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AN AIRCRAFT COMBINATION WHEELCHAIR SEAT SUITABLE FOR AIRCRAFT AISLES

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***Abstract*:** Air travel is very restricted for individuals with mobility limitations and there is a need for the design of improved accommodation for individuals in wheelchairs on an aircraft. The aim of this paper is to present an aircraft wheelchair design, referred to as the Aircraft Combination Wheelchair Seat (ACWS), that meets the requirements of the dimensions of the Airbus A321 aircraft aisles and facilitates aircraft mobility. This study focuses on the process of the design and the analysis undertaken. The universal design approach ensures the product can be used for more than one function, including, the ability to be fully integrated into the airline seat or the reverse, to be detached from the seat frame. Finite element analysis performed on both options concluded that the product was technically feasible.

Keywords: Wheelchair, aircraft, disabilities, accessibility, universal design.

Introduction

With 1.2 million people using wheelchairs in the UK (Papworth, 2016) it is important to consider the unique difficulties in completing certain common tasks. The focus area of this study are air flights, this is due to travelling being seen as a way to fulfil an individual’s need for independence (Turco,

Katz, D. & Mahomed, A.(2020). An aircraft combination wheelchair seat suitable for aircraft aisles. Journal of Accessibility and Design for All. 10(1), 1-30. doi: 10.17411/jacces.v10i1.248

1998) and promoting positive wellbeing, including improved health. In fact Pyke et al. (2016) and Smith & Diekmann (2017), amongst others, have demonstrated the wellbeing value of travelling for all individuals and that all forms of tourism contribute to and boost wellbeing. Chen et al. (2013) highlighted the positive connotation of tourism as being the opportunity to relax and recuperate. Other studies, such as Morgan et al. (2015), explored the links between wellbeing and social tourism opportunities for elderly people, noting that often it is the elderly that require mobility support in order to be able to travel and concluded that social tourism provides an opportunity for respite, escape and companionship for this group. Thus tourism positively impacts disadvantaged groups, which includes people with disabilities and health challenges and their carers, and also alleviates stress (McCabe, 2010; Morgan, 2015).

The desire for travel is the same for both individuals with or without disabilities (Yau, 2004), however, people with disabilities travel 33% less often than the general public (DCLG, 2014). This could be attributed to the fact that travelling by aircraft while in a wheelchair comes with a variety of constraints, barriers and challenges. The main being the passengers with disabilities’ wheelchair is too large to fit down the narrow aisles and into the small bathroom. The lack of provision of a user friendly onboard bathroom in aircrafts for people with disabilities has been recognised in the literature (Chang, 2011, 2012) and thus often people with disabilities opt not to travel because the facilities and services are not adequate for their needs.

Although the airlines are legally required to deliver the passenger with both equipment and assistance (EC, 2007), what is provided is very basic and needs to be improved. In particular, the wheelchairs provided cannot fit into the small bathrooms on short-haul flights, as aircrafts are only required to have disabled accessible toilets on long-haul flights. When it comes to using the toilet facilities, passengers with disabilities are currently recommended by travel blogs to avoid using the bathroom through fasting, use of incontinence pads or catheterisation (Chaluent, 2014). This is to avoid the uncomfortable manual-handling and embarrassment that comes with using the bathroom as a wheelchair-user (Davies & Christie, 2017).

Thus the aim of this study was to design a wheelchair that is compact enough to be able to fit down the narrow aisles of an aircraft and also be able to be manoeuvred into the bathroom, allowing passengers to transfer themselves over onto the toilet without having to be manually lifted. The purpose of this study is to minimise wheelchair passengers' concerns when travelling by air, to allow them to keep their dignity while using the bathroom and increasing the number of wheelchair passengers travelling by aeroplanes. This study analyses a conceptual design and discusses the mechanisms of the design.

Disability definition

Wheelchair users referred to in this study fall under the category of disabled users. The definition of the term 'disability' varies from each literature in order to best define the group of people needed for that study. This report will define disability in line with the definition provided by the UK government in the 2010 Equality Act and that provided by the World Health Organisation. An individual is defined as disabled if they have a "physical or mental impairment that has a substantial and long-term negative effect on their ability to execute normal daily activities" Equality Act (2010). The definition used by the World Health Organisation starts similarly but expands further by referring to disability as "not just being a health problem, but a complex phenomenon reflecting the interaction between features of a person's body and features of the society in which he or she lives," (WHO). With air travel being seen as the feature of society that a passenger with disabilities is confronted with. For the purpose of this study, a combination of these definitions was considered, as the aim was to facilitate travel by aircraft, and provide a more enjoyable and less intimidating experience for wheelchair-users.

Associated regulations

The regulation that was considered for this design is those enforced by the United Nations (UN), European Union (EU) and the United Kingdom (UK) government. The UN Convention on the Rights of Persons with Disabilities (CRPD) encourages the research into "universal design" which is defined as the "design of products… to be usable by all people without the need for adaption." (UN, 2006). CRPD aims to promote the idea of universal design, at minimal cost, to meet the needs of a person with disabilities and the development of using universal design in industry standards and guidelines. In 2006 the European Commission (EC), an institution of the EU, published regulation EC No 1107/2006 concerning “the rights of disabled persons and persons with reduced mobility when travelling by air,” (EC, 2007). The regulation states that individuals with disabilities have the same right as all EU citizens for free movement, which is applicable to air travel. In 2011 the EC published COM/2011/0166 a report analysing the success of the implementation of the regulation EC 1107/2006 (EC, 2011). While the application of the regulation overall made travel easier for individuals with disabilities, there were problems concerning passengers being able to use the toilet. The report acknowledged the “difficulties in implementing the regulation also as regards to in-flight assistance, in particular, assistance in moving to toilet facilities, which is the air carrier's responsibility.”

Design

The final design resulted in the Aircraft Combination Wheelchair Seat (ACWS). Figure 1 shows rendered views of the final product.

Figure 1. Rendered views of the Aircraft Combination Wheelchair Seat (ACWS) in (a) front view, (b) back view, (c) front detached view.

Design function and features

Design function

The ACWS functions as an ordinary aircraft seat when locked into position, seen in Figure 1a. In this position, the foot support can slide back and the wheelchair is held to the seat frame by the locking mechanism which stops one direction of motion, the other is stopped by the sides of the seat frame.

