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SUMMARY

An exploratory investigation of the effect of the store-attachment pitch flexibility on the flutter characteristics of a wing carrying a pylon-mounted store has been conducted in the Langley transonic blowdown tunnel. The store was mounted at the 75.5-percent-semispan position on a cantilevered, untapered wing with an aspect ratio of 4 (full span) and 45° of sweepback. The store-pylon mass was roughly the same as the wing panel mass. Two store center-of-gravity locations (about 8 and 30 percent of the local wing chord - called forward and rearward c.g. stores, respectively) were investigated with the store-attachment flexibility varied systematically to give uncoupled store-pitch frequencies from about 0.1 to 1.4 times the torsional frequency of the wing without the store. The investigation was conducted at Mach numbers principally near 0.85, although some limited tests were made at Mach numbers from about 0.8 to 1.3 to determine the effect of Mach number on the results.

For uncoupled store-pitch frequencies higher than about 0.4 of the torsional frequency of the wing without the store, variations in store-attachment flexibility had little effect on the flutter dynamic pressure, and the addition of the store to the wing reduced the flutter dynamic pressure by about 40 and 25 percent for the forward and rearward c.g. stores, respectively. In the low uncoupled store-pitch frequency range as the uncoupled store-pitch frequency approached the flutter frequency, the flutter dynamic pressure for the wing with the forward c.g. store peaked sharply with a maximum value considerably higher than that for the wing without a store. However, the effect of store flexibility was quite sensitive to store c.g. location because the flutter dynamic pressure for the wing with the rearward c.g. store dipped to a minimum value in this same store-pitch frequency range.

The aerodynamic effect of the store on the flutter characteristics is shown to be small. Limited tests to determine Mach number effects on flutter indicate that in the high subsonic range the flutter dynamic pressure decreases with increasing Mach number. A favorable compressibility effect was indicated for one of the wing-store configurations as the Mach number was increased to 1.3.

INTRODUCTION

The addition of an external store to a wing can have a considerable effect on the flutter speed of the wing. The magnitude of this effect, as well as whether it is favorable or unfavorable, depends upon a large number of wing, store, and store-attachment parameters. One of these parameters, the store-attachment flexibility, was studied in the flutter calculations reported in references 1 and 2, which showed that large increases (as well as decreases) in flutter speed are obtained by varying the flexibility of the attachment of a mass or external store to the wing. Thus, by selective adjustment of the store-attachment flexibility, the flutter speed for some wing-store configurations might be raised appreciably with little or no additional structural weight required. In order to determine whether such improvements in flutter speed could be realized experimentally, the flutter characteristics of a cantilevered sweptback wing carrying a heavy, pylon-mounted external store were obtained with the store-attachment pitch flexibility varied systematically over a wide range.

The wing used in this investigation had an untapered planform with 45° of sweepback and an aspect ratio of 4. This wing had been investigated previously for flutter both with and without stores (refs. 3 and 4). In the present study, the stores were spring-mounted to a short pylon at the 75.5-percent-semispan location on the wing, and the mass of each store-pylon was roughly the same as the wing panel mass. Two well-separated chordwise locations of the store center of gravity were obtained by testing stores of two lengths. The investigation was conducted in the Langley transonic blowdown tunnel at Mach numbers principally near 0.85, although some limited flutter tests were also made at Mach numbers between 0.76 and 1.30 to indicate the effect of Mach number on the results. A brief study was also made of the aerodynamic effect of the store on the flutter characteristics. The present results are compared with data for the wing without stores (ref. 4).

SYMBOLS

c — streamwise wing chord, ft

d — vertical distance from wing chord plane to pitch-spring center line, ft

f_e — flutter frequency, cps

f_i — frequency of ith natural vibration mode of wing with store ($i = 1, 2, \ldots, 7$), cps

$f_{w,i}$ — frequency of ith natural vibration mode of wing without store ($i = 1, 2, 3$, and 4), cps

f_s — uncoupled store-pitch frequency, cps

I_θ	mass moment of inertia of wing per unit span in pitch about a spanwise axis through local quarter-chord, slug-ft^2/ft
$I_{\theta,s}$	mass moment of inertia of store (or store with pylon) in pitch about a spanwise axis through wing quarter-chord at the 75.5-percent-semispan station, slug-ft^2
I_ϕ	mass moment of inertia of wing per unit span in roll about a local streamwise axis in wing chord plane, slug-ft^2/ft
$I_{\phi,s}$	mass moment of inertia of store (or store with pylon) in roll about a streamwise axis in wing chord plane at 75.5-percent-semispan station, slug-ft^2
$I_{\psi,s}$	mass moment of inertia of store (or store with pylon) in yaw about a vertical axis through the intersection of wing quarter-chord and 75.5-percent-semispan station, slug-ft^2
M	Mach number
m_s	mass of store or mass of store with pylon (see table II), slugs
m_w	mass of exposed wing panel (without store), slugs
q	dynamic pressure of wing with store, $\rho V^2/2$, lb/sq ft
q_w	flutter dynamic pressure at $M = 0.85$ for wing without store (see "Presentation of Results"), lb/sq ft
S_θ	static mass moment of wing per unit span in pitch about a spanwise axis through local quarter-chord, positive when center of gravity is aft of quarter-chord, slug-ft/ft
$S_{\theta,s}$	static mass moment of store (or store with pylon) in pitch about a spanwise axis through the wing quarter-chord at 75.5-percent-semispan station, positive when center of gravity is aft of quarter-chord, slug-ft
s	span of exposed wing panel, ft
T	static temperature, $^\circ$R
V	free-stream velocity, ft/sec
x	streamwise distance from wing leading edge to store (or store with pylon) center of gravity, positive rearward, ft
x_w	streamwise distance from wing leading edge to local wing center of gravity, positive rearward, ft

z vertical distance from wing plane to store (or store with pylon) center of gravity, positive down, ft

μ mass ratio parameter based on mass of wing without store, $\dfrac{m_w}{\pi \rho s \left(\frac{c}{2}\right)^2}$

ρ air density, slugs/cu ft

θ_i pylon angular deflection in pitch due to a unit load at wing station i, radians/lb

MODELS

General Description

Sketches of the cantilevered models used in the present investigation are shown in figure 1, and various model properties are presented in figures 2 to 6 and in tables I to V. Of the eighteen models employed (table II), sixteen models were used in the store-attachment pitch-flexibility tests and the remaining two models were tested to obtain an indication of the aerodynamic effects of the store on flutter. The pitch-flexibility models consisted of eight models with each store center of gravity at about 30 percent of the local streamwise wing chord (called rearward c.g. stores), and eight models with each store center of gravity at about 8 percent of the wing chord (called forward c.g. stores). Each of these models represented a different level of pitch flexibility of the store attachment to the pylon. Of the two aerodynamic-effect models, one consisted of a wing with a light essentially rigidly mounted store (model 1A) and the second consisted of the same wing with no store but ballasted so as to have nearly the same vibration characteristics (model 1B). Each store was mounted by a pylon to the wing at the 75.5-percent-semispan station (measured from the wing root).

The models are designated (see table II) by a system which identifies the wing, the store type, and the store-attachment pitch flexibility employed in a particular model. The first number designates which of 12 wing panels was used in the model. Following the wing designation is the letter R, F, A, or B which indicates, respectively, a rearward c.g. store, a forward c.g. store, the light rigidly mounted store, or the ballasted wing. The final number gives the approximate value of the uncoupled store-pitch frequency in cps. For example, model 2R63 consists of wing 2 and a rearward c.g. store with a store-attachment flexibility which resulted in an uncoupled pitch frequency of about 63 cps. Since the store-pitch frequency for the aerodynamic-effect model with the light store was not identified within the frequency range investigated, the final number is omitted from its designation.

Wings

Some geometric properties of the wing are listed in table I. The wing was geometrically and structurally similar to those used in references 3 and 4 and is sketched in figure 1(a). Each wing panel and clamping block was machined in one piece from 2024-T aluminum alloy. Holes drilled through the exposed panel (fig. 1(a)) were filled with a rubber compound flush with the surfaces of the wing. The hole sizes and layout were selected according to the data of reference 5 to give stiffness distributions which would allow the wings without stores to flutter within the dynamic-pressure range of the wind tunnel.

In figure 2 are presented the panel mass properties of wing 7, which are considered typical for all wing panels. After flutter testing, wing 5 was cut into segments for measurement of the segment properties shown in figure 2. In order to measure the natural vibration frequencies, the cantilevered wings without stores were excited by an electromagnetic shaker; the resulting frequencies and associated node lines are given in figure 3. The third mode is considered to be a predominantly torsion mode of the wings without stores.

Presented in table V is a matrix of the flexibility influence coefficients measured on wing 10 by means of the differential transformer system described in reference 6. The influence coefficients for the wing were measured at the center of gravity of each of the 18 wing segments shown in figure 2. Because the pylon may have added some local stiffening to the wing, the flexibility influence coefficients were measured with a pylon attached to the wing. In addition to the measurement of the vertical deflection at each wing station, an optical system was used to measure the angular deflection in pitch of the pylon front face due to a load at each of the wing stations (last column of table V); however, deflections at the wing stations due to a pitching moment applied to the pylon were not measured. Frequencies which were calculated for the first three modes of wing 10 by using table V and the segment masses in figure 2 agreed with the measured frequencies (fig. 3) to within 4 percent.

Stores

Some geometric properties of the stores are listed in table I. A rearward c.g. store is sketched in figure 1(b), and a forward c.g. store, which was about 19 percent shorter, is sketched in figure 1(c). Each store consisted of a cylindrical body of aluminum-alloy tubing with a 60° conical fairing at each end. The rearward c.g. stores had fairing cones made of balsa and had lead weights as ballast. The forward c.g. stores were made shorter and the front conical fairings were made of lead in order to obtain the desired center-of-gravity location.

The store was attached to the wing at the 75.5-percent-semispan location by a pylon which was simply an aluminum block of rectangular cross section. The pitch flexibility was provided by a thin, steel leaf spring which connected the store to the pylon (fig. 1(d)). Thin steel plates were used to clamp the pitch spring to the pylon lower face and to a semicylindrical block that fastened to the inside of the tubular store body. Between these clamped pieces, about 1/8 inch of spring was left free to bend and so provide limited store motion in the pitch degree of freedom. The desired pitch flexibility was obtained by varying the spring thickness from about 0.012 to 0.188 inch. When assembled, the pitch spring and attached parts were enclosed within the store body and lay along the center line of the store with only a part of the pylon exposed to the airstream (fig. 1). The pitch axis was assumed to be at the pylon front face, which was located at about 42.5 percent of the wing chord behind the wing leading edge.

The physical properties of the stores are included in table II. The mass properties for the store alone were obtained with one-half of the pitch spring attached to the store. The vertical location of the center of gravity of the store without pylon was assumed to coincide with the pitch-spring center line in calculating $I_{\theta,s}$. The uncoupled pitch frequency of each store (table II(b)) was measured by clamping the wing near the pylon and exciting the store by means of an electromagnetic shaker. The shaker stem drove against the wing surface rather than against the store.

Aerodynamic-Effect Models

The store used with model 1A was geometrically identical to a rearward c.g. store. The store body was constructed of hollow balsa and the pylon consisted of a solid balsa block glued to the wing. When the tests of wing 1 with the various stores had been completed, the store and pylon were removed and ballast weights were added to the wing until the natural vibration modes and frequencies of the ballasted wing (model 1B) approximated those of model 1A. The ballast was provided by replacing the rubber compound with solder in the wing holes indicated by x-marks in figure 1(a). The total mass of the ballast weights required (table II(a)) was somewhat greater than the mass of the store of model 1A.

The frequencies and associated node lines of the natural vibration modes for the two aerodynamic-effect models are in good agreement (fig. 4(c)) for the three lowest modes, which appear to be predominantly first bending, second bending, and first torsion, in that order. Since the flutter mode of these models would be expected to be primarily dependent on these three modes, any sizable difference in flutter speed between these models is attributed to the aerodynamic effect of the store.

Vibration Properties of Models with Flexibly Mounted Stores

Frequencies and node lines.- The natural vibration frequencies (table II(b)) and associated node lines (fig. 4) of each wing-store model were measured immediately prior to flutter testing. A brief description of each vibration mode is given in table III.

