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## ARTICLE

# Time and force required for attendants boarding wheelchair users onto aircraft

### Abstract

Ensuring equal opportunity to all transport modes, including air travel, allows disabled people the same freedom of travel available to the rest of the population. However, boarding of wheelchair users onto airplanes is physically demanding for attendant airline or airport personal whom assist and time consuming and costly for airlines. This paper presents a comparison between two methods of boarding wheelchair users, measuring the forces required and the duration taken. Participants were asked to act as attendants and to board weighted wheelchairs onto simulated aircraft vestibules using two different manoeuvre methods (“going forwards” and “going backwards”), with two different loadings (“light” and “heavy”) in two different access scenarios (“level access” and “sloped access”) between the jet-way/scissor-lift and the aircraft. The results reveal that the “going backwards” technique is a slightly faster manoeuvre method but no difference in the forces required exist between the two methods. The weight of the wheelchair affected the forces required to complete the boarding and exceeded health and safety guidelines for attendants. Reducing the height of the step between the aircraft and the jet-way or scissor-lift is recommended.

*Relevance to Industry:* The research highlights the juxtaposition between the need to board wheelchair users and the excessive force required by the attendants propelling the wheelchair.

### Introduction

In Europe more than 45 million adults have a long standing health problem or disability (European Commission, 2007). Many of these use wheelchairs to move about the environment. In the United Kingdom (UK) alone current figures for wheelchair users are estimated at 1.2 million, with 825,000 of those being regular, long term users (Huonker, Schmid et al. 1998) and their use is increasing (Manty, Heinonen et al. 2007). This group of people faces more difficulty than most in moving with ease around their environment and accessing transport options (Meyers et al, 2002; Mathews & Vujakovic, 1995; Bromley et al, 2007; Shaw & Coles, 2004; Petzäll, 1995).

Ensuring equal opportunity to travel is a key commitment in the UK, in Europe and globally. Disabled people need access to the same modes of transport available to the rest of the population. This includes air transport where wheelchair users face numerous obstacles (Chang & Chen, 2011).

Globally, disabled persons' rights are protected by United Nations' Convention on the Rights of Persons with Disabilities (UN, 2006). The rights of a person to access places and modes of transport are detailed in Article 9, which states "States Parties shall take appropriate measures to ensure to persons with disabilities access, on an equal basis with others, to the physical environment, to transportation... and to other facilities and services open or provided to the public, both in urban and in rural areas." and "... *These measures, which shall include the identification and elimination of obstacles and barriers to accessibility.*"

Mobility impaired people within Europe are protected by European Regulations (European Commission, 2007). The European Regulation (EC) 1107/2006 [page 1] states that "*disabled persons and persons with reduced mobility, whether caused by disability, age or any other factor, should have opportunities for air travel comparable to those of other citizens*". In addition, regulations demand assistance to be provided to transport passengers free of charge (EC 1107/2006).

In the UK the Department for Transport (DfT) have set out a code of practice. In it they remind that the UK laws in this area are governed by the EU regulations and that these must be met anywhere in the UK. Furthermore they state that, by law: *Companies should review their policies, procedures and practices to ensure that they meet the needs of disabled persons and persons with reduced mobility* (DfT, 2008). and they recommend that the: *Responsibility for meeting the needs of disabled persons and persons with mobility should be accepted at the highest levels and delegated to people with the skills and authority to influence the design and operation of aircraft and airport terminals or to alter procedures* (DfT, 2008).

The law is very clear that disabled people must be allowed access to be able to board aircraft and that airports and airline have a legal duty to adhere to this. However, within the airport and airline industry, providing this service can be problematic. This is because the physical effort involved in boarding a wheelchair is high.

