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INVESTIGATION OF TORSION FREE WING TREND FLUTTER MODELS.(U)
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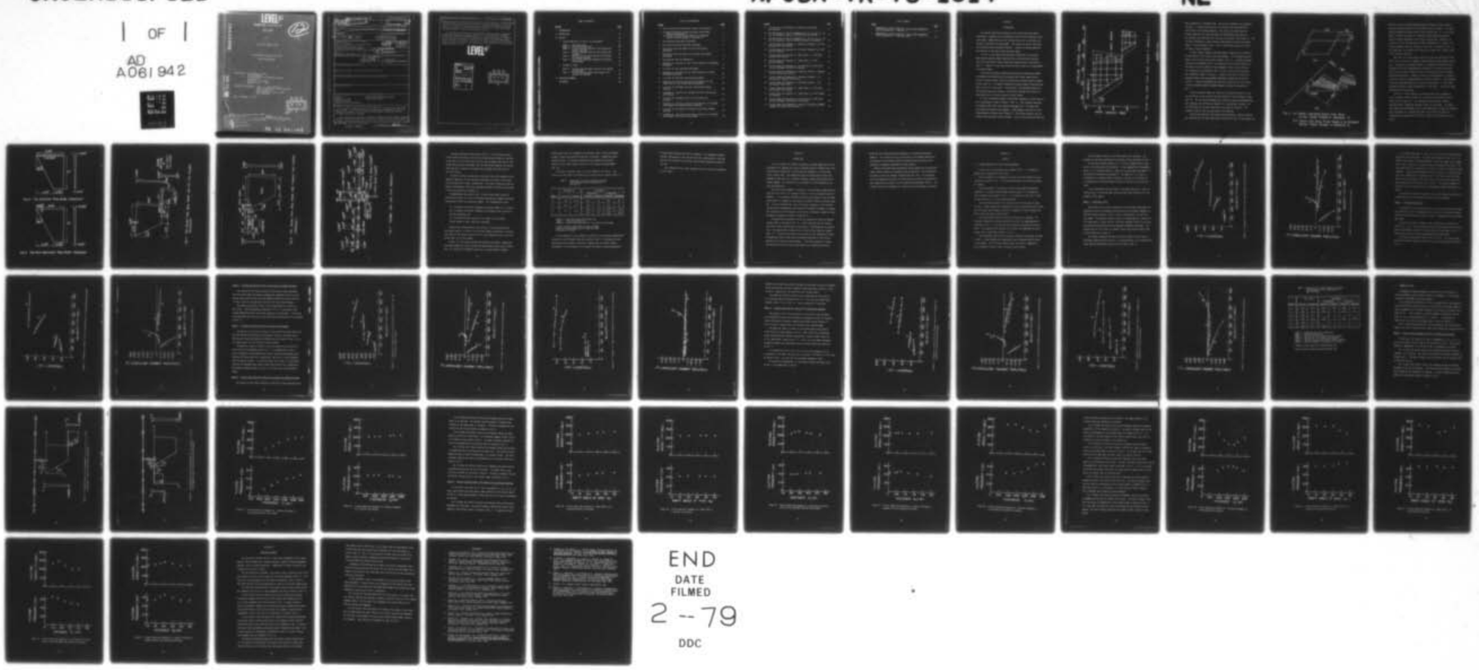

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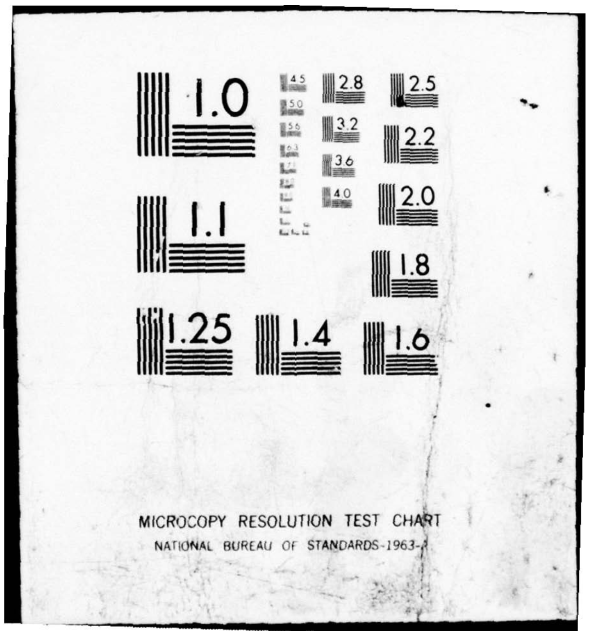
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FINAL REPORT

on

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INVESTIGATION OF TORSION FREE WING TREND FLUTTER MODELS

Submitted to: Mr. William J. Walker
Program Manager
Air Force Office of Scientific Research
Building 410
Bolling Air Force Base
Washington, D.C. 20332

Principal Investigator: Henry T.Y. Yang, Professor
School of Aeronautics and Astronautics
Purdue University
West Lafayette, Indiana 47907
(317) 749-2756

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Four types of aluminum plate flutter models of a torsion free wing (TFW) were studied: (1) cantilever wing; (2) pitch restrained wing; (3) TFW with forward trim surface; (4) TFW with aft trim surface. Models (3) and (4) included the effect of fuselage.

Free vibration analyses were performed by using the finite element program NASTRAN. Generalized aerodynamic forces were computed by using the program

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LAT2D based on the subsonic lifting surface theory of Kussner. Flutter speeds and frequencies were predicted by using the program FLTTR based on the V-g method. The predicted flutter speeds were compared with available computed and tested results. The predicted flutter speeds for the four models were compared with each other and conclusions were made.

To determine the designs that yielded higher flutter speeds, parametric studies were conducted by varying each of the six parameters: thickness parameter of the wing; thickness parameter of either trim surface; location of the wing pivot; length of the boom; swept angle of the wing; and swept angle of either trim surface. The effect of these parameters on the flutter speeds of models (3) and (4) were plotted as trend curves and discussions and conclusions were made.

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INTRODUCTION

An aircraft with free floating or torsion free wings has several advantages as compared to the conventional aircraft with fixed-root cantilever wings. Among these are the ride qualities, gust alleviation, and freedom in locating the landing gear. The concept of torsion free wing has attracted serious attention recently. Studies of various phases of the behavior of the torsion free wing have begun.

In 1970, a rigid body study conducted by Battelle Institute and NASA-Langley Research Center indicated that a free floating pivoting wing can significantly reduce turbulence-induced vertical acceleration (Ref. 1). However, it was also found that such a wing has an unacceptably low flutter speed.

A follow-on study was conducted analytically by the Boeing Company to determine the feasibility of increasing the flutter speed with an active or passive flutter stability augmentation system using the inboard aileron (Ref. 2). The system increased the flutter speed of the wing from Mach 0.34 to 0.8 at sea level. The potential ride smoothing benefits of the pivoting wing were, however, significantly reduced when flutter was suppressed with an active or passive control system.

In 1972, the General Dynamics Corporation completed a flutter analysis for a wing model as shown in Figure 1 (Ref. 3). The structure consisted of graphite cover skins with aluminum honeycomb core. The cover skins were modeled by plate finite elements. Beam elements were used to carry bending moment and shear force (Figure 1). The flutter analysis was performed using the kernel function method. The aft trim surface and the wing

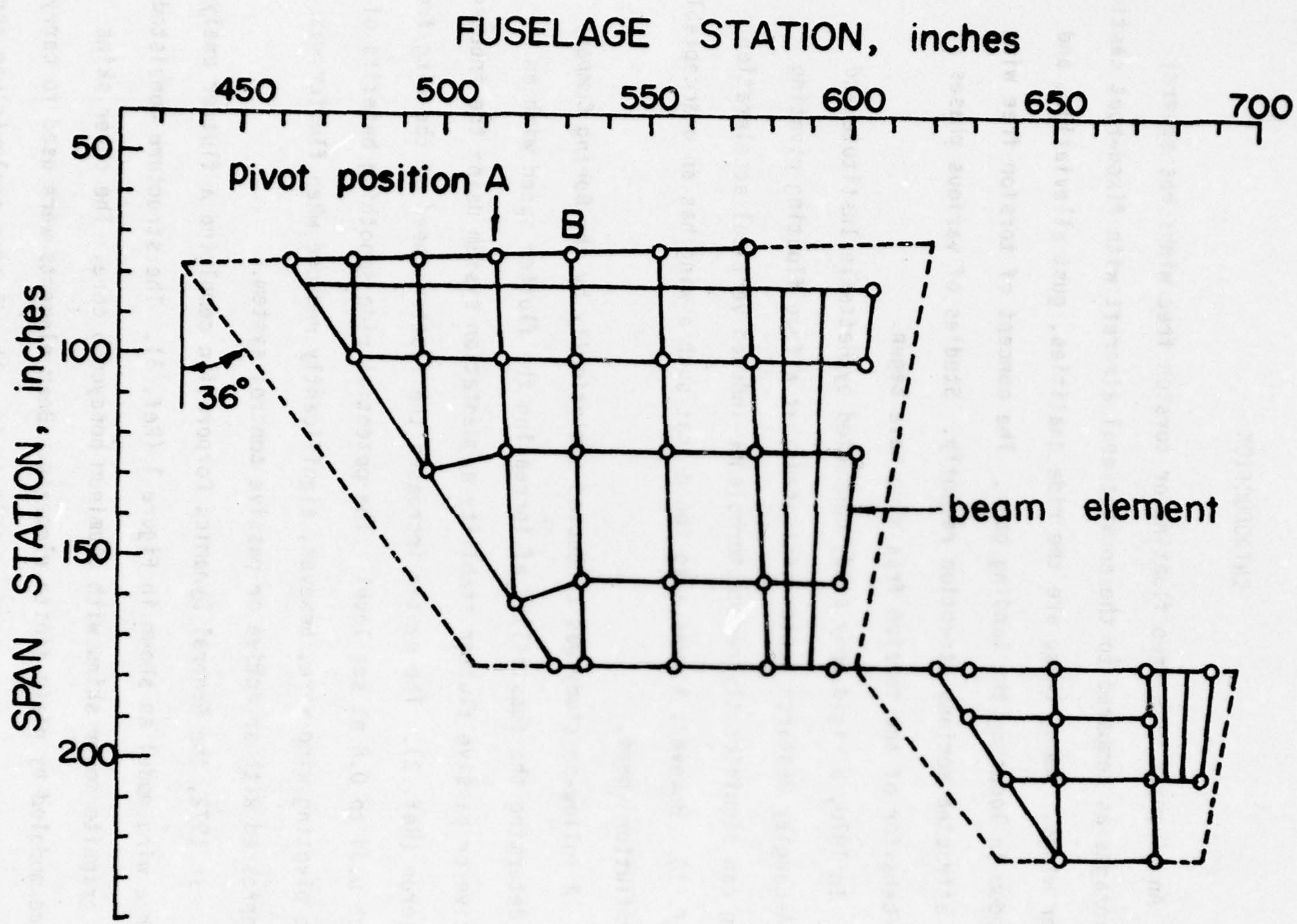

Fig. I Torsion Free Wing Flutter Model Studied in Reference 3 were connected by a chordwise boom. The wing was assumed to be clamped at the pivot. A stabilizing vane (aft trim surface) was supplied with an area of 25% of the inboard planform. The major results were that the flutter speeds at sea level were found to be 1050 knots for the pivot at location A and 1450 knots for the pivot at location B (see Figure 1). The 18 inches difference in pivot location significantly affected the flutter speed. It was concluded in Ref. 3 that a torsion free wing may be feasible from a flutter standpoint.

In 1973, General Dynamics published several reports on the studies of various phases of the torsion free wing problems. The ride-quality attributed to the torsion free wing was studied in Ref. 4. A stress and weight analysis was performed in Ref. 5 to establish the structural feasibility. The effect of wing incidence on the aerodynamic force on both the wing and fuselage was investigated in Ref. 6 using a torsion free wing model for a modified Firebee II aircraft. A stability and control study for a possible torsion free wing advanced technology fighter was carried out in Ref. 7. Mission performance was found to be feasible for five torsion free wing advanced tactical fighter maneuver airplane configurations in Ref. 8.

A radio controlled model was flown for ten accumulated hours to test the feasibility of the torsion free wing concept in the low subsonic range (Ref. 9). The test vehicle demonstrated superior acrobatic maneuverability, gust response, and stability as compared to a conventional airplane. It was also shown that no mass balancing of the wing was necessary. The concept of torsion free wing was proven to be feasible.

Prior to the testing of the radio controlled model, a flutter analysis was conducted for its balsa wood torsion free wing in Ref. 10 (see Figure 2a).

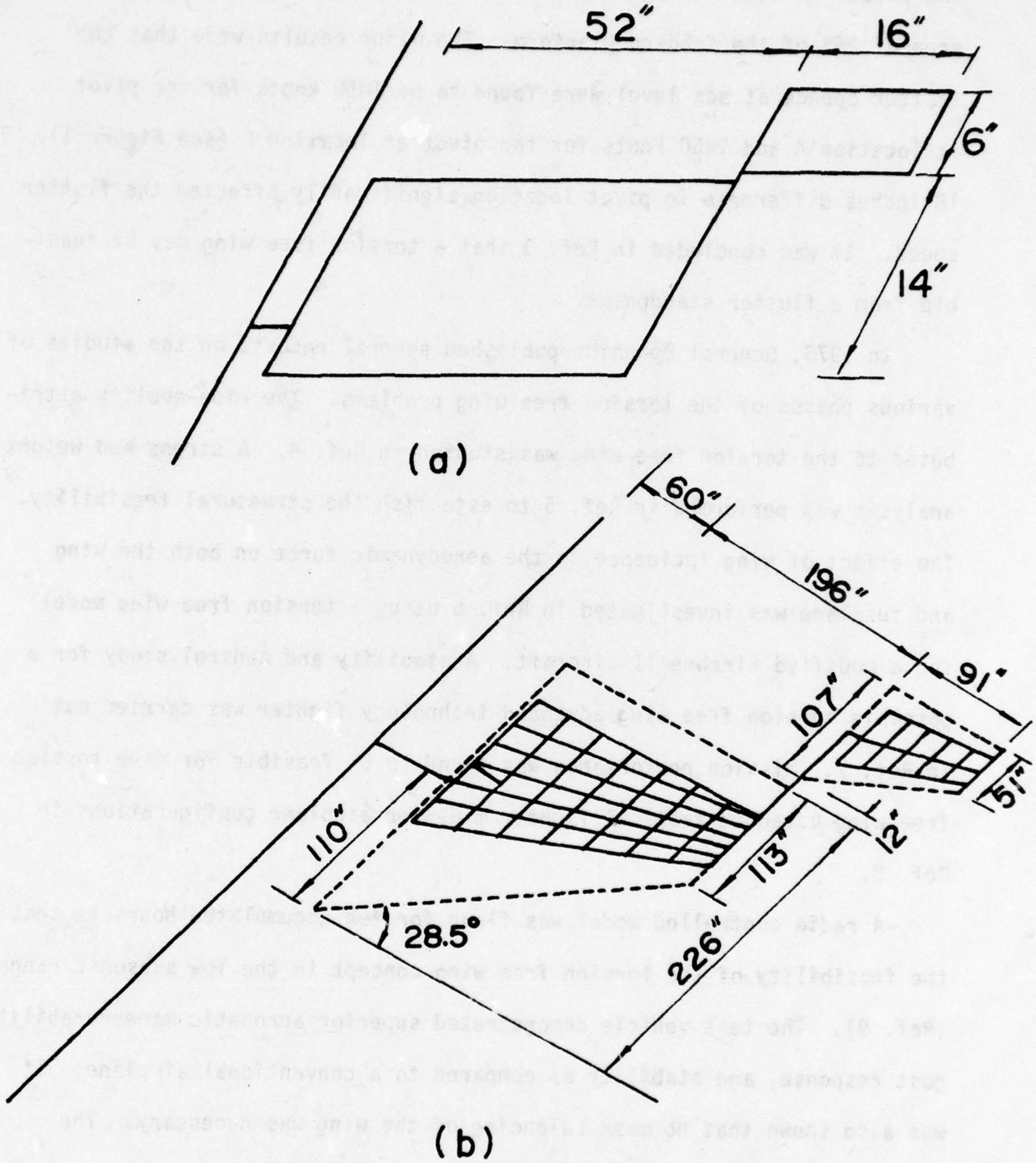

Fig. 2 (a) Radio Controlled Torsion Free Wing Flutter Model Studied in Reference 10

(b) Torsion Free Wing Flutter Model of an Advanced Tactical Fighter Studied in Reference 10

With the use of an aluminum control surface linkage, a flutter speed of 180 knots was obtained while the required value was 125 knots. The radio controlled model was flown without flutter problem (Ref. 9). In the same report, a flutter analysis of a composite torsion free wing advanced tactical fighter configuration (see Figure 2b) was also conducted. As a result of a very low torsional stiffness requirement for strength, the flutter speed was found as 190 knots at sea level. According to Ref. 11, this model was later analyzed with wing pivot clamped and a flutter speed of 377 knots was obtained.

The first set of wing tunnel flutter test data was published in 1976 (Ref. 11) as a result of a project of the Air Force Flight Dynamics Laboratory. The models investigated include (1) clamped-root cantilever wing (Figure 3); (2) pitch restrained wing (Figure 4); (3) torsion free wing with aft trim surface (Figure 5); and (4) torsion free wing with forward trim surface (Figure 6). Models (3) and (4) also consisted of a fuselage spar and a four-bar linkage mechanism as shown in Figure 7. Such mechanism allows both fuselage and wing to translate transversely. It also allows fuselage and wing to pitch independently of each other. Fore and aft body translation was not allowed.

In Ref. 11, flutter speeds and frequencies were also computed by using the kernel function method for all models and the doublet lattice method only for model (4). The computations were, however, based on measured natural frequencies and mode shapes for each model. The agreement between the experimental results and computational results was unacceptable for model (1), excellent for model (2), and fair for model (3). Divergence was experienced in the test of model (4) and flutter was not found.

