PASSENGER ACCEPTANCE OF BWB CONFIGURATIONS

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Keywords:
comfort, flight test, motion sickness, passenger acceptance, unconventional configurations

Abstract

Modern jet-aircraft are accepted as a part of the transport system throughout the world. They have a high level of commercial success and operate under state-of-the-art safety standards and environmental regulations, but it will be impossible for this type of aircraft to meet the requirements for ecologically-acceptable air transport in the next 30 to 50 years. Only new unconventional civil transport aircraft configurations promise a considerable progress in productivity as well as meeting future economic and challenging ecological constraints.

In this study the Blended Wing Body (BWB) configuration with reasonable chances to enter the market until 2030 has been chosen as a platform for the investigations. To maintain competitive advantage it is vital for new aircrafts standing at the beginning of a long life and product cycle to be as attractive as possible for the manufacturer, the airlines and the passengers over a maximum period of time. The latter issue – the attractiveness and acceptance of Blended Wing Body configurations by passengers – will be shortly addressed in the paper.

The cabin of an airplane is a complex system which must fulfil specific ergonomic requirements. For the passenger the cabin environment has to meet exclusive demands with regard to comfort, functionality and safety. Therefore the Institute of Aeronautical Engineering at the Technische Universität München has initiated an extensive survey addressing various aspects of prospective BWB cabin layouts and interior designs. Furthermore the survey covers potential anxieties like fear of flying, claustrophobia and agoraphobia and discusses their influence on the seating arrangement, the illumination, the colour of the interior and the nature and design of recreational space and cabin partitions. Another point of discussion in the questionnaire is concerned with the perception and the acceptance of stronger flight movements compared to conventional aircrafts.

In a next step the results obtained from the survey are to be validated by psychological and physiological investigations performed in a moveable cabin simulator with 16 subjects covering a broad demographic scale.

Consequently, solutions and counter-measures have been derived in order to optimise passenger acceptance of and well being in BWB configurations.

1 Introduction

With today's aircraft configurations it will be impossible to meet the requirements for ecologically-acceptable air transport in the next 30 to 50 years. Only new unconventional civil transport aircraft configurations promise a considerable progress in productivity as well as meeting future economic demands and challenging ecological constraints. One of the aircraft configurations showing a huge potential to meet latter demands could be the Blended Wing Body configuration.

The work reported here is part of an effort to assess passenger acceptance of new unconventional configurations like the BWB and all its properties.

The BWB aircraft dealed with in this report seats up to 1,000 passengers in the single-class layout and offers a substantially larger cabin than conventional aircrafts. The BWB-cabin is characterised by a considerably broader cabin area. Fig. 1 and 2 should give an impression of a BWB-cabin in comparison to a conventional layout for long-distance flights. Observably the number of parallel seat rows multiplies resulting in numerous assets and drawbacks, whose effects on the passengers ought to be investigated in this paper.

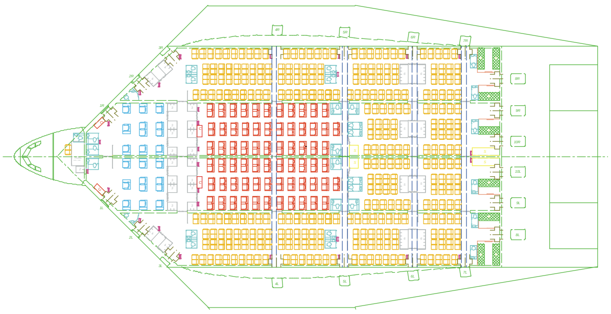

Fig. 1. Cabin layout of a BWB

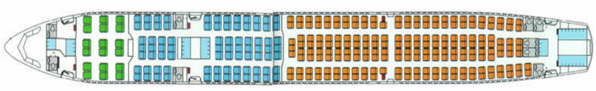

Fig. 2. Example of a conventional cabin layout on long-distance routes (Airbus A340)

The layout of a Blended Wing Body aircraft described above could cause the following consequences:

- The passengers at the most outward position of the aircraft – large distance from the airplane's longitudinal axis – are exposed to significantly increased vertical accelerations during roll manoeuvres. This may reduce the attractiveness of such an aircraft.
- The complex structure surrounding the cabin and the distance of much of the seating from the cabin walls will result in fewer or even no window seats or windows.
- The large cabin used for long-distance flights may create various unknown passenger behaviours (e.g. agoraphobia).

