NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3612

INITIAL RESULTS OF A FLIGHT INVESTIGATION OF A GUST-ALLEVIATION SYSTEM

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SUMMARY

A flight investigation of a gust-alleviation system designed to alleviate normal accelerations in the frequency range from 0 to 2 cycles per second has been recently initiated. The system is intended to improve passenger comfort in flight through turbulent air. Fundamentally, gust alleviation is accomplished by using trailing-edge wing flaps which are operated by means of an automatic control system controlled by an angle-of-attack vane located at the nose of the airplane.

The results indicate that the gust-alleviation system is at least capable of reducing the normal accelerations due to gusts by 50 percent at a frequency of 0.6 cycle per second, the natural frequency of the airplane, and by 40 percent at a frequency of 2 cycles per second. The controllability of the airplane with the gust-alleviation system in operation is adequate and it is felt that this type of control may result in improved handling qualities of the airplane.

INTRODUCTION

A theoretical study of some of the methods which can be used to obtain gust alleviation is presented in reference 1. This study has been continued for the past several years and the results have been applied to a particular airplane configuration. (See ref. 2.) These analytical investigations indicated that alleviation of the normal accelerations of the airplane could be obtained in the range of frequencies which would be expected to improve passenger comfort, that is, from 0 to about 2 cycles per second.

Based on the results of these investigations, a light transport airplane has been modified to incorporate the controls necessary for gust alleviation. Fundamentally, the system uses full-span wing flaps to maintain constant lift in flight through rough air. A portion of the elevator control is also geared to the flaps in order to adjust the pitching moment due to flap deflection, a provision which was previously found necessary in the study presented in reference 1. An angle-of-attack vane located on a boom at the nose of the airplane is used to sense the variations in gust velocity. Signals from the vane are supplied to an automatic control system which operates the flap controls in proportion to the change in angle of attack. The automatic control system is designed to attenuate sharply the gust inputs at frequencies in the neighborhood of the airplane structural frequencies in order to prevent excitation of flutter.

The material presented in this report is intended to familiarize those interested in gust alleviation with the initial flight-test results that have been obtained with this system.

DESCRIPTION OF GUST-ALLEVIATION SYSTEM

A two-view drawing of the test airplane is presented in figure 1, and photographs of the airplane, angle-of-attack-vane installation, and the various control surfaces are presented in figure 2. Pertinent dimensions of the airplane are presented in table I. The original airplane control surfaces have been modified to incorporate the necessary gust-alleviation controls. The landing flap of the original airplane has been split into two sections, and the dimensions of these controls are given in figure 1. The outboard portion of the flap has been combined with the aileron to function both as a lateral control and as a gust-alleviation device by preventing changes in lift due to gusts. This extended flap span was necessary because flight tests of the original airplane indicated that the landing flap was relatively ineffective in producing lift and that a larger flap span would be required to counteract the changes in lift that could be expected in moderately turbulent air. The entire landing flap has been modified to allow movement in an up as well as a down direction. The elevator of the original airplane has been split into three sections. The two outboard sections have been geared directly to the flaps so that a given flap deflection results in a certain deflection of the auxiliary elevators. The primary purpose of these auxiliary elevators is to counteract the pitching moment due to flap deflection. Also, by proper adjustment of the gearing between the flaps and auxiliary elevators, it is possible to obtain variations in the static margin of the gust-alleviated airplane.

In reference 1 it was pointed out that failure to account for the effects of gusts on the tail of the airplane could result in excessive pitching motions of the airplane. In an effort to offset the effects of the gusts at the tail, the portion of the flap at the wing root has been designed so that it can be geared to the main flap in a manner necessary to produce a downwash which will approximately compensate for the gust velocity at the tail. Actually, the auxiliary flap has been designed so that it can either move with the main flap, remain fixed, or move in the opposite direction from the main flap. All the flight tests so far have been made with the auxiliary flap locked in the neutral position, but future flight tests should be made with various combinations available with the system. It might be noted that the change in downwash at the tail due to flap deflection is considerably less with the auxiliary flap fixed than it would be if the main flap had extended into the wing root

A schematic diagram of the gust-alleviation system is presented in figure 3. The operation of the gust controls is apparent from this diagram. Briefly, when the vane encounters a change in angle of attack, an electrical signal is fed to the amplifier and, hence, to the variable displacement pump. The pump causes the flaps to deflect in order to oppose the change in lift on the airplane, and at the same time the auxiliary elevators are deflected in order to counteract the change in pitching moment due to flap deflection. The signal from the vane is then canceled by the feedback signal produced when the flaps are deflected. Since the airplane is no longer sensitive to angle-of-attack changes as a result of the gust-alleviation system, it becomes impossible to maneuver the airplane with the normal elevator control. As indicated in figure 3, the pilot's control is also geared electrically to the flap system. Therefore, when the pilot moves the control, he not only obtains an elevator deflection but at the same time a signal calls for a flap deflection to produce the desired change in angle of attack. The airplane responds to this flap deflection almost immediately and then, as the airplane pitches because of elevator deflection, the angle-of-attack vane causes the flaps to return to neutral and the airplane remains at the new angle of attack called for by the elevator.

The gear ratios between the various controls which were used in obtaining the flight-test data presented in this report are given in table II.

TEST PROCEDURE AND REDUCTION OF DATA

The flight tests were conducted in clear-air turbulence at an altitude of about 2,500 feet at a true airspeed of 150 miles per hour. An effort was made to fly the same course over the same terrain while recording the airplane response with both the gust-alleviation system in operation and with the basic airplane. This operation was done in an effort to obtain data under comparable conditions with the system on and off. However, the method used to analyze the data does not require that this condition be met. The data obtained are presented in time-history form, as the power spectral density of the vane angle and normal acceleration, and as the resultant amplitude ratio of these quantities as a function of gust frequency. The power spectra were obtained by using the electronic analog analyzer described in reference 3.

In order to study the controllability of the airplane, pull-up and hold maneuvers were performed with both the gust-alleviated and basic airplane configurations. These maneuvers were performed by abruptly deflecting the control against a chain stop. The data illustrating these tests are presented in time-history form. Some general flying was also done to evaluate the flying qualitites with the gust-alleviation system in operation.

