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ANALYSIS OF PASSENGER ACCEPTANCE OF COMMERCIAL FLIGHTS

HAVING CHARACTERISTICS SIMILAR TO STOL

STOL PROGRAM TECHNICAL REPORT 403208

by

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Analysis of Passenger Acceptance of Commercial Flights Having Characteristics Similar to STOL*

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Introduction

Improved quantitative data enabling reliable modal-split analysis appears to offer the key to improved service in low-density, short-haul, air transportation. To make such service economically feasible in the absence of heavy federal subsidies, one must understand how to design the system to be attractive to the user community. The entire system must be considered and the essential components include the vehicle itself, the flight characteristics of the vehicle on the types of routes under consideration, the routing and scheduling of the service, the terminal characteristics of the service, and the characteristics of the user which in turn govern his value judgment on parameters relating to the system.

The overall University of Virginia interests are focused on the development of quantitative relationships for all of the factors listed above as they relate to the user and the public, and the use of these relationships to provide a realistic evaluation of the demand for any service.

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Initially we have restricted our efforts to study the passenger and prospective user to determine quantitatively the effect of the various parameters on his subjective judgment in making a decision to use a given transportation mode or service. In order to make a start within our resources, we further restricted the first studies to the parameters involved in the travel interval, i.e., the vehicle and its trip exclusive of the terminal aspects of the travel or the specific trip preconditioning of the passenger.

Before looking at the results in detail, a brief outline of the program is in order. The first task assessed the relative importance of the various aspects of the transportation system as they related to the satisfaction of the passenger or potential passenger. This has been done through questionnaires administered both to passengers in flight and to typical groups of travelers contacted at home or at their place of business. The groups selected were such as to be representative of short-haul situations. Analysis of the responses indicated that comfort was a very important consideration in a decision to go by air and that the overall motion of the aircraft is perceived as being quite important in the determination of overall comfort. (1)

On the basis of the above results, it was decided that the first attempt at developing quantitative mathematical models should be directed toward the comfort parameter and, in particular, the effect of motion, temperature, and noise level on human evaluation of comfort. To insure realism, it was decided that data should be obtained on regularly-scheduled flights of commercial airlines. Instrumentation was prepared to measure six degrees of freedom of aircraft motion (3 linear and 3 angular), pressure, temperature, and noise level. A group of special test subjects were selected to evaluate their reactions to the aircraft environment on the basis of a five-point scale ranging from 1 - very comfortable to 5 - very uncomfortable. These numerical responses are recorded on the same time frame with the instrumentation variables. The subjects are directed to respond either at regular intervals or at instances when they sensed a change in their evaluation. They also give an overall rating to the ride.

One of the most important aspects of any modeling program designed to represent attitudes of the general public is to develop valid means to represent the public by a more limited special test-subject group. In order to minimize costs, it is highly desirable to keep this group to the smallest possible size. Thus, in order to study this relationship between general and special groups, the overall ride evaluations are obtained via questionnaires from the flight crew and regular passengers, as well as from the special test subjects.

To date we have conducted three flight-test experiments, two on regularly-scheduled airlines and one in connection with a special Twin Otter evaluation by the Federal Aviation Administration at NAFEC in Atlantic City, New Jersey. The latter used a rather large test-subject group selected from the cross section of the employees at the base.

The first commercial airline program involved a total of 100 flight segments flown aboard three different aircraft--YS-11, F-227, and B-737--for a variety of turbulence conditions and over a variety of terrain (both flat and mountainous). Stage lengths varied from 75 miles to about 300 miles with block times from 15 minutes to about 1 hour. Unfortunately it was not possible to circulate questionnaires to the passengers. Nevertheless, this program was extremely valuable, as it represented the first opportunity to obtain quantitative information suitable for use in modeling human acceptance to motions typical of short-haul operations. (2) (3)

The second commercial flight-test program concentrated on commuter-type aircraft and was made possible through the splendid assistance of officials of Allegheny Airlines and their commuter affiliates. It is now about 50% complete, and is scheduled for completion about April 1. At its conclusion, about 120 flight segments will have been flown using three different aircraft of a type applicable to the low-density, short-haul market--the Nord 262, Volpar Beech 18, and the de Havilland Twin Otter. The Twin Otter is used in conjunction with Atlantic City Airlines between Philadelphia and Atlantic City, a stage length of about 60 miles with a block time of 30 minutes. The other aircraft are used with Ransome Airlines from Washington National to Philadelphia, a distance of about 136 miles with a block time of 40 minutes. In all these flights, questionnaires are given to all passengers, and the return has been very good. Thus, in addition to the special test-subject reactions to the motion-temperature-pressure-noise environment for the development of our first model, demographic, motivational, and attitudinal data for the general-subject group is obtained. These are factors which must ultimately be incorporated in the model. Also, in this program, we are looking at a set of aircraft in a situation where competitive modes, including jet aircraft, are readily available. The major emphasis of this paper is to report the preliminary results obtained from this latest flight-test program.

Data Acquisition

A portable instrument package (Figure 1) was constructed to obtain the necessary motions and environmental parameters in the aircraft. The battery-operated package was specifically designed to fit in a small attache case which could then be placed in the normal carry-on luggage position under the forward seat. (Special arrangements are required for some of the smaller commuter aircraft.) No attempt was made to observe motions transmitted through the seat as this was felt to be more properly the subject of a separate study, perhaps done best on simulators. The case contains all items needed for the experiment, except the small tape recorder which is carried separately and is placed adjacent to or on top of the attache case, depending on the seat geometry. A single cable connection between the two is required. The small subject-response indicator and the sound pressure level meter are removed from the attache case and held in the subject's hands. After evaluating the ride during a prescribed interval, the subject then depresses the appropriate button corresponding to his subjective comfort rating which then puts a calibrated step function on the tape. In all experiments a scale of 5 was used as follows:

1 - Very comfortable
2 - Comfortable
3 - Neutral
4 - Uncomfortable
5 - Very uncomfortable

A-weighted sound levels and temperature are read manually and introduced on the data tape at a later time. This is done since the noise level is

