Design for comfort: Aircraft interiors design assessment through a human centered response model approach

31st Congress of the International Council of the Aeronautical Sciences
Belo Horizonte, Brazil; September 09-14, 2018

DESIGN FOR COMFORT: AIRCRAFT INTERIORS DESIGN ASSESSMENT THROUGH A HUMAN CENTERED RESPONSE MODEL APPROACH

S. Bagassi*, F. Lucchi*, F. De Crescenzio*, S. Piastra*

***DIN – Industrial Engineering Department,
University of Bologna, Italy**

Keywords: *Human Centered Design; Emotional Design; Virtual Reality; Comfort; Aircraft interiors Design*

Abstract

In a highly competitive global aviation environment, European regional aircraft requires continuous improvements in cabin comfort. This paper describes the design for comfort process proposed in an industrial research project, aimed at the definition of innovative design approaches to measure the affective impact on a potential user when living in and interacting with the cabin. The study is performed in the framework of CASTLE (CAbin Systems design Toward passenger welLbEing). CASTLE is a project granted under the Horizon 2020 EU's research programme in the framework of the Clean Sky 2 initiative. Requirements and recommendations for the comfort aspects to be taken into account to develop a regional aircraft's cabin were provided by Leonardo's Aircraft Division.

The methodological approach is set up in a Virtual / Augmented Reality Environment for the definition of a Human Centered Response Model for the design for comfort of regional aircraft interiors. In this context, special attention has been paid to the improvements that can be brought to the cabin interiors, and specifically to the experience that passengers can live in the aircraft of the future. The main objective of the project is to conceive, develop, prototype and test cabin interiors solutions following a HCD (Human Centered Design) methodology.

The paper analyzes the approach toward the definition of the design for comfort according to the considered cabin items and design requirements. The proper comfort metrics are selected and linked to an experimental protocol analysis for their assessment. A Virtual Reality environment has been set up to support the comfort assessment in aircraft cabin interiors, from their preliminary design.

1. Introduction

Air transport is a growing market: the air traffic is expected to double every 15 years, and the overall demand of new aircraft is estimated of 34,600 units by 2036. In 2017, 3.8 billion passengers traveled by aircraft.

In this scenario, comfort and emotional needs become significant requirements to be met by manufacturers and airliners in order to be effectively competitive.

According to the aesthetic economical model proposed in literature [1], comfort is perceived as being in an interesting, advanced and beautiful environment, available for a reasonable price. Nevertheless, time or cost constraints force designers to face trade offs and choices affecting the level of comfort perceived by the user. In the evaluation of alternative design solutions in the earliest design stages, the main issues are the availability of large and detailed mock-ups and of methods to capture user's perception in terms of emotional feelings inspired by different proposals. Therefore, the Human Centered Design (HCD) methods developed in the framework of industrial design can be

implemented in aircraft interiors design, with the final objective to define a Human Response Model for comfort assessment and design solution evaluation.

The research is performed in the framework of CASTLE [1] (CAbin Systems design Toward passenger welLbEing): the project has received funding from the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No CS2-AIR-GAM-2014-2015-01.

Clean Sky is the largest European research programme [2] developing innovative, cutting-edge technology for aircraft. Clean Sky 2 is structured in a number of demonstrators that cover the aeronautical industrial innovation needs; during the development of CASTLE project it is foreseen to provide solutions and prototypes for the Airframe Integrated Technology Demonstrator. In this context, special attention has been paid to the improvements that can be brought to the cabin interiors, and specifically to the experience that passengers can live in the aircraft of the future. The main objective of the project is to conceive, develop, prototype and test cabin interiors solutions following a HCD approach.

The design flow will be defined for each cabin item keeping in mind the user's requirements and considering the evolution of requirements at the time the CASTLE solutions will be available.

This paper deals with the definition of the Human Centered Design approach proposed for the comfort evaluations of design solutions created in the framework of the CASTLE project, focusing on the methods to capture the comfort feedback of potential users in Virtual Environments. The tools and methods are identified and an experimental case study is proposed as preparatory for comfort assessment in case of business jet aircraft.

In the paper, the general CASTLE HCD approach is described and a more detailed definition of the materials and methods for the experimental planning is proposed. Finally the description of a representative Case Study is presented.

2. HCD in cabin interiors design

According to ISO 9241-210:2010 (International Standard that provides requirements and recommendations for Human-Centered Design) HCD is an approach to interactive systems development that aims to make systems usable and useful by focusing on the users. Although such standard has been set for computer-based interactive systems, the workflow and the methods are recognized as a rule for any system interface design [3].