RESULTS AND DISCUSSION

In order to show the general effects of the gust-alleviation system in flight through turbulent air, typical time histories of some of the measured quantities for the basic airplane and the gust-alleviated airplane are presented in figure 4. These data were obtained through approximately the same region of air. The vane angle presented has not been corrected for motions of the airplane. A comparison of these two time histories indicates that the normal acceleration in the gust-alleviated case is considerably reduced – to the order of about one-third to one-half the normal acceleration of the basic airplane. A comparison of the pitching velocity shows that the values in the gust-alleviated case are slightly increased, although in either case the values are relatively small. It should be emphasized, however, that the gust-alleviation configuration for which these data were obtained represents the initial attempt at selecting the proper gear ratios between the various surfaces and that further tests with the other configurations available may result in improved alleviation of both the pitching velocity and normal acceleration.

In order to obtain a more quantitative evaluation of the gust-alleviation system, the power spectra of the normal acceleration and vane angle were obtained from records similar to those shown in time-history form. The records from which the power spectra were obtained were of about 2 minutes duration. The power spectral density of the vane angle and normal acceleration for both the basic airplane and the gust-alleviated airplane are presented in figure 5. The power spectrum of the vane angle for the basic airplane has been corrected for motions of the airplane. The effect of airplane motions on the measured vane angle was corrected by the method presented in equation (10) of reference 4. The correction was made by utilizing the formula

$$\mathrm{PSD}\left(\alpha_v\right)_o = \mathrm{PSD}\left(\alpha_v\right)_i\left[\frac{\alpha_v}{\alpha_g}\right]^2$$

where $\mathrm{PSD}\left(\alpha_v\right)_o$ is the power spectral density of the measured vane angle, $PSD(\alpha_v)_i$ is the power spectral density of the corrected vane angle, and $\left[\frac{\alpha_v}{\alpha_g}\right]$ is the amplitude ratio of vane-angle response to gust angle of attack for the vane-airplane combination. The amplitude ratio $\left[\frac{\alpha_v}{\alpha_g}\right]$ was obtained from the transfer function for the vane-airplane combination calculated for the test airplane by using both measured and estimated stability derivatives. The dynamics of the vane were neglected in these computations because of the relatively high natural frequency of the vane, approximately 40 cycles per second. The spectrum of vane angle for the gust-alleviated case has not been corrected for motions of the airplane because the transfer function of the gust-alleviated airplane has not as yet been accurately determined. It should be noted, however, that the vertical motions of the airplane in this case were smaller and that the correction for airplane motions would not be expected to alter the spectrum shape by any appreciable amount, except possibly at the lowest frequencies. In describing the data presented, the vane angle has been considered as the actual gust angle of attack.

The intensity level of the turbulence data presented in figure 5 is somewhat low with a root-mean-square value of about 0.2° of the vane angle for the frequency range from 0.2 to 2 cycles per second. However, data obtained in later flights through considerably higher turbulence levels with a root-mean-square value of about 0.45° of the vane angle for the same frequency range using the same gear ratios between the various controls indicate the same trends as those presented in figure 5.

A comparison of the spectra of the basic and gust-alleviated cases gives an indication of the amount of alleviation obtained. The actual amount of alleviation, however, is obtained by dividing the spectrum of normal acceleration by the spectrum of the vane angle. The square root of these values gives the amplitude ratio of the normal-acceleration response to variations in vane angle. (See ref. 4.) The amplitude ratio thus obtained is presented in figure 6. The data show that the normal-acceleration response of the gust-alleviated airplane has been reduced about 50 percent in the range of the natural frequency of the airplane, which is about 0.6 cycle per second, and about 40 percent at a frequency of 2 cycles per second. It appears that the gust-alleviation system with the present configuration is fairly successful in reducing the normal acceleration of the airplane in response to gusts in the frequency range for which the system was designed. However, the results presented should not as yet be considered the optimum that can be obtained with this system.

The response of the airplane to a pull-up and hold maneuver for both the basic and gust-alleviated case is presented in figure 7. The time history for the basic airplane shows the normal response of the airplane to elevator motion. The elevator deflection causes the airplane to pitch to a new angle of attack in order to produce the desired acceleration change. With the gust-alleviation system in operation, the flaps are deflected down at almost the same time that the elevator is deflected, the lag in flap deflection is a result of the lag in the servomechanism. In response to the flap deflection, the normal acceleration builds up at a faster rate than for the basic airplane. As the angle of attack increases because of elevator deflection, the flaps return to neutral and the airplane remains at the new angle of attack called for by the elevator. This maneuver illustrates the ability of the gust-alleviation system to control the airplane properly, and the pilot's opinion of this type of control motion has been favorable. As a result of this type of test and a considerable amount of general flying with the gust-alleviation system in operation in both smooth and turbulent air, it is felt that this type of control may result in improved handling qualities of the airplane.

CONCLUDING REMARKS

A flight investigation of a vane-controlled gust-alleviation system, whose fundamentals of design were based on a previous theoretical analysis, has been initiated and preliminary results have been obtained. The flight tests so far have been conducted with only one of many configurations which are available with the test airplane.

The gust-alleviation system is at least capable of reducing the normal accelerations due to gusts by 50 percent at a frequency of 0.6 cycle per second, the natural frequency of the airplane, and by 40 percent at a frequency of 2 cycles per second. The controllability of the airplane with the gust-alleviation system in operation is adequate, and it is felt that this type of control may result in improved handling qualities of the airplane.

The results presented should not as yet be considered as the optimum that can be obtained with this system.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 7, 1955.

REFERENCES

1. Phillips, William H., and Kraft, Christopher C., Jr.: Theoretical Study of Some Methods for Increasing the Smoothness of Flight Through Rough Air. NACA TN 2416, 1951.

2. Boucher, Robert W., and Kraft, Christopher C., Jr.: Analysis of a Vane-Controlled Gust-Alleviation System. NACA TN 3597, 1956.

3. Smith, Francis B.: Analog Equipment for Processing Randomly Fluctuating Data. Aero. Eng. Rev., vol. 14, no. 5, May 1955, pp. 113-119.

4. Chilton, Robert G.: Some Measurements of Atmospheric Turbulence Obtained From Flow-Direction Vanes Mounted on an Airplane. NACA TN 3313, 1954.