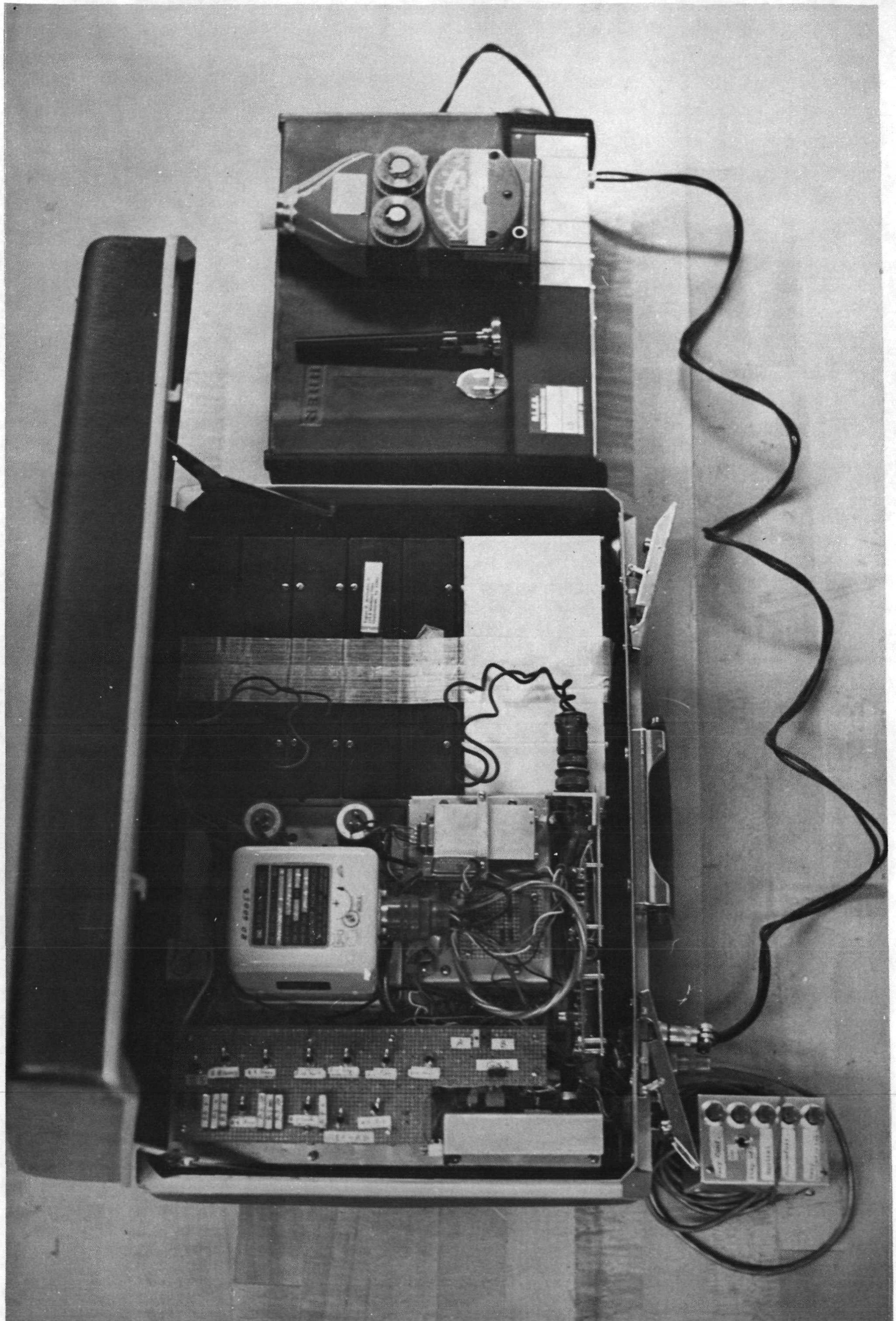

Figure 1. Portable Instrument Package

principally a function of certain activities such as taxi, takeoff, climb, cruise, etc., and changes very little during these segments. Temperature is also a slowly-varying function of time.

Linear accelerations are measured by three separate accelerometers and angular rates are obtained from a 3-axis rate gyro. The data are multiplexed and recorded on a Uher 2-channel tape recorder. A typical paper tape printout of the transcribed data is shown in Figure 2. It is later reduced for study using a time-series analysis program (4).

As they boarded the flight, a questionnaire packet was distributed to all passengers by the flight stewardess, or by one of our test subjects, properly identified to the passengers. The copy of the questionnaire is reproduced as Figure 3. The packet contained complete information and instructions for the passenger, including the request that it not be completed until directions were issued by the crew. This announcement was made by the pilot over the intercom approximately 5 minutes before start of descent. The questionnaires were collected as the passengers deplaned.

Test Subject-Passenger Comparisons

As mentioned earlier, the selection of a proper test-subject group and the fidelity with which it represents the traveling public is a matter of great importance. There are a large number of variables to be employed in the development of a quantitative model of a complete transportation system. Direct interaction with the public is a costly, laborious, and time-consuming operation. It is difficult to obtain detailed subjective-response information to stimuli other than by overall judgments recorded well after the fact. Also, variables cannot be selectively controlled during ordinary commercial flights.

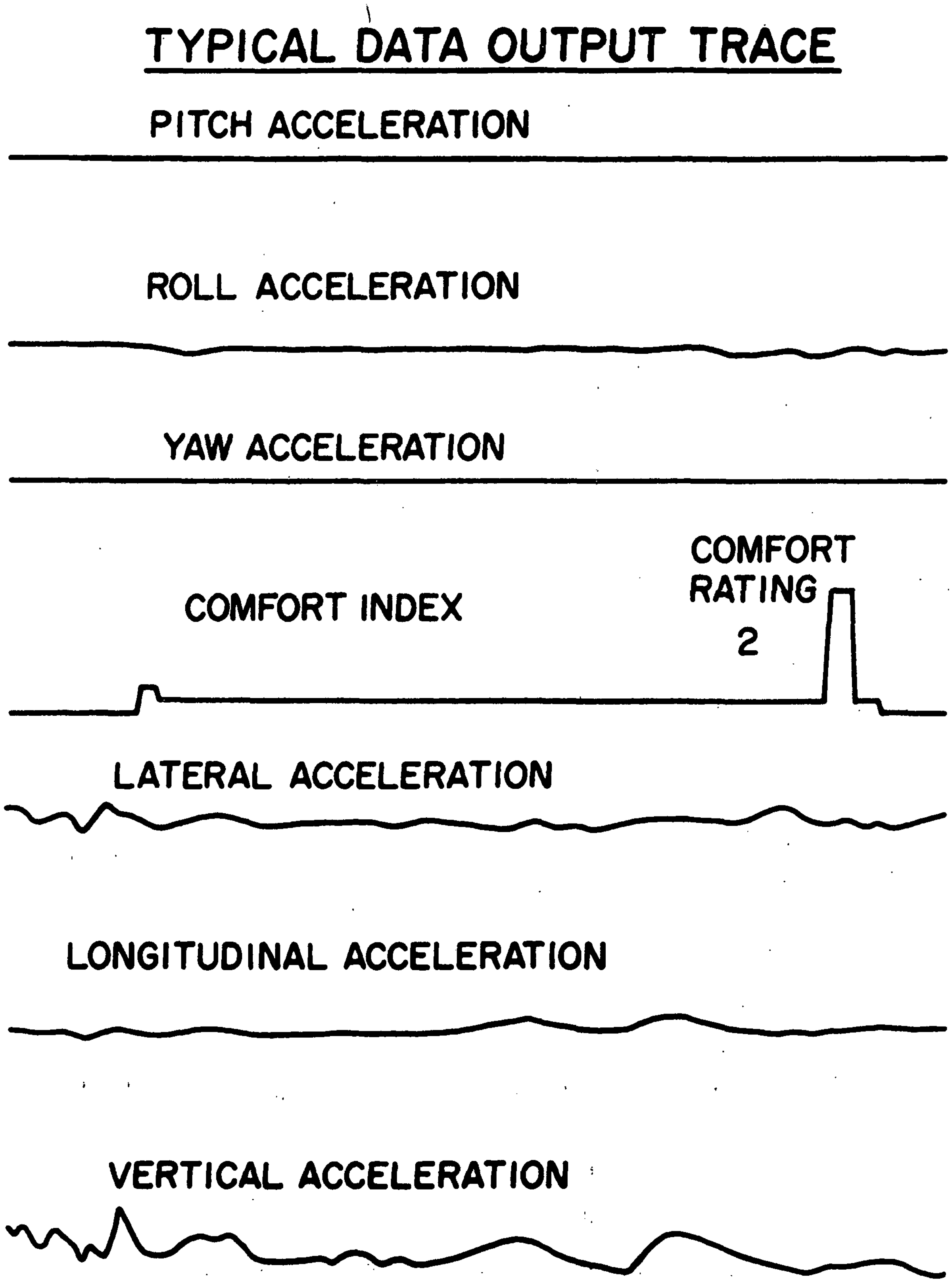

Figure 2. Typical Data Tape

[illegible]
Approval Expires 10-31-78

ALLEGHENY COMMUTER
Operated by Atlantic City Airlines, Inc.

UNIVERSITY OF VIRGINIA

This questionnaire is part of an effort by Atlantic City Airlines, the National Aeronautics and Space Administration, and the University of Virginia to obtain from you, the flying public, information to be used in the improvement of transportation systems. The goal of the program is to identify the needs and desires of airline passengers, so that future systems may increase passenger satisfaction.

Your cooperation in completing this form will be most appreciated and can only be of benefit to you, the air traveler. Thank you, and enjoy your flight.

Maurice C. Young

Maurice C. Young
President, Atlantic City Airlines, Inc.

Please indicate only your first impression on each question. You need not answer any question that offends you.

