRIBUTION

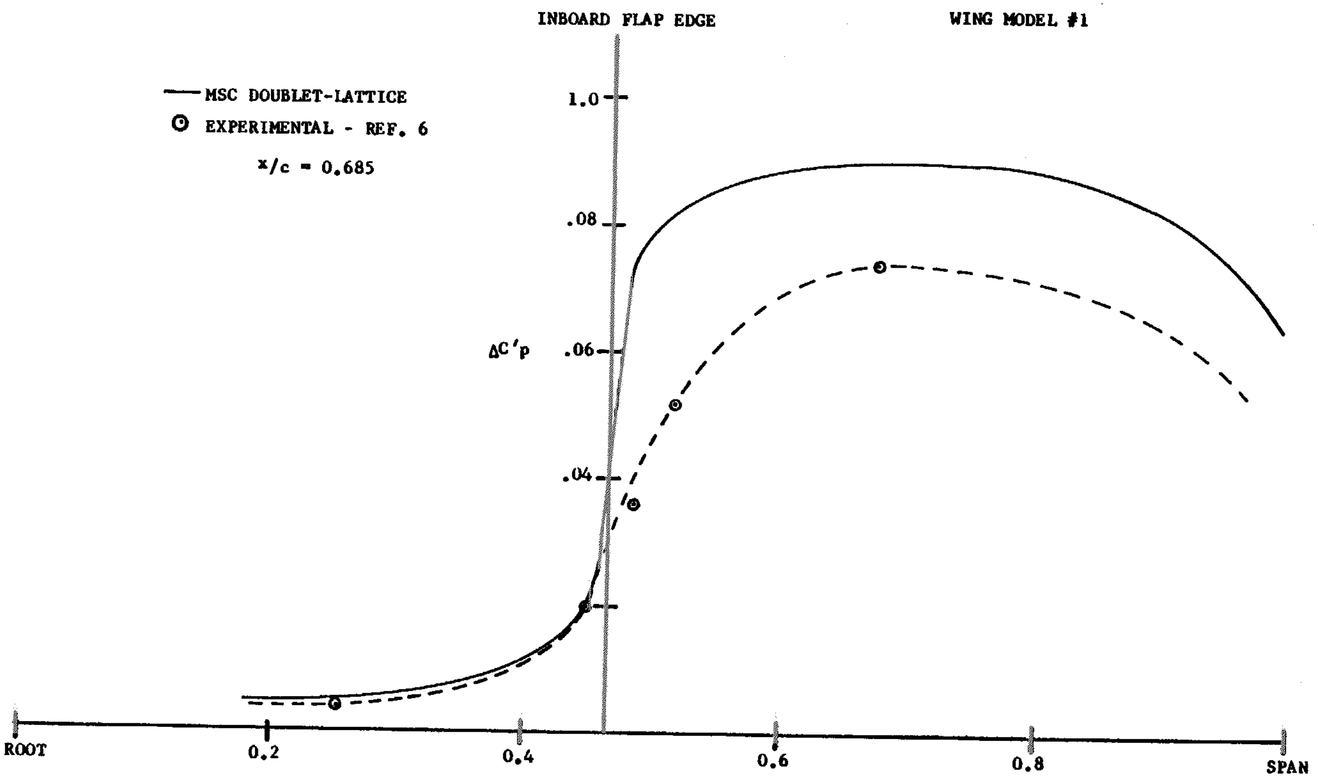


FIGURE 10
IN-PHASE PRESSURE DISTRIBUTION

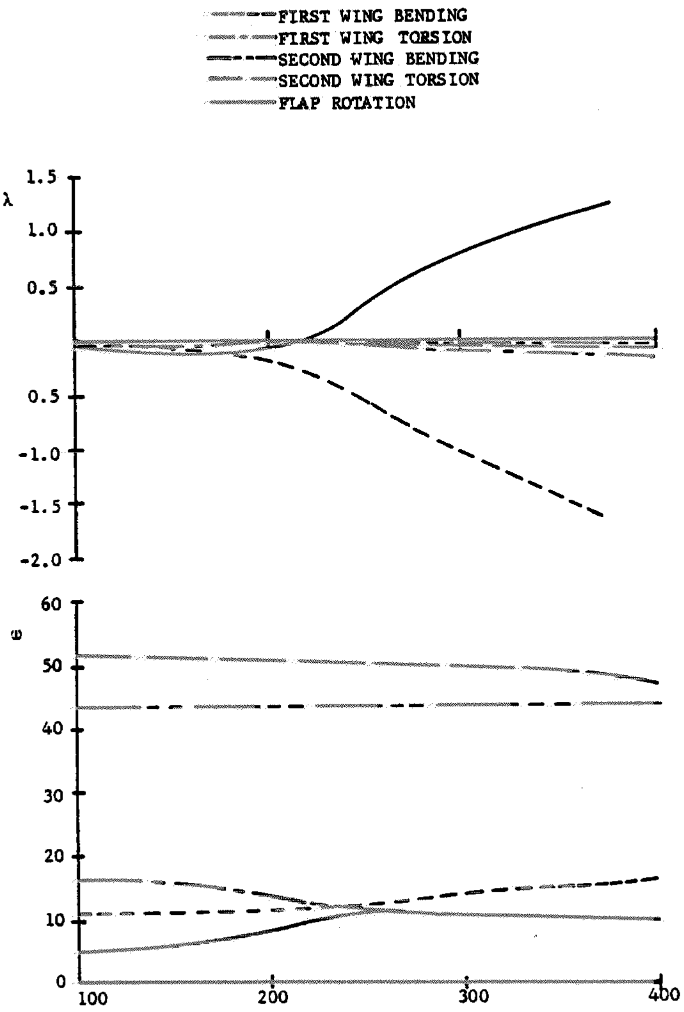


FIGURE 11

DAMPING/ FREQUENCY vs VELOCITY
USING DOUBLET-LATTICE AERODYNAMICS