Comparison of the frequencies and node lines of the most stiffly mounted store models (3R508 and 8F435) with those for the wings without stores (figs. 3 and 4) shows that the addition of the store reduced the first-torsion and the first-bending frequencies to about one-fourth and two-thirds of the values for the wings without stores, respectively, but had only a small effect on the second-bending frequency. Since the reduction in the frequency of the torsional mode was very large compared with that for the other modes, a change in the order of the vibration modes occurred: For the wings without stores, the order of the modes was, according to their fundamental responses, first bending, second bending, and first torsion; for the wings with stores, the order was first bending, first torsion, and second bending. In the higher order modes of the wings with stores, considerable coupling of the wing modes and store-pitch modes occurred, especially for the most stiffly mounted forward c.g. store configuration, model 8F435 (fig. 4(b)).

In figure 5 is presented a plot of the frequencies of the first four natural vibration modes against uncoupled store-pitch frequency; these natural vibration modes are considered most important, flutterwise, for these wing-store models. As might be expected, the change in store-attachment pitch flexibility had the greatest effect on the first-torsion (f_2) and the store-pitch (f_4) modes (figs. 4 and 5). In general, as the store-attachment pitch flexibility was increased, the frequency of the first-torsion mode and of the store-pitch mode decreased until, for the most flexibly mounted store models, the first-torsion frequency became approximately equal to or slightly lower than the first-bending frequency f_1. At the lower uncoupled store-pitch frequencies, the node line associated with first-torsion (f_2) mode appears to have moved off the wing to near the store-pitch axis. However, for models having uncoupled store-pitch frequencies less than 40 cps, the first-torsion and store-pitch modes were not easily distinguishable (see table III), and the trends evident in figure 5 were relied upon to identify these modes. The first-bending (f_1) and second bending (f_3) modes were more easily identified, and the store-attachment pitch flexibility had only a small effect on these frequencies (figs. 4 and 5). For models 4R84 and 8F58, the store-pitch mode (f_4) and the wing second-bending mode (f_3) appear to have merged into a single mode having a frequency of 246 cps and 263 cps, respectively. (See figs. 4(a), 4(b), and 5.) Calculations which employed cantilever-beam mode shapes and a simplified store representation indicated the same trends as are shown in figure 5.

<u>Mode shapes and structural damping</u>.- Mode shapes for several natural vibration modes were measured with facsimiles of models 1R31, 3R82, 6R210, 9F48, 8F48, 10F88, and 8F435. For the mode-shape measurements, short, vertical spikes of balsa were glued to the wing and store at the various stations shown in figure 6. The model was vibrated in one of its natural modes in the same manner as for measurement of the natural frequencies, and the motion was "stopped" by means of a stroboscope synchronized to the electromagnetic shaker. A direct-measuring microscope was focused on the tip of one of the spikes and the maximum displacement in vertical translation of the spike was read. The process was repeated for each station; and during the measurement of a mode shape, a reference station was rechecked frequently to be sure that the amplitude of vibration had not changed. The measured deflections at each station are given in nondimensional form in table IV for the four lowest vibration modes, along with the frequencies of the models on which the mode shapes were measured. Although the frequencies of these facsimile models differ slightly from those of the flutter-tested models (table IV), the measured mode shapes are considered to be essentially the same as those of the tested models.

The maximum error in a nondimensional deflection (table IV) is estimated to be ±0.010. Although some of the measured mode shapes indicate store-pitch motion which is in the opposite direction, relative to the wing, from that observed during measurement of the natural vibration frequencies of the flutter models (table III), this discrepancy occurs only in cases where the relative motion is so small that it is within the accuracy of the measurement. In general, the descriptions of the natural modes given in table III for the flutter models apply to the facsimile models as well.

The values of the structural damping coefficient were determined from time histories of the decay of oscillations in the first natural vibration mode induced by plucking the models in still air. The average value for the models was 0.008.

APPARATUS AND TESTS

The flutter tests were made in the Langley transonic blowdown tunnel, which has a slotted test section. The test section is octagonal in cross section and measures 26 inches between flats. During operation of the tunnel, a preselected Mach number is set by means of a variable orifice downstream of the test section. This Mach number is held approximately constant after the orifice is choked while the stagnation pressure and thus the density are increased. The static-density range is approximately 0.001 to 0.012 slug per cubic foot and Mach numbers may be obtained from subsonic values to a maximum of about 1.4. Because of the expansion of the air in the reservoir during a run, the stagnation temperature continually decreases; thus, the test-section velocity is not uniquely defined by the Mach number. Additional details of the tunnel are contained in reference 7.

In the flutter tests, the semispan models were cantilever-mounted at zero angle of attack in a sting in such a way that the model mounting block and the sting formed a 3-inch-diameter fuselage (fig. 1(a)) which extended upstream into the subsonic flow region of the tunnel. This arrangement prevented the formation of shock waves off the fuselage nose which might reflect from the tunnel walls onto the model. No reflection plane was used because past experience with similar models has indicated that the effect of any aerodynamic-load carry-over on the flutter characteristics is small. The sting and model weighed approximately 290 pounds, and the system had a fundamental frequency of about 15 cps.

Strain gages were mounted on the wing panel near the root (fig. 1(a)) and were oriented to indicate bending and torsional deflections. Time histories of the strain-gage signals, tunnel stagnation and static pressures, and stagnation temperature were obtained on a recording oscillograph. The strain-gage signals were used to indicate the occurrence of flutter and the flutter frequency. High-speed motion pictures were taken during some of the runs and were used to study the flutter modes.

Tests of models which had various levels of store-attachment pitch flexibility were made as close to $M = 0.85$ as possible; however, the actual Mach numbers at flutter ranged from about 0.78 to 0.90 with an average value of 0.85. Five of the models were tested at several Mach numbers between about 0.76 and 1.30, and the aerodynamic-effect models were tested at Mach numbers near 0.89.

PRESENTATION OF RESULTS

The results of the present investigation are presented in table VI and in figures 7 and 8, and the flutter characteristics of each model are described in table VII. In table VI, the model behavior at each data point is described by code letters, which are defined in the table footnote. For most runs, the start of flutter (F) was characterized by the sudden appearance of divergent oscillations which were easily discernible on the oscillograph records. Occasionally, the start of flutter was somewhat obscured by a region of intermittent sinusoidal oscillations which began before definite flutter. Such regions are designated as low-damping regions (D) as in reference 7. Because of the uncertain extent of the low-damping regions, only the definite flutter points are plotted in figures 7 and 8 and are considered in the discussion of the results.

To illustrate the effect of the store-attachment pitch flexibility, only one run, that nearest a Mach number of 0.85, was chosen for each model. (Each model represents a different level of store pitch stiffness.) The selected runs are those for which data are listed in the last four columns of table VI, and these data are plotted in figure 7. The data are presented in nondimensional form in an effort to account for the differences in the torsional stiffness of the various wings tested as indicated by the variation of $f_{w,3}$ in figure 3. Each dynamic pressure for a wing with stores (q) is divided by the dynamic pressure at which the same wing without stores (q_w) would be expected to flutter at $M = 0.85$. The value of q_w for each model was obtained as follows: For most conventional wings of a given planform, the flutter dynamic pressure at a particular Mach number is approximately proportional to the square of the torsional frequency; thus,

$$(q_w)_{\text{present wing}} = (q_w)_{\text{typical wing}} \frac{\left[(f_{\text{torsion}})^2\right]_{\text{present wing}}}{\left[(f_{\text{torsion}})^2\right]_{\text{typical wing}}}$$

Wing 3 from reference 4 was selected as the typical wing without store. This wing fluttered at $M = 0.847$ at a dynamic pressure of 1884 lb/sq ft and had a natural torsional frequency of 375 cps. By substituting these values and by using the third natural mode frequency $\left(f_{w,3}\right)$ as the torsional frequency for each of the present wings, the equation becomes

$$q_w = 1884 \frac{(f_{w,3})^2}{(375)^2}$$

To provide some indication of which vibration modes were most prominently involved in the flutter motion, the modal-frequency curves of figure 5 have been superimposed on the flutter frequency data in figure 7.

Presented in figure 8 are the variations with Mach number of the flutter dynamic pressure for the five models which were tested to obtain an indication of the effect of Mach number on the flutter results. Included in this figure are the data for the wing without stores (from ref. 4) and for the aerodynamic-effect models.

DISCUSSION OF RESULTS

In illustrating the effects of the store-attachment pitch flexibility, the data presented (fig. 7) were obtained at Mach numbers varying from about 0.78 to 0.90 (table VI), but are assumed in the discussion to apply to the average Mach number of about 0.85. The consequences of neglecting these variations in Mach number are examined briefly in a subsequent section, "Effect of Mach Number." In addition, there are differences in the mass properties and in the mass ratios μ for the various models tested (tables II(a) and VI, respectively); however, the effects of these differences on the flutter results are considered to be secondary in comparison with the effects of the store flexibility, and for the purposes of this report are also neglected.

Effect of Store-Attachment Pitch Flexibility

Rearward c.g. store.- For all store-attachment pitch flexibilities investigated, the wing with the rearward c.g. store (fig. 7(a)) fluttered at dynamic pressures lower than those for the wing without the store. The major effects of the store flexibility occurred at the lower store-pitch frequencies, and a minimum flutter q was obtained at $f_s/f_{w,3} \approx 0.16$ where the flutter frequency f_e, the uncoupled store-pitch frequency f_s, and the torsional frequencies f_2 were approximately coincident (fig. 7(a)). For values of $f_s/f_{w,3} > 0.16$, the flutter q rose to a maximum value at $f_s/f_{w,3} \approx 0.55$ and remained nearly constant as the store-attachment pitch flexibility was increased.

Although the flutter frequency f_e was relatively insensitive to variations in the uncoupled store-pitch frequency f_s over the entire range of the investigation, significant changes occurred in flutter trends and modes as f_s was varied through the critical range of minimum flutter q. As f_s increases above the critical range $\left(f_s/f_{w,3} > 0.16\right)$, the torsional frequency f_2 rises to a higher level and remains nearly constant in a similar manner to that noted for the flutter q. At these higher values of f_s, the flutter frequency f_e lies between the first- and second-mode frequencies (fig. 7(a)), the store-pitch motion is nearly in phase with the wing torsional motion (table VII), and the wing mode is a bending-torsion type. In contrast, as f_s decreased below the critical range $\left(f_s/f_{w,3} < 0.16\right)$, the flutter q increased although the torsional frequency f_2 decreased. In this lower range of f_s, the flutter frequency f_e was above the second-mode frequency, the store-pitch motion appeared to be out of phase with the wing torsional motion, but the wing mode was still of the bending-torsion type. Thus, in the latter range the very flexibly mounted store may be acting as a vibration absorber and delaying the start of flutter. However, the flutter mode might also be affected by the changing frequency spectrum even though the flutter frequency does not vary appreciably. In any event, the trends of these results suggest that higher flutter dynamic pressures may be realized at lower store-pitch frequencies than those investigated, although it is doubtful that stores with very flexible attachments would be practical.

Forward c.g. store.- With the forward c.g. store (fig. 7(b)), flutter dynamic pressures considerably higher than those for the wing without store were obtained for the store-pitch frequency parameter extending from a value of $f_s/f_{w,3}$ of about 0.16 down to 0.09, the lower limit of the present tests. At $f_s/f_{w,3} = 0.146$, a peak in the flutter boundary occurred where no flutter could be obtained up to $q/q_w = 1.7$, the tunnel limit. As this store-pitch frequency parameter increased above 0.146, the flutter q dropped rapidly to and remained near a level about $0.58q_w$.

At the higher store-pitch frequencies $\left(f_s/f_{w,3} > 0.23\right)$, the flutter mode for the forward c.g. stores was of the same bending-torsion type as that for the rearward c.g. stores (table VII). At these high f_s values, both the flutter q and f_2 for the forward c.g. store are essentially invariant with f_s (fig. 7(b)). Comparison of these results with those for the rearward c.g. store shows that in the high f_s range the addition of the forward c.g. store decreased the flutter q of the wing without store by about 40 percent, whereas the addition of the rearward c.g. store decreased the flutter q by only about 25 percent. As the store-pitch frequency was decreased to a value of $f_s/f_{w,3} = 0.16$, the flutter mode rapidly changed to one having smaller amplitudes and involving primarily the higher frequency vibration modes. This higher mode flutter region appeared to be bounded since both a start and stop of flutter were obtained. At the two lowest store-pitch frequencies investigated, the flutter mode appeared to consist of the first two modes in combination with the higher bending mode f_3.