The act of pushing wheeled devices, including carts and wheelchairs requires significant force (Ciriello et al, 2001; Haslam, et al, 2002; Jung et al, 2005., Petzall, 1995). The push force is affected by a number of factors. For example the forces required when manoeuvring carts is less when pushing forwards than when pulling backwards (Lawson et al, 1993; De Looze et al, 2000; Jung et al, 2005). Push handle height, weight load and orientation can also affect push forces. A review of the evidence by Jung et al (2005) showed weight load is the parameter which has the most effect in pushing wheeled device. Although handle height is also of great importance. Al-Eisawi et al (1999) found that elbow height handles make pushing or pulling the most force efficient. In general for wheelchairs handles a higher handle height is preferred for pulling than pushing. Higher than the commonly used 92cm height handles would make wheelchair manoeuvres easier (Van der Woude et al, 1995).

Manoeuvring wheelchairs has been linked with injuries for both the person in the wheelchair (when self-propelled) and the person pushing (if attendant propelled). For attendants both pushing and pulling have been found to cause lower back pain and shoulder injuries (Chaffin et al.1984; Hoozemans et al. 2004; Lee et al (2013); Pope, 1989; van der Woude, 1995). Where possible lifts are used to reduce the likelihood of injury. Some injury, particularly musculoskeletal disease, are associated with the handle height of chairs in relation to the height of

the attendant. Handles which are too low put greater pressure on forces needed to manoeuvre a wheelchair (Lee et al, 2013; van der Woude, 1995).

Within the Health and Safety Executive (HSE) guidance the force required for pulling or pushing should not exceed 150N for women and 200N for men. In addition, HSE guidance on wheelchairs boarding airplanes state "*chairs should be designed such that the force required to push and turn (on a level surface) a wheelchair or boarding chair occupied by a 99<sup>th</sup> percentile weight male should not exceed the maximum force which can be exceeded by a 5<sup>th</sup> percentile female*"(HSE, 2007). There is an issue here to balance the needs of disabled people (as represented in law) and the protection of their employees health and the economic requirements of the industry. The UK recommends they "*managing bodies should ensure that they "ensure that the appointed service provider has suitable equipment to facilitate boarding which minimises risks to staff and passengers. Equipment must be well maintained to ensure adequate availability"* (DfT, 2008)

Airlines must ensure the health and safety of the staff involved in boarding wheelchair bound passengers and therefore it is important for airlines to understand the forces necessary to move a passenger with their wheelchair onto a plane. Manoeuvring wheelchairs requires strength and boarding users onto airplanes can be especially difficult as it can require going up a step. A step of approximately 20cm is common at the entrance of an aircraft even when a jet-way is used. The force required to mount a step of this height is impossible for many to achieve (Petzäll, 1996). A ramp is often used to remove this step. However, even with the use of a ramp, the effort required for the person manoeuvring the wheelchair is significant. Where possible, airlines prefer to board wheelchair users via a lift as this reduces the effort required by staff and lowers the risk of injury. However, in many cases, even when a lift is present there is still a step between aircraft and lift.

Providing this service for disabled people is also costly for an airline. Keeping aircraft on the ground is expensive for the airlines. As a result they keep their planes in a terminal for the minimal amount of time needed for safety of the vehicle and the supply of goods (Nyquist and McFadden, 2008). However the boarding of mobility impaired passengers in wheelchairs can take a long time.

The potential mismatch between the requirement to allow disabled users access to a transport service and potential violation of Health and Safety guidelines is vital to empirically understand. Data needs to be gathered on the force levels required by different boarding methods.

In order to produce this information a small sample comparison study was carried out. The study aimed to understand the time and force required by an attendant to push a wheelchair onto an aircraft, how this changed as a result of passenger weight, wheelchair manoeuvre method (Going Forward and Going Backward), and whether the force required fell within Health and Safety guidelines. The focus for this research was limited to the manoeuvre of the wheelchair and its passenger onto the plane and did not include the requirements of transferring the passenger into and out of the transfer chair.

## **1. Methods**

### **2.1 Experimental Design**

Experiments were carried out in a real-world model of an aircraft vestibule (and on a flat version of one (see figures 1, 2 and 3)). Ten participants were asked to perform

each of the two manoeuvres, with two different wheelchair loads, three times each in the two settings. Before the recordings were made, participants tried each manoeuvre at least once in each setting. They were allowed to practice as many times as they wanted. Once the participants had finished the manoeuvres in one location they were asked to rate how demanding the manoeuvres were using the Borgs scale of perceived exertion (Borg, 1982). A force transducer was installed on the wheelchair pushbar recorded the forces applied in each trial and each trial was timed.

