NASA Contractor Report 177998

AN AIRFOIL FLUTTER MODEL SUSPENSION SYSTEM TO ACCOMMODATE LARGE STATIC TRANSONIC AIRLOADS

Wilmer H. Reed, III
DEI-Tech, Inc.
11838 Bunker Blvd., Suite 500
Newport News, VA 23606

CONTRACT NAS1-17686
OCTOBER 1985

National Aeronautics and Space Administration

Langley Research Center
Hampton Virginia 23665

CONTENTS

N86-14220#

LIST OF TABLES

SUMMARY

This paper describes the design, fabrication and laboratory evaluation tests of a pitch/plunge flutter model suspension system and associated two-dimensional MBB-A3 airfoil models. The system is designed for installation in the Langley 6-by-19-inch and 6-by-28-inch transonic blowdown wind tunnels to enable systematic study of the transonic flutter characteristics and static pressure distributions of supercritical airfoils at transonic Mach numbers. The system features variable pitch and plunge frequencies, changeable airfoil rotation axes and a self aligning control system to maintain a constant mean position of the model with changing airload. A compound spring suspension concept is introduced which simultaneously meets requirements for low plunge-mode stiffness, lightweight suspended model and large steady lift due to angle of attack without the need for excessive static deflections of the plunge spring.

INTRODUCTION

The minimum margin of safety from flutter for high performance aircraft usually occurs at transonic speeds where our analytical tools for predicting flutter are least reliable. Recent evidence from wind tunnel studies, flight test and theoretical analyses suggests that this so called "transonic flutter dip" may be even more severe for supercritical airfoils than conventional airfoils (see ref. 1 and 2, for example).

To gain further insight into the physical phenomena associated with transonic flutter of supercritical airfoils, the Air Force Systems Command sponsored an experimental research program aimed at investigating pitch/plunge flutter and the associated static pressure distributions on supercritical airfoils in a small transonic wind tunnel. The contract called for the design and fabrication of a pitch/plunge airfoil flutter test rig and two 6-inch span by 6-inch chord supercritical airfoil models equipped with static pressure orfices. One of the key research objectives of this program was to investigate and better understand the marked influence of angle-of-attack on transonic flutter which has been observed in prior studies, such as references 3 through 6. This required that the test rig be capable of keeping the flexibly mounted airfoil model centered in the wind tunnel test section with up to 1000 pound steady lift force developed. Because the system was found to have several structural deficiencies and inadequate centering force capability, the correction of which would require major modification, the test phase of the program was cancelled. The two airfoil models - MBB-A3 with and without camber - met or exceeded all requirements.

In a cooperative agreement with the Air Force, Langley Research Center subsequently contracted with DEI-Tech, Inc. to redesign and fabricate a new pitch/plunge airfoil test rig to meet the test objectives originally specified. The new apparatus would be designed to enable systematic study of transonic flutter of lifting, two-dimensional airfoils in the Langley 6-by 28-inch Transonic Blowdown Tunnel. In addition to the existing set of MBB-A3 airfoil models, a duplicate set of lightweight models, having the same profile but without pressure tubes and orifices, was built to enable investigation mass/air density ratio (μ) effects on flutter.

The purpose of this report is to describe the design, implementation, and performance testing of a pitch/plunge airfoil flutter suspension system capable of accomodating large static transonic airloads due to angle of attack.

SYMBOLS

c	Airfoil chord, in
b	Airfoil span, in
d	Distance from airfoil leading edge to airfoil cg, in
e	Length ratio of upstream to downstream compression links
E	Modulus of elasticity, psi
f_h	Uncoupled plunge frequency, hz
f_{ho}	Uncoupled plunge frequency when P = 0, hz
f	Uncoupled pitch frequency, hz
I_{cg}	Airfoil mass moment of inertia about c.g., $lb\text{-}in^2$
K_o	Spring constant of axial spring, lb/in
K_1	Spring constant of compression spring, lb/in
K_z	Effective spring constant of plunge spring, lb/in
l	Length of down stream compression link, in
L	Lift force, lb
m	Effective suspended mass of model and suspension system, $(lb\text{-}sec^2)/in$
P	Compression spring force, lb
P_o	Compression spring preload, lb

P_c	Critical compression spring preload (static instability), lb
t	Leaf spring thickness, in
X	Airfoil cordwise station measured from leading edge, in
z	Plunge-mode displacement, in
Y_u	Airfoil upper surface coordinate, in
Y_L	Airfoil lower surface coordinate, in
ρ	Free stream density, $(lb\text{-}sec^2)/in^4$
μ	Mass density ratio, $m/\pi\rho(c/2)^2b$
δ_{ST}	Static deflection of plunge spring, in

WIND TUNNELS

The airfoil flutter suspension system described herein is designed for installation in either the Langley 6-by 19-inch or the Langley 6-by 28-inch transonic blowdown wind tunnels. These tunnels have slotted top and bottom walls, turntables in both sidewalls, and were developed specifically for basic aerodynamic testing of small two-dimensional airfoil sections at Mach numbers from about 0.3 to 1.2. The 6-by 19-inch tunnel is described in reference 7. Compared to the 6-by 28-inch tunnel, it has limited Reynolds number capability (1.5×10^6 to 3.0×10^6) and its operation mode does not permit independent control of Mach number and stagnation pressure. In the present program, the 6-by 19-inch tunnel will be used primarily for functional checks and "tuning up" of the rig prior to entering the higher performance 6-by 28-inch tunnel. The 6-by 28-inch tunnel, described in reference 8, is capable of operating at stagnation pressures from 2 to 6 atmospheres. Mach number and stagnation pressure are independently controllable in a manner that tests may be conducted at Mach numbers from 0.5 to 1.0 with Reynolds number held constant up to 10×10^6 based on a 6.0-inch model chord. The operating envelopes of both tunnels are shown in Figure 1.

AIRFOIL MODELS

Static Pressure Distribution Models

Two 6-inch span, 6-inch chord airfoil models equipped with orifices and tubing for static pressure distribution measurements were provided by the Air Force. One model has an MBB-A3 profile with camber; the other, an MBB-3A profile without camber. The models were machined from stainless steel and polished to a mirror-like surface finish. Orifice locations are given in Table I and the theoretical and measured airfoil coordinates are listed in Table II.

In addition to static pressure distribution tests in which the airfoil would be rigidly mounted to turn tables in the tunnel side walls, the models can also be mounted to the pitch/plunge flutter rig for flutter testing. The airfoil pitch axes location for flutter testing can be either the 15% or 25% chord. Being of steel construction, these models are relatively heavy and, as a consequence, the mass/air density scaling parameter would probably be higher than that for most aircraft. Mass and inertia data for these models are given in Table III.

Lightweight Flutter Models

To investigate mass/air density ratio effects on flutter, two lightweight airfoil models were constructed. These models have the same geometric profiles of the existing steel airfoil models but are without pressure orifices and tubing. Constructed of graphic fiber composite skins with steel end fittings, they weigh less than 1/2 lb., about 15% of the steel airfoil weight. The aluminum molds from which the models were formed were measured and found to be within 0.002-inch of the theoretical airfoil coordinates. The lightweight models also have optional pitch axes locations of 15% and 25% chord. Mass and inertia data for these airfoils are also presented in Table III.

Static Air Loads

To estimate the maximum static aerodynamic loads expected during flutter tests in the 6-by 28-inch tunnel, use was made of the static pressure distribution measurements on the MBB-A3 airfoil given in reference 9. This estimate is for 0.8 Mach number at the maximum available dynamic pressure, 3850 p.s.f., and 5 degree angle of attack. The aerodynamic loads associated with this assumed "worst case" design conditions are: 800 lb. normal force and 1200 in-lb nose down pitch moment about the 15% chord.

PITCH/PLUNGE AIRFOIL FLUTTER SUSPENSION SYSTEM

Design Requirements

The objection of this effort is to provide an experimental capability to perform systematic pitch/plunge-type flutter tests of supercritical two-dimensional airfoils in Langley transonic blowdown wind tunnels. The combinations of pitch, f , and plunge, f_h, uncoupled frequencies required for flutter of the MBB-A3 airfoil at Mach 0.8 as a function of dynamic pressure are presented in Figure 2. Also shown are the dynamic pressures achievable at 0.8 Mach number in the 6- by 19-inch and the 6- by 28-inch transonic wind tunnels. These calculations were made by J. T. Batina, NASA-Langley, using a transonic unsteady aerodynamic code for 2-dimensional airfoils (XTRAN2L). Therefore, as a design goal the range of variation in the uncoupled pitch and plunge mode frequencies to be achieved were prescribed as f_α = 40hz to 100hz (pitch) and f_h = 10hz to 40hz (plunge). Some other specific design requirements are that the suspension system should have:

- Lightly damped uncoupled modes, characteristic of linear single degree-of-freedom dynamic systems.
- Lightweight suspended mass to enable simulation of mass/air density ratios representative of modern aircraft.
- Self aligning control system to automatically maintain the mean position of the airfoil as air loads change.
- Quick acting airfoil snubber system to suppress flutter oscillations.
- Changeable pivot locations ahead of the airfoil to simulate the steamwise bending mode shape of swept back wings which is characterized by a node line ahead the wing leading edge as illustrated in Figure 3.
- Pitch axis ("elastic axis") location variable at 15% and 25% chord.

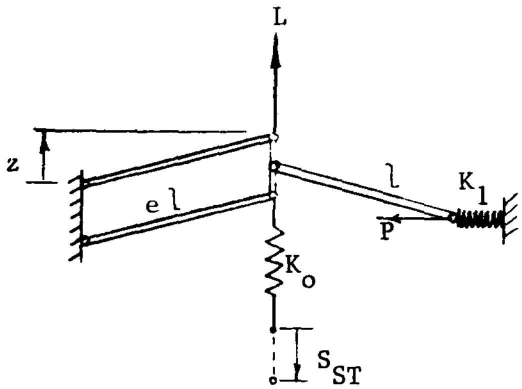
The mass and stiffness properties of the suspension system are dictated by flutter scaling considerations, that is, the suspended masses must be lightweight in order to simulate realistic mass/air density reactions and the suspension stiffness such that flutter can occur within the wind tunnel operating envelope. With the additional requirement that the system also accomodate large steady air loads, the static deflections of the suspension springs may exceed practical limits. This is especially critical for the plunge mode at low frequency settlings.

By way of illustration, assume that the moving mass of the suspension system with the airfoil model installed is 2.5 pounds and the plunge mode frequency, f_h = 10 hz. The corresponding plunge spring stiffness, K_z, is 25.6 lb/in. Thus, to counteract the 800 lb. design lift force the plunge spring must deflect 31 inches.

Compound Spring Concept

The search for a solution to meet these conflicting requirements-- that the spring system have low stiffness, high load carrying capability and a minimum weight-- led to a concept originally investigated by Molyneux in 1961 (ref. 10) as a means of vibration isolation and subsequently was further developed in unpublished work by Robert Herr of NASA Langley Research Center.

This concept involves two springs and pin-ended rigid links configured as indicated schematically in the sketch A below:



Sketch A: Compound spring concept

The horizontal spring, K_1, is preloaded to produce a controllable compressive force, P, in the rigid links. When the joined end of the links is displaced vertically through a distance z, as shown, these compressive forces act in the same direction as the displacement and thereby function as a negative stiffness tending to counteract the positive stiffness, K_o, in the axial spring. The net stiffness in the z direction is given by the equation (see Appendix A for deviation.)

$$\frac{dL}{dZ} = K_z = K_o(1 - P/P_c)$$

where

$$P_c = K_o l \left(\frac{e}{1 + e}\right)$$

P_c is the critical compressive force at which the system becomes statically unstable. (analogous to the critical load in column buckling.) Therefore, by varying the compressive force in the links the effective stiffness, K_z can be varied from a maximum value of K_o to a minimum approaching zero. An important feature of the compound-spring system is that the static deflection, $_{ST}$, needed to counteract a given load depends only on K_o, irrespective of the lower-valued effective stiffness. By contrast, the static deflection of a single linear spring system varies inversely with stiffness. Shown in figure 4 are static deflections versus plunge-mode frequency for a single-spring and compound-spring system. These results are for the same 2.5 pound suspended mass and 800 pound lift force considered in the previous example. In this case K_o was sized to produce a f_{ho} = 40hz (plunge-mode frequency when there is no force in the compression links). Note that static deflection associated with the 800 pound lift force is approximately 2 inches, for all frequencies below 40hz.