TABLE I.- PERTINENT DIMENSIONS OF THE TEST AIRPLANE

[Control-surface areas presented are areas rearward of the hinge line]

Weight, lb	9,400
Wing area, sq ft	349
Wing mean aerodynamic chord, ft	8.05
Total main-flap area, sq ft	35.4
Total auxiliary-flap area, sq ft	12.5
Tail area, sq ft	65.4
Main-elevator area, sq ft	11.8
Total auxiliary-elevator area, sq ft	10.7
Tail length, ft	22.5
Distance from angle-of-attack vane to center of gravity, ft	15.1
Measured radius of gyration about Y-axis, ft	6.53
Center-of-gravity position, percent of wing mean aerodynamic chord	26

TABLE II.- GEAR RATIOS BETWEEN VARIOUS CONTROLS

[The pilot's control column is 32 inches long]

Gear ratio between -	
Main flaps and angle-of-attack vane	-5.2:1
Auxiliary elevators and main flaps	-0.45:1
Auxiliary flaps and main flaps	0:1
Main flaps and pilot's control column	5.1:1
Main elevator and pilot's control column	1.35:1

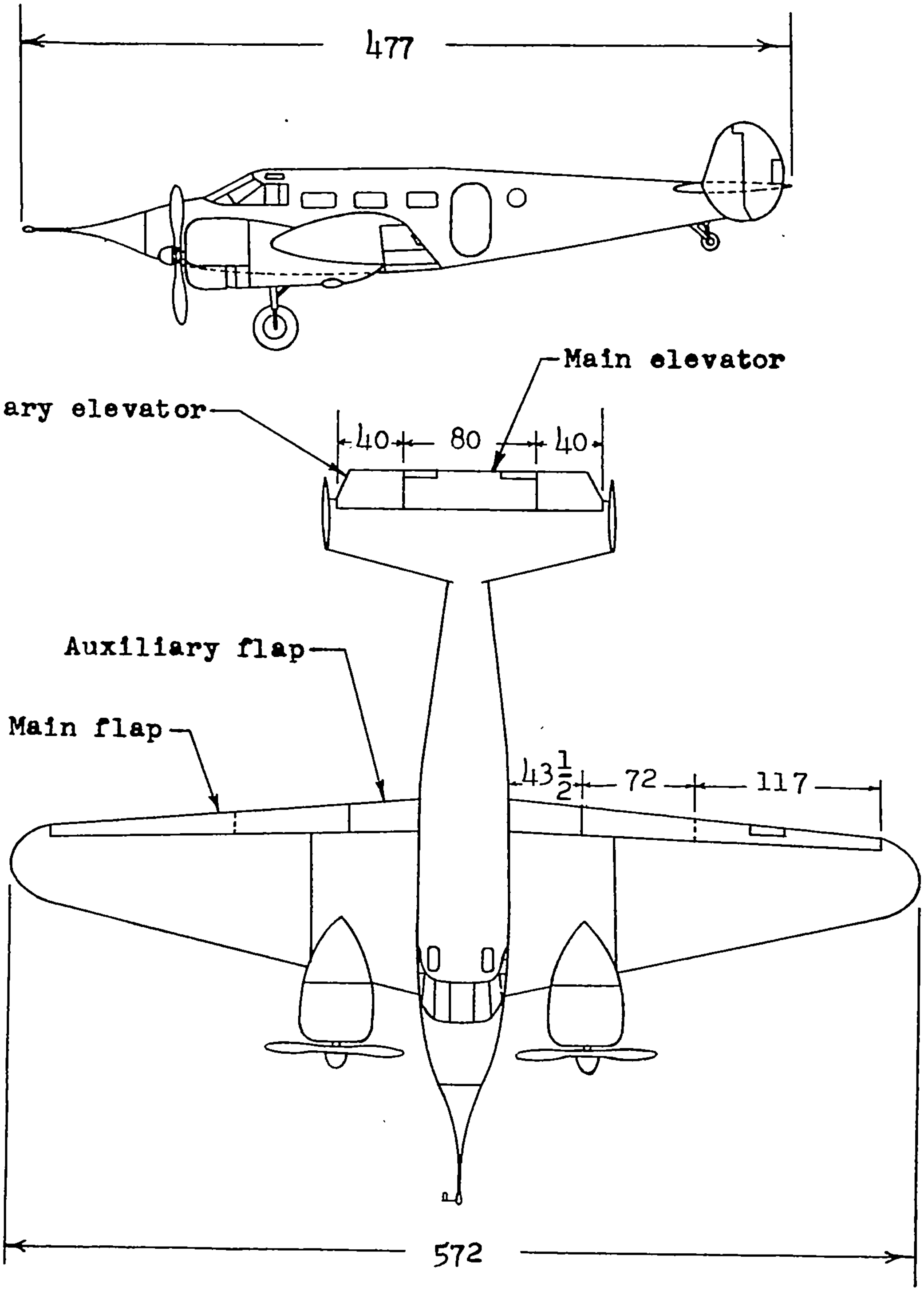
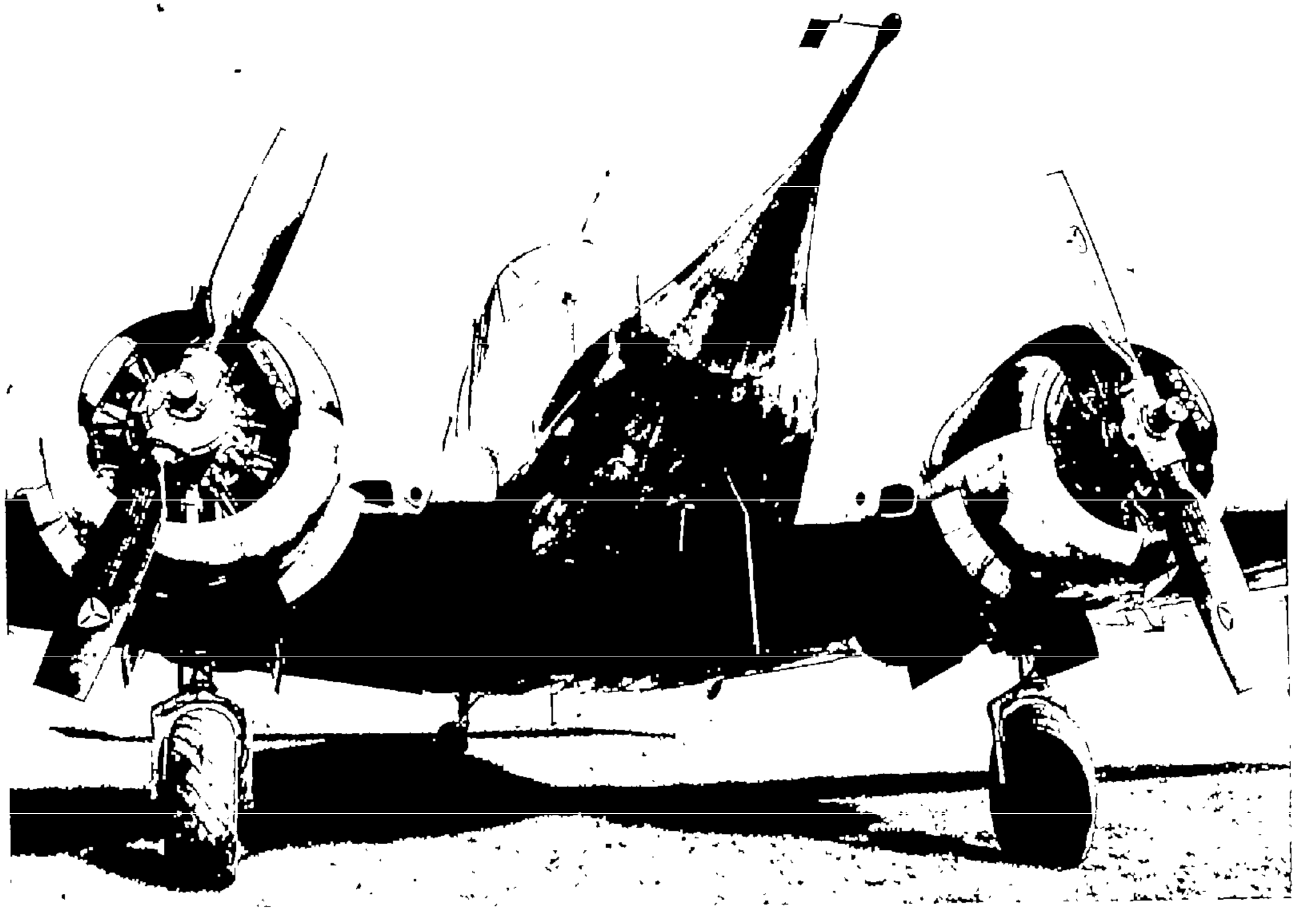