These results indicate that at store-pitch frequencies near the flutter frequency, the forward c.g. store appears to act as a vibration absorber and prevents flutter in the primarily bending-torsion mode; for the one model which did not flutter, the store prevents flutter in the four lowest modes, at least up to the maximum q investigated. As the store-pitch frequency is reduced further, the store effectiveness as a flutter suppressor decreases, and the flutter mode again contains predominantly the lower, fundamental bending and torsion modes. In general, the present results confirm the trends reported in references 1 and 2, and indicate that the use of specially designed stores could be of value for delaying flutter. For the present configuration the effective range of store-attachment pitch flexibilities is rather limited and probably could not be greatly extended even if the stores were provided with higher damping in pitch. However, it is possible that the flexible mounting of stores may in some cases lead to useful increases in flutter dynamic pressure. Nevertheless, these increases may be very difficult to attain because the flutter characteristics are functions not only of store-attachment pitch flexibility, but also of store center-of-gravity location, store mass, and Mach number (refs. 1 and 2) as well as the wing parameters.

Effect of Mach Number

In the previous discussion of the effects of store-attachment pitch flexibility, only the run with Mach number closest to 0.85 was considered for each model, and although these data were obtained at Mach numbers from approximately 0.78 to 0.90, the effect of this minor variation in Mach number was neglected. In order to determine whether the differences in Mach number for these data would affect the interpretation of the results, five of the models were tested at several other Mach numbers. The flutter data for these five models are shown in figure 8, along with the results for the wing without store (ref. 4). Data for the aerodynamic-effect models, which are also included in this figure, will be discussed in the next section.

Based on these results, the expected deviation in the flutter dynamic pressure caused by neglecting the Mach number variation is estimated to be well within the usual scatter expected in this type of test for all except two models. For these exceptions, models 4R84 and 10F88, the probable deviation is estimated to be about 9 and 6 percent, respectively; that is, the flutter dynamic pressures used (see fig. 7) are too high by these percentages. However, these discrepancies do not appreciably affect the general trends of results or previous conclusions relating to the effects of store-attachment pitch flexibility.

Because of the limited number of flutter points for any one wing-store configuration over a sizable Mach number range (fig. 8), the Mach number effects on flutter are not well defined. In general, however, these limited results indicate that in the high subsonic speed range as the Mach number is increased, the flutter q decreased. For model 5R139, a favorable compressibility effect amounting to about a 38-percent increase in flutter q was obtained as the Mach number was increased from 0.83 to 1.30; the corresponding rise in flutter q for the wing without store is about 58 percent.

Aerodynamic Effect of Stores

The two aerodynamic-effect models 1A and 1B fluttered at nearly the same Mach number and dynamic pressure, as shown in figure 8. The flutter mode appeared to be similar for the two models and the flutter frequencies differed by only about 9 percent. Thus, the aerodynamic effect of the store on the flutter characteristics does not appear to be large. This result is consistent with that of reference 8 which indicated that the aerodynamic effect of the store on the flutter characteristics is small at subsonic speeds. With these results in mind, the difference in length between the forward c.g. stores and the rearward c.g. stores used in the present investigation is considered to have little effect on the flutter characteristics.

The increase in flutter dynamic pressure for the aerodynamic-effect models over that for the wing without store (fig. 8) is attributed to the favorable effect of the forward c.g. location of the store of model 1A and of the ballast weights of model 1B. The flutter mode and frequencies for the aerodynamic-effect models were approximately the same as those for the wing without store.

CONCLUSIONS

The effect of store-attachment pitch flexibility on the flutter characteristics of a cantilevered 45° sweptback wing carrying a pylon-mounted store has been studied experimentally at Mach numbers near 0.85. The store-attachment flexibility in pitch was systematically varied to give uncoupled store-pitch frequencies ranging from about 0.1 to 1.4 times the torsional frequency of the wing without store. Two locations of the store-pylon center of gravity (about 8 and 30 percent of the local wing chord - called the forward and rearward c.g. stores, respectively) were investigated. The results indicated the following conclusions:

1. For uncoupled store-pitch frequencies higher than about 0.4 of the torsional frequency of the wing without the store, varying the store-attachment flexibility had little effect on the flutter dynamic pressure of either the forward or the rearward c.g. stores. The addition of the store to the wing reduced the flutter dynamic pressure by about 40 percent for the forward c.g. store and by about 25 percent for the rearward c.g. store.

2. In the low uncoupled store-pitch frequency range, the flutter dynamic pressure for the forward c.g. store peaked sharply with a maximum value considerably greater than that for the wing without store. This peak in the flutter dynamic pressure occurred when the uncoupled store-pitch frequency approached the flutter frequency, and was accompanied by a change in flutter mode from a fundamental bending-torsion type to one involving the higher vibration modes since the flexible store apparently suppressed the flutter in the lower modes.

3. In the low store-pitch frequency range where the flutter dynamic pressure of the forward c.g. store was a maximum, the flutter dynamic pressure of the rearward c.g. store dipped to a minimum. The effect of store-attachment pitch flexibility thus appears to be quite sensitive to store c.g. position.

4. Comparison of the flutter characteristics of a wing with a light, essentially rigidly attached store with those of a wing without a store but which was mass balanced to have similar vibration mode characteristics indicated that the aerodynamic effect of the store was very small.

5. Although the Mach number effect on flutter was not well defined because of the limited number of data points obtained, the trends indicate that the

flutter dynamic pressure decreased as the Mach number was increased in the high subsonic range. In addition, a favorable compressibility effect was indicated for one of the wing-store configurations as the Mach number was increased to 1.3.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., June 18, 1964.

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TABLE I.- GEOMETRIC PROPERTIES OF MODELS

Wing:	
Streamwise airfoil section	NACA 65A004
Sweepback angle, deg	45
Aspect ratio (full span)	4
Exposed panel aspect ratio	1.57
Taper ratio	1.0
Exposed panel span, s, ft	0.458
Streamwise wing chord, c, ft	0.292
Typical store:	
Spanwise location from wing root, percent exposed panel span	75.5
Fineness ratio (Length/Diameter) -	
Rearward c.g. store	11.1
Forward c.g. store	9.0
Length, fraction of streamwise wing chord -	
Rearward c.g. store	2.0
Forward c.g. store	1.6
Pitch axis location, fraction of streamwise wing chord	0.425
Vertical distance from wing chord plane to store center line, fraction of streamwise wing chord	0.125
Exposed frontal area of pylon, sq ft	0.00023

TABLE II.- PHYSICAL PROPERTIES OF MODELS

(a) Mass properties of stores and stores with pylons

Model	Store with pylon									Store alone					$\frac{d}{c}$
	$\frac{m_s}{m_w}$	$\frac{x}{c}$	$\frac{z}{c}$	m_s, slugs	$S_{\theta,s}$, slug-ft	$I_{\theta,s}$, slug-ft^2	$I_{\phi,s}$, slug-ft^2	$I_{\psi,s}$, slug-ft^2	$\frac{m_s}{m_w}$	$\frac{x}{c}$	m_s, slugs	$S_{\theta,s}$, slug-ft	$I_{\theta,s}$, slug-ft^2	
Rearward c.g. store configuration															
1R31	0.847	0.30	0.11	4.13×10^{-3}	5.70×10^{-5}	4.92×10^{-5}	0.556×10^{-5}	-----------	0.613	0.20	2.99×10^{-3}	-4.86×10^{-5}	4.13×10^{-5}	0.13
2R63	.855	.30	.09	4.17	6.42	5.10	-----------	-----------	.624	.18	3.04	-5.95	4.18	.13
3R82	.894	.31	.10	4.36	7.98	5.46	.682	4.87×10^{-5}	.628	.18	3.06	-5.99	4.19	.13
4R84	.855	.31	.09	4.17	7.84	5.15	-----------	-----------	.624	.20	3.04	-4.94	4.14	.13
5R139	.882	.31	.12	4.30	6.97	5.29	-----------	4.84	-----	-----	-----------	-----------	-----------	.13
6R210	.935	.32	.11	4.56	8.94	5.60	.700	5.02	.644	.19	3.14	-5.36	4.17	.13
7R245	.927	.31	.11	4.52	8.09	5.42	-----------	4.86	-----	-----	-----------	-----------	-----------	.14
3R508	.952	.32	.12	4.65	9.09	5.54	.794	5.02	-----	-----	-----------	-----------	-----------	.15
Forward c.g. store configuration															
8F37	0.862	0.09	0.13	4.20×10^{-3}	-20.12×10^{-5}	9.64×10^{-5}	0.752×10^{-5}	8.67×10^{-5}	-----	-----	-----------	-----------	-----------	0.13
9F48	.853	.06	.12	4.16	-23.38	10.05	.815	9.12	0.619	-0.13	3.02×10^{-3}	-33.60×10^{-5}	8.56×10^{-5}	.13
8F58	.866	.07	.11	4.22	-22.32	9.46	.616	9.02	.626	-.12	3.05	-33.17	8.36	.13
8F67	.866	.07	.11	4.22	-22.32	9.46	.616	9.02	.626	-.12	3.05	-33.17	8.36	.13
10F88	.882	.09	.12	4.30	-20.60	9.32	-----------	-----------	.626	-.13	3.05	-33.42	8.28	.13
11F162	.898	.09	.12	4.38	-20.98	9.68	.776	8.93	.654	-.11	3.19	-33.36	8.42	.14
12F349	1.019	.11	.14	4.97	-20.92	10.63	-----------	9.74	.693	-.08	3.38	-32.25	8.62	.15
8F435	.870	.08	.13	4.24	-21.03	9.72	.852	-----------	-----	-----	-----------	-----------	-----------	----
Aerodynamic-effect model															
1A	0.039	0.32	0.11	0.19×10^{-3}	0.42×10^{-5}	0.416×10^{-5}	-----------	-----------	-----	-----	-----------	-----------	-----------	----
1B	*.133	----	----	*.65	-----------	-----------	-----------	-----------	-----	-----	-----------	-----------	-----------	----

*This value is the mass added to wing 1 in constructing model 1B.

(b) Natural vibration frequencies of wing-store configurations

Model	f_s, cps	f_1, cps	f_2, cps	f_3, cps	f_4, cps	f_5, cps	f_6, cps	f_7, cps	$\frac{f_s}{f_{w,3}}$	$\frac{f_1}{f_{w,3}}$	$\frac{f_2}{f_{w,3}}$	$\frac{f_3}{f_{w,3}}$	$\frac{f_4}{f_{w,3}}$
Rearward c.g. store configuration													
1R31	30.9	28.6	32.9	251	215	460	591	642	0.078	0.072	0.083	0.632	0.542
2R63	62.8	29.8	56.2	252	229	507	600	639	.163	.077	.146	.655	.595
3R82	82.0	28.0	70.5	242	254	520	570	635	.222	.076	.191	.656	.688
4R84	83.5	30.0	70.5	246	246	519	615	650	.210	.075	.177	.618	.618
5R139	139.0	29.5	93.8	254	308	561	687	614	.352	.075	.237	.643	.780
6R210	210.0	31.2	107.0	270	405	580	665	738	.525	.078	.268	.675	1.013
7R245	245.0	30.8	112.0	270	429	579	665	740	.598	.075	.273	.659	1.046
3R508	508.0	26.6	102.0	224	490	585	740	843	1.377	.072	.276	.607	1.328
Forward c.g. store configuration													
8F37	36.7	37.2	29.9	250	229	345	645	460	0.092	0.093	0.075	0.627	0.574
9F48	47.6	31.3	43.0	252	235	395	660	605	.121	.079	.109	.640	.596
8F58	58.2	31.7	50.1	263	263	342	658	601	.146	.079	.126	.659	.659
8F67	67.0	31.6	54.0	247	274	404	650	615	.168	.079	.135	.619	.687
10F88	87.6	31.3	61.2	245	307	425	648	630	.231	.082	.161	.645	.808
11F162	162.0	31.2	73.7	245	417	633	633	698	.407	.078	.185	.616	1.048
12F349	349.0	29.6	75.8	233	510	469	660	845	.890	.076	.193	.594	1.301
8F435	435.0	32.1	80.0	247	540	502	670	873	1.090	.080	.201	.619	1.353
Aerodynamic-effect model													
1A	-----	43.8	350.0	222	571	---	725	---	-----	-----	-----	-----	-----
1B	-----	40.8	363.0	221	---	---	685	---	-----	-----	-----	-----	-----

TABLE III.- DESCRIPTION OF NATURAL VIBRATION MODES

OF WINGS WITH STORES

Mode number	Predominant characteristic	Description of store motion relative to wing
1	First bending	Store pitched only for lowest f_s values (close to f_1); store nose moved up as wing tip moved up for rearward c.g. stores; this relative motion was reversed for forward c.g. stores.
2	First torsion	Strong wing torsion and weak store pitch for $f_s > 40$ cps; strong store pitch and weak wing torsion for $f_s < 40$ cps; store nose moved up as wing leading edge moved up. For lowest f_s values, this mode became pure store mode; there was no node line on wing (fig. 4) and slight wing motion was similar to mode 1 motion. (Note that f_2 is nearly same as f_1.)
3	Second bending	No store pitch motion unless f_3 and f_4 were close, in which case store motion was same as for mode 4.
4	Store pitch	Strong store pitch and weak wing torsion for $f_s > 40$ cps; strong wing torsion and weak store pitch for $f_s < 40$ cps; store nose moved down as wing leading edge moved up. For models with low f_s values, store appeared to remain stationary with respect to observer while wing twisted.
5	Coupled yaw, torsion, and bending	Strong store yawing motion about store c.g.; weak wing torsion and/or bending motion. Store nose moved inboard as wing leading edge at tip moved down.
6	Third bending	Little store motion unless frequency of this mode was close to that of mode 5 or 7, as for model 11F162.
7	Coupled yaw and torsion	Weak store yaw about forward store-mounting stud and strong wing torsion motion; store nose moved inboard as wing leading edge moved up.

