Aerospace Structures Information and Analysis Center

Design Studies of Intermediate Complexity Wings

Report No. TR-98-01

April 1998

Approved for Public Release; Distribution is Unlimited

Operated for the Flight Dynamics Directorate by CSA Engineering, Inc.

FOREWORD

This report was prepared by the Aerospace Structures Information and Analysis Center (ASIAC), which is operated by CSA Engineering, Inc. under contract number F33615-94-C-3200 for the Air Vehicles Directorate, Wright-Patterson Air Force Base, Ohio. The report presents the work performed under ASIAC Task No. T-34. The work was sponsored by the Design and Analysis Branch, Structures Division, Air Vehicles Directorate of the Air Force Research Laboratory at WPAFB, Ohio. The technical monitor for the task was Dr. Vipperla Venkayya of the Design and Analysis Branch. The study was performed by Dr. Young In Moon, CSA Engineering Inc.

This technical report covers work accomplished from June, 1996 through April 1998.

TABLE OF CONTENTS

1.0 Introduction

Modern-day aircraft employ in the design stage a multidisciplinary process which involves the integration of several disciplines such as aerodynamics, structures, dynamics and controls. Structural optimization is performed to obtain minimum weight for improved performance of the aircraft at minimum cost. Weight reduction can also be achieved by optimizing the structure to meet flutter requirements and still be consistent with such requirements as strength and size constraints. Structural optimization generally involves definition of an objective function and a set of constraints as functions of the design variables. The weight is usually the objective function and the constraints are stresses, displacements, and aeroelastic instabilities such as flutter or divergence speed.

In Reference 1, structural optimization was performed on a five-spar aluminum wing model to examine the effect of sweep angle. A three-spar composite wing model was optimized with different ply-orientation angles in Reference 2. Computer programs used for optimization of both models were OPTSTAT [3] and ASTROS [4,5]. OPTSTAT (OPTimization of structures for STATic loads) optimizes structures by resizing every element in the structural model using allowable stresses as design constraints. As an energy criteria for static loads was the basis for OPTSTAT's optimization scheme, the optimization with OPTSTAT is limited to static loads. ASTROS (Automated STRuctural Optimization System) is an optimization computer program coupled with a general purpose finite element code and several linear aerodynamic codes. It minimizes the structural weight under a variety of multidisciplinary constraints. ASTROS bases its optimization scheme on modified feasible direction methods. The optimized values (minimum thicknesses under stress constraints in this case) from ASTROS optimization runs were used to perform a flutter analysis using ASTROS. Next, the same finite element wing model was optimized under the combined constraints of stress, size and flutter velocity with the model subjected to three generalized loading conditions. The design loads were computed by ASTROS under three assumed aircraft maneuvers.

In this paper, the two inter-complexity wing (ICW) models used in References 1 and 2 were analyzed using MSC/NASTRAN and the analytical predictions were compared to those published in the two papers. MSC/NASTRAN and NASTRAN were used interchangeably in this paper. The steps taken for analysis of the two ICW models were: (1) Both aluminum and composite models were first converted into MSC/NASTRAN models, (2) Optimization under strength and size constraints were then performed, (3)Flutter analyses using the optimized design values were studied, and finally (4) Optimization under both stress, size and flutter speed was studied on both models. Attention was given during the analysis to the effect of sweep angles for aluminum models, and to the effect of ply orientations for composite models. The conversion of finite element models is described in Section 2 and the NASTRAN input data decks featuring important inputs are shown in Appendix. Section 3 presents design studies of the models while Section 4 compares results obtained from running NASTRAN models to those from ASTROS and OPTSATAT runs. Sweep angles for the aluminum model vary from -10 to 30 degrees with 10 degree increments, and ply-orientations for the composite model range from -20 to 20 degrees with 10 degree increments. Section 5 presents study summaries and conclusions.

2.0 Models

This section covers the conversion of ASTROS finite element models into MSC/NASTRAN models for the analysis. There were two ICW (inter-complexity wing) finite element models used in the study. One is made of aluminum and is used for the study of sweep angle effect. A total of five sweep angles was investigated: -10, 0, 10, 20, and 30 degrees. The other ICW model is made with composite materials for skins to investigate the effect of ply -orientation. Ply orientation angles applied in this study were -20, 10, 0, 10, and 20 degrees. The other elements of this model were made of aluminum with the same material properties as used in the first model. Reference 1 presents the optimization results, under strength and size constraints, from running aluminum ICW models on OPTSTAT and ASTROS, and flutter speeds from running the optimized models on ASTROS. The models were also optimized under a flutter speed constraint in addition to stress and size constraints. The effect of ply-orientations were presented in Reference 2, following the same procedures as in the first case: two optimizations and one flutter analysis.

In the present study, all ASTROS models were converted into NASTRAN models. Optimum weights from NASTRAN models were compared to those from ASTROS and OPTSTAT, and a comparison of flutter speeds was made between NASTRAN runs and ASTROS runs.

2.1 Aluminum Models

From ten converted NASTRAN models, two models are selected and shown to present the difference in the geometry. Both models are plotted from the same viewing angles. The five spar wing model shown in Figure 1 has a 10 degree sweep angle and the one in Figure 2 has a 30 degree sweep angle. Both are shown with the aerodynamic planform overlaid on top of them. The X-axis in both figures is parallel to the free stream direction, and the grids in Figure 2 (except those at the root, Y=0.0) were obtained by translating those in Figure 1 along the +X direction by 20 degrees from Figure 1. In other words, the Y- and Z-coordinates of grids in both models remained unchanged, thus keeping the aspect ratio of the wing model constant. Both models consist of 64 quadrilateral membrane elements representing top and bottom skins, 36 shear elements representing ribs and 40 representing spars to model the substructure between top and bottom skins, and 45 rod elements are used as posts to connect the two skins. The existing ASTROS models from Reference 1 were converted into three NASTRAN models: the first model was for an optimization study under static loads with stress and size constraints, the second model was for subsonic flutter analysis using optimized properties obtained from the first model run. The third model was also for optimization under static loads with stress, size and flutter speed constraints. There were in total 15 NASTRAN models; 5 sweep angles for each of three cases.

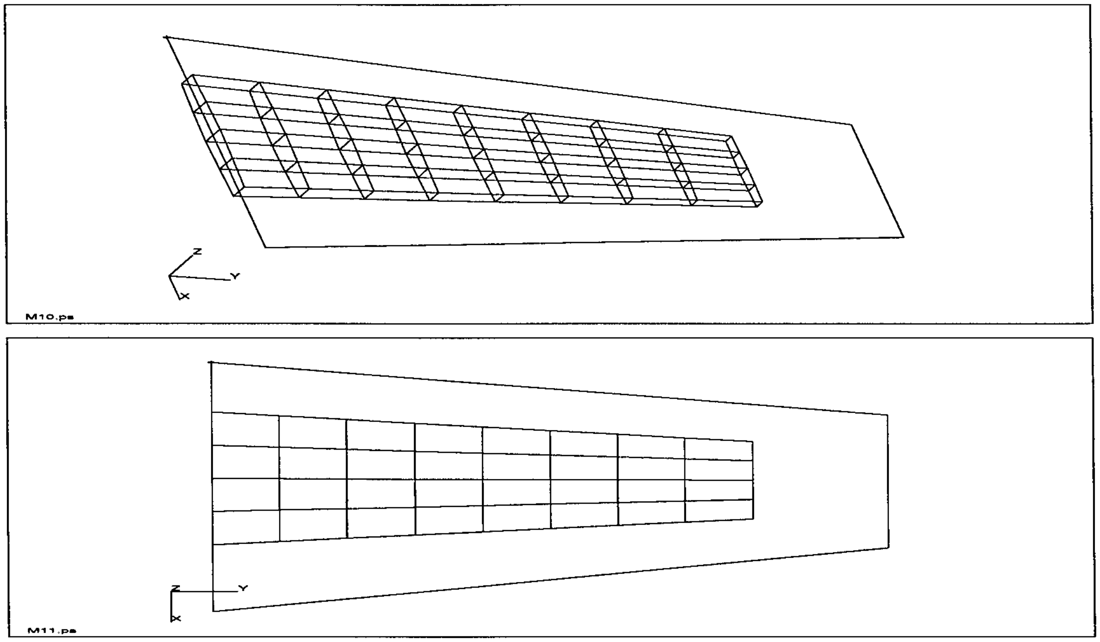

Figure 1. Five-spar Aluminum Model (10 degree sweep angle)