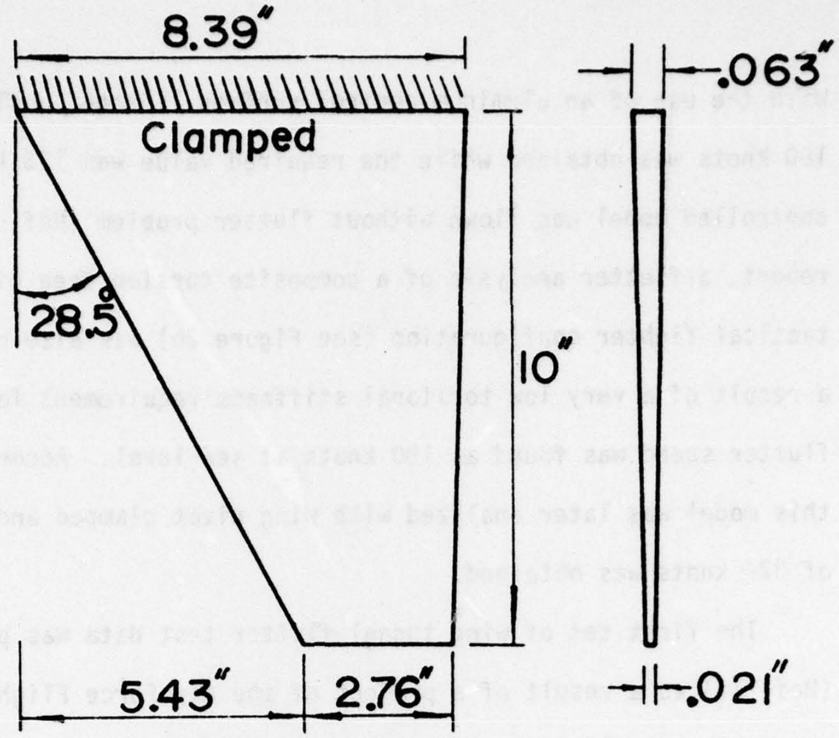

Fig. 3 The Cantilever Wing Model (Aluminum)

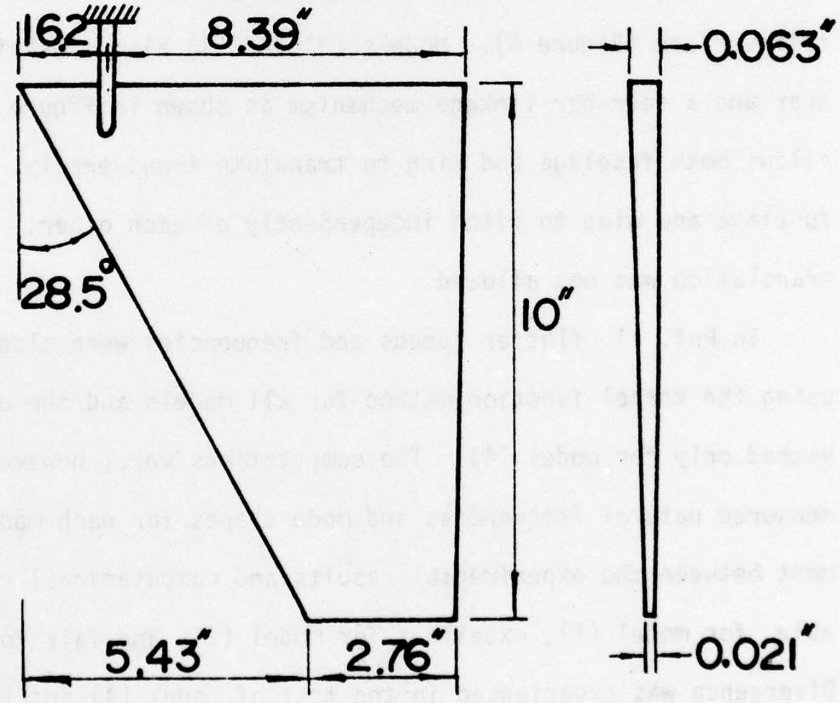

Fig. 4 The Pitch Restrained Wing Model (Aluminum)

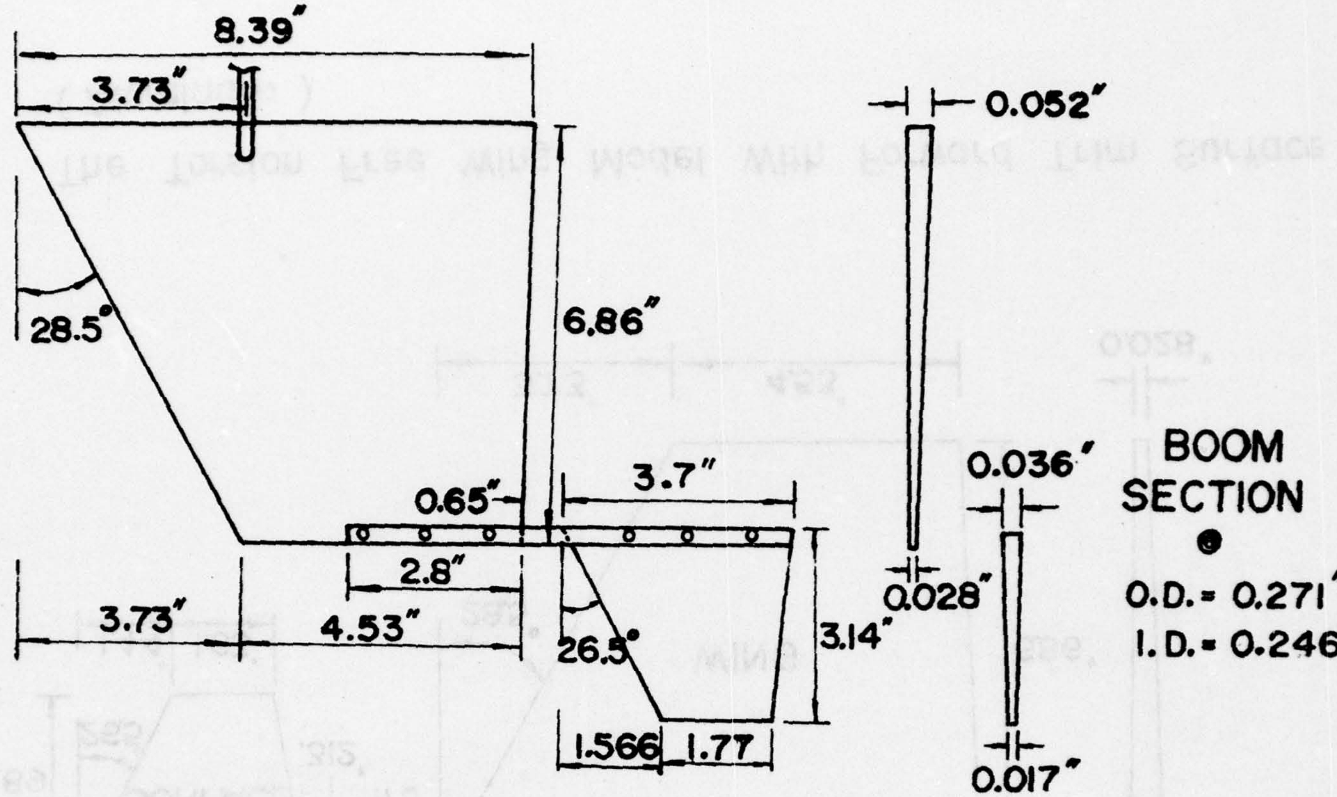

Fig. 5 The Torsion Free Wing Model with Aft Trim Surface (Aluminum)

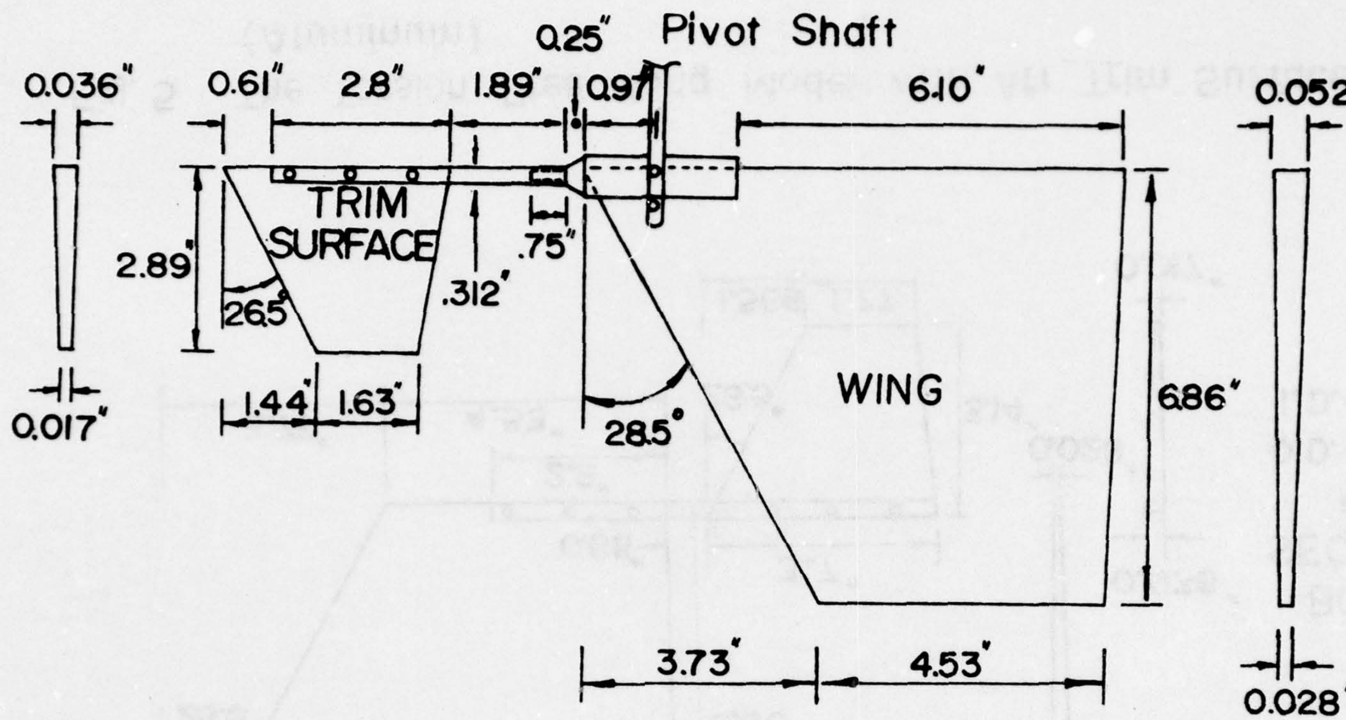

Fig. 6 The Torsion Free Wing Model With Forward Trim Surface (Aluminum)

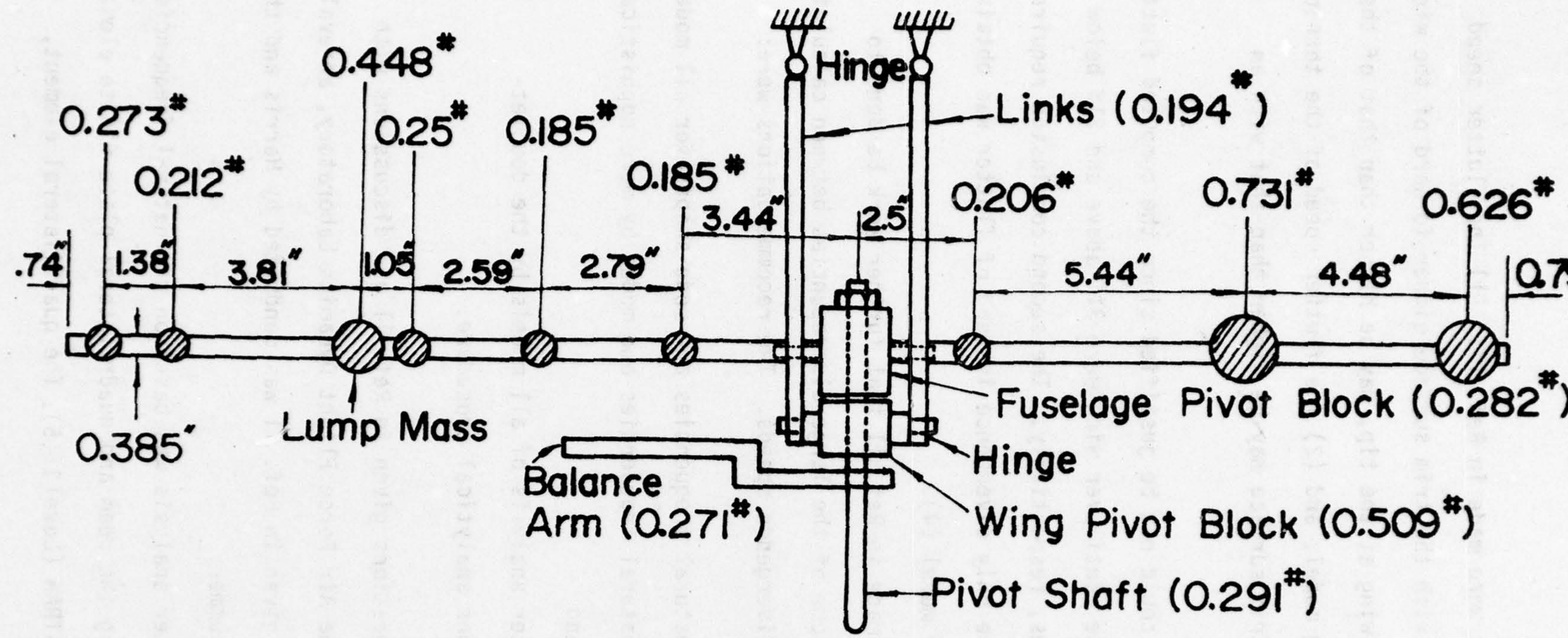

Fig. 7 Fuselage Spar and Pivot Mechanism

Two major conclusions were made in Ref. 11: (1) The flutter speed of the torsion free wing, with the trim surface either forward of the wing at the root or aft of the wing at the tip, may be higher than that of the fixed-root cantilever wing model, and (2) The flutter speed of the torsion free wing with a forward trim surface may be higher than that with an aft trim surface.

The first conclusion could not be justified since the computed flutter speed and frequency for the cantilever wing were 31% above and 21% below the wind tunnel test values, respectively. The second conclusion required further investigation since only divergence instead of flutter was obtained in the wind tunnel test of model (4).

Recommendations were made in Ref. 11 that further work be done to pinpoint the reasons for some of the large discrepancies between calculated and measured flutter and divergence speeds. The recommendations were:

(1) to compute the natural frequencies and mode shapes for all models,

(2) to measure the natural frequencies and modes by more sophisticated test procedure; and

(3) to perform flutter analysis of all models by the doublet-lattice method or other analytical procedure.

Based on the recommendations given in Ref. 11 and discussions with the project monitor at the Air Force Flight Dynamics Laboratory, an evaluation study of the results given in Ref. 11 was conducted by Harris and this writer (Ref. 12) in 1976 summer.

In Ref. 12, the flutter analysis was based on the natural frequencies and modes computed by using the beam and quadrilateral plate finite elements (Ref. 13) available in NASTRAN (Level 15.5). The quadrilateral element, consisting of four HCT triangular plate elements (Ref. 14), was considered as most suitable for analyzing wing panel structures. Lumped mass matrix option was used. The flutter computation was performed by using the doublet lattice method option available in the computer program FASTOP (Ref. 15).

The results obtained in Ref. 12 can be summarized in Table 1. The torsion free wing model with forward trim surface was not studied in Ref. 12.

TABLE 1. Comparison of Flutter Velocities (ft/sec) and Frequencies (Hertz) Between Ref. 11 and Ref. 12

Model #	REFERENCE 12		REFERENCE 11			
			Computation		Experiment	
	Velocity	Frequency	Velocity	Frequency	Velocity	Frequency
1	295	75.5	315*	65	240	87
2	191	35.7	218*	37	215	37
3	213	39.2	305*	35	210^{Δ}	9.2
			229†	42	260	43.8

\# Model 1 - Cantilever wing with clamped root
Model 2 - Pitch restrained wing
Model 3 - Torsion free wing with aft trim surface and fuselage

* Kernel function method based on measured modes
† Doublet lattice method based on measured modes
Δ Mild case of flutter

In this Research, it was proposed to perform a more detailed computational study of all the TFW models that were studied in Ref. 11 (including the one with forward trim surface) to provide a complete set of flutter results. Furthermore, it was proposed to investigate the effect of various parameters on the flutter velocity and flutter frequency. The parameters studied include: thicknesses of the wing and the trim; swept angles of the wing and the trim; position of the pivot; and distance between the wing and the trim.

Such proposed work has been completed and the results are presented in this report.

SECTION II

METHOD USED

In this research, the natural frequencies and mode shapes for all the wing models are computed by using the computer program N^STRAN (Level 15.5). The fuselage, pitching bar, and the boom are modeled by using the beam finite element CBAR. The tapered wing and the tapered trim surface are modeled by using the flat, constant thickness, quadrilateral plate finite element CQUAD2. The variation of the thickness is thus accounted for by step representation.

The plate element CQUAD2 is composed of two overlapping quadrilaterals, each with only half of its bending stiffness. One of the quadrilaterals is composed of two bending triangles divided by one diagonal while the other quadrilateral is composed of two bending triangles divided by another diagonal. For each triangle the x-axis lies along a diagonal so that internal consistency of displacements and rotations of adjacent triangles is assured. The formulation of the triangular plate finite in bending is based on those developed by Clough and Tocher in Reference 14.

The generalized aerodynamic forces are computed by using the computer program LAT2D as provided in Ref. 16. LAT2D calculates the oscillatory aerodynamic force distributions on wing-and-tail configurations in subsonic flow. The method used is based on the lifting surface theory of Kussner (Ref. 17). The basic restriction of the theory is the assumption of small disturbances, which allows that the governing equations of the flow be reduced to the classical wave equation. Since this equation is linear, the solution can be built up by superposition of elementary solutions, which for the lifting problem are pressure or acceleration-potential doublets. For aircraft with two wing surfaces, the program computes the distribution of acceleration potential doublets which satisfies simultaneously the boundary conditions on both surfaces.

Based on the generalized aerodynamic forces computed by using program LAT2D, flutter speeds and frequencies can be predicted. Such predictions are made by using the computer program FLTTR (Ref. 18). In the program FLTTR, the equations of motion are formulated on the basis of generalized mass, generalized stiffness, and the generalized aerodynamic forces. The flutter velocity and frequency are found by using the standard V-g method.

SECTION III

RESULTS

1. FLUTTER ANALYSIS OF A SET OF SIX WING MODELS

A series of six wing models were studied in Ref. 11. The same six models were re-examined in this study.

The first model is an aluminum cantilever wing with linearly varying thickness as shown in Fig. 3. The edge conditions at the root are assumed as clamped.

The second model is the same as the first one except the boundary conditions. Instead of being clamped along an edge, it is clamped by a split aluminum rod as shown in Fig. 4. The other end of the rod is fixed so that the model is a "pitch restrained wing".

The third model consists of a wing and an aft trim surface as shown in Fig. 5. Both surfaces are connected by a split aluminum tube with rivets. At 3.73 inches from the apex, the wing is clamped by a solid aluminum rod which allows the wing to pitch freely.

The fourth model consists of the third model and a fuselage. The fuselage is modeled by using an aluminum rod with nine lumped masses as described in Fig. 7. The wing and the fuselage are connected by a pivot shaft. The mechanism that provides the torsion free conditions for wind tunnel test is described in detail in Fig. 7.