TABLE IV.- MEASURED MODE SHAPES FOR WINGS WITH STORES

Model	Mode	Frequency of flutter model, cps	Frequency of facsimile, cps	Nondimensional deflection at station (see fig. 6) -																			
				11	11a	12	13	21	22	23	31	32	33	41	42	43	51	52	53	S1	S1a	S1b	S2
1R31	1	28.6	27.5	0.015	-----	0.055	0.115	0.100	0.175	0.295	0.235	0.370	0.500	0.465	0.610	0.725	0.755	0.890	1.000	------	1.620	-----	-0.940
	2	32.9	32.5	.005	-----	.050	.140	.080	.170	.320	.215	.360	.545	.430	.620	.815	.785	.935	1.150	------	-.505	-----	2.075
	3	251.0	245.0	-.005	-----	-.050	-.185	-.015	-.115	-.275	-.030	-.140	-.260	.090	-.015	-.135	.296	.245	.195	------	-.025	-----	-.020
	4	215.0	215.0	-.040	-----	-.060	-.025	-.120	-.110	-.020	-.205	-.100	.070	-.210	-.015	.240	-.065	.170	.460	------	-.010	-----	-.145
3R82	1	28.0	27.0	0.025	-----	0.165	0.345	0.240	0.495	0.820	0.655	1.010	1.440	1.250	1.615	2.080	2.035	2.380	2.850	------	1.050	-----	2.290
	2	70.5	68.5	-.030	-----	-.040	.040	-.125	-.070	.115	-.180	-.030	.255	-.185	.100	.445	-.080	.345	.705	------	-1.280	-----	1.705
	3	242.0	230.0	-.010	-----	-.045	-.175	-.020	-.140	-.300	-.055	-.155	-.275	-.025	-.020	-.060	.265	.255	.245	------	-.025	-----	-.030
	4	254.0	235.0	-.050	-----	-.035	.045	-.125	-.065	.110	-.215	-.095	.180	-.255	-.030	.265	-.210	.085	.370	------	.045	-----	-.200
6R210	1	31.2	29.5	-----	0.060	0.170	0.405	0.250	0.570	0.950	0.750	1.165	1.635	1.465	1.950	2.450	2.390	2.840	3.425	------	1.250	-----	2.745
	2	107.0	97.9	-----	-.020	-.020	.010	-.070	-.040	.050	-.140	-.030	.170	-.170	.020	.320	-.080	.200	.500	------	-.540	-----	.820
	3	270.0	258.0	-----	-.010	-.060	-.120	-.040	-.130	-.195	-.075	-.135	-.170	-.015	-.005	-.010	.160	.190	.235	------	.005	-----	-.070
	4	405.0	327.0	-----	-.025	-.030	.005	-.080	-.055	.030	-.135	-.050	.085	-.130	.005	.160	-.085	.075	.260	------	.030	-----	-.175
9F48	1	31.3	31.1	0.070	-----	0.235	.500	.340	.700	1.180	.950	1.450	2.015	1.825	2.410	2.990	2.965	3.540	4.135	2.135	------	2.000	------
	2	43.0	44.8	.000	-----	-.005	.035	-.005	.010	.060	.015	.050	.110	.045	.110	.165	.110	.175	.250	-.370	------	-.200	------
	3	235.0	226.0	-.015	-----	-.055	-.165	-.045	-.115	-.255	-.085	-.135	-.220	-.025	-.025	-.025	.190	.220	.265	.000	------	-.010	------
	4	252.0	242.0	-.060	-----	-.085	-.060	-.195	-.170	-.045	-.330	-.190	.085	-.355	-.055	.340	-.180	.195	.655	.020	------	-.045	------
8F58	1	31.7	31.2	0.047	-----	0.193	0.449	0.345	0.655	1.098	0.862	1.283	1.850	1.660	2.099	2.670	2.710	3.110	3.730	1.500	------	2.180	------
	2	50.1	49.0	-.010	-----	.000	.075	-.025	.020	.180	-.025	.105	.345	.045	.290	.575	.245	.540	.865	-1.290	------	-.785	------
	3-4	263.0	236.0	-.015	-----	-.045	-.060	-.065	-.090	-.095	-.125	-.100	-.045	-.110	-.020	.105	-.005	.135	.300	-.005	------	-.010	------
10F88	1	31.3	31.1	-----	0.055	0.180	0.420	0.280	0.585	0.995	0.780	1.200	1.750	1.540	2.055	2.605	2.480	3.055	3.615	1.150	------	1.440	------
	2	61.2	57.9	-----	-.005	-.010	.015	-.025	-.005	.044	-.035	.020	.108	-.025	.070	.192	.050	.170	.300	-.385	------	-.225	------
	3	245.0	226.0	-----	-.005	-.030	-.085	-.020	-.075	-.160	-.045	-.090	-.135	-.025	-.025	-.025	.100	.130	.150	.000	------	-.005	------
	4	307.0	284.0	-----	-.025	-.045	-.035	-.090	-.090	-.025	-.160	-.095	.045	-.175	-.020	.175	-.075	.100	.355	.025	------	.000	------
8F435	1	32.1	32.0	0.040	-----	0.155	0.380	0.235	0.530	0.920	0.680	1.080	1.530	1.335	1.740	2.235	2.209	2.594	3.040	0.810	------	-----	------
	2	80.0	77.0	-.095	-----	-.105	.050	-.325	-.200	.170	-.510	-.160	.505	-.520	.185	1.100	-.110	.780	1.720	-1.735	------	-----	------
	3	247.0	240.0	-.005	-----	-.035	-.125	-.020	-.095	-.205	-.045	-.110	-.175	-.015	-.030	-.045	.155	.160	.190	.005	------	-----	------

TABLE V.- MEASURED FLEXIBILITY INFLUENCE COEFFICIENTS OF WING WITH PYLON

Load station*	Influence coefficient, ft/lb, measured at wing station*																		θ_i, $\frac{\text{radians}}{\text{lb}}$
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1	0.0000050	0.0000025	0	0.0000033	0.0000029	0	0.0000033	0.0000046	0.0000033	0.0000079	0.0000054	0.0000008	0.0000046	0.0000013	0	0.0000088	0.0000038	0.0000021	-0.00004
2		.0000075	.0000071	.0000113	.0000138	.0000138	.0000196	.0000188	.0000258	.0000275	.0000308	.0000329	.0000354	.0000333	.0000467	.0000504	.0000546	.0000542	.00001
3			.0000283	.0000154	.0000400	.0000692	.0000504	.0000783	.0001038	.0000892	.0001092	.0001504	.0001229	.0001546	.0001904	.0001625	.0001863	.0002225	.00057
4				.0000658	.0000683	.0000654	.0001304	.0001258	.0001221	.0001717	.0001750	.0001800	.0002296	.0002179	.0002246	.0002854	.0002796	.0002921	-.00004
5					.0002408	.0001946	.0002029	.0002579	.0003325	.0003279	.0003892	.0004817	.0004725	.0005496	.0006129	.0006158	.0006671	.0007733	.00072
6						.0004200	.0002875	.0004879	.0007200	.0005463	.0007717	.0010046	.0008658	.0011021	.0013408	.0011271	.0013125	.0015971	.00233
7							.0003892	.0004650	.0005475	.0006367	.0007154	.0007904	.0009175	.0010204	.0011096	.0011883	.0012567	.0013446	.00091
8								.0007708	.0009513	.0008850	.0011400	.0013858	.0013583	.0016450	.0019238	.0018300	.0020288	.0023588	.00268
9									.0014667	.0011504	.0016867	.0022033	.0019371	.0024562	.0030492	.0026062	.0031075	.0034446	.00548
10										.0012933	.0015775	.0018517	.0019692	.0022750	.0026229	.0026462	.0028808	.0030729	.00300
11											.0019467	.0026504	.0025275	.0031879	.0037821	.0035175	.0039408	.0046308	.00596
12												.0035800	.0031621	.0040354	.0053308	.0042525	.0054658	.0064067	.00952
13													.0033000	.0039112	.0046158	.0046317	.0052083	.0058342	.00663
14														.0052025	.0061771	.0057608	.0069542	.0079350	.01100
15															.0080500	.0070154	.0083783	.0100929	.01640
16																.0066867	.0075475	.0087100	.01140
17																	.0090225	.0105312	.01540
18																		.0127933	.02070

*Load and wing stations shown in figure 2.

