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PASSENGER RIDE QUALITY RESPONSE TO AN AIRBORNE SIMULATOR ENVIRONMENT

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SUMMARY

Early studies of human response to motion were limited to the use of on-the-surface mechanical simulators. For air transportation, these ground-based simulators cannot reproduce the dynamic ranges of motion encountered aboard real aircraft. Some recent studies have been done aboard aircraft but the motion has been uncontrolled.

The present study was done aboard a special aircraft able to effect translations through the center of gravity with a minimum of pitch and roll. The aircraft was driven through controlled motions by an on-board analog computer. The input signal was selectively filtered gaussian noise whose power spectra approximated that of natural turbulence. This input, combined with the maneuvering capabilities of this aircraft, resulted in an extremely realistic simulation of turbulent flight. The test flights also included varying bank angles during turns.

Subjects were chosen from among NASA Flight Research Center personnel. They were all volunteers, were given physical examinations, and were queried about their attitudes toward flying before final selection. In profile, they were representative of the general flying public.

Data from this study include (1) a basis for comparison with previous commercial flights, that is, motion dominated by vertical acceleration, (2) extension to motion dominated by lateral acceleration, and (3) evaluation of various bank angles.

The significance of this study was its extension of the data base for the flight environment to areas previously not covered. These data should contribute to more effective modeling of subjective human response to an aircraft motion environment.

INTRODUCTION

Human response to motion has been studied for many years on many different types of vehicles (ref. 1). Early studies (refs. 2 and 3) were slanted towards crew performance using "shake" chairs. As time passed, the level of ground-based simulation became more sophisticated. The use of ground-base simulators

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is a very economical approach to researching human response to motion. However, this method lacks realism and is inherently limited in the type of motion that can be simulated. In an attempt to gain realism, some field studies (ref. 4) were done. In this case the experimentors were not able to control the motion environment so only a part of it could be studied.

One objective of studying human subjective response to motion research is to model the response as an aid in the design of future transportation systems Some work in this area has already been done (ref. 5). The success of such work will strongly depend on the completeness of the data base upon which it was formulated. An objective of this program was to provide human response data in areas beyond the capability of ground-based simulators. For this reason, an airborne simulator was used. A subject population was selected from a group of NASA Flight Research Center (FRC) volunteers and asked to evaluate their overall comfort from a passenger's viewpoint. A program of 5 flights was conducted on the NASA Flight Research Center's General Purpose Airborne Simulator (GPAS) aircraft. A flight-test engineer accompanied two subject passengers on each flight and controlled the experiment. For documentation purposes, cabin temperature and noise data were collected on selected flights. Unique on this aircraft were direct lift and side force generator control surfaces. Through these surfaces vertical and lateral accelerations can be produced on the aircraft with a minimum of pitch and roll. Single and combined axes tests were performed for subject passenger evaluation. Test flights also included a series of turns at various bank angles for evaluation. Typical test flights lasted slightly over one hour.

Data from this study include (1) a basis for comparison with data from previous commercial flights, i.e., motion dominated by vertical acceleration, (2) extension to motion dominated by lateral acceleration, and (3) evaluation of various bank angles.

TEST AIRCRAFT DESCRIPTION

The test aircraft used in this experiment was a modified JetStar Business Jet (figure 1). Modifications to the aircraft include the addition of direct lift control (DLC) and side-force generator (SFG) control surfaces. These unique features make this aircraft specially suited for the conduction of ride quality experiments. The DLC and SFG surfaces can be moved independently or in combination to provide vertical and/or lateral motion. However, due to the location of these surfaces on the aircraft, pure translational motion could not be produced but was always accompanied by a small amount of pitch and roll.

The aircraft cutaway (figure 2) shows the location of the DLC and SFG surfaces, the interior seating arrangement for subject passengers and the flight-test engineer, airborne analog computer, and data acquisition system. The seats used in this experiment were the aircraft manufacturer's original equipment as supplied with the standard aircraft.

From a tape recorder, located near the data acquisition system, a simulated turbulence signal was played into the airborne analog computer by the flight-test engineer. The airborne analog computer, in turn, generated signals to drive the DLC and SFG surfaces to induce aircraft vertical and lateral motion. The pilots monitored accelerations and made minor corrections as necessary to minimize pitch and roll.