When the wheelchair needs to be released from the frame, the handle that releases the locking mechanism is pulled, and the passenger's wheelchair is then mobile. The foot support can be used throughout the flight and not just when in motion as a means to support body weight. The four sets of twin caster heavy-duty wheels allow 360° rotation and therefore the wheelchair can be turned into any orientation. When the wheelchair needs to be reattached to the seat frame, once positioned in line with the seat frame, it slides into place and the locking mechanism is used to secure it.

The seat frame can be redesigned into any shape to keep coordinate with the commercial airlines' aesthetic. This means that the ACWS can be implemented into current aircrafts as well as future aircrafts. The cushions are covered with a non-flammable material that would be specified by the airline. The bottom cushion can be removed as it is attached to the wheelchair through Velcro. At present, it is common for passengers with disabilities to bring their own wheelchair cushion, which they can use by removing the bottom cushion.

The ACWS will have the standard lap belt used when a passenger with no disabilities is using the chair. However, there will also be a body harness that can be used by the passenger with disabilities to keep themselves upright. This is because passengers with disabilities often ask their companion to hold them upright and use their hand to push away from the seat in front (Davies & Christie, 2017). This body harness would be kept behind the back support cushion of the wheelchair, which is also attached to the wheelchair through Velcro.

Once the ACWS is purchased by the commercial airlines, further design collaboration will take place in order to implement standard functions of the airlines' seats, for example, reclining features, TV screens with associated armrest remote and leaflet pockets. At this stage, the material specified by the airline would be used to cover the back lightening holes of the ACWS.

The release handle and foot support have been dyed yellow. This is following the guidelines of the Disabled Persons Transport Committee's (DPTAC) design specification for the on-board wheelchair for commercial passenger aircraft (DPTAC, 2007). It states that handling points and controls should be marked in contrasting colours. The DPTAC also requires that there are no sharp corners or edges. This is why all the edges have been filleted to at least 2 mm.

Design features

Figure 2 shows the design features of the ACWS with reference to the description in Table 1.

Figure 2. Annotated design features of the Aircraft Combination Wheelchair Seat (ACWS). To be used in conjunction with Table 1 describing the design features.

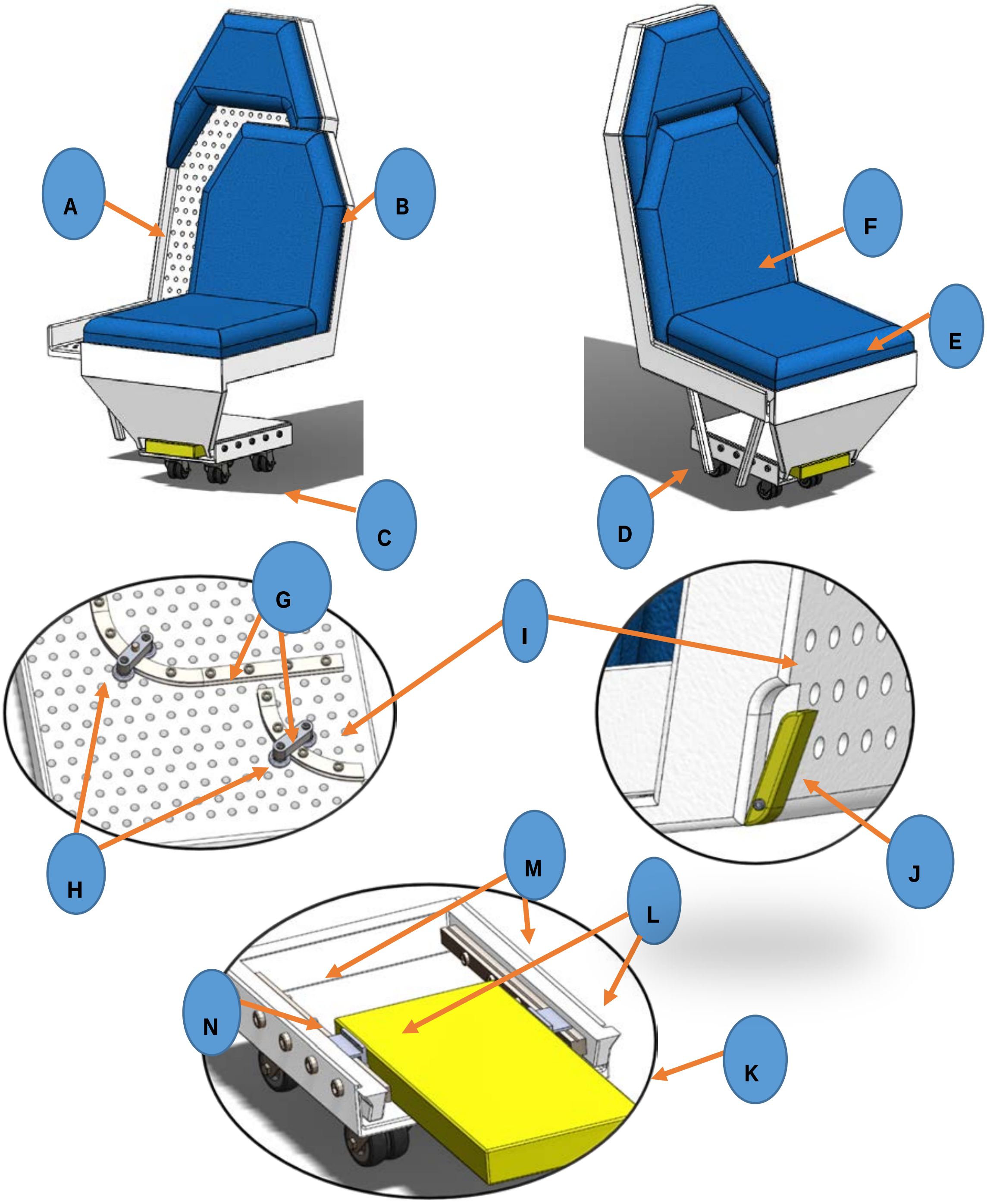


Table 1: Description of the design features of the Aircraft Combination Wheelchair Seat (ACWS) with locations seen in Figure 2.