1. Age ______

2. Sex: ☐ M ☐ F

3. Education:
   - ☐ *High School not completed*
   - ☐ High School completed
   - ☐ College

4. Occupation:
   - ☐ Housewife
   - ☐ Craftsman, Mechanic
   - ☐ Professional, technical
   - ☐ Professional, nontechnical
   - ☐ Student
   - ☐ Armed Forces
   - ☐ Secretary, Clerk
   - ☐ Salesman
   - ☐ Manager, Official, Executive
   - ☐ Other ______________

11. 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	Greatest Importance
Comfort	☐	☐	☐	☐	☐
Convenience	☐	☐	☐	☐	☐
Cost	☐	☐	☐	☐	☐
Reliability	☐	☐	☐	☐	☐
Safety	☐	☐	☐	☐	☐
Time Savings	☐	☐	☐	☐	☐
Ability to Read	☐	☐	☐	☐	☐
Ability to Write	☐	☐	☐	☐	☐
Services on Board	☐	☐	☐	☐	☐
Surroundings	☐	☐	☐	☐	☐

12. Consider the motion you are experiencing. Indicate your reaction to this *motion* by checking the *appropriate* box:
   - ☐ Very Comfortable
   - ☐ Comfortable
   - ☐ Neutral
   - ☐ Uncomfortable
   - ☐ Very Uncomfortable

(Please see last page)

5. Industry of Employment ____________________

6. Approximate Household Income (before taxes):
   - ☐ Under $5,000
   - ☐ $ 5,000-$ 9,999
   - ☐ $10,000-$14,999
   - ☐ $15,000-$19,999
   - ☐ $20,000-$24,999
   - ☐ $25,000-$29,999
   - ☐ $30,000-$34,999
   - ☐ $35,000 or more

7. What is the primary purpose of this trip?
   ☐ Business ☐ Personal ☐ Other

8. How do you feel about flying?
   - ☐ I love flying
   - ☐ I have no strong feelings about flying
   - ☐ I dislike flying
   - ☐ I fly because I have to

9. Approximately how many times have you flown in the past two years?
   - ☐ None, this is my first flight
   - ☐ 1-3
   - ☐ 4-6
   - ☐ 7-9
   - ☐ 10 or more

10. How *important* is each of the following items in *determining* your feelings of comfort? Rank them using the numbers from 1 to 9, with 1 representing the **most important**, and 9 the least important. Please use each number only once.
   - ______Pressure changes (ears pop)
   - ______Noise
   - ______Temperature
   - ______Lighting
   - ______Seat comfort
   - ______Up and down motion (bouncing)
   - ______Side to side motion (rolling)
   - ______Work space and facilities
   - ______Presence of smoke

   Other ____________________

13. How difficult does the motion of this flight make the following activities?

	Not at all Difficult	Slightly Difficult	Difficult	Extremely Difficult	Impossible
Concentration	☐	☐	☐	☐	☐
Reading	☐	☐	☐	☐	☐
Writing	☐	☐	☐	☐	☐
Sleeping	☐	☐	☐	☐	☐

14. After experiencing the motion of this flight, I would: (Check only one)
   - ☐ be eager to take another flight
   - ☐ take another flight (without any doubts)
   - ☐ take another flight (but with some doubts)
   - ☐ prefer not to take another flight
   - ☐ not take another flight

15. Suppose a high-frequency shuttle service (8 or more round trips per day) were available at your local airport, scheduled to connect with flights of over 300 miles from a larger airport some distance away. Would you use the shuttle instead of ground transportation to the larger airport, if the cost were competitive?
   ☐ Yes ☐ No

16. Suppose a 25-passenger prop jet flew from an airport 15 minutes from your home or office to cities within 300 miles. Would you use this service rather than travel to a major airport an hour away?
   ☐ Yes ☐ No

THANK YOU FOR YOUR ASSISTANCE

Figure 3. Passenger Questionnaire

Thus, one must use a test-subject group which can be checked against the general public from time to time and which can then be used extensively in controlled-variable experiments on simulators and under experimental flight conditions. The size and complexion of this group is also a critical cost factor, and since this was the first opportunity to compare test-subject results with those obtained from regular passengers, an analysis of this comparison is of more than passing interest.

A comparison of the composition of the two groups is shown in Figure 4, where data taken from general east-coast travel surveys conducted at airports is also shown. Even though the test-subject group was very small, it was not a bad representation of the particular passenger group encountered. The passengers encountered on the Allegheny flights gave evidence of being oriented much more toward technical or business occupations than was evident in the larger east-coast survey.

Figure 5 shows overall evaluations of the ride by the passengers and the special test subjects, and the crew's evaluation of how they thought the passengers reacted to the ride. On the right-hand side of the figure the results from the normal five-point rating scale are collapsed to a three-point scale, which is felt to be better suited for the purposes of the comparisons. Two principal conclusions can be drawn from this figure. The first is that the flight crew is not a very effective measure for the opinions of passengers. The second is that there is surprisingly good agreement between the response of the special test-subject group and that of the passengers.

This last conclusion is explored in more depth in Figures 6 - 8, where the collapsed scales are now used exclusively. Figure 6 compares the overall

	TOTAL NO.	SEX		AGE				OCCUPATION	
		M	F	20 & UNDER	21–40	41–60	OVER 60	EXEC., MANAGERIAL, PROFESSIONAL, TECH.	OTHER
TEST SUBJECTS	6	6	0	1	5	0	0	6	0
PASSENGERS	431	92%	8%	3%	49%	44%	4%	71%	29%
GENERAL TRAVEL SURVEYS	SEVERAL THOUSAND	75%	25%	12%	40%	35%	13%	60%	40%

	PURPOSE OF TRIP		EDUCATION		MEDIAN INCOME
	BUSINESS	OTHER	COLLEGE	NON-COLLEGE	
TEST SUBJECTS	N.A.	N.A.	6%	0	$16,000
PASSENGERS	85%	15%	85%	15%	$22,500
GENERAL TRAVEL SURVEYS	75%	25%	80%	20%	$22,000