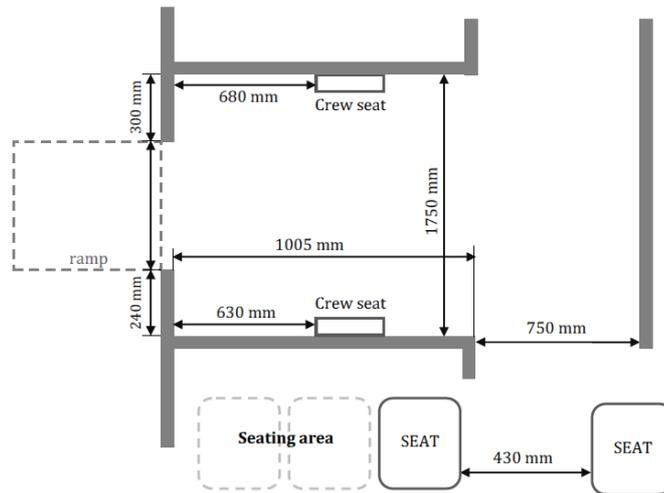


Figure 1: Aircraft Model Dimensions (drawing not to scale)



Figure 2: Flat model version of the aircraft vestibule



Figure 3: Entrance of the real-world model, side view

## 2.2 Measurements

The two methods of wheelchair manoeuvre used were:

- a. Going Forward Manoeuvre.

This manoeuvre starts with the wheelchair facing the entrance of the aircraft.

The attendant pushes it into the aircraft and turns 90° before reversing into the aisle.

b. Going Backward Manoeuvre.

This manoeuvre starts with the rear of the wheelchair facing the entrance of the aircraft. The attendant pulls the wheelchair onto the aircraft and then turns directly into the aisle.

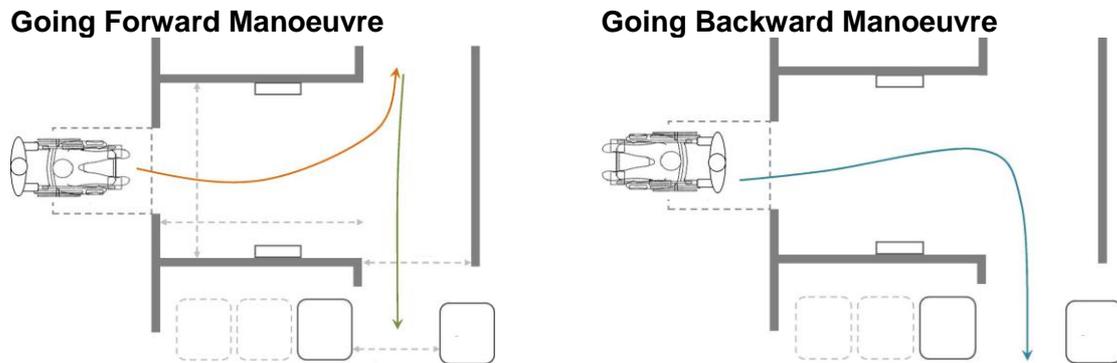


Figure 4: Going Backwards and Going Forwards Manoeuvres

Participants pushed the wheelchair using the lighter load first in the flat model followed by the real world model. They then repeated this with the heavy load in the flat first and real world model second. For each of these scenarios, participants completed by the forwards and backwards manoeuvre, although to remove order bias the order of the manoeuvres was randomized.

### 2.3 Participants

A total of 10 participants were recruited to take part, five male and five female. A convenience sampling method was used, all participants were students within UCL including undergraduates and postgraduates. All participants signed an informed consent form before taking part. The participants were aged between 18 and 27 and perceived themselves to be in good physical shape. They ranged in height from 1.53 meters to 1.91 meters and in weight from 42.3 kilograms to 86.7 kilograms. Six of the participants had experience pushing a wheelchair, however this experience was limited as only two participants had pushed a wheelchair more than once.