Figure 1.- Two-view drawing of the test airplane. All dimensions are in inches.



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(a) Nose boom and angle-of-attack-vane installation.

Figure 2.- Photographs of the test airplane.

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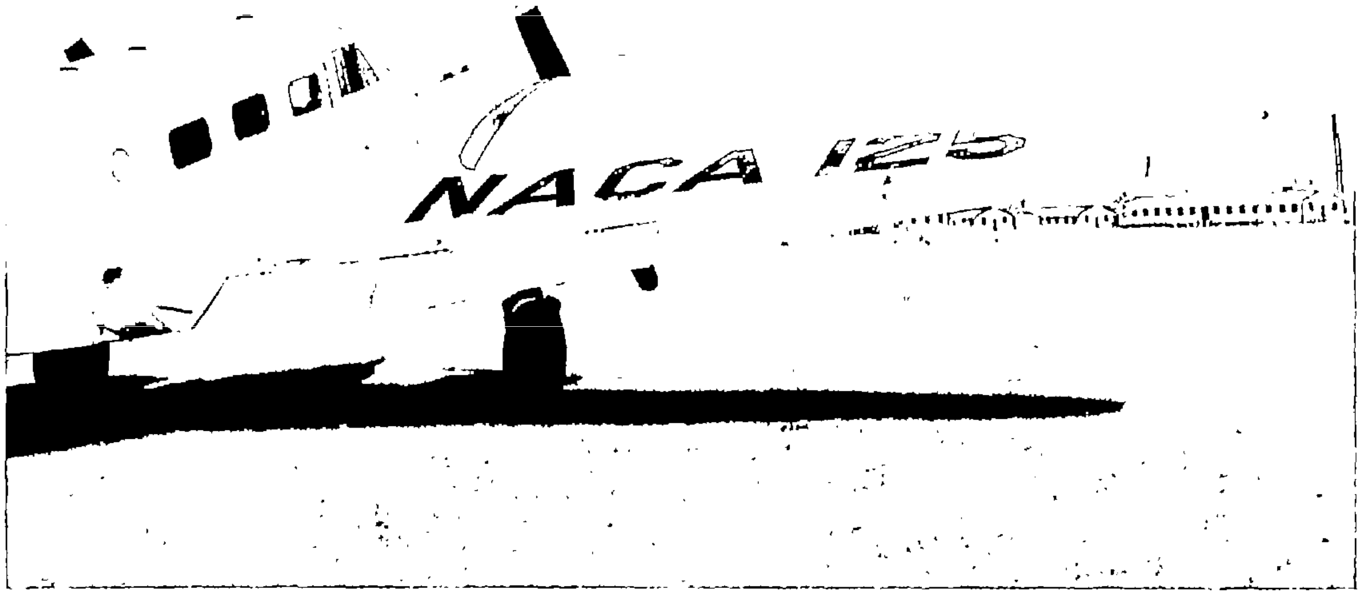
(b) Three-quarter rear view of airplane showing the various control surfaces. Gust-alleviation controls are in neutral position.

Figure 2.- Continued.



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(c) Gust-alleviation flap control in the deflected position. Note that flap and aileron move as one control and that inboard flap is fixed in neutral position.

Figure 2.- Concluded.