Figure 4. Test Subject-Passenger Compositions

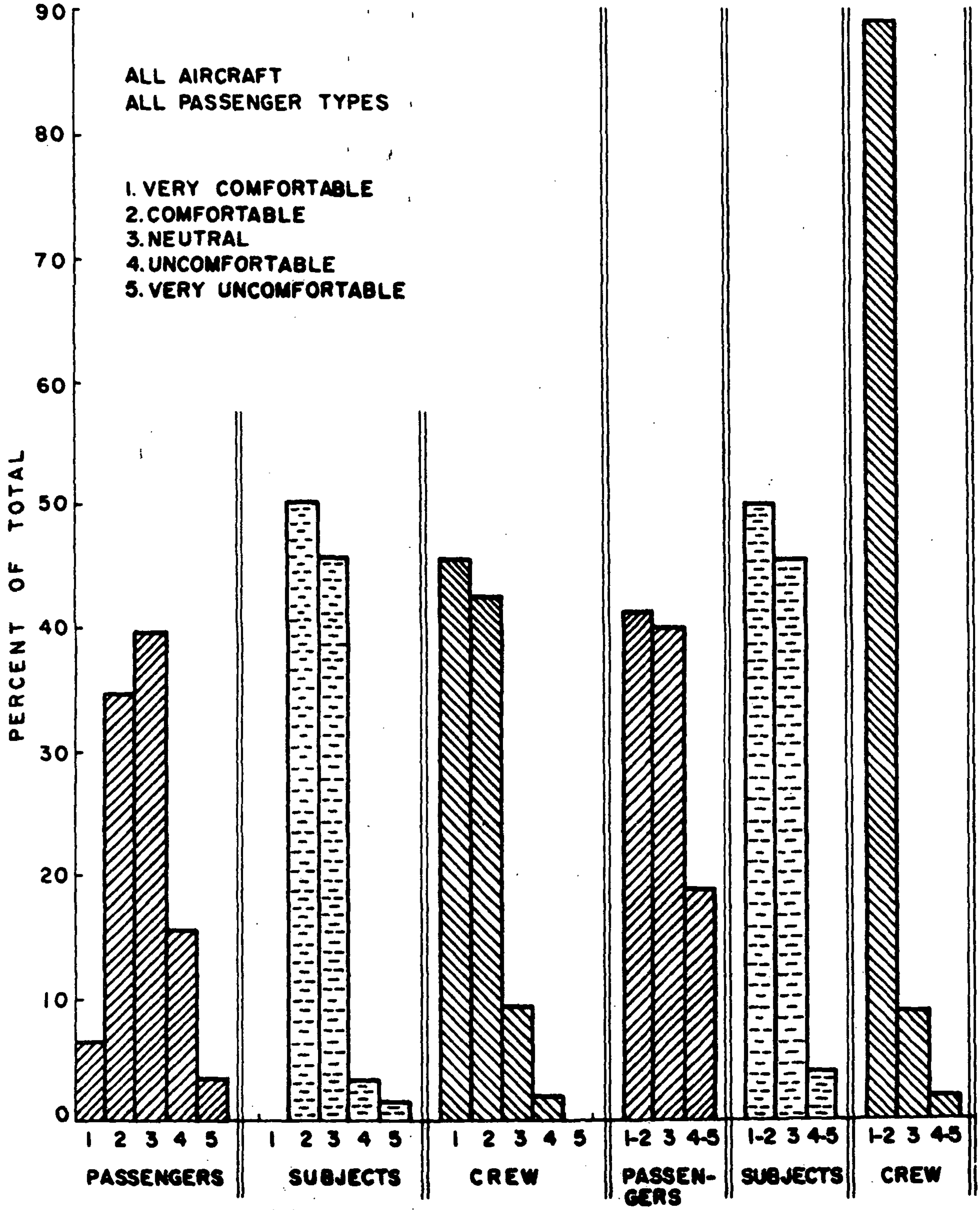

Figure 5. Passenger-Subject-Crew Evaluations--Overall Comfort

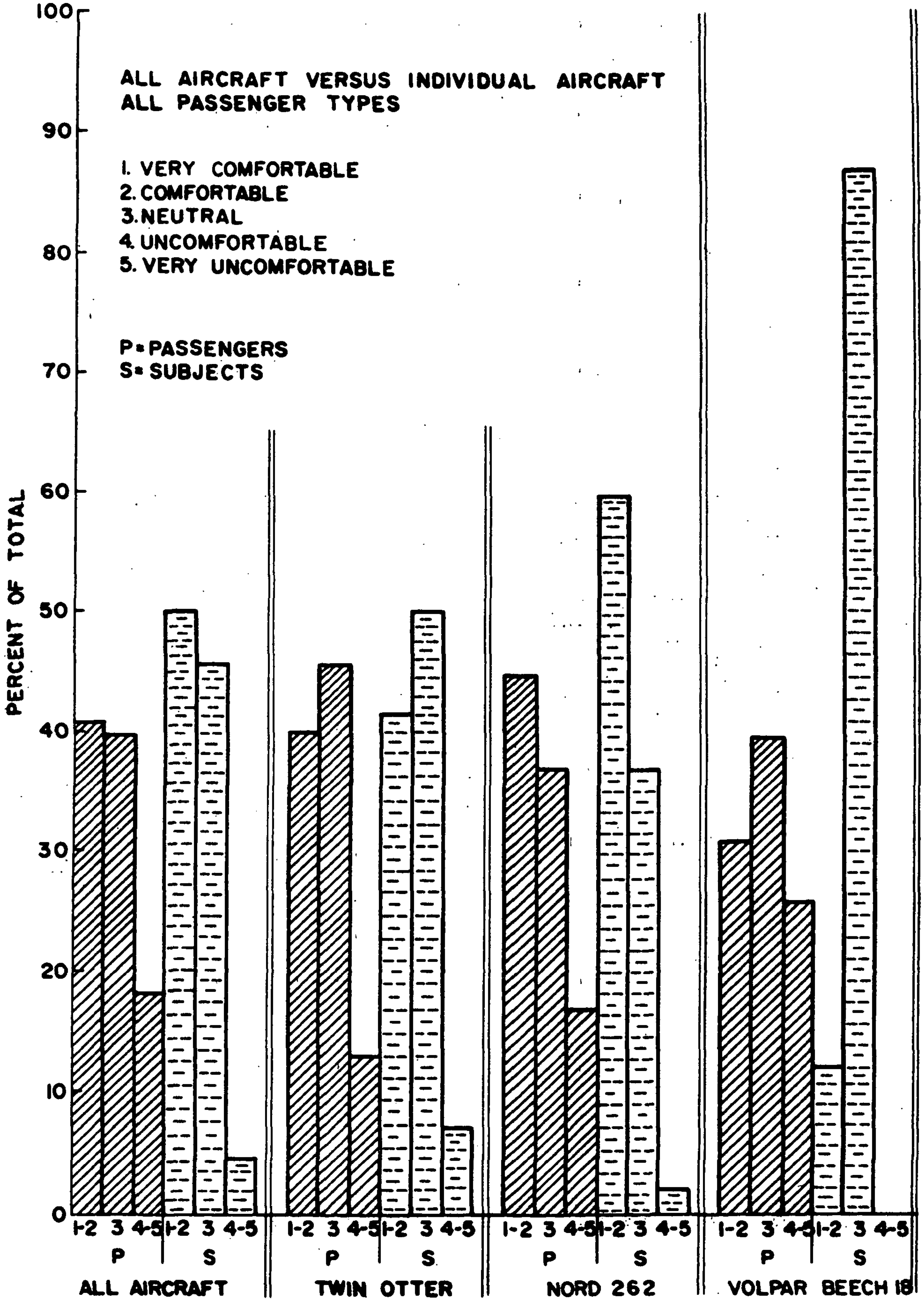

Figure 6. Passenger-Subject Evaluations for Individual Aircraft

reactions from the previous figure with the results obtained from each individual aircraft. The quantity of data obtained on the Volpar Beech 18 is still too sparse to be reliable, but otherwise the differences in comfort ratings observed between aircraft are quite small and statistically insignificant. This figure also exhibits the continued congruence between the passenger and subject reactions.

Figure 7 compares the passenger and test-subject response to questions 12 and 13 of the questionnaire, the first block repeating the data from Figure 5. There is no doubt but that the difficulty in writing and sleeping is greater than that involved in reading or concentrating. The sleeping issue is a bit puzzling and there is evidence to indicate that although in question 13 the passengers were asked to make their judgments solely on the basis of motion, they were influenced by the crowded and uncomfortable seat conditions, and perhaps also by the noise.

The general trend of the relationship between the passenger and subject reactions seems to be preserved. It appears as though the passenger ratings tend to be slightly poorer than those of the test subjects. However, this difference appears to be so consistently uniform that one might conceive of constructing a single transfer function to apply to all test-subject responses to make them statistically representative of the passengers. The other interesting aspect of this apparent similarity between the test subjects and passengers is that the size of the test-subject group is so small. Certainly, these relationships need further study, but if they hold up under scrutiny, this will represent a very important step in reducing the cost of quantitative modeling of the traveling public.

In this regard, comparison with the results obtained from applying statistical theory to select proper sample sizes is of interest. The law

