AN ABSTRACT OF THE THESIS OF

Jonathan J. Mast for the degree of Master of Science in Mechanical Engineering presented on June 13, 2007.

TITLE: Effect of Lateral Force on Passenger Comfort during a Mechanically Assisted Dependent Transfer.

Abstract approved:
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Joseph R. Zaworski

Air travel presents several problems for passengers with disabilities. One in particular is how they get from their wheelchair and to an aircraft seat. The commonly used manual transfer method is hazardous to the assistants and the passenger. There are other alternatives, but they have plenty of room for improvement. In designing a mechanical device to emulate the manual transfer method, passenger comfort is of utmost concern. This study was conducted to evaluate how various lateral forces applied to a participant's chest affected their comfort during a mechanically assisted transfer. A prototype device was outfitted with a pneumatic cylinder to adjust the lateral force applied to a participant. They were then asked to indicate their comfort. The study revealed that a lateral force of 30% of a person's body weight is required to hold them without slipping and a lateral force of 46% of a person's body weight is considered the most comfortable. Using these values further iterations of the prototype device can be designed to optimize passenger comfort.

Effect of Lateral Force on Passenger Comfort during a Mechanically Assisted Dependent Transfer

by

Jonathan J. Mast

A THESIS

submitted to

Oregon State University

in partial fulfillment of

the requirements for the

degree of

Master of Science

Presented June 13, 2007

Commencement June 2008

Master of Science thesis of Jonathan J. Mast presented on June 13, 2007.

APPROVED

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorized the release of my thesis to any reader upon request.

Jonathan J. Mast, Author

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Joseph Zaworski, for giving me the opportunity to work on such a rewarding project and providing guidance in my graduate education. I would also like to thank Dr. Robert Paasch for encouraging me to attend grad school and Dr. Kenneth Funk for overseeing my education in Human Systems Engineering. I am indebted to Sushim Koshti; all his hard work preparing the approval documents and helping set up experiments was invaluable. I would be remiss if I did not also thank my parents for their unwavering support and my brother for always making sure I kept both feet on the ground. This is by no means a complete list; to all who have been there through the years, thank you.

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This thesis is dedicated to the memory of my grandfathers who did more with the tools they were given than anyone I have known.

Effect of Lateral Force on Passenger Comfort during a Mechanically Assisted Dependent Transfer

1 INTRODUCTION

1.1 Background on Disabilities and Travel

Travel is a fundamental aspect of modern civilization. Whether for business or pleasure, travel is a part of daily life. Within the past 50 years the prevalence of air travel has skyrocketed. It has become the preferred means of transportation for people traveling distances of more than two or three hundred miles to visit family, attend that important business meeting, or to just get away from it all. For the average person there are many considerations in air travel; getting tickets, checking bags, passing security, boarding the aircraft, among many others. The process of air travel is compounded when the person happens to be disabled.

According to the Americans with Disabilities Act (ADA) a person who has a physical or mental impairment that substantially limits one or more major life activities is considered disabled. The ADA prohibits discrimination on the basis of disability in employment, state and local government, public accommodations, commercial facilities, transportation, and telecommunications (The Americans With Disabilities Act of 1990). These regulations require that commercial air travel be accessible to people with disabilities.

Another important document for people with disabilities is the Air Carrier Access Act of 1990. It requires that an airline may not refuse service to a passenger with a disability, who is otherwise qualified to fly, because of the disability. There are several regulations in place to improve aircraft accessibility. One is that at least half of the aisle seats shall have movable arm rests on aircraft with 30 or more passenger seats unless precluded by an FAA safety rule. In addition an operable on-board wheelchair shall be available on aircraft with more than 60 passenger seats. On aircraft with 100 or more passenger seats there shall be at least one designated space for storing a folding wheelchair in the cabin. There shall also be at least one accessible lavatory on aircraft with more than one aisle or more than 60 passenger seats (Nondiscrimination on the Basis of Disability in Air Travel, 2003).

Providing access to airlines is not just to satisfy government regulations; it has a significant impact on society and the economy. According to the US Census Bureau there are 51.2 million people with some level of disability and 32.5 million with a severe disability. Among the population age 15 and older, 2.7 million people require the use of a wheelchair (Americans With Disabilities: 2002, 2006). The Open Doors Organization conducted a study of adult travelers with disabilities. One result showed that 31% of adults with disabilities have traveled by air in the past 2 years. This amounts to $2.9 billion dollars per year spent on air travel alone (Zografopoulos, 2005). Considering only the population restricted to wheelchairs leads to a value of approximately $150 million per year spent on air travel alone and it’s going to keep growing. The overall economic influence of this group is significant when the additional revenue from hotels, car rentals, restaurants, and other travel related expenditures are also considered. It is predicted that by 2030 nearly 24% of Americans will have a disability; an increase of 30.9 million people (Zografopoulos, 2005).

While air travel has improved significantly for those with disabilities, it is still far from optimal. There are still many facets that present the opportunity for improvement; from navigating the airport to accessing the lavatory. The particular problem that will be further discussed is the transfer of a passenger from their wheelchair into an aircraft seat.