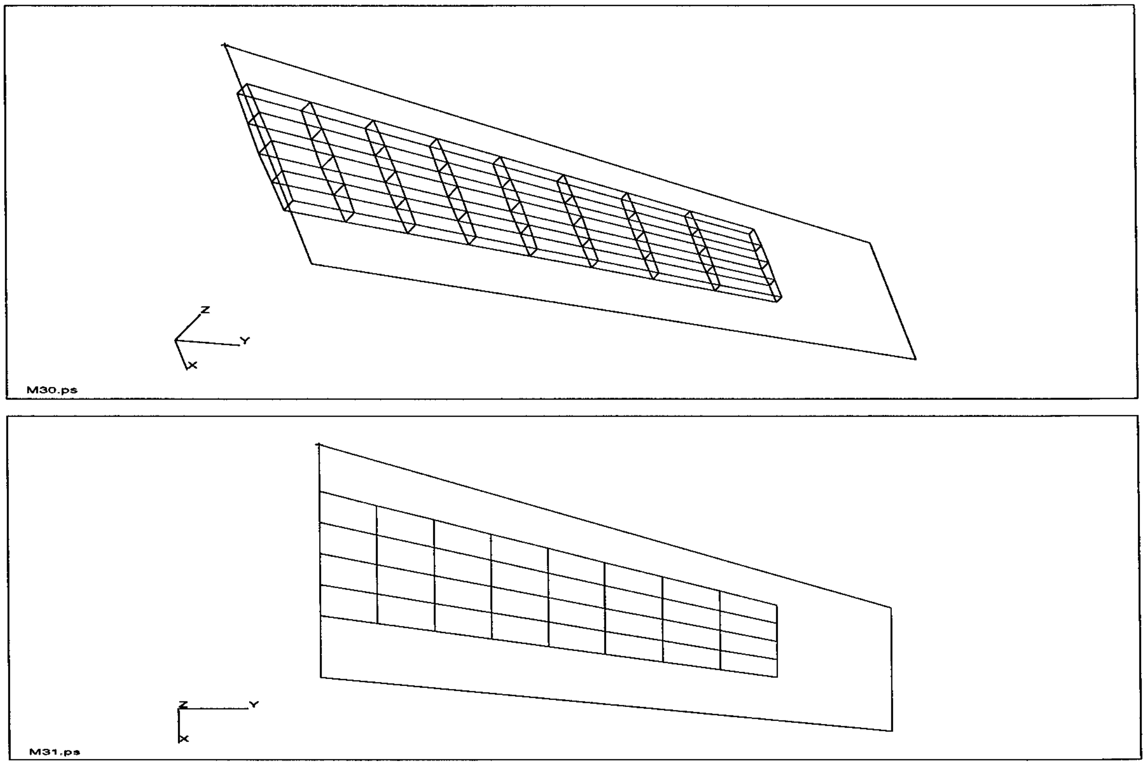

Figure 2. Five-spar Aluminum Model (30 degree sweep angle)

2.2 Composite Models

The three-spar composite model was used for optimization and flutter studies to see the effects of ply orientation angles. The angles vary from -20 degrees to +20 degrees in increments of 10 degrees. Two models are shown here to illustrate how the ply-orientation was defined. Figures 3 and 4 show three-spar wing models where ply orientations are defined by using a local coordinate system 101 (CORD 101). Top and bottom skin elements were made of graphite epoxy and defined by this local coordinate system. The global X-axis, shown at the bottom left in Figures 3 and 4 is parallel to the free stream direction, and used to define the grids and the composite layups. In other words, both grids and layups were fixed with respect to the global coordinate system. The effect of ply orientation angles was studied by introducing a local coordinate system 101 where the +x-axis of the CORD 101 was defined with respect to the mid-spar of the wing. The 0-degree fibers of the composite layup in Figure 3 coincide with the local +x-axis, while those in Figure 4 make 20 degrees with respect to this local +x-axis: which is to say that the CORD 101 was rotated 20 degrees counter-clock-wise with respect to the mid-spar of the wing. The three-spar composite model consisted of the following elements: 2 triangular composite membrane skin elements, 62 quadrilateral composite membrane skin elements, and 32 aluminum shear elements for ribs and 23 for spars, and 39 aluminum rods. The composite layup of the skins has fibers in four directions (0, 90, +45 and -45 degrees). The existing ASTROS models from Reference 2 were converted into NASTRAN models. These models were used to study the effect of ply-orientation as a variable in the design of composite structures. The optimized composite models were run on NASTRAN for flutter analysis. NASTRAN models were also optimized under combined constraints of stress, size and flutter speed.

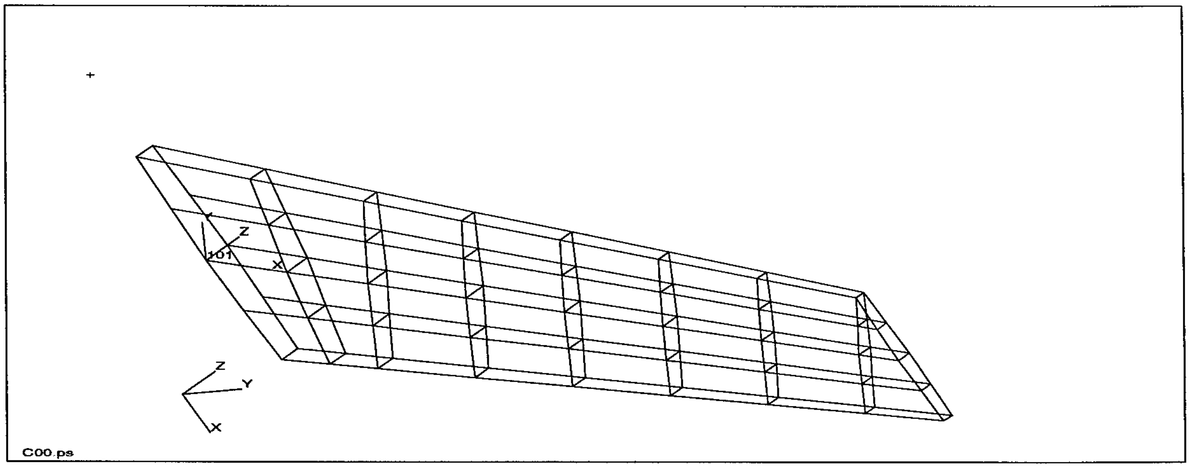

Figure 3. Three-spar Composite Model (0 degree ply-orientation)

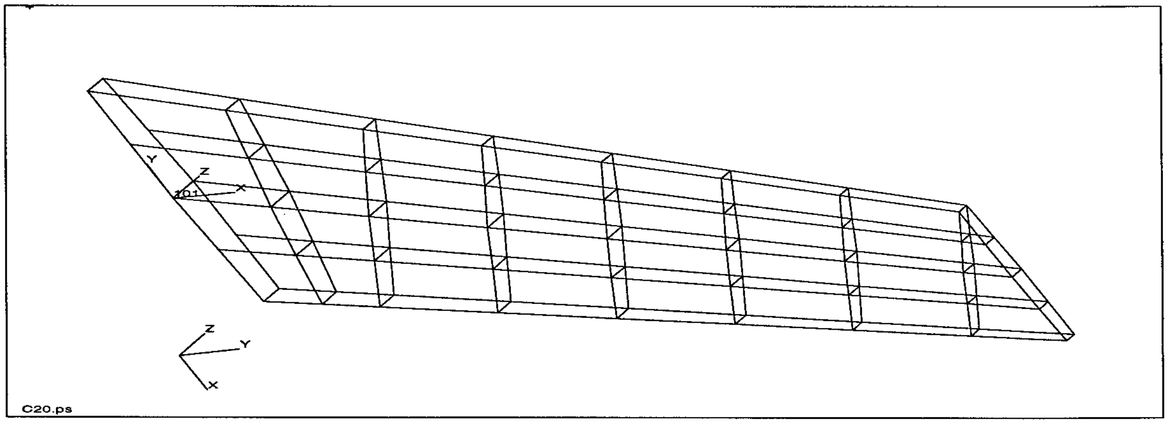

Figure 4. Three-spar Composite Model (20 degree ply-orientation)

3.0 Design Studies

3.1 Effect of Sweep Angles

Three design studies were investigated in Ref. 1 by making use of the five spar wing models (aluminum models), and sweep angles of the model varied from -10 to 35 degrees with 5 degree increments, thus investigating a total of 30 optimum design studies. The first design study involves optimization under three design loads with stress and size constraints. The applied loads were obtained from the static aeroelastic analysis using ASTROS under the following trimmed aircraft maneuvers: (1) symmetric 6g pull-up trimmed for lift, (2) antisymmetric roll with control surface rotation of 2.5 degrees, and (3) combined 1g symmetric pull-up (one sixth of Load Case 1) and antisymmetric roll (Load Case 2). The following stress constraints were imposed: normal stresses in the X- and Y-direction, and shear stress were not allowed to be bigger than 67.0, 57.0 and 39.0 ksi, respectively. The minimum skin thickness of all plate elements was 0.20 inch and the minimum cross-sectional area for the posts was 0.2 inch. Both OPTSTAT and ASTROS were used for optimization and their results were compared in Reference 1.