### 2.4 Apparatus

The experiments were carried out at the Pedestrian Accessibility and Movement Environmental Laboratory (PAMELA) in University College London, a unique multisensory pedestrian environment laboratory. Efforts were made to stay as close to conditions observed at airports. The real-world model had a 18cm step between the ground and the airplane which is the typical step size to board aircraft. A ramp with a 20° incline was used to cover the step. The flat version was completely flat with no incline or step.

#### 2.4.1 Wheelchair

A special aisle wheelchair, an AisleMaster TM 8000, the same width as wheelchairs currently available on British Airways aircraft was used in the experiments. Its dimensions are shown in Table 1 below.

Part	Dimension in centimeters
Wheel to wheel width	41
Armrest to armrest width	39

Handles width	28
Height (of chair and of handles)	96
Rear wheel to front of footrest length	69
Wheels diameter	20
Seat width	33
Seat depth	38
Backrest height	44

Table 1: Dimensions of Wheelchair

The empty wheelchair weighed 21.2kgs. The wheelchair was weighted for a light occupant of 73.35kg and a heavy occupant of 98.05kg. Including additional equipment the chair weighed a total of 94.5 kg for the light load and 119.2kg for the heavy load. Weights were balanced to mimic the balance of a persons weight distribution when seated in the wheelchair. The force transducer measured forces applied to the pushbar at 200 measurements per second. Video cameras recorded both models from four different angles each (see figure 5).



Figure 5: Four camera angle views

## 2.4 Statistical Analysis

Data was analysed using Matlab statistical software. Before analyse the force recordings were filtered using a filter of 20Hz cut-off frequency to remove some of the noise. In order to have a consistent way of finding the start and end for all the manoeuvres a threshold of  $\pm 1\text{N}$  around the initial and final offset was chosen. The initial offset is the average of the resultant between 0.5s and 1s after the beginning of the force recording. The final offset is the average of the resultant over the 4s at the end of the recording. Paired samples t-tests were used to compare the impact of the manoeuvre method, the wheelchair load and model scenario on duration and force.

## 2. Results

Whilst the manoeuvre method had no impact on the required force to complete the task (at a .05 level) it did have an impact on the speed on the task. It was found to be faster to complete the task using the going backward manoeuvre than using the going forward manoeuvre with a heavy load on the flat and both the heavy load and

the light load in the real-world model.

Location	Weight	Manoeuvre	Duration (in seconds)		Maximum resultant/N	
			Mean	SD	Mean	SD
Flat model	Light	Forward	14.9	2.25	175.8	26.6
		Backward	14.1	2.66	176.3	45.5
	Heavy	Forward	14.2	2.08	208.1	39.5
		Backward	13.1	1.46	202.4	33.0
Real- World	Light	Forward	13.3	1.62	219.9	26.6
		Backward	12.7	1.19	230.7	22.9
	Heavy	Forward	13.3	1.61	273.0	37.2
		Backward	11.8	4.04	281.4	31.7

Table 2: Average and standard deviation of time and maximum resultant required to do the manoeuvres

[Insert Table 3]

Table 3: Impact of the manoeuvring method and load on maximum resultant and duration: paired samples t-test results. (\* differences in means are statistically significant at level .05)

In most cases, the wheelchair load has a statistically significant impact on manoeuvre duration and maximum resultant at the level .05. The only exceptions are the durations on the flat model and in the real-world model when using the going forward maneuvering method. Manoeuvre performed with the heavier weight can be up to 1 second quicker on average than the task done with the lighter load. In all conditions the heavier load required more force than the lighter loads.

The key difference between the flat model version and the real-world model version of the experiment was the step which is traversed over using a ramp in the real-world model version. Participants performed the manoeuvres faster in the real-world model than they did on the flat model however no difference in forces was found.