The standard describes six principles of HCD: the design is based upon an explicit understanding of users, tasks and environments; users are involved throughout design and development; the design is driven and refined by user-centered evaluation; the process is iterative; the design addresses the whole user experience; the design team includes multidisciplinary skills and perspectives.

According to such analysis, the Human Centered Design process proposed in CASTLE is presented in Fig. 1.

Fig. 1 CASTLE HCD Approach

A Human Response Model will be developed to evaluate the potential design solutions at any stage of the design development. The definition of user expectations and key design drivers guide the definition of users requirements and comfort metrics. A set of evaluation criteria and

[1] The CASTLE Consortium comprises eleven partners, all providing a strongly multidisciplinary R&D team. The CASTLE consortium is coordinated by GEVEN S.p.A.. The contents of this paper reflect only the author's views and the Clean Sky 2 Joint Undertaking and the European Commission are not liable for any use that may be made of the information contained therein.

evaluation measures must be defined in order to collect all the information needed to validate the design solutions. This is usually performed by showing the prototypes to users, observing them as they perform specified tasks and using their feedback to improve the design, since the early design stages. This process is iterated until design objectives are met.

Comfort assessment implies both objective and subjective ratings, as well as aircraft interior design is guided by ergonomics objective criteria and emotional, aesthetical and feelings principles. In the evaluation of alternative design solutions in the earliest design stages, the main issues are the availability of large and detailed mock-ups and of methods to capture user's perception in terms of emotional feelings inspired by different proposals. In fact, since the comfort and well-being are subjective and qualitative assessments of a product's or service's user, the evaluation of alternative configurations is commonly based on subjective rankings that participants perform by filling questionnaires during or after experiencing a prototype of the product [4]. The final real challenge is related to the development of methods and criteria on the evaluation of products' overall comfort performances ([5], [6], [7], [8]).

Subjective state of comfort and well-being can be measured through questionnaire survey using psychometric scales. Psychometric scales are the most widely used methods in survey research. They require the raters or respondents to assign a value, sometimes numeric, to the rated object, to quantify estimations of variables such as feeling, opinions or attitudes, that cannot be measured directly, or when their values cannot be observed. A Likert Scale is typically a 5, or 7, or 11 (i.e., even number) point scale, which asks a user to express how much they agree or disagree with a statement.

In the conceptual design phase the methods that allow evaluating design solutions against user's requirements through virtual simulations should be considered. This includes scenarios and conditions that can be representative of the human's experience in the cabin. A Human in The Loop simulations approach is considered: it refers to the creation of a simulated environment, mainly a virtual environment, in which a real user is immersed and is asked to perform a specific task while his or her feedback is collected. This class of simulations aims to assess the user satisfaction level of each design solution, which is a major requirement for the comfort and well being of the passenger.

The assessment is performed through the comparison of different design solutions with ratings and / or ranking approaches. Subjective state of comfort and well-being is measured through questionnaire survey using psychometric scales. Together with the subjective ratings of comfort also objective measures of the comfort perceived by the user during the Human in the Loop simulations in virtual environments will be studied and, once the method will be tuned, it will be implemented in CASTLE validations. These measures are defined as psychophysiological and are used to denote physiological responses of the human body, which can be monitored in a non-invasive way and are affected by psychological or mental processes. Hence, their measurement allows a quantitative assessment of cognitive states, including mental work, arousal, stress-strain processes, fatigue, discomfort and emotion. At present, analysis of psychophysiological measurements is considered the more natural way to provide a quantitative assessment of comfort, since any factor affecting stress and discomfort or fatigue has a clear impact on physiological activity.

A second comfort assessment method is based on the Human Model in the Loop simulation, to capture the human's feedback at preliminary design. It refers to the use of mathematical models of the human body and of its behavior in a 3D environment. Virtual Manikins refer to this class and are a valuable tool to assess the ergonomics aspects such as the living space of a seat and of a specific lay out of the cabin.

The complete CASTLE evaluation procedure is depicted in Fig. 2. The focus of this preliminary research activity is the validation of the methodology proposed in the human in the loop simulation for cabin interiors design. The process will be further integrated with both subjective and objective evaluation and with the human model in the loop simulation. Finally, results coming from the different approaches will be

compared and properly combined to derive a global comfort index for the proposed design solution. It can be used to quantify the comfort state and summarize the measurements in a straightforward quantitative way. The same approach will be used for the evaluation of the design of both regional and business jet cabin interiors.

