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NONMOTION FACTORS WHICH CAN AFFECT RIDE QUALITY

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SUMMARY

Data pertaining to nonmotion factors affecting ride quality of transport aircraft have been obtained as part of NASA in-house and sponsored research studies carried out onboard commuter-airline and research aircraft. From these data, quantitative effects on passenger discomfort of seat width, seat legroom, change in cabin pressure, and cabin noise are presented. Visual cue effects are also discussed.

INTRODUCTION

Ride quality can be defined as the impact on the passenger of all aspects of the carrier-vehicle physical environment that affect his acceptance of the ride. Within this definition, environmental factors other than motion and vibration would be included. These other factors are the subject of this paper. Surveys of travelers using a given mode of transportation are useful in identifying the importance of various environmental factors. Abridged results from one British survey (ref. 1) are shown in figure 1. In this survey, travelers were asked to rank in preference 18 suggested improvements for railway coaches. The 18 improvements covered a variety of items ranging from Extra entertainment to More luggage space. In the cumulative order of preference, four of the top five suggested improvements concerned ride quality: Less vibration, More space, Less noise, and Better seats. These results are typical of survey findings for other modes of transportation (refs. 2 and 3), where various ride-quality factors rank high in importance from the traveler's viewpoint.

Some new information pertaining to nonmotion factors affecting ride quality of aircraft has been obtained as part of NASA in-house and sponsored research studies carried out onboard airline and research aircraft. No attempt was made in these studies to determine systematically the effects of varying specific nonmotion factors on ride quality. Data which will be presented were only incidentally obtained and therefore are of limited scope. A brief overview will first be given of the airline traveler surveys from which much of the data originated to provide a proper background for subsequent discussion of individual factors.

AIRLINE TRAVELER SURVEYS

Small transport aircraft used by feeder lines and commuter lines can provide much valuable ride-quality information because a significant percentage of travelers often rate their ride as marginal at best. Lack of good ride quality is associated with a lack (by economic constraints) of features and characteristics common to the much larger and heavier jet transports. Four such small commuter aircraft, shown in figure 2, were the subject of recent ride quality studies (ref. 4) carried out by the University of Virginia under NASA grant. The aircraft include the 19-passenger De Havilland of Canada DHC-6 twin-engine turboprop, commonly known as the Twin Otter; the 26-passenger Aerospatiale Nord 262 twin-engine turboprop; the 13-passenger Beech 99 twin-engine turboprop; and the 26-passenger Sikorsky S-61 helicopter. Each of the aircraft was used by a different airline; hence, operating conditions differed somewhat between aircraft. All operations took place, however, in the north-eastern part of the United States.

Table I provides an overall summary of traveler survey information. More than 800 travelers participated. Trip time ranged between 20 and 60 minutes for the three fixed-wing aircraft and between 7 and 10 minutes for the helicopter. Near the end of the trip the passengers rated the overall trip ride on a 7-point (undefined) descriptor scale ranging from Very uncomfortable to Very comfortable. The ride was given some form of uncomfortable (Somewhat uncomfortable, Uncomfortable, or Very uncomfortable) rating by slightly more than 30 percent of the passengers riding in each of the three fixed-wing aircraft and by 12 percent of the passengers riding in the helicopter. The relatively low percentage of helicopter passengers who expressed discomfort may have resulted from the relatively brief time of the trip. On the basis of general observations of passenger reactions to riding helicopters, an increase in trip time to 30 or 40 minutes could well result in a greater percentage of passengers who would be uncomfortable. In addition to obtaining the passengers' assessment of the overall trip ride quality, the investigators obtained passengers' opinions concerning their satisfaction with various motion and nonmotion factors believed to affect ride comfort. Some of the nonmotion factors identified as significant are discussed in the following section. A complete discussion of all factors is given in reference 5.

