(NASA-CR-146077) PASSENGER COMFORT DURING TERMINAL-AREA FLIGHT MANEUVERS M.S. Thesis. (George Washington Univ.) 124 p HC $5.50 CSCL 05E
N76-15781
Unclas
G3/53 09381

PASSENGER COMFORT DURING TERMINAL-AREA FLIGHT MANEUVERS

By

Ward Elliott Schoonover, Jr.
B.S., Aerospace Engineering,
Virginia Polytechnic Institute
1969

A Thesis Submitted to the Faculty of
The School of Engineering and Applied Science
of the George Washington University
in Partial Satisfaction of the Requirements
for the Degree of Master of Science

February 1976

Thesis directed by
Dr. John D. Shaughnessy
Associate Professorial Lecturer in Engineering

ABSTRACT

Complex terminal-area flight maneuvers being considered for airline operations may not be acceptable to passengers. To provide technology in this area, a series of flight experiments was conducted by the National Aeronautics and Space Administration using the U.S. Air Force Total In-Flight Simulator (TIFS) Aircraft to obtain passenger subjective responses to closely controlled and repeatable flight maneuvers. In 8 test flights, reactions were obtained from 30 passenger subjects to a wide range of terminal-area maneuvers, including descents, turns, decelerations, and combinations thereof. Analysis of the passenger rating variance indicated that the objective of a repeatable flight passenger environment was achieved. Multiple linear regression models developed from the test data were used to define maneuver motion boundaries for specified degrees of passenger acceptance.

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to the National Aeronautics and Space Administration for its support of the research for and preparation of this thesis. Special appreciation is due his wife for her loving patience, encouragement, and assistance. The technical advice and guidance of Dr. John D. Shaughnessy (thesis advisor) and of Mr. D. William Conner are greatly appreciated. For their editorial and typing services, the author sincerely thanks Mss. Frances Sabo, Margaret Schoonover, Kathy Chappell, and Doris Vandeveer.

TABLE OF CONTENTS

Page

Appendix

LIST OF TABLES

TABLE

TABLE

LIST OF FIGURES

Figure

LIST OF SYMBOLS

b	regression model coefficient
D.O.F.	statistical degrees-of-freedom
F	ratio of two independent chi-square random variables, each divided by its degrees-of-freedom
h	aircraft pressure altitude, ft
$\dot{h}$	aircraft rate of climb, ft/sec
n_x	longitudinal acceleration of aircraft center of gravity, g-units ($+n_x$ pushes passenger into seat back)
n_y	lateral acceleration of aircraft center of gravity, g-units ($+n_y$ pushes passenger to left)
n_z	normal acceleration of aircraft center of gravity, g-units ($+n_z$ lifts passenger out of seat bottom)
p	aircraft roll rate, deg/sec ($+p$ moves right wing downward)
q	aircraft pitch rate, deg/sec ($+q$ moves aircraft nose upward)
r	aircraft yaw rate, deg/sec ($+r$ moves aircraft nose to right)
R	sample correlation coefficient
R^2	coefficient of multiple determination
$\bar{R}$	mean passenger comfort rating
Δt	maneuver duration, sec

V_i	aircraft indicated airspeed, kt
γ	aircraft flight path angle, deg (+ γ for aircraft climbing)
θ	aircraft pitch angle, deg (+θ is aircraft nose up)
μ	mean value
$\lvert\mu\rvert$	mean deviation from zero
ξ	root-mean-square value
σ	standard deviation
ϕ	aircraft roll angle, deg (+ϕ is right wing down)
$\uparrow$	maximum deviation from zero (+ or -)

Subscript:

f	value at end of maneuver

Notation:

rms	root-mean-square

CHAPTER I

INTRODUCTION

The successful development and operation of any passenger transportation system involves many factors; principal among these is the system's acceptability to its passengers. It would be senseless, for example, to double the block speed of an aircraft by compromising its ride comfort or apparent safety to the extent that few people will be willing to ride the aircraft. In-depth field studies to define and rank the various factors influencing passenger acceptance of transport aircraft have been conducted within the last several years (refs. [1] and [2]). Findings of these studies indicate that air travelers generally consider safety, reliability, time savings, convenience, and comfort (in that order) to be more important than trip cost in determining overall satisfaction with a given vehicle.

The development of passenger transport aircraft has historically included simultaneous improvements in all five of the above key factors. However, as in all design evolutions, a point of trade-off has been reached in the terminal area where aircraft are operated at far-from-optimum flight conditions. For years, commercial passenger aircraft have taken off and landed along straight, shallow, and unaccelerating flight paths, which have, as a side benefit, ensured passenger comfort. Rapidly increasing fuel prices are, however, demanding fuel conservation. To conserve fuel and to reduce air-traffic congestion in the terminal area, system planners are considering complex flight maneuvers, including curved approaches, decelerations, and turns near the ground.

In addition, some proposed aircraft noise-reduction procedures involve steep landing approaches. Flight research to determine the feasibility (from the vehicle/system standpoint) of incorporating such unusual flight maneuvers into routine operations is part of NASA's Terminal-Configured-Vehicle Program (ref. [3]). Such maneuvers, however, may not be acceptable to passengers since certain combinations of linear and angular motions can be upsetting to the human vestibular system (ref. [4]). As ride comfort is a significant factor in determining acceptance and use of air transportation, a need exists for technology which will allow prediction of the degree of passenger comfort for terminal-area flight maneuvers.

Ride-comfort research has been conducted both in the field, aboard commercial and research vehicles, and in the laboratory using motion simulators. Field testing and laboratory experiments have provided substantial capability in predicting passenger comfort in a vibrating flight environment (ref. [5]). Several years ago, however, exploratory flight experiments concerning maneuver effects on ride quality conclusively indicated that criteria are needed which include more than just vertical and lateral oscillatory motions (ref. [6]).

Laboratory simulators lack motion capability sufficient to simulate sustained flight maneuvers; whereas, field tests aboard commercial vehicles do not allow precise control and repetition of a given maneuver. A very limited investigation of passenger comfort during turning flight maneuvers was conducted in 1971, using a two-place Navion aircraft and two pilots as passenger subjects (ref. [7]). Unpublished results of this study suggest a maximum roll rate of 15 deg/sec for simple turns and 20 deg/sec for S-turns. However, technology applicable to flight maneuvers in general and based on responses of typical air travelers does not exist.

To provide the technology from which ride-quality predictive relations and criteria can be established for terminal-area maneuvers, the present flight experiments were conducted by the NASA as part of a broader ride-quality experiments program using the U. S. Air Force Total In-Flight Simulator (TIFS) aircraft (fig. 1). For this experiments program the TIFS variable-stability flight control system was modified to accept aircraft motion-command signals from a magnetic tape. The TIFS thus modified, was used to expose passenger test subjects to closely controlled and repeatable flight maneuvers. This thesis describes the experiments, the analysis applied to the data to produce various ride-comfort models, and the maneuver-motion boundaries obtained when the models were exercised for various degrees of passenger acceptance. It is anticipated that results presented herein will be most useful in the design of new, more complex approach and departure flight paths, as well as of aircraft having such flight path capability.

CHAPTER II

TEST VEHICLE

Basic TIFS Aircraft

The TIFS is a C131-H transport (similar to a Convair-580 commercial transport) modified into a variable-stability research aircraft (ref. [8]). Principal uses for the TIFS include handling-quality evaluation and pilot training for advanced configurations prior to actual vehicle production. The TIFS, for example, has been used to simulate the NASA space shuttle, the USAF B-1 bomber (ref. [9]), and a Concorde-type supersonic transport (ref. [10]). Figure 2(a) illustrates the distinctive features of the basic TIFS aircraft. A simulation cockpit, mounted on the nose of the C-131, is designed to place evaluation pilots (who are the aircraft motion command sources) in a cockpit environment configured to closely duplicate that of the cockpit of the aircraft being simulated. The flight motion characteristics of the aircraft being simulated are also matched through use of special variable stability features of the aircraft which include special motion control surfaces and an analog computer. Safety pilots, located in the original Convair cockpit, monitor the simulation in progress and have the capability of disengaging the variable-stability system and resuming control of the aircraft at any time.

The special motion control surfaces provide independent control of the forces along and moments about all three motion axes. Included are aerodynamic surfaces mounted vertically above and below each wing to provide side-force variation with very little rolling or yawing moment, aileron-type flaps immediately outboard of the engines to provide direct lift control, and servo-operated throttles to provide longitudinal force variation. High-performance electrohydraulic actuators drive the existing ailerons, elevator, and rudder to produce rolling, pitching, and yawing moments, respectively. Inputs to the analog computer come from the evaluation pilot's controls and airplane motion sensors. To simulate the flight characteristics of another aircraft, the analog computer circuitry is used to alter the stability and control characteristics of the TIFS. With appropriate adjustments, the new stability and control characteristics experienced by the evaluation pilots can match those of the particular aircraft being simulated. A digital recording system capable of recording 58 individual variables, such as airplane motions and pilot control inputs, logs the test results for engineering evaluation of the simulation. Further details of the basic TIFS aircraft can be found in reference [8].

Airframe and Cabin Interior Modifications

Figure 2(b) illustrates the TIFS modifications made for ride-quality testing. The standard TIFS simulation cockpit was replaced with a nose fairing to reduce weight. Aft-mounted ballast was also removed to accommodate the additional weight required for cabin interior refurbishment, magnetic tape recorder, increased number of passengers, and increased fuel loading (to minimize ground delay time between flights).

The aircraft forward cabin section between the cockpit and computer (fig. 3(a)) was outfitted with wood paneling, curtains, and a carpet to create an airline-type environment. Five pairs of standard Convair seats (fig. 3(b)) were provided for the 10 test subjects. Each passenger seat was provided with a reading light, an adjustable outlet of conditioned air, a seat pocket with airsickness bag, and an emergency evacuation instruction card. A restroom, equipped with a marine-type toilet, was provided adjacent to the test subject area. The TIFS hydraulic console area was soundproofed and trimmed with wood paneling to muffle the sound of the continuously-operating hydraulic boost pumps. All but one pair of test subject seats were adjacent to a window. For the flight-test director, an additional double seat was provided immediately behind the test subjects, together with voice communications to the pilots and test engineer and a public address system for instructing the passenger subjects during flight. A closed-circuit television camera was mounted ahead of the seating area but behind a panel to record activity of a few of the test subjects. The video image was both recorded and viewed on a monitor located at the flight-test director's seat.

Variable Stability System Modifications

General block diagrams illustrating changes made in the TIFS Variable-Stability System (VSS) are shown in figure 4. For the basic TIFS system (upper-block diagram), pilot control inputs are electronically converted by a computer model of the simulated vehicle into appropriate vehicle motion response signals. These signals are then combined by a feed-forward system in the computer to generate commands to the TIFS flight control surfaces necessary to produce the appropriate aircraft motions. Feedback loops correct errors in the resulting aircraft motions. For the ride-quality experiments (lower-block diagram), the pilot-control inputs were replaced by magnetic tape command signals. These command signals were then combined, with appropriate filtering and shaping, to generate commands to the TIFS flight control surfaces necessary to produce the desired aircraft motions. The response feedback system was retained. The general scheme illustrated by this block diagram was followed for each of the motion command signals: angle of attack, angle of sideslip, pitch angle, roll angle, yaw rate, and true airspeed.

To illustrate the system approach as well as techniques used to cope with various problems encountered, the detailed block diagram design for the roll angle command is presented in figure 5. The blocks in bold outline identify additions made to the system. The motion command signals were initially modified by a low-pass filter to eliminate signal content above 4 Hz which were found to excite airplane structural modes and produce undesirable motion at the passenger location. Spurious high-amplitude spikes in the motion command signals, produced by the FM playback unit, caused automatic VSS disengagement. This problem was corrected by reducing the first-order low-pass filter corner frequency to 1 Hz, and by adding a fourth-order low-pass filter having a 5 Hz corner frequency. To remove signal transients during recorder start and stop operations, a variable attenuator was added to linearly increase the motion command signals from full attenuation to full strength over a 10-second interval after the recorder was started. The same circuit also diminished the signals back to full attenuation in the last 10 seconds before the recorder was stopped. A sidestick controller (which controlled pitch as well as roll) gave the copilot the capability of providing aileron trim and of maneuvering the aircraft with the VS system engaged to avoid cloud formations containing turbulence and to maintain altitude and air traffic clearance.

An integral feature of the TIFS variable-stability system is a provision to monitor specific signal channels and to automatically disengage the VSS if any one of the monitored channels exceeds a predetermined safe level.

The pilots could also disengage the VSS at any time using either a control-wheel-mounted switch or a center console switch.

Motion Control System Performance

In general, the TIFS proved to be an excellent vehicle for providing prescribed, closely controlled, and repeatable test motions. As illustration, figure 6 presents time histories of four appropriate motion parameters measured during a particular maneuver flown on two different flights. The maneuver shown is a turning deceleration with pitchover, which was probably the most complex and extreme maneuver tested, and therefore, was one of the most difficult to repeat. Differences in parameter values are relatively minor between flights and are essentially constant over the time duration of the maneuver for the three parameters (roll angle, pitch angle, and indicated airspeed) which were specifically controlled by the motion command tape. Differences could be expected to remain nearly constant during a commanded maneuver because each of the three parameters was recorded on the drive tape in terms of parameter deviation from a reference flight condition. The slight shifts in parameters between the two flights are associated with minor changes in reference flight conditions by the copilot to avoid weather, to stay within a certain test area, or to increase/decrease test altitude. The positive shift in pitch angle (from flight A to flight B) is accompanied by a positive shift in airspeed because of a simultaneous positive shift in flight path angle.

CHAPTER III

FLIGHT TESTS

Flight Maneuvers

Maneuvers investigated individually consisted of one of three basic components (steady descent, simple turn, or longitudinal deceleration) of typical terminal-area flight maneuvers. A few combinations of two or three of these components were used to study subjective responses to more complex maneuvers (for example, a turning deceleration with pitchover, etc.). The ranges of maneuver motion parameters (for example, flight-path angle, roll angle, etc.) were chosen to: (1) fall within the TIFS maneuver envelope and (2) somewhat exceed the motion parameter ranges normally encountered during terminal-area maneuvers of present commercial passenger aircraft.

The maneuver test drive tapes were generated by flying the TIFS through the sequence of maneuvers. No two maneuvers of the same type were presented sequentially. Several preliminary check-flights were devoted to determining the aircraft configuration and piloting sequence necessary for the various maneuvers and to practice execution of the maneuver sequence in a continous and timely manner. This was found to be possible if the maneuvers were spaced no less than 90 seconds apart. The entire 48-maneuver sequence required a minimum of 72 minutes of flight time. Concern that the results of a single test of this duration might be compromised by subject fatigue led to division of the test sequence into two equal test tapes, each having 24 segments and approximately 36 minutes in duration. In a few instances, flight envelope restrictions and inaccuracy of maneuver execution during the drive tape preparation caused slight unintended motions in particular maneuvers; however, in general, this technique for generating a maneuver command tape was quite successful.

A descriptive and parametric summary of the maneuvers as recorded on the two command tapes is presented in table I. Of the 10 motion parameters listed, only maximum pitch angle, maximum roll angle, and indicated airspeed were directly specified by individual signals on the maneuver command tapes. The remaining seven parameters were free to vary from flight to flight. With the exception of pressure altitude (whose initial value varied from flight to flight) repetition between flights of parameter values for a given maneuver was excellent. Very few of the actual test maneuvers were contaminated by undesired motions due to atmospheric turbulence.

Passenger Subjects

Thirty passenger subjects were chosen from among NASA employees, university students, and the general public, to include a range of age and previous flight experience and to represent air travelers in general. Each candidate subject submitted a completed health questionnaire (app. A, questionnaire I) to the Langley Medical Officer for approval of his participation in the flight experiments. Passenger subjects thus approved completed a background survey questionnaire (app. A, questionnaire II) which was used to determine demographic characteristics and attitudes concerning flying (table II(a)). Comparisons of the subjects' characteristics with those of general air travelers (refs. [1] and [11]) are shown in table II(b) and figure 7. The data in table II indicate that in the present study the air traveler was well represented, with the possible exception that the test subjects fly more for nonbusiness reasons and enjoy flying more. Figure 7(a) presents the importance of various factors determining overall trip satisfaction. Both general air travelers and the maneuvers experiments subjects rank *comfort* equal to or greater than *cost* in importance. The relatively greater importance to the maneuvers subjects of cost is probably because a greater portion of their flights are made for nonbusiness purposes and therefore at personal expense. Figure 7(b) indicates the importance of various factors determining passenger comfort; for the six most important factors, good agreement exists between the maneuvers subjects and general air travelers. Agreement was not good for the three lowest ranking factors: presence of smoke, lighting, and workspace. Estimates of the importance to comfort of these three factors contrast with estimates of the relative importance of in-flight passenger activities (fig. 7(c)): The maneuver test subjects appear more sensitive to the presence of smoke, yet rank smoking greater in importance as an activity. They also indicate a greater importance of lighting and workspace, yet indicate an activity-preference for thinking, viewing, talking, and daydreaming rather than reading, eating, or writing. This discrepancy may be due in part to differences in passenger interpretation of the term "workspace" (perhaps including equating with roominess in general). The subjects' stated preference for viewing is in agreement with later findings concerning passenger subject activities during test flights and may have influenced their ride comfort assessments by providing increased visual motion cues. In summary, table II and figure 7 indicate that with regard to demography, flight experience and attitudes toward flying, the 30 TIFS maneuver test subjects were reasonably representative of air travelers in general.

Test Procedure

Approximately 1 hour prior to a given test flight, 10 of the test subjects were assembled and briefed on the purposes of the TIFS Ride-Quality Program in general and of the upcoming flight in particular. The subjects were informed of the types and magnitudes of motion to be experienced and of the ability of any subject at any time to terminate the input motion by a simple hand signal (such termination, in fact, occurred just once). After all questions were answered, each subject signed the manifest, and boarded the aircraft.

Once all passenger subjects were aboard and seated with seat belts secured, the TIFS aircraft took off and during about 15 minutes climbed to the appropriate test area, altitude, and heading. The aircraft was then trimmed in straight and level flight and the variable-stability system engaged. The motion-command tape recorder was started and the motion command signals were brought to full strength. For the next 30 to 40 minutes, the aircraft was piloted by the tape recorder, with the exception of occasional pitch and roll trim changes by the copilot to keep the aircraft within safe test airspace. As the various test maneuvers were experienced in the aircraft, the beginning and end of each evaluation interval (typically 30 sec) were announced over the aircraft's public address system by the test direction. At the end of each evaluation interval, each passenger subject recorded on a rating sheet (app. A, questionnaire III) his estimate of his own total comfort on a 7-point rating scale employing undefined descriptors ranging from "Very Comfortable" to "Very Uncomfortable" (see table III). In addition, each subject was asked to report in a "Comments" column any aspect of the passenger environment which he considered dominant in his assessment of personal comfort. Upon completion of the entire set of motion test segments, the motion command signals were attenuated, the tape recorder was stopped, the variable-stability system disengaged, and the aircraft returned to the Langley Research Center and landed. During the return trip, the passenger subjects completed summary questionnaires (app. A, questionnaire IV) stating their assessments of the overall comfort (using the 7-point scale) of the test ride and of specific aspects of ride comfort (for example, motion, noise, seat comfort, etc.). Upon landing, the passengers deplaned and, after a short debriefing, were dismissed.

CHAPTER IV

FLIGHT TEST RESULTS

The 2 motion command tapes contained a total of 48 unique flight maneuvers (24 on each tape). Each command tape was tested 4 times for a total of 8 maneuver test periods. Each of the 48 unique flight maneuvers was therefore repeated 4 times. Each of the resulting 192 test maneuvers was evaluated by 10 passenger-subjects. A grand total of 1920 individual ride-comfort ratings were thus obtained.

Aircraft Maneuver Motion Data

A total of 58 aircraft motion, aerodynamic, and flight control variables were measured and digitally recorded (at 50 samples of each variable per second) continuously throughout each of the 8 maneuver test periods. For example, the aerodynamic variables included such qualities as the aircraft angle-of-attack and sideslip angle. Examples of the flight control variables recorded are the aileron, elevator, flap and rudder deflections, and engine throttle position. Of the aircraft motion variables recorded, the 13 variables listed in table V were selected for subsequent data reduction and analysis.

As previously mentioned, the reason for using pre-recorded magnetic tape signals to command the aircraft flight motions was the requirement that the same flight maneuvers be evaluated by more than one subject group during different flights. Comparison of time histories of the 13 aircraft motion variables during flight-to-flight repetition of any specific test maneuver indicates that this requirement was met. During the 8 test flights, the maneuver-motion-variable values presented in table I were achieved to within 10 percent. The single exception to this was pressure altitude, which varied considerably because of deliberate reduction of initial (start of maneuver tape) altitude as the flight program progressed and because of copilot control inputs between test maneuvers. Only during two test maneuvers did the aircraft encounter noticeable atmospheric turbulence.

A minor malfunction of the data recorder caused distortion of low-amplitude oscillatory motion tape signal content throughout 4 of the 8 maneuver test periods. This distortion had negligible effect on the present analysis but precluded spectral analysis of the motion data.

Passenger Subjective Response Data

To illustrate the range of ride-comfort ratings obtained, the 240 ratings from the first test flight are presented in table IV. The mean of ten subject ratings for a given maneuver ranged from 1.10 (very comfortable) to 5.60 (between somewhat uncomfortable and uncomfortable), while the mean of the 24 ratings given by a single subject during any single flight ranged from 1.50 (between very comfortable and comfortable) to 5.13 (somewhat uncomfortable). Rating standard deviations were approximately equivalent in both cases (ranging from 0.30 to 1.91 and from 0.50 to 1.90, respectively), suggesting that variation among subject responses to a given maneuver or maneuver sequence was as significant as variation in responses among maneuvers. A comparison of the mean of a given subject's responses to the 24 maneuvers in a single flight with his overall comfort assessment of that flight (from the post-flight questionnaire) is shown in figure 8. Those subjects whose mean ratings for the 24 maneuvers were on the comfortable side of neutral appear to have either forgotten or forgiven part of their experience in making an overall comfort assessment. Conversely, those subjects whose mean ratings for the 24 maneuvers were on the discomfort side of neutral tended to give worse overall comfort ratings. In making overall comfort assessments, subjects avoided both rating scale extremes (very comfortable and very uncomfortable) altogether and tended to avoid the midpoint (neutral). Most subjects found the flights to be slightly on the comfortable side of neutral (mean rating = 3.60). The standard deviation of all the comfort ratings (1.513) is much larger than that of ratings obtained while using a similar comfort scale in vibratory motion experiments (For examples see ref. [13]).

Responses to the post-flight questionnaire indicated that 6 of the 30 passenger subjects used airsickness medication in the past, although none used it during these flight experiments. Seven subjects reported experiencing some symptoms of motion sickness during the maneuver experiments. The predominant activities during flight were thinking, looking out the window, and talking (in that order). Most subjects said the seats were comfortable. By far the motion found most uncomfortable was the sudden descent (pitchover following a longitudinal deceleration). The non-motion factors found most uncomfortable were the noise level, cabin pressure changes, and temperature (in that order). All other non-motion factors were rated as comfortable.

The relationship between passengers' overall comfort assessments and their satisfaction with the ride is shown in figure 9. Here a "satisfied" passenger is one who at the end of the ride expresses willingness to take another ride with no doubt or hesitation. Data from the TIFS maneuver experiments are compared with data from commercial airline flights (ref. [1]). Because of the general agreement between the 2 sets of data and because the commercial flight data is based on a substantially larger sample, in subsequent discussion the commercial flight relationship is used.

Analysis of variance applied to the passenger response data (detailed in appendix B) confirmed that the objective of presenting a repeatable flight environment to passenger-subjects on different flights was achieved. The particular maneuver being tested and the passenger seat location were found to significantly affect the subjective rating given, while the variation in ratings given between repetitions of a given maneuver sequence were insignificant. Seat location effects can be largely explained by three seats which were non-reclining and in a noiser location than the other seven. Significant multiple-factor effects exist which were not found to be explainable by known passenger-subject characteristics.

CHAPTER V

MULTIPLE LINEAR REGRESSION ANALYSES

To determine the relationship(s) between passenger comfort ratings and measures of the aircraft motion, the experimental data obtained were analyzed by multiple linear regression. It should be emphasized that regression analysis is simply data-fitting (that is, determining an empirical equation which characterizes the observed relationship between a dependent variable (the passenger comfort rating) and one of more independent variables (the measured aircraft motion variables)). The basis for determining the most appropriate equation is minimization of the mean square error, where error is the arithmetic difference between a given comfort rating and the corresponding rating predicted by the equation. Thus, the resulting equation is empirical and not based on fundamental cause-effect relationships characterizing human response to motion. This point is too frequently overlooked by those unfamiliar with regression analysis. Linear regression analysis was performed because of its relative simplicity of interpretation, both in the analysis itself and in practical application of the analysis results.

Linear regression analysis was performed in two ways. First, all of the data were analyzed as a whole to develop a comfort model (predictive equation) based on maneuvering motions in general. The data were then subdivided into individual maneuver types (turns, descents, decelerations, S-turns, and turning decelerations) and a model developed for each maneuver type. The predictive accuracy of the general model and of the particular model were compared for each type of maneuver. In all analyses, individual subjective ratings were used rather than the mean rating given a particular maneuver.

A motion variable sampled across a finite time interval can have several different measures (for example, mean value, root-mean-square value, mean deviation, standard deviation, etc.). Which of these measures most closely relates to passenger comfort during flight maneuvers has not been determined. It might be that different motion variables have different most-appropriate measures. Therefore, both the general regression analysis and the partitioned analyses were conducted employing five different measures of each motion variable. A more detailed discussion of the regression analysis employed is presented in appendix C.

Summary Regression Model

Table VI presents the order in which the 13 motion variables entered the regression when the variables were measured in each of 5 ways (maximum deviation, mean value, mean deviation, root-mean-square, and standard deviation) plus a combination of root-mean-square and standard deviation. Also shown for each regression step is the coefficient of multiple determination (R^2) which is the proportion of the total variation in individual comfort ratings accounted for by the regression model at that regression step. None of the regression models accounts for more than 40 percent of the variation in individual comfort responses. The composite (rms and standard deviation) model is the best linear model found after testing many possible variable and variable-measure combinations (not presented herein). For a given model, R^2 also provides an indication of the improvement in model fit to the data obtained by adding another variable. As a general guide, to merit inclusion in the model (thus increasing its complexity), it was assumed that an additional variable should account for at least an additional 1 percent in the variation in comfort ratings. For the best model, 4 variable measures σ_{n_x}, σ_{n_y}, σ_{n_z} and $\xi_{\dot{h}}$ together account for more than 36 percent of the variation in individual comfort ratings. Adding ξ_{v_i} as a fifth variable only accounts for an additional 0.8 percent. In fact, a regression model employing all 13 variables, instead of just 4, accounts for less than an additional 3 percent in rating variation. The most appropriate summary regression equation, then, seems to be one incorporating the first 4 variable measures in the last column, specifically

$$\bar{R} = 1.477 + 12.3\,\sigma_{n_x} + 32.8\,\sigma_{n_y} + 11.6\,\sigma_{n_z} + 0.0220\,\xi_{\dot{h}} \tag{1}$$

Statistics for this model are presented in table VII. The model accounts for 36.3 percent of the variation in individual comfort responses. The remaining 63.7 percent includes 54.1 percent due to variation in responses by the 10 subjects experiencing any given maneuver (recall the large standard deviations of responses to a single maneuver). The remaining 9.6 percent is error. While the rms error with respect to individual responses using this model is 1.209, when the variation in individual ratings for a given maneuver is accounted for, the rms error with respect to mean ratings is only 0.469. While the correlation between the regression model and individual comfort ratings is only 0.602, the correlation between the model and the mean rating given each maneuver is 0.951. The regression has an F-value of 272 and is thus significant to at least the 0.0005 level; that is, there is less than a 0.05 percent chance that the regression coefficients are in reality all zero and that the given equation results by chance.

