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Aircraft Preliminary Design: a windowless concept

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ABSTRACT

This paper describes the preliminary design of a short-medium range windowless aircraft, with the aim to reduce fuselage weight. As a matter of fact, the aircraft weight reduction is the main element to reduce fuel consumption providing advantages in terms of operational costs reduction and environmental impact of the flight operations.

An innovative solution based on OLED (Organic Light Emitting Diode) technology is considered to improve passengers' comfort avoiding claustrophobic effects that can arise from the elimination of traditional windows. A traditional configuration is considered as reference: weight and cost reduction provided by the introduction of a windowless configuration are assessed by means of analytical study.

Moreover, the preliminary design activity has been coupled with the development of a digital mock-up. A small-scale demonstrator of the selected configuration has been manufactured by means of a rapid prototyping technique.

1 INTRODUCTION

Next generation aircraft will have to face the challenge of 4.6 per cent year growth of air traffic together with even more strict constraints in terms of environmental impact (source: Airbus Global Market Forecast 2015-2034). As a matter of fact, the aircraft weight reduction is the main element to reduce fuel consumption providing advantages in terms of operational costs reduction and environmental impact of the flight operations.

Windowless concepts are considered a challenging solution for innovative aircraft configurations, in order to reduce weights and manufacturing and operating costs, or to increase performances and flight ranges. The windowless concept has been explored in literature by means of preliminary studies in the following fields of application:

I. Windowless cockpit
II. Windowless cabin as a consequence of blended wing body configuration
III. Windowless cabin as an alternative solution to reduce weight in traditional cabin design

The windowless cockpit concept has been promoted in Europe by Airbus. The concept described in [1] removes the windows or reduces them to partial views of the outside world aiming, at the same time, to widen the pilot's field of view by means of a display formed by back projection, lasers, holograms, or OLED imaging systems fed by cameras outside the fuselage.

The removal of traditional windows in the cockpit is often considered as a further development of Enhanced Cockpit Visual and Flight Information System (ECVFIS) environment initially developed to enhance situation awareness and/or decrease workload.

In some studies the concept proposed includes total removal of cockpit windows and replacement with an up to 360° visual system where visual information are obtained by all-weather cameras (LLLTV/IR) and presented via collimation visual all around the pilot [2].

The total absence of opening in the blended wing body cabin is one of the major obstacles to the success of that configuration for large passenger aircraft. This is mainly due to the inability to provide an adequate number of safety exits. Moreover, the lack of external view for the passenger is considered as a severe limitation for that configuration and, in order to overcome that issue, some windowless cabin concepts have been developed [3] [4].

As far as structural design is concerned, the removal of windows from a passenger aircraft is nothing but a simplified version of the fuselage. It implies the removal of all the openings - except for doors and safety exits – together with the relative reinforcements.

Thus, the main challenge for such a configuration is to provide passengers with the same comforting aspect of a traditional window, avoiding any claustrophobia feeling. Since it is a psychological reaction to an uncomfortable condition, one of the most promising solutions is to recreate a condition similar to the one provided by fuselage windows, by the introduction of artificial views trough high fidelity displays. Some concepts described in literature make use of huge displays in order to provide a wider view than the one offered by the traditional windows.

The proposed windowless concept plane intends to keep the traditional cabin arrangement while replacing window holes with hidden screens. The proposed concept has some advantages compared to the other mentioned: i) it does not require a complete redesign of the cabin and its electrical system, ii) it can be directly implemented on existing cabin designs, iii) it minimizes modifications to cabin interiors making people more confident with the interiors configuration.

2 CONCEPT DESCRIPTION

The proposed concept considers a regional aircraft as reference configuration, evaluating a windowless design solution that implies the following benefits:

- fuselage structure is lighter and, consequently, fuel consumption is lower and the environmental impact is minor;
- the manufacturing modes are simpler so that the related costs are lower;
- the fuselage structure is more resistant to fatigue damage.

It is known that in aviation industry the weight and the fuel consumption are fundamental parameters. A lighter plane means less fuel consumption, consequently less CO_2 emission and more affordable tickets.

On the other hand, to get benefits, some challenging issues have to be considered in the design process in order to take advantage of such a concept. Passengers' comfort is one of the main requirements that a windowless concept has to take care of. The claustrophobia feeling is one of the most important obstacles to the introduction of such a concept.

In this study, windows have been replaced with HD flexible OLED screens connected to external cameras, while a common cabin layout has been considered, to allow passengers feel more comfortable with the cabin environment. Further interactive functions are added to the screens allowing the user to select a preferred view among the unfiltered images from the outboard camera or add georeferenced geographical information or weather conditions at the arrival. When landed, the crew can make use of the cameras to check ground to be clear from FOD (Foreign Object Debris). Further functions could be implemented according to airliners requirements, such as:

- the possibility to take pictures of the outside world from the camera incoming video and download them on personal smartphone;
- the possibility to receive superimposed geographical information about the places flying-by;
- the crew can get live images by the outboard cameras so that, for example, in the case of an engine failure they could evaluate with their own eyes the problem's entity and could monitor it during the flight;
- the crew can use the screens in order to communicate in a better way with the passengers: for example, during a safety landing, the screen could display the nearest exit or the correct passengers' attitude.