1.2 The Manual Transfer Process

Currently the most common method for moving passengers with disabilities from a wheelchair into an aircraft seat is with a manual transfer process. Two assistants physically lift a person from their chair and move them to another. One assistant lifts the person from under the arms while the other lifts them from their legs.

This transfer usually happens 4 times for a single flight. When initially boarding a flight the passenger must be moved from their personal wheelchair to a narrower aisle chair. This aisle chair is needed because most aircraft aisles are too narrow to accommodate a regular wheelchair. Once they reach their assigned seat they are transferred from the aisle chair to the aircraft seat. When disembarking they must be transferred from the aircraft seat to the aisle chair and then from the aisle chair back into their personal chair. An example of this transfer is shown in Fig. 1.

Figure 1: Example of a manual transfer with two assistants

Several problems exist with this method as can be readily seen from the photo. First is the risk of injury to both the assistants and the passenger. The positions the assistants must lift from puts them at risk for lower back problems. The passenger can be handled roughly or even accidentally dropped. Since they must be lifted several times for each flight there is a repeated chance of injury. Prior arrangements need to be made so that trained staff are available at each leg of the trip to facilitate the transfer. There must be at least two assistants of sufficient strength for a successful transfer; even so the chance of injury is high. It is an undignified process that may occur in the presence of other passengers and requires a physical closeness that can make many passengers feel uncomfortable.

1.3 NCAT Computer Poll

In January 2005 the National Center for Accessible Transportation (NCAT) at Oregon State University (OSU) conducted a computer poll. This poll asked people with disabilities to evaluate their experiences with various aspects of air travel. Those responding varied in their degree of independence, from fully independent (1) to fully dependent (5). The aspects of their experience were rated on a 1 to 5 scale with 1 being an excellent experience and 5 being a terrible experience. The evaluations of the transfer process were of particular interest. Of those providing responses to the transfer process 65 had an independence level of 1, 26 had an independence level of 2, 26 had an independence level of 3, 20 had an independence level of 4, and 76 had an independence level of 5. The transfer process was split into four sections: from their personal chair to the aisle chair, from the aisle chair to the aircraft seat, from the aircraft seat back to the aisle chair, and finally from the aisle chair to their personal chair once they reached their destination. The transfer process rating results are shown in Fig. 2.

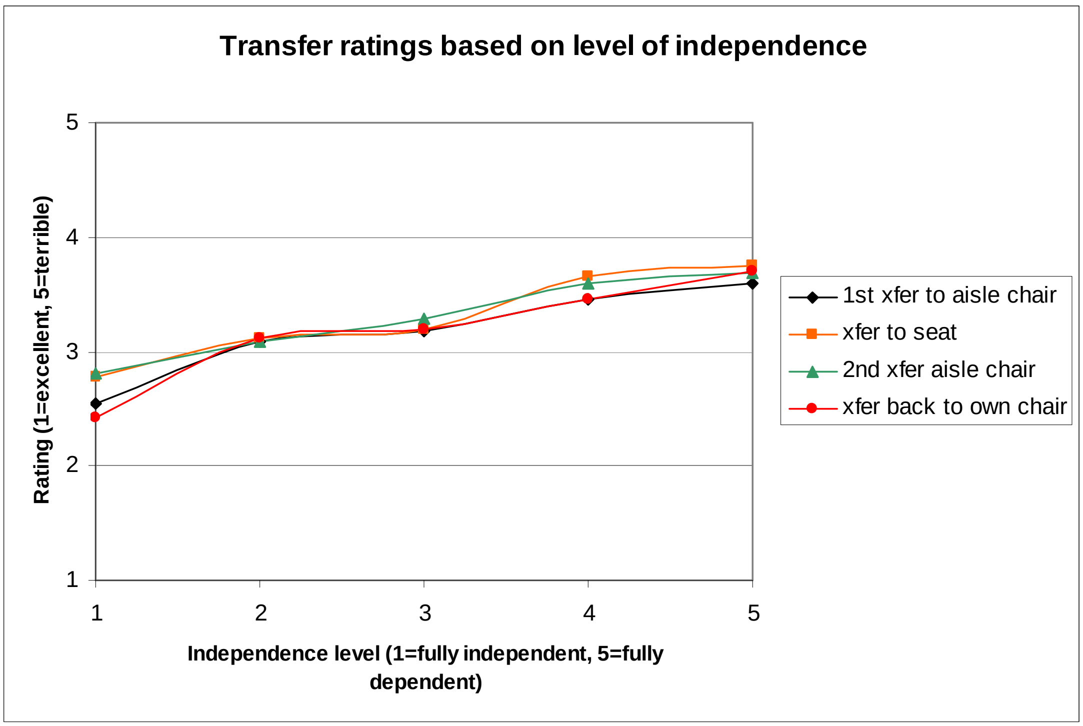

Figure 2: Average transfer ratings based on passenger independence level

As a person's dependence level increases their experience with the transfer process becomes worse. This likely has something to do with the amount of physical assistance that must be provided. The necessary increase of physical assistance is not only hard on the agents but on the passengers as well. Three common complaints from the poll were: rough handling by the assistants (passengers treated like baggage), assistants need to be strong enough to do the job, and that personnel were rude and unwilling to help. These problems can be associated with the difficulties involved with the current manual transfer process.