EFFECTS OF NONMOTION FACTORS

Seat Width

In small aircraft, constraints on interior volume and the economic need to accommodate as many passengers as safety will allow limit the width of seats to a value considerably less than that normally used in larger aircraft and in other public transport vehicles. Figure 3 presents in bar graph form the percentage of passengers expressing dissatisfaction with the width of the seats for each of the four aircraft of the survey. Values range from 39 percent to

67 percent. Also shown in each bar graph is the percentage of passengers that indicated strong feelings about seat-width discomfort. Strong feelings were expressed by less than one-fourth of those giving a discomfort rating to seat width.

Seat width differed between types of aircraft. In the lower part of figure 3 is presented the variation of percent passengers dissatisfied as a function of measured seat width. The data indicate a linear relationship, which, if extrapolated to zero dissatisfaction, indicates that seats ideally should be about 60 cm wide. Although seat shape and firmness differed between aircraft, questionnaire answers revealed that the great majority of passengers considered shape and firmness characteristics of these seats to be satisfactory.

Legroom and Workspace

In addition to width, there are other factors in seating which can affect ride comfort to some extent. In tourist-class sections of conventional-size jet transports, each seat row generally consists of a group of three seats on each side of the aisle. Although seat width may be ample, a passenger sitting in the center seat, when both adjacent seats are occupied, has little freedom of movement, particularly if a task, such as eating a meal, is being performed. Also, both reduced floor width for window-seat passengers adjacent to an incurving fuselage shell and insufficient seat pitch (fore-and-aft spacing) will tend to limit passenger leg movement, which in turn can adversely affect ride comfort, particularly for long trips.

Figure 4 presents in bar graph form the percentage of passengers expressing dissatisfaction with the amount of legroom. Values range from 63 to 73 percent for the fixed-wing aircraft and 28 percent for the helicopter. Of those expressing discomfort, up to 40 percent indicated strong feelings. In the lower part of figure 4 is presented the variation of percent passengers dissatisfied as a function of legroom measured from the front edge of the seat. A nonlinear relationship is indicated, with rapid reduction in dissatisfaction as the legroom is increased beyond 24 cm. Extrapolation of the results indicates that a legroom of about 28 cm should be satisfactory to practically all passengers.

In the survey, passengers were also queried about adequacy of workspace (which may be inferred to include both side-to-side and fore-and-aft space in front of the passenger). Responses were very similar to those for legroom, with values for percent uncomfortable ranging from 66 to 81 percent for the fixed-wing aircraft and 43 percent for the helicopter.

Change In Cabin Pressure

The rate of change of cabin pressure which occurs in aircraft depends on how the aircraft is operated and whether or not the cabin is pressurized. Smaller transports oftentimes are not pressurized, and, except for the Nord

262, this is true for the four aircraft of the survey. Terminal-area maneuvers used to minimize time and costs for short-haul operations generally involve rates of climb and descent which change cabin altitude (pressure) at a far greater rate than recommended. Such was the case for the aircraft surveyed, as shown in figure 5. At the top of the figure is presented in bar graph form the percent passengers dissatisfied for each aircraft. Values range from 26 to 60 percent.

Measured rates of change of altitude or pressure are not available for the four aircraft surveyed but are available from another study utilizing the U. S. Air Force Total In-Flight Simulator (TIFS) research aircraft. In this study, also reported in the present compilation (ref. 6), the effect of various flight maneuvers on ride quality was determined. During the course of the study, written comments incidentally offered by the test subjects for certain maneuvers oftentimes indicated discomfort due to change in cabin pressure. Data for 423 test-subject—maneuver situations are available and have arbitrarily been divided into 5 groups with each group covering a specific, nonoverlapping range of rate of change in cabin altitude. Within each group the percent of passengers offering comments of dissatisfaction was determined and the results are presented in the lower part of figure 5 as a function of rate of change of cabin altitude. At rates from zero to 150 meters per minute, no dissatisfaction was expressed. Dissatisfaction was first evidenced by a small percentage of passengers in the range of rates between 250 and 350 meters per minute and then increased almost linearly to more than 50 percent dissatisfied when the rate of change of cabin altitude was between 850 and 1100 meters per minute. Although a direct relation between these data and the airline survey data cannot be established, the trends shown in figure 5 certainly indicate that all four aircraft must have engaged in rather rapid rates of change of altitude during some portion of their journeys.

