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Parameter Sensitivity Analysis and Structural Development of an Airliner Lavatory Unit by Means of Finite Element Method

The current lavatory blocks – which can be found on the board of different airliners – are connected to the aeroplane structure not just through their lower attachments but through their upper ones as well. This upper attachment makes their installation and rearrangement procedures difficult and time-consuming. Therefore, investigations are being carried out to ignore the mentioned attachment together with keeping the requirements.

Structural stress analyses have been completed in the present work for the lavatory block without upper attachment using some solutions for increasing the structural integrity, in order to learn the effects of various static loads. The results of the different scenarios are investigated and compared to the outcomes of the lavatory block without upper attachment. In order to get a solution that meets the related safety requirements, parameter-sensitivity analyses of the lavatory structure have been completed. Based on the results of the survey and keeping the targets, the cost-effectiveness, feasibility and possible future tests in mind, a configuration that meets the authority requirements is determined.

The advantages and disadvantages of the modifications are discussed, and suggestions are made at the end for the further steps to proceed.

Keywords: *Diehl, airliner, lavatory blocks, sandwich-structured composite, quasi-static structural strength analysis*

1. Introduction

Diehl Aviation was founded in 1957 in Germany. In the beginning, it dealt with the maintenance of its company's aeroplanes, later it was contracted to maintain the autopilot systems of the Noratlas aeroplanes. In the 1970s, Diehl was involved in the development of the cabin lights and other electric units for the A300 program.

In 2003 it started to develop onboard systems for the A380 airliner, then in 2005 Diehl participated in the development of some cabin interior systems, units and parts. Diehl took part in the A350 (Extra Wide Body) program in 13 different areas. In Hungary, Diehl Aviation built its first factory in 2011 in Nyírbátor where nowadays, around 700 employees work. They make cabin interior covers, overhead stowage compartments and composite parts for the air conditioning systems. In December 2017, Diehl Aviation Hungary Ltd. opened an engineering and service office in Debrecen where the design and simulation of the cabin interior parts and the tools took place thus being involved in the development process. Nowadays, Diehl Aviation is responsible for the development of the whole cabin interior covers including the passenger area, the door and entrance area, the overhead stowage compartments, the sidewalls, the decorations, the lavatory units, the lightning and other stowage units which are used in the cabin [1].

The development project presented in this publication started some years ago when an aeroplane manufacturer asked Diehl Aviation to outline a concept of a future cabin interior including the lavatory units as well. One of the requirements of the aeroplane manufacturer was to make the installation process of the lavatory units simpler. The reason behind this could be to decrease the time required for assembling an aeroplane, which could satisfy the increasing demand for certain types of aeroplane. Decreasing the installation time has another useful aim. Nowadays, inspecting the market demands, there are increasing needs for rearranging the interiors of airliners on some routes. This could happen because of modernisation (retrofit) or a change in the number of passengers. The aim of the airlines is to make these changes as quickly as possible.

The rearrangement of the lavatory unit is a relatively complex and time-consuming task. Therefore, based on the initiative of the aeroplane manufacturer the attachment on the top of the lavatory would be removed, thus, the lavatory unit would be attached to the aeroplane only by its four lower attachments. Since Diehl Aviation makes the design, the mechanical simulation, the test and the production of the lavatory units, the analyses of these concepts are also the tasks of the company.

In the frame of this research and development project, some solutions have been suggested and analysed in HyperWorks software by using the finite element method for a lavatory unit of an airliner. After carrying out the parameter-sensitivity analyses, a smart solution has been proposed, which satisfies the requirements the best way. Thus, while carrying out the slightest change in the lavatory structure, the aim is to reduce the mass, the displacement, the stresses appearing in the materials and the forces acting on the aeroplane structure in order to meet the requirements of the aviation authority.

The rest of the study is organised as follows:

In section *The structure of the lavatory unit* the structural build-up of a lavatory is introduced which is connected to the aircraft structure by 5 attachments.

Section *The structural analysis of a lavatory unit* is about the related requirements and the introduction of the used finite element modelling techniques.

Section *Parameter sensitivity analyses* contains the finite element analyses and results of the lavatory without the upper attachment and another 8 structurally modified lavatories.

Conclusions is a brief summary of the path which led to a model complying with the criteria. It also includes possible future development actions.

2. The structure of the lavatory unit

The structure of the lavatory unit in question consists of a ceiling, a base, an inboard, an outboard, a forward and an aft panel (see Figures 1 and 2). The panels are made from a glass fibre reinforced composite sandwich structure, which allows light and durable structural build-up. Every individual panel is connected to each other by screwed joints in different kinds of inserts. One should note that the outboard panel is not closed fully, it is not connected to the base panel. The reason for that is the space required by the three tubes (potable water, vacuum water and wastewater) going in and out of the lavatory unit.

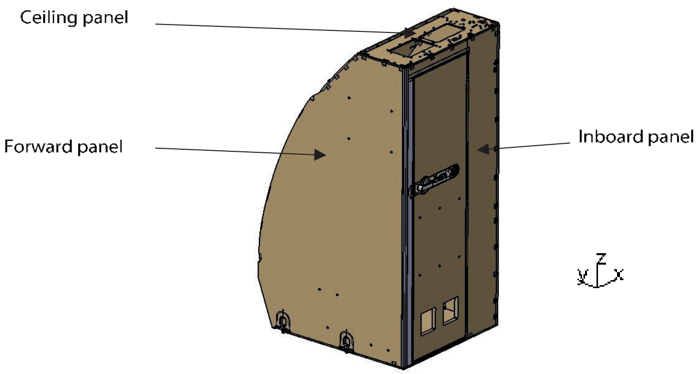

Figure 1.
Isometric view of the lavatory unit with the panel names included, looking from the inboard panel direction [2]

