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Validation of a turboprop cabin demonstrator

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Abstract. Turboprop aircraft should be improved as they are more environmentally friendly aircraft compared to turbojet aircraft but noise and vibration are often too high for passengers. A simple and uncomplicated way to carry out experiments is using a demonstrator. To determine whether the demonstrator represents the reality, it must be validated. In this project, real flights were first conducted in a turboprop aircraft. During two 70-minute flights, 94 subjects answered questions about symptoms, mood or comfort levels related to noise and vibration, among other things. In the next step, investigations will be carried out in the demonstrator under the same conditions as the real flights. Both results will be compared with each other. If the data from the demonstrator corresponds to that of the real flights, the demonstrator is considered to have been successfully validated. The requirement for this is that the demonstrator data lies within the confidence intervals of the results from the real flights. The aim is to validate a full-scale on-ground demonstrator of a regional turboprop aircraft cabin that will be used for multiple tests like subject tests and comfort evaluation, composite materials and structures, systems and energy consumption.

1. Introduction

Turboprop aircraft are more environmentally friendly for short-haul flights due to less carbon emission compared to turbojet aircraft [1]. The problem of these type of aircraft is that they generate more noise and vibration due to the propellers and engine [2]. The difference compared to turbojet aircraft could be 10 to 30 decibel [3]. More noise and vibration could have a negative impact on passengers. Both factors are the main factors influencing the discomfort perception of passengers in a turboprop aircraft [4]. Other studies reported similar results: Passengers felt less comfortable, restless and deteriorated if the sound pressure level is high [5].These negative impacts not only affect passengers, also the cabin crew could be influenced by noise and vibration showing worse performance, health, or wellbeing [6]. If the passengers rate an aircraft as too loud and perceive too much vibration, their comfort and satisfaction rating decreases. Consequently, their willingness to choose these types of aircraft again will decrease, too [7]. Therefore, it is essential to examine and improve turboprop aircraft.

Because simulations for subjective perception are not possible at the moment and real flights are too complex and expensive, demonstrators are particularly well suited. However, these are only useful when they are validated. Validation is essential to verify that the demonstrator produces the same results as a real turboprop aircraft and that its function is correct [8]. For this purpose, validation tests and validation environment need to be defined [8]. It is necessary to collect passengers' reactions during a real flight and to compare them with results from the demonstrator. After the validation, the demonstrator can also be used for different scenarios or other areas of application. Thus, demonstrators are a good way to carry out investigations quickly and economically.

The goal of the CleanSky2 Regional Aircraft project is to develop, validate, and evaluate a cabin demonstrator for turboprop aircraft (see figure 1).

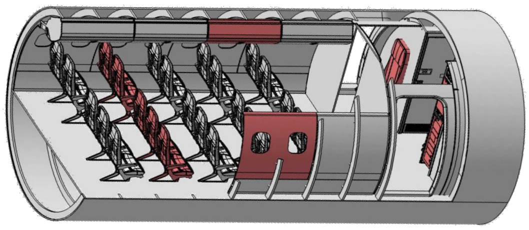

Figure 1. 3D CAD model of the turboprop cabin demonstrator.

2. Methods

To validate the turboprop cabin demonstrator, data of a real flight and of a simulated flight in the demonstrator are needed. The data from the real flights have already been collected, the data from the simulator will be gathered in the winter of 2023/24.

2.1. Procedure and measures of the real-flight

Two real flight observation studies were carried out in an ATR72-500 taking off and landing at the Rotterdam The Hague Airport, the Netherlands, in November 2021. During two 70-minute flights (see figure 2 for the exact test sequence), 94 subjects (52 participants during 1st flight, 45 participants during 2nd flight) answered questions about the following topics:

- Comfort rating about acoustic and thermal environment, vibration, air quality, light, and general comfort and discomfort (adapted versions of the Ideal Cabin Environment (ICE) Questionnaire (ICE Project, 2010), the Occupant Indoor Environmental Quality (IEQ) Survey [9, 10], ISO 28802 [11] and ISO 2631-1 [12])
- Postural sensations [13], spatial [13, 14] and visual perception [14]
- Mood [15]
- Symptoms ([16, 17], expanded by symptoms from reviews [18-21])
- Flight experience questions (adapted [22, 23])
- And other variables like intolerance of discomfort, noise sensitivity, and sociodemographic questions

The main questions are about the acoustic environment and vibration because they are particularly important for the characteristics of a turboprop aircraft. Consequently, the following questions were asked about the acoustic environment during ascent, middle of cruising phase, and descent:

- Comfort (1 = *no comfort*, 10 = *extreme comfort*) and discomfort (1 = *no discomfort*, 10 = *extreme discomfort*)
- Acceptability (1 = *very unacceptable*, 7 = *very acceptable*)
- Pleasantness (1 = *very unpleasant*, 7 = *very pleasant*)
- Loudness (1 = *very loud*, 7 = *very quiet*)
- Preferred loudness (1 = *much louder*, 7 = *much quieter*)
- Annoyance (1 = *not annoying*, 4 = *very annoying*)
- Open question: all sources of noise in the environment