Cabin Noise

Passenger surveys indicate cabin noise to be a common source of discomfort for various air, surface, and marine forms of public transportation. Even in large jet transports the noise level can be quite low near the front of the aircraft but can be uncomfortably high near the rear. The four commuter aircraft of the airline survey were no exceptions, as can be seen by the bar graphs presented in figure 6 for percent passengers expressing discomfort from cabin noise. Discomfort levels ranged between 60 and 70 percent for all four aircraft, with 10 to 25 percent feeling strongly. The discomfort results from a noise environment which varies during the trip as the aircraft climbs, cruises, and descends to landing. No attempt has yet been made to equate cabin noise dissatisfaction from this survey with measured noise environment.

Limited information is available, however, concerning effects of cabin noise level on passenger comfort rating. A brief in-house flight study was recently carried out on a Boeing 737 airplane at Langley Research Center. In the study 13 passenger subjects rated their comfort associated with noise and vibration during 1-minute segments of straight and level flight. A range of vibration and noise levels was obtained by varying aircraft thrust, forward speed, and position of the landing gear and drag brakes. Figure 7 presents the variation of average rating of comfort with cabin noise level for a constant (vertical) vibration condition of 0.047g. Comfort rating was indicated by the test subjects on a 5-point scale, with 1 as Comfortable and 5 as Uncomfortable. The data showed a reasonably consistent trend, with average comfort rating increasing from a value of 1 to 4 as noise level in the cabin increased by about 15 dB(A).

The interrelated effects of noise and vibration, however, were not clearly established during the study. This was particularly true when noise level was maintained constant and vibration level was allowed to vary. Much more research is required to establish quantitatively the contributions of noise to passenger discomfort in combined environment situations. Such information is needed since likely candidate concepts of advanced transports (large civil helicopters, powered-lift jet aircraft, etc.) may well have significantly high levels of interior noise in combination with other worrisome environmental inputs. In a paper presented earlier in this compilation (ref. 7), Stephens describes the magnitude of the problem and suggests areas for future research.

Visual Cue Effects

Another factor which can affect passenger ride comfort is the presence or absence of visual cues from outside the vehicle. Most vehicles are equipped with windows for various reasons, some of which are psychological (e.g., to minimize claustrophobia). Although quantitative information regarding visual cue effects on ride comfort is lacking, several observations made during recent ride-quality investigations are worth mentioning. For random-motion ride environments, presence of a window adjacent to the seat appears to have a slightly favorable effect on comfort as observed in preliminary checkout studies of a helicopter to be used for ride-quality research (ref. 8). If an aircraft carries out tight turns at a relatively low altitude, however, an unfavorable effect can result because of the passenger's natural instinct to turn the head simultaneously to look out the window at the rapidly changing visual scene. The resulting change in force vector on the vestibular organs produces a discomfort sensation which can be significant if head motion is rapid. Another unfavorable visual cue situation results from flickering light due to interruption of sunlight by the rotor blades. This situation occurred during the helicopter checkout studies cited above. Only a small percentage (<10 percent) of passengers are generally affected, but the effects can be quite severe. Light flicker at appropriate frequencies can even lead to seizures by persons prone to epilepsy. Fortunately, light flicker can be minimized by darkening light-reflecting surfaces and by tinting the windows.

CONCLUDING REMARKS

For various modes of travel by air, surface, and water, passenger surveys have identified nonmotion factors as important contributors to ride discomfort.

Ride-quality information has been obtained for such factors in passenger studies onboard four types of commuter aircraft. Considerable discomfort was specifically identified for seat width, legroom, and workspace and was quantitatively related in terms of percent passengers dissatisfied as a function of pertinent dimensions. A significant percentage of passengers were dissatisfied with excessive rate of change of cabin altitude (pressure). In a separate study using a research aircraft, percent of passengers dissatisfied was quantitatively related to rate of change of cabin altitude. In the commuter aircraft, a majority of passengers were also dissatisfied with the cabin noise levels. Preliminary exploration in a jet transport indicated that although passenger comfort rating could generally be related to noise level, the combined effects on comfort of noise, vibration, and other factors are complex, and much research is required to better understand and quantify contributions of individual factors to overall passenger discomfort in combined-environment situations. Visual cue effects by passengers sitting adjacent to windows were indicated to affect ride comfort unfavorably for two situations which could occur in transport aircraft.