Location	Design Feature	Description
A	Stationary Seat Frame	A seat frame was needed to be able to house the detachable wheelchair (B) and secure it in place for the duration of the flight. This means that the seat can also be used by a non-disabled passenger.
B	Detachable Wheelchair	The wheelchair was designed to be detachable and to be used when needed. It is able to fit snugly and securely into the seat frame (A).
C	Wheels	4 sets of twin heavy duty caster wheels would be purchased from a supplier and evenly distributed on the bottom on the wheelchair. The wheels have 360^{O} rotation and should not need replacement during the lifetime of the ACWS. They will be screwed into the bottom housing (N).
D	Seat Frame Legs	2 legs have been designed on the window side seat frame to be able to stabilise and hold the weight of the seat frame (A) while wheelchair (B) is detached. There are no legs on the aisle side of the ACWS as would interfere with the movement of the wheelchair.
E	Bottom Cushion	The bottom cushion was designed to be 8 cm thick, as recommended by Ragan et al. (2002), showing this to be the optimal height. It is attached to the wheelchair (B) with Velcro as to be removed if the passenger with disabilities chooses to use their own cushion.
F	Wheelchair Back Cushion	The back cushion of the wheelchair (B) is also attached with Velcro. This is to allow the implementation of a body harness the passenger with disabilities requests one to hold their upper body during landing or turbulence.
G	Curved Linear Roller Guide Rails	The curved linear roller guide rails were chosen as to allow smooth movement of the wheelchair. The guide rails are screwed into the seat frame (A). They would be purchased from a supplier and should last the lifetime of aircraft.
H	Curved Linear Rollers	Ball-bearing rollers that are bought together with the guide rails (F). They move with each other to ensure smooth transitions of the passenger with disabilities. The rollers are attached to the wheelchair (B) and are used to align the wheelchair (B) back to the stationary frame (A).

Location	Design Feature	Description
I	Lightening Holes	The wheelchair lightening holes were added as a weight reduction technique, reducing 7.59 kg. This will improve the fuel economy of the aircraft and in turn, save the airline money. The holes were iteratively designed to be 12 mm on the seat frame (A) and 15 mm on the wheelchair (B).
J	Locking Mechanism Handle	The handle is connected to the locking mechanism that securely connects the wheelchair (B) to the seat frame (A). When the handle is pulled back the handle releases, the spring clamp mechanism and the wheelchair (B) can be moved along the curved linear guide railings (G). When wheelchair (B) needs to be reattached, the clamp is forced open and keeps the wheelchair (B) in place.
K	Foot Support	The foot support was added in accordance with the DPTAC guidelines (2007) to help take the weight of the lower body of the disabled passenger. It can be slid back into the hole between the wheelchair (B) and bottom housing (N) when not required.
L	Linear Rollers	These linear rollers will be used to move the foot support (K) in and out of the wheelchair housing (N). They will be screwed onto the foot support (K).
M	Linear Roller Guide Rails	These straight linear guide rails will be purchased with the linear rollers (L) for movement of the foot support (K). They will be screwed into the wheelchair (B).
N	Bottom Housing	The bottom housing was designed to allow assembly of the ACWS. It will be placed around the bottom of the wheelchair (B) and screwed in.

Aesthetics and ergonomics

Aesthetics

The concept of universal design relates to the aesthetics of a product. This is because instead of having two products that perform similar tasks but for different demographics, they are incorporated into one product that allows both functions to take place. This is portrayed in this design by instead of having an airline seat in place and a wheelchair stored on-board, the ACWS was designed to allow both functions to take place. This reduces storage on the aircraft, which in turn can additionally improve the aesthetics of the interior of the aircraft.

To ensure that the ACWS appears to be aesthetically pleasing, it was designed with a line of symmetry down the middle. This is pleasing to the eye as well as reducing the assembly and manufacture time. The locking mechanism handle was designed to be in line with the side of the ACWS instead of perturbing for aesthetic purposes as well as to avoid catching people walking past the ACWS.

The overall aesthetics of the ACWS would be designed in accordance with the commercial airline that purchases the product. This is because further design collaboration will take place to ensure the shape matches the airline's preference as well as the colour scheme. Furthermore, additional airline seat functions can be included such as reclining features, TV screens with associated armrest functions and leaflet pockets.

Ergonomics

The ergonomics of ACWS were important to consider to ensure dimensional feasibility is used in the tight restrictions of an aircraft. The starting point of the design process was using the seat dimensions of an Airbus A321 (AIRBUS, Blagnac Cedex, France) and iteratively designing the ACWS to ensure it meets these constraints. Figure 3 shows a sketch of the interior of an Airbus 321 aircraft aligned with the ACWS, demonstrating that the ACWS adheres to the dimension requirements.

Figure 3: Sketch of interior of Airbus A321 with ACWS (a) showing the cross-section and (b) showing seat pitch.

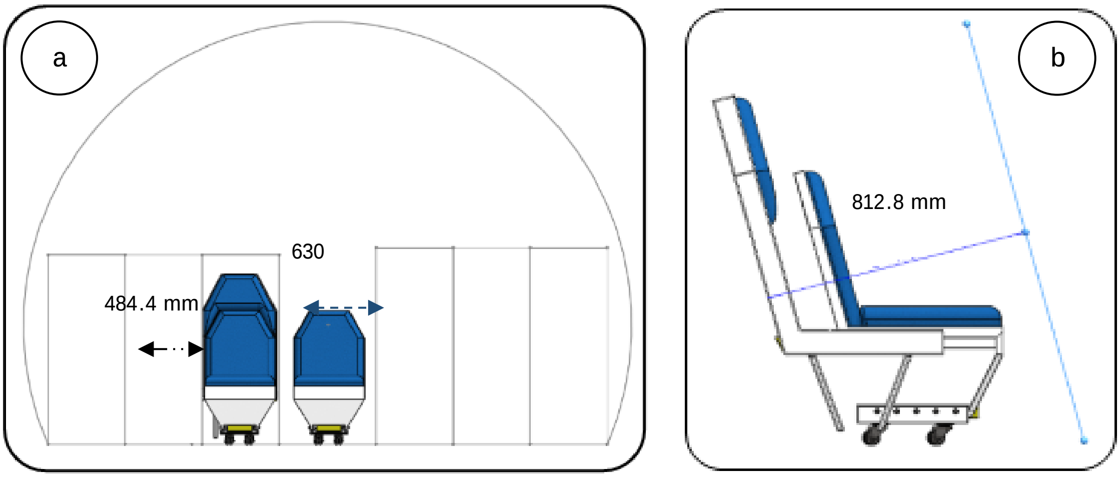


Figure 3a shows the width of the Airbus A321 seat, which equates to 485 mm, in comparison the ACWS has a width of 484.4 mm. Furthermore, the width of the aisle is 630 mm, thus the proposed wheelchair can comfortably be used in the aisle and there is adequate room for the wheelchair to be detached and reattached with the passenger with disabilities in position. The seats pitch is 812.8 mm, which is defined as the measurement from the back panel of a passenger's seat to the back panel of the seat in front. Figure 3b demonstrates that when the wheelchair is detached from the ACWS, there is still a clearance of 144.4 mm between the wheelchair and the seat in front for the passengers with disabilities' legroom.