Moreover, the following questions regarding vibration were asked during ascent, middle of cruising phase, and descent:

- Comfort (1 = *no comfort*, 10 = *extreme comfort*) and discomfort (1 = *no discomfort*, 10 = *extreme discomfort*)
- Acceptability (1 = *very unacceptable*, 7 = *very acceptable*)
- Pleasantness (1 = *very unpleasant*, 7 = *very pleasant*)
- Overall vibration and experienced vibration of different body areas (1 = *no vibration*, 5 = *very strong vibration*)

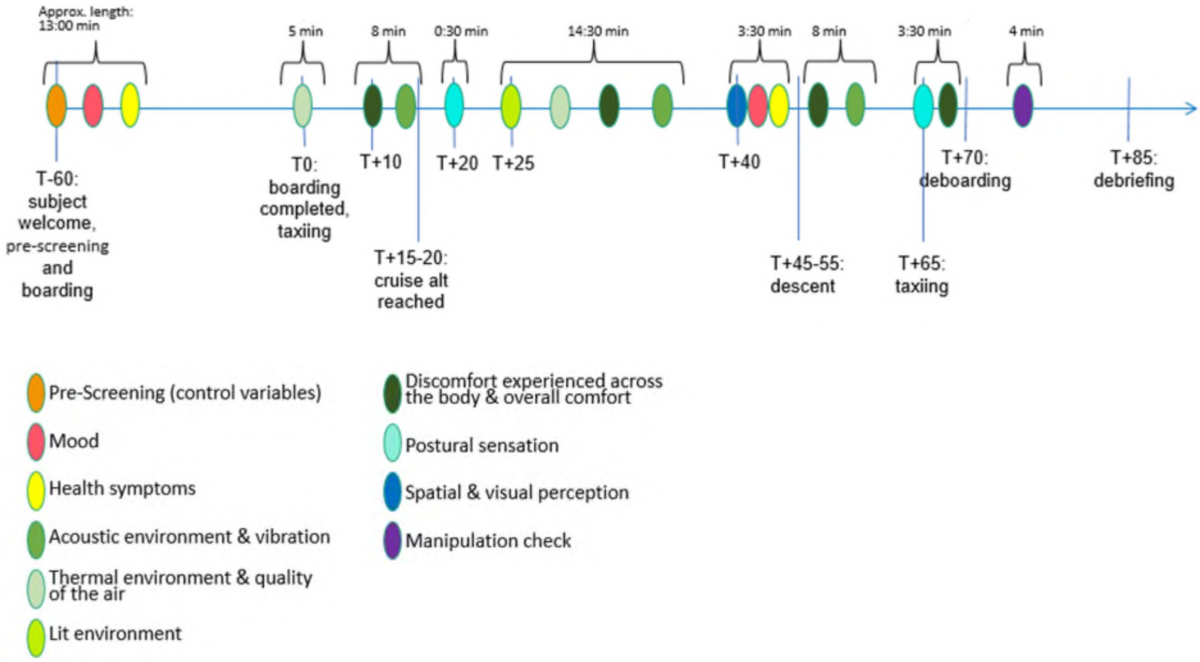

Figure 2. Test sequence of the real and simulated flights.

In addition to the questionnaire data, some environmental data were also collected, such as cabin pressure, temperature, humidity, CO_2, and noise. These data are used to create similar environmental conditions in the demonstrator and to verify it technically.

2.2. Planned investigations in the demonstrator

The Passenger Cabin Ground Demonstrator is a full-scale fuselage section of a future regional aircraft consisting of the door/galley area and five rows of seats. The demonstrator's aim is to validate innovative systems and human centered design concepts within the CleanSky2 Regional Aircraft project. The passenger cabin is a CleanSky JU Leader LEONARDO Aircraft Demonstrator for all aspects concerning research, technological maturation, design, manufacturing and integration. It will be in the course of the project transferred to Fraunhofer for thermal and comfort testing. Within Fraunhofer, the demonstrator will be equipped with an ECS (environmental control system) emulation system and an exterior conditioning to be able to thermally imitate the operation of the cabin section over a flight cycle. Noise and vibration will be simulated based on the measurements performed in the in-flight tests. For this, loudspeakers are distributed in the cabin and shakers are mounted under the seats. Tests on subjects will be performed in the demonstrator. A sample will be used that is based on samples recorded during the real flight. Where the sample deviates, the differences will be included as control variables. Conditions and questions will also be the same as in the real flight (see 2.1).

3. Results

3.1. Results of the real-flight

Overall, 58 men and 36 women participated with an average age of 33.86 ± 14.31 years. More than half of the test subjects already reported experience with a turboprop aircraft and indicated a positive attitude towards flying.