TABLE VI.- COMPILATION OF RESULTS

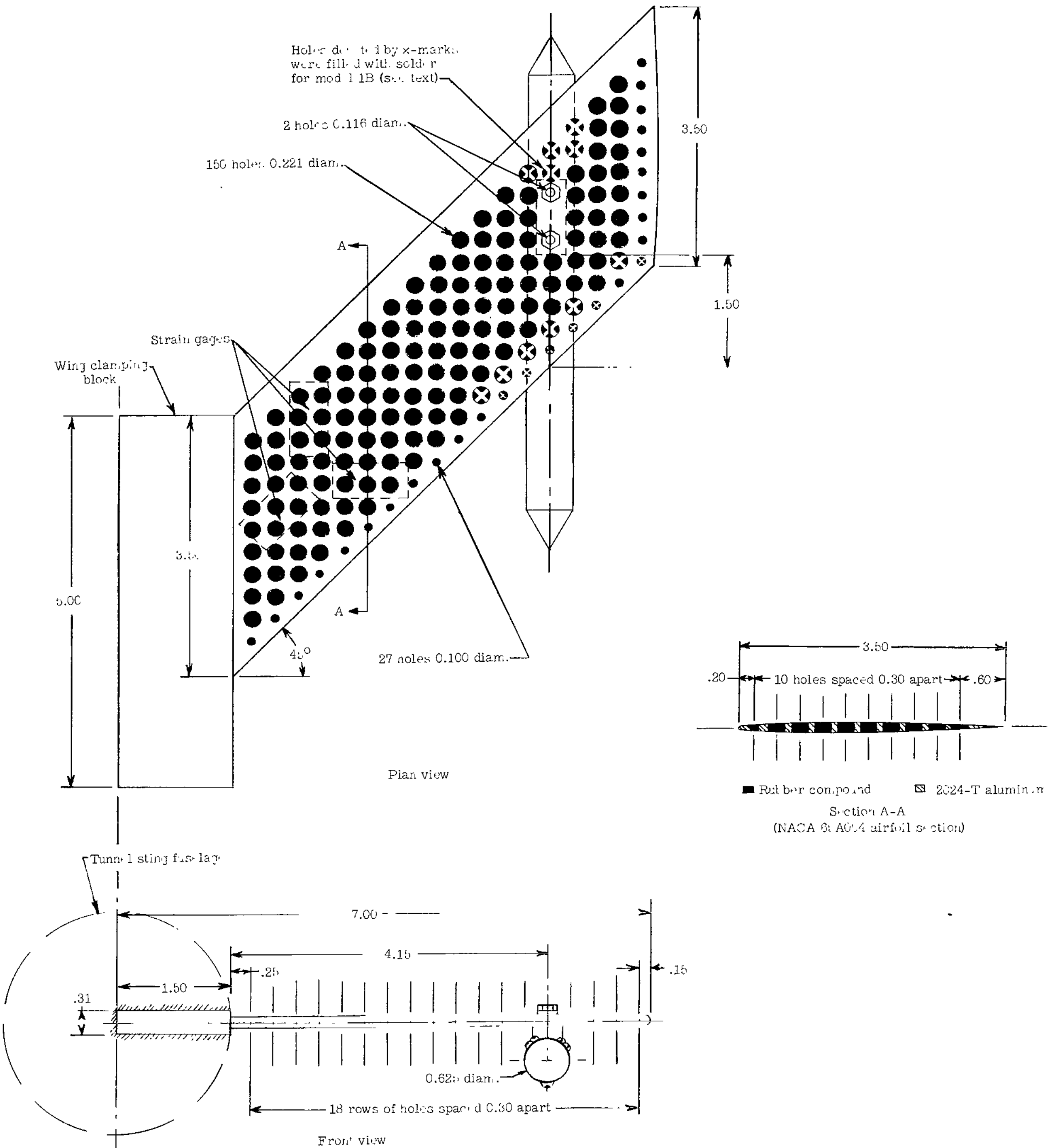
Model	Run-point number*	Model behavior**	M	q, lb/sq ft	ρ, slug/ft^3	T, °R	V, ft/sec	μ	f_e, cps	$f_{w,3}$, cps	Data plotted in figure 7 (M ≈ 0.85) $\frac{f_s}{f_{w,3}}$	q_w, lb/sq ft	$\frac{q}{q_w}$	$\frac{f_e}{f_{w,3}}$
							Rearward c.g. store configuration							
1R31	1-1	D	0.847	1248	0.0031	469	899	51.3	---	397	-----	----	-----	-----
	1-2	F	.837	1333	.0034	466	886	46.8	55	397	0.078	2112	0.631	0.139
2R63	2-1	F	.777	1009	.0029	477	832	54.8	50	385	-----	----	-----	-----
	3-1	F	.837	880	.0022	473	892	72.3	55	385	.163	1986	.443	.143
3R82	4-1	F	.802	1094	.0030	463	846	53.0	62	369	-----	----	-----	-----
	5-1	D	.840	1047	.0027	461	884	58.9	---	369	-----	----	-----	-----
	5-2	F	.848	1058	.0027	460	891	58.9	61	369	.222	1825	.580	.165
	6-1	F	.907	909	.0020	451	944	79.5	55	369	-----	----	-----	-----
4R84	7-1	F	.783	1106	.0031	482	842	51.3	57	398	.210	2123	.521	.143
5R139	8-1	F	.831	1462	.0041	426	841	38.8	67	395	.352	2091	.699	.170
	9-1	F	1.305	2004	.0027	362	1217	58.9	72	395	-----	----	-----	-----
6R210	10-1	F	.859	1633	.0043	426	869	37.0	64	400	.525	2144	.762	.160
7R245	11-1	D	.833	1575	.0044	426	843	36.1	---	410	-----	----	-----	-----
	11-2	F	.834	1686	.0048	422	840	33.1	71	410	.598	2253	.748	.173
3R508	12-1	F	.826	1333	.0037	433	843	43.0	71	369	1.377	1825	.730	.192
							Forward c.g. store configuration							
8F37	13-1	D	0.915	2598	0.0057	450	952	27.9	---	399	-----	----	-----	-----
	13-2	F	.902	2749	.0063	443	930	25.2	98	399	0.092	2133	1.289	0.246
9F48	14-1	F	.817	2933	.0086	427	828	18.5	104	394	.121	2080	1.410	.264
	15-1	F	1.030	2821	.0054	405	1016	29.4	100	394	-----	----	-----	-----
8F58	16-1	Q	.901	3639	.0090	415	900	17.7	---	399	.146	2133	1.706	-----
8F67	17-1	D	.766	962	.0029	468	812	54.8	---	399	-----	----	-----	-----
	17-2	F	.867	1462	.0036	451	903	44.2	250	399	.168	2133	.685	.627
	17-3	E	.883	2720	.0068	426	894	23.4	250	399	.168	2133	1.275	.627
	17-4	Q	.880	3326	.0087	408	872	18.3	---	399	.168	2133	1.559	-----
10F88	18-1	F	.792	1107	.0032	450	824	49.7	56	380	.231	1935	.572	.147
11F162	19-1	F	.850	1225	.0031	450	884	51.3	62	398	.407	2123	.577	.156
12F349	20-1	F	.827	1251	.0034	454	864	46.8	65	392	.890	2059	.608	.166
8F435	21-1	F	.840	1241	.0031	469	892	51.3	63	399	1.090	2133	.582	.158
	22-1	F	.983	1096	.0021	455	1027	75.7	65	399	-----	----	-----	-----
							Aerodynamic-effect model							
1A	23-1	F	0.897	1944	0.0046	434	916	34.6	134	---	-----	----	-----	-----
1B	24-1	F	.874	1976	.0050	433	892	31.8	123	---	-----	----	-----	-----

*The first number indicates the run and the second number, the data point.

**Model behavior code: D, start of low damping; F, start of flutter; E, end of flutter with q increasing; Q, maximum q reached during run, no flutter.

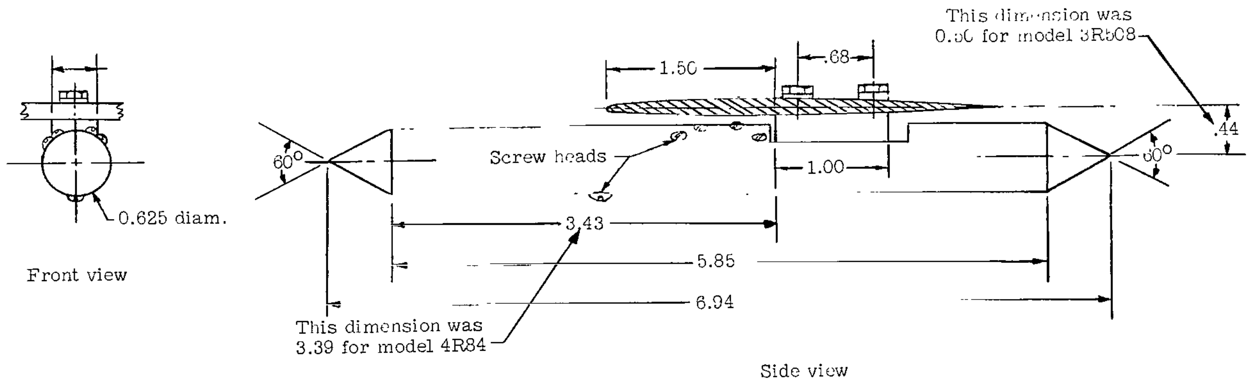
TABLE VII.- DESCRIPTION OF MODEL FLUTTER CHARACTERISTICS

Model	$\frac{f_s}{f_{w,3}}$	Flutter characteristics
1R31	0.078	Flutter frequency was higher than second-mode (torsional) frequency (fig. 7(a)). Flutter mode appeared to be of bending-torsion type but with some store pitch motion relative to wing in opposite direction from wing torsional motion.
2R63	.163	Flutter frequency between f_1 and f_2 (fig. 7(a)). Flutter mode appeared to be of bending-torsion type with some store-pitch motion relative to wing in same direction as wing torsion. Store motion appeared to lag slightly behind wing motion.
3R82	.222	Same as for model 2R63.
4R84	.210	Same as for model 2R63.
5R139	.352	Same as for model 2R63.
6R210	.525	Same as for model 2R63, but no discernible store motion relative to wing.
7R245	.598	Same as for model 2R63, but no discernible store motion relative to wing.
3R508	1.377	Same as for model 2R63, but no discernible store motion relative to wing.
8F37	.092	Flutter frequency between f_2 and f_4 (fig. 7(b)). Flutter mode did not appear to be of simple bending-torsion type; it involved some reflex bending of wing along the semispan. Store appears to move somewhat randomly with respect to wing.
9F48	.121	Same as for model 8F37.
8F58	.146	Model was flutter-free at the maximum dynamic pressure available at $M \approx 0.85$.
8F67	.168	Soon after start of run 17, continuous, low-amplitude oscillations at a frequency of about 250 cps began. Amplitude of oscillation increased regularly as dynamic pressure was increased until it reached a magnitude which was felt to indicate that model was close to flutter. This point was chosen as the start-of-low-damping point. Amplitude continued to increase until, at a dynamic pressure of 1,462 lb/sq ft, a rather abrupt increase was taken to indicate the start of flutter. Flutter oscillations were continuous and regular until a dynamic pressure of 2,720 lb/sq ft was reached, at which point they stopped abruptly. No further flutter or oscillations were encountered as dynamic pressure was increased to maximum reached during run. No motion pictures were obtained during this run.
10F88	.231	Same as for model 2R63.
11F162	.407	Same as for model 2R63.
12F349	.890	Same as for model 2R63, but no discernible store motion relative to wing.
8F435	1.090	Same as for model 2R63, but no discernible store motion relative to wing.

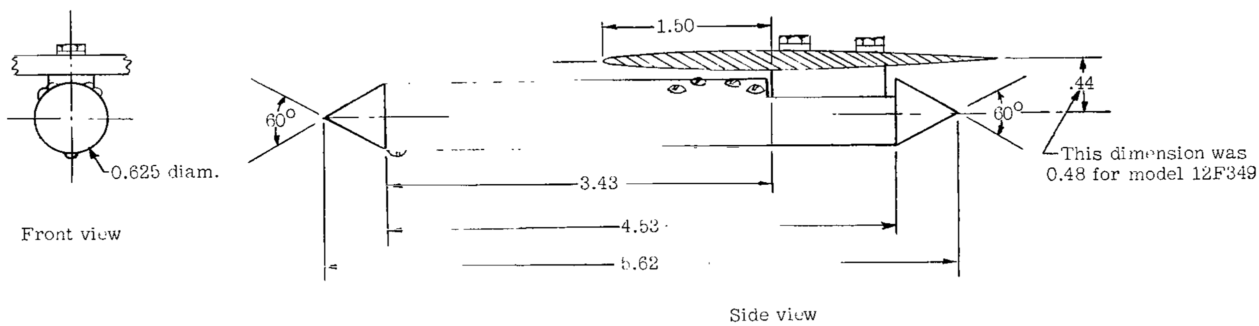


(a) Wing with rearward c.g. store.

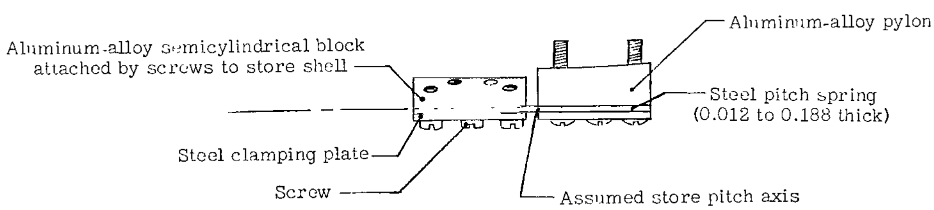
Figure 1.- Sketch of models. All dimensions are in inches unless otherwise specified.



(b) Rearward c.g. store.



(c) Forward c.g. store.



(d) Sketch of pitch-spring mounting arrangement.

Figure 1.- Concluded.