The fifth model consists of a wing and a forward trim surface as shown in Fig. 6. Both surfaces are connected by split aluminum tubes as shown in the figure. At 0.97 inches from the apex, the wing is clamped by a solid aluminum rod which allows the wing to pitch freely.

The sixth model consists of the fifth model and a fuselage. The fuselage and the pivot mechanism are the same as those described in Fig. 7.

In the free vibration analysis, a 4 x 4 finite element mesh is used for all of the wings and trim surfaces. In the computation of aerodynamic forces, a 4 x 4 doublet lattice is used for the cantilever wing (model 1) and the pitch restrained wing (model 2). For models 3, 4, 5, and 6, a 6 Chordwise by 5 spanwise doublet lattice is used for all the wings and a 5 chordwise by 4 spanwise doublet lattice is used for all the trim surfaces.

In all the present flutter analysis, five modes were used. Since no flutter occurs in the fifth mode, only four modes were plotted in all the figures in this report.

Model 1 - Cantilever Wing

The results for the flutter analysis of the cantilever wing model are presented as plots of frequency versus velocity and structural damping coefficient versus velocity in Figs. 8 and 9, respectively, for the first four modes. The model was found to flutter in second mode at a velocity of 273 ft/sec which is lower than the 315 ft/sec computed in Ref. 11 by using the Kernel function method based on measured frequencies and modes. The present value of 273 ft/sec is, however, higher than the 240 ft/sec found by wind tunnel test of Ref. 11.

The flutter frequency was found to be 67 Hz which is very close to the Kernel function result of 65 Hz. On the other hand, it is substantially lower than the experimental value of 87 Hz given in Ref. 11.

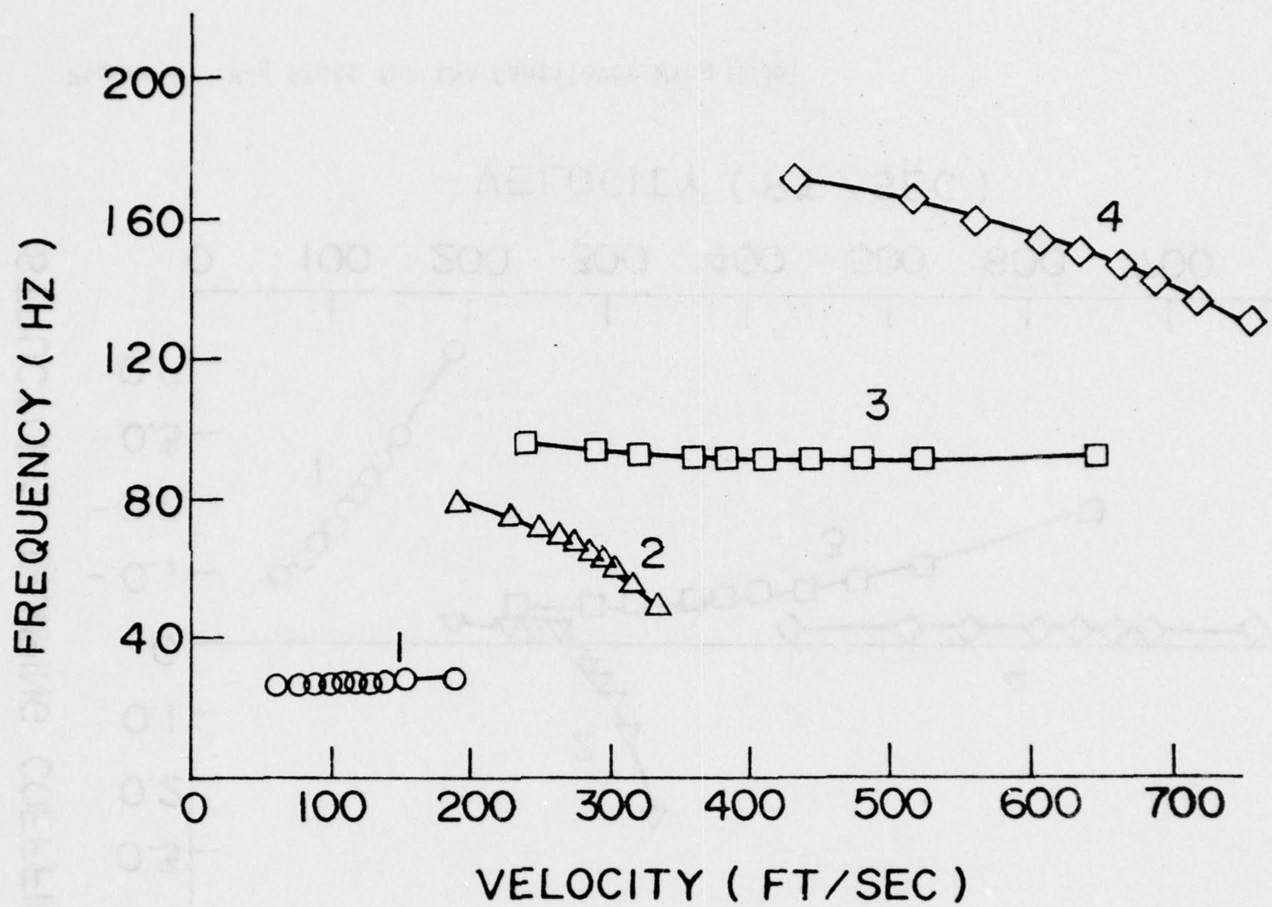

Figure 8. Frequency Vs. Velocity for the Flutter Analysis of Cantilever Wing Model

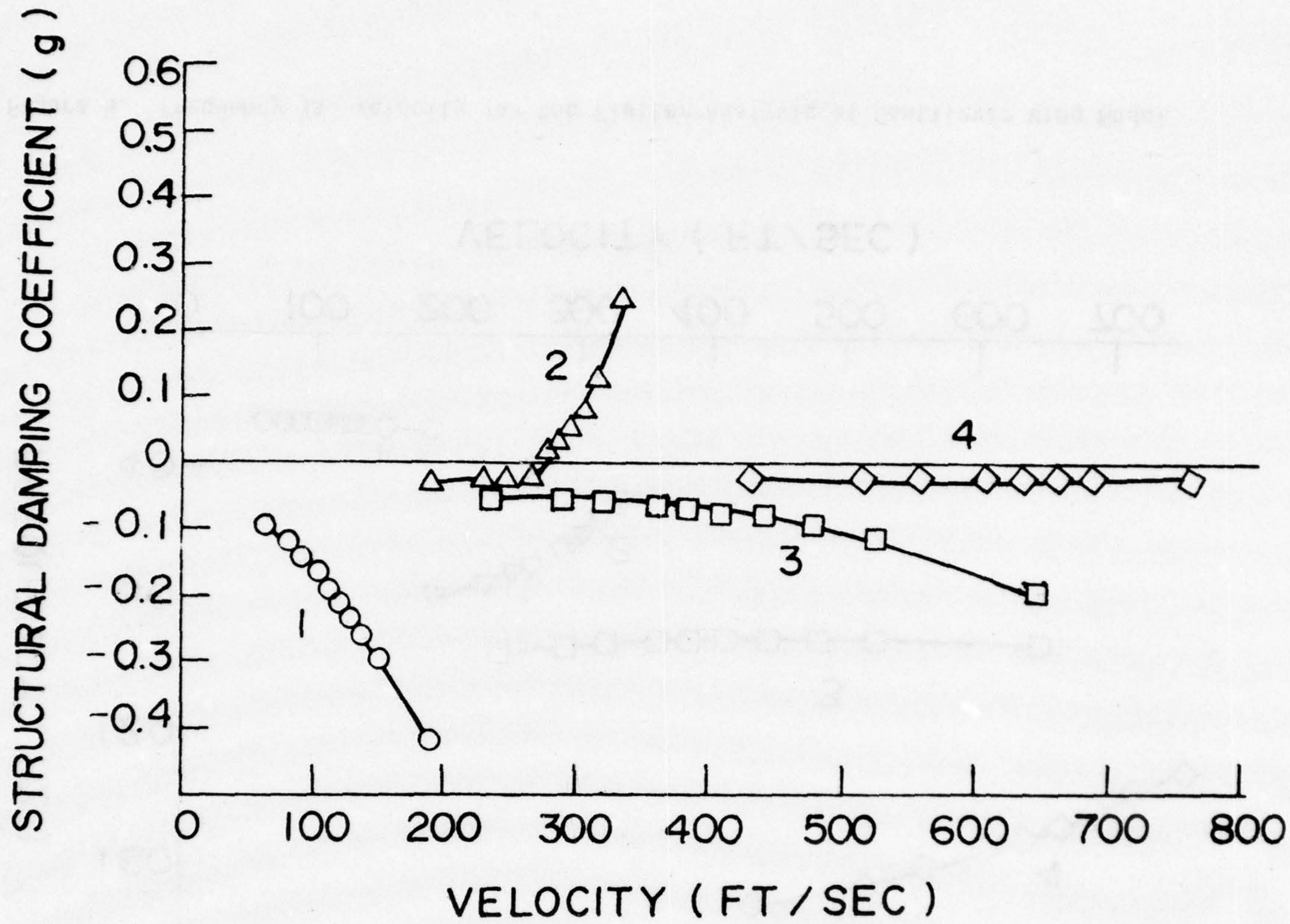

Figure 9. V-g Plots for the Cantilever Wing Model

In a letter dated June 13, 1978, Dr. Stephen M. Batill provided some test results for this model. The tests were conducted in the 2 ft x 3 ft subsonic wind tunnel of the USAF Academy. Four strain gages were attached to the root of the model to measure torsion and bending at the root. The strain gage data were recorded on strip charts in order to determine flutter frequency. Tunnel speed was measured using the tunnel's manometer system. Tests were conducted on two different days. The flutter velocities were found to be in the range of 256 to 287 ft/sec and the flutter frequencies were found to be in the range of 65.5 to 84 Hz. The present computed results are in close agreement with the experimental results obtained by Dr. Batill.

The reason to analyze this model is to use this conventional design as a comparative basis to evaluate the torsion free wing designs.

Model 2 - Pitch Restrained Wing

The results for the flutter analysis of the pitch restrained wing model are presented as plots of frequency versus velocity and structural damping coefficient versus velocity in Figs. 10 and 11, respectively, for the first four modes.

The model was found to flutter in the second mode at a velocity of 209 ft/sec. This is the case where the Kernel function result of 218 ft/sec and the experimental value of 215 ft/sec agree with each other in Ref. 11. Both values are quite close to the present value of 209 ft/sec.

The flutter frequency was found to be at 33.8 Hz. This value agrees well with the Kernel function result of 37 Hz and the experimental value of 37 Hz.

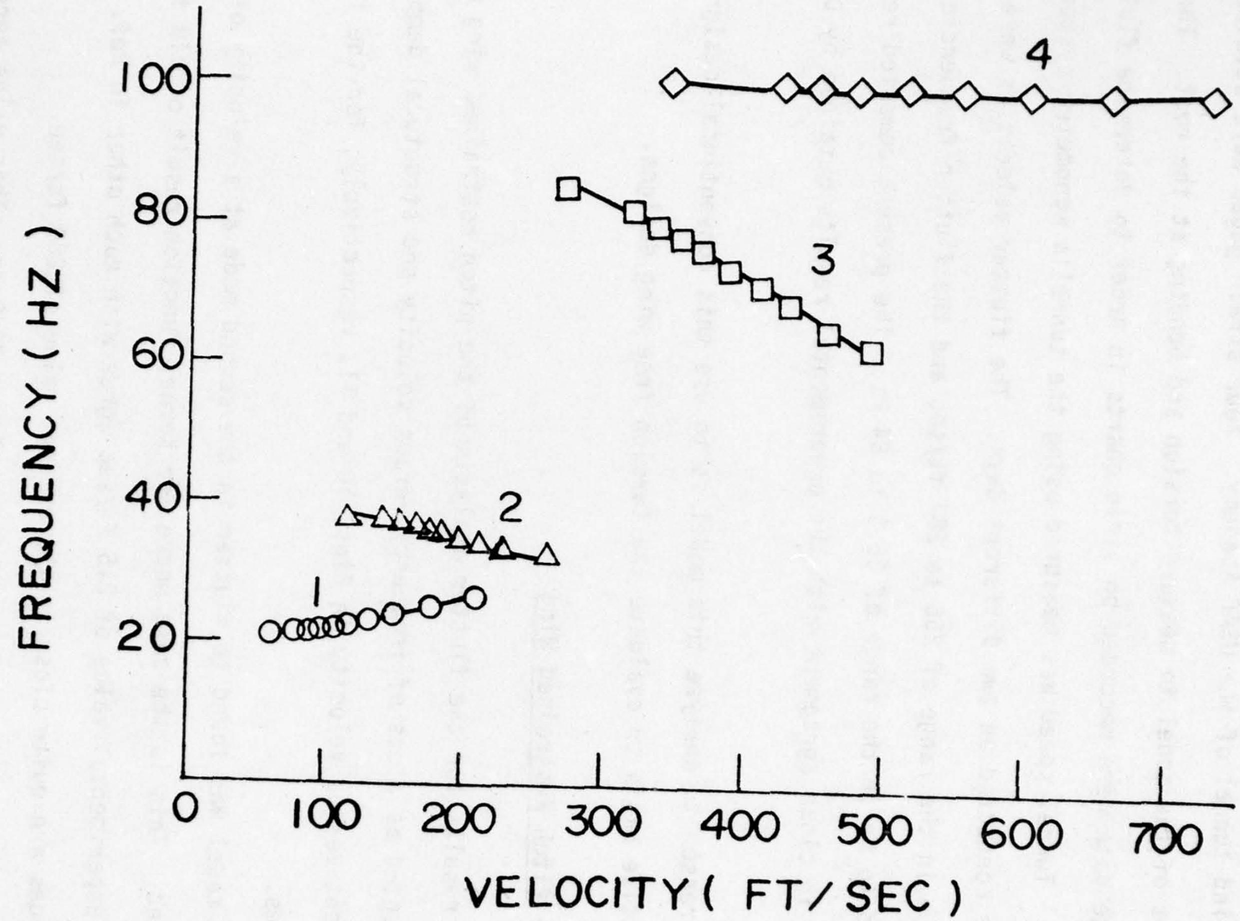

Figure 10. Frequency Vs. Velocity for the Flutter Analysis of Pitch Restrained Wing Model

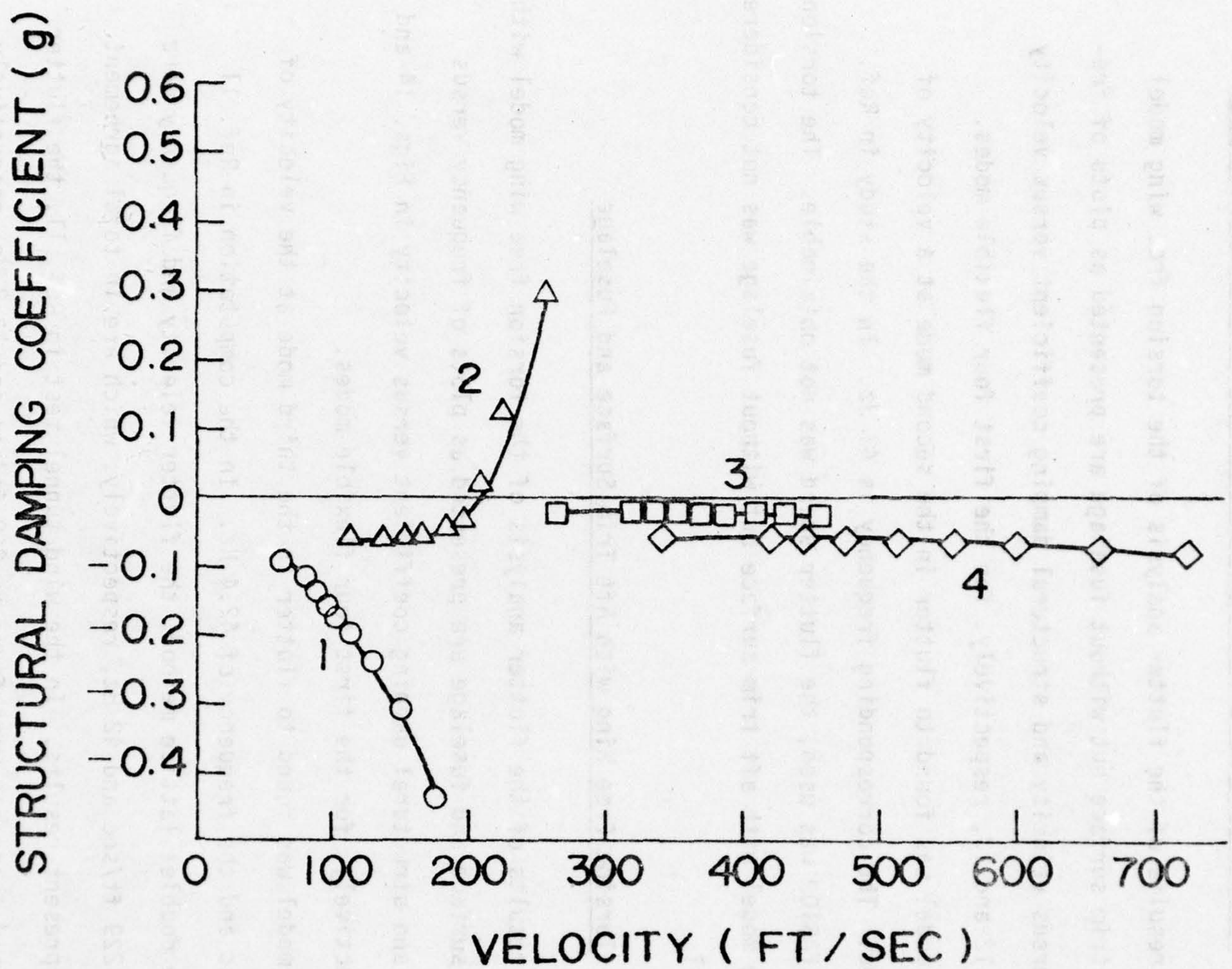

Figure 11. V-g Plots for the Pitch Restrained Wing Model

Model 3 - Torsion Free Wing with Aft Trim Surface But without Fuselage

The results of the flutter analysis of the torsion free wing model with aft trim surface but without fuselage are presented as plots of frequency versus velocity and structural damping coefficient versus velocity in Figs. 12 and 13, respectively, for the first four flexible modes.

The model was found to flutter in the second mode at a velocity of 229 ft/sec. The corresponding frequency is 42 Hz. In the study in Ref. 12 where FASTOP was used, the flutter speed was not obtainable. The torsion free wing model with aft trim surface but without fuselage was not considered in Ref. 11.

