Passenger Ride Quality in Transport Aircraft

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Quantitative relationships are presented which can be used to account for passenger ride quality in transport aircraft. These relations can be used to predict passenger comfort and satisfaction under a variety of flight conditions. Several applications are detailed, including evaluation of use of spoilers to attenuate trailing vortices, identifying key elements in a complex maneuver which leads to discomfort, determining noise/motion tradeoffs, evaluating changes in wing loading, and others. Variables included in the models presented are motion, noise, temperature, pressure, and seating.

Nomenclature

a	= acceleration
C	= comfort rating on a seven-point scale
db(A)	= A-weighted noise level, dB
E	= event (given ride situation)
g	= acceleration of gravity, 9.8 m/s^2
$\dot{h}$	= rate of change in altitude, m/min
l	= seat legroom, cm
p	= roll rate, deg/s
S	= satisfaction
T	= temperature, °C
V	= indicated airspeed, knots
w	= seat width between armrests, cm
γ	= flight-path angle, deg
δ	= Kroneker delta
θ	= pitch angle, deg
σ	= standard deviation of acceleration, g
ϕ	= roll angle, deg

Subscripts

cm	= compound maneuver
dc	= descent or climb maneuver
E	= event
env	= environmental (factors other than maneuvers, seating space)
$\dot{h}$	= rate of change in altitude
l	= longitudinal direction
man	= maneuver
max	= maximum
mot	= motion
no	= noise
po	= pitchover
seat	= seating space
T	= temperature
t	= transverse direction
trip	= total trip
turn	= turning maneuver
v	= vertical direction
z	= normal direction to cabin floor

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Introduction

PASSENGER ride quality or comfort can have a significant influence in determining acceptance and use of various modes of air transportation. The definition of ride comfort as used in the present paper is expressed as the impact on the passenger of all aspects of the vehicle's physical environment that affect acceptance of the ride. The time has arrived when some reasonable level of comfort is expected by the traveling public. Advent in the late 1950's of jet transports, cruising at high altitude where the air is generally smooth, made possible levels of ride comfort in long-haul transportation far superior to anything previously attainable. Many situations still arise, however, where ride comfort can be adversely affected if special attention is not given in the design and/or operations of the aircraft.[1] This paper provides quantitative relations to account for ride comfort for a variety of flight conditions.

Circumstances or occurrences which can lead to ride comfort problems fall into three general categories: input environments to the vehicle, aircraft operations, and aircraft configurations. Input environments which influence the ride-motion environment consist of both naturally occurring phenomena such as gusts or turbulence and man-generated phenomena such as trailing-vortex wakes. Aircraft operations influence ride environments through such things as motions caused by maneuvers, pressure changes caused by rapid descents, or temperature extremes caused by inadequate air-conditioning equipment. Finally, aircraft configurations influence the ride environment through aerodynamic perturbing forces, onboard equipment such as powerplant noise and vibrations, and passive equipment that directly interfaces the passengers, e.g., marginal-size seats with limited elbowroom and legroom. The present work describes useful relations that have been derived for addressing air transport ride problems, together with several applications of these relations to illustrate their usefulness.

Research Program: Analysis Method

A schematic of the analysis method[2] to assess ride comfort is illustrated in Fig. 1. A vehicle forcing function (e.g., turbulence and maneuvers) is converted into a ride-motion environment for the passenger using the appropriate transfer function for the vehicle system being analyzed. This environment, together with other inputs (e.g., noise and temperature), provides a total ride environment from which a comfort evaluation is obtained using a transfer function which is constructed to represent the passenger's reaction to these stimuli. Since response to a given ride environment can vary widely between subjects, a statistical approach is em-

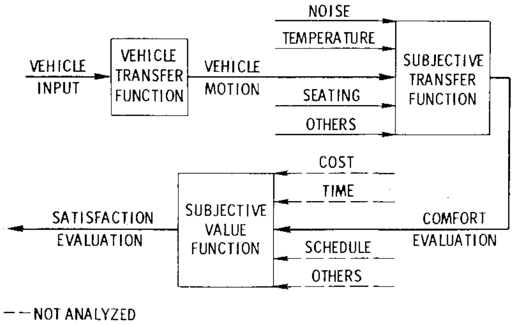

Fig. 1 Analysis method employed to assess ride comfort.

ployed wherein the evaluation is expressed as a mean subjective comfort response. The calculated evaluation of comfort is then transformed to an evaluation of the passenger's satisfaction with the flight in the context of the overall trip. Since trip satisfaction can also be influenced by factors other than ride comfort (e.g., cost, time, schedule, and safety), transfer functions from ride comfort to trip satisfaction must reflect these attributes. Thus, the satisfaction models are related to a particular type of operation (in the case presented herein, U.S. commuter operations). However, the model for comfort response is less dependent on these factors and, hence, can be applied somewhat more generally.