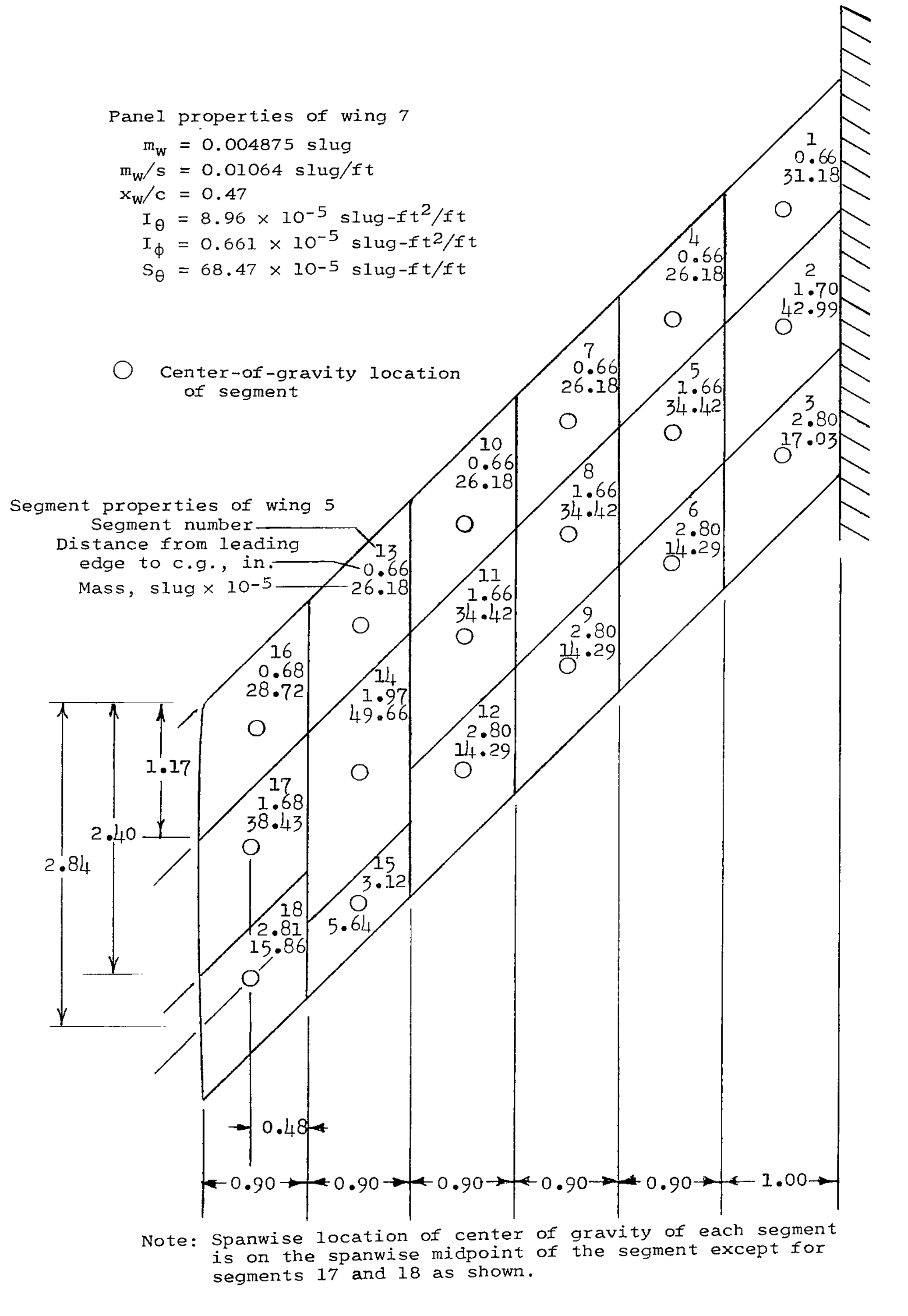
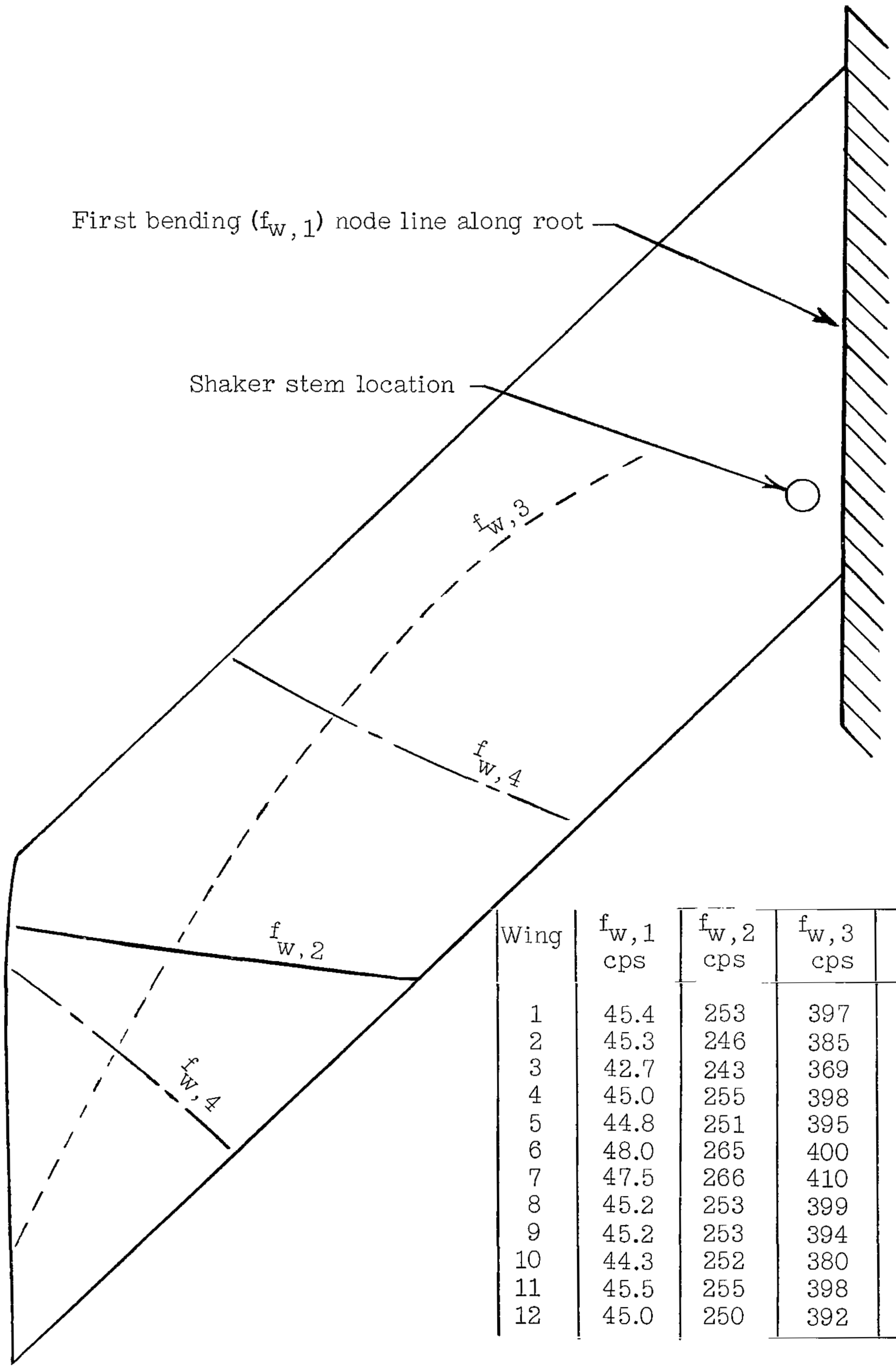
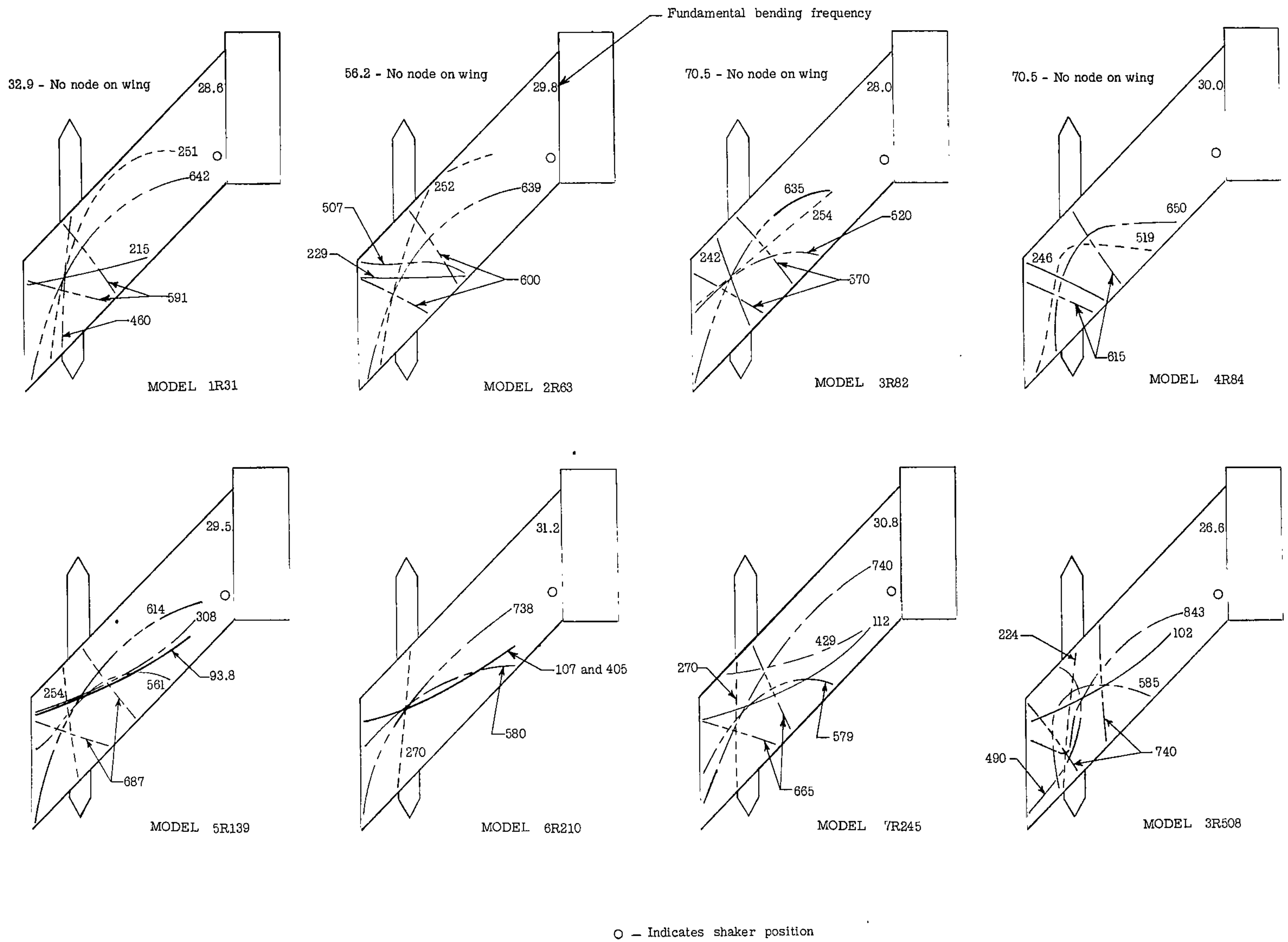


Figure 2.- Typical panel and segment properties of wing without pylon store. All dimensions are in inches unless otherwise specified.



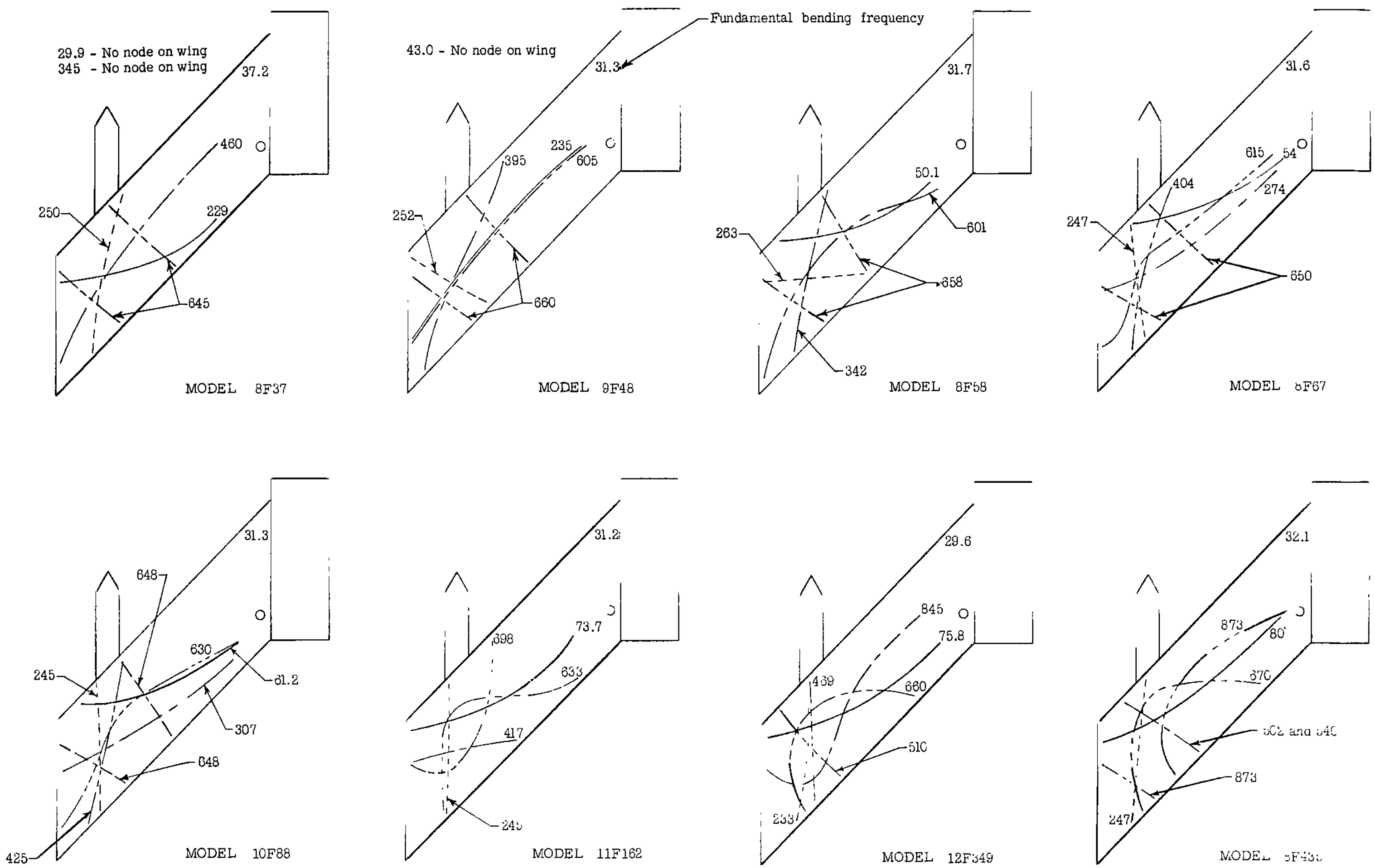
Wing	$f_{w,1}$ cps	$f_{w,2}$ cps	$f_{w,3}$ cps	$f_{w,4}$ cps
1	45.4	253	397	705
2	45.3	246	385	690
3	42.7	243	369	670
4	45.0	255	398	703
5	44.8	251	395	700
6	48.0	265	400	720
7	47.5	266	410	720
8	45.2	253	399	710
9	45.2	253	394	708
10	44.3	252	380	681
11	45.5	255	398	704
12	45.0	250	392	700

Figure 3.- Natural vibration frequencies and typical node lines for the wings without stores.