INSTRUMENTATION AND DATA ACQUISITION

All aircraft motion parameters and the subject passenger responses were collected using a standard NASA Flight Research Center data acquisition system (DAS). The DAS samples the data 40 times per second, translates the data into pulse code modulated (PCM) format, and then records it on magnetic tape. Table 1 lists the parameters recorded on the DAS. For documentation purposes on selected flights, the passenger cabin temperature and noise level were recorded by the flight-test engineer using hand-held instruments.

The subjects were asked to rate their reactions to the flight motions according to a five-point scale ranging from very uncomfortable to very comfortable, as shown in table 2. The ratings were made by pushing one of five buttons on a box attached to the seat arm (figure 3). Although the subjects were instructed to change their ratings as they felt the need, it was necessary to obtain a considered rating during the last 15 seconds of each one minute test segment. To accomplish this, there was a command light on the rating box which was lit to request ratings. A reset button was also on the box and the subjects were requested to push this before any rating. This aided in removing signal ambiguity during data reduction.

An instrumentation package containing accelerometers and gyros was located in an area of the DAS near the aircraft center of gravity and was attached directly to the airframe.

TEST PROCEDURE

Since the results from this program would primarily impact the general flying public, it was desirable to obtain a subject population parallel to the makeup of that public sector. Consequently, volunteers were solicited from among Flight Research Center employees through the simple expedient of posting a notice on the bulletin boards requesting participation in a research flight program. No special incentives were offered, but employee interest in FRC activities was strong enough to result in 35 applications. For a variety of legal and medical considerations, only permanent full-time NASA employees in good health were accepted. Coupled with normal attrition over the life of the program, this finally reduced to a subject population of 16. The composition of this group compared favorably with the demographics of passengers on commuter aircraft in the northeast (ref. 6).

After selection, the subjects were asked to fill out a questionnaire to ascertain their general attitude towards flying for transportation. In general, the subjects enjoyed flying, even though most passengers flew on business trips. Prior to beginning the actual flights, the subjects were briefed on the nature of the program and their part in it. They were also given an explanation of the capabilities of the aircraft but were not told specifically what would occur during flight. When the flight program began, an assignment schedule was drawn up to permit each pair of subjects to report immediately before their flight for a final briefing.

Due to the onboard instrumentation, there was only room for two passengers at a time. Every effort was made to get all passengers enough flights in both seats to cover all the combinations available from the turbulence simulation system. Immediately following each flight, a quick debriefing was held to note any unusual occurrences. All passengers were also issued notebooks and encouraged to make whatever comments they wished. These comments are being studied for possible inclusion in a later report.

The simulated turbulence tape was generated by shaping a random signal on an analog computer and then recording it on magnetic tape. The random signal was obtained from a gaussian noise generator. The output of this source is a band of noise of uniform spectral density between 0 and 35 Hz. On the analog computer, this signal was shaped by using a second-order low pass filter with 0.7-Hz break frequency. These filter characteristics were chosen to generate an output signal whose power spectrum approximates that of natural turbulence (figures 4 and 5). The filter output was then scaled to be compatible with the maximum allowable input to the tape recorder. Three tape recorder channels were recorded with 1/3, 2/3, and maximum of full-scale signal amplitude. Another channel of the tape recorder was recorded with several test profiles containing 9 or 10 one minute segments. Each segment was manually adjusted to 0, 20, 40, 60, 80, or 100 percent of maximum amplitude. Segments of varying amplitudes were combined into test profiles either in a staircase or random fashion. A fifth recorder channel triggered the extra light on the subject's rating box to request a comfort rating during the last 15 seconds of each test segment. Subsequent subject comments indicated the need for an audible signal as well.

All test data were collected at an altitude of 6.1 km (20000 ft) and 250 knots indicated airspeed. The basis flight plan consisted of the following phases (with approximate times for each):

1. Take-off and climbout (20 minutes);

2. Simulated turbulence run 1 (10 minutes);

3. Turn number 1, 180° at 20° bank angle (5 minutes);

4. Simulated turbulence run 2 (10 minutes);

5. Turn number 2, 180° at 30° bank angle (4 minutes);

6. Turn number 3, 180° at 40° bank angle (4 minutes);

7. Descent and land (15 minutes).

During test profiles 1 and 2, the tape of simulated turbulence was played into the airborne analog computer which drove the DLC and SFG surfaces. By utilizing one or more tape recorder channels, single or combined axes tests were accomplished.