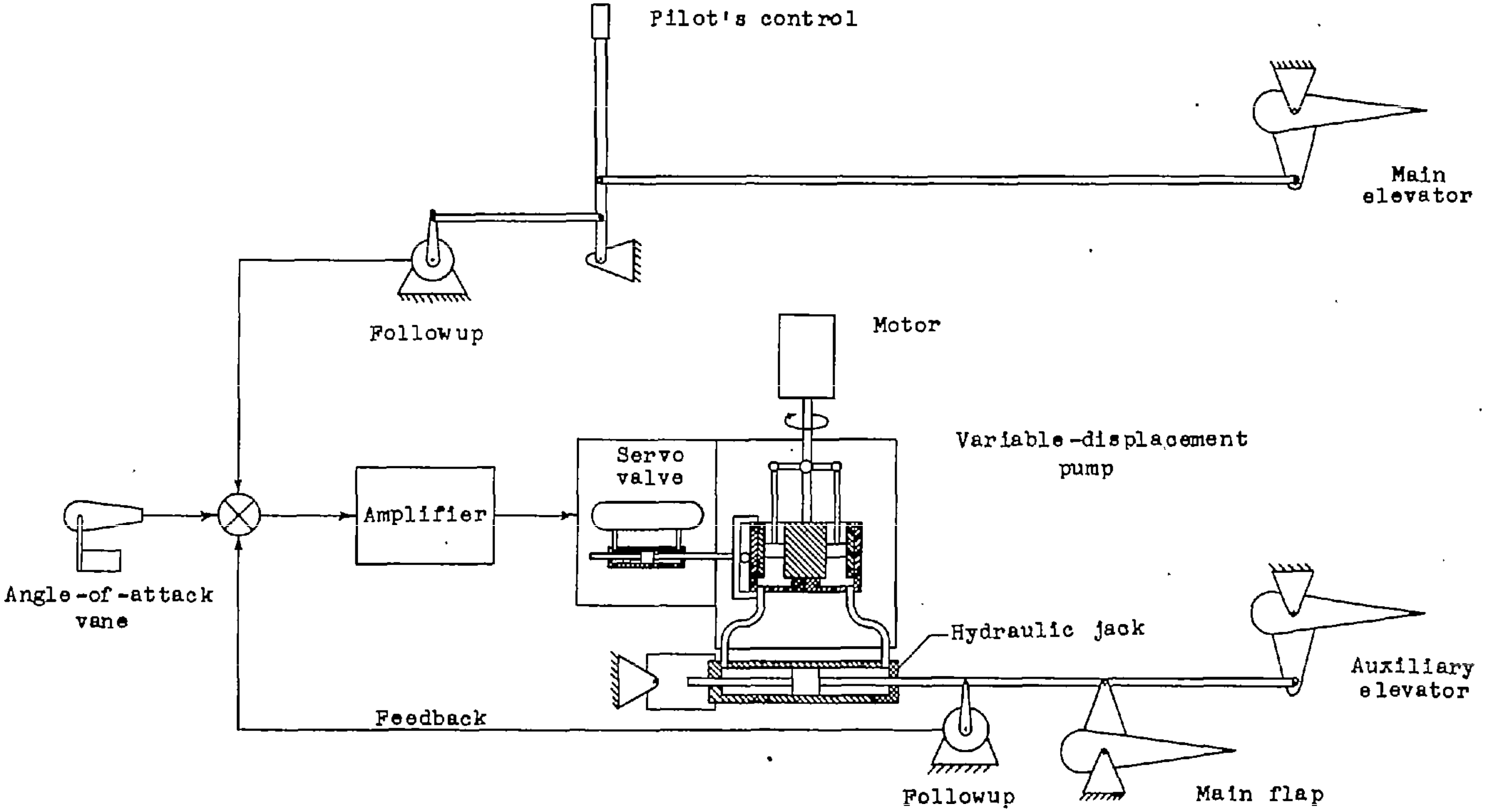
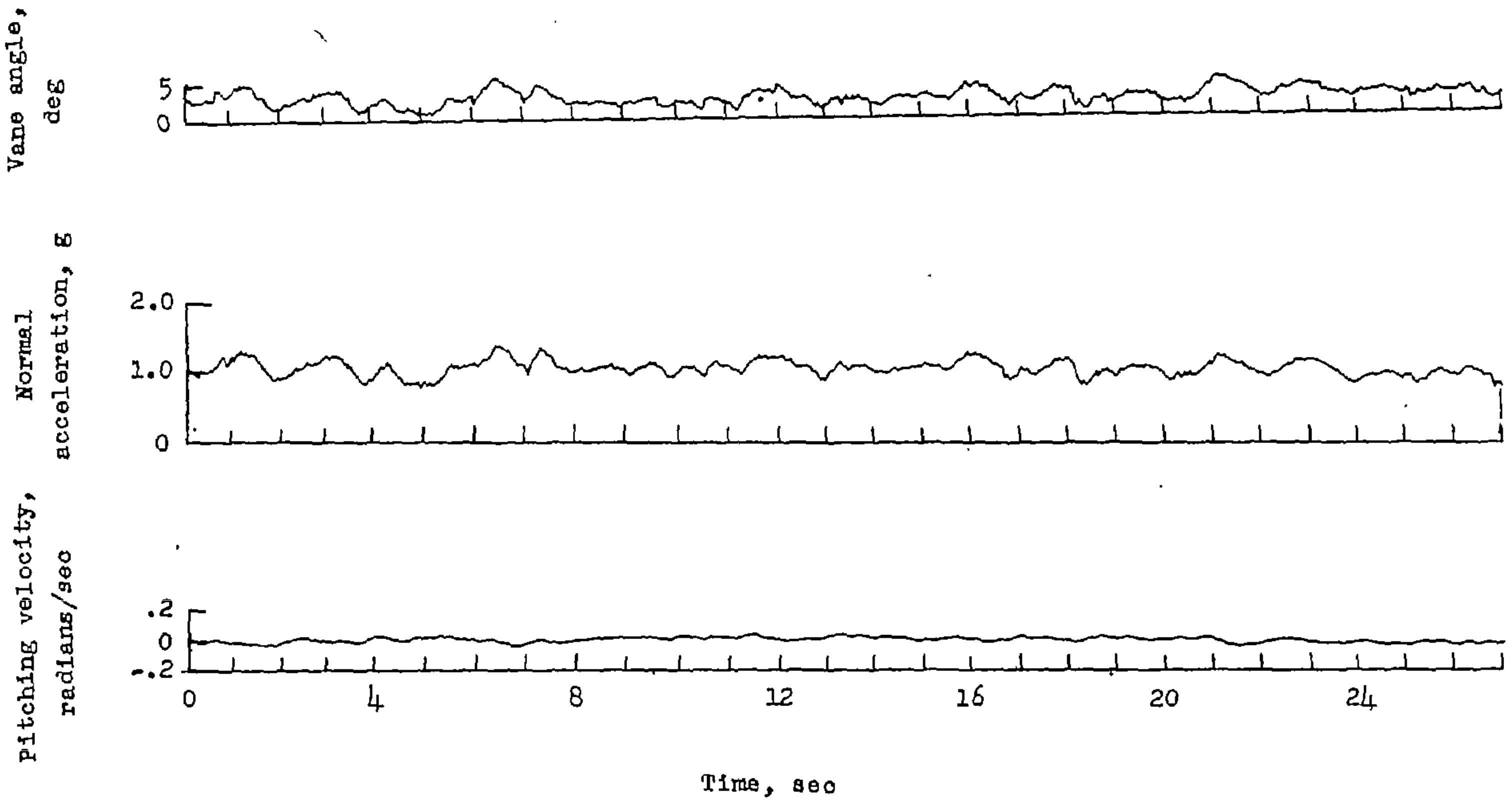
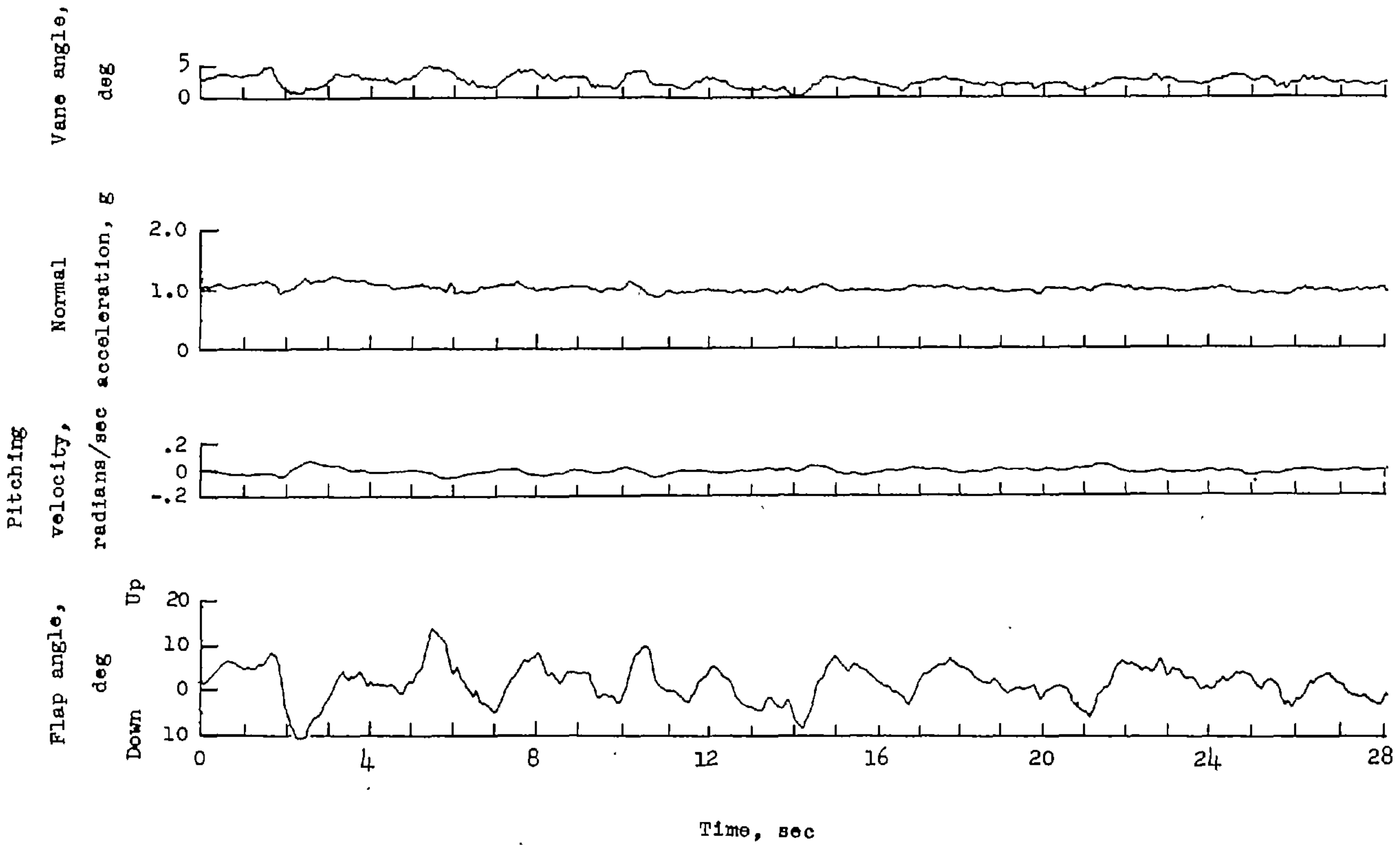