DESIGN IMPLEMENTATION

General Description

The implementation of suspension system design concepts into functional hardware may be described by referring to figures 5 through 7. Figure 5 shows drawings for the suspension system installation in the 6- by 28-inch wind tunnel. The pitch/plunge linkage mechanism which suspends the airfoil model, is mounted to and rotates with turntables installed in the test section side walls of either the 6- by 19-inch or 6- by 28-inch tunnel. Photographs of this linkage mechanism (figure 6) and an exploded view of the model attachment components (figure 7) reveal some construction details.

The airfoil model is supported at each end by drag links which extend forward to pivot axes on the C-frame mounting fixture which attaches to the turntable. When the drag links are configured as a four-bar parallelogram, the plunge mode exhibits pure translation. Also, to enable simulation of the bending mode of a swept back wing, two forward knife-edge pivot locations are available, as shown at the top of figure 5. To minimize friction, rotational bearings throughout the system are either cross-beam flexures or knife edges.

Plunge mode stiffness and lift balancing forces are provided by cantilevered leaf springs located above and below the model on either side of the test section. These springs are connected to the model by means of single-strand wires. (It was found that braided wire cable produced excessive damping.) The lower spring set with two springs on each side, is designed to counteract airfoil lift and the upper springs serve to maintain tension in the system. These springs, as well as those used for the pitch mode, are made of laminated fiberglass sheet stock with constant thickness and tapered planform. Some significant benefits offered by the use of fiberglass over other candidate spring materials are discussed later in the paper.

To implement the compound-spring concept illustrated earlier, the compression spring (K_1 in sketch A) takes the form of an elastically deformed beam supported at the center by a compression link and loaded at each end by threaded tension rods with nuts as shown in figures 5 and 6. The compression force, and consequently the plunge-mode frequency, is proportional to the number of turns of the nuts used to deform the compression spring.

To suppress flutter, quick-acting snubbers are provided which apply a braking force to the plunge mode via the pretension wires.

The pitch spring stiffness and static balancing moments are imparted to the model through a pitch arm connected by tensioned wires to the main pitch springs and pre-tension spring as indicated in figure 6. The airfoil pitch shaft and cross-beam flexure are clamped in the pitch arm housing, providing frictionless rotation of the airfoil through $\pm 5^{o}$ relative to the mean angle-of-attack setting which is controlled by the turntable angle.

Self Alignment Control System

The suspension system is equipped with a dual mode control system. The control system may be operated in either a manual mode, allowing full manual control over airfoil pitch and plunge position, or in automatic mode which automatically maintains the airfoil in a previously established neutral position. The airfoil is positioned and balanced in the neutral zone by means of two 1500 lb. linear electric-motor-driven actuators. Each actuator has a four-inch stroke which provides capability for airfoil pitch variations of $\pm 1/2^{o}$ and plunge variations of ± 0.5-inches. Each actuator is independently controlled and operated via a control box. The actuators also maintain position by counteracting the static lift and pitching airloads. Details of the control box, control panel layout, and complete circuit diagram for the control system electronics are contained in Appendix B. To avoid the addition of damping, non-contacting optical sensors are used to sense the airfoil positions. The optic sensors are operational in automatic mode and provide signals to engage the appropriate actuator and drive the airfoil back to the neutral position. The control panel indicators, also operational in automatic mode, indicate general airfoil position and operational status of actuators. Foul lights are provided to signal the airfoil contacting the stops. Foul indicators are operational in either manual or automatic modes.

The control box contains the snubber actuation switch and snubber indicator light. The snubber is provided as a manual flutter suppression system.

Spring Design

A considerable number of engineering trade-off studies were made to determine the spring design and material properties best suited to satisfy conflicting requirement regarding stiffness, strength, weight and static deflection. These studies led to the selection of a uniformly stressed cantilevered leaf spring having constant thickness, linearly tapered planform, and loaded at the tip. For a given length and base dimension of the spring, the thickness required to provide a specified spring constant was determined by linear theory in terms of the bending modulus of elasticity of the spring material. Specification of a static applied load at the end of the spring then defines the stress. Figure 8 shows results of calculations of the variation of stress with bending modulus of elasticity for given spring stiffnesses. These results are also for the 2.5 pound suspended mass and 800 pound lift condition considered in earlier examples. The suspended mass and lift load is assumed to be equally shared by a set of four plunge springs, the length and base width of which are 11 inches and 2.5 inches. The family of curves in figure 8 are presented in terms of plunge-mode frequencies and spring thicknesses for $P/P_c = 0$. Trends shown in figure 8 obviously point toward the selection of a low elastic modulus, high strength spring material. For the present design the choice was laminated fiberglass sheet stock having a modulus of elasticity of about 3.5×10^6 psi and an ultimate stress of 80,000 psi. Also shown in figure 8, for comparison, is stainless steel spring material with a modulus of elasticity of 30×10^6 psi and ultimate stress of 155,000 psi.

Instrumentation

Pretension springs are instrumented with strain gauges to enable the measurement of pitch and plunge mode deflections. In addition, a more sensitive measure of airfoil pitch angle is obtainable via a metallic film potentiometer connected in a bridge circuit to sense motion of the pitch arm. The mean normal force and pitching moment loads on the airfoil are monitored by means of strain-gauged ring-type load cells installed in the pitch and plunge spring cables.

LABORATORY TESTS

Proof Load Test

To demonstrate the structural integrity of the suspension system, proof load tests were performed at 120% of design load conditions. The loading fixture consisted of a metal-beam frame which duplicated the wind tunnel structure in the vicinity of the turn tables and other system tie down points. A metal loading pad, bonded to the undersurface of the airfoil model, was blocked from beneath by a spanwise roller pivot at mid chord. Using the plunge-mode actuator, a vertical force was produced at the airfoil pitch axis (15% chord) and reacted by an opposing "lift" force acting at the midchord. Several structural weaknesses were discovered and corrected during load build up, after which the suspension system successfully withstood the 1000 pound maximum simulated lift load.

Stiffness Measurements

Pitch and plunge stiffness measurements were obtained by applying an upward force at the airfoil mid chord and measuring the resultant pitch angle and vertical displacements relative to the neutral position. Some typical results from such measurements shown in figures 9 and 10. For the plunge mode, (figure 9) the vertical deflection due to vertical force is given for three compression force ratios: P/P_c = 0, 0.37, and 0.75. Also shown for comparison with the measured data are predictions based on theory (see equation 5 in Appendix A.) Note that both theory and experiment indicated a tendency toward increasing stiffness for spring deflections greater than about 0.25 inches. The maximum plunge deflection is limited by mechanical stops set at $\pm$ 1/2 inch.

Pitch-mode stiffness characteristics are presented in Figure 10. Over the 0^{o} to 2^{o} pitch angle range of the test, the variation of pitch angle with applied moment is essentially linear and insensitive compressive force ratios.

Modal Characteristics

To determine modal frequency and damping characteristics of the suspension system, frequency response functions were measured using a digital modal analyzer and impact testing techniques. The airfoil model was tapped with an instrumented hammer and the acceleration response measured.

Some typical frequency response measurements obtained on the suspension system are shown in figure 11. Note that as the spring compression force is increased from zero to 87% of its critical value, the plunge mode frequency decreases from 28.5hz to 11.6hz. Also, damping of the plunge becomes more pronounced with increasing compression force. Experience with the system has shown that there is an upper practical limit for the compressive force above which the plunge mode ceases to behave as a lightly damped single degree-of-freedom system. This usually occurs in the vicinity of P/P_c = 0.8 to 0.9. The pitch-mode frequency and damping, on the other hand, is unaffected by such changes.

The change in plunge-mode frequencies indicated by the frequency response functions (figure 11) is plotted in figure 12 as a function of the compression force ratio P/P_c. Also plotted are similar results obtained using a stiffer set of plunge springs which provide a maximum frequency of f_{ho} = 37.4hz. The predicted curve shown in figure 12 is seen to be in reasonable agreement with the measured results.

Self Alignment Control System

The self aligning control system functions to maintain the airfoil's vertical position and pitch angle within prescribed bounds for changing mean aerodynamic load conditions. The accuracy of position control depends upon the width of the deadband setting within which the optic position sensors are inactive. The choice of a suitable deadband setting involves trade-offs between positioning accuracy and stable operation. The smaller the deadband the better the accuracy. However, should the deadband become too small the control system will encounter limit cycle oscillations.

To evaluate the performance characteristics of the self-alignment control system, the transient response of the system following the abrupt release fo a 100-lb. normal force acting at the airfoil midchord (pitch axis at 1/4 chord) was measured. figure 13 shows sample time histories of pitch and plunge motion as the actuators drive the airfoil back to its initial trimmed state. Typically, the control system maintains steady state alignment of the airfoil with accuracies better than $\pm$ 0.1" plunge deflection and $\pm$ 0.1 degrees pitch angle.

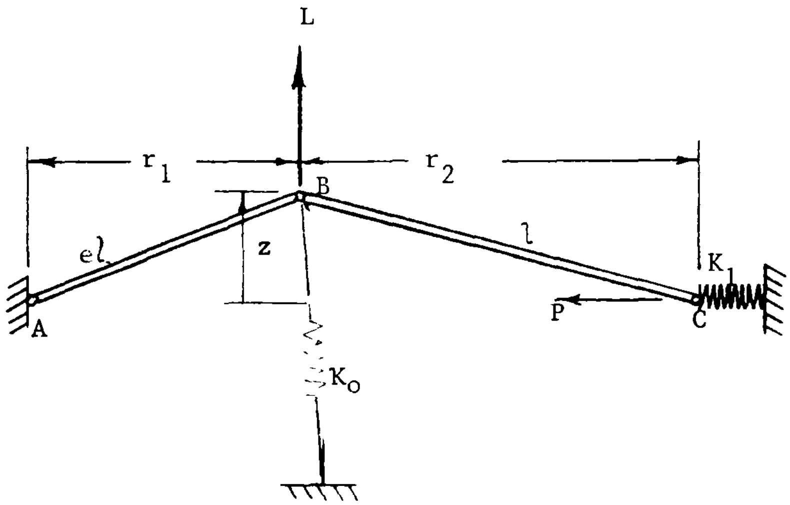
CONCLUDING REMARKS

This paper has described a flutter model suspension system designed to enable systematic investigations of pitch/plunge flutter characteristics of two-dimensional airfoils in the Langley 6-by 28-inch transonic wind tunnel. Also described were the MBB-A3 airfoil models to be used to obtain flutter stability boundaries and static pressure distributions.

The suspension system design approach introduced a compound spring concept which simultaneously meets requirements for relatively low plunge mode stiffnesses, lightweight suspended models, and large steady lift force due to angle of attack while keeping the static deflections of the plunge spring within reasonable limits. The system features pitch and plunge frequencies that can be varied over a wide range, lightweight moving masses needed to simulate the mass-air density scaling parameter, changeable airfoil rotation axes, and a self aligning control system which maintains position of the airfoil in test section under changing airloads. In addition, pivot axes ahead of the airfoil are provided so that the bending motions of sweptback wings can be simulated by the airfoil plunge mode.

It is anticipated that this airfoil flutter testing apparatus will provide a research tool to enable better understanding of the transonic flutter behavior of the MBB-A3 and other supercritical airfoils to follow.

APPENDIX A: Derivation of Compound Spring Equations



Compound Spring System

The compound spring system shown in the sketch consists of rigid members AB and BC that are hinged at point B and subjected to compressive force P due to compression of the horizontal spring K_1. Let L be the vertical force (lift) acting at B required to displace B at distance z. This movement is resisted by the stretching of spring Ko but is assisted by forces in the compression links as they become inclined upward. In other words, the compression links act as negative springs in opposition to the restoring force of spring Ko.

Assume z to be small relative to the length of members AB and BC. P_{AB} and P_{BC} are the axial forces in links AB and BC necessary to balance the vertical component of compression force P in spring K .