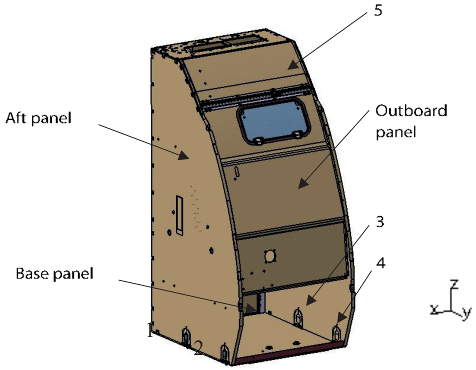

Figure 2.
Isometric view of the lavatory unit with the panel names and attachment points numbering included, looking from the outboard panel direction [2]

The panels are made from a Glass Fibre Reinforced Plastic (GFRP) sandwich structure which has different types and thicknesses of honeycomb pattern core material. Each reinforced point is strengthened by a core filler, which is also a thermosetting material and as such it solidifies after making, further increasing the strength. After machining different inserts can be placed inside of them.

The lavatory connection points to the aircraft structure can be seen in Figure 2. The unit is attached to the Seat Track (ST) at four points at the bottom. On the top, it is connected to the fuselage frame by a tie rod.

3. The structural analysis of a lavatory unit

3.1. Introduction of the authority and manufacturer requirements

The airliners in which the lavatory units are built, count as large aeroplanes powered with turbine engines according to the European Union Aviation Safety Agency (EASA) regulations [3]. For these aeroplanes the EASA Certification Specification (CS) 25 regulations are valid.

The EASA CS 25.561 paragraph applies to the circumstances of the emergency landing; therefore, this is compulsory for the lavatory unit.

These are the minimum requirements that must be taken into consideration during the design of a jet-powered large aeroplane and which applies to the lavatory unit discussed in this study. The aircraft manufacturer can prescribe stricter requirements in some cases.

According to the CS 25, the relevant inertial load requirements for the static finite element analysis are as follows: Upward (UWD) +Z direction 3.0g; Forward (FWD) –X direction 9.0g; Sideward (SWD) (both in right- and left-wing direction) +–Y direction 3.0g; Downward (DWD) –Z direction 6.0g and Rearward (RWD) +X direction 1.5g (see Figures 1 and 2). For the UWD and DWD directions, the manufacturer defines higher inertial loads than the ones in the CS 25.

The lavatory unit can deform to a certain extent towards the passenger area under the influence of the loads. Furthermore, based on test results, the maximum stresses that the panels can withstand are given.

In addition, it is important to take into consideration the magnitude and the direction of the different forces acting on each of the lavatory attachment points due to the static loads. According to CS 25.561, the structure must meet the static requirements with a safety factor of 1.33. Hereinafter during inspections, comparing the acting forces to the allowable (limit) forces reduced by 1.33 safety factor, the value of the so-called Reserve Factor (RF) has to be at least 1 or higher.

The reserve factors calculated from the resulting forces on each attachment point can be calculated by Equation (1).

$$Reserve\ factor = \frac{Allowable\ force\ reduced\ by\ safety\ factor}{Resulting\ force} \geq 1 \tag{1}$$

3.2. The Finite Element Model of a lavatory unit

The meshed model of the current lavatory unit was made in HyperMesh software at Diehl Aviation and can be seen in Figure 3.

The meshed model contains 2D elements basically, however, 3D elements are used for the modelling of the upper attachment bracket. The application of 2D elements is the most appropriate to model composite sandwich structures. Each of the panels are built up from different types of GFRP materials. Their properties are defined according to the material database of Diehl Aviation GmbH.

The lavatory units are analysed with and without their doors. Usually, the lavatory without the door is the one that is more crucial; therefore, it serves as a basis for this investigation.

Some components, mounted on the lavatory unit, are modelled neither in Computer Aided Design (CAD) nor in the Finite Element Model (FEM). These parts are only accessories and they do not contribute to the structural stiffness of the lavatory unit, they neither take part in carrying loads. They affect the mechanical properties of the lavatory unit only by their inertia, centre of gravity position and mass. Therefore, these items are considered by their centre of gravity and mass. Such items are, for example, the baby bassinet, the toilet, the mirror and so on.

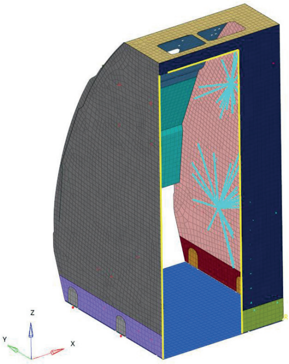

Figure 3.
The meshed geometrical model of the lavatory unit [2]

During the analyses, the results are presented relative to the maximum allowable displacements and forces given in the requirements. The allowable values are always considered as 100%. In most of the cases those load steps, which have no critical effect on the lavatory structure, are not discussed in detail regarding the scope of this study. Besides, it is important to mention that by using linear material properties the software visualises the displacement of the structure also in case of stresses which are higher than the ones the material can resist. However, this visualisation is not appropriate because such high displacements and stresses cannot be formed in reality, since the analysed part would break by then.

4. Parameter sensitivity analyses

4.1. Analysis of the lavatory unit without upper attachment

In the case of the lavatory unit in question, the upper attachment is removed, thus, it becomes less stiff than the original variant.

Regarding the simulation results, particularly big, about 1,525% displacement of the allowable appears at the outboard panel in case of FWD load case (see Figure 4). The large-scale displacement forms due to the cut-out on the outboard panel primarily. On this part of the lavatory constantly growing displacements can be experienced by going upwards in the Z direction. After the cut-out section, the displacement is constant. The base panel deforms in a wave shape: downwards and upwards too. This can be explained mainly by the effect of the weight of the toilet.