Background

Turbulence environment forcing functions have been measured and reasonably well quantified in statistical terms[3,4] as a function of factors such as altitude, terrain, and time of year. Vehicle transfer functions also exist (e.g., Ref. 5) and, for the larger transport airplanes, are generally well quantified because of other needs (e.g., aircraft dynamic stability and structural dynamics). Factors significant in affecting subjective reaction have not previously been well defined in regard to identification or to quantification of their character and magnitude.[6] Thus, an adequate subjective transfer function has not been available, since most prior research efforts generally have been limited to laboratory studies of vertical and transverse sinusoidal motions (e.g., Ref. 7). Much of the work has been directed toward tolerances and levels of task performance and has dealt with relatively high motion magnitudes in the discomfort regime. [These were, in fact, the type of data that subsequently provided the basis for International Standardization Organization (ISO) standard ISO-2631,[8] which offers provisional guidance for ride comfort vibration levels.] Consequently, ride comfort evaluation technology was generally qualitative in character. Subjective value-function technology was limited to only a few areas (costs and trip time), whereas ride comfort effects were a relatively unknown quantity.

technology (e.g., Ref. 9) indicated that implementation of the analysis method outlined in the previous section would require inputs and quantitative relations which could only be obtained from additional data generated by carefully structured experiments. Thus, this was the approach taken.

Experimental Effort

The results presented are derived from a research program active for the past five years at the University of Virginia under NASA sponsorship. Figure 2 illustrates the methods which produced experimental data for use in the modeling of ride comfort. Basically, subjective evaluations of ride comfort were obtained and compared with the measured ride environment. These evaluations were obtained for both fare-paying passengers and experienced test subjects traveling onboard scheduled air carriers (e.g., Refs. 10 and 11) and for test subjects in controlled experiments on research aircraft[12,13] or ground-based simulators.[14,15] When commercial air carriers were used, test subjects gave subjective ratings periodically during the flight plus an overall rating for the total flight, while, simultaneously, fare-paying passengers gave an overall rating at the conclusion of the flight. Data from the air carriers were particularly useful in qualitatively identifying both the environmental factors important in real-world situations and the nature and magnitude of these environmental factors.

The information generated was modeled to obtain passenger comfort as a function of various ride environment inputs. These models represent complex relations for multiple-degree-of-freedom random inputs obtained by regression analysis of flight data.[16–18]

Useful Ride Comfort Relations

Three relations which are useful in addressing the ride comfort in problem situations on transport aircraft have been developed as follows:

1) Comfort model relation: to provide the subjective transfer function for relating ride environment to ride comfort (see Fig. 1).

