14. A FLIGHT WITH A VIEW

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14.1 Introduction

Windows in commercial passenger aircraft have not changed considerably in the past decades. The reason for this evolutionary standstill is not entirely clear, but one reason might be the conservative nature of the airplane industry. Windows in modern buses and trains are much larger in comparison with the small cut-outs found in current airplanes. This is due to the fact that the size of windows is critical for the structure in airplanes. Aircraft manufacturers avoid risks and expensive research by replacing the old window designs into their new products. As a result aircraft windows are always small. Passengers currently have an increasing demand for comfort which is directly linked to a better view. The most trivial manner to adhere to their demands is by increasing the window area and therefore increasing their view. New technologies and materials that have been developed in the last decades can assist in accomplishing this.

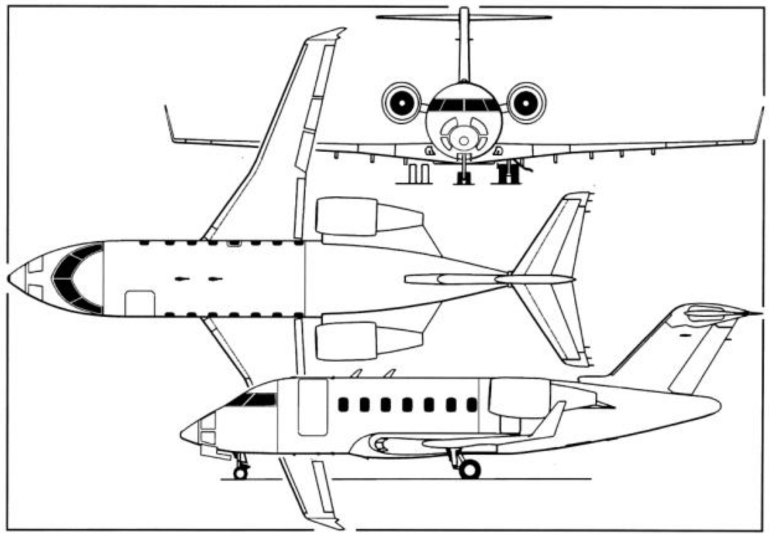

Figure 14.1: Bombardier Challenger 601

14.2 Requirements

In this project the team is assigned the task to double the effective view of passengers flying with a small aircraft, similar to the Bombardier Challenger 601 (as can be seen in figure 14.1). The goal is to come up with a conceptual design of the window and the fuselage around it. To reach this goal, materials that are still under research, like self-healing aluminium (SHA) and transparent load bearing composites can be used. In addition to physically increasing the windows, optical tricks like mirrors or prisms can also be used. One restriction in this area is the use of LCD screens. The use of such electrical solutions has been excluded by the customer as part of the project requirements. Research has shown that passengers do not consider this visual aid as the actual view outside the aircraft. Furthermore, the improved design must be weight neutral. This means that the redesigned fuselage cannot weigh more than the original. The last requirement is the new design has similar maintenance properties to the original aircraft. Maintenance intervals should stay the same or even increase.

14.3 Current window design

In order to be able to redesign aircraft windows, it is important to understand how they are currently constructed. The windows in aircraft can be seen as cut-outs in an otherwise perfect aluminium cylinder. Aircraft cruising at high altitudes have pressurised cabins. This pressurisation causes tensional forces in the skin. The result of these tensional forces can be seen in the schematic picture shown in figure 14.2. It is clear that around the windows stress concentrations will appear, since the windows themselves cannot transfer loads. As a consequence, the windows need to be surrounded by heavy reinforcements. This is the basic concept behind current aircraft windows. The reinforcements carry the loads and the polycarbonate of the window just maintains the pressurisation.

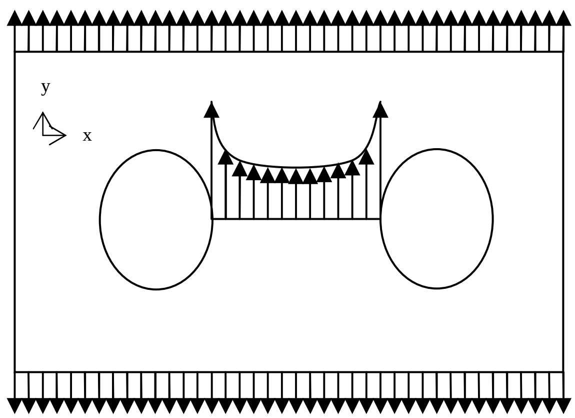

Figure 14.2: Stress concentrations around cut-outs loaded in tension

14.4 Concepts

In order to achieve the goal of doubling the view, extensive research was done to come up with different concepts. This research was split into two parts: structural and optical solutions.