Big displacements are formed also in the UWD and the DWD load cases but these are not significant towards the passenger area.

In the SWD cases, slight displacements can be experienced towards the passenger area. Only the base panel deforms more due to the inertia of the toilet unit. More crucial in this load case is the displacement of the base panel towards the aircraft cover.

The RWD load case results in a 294% displacement of the allowable. Regarding that, it is similar to the one in the FWD load case, i.e. constantly large displacement can be experienced from the bottom of the outboard panel.

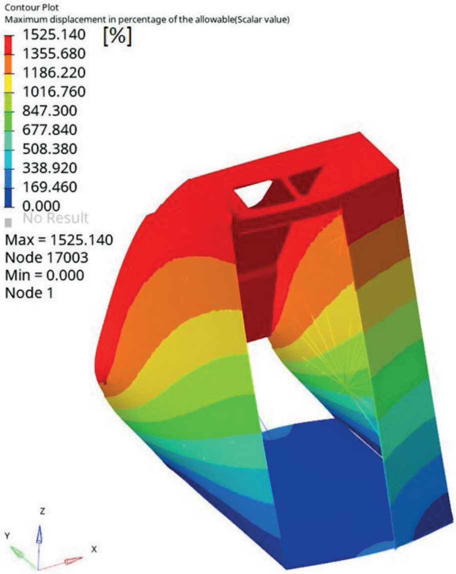

Figure 4.
The maximal relative displacement ratios (actual displacements in the percentage of the allowable displacement) in the structure of the lavatory without upper attachment under FWD load [the authors]

The structure thus formed does not have proper stiffness, it does not meet the displacement criteria and furthermore, high forces appear at the attachment points, which cause a reduction in the reserve factors.

It can be seen from the analysis of the lavatory unit without upper attachment that the structure needs to be reinforced by means of all criteria in order to meet the requirements. During the modifications, cost efficiency needs to be kept in mind. It also needs to be taken into consideration that the more complicated modifications could have a negative effect on the approval process and future tests.

4.2. The effect of the material modification

Leaving the honeycomb structure unchanged, Carbon Fibre Reinforced Plastic (CFRP) material is used instead of glass fibre reinforced plastic. The carbon fibre is stronger and is expected to ensure a higher stiffness for the structure. However, it is more expensive and could influence future tests (e.g. flammability tests). The properties of the carbon fibre reinforced plastic layers are set according to the material database of Diehl Aviation GmbH.

Regarding the results, the appeared maximal displacement in the FWD load case is approximately 600% of the allowable (see Figure 5). Still high, 120% displacement of the allowable can be seen towards the passenger area in the RWD load case. This displacement, however, is significantly lower than the one in the previous analysis.

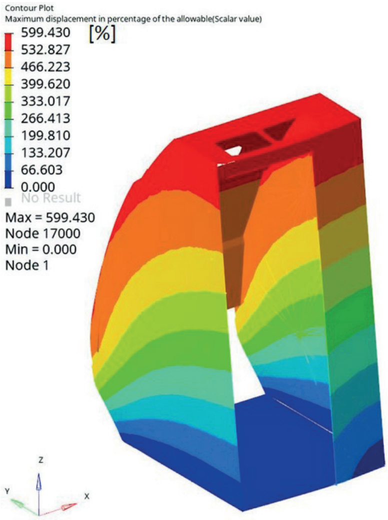

Figure 5.
The maximal relative displacement ratios (actual displacements in the percentage of the allowable displacement) in the CFRP structure lavatory unit in the FWD load case [the authors]

The forces acting on the lower attachments remained within the allowable limits. The lowest reserve factor is 1.15, which occurs on the first attachment point in the Z direction in the FWD load case just like in the former analyses.

From the analysis of the lavatory unit made of CFRP structure, it turns out that it does not meet the requirements. The displacement is reduced significantly. The forces on the attachments are high, the reserve factors are reduced but they still remain above 1. Furthermore, the advantage of this structure is that the mass of the lavatory is reduced. One of the disadvantages could be the higher price of carbon fibre.

4.3. The effect of the core material thickness

Increasing the thickness of the core material of the panel sandwich structure counts as an easier change. This is expected to result in an increase in the structural and bending stiffness until a certain point.

The effect of 2.5 mm, 5 mm, 10 mm, 15 mm, 20 mm and 25 mm honeycomb thicknesses are investigated. Every panel thickness of the lavatory unit is increased uniformly.

To make the results clearer, they are shown in a diagram (see Figures 6 and 7). To prevent the decrease of the interior area of the lavatory unit, every panel is thickened towards the passenger area except the base panel. The thickness of the latter one is increased to the inside of the lavatory unit because the aircraft floor and the lavatory attachments limit the space on the bottom.

In Figures 6 and 7 the results of the formerly analysed lavatory unit without upper attachment are represented too for comparability. These results belong to the 0 mm core material thickness increase.