A 90 percent confidence interval for each coefficient is shown in table VII. For example, although it is not certain that a repetition of the flight maneuver experiments and regression analysis would result in a σ_{n_z} coefficient of 11.6 there is a 90 percent chance that the σ_{n_z} coefficient obtained would lie between 10.5 and 12.7. Also shown is the portion of the average comfort rating contributed by each variable. It is apparent from these data that σ_{n_z} is not only the variable measure whose regression coefficient is most accurately known, but also the largest single contributor to the average comfort rating.

Simple Turns and S-Turns

Simple turns (fig. 10) were flown at constant altitude and specified constant airspeeds. The aircraft was rolled into a specified roll angle with a specified maximum roll rate. After about 20 seconds of steady turning flight, the aircraft was brought back to straight and level flight, with approximately the same maximum roll rate. The maneuver evaluation interval began approximately 5 seconds before the beginning of roll into the turn and ended about 5 seconds after the return to straight and level flight.

Regression analysis was applied to the 68 individual turning maneuvers (table VIII). The arbitrarily assumed requirement that an additional variable increase R^2 by at least 1 percent limited the choice of regression model to one of two: either a model including σ_{ϕ} and σ_{n_y} or a model including $\uparrow_{\phi}$ and $\uparrow_{n_y}$. There are only minor differences in the statistics for the two models and the latter is chosen primarily because of its relative simplicity of measure.

The maximum n_y deviations always occurred during turn entry and exit (that is, those portions of the turning maneuver were not fully coordinated ($n_y = 0$)). Because $\uparrow_{n_y}$ was related to $\uparrow_p$ (correlation = 0.77) and $\uparrow_p$ was a primary test parameter, a regression was done using $\uparrow_{\phi}$ and $\uparrow_p$, which resulted in the following model:

$$\bar{R} = 0.395 + 0.0640 \uparrow_{\phi} + 0.0653 \uparrow_{p} \qquad (2)$$

Statistics for this model are presented in table IX and are further discussed later. Airspeed (which ranged from 138 kt to 214 kt) and altitude (which ranged from 1400 ft to 10,900 ft) during simple turns had only secondary effects on comfort and their addition made little improvement in the above regression model.

S-turns (fig. 11) were also flown at constant altitude and specified airspeeds. About five seconds after the beginning of the maneuver segment, the aircraft was rolled to a specified roll angle. After a fixed time interval (0, 10, or 20 seconds) at this roll angle, the aircraft was rolled to an equal, but opposite, roll angle. After about 10 seconds at this roll angle, the aircraft was brought back to straight and level flight and five seconds later the maneuver segment ended. All roll transients were with a specified maximum roll rate.

Analysis of the S-turn data (table X) in general produced an order of variable and variable measure similar to that for simple turns. For this reason, and to obtain a comparison between a simple turn model and an S-turn model, the following S-turn model employing $\uparrow_p$ and $\uparrow_{\phi}$ was developed:

$$\bar{R} = -0.185 + 0.0785 \uparrow_{\phi} + 0.0806 \uparrow_{p} \qquad (3)$$

For statistics of this model see table XI. Figure 12, which is a plot of the two models (eqs. 2 and 3) graphically illustrates their similarity. A statistical test of significance (t-test) indicated less than a 5-percent chance that differences in regression coefficients between the two models were anything more than chance occurrences. Therefore a composite regression model was generated using combined simple-turn and S-turn data:

$$\bar{R} = 0.293 + 0.0665 \uparrow_{\phi} + 0.0697 \uparrow_{p} \tag{4}$$

Statistics for this model are presented in table XII, including a comparison of its predictive accuracy with that of the summary regression model developed earlier. The above model is only slightly more accurate in its fit to the turn and S-turn data than is the summary model but has the distinct advantage of employing only the relatively simple measure of maximum roll angle and maximum roll rate.

A plot of equation 4 and mean ratings for the 23 unique simple turns and S-turns are shown in figure 13. Each mean-rating data point shown is the average of the 40 individual ride comfort ratings given one unique turning maneuver, as that maneuver was repeated on 4 different flights. The corresponding roll angle and roll rate for that point are the average maximum roll angle and maximum roll rate over the 4 repetitions of that maneuver.

In agreement with the regression equation, these points indicate a general trend for an increased roll rate to evoke a less favorable response. For a moderate maximum roll rate (15 deg/sec) passenger ratings generally became somewhat uncomfortable when the maximum roll angle exceeded 40°
Just as confidence intervals were developed for individual regression coefficients, confidence intervals were developed indicating the probable range of mean comfort ratings to be expected should the experiment be repeated.
Figure 14 presents 90-percent confidence intervals for the mean comfort response during a turn made with a maximum roll rate of 15 deg/sec. The solid line indicates the most likely linear variation of mean comfort rating with

roll angle. Although one cannot guarantee that repeating the turns experiment would result in mean comfort ratings falling on the solid line, one can predict, with a 90-percent probability of being correct, that the mean ratings so obtained will fall within the limits shown. Also shown in figure 14 are mean comfort ratings for turning flight obtained by the University of Virginia during ride-quality experiments (ref. [12]) aboard the NASA General Purpose Airborne Simulator (GPAS). These data are in substantial agreement with the regression model, particularly at roll angles less than 40°.

The information in figures 9 (ref. [8] data) and 13 can be used to form a linear relationship between rolling motion in a turn and passenger satisfaction, shown in figure 15. A pilot wishing to satisfy at least 95 percent of his passengers (with regard to comfort) will limit his roll angle during turns (for a 10 deg/sec maximum roll rate) to 20°. Reducing the maximum roll rate during the turn only slightly increases the allowable maximum roll angle. Written passenger comments on individual maneuvers occurred quite consistently when either the roll angle exceeded 40° (typically described as a "lightheaded feeling" or a "sinking feeling") or the maximum roll rate exceeded 15 deg/sec (typically described as "abrupt"). This result should be used with caution, however, as there may be a significant difference between the level of motion at which a passenger first becomes uncomfortable and the motion level at which he is uncomfortable enought to make a written comment.

Steady Descents

Steady descent maneuvers (fig. 16) were tested by gradually bringing the aircraft to a specified pitch angle and flight path angle and announcing the beginning and end of the evaluation interval before retrimming the aircraft for the next maneuver. On occasion, the exit from an unusually steep descent was somewhat abrupt and immediately followed announcement of the end of the evaluation interval. Subjects, however, had been specifically asked to evaluate only what they experienced during the evaluation interval.

A preliminary examination of the subjective responses obtained during steady descents indicated a definite symmetry about a zero pitch angle (that is, that an aircraft pitch angle produced a similar degree of discomfort whether the aircraft were pitched nose up or nose down). Because this symmetry cannot be properly accounted for in a linear model employing the signed pitch angle, prior to regression all mean and maximum pitch angle values were converted to absolute values. Regression analysis of the resulting data (table XIII) suggests the following model:

$$\bar{R} = -0.1507 + 0.0981\ |\uparrow_{\theta}| - 0.118\ \uparrow_{\gamma} + 0.0195\ \uparrow_{V_i} \tag{5}$$

Statistics for this model are given in table XIV. Mean rating contributions imply that for a given airspeed, aircraft pitch angle and flight path angle are of equal importance. This finding contrasts with the fact that while few passengers commented at all on the steepness of the aircraft pitch angle (up to 13.8° nose-down), many passengers complained about rapid changes in cabin pressure. It is expected that repeating this experiment in a pressurized aircraft would result in a greatly reduced influence of flight path angle. Plots of ride comfort rating versus aircraft pitch angle are shown for several flight path angles and two airspeeds in figure 17. Also shown in the figure are the means of data points obtained at flight conditions (flight path angle and airspeed) approximating those applicable to the regression lines. The relatively larger amount of data scatter near zero pitch angle is due to passenger responses to factors other than aircraft motions (for example, noise, temperature, etc.). A 90-percent confidence interval for mean passenger comfort rating during steady descents at an airspeed of 200 kt and flight path angle of -6° is shown in figure 18. The most likely variation of mean comfort rating with pitch angle is that indicated by the solid line. There is a 90 percent chance that repetition of any test point in this part of the experiment (v_i = 200 kt, γ = -6°) would result in a mean comfort rating falling within the limits (dotted lines) shown.

As previously mentioned, passenger subjects were quite specific and consistent in complaints of ear discomfort due to pressure changes during descents. A plot of the percentage of passengers aboard who specifically commented on ear discomfort versus descent rate is shown in figure 19. These data suggest that in order to limit ear discomfort to only 5 percent of the passengers aboard, descent rates in an unpressurized aircraft should be limited to 400 ft/min. A crossplot of data from figures 9 and 17 yields the passenger acceptance relationships shown in figure 20. As an example, a pilot of an unpressurized aircraft making a 6° approach at 200 kt and a pitch angle of 2° nose down, thus satisfying 90 percent of his passengers, could, by raising the nose slightly and slowing to 150 kt, satisfy 97 percent of his passengers with regard to comfort.

Longitudinal Deceleration With Pitchover

Longitudinal decelerations (fig. 21) were accomplished by placing the aircraft in a slight climb, nose up, with near-maximum engine power. The engine power was then abruptly reduced and the aircraft allowed to follow a curved flight path as the airspeed decreased with pitch attitude held constant.

As the airspeed approached a normal-landing final approach speed, the aircraft was pitched over to a nose-down attitude. The average longitudinal deceleration, the final pitch angle, and the pitchover rate were varied. The evaluation interval began about 5 seconds before the engine power reduction and ended about 5 seconds after obtaining the final pitch angle.

Regression analyses of data obtained during longitudinal decelerations followed by pitchover (table XV) suggest that the most appropriate model of passenger comfort during that type of maneuver is simply

$$\bar{R} = 1.749 + 22.1\ \xi_{n_z} \tag{6}$$

The fact that n_z in this maneuver is typically zero except during the pitchover agrees with the fact that subjects typically found only the pitchover at the end of the deceleration to be uncomfortable, and that the discomfort of the pitchover was due to the "heave" motion experienced. Subjects commented on the deceleration itself only in terms of anxiety over the obvious (noise level) reduction in engine power. The fact that the maximum longitudinal deceleration obtained (0.184 g) stimulated no comment whatsoever, agrees with findings of the Japanese National Railways that rail passengers made no objection to sustained decelerations of up to 0.17 g (ref. [14]).

Statistics of the above regression model are given in table XVI. The coefficient of ξ_{n_z} is known quite accurately. The model fits the mean rating data to within an rms error of about one-third rating point, somewhat better than the summary regression model. The maneuvers themselves and the model together account for approximately one-third of the individual rating variance, while differences of opinion among the ten subjects evaluating any given descent maneuver accounted for nearly twice as much rating variance.

The deceleration model (eq. 6) was exercised by assuming an aircraft with the TIFS wing-loading and lift characteristics. The maneuver was assumed to include a smooth decrease in airspeed while at constant zero pitch angle, followed by a smooth reduction in pitch angle. It was assumed that the deceleration took 20 seconds and the pitchover 5 seconds. This maneuver time history was synthesized on a digital computer by an iterative program having a solution interval equal to the flight data sample interval (0.02 sec). The resulting normal acceleration time histories, and hence rms values, closely approximated those of corresponding experimental maneuvers.

The variation of passenger comfort with average pitch rate during pitchover predicted by the regression model is shown in figure 22 for three final pitch angles and two values of airspeed at pitchover. The final pitch angle and rate at which the aircraft pitches over have dominant effects on passenger comfort. The model also indicates that even a substantial longitudinal deceleration (0.157 g average for the 140 kt case) results in a net improvement in passenger comfort by reducing the airspeed, and hence normal acceleration, during pitchover. Each experimental data point shown represents an average of the 40 individual comfort ratings and four sets of motion measure for one of the 10 unique deceleration-pitchover maneuvers tested. Agreement between the model and experimental data is good.

A 90 percent confidence interval for the variation of mean comfort rating with average pitch rate (final pitch angle of -10°, 200 kt airspeed) is shown in figure 23. While the solid line indicates the most likely mean rating, there is a 90 percent probability that repeating the experiment would result in mean ratings falling within the broken lines. Cross-plotting the data of figures 9 and 22 results in the passenger-acceptance relationships shown in figure 24.

Constant acceptance boundaries with respect to final pitch angle and average pitch rate are shown for two airspeeds. For a small change in pitch attitude (which would normally be accomplished with a small pitching rate) a substantial average pitching rate is permissible. For large changes in pitch attitude (where one might expect correspondingly large values of pitch rate) the allowable pitching rate for a given acceptance level is sharply curtailed. Increased airspeed moves the acceptance boundary curves toward the origin. At normal approach speeds (140 to 200 kt), 95 percent passenger acceptance implies average pitch rates not to exceed 0.5 deg/sec for small changes in pitch attitude or 0.1 deg/sec for large changes in pitch attitude.

Turning Decelerations With Pitchover

Four different maneuvers of this type were tested. One purpose was to determine which of the preceding simpler maneuvers would have dominant influence on comfort in a more complex maneuver. The second purpose was to determine if the regression models developed for simpler maneuvers could be combined to closely model the data obtained in a more complex maneuver. The maneuver (fig. 25) began about 5 seconds after start of the evaluation interval with a roll (at moderate rate) into a turn of specified roll angle and duration. During the roll into the turn, the engine power was reduced and the airspeed allowed to decrease with pitch attitude maintained. Near the end of the deceleration the aircraft was rolled out of the turn and pitched over to a steady descent condition. This flight condition was maintained through the end of the evaluation interval. Regression analysis (table XVII) of the motion data from the 16 unique maneuvers and 160 individual ratings suggests the following model:

$$\bar{R} = 4.871 + 0.225\,\sigma_{\gamma} - 0.0557\,\sigma_{V_i} \qquad (7)$$

Statistics for this model are given in table XVIII. The model fits the data quite well (mean rating rms error of 0.278) and indicates that the pitchover portion of the maneuver was the dominant factor influencing passenger comfort. This finding is in agreement with the subjects' written comments in which the pitchover was the dominant complaint, steepness of the turn was second, and almost none complained of the deceleration. As in the simpler deceleration plus pitchover (without turning) the longitudinal deceleration (proportional to σ_{V_i}) had a beneficial effect on comfort. The reason for this is probably the same as in the case of the simpler maneuver: reduced airspeed at pitchover results in reduced normal acceleration during the pitchover, and hence increased comfort. Although including σ_{n_z} in the model increases the portion of rating variance accounted for by the model from 13.1 to 14.8 percent, it also greatly increases the uncertainty of the other coefficients. The F-statistic for this model indicates only a 0.1 percent chance that the regression coefficients occurred by chance. However, because the model is based on such a small portion of the total rating variance obtained during this type of maneuver, no parametric plots based on the model are presented. Estimating the comfort of these maneuvers using the model developed for simple- and S-turns (eq. 4) resulted in an average underestimation of 0.98 rating point, indicating that the subjects were responding to more than just the turn. The same exercise using the simple deceleration-with-pitchover model (eq. 6) yielded an average overestimation of 0.27 rating point, probably because the negative n_z (passenger pushed into the seat) during the turning portion of the maneuver is not nearly as uncomfortable as the positive n_z (passenger lifted out of the seat) developed during pitchover. In another analysis approach each turning deceleration motion time history was divided into three segments: turn entry, steady turn plus deceleration, and turn exit plus pitchover. The four motion variables and variable measures thought most appropriate in each segment were reevaluated from the basic data tape. Regression analysis using the resulting data indicated that the variable accounting for most of the discomfort was the pitch rate during pitchover. With that portion of the variance accounted for, the next most significant variable was the maximum normal acceleration during turn entry. Again, these findings are in complete agreement with the subjects' written comments. The model itself, however, failed to fit the rating data nearly as well as equation 7. In summary, it was determined that in a complex maneuver of this type, passengers react mostly to the pitchover, somewhat less to the turn, and little, if at all, to the deceleration. The limited number of unique maneuvers tested and the resulting limits on variable range so reduced the rating variance due to the maneuvers themselves that no satisfactory regression model could be developed. For this reason it is suggested that for this and other compound maneuvers the summary regression model be used to predict passenger comfort.

CHAPTER VI

CONCLUSIONS

A series of flight experiments has been conducted using a variable-stability research aircraft and a significant number of passenger subjects to investigate the passenger comfort of terminal-area flight maneuvers. Analysis of the variance in the comfort ratings obtained indicated that the objective of repeating the passenger environment from flight-to-flight by magnetic tape control of the aircraft was obtained. The same analysis and subsequent analyses, however, indicated that the rating variance due to differences among individual subjects responding to the same motion environment can be as large as or larger than the rating variance due to differences in the maneuvers themselves. The data obtained have been analyzed through multiple linear regression to produce several ride-comfort models. Each model expresses the passenger comfort rating of a given flight maneuver as a linear function of one or more of the motion variables measured during that maneuver. Optimum measures (mean value, root-mean-square, standard deviation, etc.) of the motion variables were determined for each type of flight maneuver tested. A summary model was generated using the entire data set collectively and is recommended for predicting the passenger comfort of compound maneuvers, such as turning decelerations

Modeling of simple turn and S-turn data indicated no significant differences in passenger response to the two types of turn. The analysis also indicated that passenger comfort was most closely described as a function of maximum roll angle and maximum roll rate, with little or no influence of airspeed or altitude. A goal of 95 percent passenger satisfaction implies a maximum roll angle of 20^o and a maximum roll rate of 10 deg/sec.

The comfort model obtained for steady descents indicates a significant influence of pitch attitude, flight path angle, and airspeed. However, it is thought that the influence of the latter two motion variables was due to cabin pressure changes during the descents, rather than the motion variables themselves. A goal of 95 percent passenger satisfaction suggests a maximum descent rate (for unpressurized aircraft) of 400 ft/min and a maximum nose-down pitch angle of 6^o during normal 3° approaches.

Passenger comments and modeling of comfort ratings obtained during simple decelerations followed by pitchover indicate that the normal acceleration transient during pitchover was the dominant influence on comfort. Exercising the resulting regression model with computer-synthesized maneuver time histories indicates that a substantial longitudinal deceleration can actually improve overall passenger comfort by reducing the airspeed, and hence, the normal acceleration during pitchover. At normal approach speeds, a goal of 95 percent passenger satisfaction suggests maximum pitch rates of 0.5 deg/sec.

Regression analysis of data from several compound maneuvers (turning decelerations with pitchover) produced a model which fit the data quite well. The data base for the model, however, was such that the model was based on only a small portion of the total variance in individual ratings. It is, therefore, suggested that for compound maneuvers the summary regression model be used. It was also determined that in a compound maneuver of the type tested, passenger comfort relates most closely to the pitchover portion, next closest to the turn, and little if at all to the longitudinal deceleration.

APPENDIX A

PASSENGER QUESTIONNAIRES

Questionnaire I (pp. 35 - 36) was completed by each prospective passenger-subject and was the basis for approval or disapproval by the Langley Medical Officer of that subject's participation in the maneuver experiments.

Questionnaire II (pp. 37 - 40) was completed by each passenger-subject prior to his participation in the maneuver experiments, and was used to determine his background, previous flight experience, and attitudes toward flying.

Questionnaire III (pg. 41) was completed by each passenger-subject aboard each test flight and obtained that passenger's comfort evaluation of each of the 24 maneuvers tested during that flight.

Questionnaire IV (pp. 42 - 44) was completed by each passenger-subject aboard each test flight and obtained that subject's evaluation of the comfort of the test flight as a whole, and of particular aspects of comfort during that flight.

Questionnaire I

STANDARD FORM 93
JANUARY 1971
GSA FPMR 101-11.8

Approved
Office of Management and Budget No 29-R0191

REPORT OF MEDICAL HISTORY

(THIS INFORMATION IS FOR OFFICIAL AND MEDICALLY-CONFIDENTIAL USE ONLY AND WILL NOT BE RELEASED TO UNAUTHORIZED PERSONS)

1. LAST NAME—FIRST NAME—MIDDLE NAME

2 SOCIAL SECURITY OR IDENTIFICATION NO

3 HOME ADDRESS *(No. street or RFD, city or town, State, and ZIP CODE)*

4 POSITION *(City, grade, component)*

5. PURPOSE OF EXAMINATION

6 DATE OF EXAMINATION

7. EXAMINING FACILITY OR EXAMINER, AND ADDRESS *(Include ZIP Code)*

8. STATEMENT OF EXAMINEE'S PRESENT HEALTH AND MEDICATIONS CURRENTLY USED *(Follow by description of past history, if complaint exists)*

9. HAVE YOU EVER *(Please check each item)*			10 DO YOU *(Please check each item)*		
YES	NO	*(Check each item)*	YES	NO	*(Check each item)*
		Lived with anyone who had tuberculosis			Wear glasses or contact lenses
		Coughed up blood			Have vision in both eyes
		Bled excessively after injury or tooth extraction			Wear a hearing aid
		Attempted suicide			Stutter or stammer habitually
		Been a sleepwalker			Wear a brace or back support

11. HAVE YOU EVER HAD OR HAVE YOU NOW *(Please check at left of each item)*

YES	NO	DON'T KNOW	*(Check each item)*	YES	NO	DON'T KNOW	*(Check each item)*	YES	NO	DON'T KNOW	*(Check each item)*
			Scarlet fever, erysipelas				Cramps in your legs				"Trick" or locked knee
			Rheumatic fever				Frequent indigestion				Foot trouble
			Swollen or painful joints				Stomach, liver, or intestinal trouble				Neuritis
			Frequent or severe headache				Gall bladder trouble or gallstones				Paralysis (include infantile)
			Dizziness or fainting spells				Jaundice or hepatitis				Epilepsy or fits
			Eye trouble				Adverse reaction to serum, drug,				Car, train, sea or air sickness
			Ear, nose, or throat trouble				or medicine				Frequent trouble sleeping
			Hearing loss				Broken bones				Depression or excessive worry
			Chronic or frequent colds				Tumor, growth, cyst, cancer				Loss of memory or amnesia
			Severe tooth or gum trouble				Rupture/hernia				Nervous trouble of any sort
			Sinusitis				Piles or rectal disease				Periods of unconsciousness
			Hay Fever				Frequent or painful urination				
			Head injury				Bed wetting since age 12				
			Skin diseases				Kidney stone or blood in urine				
			Thyroid trouble				Sugar or albumin in urine				
			Tuberculosis				VD—Syphilis, gonorrhea, etc.				
			Asthma				Recent gain or loss of weight				
			Shortness of breath				Arthritis, Rheumatism, or Bursitis				
			Pain or pressure in chest				Bone, joint or other deformity				
			Chronic cough				Lameness				
			Palpitation or pounding heart				Loss of finger or toe	12. FEMALES ONLY HAVE YOU EVER			
			Heart trouble				Painful or "trick" shoulder or elbow				Been treated for a female disorder
			High or low blood pressure				Recurrent back pain				Had a change in menstrual pattern

13. WHAT IS YOUR USUAL OCCUPATION?

14. ARE YOU *(Check one)*
☐ Right handed ☐ Left handed

93-101

ORIGINAL PAGE IS
OF POOR QUALITY

YES	NO	CHECK EACH ITEM YES OR NO. EVERY ITEM CHECKED YES MUST BE FULLY EXPLAINED IN BLANK SPACE ON RIGHT
		15. Have you been refused employment or been unable to hold a job or stay in school because of: A. Sensitivity to chemicals dust, sunlight, etc.
		B. Inability to perform certain motions.
		C. Inability to assume certain positions.
		D. Other medical reasons *(If yes, give reasons.)*
		16. Have you ever been treated for a mental condition? *(If yes, specify when, where, and give details).*
		17. Have you ever been denied life insurance? *(If yes, state reason and give details.)*
		18. Have you had, or have you been advised to have, any operations? *(If yes, describe and give age at which occurred.)*
		19. Have you ever been a patient in any type of hospitals? *(If yes, specify when, where, why, and name of doctor and complete address of hospital.)*
		20. Have you ever had any illness or injury other than those already noted? *(If yes, specify when, where, and give details.)*
		21 Have you consulted or been treated by clinics, physicians, healers, or other practitioners within the past 5 years for other than minor illnesses? *(If yes, give complete address of doctor, hospital, clinic, and details.)*
		22. Have you ever been rejected for military service because of physical, mental, or other reasons? *(If yes, give date and reason for rejection.)*
		23 Have you ever been discharged from military service because of physical, mental or other reasons? *(If yes, give date, reason, and type of discharge: whether honorable, other than honorable, for unfitness or unsuitability.)*
		24. Have you ever received, is there pending, or have you applied for pension or compensation for existing disability? *(If yes, specify what kind, granted by whom, and what amount, when, why.)*

I certify that I have reviewed the foregoing information supplied by me and that it is true and complete to the best of my knowledge.
I authorize any of the doctors, hospitals, or clinics mentioned above to furnish the Government a complete transcript of my medical record for purposes of processing my application for this employment or service.

TYPED OR PRINTED NAME OF EXAMINEE	SIGNATURE

NOTE: HAND TO THE DOCTOR OR NURSE, OR IF MAILED MARK ENVELOPE "TO BE OPENED BY MEDICAL OFFICER ONLY."

25. Physician's summary and elaboration of all pertinent data *(Physician shall comment on all positive answers in items 9 through 24. Physician may develop by interview any additional medical history he deems important, and record any significant findings here.)*

TYPED OR PRINTED NAME OF PHYSICIAN OR EXAMINER	DATE	SIGNATURE	NUMBER OF ATTACHED SHEETS

REVERSE OF STANDARD FORM 93

GPO 1971 O 427 090

Questionnaire II

O. M. B. No. 104-S 73001
Approval Expires 1-31-73

NASA

This questionnaire is part of an effort by the National Aeronautics and Space Administration and the University of Virginia to obtain information from the flying public to be used in the design of future transportation systems. The goal is to identify the needs and desires of airline passengers so that they can be satisfied by future systems. Your cooperation in completing this form will be appreciated and can only benefit you, the air traveler.

We would like only your first impressions on each question, and you need not answer any questions that offend you.

Thank you for your cooperation.

1. Age ——— 2. Sex: ☐ Male ☐ Female

3. Occupation ____________________

4. In a sentence or two, how do you feel about flying? (Examples — I love to fly; I do it whenever possible; or I hate to fly and do so only when forced to by my job.)

____

____

5. Primary purpose of most of your flights?

☐ Business ☐ Personal ☐ Other

6. Who provides the funds for most of your flights?

☐ Business ☐ Personal ☐ Other

7. How often do you fly? (Examples — Once a week, once a month, etc.)

____

8. Place a check in the box which describes the importance of each of the following in determining your satisfaction with an airplane ride.

	Unimportant	Very Little Importance	Somewhat Important	Very Important	Of Greatest Importance
Comfort	☐	☐	☐	☐	☐
Convenience	☐	☐	☐	☐	☐
Cost	☐	☐	☐	☐	☐
Reliability	☐	☐	☐	☐	☐
Safety	☐	☐	☐	☐	☐
Time Savings	☐	☐	☐	☐	☐
Ability to Work	☐	☐	☐	☐	☐
Services on Board	☐	☐	☐	☐	☐
Surroundings	☐	☐	☐	☐	☐
Services in Terminal	☐	☐	☐	☐	☐

9. Place a check in the box which describes the importance of each of the following in determining your feeling of comfort on an airplane ride.