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TABLE I.- TRAVELER SURVEY SUMMARY BY AIRCRAFT TYPE

AIRCRAFT	DHC-6	N-262	B-99	S-61
TRAVELERS SURVEYED (Total Number)	200	156	133	339
AVERAGE TRIP TIME (Minutes)	20-25	35	25-60	7-10
UNCOMFORTABLE TRIP RIDE (Percent Passengers)	33	31	31	12

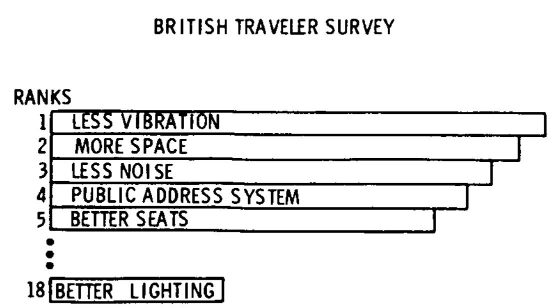

Figure 1.- Preferred improvements for railway coaches from British traveler survey.

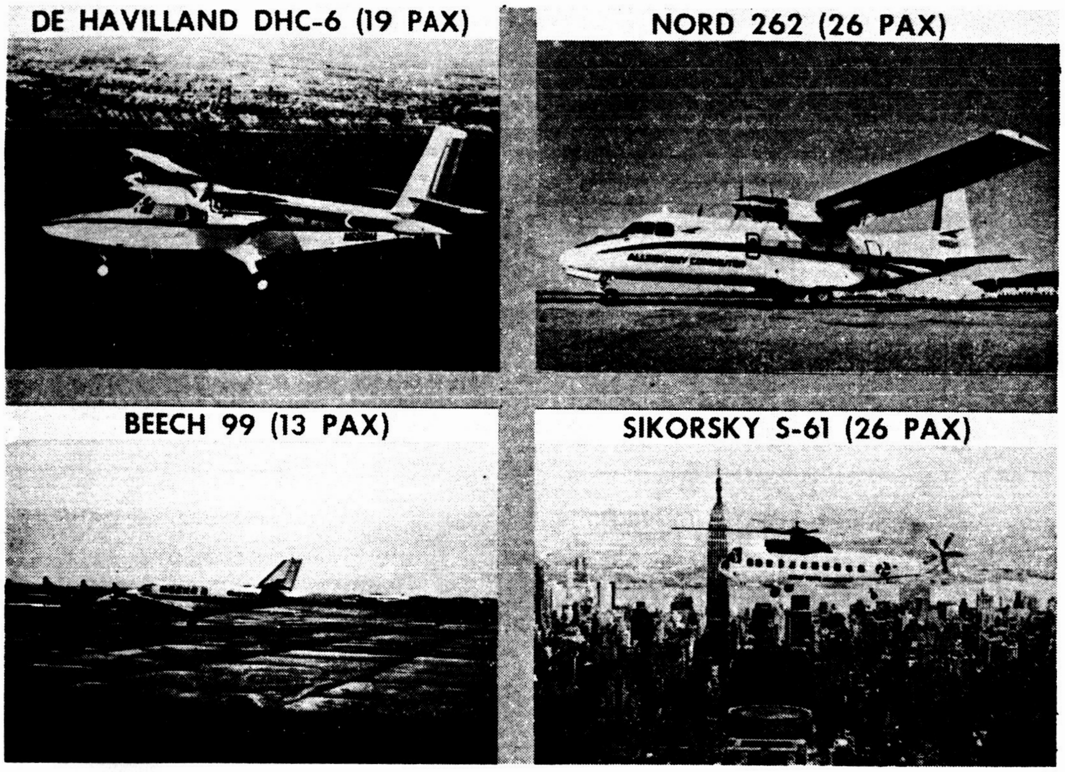

Figure 2.- Aircraft of commuter airline traveler survey.