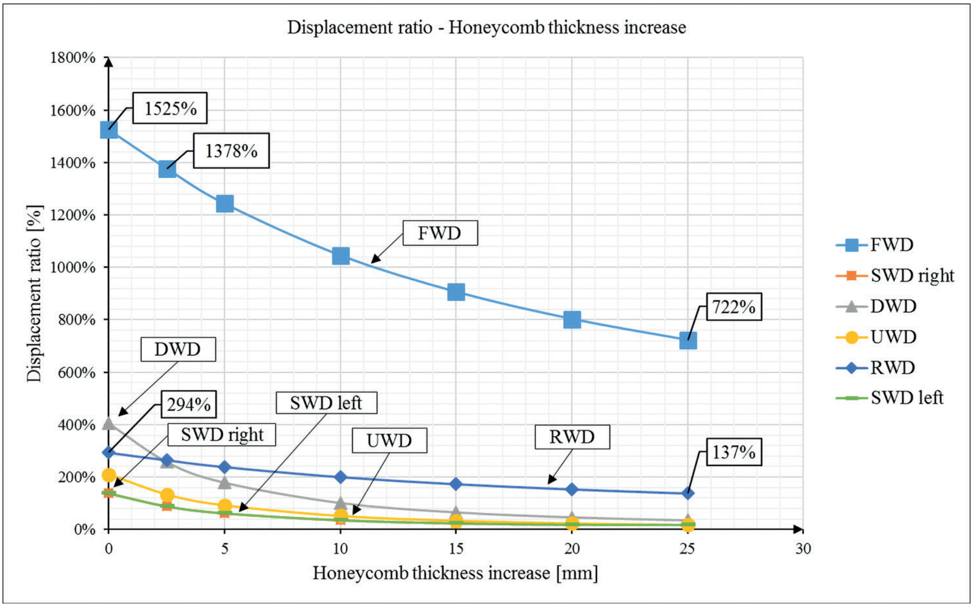

Figure 6.
The maximal displacement ratios (actual max. displacements in the percentage of the allowable displacement) of the elements of the lavatory unit in the function of the honeycomb thickening in the different load cases (the graphs of the two SWD load cases coincide with each other) [the authors]

As it can be clearly seen in Figure 6, the displacement values show a decreasing tendency. In the FWD load case, the former 1,525% displacement ratio is reduced approximately to 1,378% with the 2.5 mm core material thickness increase. Due to the 25 mm thickness increase also in the FWD load case, the displacement is only around 722% of the allowable. The value is still high, but it is less than half of the value in the initial state (without fixation at the top).

Concerning the RWD load case, the maximal displacement to the direction of the passenger area decreases to 137% from the initial 294%, which is still considered to be high.

The forces that appeared on the attachments (for attachment numbering please see Figure 2) are not uniform. Considering the most crucial FWD load case, the changes of the Z directional reserve factors are shown in Figure 7. (The reserve factors are low in the Z direction mainly.) Initially, the reserve factors on lower attachments 1 and 3 are increased, thus, the Z directional forces are decreased due to the increase of thickness. On attachments 2 and 4, the values of the reserve factor are continuously and constantly decreased.

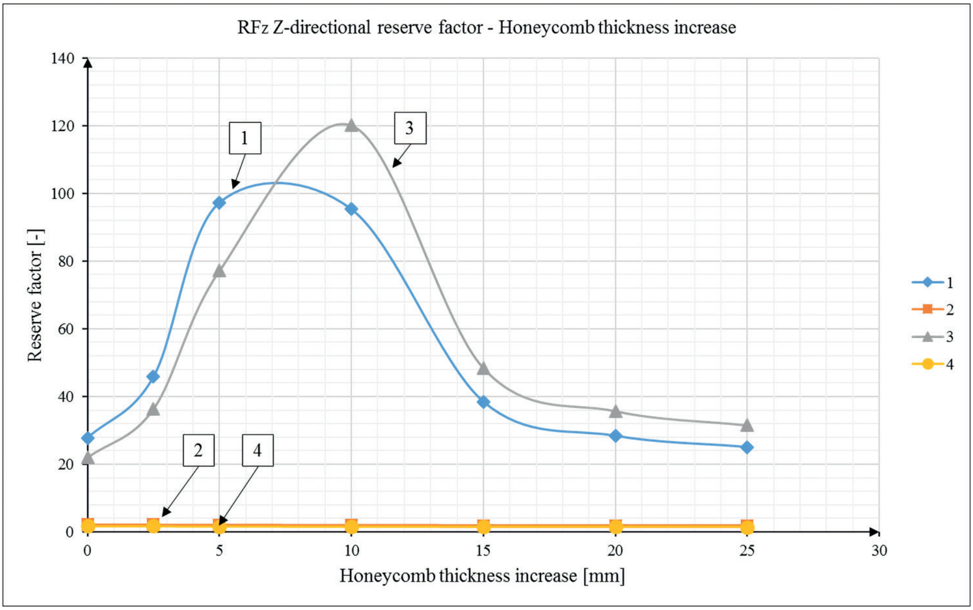

Figure 7.
The tendency of the reserve factors calculated from the Z directional forces on the lower attachments 1, 2, 3 and 4 as a function of the honeycomb thickening (the values of the 2nd and 4th attachment points coincide with each other)
[the authors]

The thickness increase of the core material resulted in a positive effect in total. However, after a certain point, it had its negative effect felt. We can say that in the case of 2.5–10 mm core material thickness increase the displacements can be reduced.

4.4. The effect of the number of the PrePreg layers

After the examination of the effect of the core material thickness, the next step is to determine how the number of the PrePreg composite layers can influence the analysed parameters. Certainly, increasing the number of the composite layers could be more expensive than the thickening of the core material; however, presumably its effect is not negligible.

The number of layers is increased in pairs in each panel, i.e. two added layers mean one layer per side. So, in total 8 layers are added step by step during the 4 analyses. The added layers always have the same material properties as the original panel. The thickness of each added layer equals the thickness of the original layer.

The results are shown in a diagram in this case as well to make them clearer. The maximal displacement ratios as the function of the added number of layers in each case are described in Figure 8. The results of the previously analysed lavatory unit without upper attachment (which has the original layer setup) are represented too for comparability at 0 on the horizontal axis.