On the following pages the psychological and physiological aspects regarding the above-mentioned influences affecting the passengers will be analysed in a two-fold approach:

In the beginning a survey was carried out to be able to assess passenger acceptance in novel, unconventional aircraft configurations (compare section 2). In order to validate specific results from the questionnaire campaign flight tests in a large moveable cabin simulator are to be performed. These tests are expanded later in this paper.

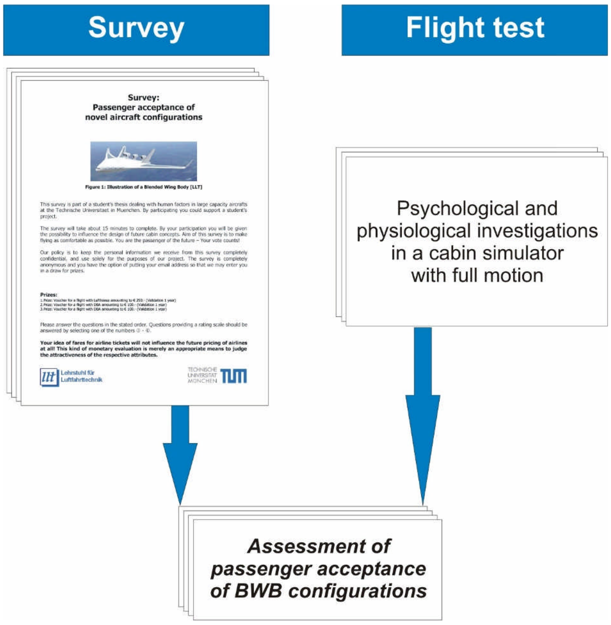

Fig. 3. Two-fold approach for the assessment of passenger acceptance

2 Questionnaire campaign

To be able to predict the psychological as well as the physiological effects on the passenger of a flying wing, a questionnaire was designed [16]. It should help answer mainly questions arising from the following topics, which were all addressed in the survey:

1. Evaluation of an increased incidence of phobias, its reasons and possible solutions/countermeasures.

2. Evaluation of an increased incidence of motion sickness, its reasons and possible solutions/countermeasures.
3. Assessment of the effect of a reduced number of windows or even complete lack of external reference and the acceptance of alternative means and its design.
4. Estimation of the psychological impact on the BWB-passenger due to increased roll velocities and accelerations.

In order to maximize the response rate, the questionnaire was designed to be as short as possible, easy to administer, clear, self-explanatory and anonymous.

2.1 Method

In order to obtain reasonably representative data from the evaluation of the questionnaire, the survey was distributed by means of several instruments (compare fig. 4).

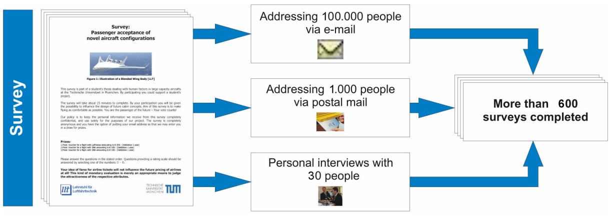

Fig. 4. Distribution of the questionnaire

Besides contacting more than 100,000 addressees via e-mail, at least 1,000 persons were informed about the questionnaire campaign by flyers, which were distributed via postal-mail. The survey was available in the worldwide web for the period of one month. By using a *.pdf-document consisting of form fields the evaluation procedure could be dramatically simplified. The data which was filled in on the website was automatically re-transferred via e-mail to the Technische Universität München. Additionally personal interviews were performed at the 'Munich Airport International' in order to ascertain differences in the means of electronic, anonymous and face-to-face interviews.

2.2 Sample

The sample consisted of 633 participants from various regions all around the world, whereas the majority of the contributors were from Germany. With regard to the socialstatistical data it must be mentioned that the bandwidth of ages varies from 18 to 68 (the lower limit results from the restriction of the participants' age to at least 18 years) while the average participant has an age of only 32.7 years. Two third of the interviewees were less than 30 years old. The reason for that phenomenon could be the way of distributing the questionnaire through the medium internet as described in the section above. Compared to an investigation published by Robert Bor [1] the age of the average airline passenger is 45.3 years. That is to say that the sample over-represents young passengers as shown in fig. 5. Given the distribution procedure for the questionnaire, these differences are quite reasonable.