NASTRAN models were generated from ASTROS models and studied to compare NASTRAN results with those from both OPTSTAT and ASTROS. Five sweep angles were investigated in this study: from -10 to +30 degrees with 10 degree increments. Figures 1 and 2 show the structural model with sweepback angles of +10 and +30 degrees, respectively, overlaid in the aerodynamic planform. With the NASTRAN models available, three design studies were conducted, combined with five sweep angles, in this paper. The first design case was an optimization study under stress and size constraints only. There was a total of 153 independent design variables for sizing. The second design study was a subsonic flutter analysis using the optimized values from the first case. Another optimization study was performed in the third case under combined constraints of stress, size and two separate flutter speeds: 23,565 in/sec (1,163.49 knots) and 11,421.6 in/sec (563.93 knots). The first flutter speed was the maximum flutter speed corresponding to the 5 degree sweep angle in Reference 1 and the second one was the flutter speed for the constraint in Reference 2, corresponding to -10 degree ply orientation. The purpose of applying two flutter speeds was to see the effect of flutter speed in optimization.

3.2 Effect of Ply-orientation Angles

The three-spar wing models shown in Figures 3 and 4 were obtained from Reference 2 where design studies were conducted to study the effect of ply orientation angles using OPTSTAT and ASTROS for weight optimization and flutter analysis based on the doublet-lattice method. The basic composite layup had four fiber directions (0, 90, +45 and -45), and fiber sizes in +45 and -45 degrees were kept to be equal for balance. Ply orientation was not a variable, but rather fixed. And the angle of layup orientation was varied with resecpt to the mid-spar of the wing.

As was shown in the first case of the aluminum models, the composite model was first optimized for thicknesses under static loads with stress and size constraints. The stress constraints were imposed on elements of aluminum and those of composite material as well. For aluminum elements: maximum stresses in tension, compression and shear were 67, 57 and 39 ksi, respectively. The minimum thickness was 0.20 inch. For composite elements: the maximum allowable stress in both directions was limited to 115 ksi and the minimum allowable ply thickness was 0.00525 inch. The number of independent design variables was 158. MSC/NASTRAN optimizes four fibers in one layup as a whole, keeping the size of fibers equal, while ASTROS optimizes them independently. The second design study was run for subsonic flutter analysis using optimum designs obtained under stress and size constraints from the first case. The third case was another optimization by imposing a flutter speed constraint in addition to strength and size constraints. Two flutter speeds were imposed as constraints for comparison as was in the aluminum models. The three independent static loads for optimization, and the nonstructural mass properties of the wing applied to the models for the flutter analysis were from Reference 2.

4.0 Results and Comparisons

4.1 Aluminum Models

A typical behavior of convergence history of aluminum models is presented in Figure 5 which is the design iteration history of a 10 degree sweep angle model with stress and size constraints. For all cases considered, convergence behavior has been similarly smooth. The optimized weight for this 10 degree wing model was 181.123 lbs from the ASTROS run, and NASTRAN yielded an optimum weight of 168.56 lbs at convergence. Optimized weights of the aluminum wing model are plotted against sweep angles in Figure 6 where the model was optimized for static loads under strength and size constraints. The overall trend is that the optimum weight is not sensitive to sweep angles in all runs from three programs: OPSTAT, ASTROS and MSC/NASTRAN. The difference in optimum designs between OPTSTAT and ASTROS is about 11 % and it was attributed to the method of both imposing the constant criteria and linking the top skins to bottom skins [1]. OPTSTAT optimizes each skin separately while both ASTROS and MSC/NASTRAN link the top skins to the bottom skins. MSC/NASTRAN presents the lowest optimum weights among the three programs: an average of about 8 % lower than ASTROS.

