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The Design Challenges of Finding Engineering Solutions for the Ingress and Egress of Disabled Passengers into Small Sub-Regional Aeroplanes

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ABSTRACT

Examples of design solutions for the ingress and egress of wheelchair users into large and small passenger aeroplanes already exist on the market. However, they are predominantly ground-based, expensive, single-aircraft solutions. The Innovate UK HEART project aimed to address this gap by developing accessible designs for smaller aircraft with 19 seats or fewer. The approach taken was a systematic user-centred Inclusive Design methodology based on functional, analytical capability analysis (Langdon et al., 2010) and an end-to-end design method exploring a design space of alternative technical and ergonomic design (Stanton et al., 2021). The developed designs needed to align with the needs, expectations, and lived experiences of its intended users. The design process was therefore based around disabled users and their experience. The project prioritised user-centred design, ensuring that proposed solutions were not only technically feasible but also practically usable by operators. Key technical issues include restricted space, vertical movement such as reaching and descending from the aircraft door level, and rotational and horizontal movement required for passengers to enter the aeroplane. Early trials with a prototype were successful in engineering terms and were received positively by collaborating disabled users, suggesting that the operation of the lifting equipment was potentially beneficial for disabled passengers if scaled up to airline service.

Keywords: Aircraft ingress and egress, Design workshop, Technical workshop, Regulations, Inclusion audit, Design requirements

INTRODUCTION

The Hydrogen Electric and Automated Regional Transportation (HEART) project of the Innovate UK's Future Flight Challenge included a design analysis exploring alternative mechanical and ergonomic design solutions for implementation in specific aircraft. This involved a series of workshops and carried out an online inclusion survey as part of the integrated methodology. The project was to support inclusive air travel for people with capability variations, such as low vision or physical movement difficulties, for example, wheelchair users. Design solutions for ingress and egress for wheelchair users existed in the market; however, they were not suited to all aircraft and circumstances. The HEART Project was concerned with hydrogen-electric aircraft with 19 seats or fewer, single and/or multiple-engine piston land (ASSI, Part 135 Commercial Air Transport Operations (CATO)) (ASSI, 2024), (CAA, 2023). To fill this gap, the project explored alternative solutions for ingress and egress. The project also considered the potential to carry passengers who use a wheelchair and the associated requirements. An inclusive design methodology was utilised based on functional, analytical capability measurement (Persad et al., 2006).

There were two types of pertinent regulations to consider when designing for inclusive air travel. The first considers passengers' rights, and the second considers airworthiness and safety. In the UK, the Equality Act 2010 contains a specific exclusion that the general duty to make reasonable adjustments for disabled passengers does not apply to transporting people by air. However, the European Commission (legislation.gov.uk, 2006) Regulation No 1107/2006 concerning the rights of disabled persons and persons with reduced mobility when travelling by air still applies in the UK (CAA, 2019). The Certification Specifications (CS) (EASA, 2023) vary according to the class of aircraft. For the design of the HEART Project, the relevant certification specifications were CS-23 for normal and utility commuter category aeroplanes, which provide the technical requirements for certification of small aeroplanes. Any design solutions for ingress and egress, or carrying a wheelchair in the cabin, needed to be developed in the context of the existing certification. Therefore, if any modification needed to be done, for example, modification for ingress and egress purposes, it must comply with CAA, CS-23. These specifications were important for wheelchair access and manoeuvrability. Furthermore, for design purposes, the height between the ground and the door needed to be considered for the range of aircraft.

RESEARCH GAP

Solutions for ingress and egress for disabled people, especially wheelchair users, already existed in the market; however, they were not suitable for all aircraft and circumstances. As a result, the HEART project addressed a critical gap in aircraft accessibility, particularly for smaller aircraft operating with 19 seats or fewer under CATO (Controlled Airspace Take-Off and Landing Operations). Traditional ingress and egress solutions did not suit these aircraft due to their size with limited spaces (i.e. small fuselages and narrower doors) or operational environments (i.e. low ground clearance, which made traditional stairs or boarding ramps impractical or unsafe). To address this gap, the HEART project explored alternative solutions.