During single-axis testing a staircase or random profile was inputted to either the vertical or lateral axis while no input was made to the other axis. For combined-axes tests a staircase or random profile was inputted to one of the axes while a constant level of 1/3, 2/3, or maximum of full-scale signal amplitude was inputted to the other axis. All bank angle maneuvers were performed manually by the pilots and were to be made as well coordinated as possible. Both left and right bank maneuvers were evaluated with bank angles varying from 21° to 47°.

All data recorded on the DAS were reduced using the NASA Flight Research Center's Control Data Cyber 70 computer. Each one minute segment of each profile was partitioned into twelve 5 second parts. Mean and standard deviation values of vertical and lateral acceleration were computed for each part as well as for the entire one minute segment. The passenger subjective comfort rating was obtained by extracting the last rating found during the final 15 seconds of each one minute segment. These acceleration and rating data were then used to determine threshold values for comfort ratings of 2, 3, and 4 for each subject passenger on each flight. Ratings 1 and 5 were not included because of a general reluctance by the subjects to select these values. These threshold values were averaged over all subjects and all flights to generate the final comfort boundaries. The bank maneuver data were obtained by taking the passenger subjective comfort rating after a steady-state bank angle had been achieved. Lateral accelerations were examined to ensure the bank maneuver was well coordinated. The bank angles were averaged over all subjects for comfort ratings of 2, 3, and 4 to determine the final relationship. Computations were made using standard techniques. The cabin temperature and noise data were hand tabulated in a notebook. These data were averaged over all flights to obtain the final values of $71^{\circ} \pm 3^{\circ}$F and 91 ± 2 dB.

RESULTS AND DISCUSSION

The fidelity of the motion simulation was evaluated by comparing the power spectral density (PSD) plots for the basic aircraft's typical response to natural turbulence, single-axis simulation, and combined-axes simulation. Figure 4 shows this comparison for vertical acceleration and figure 5 for lateral acceleration. These two plots indicate that the simulation profiles were representative of the natural turbulence case. Only acceleration variations about the mean value were used to generate these plots. Because the DLC and SFG surfaces are not located at the aircraft center of gravity, some pitching and rolling motion, respectively, is associated with the movement of these surfaces. These motions were kept to reasonably low levels by the pilot's use of manual controls. The pilots indicated the sharp "bucking" motion associated with natural turbulence was not as intense for the simulated turbulence.

Subjective data from single- and combined-axes tests are shown in figure 6. Only subject passenger ratings of 2, 3, and 4 were considered since there was a general reluctance on the part of the subject passengers to select the extreme ends of the rating scale. A wider choice of ratings should produce greater resolution. The solid curves are faired lines drawn through the average threshold data values. The straight line drawn at an angle through the origin shows the limit of previously collected commercial airline data (ref. 7). Data above this line duplicated and corroborated previous work. The data below the line represents an expansion of the data base as a result of this experiment to include motion which is dominated by lateral acceleration. This area of data was previously undefined in terms of riding quality for an aircraft environment. As indicated by earlier studies, the results show subject passengers are about twice as sensitive to lateral as compared to vertical accelerations. Also, subject passengers appear to be slightly more tolerant to vertical acceleration in the presence of a low level of lateral acceleration. Originally, the data were broken into groups according to sex, seat position, and flying experience. The results from these various data groupings did not indicate significant differences from the total group result. However, a volunteer group such as this is strongly disposed towards liking to fly.

Figure 7 shows the relationship of subject passenger comfort rating and bank angle. The normal acceleration during the bank was monitored to insure that the turn was coordinated. In general, any deviation on the part of the subject passenger from an upright posture increases the level of discomfort. For the aircraft used in this experiment, when a left bank was performed, the subject passenger could not see out of the left-hand windows because of the presence of the airborne simulation equipment and therefore lost sight of the horizon. However, no significant difference in the data was observed between left and right bank angles. Based on the results of this test, present commercial airline operating procedure limiting maneuvering bank angles to about 20° is acceptable from a passenger comfort standpoint, 30° being a maximum acceptable bank angle during a coordinated turn.