	Unimportant	Very Little Importance	Somewhat Important	Very Important	Of Greatest Importance
Pressure Changes	☐	☐	☐	☐	☐
Noise	☐	☐	☐	☐	☐
Temperature	☐	☐	☐	☐	☐
Lighting	☐	☐	☐	☐	☐
Seat Comfort	☐	☐	☐	☐	☐
Up & Down Motion (bouncing)	☐	☐	☐	☐	☐
Side to Side Motion (rolling)	☐	☐	☐	☐	☐
Work Space and Facilities	☐	☐	☐	☐	☐
Presence of Smoke	☐	☐	☐	☐	☐

10. Which **five** of the following activities occupy most of your time in flight? Rank them using the numbers from 1 to 5 to show the position of each, with 1 representing the **most time** and 5 the least time. Use each number only once.

—— Eating
—— Drinking
—— Sleeping
—— Reading
—— Conversation
—— Writing
—— Daydreaming
—— Smoking
—— Looking out the window
—— Thinking
—— Walking in the aisle

11. Below are some statements about air travel in general. Considering your **overall flight experience,** place a check in the column which indicates the degree to which you agree with each statement.

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
The ride is very comfortable	☐	☐	☐	☐	☐
Writing is difficult during flight	☐	☐	☐	☐	☐
Service in the air is generally very good	☐	☐	☐	☐	☐
Flying is too expensive	☐	☐	☐	☐	☐
Service in the terminal is very good	☐	☐	☐	☐	☐
Reading is easy during flight	☐	☐	☐	☐	☐
It is easy to sleep during flight	☐	☐	☐	☐	☐
Conversation is easy during flight	☐	☐	☐	☐	☐
Eating is easy during flight	☐	☐	☐	☐	☐
Airplane seats are comfortable	☐	☐	☐	☐	☐
Concentration is difficult while flying	☐	☐	☐	☐	☐
It is easy to relax while flying	☐	☐	☐	☐	☐
I am more tired at the end of a flight than at the beginning	☐	☐	☐	☐	☐
Airplane interiors are in excellent condition	☐	☐	☐	☐	☐
I feel cramped due to lack of seating space on airplanes	☐	☐	☐	☐	☐

12. If you are going on a trip, what are some of the factors you would consider in choosing to go by air rather than by another mode of transportation (such as train, bus, car, etc.)?

____

____

13. Please fill in the table below for your past few intercity trips, as best as you can remember.

Trip	Route	Mode	Purpose of Trip	Length of Stay
1	From: To:	☐ Automobile ☐ Train ☐ Airplane ☐ Bus	☐ Business ☐ Other	
2	From: To:	☐ Automobile ☐ Train ☐ Airplane ☐ Bus	☐ Business ☐ Other	
3	From: To:	☐ Automobile ☐ Train ☐ Airplane ☐ Bus	☐ Business ☐ Other	
4	From: To:	☐ Automobile ☐ Train ☐ Airplane ☐ Bus	☐ Business ☐ Other	
5	From: To:	☐ Automobile ☐ Train ☐ Airplane ☐ Bus	☐ Business ☐ Other	

The success of this program depends on your understanding of the questions asked and our knowledge of your feelings. To accomplish this, we would like to discuss this questionnaire in greater depth with you. If you are willing, please put your name and telephone number at which we can contact you in the space below and we will make an appointment to talk to you at your convenience.

Name: ____________________________ Telephone Number: ____________

Questionnaire III

TIFS

Please indicate below your comfort assesment of each maneuver, as it is announced. Please comment on any aspect of your comfort you find outstanding.

	Very Comfortable	Comfortable	Somewhat Comfortable	Neutral	Somewhat Uncomfortable	Uncomfortable	Very Uncomfortable	Comments
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

20								
21								
22								
23								
24								

Questionnaire IV

1. Indicate your overall reaction to this flight:

   - ☐ Very Comfortable
   - ☐ Comfortable
   - ☐ Somewhat Comfortable
   - ☐ Neutral
   - ☐ Somewhat Uncomfortable
   - ☐ Uncomfortable
   - ☐ Very Uncomfortable

2. After experiencing this flight, I would: (check only one)

   - ☐ be eager to take another flight
   - ☐ take another flight without any hesitation
   - ☐ take another,flight, but with some hesitation
   - ☐ prefer not to take another flight
   - ☐ not take another flight

3. Indicate your reaction to the following motions of the aircraft:

	Not Uncomfortable	Somewhat Uncomfortable	Very Uncomfortable
Up and down (bouncing). . .	☐	☐	☐
Backward and forward. . . .	☐	☐	☐
Side to side.	☐	☐	☐
Sudden descents	☐	☐	☐
Sudden jolts.	☐	☐	☐
Turning	☐	☐	☐
General vibration	☐	☐	☐
Other (specify): ________	☐	☐	☐

Comments:

4.0 Check the box which indicates your feelings about each of the following items on this flight

	Not Uncomfortable	Somewhat Uncomfortable	Very Uncomfortable
Lighting	☐	☐	☐
Pressure (on ears)	☐	☐	☐
Noise	☐	☐	☐
Odors (other than tobacco smoke	☐	☐	☐
Presence of tobacco smoke	☐	☐	☐
Temperature	☐	☐	☐
Ventilation	☐	☐	☐
Workspace	☐	☐	☐

5. Indicate your reaction to each of the following statements:

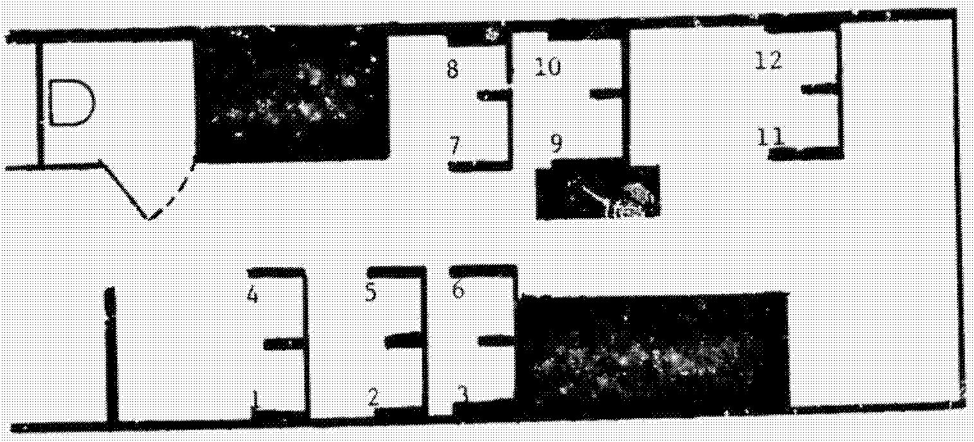
	Agree	Disagree	Strongly Disagree
The seat has enough leg room. . .	☐	☐	☐
The firmness of the seat is satisfactory.	☐	☐	☐
The seat is wide enough	☐	☐	☐
The shape of the seat is satisfactory.	☐	☐	☐
The seat can be adjusted to your satisfaction	☐	☐	☐

6. Check the box which indicates how much time during this trip you spent doing each of the following:

	Little or none	Some	Considerable
Reading	☐	☐	☐
Writing	☐	☐	☐
Talking	☐	☐	☐
Looking out the window.	☐	☐	☐
Dozing.	☐	☐	☐
Thinking.	☐	☐	☐
Drinking or eating.	☐	☐	☐

If any of the above were difficult to perform, which one(s)?________________

7. Specify your seat location: (check one)



8. Have you taken airsickness medication?

Previously	Yes ☐	No ☐
This flight	Yes ☐	No ☐

Did you experience any symptoms of airsickness on this flight?

Yes ☐ No ☐

COMMENTS

APPENDIX B

RIDE COMFORT RATING ANALYSIS OF VARIANCE

An individual ride comfort rating, R_{ijkl}, is identified within the whole array of ride comfort ratings obtained by four factor indices i,j,k, and l, which are defined as follows:

Factor A	$i = 1,2$	Maneuver motion command tape (Tape I or Tape II) piloting the aircraft at time rating was obtained
Factor B	$j = 1,2,3,4$	Repetition of Tape I or II during which rating was obtained
Factor C	$k = 1,2,\ldots,24$	Individual test maneuver for which rating was obtained
Factor D	$l = 1,2,\ldots,10$	Seat in which the passenger giving the rating was seated

Thus, with two motion command tapes, each tested 4 times, with each tape repetition providing 24 individual test maneuvers, and each test maneuver evaluated by 10 subjects, there are 1920 (2x4x24x10) individual ride comfort ratings R_{ijkl}. Each rating is uniquely defined by the 4 factor indices i, j, k, and l.

Analysis of variance determines which, if any, of the 4 factors (A, B, C, or D) or combinations of factors (e.g. A with B, B with D, A with C with D, etc.) account for substantial portions of the statistical variance in the ride comfort ratings obtained. This determination is equivalent to determination of which of the 4 factors or combinations of factors exerted substantial influence on the ride comfort ratings obtained.

Discussion of Mathematical formulas Employed

The mathematical formulas used in the analysis of variance (See table B - I for numerical examples) are presented in this section. For an individual factor (Factor A, for example), the rating sum of squares (S_A) is determined as follows:

$$S_A = \frac{\sum_{i=1}^{2} T_i^{2}}{4 \times 24 \times 10} - \frac{T^{2}}{1920} \qquad [= 30.3]$$

where: $$T_i = \sum_{j=1}^{4} \sum_{k=1}^{24} \sum_{l=1}^{10} R_{ijkl}$$

$$T = \sum_{i=1}^{2} \sum_{j=1}^{4} \sum_{k=1}^{24} \sum_{l=1}^{10} R_{ijkl}$$

Similarly, the sums of squares for the remaining individual factors (B, C, and D) are, respectively:

$$S_B = \frac{\sum_{j=1}^{4} T_j^2}{2 \times 24 \times 10} - \frac{T^2}{1920} \quad [= 6.9]$$

$$S_C = \frac{\sum_{k=1}^{24} T_k^2}{2 \times 4 \times 10} - \frac{T^2}{1920} \quad [= 271.8]$$

$$S_D = \frac{\sum_{\ell=1}^{10} T_\ell^2}{2 \times 4 \times 24} - \frac{T^2}{1920} \quad [= 143.7]$$

A two-factor interaction is the effect on the rating variance of a combination of two factors. For the two-factor interaction AB (motion command tape with tape repetition) the rating sum of squares (S_{AB}) is:

$$S_{AB} = \frac{\sum_{i=1}^{2} \sum_{j=1}^{4} T_{ij}^2}{24 \times 10} - S_A - S_B - \frac{T^2}{1920} \quad [= 24.8]$$

where: $T_{ij} = \sum_{k=1}^{24} \sum_{\ell=1}^{10} R_{ijk\ell}$

Similarly:

$$S_{AC} = \frac{\sum_{i=1}^{2} \sum_{k=1}^{24} T_{ik}^{2}}{4 \times 10} - S_{A} - S_{C} - \frac{T^{2}}{1920} \quad [= 534.7]$$

$$S_{AD} = \frac{\sum_{i=1}^{2} \sum_{\ell=1}^{10} T_{i\ell}^{2}}{4 \times 24} - S_{A} - S_{D} - \frac{T^{2}}{1920} \quad [= 81.0]$$

$$S_{BC} = \frac{\sum_{j=1}^{4} \sum_{k=1}^{24} T_{jk}^{2}}{2 \times 10} - S_{B} - S_{C} - \frac{T^{2}}{1920} \quad [= 74.7]$$

$$S_{BD} = \frac{\sum_{j=1}^{4} \sum_{\ell=1}^{10} T_{j\ell}^{2}}{2 \times 24} - S_{B} - S_{D} - \frac{T^{2}}{1920} \quad [= 359.7]$$

$$S_{CD} = \frac{\sum_{k=1}^{24} \sum_{\ell=1}^{10} T_{k\ell}^{2}}{2 \times 4} - S_{C} - S_{D} - \frac{T^{2}}{1920} \quad [= 104.6]$$

A three-factor interaction is the effect on the rating variance of a combination of three factors. For the three-factor interaction ABC (motion command tape with tape repetition with individual flight maneuver) the rating sum of squares (S_{ABC}) is:

$$S_{ABC} = \frac{\sum_{i=1}^{2}\sum_{j=1}^{4}\sum_{k=1}^{24} T_{ijk}^{2}}{10} - S_{AB} - S_{AC} - S_{BC} - S_{A} - S_{B} - S_{C} - \frac{T^{2}}{1920} \quad [=73.5]$$

where: $$T_{ijk} = \sum_{l=1}^{10} R_{ijkl}$$

Similarly:

$$S_{ABD} = \frac{\sum_{i=1}^{2}\sum_{j=1}^{4}\sum_{l=1}^{10} T_{ijl}^{2}}{24} - S_{AB} - S_{AD} - S_{BD} - S_{A} - S_{B} - S_{D} - \frac{T^{2}}{1920} \quad [=428.5]$$

$$S_{ACD} = \frac{\sum_{i=1}^{2}\sum_{k=1}^{24}\sum_{l=1}^{10} T_{ikl}^{2}}{4} - S_{AC} - S_{AD} - S_{CD} - S_{A} - S_{C} - S_{D} - \frac{T^{2}}{1920} \quad [=179.3]$$

$$S_{BCD} = \frac{\sum_{j=1}^{4} \sum_{k=1}^{24} \sum_{\ell=1}^{10} T_{jk\ell}^{2}}{2} - S_{BC} - S_{BD} - S_{CD} - S_{B} - S_{C} - S_{D} - \frac{T^2}{1920} \quad [= 464.3]$$

The total variance sum of square (S) is:

$$S = \sum_{i=1}^{2} \sum_{j=1}^{4} \sum_{k=1}^{24} \sum_{\ell=1}^{10} R_{ijk\ell}^{2} - \frac{T^2}{1920}$$

The error sum of squares is:

$$S_e = S - \begin{bmatrix} S_A + S_B + S_C + S_D \\ + S_{AB} + S_{AC} + S_{AD} + S_{BC} + S_{BD} + S_{CD} \\ + S_{ABC} + S_{ABD} + S_{ACD} + S_{BCD} \end{bmatrix}$$

The number of degrees-of-freedom for a given factor is defined as <u>one</u> less than the dimension of that factor. Factor C, for example, has 23 (24-1) degrees-of-freedom. The two-factor interaction BC has 69 [(4-1) x (24-1)] degrees-of-freedom. The three-factor interaction BCD has 621 [(4-1) x (24-1) x (10-1)] degrees-of-freedom.

The mean square for any individual factor or factor interaction is defined as its sum of squares divided by its degrees-of-freedom. For example, the mean-square value for the two-factor interaction BD is 13.3 (359.7/27).

The F statistic for any individual factor or factor interaction is defined as the ratio of the mean-square value for that factor to the error mean-square value. For example, the F statistic for the three-factor interaction ABD is 17.7 (15.9/0.9). The F statistic for any individual factor or factor interaction can be used together with a tabulation of the statistical F-distribution to determine the probability that variations in the ride comfort ratings obtained were influenced by that particular factor or combination of factors. This is done by scanning F-distribution tabulations to determine the minimum significance level (a table parameter defined below) for which the tabulated F value (having paired degrees-of-freedom equal to those of the analysis-of-variance error term and of the factor in question) does not exceed the F statistic for the factor in question. The significance level (α) thus determined is the probability that any apparent effect of the factor in question occurred, in fact, merely by chance. Subtracting this probability from unity ($1-\alpha$) yields the probability that the factor in question had significant influence on the variance in ride-comfort ratings obtained. For example the F statistic for Factor B is 2.6 with 3 degrees of freedom. The error term has 621 degrees-of-freedom. Examination of F - distribution tables at a combination of 3 and 621 degrees-of-freedom yields tabulated F values of 2.08 for α = 0.10, 2.58 for α = 0.05, and 2.79 for α = 0.025. Therefore, there is at least a 5-percent probability (α = 0.05) that the factor B did not influence the ratings obtained. Conversely, there is somewhat less than a 95-percent probability that the ratings were influenced by repetition of a given maneuver motion command tape (Factor B).

Discussion of Analysis Results

It can be said with a 0.1 percent chance of error (0.001 significance level) that among the individual factors the maneuver tape, maneuver segment, and passenger seat affect subjective responses. Only by accepting a 10 percent probability of error can one say that repetition of a given maneuver tape had an influence on the subjective responses obtained. This result is gratifying because it indicates that the objective of repeating the flight maneuver sequence through magnetic-tape control of the aircraft was achieved. The dominant main effect appears to be the individual maneuver segment (as was intended). The two maneuver tapes were so individually structured as to present two approximately equivalent series of maneuvers.

Employing the procedures defined previously and sub-factors, the sum of squares attributed to seat location (Factor D) can be further partitioned in several ways, as shown in Table B-II. In this table, the partial sum of squares for each sub-factor is that portion of the sum of squares due to seat location (143.7) which is in turn due to the particular sub-factor. Whether a seat was next to a window or on the aisle, and whether the seat was in the forward or aft cabin had little apparent effect on the subjective responses given by a passenger in that seat. The sub-factor accounting for 84 percent of the sum of squares due to seat location seems to be whether or not the seat could be reclined. Seats 3 and 6 were prevented from reclining by a wall panel immediately behind, while the same was true of seat 10 because of a video recorder mounted immediately behind the seat. Another possible reason for this contrast is that the noise level measured at the less comfortable seats exceeded the level at the other seats. Although the noise-level difference appeared to the minor, the noise at seats 3 and 6 included a high-pitch whine from the hydraulic equipment behind the paneling. The difference in mean subjective response between the reclining and non-reclining seats is 0.55.

Although four of the six two-factor interactions (tape/repetition, tape/segment, tape/seat, and repetition/seat) are significant at the 0.001 level, the tape/seat and repetition/seat interactions are dominant, together accounting for 71 percent of the two-factor sum of squares. The magnitude of the tape/repetition interation could be expected as the two tapes and individual segments within a given tape contained widely-varied maneuvers. The substantial repetition/seat interaction was also expected, as repetition of either tape sequence was preceded by at least a shuffling of subjects among seats and most often by a change of subjects altogether.

The tape/repetition/seat interaction was found to be significant at the 0.001 level. The interaction sum of squares (which spans the data obtained from the entire passenger subject population) can be partitioned among various passenger-subject characteristics as shown in Table B-III. Data for defining these contrasts were obtained from the test-subject schedule and personal background questionnaires. The partition according to general attitude toward flying was determined by whether or not the subject included any expressions of apprehension describing his general attitude toward flying. The partition according to previous maneuver experiments experience was determined by whether or not the subject had flown on a previous maneuver experiment flight. While none of these sub-partitions accounts by itself for a substantial portion of the tape/repetition/seat interaction, all except sex indicate effects on the interaction which are significant at the 0.001 level. The mean subjective rating given by males was 3.57 while the mean rating given by females was 3.63.

In summary, analysis of variance applied to the passenger response data indicates that the objective of presenting a repeatable flight environment to passenger-subjects on different flights was achieved. The particular maneuver being tested and the passenger seat location were found to significantly affect the subjective rating given, while the variation in ratings given between repetitions of a given maneuver sequence were insignificant. Seat location effects can be largely explained by three seats which were non-reclining and in a noisier location than the other seven. Significant two and three factor interactions exist which were not found to be explainable by known passenger-subject characteristics.

Table B-I - Comfort Rating Analysis of Variance

Source of variation	Sum of squares	D.O.F.	Mean Square	F
Main Effects:				
A (Maneuver tape)	30.3	1	30.3	33.7
B (Tape Repetition)	6.9	3	2.3	2.6
C (Maneuver Segment)	271.8	23	55.3	61.4
D (Seat)	143.7	9	16.0	17.8
Two-factor interactions:				
AB	24.8	3	8.3	9.2
AC	534.7	23	23.2	25.8
AD	81.0	9	9.0	10.0
BC	74.7	69	1.1	1.2
BD	359.7	27	13.3	14.8
CD	104.6	207	0.9	1.0
Three-factor interactions:				
ABC	73.5	69	1.1	1.2
ABD	428.5	27	15.9	17.7
ACD	179.3	207	0.9	1.0
BCD	464.3	621	0.7	0.8
ERROR	539.4	621	0.9	——
TOTAL	4397.2	1919		

Table B-II - Analysis of Variance - Seat Location Effects

Location Effects

Source of variation	Sum of squares	D.O.F.	Mean square	F
Seat Location (D)	143.7	9	16.0	17.8
Window-Aisle	(3.1)	(1)	(3.1)	(3.4)
Front-Rear	(0.6)	(1)	(0.6)	(0.6)
Reclining-Fixed	(120.6)	(1)	(120.6)	(134.0)

Table B-III - Analysis of Variance - Effects of Passenger Characteristics

Characteristics Effects

Source of variation	Sum of squares	D.O.F.	Mean square	F
Tape/Repetition/Seat Interaction (ABD)	428.5	27	15.9	17.7
General Attitude Toward Flying	(79.9)	(1)	(79.9)	(88.8)
Previous Flight Experience	(37.3)	(1)	(37.7)	(41.4)
Maneuver Experiments Experience	(27.0)	(1)	(27.0)	(30.0)
Age	(13.9	(1)	(13.9)	(15.4)
Sex	(5.2)	(1)	(5.2)	(5.8)

APPENDIX C

MULTIPLE LINEAR REGRESSION ANALYSIS TECHNIQUE

Present Regression Analysis Technique

The stepwise linear regression analysis computer program used in the present analysis is so named because it develops linear regression equations in several steps. The first step determines the coefficients of an equation expressing the ride comfort rating as a linear function of one of the 13 measured aircraft motion variables (Table V). The variable which is chosen (through logic routines within the program) is that variable which minimizes the root-mean-square (rms) error between the actual ride comfort ratings and corresponding ratings predicted by the regression equation. An equivalent expression of this criterion is that the variable chosen is that variable which maximizes the regression coefficient of multiple determination (R^2), which is the proportion of the total variance in individual ride comfort ratings accounted for by the regression equation. The next step in the stepwise regression analysis program is expansion and modification of the regression equation to express the ride comfort rating as a linear function of two of the measured motion variables. Again, the variable added to the regression equation is that variable which makes the greatest increase in the regression coefficient of multiple determination (R^2). This stepwise process repeats, with the regression equation growing to include one more motion variable at each step, until either the regression equation includes all 13 measured motion variables, or no further improvement in R^2 is possible. As an example, consider the data presented in Table VI. The first column simply indicates the 13 possible regression steps. The remaining 12 columns are in 6 pairs. Each pair describes the order in which the 13 motion variables were incorporated into the regression equation when these 13 variables were <u>measured</u> in one or 6 ways (mean value, mean deviation, standard deviation, root-mean-square, maximum deviation and a combination of root-mean square and standard deviations). For example, the first column pair indicates that when the 13 motion variables were measured in terms of their mean values (μ), the first variable chosen (Step 1) by the stepwise regression program was the mean value of pitch rate (μ_q). The resulting R^2 is 0.046; that is, 4.6 percent of the variance in individual ride comfort ratings is accounted for by an appropriate equation describing ride comfort ratings as a linear function of pitch rate only. When the mean value of longitudinal acceleration (μ_{n_x}) was included as a second term in the regression equation (Step 2), R^2 grew to 0.174. This large jump in R^2 is due to a synergistic effect whereby two variables can together account for a proportion (R^2) of the rating variance which is larger than the sum of the R^2 for each variable considered individually. The stepwise process of adding variables to the regression continues until beyond Step 10 no further improvement in R^2 is possible using any of the three variables thus far left out of the regression.

At each regression step, the program determines not only the coefficients of the appropriate regression equation, but also various statistical parameters which allow evaluation of: the degree to which the regression equation as a whole fits the experimental data, the relative importance of individual terms in the regression equation, and the accuracy to which individual coefficients in the regression equation are known. For example, consider the data presented in table VII. The "model" shown is simply the regression equation which developed in the fourth regression step in the last column pair of table VI, discussed previously. The variable coefficients in this equation amount to a least-squares-fit of a finite sample of experimental data. If the maneuvers experiments were to be repeated and the same analysis technique employed, there is practically no chance that exactly the same regression coefficient values would be obtained. Based on the analyzed data, the regression analysis program determines for each variable coefficient a numerical confidence interval within which that coefficient would fall with a given probability if the experiment were repeated For example (table VII), although it is not certain that repetition of the maneuver experiments and data reduction would result in a coefficient of σ_{n_x} equal precisely to 12.3, there is a 90 percent probability that the coefficient of σ_{n_x} would fall between 9.4 and 15.2. A corresponding confidence interval for a higher probability would be wider and for a lower probability would be more narrow. These confidence intervals tell the user of such a regression equation how accurately the individual regression coefficients are known. The "Mean Rating Contribution" (table VII) for each motion variable is simply the product of that variable's regression coefficient and the mean value of the variable over all the experimental data on which the model is based. The sum of the mean rating contributions by individual terms in the regression equation is equal to the mean ride comfort rating for the data on which the model is based. "Correlation with individual ratings" is the simple correlation coefficient between individual ride comfort ratings and corresponding ratings predicted by the regression equation. "Correlation with mean ratings" is the simple correlation coefficient between the mean of the 10 individual ratings given individual maneuvers and the corresponding ratings predicted by the regression equation. Because the regression predicts only one rating value for any given maneuver and cannot account for differences of opinion among the 10 subjects who evaluated the maneuver, the correlation with mean ratings is always greater than or equal to the correlation with individual ratings. For the same reason the "rms error with respect to individual ratings" is always greater than or equal to the "rms error with respect to mean ratings." Here error is again defined to be the arithmetic difference between an experimental ride comfort rating and the corresponding rating predicted by the regression equation. The "Regression F" value is a statistical quantity which indicates the probability (however small) that the entire regression equation resulted by chance. The Regression F thus is indicative of the confidence to be placed in the regression as a whole.

The total ride comfort rating variance can be divided into portions (expressed as percentages) due to several factors as shown at the bottom of table VII. The first portion is that portion (36.3 percent) which is due to differences among the various flight maneuvers tested and which is thus explained by the regression model. This percentage is identical to R^2 discussed earlier. The remaining error variance (63.7 percent in this example) is mostly (54.1 percent) accounted for by the differences of opinion among the 10 subjects evaluating any particular maneuver. The first two portions thus indicate the relative influences of differences among test maneuvers and of differences among test subjects on variance of the ride comfort ratings obtained. The last portion is that rating variance which could not be explained and is thus considered to be error.

Regression Analysis Formulas

An experimental data variable can be related to one or more other variables of the experiment through the linear equation:

$$\bar{R} = a_1 x_1 + a_2 x_2 + \cdots + a_n x_n \tag{C-1}$$

$$= \sum_{j=1}^{n} a_j x_j \qquad = AX$$

where R is the data variable of interest (in this case the predicted ride comfort rating); X is the vector $[x_1, x_2, \ldots, x_n]^T$ of independent motion variables (here the vector of aircraft motion variables); A is a vector $[a_1, a_2, a_3, \ldots, a_n]^T$ of coefficients determined through multiple linear regression analysis of the experimental data.

Basic Procedure.- The experimental data are obtained in data sets having one value of the dependent variable (R_i) paired with one set of independent motion-variable values (X_{ij}) such that:

$$R_i = a_0 + \sum_{j=1}^{n} a_j X_{ij} + e_i \tag{C-2}$$

where e_i is a random residual equal to the arithmetic difference between the experimentally observed R_i and the calculated sum:

$$a_0 + \sum_{j=1}^{n} a_j x_{ij} \tag{C-3}$$

The regression coefficients $A = [a_j]$ are determined by using least-squares-analysis to minimize the error sum-of-squares:

$$\sum_{i=1}^{m} e_i^2 \tag{C-4}$$

The procedure for doing this is as follows:

A leading column of ones (unity values) is appended to the $m \times n$ matrix of experimental motion-variable values $X = [x_{ij}]$ to create the matrix X':

$$X' = \begin{bmatrix} 1 & x_{11} & x_{12} & \cdots & x_{1n} \\ 1 & x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{C-5}$$

Least-squares-analysis results in the following expression for the regression coefficient vector A:

$$A = [X'^T X']^{-1} X'^T R \tag{C-6}$$

The vector A has dimension (n + 1) and includes the constant coefficient a_0.