MATERIALS AND METHODS

The Technical and Design workshops were fundamental components of the Methodology. These workshops were conducted with 8 and 10 participants, respectively. Among the attendees, there was one person with known disabilities (paraplegia) and consortium partners who were stakeholders in the HEART Project. The participants included:

- An ex-CAA regulator and Consortium Leader
- A collaborating wheelchair user with an engineering background
- A flight test engineer from the Britten Norman Aerospace company
- A Product engineer with a background in artistic rendition
- A Project Principal from Mott MacDonald Engineering consultancy
- Two workshop facilitators and three researchers.

The methodology for the technical workshop was based on Stanton et al., (2021). It involved capturing themes and details of technical discussions through qualitative thematic analysis based on grounded theory (Goodman-Dean et al., 2010). The proceedings were recorded in video and audio formats and transcribed using automated transcription. These transcriptions were then error-checked and coded thematically using a Grounded theory approach and NVivo (V20) software and the results summarised. Researchers subsequently recoded after engineering discussions, and the report was enhanced with benchmarking of existing solutions.

The Design workshop methodology focused on identifying key design thinking themes and new concepts. Researchers reviewed and refined these concepts after the workshop, then filtered them according to engineering requirements that were previously established in a technical workshop.

EMERGENT DESIGN CONCEPTS

The workshop participants were tasked with generating ideas aligned with the project's aims. These ideas were detailed in concept sheets, the template for which included several key sections exemplified below.

DESIGN PROCESS

The methodology centered on methods derived from a framework designed for human interfaces in automotive automation (Stanton et al., 2021). The design process presented the procedures used during the technical workshop. After determining the requirements discussed in the workshop, new design solutions were assessed according to these requirements at the conclusion of the session. The workshops resulted in alternative designs that fulfilled relevant engineering criteria. The concept development process was divided into two stages throughout the workshop. The objective was to produce a shortlist of viable design concepts. These concepts were then collectively reviewed to generate a narrower selection of options. The intention was to build solutions for subsequent evaluation that were engineering valid. For each shortlisted idea, an individual summary sheet was produced following the approach outlined. These designs were subsequently reviewed by disabled users, and discussed using qualitative and quantitative input from the HEART project.

EMERGENT CONCEPTS

The design workshop was followed by technical meetings to review the engineeing, aiming to eliminate duplication and merge similar designs.

Concept sheets were prepared for filtered ideas based on the workshop's convergence principle. The finalised design concepts were verified by workshop feedback and then drawn in CAD or graphic rendition. Hence, the following design concepts in Table 1 were screened for further steps of consideration.

Table 1: Emerged design concepts.

S.n.	Design Concepts	S.n.	Design Concepts
1.	Lifting equipment	7.	Roof rail/Pulley
2.	Swivel passenger seat	8.	Are you sitting comfortably?
3.	Sliding floor cassette	9.	Front or rear-loading aircraft
4.	Aircraft Kneeling	10.	Conveyor belt/Tesco trolley ramp
5.	Ramps (Turntable and Flex Bend)	11.	Expandable airbag lift
6.	Concertina bendy Ramp	12.	The merged concept of Cassette and Turntable + Flex bend

Each of the above design concepts was summarised in a "Design Concept Summary Sheet". The summary sheet was created from a template with the following titles and descriptions, illustrating the emerging concept BN Lift.

BN Lift Concept Summary

The BN Lift had developed as a lifting device for physically disabled people, especially wheelchair users, to use on BN Islander aeroplanes. The idea was developed by considering the engineering requirements as discussed in the technical workshop, such as the height between the ground level and the ingress of the door and the distance between the wheel and the door, including securing straps to prevent falling from the platform and back support for stability and safe operation.

Assumptions With Schematic

The images below display the BN Islander aeroplane, emphasising the significant distance between the wheel and the ingress door. This height difference from the ground presented a challenge for wheelchair users. Existing aviation solutions, such as the scissor lift, Ambulift, and Aviramp, were unsuitable due to size constraints and were only effective for larger aeroplanes. Consequently, a lifting device was conceived, illustrated in Figure 1. To ensure safety, the device included back support and straps for enhanced stability and security.