Structural solutions
The most straightforward way to increase the view is to increase the size of the windows. To counteract the larger stress concentrations that

follow from this, several concepts were addressed. The fuselage could be made of a different material. Composites, GLARE and SHA are all good candidates to replace the standard aluminium. SHA has the capability to repair micro cracks that occur due to the cyclic loading of the pressurisation. Using this material would make fatigue less critical and would mean that fewer reinforcements will be necessary around the windows. The same is true for a fuselage made of composites or GLARE.

Another approach to the challenge is to replace the polycarbonate of the window. Polycarbonate has good impact properties and is excellent for standard aircraft windows. However, polycarbonate cannot be loaded under tension. Replacement by another transparent material that can handle the tensional loads would make the windows load-bearing. As a result, the peak stresses, which can be seen in figure 14.2, will be smaller. This solution would mean that fewer reinforcements are necessary.

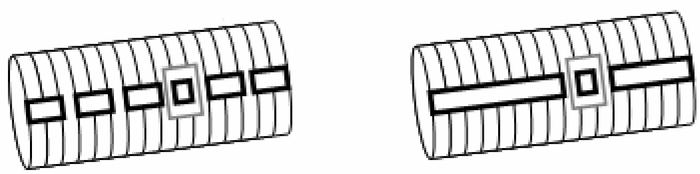

Figure 14.3: Left: conventional, discrete windows. Right: Stretched windows.

Considering the shape of the windows, two concepts were investigated. The first option would be to keep the windows discrete and just increase their size. The second option is to have large stretched windows that span the side of the aircraft. A schematic representation can be seen in figure 14.3.

Optical solutions

Instead of increasing the size of the windows, optical solutions were considered as well. Mirrors placed next to windows in between the inner and outer pane could increase the perceived view. Another option is the use of prisms to deflect the light. The inner part of the window can be covered with a thin prism film. Passengers not directly beside the window can still be able to look through it and have a nice view.

Trade-off

After several weeks of investigations, one final concept had to be chosen. It was decided that the optical solutions could be implemented with every structural solution, so these were left out of the trade-off. The criteria used were: view increase, weight, technical feasibility and maintainability. The trade-off resulted in the conclusion that the stretched window was a better option than the conventional discrete windows. To be able to accomplish this, a load-bearing material would have to be used to replace the polycarbonate. For the fuselage self-healing aluminium was chosen to be the best material. Using this, aircraft manufacturers specialised in aluminium airplanes would not have to change their production lines.

14.5 Final design concept

Incorporating a stretched window in an aircraft structure introduces a large weakening of the structure. Simply introducing a large cut-out in the structure without additional reinforcements would lead to severely weakening of the structure. Instead of using weight increasing, reinforcing elements the concept of load bearing window is implemented. Furthermore several airframe parts have been redesigned in order to accommodate the stretched window panel. The implementation of load bearing windows puts severe requirements on the materials that are to be implemented. The material should be at least 85% transparent. The window material should also have mechanical properties that are comparable to structural aerospace materials. Furthermore the materials used in the window panel should be connected to the rest of the fuselage structure. Based on those requirements it can be noted that current window materials like polycarbonate and silica glass do not meet the requirements. The load bearing window concept is determined by the selection and implementation of suitable materials that can meet the set requirements.

14.6 Material selection

Load bearing transparent nano-composite

At this moment there are no off-the-shelf materials available that have good transparency in combination with sufficient mechanical properties required for the implementation in the aircraft structure. However results from several researches show promising developments concerning transparent composite materials that incorporate nanofibres in their matrix (as can be seen in figure 14.4).

The transparency issue is solved by application of nanofibres with diameters less than the wavelength of visible light. Using nanofibres that are produced from materials with satisfying mechanical properties gives the possibility of making a stiff and strong composite. The nanofibres will be embedded in a transparent matrix material. A composite material incorporating S-glass nanofibres and high heat-heat epoxy is an acceptable nano-composite that could be used as a transparent load-bearing window material.