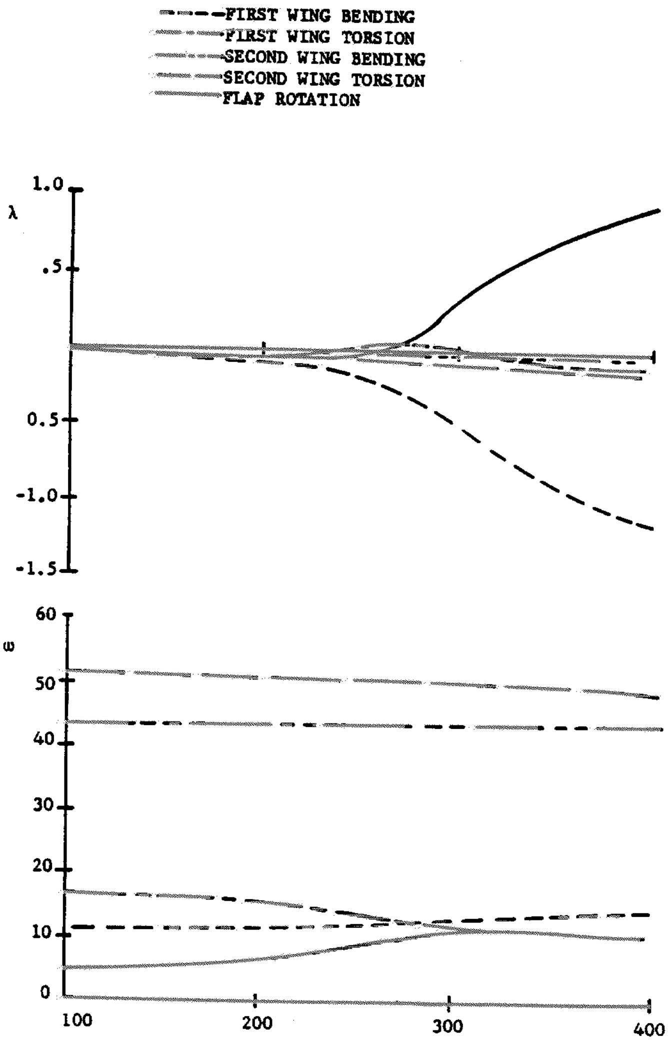


FIGURE 12

DAMPING/FREQUENCY vs VELOCITY
USING DOUBLET-LATTICE AERODYNAMICS,
REDUCED TO MATCH EXPERIMENTAL DATA

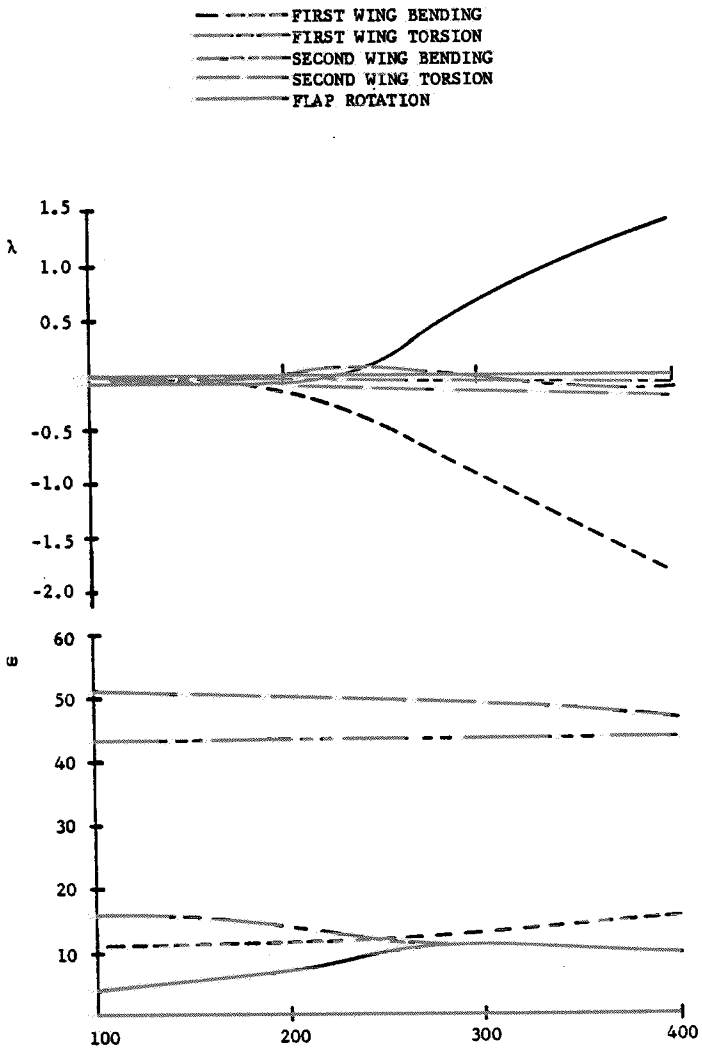


FIGURE 13

DAMPING/FREQUENCY vs VELOCITY