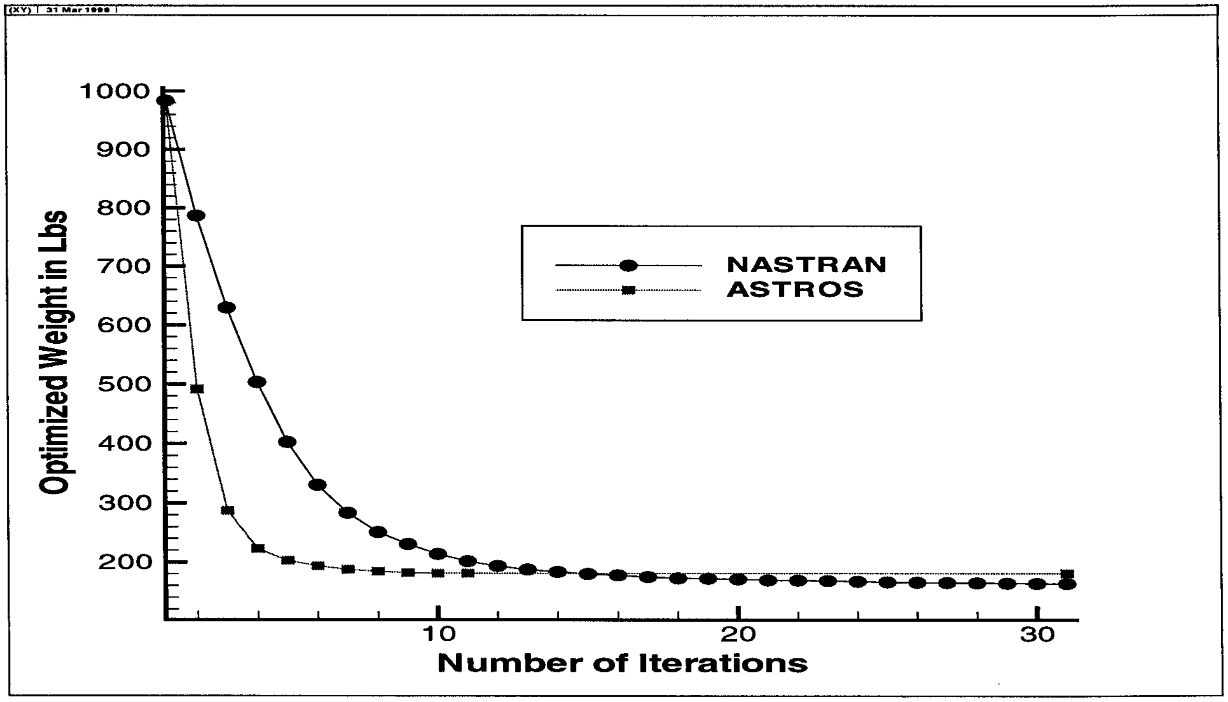

Figure 5. Convergence History

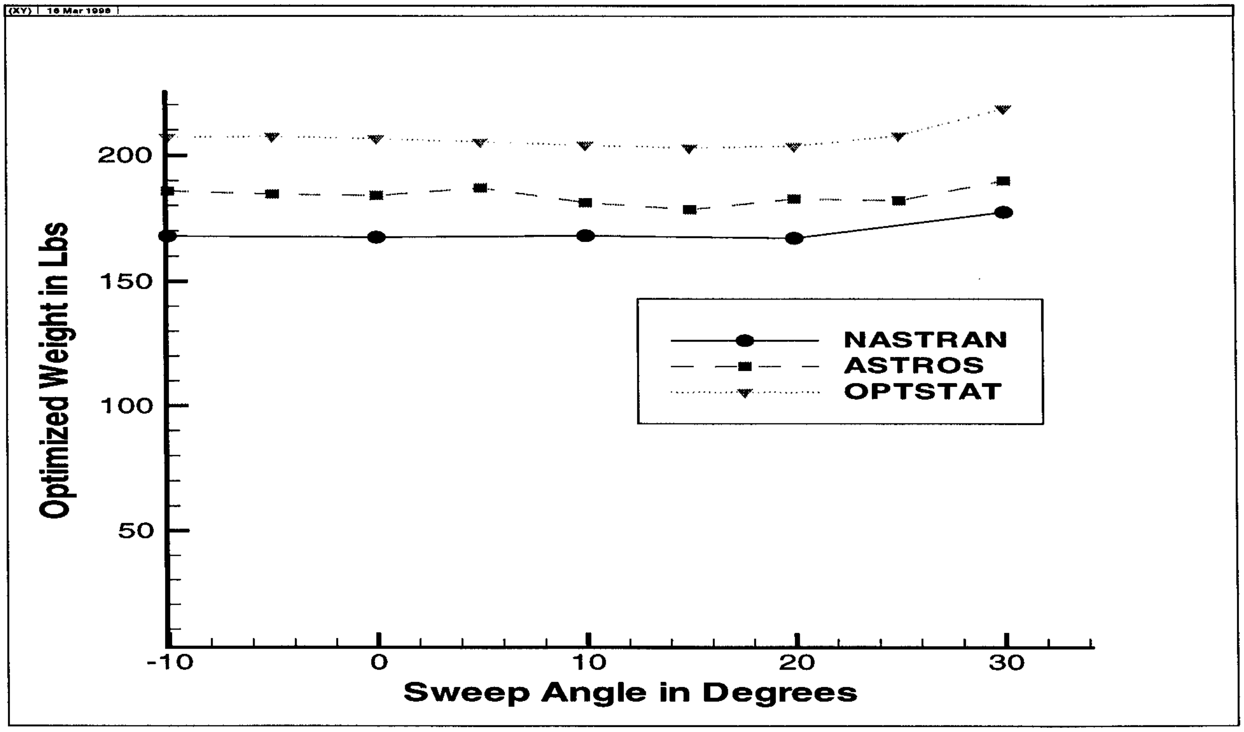

Figure 6. Optimum Weight vs Sweep Angle

The second case involved running the aluminum models on MSC/NASTRAN for flutter analysis using the optimized design values. The P-K method of flutter analysis was used and two typical results are shown. Figure 7 is shown for the computation of flutter speed at 10 degree sweep angle and Figure 8 at the 30 degree angle. The lowest flutter speed for the 10 degree sweep angle wing is a coupled first bending and torsion mode flutter. The flutter speed in NASTRAN run where the damping goes to zero is 20,874 in/sec (1,030.6 knots) at 18.202 Hz, and Figure 8 presents the flutter speed of the 30 degree sweep angle model to be 19,313 in/sec (953.57 knots) at 17.92 Hz. The flutter speeds are plotted in Figure 9 over sweep angles ranging from -10 to 30 degrees and compared to ASTROS predictions[1]. Contrary to what was seen in the previous case of optimum design where optimum weights were not sensitive to sweep angles, it can be seen in Figure 9 that the flutter speed varies significantly over the range of sweep angles and that the trend of variations is similar in both ASTROS and MSC/NASTRAN runs. The lowest flutter speed was 922.7 knots at -10 degree sweep angle and the highest speed was 1,058.7 knots at 0 degree sweep angle in MSC/NASTRAN runs. ASTROS presents the lowest flutter speed of 910.29 knots at 25 degree and the highest flutter speed of 1163.49 knots at 5 degree sweep angle [1].