The total axial reaction force is then

$$L = zK_o + P_{AB} + P_{BC} \tag{1}$$

$$= zK_o - P(z/r_1) - P(z/r_2) \tag{2}$$

where

$$P = P_o + K_1 \ell [(1 + e) - (r_1/\ell + r_2/\ell)] \tag{3}$$

substituting equations 3 into 2

$$L = K_o z - [P_o - K_1 \ell (1 + e - r_1/\ell - r_2/\ell)] (z/r_1 + z/r_2) \tag{4}$$

since

$$r_1 = l\sqrt{e^2 - (z/l)^2}$$

$$r_2 = l\sqrt{1 - (z/l)^2}$$

equation 4 can be written

$$L = K_o z - z/l \left[P_o - K_1 l\left(1 + e - \sqrt{e^2 - (z/l)^2} - \sqrt{1-(z/l)^2}\right)\right] \times \left[\frac{z}{\sqrt{e^2-(z/l)^2}} + \frac{z}{\sqrt{1-(z/l)^2}}\right] \quad (5)$$

The effective spring constant, K_z, is obtained by differentiation of equation 5

$$K_z = \frac{dL}{dz} = A + \frac{Be^2 + Ce^2\sqrt{1 - (z/l)^2}}{[e^2 - (z/l)^2]^{3/2}} - \frac{2C(z/l)^2}{\sqrt{[e^2 - (z/l)^2][1-(z/l)^2]}} + \frac{B + C\sqrt{e^2 - (z/l)^2}}{[1 - (z/l)^2]^{3/2}} \quad (6)$$

where $A = l(K_o - 2K_1)$

$B = K_1 l(1 + e) - P_o$

$C = -K_1 l$

The effective spring constant for the system when the external load is counteracted by the static deflections of K_o is obtained by setting $Z = 0$ in equation 6

$$K_z = K_o - P_o/l\left(\frac{1 + e}{e}\right) \quad (7)$$

When $K_z = 0$ the system has neutral static stability, thus the critical compression force, P_c, above which the system becomes statically unstable, may be determined from equation 7 by letting $K_z = z = 0$ and solving for $P_o = P_c$ to obtain

$$P_c = K_o l\left(\frac{e}{1 + e}\right) \quad (8)$$

Thus, the effective stiffness for the compound spring system in its neutral position becomes simply

$$K_z = K_o(1 - P/P_c) \quad (9)$$

or in terms of the uncoupled plunge mode frequency

$$f_h = \frac{1}{2\pi}\sqrt{\frac{K_z}{m}} \tag{10}$$

therefore

$$f_h/f_{ho} = \sqrt{1 - P/P_c} \tag{11}$$

WIRING DIAGRAM

o Sensor plug

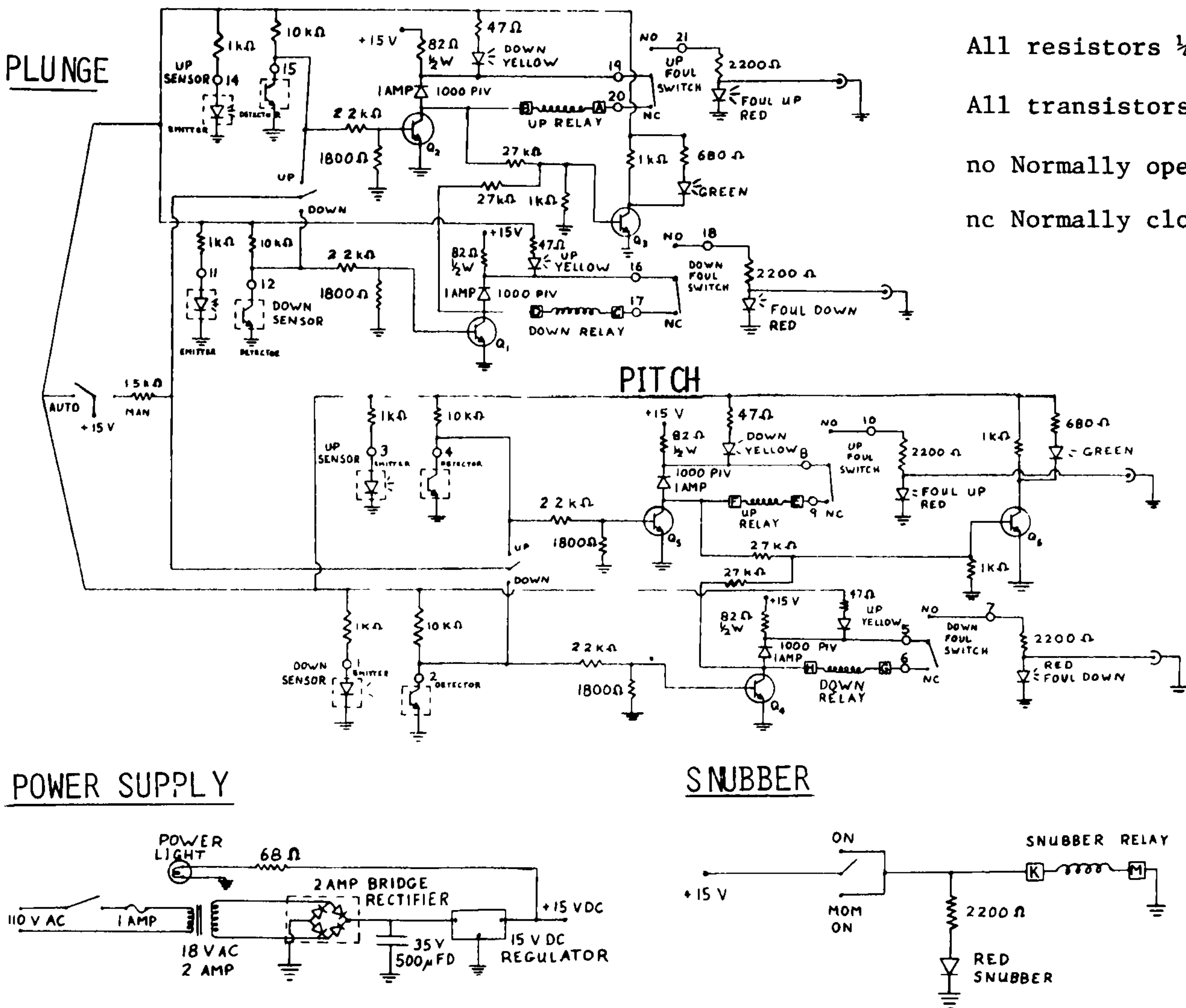
□ Relay box plug

All resistors ¼ W unless specified

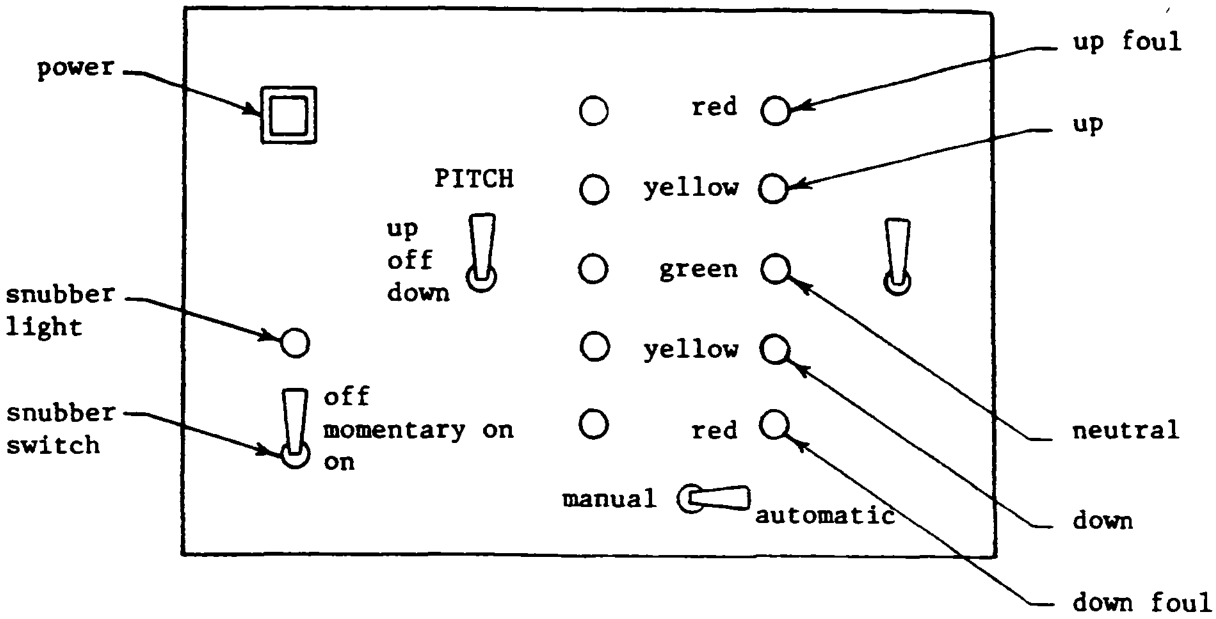
All transistors 2N2222

no Normally open

nc Normally closed



CONTROL PANEL



Power Button: Activates the control box.

Automatic/Manual Switch: Transfers the system from manual to optic sensor automatic control.

Pitch and Plunge Switches: Are used only in the manual mode. Switching plunge up - drives airfoil up; plunge down - drives the airfoil down; pitch up - increases the angle of attack; pitch down reduces the angle of attack.

Indicator Lights: Shows the status of the airfoil. Illumination of the red lights indicates that the airfoil is against the stops, green lights indicate that the airfoil is in the neutral position, and yellow lights indicate that the actuator is driving the airfoil toward the neutral position.

Snubber Switch: Activates the snubbers which damp vibrations. The snubbers may be activated in momentary bursts (the upper switch position) or continuously (the down switch position.)

REFERENCES

1. Farmer, Moses G.; Hanson, Perry W.; and Wynne, Eleanor C.: "Comparison of Supercritical and Conventional Wing Flutter Characteristics." NASA TM-72837, 1976.

2. Houwink, R.; Kraan, A. N.; and Zwaan, R. J.: "A Wind-Tunnel Study of the Flutter Characteristics of a Supercritical Wing." AIAA Paper Number: 81-0651, 1981.

3. Ashley, H.: "Role of Shocks in the `Sub-Transonic' Flutter Phenomenon." Journal of Aircraft, Volume 17, Number 3, March 1980, pages 187-197.

4. Dobbs, S. K.; Miller, G. D.; and Stevenson, J. R.: "Self Induced Oscillations and Wind Tunnel Tests of a Variable Sweep Wing." Presented at the AIAA/ASME/ASCE/AHS 26th Annual Structures, Structural Dynamics, and Materials Conference, Orlando, Florida, April 15-17, 1985.

5. Yates, E.C., Jr., Wynne, E.C., and Farmer, M.G.: "Measured and Calculated Effects of Angle of Attack on the Transonic Flutter of a Supercritical Wing", Proceedings of the AIAA/ASME/ASCE/AHS 23rd Annual Structures, Structural Dynamics, and Materials Conference, New Orleans, Louisiana, May 1982, pages 122-144.

6. Edwards, J.W.; Bennett, R.M., Whitlow, W., Jr., and Seidel, D.A.: "Time-Marching Transonic Flutter Solutions Including Angle-of-Attack Effects", Proceedings of the AIAA/ASME/ASCE/AHS 23rd Annual Structures, Structural Dynamics and Materials Conference, New Orleans, Louisiana, May 1982, pages 220-233.