DOUBLET-LATTICE AERODYNAMICS, FLAP
AERODYNAMICS REDUCED 20 PERCENT

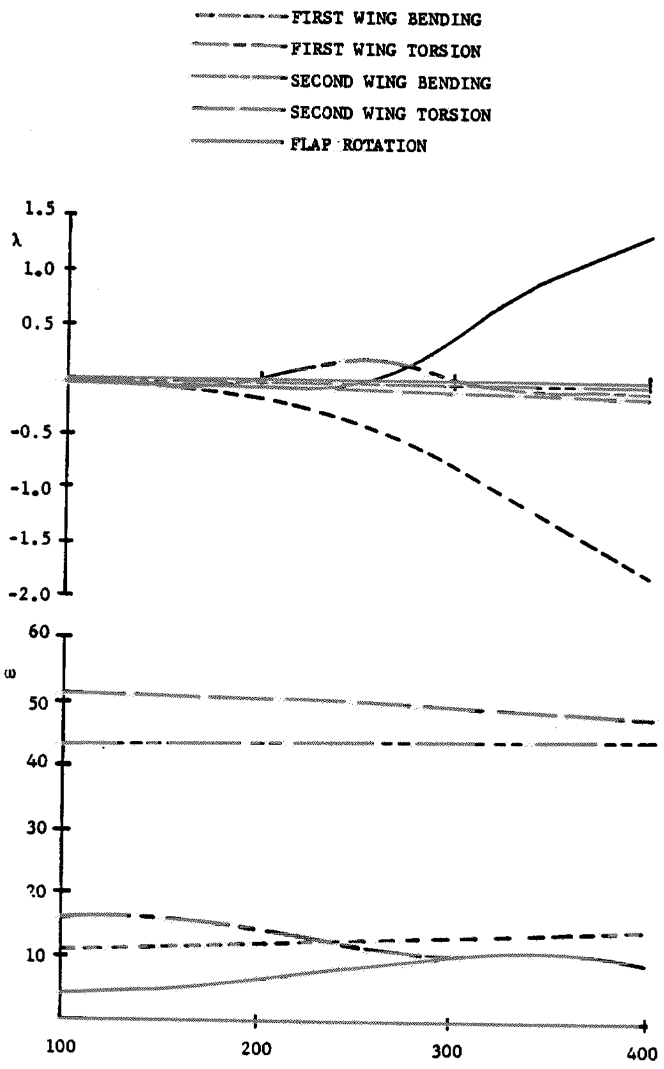


FIGURE 14

DAMPING/FREQUENCY vs VELOCITY
DOUBLET-LATTICE AERODYNAMICS, FLAP
AERODYNAMICS REDUCED 40 PERCENT