The stepwise linear regression analysis computer program employed in the current analysis (Subroutine G2.3, SWRA, in the Langley Research Center computer library) employs the above technique with one significient refinement. Instead of immediately determining coefficients $[a_j]$ for an n-term regression equation, the program first determines the two coefficients most appropriate (in the least-square-error sense) for a two-term relationship:

$$\bar{R} = a_0 + a_k x_k \qquad \text{(C-7)}$$

where x_k is tnat single motion variable which, in the regression equation, minimizes the mean-square residual. In other words, x_k is that single motion variable whose observed values can best account (in a two-term-linear expression) for the observed variance of the dependent variable $\bar{R}$. With this partial variance removed from the total variance of $\bar{R}$, the program then expands and adjusts the regression equation (matrix A of regression coefficients) to include an additional term. The next term added, once again, is chosen from among the remaining variables to be that variable whose observed values best account for the remaining variance of the dependent variable $\bar{R}$. This process is repeated until either all available independent variables have been included in the regression equation or until no further significant reduction in mean-square residual is possible.

Confidence intervals.- A 100(1 - α)% confidence interval for the regression coefficient a_j is defined as:

$$a_j \pm t_{\alpha/2,\, m-k-1}\, s_{a_j} \qquad \text{(C-8)}$$

where a_j is the coefficient value as determined by linear regression; $t_{\alpha/2,\, m-k-1}$ is the value of the statistical parameter t at the $\alpha/2$ significance level and with $m - k - 1$ degrees-of-freedom (m is the number of data points on which the analysis is based and k is the number of variables in the regression equation); s_{a_j} is the standard error of the regression coefficient a_j which is defined as follows:

$$s_{a_j} = S\sqrt{m c_{jj}} \tag{C-9}$$

In equation (C-9) c_{jj} is the $j^{\underline{th}}$ diagonal element of the matrix B, defined as:

$$B = \left[X'^T X'\right]^{-1} \tag{C-10}$$

and S is the regression standard error-of-estimate:

$$S^2 = \frac{\sum_{i=1}^{m} e_i^2}{m - K - 1} \tag{C-11}$$

A $100(1 - \alpha)\%$ confidence interval for the mean rating is given by:

$$R_0 \pm t_{\alpha/2,\, m-K-1}\, S\sqrt{X_0^T B X_0} \tag{C-12}$$

where R_0 is the rating predicted by the regression equation for the matrix of flight variables, and all other quantities are as previously defined.

Correlation.- The correlation coefficients r are determined by the simple correlation relationship:

$$r^2 = \frac{\left[\sum_{i=1}^{m} R_i R_{c_i} - \left(\sum_{i=1}^{m} R_i\right)\left(\sum_{i=1}^{m} R_{c_i}\right)\right]^2}{\left[\sum_{i=1}^{m} R_i^2 - \left(\sum_{i=1}^{m} R_i\right)^2\right]\left[\sum_{i=1}^{m} R_{c_i}^2 - \left(\sum_{i=1}^{m} R_{c_i}\right)^2\right]} \tag{C-13}$$

where R_i is the $i^{\underline{th}}$ observed experimental rating and R_{c_i} is the corresponding rating as predicted by the regression equation.

Root mean-square (rms) error.- The root-mean-square (rms) error e_{rms} is defined by the relationship:

$$e_{rms}^2 = \frac{1}{m-k-1} \sum_{i=1}^{m} e_i^2 \tag{C-14}$$

Regression F-value.- The regression F-value is defined as the ratio of the rating variance accounted for by the regression (V_R) to the error variance S^2.

$$F = V_R / S^2 \tag{C-15}$$

where

$$V_R = A^T X'^T R \tag{C-16}$$

Partitioning of rating variance.- The total rating variance V can be partitioned as follows:

$$V = V_R + V_{subj} + V_{error} \tag{C-17}$$

where V_R is the rating variance accounted for by the regression equation and is as previously defined; V_{subj} is the rating variance accounted for by differences in subject ratings given any particular maneuver:

$$V_{subj} = \sum_{i=1}^{m_i} \sum_{j=1}^{10} (R_{ij} - \bar{R}_i) \tag{C-18}$$

In equation (C-18) R_{ij} is any one of 10 individual ratings obtained during the i^{th} test maneuver; $\bar{R}_i$ is the mean rating obtained during the i^{th} test maneuver; and m_i is the number of test maneuvers on which the regression equation is based. The V_{error} term is the error variance (due to lack-of-fit of the regression model).

REFERENCES

[1] Richards, L. G.: "Ride Quality Evaluation I: Questionnaire Studies of Airline Passenger Comfort," Ergonomics, 1975, vol. 18, no. 2, pp. 129-150.

[2] Jacobson, I. D., and Richards, L. G.: "Ride Quality Evaluation II: Modeling of Airline Passenger Comfort," Ergonomics, 1975, vol. 18, no. 6.

[3] Reeder, J. P.: Future Airborne Systems for Terminal Area Operations. Paper presented at the 18th Symposium of the Society of Experimental Test Pilots, September 1974.

[4] Gillingham, K. K.: A Primer of Vestibular Function, Spatial Disorientation, and Motion Sickness. Aeromedical Review No. 466, USAF School of Aerospace Medicine, Brooks Air Force Base, Texas, June 1966.

[5] Jacobson, I. D., Kuhlthau, A. R., and Richards, L. G.: "Application of Ride Quality Technology to Predict Ride Satisfaction for Commuter-Type Aircraft." NASA TM X-3295, December 1975.

[6] Conner, D. W., and Schoonover, W. E., Jr.: "Status of STOL Ride Quality and Control." NASA SP-320, 1972, pp. 215-226

[7] Seckel, E., and Miller, G. E.: "Exploratory Flight Investigation of Ride Quality in Simulated STOL Environment." NASA TM X-2620, 1972, pp. 67-90.

[8] Reynolds, P. A., Wasserman, R., Fabian, G. J., and Motyka, P. R.: Capability of the Total In-Flight Simulator (TIFS). AFFDL-TR-72-39, July 1972, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio.

[9] Wasserman, R., and Motyka, P. R.: In-Flight Investigation of the B-1 Flight Control System. AFFDL-TR-73-139, Dec. 1973, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio.

[10] Wasserman, R., and Mitchell, J. F.: In-Flight Simulation of Minimum Longitudinal Stability for Large Delta-Wing Transports in Landing Approach and Touchdown. FAA-RD-73-43, Washington, D.C., 1973.

[11] Lee, W., and Jacobson, I. D.: Characteristics of the Air Traveler - A Selective Review. Univ. of Virginia Memo. Rep. 403204, June 1972.

[12] Jacobson, I. D., and Rudrapatna, A. N.: Flight Simulator Experiments to Determine Human Reaction to Aircraft Motion Environment. NASA CR-140055, Univ. of Virginia, July 1974.

[13] Stone, R. W., Jr.: Human Comfort Response to Random Motions with a Dominant Vertical Motion. NASA TM X-72691, May 1975.

[14] Matsui, S.: "Comfort Limits of Retardation and Its Changing Rate for Train Passengers." Japanese Railway Engineer, vol. 3, no. 1, March 1962.

TABLE I - Descriptive and Parametric Summary of Test Maneuvers

(a) Maneuver Command Tape I

Maneuver No.	Maneuver Description	Max. Longit. Accel. (n_x), g-units	Max. Normal Accel. (n_z), g-units	Flight Path Angle (γ), deg	Max. Pitch Angle (θ), deg	Max. Roll Angle (ϕ), deg	Max. Roll Rate (p), deg/sec	Max. Pitch Rate (q), deg/sec	Pressure Altitude (h), ft	Climb Rate ($\dot{h}$), ft/sec	Indicated Airspeed (v_i), kt
1	Steady Descent			-2.6	+2.4				10,400	-14	144
2	Simple Turn					21	16		9,600		204
3	Longitudinal Deceleration	-.19	+.25		-4.8			-2.0	9,700		207
4	S - Turn					28	20		9,400		162
5	Steady Descent			-9.7	-1.7				8,700	-48	150
6	Turning deceleration with pitchover	-.20	+.25		+3.2	30	17		8,500		209
7	Simple Turn					31	19		9,200		164
8	Longitudinal Deceleration	-.10			-4.3			-2.0	9,100		212
9	Simple Turn					46	24		8,200		161
10	Steady Descent			+0.4	-2.1				8,000	+5	204
11	Simple Turn					47	18		8,100		205
12	Longitudinal Deceleration	-.18	+.35		-2.7			-3.0	8,700		198
13	S - Turn					42	23		8,800		159
14	Steady Descent			-7.1	-9.7				8,700	-49	206
15	Simple Turn					30	18		7,000		135
16	Longitudinal Deceleration	-.14	+.40		-7.1			-4.5	6,900		210
17	Simple Turn					32	23		6,900		161
18	Turning deceleration with pitchover	-.19			-5.5	39	18		6,900		215
19	Steady Descent			+0.5	+5.7				7,300	+2	143
20	Simple Turn					45	19		7,200		162
21	Longitudinal Deceleration	-.17	+.22		-.2			-3.1	7,400		199
22	S - Turn					28	17		7,900		161
23	Steady Descent			-3.5	-2.2				7,800	-28	200
24	Simple Turn					29	15		7,300		204

TABLE I - Continued

(b) Maneuver Command Tape II

Maneuver No.	Maneuver Description	Max. Longit. Accel. (n_x), g-units	Max. Normal Accel. (n_z), g-units	Flight Path Angle (γ), deg	Max. Pitch Angle (θ), deg	Max. Roll Angle (ϕ), deg	Max. Roll Rate (p), deg/sec	Max. Pitch Rate (q), deg/sec	Pressure Altitude (h), ft	Climb Rate $(\dot{h})$, ft/sec	Indicated Airspeed (v_i), kt
1	Simple Turn					38	24		10,500		165
2	Steady Descent			+0.5	+2.1				10,400	+3	156
3	Simple Turn					18	6		10,400		165
4	Longitudinal Deceleration	-.10	0		-.2			0	10,400		208
5	S - Turn					24	10		10,200		166
6	Turning, decelerating with pitchover	-.09			-3.7	40	8		10,400		208
7	Simple Turn					37	8		9,800		202
8	Longitudinal Deceleration	-.12	+.20		-0.5			-1.8	9,900		204
9	Simple Turn					45	22		9,800		163
10	Steady Descent			-11.1	-13.4				9,400	-73	195
11	Simple Turn					26	10		7,600		142
12	Longitudinal Deceleration	-.10	+.46		-5.7			-2.0	8,000		209
13	S - Turn					41	11		7,400		161
14	Steady Descent			-6.4	-5.7				7,200	-38	140
15	Simple Turn					44	8		6,100		163
16	Longitudinal Deceleration	-.13	+.37		-3.7			-2.7	6,600		210
17	Simple Turn					36	24		6,400		162
18	Turning, Decelerating with pitchover	-.10			-4.6	27	10		6,000		212
19	Steady Descent			-3.2	-2.0				6,400	-17	158
20	Simple Turn					38	10		6,300		162
21	Longitudinal Deceleration	-.20	+.47		-4.1			-4.3	7,000		208
22	S - Turn					40	11		7,200		165
23	Steady Descent			-4.4	-5.8				7,400	-29	198
24	Simple Turn					15	6		7,000		136

Table II - Passenger Subject Characteristics

(a) Responses to background questionnaire

				FLYING			
SUBJECT	AGE	SEX	OCCUPATION	FREQUENCY (flights per year)	USUAL PURPOSE -- (Personal,	USUAL FUNDING Business)	ANY ANXIETY? (Yes, No)
1	21	M	student	2	P	P	N
2	38	M	engineer	100+	B	P	N
3	30	M	bus driver	1	P	P	N
4	20	F	student	12	P	P	N
5	36	M	comm. pilot	100+	P&B	B	N
6	53	M	engineer	12	B	B	N
7	23	M	sales mgr.	3	P	P	N
8	20	M	student	4	P	P	N
9	36	F	secretary	2	P	P	N
10	25	M	military	12	P	P	N
11	20	M	student	0	B	B	N
12	22	F	secretary	1	P	P	Y
13	28	M	engineer	100+	B	B	N
14	44	M	professor	3	B	B	N
15	56	M	mechanic	40	P&B	P	N
16	42	F	professor	3	P	P	N
17	19	M	student	2	P	P	N
18	24	M	student	4	B	B	N
19	55	F	secretary	0	P	P	Y
20	54	M	mechanic	1	B	B	Y
21	35	F	librarian	2	P	P	N
22	33	F	homemaker	1	P	P	Y
23	32	M	engineer	30	B	B	Y
24	27	M	data mgt.	3	P	P	N
25	35	F	data mgt.	6	P	P	N
26	35	F	data mgt.	6	B	B	N
27	43	F	homemaker	0	P	P	N
28	20	F	student	1	B	B	N
29	54	M	contractor	1	P	P	N
30	32	M	engineer	12	B	B	N

Table II - Continued

(b) Comparison with air travelers in general

Characteristics	General Air Travelers, percent (refs. [1] and [11])	Maneuvers Subjects, percent
Age:		
20 yr. and under	18	17
21 to 40 yr.	45	56
41 to 60 yr.	32	2
61 yr. and over.	5	0
Sex:		
Male	75	63
Female	25	37
Frequency of flying:		
0 (flights/year)	2.3	10.0
1-5	32.0	53.3
5+	65.7	36.7
Purpose of trip:		
Business	75	40
Personal	25	60
Attitude toward flying:		
Enjoy flying	60	84
Have no strong feelings	35	16
Dislike flying	4	0

Table III. - Ride Comfort Rating Scale

1...........Very Comfortable
2...........Comfortable
3...........Somewhat Comfortable
4...........Neutral
5...........Somewhat Uncomfortable
6...........Uncomfortable
7...........Very Uncomfortable

Table IV - Sample of Passenger Ride Comfort Ratings

			SEAT											
			1	2	3	4	5	6	7	8	9	10		
			SUBJECT											
			13	11	15	23	28	7	26	16	21	18		
	FLT	SFG	COMFORT RATING										MEAN	STD. DEV.
Steady Turn	1	1	5	3	6	5	2	5	6	1	3	5	4.1	1.64
Steady Descent	1	2	2	2	2	4	1	1	2	1	1	2	1.8	.87
Steady Turn	1	3	2	2	2	4	1	1	2	1	1	3	1.9	.94
Longitudinal Deceleration	1	4	3	3	3	4	2	2	2	1	3	4	2.7	.90
S - Turn	1	5	3	3	4	4	1	2	2	1	5	5	3.0	1.41
Turning, Decelerating Descent	1	6	5	4	6	5	3	5	6	1	5	6	4.6	1.50
Steady Turn	1	7	4	3	5	4	1	3	4	1	2	5	3.2	1.40
Longitudinal Deceleration	1	8	5	4	2	5	2	4	3	1	4	5	3.5	1.36
Steady Turn	1	9	6	4	5	6	2	3	6	2	7	6	4.7	1.73
Steady Descent	1	10	5	5	6	7	5	6	6	2	5	7	5.4	1.36
Steady Turn	1	11	4	3	3	5	2	3	2	2	5	5	3.4	1.20
Longitudinal Deceleration	1	12	5	4	5	6	3	4	3	2	3	6	4.1	1.30
S - Turn	1	13	6	4	5	7	2	3	6	2	5	6	4.6	1.69
Steady Descent	1	14	3	3	1	4	6	2	3	1	2	2	2.7	1.42
Steady Turn	1	15	5	4	3	5	2	2	6	2	3	5	3.7	1.42
Longitudinal Deceleration	1	16	6	5	4	7	4	5	5	2	5	6	4.9	1.30
Steady Turn	1	17	3	4	4	5	1	3	2	2	5	5	3.4	1.36
Turning, Decelerating Descent	1	18	7	5	6	7	5	6	6	2	5	7	5.6	1.43
Steady Descent	1	19	1	2	1	4	2	1	2	1	2	6	2.2	1.54
Steady Turn	1	20	4	3	4	4	1	2	3	1	4	5	3.1	1.30
Longitudinal Deceleration	1	21	6	5	5	7	6	5	6	2	5	7	5.4	1.36
S - Turn	1	22	5	6	3	5	3	3	4	2	3	5	3.9	1.22
Steady Descent	1	23	4	5	2	5	4	3	3	2	3	5	3.6	1.11
Steady Turn	1	24	2	2	1	4	3	1	2	1	2	2	2.0	.89

Table V. - TIFS Motion Variables Chosen For Analysis

1 Normal Acceleration
2 Transverse Acceleration
3 Longitudinal Acceleration
4 Roll Rate
5 Pitch Rate
6 Yaw Rate
7 Roll Angle
8 Pitch Angle
9 Heading
10 Flight Path Angle
11 Altitude
12 Climb Rate
13 Indicated Airspeed

Table VI - Order of Variable Entry and Coefficients of Multiple Determination - Summary Regression Model

	Mean		Mean Dev.		Std. Dev.		RMS		Max. Dev.		RMS& Std. Dev.	
Step	Var.	R^2	Var.	R^2	Var.	R^2	Var.	R^2	Var.	R^2	Var.	R^2
1	μ_q	.046	$\lvert\mu\rvert_{n_z}$	.204	σ_{n_z}	.292	ξ_{n_z}	.243	$\uparrow_{v_i}$	.049	σ_{n_z}	.292
2	μ_{n_x}	.174	$\lvert\mu\rvert_{\dot{h}}$	.286	σ_{n_x}	.335	$\xi_{\dot{h}}$	.309	$\uparrow_q$	.088	σ_{n_x}	.335
3	μ_{n_z}	.208	$\lvert\mu\rvert_q$	.301	σ_{n_y}	.342	ξ_p	.313	$\uparrow_\gamma$	.115	$\xi_{\dot{h}}$	.348
4	Δt	.214	$\lvert\mu\rvert_{n_x}$	.308	$\sigma_{\dot{h}}$	.355	ξ_ϕ	.335	$\uparrow_{\dot{h}}$	.142	σ_{n_y}	.363
5	μ_h	.221	$\lvert\mu\rvert_p$	.315	σ_{v_i}	.362	Δt	.342	Δt	.154	ξ_{v_i}	.371
6	$\mu_{\dot{h}}$	.225	$\lvert\mu\rvert_\phi$	.322	σ_q	.370	ξ_{v_i}	.348	$\uparrow_h$	.165	$\sigma_{\dot{h}}$	.378
7	μ_{n_y}	.229	$\lvert\mu\rvert_\theta$	.327	σ_γ	.370	ξ_{n_x}	.355	$\uparrow_r$	.176	σ_h	.384
8	μ_ϕ	.232	Δt	.331	σ_θ	.371	ξ_γ	.358	$\uparrow_p$	.181	ξ_{n_x}	.385
9	μ_{v_i}	.235	$\lvert\mu\rvert_h$	.336	σ_h	.371	ξ_q	.359	$\uparrow_{n_x}$	.183	ξ_{n_z}	.386
10	μ_γ	.240	$\lvert\mu\rvert_{v_i}$	.338	σ_p	.371	ξ_r	.362	$\uparrow_{n_y}$	.185	Δt	.387
11	-	-	$\lvert\mu\rvert_r$	.343	σ_ϕ	.372	ξ_θ	.362	$\uparrow_\phi$	.186	ξ_r	.388
12	-	-	$\lvert\mu\rvert_\gamma$	.344	σ_r	.372	ξ_h	.362	$\uparrow_\theta$	.186	ξ_p	.390
13	-	-	$\lvert\mu\rvert_{n_y}$	.344	Δt	.372	ξ_{n_y}	.362	$\uparrow_{n_z}$	.186	ξ_h	.390

Table VII - Regression Model of Passenger Comfort During Flight Maneuvers in General

Model:	$\bar{R} = 1.477$	$+ \; 12.3\sigma_{n_x}$	$+ \; 32.8\sigma_{n_y}$	$+ \; 11.6\sigma_{n_z}$	$+ \; .0220\xi_{\dot{h}}$
Coefficient 90% Confidence Intervals:		$9.4 \le b_x \le 15.2$	$24.7 \le b_y \le 40.9$	$10.5 \le b_z \le 12.7$	$.0174 \le b_{\dot{h}} \le .0266$
Mean Rating Contribution:	$3.602 = 1.477$	$+ \; .382$	$+ \; .368$	$+ \; 1.065$	$+ \; .310$

Correlation with individual ratings:	.602
Correlation with mean ratings:	.951
RMS error with respect to individual ratings:	1.209
RMS error with respect to mean ratings:	.469
Regression F:	272

Percentage of rating variance due to:

Maneuvers (explained by model)	36.3
Differences among subject ratings of any given maneuver	54.1
Error (model lack-of-fit)	9.6

Table VIII - Order of Variable Entry and Coefficients of Multiple Determination - Simple Turn Models

	Mean		Mean Dev.		Std. Dev.		RMS		Max. Dev.	
Step	Var.	R^2	Var.	R^2	Var.	R^2	Var.	R^2	Var.	R^2
1	μ_q	.265	$\|\mu\|_p$	.333	σ_ϕ	.346	ξ_p	.324	$\uparrow_\phi$	.336
2	μ_θ	.284	$\|\mu\|_\gamma$	.354	σ_{n_y}	.371	$\xi_{\cdot}$	.362	$\uparrow_{n_y}$	.373
3	μ_γ	.294	Δt	.370	σ_h	.379	Δ_t	.371	$\uparrow_p$	.375
4	$\mu_{\dot{h}}$	.298	$\|\mu\|_{n_y}$	.374	σ_p	.382	ξ_γ	.380	$\uparrow_h$	.377
5	μ_{n_y}	.302	$\|\mu\|_h$	.376	σ_{n_z}	.383	ξ_{n_z}	.388	Δt	.380
6	μ_h	.303	$\|\mu\|_{\dot{h}}$	.378	Δt	.389	$\xi_{\dot{h}}$	.392	$\uparrow_{v_i}$	.380
7	μ_ϕ	.306	$\|\mu\|_{v_i}$	.381	σ_{v_i}	.392	ξ_ϕ	.396	$\uparrow_\gamma$	.381
8	μ_r	.310	$\|\mu\|_{n_z}$	.382	σ_θ	.392	ξ_{n_x}	.400	$\uparrow_{\dot{h}}$	.391
9	μ_p	.311	$\|\mu\|_e$	.383	σ_γ	.393	ξ_{v_i}	.402	$\uparrow_r$	.394
10	μ_{n_z}	.312	$\|\mu\|_r$	.384	$\sigma_{\dot{h}}$	.393	ξ_{n_y}	.403	$\uparrow_\theta$	.394
11	Δt	.312	$\|\mu\|_q$	.384	σ_q	.393	ξ_q	.404	$\uparrow_q$	.395
12	μ_{v_i}	.312	$\|\mu\|_\phi$	.385	σ_r	.394	ξ_θ	.404	$\uparrow_{n_x}$	.395
13	-	-	$\|\mu\|_{n_x}$	.385	-	-	ξ_h	.404	$\uparrow_{n_z}$	.395

Table IX - Regression Model of Passenger Comfort During Simple Turns

Model:	$\bar{R} = .395$	+	$.0640\uparrow_{\phi}$	+	$.0653\uparrow_{p}$
Coefficient 90% Confidence Intervals:			.0[illegible]9$\le b_{\phi} \le .0731$		$.0465 \le b_{p} \le .0841$
Mean Rating Contribution:	$3.459 = .395$	+	2.119	+	.945

	Above Model	Summary Model
Correlation with individual ratings:	.606	-
Correlation with mean ratings:	.958	.940
RMS error with respect to individual ratings:	1.203	-
RMS error with respect to mean ratings:	.403	.454
Regression F:	196	-

Table X - Order of Variable Entry and Coefficients of Multiple Determination - S-Turn Models

Step	Mean		Mean Dev.		Std. Dev.		RMS		Max. Dev.	
	Var.	R^2	Var.	R^2	Var.	R^2	Var.	R^2	Var.	R^2
1	μ_q	.225	$\|\mu\|_{n_z}$	.253	σ_{n_z}	.298	ξ_{n_z}	.269	$\uparrow_r$	.325
2	μ_ϕ	.306	$\|\mu\|_p$	.308	σ_{n_y}	.350	ξ_{n_y}	.323	$\uparrow_h$	.335
3	μ_{n_y}	.323	Δt	.324	σ_θ	.361	ξ_{v_i}	.335	$\uparrow_{v_i}$	.354
4	μ_{v_i}	.331	$\|\mu\|_h$	.328	$\sigma_{\dot{h}}$	.362	ξ_h	.341	$\uparrow_\phi$	.356
5			$\|\mu\|_\phi$	.338	σ_γ	.364	ξ_r	.352	$\uparrow_p$	.363
6	μ_h	.338	$\|\mu\|_{\dot{h}}$	.346	σ_q	.365	ξ_{n_x}	.363	$\uparrow_{n_z}$	.365
7	μ_r	.342	$\|\mu\|_\theta$	.362	Δt	.366	ξ_ϕ	.365	$\uparrow_\gamma$	.367
8	μ_θ	.344	$\|\mu\|_q$	.363	σ_p	.369	ξ_p	.371	$\uparrow_{n_x}$	.370
9	Δt	.347	$\|\mu\|_r$	.364	σ_r	.373	$\xi_{\dot{h}}$	.372	Δt	.371
10	μ_{n_z}	.348	$\|\mu\|_{n_y}$	.365	σ_ϕ	.375	ξ_θ	.373	$\uparrow_\theta$	.371
11	μ_{n_x}	.340	$\|\mu\|_{n_x}$	.368	σ_h	.375	ξ_q	.374	$\uparrow_{n_y}$	.371
12	μ_p	.349	-	-	σ_{v_i}	.376	-	-	$\uparrow_q$	.371
13	-	-	-	-	-	-	-	-	-	-

Table XI - Regression Model of Passenger Comfort During S-Turns

Model:	$\bar{R} = -.185$	+	$.0785\uparrow_{\phi}$	+	$.0806\uparrow_{p}$
Coefficient 90% Confidence Intervals:			$.0631 \leq b_{\phi} \leq .0938$		$.0536 \leq b_{p} \leq .1075$
Mean Rating Contribution:	$3.883 = -1.85$	+	2.771	+	1.297

	Above Model	Summary Model
Correlation with individual ratings:	.582	-
Correlation with mean ratings:	.977	.919
RMS error with respect to individual ratings:	1.150	-
RMS error with respect to mean ratings:	.301	.371
Regression F:	61	-

Table XII - Regression Model of Passenger Comfort During Simple Turns and S-Turns

Model:	$\bar{R} = .293$	+	$.0665\uparrow_{\phi}$	+	$.0697\uparrow_{p}$
Coefficient 90% Confidence Intervals:			$.0588 \leq b_{\phi} \leq .0742$		$.0544 \leq b_{p} \leq .0850$
Mean Rating Contribution:	$3.570 = .293$	+	2.239	+	1.038

	Above Model	Summary Model
Correlation with individual ratings:	.604	-
Correlation with mean ratings:	.961	.934
RMS error with respect to individual ratings:	1.192	-
RMS error with respect to mean ratings:	.414	.434
Regression F:	264	-
Percentage of rating variance due to:		
Maneuvers (explained by model)	36.5	
Differences among subject ratings of any given maneuver	55.8	
Error (model lack-of-fit)	7.7	