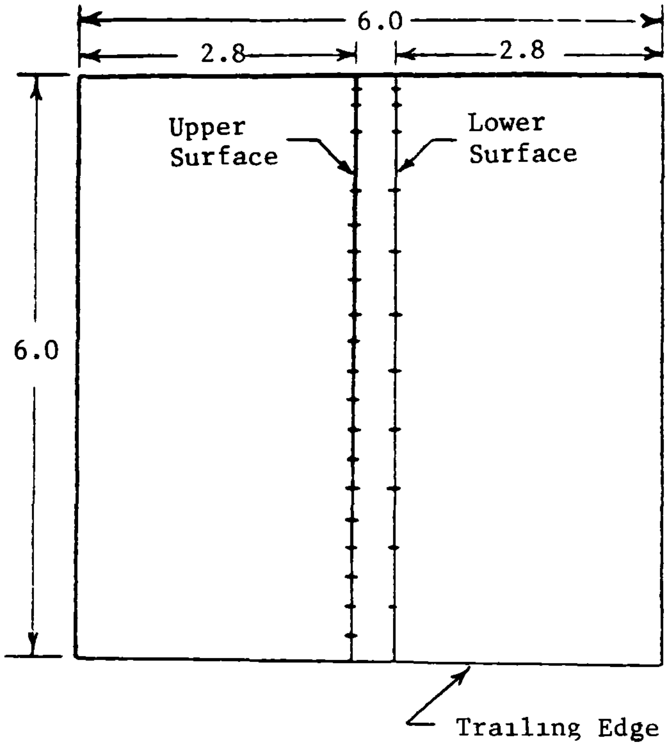
7. Ladson, C.L.: "Description and Calibration of the NASA-Langley 6- by 19-inch Transonic Wind Tunnel. NASA TN D-7582, 1973.

8. Ladson, C.L.: "Description and Calibration of the NASA-Langley 6- by 28-inch Transonic Wind Tunnel". NASA TN D-8070, 1975.

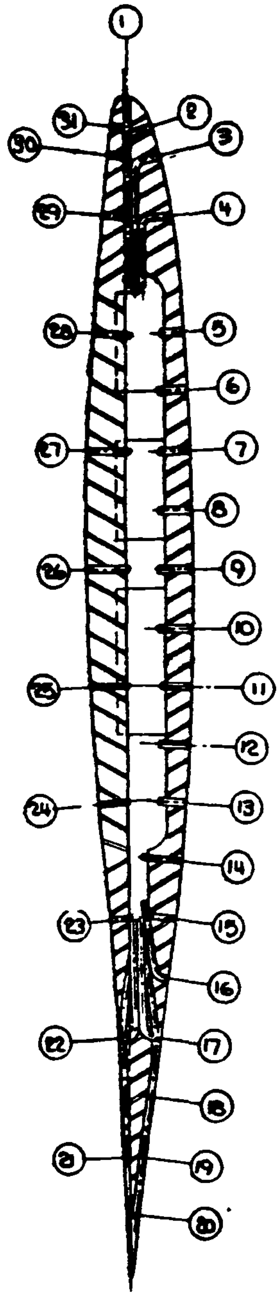
9. Bucciantini, G.; Oggiano, M.S.; and Onorato, M.: "Supercritical Airfoil MBB-A3 Surface Pressure Distributions, Wake and Boundary Condition Measurements." Report of the Fluid Dynamics Panel Working Group 04, AGARD Advisory report Number 138, May 1979.

10. Molyneux, W.G.: "Design of Non-Linear Supports for Vibration Isolation of Very Low Frequencies." The Engineer, Volume 211, Number 5501, June 1961.

TABLE I: Static Pressure Orifice Locations on MBB-A3 Airfoil Models



AIRFOIL PLANFORM



ORIFICE LOCATIONS			
Upper Surface		Lower Surface	
Press. Tap No.	Dist. From L.E., IN	Press. Tap No.	Dist. From L.E., IN
1	0	21	5.40
2	.15	22	4.80
3	.30	23	4.20
4	.60	24	3.60
5	1.20	25	3.00
6	1.50	26	2.40
7	1.80	27	1.80
8	2.10	28	1.20
9	2.40	29	.60
10	2.70	30	.30
11	3.00	31	.15
12	3.30		
13	3.60		
14	3.90		
15	4.20		
16	4.50		
17	4.80		
18	5.10		
19	5.40		
20	5.70		

TABLE IIa: MBB-A3 Uncambered Airfoil Coordinates

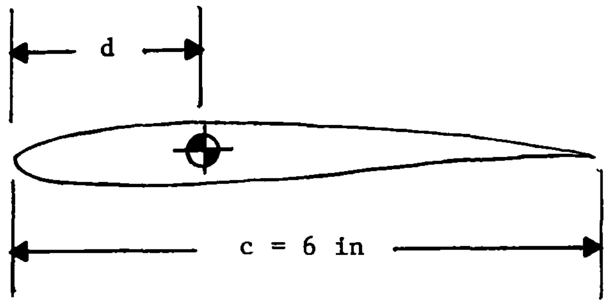
Theorectical Contour			Measured		Deviation x 10^3	
X/c	Y_u/c	Y_L/c	Y_u/c	Y_L/c	$\Delta Y_u/c$	$\Delta Y_L/c$
0.0012	0.0048	0.0048	0.0050	0.0045	0.250	0.300
0.0021	0.0060	0.0060	0.0061	0.0051	0.050	0.967
0.0125	0.0128	0.0128	0.0130	0.0125	0.280	0.250
0.0275	0.0174	0.0174	0.0177	0.0172	0.350	0.016
0.0375	0.0195	0.0195	0.0197	0.0194	0.250	0.083
0.0541	0.0223	0.0223	0.0225	0.0222	0.180	0.050
0.0761	0.0254	0.0254	0.0255	0.0253	0.117	0.050
0.1055	0.0289	0.0289	0.0289	0.0288	0.067	0.067
0.1602	0.0342	0.0342	0.0343	0.0341	0.067	0.067
0.2172	0.0384	0.0384	0.0385	0.0384	0.050	0.000
0.2655	0.0411	0.0411	0.0411	0.0411	0.033	0.016
0.3919	0.0442	0.0442	0.0442	0.0444	0.017	0.200
0.4929	0.0423	0.0423	0.0422	0.0424	0.033	0.150
0.5964	0.0360	0.0360	0.0362	0.0363	0.117	0.267
0.6478	0.0318	0.0318	0.0319	0.0321	0.113	0.317
0.7030	0.0267	0.0267	0.0269	0.0271	0.183	0.430
0.7905	0.0183	0.0183	0.0186	0.0190	0.317	0.730
0.9078	0.0080	0.0080	0.0086	0.0088	0.583	0.817
0.9668	0.0034	0.0034	0.0036	0.0041	0.283	0.730
1.0000	0.0008	0.0008	0.0003	0.0010	0.483	0.250

TABLE IIb: MBB-A3 Cambered Airfoil Coordinates

Theorectical Contour			Measured		Deviation x 10^3	
X/c	Y_u/c	Y_L/c	Y_u/c	Y_L/c	$\Delta Y_u/c$	$\Delta Y_L/c$
0.0012	0.0070		0.0072		0.217	
0.0021	0.0088		0.0897		0.167	
0.0075		0.0057		0.0060		0.267
0.0125	0.0186		0.0189		0.317	
0.0225		0.0088		0.0089		0.050
0.0275	0.0252		0.0255		0.283	
0.0325		0.0102		0.0102		0.033
0.0375	0.0282		0.0286		0.330	
0.0480		0.0118		0.0119		0.117
0.0541	0.0322		0.0325		0.350	
0.0681		0.0136		0.0139		0.230
0.0761	0.0364		0.0367		0.350	
0.0947		0.0160		0.0163		0.230
0.1055	0.0408		0.0411		0.350	
0.1602	0.0468	0.0215	0.0471	0.0218	0.280	0.217
0.2172	0.0513	0.0256	0.0515	0.0258	0.230	0.230
0.2655	0.0539	0.0283	0.0541	0.0286	0.220	0.267
0.3919	0.0568	0.0316	0.0570	0.0320	0.230	0.350
0.4927	0.0553	0.0293	0.0554	0.0296	0.100	0.330
0.5964	0.0497	0.0224	0.0498	0.0229	0.150	0.483
0.6428	0.0453	0.0183	0.0455	0.0189	0.180	0.530
0.7030	0.0394	0.0140	0.0394	0.0147	0.830	0.630
0.7905	0.0283	0.0082	0.0288	0.0088	0.450	0.567
0.9078	0.0134	0.0026	0.0142	0.0033	0.820	0.650
0.9668	0.0059	0.0008	0.0067	0.0013	0.850	0.467
1.0000	0.0016	0.0000	0.0021	0.0015	0.517	0.150

Table III: System Weights and Inertias

AIRFOIL MODELS



MBB-A3 AIRFOIL	MATERIAL	d/c	Wt., lb.	Icg $lb\text{-}in^2$
Cambered	Steel	.449	2.837	6.000
Symmetric	Steel	.445	2.782	5.930
Cambered	Graphite	.292	.451	.675
Symmetric	Graphite	.292	.442	.668

SUSPENSION SYSTEM

Effective moving weight = 2.13 lb

Inertia about pitch axis = 2.20 $lb\text{-}in^2$

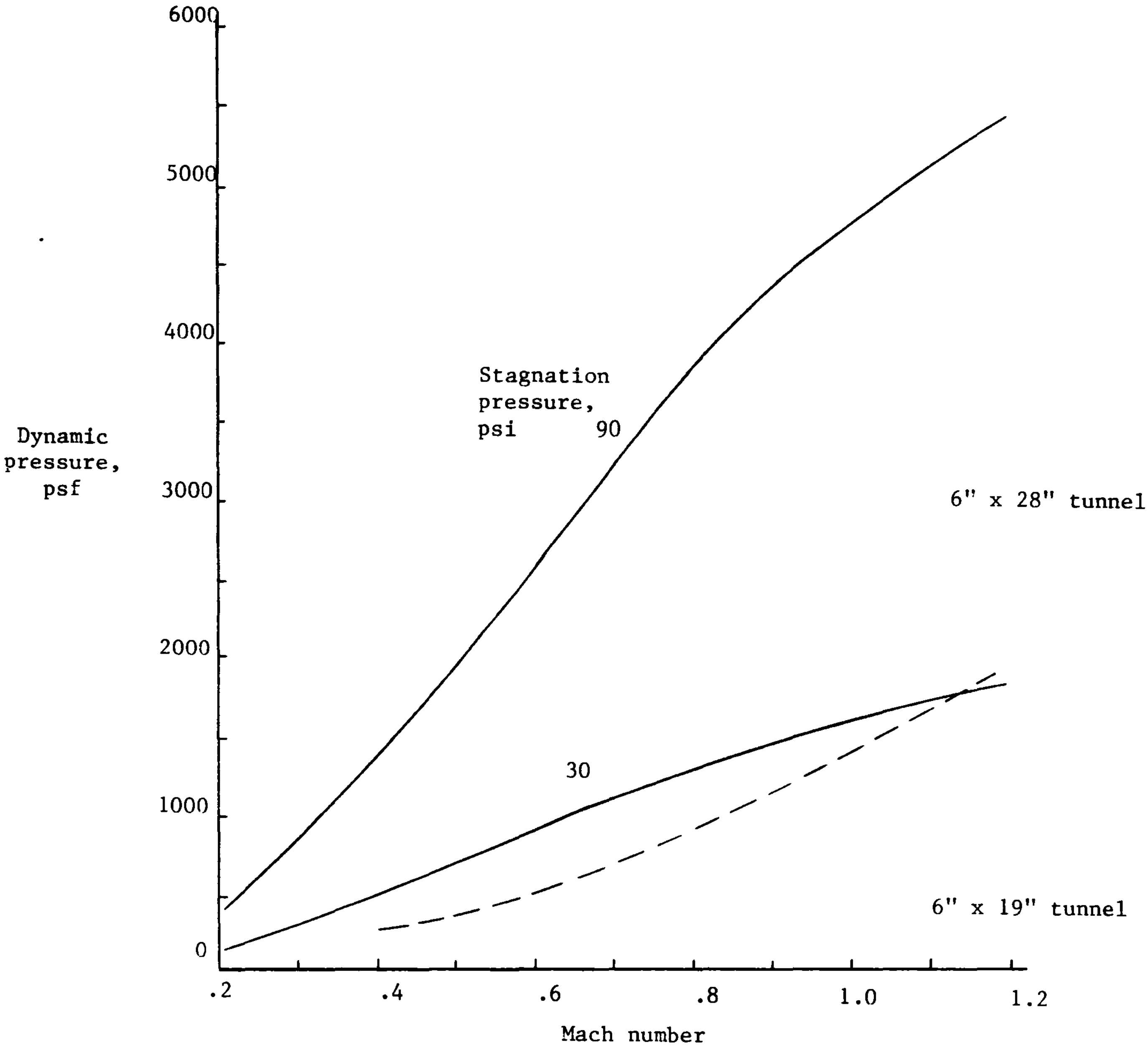


Figure 1: Dynamic pressure capabilities of the Langley 6-by 28-inch transonic blowdown wind tunnels.