Concept Description

The main purpose of this design was to lift wheelchair users from ground level to the sill level of the aeroplane door. This height was fixed, assuming a level surface during normal undercarriage operation. The upper fixing point was located on the seat rails next to the door, while the lower part of the lifting device rested on an adjustable rubber pad to account for variations in ground level.

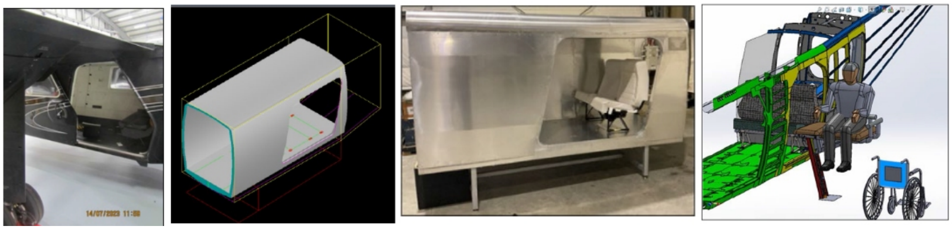

Figure 1: BN Islander lifting device concept, (a) distance between the wheel and the ingress door, (b) model of the Fuselage construction, (c) fuselage rig with the seat, (d) BN Islander lifting device concept.

The sitting platform was securely attached to a lifting device, featuring components like an armrest and straps to ensure the wheelchair was safely secured. The platform was elevated gradually using a lead screw mechanism, which could be operated either manually or with a battery-powered device. The lead screw was actuated via a square drive at the top, such as with a cordless drill. Once the platform was raised to the level of the aircraft chair, the user could transfer to the aircraft chair using a sliding support panel. Additionally, the lifting device was designed to be packable and could be safely stored in the aeroplane's storage area.

Operational Considerations

Based on the engineering requirements, Britten Norman OEM1 (Original Equipment Manufacturer) adopted the lifting device solution as depicted in Figure 1. For safety, the sidebar armrests and straps to secure the user were discussed during the design workshop, which was developed during the trial session. These safety features were considered during the usage trials. Additionally, the number and positions of the handles were determined during live trials, based on user feedback. Operating this device required a trained individual to handle the electrical actuator and assemble the equipment After use, the entire lifting device could be folded and stored.

Inclusion Considerations

According to the "National Care Service; Adult Social Care: Equality Evidence Review" by the Scottish government (Government, 2022), 50% of the adult population was over the mean population age. Many of these individuals were elderly and faced varying levels of difficulty in daily life. This underscored the necessity for new research to support inclusive air travel, ensuring that these solutions could be evidenced to support new regulations.

The development of this lifting device was meaningful for those who were physically disabled, especially those with wheelchairs. Wheelchair users were able to transfer to the seat provided on this device using a familiar movement. They were then secured using the straps. The device was provided with an armrest, back support, and a bar around the chair to hold if needed. This device helped wheelchair users get in and out of the aeroplane with ease.

INCLUSION CATEGORIES

A table categorising difficulty levels for each functional area was developed using inclusive design principles from "Designing a More Inclusive World" (Waller et al., 2010). As shown in Table 2, these tables were based on UK disability data (Martin and Elliot, 1992; Langdon et al., 2015) and maintained consistency across all design concepts. For example, the five common classifications of functional impairment were considered as: Category A: Low capability (purple colour category); Category B: Low to moderate capability (lavender colour category); Category C: "Moderate" to "light to moderate" capability impairment (orange colour category); Category D: "Light to moderate" to "no discernible difficulty"s.

Table 2: Example inclusion category card. B: low to moderate capability.