Table XIII - Order of Variable Entry and Coefficients of Multiple Determination - Steady Descent Models

	Mean		Mean Dev.		Std. Dev.		RMS		Max. Dev.	
Step	Var.	R^2	Var.	R^2	Var.	R^2	Var.	R^2	Var.	R^2
1	$\|\mu_\theta\|$	.374	$\|\mu\|_{n_z}$	.389	σ_{n_z}	.348	ξ_{n_z}	.359	$\|\uparrow_\theta\|$	.311
2	Δt	.384	$\|\mu\|_{n_x}$	.419	σ_h	.384	ξ_{n_x}	.437	$\uparrow_{v_i}$	.373
3	μ_h	.399	$\|\mu\|_h$	.434	σ_p	.427	ξ_p	.447	$\uparrow_\gamma$	.438
4	μ_{n_x}	.412	$\|\mu\|_r$	.446	σ_{n_x}	.434	$\xi_{\dot{h}}$	.454	$\uparrow_p$	.448
5	μ_{n_y}	.422	$\|\mu\|_q$	.450	σ_γ	.440	ξ_{r_y}	.458	$\uparrow_{n_x}$	.458
6	μ_{v_i}	.429	$\|\mu\|_{n_y}$	.454	σ_q	.442	ξ_h	.464	$\uparrow_{n_y}$	.466
7	μ_{n_z}	.446	$\|\mu\|_{\dot{h}}$	.460	σ_θ	.447	ξ_r	.469	$\uparrow_h$	.470
8	$\mu_{\dot{h}}$	.455	$\|\mu\|_p$	.466	$\sigma_{\dot{h}}$	.450	Δt	.471	$\uparrow_\phi$	.470
9	-	-	$\|\mu\|_{v_i}$	.470	σ_{n_y}	.451	ξ_{v_i}	.472	$\uparrow_r$	.472
10	-	-	$\|\mu\|_\gamma$	.479	σ_ϕ	.453	ξ_γ	.473	$\uparrow_{\dot{h}}$	.472
11	-	-	Δt	.482	σ_r	.453	ξ_q	.475	$\uparrow_q$	.472
12	-	-	$\|\mu\|_\theta$	.482	Δt	.457	-	-	$\uparrow_{n_z}$	.473
	-	-	$\|\mu\|_\phi$	.482	-	-	-	-	Δt	.473

Table XIV - Regression Model of Passenger Comfort During Steady Descents

Model: $\bar{R} = -1.507 + .0981|\uparrow_\theta| - .118\uparrow_\gamma + .0195\uparrow_{v_i}$

Coefficient 90% Confidence Intervals:

$.0647 \le b_\theta \le .1315$

$-.145 \le b_\gamma \le -.091$

$.0157 \le b_{v_i} \le .0233$

Contribution To Mean Rating: $2.980 = -1.507 + .507 + .512 + 3.469$

	This model	Summary model
Correlation with individual ratings:	.662	-
Correlation with mean ratings:	.952	.849
RMS error with respect to individual ratings:	1.135	-
RMS error with respect to mean ratings:	.460	.586
Regression F:	113	-
Percentage of rating variance due to:		
Maneuvers (explained by model)	43.8	
Differences among subject ratings of any given maneuver	46.9	
Error (model lack-of-fit)	9.3	

Table XV - Order of Variable Entry and Coefficients of Multiple Determination - Decelerations with Pitchover

	Mean		Mean Dev.		Std. Dev.		RMS		Max. Dev.	
Step	Var.	R^2	Var.	R^2	Var.	R^2	Var.	R^2	Var.	R^2
1	μ_h	.127	$\lvert\mu\rvert_{n_z}$	.308	σ_q	.315	ξ_{n_z}	.323	$\uparrow_{n_z}$	.251
2	μ_{v_i}	.223	$\lvert\mu\rvert_{n_x}$	.315	σ_h	.321	ξ_{v_i}	.328	$\uparrow_{n_y}$	.279
3	μ_γ	.239	$\lvert\mu\rvert_{v_i}$	.319	σ_{n_x}	.325	ζ_θ	.336	$\uparrow_{v_i}$	.291
4	μ_{n_y}	.247	$\lvert\mu\rvert_\theta$	.337	σ_{v_i}	.331	ξ_{n_y}	.340	$\uparrow_h$	.304
5	μ_r	.251	Δt	.342	Δt	.334	ξ_q	.342	$\uparrow_{n_x}$	.305
6	μ_q	.254	$\lvert\mu\rvert_p$	.345	σ_r	.337	ξ_ϕ	.346	$\uparrow_q$	.308
7	$\mu_{\dot h}$	.257	$\lvert\mu\rvert_h$	.345	-	-	Δt	.346	$\uparrow_p$	.308
8	μ_ϕ	.264	$\lvert\mu\rvert_{n_y}$	.347	-	-	ξ_p	.347	$\uparrow_r$	.309
9	μ_{n_z}	.265	$\lvert\mu\rvert_q$	.348	-	-	ξ_h	.347	$\uparrow_\phi$	.310
10	Δt	.267	$\lvert\mu\rvert_{\dot h}$	.349	-	-	ξ_{n_y}	.348	$\uparrow_{\dot h}$	.310
11	-	-	$\lvert\mu\rvert_\gamma$	.350	-	-	ξ_{n_x}	.348	$\uparrow_\gamma$	.316
12		-	-	-	-	-	$\xi_{\dot h}$	.348	-	-
13			-	-	-	-	-	-	-	-

Table XVI - Regression Model of Passenger Comfort During Decelerations with Pitchover

Model: $\bar{R} = 1.749 + 22.1\varepsilon_{n_z}$

Coefficient 90%
Confidence Intervals: $19.5 \le b_z \le 24.7$

Mean Rating Contribution: $4.007 = 1.749 + 2.258$

	This model	Summary model
Correlation with individual ratings:	.568	-
Correlation with mean ratings:	.973	.879
RMS error with respect to individual ratings:	1.186	-
RMS error with respect to mean ratings:	.332	.450
Regression F:	190	-

Percentage of rating variance due to:

Maneuvers (explained by model)	32.3
Differences among subject ratings of any given maneuver	62.4
Error (model lack-of-fit)	5.3

C. 2

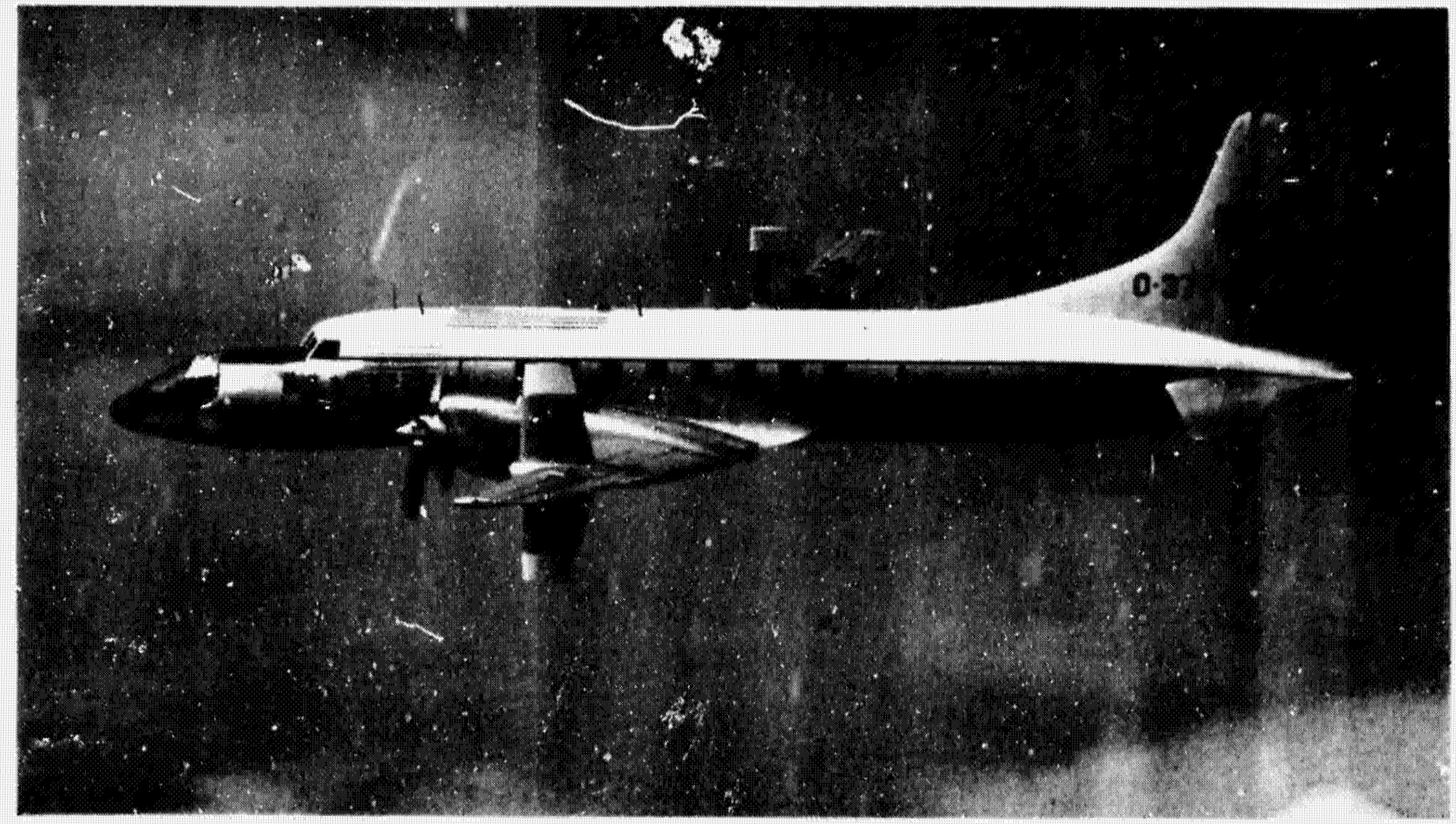
Table XVII - Order of Variable Entry and Coefficients of Multiple Determination Turning Decelerations with Pitchover

	Mean		Mean	Dev.	Std.	Dev.	RMS		Max.	Dev.
Step	Var.	R^2	Var.	R^2	Var.	R^2	Var.	R^2	Var.	R^2
1	μ_θ	.115	$\|\mu\|_{v_i}$	.068	σ_{v_i}	.094	Δt	.065	$\uparrow$ [illegible]	.096
2	μ_{n_y}	.135	$\|\mu\|_\gamma$	.096	σ_γ	.134	ξ_p	.121	Δt	.115
3	μ_r	.139	$\|\mu\|_\theta$	.118	σ_{n_z}	.148	ξ_h	.139	$\uparrow_{n_y}$	.129
4	μ_q	.145	$\|\mu\|_{n_y}$	.130	$\sigma_{\dot h}$	.150	ξ_{n_y}	.143	$\uparrow_{n_z}$	.134
5	μ_{n_x}	.149	$\|\mu\|_{\dot h}$	.132	σ_θ	.151	$\xi_{\dot h}$	.145	$\uparrow_\phi$	.152
6	Δt	.155	-	-	σ_h	.151	ξ_r	.145	-	-
7	μ_{v_i}	.157	-	-	σ_{n_x}	.153	ξ_{n_z}	.148	-	-
8	μ_h	.160	-	-	σ_q	.154	-	-	-	-
9	μ_p	.163	-	-	σ_{n_y}	.155	-	-	-	-
10	μ_γ	.167	-	-	$-(\sigma_\gamma)$	.152	-	-	-	-
11	μ_{n_z}	.167	-	-	σ_r	.154	-	-	-	-
12	-	-	-	-	σ_p	.157	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-

Table XVIII - Regression Model of Passenger Comfort During Turning Decelerations with Pitchover

Model:	$\bar{R} = 4.871$	+	$.225\sigma_{\gamma}$	-	$.0557\sigma_{v_i}$
Coefficient 90% Confidence Intervals:			$.086 \leq b_{\gamma} \leq .364$		$-.0771 \leq b_{v_i} \leq -.0343$
Mean Rating Contribution:	$4.344 = 4.871$	+	.476	-	1.003

	This model	Summary model
Correlation with individual ratings:	.366	-
Correlation with mean ratings:	.979	.172
RMS error with respect to individual ratings:	1.278	-
RMS error with respect to mean ratings:	.278	.630
Regression F:	12	-
Percentage of rating variance due to:		
Maneuvers (explained by model)	13.4	
Differences among subject ratings of any given maneuver	82.4	
Error (model lack-of-fit)	4.2	



(a) Basic TIFS

Figure 1.- USAF Total In-Flight Simulator

(b) TIFS as modified for ride-quality research

Figure 1.- Concluded

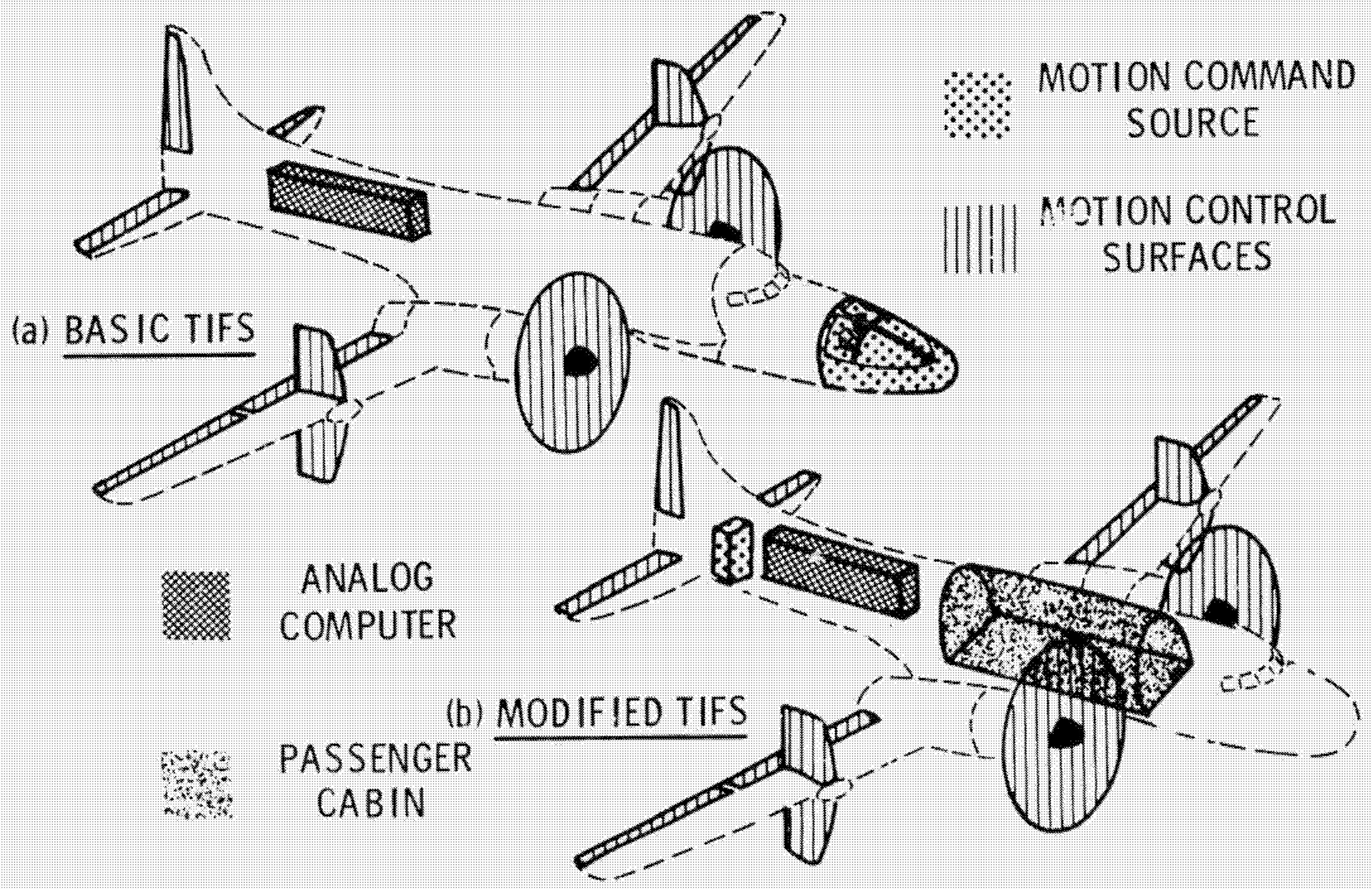
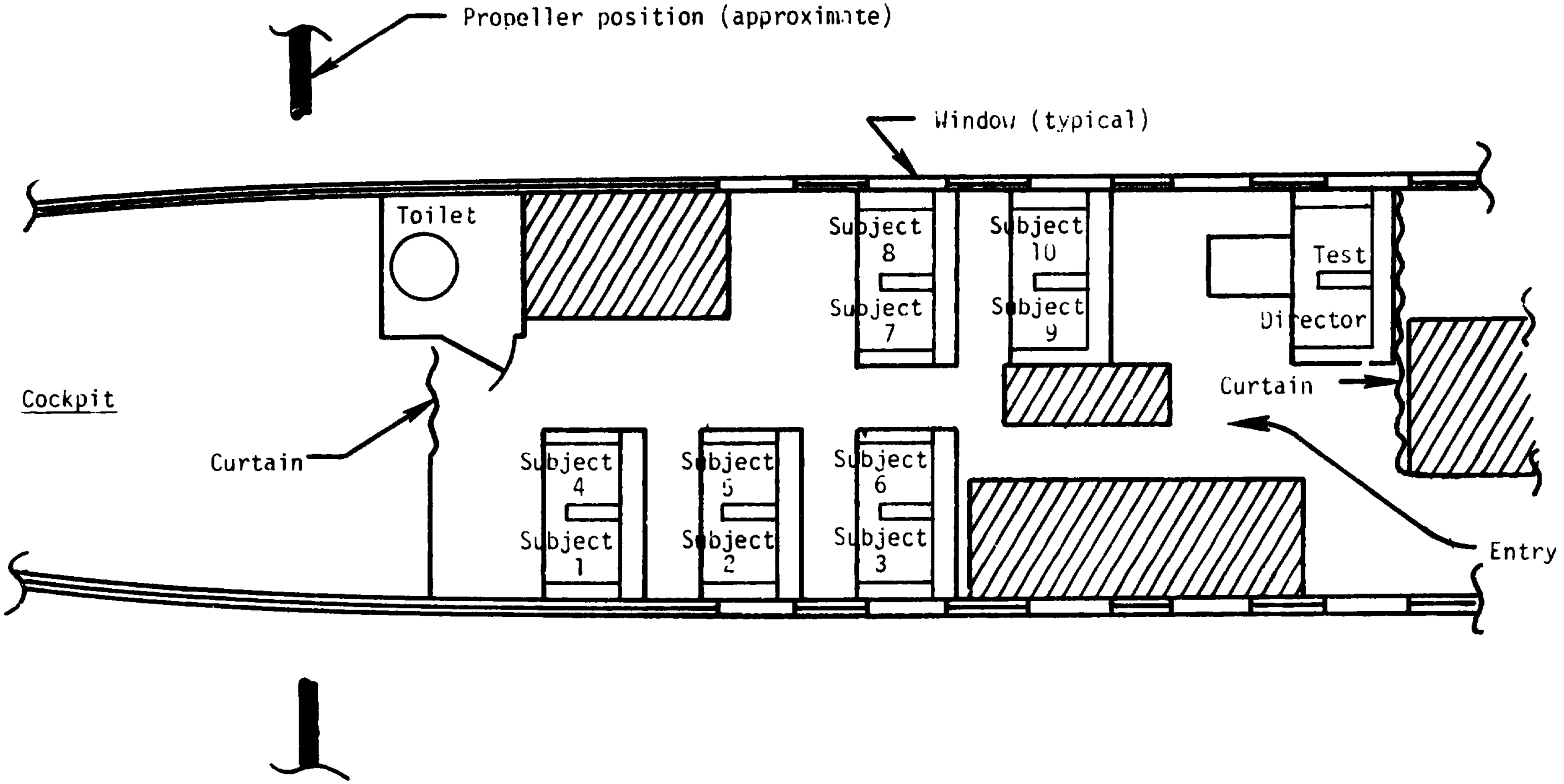


Figure 2. - TIFS modifications for ride-quality research.

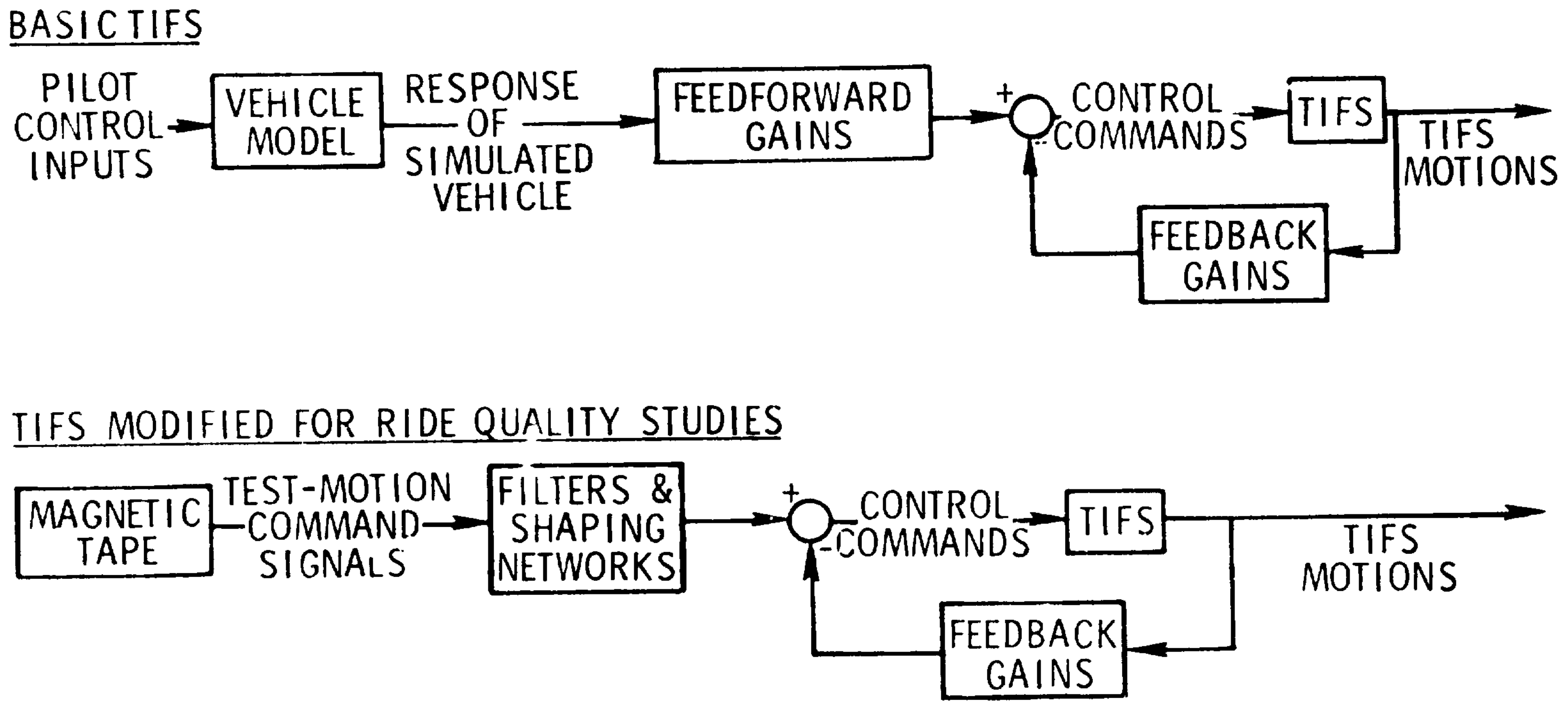
(a) Passenger cabin looking aft

Figure 3. - TIFS ride-quality experiments passenger cabin.



(b) Passenger Cabin Floor Plan

Figure 3 - Concluded


BASIC TIFS

TIFS MODIFIED FOR RIDE QUALITY STUDIES

Figure 4. - TIFS variable-stability system.

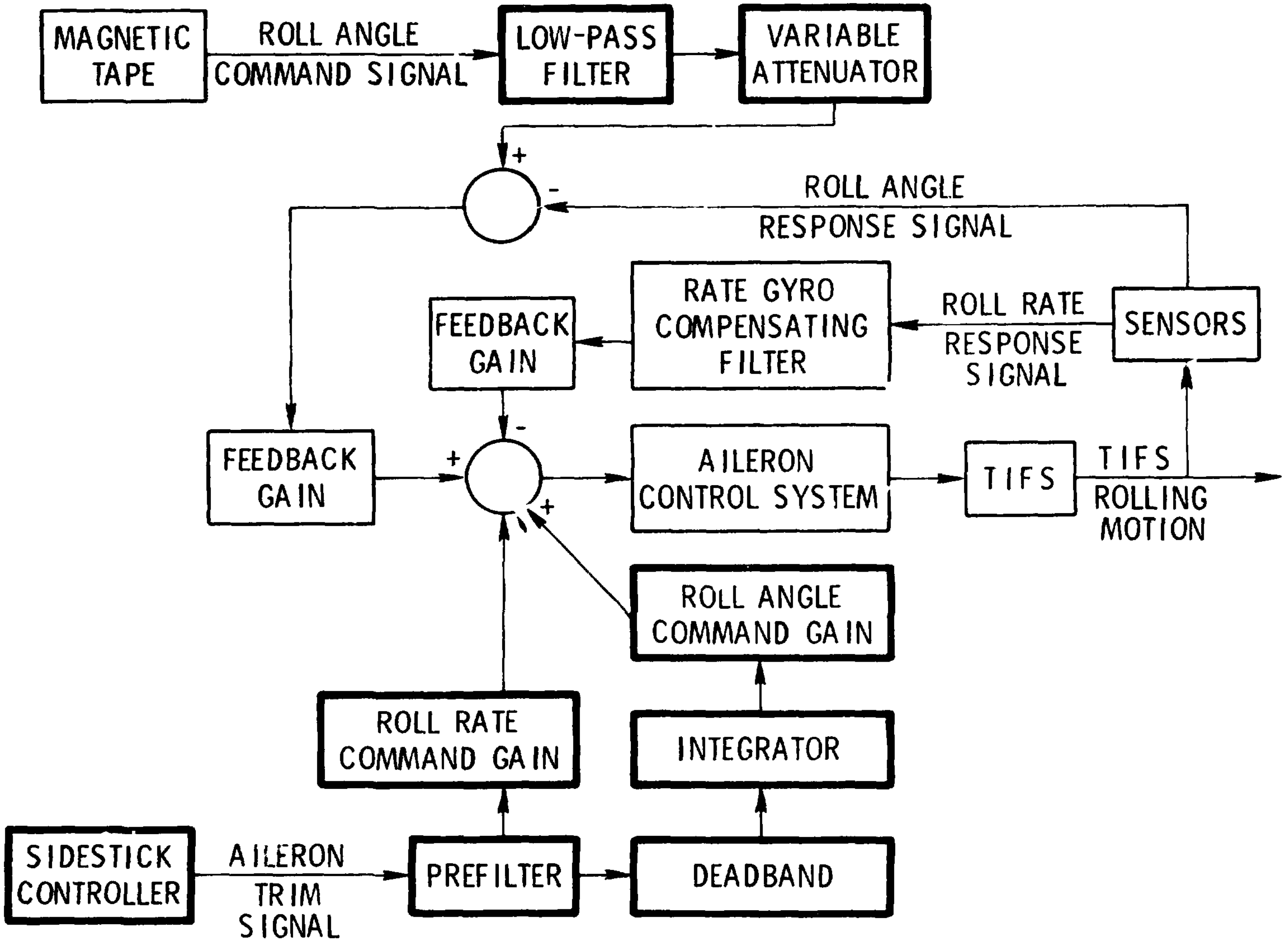


Figure 5. - Example control loop mechanization (aileron channel).