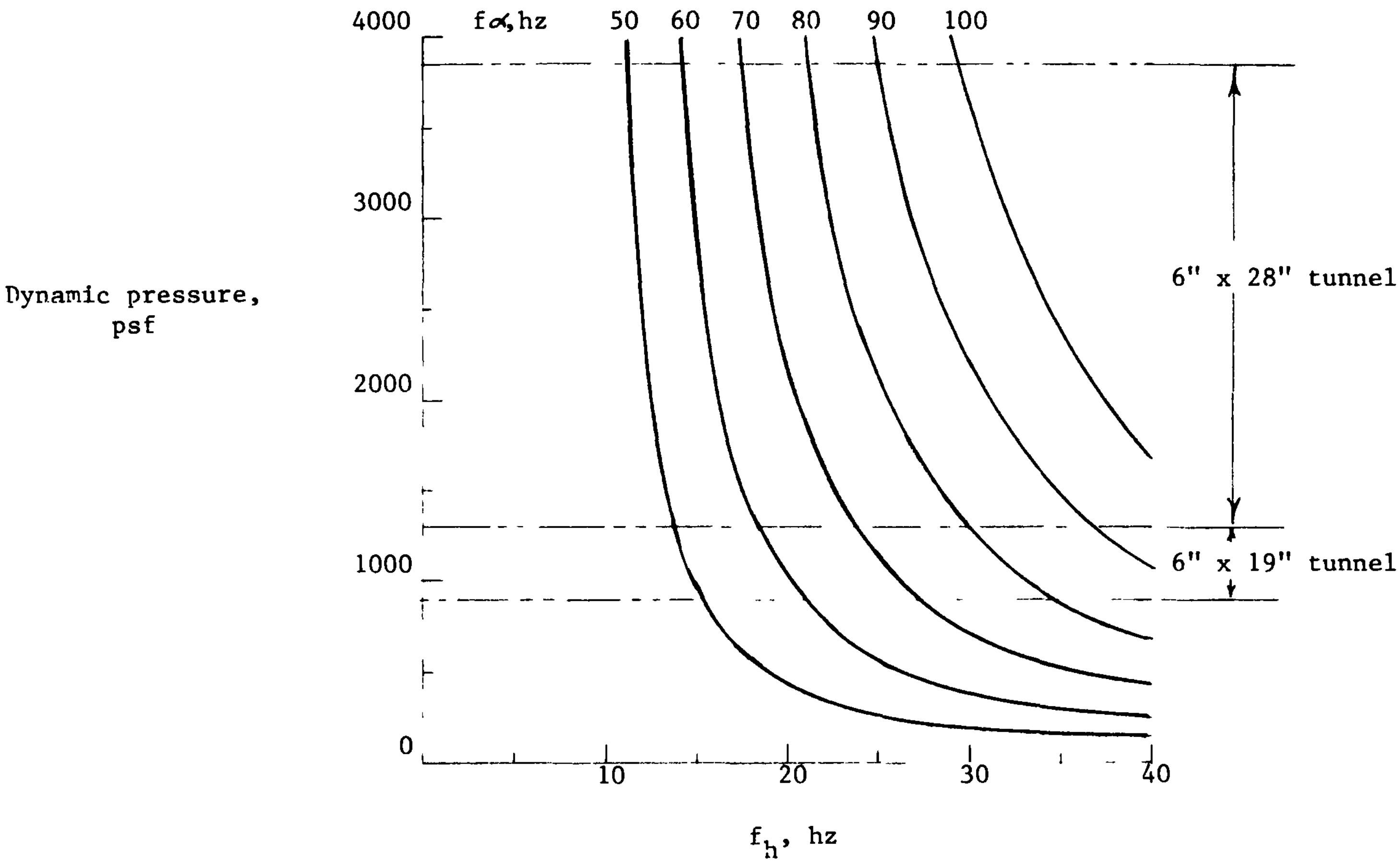


Figure 2: Flutter boundaries predicted for the MBB-A3 cambered airfoil model for: $M = 0.8$, $\alpha = 1.0°$, $\mu = 100$, ¼ chord pitch axis

PLUNGE MODE SHAPES OF 2-D AIRFOIL SECTIONS

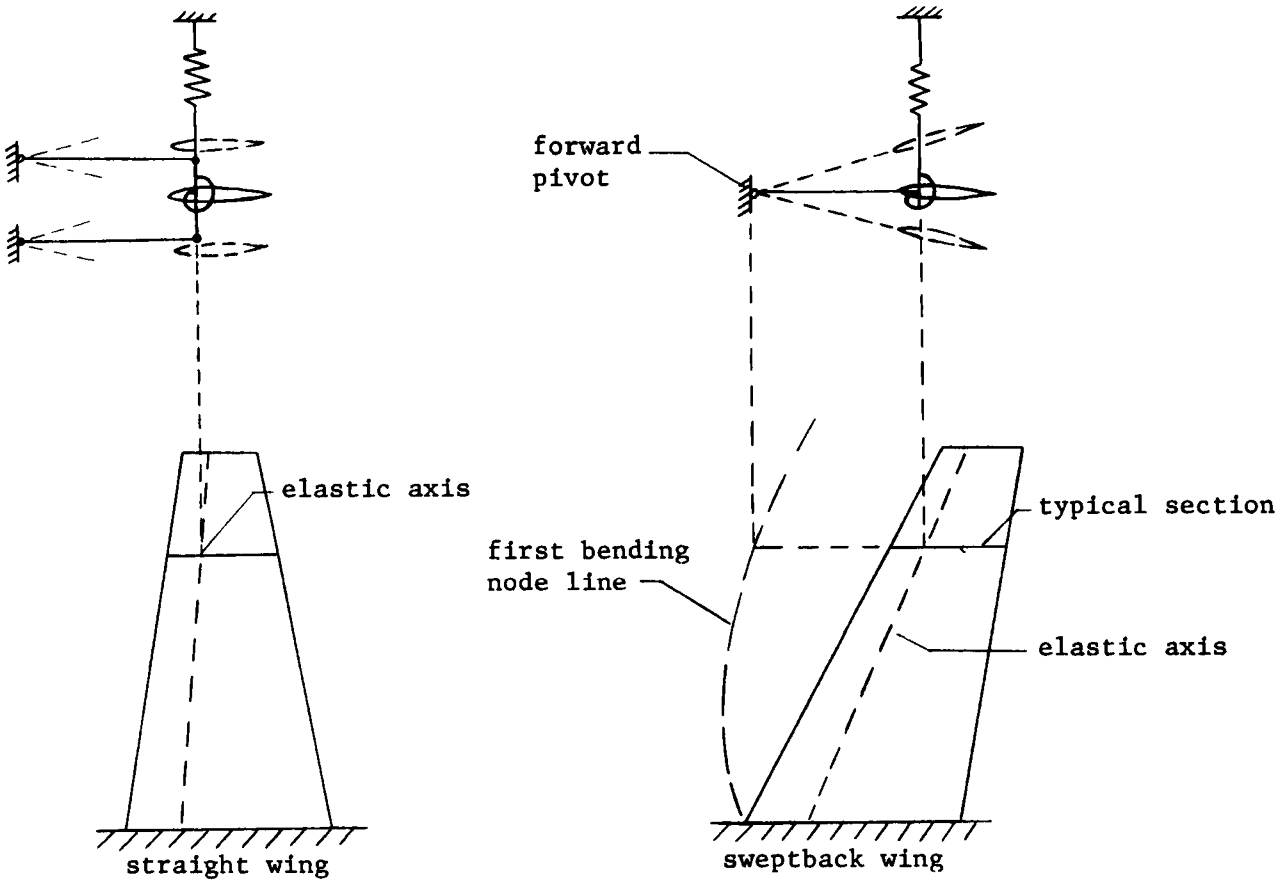


Figure 3: 2-D airfoil representation of bending modes of straight and sweptback wings.

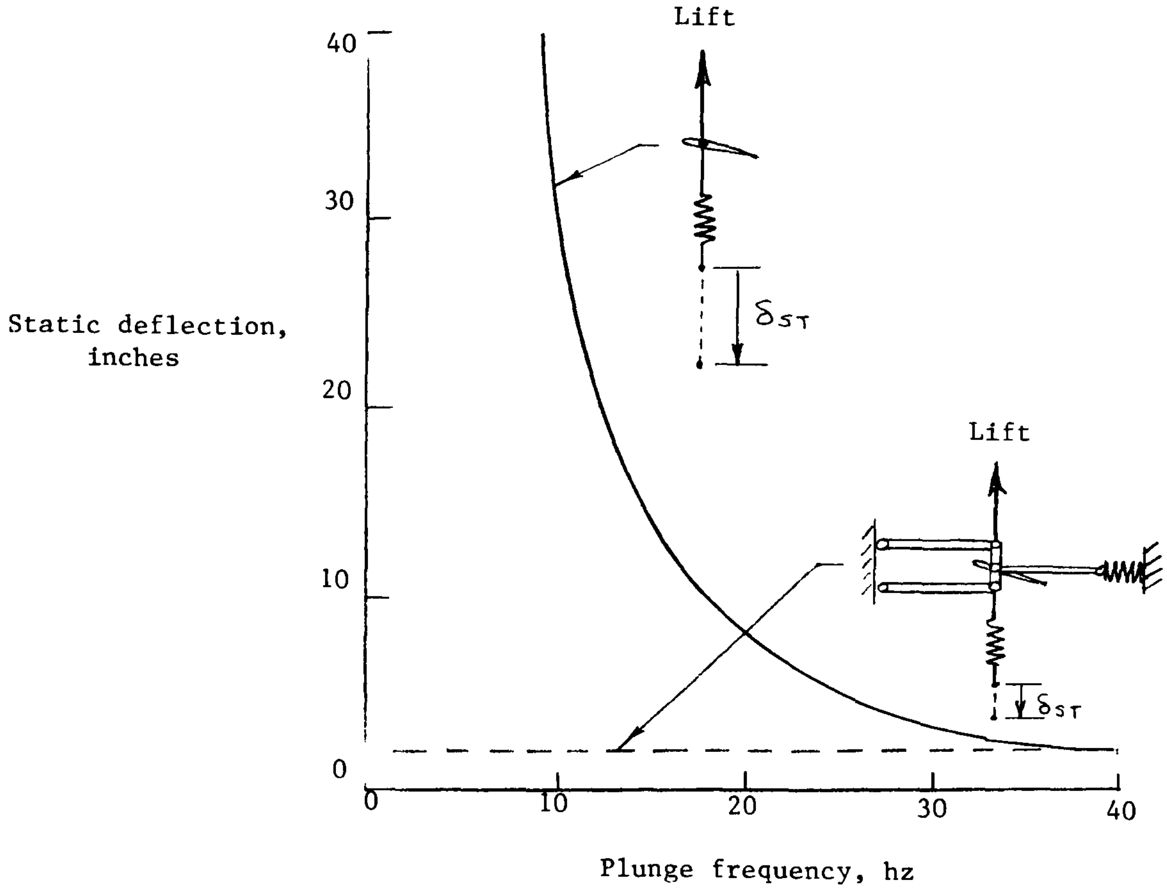


Figure 4: Static spring deflection required to counteract 800-lb steady lift on 2.5-lb. suspended mass for single-spring and compound-spring suspension systems.