1.4 Overall Project Objectives

There are many areas in air travel that can benefit from a new approach, especially in regards to making it accessible to passengers with disabilities. One area in particular is the wheelchair to aircraft seat transfer process. It is hazardous to both the passenger and agents as well as being unpleasant and undignified

The overall objectives of the design project at NCAT are to address the major issues in the passenger transfer process. The first consideration is to reduce injury occurrence for both the passengers and airline agents. This will improve travel and working conditions and reduce insurance claims. Another goal is to make the entire process simpler. This will improve the passenger experience and may reduce the need for additional agents. Any proposed method should not compromise a passenger's dignity. It should also be easily implemented and readily available to the vast majority of commercial flights.

1.5 Proposed Solution

By moving away from the manual transfer process and going towards a mechanically assisted method, these issues should be greatly improved if not eliminated. The current design approach is to emulate the main aspects of the manual transfer process with a mechanical system. This involves lifting the passenger from mid-chest just below the arms by “squeezing” in and lifting up. In addition the legs are grasped near the mid-thigh and lifted up. One reason to emulate the manual transfer is that, aside from the risk of injury and physical contact, it is an effective transfer method. If this method can be accomplished with a mechanical device then the required physical contact can be greatly reduced, to a level even less than that required with other devices where a sling needs to be placed under a passenger.

In the current mechanical design molded arm pads are used to grasp a person about their chest and lift them up at the same time that leg supports are used to secure a person’s legs and help provide some of the lifting force. An electric actuator provides the necessary force to lift the passenger. The need for a person to provide heavy lifting is eliminated and the process can be completed with only one assistant. A computer rendering of the general device is shown in Fig. 3.