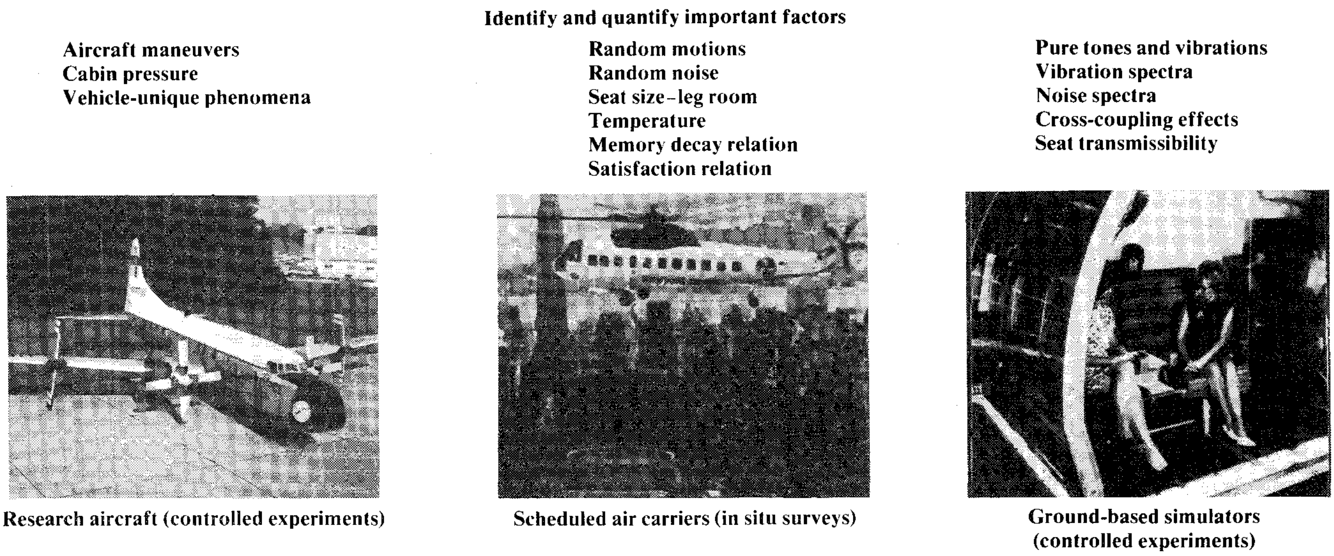

Fig. 2 NASA ride comfort research program: subjective evaluation – passengers (total trip) and/or test subjects (periodically); ride environment – continuously measured and recorded.

2) Ride satisfaction relation: to provide the subjective value function for relating ride comfort to trip satisfaction (see Fig. 1).

3) Response integration relation: to provide a method for appropriately weighting and summing the series of local comfort ratings (experiences) during a trip to obtain an overall evaluation of comfort and satisfaction for the entire trip.

Comfort Model Relation

From the several models of comfort rating developed during the course of the research effort, a composite model has been developed which is comprised of the more important ride environmental factors in a relatively simple form. This model, shown schematically in Fig. 3, was derived primarily from flight data obtained in small- to medium-size (15 to 60 passengers) turboprop airplanes in short-haul type operations and, thus, may not be fully applicable to other transport situations. The model provides a numerical rating of subjective comfort response C, where C has the following descriptors: 1 = very comfortable, 2 = comfortable, 3 = somewhat comfortable, 4 = neutral, 5 = somewhat uncomfortable, 6 = uncomfortable, and 7 = very uncomfortable. The model lists in parallel the three groupings of maneuver factors, environmental factors (motion, noise, temperature, and pressure), and seating-space factors, inasmuch as data analysis to date indicates little additive or cross-coupling effects between these three groups. Relations for the maneuver factors group are based on regression analysis of controlled-experiment results (1920 test subject data points) obtained from a NASA in-house effort using the U.S. Air Force Total In-Flight Simulator (TIFS) research aircraft (see Ref. 16). Relations for the environmental factors group and for the seating-space factors group are based on results of scheduled air carrier surveys (2976 test subject data points) conducted by the University of Virginia.

According to the model, the mean subjective comfort rating for a unique ride event (situation) is the maximum value provided by any of the three factor groups for that event:

$$C_E = \max(C_{\mathrm{env}}, C_{\mathrm{man}}, C_{\mathrm{seat}})$$

The model relates the mean subjective comfort to the factors of each factor group as follows:

Environmental Factors Group

$$C_{\mathrm{env}} = 2 + C_{\mathrm{mot}} + C_{\mathrm{no}} + C_{\dot{h}} + C_T$$

where

$$C_{\mathrm{mot}} = 18.9\sigma_{a,v} + 12.1\sigma_{a,t} \qquad (\sigma_{a,v} \geq 1.6\sigma_{a,t})$$

$$= 1.62\sigma_{a,v} + 38.9\sigma_{a,t} \qquad (\sigma_{a,v} < 1.6\sigma_{a,t})$$

$$C_{\mathrm{no}} = 0.19\,[\mathrm{dB}(A) - 85]$$

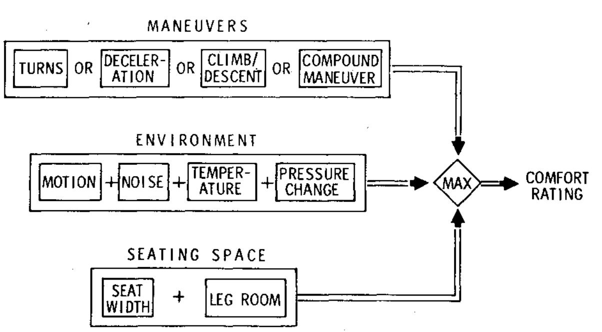

Fig. 3 Block diagram of comfort rating model for use as the subjective transfer function.