Model 4 - Torsion Free Wing with Aft Trim Surface and Fuselage

The results of the flutter analysis of the torsion free wing model with aft trim surface and fuselage are presented as plots of frequency versus velocity and structural damping coefficient versus velocity in Figs. 14 and 15, respectively, for the first four flexible modes.

The model was found to flutter in the third mode at the velocity of 229 ft/sec and the frequency of 42.4 Hz. In the computation in Ref. 11 using the doublet lattice method, the flutter velocity and frequency were found as 229 ft/sec and 42 Hz, respectively, which are in total agreement with the present results. In the wind tunnel test in Ref. 11, the flutter velocity and frequency were found as 260 ft/sec and 43.8 Hz, respectively. The present computed flutter velocity is 12% lower than the experimental values.

Model 5 - Torsion Free Wing with Forward Trim Surface but without Fuselage

The results of the flutter analysis of the torsion free wing model with

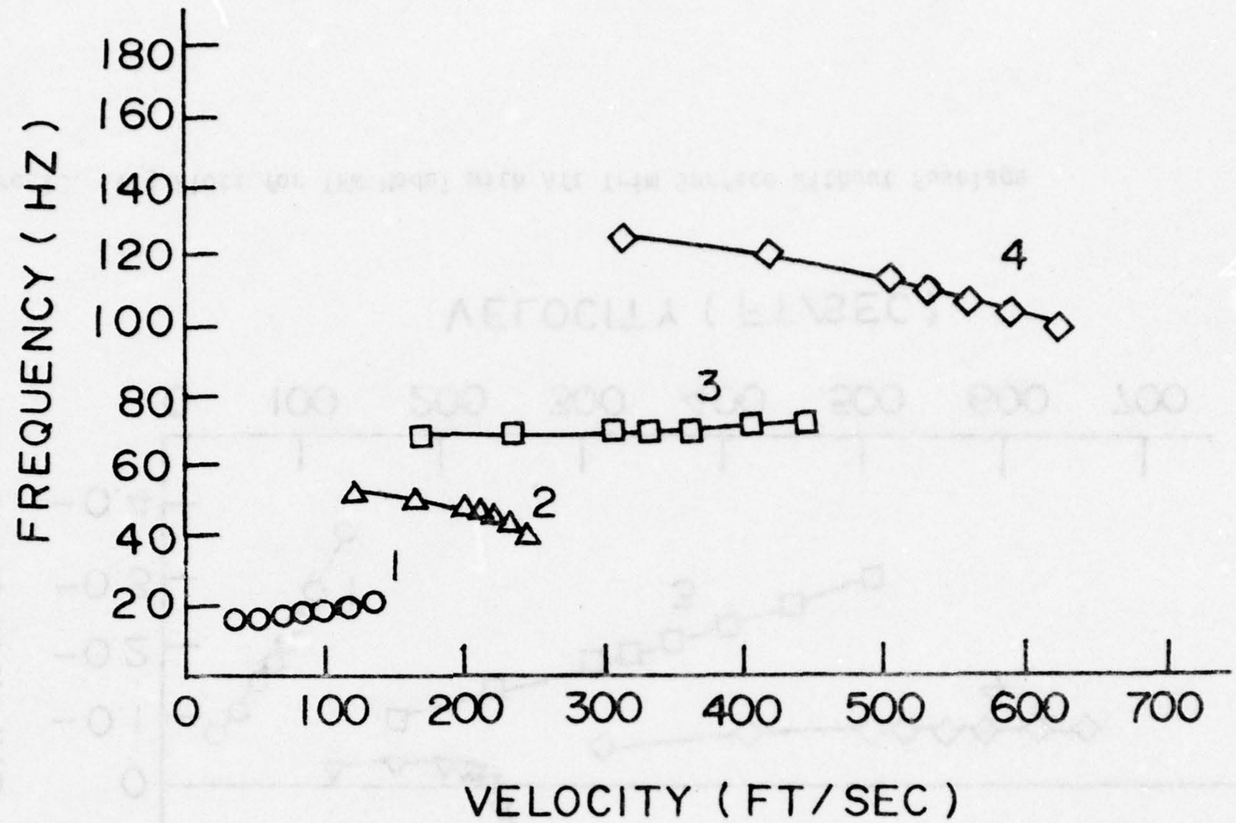

Figure 12. Frequency Vs. Velocity for the Flutter Analysis of TFW Model with Aft Trim Surface Without Fuselage

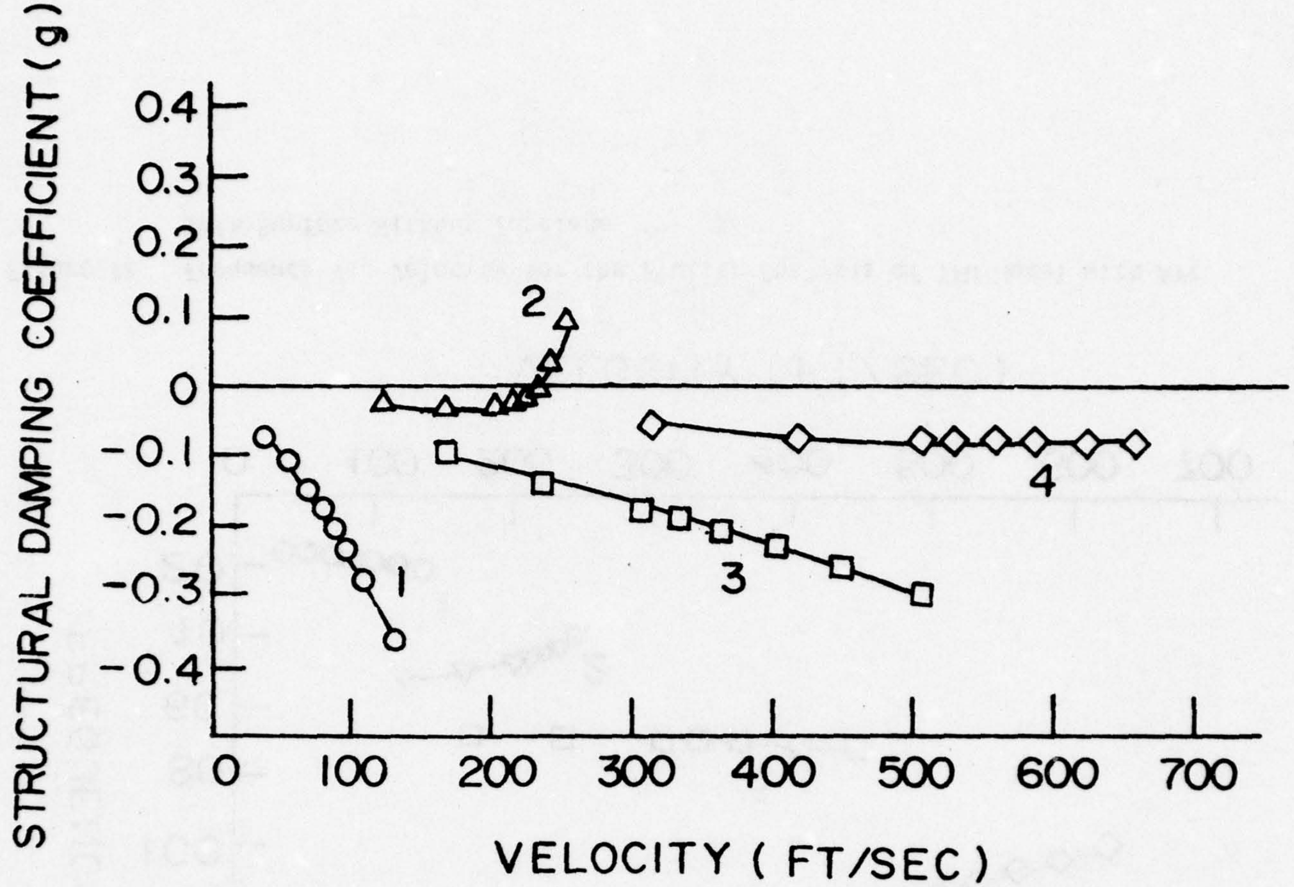

Figure 13. V-g Plots for TFW Model with Aft Trim Surface Without Fuselage

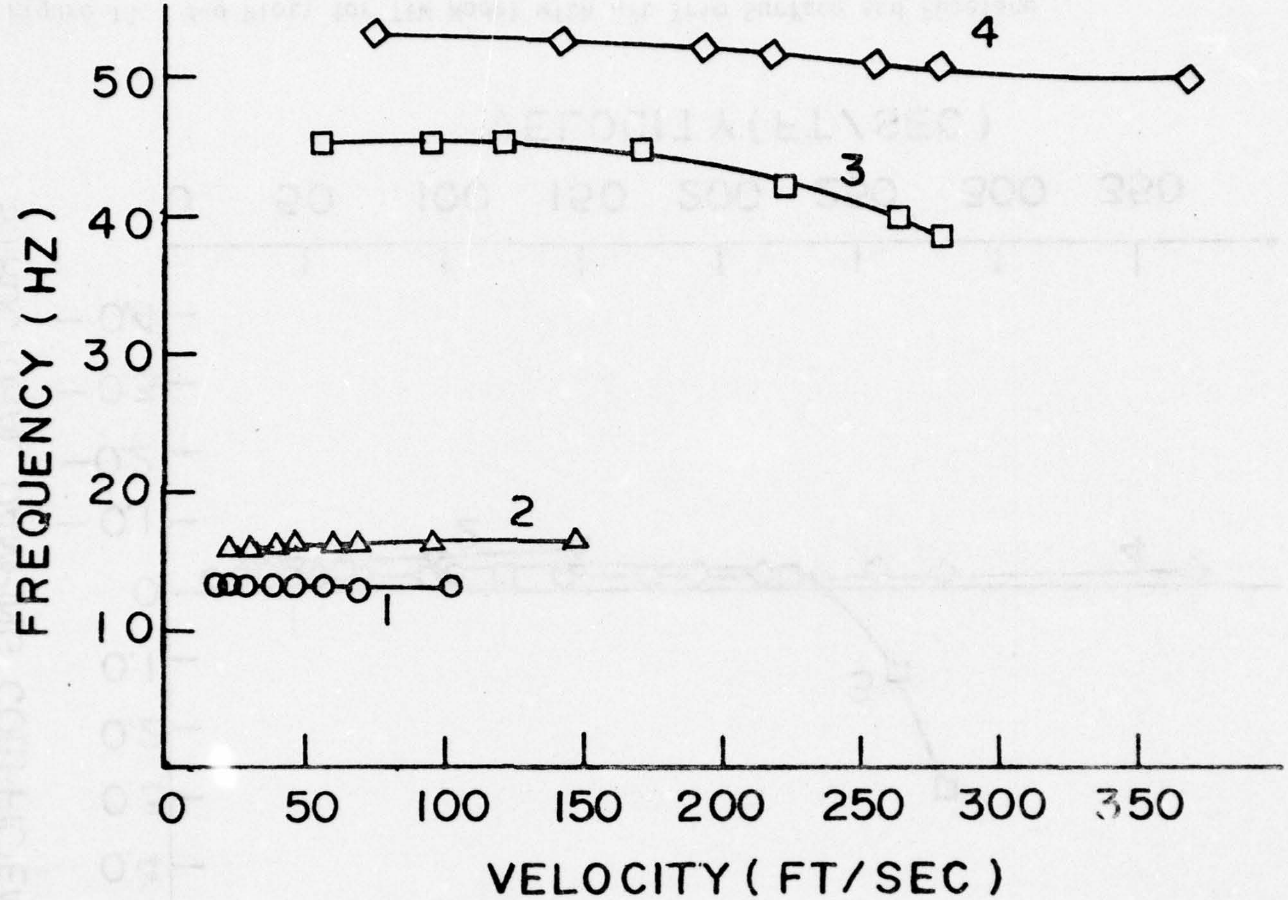

Figure 14. Frequency Vs. Velocity for TFW Model with Aft Trim Surface and Fuseline

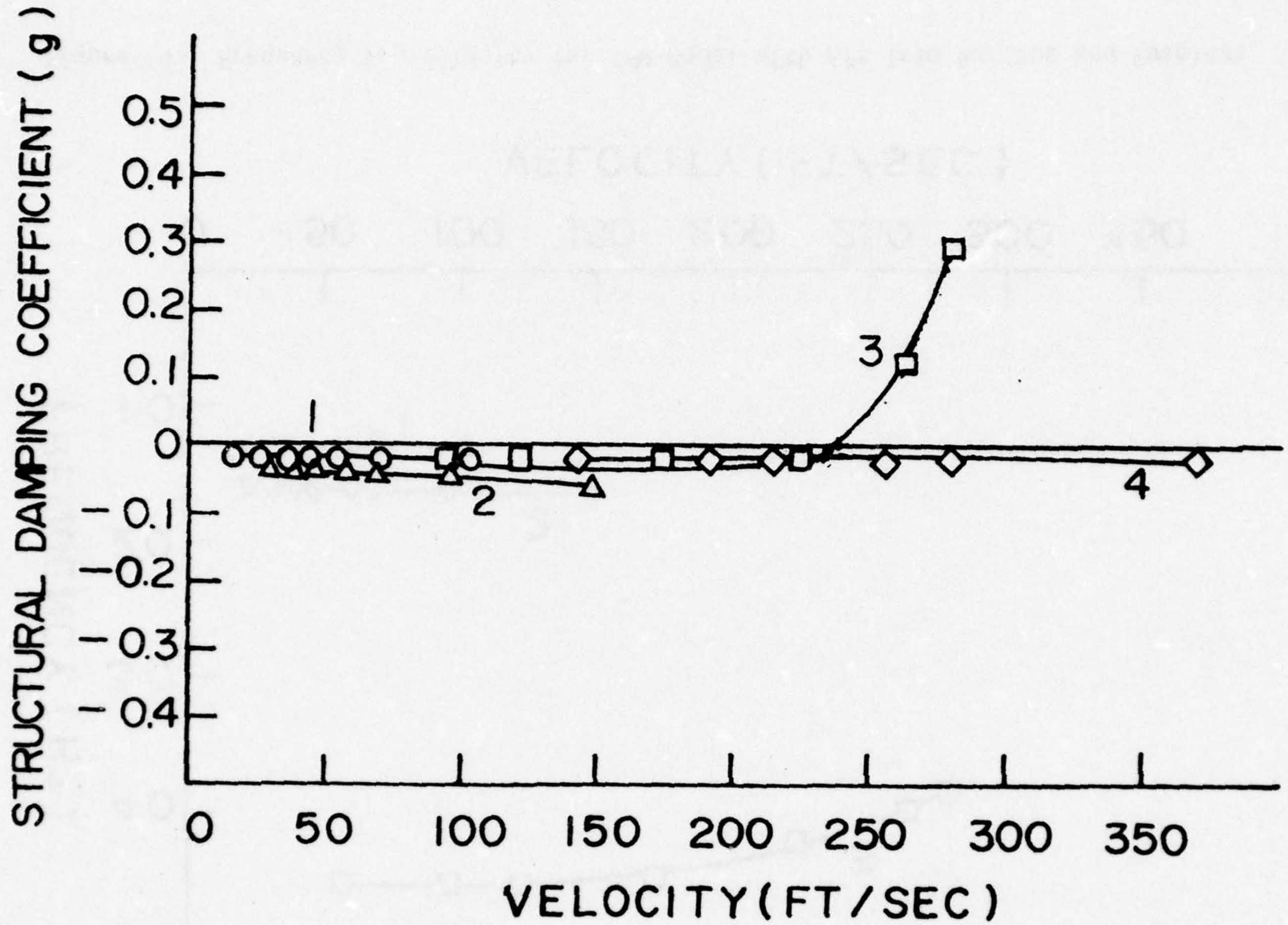

Figure 15. V-g Plots for TFW Model with Aft Trim Surface and Fuselage

forward trim surface but without fuselage are presented as plots of frequency versus velocity and structural damping coefficient versus velocity in Figs. 16 and 17, respectively, for the first four flexible modes.

The model was found to flutter in the second mode at the velocity of 219 ft/sec and the frequency of 47.3 Hz. This case has neither been studied in Ref. 11 nor in Ref. 12. Thus no comparison can be made.

<u>Model 6</u> - <u>Torsion Free Wing with Forward Trim Surface and Fuselage</u>

The results of the flutter analysis of the torsion free wing model with forward trim surface and fuselage are presented as plots of frequency versus velocity and structural damping coefficient versus velocity in Figs. 18 and 19, respectively, for the first four flexible modes.

The model was found to flutter in the fourth mode at the velocity of 289 ft/sec and the frequency of 62 Hz. Both values are considerably higher than the Kernel function computational results of 223 ft/sec and 31 Hz, respectively, found in Ref. 11. This is the case where divergence instead of flutter was experienced during the wind tunnel test conducted in Ref. 11.

It is noted that in this case, the pivot axis was assumed to be at a distance of 1.62 inches from the apex of the wing. The value of 0.97 inches as marked in Fig. 7 was used for the subsequent parametric study.

For clarity of presentation, all the present results and those given in Ref. 11 are summarized in Table 2.