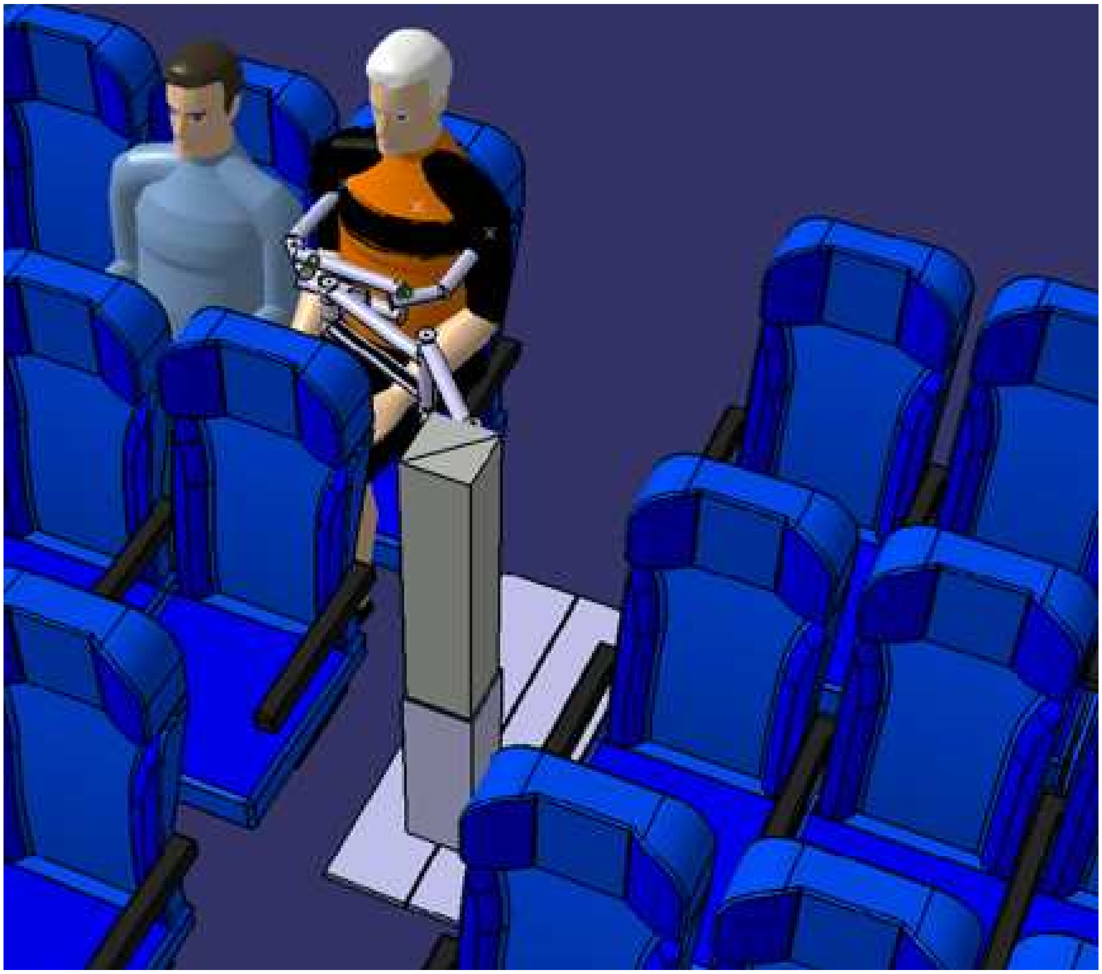

Figure 3: Catia model of the proposed mechanical transfer device

There are several factors that need to be addressed in the design other than just the transfer in general. The device needs to function in the confined space of a small commercial aircraft. It needs to be relatively lightweight and maneuverable. It needs to be easy and intuitive to use. It should function in all types of commercial aircraft. It should be able to transfer a large passenger, up to a single seat capacity of approximately 300 pounds.

1.6 Need for a Comfortable Force Range

One of the main design features of the proposed solution is to have a mechanical device apply a “squeezing” force on both sides of a person’s chest as they are being lifted up. In a manual transfer, this “squeezing”, or lateral force as it is referred to throughout the rest of the thesis, is applied by an assisting agent. It can vary based on the physical strength and stature of the agent as well as with the characteristics of the passenger being transferred and the geometry of the lift being performed. As a result, the passenger experiences an inconsistent lateral force that may be very uncomfortable and increases the risk of injuries.

With a mechanical device to apply the lateral forces, the passenger can experience a much more consistent transfer. The issue then becomes determining what the magnitude of the lateral force should be. A single value for the force could arbitrarily be assigned, but there would be no justification, other than an educated guess, that the chosen force is appropriate. Adjustability could be built into the system allowing for the lateral force to vary over a wide range. An optimum force for each person would exist for this situation. There would, however, be the potential for injury, as too little or too much force could just as easily be selected. In addition, this would increase the complexity and create an extra adjustment that the agent would have to understand and master.

The passenger is the only one truly affected by this lateral force. It plays a large role in the overall comfort of the transfer process. An optimal force would maximize comfort for the majority of passengers while reducing complexity and increasing the usability. To select the optimum force, or range of forces, a study examining the effect of lateral force on passenger comfort was needed. This will result in concrete information that can be used to optimize this aspect of the proposed aisle chair design.

1.7 Summary

With innovations occurring in nearly every facet of daily life, it is time to make air travel a more pleasurable experience for the millions of people with disabilities. There are several regulations in place to improve accessibility but they are far from ideal. The most common method for transferring a wheelchair bound passenger to their aircraft seat is physical lifting. It is potentially injurious to both the passenger and the assistants, as well as being an uncomfortable procedure. Development of a mechanical device to assist in the transfer will reduce injuries and make it a more pleasurable experience for all involved.

2 BACKGROUND

In this section the work leading up to the subject of this thesis is described. It begins with a look at some of the existing transfer methods followed by some examples of proposed alternative methods including the design which is the basis for the current research. In addition it covers the importance of this research as well as three important considerations for successful testing.

2.1 Existing Transfer Methods

Currently there are many methods for transferring people with disabilities from one place to another. Most are used for getting someone from a bed to a wheelchair or vice versa. There are few methods for transferring to an aircraft seat. The following discussion covers the common manual transfer method, a device that emulates this manual transfer method, and two mechanical devices designed specifically for the aircraft environment.

2.1.1 Manual transfer

As mentioned previously the most common method for moving passengers with disabilities from a wheelchair into an aircraft seat is with a manual transfer process. This method requires two assistants, one in front and one behind, to physically lift a passenger into or out of a seat. Intuitively this seems hazardous to the assistants and the passengers. However there has been little research on the actual hazards associated with this method in an aircraft setting.

2.1.1.1 Biomechanics study

A recent biomechanics study, conducted by Dr. Michael Pavol with NCAT, examined the risk factors associated with a manual transfer in an aircraft environment. Several volunteers with little experience in dependent transfers were asked to transfer two anthropometric dummies in a simulated aircraft environment. The dummies represented a 50^{th} percentile male passenger and a 50^{th} percentile female passenger. Reflective markers were attached to the participants and their trajectories were recorded with a motion capture system. Force plates were used to record the ground forces acting on the rear assistant and an accelerometer was attached to the dummies to record their accelerations during a transfer. The experimental setup is shown in Fig. 4 and examples of the actual experiment are shown in Fig. 5 (Pavol, Welsch, & Higginson, 2006).