$$C_{\dot{h}} = 0.005(\dot{h} - 90)\delta_{\dot{h}} \qquad (\delta_{\dot{h}} = 1 \text{ for } \dot{h} > 90\ \mathrm{m/min})$$

$$(\delta_{\dot{h}} = 0 \text{ for } \dot{h} \geq 90\ \mathrm{m/min})$$

$$C_T = 0.054(T - 20.5)\delta_T$$

$$(\delta_T = 1 \text{ for } 2 + C_{\mathrm{mot}} + C_{\mathrm{no}} + C_{\dot{h}} > 3.4)$$

$$(\delta_T = 0 \text{ for } 2 + C_{\mathrm{mot}} + C_{\mathrm{no}} + C_{\dot{h}} \leq 3.4)$$

Maneuver Factors Group

$$C_{\mathrm{man}} = C_{\mathrm{turn}} \text{ or } C_{\mathrm{po}} \text{ or } C_{\mathrm{dc}} \text{ or } C_{\mathrm{cm}}$$
(depending on type of maneuver)

where

$$C_{\mathrm{turn}} = 0.293 + 0.0665\,|\phi_{\max}| + 0.07\,|p_{\max}| + C_{\mathrm{no}} + C_{\dot{h}} + C_T$$

$$C_{\mathrm{po}} = 1.75 + 22.1a_{z,\mathrm{rms}} + C_{\mathrm{no}} + C_{\dot{h}}C_T$$

$$C_{\mathrm{dc}} = 0.151 + 0.098\,|\theta_{\max}| - 0.118\gamma_{\max} + 0.019V_{\max} + C_{\mathrm{no}} + C_{\dot{h}} + C_T$$

$$C_{\mathrm{cm}} = 1.48 + 12.3\delta_{a,l} + 32.8\sigma_{a,t} + 11.62\sigma_{a,v} + 0.22\dot{h}_{\mathrm{rms}} + C_{\mathrm{no}} + C_{\dot{h}} + C_T$$

Seating Space Group

$$C_{\mathrm{seat}} = 1 + 0.0077(63 - w)^2 + 0.16(30 - l)^{2^{1/2}}$$

$$(\text{for } 30 < w \leq 63 \text{ and } 18 < l \leq 30)$$

The equations presented are intended to provide first-order evaluations of ride comfort.

Ride Satisfaction Relation

Comfort judgments need to be related to a more value-oriented variable to provide assessment of the influence of ride comfort on traveler acceptance and use of a system. The value-oriented variable chosen was the percentage of passengers satisfied with the ride, that is, the fraction of passengers who, when queried at the conclusion of a flight, said they would be willing to take at least another flight without hesitation. Based on data (861 passenger samples) from questionnaires completed by passengers during surveys, the satisfaction relation shown graphically in Fig. 4 was established.[9] This relation can be applied to subjective response data about comfort to obtain the probability of satisfying a given percentage of the passengers. Implicit in the output, however, are all the input variables to the subjective value function resulting from system operating parameters as illustrated in Fig. 1. Research to date has made no attempt to separately quantify the effects of each input variable; however, such quantification is ultimately needed to tradeoff comfort with other system components.

Response Integration Relation

During an aircraft flight, a series of unique ride environmental events is experienced by the passengers. While the mean comfort rating of each of these events can be established by application of the comfort-rating model described, the problem remains concerning the manner in which these "local" comfort ratings (experiences) can be integrated to obtain an overall response for the entire flight. This problem was addressed by employing comfort-rating data obtained from the special group of test subjects who rode scheduled airlines. To a high degree of accuracy, the overall comfort ratings of these subjects were found to be related to the mean overall response of the passengers onboard the same

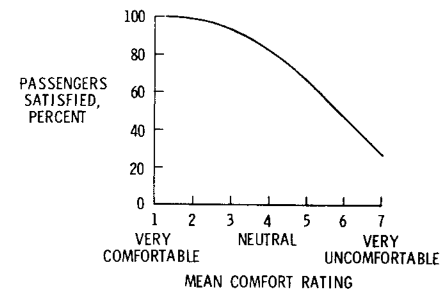

Fig. 4 Ride satisfaction relation.

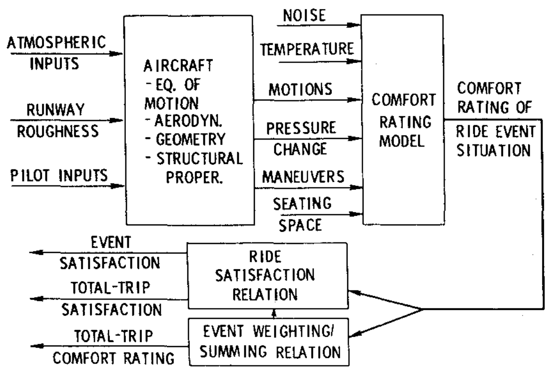

Fig. 5 Predictive method for ride comfort and passenger satisfaction as developed to date.