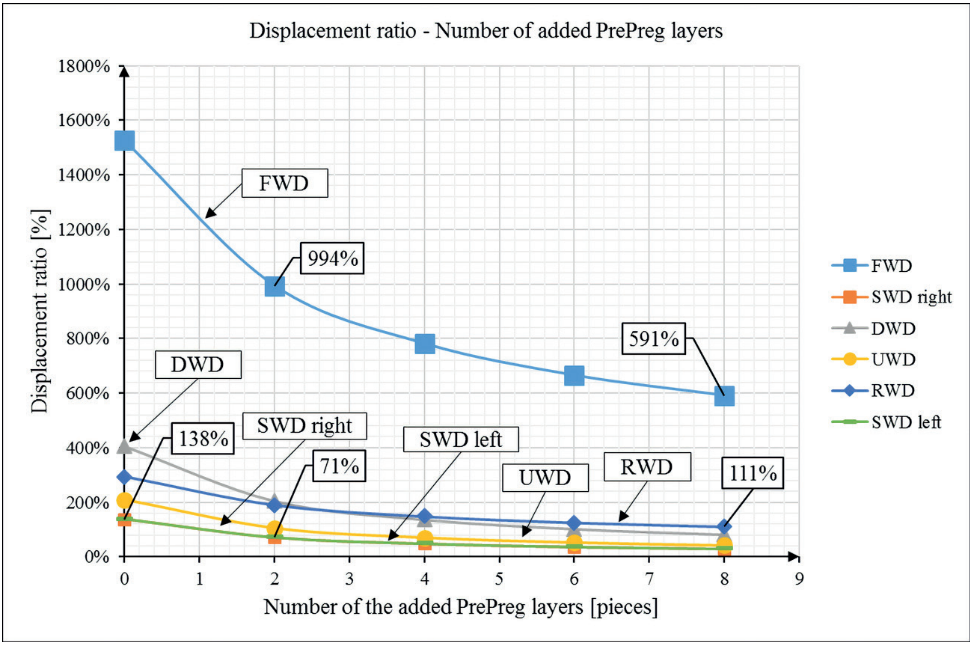

Figure 8.
The maximal displacement ratio (actual max. displacements in the percentage of the allowable displacement) of the elements of the lavatory unit as a function of the number of the added composite layers in the different load cases (the graphs of the two SWD load cases coincide with each other) [the authors]

Notice that already one added layer per side mitigates the displacement in the FWD load case to 994% of the allowable. In the case of the SWD load case, the mentioned layer increase has led to 71% displacement, almost half of the former 138% value. Similar results can be observed in the other load cases, too. Further increasing the number of the layers does not have such a significant effect on the maximal displacement but in case of 8 added layers, the maximal displacement is only 591% in the FWD load case. In the RWD load case, the maximal displacement is decreased to 111%, which presumably can reach the required value by further adding 1 or 2 layers. However, the structure would not meet the requirement in the FWD load case either, so further increasing the composite layer numbers would only have a minor effect on the maximal displacement values.

The appearing forces on the attachments remain in the allowable limits, though the reserve factors show a decreasing tendency in many cases. This is most significant on the fourth attachment in the Z direction since the reserve factor there has decreased to 1.25

from the previous 1.79 value due to the layer number increase in the FWD load case. This is the lowest value in this analysis.

Increasing the number of glass fibre reinforced composite layers has a significant effect on up to two added layers (one layer per side). In the RWD load case, the allowable displacement value is managed to be approached. The mass increase in the case of adding 8 layers is 28.5 kg. The analysed lavatory unit has not met the displacement criterion in the FWD and RWD load cases yet but the consequences could be important for future designs.

4.5. The effect of the CFRP stiffening rods

In the analyses so far, the already existing structure of the lavatory unit was modified. In the upcoming analyses, the goal of the investigations is to see what the effect of implementing different stiffeners into the structure is.

It is well visible till now that the RWD and the FWD load cases are the ones, which cannot satisfy the criteria. In these cases, the lavatory unit usually deforms forward and backward. This gives the idea to integrate some CFRP stiffening rod structure into the forward and the aft panels primarily. In order to create a joint structure, the rods are bonded in pairs along with the outboard panel. The location of the stiffeners and their connection to the lower attachments (magnified image) is shown in Figure 9.

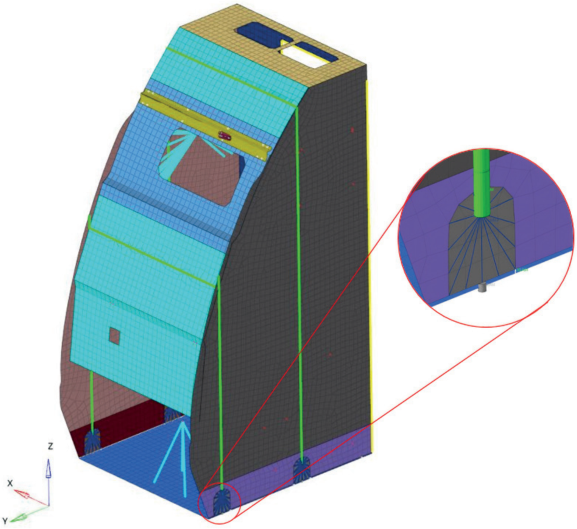

Figure 9.
The location of the stiffening rods and their connection [the authors]

In the magnified image the rod is presented in 3D to make it more visible.

The reinforcement is a composite tube with an outer diameter of 10.5 mm and an inner diameter of 9.5 mm. The two characteristic values of its material are set according to the following [4]:

Modulus of elasticity: E = 94 msi = 648 GPa

Tensile strength in fibre direction: Rm = 414 ksi = 2854.43 MPa

The mass increase of the structure is basically negligible. The reinforced structure decreases the maximal displacement by 600% in the FWD load case. In the RWD load case, the displacement is reduced by 130%, which can be considered a significant decrease. Regarding the maximal displacement in the other load cases, almost no change can be observed.