Material selection

Material selection was carried out on all the components that would be manufactured specifically for the Aircraft Combination Wheelchair Seat (ACWS), which was identified as the detachable wheelchair frame, the stationary seat frame and the foot support platform, thus focusing on the larger more complex components. The material selection was completed using CES EduPack (Granta Designs Ltd., Cambridge, UK) such that a broad range of materials were evaluated simultaneously.

Background research concluded that aluminium is commonly used for the main supporting structure of aircraft seats (Kokorikou, 2016), however, lightweight thermoplastic composites (Veazey, 2017) are growing in popularity. These materials were used as the basis for the selection process with the influencing factors being density, cost and strength.

Selection process

Seat frame and wheelchair frame

The same material was selected for the stationary seat frame and detachable wheelchair frame. This was decided on the basis that the spring locking mechanism locks the detachable wheelchair into position on the stationary seat frame as required. In line with the materials currently used for aircraft seats, the appropriate choices for both the frame material are either aluminium or thermoplastic. A combination of different materials was avoided as this would increase the manufacturing costs, since additional equipment would be required for the different processing techniques.

The mass and cost of the ACWS need to be minimised so that the overall weight of the product compared to that of the standard aircraft seat is not significantly increased, and it is still profitable with airline providers. Furthermore, the strength of the stationary seat frame must be sufficient in order to withstand the mass of the fully-loaded detachable wheelchair. Equations 1-4 were used for the analysis.

$$\boldsymbol{mass = volume * density} \text{ (1)}$$

$$\boldsymbol{where\ volume = area * length} \text{ (2)}$$

$$\boldsymbol{yield\ stress > \frac{force}{area}} \text{ (3)}$$

The area can be eliminated from the equation since it is a constant of the design. Therefore;

$$mass > force * length * \frac{density}{yield\ stress} \quad (4)$$

Hence the mass of the ACWS can be minimized by maximizing the (yield stress)/(density) ratio. The design requirements were determined and subsequently entered into CES Edupack as constraints and objectives. An initial tree stage was applied as to only consider either Aluminium alloys or thermoplastics, depending on which were being analysed. A limit stage was applied to refine the material properties, as shown in Table 2.

Table 2: Material Property Constraints used in CES Edupack

Property	Constraint	Explanation
Yield Strength	3 MPa	Minimise yielding
Young's modulus	3.5 MPa	Minimise deflection
Recyclable	Yes	Not impact the environment
Metal Casting (only Al Alloys)	Excellent, Good	As casting most appropriate primary process for metals based on geometry
Polymer Injection Moulding (only thermoplastics)	Excellent, Good	As injection moulding most appropriate primary process for thermoplastics based on geometry
Flammability	Self-extinguishing, Non-Flammable	Requirement for materials in airlines (FAA,1986)

The analysis concluded that the most appropriate materials for the seat and wheelchair frame were Aluminium A206 or Polyetherketoneketone (PEKK). The material properties are summarised in Table 3 and 4. Further analysis concluded that although the initial material cost price for PEKK is much higher in comparison to Aluminium A206, the fuel burnt saving for the lifetime of the aircraft is higher (Red, 2014), which can be 25-30 years depending on the manufacturer (Maksel, 2008). Furthermore, the mass of PEKK compared to Aluminium A206 is quoted as approximately less than half. Therefore, for the purpose of this study, PEKK was selected as the material of choice for the frame.

Table 3: Material Properties for Aluminium, A206.0, permanent mould cast T7.

Property	Value	Midpoint
Price	1.57 - 1.67 GBP/kg	1.62 GBP/kg
Density	$2.77*10^3$ - $2.83*10^3$ kg/m^3	$2.80*10^3$ kg/m^3
Young's Modulus	69.4 – 71 GPa	70.2 GPa
Yield Strength (elastic limit)	333 – 357 MPa	345 MPa

Table 4: Material properties of PEKK (unfilled, semi-crystalline)

Property	Value	Midpoint
Price	65.8 - 73.4 GBP/kg	69.9 GBP/kg
Density	$1.3*10^3$ – $1.32*10^3$ kg/m^3	$1.31*10^3$ kg/m^3
Young's Modulus	4.29 – 4.52 GPa	4.405 GPa
Yield Strength (elastic limit)	135 – 141 MPa	138 MPa

One other important factor is the material used to create the cushion. This is particularly relevant for passengers with disabilities since one of the causes of pressure ulcers is related to being seated on an inappropriate surface for long periods of time (Schmeler, 2000). The cushion is used to redistribute forces away from the bony prominences by decreasing the magnitude of pressure (Sonenblum, 2014).

In summary, these all tend to be a firm, lightweight form of foam that is easily cut to the correct size and shape. As the requirements for cushion material is not quantifiable but rather assessed by how the material performs through experimentation, a selection process using CES Edupack was not deemed appropriate. The cushion material was chosen based on research and experimental analysis.

Several studies have concluded that while personal preference for each individual wheelchair user in terms of cushion material is likely to vary, overall the ROHO brand cushions is the most effective under average test conditions (Sonenblum, 2014; Yuen, 2001). The use of the ROHO brand of cushions was considered in this study however, since the range of ROHO products enables bespoke selection for each intended user, a brand selection was disregarded and deemed inappropriate. The focus instead was placed on the material used to manufacture the ROHO cushions, which was identified as polyurethane foam (ROHO, Belleville, IL 62221-5429, USA). Furthermore, the analysis of polyurethane foam using CES Edupack concluded that the material is suitable for use in aircrafts. The material properties of the polyurethane foam (elastomeric, open cell, 0.024) is shown in Table 5.

Table 5: Material Properties for Polyurethane foam (elastomeric, open cell, 0.024)

Property	Value	Midpoint
Price	4.88 – 5.37 GBP/kg	5.13 GBP/kg
Density	26 – 32 kg/m^3	29 kg/m^3
Relative Density	0.02 – 0.025	0.0225
Flammability	Slow-burning	N/A

Since polyurethane is deemed a slow-burning material, a non-flammable cover has been selected, which is consistent with airline regulations (FAA, 1986). Furthermore, studies have concluded that the benefits of a cushion thickness greater than a 80 mm plateau is negligible since pressure sores that develop using a cushion at this thickness is in fact attributed to other factors, for instance, seating posture or cushion material (Ragan, 2002). This was considered in the final design of ACWS, where a cushion thickness of 80 mm can be seen.