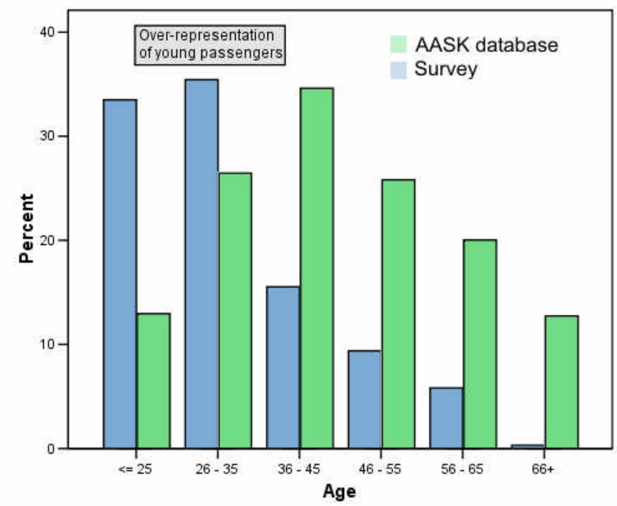

Fig. 5. Age distribution of the sample in comparison to the AASK database [1]

To account for the representativeness of the survey the sample had to be weighted according to the age distribution mentioned in [1] and shown in the figure above. This results in the characteristics of the sample as presented in tab. 1, which also compares the sample with the characteristics of the general flying public.

2.2.1 Representativeness of the sample

One of the most stringent requirements for the significance of surveys is its representativeness.

Therefore the structure of the sample must meet the composition of the treated population. A sample is assumed to be representative if an adequate structural copy of the population concerning BWB topics is chosen by random sampling and is used as interviewees of the questionnaire campaign.

	Sample	*Weighted sample*	*General surveys*	
Sex				
Male	76.5%	83.3%	60.5%	[1]
Female	23.5%	16.7%	39.5%	
Purpose of trip				
Business	32.9%	50.2%	35-45%	[9]
Private	67.1%	49.8%	55-65%	
Class				
Economy	87.1%	78.7%	79.5%	[9]
Business	12.9%	21.3%	20.5%	
Type of airline				
Scheduled	78.0%	76.2%	77%	[5]
Charter	22.0%	23.8%	23%	

Tab. 1. Characteristics of the sample

According to tab. 1 it can be seen that the sample over-represents males and people who travel for business reasons. The ratio of economy and business passengers as well as between passengers on charter and scheduled flights closely approximates the general flying public.

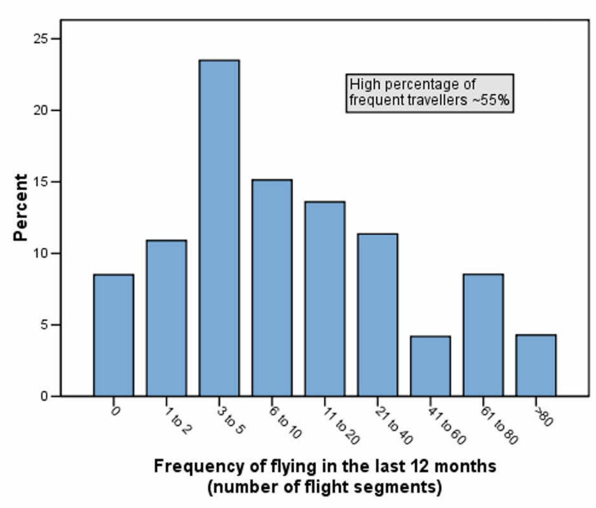

Fig. 6. Flight experience of the sample

The questionnaire also asked for the participants' frequency of flying in the last 12 months and the average duration of the last five flights – the results are given in fig. 6 and 7 respectively.

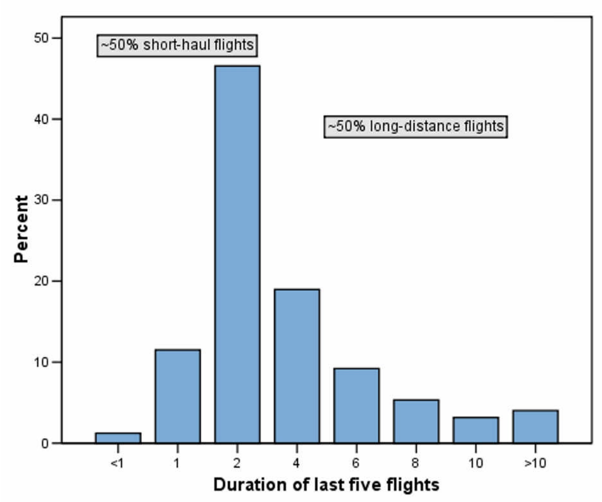

Fig. 7. Duration of flights

As may be seen in these figures, the sample contains a high percentage of frequent travellers with a well-balanced duration of the flights.