[Insert Table 4]

Table 4: Impact of the level difference on maximum resultant and duration: paired-samples t-test results

The strength of the pusher is a parameter that could potentially influence manoeuvre duration and peak recorded forces. Pearson product-moment correlation coefficients were used to verify whether a relationship between a persons strength and the time and force needed existed (Table 5). From these results it does not appear that a persons strength impacts the time taken to perform the manoeuvre or the maximum forces used. In addition there is no correlation between the force applied and the time taken to complete the manoeuvre.

[Insert Table 5]

Table 5: Pearson correlation coefficients between time, peak forces and participants strength

### 3. Discussion

Whilst the results show the moving forward manoeuvre takes longer than the moving backwards manoeuvre the difference is not large. The maximum difference in the real world model with the heavier weight is 1.43seconds, a small difference at the human scale and compared to the standard deviation of the manoeuvre duration.

The decision to choose one over the other should be left to be made by the passenger and the attendant.

Participants tended to perform manoeuvres faster with the heavier weight. This could be a result of a learning effect as participants had little or no prior experience with wheelchair handling before the experiments took place and the heavier weight trials were always performed last. However attempts were made to combat any learning effects by allowing participants to practice the manoeuvres before the trials began. Peak resultant forces were higher with the heavier load than the lighter one. This follows the physics principal that friction between the wheels and the floor is proportional to the weight.

The strength of the pusher is not correlated to either the speed of completing the manoeuvres or to the peak forces used. It appears that the pushers skill is what matters.

Manoeuvres were performed faster in the real world model than in the flat model. This was unexpected as the step and incline of the model could have been assumed to slow the manoeuvre done. This result can be explained by the behavior of the pushers who, anticipating the incline, tended to take a run-up to go up the ramp. As they had a dummy in the wheelchair rather than a real person they may have been more willing to take risks by moving faster. Certainly, peak forces were significantly higher for the trials completed in the real world model.

### 3.1 HSE guidelines

Almost all the forces required to complete the task exceed the HSE guidelines, as illustrated in the figures below. All manoeuvres under all settings exceeded guidelines for women. Only light manoeuvres in the flat model going both forwards and backwards did not exceed the guidelines set for men.

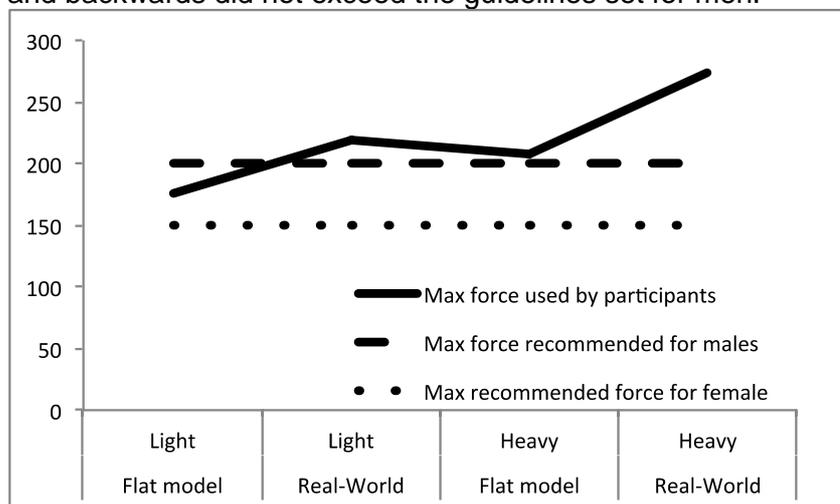


Figure 6: Average maximum forces using the Going Forwards manoeuvre and the recommended maximum forces used by males and females.