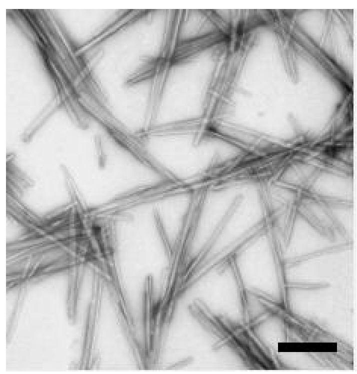

Figure 14.4: Composition of a nanofibre composite

Self-Healing-Aluminium

The SHA bears a close resemblance to the widely used 2024-T3 alloy. The main characteristic of SHA is its improved fatigue properties. The microstructure of the material is able to fill the cracks almost directly after they have occurred, leading to a fatigue limit almost three times higher than normal aluminium. The implementation of this material in areas that are particular sensitive to fatigue and where the structure is designed to address fatigue loading would give the possibility to reduce the weight of the current aircraft structure. The structural requirements put on the design of the fuselage are largely fatigue driven. This means that use of SHA instead of ordinary aerospace aluminium alloys in fuselage structure would require less material to cope with the fatigue loading, ultimately leading to a significantly lighter structure. Furthermore the SHA is used in the integrated window panel at places where high stress concentrations are expected.

14.7 Design and production of the window panel

The load bearing window is considered a part of the fuselage structure. In order to keep the load-bearing windows replaceable they are integrated in a window panel. This panel is connected to the rest of the fuselage structure using conventional joining methods like rivets or bolts. The window panel is the key component in this design. From a structural point of view it is regarded as an ordinary skin panel that has to withstand the loading conditions applied to it.

This is the reason the window can be rectangular. In this load-bearing design there will be substantially smaller stress concentrations. The window panel has to account for the load transfer to the rest of the fuselage, putting high requirements on the joint between the window panel and the rest of the fuselage. In order to address requirements as efficient as possible a laminated build up of the window panel has been applied. Figure 14.5 is a schematic representation of the build-up of the panel.

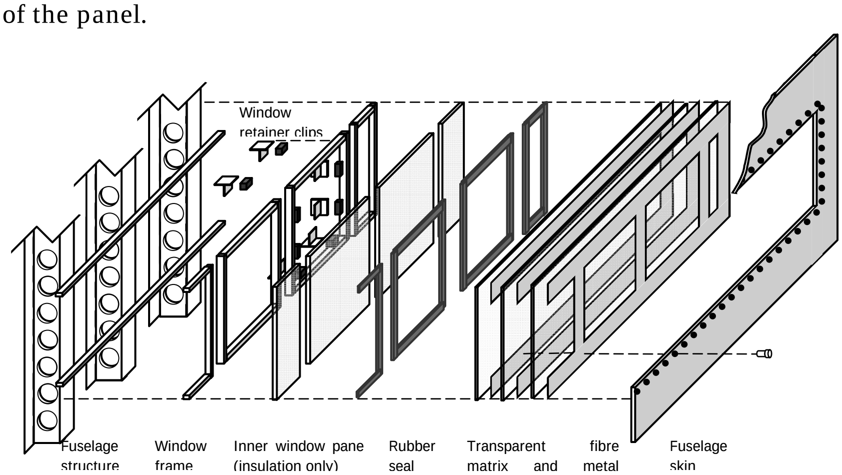

Figure 14.5: Schematic representation of the laminated window panel buildup

The panel can be divided in two different areas. Both areas are load bearing, however the relatively low stiffness of the transparent material requires larger thickness in order to cope with the buckling loads. Whereas the outer edges of the material are reinforced with thin layers of SHA in combination with continuous glass fibres. This can be seen in the cross-section in figure 14.6.

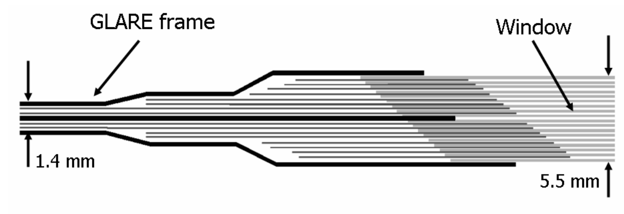

Figure 14.6: Cross-section at the edge of window panel

The laminar build-up is crucial in this design, as it will ensure good load transfer between the load-bearing window and the fuselage. Furthermore the laminar build up of the window panel will enable a smooth transition between the different thicknesses in the window panel, reducing the stress levels in those areas. The end result is shown in the figure 14.7.