CONCLUDING REMARKS

A flight program of 55 flights was conducted to evaluate subjective human response to an aircraft motion environment. As a result of this program the data base has been expanded to include a motion environment dominated by lateral acceleration and to include bank angle information. The results reinforce the statement that subjects are about twice as sensitive to lateral as to vertical acceleration. The results also showed that current airline practice of limiting bank maneuvers to 20° provides minimal passenger discomfort.

A five-point rating scale was used throughout the program. Because of the reluctance of the subject to select either one or five, the rating scale collapsed to effectively a three-point scale. This represents a minimum number rating scale and it would be highly desirable to obtain more resolution.

During the tests a light on the rating box was lit to request a subject rating. It was felt that an audible signal would permit the subject to engage in more normal flight activities without having to continuously monitor the light.

As with all experiments of this type, the subject group is a continuous problem. It is desirable to have a larger and more representative group of the flying public to participate in such tests in the future.

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TABLE I.- DATA ACQUISITION SYSTEM PARAMETERS

ATTITUDE RATE	PITCH ANGULAR ACCELERATION
ALTITUDE	ROLL ANGULAR ACCELERATION
AIRSPEED	YAW ANGULAR ACCELERATION
PASSENGER RATING (2)	NORMAL ACCELERATION
PITCH ANGLE	LATERAL ACCELERATION
ROLL ANGLE	LONGITUDINAL ACCELERATION
PITCH ANGLE RATE	AIRCRAFT TURBULENCE INPUT SIGNAL (3)
ROLL ANGLE RATE	DIRECT LIFT FLAP ANGLE
YAW ANGLE RATE	SIDE FORCE GENERATOR ANGLE