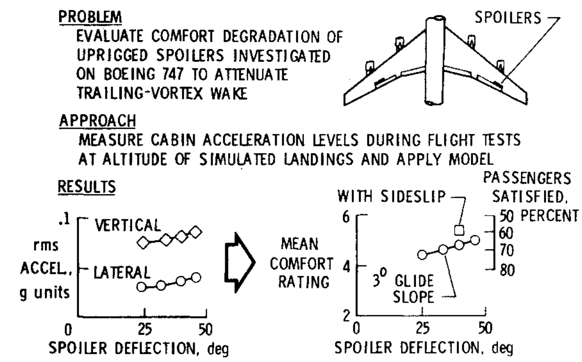

Fig. 6 Ride evaluation of uprigged spoilers.

aircraft.[19] An approximate relationship was established for weighting the series of local comfort ratings (obtained periodically) of the test subjects into a rating which closely matched their overall trip comfort rating. For a series of local ride events of equal time duration, E_1, E_2, E_3,...,E_n, the corresponding weighting factors to be applied to the event comfort rating can be expressed as $1^{3/4}, 2^{3/4}, 3^{3/4},...n^{3/4}$. The relationship, a ¾-power weighting function, is assumed appropriate for weighting any series of local mean comfort-rating experiences into an expected total trip mean reaction of passengers. This weighting implies that a memory decay occurs (events at the beginning of a flight being less important than events at the end) such that a passenger's overall reaction to the flight is a stronger function of the latter portions of the flight than the beginning. The total trip comfort rating in equation form is

$$C_{\text{trip}} = \sum_{E=1}^{n} E^{3/4} C_E \bigg/ \sum_{E=1}^{n} E^{3/4}$$

Technology Applications

When inserted into the analysis method previously outlined, the three ride comfort relations described in the previous section provide a predictive capability as shown in Fig. 5. The rating value provided by the comfort-rating model for a given ride situation can be used as an input either to the ride satisfaction relation for determining ride event satisfaction or to the event weighting/summing relation for determining total trip comfort and total trip satisfaction. The method shown in Fig. 5 or selected portions thereof can be used to address a variety of transport aircraft problem situations. Example applications are presented below to illustrate various uses to meet different types of needs.

Evaluation of Uprigged Spoiler

One of the simple applications of the technology is in evaluating the ride comfort for a given measured environment within the aircraft. One such application was carried out in evaluating the effects of uprigged spoilers on ride comfort during landing approach. Use of such uprigged spoilers during landings is a promising approach for reducing the magnitude of trailing vortices from large transports and, thereby, reducing the hazard of upset to following aircraft[20] because of these vortices.

Since the deployment of spoilers is known to worsen the ride environment in aircraft, an exploratory ride comfort investigation was carried out at the NASA Dryden Flight Research Center to evaluate ride effects. Portable equipment for measuring and recording the motion environment was placed onboard a Boeing 747 airplane for one flight of simulated landings at high altitude ($\approx$3000 m) during which uprigged spoilers of various deflections were deployed (Fig. 6). The dynamic motion of the ride environment was measured, and typical results are shown at the left in the lower portion of the figure. These results were used as inputs to the C_{mot} equation of the comfort-rating model to provide mean comfort ratings for various amounts of spoiler deflection and for sideslip at a single spoiler deflection. These results are shown at the lower right of Fig. 6. A scale of percent passengers satisfied, obtained from the ride satisfaction relation of Fig. 4, is also incorporated. The results indicate that the use of uprigged spoilers would degrade the number of passengers satisfied with the ride by 10 to 15%, depending on spoiler deflection. For real landings at much lower altitude, where a higher level of air turbulence can be expected, use of uprigged spoilers could possibly have a somewhat greater adverse effect on ride comfort.

Identification of Key Factor in Complex Maneuver

A combination of ride environment factors, experienced either simultaneously or in close succession, can result in an uncomfortable ride without direct indication of which factor or factors contributed most to discomfort. Such a situation occurred in an investigation[16] by NASA using a research aircraft in a curved decelerating descent typical of that which could be employed, using advanced navigation aids, for localizer/glide-slope capture in a relatively short distance. A mean comfort rating of 4.8 (somewhat uncomfortable) was given by test subjects who rode in the aircraft. Use of the comfort-rating model was employed to identify which factor or factors in the maneuver provided the greatest adverse influence on ride rating.