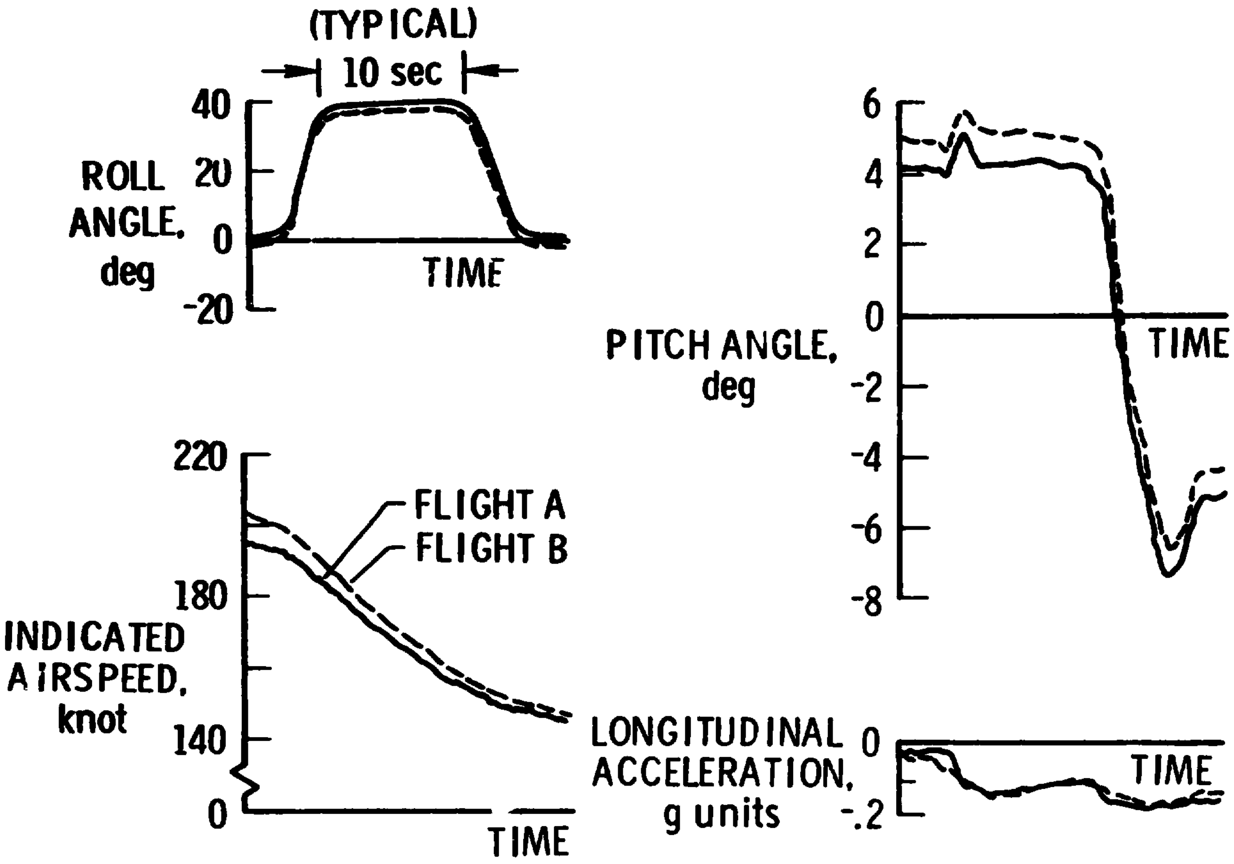
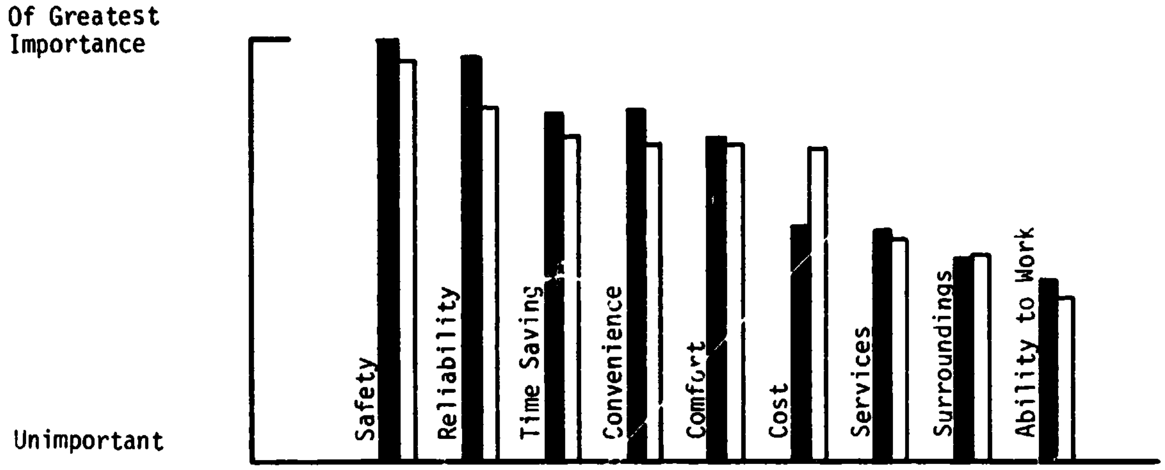
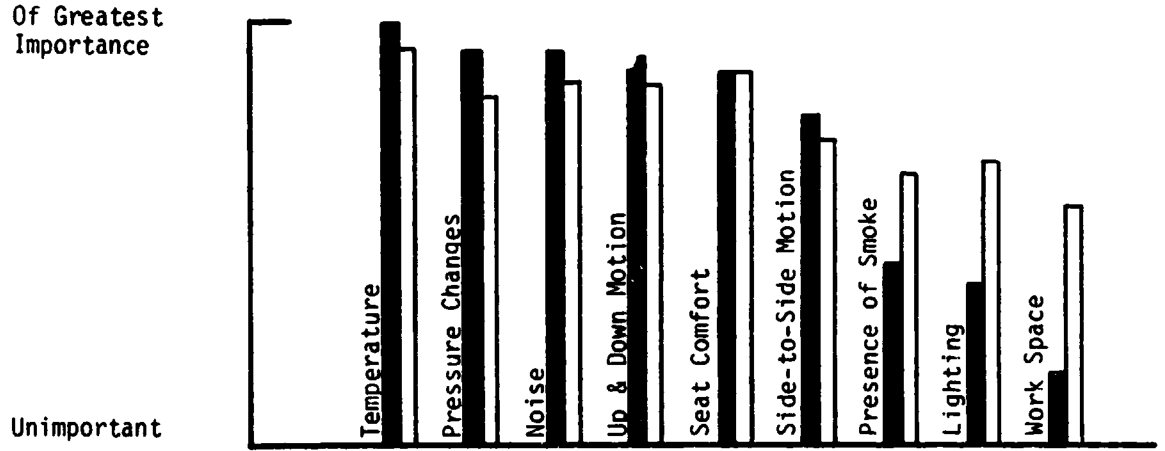


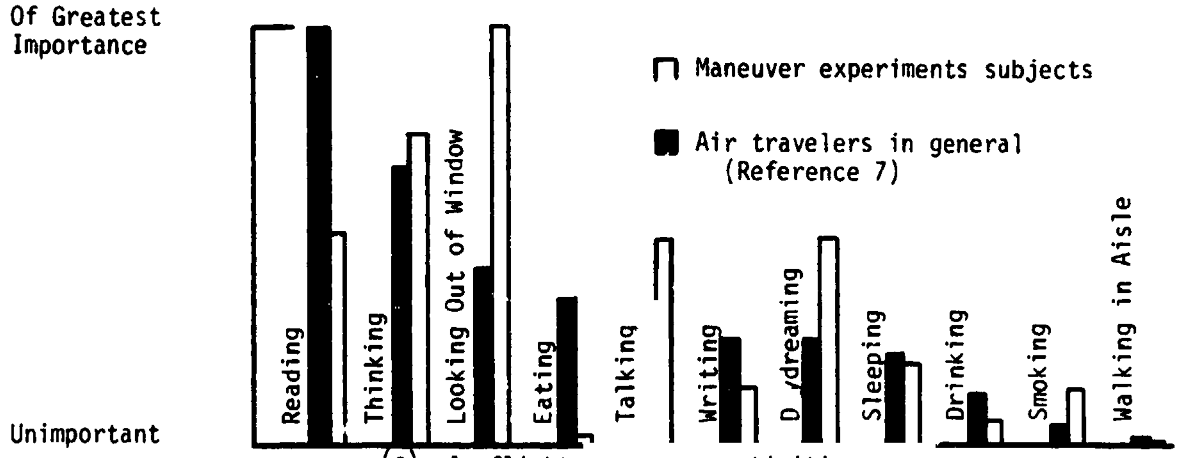
Figure 6. - Example of TIFS maneuver repeatibility (turning deceleration with pitchover).



(a) Factors determining overall trip satisfaction



(b) Factors determining passenger comfort



(c) In-flight passenger activities

Figure 7 - Comparison of attitudes of maneuver experiments passenger subjects and of air travelers in general toward various aspects of air transportation.

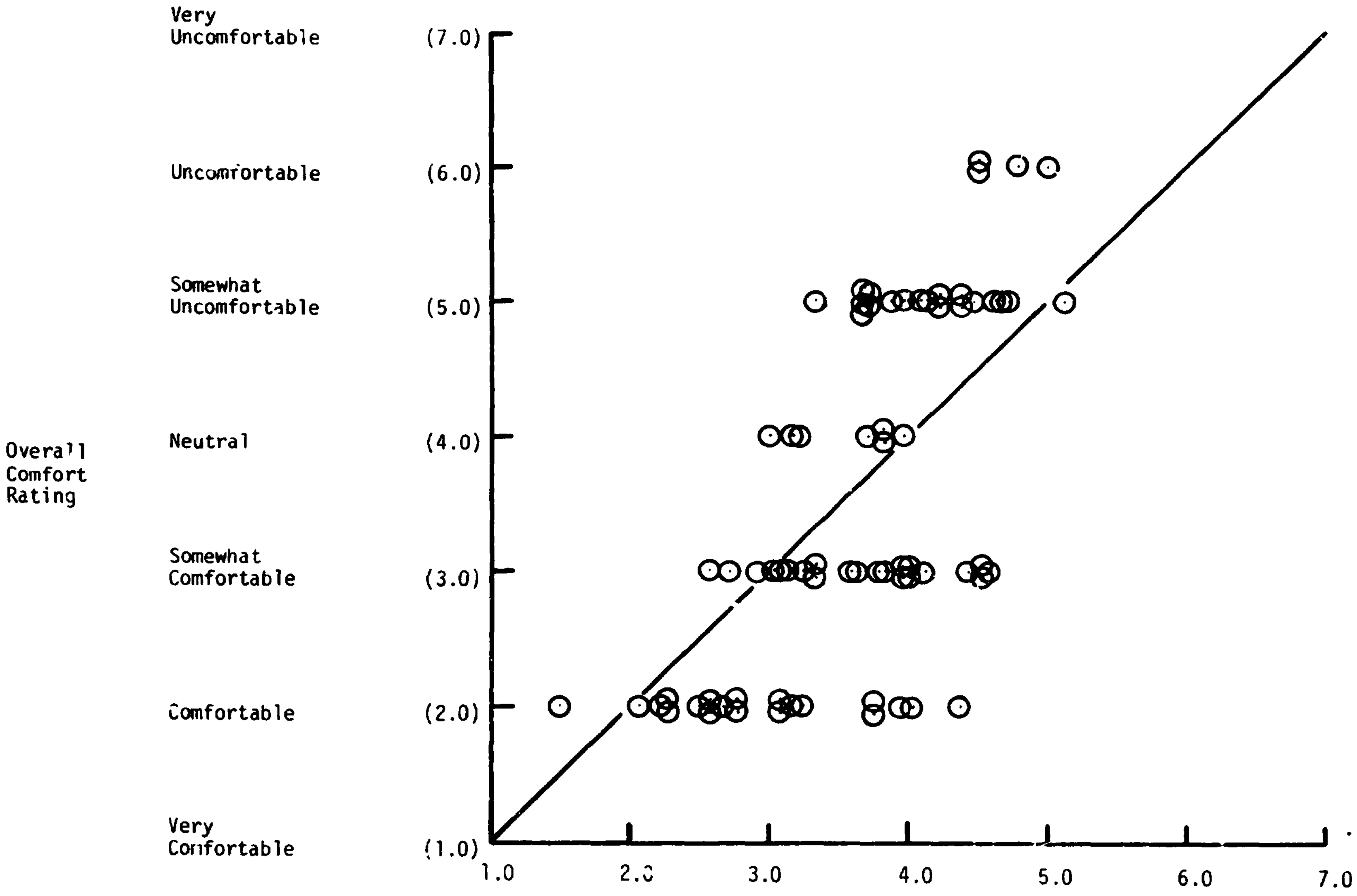


Figure 8 - Comparison of the mean of an individual subjects' ratings of the 24 maneuvers in a single flight with his overall comfort rating for that flight.

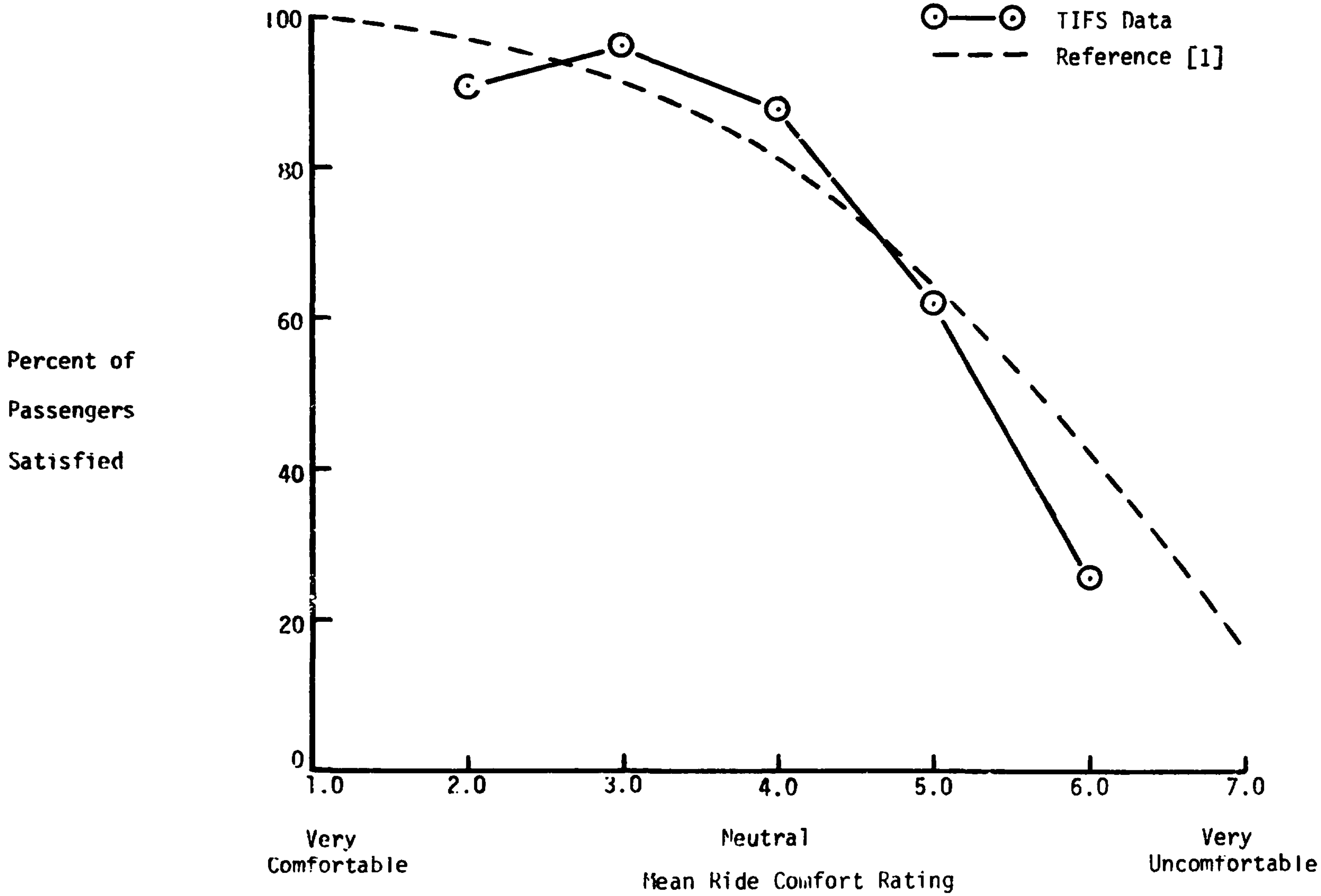


Figure 9. - Relationship between comfort and passenger satisfaction.

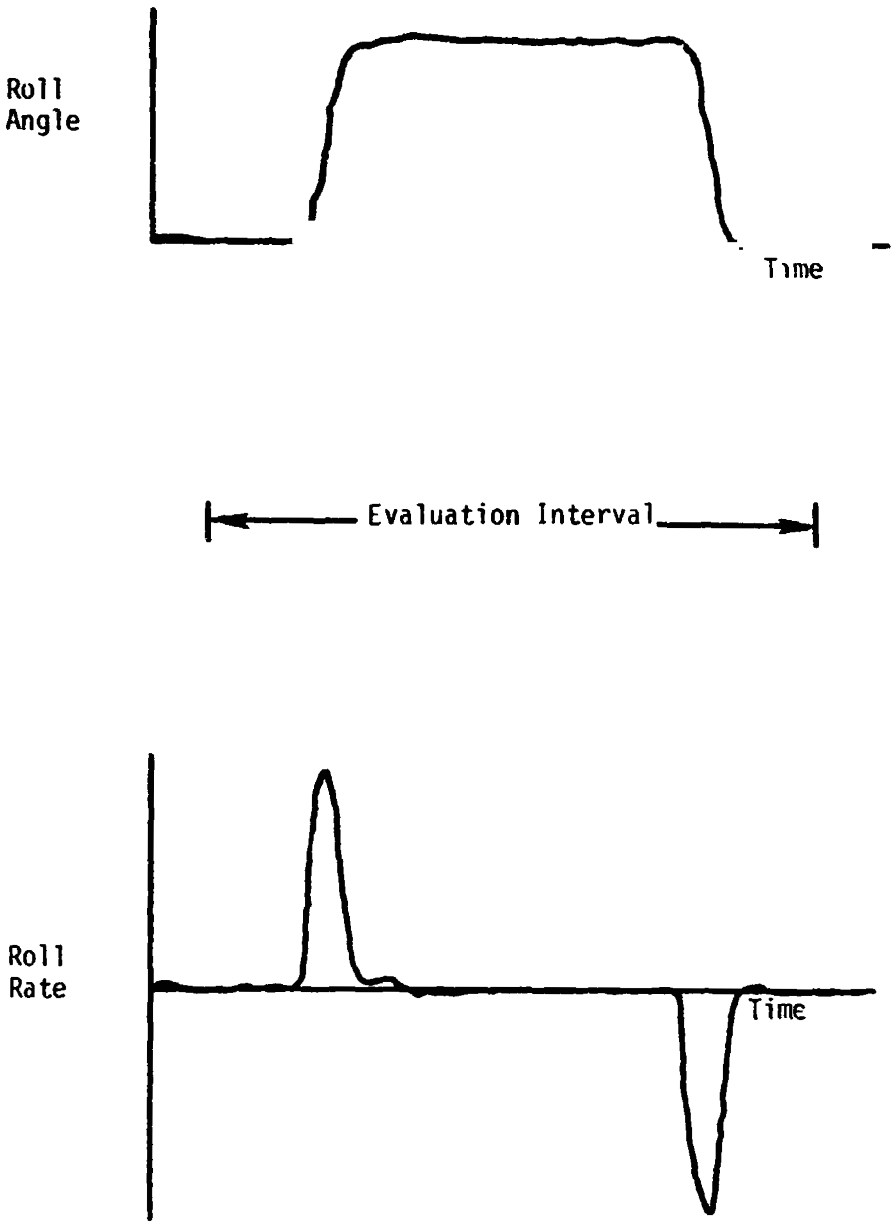


Figure 10 - Example simple turn maneuver.

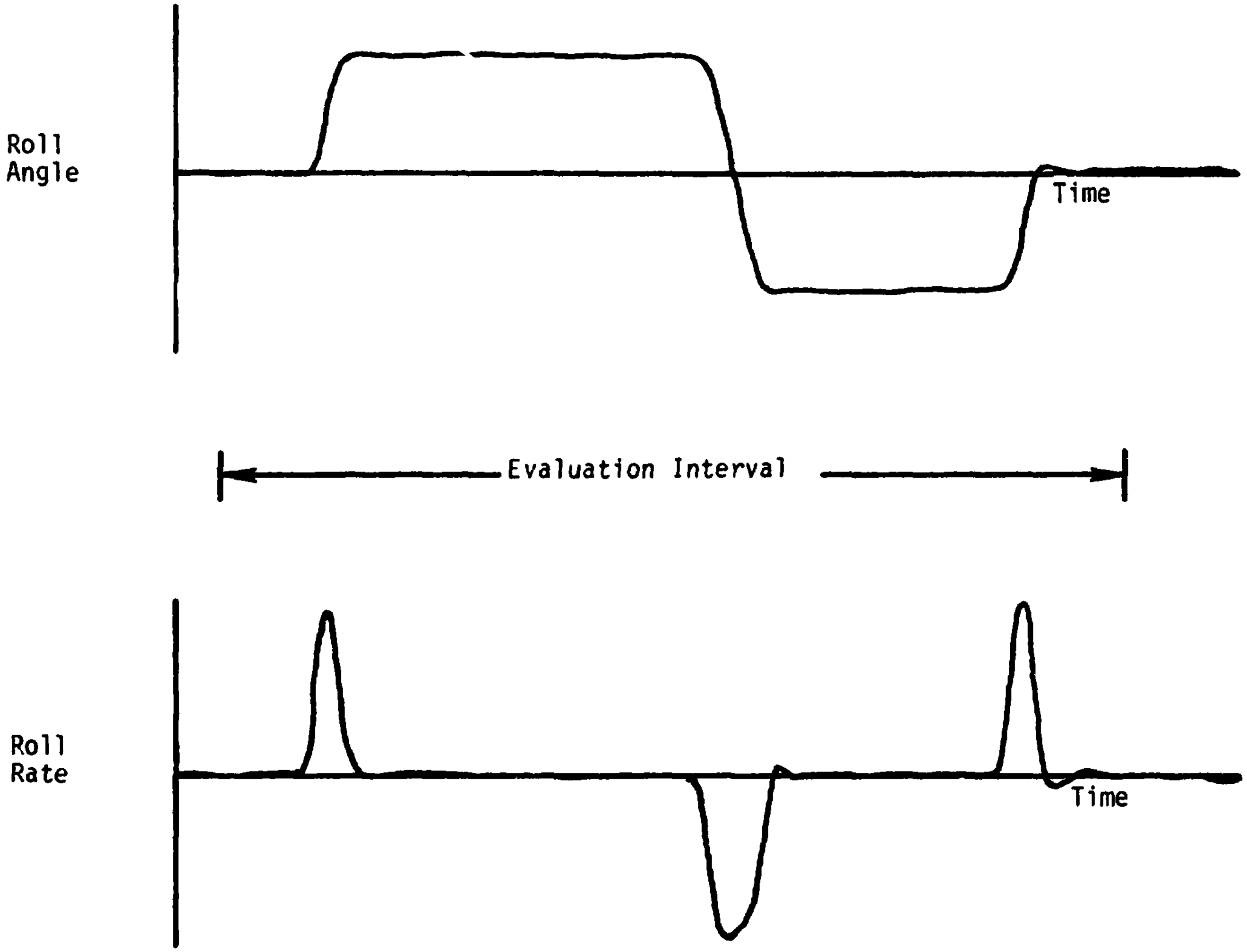


Figure 11 - Example S-turn maneuver.

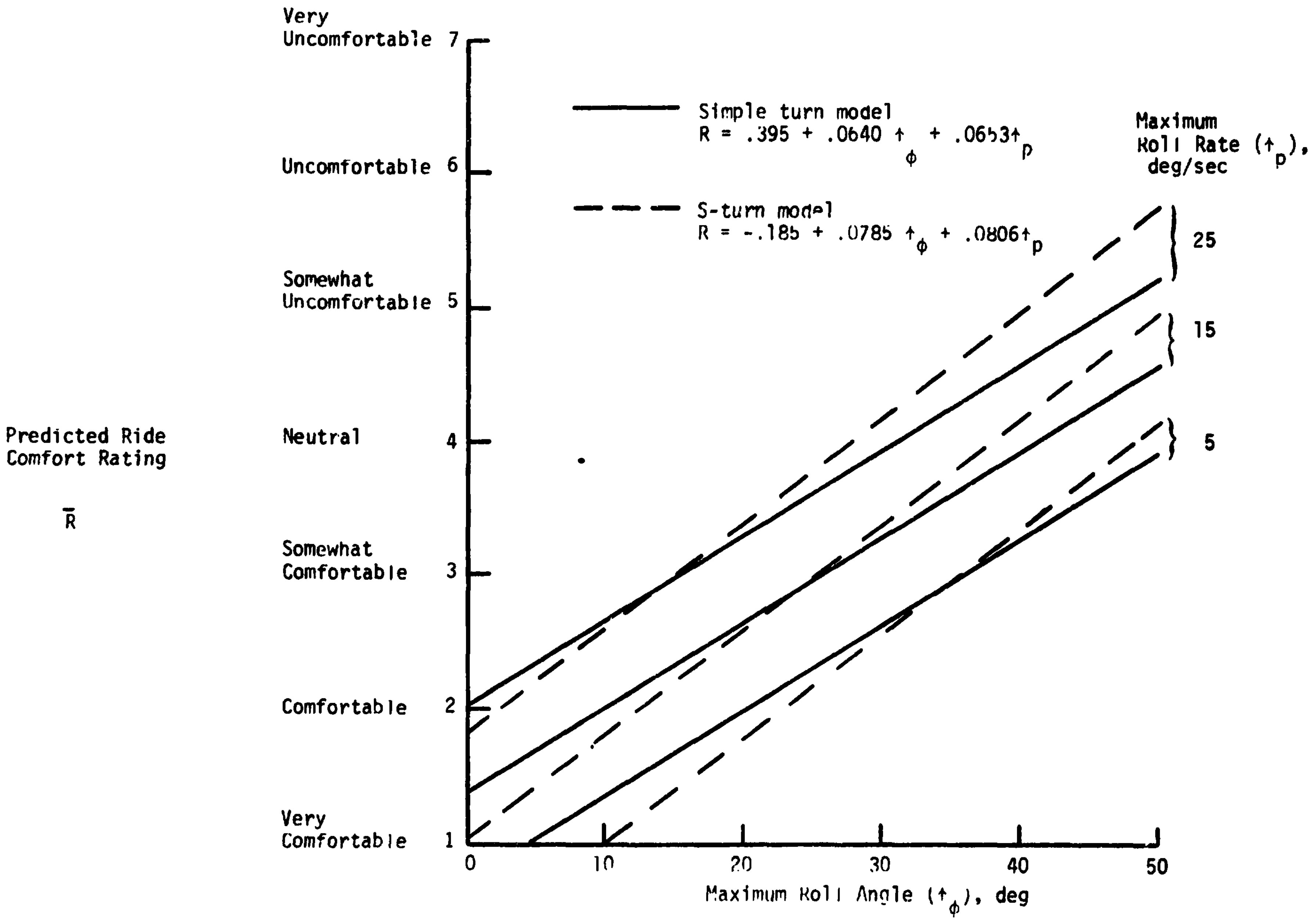


Figure 17. - Comparison of simple turn and S-turn regression models.