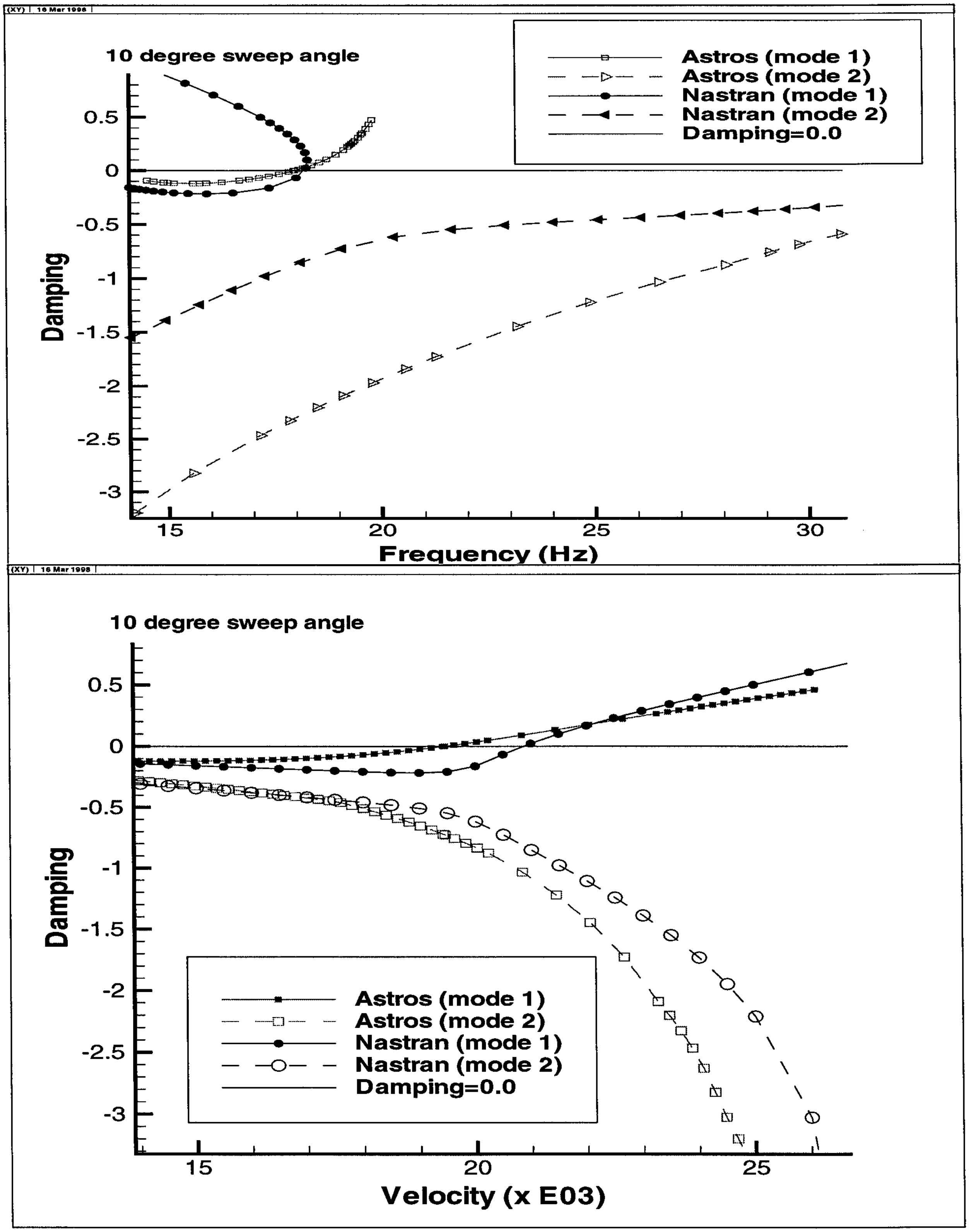

Figure 7. Computation of Flutter Speed for the 10 degree Sweep

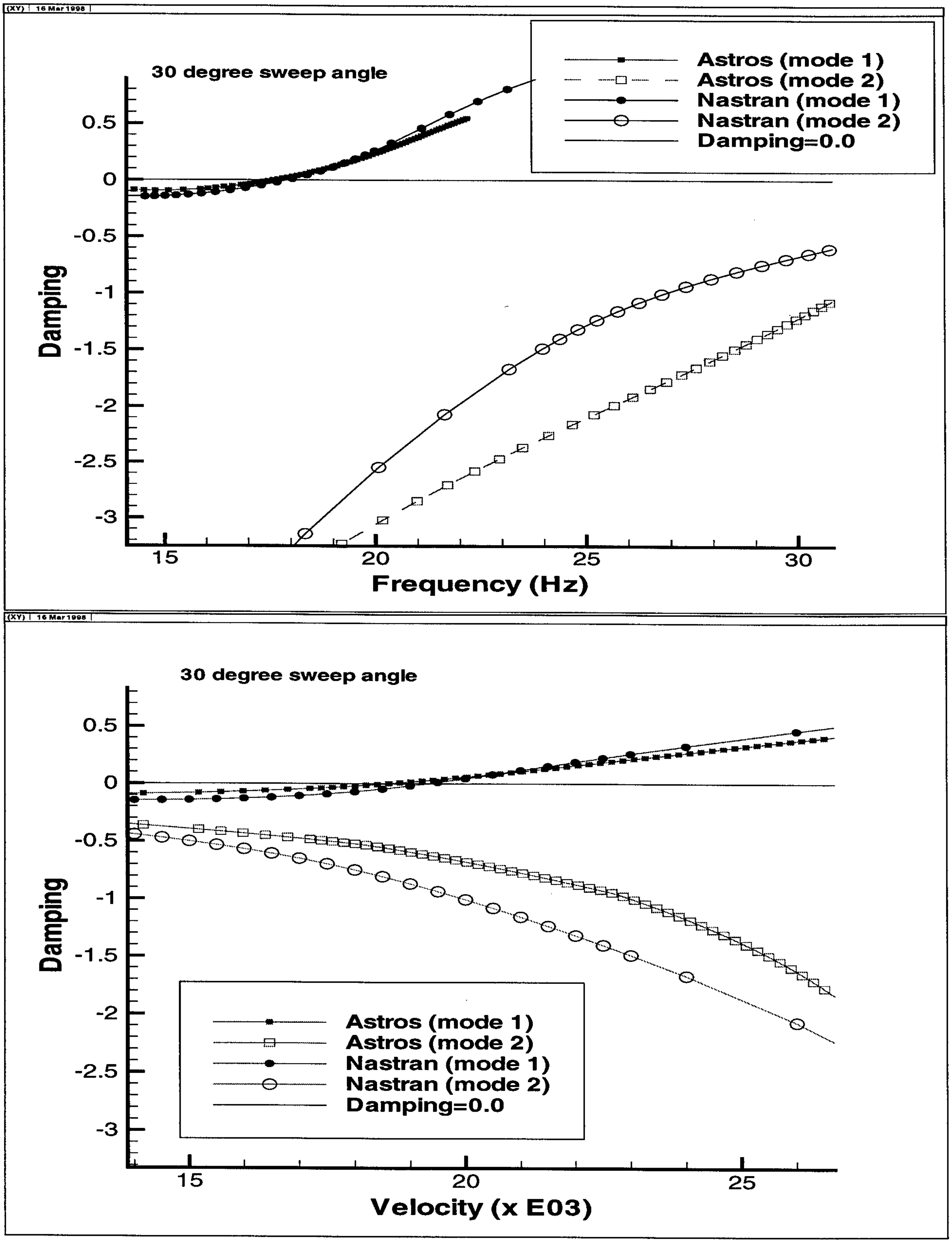

Figure 8. Computation of Flutter Speed for the 30 degree Sweep

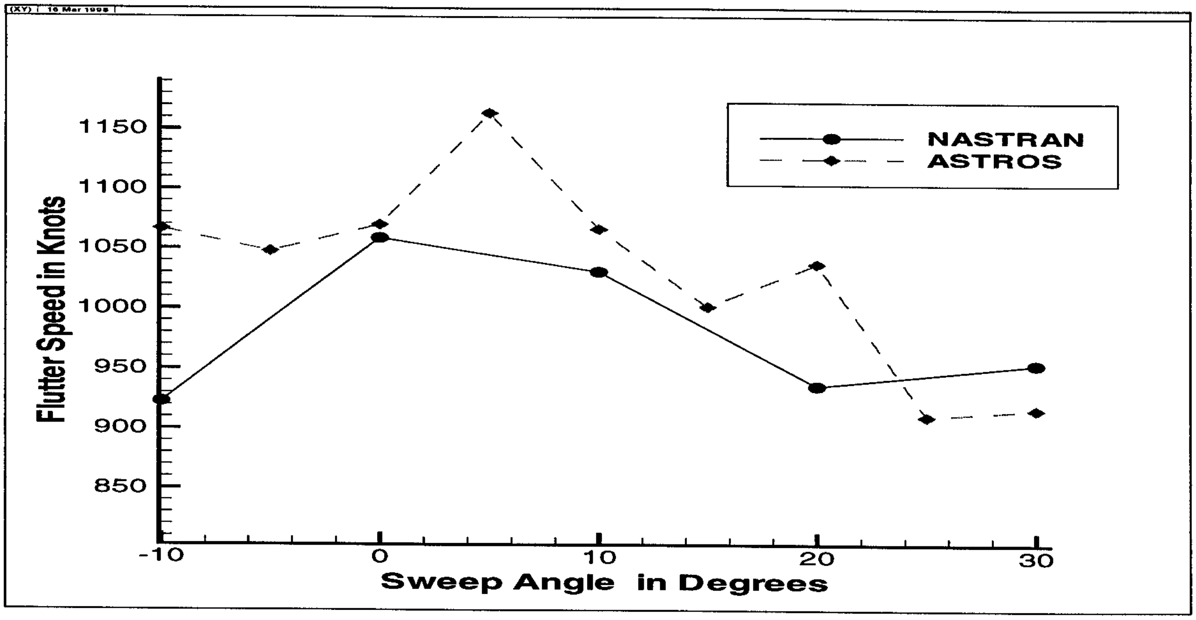

Figure 9. Flutter Speed vs Sweep Angle

The third case involved running the original model for optimum design subjected to the same generalized loading conditions as in the first case, but the flutter speed constraint was added to the existing stress and size constraints. The imposed flutter speed was 23,565 in/sec (1163.5 knots), which was the flutter speed constraint used in Reference 1. Figure 10 shows optimized weights of both MSC/NASTRAN and ASTROS models under the two types of constraints. The MSC/NASTRAN model subjected to both constraints at -10 degree sweep angle, for example, presents the optimized weight to be 164.637 lbs which is a little less than the optimized value of 167.91 lbs subjected to the stress and size constraints only. This implies that the additional flutter constraint does not affect the computation of optimum weight under the strength constraints.

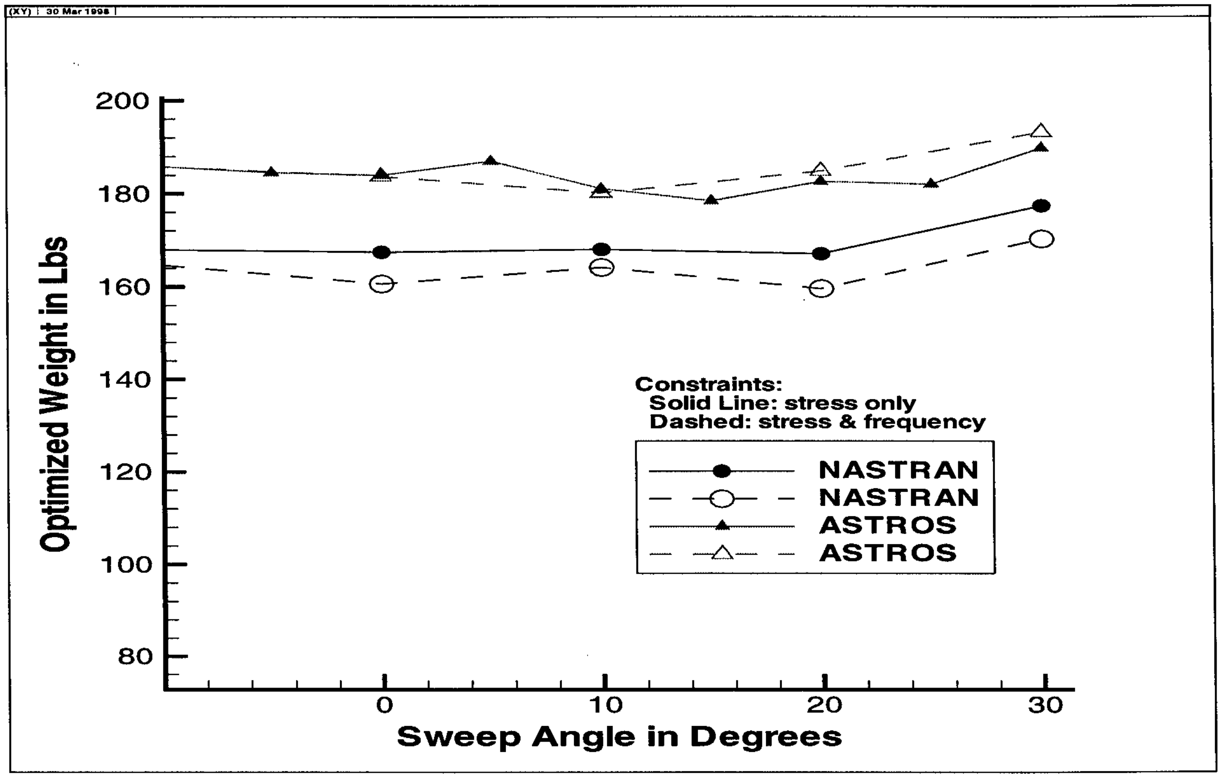

Figure 10. Optimum Weight vs Sweep Angle

4.2 Composite Models

As in the case of aluminum models, all the design studies with composite models were carried out in three cases. Figure 11 plots the result of the first case study where the model was optimized under stress and size constraints only. The lowest optimum weight from the MSC/ NASTRAN composite model was 25.68 lbs at -10 degree ply orientation angle and the highest weight was 27.605 lbs at -20 degree angle. It is clear from this figure that the ply orientation does not affect the computation of optimum weights of this composite model. The MSC/NASTRAN model optimizes and yields much lower weight than both ASTROS and OPTSTAT [1]. In the second case, the optimized model was run for flutter analysis and the results are shown in Figure 12. The range of flutter speeds was from 517.43 knots at -20 degree ply orientation angle to 545.81 knots at 10 degree angle. Again it is shown in this figure that the flutter speed is insensitive to the ply orientation. The third design study is to see if additional flutter constraint makes any difference in optimization under static loads. Figure 13 compares the results and concludes that flutter speed constraint does not affect the optimum design of the composite model under static loads.