TABLE II.- COMFORT RATING SCALE

RATING	DESCRIPTOR
1	VERY COMFORTABLE
2	COMFORTABLE
3	NEUTRAL
4	UNCOMFORTABLE
5	VERY UNCOMFORTABLE

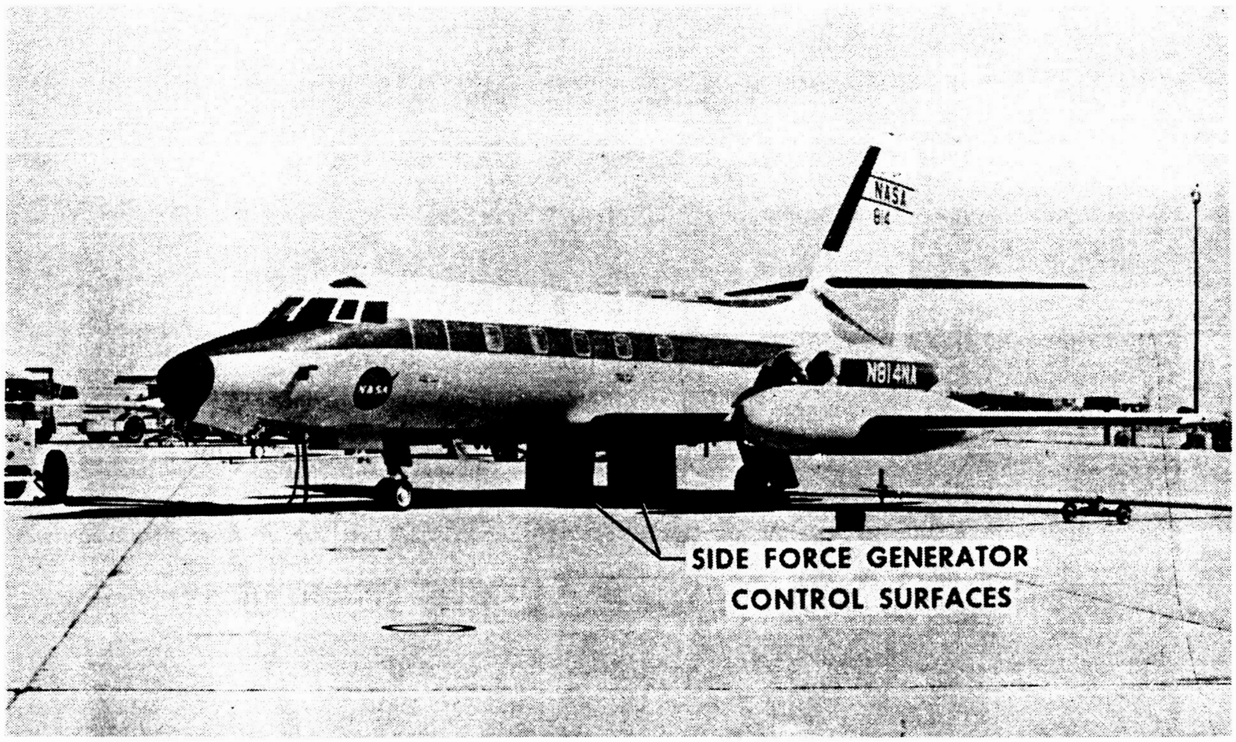

Figure 1.- NASA Jetstar.

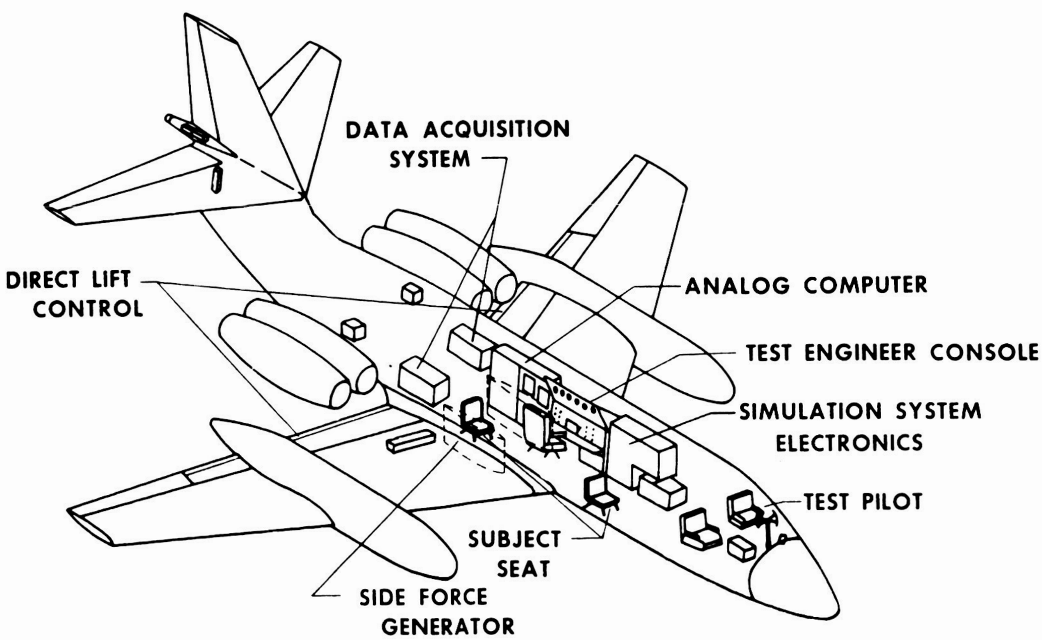

Figure 2.- NASA General Purpose Airborne Simulator (GPAS).