When compared to the reference configuration, the cabin seems exactly the same as air travellers are used to, in order to achieve an internal cabin layout, which would results comfortable for passengers. Thus, passengers are expected to better accept the idea that windows are actually screens representing images captured by external cameras.

Windowless concepts usually lack in the development of the visualization system and tools, with the result of a poor realistic view: passengers view is expected to be of high quality and the projected image to be associated to passenger position in the aircraft changing from line to line and from site to site. The proposed system aims at solving this fundamental issue taking advantages of optic systems and advanced video technologies. The space between the false windows and screens is exploited to provide different images in function of the line-of-sight angle, giving the sense of perspective, as stereoscopic or eye-tracking system would result too intrusive for the users.

3 DESIGN METHODS AND TOOLS

The proposed windowless concept arises as a trade-off between outer reach technology-driven solutions that fully exploit the most innovative visualization technologies and an application driven approach starting from users' needs.

A deep analysis of the state of the art related to available and future technologies has been firstly performed. The latest outcomes in OLED screens technology and the improvements expected in the next years have been investigated in order to define currently available technologies and the main advances that are foreseen in the next future, when a windowless project could be finally considered for the marketplace.

As far as users' opinion is concerned, the results of a previous survey conducted by a group of students at the University of Bologna were considered. They showed that about the 80% of usual passengers would not travel by a windowless plane mainly because they would expect to feel claustrophobic. The same study showed that most passengers are interested in potential additional functions provided by the proposed concept such as taking pictures directly from the outside cameras, getting geographical information displayed on the screens or checking weather conditions at the landing site on their own window/screen.

The preliminary design activity has been coupled with the development of a Digital Mock-Up (DMU) representing all the features included in the concept. The use of DMU allowed to measure data relevant for the concept assessment, moreover it permitted to make some preliminary evaluation about the ergonomics of the design solution.

A small-scale demonstrator of the selected configuration has been manufactured by means of rapid prototyping techniques. It represents a portion of the fuselage in 1:10 scale. It consists in three main subsystems: i) the cabin/fuselage shell ii) an LCD 4.3" screen connected to iii) a camera system.

Starting from a simplified version of the DMU, the small-scale cabin/fuselage shell has been manufactured by means of Additive Manufacturing techniques exploiting a Fortus 250 3D printer. The shell has been assembled with the screen and a camera system in order to obtain a small-scale prototype of the whole system. The prototype can be used both for design review purpose and for dissemination of the concept.

Finally, the main benefits from a windowless design solution have been assessed and compared with the reference aircraft. Weight and cost saving and CO_2 emission reduction are evaluated. A numerical method is developed to estimate advantages, both from a design and an economic point of view. The stress on the fuselage has been computed, on the basis of the state of the art equations and rules, in order to evaluate the impact on structures from windows removal. The "neutral-hole stress theory" is used for defining structural equations and evaluates variations in structure's weights. This theory is usually considered to calculate necessary reinforcements to make holes in the fuselage without loosing is structures strength. In this case, this theory is considered for calculating the reinforcement that would not be necessary anymore removing windows holes from the fuselage. In this way, the neutral-hole theory gives approximation of the weight reduction, through the removal of structural components commonly used to make the stress on the window hole neutral.

On the basis of the resulting weight reduction, a cost analysis is performed. Some important factors related to reduction in fuel consumptions and consequently in CO_2 emissions are considered. The savings for a single medium range mission are firstly estimated, than a full year data and finally the whole lifetime of an aircraft (approximately 25 years) are evaluated.