Manufacturing process

PEKK components

The Aircraft Combination Wheelchair Seat (ACWS) components, manufactured from PEKK are the seat frame, wheelchair, release handle, foot support and bottom housing. PEKK is a suitable material for both additive manufacturing (Scott, 2017) and injection moulding as primary processes. However, due to the complexities of the components, additive manufacturing would increase manufacturing time and cost. Therefore, it is recommended that the PEKK components are manufactured using injection moulding as the primary manufacturing process. The secondary processes that can be applied to PEKK include turning, boring and grinding, to create the lightening holes, screw holes and filets on all the PEKK components.

Polyurethane foam components

The components made from polyurethane foam are the three cushions. The foam is bought from the suppliers in sheets with the specified thickness. Hot wire or water jet cutting can be used to shape the cushions. It is recommended that the cushions are covered in a non-flammable material specified by the airline provider. Once covered, no further processes will need to be applied to the polyurethane foam cushions.

Assembly plan

The assembly plan for the ACWS is summarised in Table 6.

Table 6: Assembly Plan for the ACWS

Task	Parts	Description
1	Seat Frame, Curved Linear Roller Guides	Line up the guide rails with the 10 mm holes on the seat frame, with the shorter rail on the aisle-side. Screw in the 10 mm screws from the supplier with a screwdriver and tighten with a wrench.
2	Wheelchair, Curved Rollers	Line up the rollers on the underside of the wheelchair with the 10 mm holes. Screw in 10 mm screws with screws from the supplier using a screwdriver.
3	Wheelchair, Straight Linear Roller Guides	Line up the 8 mm screws with the holes on both sides of the wheelchair. Screw in the 8 mm screws from the supplier with a screwdriver and tighten with a wrench. Apply back roller stops.
4	Straight Rollers, Foot Support	Line up the rollers on the sides of the foot support with the 3 mm holes. Screw in 3 mm screws with screws from the supplier using a screwdriver, tighten with a wrench.

Task	Parts	Description
5	Bottom Housing, Wheels	Line up the wheels with the 5 mm holes in the bottom housing. Screw in the 5 mm screws using a screwdriver and tighten with a wrench.
6	Bottom Housing, Wheelchair	Line up the back of the bottom housing with the back of the wheelchair. Screw in the 12 mm holes and tighten with a wrench.
7	Foot Support, Wheelchair	Slide the linear roller on the linear guide rails and apply front stops.
9	Bottom Cushion, Velcro, Wheelchair	Remove the cover from Velcro strips and apply one side to wheelchair and other to bottom cushion. Ensure strips are lined up. Place the bottom cushion on the wheelchair.
10	Wheelchair, Velcro Wheelchair Back Cushion	Remove the cover from Velcro strips and apply one side to wheelchair and other to wheelchair back cushion. Ensure strips are lined up. Place wheelchair back cushion on the wheelchair.
11	Locking Mechanism, Seat Frame, Release Handle	Connect the locking mechanism to the handle. Place the locking mechanism in the seat frame, with handle in place.
12	Seat Back Cushion, Seat Frame	Attach the seat back cushion to the seat frame.
13	Wheelchair, Seat Frame	Line up the curved linear rollers with the curved rollers and apply stops. Push the wheelchair into the locking mechanism

Analysis

To validate that the Aircraft Combination Wheelchair Seat (ACWS) is appropriate in both design and material selection, Finite Element Analysis (FEA) was carried out on the critical components. This is to determine possible areas of stress failure and to examine stresses within the structure. FEA was also used to validate whether the lightening holes incorporated into the wheelchair and seat frame were technically feasible. The critical components were deemed to be the seat frame and the wheelchair manufactured from PEKK with the FEA software used being Abaqus CAE (Dassault Systémes, Paris, France). The Disabled Persons Transport Advisory Committee's (DPTAC) Design Specification for On-Board Wheelchair for

Commercial Passenger Aircraft states that testing loads on the wheelchair should take place at 2.5 kN evenly distributed across the base of the wheelchair, which was used for the ACWS. The analysis took place on the wheelchair when detached and then locked into the seat frame. The seat frame was not analysed in isolation as it is not intended that it would be loaded in this way.

Analysis of solid components

Initially, the solid components were analysed to ensure that the design itself was technically feasible. If a failure occurred at this stage, the ACWS was improved to prevent this. Methods used included increasing the thicknesses or angle that the wheelchair bends into the bottom housing.

Solid detached wheelchair

The solid wheelchair CAD model was imported into Abaqus and meshed using tetrahedron shaped meshing elements. This shape is commonly used for complex 3-dimensional models. The mesh of the solid wheelchair is shown in Figure 4a.

The mesh consisted of 18,312 nodes, which equated to 9324 tetrahedral elements. The boundary conditions set at zero rotation and displacement were at the base of the wheelchair where it meets the bottom housing. The boundary conditions and where the model was statically loaded is seen in Figure 4b.

The model was run, and the results examined to ensure that the maximum stress on the wheelchair did not exceed the yield strength elastic limit of PEKK. The deformed model with the Von Mises stress measurement is seen in Figure 4c.

Figure 4: (a) FEA mesh used for the solid detached wheelchair in isolation; (b) Boundary conditions and load applied to the detached wheelchair; (c) Deformed solid detached wheelchair showing maximum stress concentration.