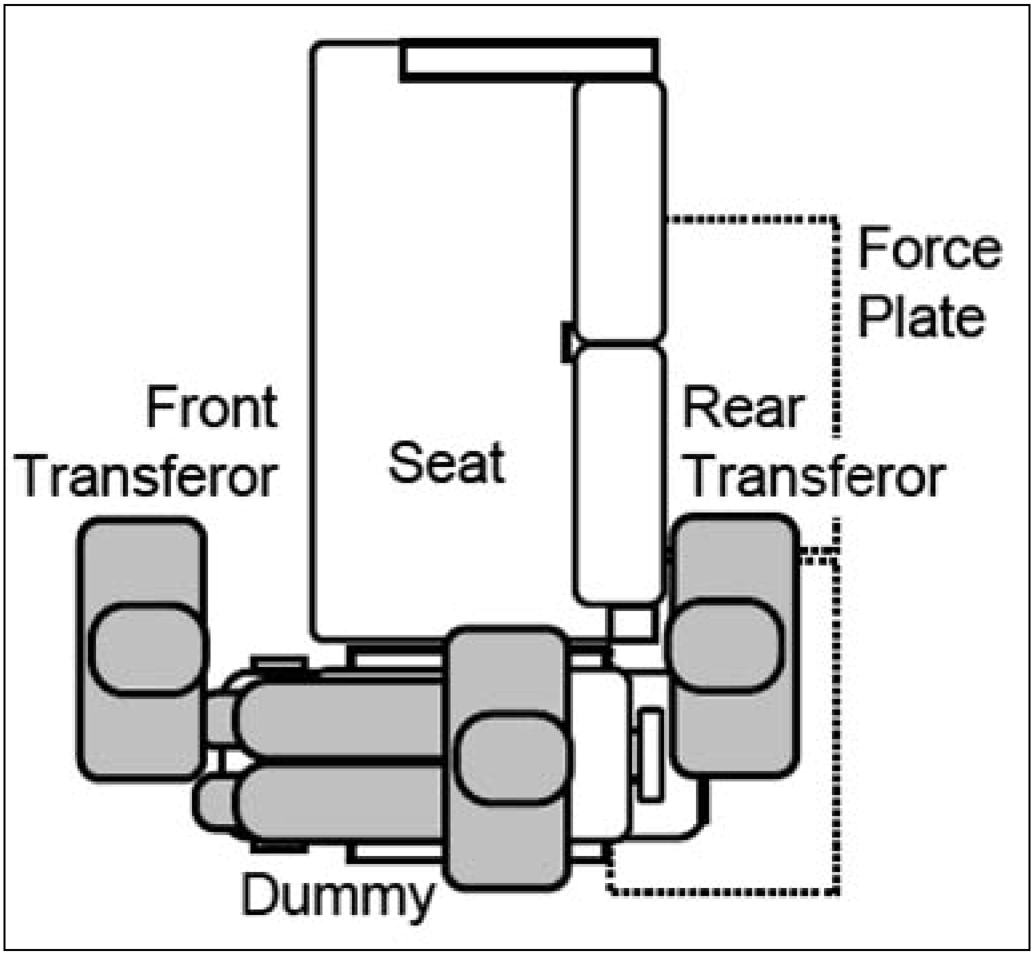

Figure 4: Experimental setup for evaluating the manual transfer method (Pavol, Welsch, & Higginson, 2006)

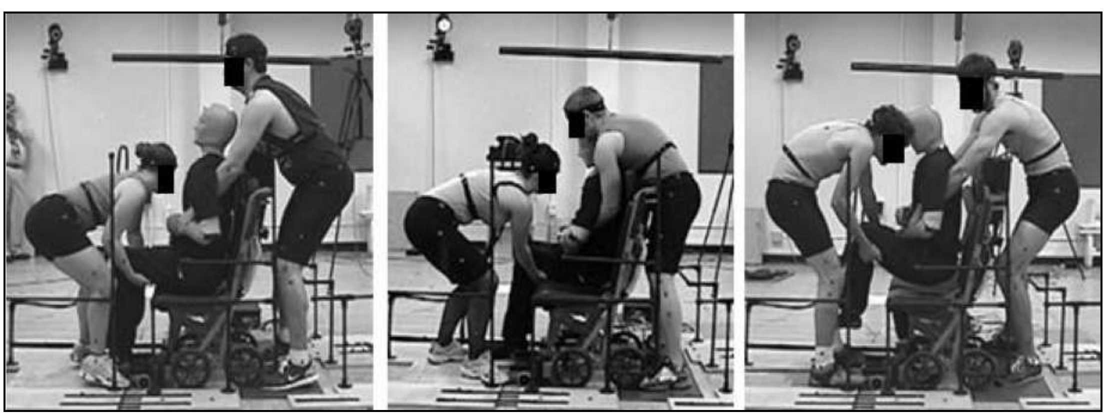

Figure 5: Examples of actual test procedure (Pavol, Welsch, & Higginson, 2006)

The results from the study show that the manual transfer method puts the assistants at high risk for lower back injuries and potentially places the passenger at risk. Transferring the large dummy under the constrained conditions of an aircraft setting resulted in 89% and 100% probabilities of being at high risk of lower back injury for the front and rear assistants respectively. Injury to the passenger appeared to depend primarily on the assistants performing the transfer. Some groups handled the dummy more roughly than others resulting in higher acceleration readings (Pavol, Welsch, & Higginson, 2006).