Anyhow the demand on an adequate representativeness is not obligatory in that case that the questionnaire only aims at gaining general and not very detailed information about new unconventional aircraft configurations and its effects on the passengers.

2.2.2 Reliability of the sample

The reliability of a questionnaire campaign only depends on the size and quality of the sample. The smaller the group of participants the more uncertain results will be obtained. To achieve a margin of results as close as possible to the so-called population the sample has to be large enough. The perfect size of a sample according to various pollsters is at around n=2,000 [6].

To be able to determine the minimum size of the sample the following question must be answered: "How small is a sample allowed to be in order to still enable a significant extrapolation to the population?" According to the size of the sample of 633 participants the bandwidth of the statistical spread of the results in the population varies at 2% with a probability of 68.3% (compare [6]). In view of a higher level of significance of 95.5% the bandwidth increases to 4%.

Finally the size of the sample can be assumed as being large enough for a fairly high level of significance at a low statistical spread of the results.

2.3 Results

Standard statistical techniques were used to explore the responses to individual items of the questionnaires as well as to study relationships between responses to sets of items. The data analyses were performed in the SPSS program package.

In the following sections the results are discussed in the same order as they were addressed in the questionnaire (compare [16]).

2.3.1 New service and entertainment concepts

Due to the increased cabin area, an establishment of service- and entertainment areas like bars, cafés, lounges, rest compartments, fitness rooms, etc. would be feasible. In addition the aircraft could be equipped with onboard-networks, video-systems, games, internet and virtual-reality systems. The relative attractiveness of these two factors (entertainment areas and systems) are shown in figure 8.

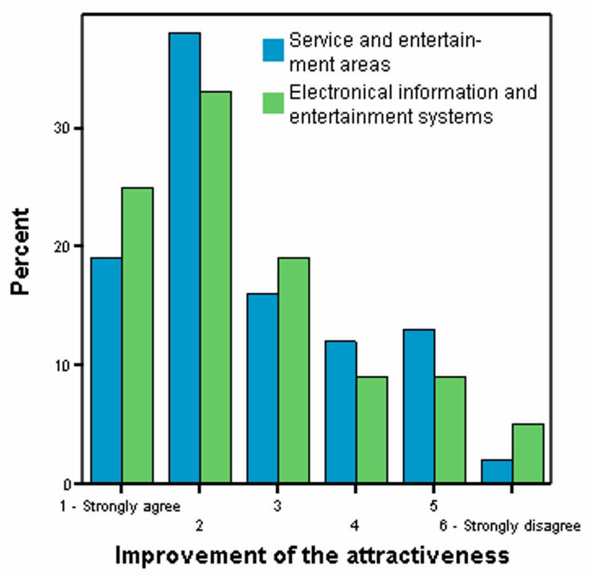

Fig. 8. Gain in attractiveness through novel concepts

According to this figure both concepts find favour with the participants since more than two third judged them at least somewhat improving the attractiveness on long-distance flights. Compared to a conventional flight not offering the above-mentioned establishments the interviewees are willing to pay 8.7% and 6.1% more for new service- and entertainment areas and electronic entertainment systems respectively.

2.3.2 Design of the cabin atmosphere

In this section the design of the cabin atmosphere and other aircraft related parameters and their influence on the susceptibility to various anxieties, that are expected to occur more frequently in BWB aircrafts, are investigated.

1. Fear of flying

Statistically every third passenger suffers from fear of flying (anxiety, trepidation both during and before flights). These numbers correlate quite well with the rate of passengers suffering from fear of flying in the questionnaire campaign: 34.0%.

2. Claustrophobia

The major part of the participants never suffered from claustrophobia during flights. Only 4.5% frequently suffer from that kind of phobia in aircrafts.

3. Agoraphobia

The incidence of agoraphobia is more prevalent than of claustrophobia: 8.7% of the participants regularly suffer from that anxiety.