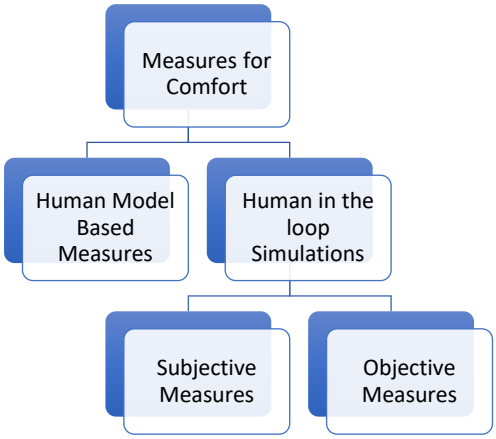

Fig. 2 Overall evaluation procedure foreseen in CASTLE for comfort assessment

3. Methods and tools for implementing and experimenting comfort in the design of cabin interiors

The HCD approach is at the basis of the design for comfort method applied for cabin interiors design, defining criteria and measures to evaluate cabin design solutions, against usability, ergonomics and comfort requirements, throughout a holistic approach. Such method considers the major of the comfort metrics relevant in cabin interior environment (such as visual, interactive, postural, living space, vibro-acoustic or tactile) and cope whose assessments in a multidisciplinary manner, till the early design stages.

To this aim, starting from the analysis of both key drivers and design requirements, a list of the most relevant comfort, ergonomics and usability variables are considered in the cabin design.

In the framework of CASTLE project, comfort design is associated to the evaluation of alternative design solutions in the earliest design stages: mock-ups are implemented in Virtual/Augmented Reality environments and methods to capture user's perception are considered in terms of emotional feelings inspired by the different proposals. Human in the loop assessment approach is implemented to evaluate user comfort, provided by the emotional feeling arose within the virtual experience. Questionnaires are considered to subjectively evaluate the design solutions during or after experiencing a prototype of the product, or on objective metrics collected by physiological measures. According to Kuijt-Evers et al. [9] analysis, questionnaires are voted to cope with three main categories of descriptors of comfort, in relation to the perception / use of each element:

- functionality (e.g., reliable, working, effective);
- physical interaction (e.g., easy to use, safe, comfortable);
- appearance (e.g., styling, nice colors, professional design).

Starting from design requirements and cabin items, comfort metrics are derived, in order to define the foreseen type of analysis, the measurement method and the simulation approach. Comfort assessment is achieved through:

- visual comfort;
- interaction comfort (usability, ergonomics such as reachability, accessibility and visibility);
- postural comfort (including postural angle, sitting pressure distribution, surfaces of contact);
- living space comfort.

The Experimental Procedure Plan consists of a set of methodological procedures, defining the approach for tests execution. Comparative evaluation should be considered among different solutions, configurations or differences in colors and materials selection, according with the provided 3D models.

In the Human in the loop experiments, comfort metrics are evaluated in a virtual environment, in which a proper number and combination of voluntary subjects experience a virtual mock up of one or more cabin items.

The experimental procedure is composed of three steps:

1. experimental planning;
2. experimental execution and data collection;
3. data analysis and reporting.

The experimental plan starts with provision of the 3D CAD models, including color and material features, from the design domain to the evaluation domain.
3D models contribute to the definition of a scenario and a storyboard of tasks to be simulated in the virtual environment, to assess the comfort metrics of each cabin item. The preliminary phase consists in the set up of the Virtual mock-up in a semi-immersive Virtual Reality Environment. The experimental requirements are refined in order to define user involvement in the experiment and the questionnaires and / or comfort measurement procedures for evaluation assessment.
During the second phase, the experiment is run, and, finally, a questionnaire results the subjective rating evaluation. In the final reporting phase experiment outputs are collected and the data are analysed. **Table 1** provides details of each phase and a description of the tasks to be performed.