(a) Models with rearward c.g. stores.

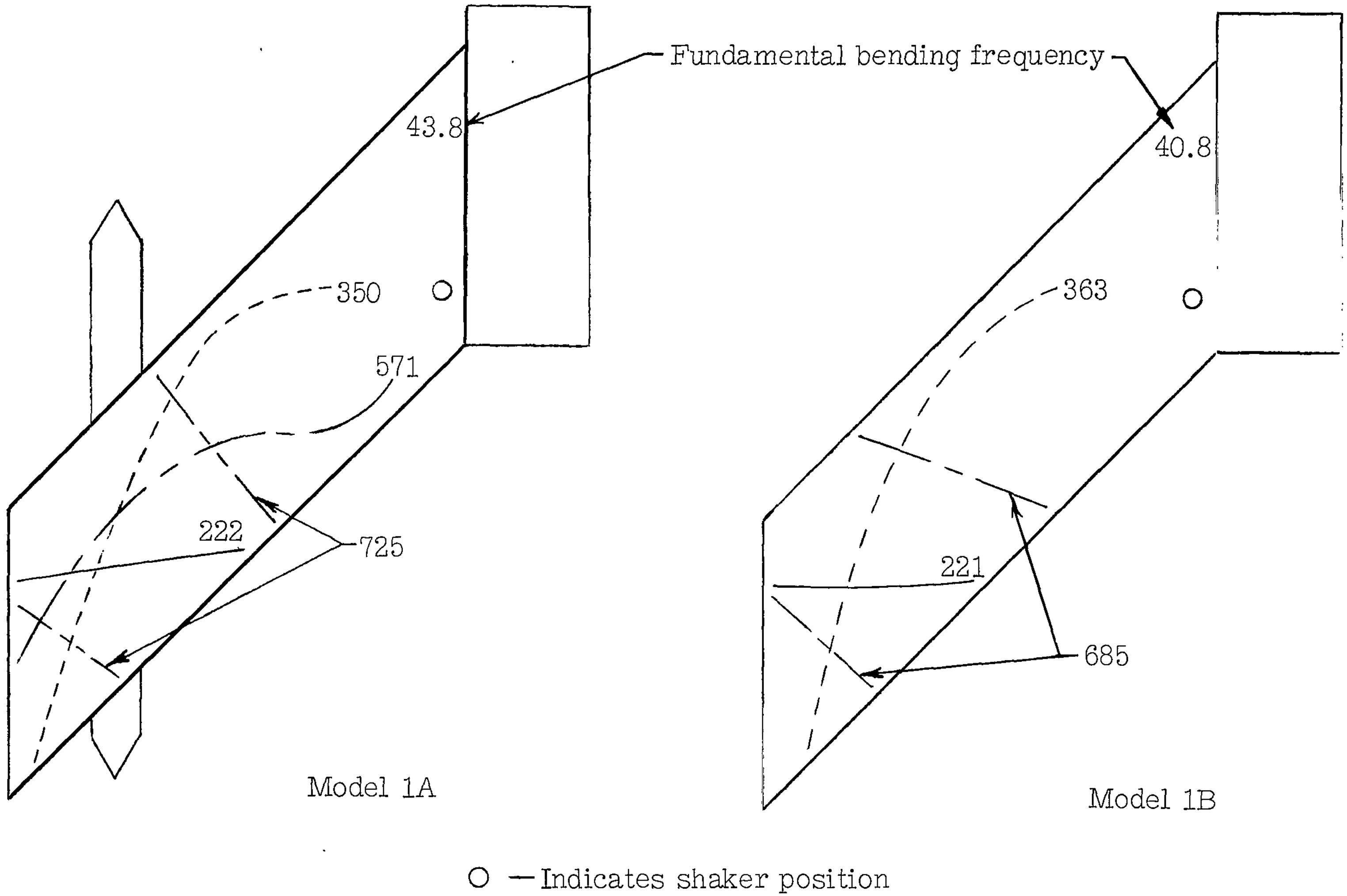
Figure 4.- Natural vibration frequencies and node lines of wing-store models. All frequencies in cps.



○ – Indicates shaker position

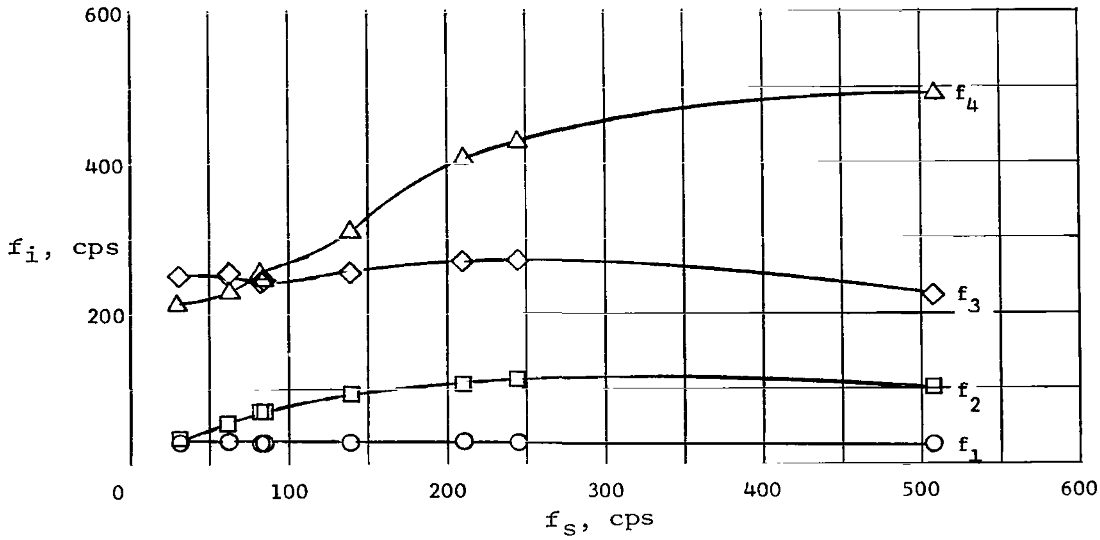
(b) Models with forward c.g. stores.

Figure 4.- Continued.

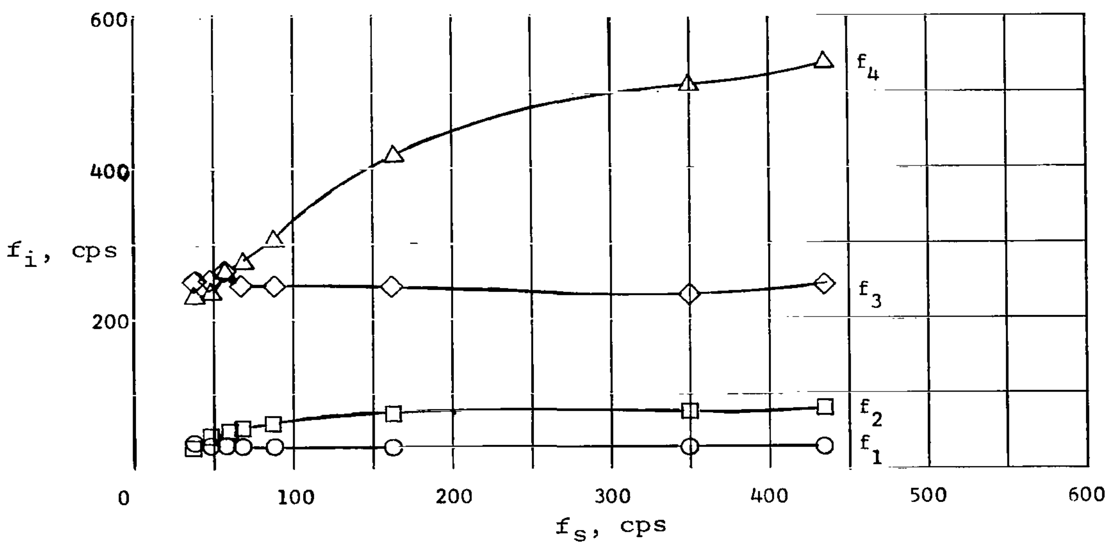


(c) Aerodynamic-effect models.

Figure 4.- Concluded.



(a) Models with rearward c.g. store.



(b) Models with forward c.g. store.

Figure 5.- Effect of store-attachment pitch flexibility on natural vibration frequencies of wing-store models.