As shown in Fig. 7, the approach followed was to divide the complex maneuver into simple segments which could be analyzed individually. Generally each segment had only one dominant ride environment factor. For each segment, input of the maneuver to the ride was quantified, and the comfort rating for that input was determined by use of the motion component of the comfort-rating model for maneuvers. Finally, the comfort rating was converted to expected ride satisfaction through use of the satisfaction relation. As can be seen from the results of Fig. 7, the key segment identified was that which involved a 3.2-deg/s pitchover of the aircraft in which the predicted ride rating was 5.1 and predicted passenger (PAX) satisfaction was 61%. The negative normal

PROBLEM
IDENTIFY KEY FACTOR(S) INFLUENCING THE "SOMEWHAT UNCOMFORTABLE" RATING GIVEN BY TEST SUBJECTS

APPROACH						
•DIVIDE COMPLEX MANEUVER INTO SIMPLE SEGMENTS	STRAIGHT AND LEVEL	TURN ENTRY	DECEL. IN 20° TURN	TURN EXIT	PITCH-OVER	STEADY DESCENT
•QUANTIFY MANEUVER RIDE INPUT	NONE	8°/sec ROLL	0.08 g LONG.	-10°/sec ROLL	-3.2°/sec PITCH	-5° PITCH/ 550 m/min
•APPLY COMFORT RATING MODEL	2.0	2.4	2.0	2.6	5.1	3.2/4.3
•APPLY SATISFACTION RELATION (% PAX)	98	96	98	94	61 ↑ KEY FACTOR	89/76

Fig. 7 Ride evaluation of a complex maneuver.

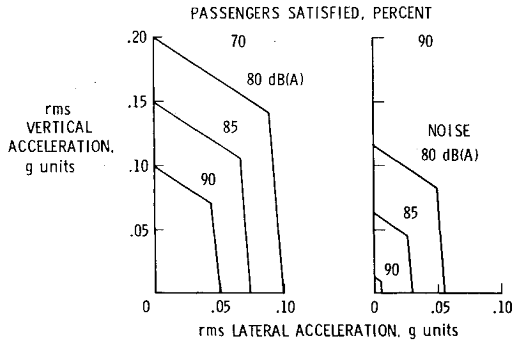

Fig. 8 Equicomfort combinations of motion and noise.

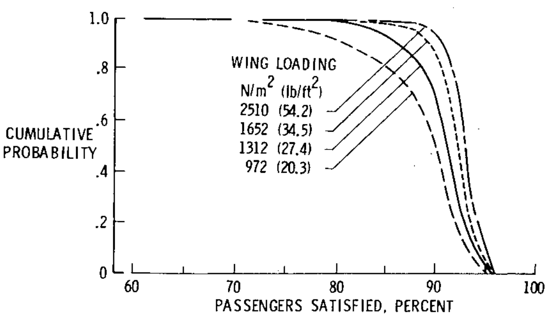

Fig. 9 Effect of variation of wing loading on ride satisfaction of commuter-type transport aircraft.

acceleration experienced in this pitchover was quite unpleasant to passengers. Deceleration before pitchover, such as was carried out during the turn, rather than after pitchover was a wise choice, since it reduced as much as possible the magnitude of the negative normal acceleration.

Derivation of Equicomfort Levels of Environments

The comfort-rating model and ride satisfaction relation can be used not only to evaluate passenger response to a given input environment (as illustrated in the previous example) but also to derive an upper boundary of the magnitude of a ride environment which could be expected to provide a given level of passenger satisfaction. Since a ride environment consists of a combination of various environmental components, information on component combinations is desirable. The present example (Fig. 8) considers three environmental components: vertical random motion, transverse random motion, and noise. For many ride event situations, these three components are often the most important factors affecting comfort in transport aircraft.

The approach used was to determine the mean comfort-rating value (from Fig. 4) which corresponded to the desired value of the percent of passengers to be satisfied. The comfort-rating model was then used to obtain the information needed to construct the graphs shown in Fig. 8. The graph's present levels of environment combinations consistent with obtaining either of two levels of number of passengers satisfied—70 or 90%. In applying any such information to an aircraft situation, the user should remember that the levels of both the motion and noise environment generally are significantly higher in the rear portion of transport aircraft than in the forward cabin.

The approach described could be used to generate such relations for any component combination of the comfort-rating model. Such ride comfort relations should prove useful in carrying out cost-benefit tradeoffs between alternate approaches for improving the ride comfort of a given aircraft design.