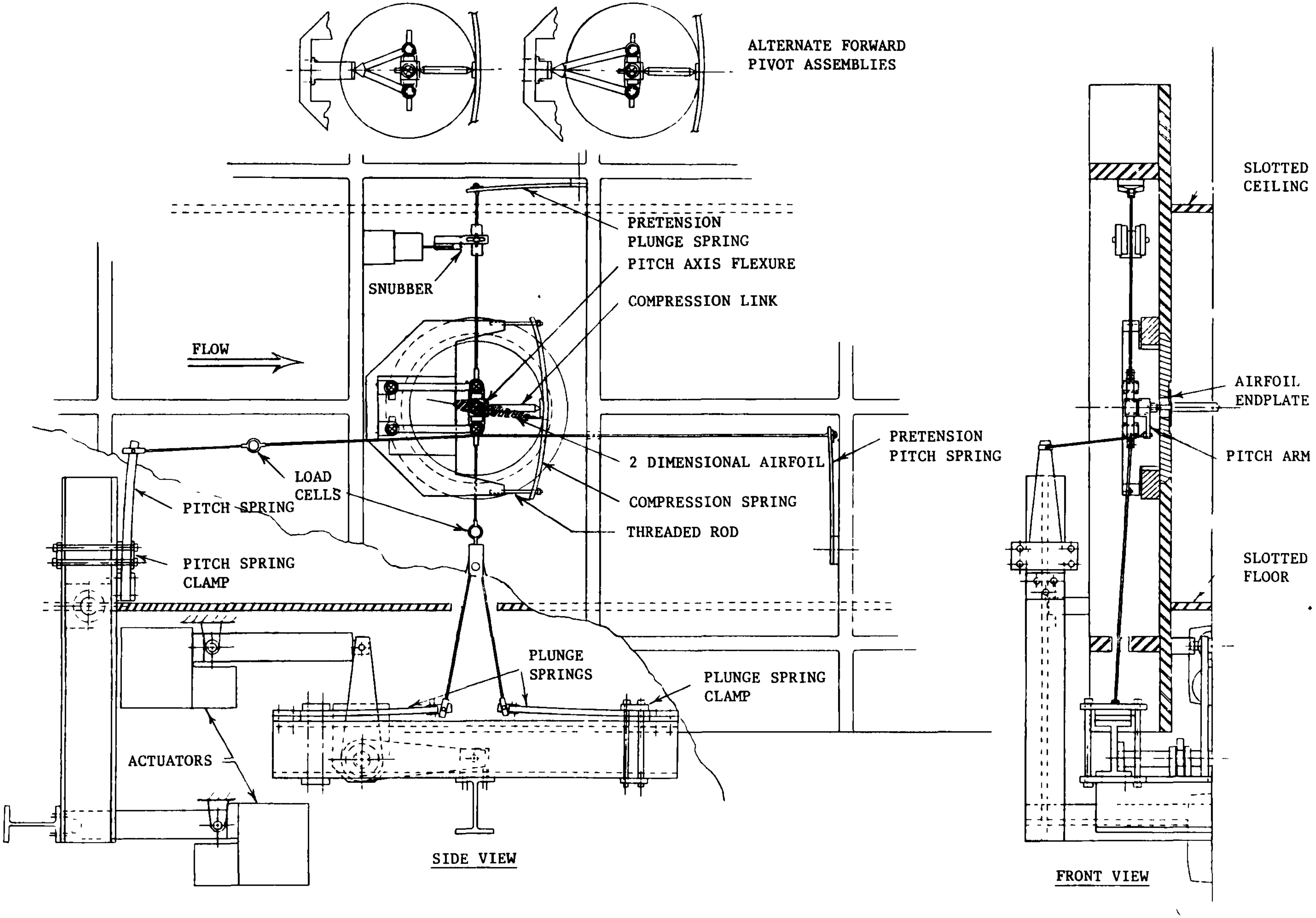


Figure 5. Pitch/plunge airfoil flutter suspensions system installation in the Langley 6-by-28 inch transonic tunnel