2.1.1.2 Patient transfers in health care

Manually lifting and transferring dependent patients in a hospital or assisted living facility places the nurses and assisting staff at a high risk for injuries. Nearly 40,000 nurses report back injuries each year; making it one of the leading occupations for back injuries. Overall costs related to back injuries in the health care industry is approximately $20 billion annually (Safe Patient Handling and Movement, 2005). There is also a reduction in workplace efficiency as many nurses need to take time off to recover from transfer related injuries.

The task of transferring a dependent patient (e.g., from a wheelchair to a bed) is inherently dangerous to those performing the transfer. The amount of weight which an assistant must lift varies considerably depending on the patient and can be far in excess of 100 lbs. The environments in which many of these transfers take place are not conducive to assistant safety with furniture in the way, the need to lean over beds, and confined spaces in which to move around. The National Institute of Occupational Safety and Health (NIOSH) provides guidelines for manual lifting tasks. The maximum weight that should be lifted by an average worker under controlled conditions is 51 lbs (Ergonomic Guidelines for Manual Material Handling, 2007).

Not only are patient transfer activities hazardous on their own, the regularity at which they must be performed also dramatically increases the risk of injury. A nurse or assistant often must transfer a patient in and out of bed, help them to the restroom, and get them in and out of a bath or shower, in addition to many other patient transferring and positioning tasks. They often exceed the maximum suggested weight several times during a single shift.

2.1.2 SureHands

There are several options available in assistive lifting devices for home and institutional settings. One of these is made by SureHands Lift and Care Systems (SureHands). SureHands is a cleverly designed mechanical device to facilitate lifting a person comfortably and securely with a minimum of direct interaction with that person. An example of SureHands in use is shown in Fig. 6.

Figure 6: SureHands device in use with an overhead hoist

The SureHands device emulates the manual transfer process very well. Two formed arm pads are placed on a person's chest just under their arms. The geometry of the device generates a lateral force which is proportional to the person's body weight. This replaces the need for an assistant to lift the person about the torso. There are two leg supports which position the person in a sitting position. They also serve as a replacement to an assistant to lift at the legs.

There are many benefits to this lifting mechanism. The lateral force produced by the device is proportional to the person’s body weight and therefore inherently adjusts to each person using it. It is a simple design with few moving parts to fail and few adjustments needed to use it. It also reduces the need for uncomfortably close contact such as occurs when an assistant needs to position a sling under a person.

While this device works well in a larger setting where there is room for a large lifting device or a permanently installed hoist, adapting for use in an aircraft environment is another story. Its design requires that lifting occur from a point above the device. In an aircraft, especially when getting into the seats, there is little head room due to the position of the overhead compartments. Therefore the device would need to be lifted from below. A redesign of the device utilizing the lifting principals is necessary for it to properly function in an aircraft.

2.1.3 Sling systems

One of the more popular solutions for assisted transfers is through the use of a sling and hoist. A sling is positioned under the person and is then attached to a lifting device. There are many styles of slings for various uses.

Depending on the style, they can provide substantial support and safety. However, they can be cumbersome and time consuming to use. They also require a level of physical closeness when positioning, which many people may find disagreeable. Due to their prevalence as a lifting system there are a couple that are aircraft specific solutions.

2.1.3.1 Haycomp (Products: Eagle 2)

The Haycomp Eagle 2 is a viable solution for transferring passengers from their wheelchair to an aircraft seat. It is a one step transfer process, in that the passenger is only lifted once between the wheelchair and seat. It is designed to work in B717 and larger Boeing and Airbus aircraft. The maximum weight is limited to 440 lbs. The sequence starts with the frame being positioned over a passenger's wheelchair. A sling is then positioned under the passenger so that the passenger can be lifted out of their personal chair. With the passenger hanging in the sling, the frame is then rolled into position so that the passenger is above the airline seat. The passenger is then lowered and the sling removed.

There are a few drawbacks to this system. Due to its design only the starboard side seats are accessible. The passenger remains suspended in the sling while being moved from their wheelchair to the seat. There is also the need to position (and later remove) a sling underneath the passenger, a process which can be difficult and violates their personal space.

2.1.3.2 Xpiration (XP Equipment: XP BoardingChair)

The XP BoardingChair made by Xpiration is a combination aisle chair and hoist. As with the Eagle 2 it uses a sling to lift and support the passenger. During transport from their wheelchair to the seat the passenger is seated on the built-in chair while the sling remains in place. It is designed to assist passengers weighing up to 315 lbs. While the need for physical closeness is greatly reduced from the manual transfer method there is still the difficulty and intimacy of positioning and removing the sling.

2.2 Alternative Transfer Methods

As with many daily tasks the area of transferring people with disabilities is not lacking in innovative ideas. Many of these can be found in a variety of patented designs. In addition, the NCAT lab has been working on improving the aircraft transfer problem specifically.

2.2.1 Patents

There are many patents on designs for devices that attempt to make it easier to transfer people with disabilities. Of particular interest are those devices which are relatively compact, mobile, and work in conjunction with a wheel chair. These devices may or may not be physically attached to a wheelchair. The following section presents some examples (figures 7-12) of relevant designs that may provide solutions to the aircraft accessibility problem.