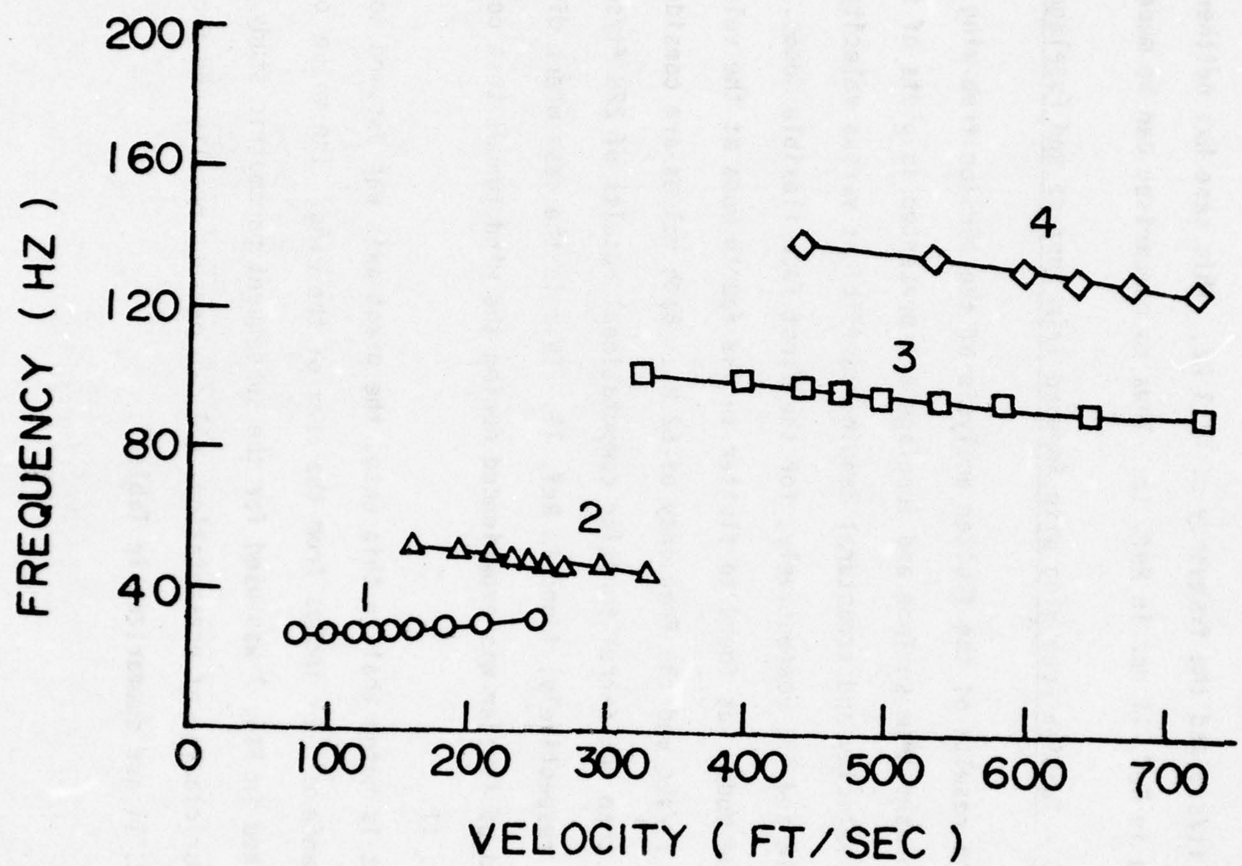

Figure 16. Frequency Vs. Velocity for the Flutter Analysis of TFW Model with Forward Trim Surface Without Fuselage

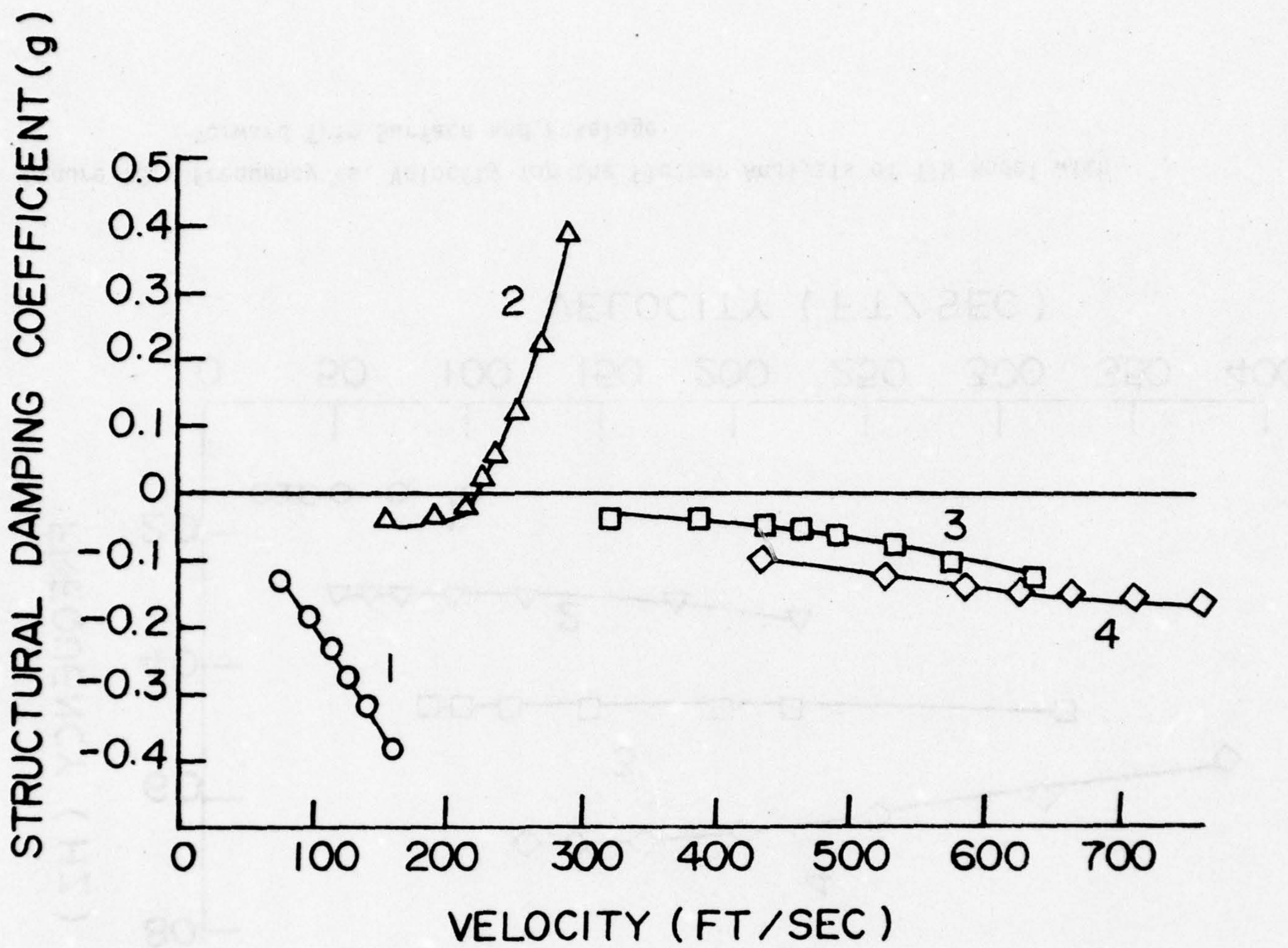

Figure 17. V-g Plots for TFW Model with Forward Trim Surface Without Fuselage

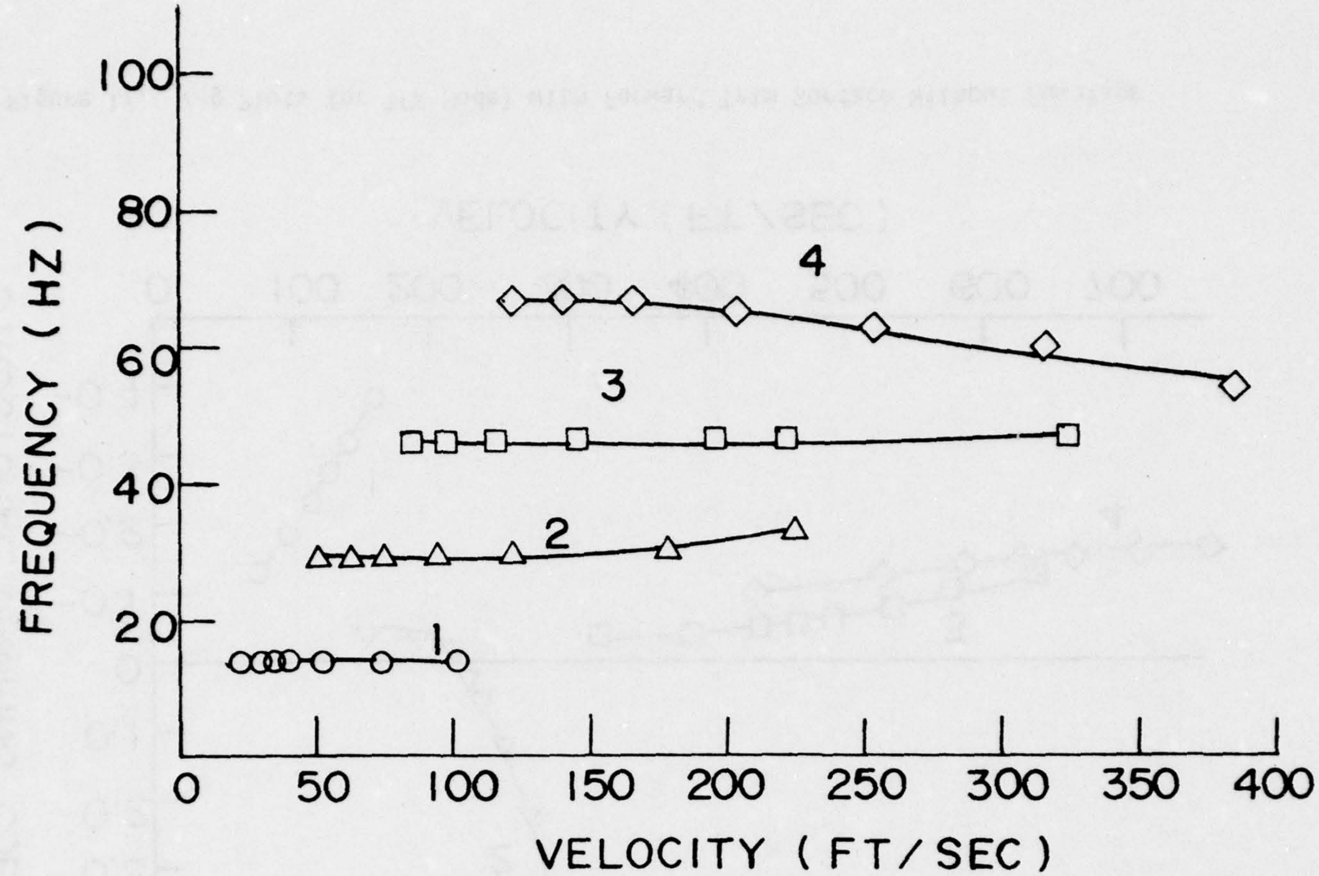

Figure 18. Frequency Vs. Velocity for the Flutter Analysis of TFW Model with Forward Trim Surface and Fuselage

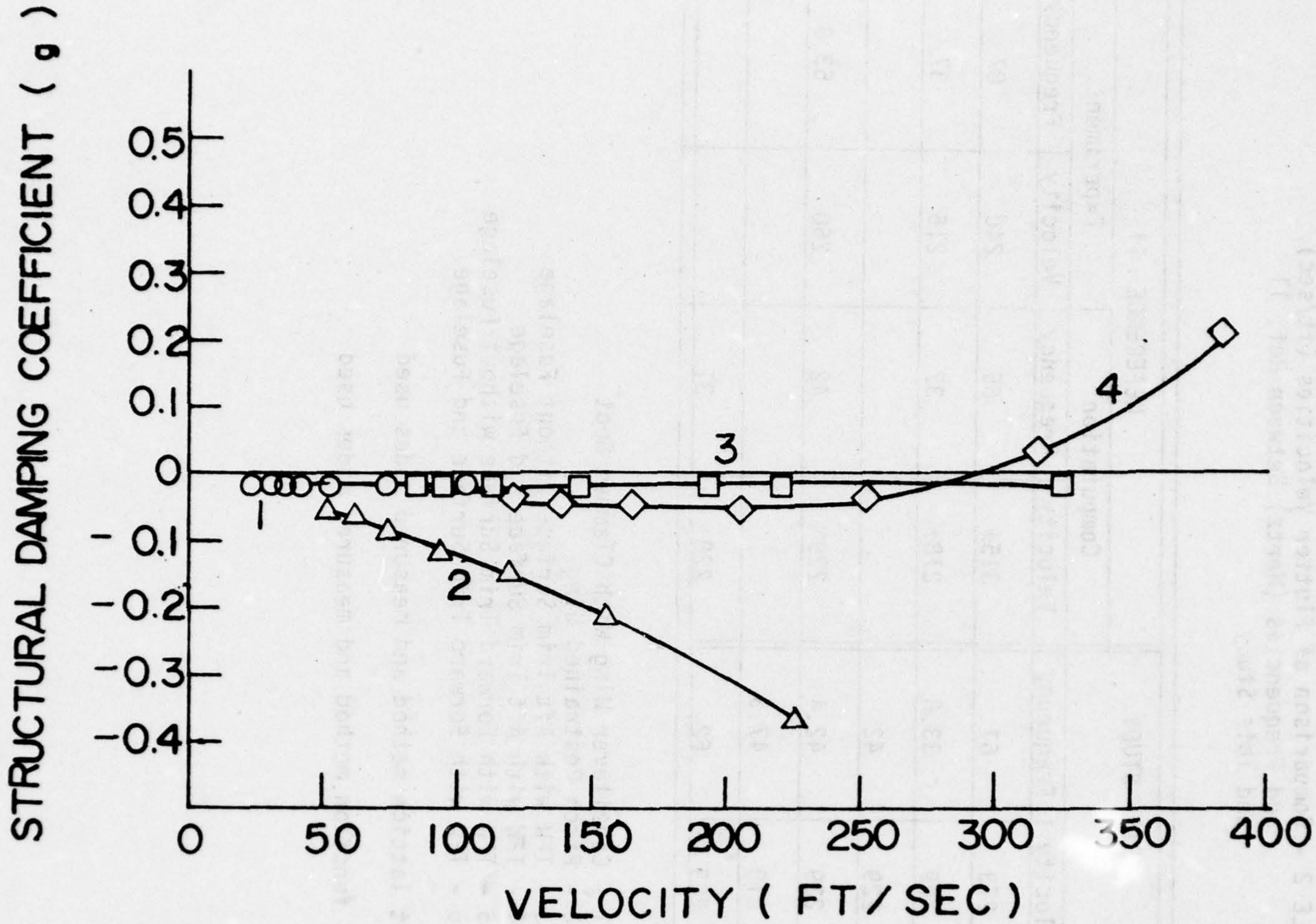

Figure 19. V-g Plots for the TFW Model with Forward Trim Surface and Fuselage

TABLE 2 - Comparison of Flutter Velocities (ft/sec) and Frequencies (Hertz) Between Ref. 11 and This Study

	THIS STUDY		REFERENCE 11			
			Computation		Experiment	
Model #	Velocity	Frequency	Velocity	Frequency	Velocity	Frequency
1	273	67	315†	65	240	87
2	209	33.8	218†	37	215	37
3	229	42				
4	229	42.4	229*	42	260	63.8
5	219	47.3				
6	289	62	228†	31		

Model 1 - Cantilever Wing With Clamped Root
Model 2 - Pitch Restrained Wing
Model 3 - TFW with Aft Trim Surface without Fuselage
Model 4 - TFW with Aft Trim Surface and Fuselage
Model 5 - TFW with Forward Trim Surface without Fuselage
Model 6 - TFW with Forward Trim Surface and Fuselage

* Doublet lattice method and measured modes used

† Kernel function method and measured modes used

2. PARAMETRIC STUDY

The purpose to perform parametric study was to find the effect of various parameters on the flutter velocity and frequency. In such study, only Model 4 and Model 6 were investigated.

Fig. 20 shows the definitions of the six parameters for the parametric study of the torsion free wing with aft trim surface and fuselage (Model 4). The six parameters are: thickness parameter of the wing T_1; thickness parameter of the trim surface T_2; distance between the wing apex and the pivot axis x_1; distance between the wing and the trim surface x_2; swept angle of the wing θ_1; and swept angle of the trim surface θ_2.

Fig. 21 shows the definitions of the six parameters for the parametric study of the torsion free wing with forward trim surface and fuselage (Model 6).

Model 4 - Torsion Free Wing Model with Aft Trim Surface and Fuselage

In this case, the values of all the six parameters T_1, T_2, x_1, x_2, θ_1, and θ_2 were chosen to be the same as those defined in Fig. 5. During each parametric computation, only one out of the six parameters was varied.

Fig. 22 shows the flutter velocity and frequency versus the thickness parameter T_1 of the wing. The results indicate that the flutter velocity increases with T_1. The small triangles give the results for the original model as defined in Fig. 5.

Fig. 23 shows the flutter velocity and frequency versus the thickness parameter of the aft trim surface. The flutter velocity appears to increase very slightly as the thickness T_2 increases. The small triangles give the results for the original model as defined in Fig. 5.

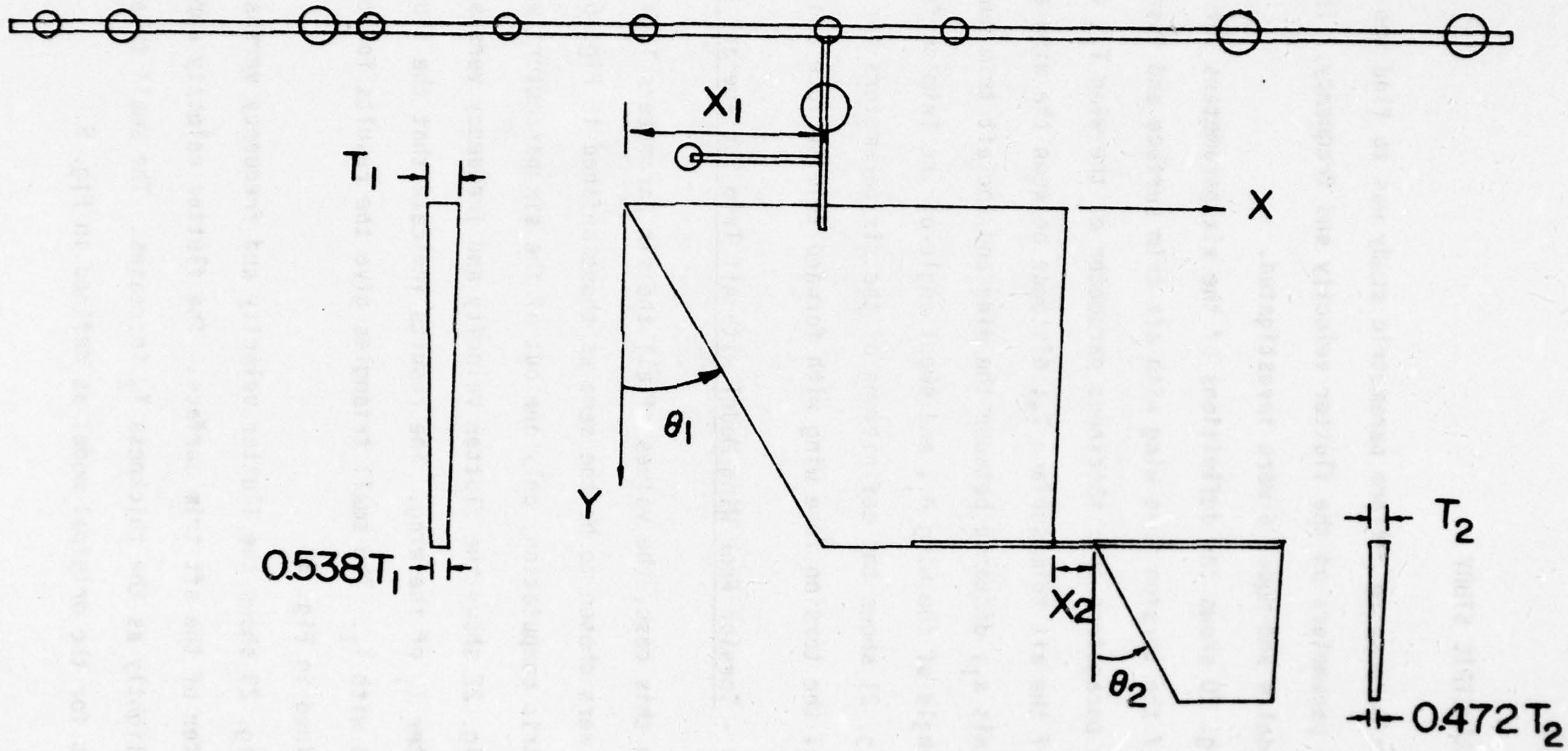

Figure 20. The Definitions of the Six Parameters (T_1, T_2, θ_1, θ_2, x_1, x_2) For the Parametric Study of TFW with Aft Trim Surface