Human in the loop assessment	
Experimental Planning	Item vs comfort metrics: mapping to protocol analysis VR system Model type and features/configurations Storyboard description Questionnaire definition for subjective evaluation assessment Users to be involved/experimental total timing
Experimental Execution and data collection	Recruitment and Scheduling User training Run of the experiment Questionnaire provision and debriefing
Analysis and Reporting	Collection Analysis of data coming from the experiments, in relation of simulation method and subjective ranking Reporting

Table 1 Description of the processes for the Human in the loop assessment

4. Case Study

The proposed methodology aims to define a HCD approach for comfort assessment for novel and future aircraft interiors design. To this aim, a test case is considered and a Virtual Reality environment is set up for the purpose.
The 3D CAD model of a novel business jet aircraft is preliminary considered for validating the comfort assessment process.
Future business jets have to be office centered, aesthetically pleasant, and luxury feeling. Cabin areas should preserve private space, while another functional zone should be voted to socializing, dining or having meetings. The user experience is the key issue of the design.
According to this purpose, the Virtual Reality domain is supporting the design domain, with a twofold usage of Virtual Reality systems: Virtual Reality can support the conceptual design process both in the down selection of design solutions and in the validation of the proposed solutions. More architectures are set up, according to simulation requirements, users to be involved in the same simulation session and functions to be provided. In concept validation phases, single user simulation is considered, while in debriefing session multiusers are expected. On the other hand, in concept selection processes and design review sessions, more users (multiusers interface) are required to take part to the same virtual session, mainly designers, developers or researchers. The main functions to be provided to the simulation are:

- user-friendly navigation of the virtual model;
- introduction of User-model Interaction systems;
- capability to compare different design alternatives in terms of texture, light positions, seat layout in the cabin, different lining and stowage bin solutions, different combination of seat features like tray table, seatback and armrest positions;
- capability to verify part interferences in the CAD model;
- realism (texture, light emission properties, materials appearances, etc.) levels could be different according to the objective of the verification.

Several Virtual Reality technologies are considered as useful to meet simulation

objectives, as proposed in Fig. 3. Screen Projection Systems and Head Mounted Displays compose the VR architecture. Screen projection systems enhance the collaborative design review, since more users can participate to the same Virtual Environment even if with different levels of interaction and presence. In particular, Cave Automatic Virtual Environment – CAVE – is an active 3D stereoscopy system based on rear-projected screens; it is coupled with interactive systems, that allow to a single user to cooperate with the Virtual Environment and the scene. On the other hand, Passive Stereo Theatre – PST – is a passive 3D stereoscopy front projected screen. It is devoted to design review and debriefing sessions since it is particularly useful in multi-users applications with low level of interaction among user / virtual scene, but properly addresses the requirement of creating a user friendly environment to perform preliminary tests or multidisciplinary sessions.
Head Mounted Display (HMD) allows higher immersion of the user in the scene, with high interaction and low presence. A single user will experience the Virtual Environment at each experimental session. See-through Head Mounted Display is test to enhance user presence in the interaction with cabin items, similarly to an Augmented Reality tool. It can also be used in couple with Screen Projection Systems to better assess spaces and environment.

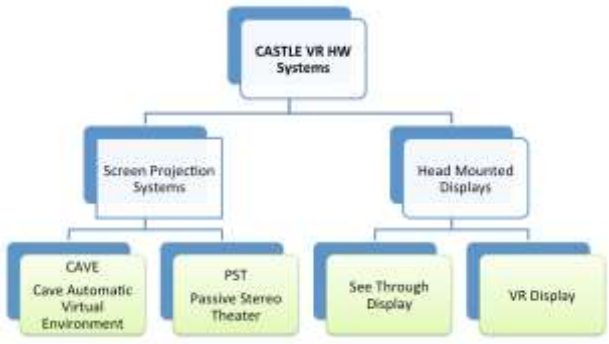

Fig. 3 Virtual Reality architecture used for cabin comfort design assessment

A 3D CAD model of a novel business jet cabin configuration has been provided in the framework of CASTLE project and used to validate the methodology. The entire geometric model of the business cabin is loaded in IC.IDO Software, to be processed and to create the virtual scenario. IC.IDO.® is a 3D immersive VR software, provided by ESI® Group, supporting industrial decision making processes and digital mock-up verifications. The model is completed with materials and textures information (Fig. 4); the virtual environment is loaded in PST (Fig. 5), CAVE (Fig. 6), and see-through HMD (Fig. 7), at the Virtual Reality Laboratory at University of Bologna facilities.