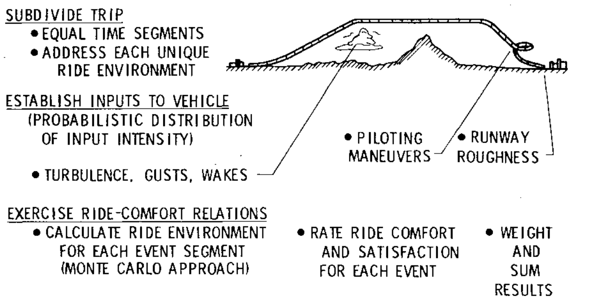

Fig. 10 Approach for total trip prediction of ride comfort and satisfaction.

Importance of Wing Loading

Ride comfort models can be used to provide the designer with direct tradeoff information about the effect on ride comfort which results from varying any particular aircraft parameter which affects the vehicle transfer function. To illustrate, the effects on ride comfort of varying the wing loading of a commuter-type aircraft have been addressed (see Fig. 9). The ride situation selected was that of a 5670-kg (12,500-lb) unswept wing aircraft cruising in straight and level flight and experiencing the atmospheric turbulence inputs found at a 900-m alt over mountainous terrain. Noise, temperature, and seating space were considered to be satisfactory. The vertical and lateral responses of the aircraft to the probabilistic distribution of atmospheric turbulences were first calculated for a range of wing loading conditions to provide the expected ride environment. The comfort-rating model and ride satisfaction relations were then used to convert the calculated ride environment into a ride satisfaction evaluation expressed in terms of the cumulative probability of achieving a given percent of passengers satisfied with the ride situation.

The cumulative probability curves for four wing loadings are shown in Fig. 9. At both ends (final few percent) of the probability curves, the satisfaction values and trends should not be considered to be particularly accurate because of limitations in the comfort data analysis and modeling (e.g., linear regression analysis and linear modeling). Over most of the range, however, and including the knee of each of the curves, the probability characteristics should be significant and reasonably valid. In the range of 80 to 90% of satisfied passengers, very significant improvements are evidenced as wing loading is progressively increased from 972 N/m² (about 20.3 lb/ft²) to 2510 N/m² (54.2 lb/ft²). The trends also indicate that further increase in wing loading would not be particularly beneficial.

Prediction of Total Ride Characteristics

Full exercise of the method presented in Fig. 5 is required to predict total trip ride comfort and passenger satisfaction. Further details are outlined in Fig. 10, wherein the trip is divided into equal time segments of duration appropriate for addressing each ride environment event. For each event situation, inputs to the aircraft need to be established. Some inputs, such as turbulence, are random in nature and are a function of altitude, geographic features, and time of day. Other events, such as maneuvers, are more controlled in nature but still can have random variations. Inputs, therefore, need to be described in terms of probabilistic distribution of intensity. With these inputs, the vehicle transfer characteristics, and the ride relations described earlier, a Monte Carlo type approach can be used to calculate the probable ride comfort rating and passenger satisfaction for each segment of the trip. These results can then be weighted through use of the memory decay relation, summed, and normalized to provide values for the total trip.

The approach just described was used to calculate the ride characteristics for a commuter airline demonstration project. This project, the Canadian Airtransit STOL Demonstration Program, was considered to be particularly attractive for such study because of 1) addition of comfortable seats with generous seating space to an aircraft otherwise considered to have a nonluxury ride; 2) use of STOL terminal area operations; 3) opportunity for comparison with the ride experience of U.S. commuters; 4) tailoring of trip to enhance business traveler acceptance (high-frequency schedule, downtown-to-downtown time saving, and total trip service approach); and 5) because trip situation (aircraft configuration, flight operations, type travelers) was considered to be sufficiently different from the model development database situations to serve as a check on model validity. As shown at the top of Fig. 11, ride environment measurements and passenger ratings of the trip were obtained on 61 flights of the DHC-6-300 aircraft used by Airtransit. The average duration of each flight was 52 min. The analytical prediction of ride used 26 two-minute event segments (2 climb, 2 turn, 20 straight and level at 1050-m alt, and 2 descent) and included effects of temperature, noise, and seating, as well as of motions and maneuvers. Takeoff and landing ride on the runway were not included. Further description of the Airtransit operations and of the associated ride comfort study is given in Ref. 21.

Comfort rating results are presented in the lower portion of Fig. 11 in terms of the cumulative probability of achieving given values of comfort based both on prediction and on actual passenger surveys. The predicted probability of achieving a given comfort rating agreed with survey data for the higher rating values and was conservative (predicted a lesser probability) for the lower rating values, with the predicted curve displaced toward the uncomfortable direction a maximum of 0.7 rating point. This degree of agreement is considered to be very good.