The relative influence of three to nine parameters relating to the incidence of the above-mentioned fears is shown in figure 9. The mean ratings are shown for each of the factors only for those passengers that ever suffered from the phobias.

Strong flight movements, the condition of the aircraft and the reputation of the airline are of greatest influence to the genesis of both fear of flying and claustrophobia. Unexpected flight manoeuvres as well as turbulent air have a great influence on the incidence of fear of flying but seem to be slightly less responsible for claustrophobic effects. The greatest discrepancy occurs for fully occupied aircrafts, which seems much more influencing the incidence of claustrophobia than fear of flying.

All three parameters causing agoraphobia are judged as very essential for the genesis of agoraphobia (no mean rating fell below 3.5).

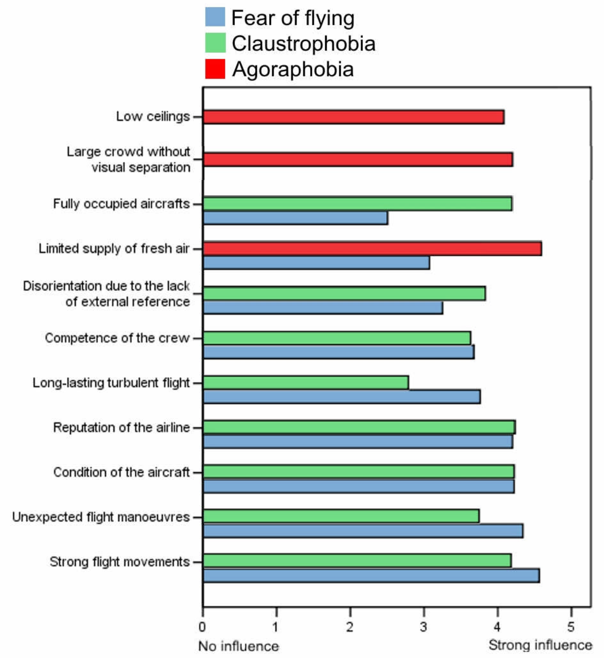

Fig. 9. Factors influencing the genesis of fears

With regard to the cabin design, a flexible cabin concept allowing the adjustment of the cabin layout before every flight enjoys great popularity under the participants of the questionnaire (∅ 2.1, rating from '1 – very good' to '6 – very bad').

2.3.3 Windows

For most of the participants the availability of external view plays a major role in a BWB configuration. This can be manifested by the huge percentage of interviewees ticking '1 – Very important': 33.1%; the mean on the rating from 1 to 6 is 2.66.

Talking about alternatives to windows passengers tend to accept a video system through which various camera perspectives to the outside could be selected as a substitution to real windows. The installation of monitors in the backrest of the seat in front of each passenger instead of having artificial windows in the cabin walls, enables the airlines to implement additional features. In that case travellers could switch between various options like video-on-demand, navigational information, etc.

The respondents indicated which of five different features of a video-system they thought being most attractive. The order of attractiveness of these characteristics is shown in figure 10. Various, selectable perspectives as well as a digital zoom are clearly the most attractive features. Both attributes have a modal rank of 1 (more than 50%).

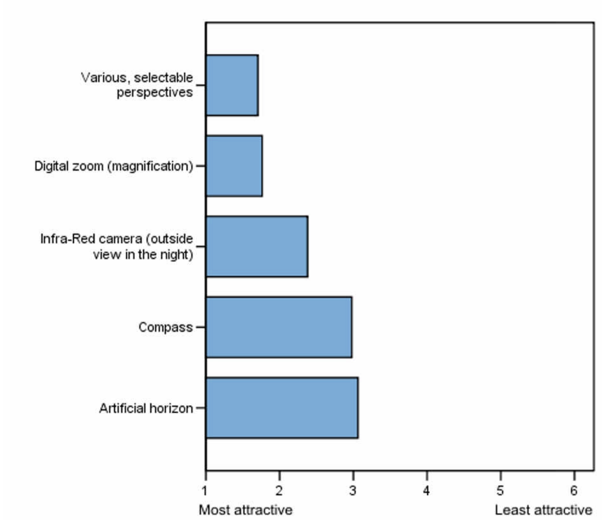

Fig. 10. Ranking of video-system features

An infra-red camera allowing for an outside view during night times is a commonly desired element (mode 1), while additional navigational information like a compass or an artificial horizon are dispensable items for passengers.