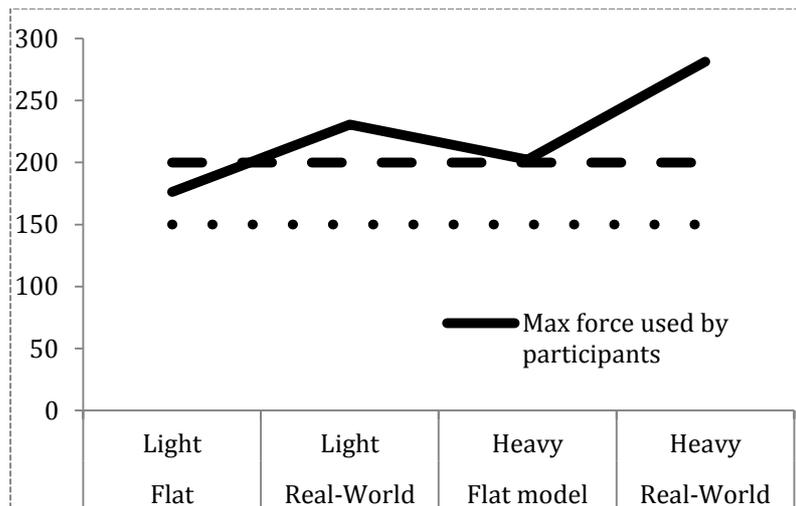


Figure 7: Average maximum forces using the Going Backwards manoeuvre and the recommended maximum forces used by males and females.

Peak forces measured in all the experiment variations are higher than the HSE guideline for women of 150N. The easiest boarding variation used 117% and the hardest boarding variation used 188% of the maximum recommended force for women. For male workers, the guidelines of 200N were exceeded in all cases except in the case of manoeuvres done with the lighter weight on the flat model. The easiest boarding variation used 88% and the hardest boarding variation used 141% of the maximum recommended force for women.

The weights being pushed are not unrealistic to what could be expected in reality. In this experiment the wheelchair weighted a total of 94.5kg for the light load and 119.2kg for the heavy load. In the UK the average women weighs 70.7kg and the average man, 84.1kg (Health Survey for England, 2012). With the additional 21.2kg of the transfer wheelchair the averages are 91.9kg (female) and 105.3kg (male). The heavier load in the experiment corresponds to a person heavier than average, but is not an unrealistic amount.

Moreover, a ramp was used in the experiments, and it is not always the case at the airport. Using a ramp makes going over the step easier as tilting or lifting the chair is not necessary. The forces required from the airline/airport employees when boarding wheelchair users without a ramp are likely to be even higher than those measured here. When a step is present at the entrance of an aircraft the use of a ramp is advisable with heavier passengers in order to avoid employees exerting forces that are well above the guidelines.

The max forces might be reduced by raising the handle height of the wheelchair used. Multiple studies provide evidence that low handle height causes greater forces for attendant pushing (Lee et al, 2013; van der Woude, 1995). Van der Woude (1995) recommend that a handle height of 1.19m would provide most attendants with comfortable shoulder-handle ratio. Given that the handle height of the wheelchair used for these experiments was 96cm a higher height may change the results of the maximum forces used to be under the HSE guidelines. This would need to be investigated.

The study has some limitations. As mentioned, the limited experience by participants of manoeuvring a wheelchair may have resulted in a learning effect as the trials progressed. Whilst this was tempered by allowing participants to practice and by randomising the directions of the manoeuvres and the model, it may have affected

the duration of the heavy manoeuvres versus the light manoeuvres. It is also important to be prudent when extrapolating the results described here to real life conditions as experimental conditions may differ from what is observed at airport. Different airports will have different layouts and structures in place which affect step height between terminal and aircraft. Whatever the layout in place at any airport, reducing the step height at the entrance to the aircraft is advisable.

#### **4. Conclusions**

Balancing required assistance of wheelchair user passengers, protection of employees health and economic competitiveness is an issue currently encountered by the air transport industry. This study addresses parts of this problem by focusing on time and force required by an airport or airline employees to board a wheelchair user. Through experiments carried out in an aircraft real-world model and its flat model counterpart, both manoeuvre duration and force applied by the attendance were measured and analysed. Manoeuvres in the going backwards technique are done quicker than those in the going forwards position. No differences were observed in the manoeuvre technique used and the force required. Therefore the choice of the manoeuvre used should be left to the passengers and employees. Forces required from wheelchair attendants exceeded the HSE guidelines in most cases. The level difference at the entrance of the aircraft seems to be responsible for the high forces required. Reducing the height of the step between the aircraft and the jet-way or scissor-lift is recommended.

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