Figure 3.- Schematic diagram of the gust-alleviation control system.



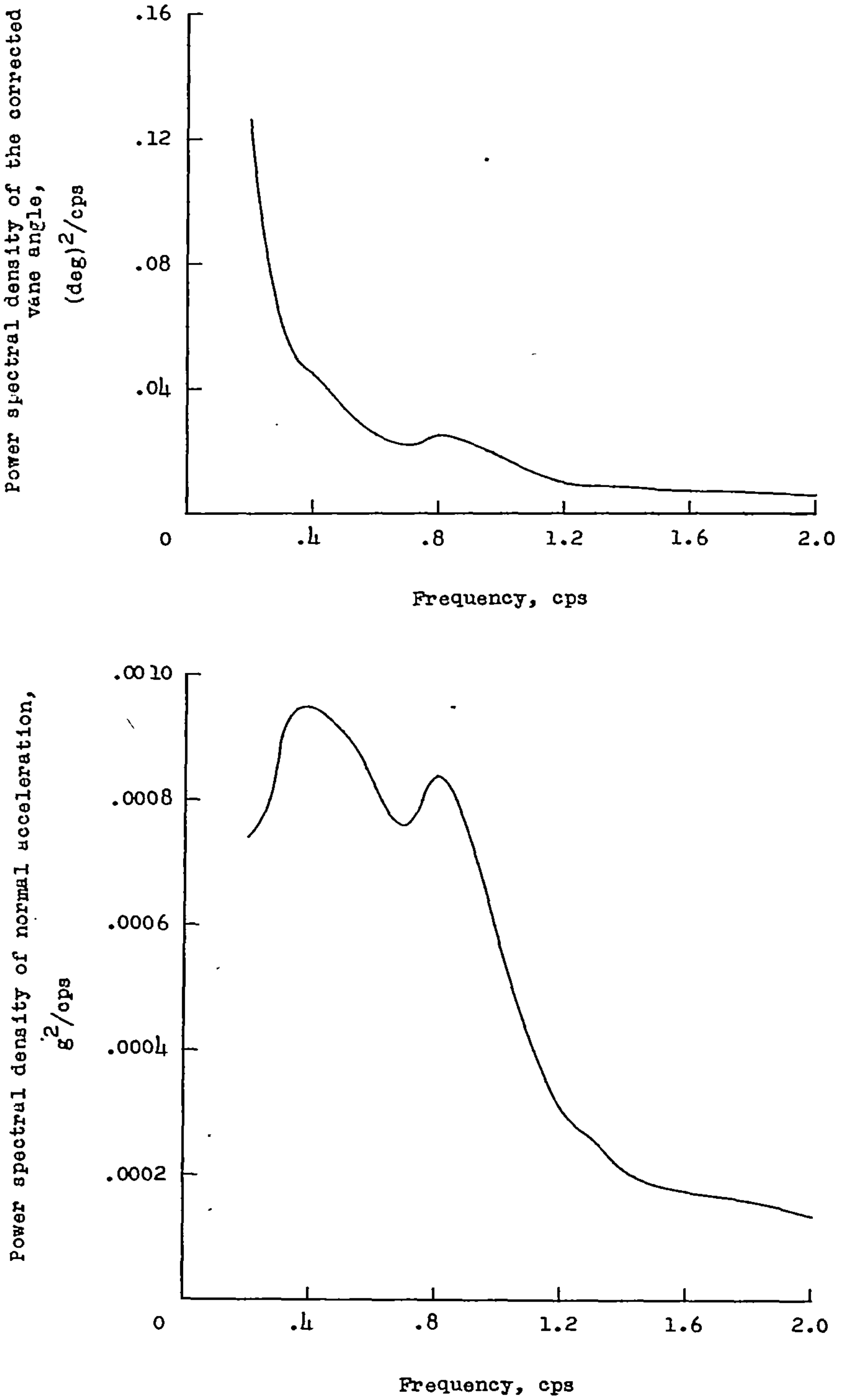
(a) Basic airplane.