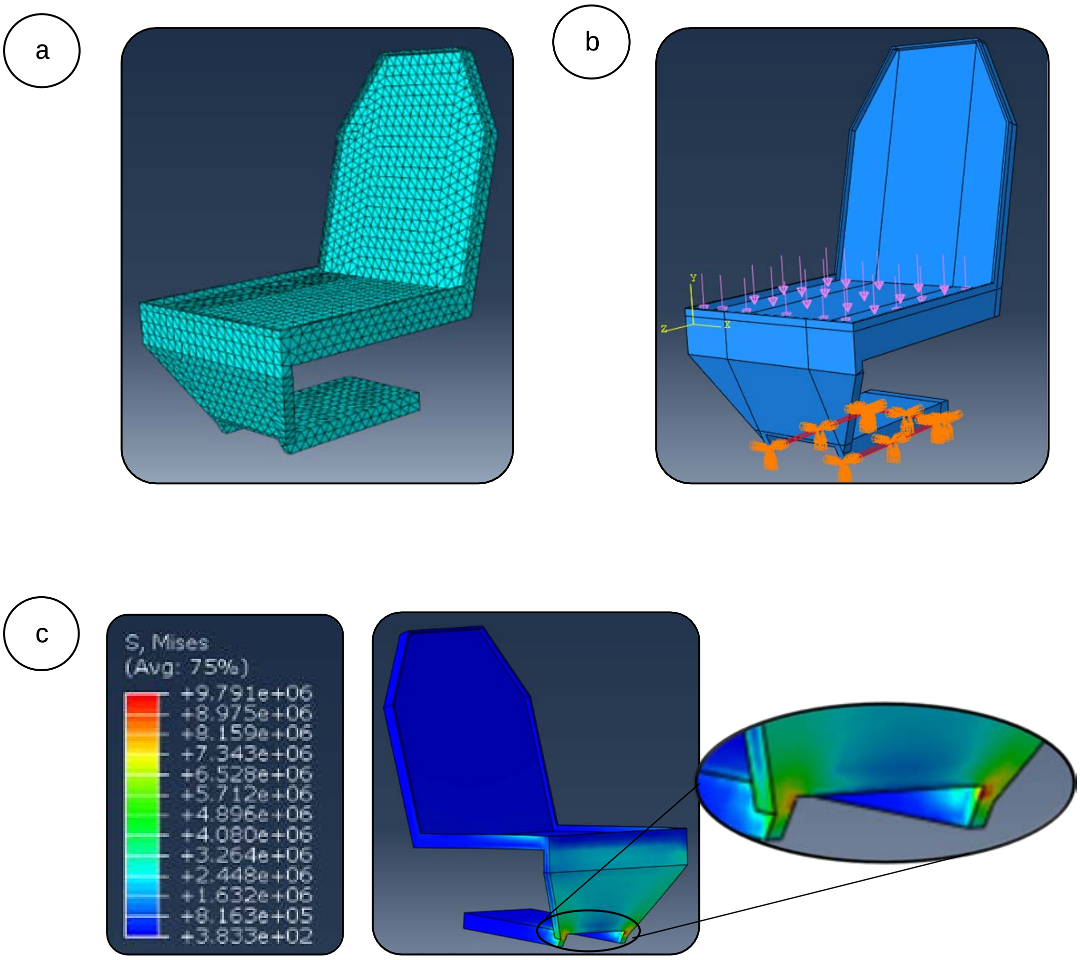


Figure 4c shows that maximum stress on the solid wheelchair occurs at the corners of the hole where the foot support is housed. In comparison to the yield strength elastic limit of PEKK (138 MPa), the stress at these corners is much lower. Therefore, based on this favourable difference, it was concluded that since the maximum stress on the loaded wheelchair is not comparable to the yield strength elastic limit of PEKK, this material selection and design was technically feasible.

Solid wheelchair locked into the seat frame

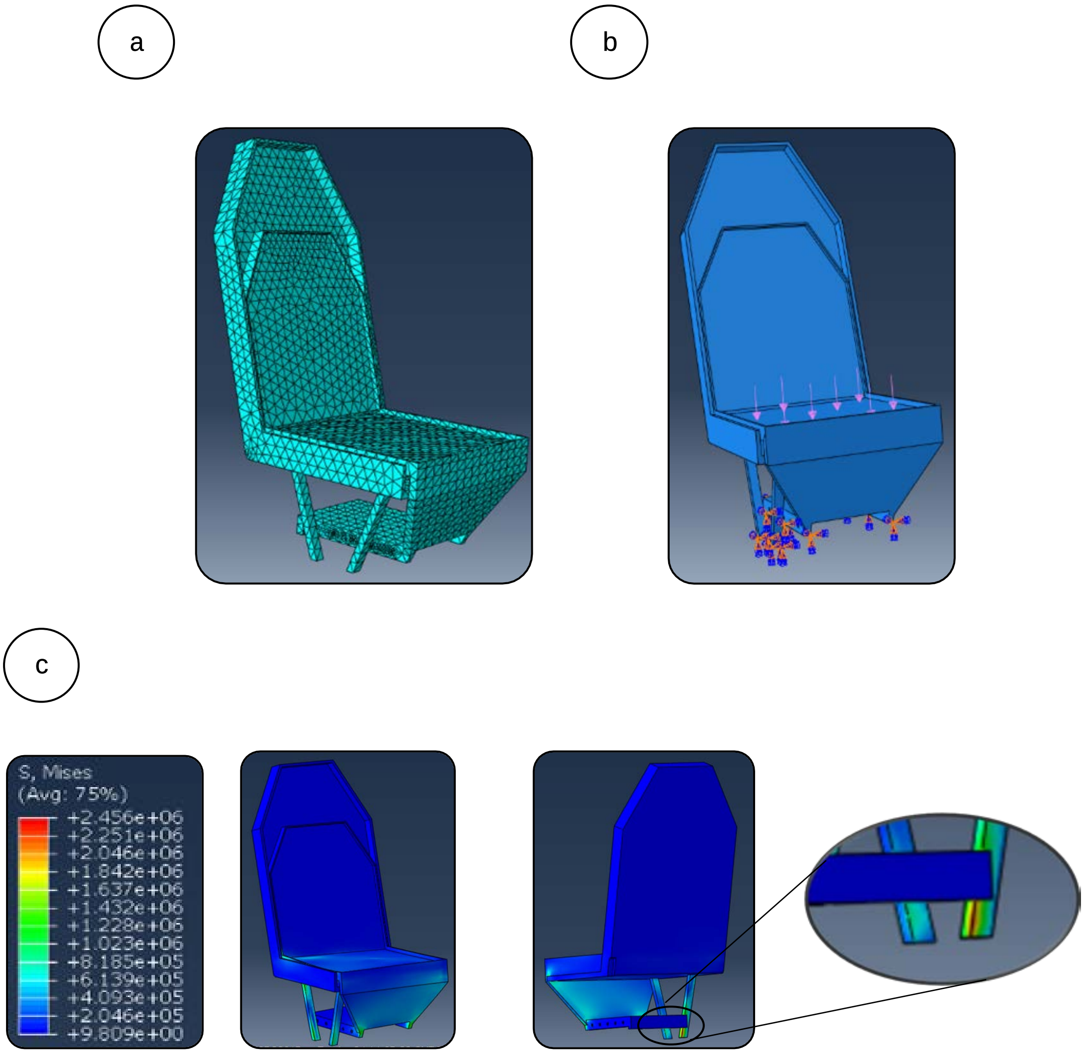
The next model created and analysed, demonstrated how the wheelchair locked into the seat frame. This model was meshed using the same tetrahedral shapes, seen in Figure 5a.