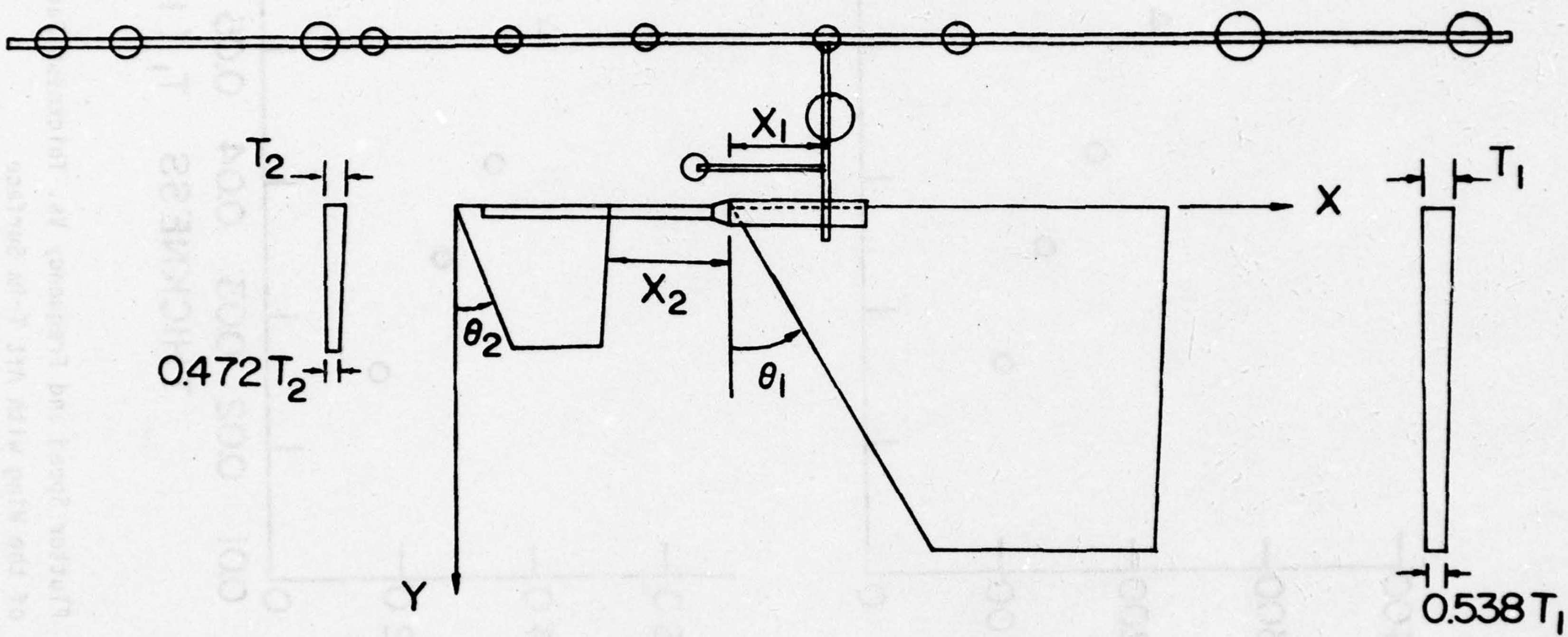

Figure 21. The Definitions of the Six Parameters (T_1, T_2, θ_1, θ_2, x_1, x_2) For the Parametric Study of TFW with Forward Trim Surface

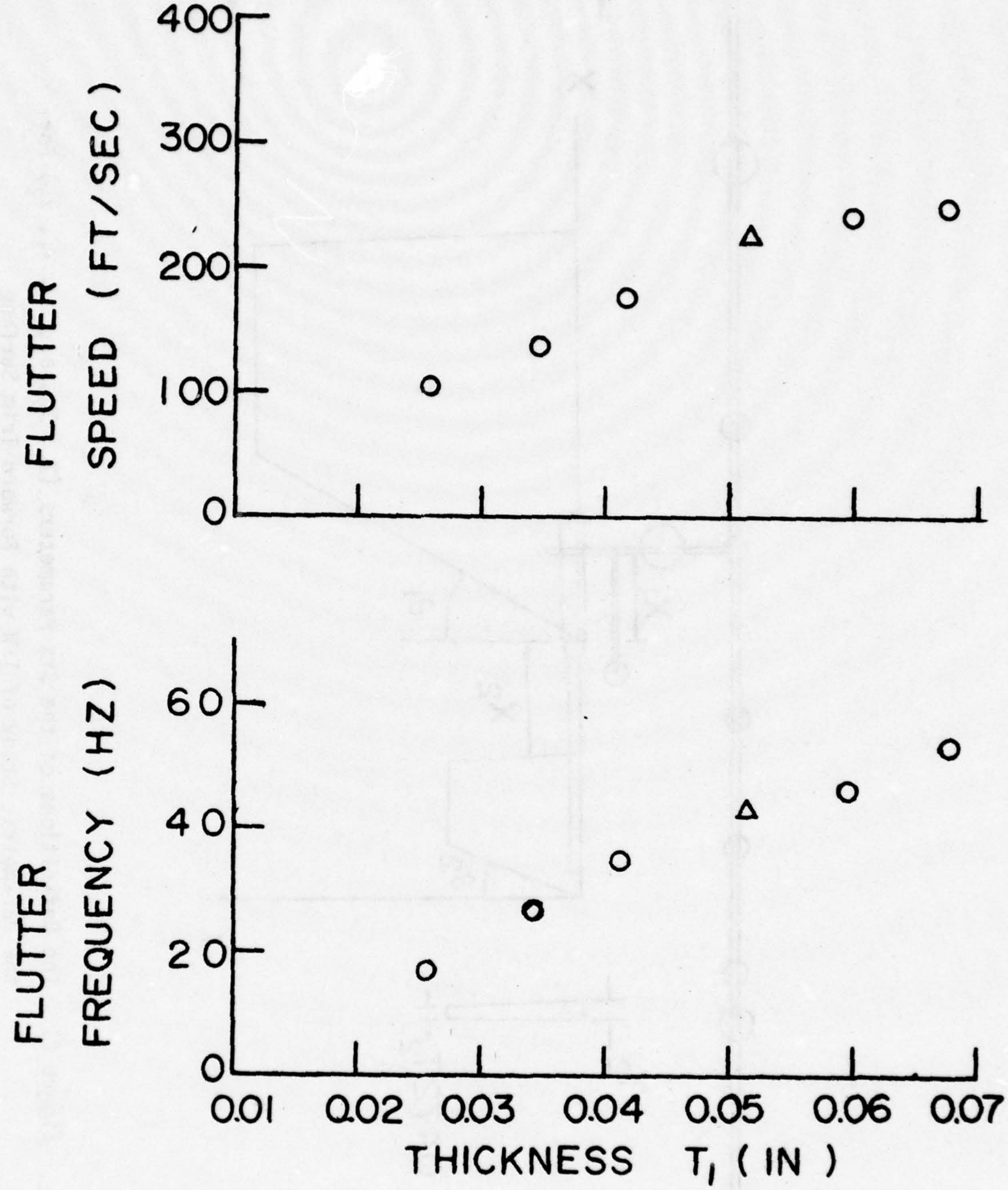

Figure 22. Flutter Speed and Frequency Vs. Thickness Parameter T_1 of the Wing with Aft Trim Surface

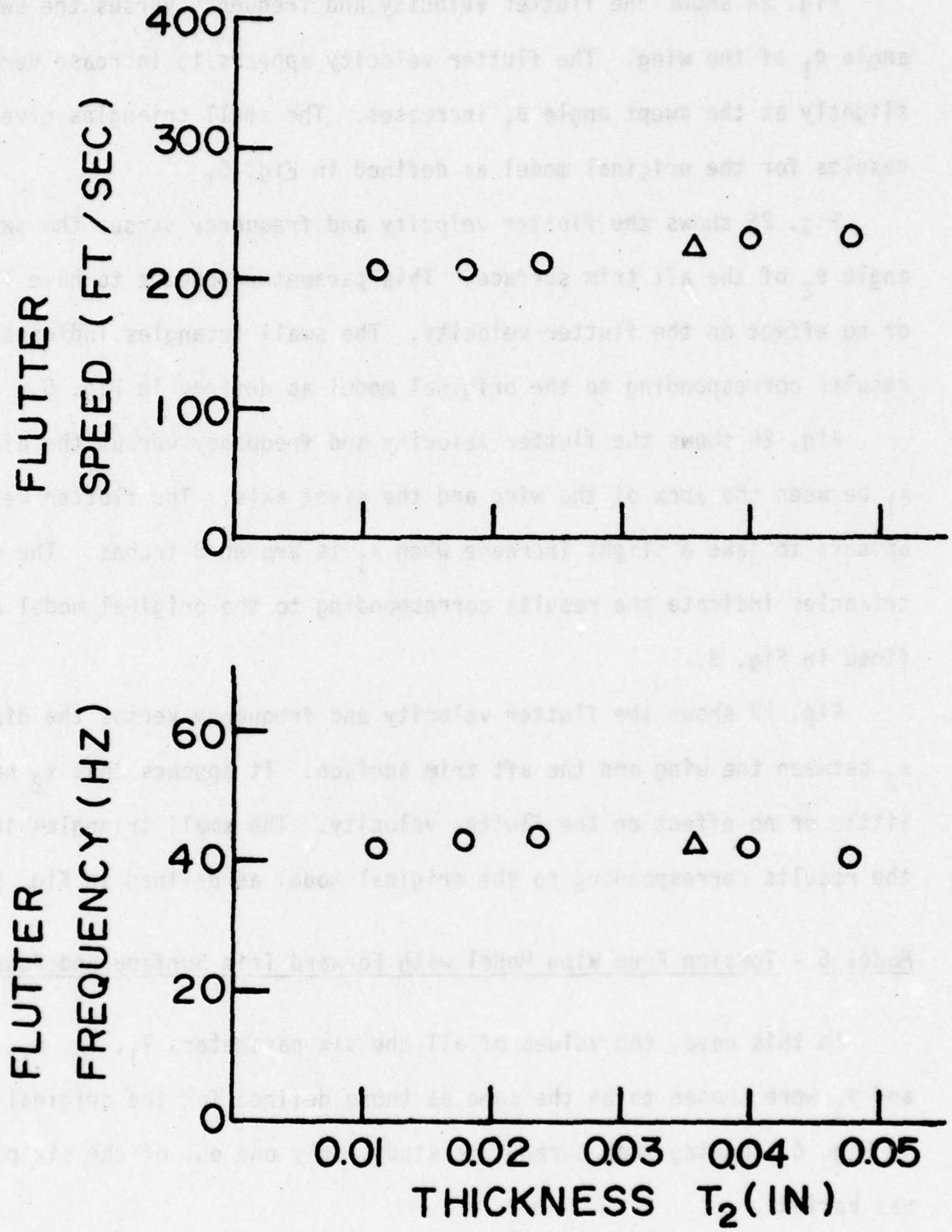

Figure 23. Flutter Speed and Frequency Vs. Thickness Parameter T_2 of the Aft Trim Surface

Fig. 24 shows the flutter velocity and frequency versus the swept angle θ_1 of the wing. The flutter velocity appears to increase very slightly as the swept angle θ_1 increases. The small triangles give the results for the original model as defined in Fig. 5.

Fig. 25 shows the flutter velocity and frequency versus the swept angle θ_2 of the aft trim surface. This parameter appears to have little or no effect on the flutter velocity. The small triangles indicate the results corresponding to the original model as defined in Fig. 5.

Fig. 26 shows the flutter velocity and frequency versus the distance x_1 between the apex of the wing and the pivot axis. The flutter velocity appears to take a slight increase when x_1 is around 3 inches. The small triangles indicate the results corresponding to the original model as defined in Fig. 5.

Fig. 27 shows the flutter velocity and frequency versus the distance x_2 between the wing and the aft trim surface. It appears that x_2 has little or no effect on the flutter velocity. The small triangles indicate the results corresponding to the original model as defined in Fig. 5.

Model 6 - Torsion Free Wing Model with Forward Trim Surface and Fuselage

In this case, the values of all the six parameters T_1, T_2, x_1, x_2, θ_1, and θ_2 were chosen to be the same as those defined for the original model in Fig. 6. During each parametric study, only one out of the six parameters was varied.

Fig. 28 shows the flutter velocity and frequency versus the thickness parameter T_1 of the wing. The small triangles indicate the results corresponding to the original model as defined in Fig. 6. It appears that the

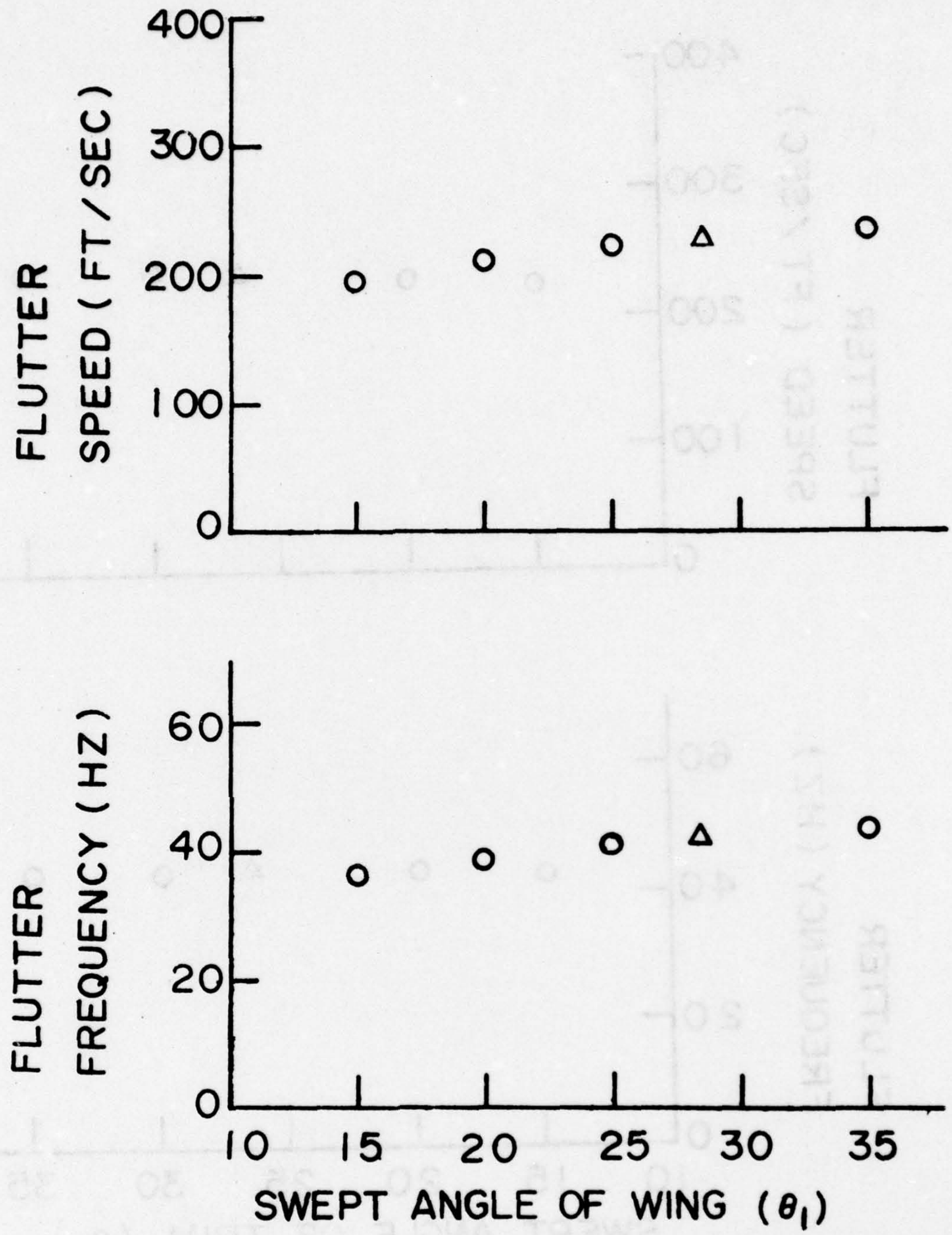

Figure 24. Flutter Speed and Frequency Vs. Swept Angle θ_1 of the Wing with Aft Trim Surface