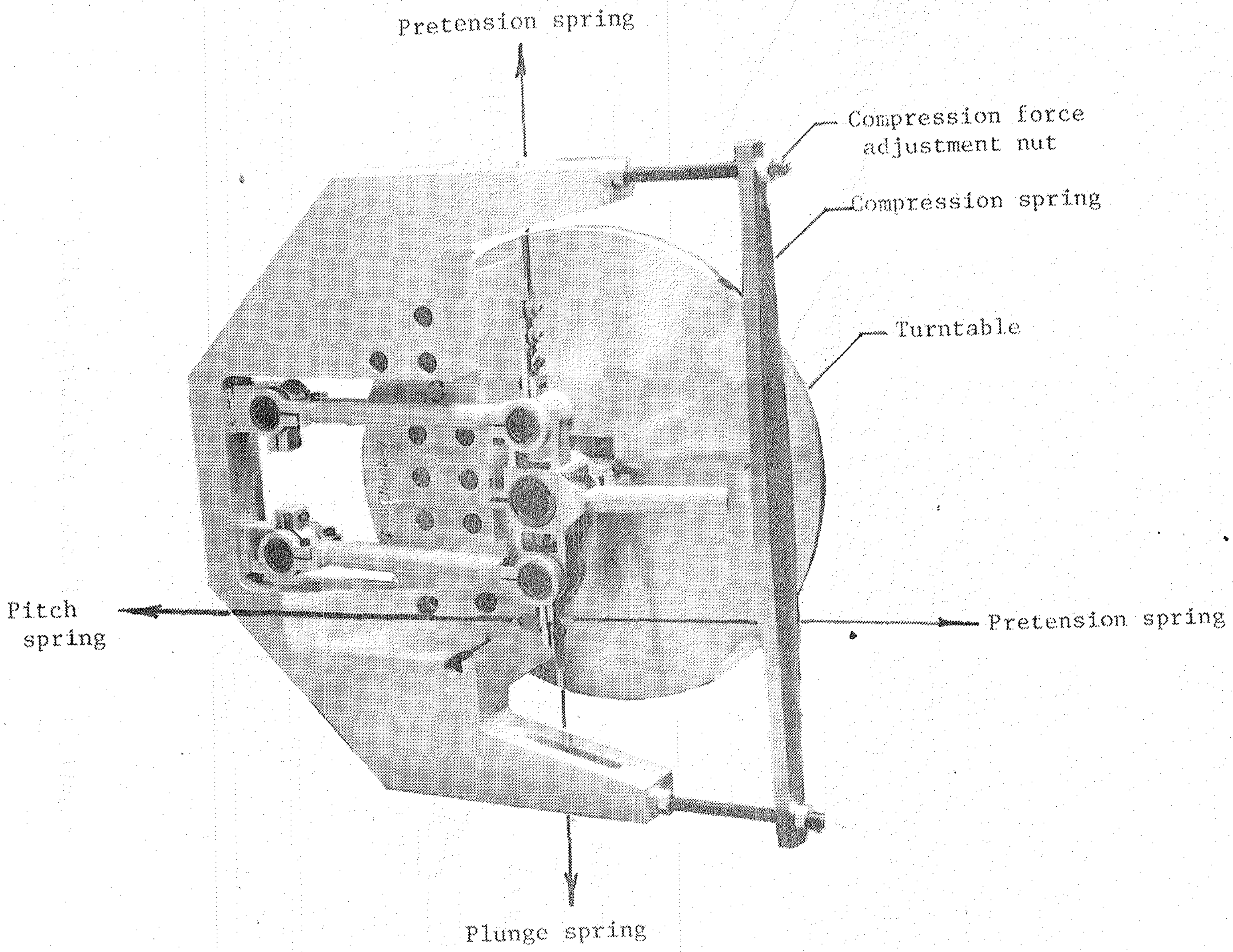


Figure 6: Plunge mode linkage arrangement

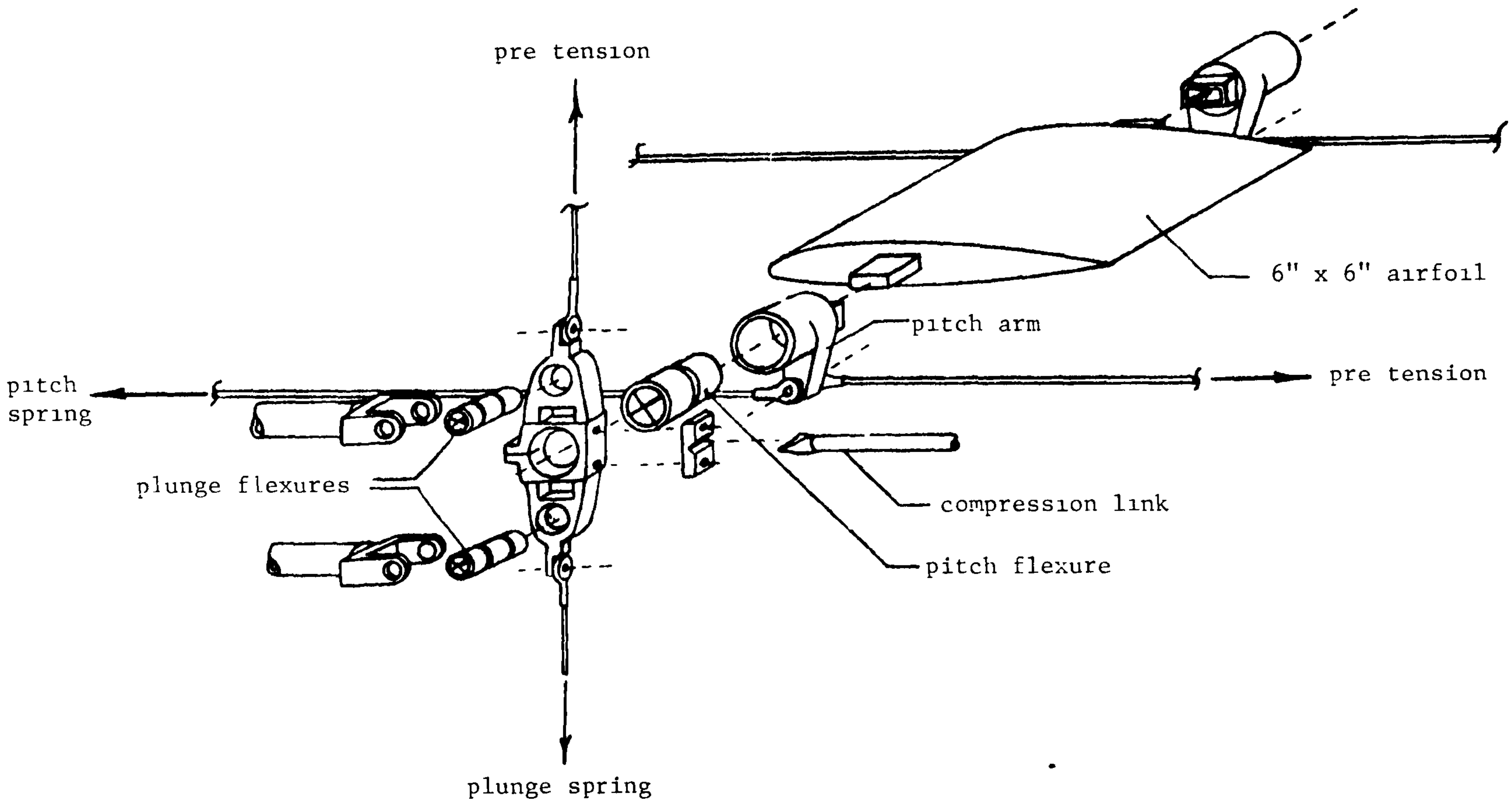


Figure 7: Airfoil model attachment details

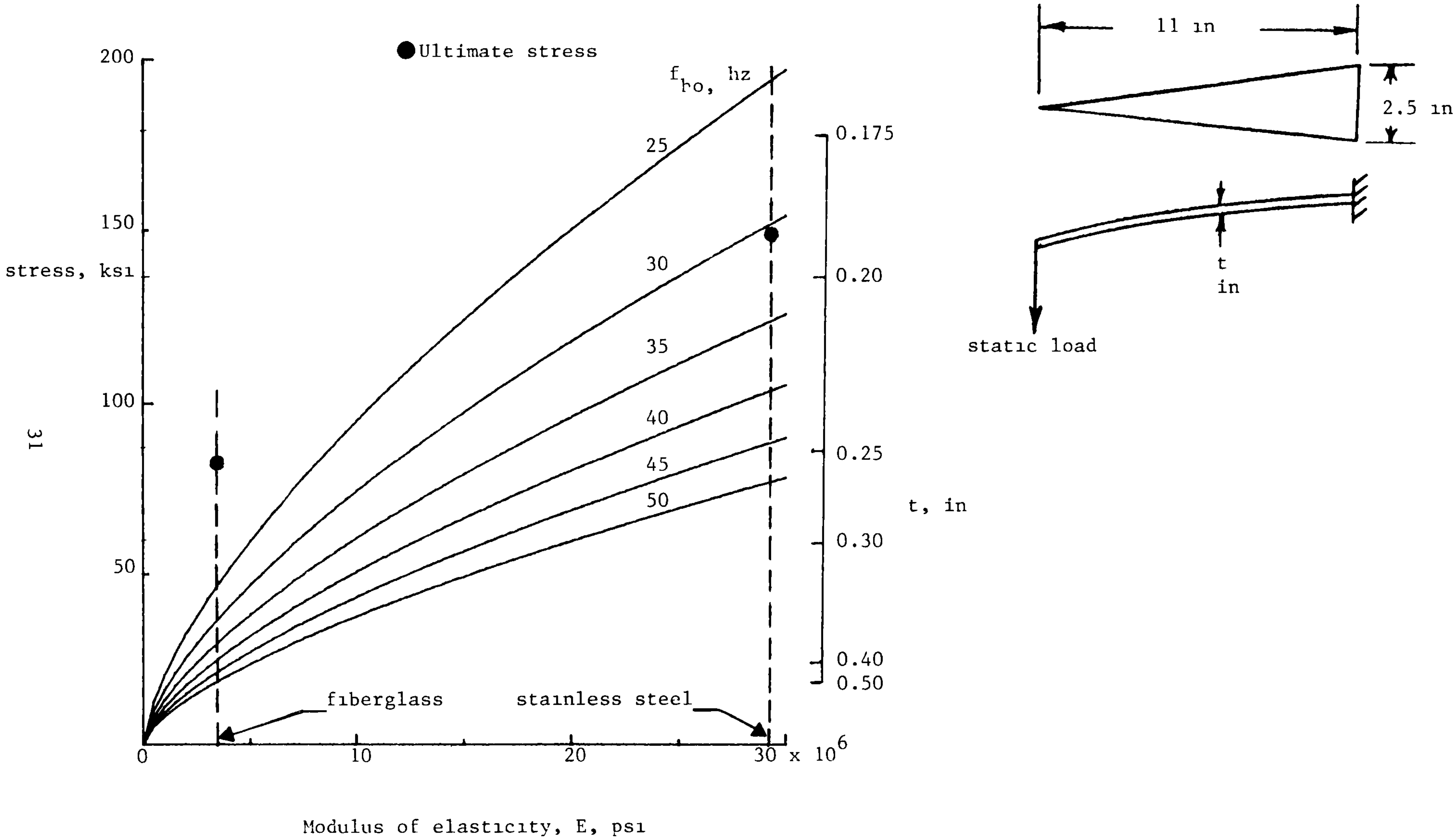


Figure 8: Plunge spring design curves.

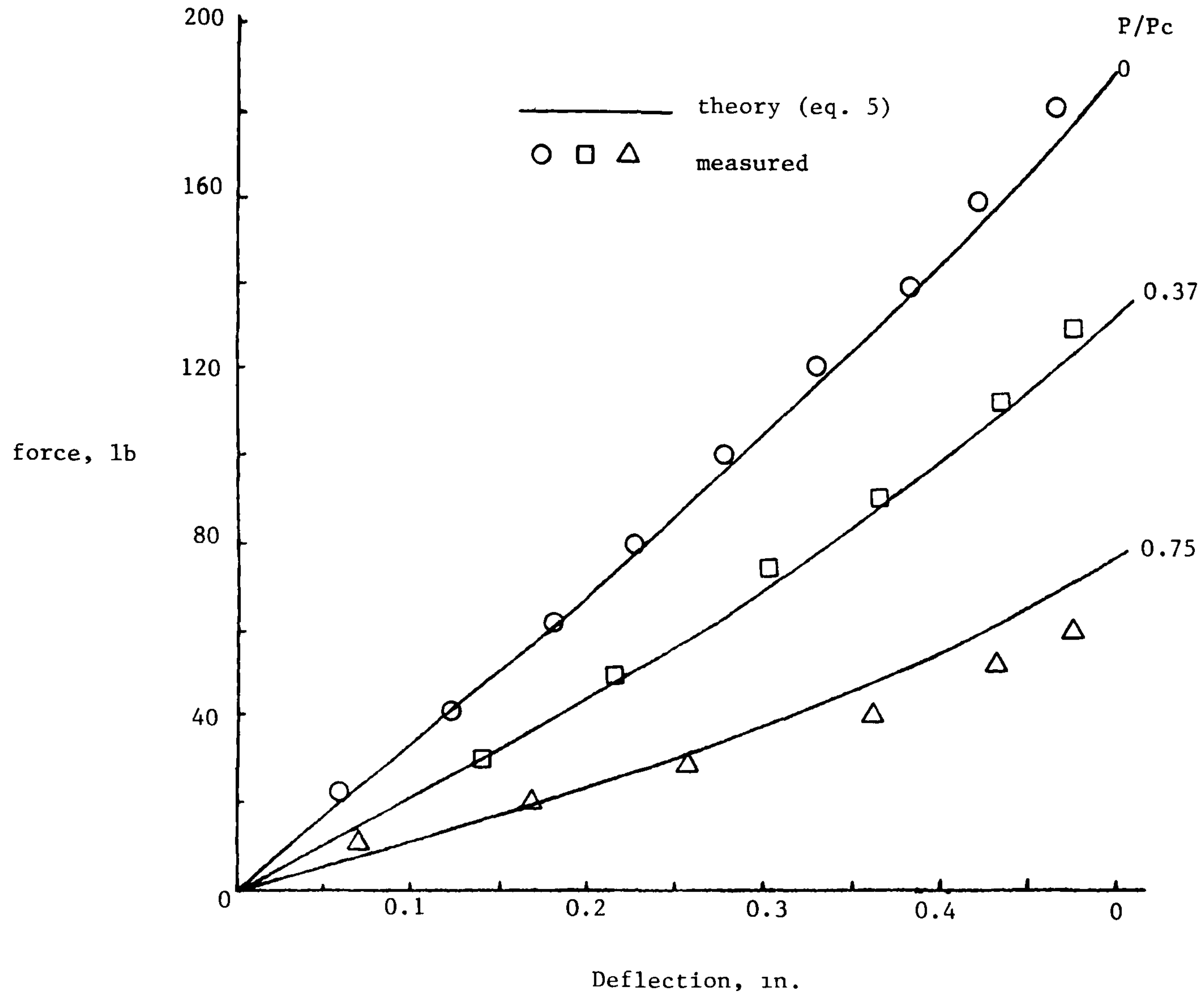


Figure 9: Plunge mode stiffness characteristics.

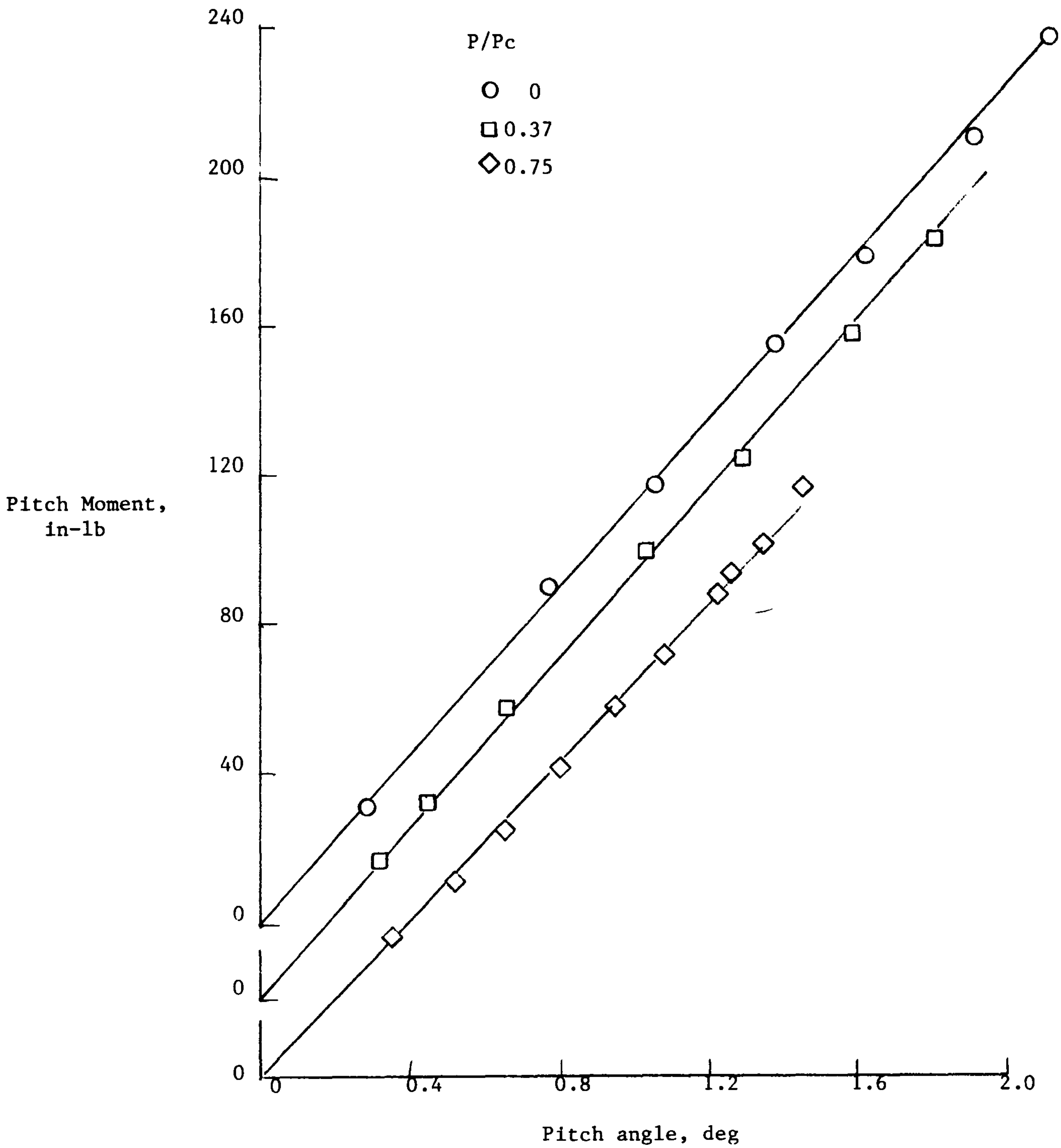


Figure 10: Pitch-mode stiffness characteristics.