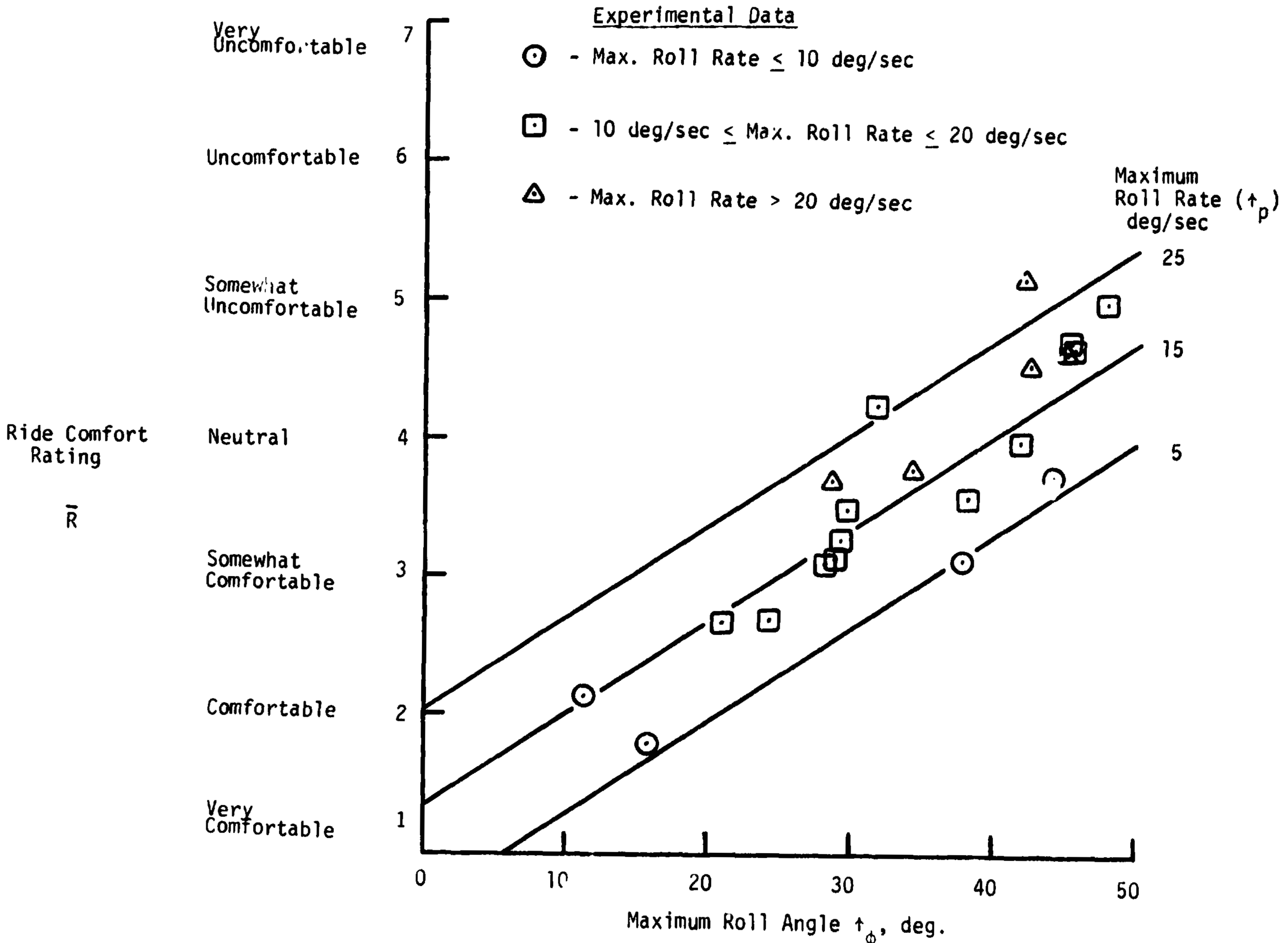


Figure 13 - Predicted and experimental ride comfort ratings during simple turns and S turns.

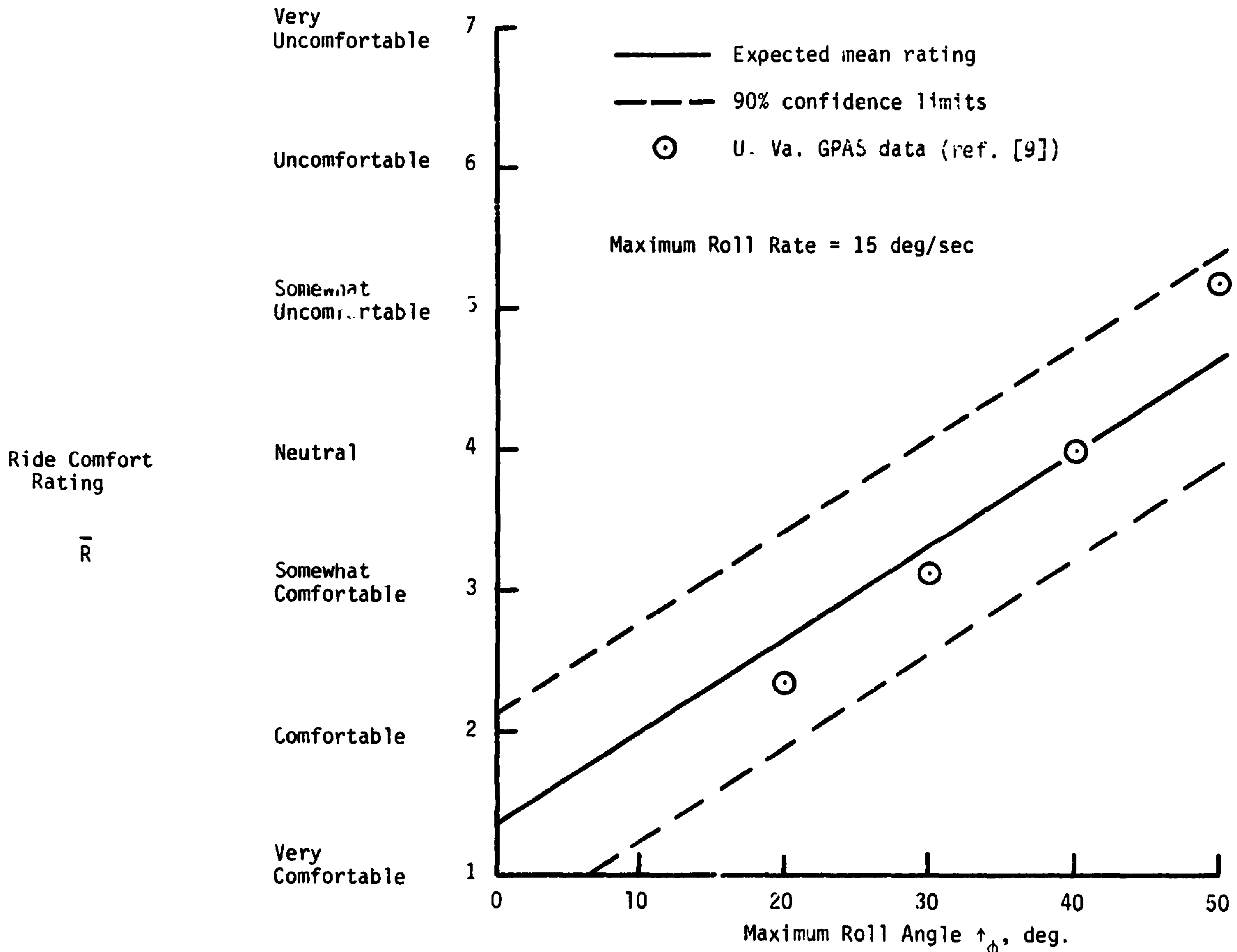


Figure 14 - Mean rating confidence interval and comparison with data from another experiment.

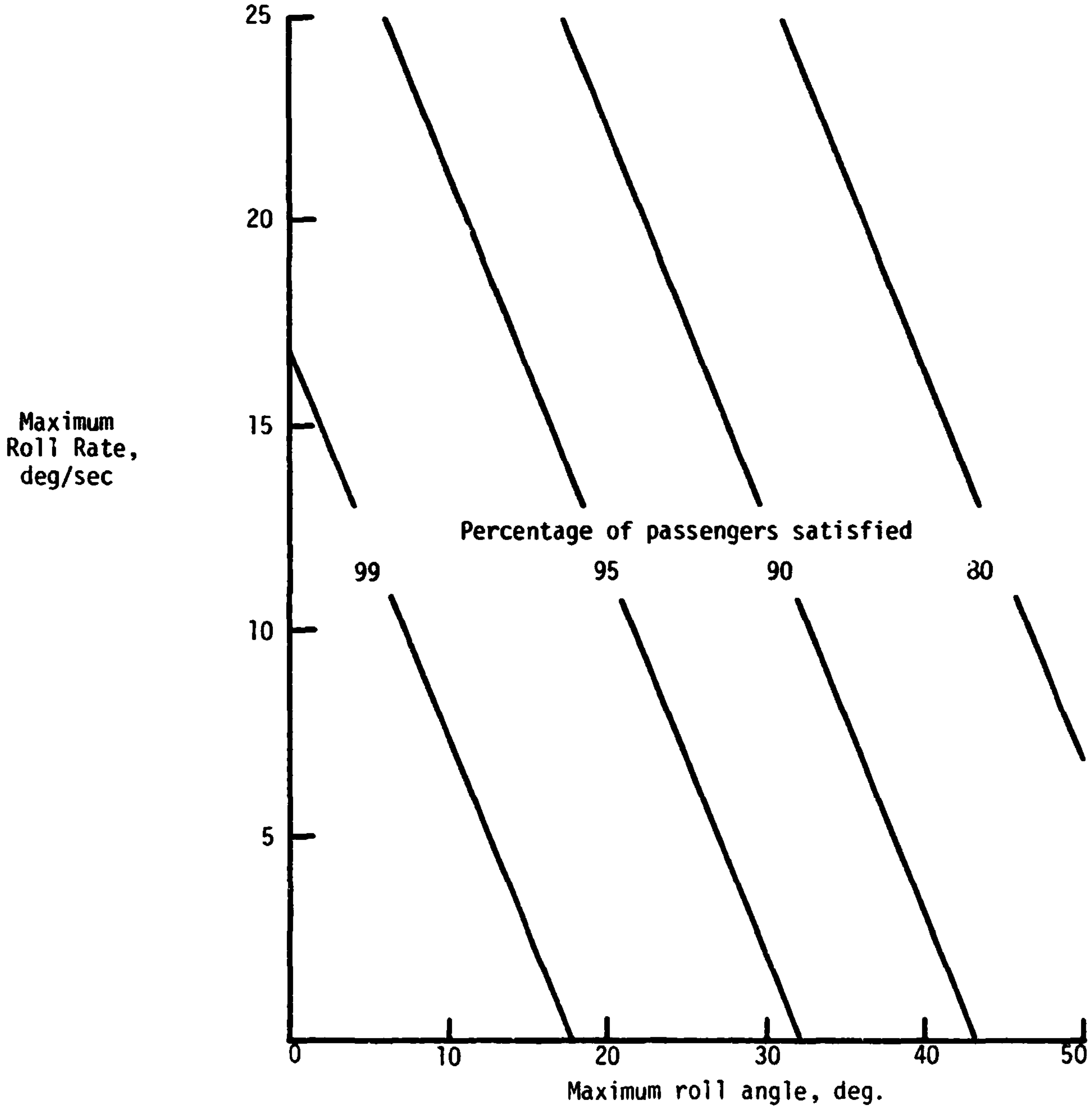


Figure 15 - Passenger satisfaction during simple turns and S-turns.

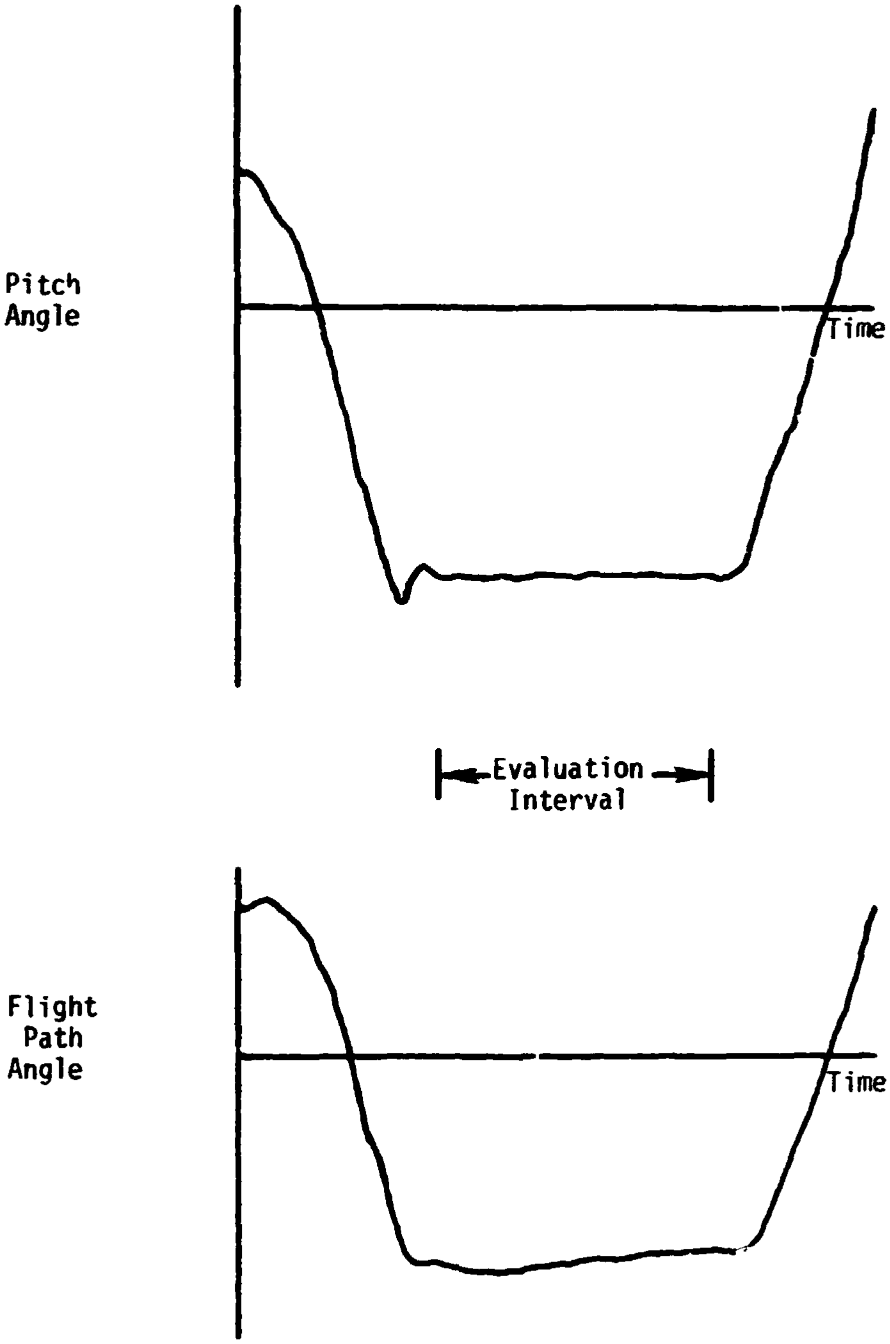
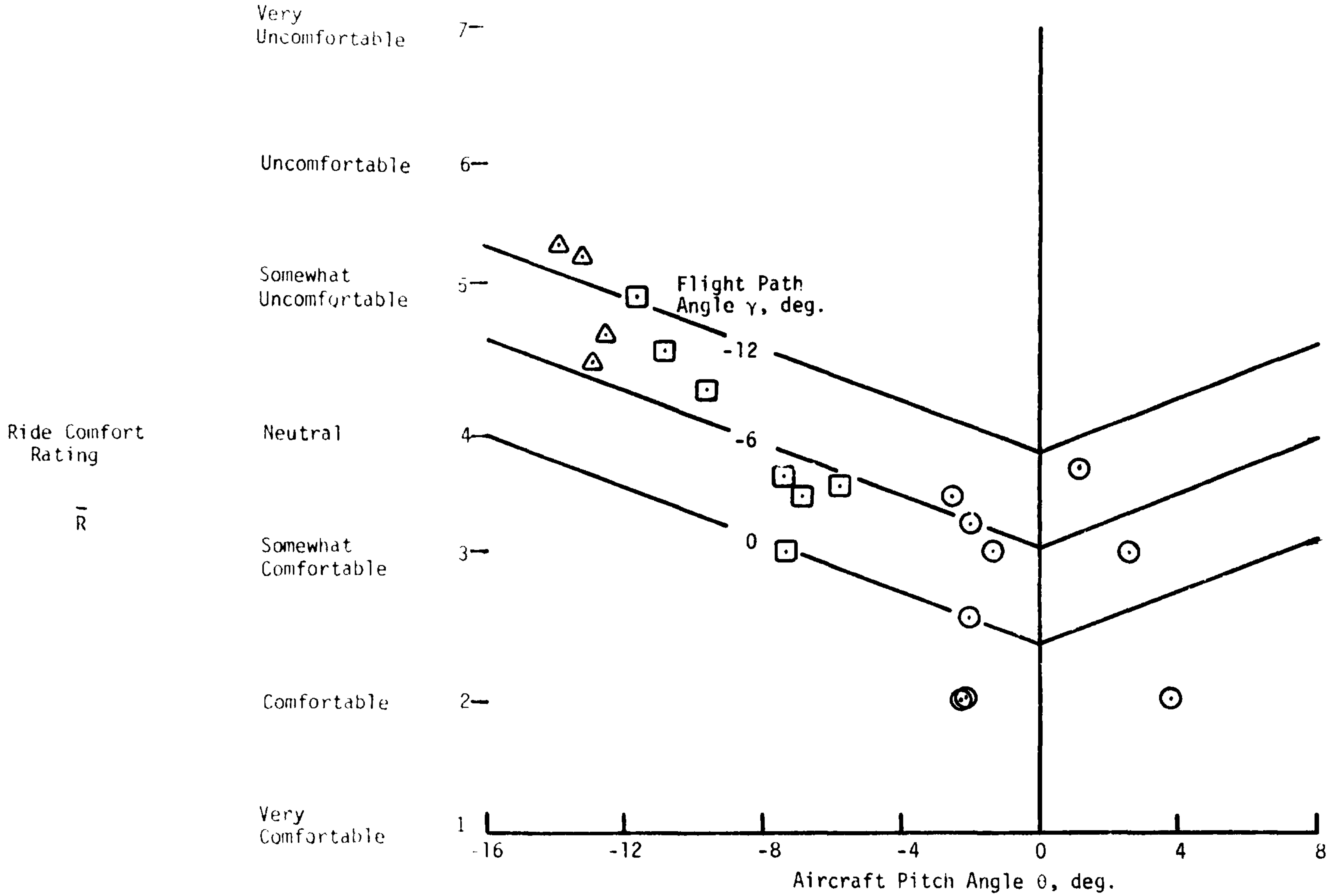
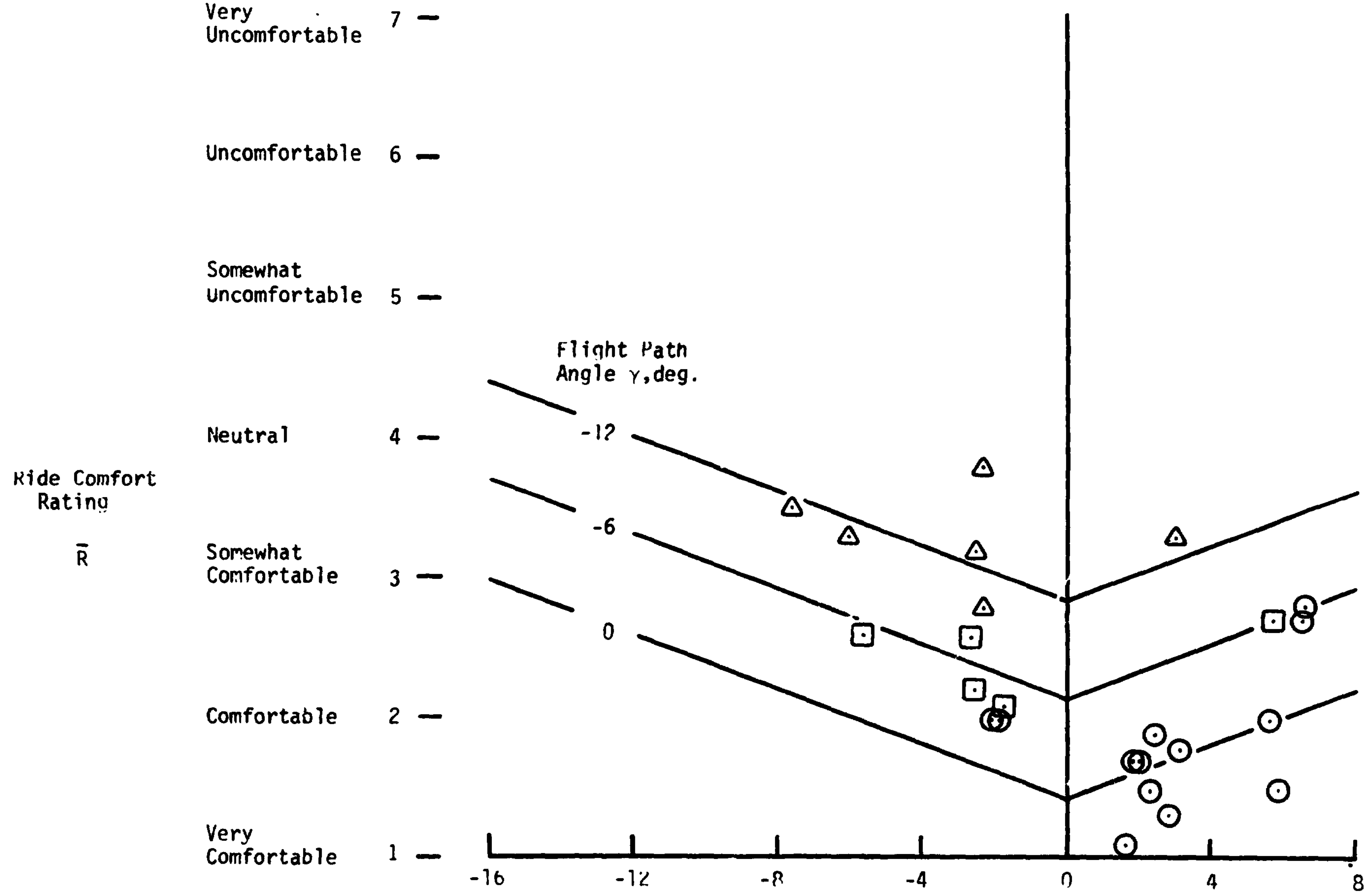


Figure 16 - Example steady descent.



(a) Indicated Airspeed = 200 kt.

Figure [illegible]. - Mean passenger comfort ratings during steady descents.



(b) Indicated Airspeed = 150 kt.

Figure 17 - Concluded.

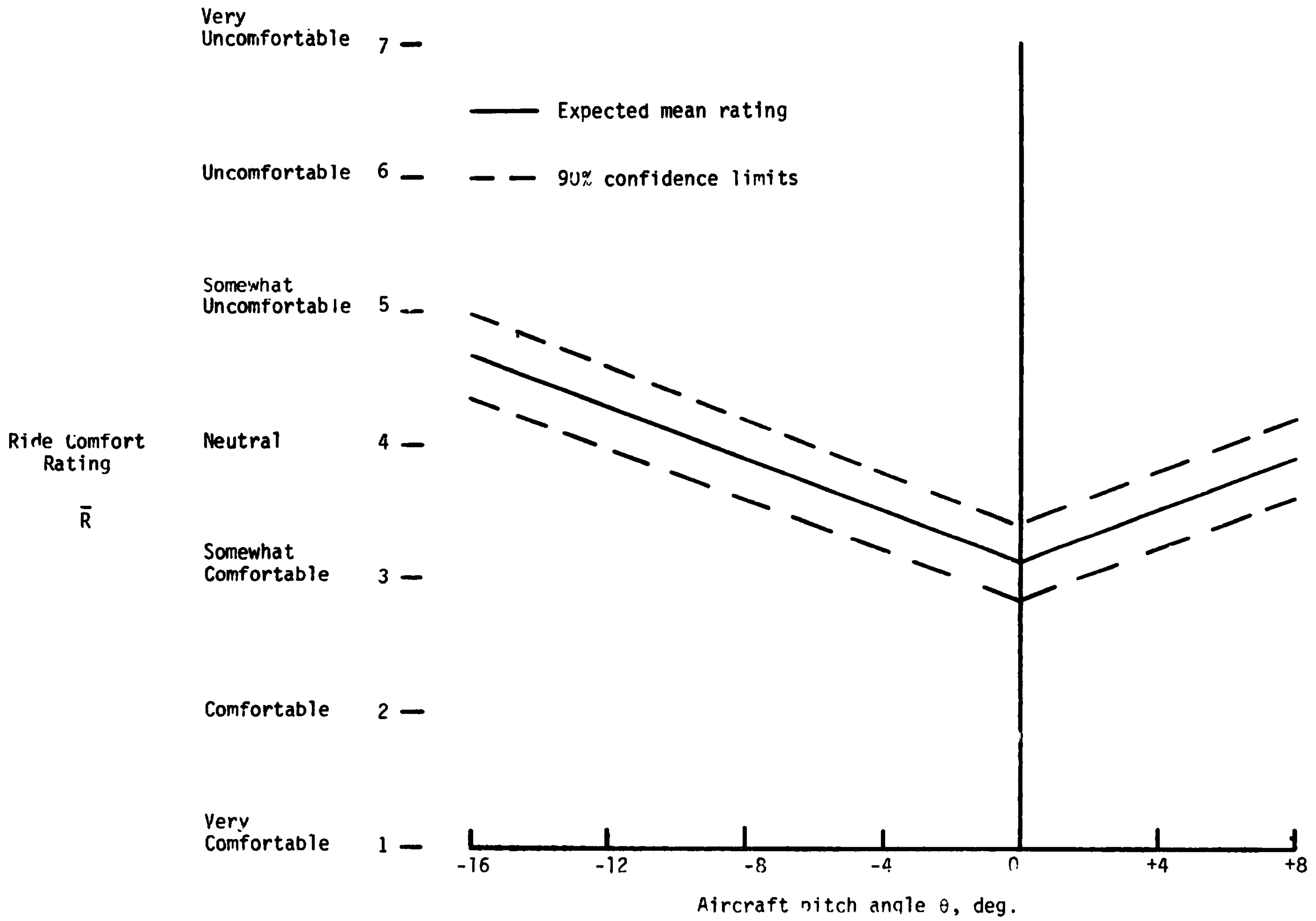


Figure 18 - 90-percent confidence interval for mean ride comfort rating during steady descents.