The forces acting on the lower attachments are under the limit value. The lowest reserve factor is 1.22, which is due to the Z directional force at the fourth attachment point in the FWD load case.

In total, the composite rods could have a significant effect on the displacement in the FWD and the RWD load cases. Its effect is approximately the same as adding 4 GFRP composite layers to each panel; however, its advantage is that it causes less mass increase. Some of its disadvantages can be the price and its effect on the flammability tests. Its application also raises some questions regarding the manufacturing processes. It is a fairly complicated process to integrate a carbon composite tube inside of a core material of a large panel and to glue it with its environment.

4.6. The effect of the reinforcement panel

Previously it was shown that generally, the largest displacements form above the cut-out section of the outboard panel. On these parts generally, uniform displacement can be observed. Due to the cut-out section, displacements grow to a large extent in the surrounding panels up to the top of the cut-out section.

The potable water, vacuum waste and waste water tubes are connected to the lavatory unit through the mentioned cut-out section.

However, the tubes do not require as large space as the cut-out itself is. Therefore, it is possible to close the cut-out section with a reinforcement panel (see Figure 10). In the finite element model, the reinforcement panel is connected to the surrounding panels by its nodes, so they act as one unit. Expectedly, it would not have a significant effect on the preliminary results if the connections were modelled by screwed joints. Three holes are placed on the reinforcement panel for the tubes mentioned previously. As it is observable, the panel itself is not totally plain. Folding it in two places ensures a greater stiffness and resistance to the loads. The material properties and the layer setup of the reinforcement panel are the same as the ones of the outboard panel.

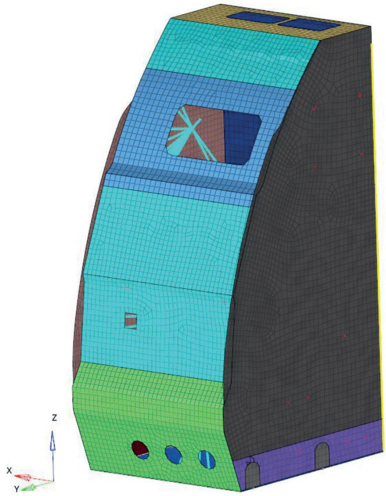

Figure 10.
The reinforcement panel design (green) [the authors]

The reinforcement panel influenced the results of the static stress simulation in a positive way in most of the cases. In the FWD load case, the maximal displacement is reduced to 252% of the allowable, which is the most significant change so far. However, it does not meet the requirements yet. It can be seen in Figure 11 that the shape of the displacement has also been changed. The lavatory unit deforms from the base panel progressively but the elements of the inboard panel still deform more than the elements of the outboard panel at the same height.

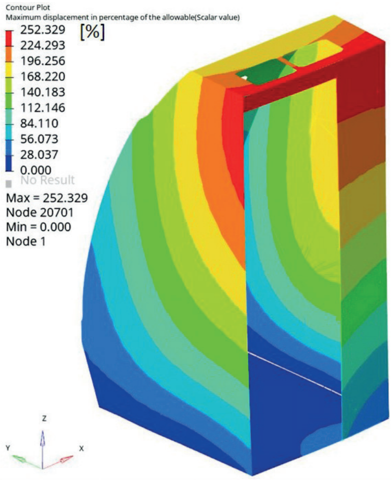

Figure 11.
The maximal relative displacement ratios (actual displacements in the percentage of the allowable displacement) in the FWD load case as an effect of the reinforcement panel [the authors]

The maximal displacement is 50% of the allowable in the SWD load case. This displacement is located on the base panel of the lavatory unit. In the UWD and DWD load cases, the lavatory unit has already met the requirements. Although the appearing displacements are big, they do not move towards the passenger area. In this case, as an effect of the DWD load case, a 70% displacement forms on the base panel in the negative Z direction and 36.7% displacement in the positive Z direction on the same panel in the UWD load case. So, the SWD, DWD and UWD displacements have met the requirements not only due to their directions but due to their magnitudes as well. In the RWD load case, the highest displacement of the upper parts of the lavatory unit is 46.9% of the allowable value and it moves towards the passenger area.

The force in the Z direction on the fourth attachment point shows an unfavourable result in the FWD load case. On this attachment, the reserve factor has been decreased to 0.83. Also, due to the FWD load, the reserve factor on the second attachment is reduced to 1.04.

It can be concluded that the reinforcement has a favourable effect on the displacement distribution and the magnitude of the maximal displacements. The mass of the reinforcement panel is 3.2 kg. The structure shows a big overload due to the FWD load on the fourth attachment where too much force is generated in the Z direction. The structure still does not meet the requirements but this solution has yielded significant results.

4.7. The effect of the door

The original lavatory unit has met the requirements without taking the door as a stiffening unit into consideration. However, recent studies have shown that in the FWD load case the elements of the inboard panel also deform significantly. Not taking the door into consideration also contributes to this result.