	Description	ONS Leve	ONS descriptives	Notes
Category B	**Moderate**			
	Vision	2	Required to Read a large print book	
	recognition	2	Required to Recognise a friend across the room,	
	Hearing			
	speech	2	Required to Use an ordinary telephone	
	sounds	2	Required to Hear a telephone bell	
	Physical movement	2	Required to Walk 175 metres (≈ 200 yds) without stopping	
	steps	2	Required to Manage 12 steps, using a handrail if necessary	
	balance	2	Required to Balance for short periods of time, without holding on to something	
		1	Required to Bend down far enough to touch knees, and then straighten up again	
	Thinking	1	Required to Think clearly, without muddling thoughts	
	sequence	1	Required to Do something without forgetting what the task was whilst in the middle of it	
		1	Required to Remember to turn things off, such as fires, cookers or taps	
Not an ONS scale	**Systemic**	2	Required to Walk 175 metres (≈ 200 yds) without stopping	
	Dexterity	2	Required to Pick up and carry a pint of milk with either the left or right hand	
	Reach & Stretch	1	Required to Reach one arm out in front (for long periods)	
	Bending	1	Required to Bend down far enough to touch knees, and then straighten up again	

Inclusion Audit Method

All steps in the task analysis for ingress and egress were compared across the four different tables, and the matching category was selected.

Inclusion Audit for BN Lifting Equipment

The inclusion audit was conducted for all functional categories of individuals performing different tasks, with their corresponding categories based on the category tables. The inclusion audit for the BN's Lift is detailed in Table 3. For the BN Lift, the mental capability functional area was predominantly categorised as lavender colour. This indicated that individuals with low capability (purple colour category) could be assigned to this task, as the purple colour category implied no requirement for thinking or memorising sequences during the task. In terms of stamina, the orange colour category indicated that moderate strength was required for these tasks. However, in some cases, stamina was categorised as purple, meaning no strength was needed since the task involved merely sitting on the lifting platform.

Table 3: Inclusion of audit for the BN lift equipment.

Steps	Concept 1. BN lift				
Up	**Vision**	**Physical**	**Hear**	**Mental**	**Stamina**
Step 1: Wheelchair alongside a platform and slide to a platform					
Step 2: Elevate a platform up controlled by cabin crew					
Step 3: Slide to an aircraft seat					
Step 4: Folding and storing of a wheelchair					
Down					
Step 5: Slide to a platform from aircraft seat					
Step 6: Lower down a platform controlled by cabin crew					
Step 7: Unfold a wheelchair and slide to a wheelchair					

Tasks that required good vision, physical movement, and hearing were categorised as having "moderate to light moderate" to "light moderate to no difficulty". Good vision was essential for reading signs, and identifying items such as platforms, armrests, and doorways. Physical movement, primarily involving the arms, was necessary for tasks like picking up and folding a wheelchair, as well as the reach and stretch required to hold the armrest and to maintain balance. Moderate hearing was important to follow instructions amidst the background noise.

DISCUSSION

Following the inclusion audit, most design concepts were marked with a purple colour for Stamina, while only a few had high demands for Mental capabilities. Predominantly, the design concepts were scored as lavender and orange colours, categorised using the four-card colour system.

Table 4: Scores of design concepts based on inclusion audit.

Concept number	Concepts / Colour	Purple	Lavender	Orange	Green
1	Concept 1. BN lift	2	18	18	0
2	Concept 2: Expandable air bag	2	15	18	0
3	Concept 3: Conveyor belt/ Tesco trolley ramp/ Caterpillar track	2	11	22	0
4	Concept 4: Ramp turntable or Flex bend	0	14	21	0
5	Concept 5: Concertina ramp/ folding ramp	0	20	21	0
6	Concept 6: Aircraft kneeling	2	14	19	0
7	Concept 7: Passenger swivel seat with a lifting device	2	15	18	0
8	Concept 8: Sliding floor cassette	2	15	18	0
9	Concept 9: Roof rails/ pulleys/Hoist	2	15	18	0
10	Concept 10: Front or rear-loading aircraft	0	14	16	0
11	Concept 11: Sitting comfortably	0	13	15	0

Based on the capability category cards, scores were assigned by counting the number of category colours in each design concept, as shown in Table 5. For example, design concepts needed to be economical, simple, safe, and possess face validity. From the task analysis, individuals needed at least one eye for vision to see instructions, doorways, pathways, straps, and locks. They also required dexterity and the use of both hands to roll a chair while holding the device arms. Stamina was necessary to slide onto and off the seat, along with the ability to bend. Thinking was required to understand sequences of movement. Sufficient hearing was required to perceive instructions from crew members in noisy environments.