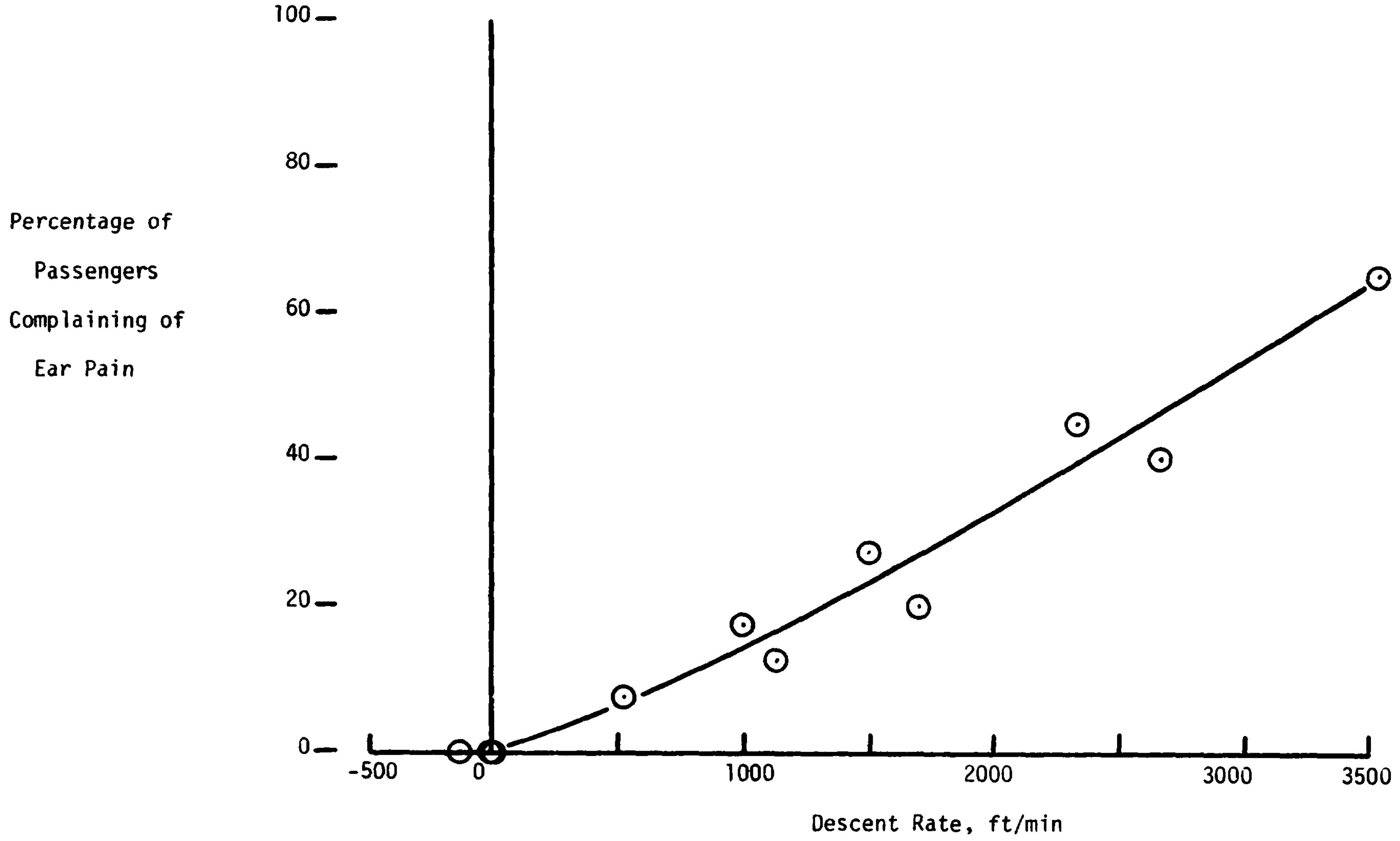


Figure 19 - Passenger discomfort due to cabin pressure changes during descent in an unpressurized aircraft.

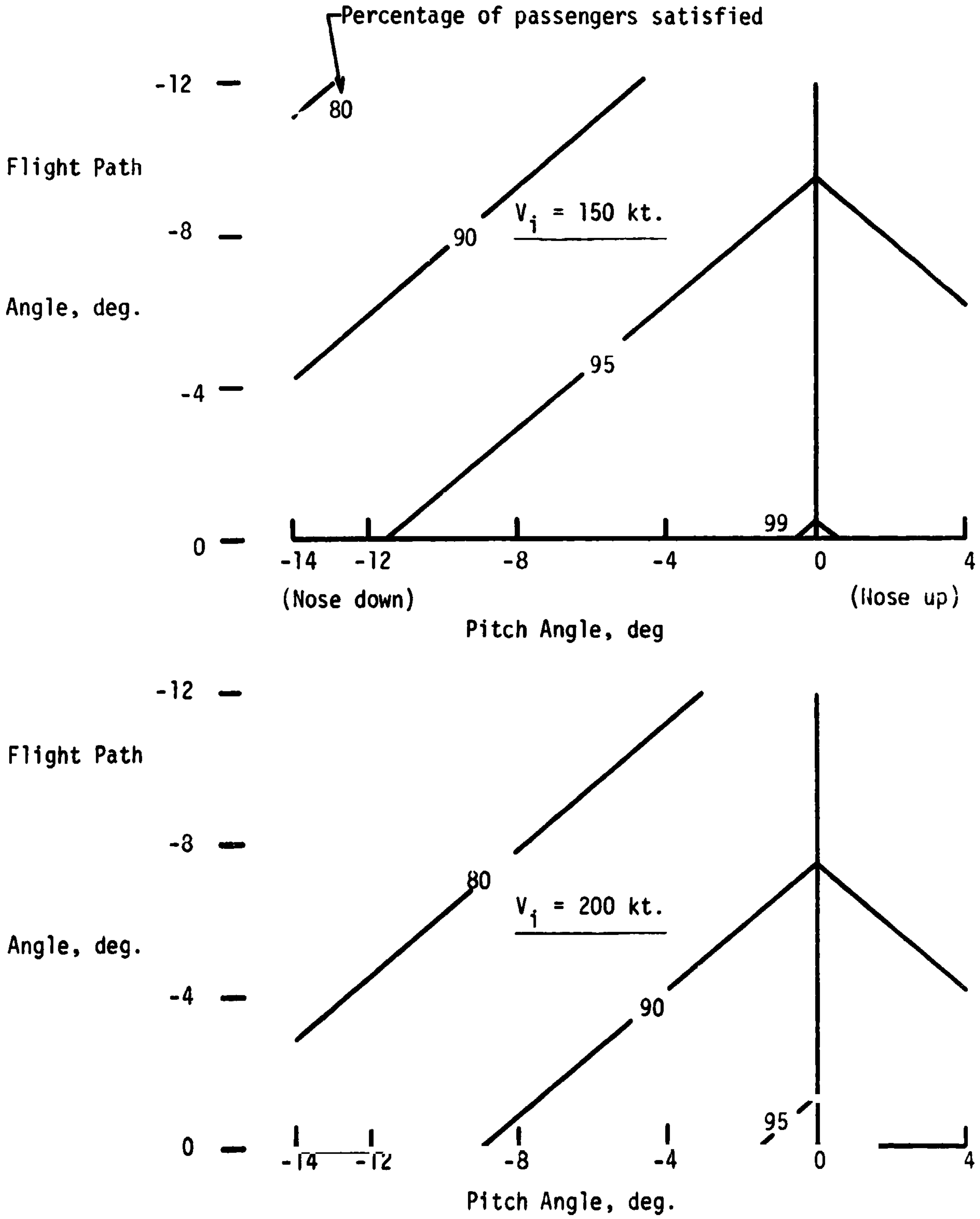


Figure 20 - Passenger satisfaction during steady descents.

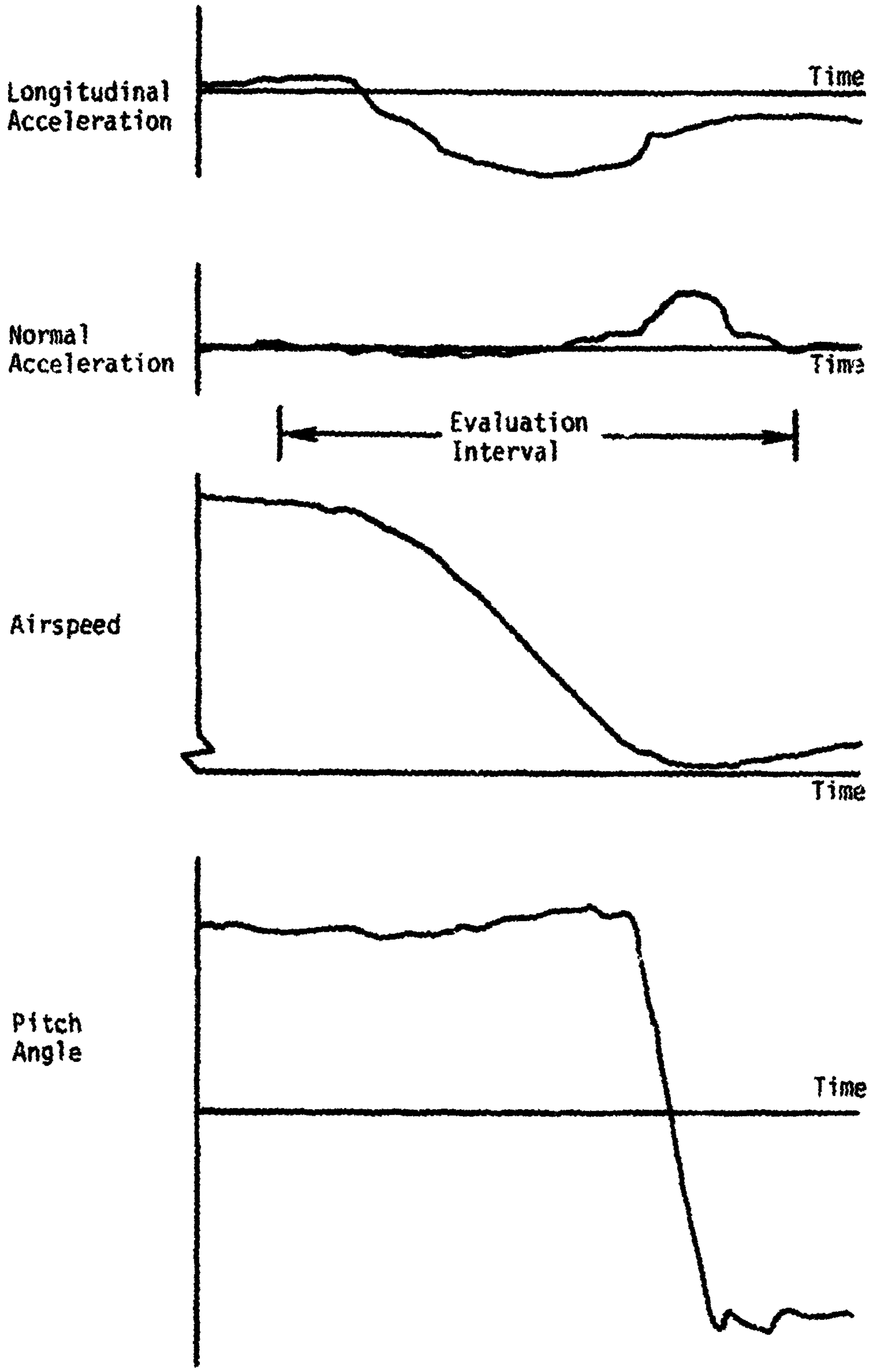


Figure 21 - Example longitudinal deceleration with pitchover.

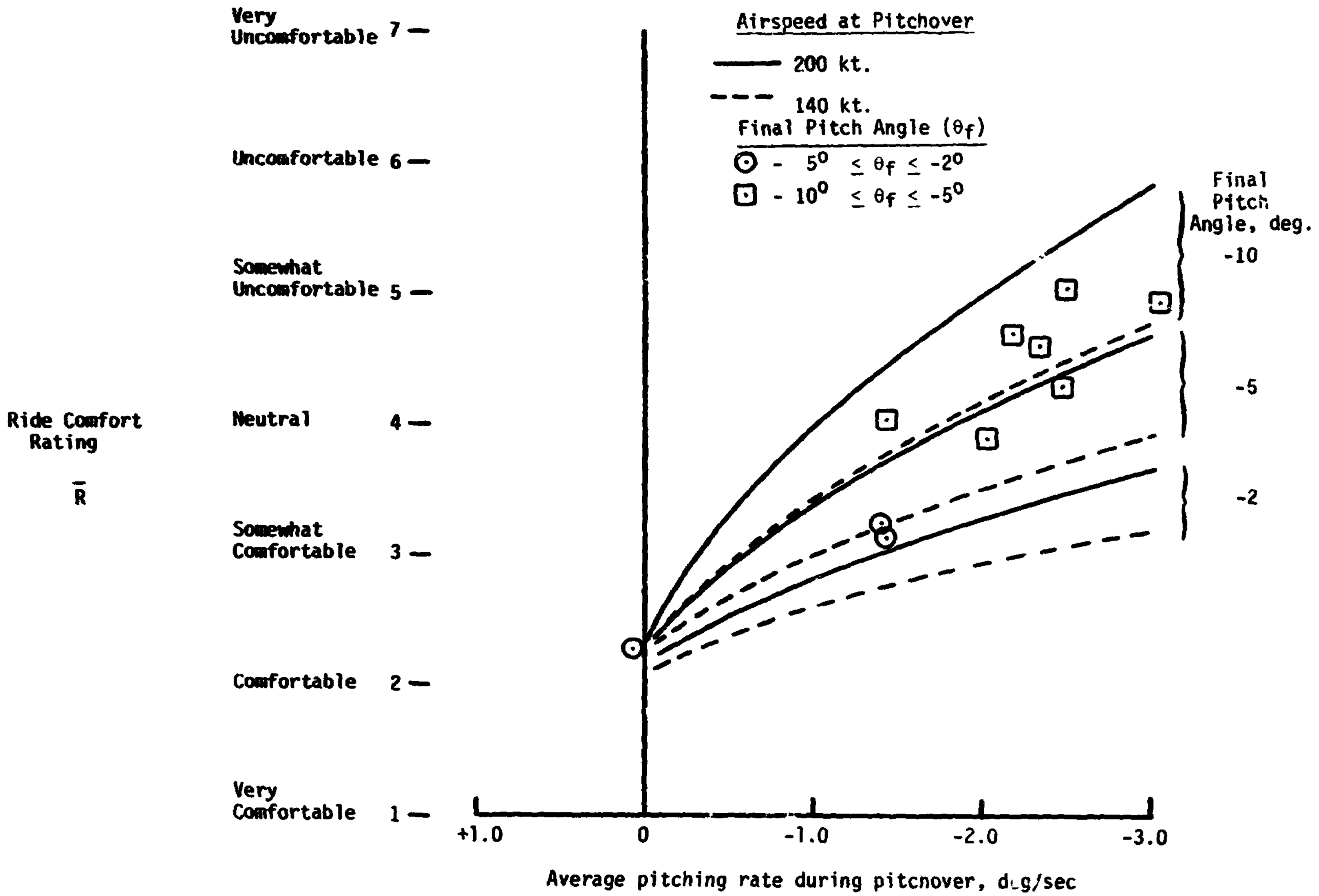


Figure 22 - Model-predicted and experimental ride comfort ratings during longitudinal decelerations with pitchover.

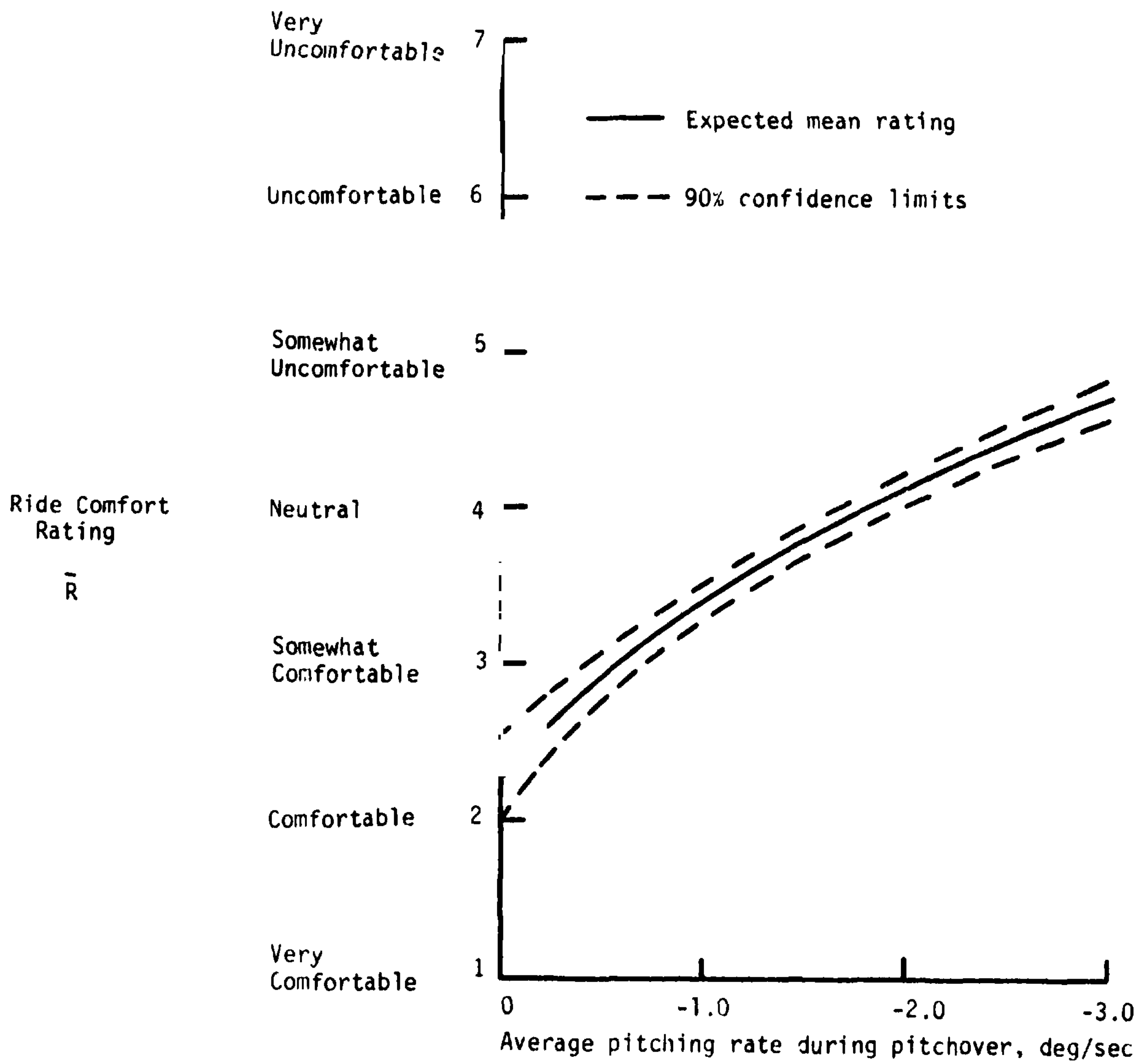
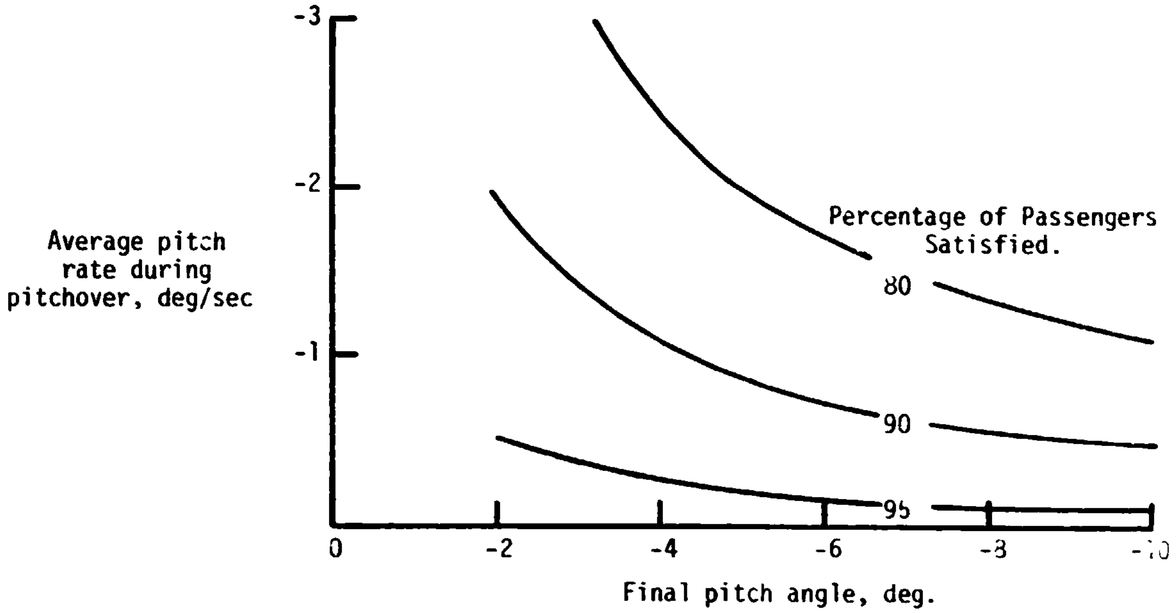
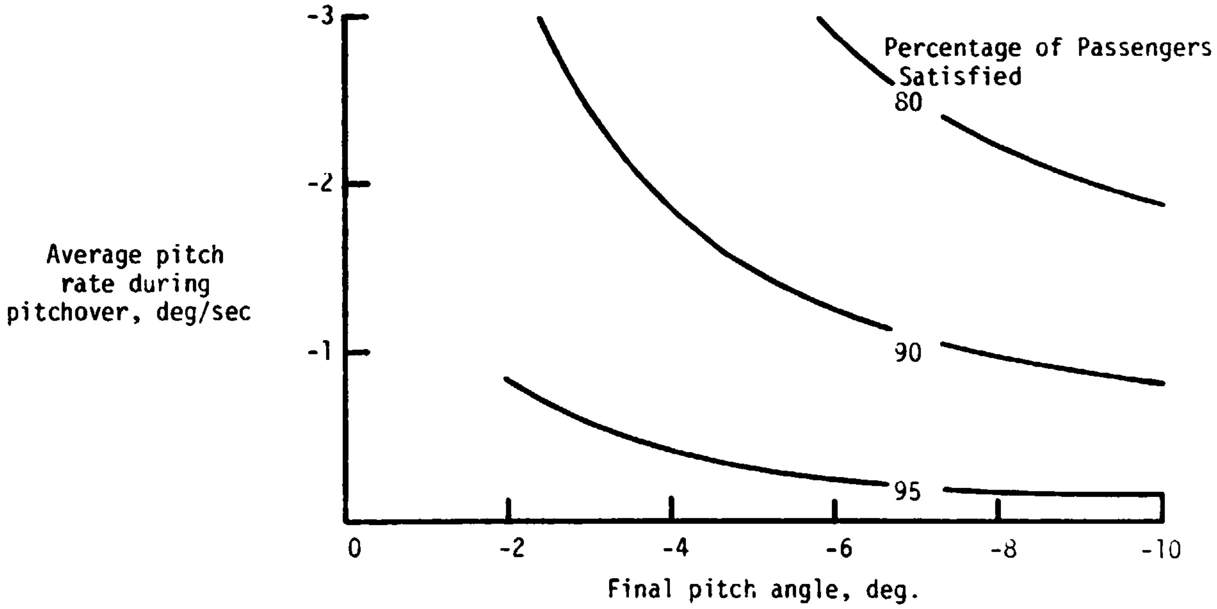


Figure 23 - 90-percent confidence interval for mean ride comfort rating during longitudinal decelerations with pitchover.



(a) Airspeed at pitchover = 200 kt.



(b) Airspeed at pitchover = 140 kt.

Figure 24 - Passenger satisfaction during longitudinal decelerations with pitchover.

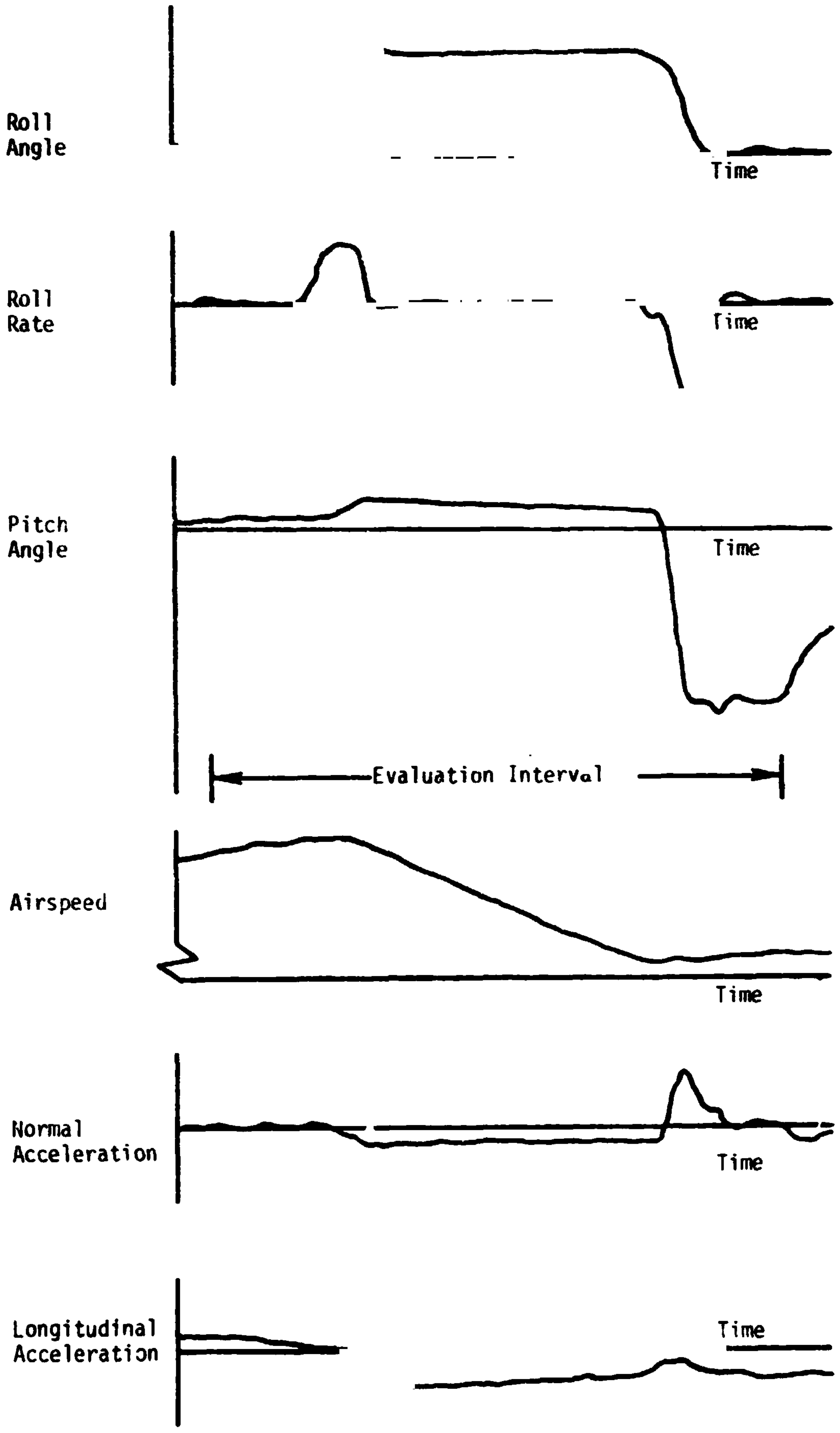


Figure 25 - Example turning deceleration with pitchover.