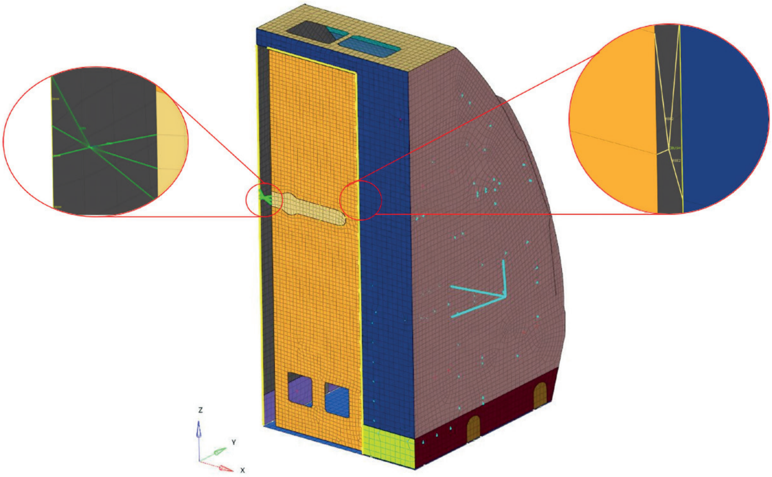

Figure 12.
The lavatory unit design with door [the authors]

The model of the simplified door of the lavatory unit together with the assembly is shown in Figure 12.

There are two bigger cut-outs on the lower part of the door panel, which are worth considering during the static stress analysis. The model of the latch is in the middle of the door which is modelled by a 10 mm-wide aluminium plate in this case. The materials and layer setup of the door are the same as the ones of the inboard panel.

Regarding the results, significant improvement is reached; however, the 538% displacement on the outboard side in the FWD load case shows that the toilet unit still has a big effect on the structure (see Figure 13).

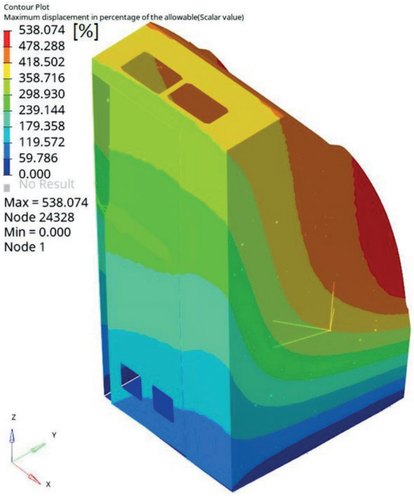

Figure 13.
The relative displacement ratios (actual displacements in percentage of the allowable displacement) as an effect of the door in the FWD load case [the authors]

Concerning the RWD load case, a displacement of 105% of the allowable is reached which is still slightly above the required value. In the SWD load case 138%, in the UWD load case 210%, in the DWD load case approximately 410% maximal displacements of the allowable have been reached. However, these values are not significant since their direction does not affect the passenger area.

Summarising the above, the door has a positive effect on the displacements of the lavatory unit without upper attachment. However, because of the calculated lower reserve factors at the attachments and because of the large displacement in the FWD and in the RWD load cases, the door itself does not have enough effect to make the lavatory without upper attachment meet the requirements.

4.8. First combined structure: the effect of the door and the reinforcement panel

Many other parameters and structure modification still could be examined but based on the experiences it is worth creating a combination of the structures examined so far.

In the first case, the combined effect of the door and the reinforcement panel is examined. The displacement of the mesh elements in the FWD load case can be observed in Figure 14. The highest displacement is 120% of the allowable, which is still high. The displacement of the aft panel directs towards the interior of the lavatory unit, meanwhile, the inboard and door panels move towards the passenger area. Regarding both the magnitude and the direction of the displacement in the other load cases, the lavatory meets the requirements.

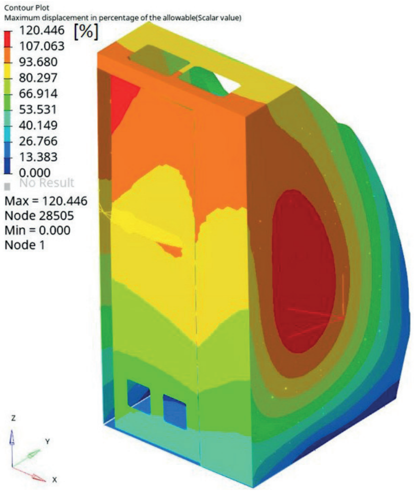

Figure 14.
The maximal relative displacement ratios (actual displacements in the percentage of the allowable displacement) of the first combined structure (door and reinforcement panel) in the FWD load case [the authors]

The forces on the attachments are smaller than the allowable. The lowest reserve factor is 1.75 which is calculated from the force in the Z direction on the fourth attachment in the FWD load case.

In the first combined structure, the combined effect of the door and the reinforcement panel is analysed. In conclusion, their effects are positive in terms of both the maximal displacement and the appearing forces on the attachments.

The resulted displacement value in the FWD load case is still above the one defined in the requirement. However, the required value is approached much better than before.

4.9. Second combined structure: the effect of panel thickness increase, door and reinforcement panel

The structure analysed in the previous subchapter has approached the required value; therefore, it serves as a good basis to create the next combined structure. The second combined structure contains the reinforcement panel and the door, furthermore the layer setup of the panels has been changed. In some panels, only the number of the glass fibre reinforced plastic layers is increased while others contain an increased core material thickness too. However, there are some panels that remained unchanged. The FWD load case has been considered as a basis during the creation of the new design because the structure has already reacted favourably in the other load cases.

The properties of the forward and the aft panel and their reinforced parts are the same in pairs. The number of the GFRP layers has been increased by one layer per side and their core material thickness is also increased by 10 mm. The inboard panel and the door as well are modified by adding one GFRP layer per side. Their honeycomb structure has remained unchanged since presumably they are exposed to little bending and twisting loads. One composite layer per side is added to the ceiling panel. In addition, in the base panel, the honeycomb structure thickness is increased by 10 mm. There is no change on the outboard panels, so the properties of the reinforcement panel have remained the same too.