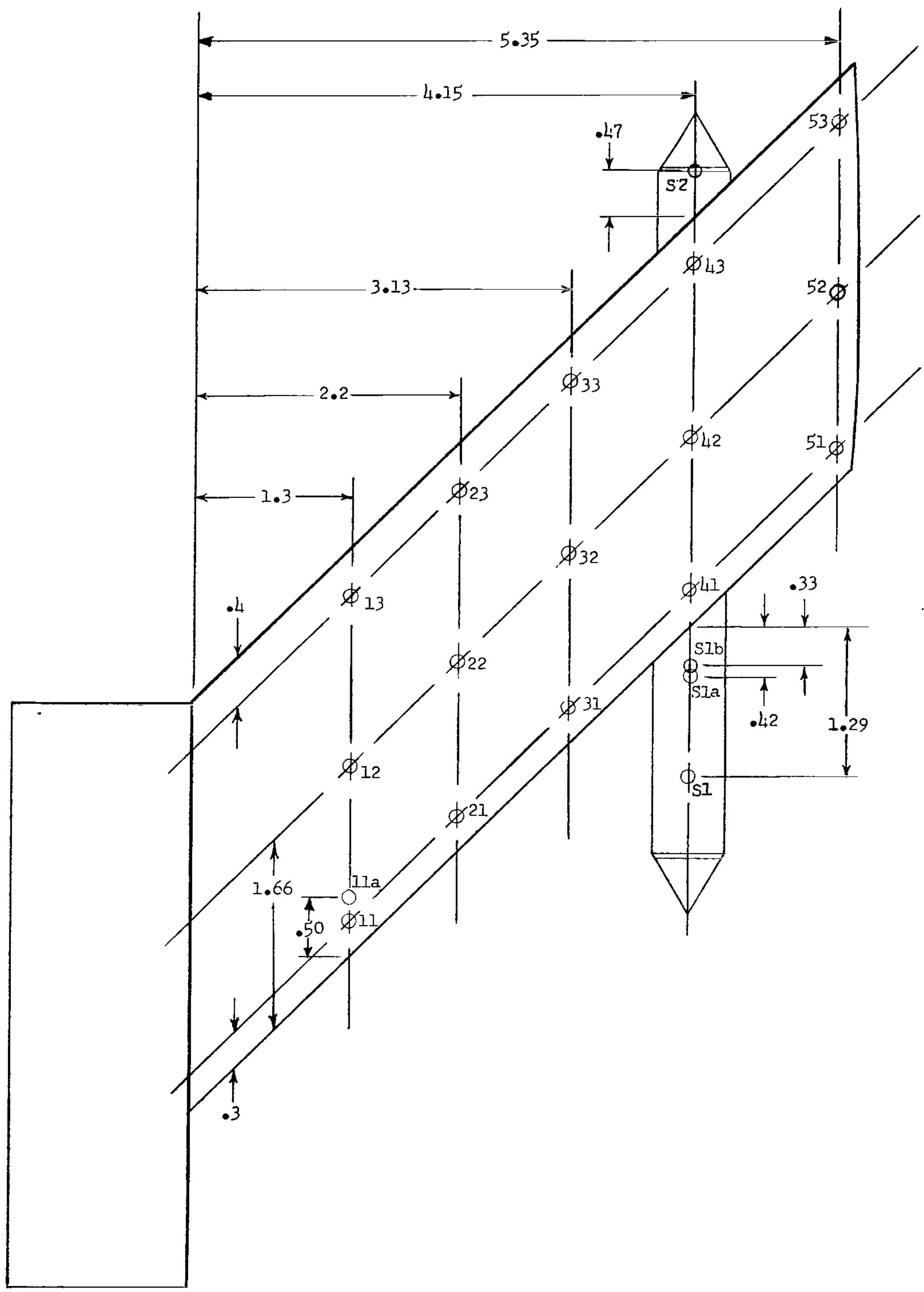
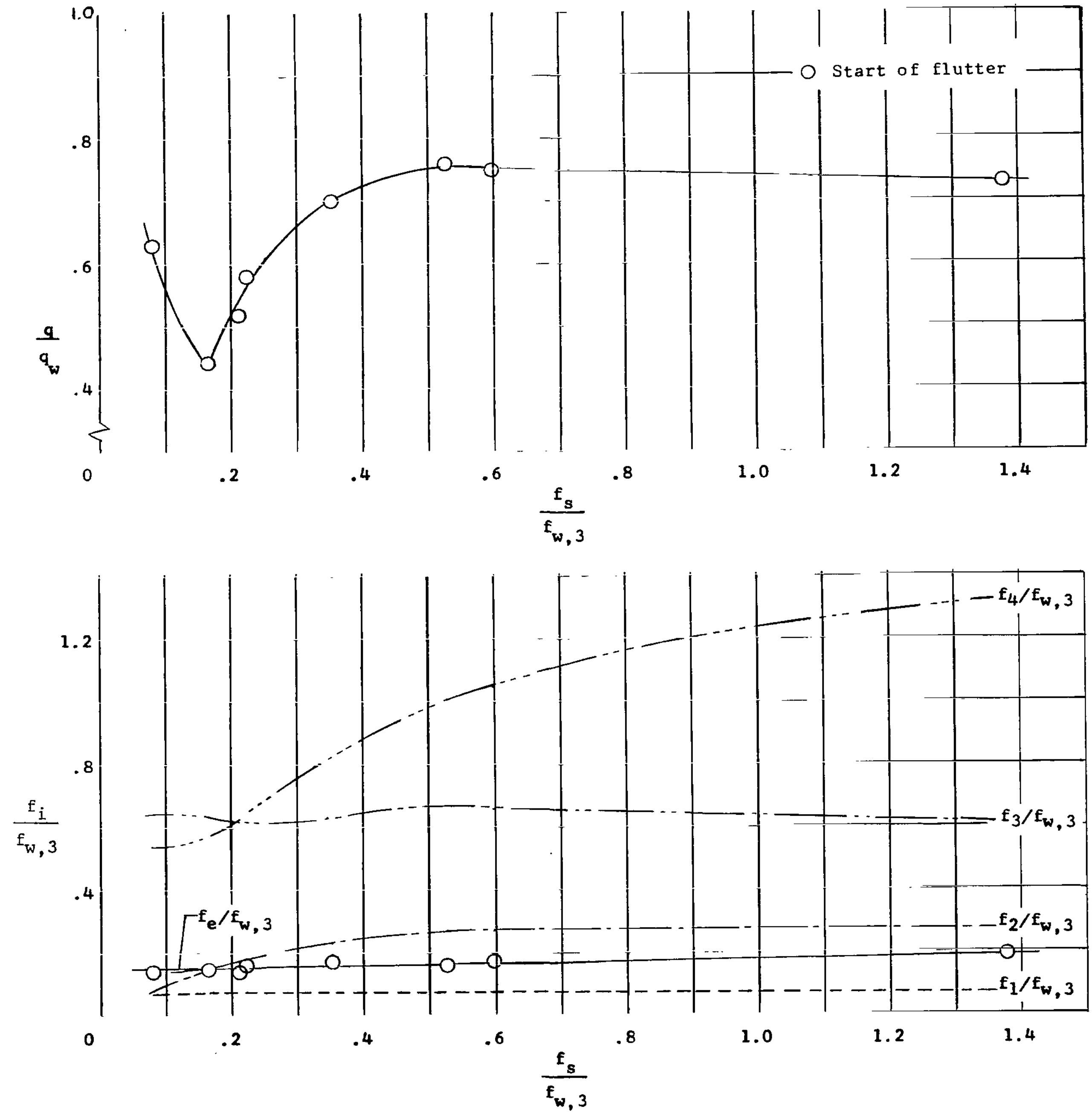
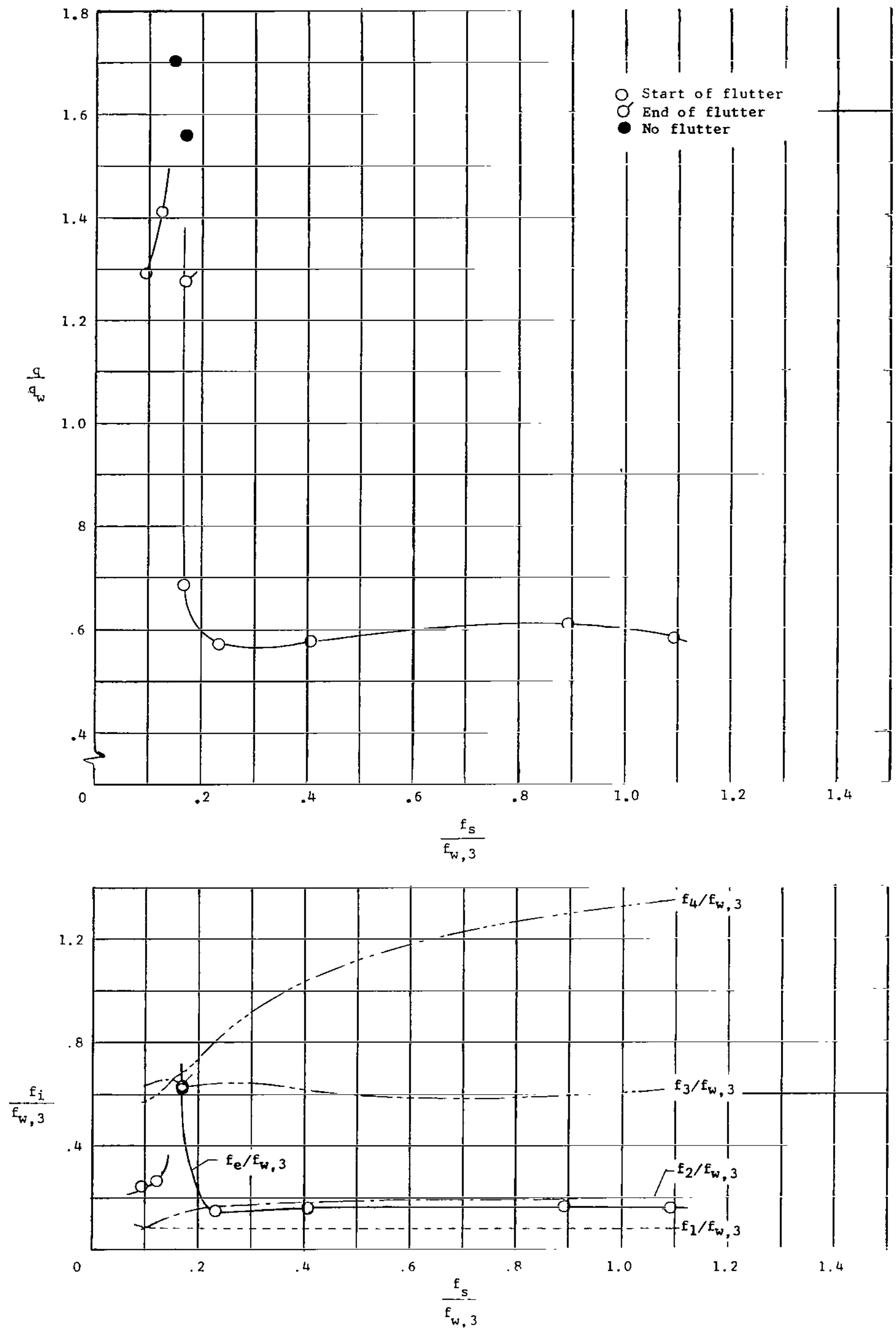


Figure 6.- Sketch of model showing positions at which mode shape deflections were measured. All dimensions are in inches.



(a) Rearward c.g. store.

Figure 7.- Effect of store-attachment pitch flexibility on the flutter characteristics of the wing-store configurations. $M \approx 0.85$.



(b) Forward c.g. store.

Figure 7.- Concluded.

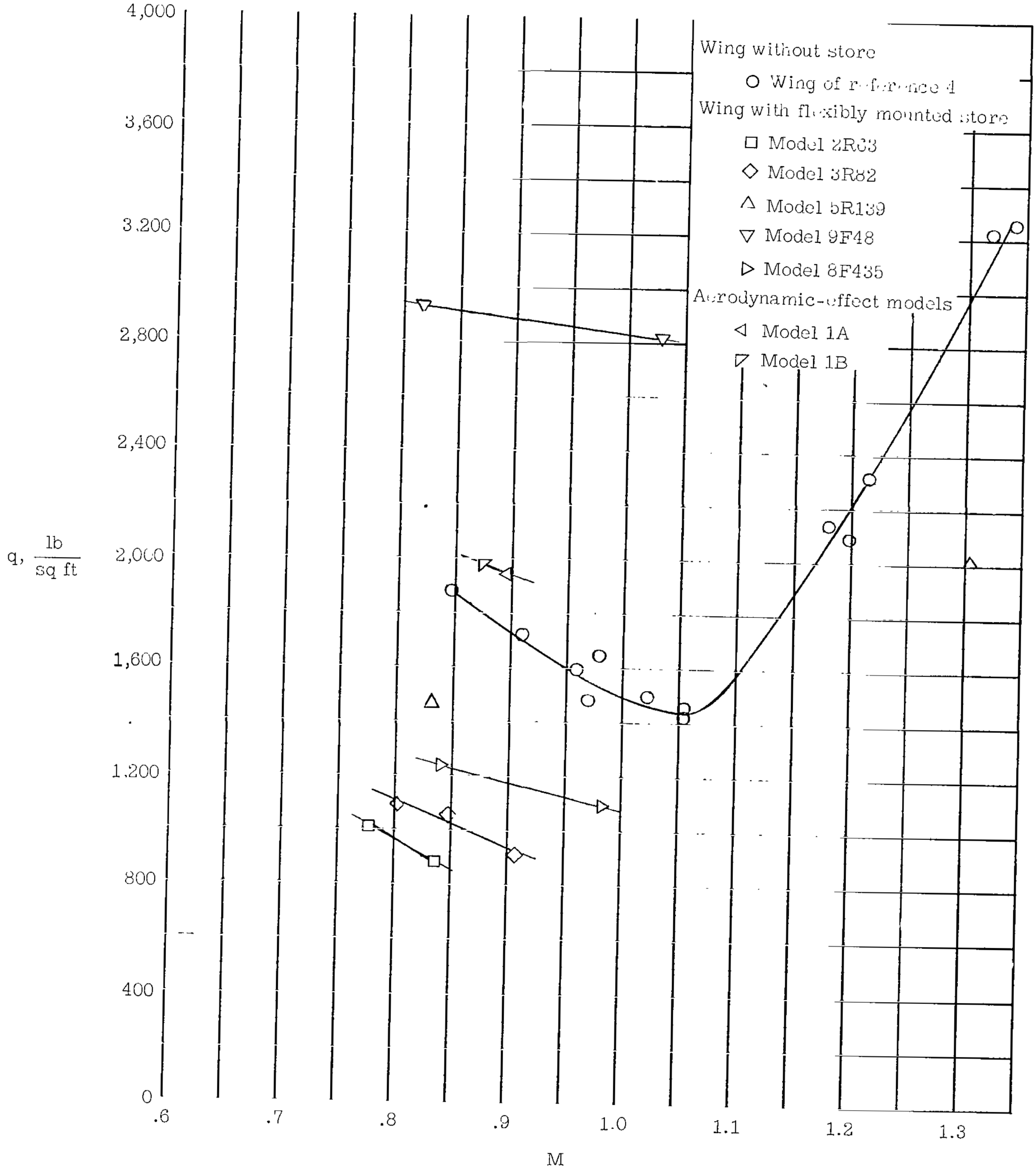


Figure 8.- Variation of flutter dynamic pressure with Mach number for several models.

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