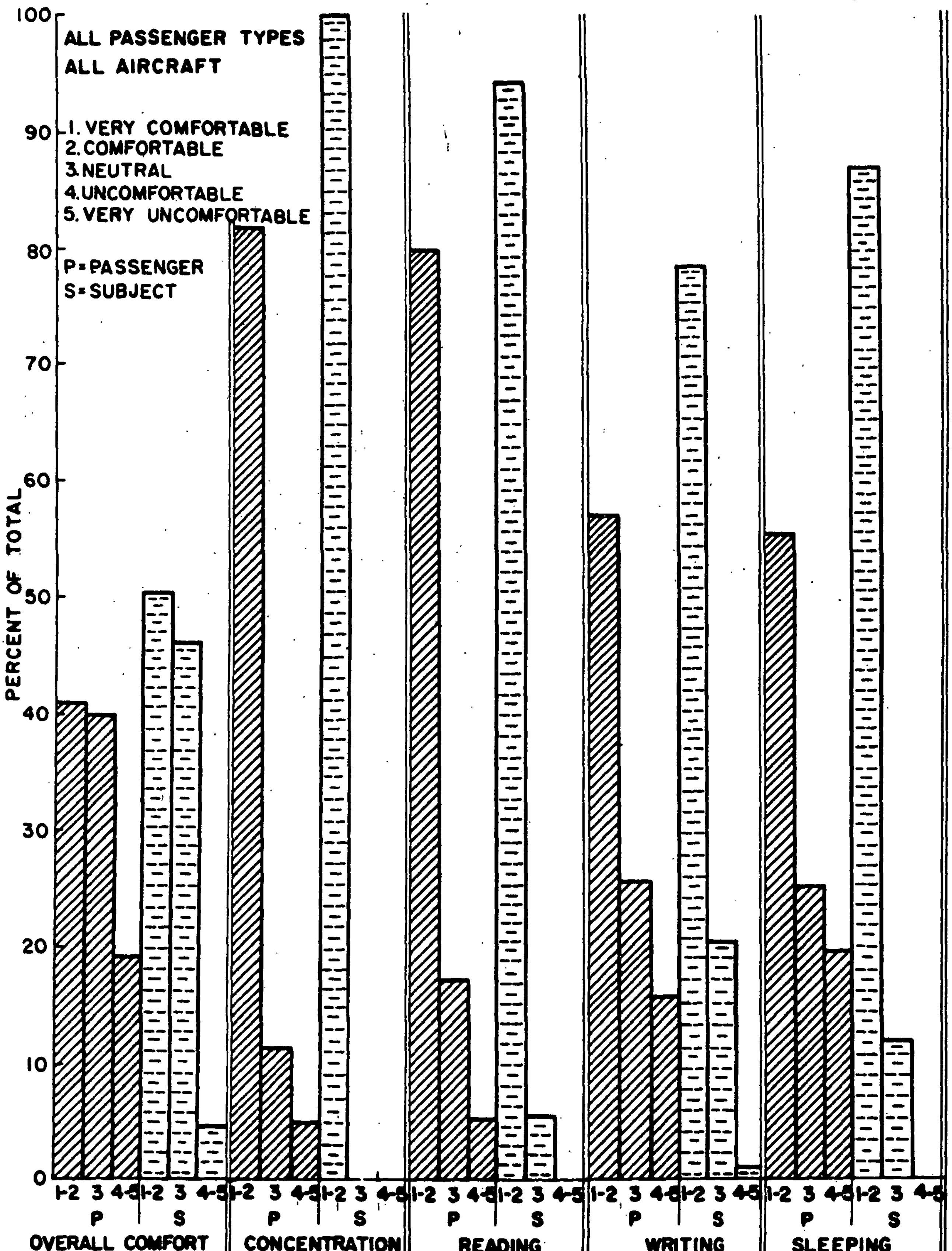

Figure 7. Passenger-Subject Evaluations of Activity

of large numbers predicts that for sufficiently large random samples, the sample average is likely to be near the population average. The central limit theorem then can be used to estimate the probable magnitude of the discrepancy and to determine the sample size necessary for reliable estimates. The calculation requires a value for σ^2, the square of the standard deviation, and when designing test groups in advance, it is necessary to estimate this number. The tendency always is to be conservative. In the case of the current program, a calculation, with the normal conservatism in the choice of σ^2, indicated that to achieve agreement on the average of $\pm\frac{1}{2}$ between the comfort ratings of the special test-subject group and the passengers with a 90% confidence level would require 13 test subjects. Circumstances allowed the use of only six, and a comparison of the ratings in the data presented in Figures 6 and 7 shows that the agreement between test subjects and passengers was indeed well within this limit of $\pm\frac{1}{2}$. In fact, in the case of the overall comfort ratings, the difference in mean values was only .17. This would indicate that the choice of σ^2 was probably too conservative, and indeed a check of the data shows this. Selecting an improved σ, based on the data, indicates that with 6 subjects a confidence level of 82.4% should be expected to get $\pm\frac{1}{2}$ agreement. Thus, it appears as though the theory gives a boost to the concept of a small test-subject group. Furthermore, it is interesting to recall that the test group also violated a general assumption of the analysis--that the sample group was randomly distributed in the population.

In order to probe for the causes of the slight differences between the passenger and subject responses, the passenger data were analyzed in more detail. The results are given on the left side of Figure 8 where the

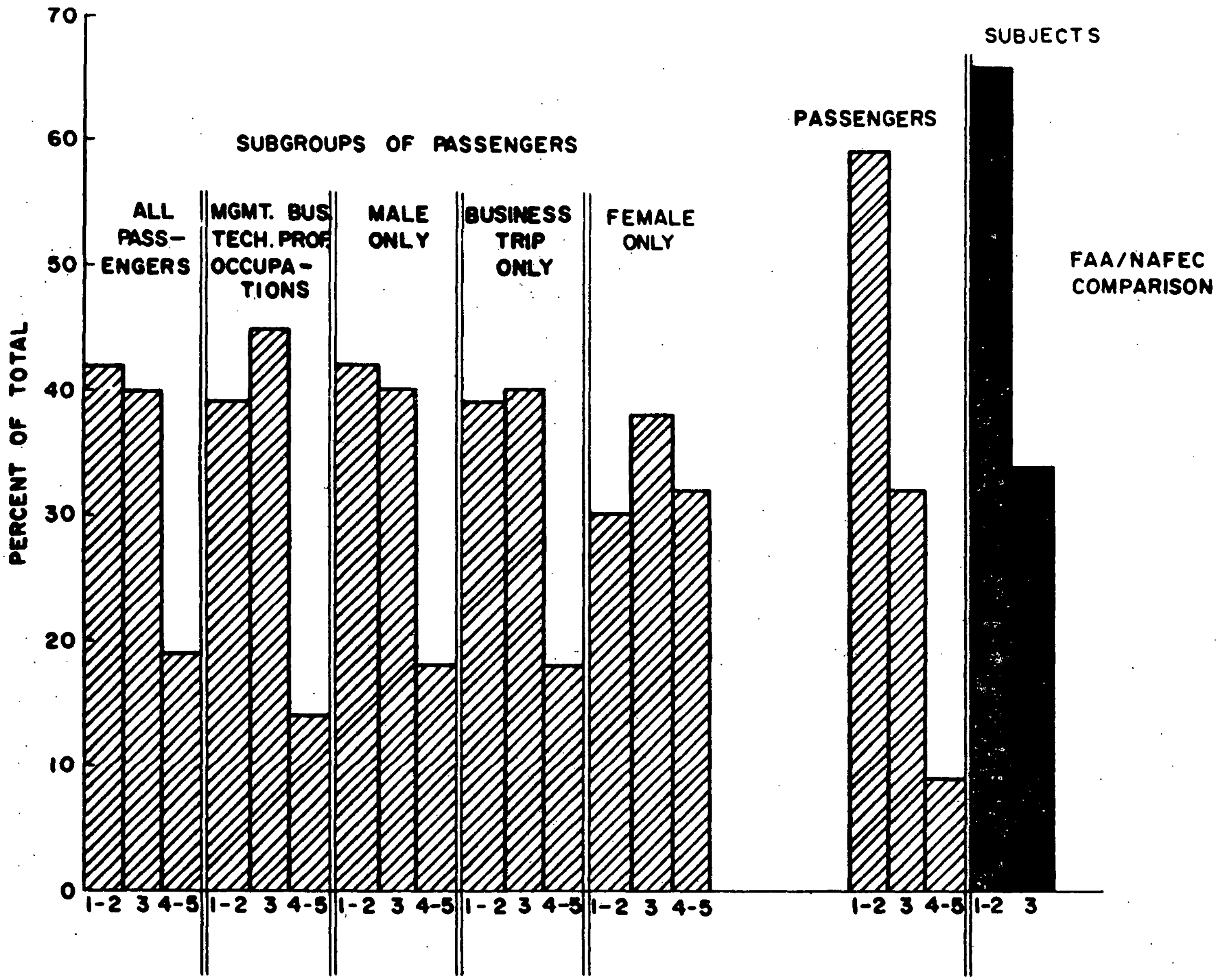

Figure 8. Analysis of Responses of Passenger Subgroups

overall subjective comfort ratings are plotted for various subgroups of the passenger population. They are remarkably similar to the total group except for the relatively small sample of female passengers, who tend to be somewhat more severe in their ranking. Thus the need for heterogeneity in a special test-subject group is uncertain.

The right-hand side of Figure 8 approaches the relationship between the test subjects and passengers from yet another viewpoint. These plots represent overall rating comparisons between our same group of test subjects and the special passenger group of NAFEC employees. The evaluations were done in a Twin Otter, primarily operating in a landing-takeoff mode. The flight conditions were relatively smooth and although both groups rated these flights better than they did the commercial flights, the same comparative similarity exists between the two groups. Once again, the subjects tend to give a slightly better rating than the passengers, and one can well imagine that the same transfer function that would match the responses in Figure 5 would also work here.