Total trip satisfaction results are presented in Fig. 12 in terms of cumulative probability distribution, based both on prediction and on actual passenger survey responses. Agreement was fair over the knee of the curve. Also included in Fig. 12 are calculated results for the Airtransit situation but with two differences typical of a U.S. commuter operation using DHC-6 aircraft: use of conventional 19-passenger seating rather than 11-passenger seating, and use of estimated turbulence conditions associated with cruise at 600-m altitude rather than at 1050 m. The predictions are in very good agreement with passenger survey data from U.S. commuter airlines operating over a trip length approximating that of Airtransit. The difference in both predicted and survey results for the two operations indicates that the combination of different seating and turbulence factors does have a very significant influence on passenger satisfaction. Comparison of the end-point passenger survey results for the two carriers indicates a surprisingly large difference in probability of satisfying (willing to take another trip having the same ride) all passengers on a trip. The probability was over 60% for the Airtransit situation but less than 10% for the U.S. commuter. Very likely, the high fraction (93%) of the business-trip

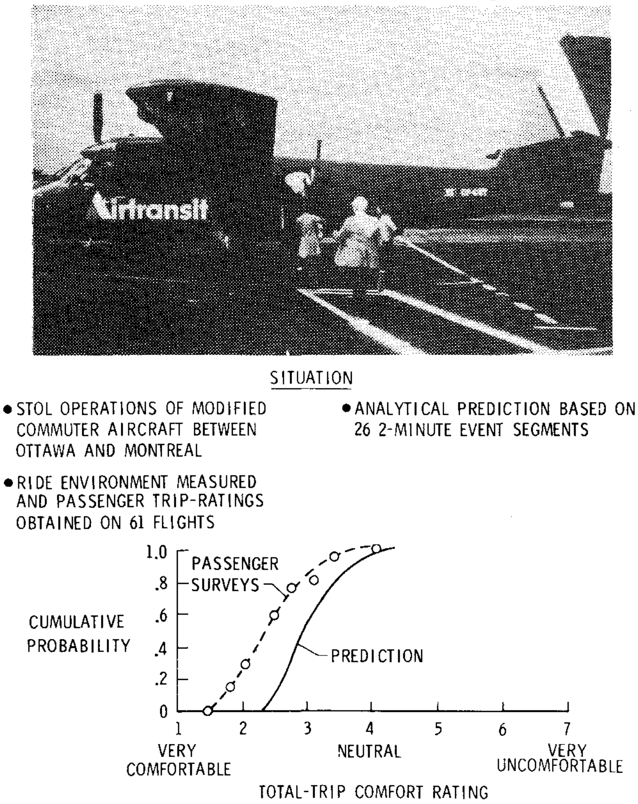

Fig. 11 Total trip ride comfort for STOL demonstrator transport.

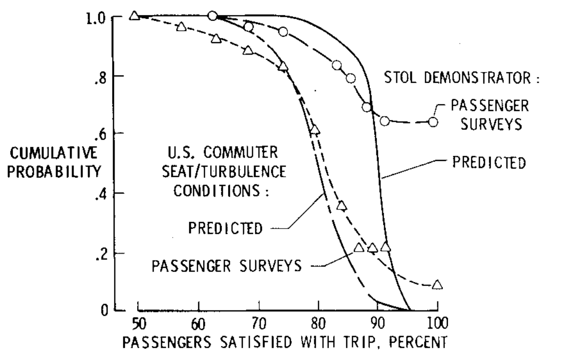

Fig. 12 Total trip satisfaction for STOL demonstrator transport.

commuters on the Airtransit flights liked the special operational features incorporated to enhance business traveler acceptance (see item 4 mentioned previously), and they were not as adversely influenced by a less comfortable ride as predictions would indicate. Better predictive treatment of trip satisfaction must await the development of a good disaggregate demand model in which ride comfort is included as only one of the number of factors (e.g., trip cost, trip time, and schedule frequency) believed to have significant influence.

Concluding Remarks

This research has resulted in the collection of a very substantial amount of ride environment and ride comfort data. Three relations, derived from these data, which are considered particularly useful for addressing transport aircraft ride comfort situations, have been described with sufficient quantitative definition for practical application. Five applications of these relations have been presented to illustrate their effectiveness and limitations in addressing various ride problems or situations in aircraft design and system operations.

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