2.3.4 Perception of flight movements

This part of the survey asked for the influence of specific flight manoeuvres on the feeling of comfort and the genesis of motion sickness. More than 50% of the participants feel well or even very comfortable (mode 2 on a rating from '1 – very comfortable' to '6 – very un-comfortable', compare table 2) according to their personal assessment during extreme roll rates in final approach. Partitioning the sample by sex, women feel less comfortable than male respondents (modal rank 5 for females versus 2 for males). When age is used as the partition, younger people rate roll manoeuvres as of less influence on well-being than passengers older than 45 years.

Level of comfort	Sample	Sex		Age	
		Male	Female	<=45	>45
1	10.2%	10.7%	7.9%	14.6%	4.5%
2	24.5%	27.1%	11.4%	21.3%	28.7%
3	22.3%	21.6%	25.5%	26.6%	17.0%
4	20.3%	20.7%	18.6%	19.3%	21.4%
5	18.3%	16.1%	29.3%	13.8%	24.2%
6	4.3%	3.7%	7.2%	4.4%	4.2%

Tab. 2. Level of comfort during roll manoeuvres

Only 5.6% of the respondents frequently suffer from airsickness on long-distance flights. Moreover the questionnaire asked subjects to rank various factors with respect to their influence on motion sickness. This is shown in the figure below:

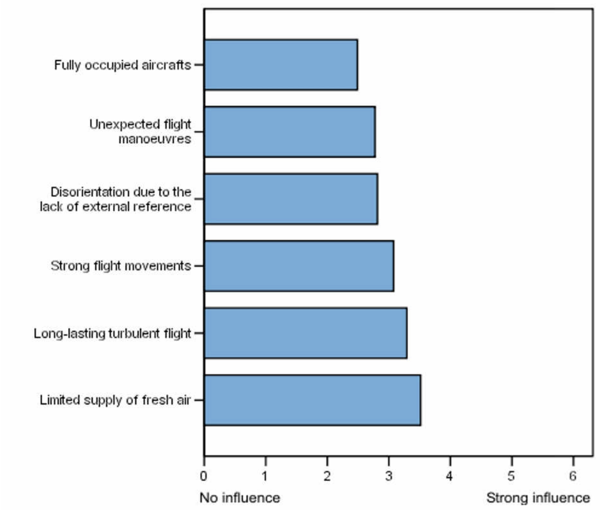

Fig. 11. Factors influencing the genesis of airsickness

Limited supply of fresh air together with long-lasting turbulent phases as well as strong flight movements are rated as being the parameters which have a great influence on the genesis of motion sickness on long-distance flights. Whereas high load factors and the lack of external reference scarcely account for an increase in susceptibility to airsickness in BWB configurations.

The video-systems that were addressed in a previous section of this paper in order to substitute windows in a BWB aircraft could also be equipped with additional features for the purpose of the prevention of motion sickness. Figure 12 shows the rank order of these features.

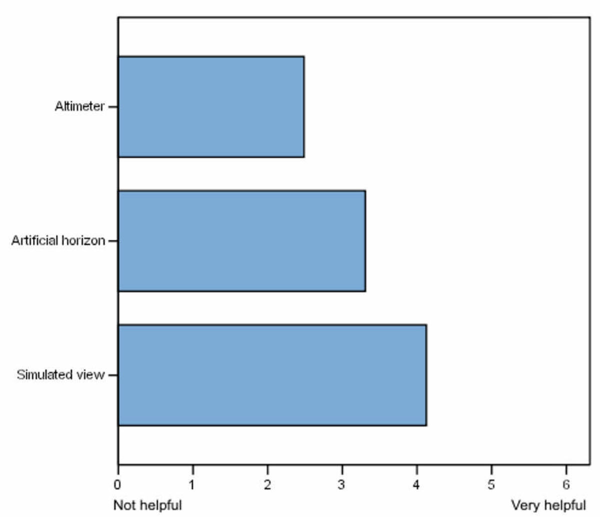

Fig. 12. Ranking of video-system features capable of reducing airsickness

The simulated view as discussed earlier in this paper is a feature that is rated as being of great help in preventing the incidence of motion sickness. Participants assess elements that are usually only installed in the cockpit, like an altimeter or an artificial horizon, as of less help for the protection against airsickness.