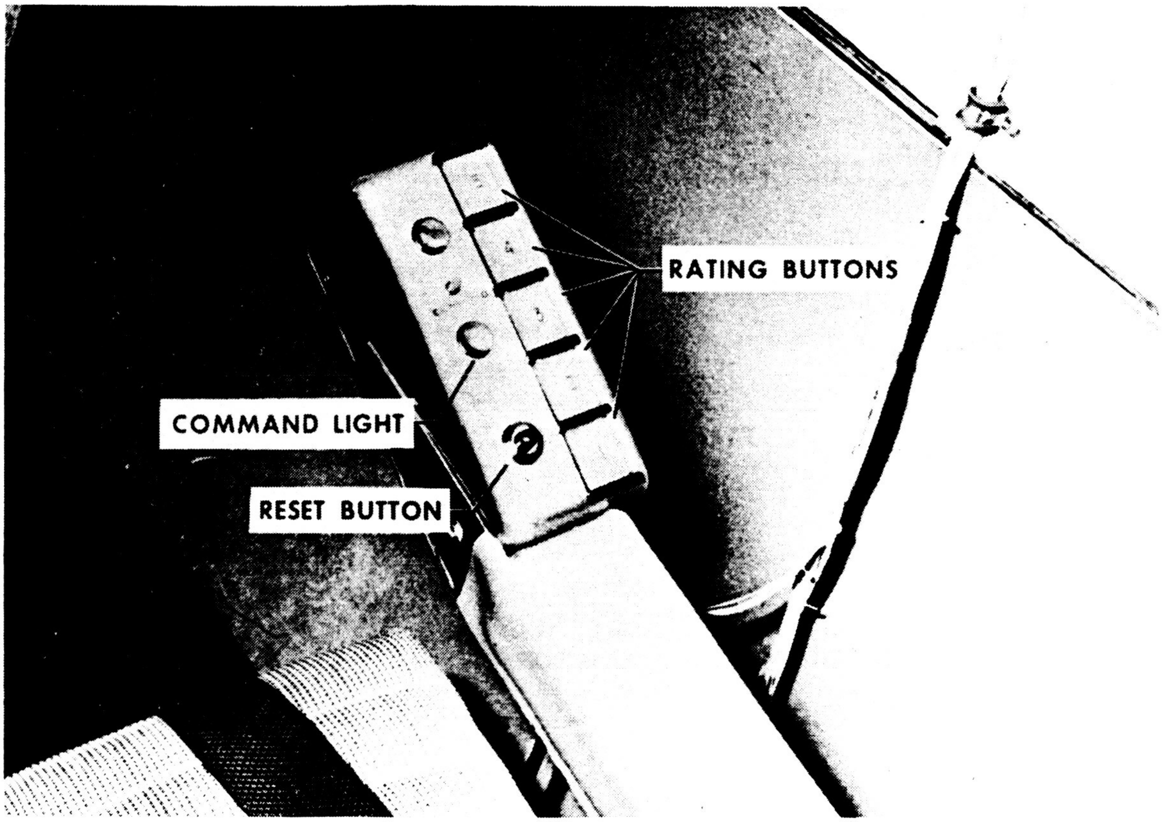

Figure 3.- Rating box installed on arm
of Jetstar passenger seat.