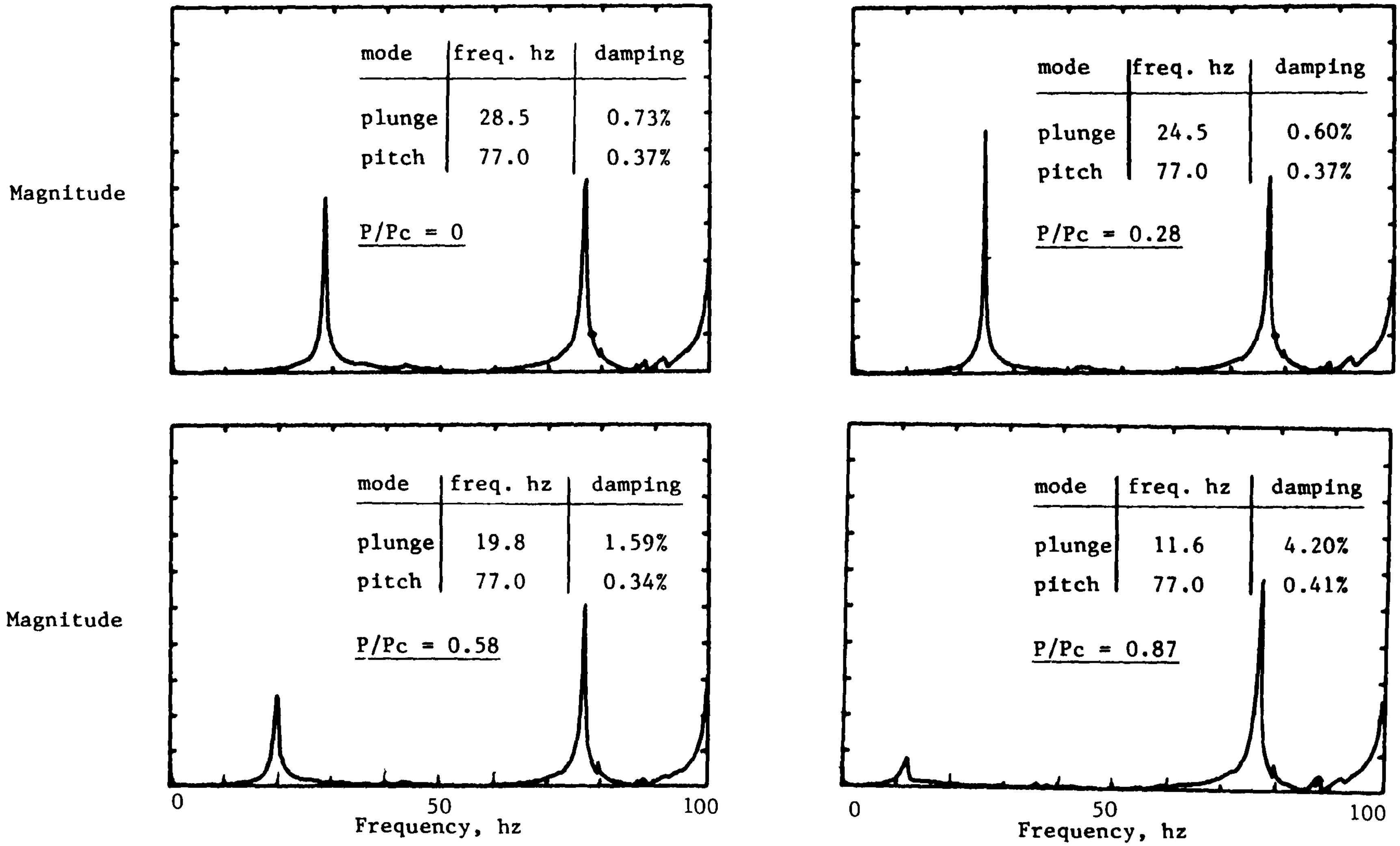


Figure 11: Suspension system frequency response measurements.

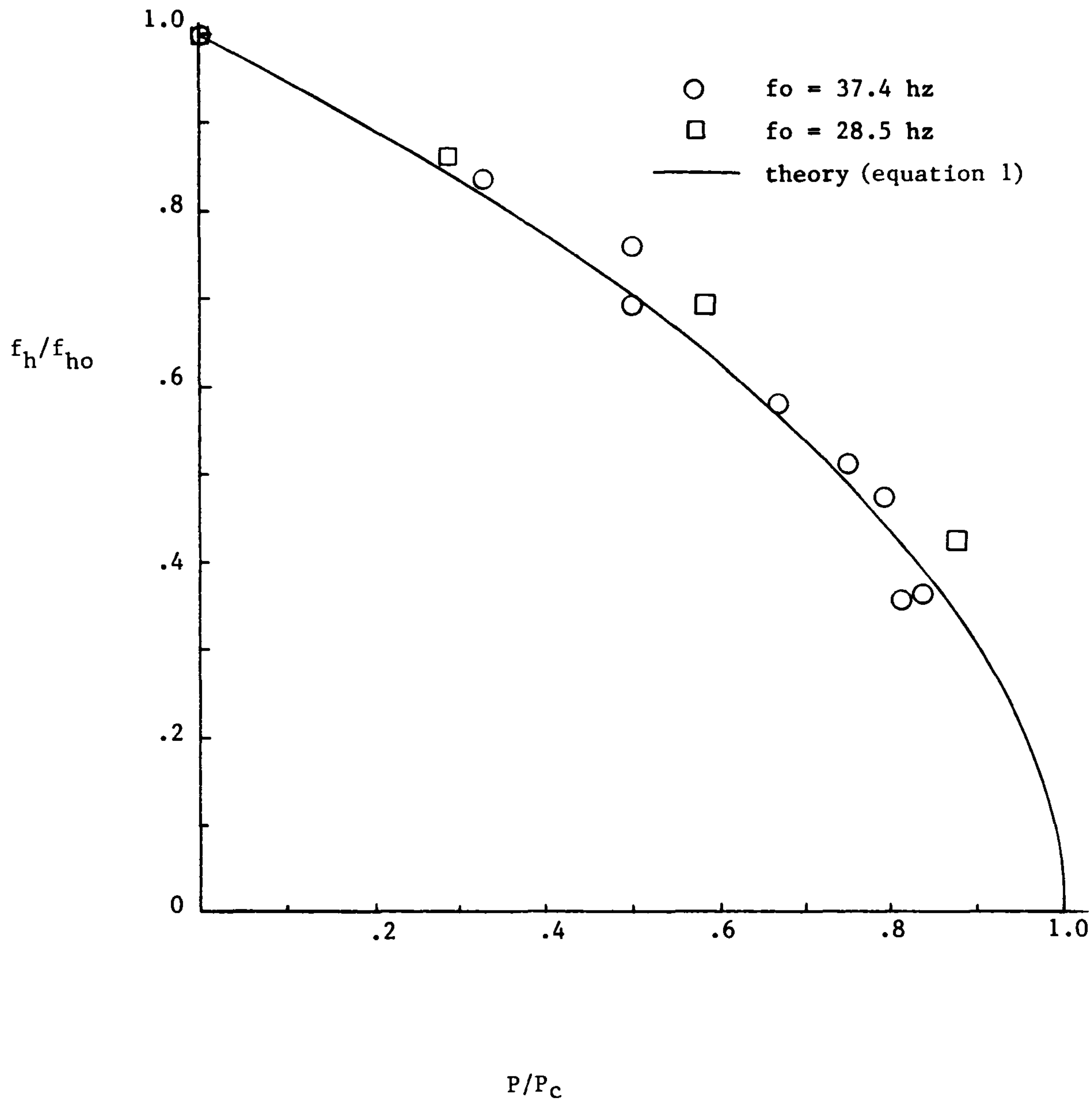


Figure 12: Plunge frequency variation with spring compression force ratio.

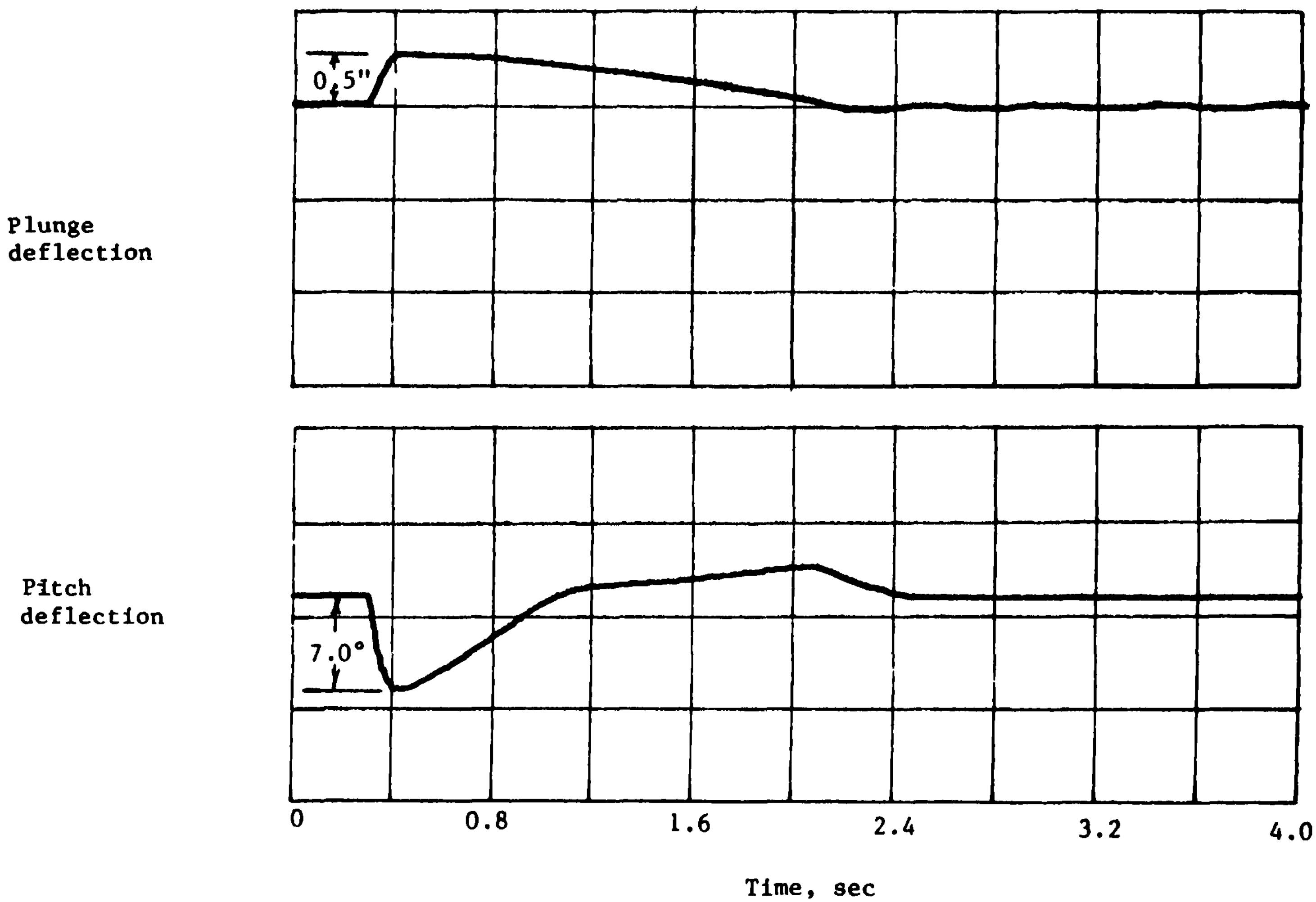


Figure 13: Response of self-alignment system after release of 100-lb lift load acting at midchord. (Pitch axis at 1/4 chord)

Standard Bibliographic Page

1 Report No NASA CR-177998	2 Government Accession No	3 Recipient's Catalog No
4 Title and Subtitle An Airfoil Flutter Model Suspension System to Accommodate Large Static Transonic Airloads		5 Report Date October 1985
		6 Performing Organization Code
7 Author(s) Wilmer H. Reed, III		8 Performing Organization Report No D-8402-3
9 Performing Organization Name and Address DEI-Tech, Inc. 11838 Bunker Boulevard, Suite 500 Newport News, VA 23606		10 Work Unit No
		11 Contract or Grant No NAS1-17686
12 Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		13 Type of Report and Period Covered Contractor Report
		14 Sponsoring Agency Code 505-63-21-02

15 Supplementary Notes

Langley Technical Monitor: Maynard C. Sandford - Final Report

16 Abstract

This paper describes a pitch/plunge flutter model suspension system and associated two-dimensional MBB-A3 airfoil models. The system is designed for installation in the Langley 6-by-19-inch and 6-by-18-inch transonic blowdown wind tunnels to enable systematic study of the transonic flutter characteristics and static pressure distributions of supercritical airfoils at transonic Mach numbers. A compound spring suspension concept is introduced which simultaneously meets requirements for low plunge-mode stiffness, lightweight suspended model and large steady lift due to angle of attack without the need for excessive static deflections of the plunge spring. The system features variable pitch and plunge frequencies, changeable airfoil rotation axes and a self aligning control system to maintain a constant mean position of the model with changing airload.

17 Key Words (Suggested by Authors(s)) Flutter 2-D Airfoil Transonic Wind Tunnel Suspension Systems	18 Distribution Statement Unclassified - Unlimited Subject Category 02

19 Security Classif (of this report)	20 Security Classif (of this page)	21 No of Pages	22 Price
Unclassified	Unclassified	38	A03

For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA Langley Form 63 (June 1985)

End of Document