This mesh consisted of 46,377 nodes equalling 24,575 elements, which was higher in comparison to the scenario of the wheelchair being analysed in isolation. This can be explained by the fact that the approximate size of the elements were kept the same. The same boundary conditions were set, as compared to the wheelchair in isolation scenario, except that in this new scenario, the bottom of the seat frame legs has been incorporated into the CAD model as shown in Figure 5b.

The loaded model was then run to ensure that the passenger could remain safely seated on the seat. The deformed model with the Von Mises stress measurement is shown in Figure 5c.

The results concluded that when locked into position, the maximum stress concentration occurs on the inner side of the back seat frame leg. This can be explained by the greater force experience in this location from the evenly distributed 2.5 kN load as well as the mass of the back panel of both the seat frame and wheelchair. This can be rectified by thickening the cross-section of the leg and filleting the corners to 2 mm. Overall the model can still be determined technically feasible as the maximum stress concentration seen in the key is 3.5 MPa and the yield strength elastic limit of PEKK in comparison is 138 MPa.

Figure 5: (a) FEA mesh used for the solid wheelchair locked into seat frame; (b) Boundary conditions and load applied to the solid wheelchair when locked into seat frame; (c) Deformed solid wheelchair locked into seat frame showing maximum stress concentration.



From both the scenarios, the loaded wheelchair analysed in isolation and then locked into the seat frame, the maximum stress concentrations did not approach the yield strength elastic limit of PEKK (138 MPa), thus the product was determined technically feasible. The maximum greater stress experienced on the detached wheelchair when it is locked into the seat frame can be explained by the additional support that the seat frame legs provide. This is shown in Figure 5c as stress has decreased across the front sweep of the wheelchair and is experienced on the seat frame legs.

Analysis of components with lightening holes

The use of lightening holes can be seen in both the aviation and automotive industry (Sawyer, 2012; Vellaichamy, 1990), whose function is to reduce mass while maintaining sufficient strength. The driver for these industries to use mass saving methods is to reduce fuel consumption of the respective vehicles (Jemiolo, 2015), with the ultimate motivation for improving design features being a reduction in costs. In order to meet the criteria of the product design specification, the use of lightening holes to reduce the mass of the ACWS was investigated on both the seat frame and wheelchair.

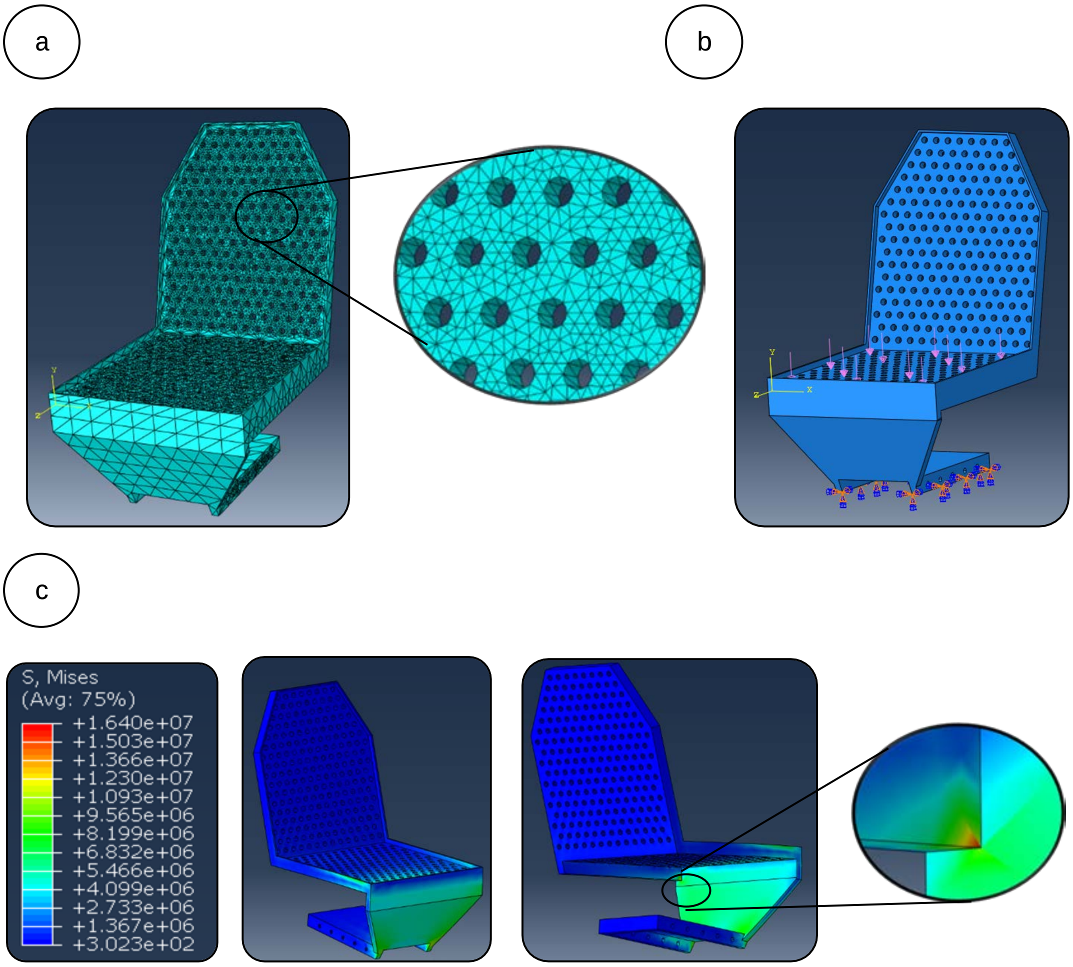
Detached wheelchair with lightening holes

The wheelchair lightening holes were chosen to have a diameter of 15 mm with holes in the same row being 30 mm away as well as the distance of the rows being 30 mm. This resulted in a mass saving of 5.41 kg. The mesh of this model used tetrahedral shapes which can be seen in Figure 6a.

The mesh of this model consisted of 213,342 nodes which equates to 131,128 elements. This is greater than that reported for the solid models due to the lightening holes needing to be meshed as well as the face meshes, thus increasing in complexity. The boundary conditions and load were kept the same as the solid wheelchair to ensure a consistent testing method, seen in Figure 6b.

This model was then run to determine if the implementation of the lightening holes were technically feasible, seen in Figure 6c.

Figure 6: (a) FEA mesh used for the detached wheelchair with lightening holes; (b) Boundary conditions and load applied to the detached wheelchair with lightening holes; (c) Deformed detached wheelchair with lightening holes showing maximum stress concentration.