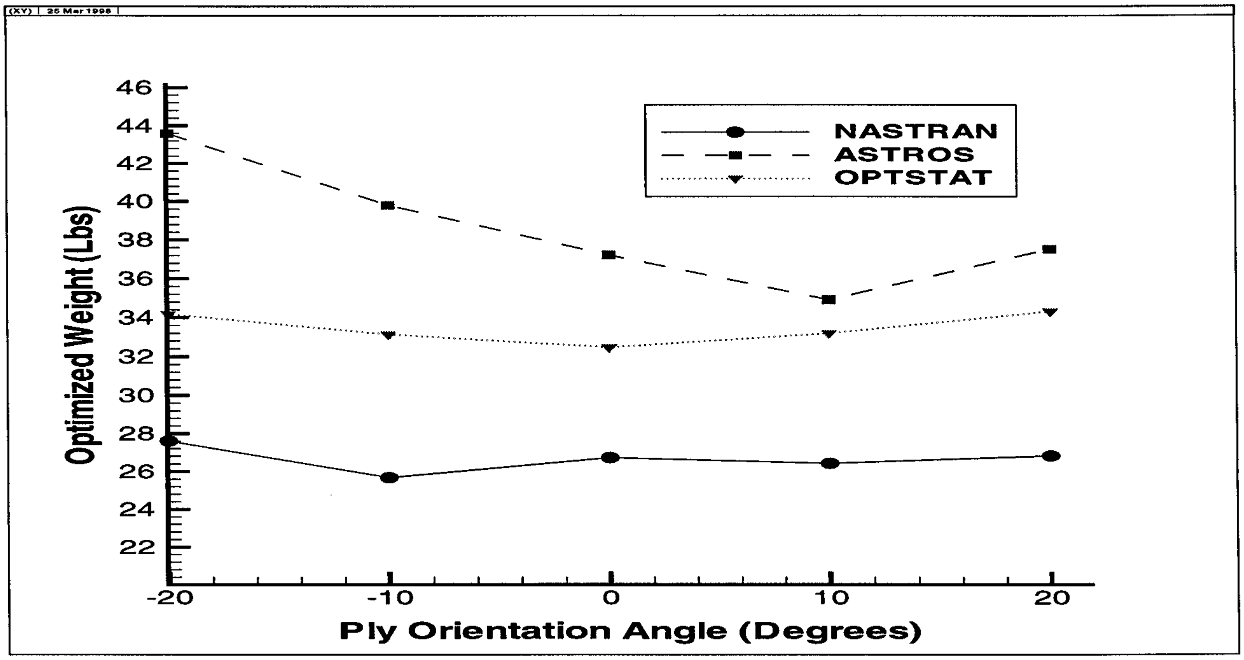

Figure 11. Optimum Weight vs Ply Orientation Angle

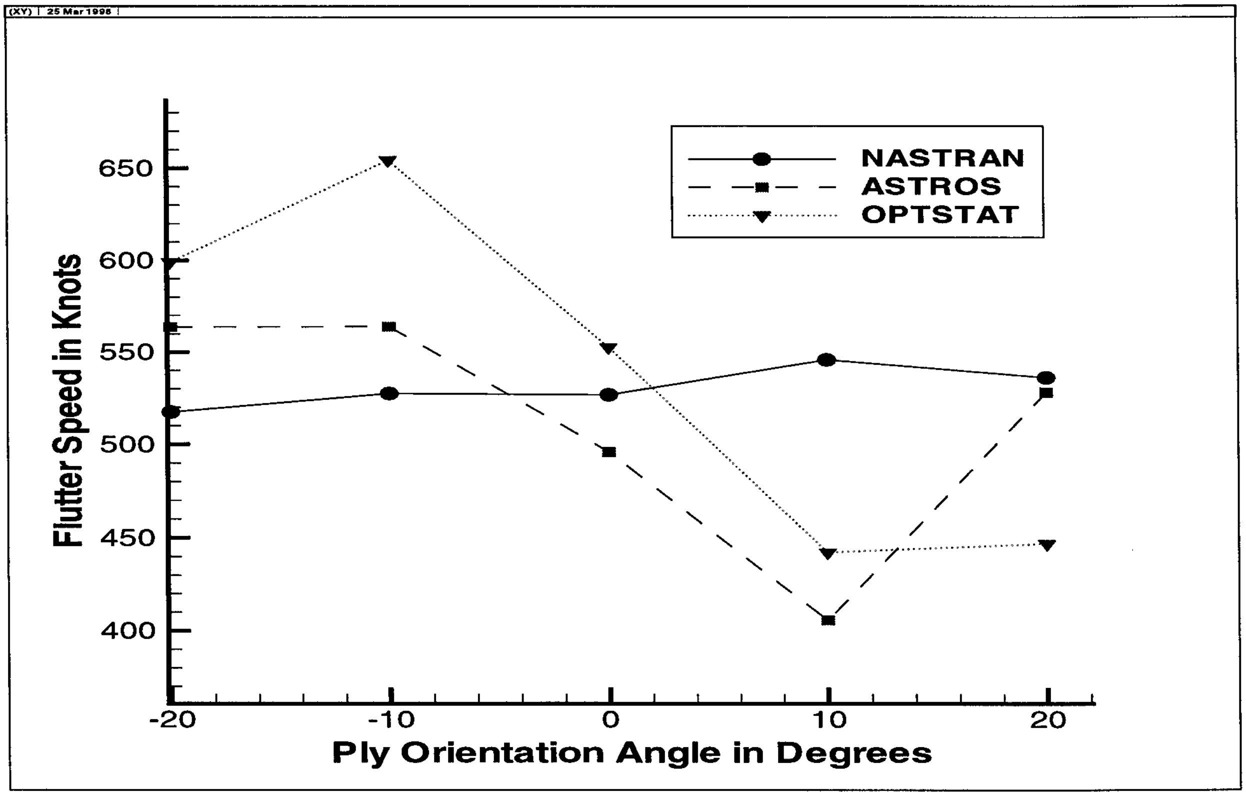

Figure 12. Flutter Speed vs Ply Orientation Angle

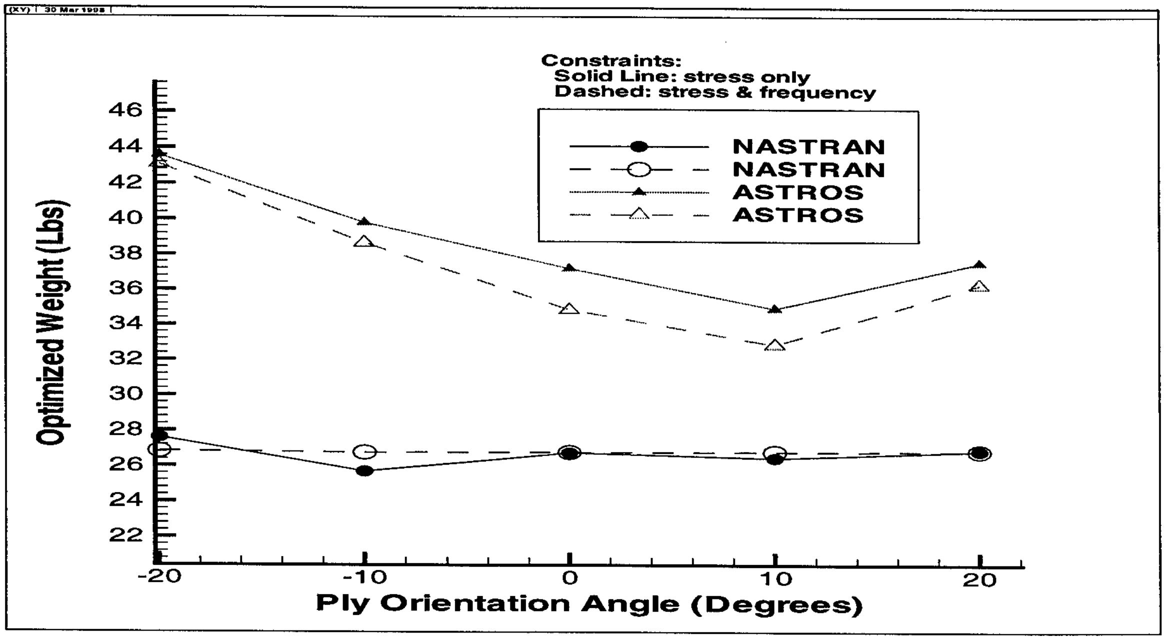

Figure 13. Optimum Weight vs Ply Orientation Angle

5.0 Summary and Conclusion

In this paper, design studies were conducted using two intermediate-complexity wing models: the five-spar aluminum wing model was first optimized to investigate the effect of sweep angles varying from -10 to +30 degrees, and the composite three-spar wing model was used to study the effect of ply orientation angles ranging from -20 to +20 degrees. ASTROS models were first converted into MSC/NASTRAN models and the results from NASTRAN runs were compared to ASTROS predictions. The results presented in Section 4 can be summarized as follows:

1) Optimum designs were found insensitive to change in sweep angles for aluminum models and to ply orientation angles for composite models,

2) Optimum weights were not changed by imposing additional flutter constraint to existing stress and size constraints,

3) Flutter speeds were affected by sweep angles for aluminum models and by ply orientation angles for composite models, except for the optimized NASTRAN composite models whose flutter speeds did not vary much, and

4) NASTRAN presented lower optimum weights than ASTROS: about 8 to 10% in aluminum models, and 25 to 40% in composite models.

6.0 References

1. V.B. Venkayya, V.A. Tischler, and G. Bharatram, "Multidisciplinary Issues in Airframe Design", AIAA-96-1386-CP

2. V.A. Tischler and V.B. Venkayya, "Ply Orientation as a variable in Multidisciplinary Optimization", Fourth Air Force/NASA/AIAA Conference on Recent Advances in Multidisciplinary Analysis and Optimization", Cleveland, Ohio, September 1994

3. V.B. Venkayya and V.A. Tischler, "OPTSTAT - A Computer Program for the Optimal Design of Structures Subjected to Static Loads", TM-FBR-79-67, June 1979

4. E.H. Johnson and V.B. Venkayya, "Automated STRuctural Optimization System (ASTROS), Vol. I - Theoretical Manual", AFWAL-TR-88-3028, Dec. 1988

5. D.J. Neil, and D.L. Herendeen, "ASTROS Enhancements, Vol. I - ASTROS User's Manual", WL-TR-3004

Appendix

1. Optimization under Stress Constraints

```
ID,OPT, WING_10
SOL 200   $ Optimization
TIME 50
CEND
TITLE = ICW MODIFIED SWEEP - STRESS CONSTAINTS
SUBTIT = 153 DESIGN VARIABLES : MSC/NASTRAN model
SPC=100
DESOBJ(MIN)=219
DESSUB=229
$
$- - - three subcases for three loads (LOAD=100/200/300) - - -
SUBCASE 1
 ANALYSIS=STATICS
  LOAD=100
$
BEGIN BULK
$
$ - - - Design Optimization Parameters - - - -
DOPTPRM,APRCOD,2,DESMAX,20,DELOBJ,0.00001,CTMIN,0.0001,+dop
+dop,ITRMOP,6,ITMAX,25
$
$ ------- grids ------
GRID        1       28.6086 86.4000  1.1700
GRDSET                                        456
$
$ ------ elements --------
$  CSHEAR 65 for rib, CSHEAR 101 for spar
CQUAD4       1     1     1    11    13     3
CSHEAR      65    65     1     2     4     3
CSHEAR     101   101     1     2    12    11
CROD       125   125     1     2
$ ------- properties ------
PSHELL       1     3  1.0
PSHEAR      65     1  1.0
PSHEAR     101     1  1.0
PROD       125     2  1.0
$
MAT1   1      10.5E+06      .3      2.588E-4                  +MAT1
+MAT1  6.70E+045.70E+043.90E+04
SPC1,100, 123, 81, THRU, 90
$
$ -- - - - - Design variables for skins - - - - -
DESVAR, 1, QD1,1.0,0.02,1000.0
$  - - - - - - Link top and bottom skins - - - - - -
DLINK,301,33,0.0,1.0, 1,1.0
```

```
$ - - - - - - connect design variables to properties - - - - -
DVPREL1,1,PSHELL,1,4,,,,,+dp1
+dp1,1,1.0
$ - - - - - - Design variables for spars- - - - - - -
DESVAR, 101,SPAR1 ,1.0,0.02,1000.0
$  - - - - - connect design variables to properties  - - - - -
DVPREL1,101,PSHEAR,101,4,,,,,+dp1
+dp1,101,1.0
$
$  - - - - - Design variables for ribs  - - - - -
DESVAR,65,RIB65,1.0,0.020,1000.0
DVPREL1,65,PSHEAR,65,4,,,,,+d65
+d65,65,1.0
$
$  - - - - - Design variables for posts - - - - -
DESVAR,125,POST125,1.0,0.02,1000.0
DVPREL1,125,PROD,125,4,,,,,+dp125
+dp125,125,1.0
$
$  - - - - -  Design Objective  - - - - -
DRESP1,219,W,WEIGHT
$
$ structural response as constraints
$ for skins
DRESP1,1,CQD1 ,STRESS,PSHELL,,9,,1
$ for ribs
DRESP1,65,SH65 ,STRESS,PSHEAR,,2,,65
$ for spars
DRESP1,101,SH101 ,STRESS,PSHEAR,,2,,101
$ for posts
DRESP1,125,ROD125 ,STRESS,PROD,,2,,125
$
$
$  - - - - - STRESS CONSTRAINTS  - - - - -
$ for skins (VonMises)
DCONSTR,229, 1,-67000.,67000.
$ for ribs (Max. Shear)
DCONSTR,229,65,-39000.,39000.
$ for posts (VonMises)
DCONSTR,229,125,-67000.,67000.
$ for spars (max. shear)
DCONSTR,229,101,-39000.,39000.
$
$ applied forces
FORCE     100     1     21494.7    0.0    0.0    1.0
FORCE     200     1      -372.2    0.0    0.0    1.0
FORCE     300     1      3210.0    0.0    0.0    1.0
 ENDDATA
```