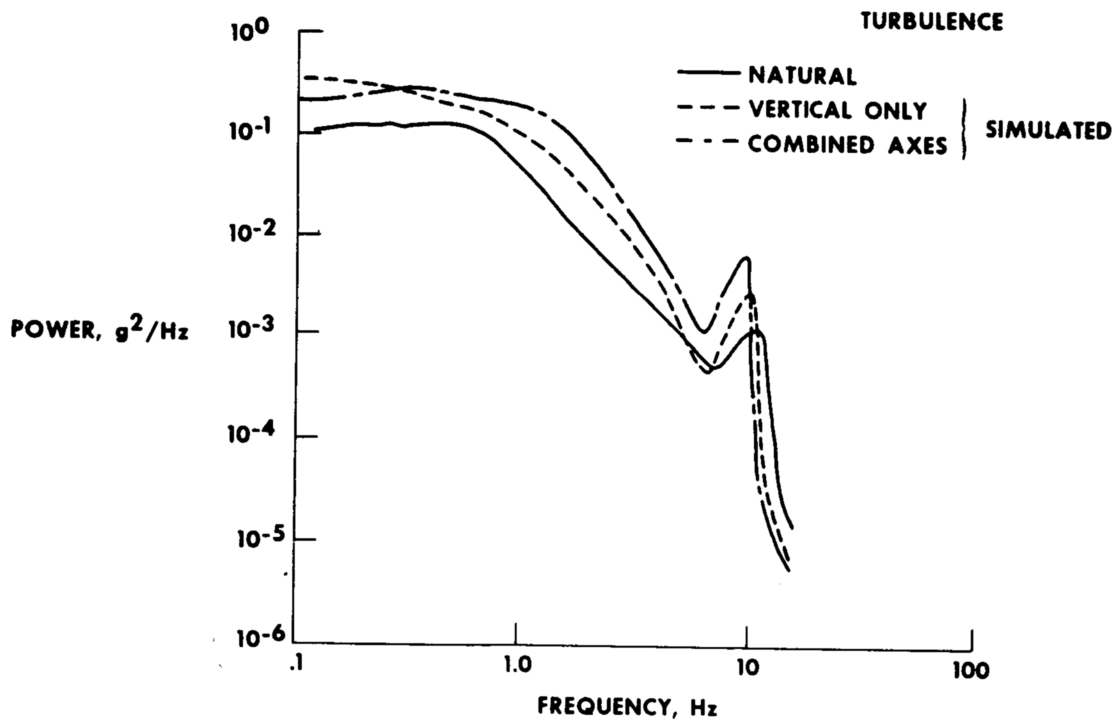

Figure 4.- Power spectral density of aircraft response to vertical acceleration.

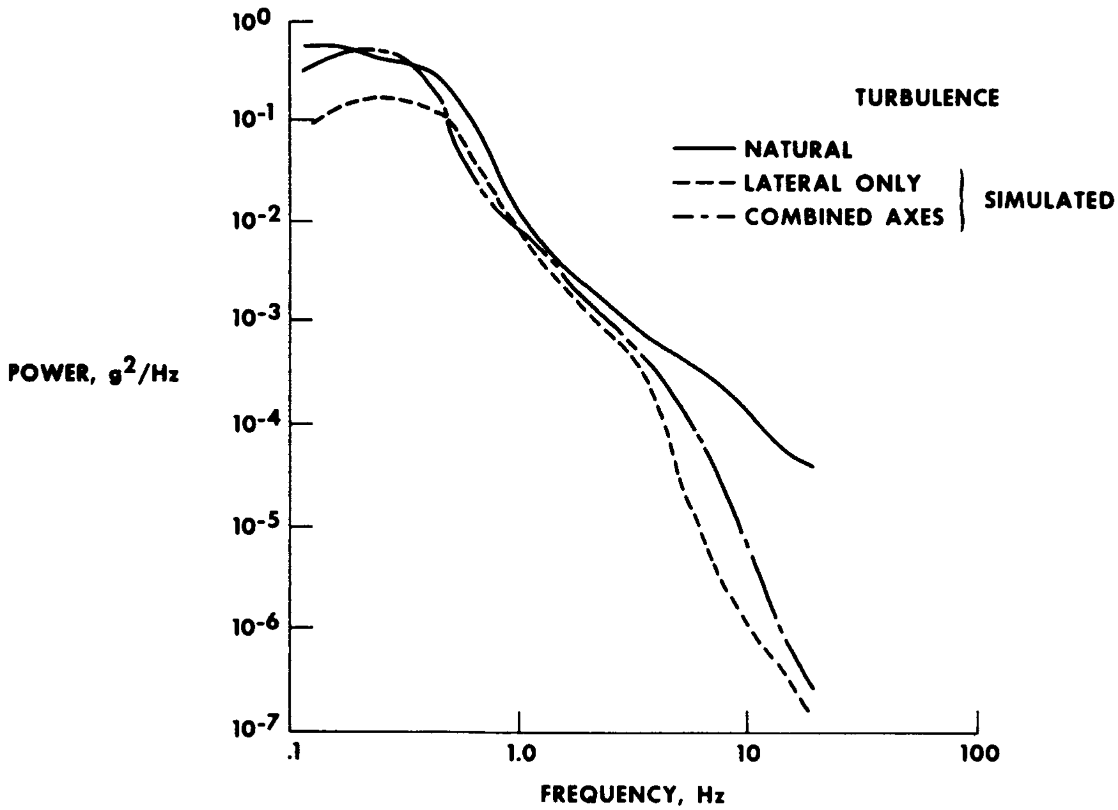

Figure 5.- Power spectral density of aircraft response to lateral acceleration.