As a result of the changes, the value of the greatest displacement is 87% of the allowable value in the FWD load case (see Figure 15). This complies with the criterion. The maximal displacement is 20% in the SWD and the DWD load cases, 10% in the UWD load case and approximately 16% of the allowable value in the RWD load case. All displacements are below the allowable value defined in the requirement.

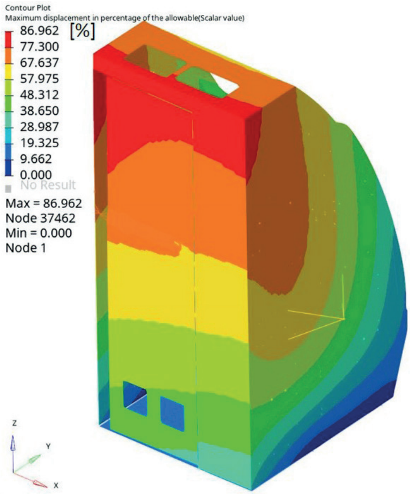

Figure 15.
The maximal relative displacement ratios (actual displacements in the percentage of the allowable displacement) of the second combined structure (increased panel thickness, door and reinforcement panel) in the FWD load case
[the authors]

After that, the tension, compression and shear stresses that appeared in each panel are also analysed. In case of the second combined structure, the formed stresses remained below the allowable values defined for each panel separately. These results are not discussed in the other scenarios due to the limited available extension.

In the FWD load case, the lowest reserve factor is 1.52 which can be calculated in the 4th attachment in Z direction. This value complies with the criterion.

In terms of the displacements, the stresses and the forces acting on the attachments, the second combined lavatory structure complies with the static stress requirements. The resulting lavatory without upper attachment is 11.36 kg heavier than the original unit.

To take the door into account as a load carrier and connecting item, the door latch needs to be redesigned expectedly.

5. Conclusions

The current airliner lavatory units have a 5th upper attachment besides their 4 lower ones. This makes their installation time consuming and more difficult. The aim of this study is to find such a lavatory design that is connected to the aeroplane only by its four lower attachments and still meets the static load requirements set by the aviation safety authorities and the aeroplane manufacturer. As it is shown at the beginning, removing the upper attachment led to a 1,525% maximal displacement compared to the allowable values in the requirement. Therefore, the lavatory unit without upper attachment would fail to comply with the requirements. Hence, parameter sensitivity analyses were carried out to see which modification provides suitable solutions. It can be seen that changing the parameters uniformly meant an advantage in terms of certain requirements while from other requirements point of view it was neutral or it had disadvantages. As investigations progressed, the complexity of the problem became obvious. So, with the possibly simplest change in structure, with minimising the mass-increase and cost, with thinking about the future tests and design changes and taking the regulations and the requirements into account, it was necessary to change the structure of the lavatory unit in several fields, i.e. it was necessary to carry out combined analyses.

The results of the previous parameter sensitivity analyses and the conclusions drawn from them have contributed to the first presented combined structure modifications with significant improvements. Although they gave a great stiffness to the structure, the door and the reinforcement panel installation were not enough to meet the requirements.

The second combined structure – which contains a reinforced panel layup additionally to the door and reinforcement panel – has such a design, by which the lavatory unit without upper attachment meets the applicable displacement, tension, compression, shear stress and reserve factor requirements. As a result of the design, the highest displacement is 87% of the allowable value given in the requirement. The lowest reserve factor is 1.52. Compared to the lavatory unit without upper attachment, the biggest displacement is reduced by 94.3%. The lowest reserve factor (which is formed on the 4th attachment in both cases) is reduced by 15.1%.

Such a design of the lavatory unit without upper attachment might require changes in the door latch and in the static test implementations to some extent.

The model could be more specific by modelling the door latch and the hinges in a more detailed way. After that dynamic, vibration, safety and other investigations need to be made. The validation of the results by tests is necessary in every case.

There are mechanical simulations of the further configurations and designs in progress which could lead either on their own or with the results of this current study to solutions, which comply with the requirements.

Notations

E	Modulus of elasticity (Young modulus) [N/mm^2]
g	Gravitational acceleration [m/s^2]
R_m	Tensile strength [N/mm^2]

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Repülőgép-mosdóblokk továbbfejlesztése véges elemes szilárdságtani analízis és paraméterérzékenységi vizsgálatok segítségével

Az utasszállító repülőgépekben található jelenlegi mosdóblokkok alsó rögzítéseik mellett felül is csatlakoznak a repülőgép törzskereteihez. A felső rögzítés beszerelésüket és átrendezésüket megnehezíti és időigényessé teszi, ezért vizsgálatok folynak az említett rögzítés elhagyására az előírások betartása mellett. Ezért, a jelen munka célja, hogy megvizsgáljuk a felső rögzítés nélküli, továbbfejlesztett mosdóblokkok viselkedését különböző statikai igénybevételek hatására, és összehasonlítsuk ezt az egyszerű, felső rögzítés nélküli mosdóblokk esetén kialakult szilárdságtani számítások eredményeivel. A biztonsági előírásoknak megfelelő kialakítás elérése érdekében paraméterérzékenységi vizsgálatokat végeztünk. A számítások eredményei alapján kitűzött célokat, a költséghatékonyságot, a kivitelezhetőséget és az esetleges későbbi teszteket szem előtt tartva meghatároztunk egy olyan konfigurációt, amelyben a felső rögzítés nélküli mosdóblokk megfelel a hatósági előírásoknak. A munka következő részeiben bemutatjuk a változtatások előnyeit és hátrányait, majd javaslatot teszünk a további fejlesztési lépésekre.

Kulcsszavak: *Diehl, utasszállító repülőgép, mosdóblokk, kompozit szendvicsszerkezet, kvázi-statikus szerkezetanalízis*

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