2. Flutter Analysis

```
ID, PAPER,FLUTTER
SOL 75
TIME 10
CEND
TITLE = 5 SPAR ICW - 30 DEG SWEEP
SUBTITLE = FLUTTER ANALYSIS - MSC/NASTRAN model
DISP = ALL
SPC = 1
MPC = 200
METHOD = 10
FMETHOD = 20
BEGIN BULK
$
$ - - - Design Optimization Parameters - - - -
DOPTPRM APRCOD  2     DABOBJ  0.0001  DELOBJ  0.00001 CTMIN   0.0001  +DOP
+DOP    ITRMOP  6     ITMAX   75
$
$ - - - boundary conditions -----
SPC1,   1, 123456,  81,  THRU,  90
SPC1,   1,   456,    1,  THRU,  80
$
ASET1, 345,  216,  THRU,  217
ASET1   3     73     63     53     43     33     37     23     +BC
$
OMIT1,  12,  201,  THRU,  217
$
MPC     200     71      1      1.0     207     1      -.8924        +1AA
+1AA            207     5      -1.8500 207     2       -.4512       +2AB
+2AB            207     4      .9353
$
EIGR    10      GIV                    6
$
CONM2           301     207     2 20.50 -1.904                      +1A
+1A                     224.
$
$  * * *  UNSTEADY AERO MODEL * * *
$
AERO                    69.0    1.147E-7
$
CAERO1  1010    1                       100     200     1       +CA1
+CA1    0.0     0.0     0.0     90.0    63.0    108.0   0.0     48.0
PAERO1  1
$
AEFACT  200     0.0     0.095   0.190   0.286   0.429   0.572   0.715   +AE2
+AE2    0.858   1.0
AEFACT  100     0.0     0.150   0.300   0.400   0.500   0.600   0.700   +AE1
+AE1    0.800   0.900   1.000
```

```
$
$ * * * * FLUTTER FLIGHT CONDITION * * * *
$
FLUTTER 20    PK    30    70    40    L    6    1.00E-03
FLFACT  30    1.0
FLFACT  70    .9
FLFACT  40    12000.0 12500.0 13000.0 13500.0 14000.0 14500.0 15000.0 +KPQ
$
MKAERO1 0.90                                          +MK1
+MK1    0.0001  0.150  0.300  .5000  1.0    5.0    10.0   15.0
$
$ * * * * AERO-STRUCTURAL INTERCONNECTION * * * *
$
SPLINE1 30     1010   1010   1049   40     10.0
SPLINE1 40     1010   1050   1081   60     10.0
SET1    60     1      3      5      7      9      11     13     +ST1
+ST1    15     17     19     21     23     25     27     29     +ST2
+ST2    31     33     35     37     39     301    302    303    +ST3
+ST3    304    305    306
SET1    40     21     23     25     27     29     31     33     +S41
+S41    35     37     39     41     43     45     47     49     +S42
+S42    51     53     55     57     59     61     63     65     +S43
+S43    67     69     71     73     75     77     79     81     +S44
+S44    83     85     87     89     305    306    307    308
$
$ - - - - grids - - -
GRID    1               62.0000 86.4000 1.1700
$
MAT1    1      10.5E+06       .3     .1                        +MAT1
+MAT1   6.70E+045.70E+043.90E+04
$
PARAM   WTMASS  .00259
PARAM   GRDPNT  0
$
$ * * * Elements * * * *
$  CSHEAR 65 for rib, CSHEAR 101 for spar
CQUAD4      1     1     1     11    13    3
CSHEAR      65    65    1     2     4     3
CSHEAR      101   101   1     2     12    11
CROD        125   125   1     2
$
$ * * * optimized properties * * *
PSHELL   1    3     0.08238
PSHEAR   65   3     0.19566
PSHEAR   101  1     0.18854
PROD     125  2     0.42961
ENDDATA
```

3. Optimization under both Stress and Flutter Constraints

```
ID,OPT, WING_10
SOL 200   $ Optimization under both constraints
TIME 50
CEND
TITLE = ICW 10 DEG SWEEP - stress & flutter constraints
SUBTIT = 153 DESIGN VARIABLES : MSC/NASTARAN model
MPC=200
SPC=100
STRESS=ALL
DESOBJ(MIN)=345
$
$  stress optimizations under three loads (LOAD=100/200/300)
SUBCASE 1
 ANALYSIS=STATIC
 DESSUB=229
 LOAD=100
$
$ - - - -  optimization under flutter constraint  - - - -
SUBCASE 4
 ANALYSIS=FLUTTER
  DESSUB=239
  METHOD=11
  FMETHOD=22
BEGIN BULK
$
$ - - - 229 for stress and 239 for flutter - - - -
DCONADD,1,229,239
PARAM    WTMASS  .00259
PARAM   GRDPNT  0
$
$ - - - - grids - - - - -
GRID         1        28.6086 86.4000  1.1700
$ - - - elements  - - -
CQUAD4        1      1      1     11      13      3
CSHEAR       65     65      1      2       4      3
CROD        125    125      1      2
$
$ - - - properties - - - -
PSHELL        1      3  1.0
PSHEAR       65       1  1.0
PSHEAR      101       1  1.0
PROD        125      2  1.0
$
MAT1    1      10.5E+06       .3      2.588E-4                      +MAT1
+MAT1   6.70E+045.70E+043.90E+04
$
EIGR    11      GIV                        6
```

```
$
$*******************************
$  UNSTEADY AERO MODEL for flutter analysis *
$*******************************
$
AERO            69.0  1.147E-7
$
CAERO1  1010   10                    100    200    1     +CA1
+CA1    0.0     0.0    0.0    90.0   19.04  108.0  0.0    48.0
PAERO1  10
AEFACT  200    0.0    0.095  0.190  0.286  0.429  0.572  0.715  +AE2
+AE2    0.858  1.0
AEFACT  100    0.0    0.150  0.300  0.400  0.500  0.600  0.700  +AE1
+AE1    0.800  0.900  1.000
$
$  flight condition for flutter analysis
$
FLUTTER 22     PK     20     30     40     L      6      1.00E-03
FLFACT  20     1.0
FLFACT  30     0.9
FLFACT  40     10126.8 15190.2 17215.5 18228.0 19241.0 20250.0 21000.0 +abe
+abe    21266.5 21775.0 22380.0 23000.0 23291.0 23565.0
$
MKAERO1 0.90                                       +MK1
+MK1    0.0001  0.13333 0.1818  .3000  0.40   1.00   2.00
$
$    AERO-STRUCTURAL INTERCONNECTION
$
SPLINE1 30     1010   1010   1049   40     10.0
SPLINE1 40     1010   1050   1081   60     10.0
$ SET1 (60 & 40) same as those in flutter analysis (p. 20)
SET1    60     1      3      5      7      9      11     13     +ST1
+ST3    304    305    306
SET1    40     21     23     25     27     29     31     33     +S41
+S44    83     85     87     89     305    306    307    308
$  CONMass for flutter analysis
CONM2      301    207      2 20.50  -1.904                      +1A
$
$ - - - - Boundary Conditions for flutter analysis - - - -
$
ASET1   3      73     63     53     43     33     37     23     +BC
OMIT1,  12,  201,  THRU,  217
$
SPC1,  100, 123456,   81,  THRU,  90
SPC1,  100,    456,    1,  THRU,  80
SPC1,  100,      6,  201,  THRU,  217
MPC     200    71     3      1.0    207    3      -1.0
MPC     200    308    3      1.0    213    3      -1.0         +s46
+s46           213    4      1.934  213    5      19.613
$
```

```
$* * * * * * * * * * * * * * * * * *
$   optimization of structure    *
$* * * * * * * * * * * * * * * * * *
$
$ design variables for skins
DESVAR, 1, QD1,1.0,0.02,1000.0
DLINK,301,33,0.0,1.0, 1,1.0
DVPREL1,1,PSHELL,1,4,,,,,+dp1
+dp1,1,1.0
$
$ Design variables for spars
DESVAR, 101,SPAR1 ,1.0,0.02,1000.0
DVPREL1,101,PSHEAR,101,4,,,,,+dp01
+dp01,101,1.0
$
$ Design variables for ribs
DESVAR,65,RIB65,1.0,0.020,1000.0
DVPREL1,65,PSHEAR,65,4,,,,,+d65
+d65,65,1.0
$
$ Design variables for posts
DESVAR,125,POST125,1.0,0.02,1000.0
DVPREL1,125,PROD,125,4,,,,,+dp125
+dp125,125,1.0
$
$
$ Design Objective$
DRESP1,345,W,WEIGHT
$
$ Design sensitivity response as constraints
DRESP1,1,CQD1 ,STRESS,PSHELL,,9,,1
DRESP1,65,SH65 ,STRESS,PSHEAR,,2,,65
DRESP1,101,SH101 ,STRESS,PSHEAR,,2,,101
DRESP1,125,ROD125 ,STRESS,PROD,,2,,125
$
$
$ STRESS CONSTRAINTS
$ skins
DCONSTR,229, 1,-67000.,67000.
$ ribs
DCONSTR,229,65,-39000.,39000.
$  spars
DCONSTR,229,101,-39000.,39000.
$  posts
DCONSTR,229,125,-67000.,67000.
$ spars
DCONSTR,229,170,-39000.,39000.
$
```

```
$ forces: 10 degree sweep
FORCE    100   1    21494.7   0.0   0.0   1.0
FORCE    200   1     -372.2   0.0   0.0   1.0
FORCE    300   1     3210.0   0.0   0.0   1.0
$
$****************
$   Optimization for flutter *
$****************
$
DCONSTR,239,701,-1.0+10,-0.1
DRESP2,701,DAMP,703,,,,,,+sp2
+sp2,DRESP1,702
$
DEQATN   703    f(a)=(a-0.01)/0.1
DRESP1,702,FLUTTER,FLUTTER,,,,,88,+d301
+d301,20,30,41
SET1,88,4,THRU,6
FLFACT,41,21000.0,21775.0,23565.0
$
$   Optimization Control Parameters
$
PARAM,CDIF,YES
PARAM,NASPRT,3
DOPTPRM,DESMAX,25,DABOBJ,0.0001,DELOBJ,0.00001,CTMIN,0.0001,+dop
+dop,ITRMOP,6,ITMAX,30
ENDDATA
```