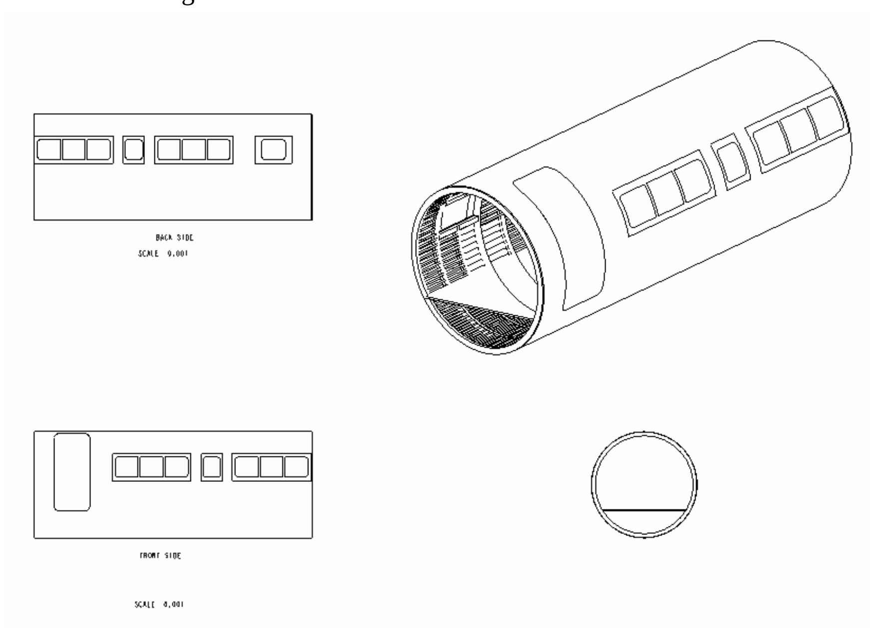

Figure 14.7: Technical drawings of the fuselage with enlarged windows

14.8 Conclusions

The main conclusion of this project is that it is possible to increase the view of the passenger significantly. The design proposed by the team increases the window area to 4.24 m^2. Compared to current aircraft windows that have a total area of 1.2 m^2, this means an increase of 250%. The design has proven to be lighter than the current aircraft and no extra maintenance is needed as the window panel is supposed to be subject to the same inspections as the skin. The window panel is thus producible, weight and maintenance neutral and the comfort of the passenger will be significantly improved. This could only be achieved with the utilization of new materials. The application of SHA will make the implementation of the design easier, also pruning the total weight of the structure. Optical devices and interior design solutions are relatively easy to implement in any structural design and might be very useful in upgrading the view on existing aircraft. Although a large amount of research remains to be done for the proposed design to reach maturity, it should be possible to reach a significant increase in the view using the new concept of load bearing windows and making use of new materials under development. Looking at the business jet market, it becomes clear that the demand for these jets is growing. It is expected that 24,000 jets will be sold until 2025. This means that there definitively is market for this product. Although a price increase is expected, this will not make the new design uncompetitive. The total price of the business jet will only be 8% more. Such a small increase is very acceptable in this exclusive market.

14.9 Recommendations

The choice of the design is inevitably based on numerous assumptions. Sometimes equally valid design options are being rejected because of lack of time to investigate them properly, because the design team lacks background in the specific area or because they do not fit within the definition of the project. With respect to the design choices made, the team recommends the following:

- Research in the possibilities offered by optical devices, most notably prism films
- Research in the possibilities of a complete composite fuselage

- Extensive fatigue research to prove the feasibility of the design and to qualify it for real aircraft.
- Investigation of the possibility to increase the stiffness of the transparent composite
- Detailed analysis of the load cases, using exact dimensions of the aircraft
- Analytical analysis of the joint between the fuselage and the panel and between the transparent material and the frame
- Detailed numerical analysis of the fatigue properties of the design
- Research in the production/manufacturing methods which facilitate the use of novel materials