General Passenger Attitudes

In designing an air transportation system, it is important to know that you are meeting the needs of the market--or more exactly that you devote adequate attention in your design to those parameters in the system which are considered important by the passengers and prospective passengers. Reference (1) reports the results of a preliminary survey which we made of 165 members of an academic community who were frequent travelers. Included in this survey is the identification of the attitudes and preferences of these individuals relative to various attributes and parameters of air travel.

The data were gathered through questionnaires and interviews administered in the office of the respondent. Similar information was obtained from the passengers aboard the Allegheny Commuter flights--questions 10 and 11 on the questionnaire.

A comparison of the results obtained from question 11 is shown on Figure 9. Although the rank order of the variable is identical, as can also be seen in Figure 10, there is one significant difference. If the data are regarded from the viewpoint of relative groupings of parameters of roughly equivalent importance, it can be seen that comfort has shifted from group 3 (comfort-cost-terminal services in the first survey) to group 2 (time savings-convenience-comfort) in the new survey. We feel that this effect is very real and is illustrative of the type of factors which must be kept in mind when working with both ground-based and flight-based data. The respondent's value judgment changes when he is confronted with making a decision in situ, as opposed to his recollection of his past experiences. The same effect can be seen in looking at the relative importance of pressure changes between flight-based and ground-based responses (see first and last columns of Figure 11). From the point of view of acceptance modeling, or of the actual judgment of the individual in selecting a mode for his next trip, the ground-based response may be the most accurate.

In Figure 10, the data obtained from question 11 is analyzed by comparing subgroupings of the passenger population with the total population, and with the results of the earlier ground-based study. The only major differences are those figures which have been circled. The principal difference is that women and those traveling on personal matters tend to downgrade time-savings.

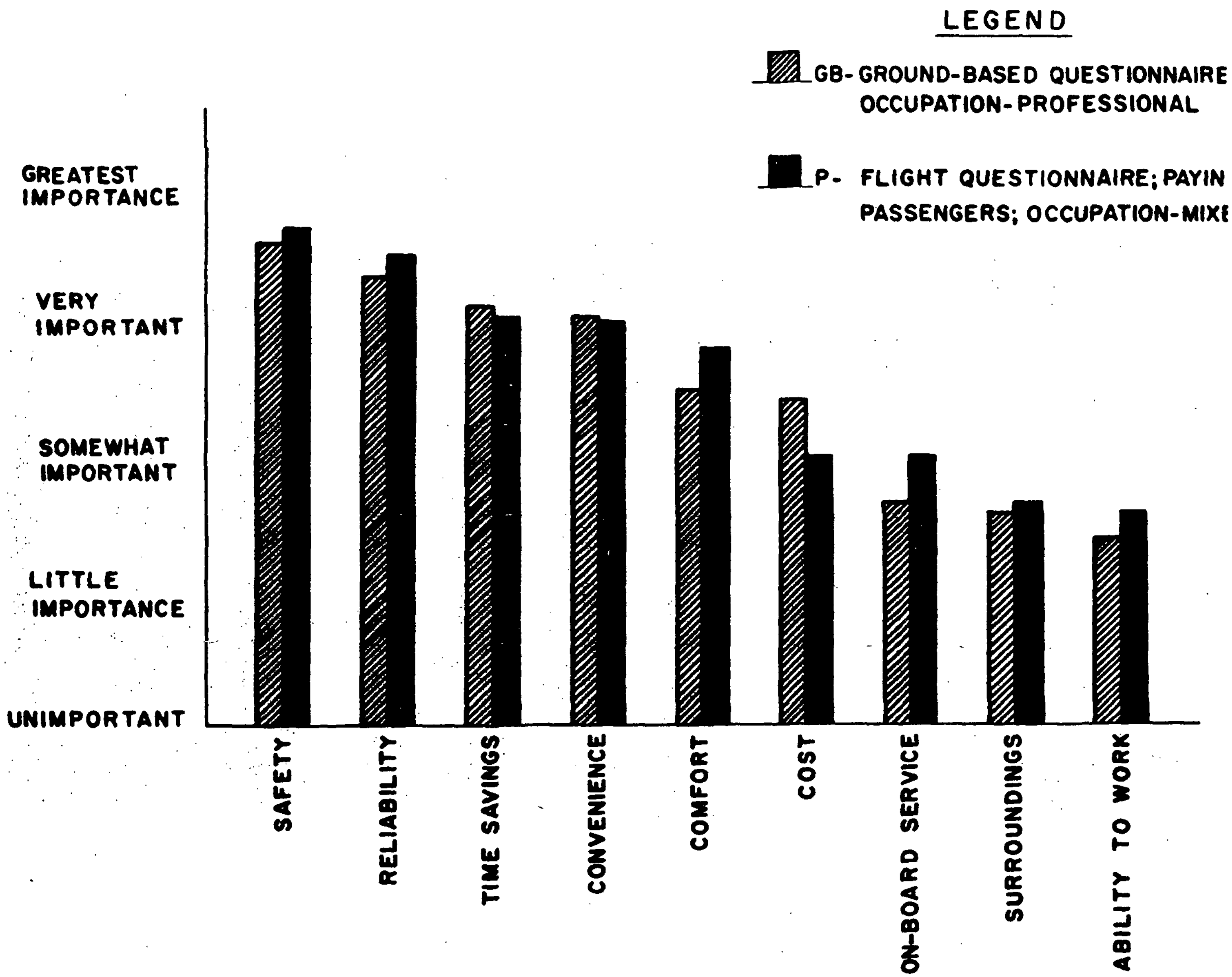

Figure 9. Factors in Air Travel Satisfaction

	Total Sample	Sex		Occupation	Purpose of Trip		Attitude Toward Flying		
	All	Male	Female	Prof,Tech	Bus	Pers	Love to Fly	Fly Because I Have to	Ground Based Survey
SAFETY	1	1	1	1	1	1	1	1	1
RELIABILITY	2	2	2	2	2	2	2	2	2
TIME SAVINGS	3	3	$\boxed{4}$	3	3	$\boxed{5}$	3	3	3
CONVENIENCE	4	4	3	4	4	3	4	4	4
COMFORT	5	5	5	5	5	4	5	5	5
COST	6	6	7	6	6	6	6	6	6
SERVICES ON BOARD	7	7	$\boxed{6}$	7	9	7	7	7	7
ABILITY TO READ	8	8	9	8	8	9	8	8	*
SURROUNDINGS	9	9	$\boxed{8}$	9	$\boxed{7}$	8	9	9	8
ABILITY TO WRITE	10	10	10	10	10	10	10	10	*9

*called ability to work in this survey.

Figure 10. Subgroup Evaluation of Factors in Air Travel Satisfaction

individuals traveling on business appear to place an unusually high ranking on the importance of surroundings and women also seem to be more sensitive to aesthetics.

Figure 11 takes the same approach in looking at some of the factors which contribute to comfort. Here several interesting results are apparent. The aforementioned inclination of ground-based observation to reflect a rather rapid memory decay is again evident. Another factor which emerges is the manner in which the lack of exposure of the passengers to certain variables affects responses. Objections do not arise until the respondent is actually confronted with the situation. The pressure-change discrepancy may have some of this ingredient. The seat-comfort factor seems to indicate that while the desire for a comfortable seat is always high on all lists, it only reaches the top spot (in fact 34% of the respondents ranked this factor first) when the respondent gets in an uncomfortable seat, and then primarily by those who are affected the most; e.g., women, generally of smaller stature than men, relegate seat comfort to second position. Another interesting feature of Figure 11 is the fact that those passengers who generally are not avid fans of flying are very sensitive to up-and-down motion. At the same time, they are not unduly bothered by side-to-side motion. This latter property is not regarded as a significant factor, but rather as an indication that the human being is not particularly adept at identifying and separating the two modes of motion, and hence tends to classify all flight motion as up and down. Additional information about the relative importance of the various motion modes is contained in the next section, where the direct relationships between recorded motion and test-subject responses are presented.