Table 5: Scores of top rank design concepts based on the Pugh matrix

S.No.	Requirements/Design Concepts	BN Lift	Air Bag	Conveyor Belt
	Design related constraints			
1	Engineering standard for door size, type and location	+	+	+
2	Door and wing configuration	+	+	+
3	Height between the ground level and ingress door	+	+	+
4	Distance between the wheel under the wing and the ingress door	+	+	+
5	Mechanism of lifting device, size and weight measurements, distances from undercarriage/ winds and load capacity by the lift	+	-	-
6	Engineering stnadard for seating arrangement and fixing seat sizes	+	+	+
7	The locking system of the wheelchair while lifting and inside the cabin to make it secure	+	+	+
8	The position of the handrail to be held by the wheelchair user while they are being lifted by the lifting device	+	+	+
9	The position of the handle to hold to get into the cabin and to hold while in the cabin	+	+	+

Continued

Table 5: Continued

S.No.	Requirements/Design Concepts	BN Lift	Air Bag	Conveyor Belt
10	The connection strength of the handle on the body of the plane in the cabin	+	+	+
11	Engineering specifications and standards for fixing handles and lifting devices	+	+	-
12	The considerations of lifting a wheelchair			
	using a battery power (on aircraft or off aircraft)	+	+	+
	using a hand tools (e.g., cordless power drill)	+	-	+
13	Weight	+	+	+
	General			
14	Cost (low or high)	+	+	-
15	Transportation charge (low or high)	+	+	-
16	Weather sustainable (Yes or No)	+	+	+
17	Manufacture difficulty (Yes or No)	-	-	+
18	Materials availability (Easy or Difficult)	+	+	-
19	Safety	+	+	+
20	Operation (easy or difficult)	+	+	-
	Educational and training			
21	Carer/ Help needed (Yes or No)	+	+	+
22	Training for operation (Yes or No)	+	+	+
	Total (+)	22	20	17
	Total (-)	1	3	6

To analyse the emerging design concept, the Pugh Matrix scoring system was used, as detailed in Table 6, with only a limited number of concepts (Pannell, 2023) shown. The requirements were divided into three constraints: "Design-related," "General," and "Training and education." Engineering requirements were classified with terms like "Low," "High," "Yes," "No," "Easy," and "Difficulty" for each design concept. After scoring, the concepts were ranked based on their alignment with engineering requirements.

CONCLUSION

The workshop aimed to broaden design options and foster innovative ideas for inclusive air travel equipment, particularly addressing wheelchair access to small aircraft. Experts tackled key technical challenges within regulatory and user requirements. Afterward, selected design concepts were summarised and evaluated, resulting in novel solutions that met both engineering and inclusion criteria for real-world application.

The BN Lift concept was determined to be the most appropriate for small aircraft such as Islanders, following evaluations conducted with the Pugh matrix, inclusion audit, and assessment form system. The BN Lift received only one negative among 23 design constraints, while others such as an expandable airbag system received three negatives. Results from the inclusion audit were similar for both concepts; however, the assessment form identified further differences in areas such as reach and stretch, bending, and standing, although these factors were only assessed for a limited number of best ranked options. Considering all criteria, including design constraints, the BN Lift concept design was predominant. Initial trials demonstrated that the lifting device effectively addressed the vertical access challenge and enabled the user to achieve horizontal access independently. This method was considered safe and non-stigmatic for accessing the aircraft. Additionally, it was established that the device could be introduced to the Islander aircraft without requiring modifications to the airframe. The project represents a significant first step towards developing a device that enhances accessibility for small aircraft over a wide range of capabilities. Further testing could involve trials on actual aircraft to evaluate their performance with the existing doorframe and within the confined space beneath the aircraft wing and between the door and the landing gear. The device is likely not suitable for all low capability passengers, so additional testing with a larger user group will be mandatory to determine the range of usage cases. Further trials could also identify the types of aircraft the device can best operate with, and explore the potential for modified versions of the device to be tested with these aircraft.

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