The maximum stress concentration shown by the inset of Figure 6c occurred at the inner corner, underneath the loaded position of the wheelchair. This would be due to the shape of this ledge, used to cover the gap between the wheelchair and seat frame when attached. This stress concentration would be rectified by filleting the ledge. Overall, it can be seen that the detached wheelchair with lightening holes has stress concentrations that are below the PEKK yield strength elastic limit of 138 MPa.

Wheelchair locked into seat frame with lightening holes

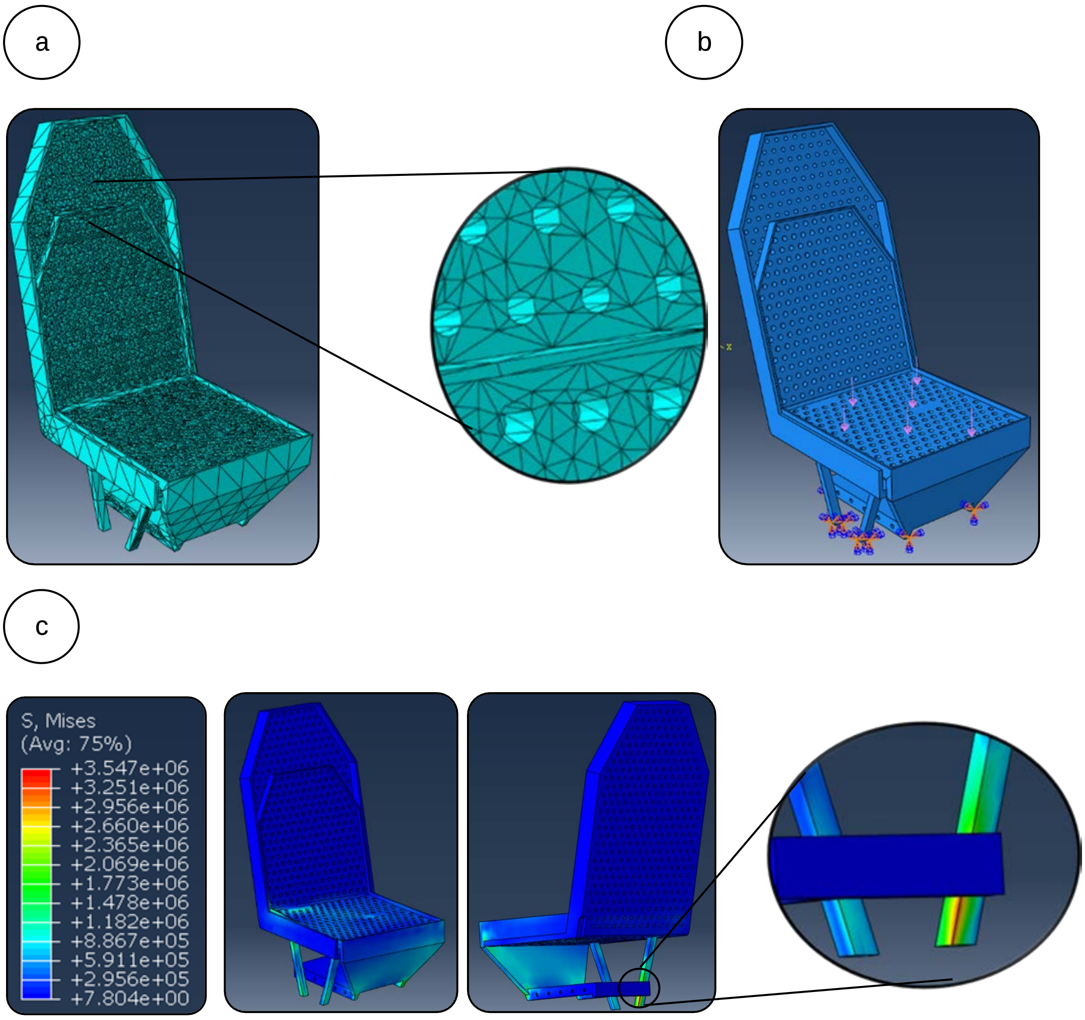
The wheelchair with lightening holes was then modelled as being locked into the seat frame as per previous analysis when the solid components were analysed. Lightening holes with a diameter of 12 mm and with holes in the same row being 30 mm away as well as the distance of the rows being 30 mm, were incorporated into the CAD model. This gave a mass saving of 2.18 kg, thus a total mass saving of the ACWS to be 7.59 kg. As shown previously for the other scenarios, the mesh of this model used tetrahedral shapes which can be seen in Figure 7a.

This mesh consisted of 228,379 nodes equating to 134,891 elements, thus producing the largest mesh due to both the wheelchair and frame being incorporated into the CAD model and the presence of the lightening holes. To ensure a consistent testing method, the boundary conditions and load, seen in Figure 7b, were the same as the model with no lightening holes, discussed previously.

From there the model was run to deem if the lightening holes on both the seat frame and wheelchair were technically feasible. The results are summarised in Figure 7c.

This maximum stress concentration of this model similarly occurs at the inner wall of the back legs of the seat frame. This can be rectified by thickening the cross-section of the leg and filleting the corners to 2 mm. However, this stress concentration is still below the PEKK yield strength elastic limit of 138 MPa.

Figure 7: (a) FEA mesh used for the wheelchair locked into seat frame, both with lightening holes; (b) Boundary conditions and load applied to the solid wheelchair when locked into seat frame, both with lightening holes; (c) Deformed solid wheelchair locked into seat frame, both with lightening holes, showing maximum stress concentration.



From this model and the detached wheelchair with lightening holes, the max stress does not reach the 138 MPa yield strength elastic limit of PEKK, thus the ACWS design and the selection of PEKK can be deemed technically feasible. Furthermore, varying the size of the elements and the nodes did not alter the results substantially.

Conclusions

The challenges in disabled travel experiences are well documented in the literature. The increasing adoption of equality and diversity measures within the society and the use of air travel by both abled and less abled passengers, has driven the development of this Aircraft Combination Wheelchair Seat (ACWS). This study presented a conceptual design, explained the mechanisms of the ACWS design and analysed the design. The novelty of the design is the dual function of its use as an ordinary aircraft seat when locked into position and as a wheelchair when it is disengaged. The suggested ACWS meets the requirements of the dimensions of the Airbus A321 aircraft aisles and facilitates aircraft mobility. FEA analysis concluded that the choice of PEKK and the use of lightening holes was technically feasible.

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