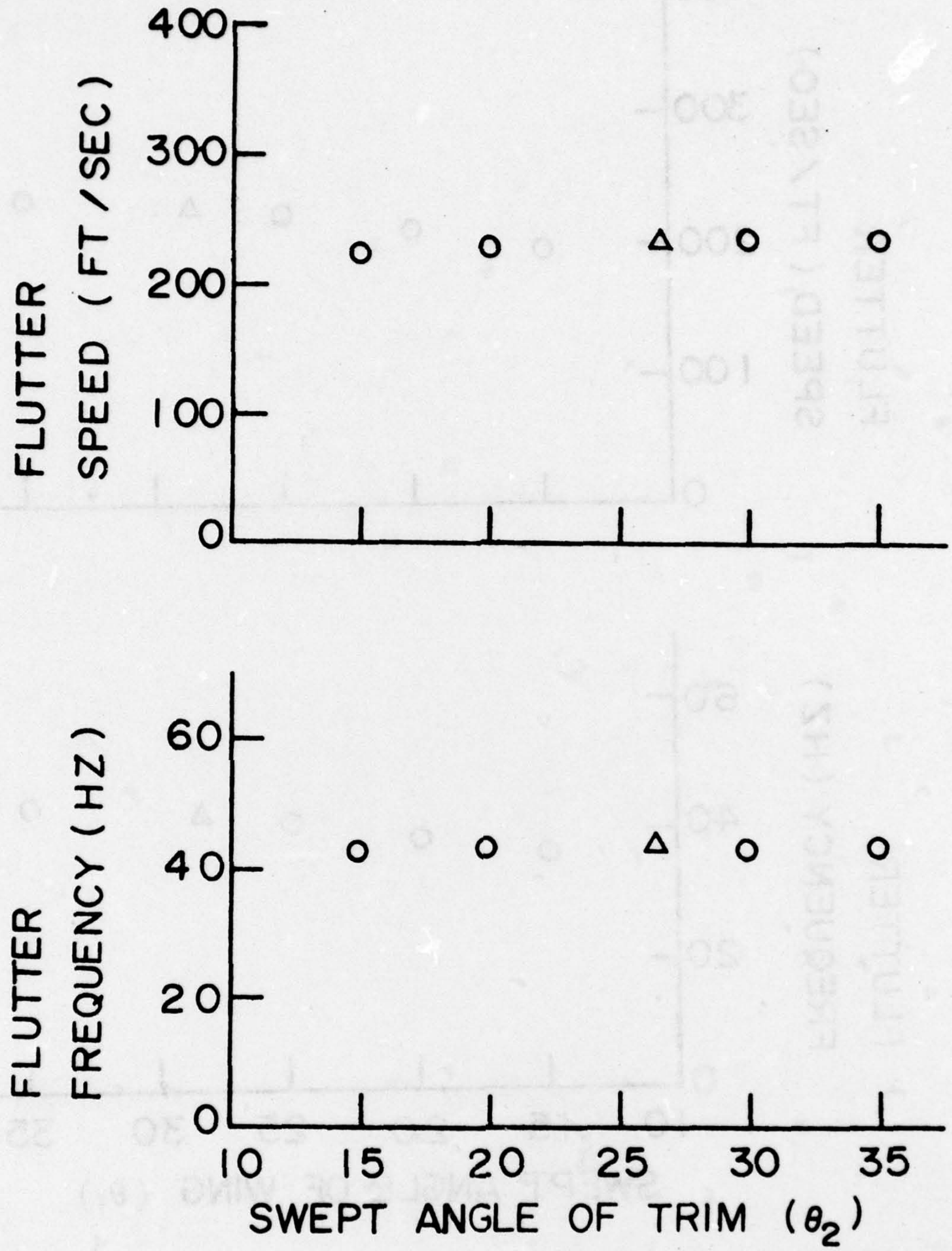

Figure 25. Flutter Speed and Frequency Vs. Swept Angle θ_2 of the Aft Trim Surface

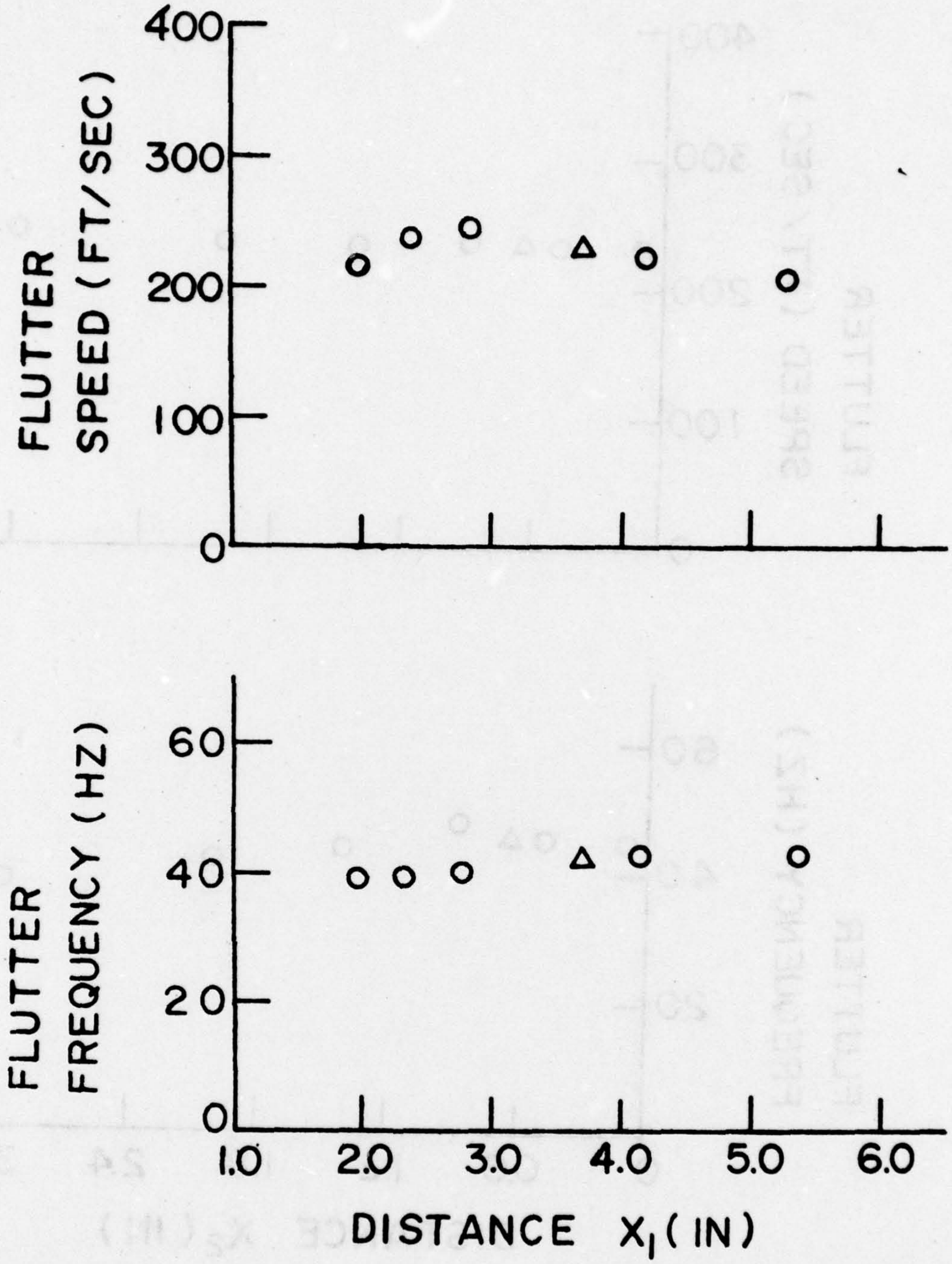

Figure 26. Flutter Speed and Frequency Vs. the Position of Pitch Point for the TFW Model with Aft Trim Surface

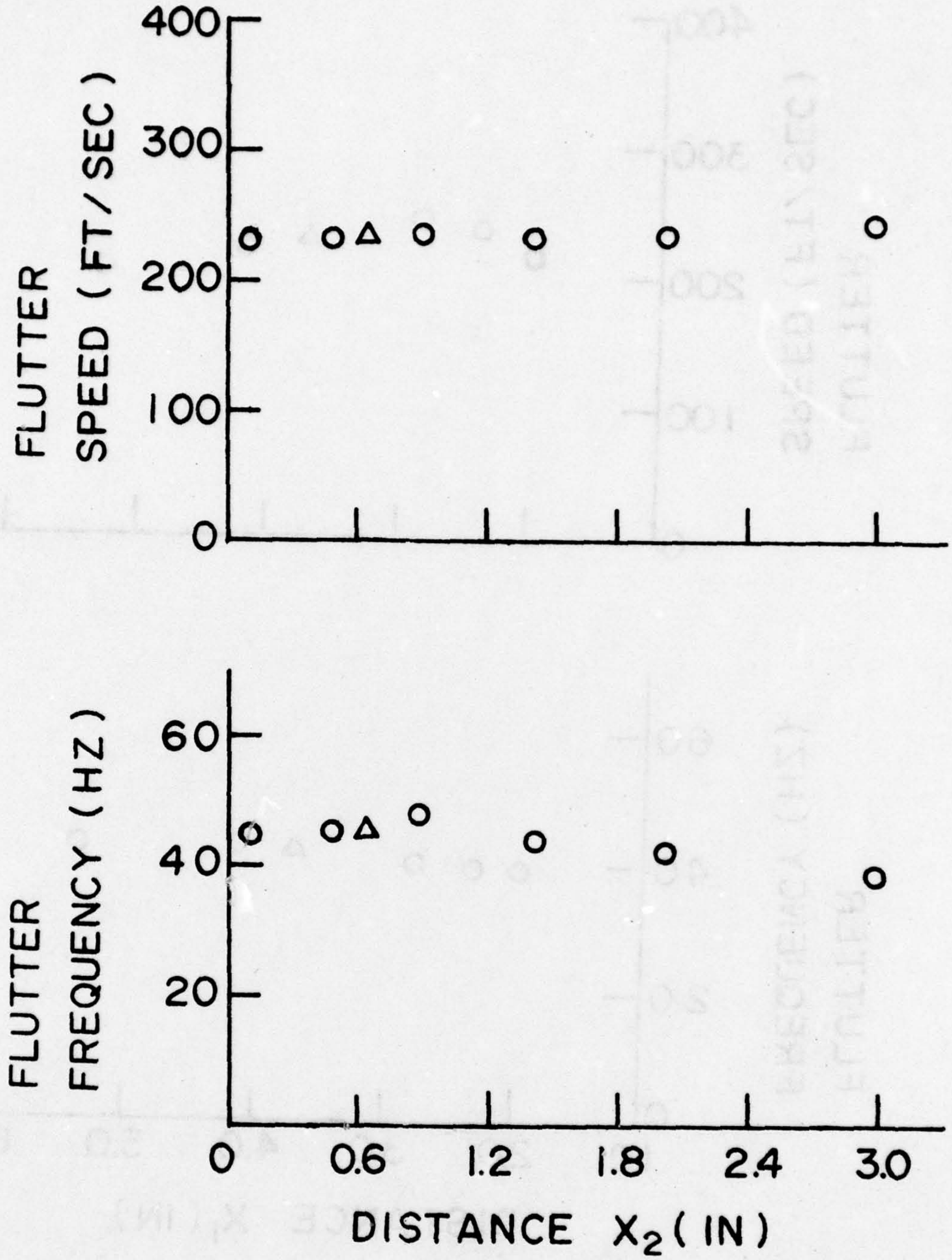

Figure 27. Flutter Speed and Frequency Vs. Length of the Boom x_2 Between Aft Trim Surface and the Wing

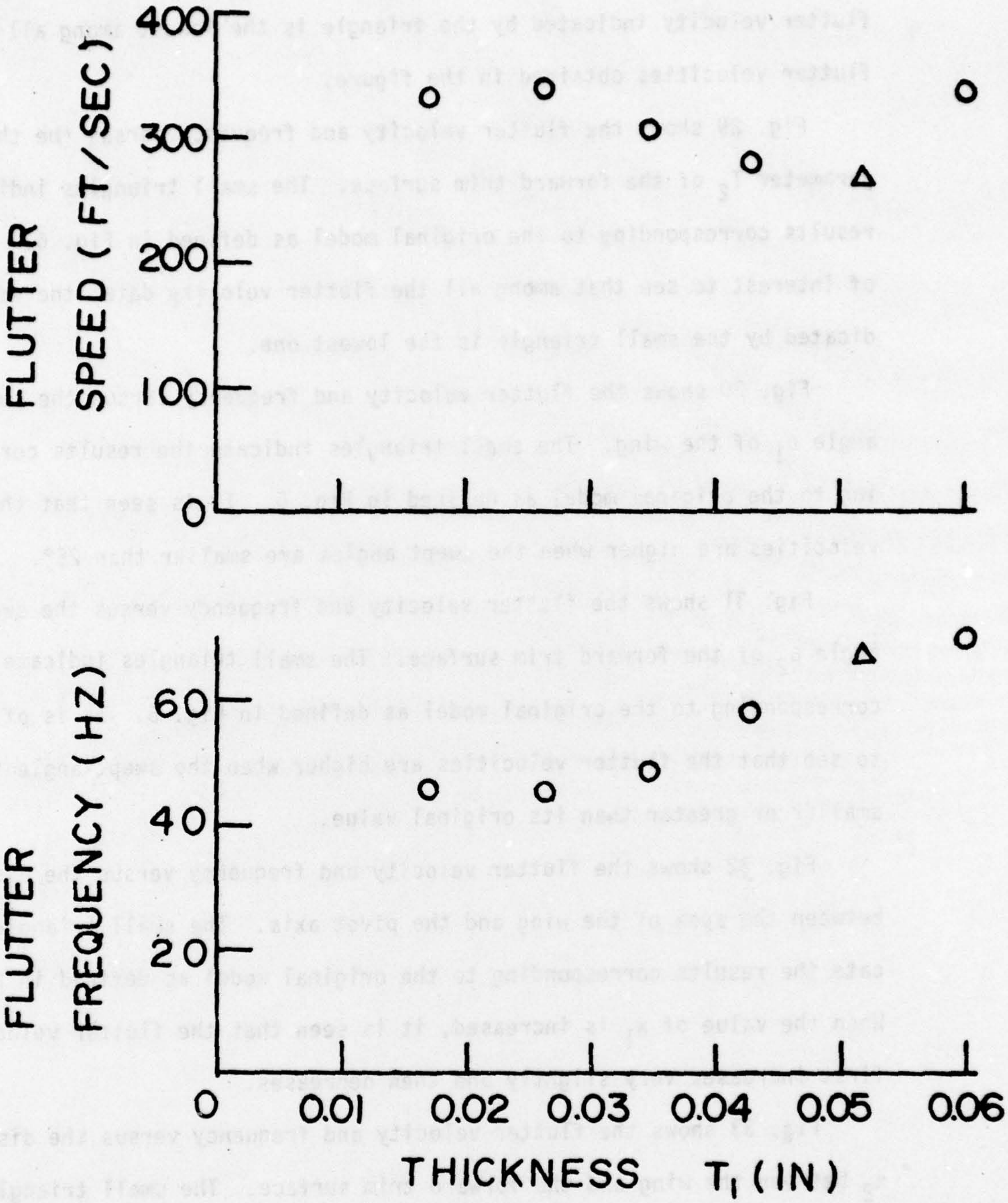

Figure 28. Flutter Speed and Frequency Vs. Thickness Parameter T_1 of the Wing with Forward Trim Surface

flutter velocity indicated by the triangle is the lowest among all the flutter velocities obtained in the figure.

Fig. 29 shows the flutter velocity and frequency versus the thickness parameter T_2 of the forward trim surface. The small triangles indicate the results corresponding to the original model as defined in Fig. 6. It is of interest to see that among all the flutter velocity data, the value indicated by the small triangle is the lowest one.

Fig. 30 shows the flutter velocity and frequency versus the swept angle θ_1 of the wing. The small triangles indicate the results corresponding to the original model as defined in Fig. 6. It is seen that the flutter velocities are higher when the swept angles are smaller than 25°.

Fig. 31 shows the flutter velocity and frequency versus the swept angle θ_2 of the forward trim surface. The small triangles indicate the results corresponding to the original model as defined in Fig. 6. It is of interest to see that the flutter velocities are higher when the swept angle is either smaller or greater than its original value.

Fig. 32 shows the flutter velocity and frequency versus the distance between the apex of the wing and the pivot axis. The small triangles indicate the results corresponding to the original model as defined in Fig. 6. When the value of x_1 is increased, it is seen that the flutter velocity first increases very slightly and then decreases.

Fig. 33 shows the flutter velocity and frequency versus the distance x_2 between the wing and the forward trim surface. The small triangles indicate the results corresponding to the original model as defined in Fig. 6. It is seen that the value of x_2 has little effect on the flutter velocity. However, the small triangle indicates the highest flutter velocity in the figure.

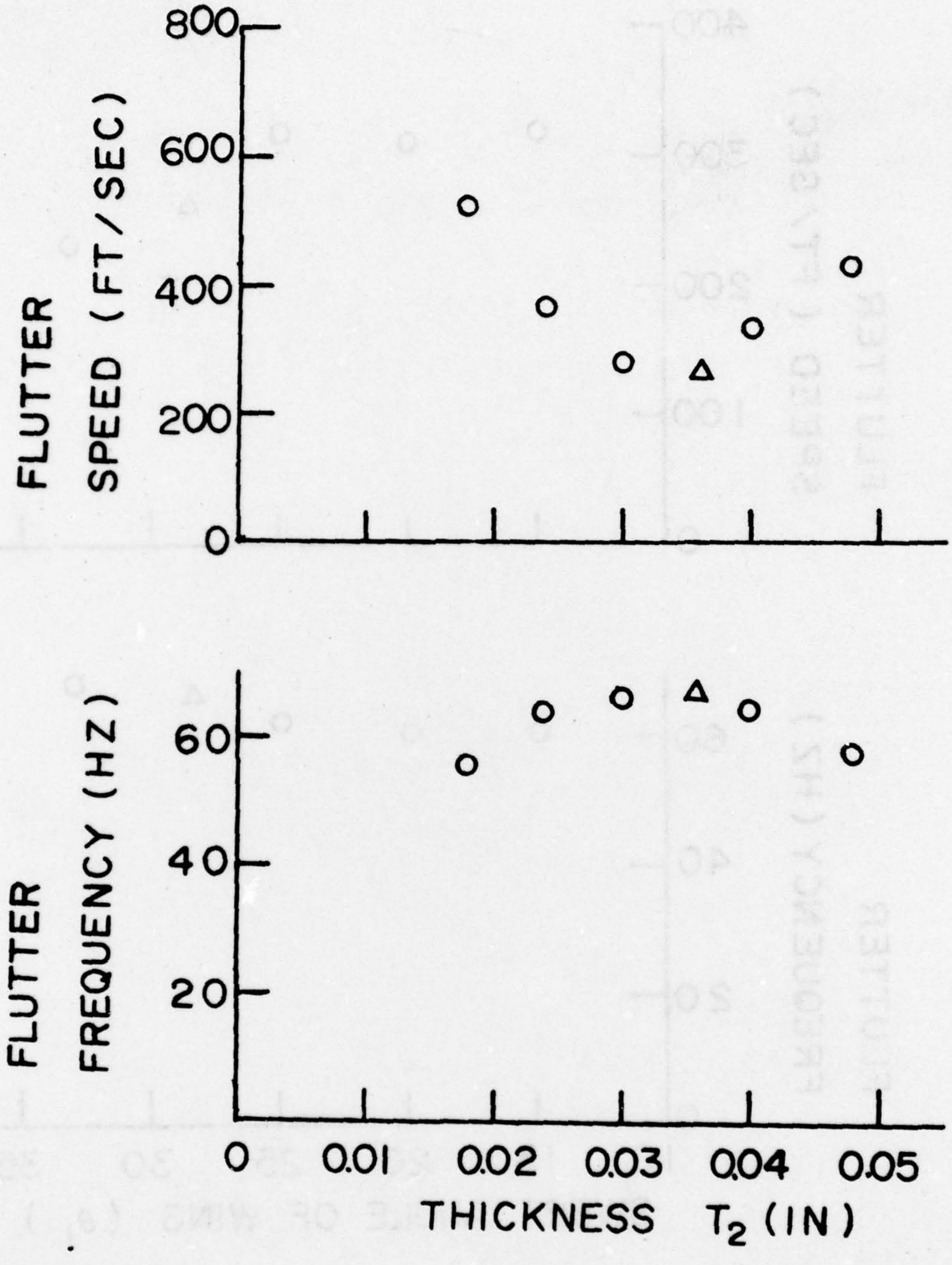

Figure 29. Flutter Speed and Frequency Vs. Thickness Parameter T_2 of the Forward Trim Surface