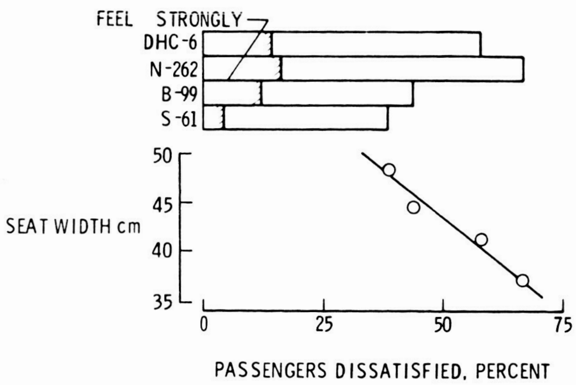

Figure 3.- Discomfort from seat width from airline traveler survey.

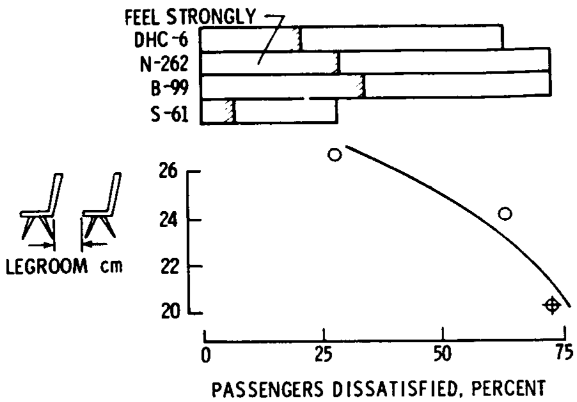

Figure 4.- Discomfort from seat legroom from airline traveler survey.

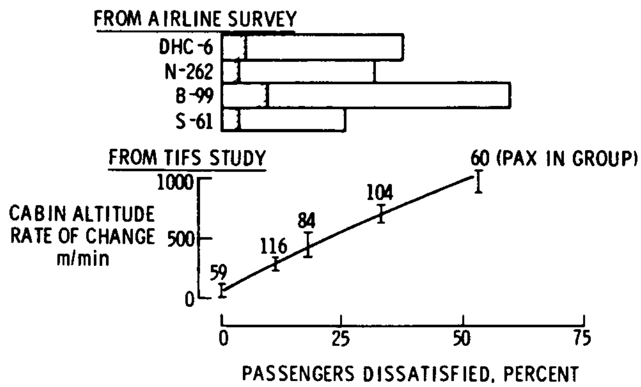

Figure 5.- Discomfort from change in cabin altitude (pressure).

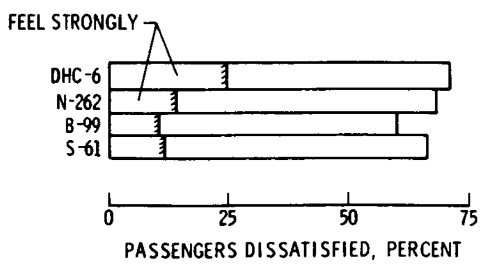

Figure 6.- Discomfort from cabin interior noise from airline traveler survey.

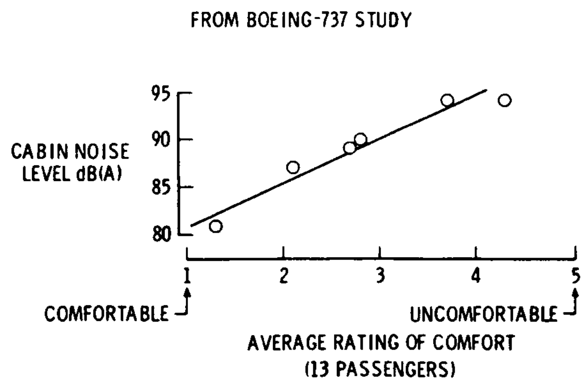

Figure 7.- Effect of noise level on passenger comfort rating.