The results showed that noise is the biggest discomfort factor, but this discomfort decreased significantly over time. Vibration was rated as more comfortable than noise. It is slightly noticeable that the comfort of vibration increased during the flight. These results are shown in figure 3. Also in the evaluation of acceptability and pleasantness, it is evident that vibration was rated better than noise. Pleasantness of noise was rated worst, but increased significantly towards the end of the flight. Subjects preferred a quieter aircraft and perceived the noise as loud. Both points improved over time. The noise slightly annoyed the subjects throughout the entire flight. Air conditioning, engine, low or high frequency noise, and wind were a frequent responses when asked about noise sources. In addition, the subjects generally perceived less vibration, which also remained relatively constant over time. The perceived vibration of feet and thigh decrease significantly over time.

3.2. Results of the investigations in the demonstrator

Passengers' reactions in the demonstrator will be compared with the real-flight data by replicating all possible environmental conditions from the real flights in the demonstrator. The goal is that the questionnaire data fall within the confidence intervals of the real-flight data. If the demonstrator results are within the confidence intervals of the real-flight data, the validation was successful and the Passenger Cabin Ground Demonstrator can be used for multiple investigations. If the demonstrator results are not within the confidence intervals of the real-flight data, causes must be investigated. On the one hand, technical conditions can be a reason, on the other hand, it could be due to the sample. Therefore, it is important to check possible differences in the sample as well as to verify the technical aspects again. This process must be checked and repeated until the results of the real flight match those of the simulated flight, or if differences in the sample can explain the discrepancy, so that it can be assumed that the verification was successful.

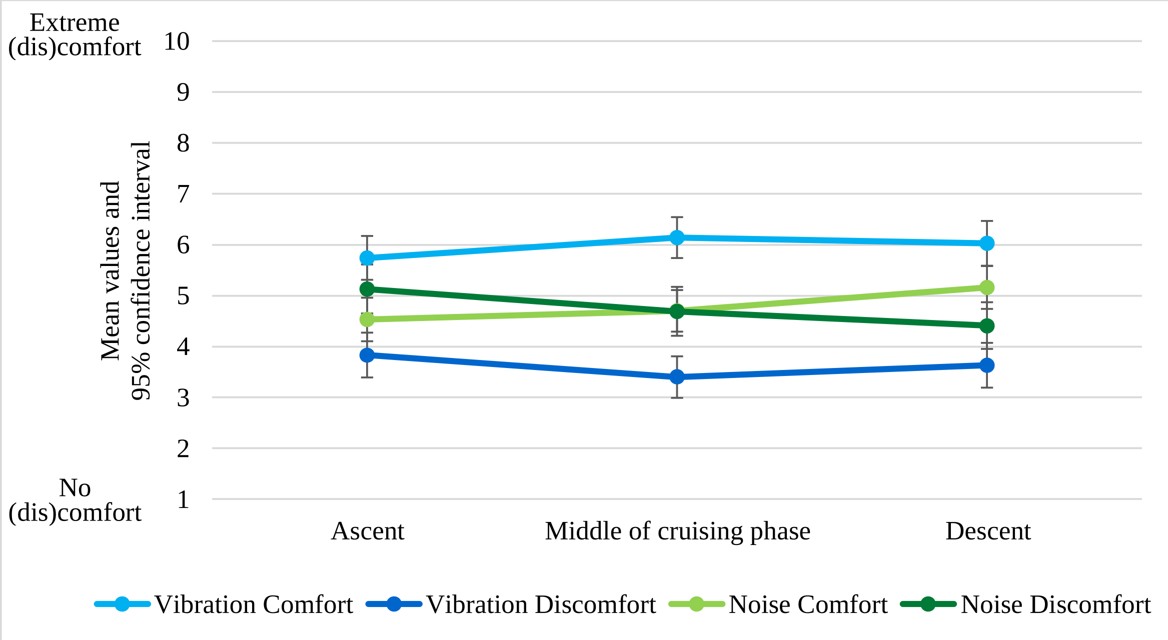

Figure 3. Comfort and discomfort from noise and vibration.

4. Discussion

Since turboprop aircraft are more environmentally friendly compared to turbojet aircraft but at the same time loud and prone to vibration, they should be improved. To investigate effective methods of improvement alternative design changes must be tested. The simplest method to conduct various test setups and subject studies is to use a demonstrator. But it is essential to validate the demonstrator to be able to transfer the results to real flights.

The results from the real flights were able to confirm other studies [e. g. 3, 5] that especially noise is the biggest discomfort factor for passengers. With this data, it is possible to validate the demonstrator. For this purpose, the same test setup used in the real flights needs to be replicated in the demonstrator and the demonstrator data must be within the confidence intervals of the real-flight data. The next step is to set up the demonstrator, to verify it technically and finally to perform tests on subjects. When the validation is successful, the cabin demonstrator can be used for different scenarios or other areas of application.

If it can be achieved to improve noise and vibration in a turboprop aircraft through the demonstrator, thus making the aircraft more comfortable, more passengers are willing to fly with turboprop airplanes. As a result, less fuel and CO_2 emissions are consumed on short-haul flights compared to a turbojet aircraft, which in turn has a positive impact on the environment. In our real-flight study, more than 80% of the participants would choose a turboprop aircraft again what is a good starting point to use these airplanes more frequently.

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CLEAN AVIATION

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