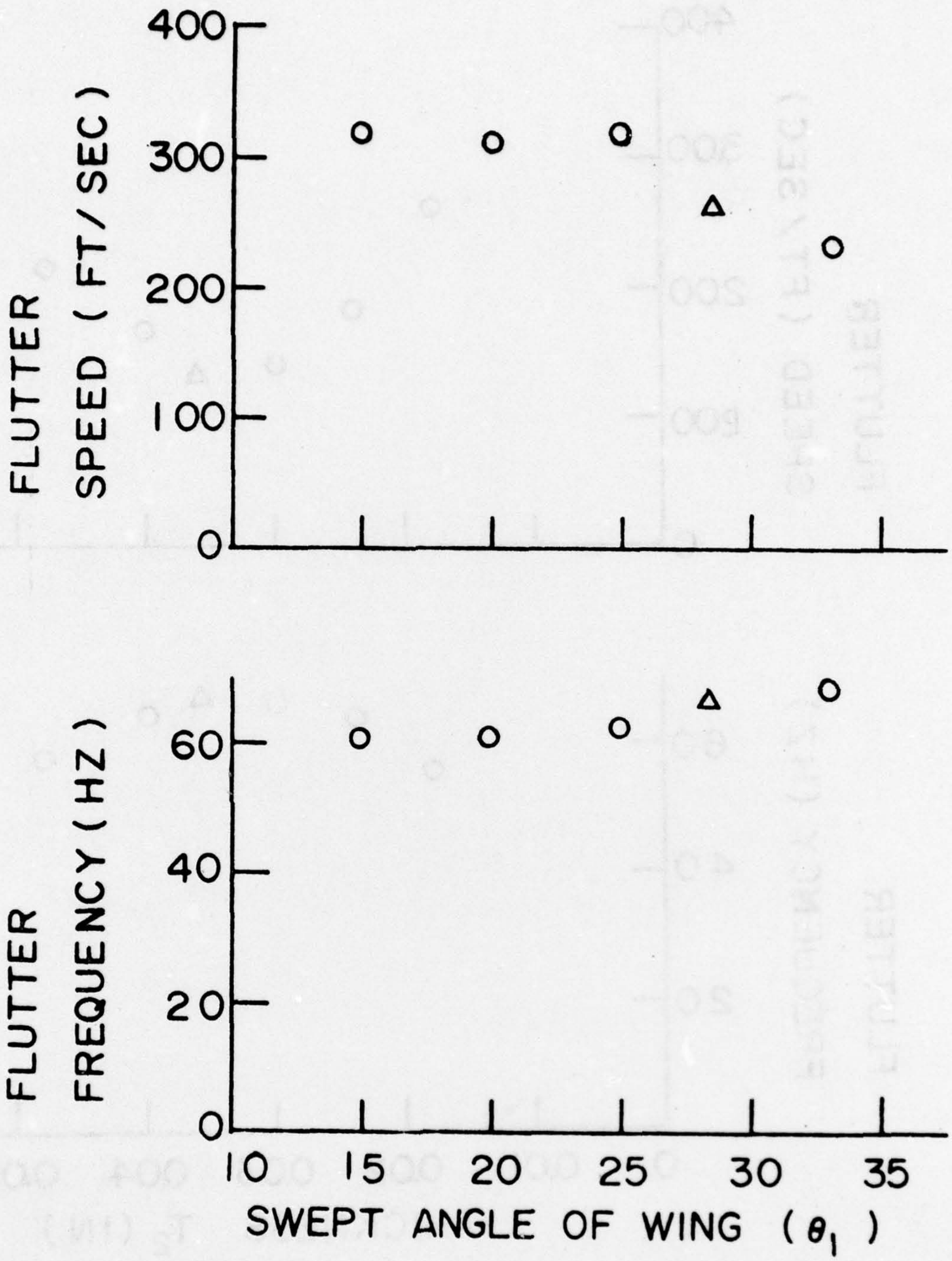

Figure 30. Flutter Speed and Frequency Vs. Swept Angle θ_1 of the Wing with Forward Trim Surface

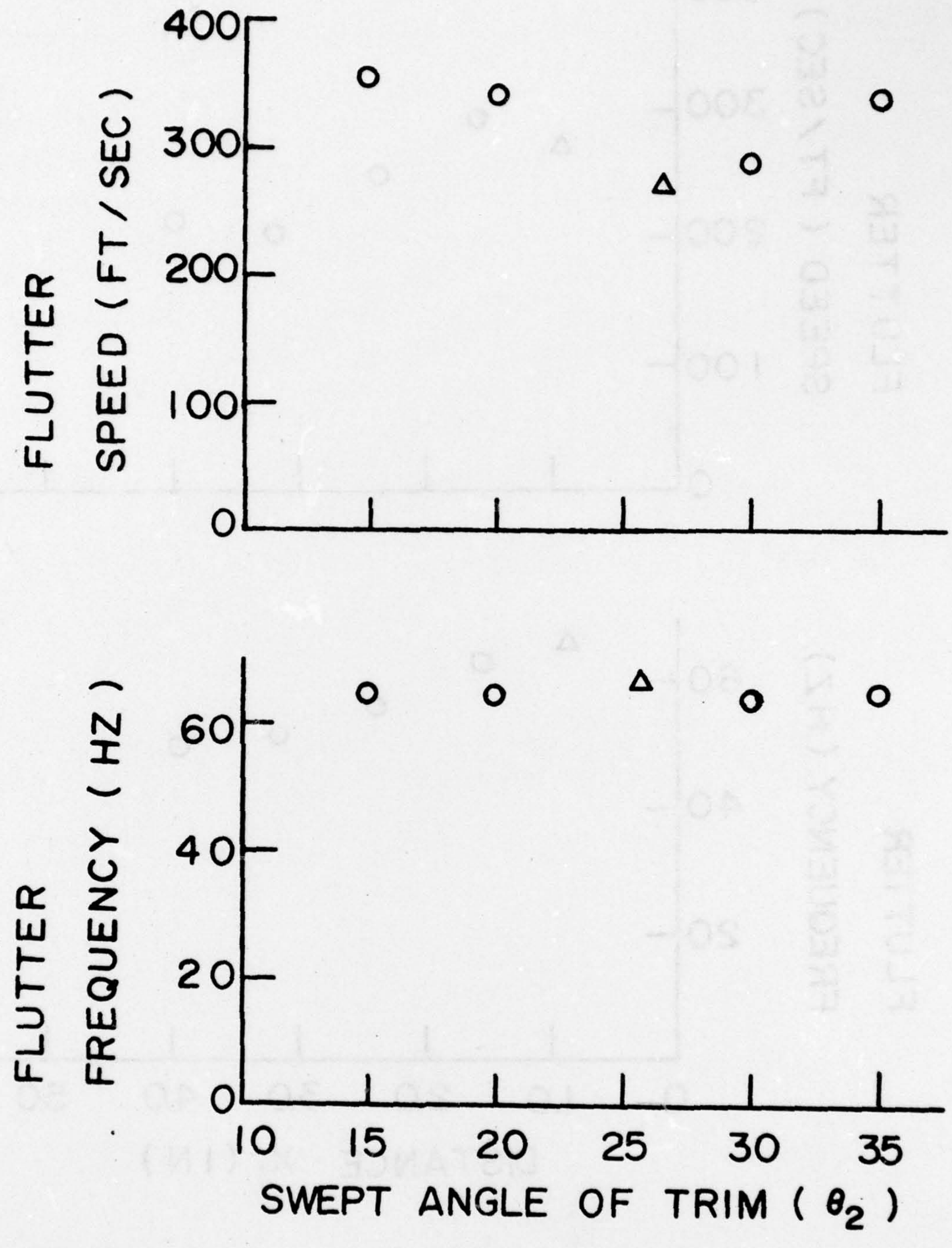

Figure 31. Flutter Speed and Frequency Vs. Swept Angle θ_2 of the Forward Trim Surface

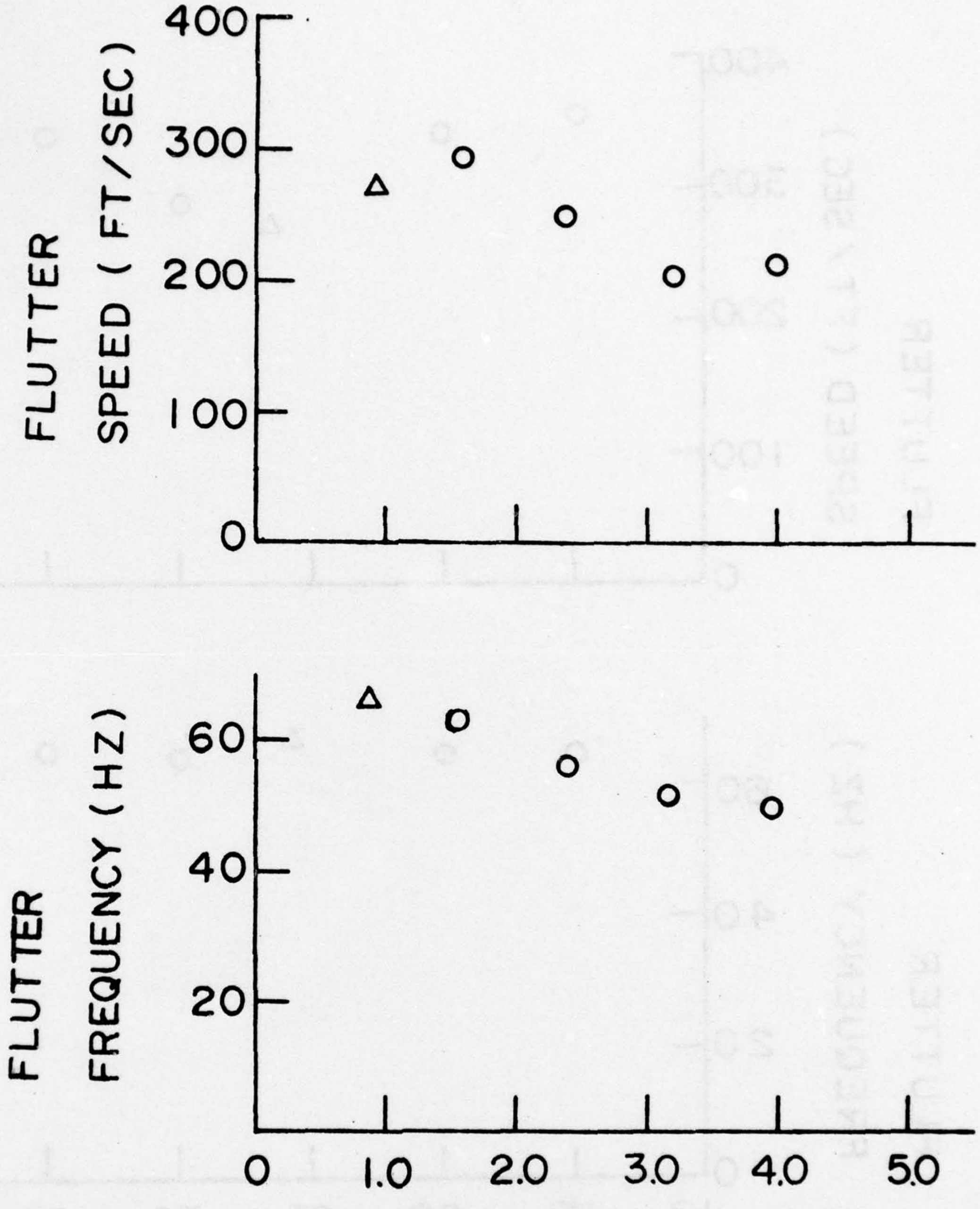

Figure 32. Flutter Speed and Frequency Vs. the Position of Pitch Point for the TFW Model with Forward Trim Surface

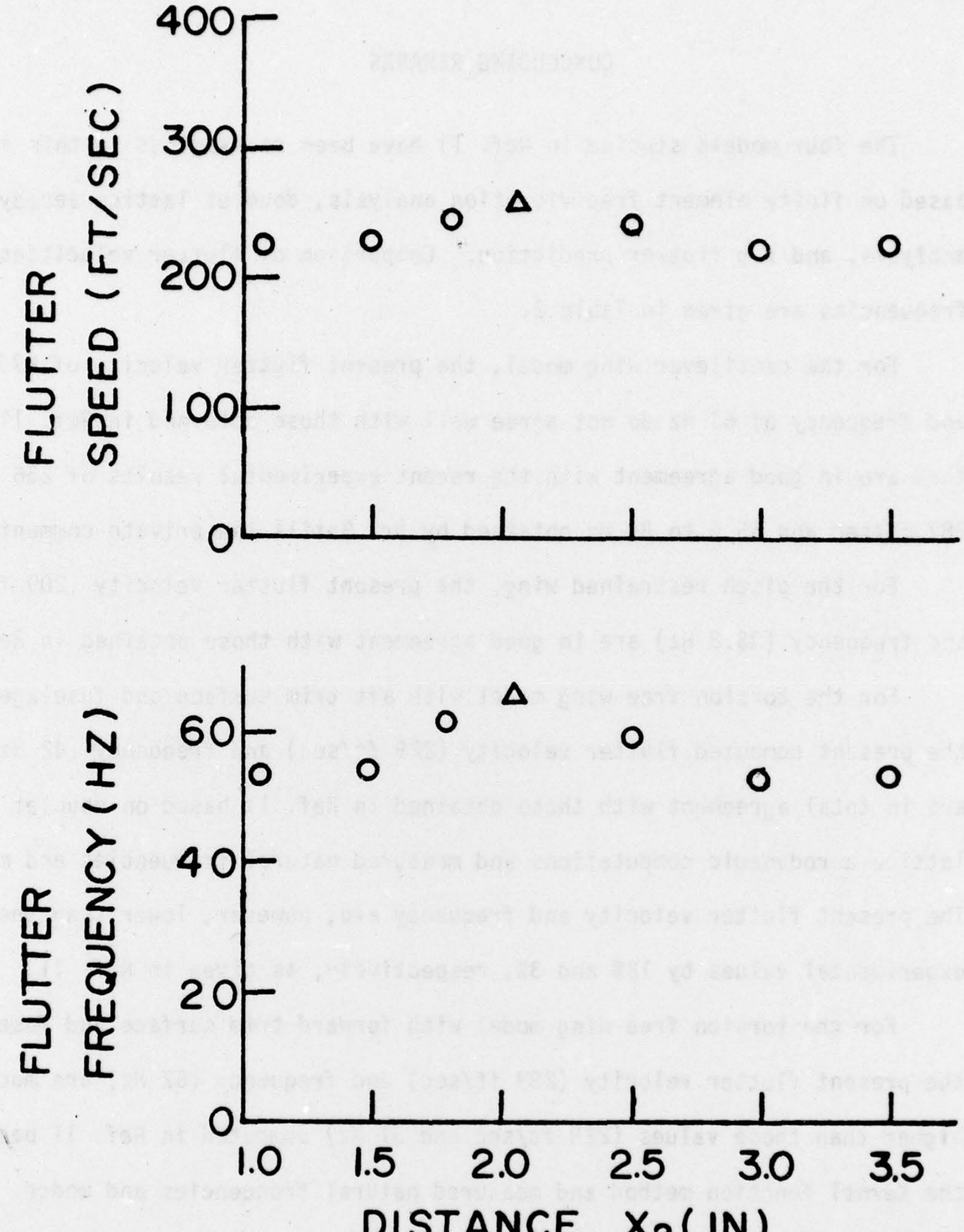

Figure 33. Flutter Speed and Frequency Vs. Length of the Boom x_2 Between Forward Trim Surface and the Wing

SECTION IV

CONCLUDING REMARKS

The four models studied in Ref. 11 have been re-examined in this report based on finite element free vibration analysis, doublet lattice aerodynamic analysis, and V-g flutter prediction. Comparison of flutter velocities and frequencies are given in Table 2.

For the cantilever wing model, the present flutter velocity of 273 ft/sec and frequency of 67 Hz do not agree well with those obtained in Ref. 11. But they are in good agreement with the recent experimental results of 256 to 287 ft/sec and 65.5 to 84 Hz obtained by Dr. Batill in a private communication.

For the pitch restrained wing, the present flutter velocity (209 ft/sec) and frequency (33.8 Hz) are in good agreement with those obtained in Ref. 11.

For the torsion free wing model with aft trim surface and fuselage, the present computed flutter velocity (229 ft/sec) and frequency (42 Hz) are in total agreement with those obtained in Ref. 11 based on doublet lattice aerodynamic computations and measured natural frequencies and modes. The present flutter velocity and frequency are, however, lower than the experimental values by 12% and 3%, respectively, as given in Ref. 11.

For the torsion free wing model with forward trim surface and fuselage, the present flutter velocity (289 ft/sec) and frequency (62 Hz) are much higher than those values (228 ft/sec and 31 Hz) computed in Ref. 11 based on the Kernel function method and measured natural frequencies and modes. Due to the occurrence of divergence, experimental values for flutter velocity and frequency were not obtained in Ref. 11.

The present computation shows that the flutter velocity (289 ft/sec) for the torsion free wing model with forward trim surface is higher than that (229 ft/sec) for the torsion free wing model with aft trim surface.

The present value of 289 ft/sec is also higher than the experimental value of 260 ft/sec for the torsion free wing model with aft trim surface as given in Ref. 11. Ref. 11 also provided a flutter velocity of 228 ft/sec based on Kernel function aerodynamics and measured modes for the torsion free wing model with forward trim surface.

Although a conclusion may not be drawn, the present computation shows that the flutter velocity (289 ft/sec) for the torsion free wing model with forward trim surface is not lower than that (273 ft/sec) for the conventional cantilever wing model.

In the parametric study, six parameters ($T_1, T_2, \theta_1, \theta_2, x_1$ and x_2) have been considered. Flutter velocity and frequency for the torsion free wing model with aft trim surface and the model with forward trim surface have been obtained by varying one of the six parameters.

For the torsion free wing model with aft trim surface, it is found that the flutter velocity and frequency increases as the wing (with aft trim surface) becomes thicker. All the other five parameters have small effect on the flutter velocity and frequency.

For the torsion free wing model with forward trim surface, it was found that the boom length has small effect on the flutter velocity and frequency. All the other five parameters do have obvious effect on the flutter velocity and frequency. Such results are presented in Figs. 28 to 32.

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