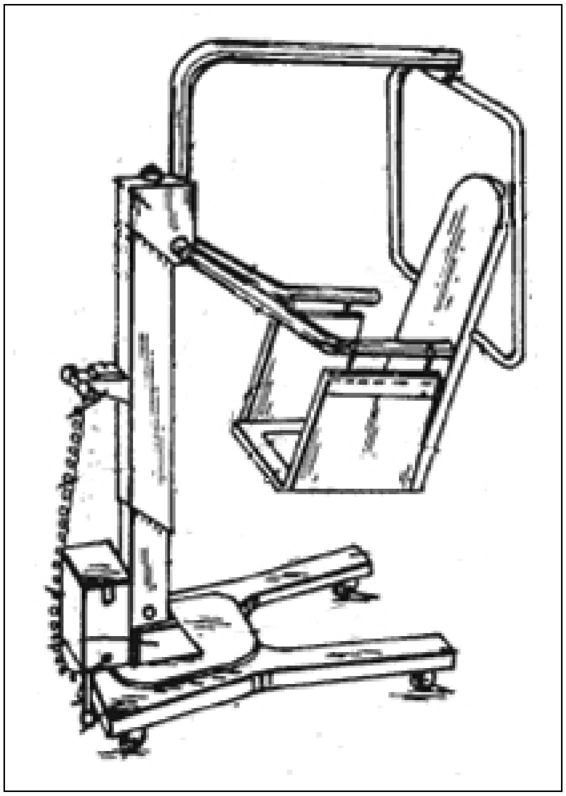

Figure 7: Patient Transfer Apparatus (Patent No: US 3,940,808)

The Patient Transfer Apparatus presents some novel ideas in assisting the transfer of people with disabilities. First it is a stand-alone device that can work with a variety of wheelchairs and other furniture. The lifting force is provided by an electrically actuated column reducing the risk of injury both to the patient and assistant. It also allows for the use of various style slings depending on the task. Since it is a stand-alone device a passenger would need to be transferred to a separate aisle chair or remain suspended in the device while boarding an aircraft. In addition, this design would require direct access to the front of a seat to complete the transfer.

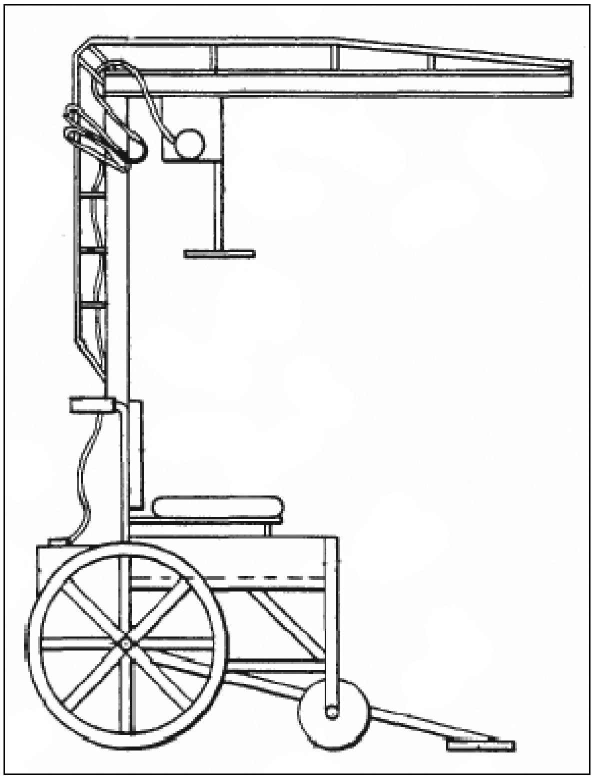

Figure 8: Wheelchair Mounted Invalid Lift (Patent No: US 4,999,862)

There are a few potentially useful design features to note with the Wheelchair Mounted Invalid Lift. One is that the lifting device and wheelchair are combined as a single unit. This is a benefit as the person doesn’t need to remain suspended during transport. The lifting force is provided by an electrical winch which reduces the physical demands of the assistant. Another feature is that once a person is lifted they can be moved forward in relation to the chair. This extends the overall reach of the device. A stabilizer in front of the chair prevents the device from tipping in this extended state. The main limitation preventing this device from adequately functioning in an aircraft setting is that the lifting point is overhead of the passenger. This would cause interference with the overhead compartments in an aircraft.