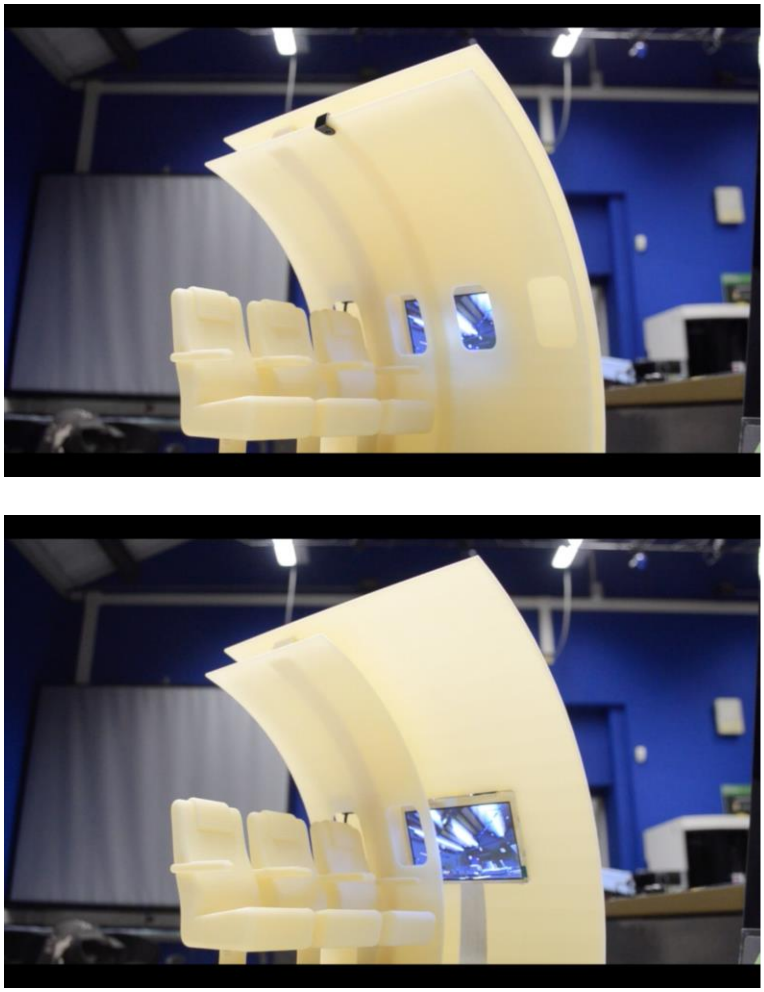

Fig. 1 The small-scale demonstrator of the proposed concept

4 DISCUSSION OF RESULTS

The weight savings are evaluated by comparing the central fuselage section for the windowless and the common configuration of an A320; the total weight of all Plexiglas/Lexan plane and the weight due to structure reinforcement are calculated. Standard densities for Lexan end Plexiglas are used to evaluate the windows weight.

Considering N=64 windows, the saved weight is:

$$W_{windows} = A * N * [\rho_{lexan} * (t_1 + t_2) + \rho_{plexiglas} * \ t_3]$$

Where t and A represent thickness and the area of the three layers used in windows respectively.

The windowless fuselage is then considered:

$$W_{skin\ only} = D * L * t * \rho_{alloy} * \pi$$

$$W_{near\ hole\ reinforcement} = 2 * L * \left(t_{reinforcement} - t\right) * \rho_{alloy}$$

$$W_{window\ metal\ frame} = \sqrt{2} * A_0 * k * b_{semiminor\ axis\ of\ window} * \rho_{alloy} * N_{window}$$

$$W_{alloy\ removed} = 2 * a_{semimajor\ axis} * b_{semiminor\ axis\ of\ window} * N_{window} * \rho_{alloy} * t$$

$$W_{montor\ camera\ and\ systems} = (W_{monitor} * N_{window} + W_{camera} * N_{cameras}) * X$$

In the last equation X is a coefficient slightly major than one that considers the extra weight associated with the installation of each monitor and camera, accounting for structures and cables.

The weight of the windowless fuselage is then assessed against the weight of the traditional fuselage:

$$W_{trad\_fuselage} = W_{skin\ only} - W_{alloy\ removed\ to\ make\ windows} + W_{window\ metal\ frame} + W_{near\ hole\ reinforcement} + W_{windows} = 2155.4kg$$

$$W_{windowless\ fuselage} = W_{skin\ only} + W_{montor\ camera\ and\ systems} = 1560kg$$

According to available data, the weight saving is around 600kg, about 30%. A lighter structure can be tuned to save further weight in other systems too: for each kilogram saved during the design phase, the total plane weight decreases by 1.25 kg. According to this classical assumption, the proposed concept should bring a saving of 750kg.

Weight is always associated to a decrease in fuel consumption. On the other side the building of a complete new fuselage will introduce new costs to reorganize the production line. Considering a standard mission the fuel consumption is estimated. Results are extremely encouraging: 1.2% saved, money speaking a single flight costs about 235$ less. Assuming that the plane has the possibility to achieve two flights a day, 315 days a year, the airlines would save about three million dollars. Considering the environmental aspect, the CO_2 emission is about 2.5 kg per litre of fuel that means that the windowless concept would produce 570 kg less CO_2 than the traditional configuration. It represents just one point per cent of the total emission, but when multiplied by the number of aircraft operating (about 3600 Airbus A 320 today) they would spare four million kilos of CO_2 each day: the equivalent of 1.000.000 cars.

5 CONCLUSIONS

The proposed concept addresses the challenge of a green and affordable air transport system in an effective way. It is a first step in a development process that needs more accurate and deep analysis. The stresses analysis performed took into account just the static design criteria. The proposed method evaluates the stresses acting on the structure near the window-holes and obtains the amount of weight saved with a good approximation. Further studies of the structural design, for the definition of more convenient structural solutions of the fuselage would lead to a more precise estimation of the weight saving. It would be also important to get a deeper analysis of fatigue and damage tolerance behaviour of a windowless-structure.

As already cited, a mass reduction in any system of the airplane implies lower fuel consumption. Than the total weight is even lower and, for example, lighter landing gear could be sufficient to carry the plane weight. This process could improve weight savings of about 25%.

Furthermore, the fact that there is no more structural limitation on the windows sizes means that people could enjoy views of the outside panorama bigger than actual ones. According to different airlines, it could be possible to redesign the cabin layout so that first class passengers could enjoy wider screens, while the rest of the fuselage is equipped with standard monitors. Further developments will include an estimation of the extra power requested by the screens and cameras system together with an analysis of maintainability of the whole system.

6 REFERENCES

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