Figure 4.- Time histories of airplane motions in flight through turbulent air.



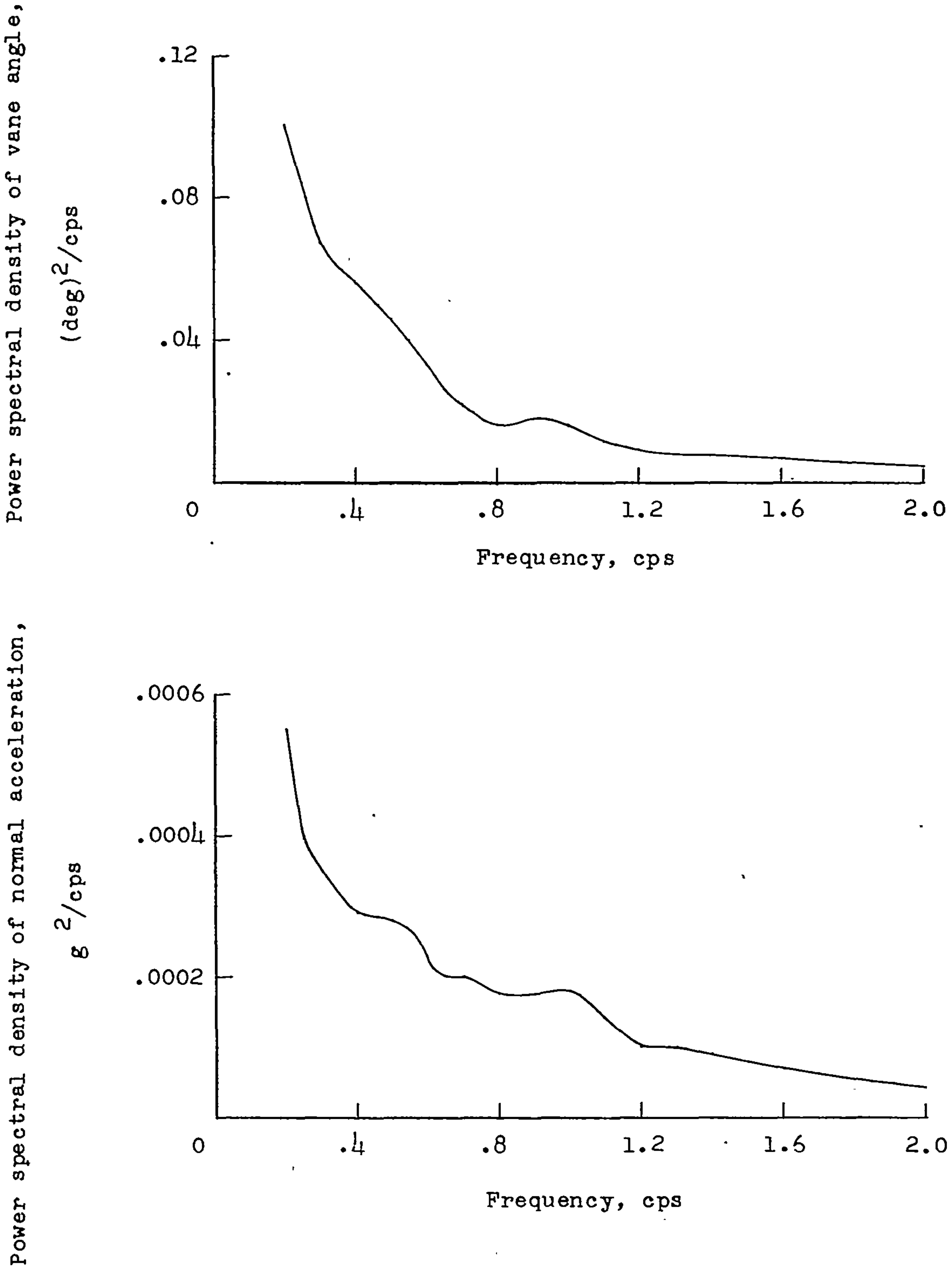
(b) Gust-alleviated airplane.

Figure 4.- Concluded.



(a) Basic airplane.

Figure 5.- Power spectral density of the vane angle and normal acceleration in flight through turbulent air.



(b) Gust-alleviated airplane.

Figure 5.- Concluded.