In question 14 the passengers were asked to state their conclusions about taking another flight based on the impressions formed during the current

	Total Sample	Sex		Occupation	Purpose of Trip		Attitude Toward Flying		
	All	Male	Female	Prof,Tech	Bus	Pers	Love to Fly	Fly Because I Have to	Ground Based Survey
SEAT COMFORT	1	1	$\boxed{2}$	1	1	1	1	1	2
NOISE	2	2	1	2	2	3	2	2	3
TEMPERATURE	3	3	3	3	3	2	3	4	$\boxed{1}$
PRESSURE CHANGES	4	4	4	4	4	4	4	5	$\boxed{8}$
UP & DOWN MOTION	5	5	5	5	5	5	5	$\boxed{3}$	4
SIDE TO SIDE MOTION	6	6	6	6	6	6	7	6	5
WORK SPACE	7	7	8	8	7	9	8	7	9
LIGHTING	8	8	7	7	8	7	$\boxed{6}$	9	6
SMOKE	9	9	9	9	9	8	9	8	7

Figure 11. Subgroup Evaluation of Flight Parameters

flight. An overall comparison of their response to this question with their overall comfort rating of the current flight is presented in Figure 12. There is a definite correlation between these factors. One-hundred percent of those people who were very comfortable had no doubts about taking another flight and 94% of those who declared themselves as comfortable would go again. However, only 51% of those who rated themselves as uncomfortable said they would have no doubt about taking another trip, and perhaps even more significant is the 21% and 57% of those who rated the ride uncomfortable and very uncomfortable, respectively, who registered strong doubts. This kind of analysis should prove very useful in establishing ride-quality criteria, as will be illustrated in the concluding section of the paper.

Figure 13 summarizes the effect of comfort on the ability of the passengers to engage in other activities. The first entry repeats some information from Figure 12 on a collapsed scale. The next two entries demonstrate a good correlation between comfort and ability to read and to concentrate. The 41% of the passengers who were comfortable or very comfortable had no difficulty in their activities. Correspondingly, the 18% who were uncomfortable reported that they had great difficulty. The story with writing is somewhat different. One must conclude from the data that it may indeed be difficult to write even though one is comfortable.

Certainly the importance of comfort in ride quality is clearly indicated by the responses presented in this section.

Modeling

There are many approaches to developing mathematical models to relate the observed motion components to the test-subject responses. These run

	EAGER	NO DOUBT	SOME DOUBT	PREFER NOT	NEVER
VERY COMFORTABLE	75	25	0	0	0
COMFORTABLE	22	72	5	1	0
NEUTRAL	5	75	12	8	0
UNCOMFORTABLE	3	48	28	18	3
VERY UNCOMFORTABLE	0	14	29	36	21

Figure 12. Effect of Comfort on Desire to Take Another Flight

	PERCENT
VERY COMFORTABLE, COMFORTABLE, NEUTRAL	81.2
EAGER, WITHOUT DOUBTS	79.3
VERY COMFORTABLE, COMFORTABLE	41.3
ABILITY TO CONCENTRATE (NO DIFFICULTY)	53
ABILITY TO READ (NO DIFFICULTY)	40.8
UNCOMFORTABLE, VERY UNCOMFORTABLE	18.4
ABILITY TO CONCENTRATE (DIFFICULT, VERY DIFFICULT, IMPOSSIBLE)	17.0
ABILITY TO READ (DIFFICULT, VERY DIFFICULT, IMPOSSIBLE)	20.1
VERY COMFORTABLE, COMFORTABLE	41.3
ABILITY TO WRITE (NO DIFFICULTY)	24.2

Figure 13. Effect of Comfort on Passenger Activities

the gamut from a simple linear model, where the frequency content of the motion is averaged in a gross manner, to very sophisticated approaches to determining nonlinearities and the effects of the frequency spectrum. As the degree of sophistication increases, so does the requirement for the amount of data to calibrate the model.

Thus, although working with two fundamental approaches to modeling, most of the analysis to date has only dealt with the simpler approximations of the models. Nevertheless, these have been quite fruitful. We are steadily accumulating the mass of data required for a more detailed analysis. Briefly, the two models upon which we are concentrating our effort at present are as follows. In the first approach, representing an extension of work done by Van Deusen (5), only the rms value of each motion component is considered during each sampling period. In the second approach, we have introduced frequency by dividing the frequency spectrum of each motion component into discrete frequency bands of arbitrary size.

Accelerations are used to describe the motions and in the rms approach, the comfort, C, of the passenger is related to the rms accelerations and their cross correlations by

$$C = C_o + \sum_{j=1}^{6} \alpha_j \, \bar{a}_j^{\,\nu_j} + \sum_{j=1}^{6} \sum_{i=j+1}^{6} \beta_{ij} \, \bar{b}_{ij}^{\,\mu_{ij}}$$

where

$$\bar{a}_j = \sqrt{\frac{1}{T} \int_0^T a_j^2 (t) \, dt}$$

are rms accelerations in the vertical, transverse, longitudinal, pitch, roll, and yaw directions, and

$$\bar{b}_{ij} = \sqrt{\frac{1}{T} \int_0^T a_i\ (t)\ a_j\ (t)\ dt} \qquad i \neq j$$

are the cross correlations of each variable with all others. The α_j's and β_{ij}'s are weighting factors, and the ν_j's and μ_{ij}'s are scaling exponents. A physical interpretation of the model is to consider the α's and β's as sensitivities of the human subject to the different directions of acceleration, and the scaling exponents as representative of the nonlinearity of the human sensor.

The frequency sensitive model gives rise to the equation

$$C = C_o + \sum_{i=1}^{6} \sum_{\Delta f=1}^{N} K_{i,\Delta f}\ \bar{a}_{i,\Delta f}^{\varepsilon_{i,\Delta f}} + \sum_{i=1}^{6} \sum_{j=i+1}^{6} \sum_{\Delta f=1}^{N} \Lambda_{i,j,\Delta f}\ \bar{b}_{i,j,\Delta f}^{\eta_{i,j,\Delta f}}$$

where as before the K's and Λ's are weighting factors, ε's and η's nonlinearities; $\bar{a}$ the rms value for each degree of freedom i, and $\bar{b}$ the correlation coefficient for each pair of directions are subdivided into frequency bands, Δf. Additional thoughts on modeling can be found in references (2) and (3).

A linear model has many useful features and properties, so it is natural to use it first when looking at a new set of data. Thus restricting the first approach to a linear presentation, discarding cross-correlation terms, and using the data from the first flight-test programs (YS-11, F-227, and B-737 aircraft), the following model resulted:

$$C = 1.85 + 11.5\bar{a}_{vert} + 5.7\bar{a}_{trans} + 1.0\bar{a}_{long} + 0.2\bar{a}_{pitch} + 0.2\bar{a}_{roll} + 1.5\bar{a}_{yaw}$$

where the linear accelerations have the units of "g's" and the angular accelerations, rad/sec^2.

Since there is a relationship between the value of the coefficients and the amount of the particular acceleration present, it is necessary to look at the total contribution of each term to the value of C in order to interpret this model. On the average, these contributions are as follows:

vert	0.9	yaw	0.13
trans	0.15	roll	0.06
long	0.01	pitch	0.02

Thus, the vertical motion can definitely be established as the most important by far in these flight situations.

The inclusion of nonlinear effects and cross-correlation terms using these same data from the first flight-test program is currently underway. The indications, as far as nonlinearities are concerned, are that an improved fit can be obtained by dropping the longitudinal term (these motions are essentially negligible in the aircraft), and adding an additional term in the square root of the rms vertical acceleration. A significant cross-correlation effect between the transverse and vertical acceleration is observed. The term has a negative coefficient, the net result of the inclusion means that the comfort index for a given motion will tend to be lower than the values that would have been predicted by the simple model. However, the influence is somewhat complex as the term also has the effect of altering the coefficients of the individual acceleration terms.

The data from the Allegheny Commuter flights are now in the process of being modeled in a manner similar to the above. Although the process is by no means complete, some results are in hand and they are most interesting. The logical question was whether or not the same model would apply? There was some reason to hope that it might, because an examination of the data from the first flight-test program by individual aircraft did not lead to large discrepancies from the overall model. However, upon introducing select data points from the second flight-test series into the model, it was discovered that the calculated values of C agreed well with the observed values except when there was a large transverse component. In these cases, the model was consistently low in its prediction. The first models constructed from the data by the usual regression analysis techniques confirmed this fact, predicting average relative contributions of the terms as follows:

vert	0.35
trans	0.40
roll	0.20

where sufficient data does not yet exist to evaluate the other coefficients with confidence. Hence, at the present time all that can be inferred quantitatively is that the transverse motion has a much greater influence on ride comfort in this series of flights involving light aircraft than was previously evident when larger vehicles were used.