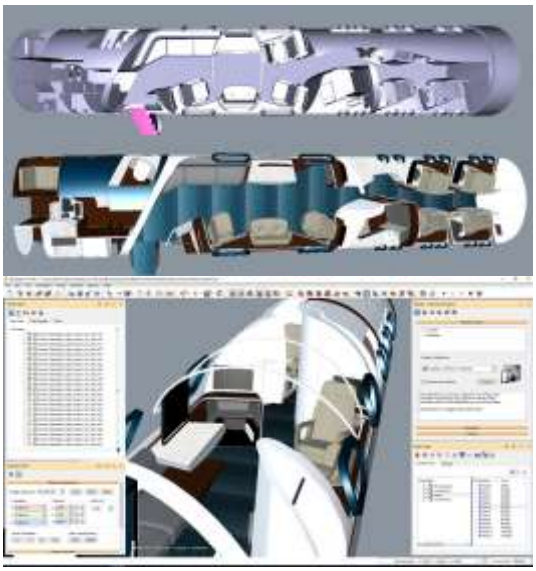

Fig. 4 Processing of the business jet 3D CAD model

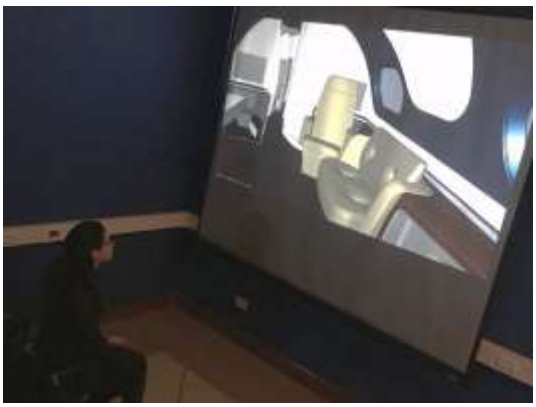

Fig. 5 Visualization of the Virtual Scenario in the Passive Stereo Theater

While in the design review domain only the navigation of the model by designers and experts of the team is foreseen, in the validation domain a storyboard is provided, potential users are recruited and settled into the virtual environment, and, finally, a proper evaluation procedure is considered.

Fig. 6 Navigation of the business jet model in CAVE

Fig. 7 Virtual Scene as displayed on HMD

5. Discussions and Developments

This paper reports the study on the tools and methods to measure comfort and well being in Virtual Reality environments for the assessment of the CASTLE cabin prototypes. The approach aims to enhance the Human Centered Design in cabin interiors for future aircraft and is based on the introduction of innovations in the type of measures used to collect the feedback of users involved in human in the loop simulations.
The process will be iterated along the entire duration of CASTLE. The tools and methods to capture the user's feedback in the early design phase - both subjective/qualitative and objective/quantitative - can be adapted to the high maturity level of the physical prototypes that will be produced in the late phase of the project.

References

[1] Dumur E, Barnard Y and Boy G. Designing for comfort. *Human factors in design*, pp. 111-127, 2004.

[2] www.cleansky.eu

[3] ISO 9241-210:2010, Ergonomics of human-system interaction -- Part 210: Human-centred design for interactive systems.

[4] Kim, C., Lee, C., Lehto, M. R., & Yun, M. H, *Affective evaluation of user impressions using virtual product prototyping*. Human Factors and Ergonomics in Manufacturing & Service Industries, 21.1, pp 1-13, 2011.

[5] M. P. De Looze, L. FM Kuijt-Evers, and J. A. A. P. Van Dieen, *Sitting comfort and discomfort and the relationships with objective measures*, Ergonomics 46.10: 985-997, 2003.

[6] Moes, N. C. C. M. "Analysis of sitting discomfort, a review." Contemporary Ergonomics 2005 (2005): 200-204.

[7] P. Vink, S. Hallbeck, Editorial: *Comfort and discomfort studies demonstrate the need for a new model*, Applied Ergonomics, Volume 43, Issue 2, March 2012, Pages 271-276, ISSN 0003-6870, http://dx.doi.org/10.1016/j.apergo.2011.06.001.

[8] Naddeo, A., Cappetti, N., Vallone, M., & Califano, R., *New trend line of research about comfort evaluation: proposal of a framework for weighing and evaluating contributes coming from cognitive, postural and physiologic comfort perceptions*. In Advances in Social and Organizational Factors, Edited by Peter Vink, Published By "Advances in Human Factors and Ergonomics" Conference, 2014.

[9] Kuijt-Evers, L. F. M., et al., *Identifying factors of comfort in using hand tools*, Applied Ergonomics 35.5 (2004): 453-458.

8 Contact Author Email Address

sara.bagassi@unibo.it
f.lucchi@unibo.it
francesca.decrescenzio@unibo.it

Copyright Statement