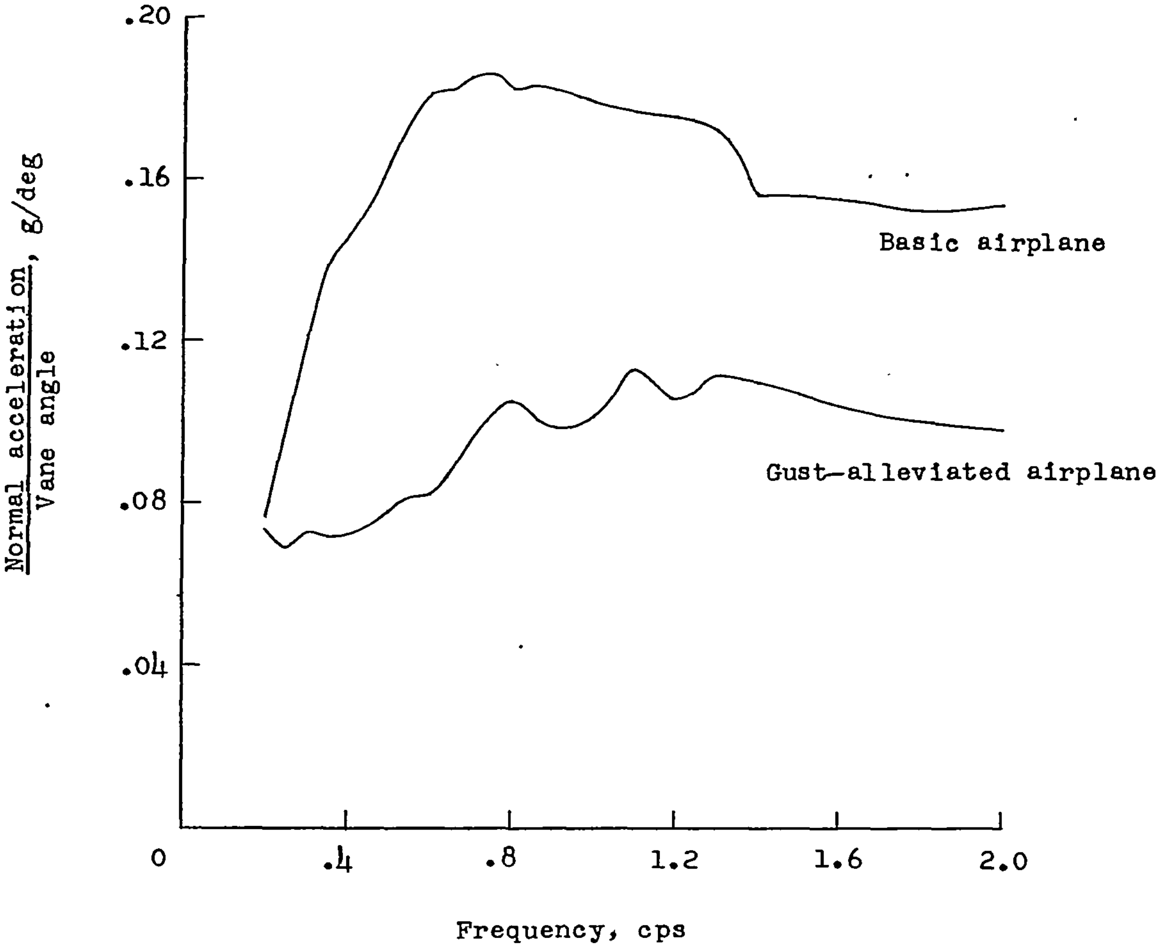
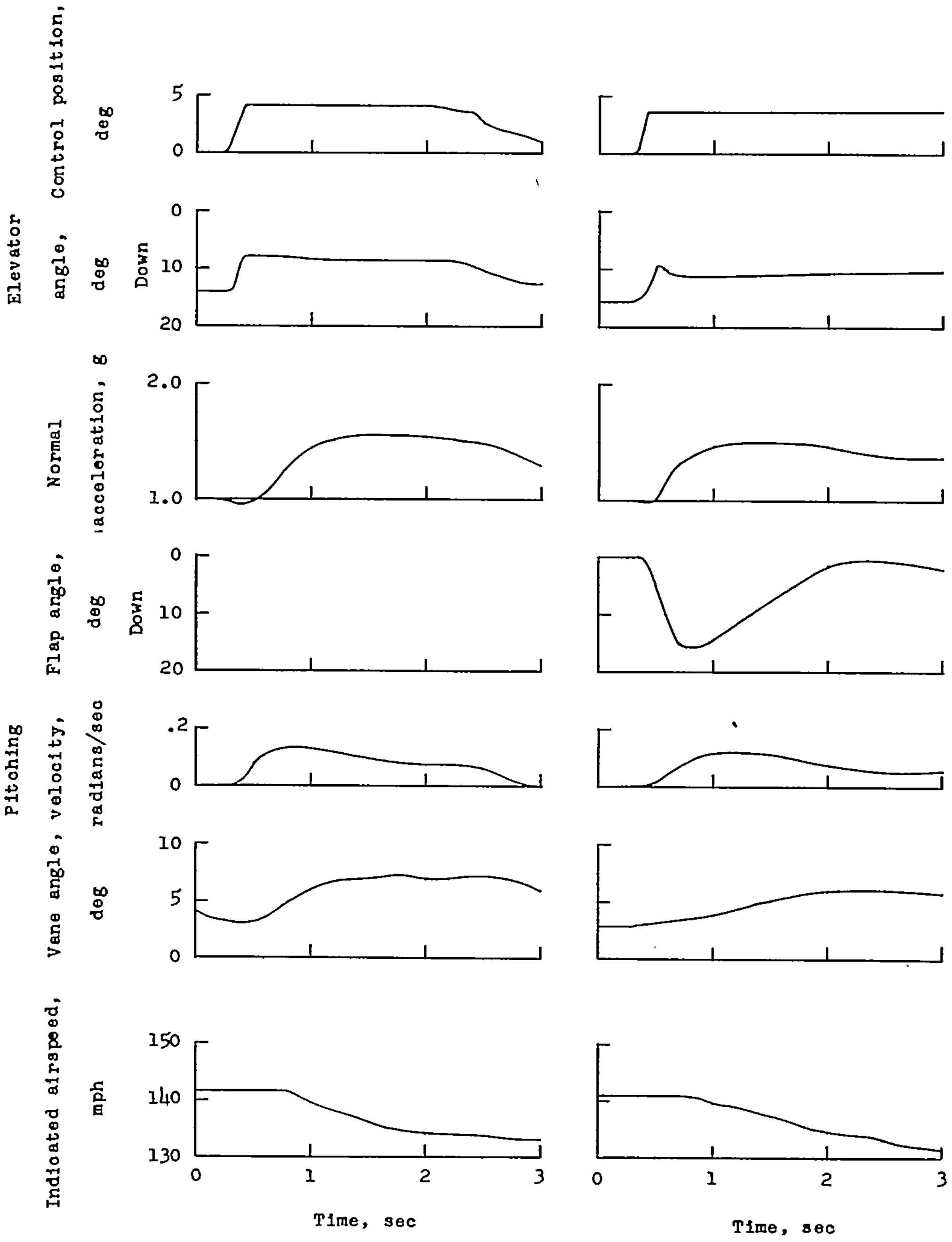


Figure 6.- Amplitude ratio of normal acceleration to vane angle for test airplane in flight through turbulent air. A comparison is shown of the basic airplane with the gust-alleviated airplane.



(a) Basic airplane.

(b) Gust-alleviated airplane.

Figure 7.- Time histories of airplane response to a pull-up and hold maneuver for the basic airplane and the gust-alleviated airplane.

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