3 Flight test

In order to validate the results obtained in the questionnaire campaign, flight tests in a moveable cabin simulator are to be performed. Since the maximum loading on the passengers is expected to be roughly three to four times higher than in today's aircrafts due to the increased maximum distance to the longitudinal axis of the airplane, the effects of strong roll manoeuvres must play a major role in the definition of the flight mission for the experiment. The influence of roll motions on the passengers need to be not only examined with regard to maximum accelerations and velocities but also to comfort limitations.

In order to obtain reasonable and utilisable results the experiment has to consist of two distinct parts. The first part is a flight on board a conventional flight-simulator aircraft whereas the second flight is to be performed in a BWB aircraft. This approach allows to compare the results of the BWB flight test with the outcome of the conventional test data. Latter can only be guaranteed if the same conditions are used for both experiments. Therefore both 'aircrafts' will revert to the same flight mission except for higher accelerations during roll manoeuvres in the BWB configuration.

Given that both psychological and physiological investigations need to be performed in a cabin simulator, questionnaires have to be distributed to each subject to determine its reactions to the flight. In addition the passengers need to be equipped with a medical meter capable of measuring various parameters that are likely to change as symptoms of motion sickness or fear of flying develop. These parameters are heart rate, breathing rate and dermal conductance.

Finally the results from the questionnaires as well as the medical values have to be compared to the occurring accelerations and loads in both configurations – conventional and BWB.

4 Solutions and countermeasures

In order to guarantee the acceptance of a Blended Wing Body, the minimization of all negative effects, which – as shown in this paper – are presumably to be expected during BWB flight operations is of paramount priority. The following advices shall give impulses to further detailed analysis in the corresponding technical disciplines:

The increased accelerations and velocities mainly during roll manoeuvres call for a strict use of seat belts not only for passengers but also for the flight attendants during strong flight manoeuvres as well as turbulent phases. Moreover the hand luggage of the passengers and other equipment has to be securely stored in the cabin of the aircraft.

To minimize the incidence of air sickness of the passengers, a reduction of roll rates during flight manoeuvres to less than 0.5°/s can already promise great success particularly in cruise. An artificial view to the outside would have two positive effects on the passengers regarding the sensitivity to air sickness: On the one hand a psychosomatic disposition caused by uncertainty and/or by fear of flying could be weakened and on the other hand a visual escapement for air sickness can be excluded. However the influence of the lack of external reference is only of less importance on the incidence of motion sickness.

Generally, a more flexible autopilot control would be desirable in favour of the passenger comfort in BWB aircrafts. The manoeuvres should be optimised with respect to minimum roll rates and accelerations.

In order to increase the feeling of comfort in a BWB configuration the passengers are in favour of service areas (cafés, bars, rest compartments, etc.) and electronic entertainment systems (onboard-networks, video-systems, games, internet, etc.).

Beyond it sufficient supply of fresh air and additional video-system features like an external view promise a distinct decrease in the susceptibility of motion sickness. Phobias can be drastically reduced on the one hand by dividing a large BWB cabin into smaller compartments and on the other hand by changing the flight path in case of turbulent air or in expectations of strong flight movements.

5 Conclusion

It can be stated that the incidence of phobias like fear of flying, claustrophobia and agoraphobia could increase somewhat in flying wing aircrafts but do not significantly influence well-being of the passengers in a BWB.

The low number of windows or even the complete lack of external reference results in a decreased attractiveness for the passengers and in a slight increase of motion sickness, nevertheless this negative effect could be compensated by the installation of video systems offering artificial view to the outside. This would prevent the vestibular-visual interaction from being disturbed. Additionally these systems should be equipped with some kind of further information like navigational information, video-on-demand, etc.

The higher impact on the passengers due to the increased lateral distance to the longitudinal axis for those seats positioned in the most outward area of the cabin does not have a negative influence on the comfort of the passengers but should be further evaluated keeping in mind the lack of external reference. The combination of both higher accelerations during roll manoeuvres and the lack of outside view could entail an increase in motion sickness and therefore should not be disregarded in designing the interior of a blended wing body aircraft. The flight test described in this paper will clarify this interrelation.

The BWB aircraft as described and analysed in the survey would be accepted by the majority. By passing the economical cost-effectiveness on to the passengers through affordable flight tickets they would not assess a BWB configuration less attractive than conventional aircrafts.

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