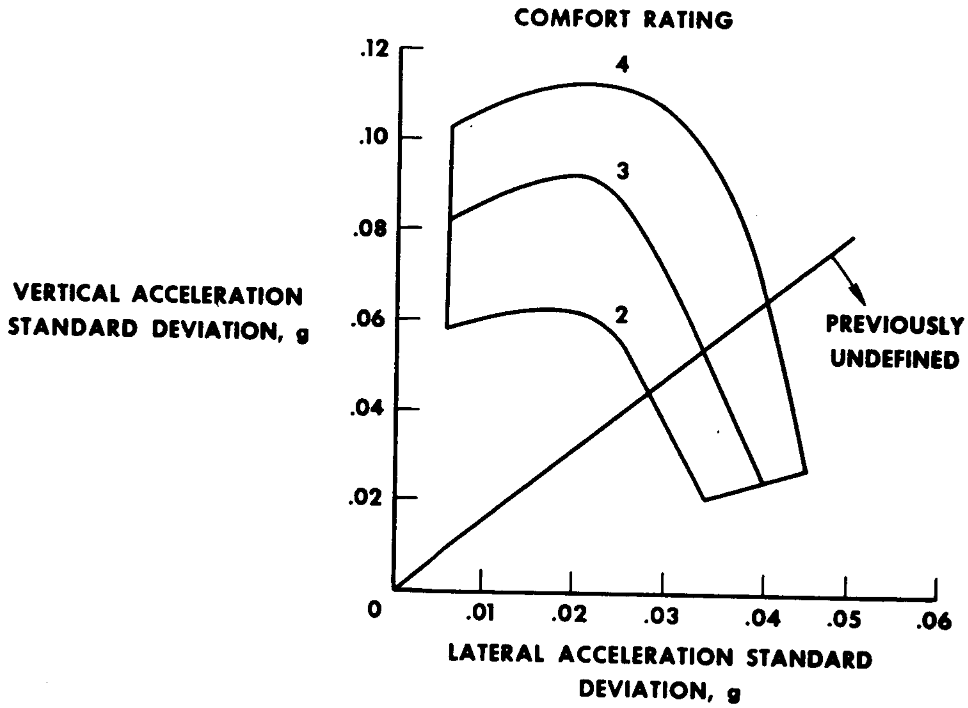

Figure 6.- Passenger response to aircraft accelerations.

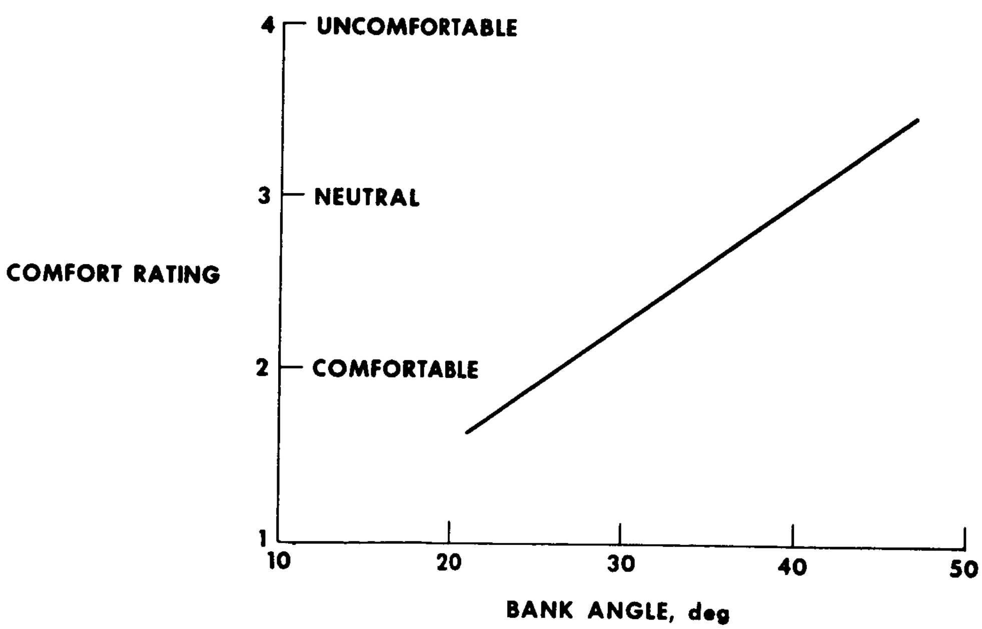

Figure 7.- Passenger response to bank angle.