Applications

The comfort model, as ultimately deduced, will have several useful applications. First of all, it will be used to evaluate the comfort component of the overall demand model, as applied to the characteristics of a given system. It can also be used by the airlines, or the air traffic controller, to estimate the effect on comfort of various turns and maneuvers introduced in approach patterns or flight trajectories. Finally, it can be used by the aircraft designer to establish criteria for the specification of ride-smoothing systems of a new or improved design. The following simple example will illustrate this application.

An examination of flight records of the aircraft on which we have flown shows that the atmospheric characteristics and the normal control characteristics of these aircraft are such that (when taken together) motions in the longitudinal, roll, pitch, and yaw modes are all small contributors to discomfort relative to motions encountered in the vertical and transverse directions. The problem then is to smooth the aircraft motion in these latter two directions by the incorporation of additional control equipment. The degree of improvement necessary to insure passenger comfort is a critical factor since the cost of the control system will be strongly dependent on it. Thus, criteria for motion limits acceptable to passengers are very important.

The solution to this problem can be found from the model representations presented in the last section, used in conjunction with the response data obtained from the passenger. For simplicity, a linear model is used, and as a first approximation appropriate values can be selected for the pitch, yaw, roll, and longitudinal amplitudes based on the analyses of flight data. As an example, taking values from our experimental flight program such that the actual amplitudes are less than these values 90% of the time, and eliminating them from the model equation, a single equation relating the transverse acceleration, $\bar{a}_T$, and the vertical acceleration, $\bar{a}_V$, is obtained.

$$\bar{a}_V + 0.5\bar{a}_T = 0.087C - 0.238$$

The value of C which is pertinent in this application is one which will produce a ride judged as satisfactory by the passengers. The information contained in Figure 12 can be used to provide guidance in the choice of C. For example, this tells us that if C = 4, then a ride could result which will satisfy only 51% of the passengers. On the other hand, a choice of C = 3 will provide a satisfactory ride to 80% of the passengers. Figure 14 shows a plot of this design equation for three values of C. Others could, of course, be added, if desired, and the percentages of satisfied customers estimated from the data of Figure 12. The reader is cautioned that because of the conservative estimates placed on the pitch, roll, yaw, and longitudinal accelerations, a lower bound on C exists (for the 90th percentile taken above, it is approximately 2.7). Obviously, the present sample is small, and the source of data is restricted to a small number of aircraft. However, as the amount of data accumulates, this approach should yield a very reliable estimate of anticipated public satisfaction with ride quality.

Returning to Figure 14, the designer thus needs to make provision for maintaining aircraft motion below the selected limiting line, for a percentage of the flight time selected in conjunction with a study of normal frequency of encounter records, to keep excursions above the line few in number over the stage length of the flight.

Incidently, in this regard, it is interesting to note that a careful analysis of the relationship between the comfort evaluations made by the special test subjects during each rating interval, and their subsequent overall ratings of the total flight, shows that they are in excellent agreement. In fact, if the individual interval ratings are averaged over the entire trip, these averages are within 0.5 of the overall ratings 86% of the time. Thus,

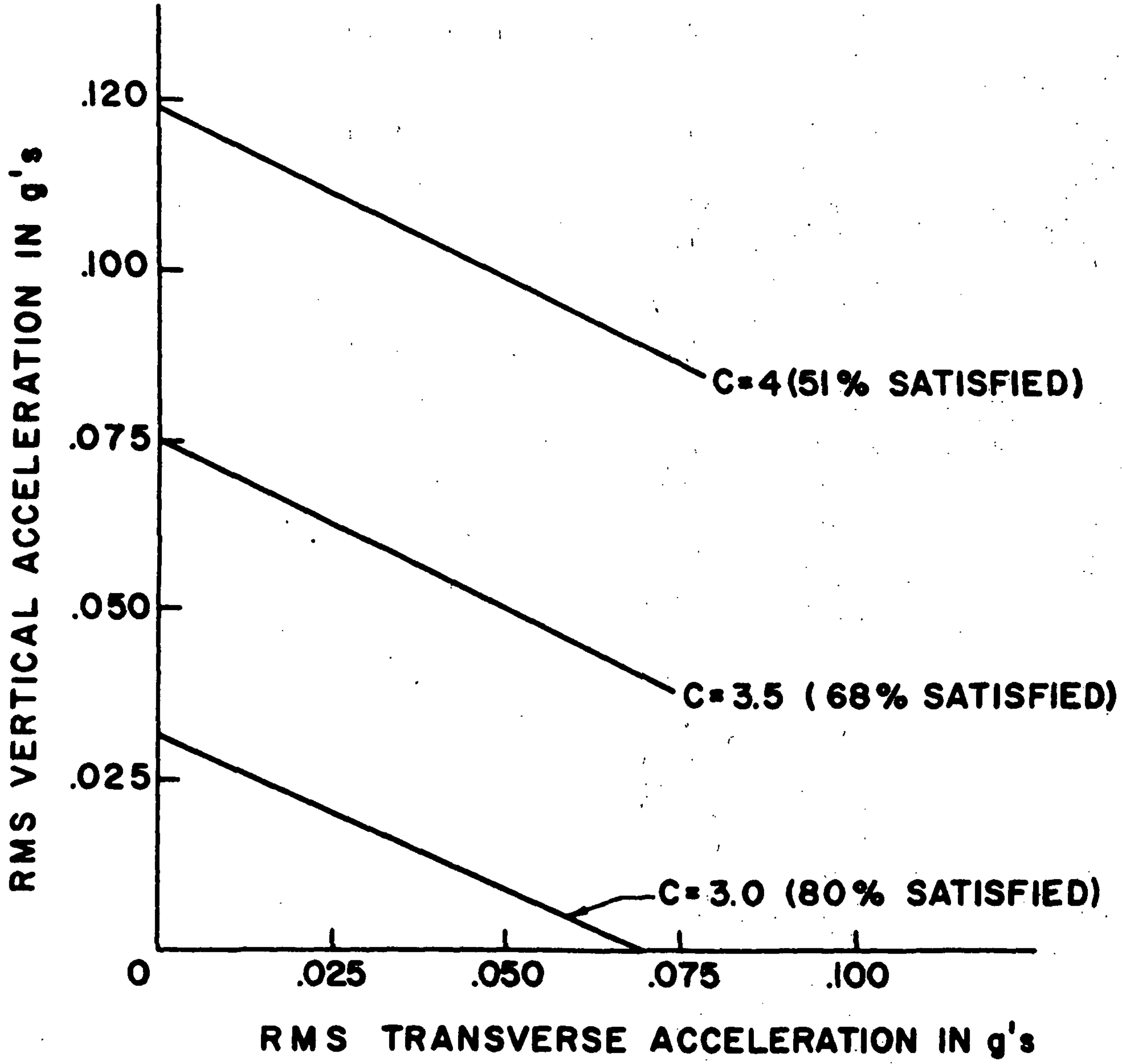

Figure 14. Design Criteria for Relationship Between Vertical and Transverse Motion

although the model was calibrated on the basis of the data from these individual rating intervals, the confidence level for conclusions drawn from it for overall flight conditions should be high.

Conclusions

Previous work in the development of quantitative models for the prediction of passenger reaction to motion and vehicle environment parameters in flight has been extended to include a class of aircraft appropriate for low-density, short-haul service. For the first time, it has been possible to correlate the model development and application with direct responses from the passengers. The results of these studies indicate that apparently it may be possible to obtain quantitative response inputs from an usually small special test-subject group which will be representative of the general traveling public. Additional data which indicate the importance of comfort as a factor in evaluating ride quality has been obtained, and identification of the factors which contribute to judgments regarding comfort level has been improved. In this regard, seat comfort and seat spacing is very vital in the smaller aircraft. Finally, mathematical modeling applied in conjunction with passenger reaction data has been shown to be very useful for establishing ride-quality design criteria.

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