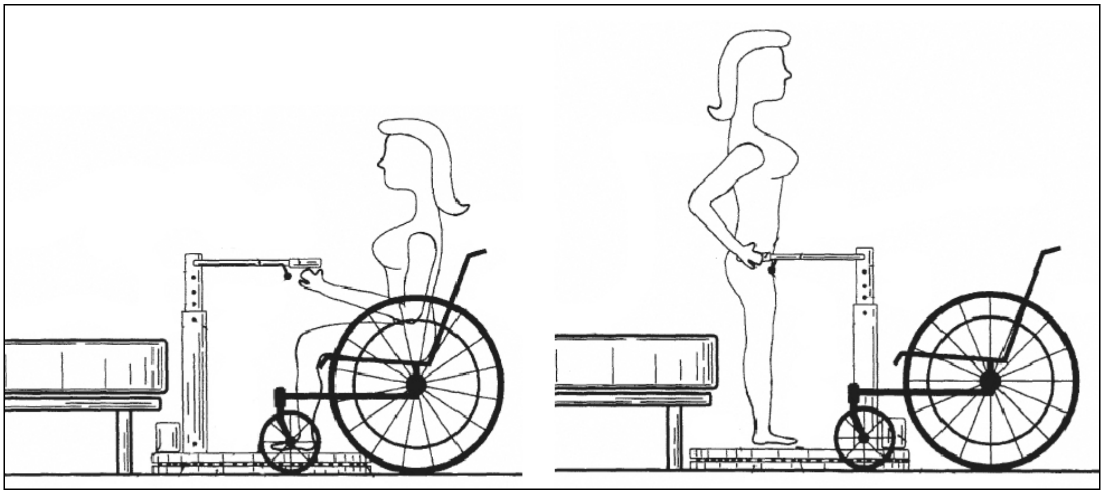

Figure 9: Person Lifter/Rotator (Patent No: US 5,524,303)

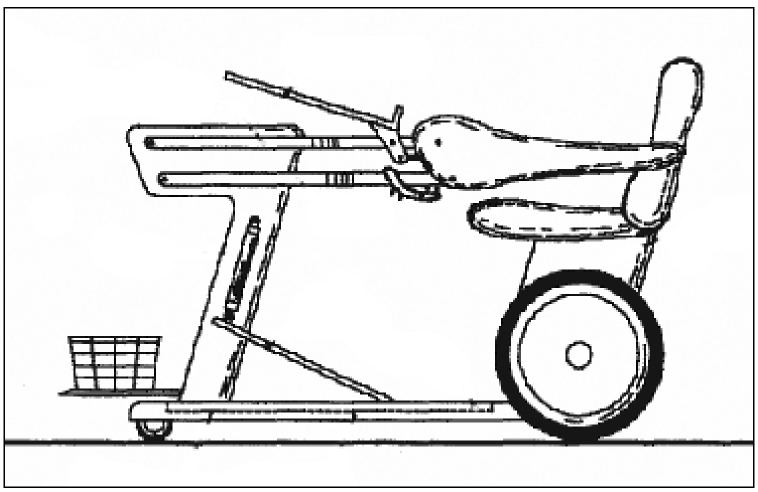

Figure 10: Person Lifter/Rotator power chair alternative

The Patient Lifter/Rotator adds a rotational component to the device which allows a person to be positioned to the front or side of the device. There are also design variants for either a stand-alone device or one that is incorporated into a wheelchair or power chair. The person is not actually lifted by the device however. It is used more as a support aid, requiring the person to posses a certain amount of upper and lower body strength. Someone requiring a fully dependent transfer would not benefit from it.

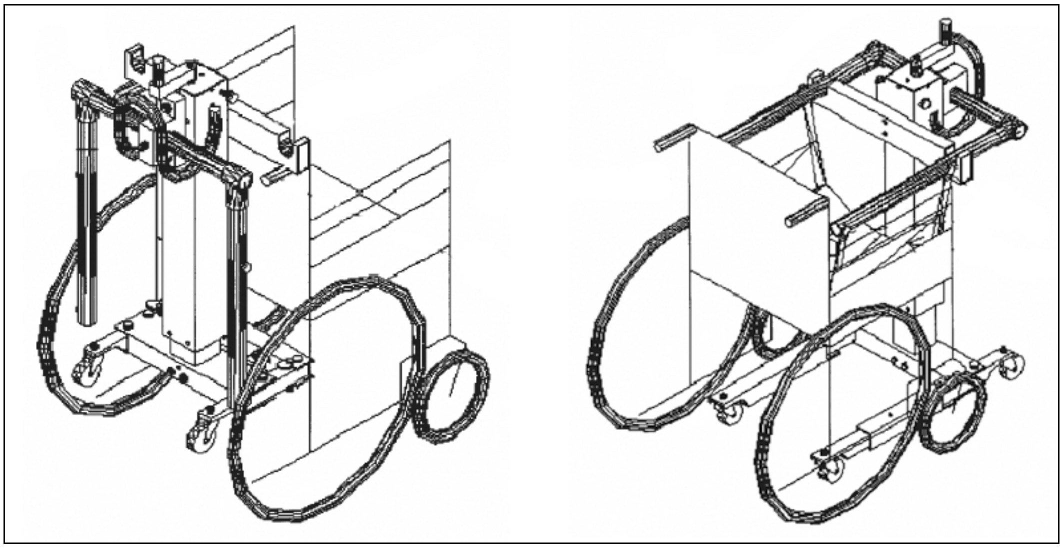

Figure 11: Compact Portable Patient Lift (Patent No: US 6,430,761 B1)

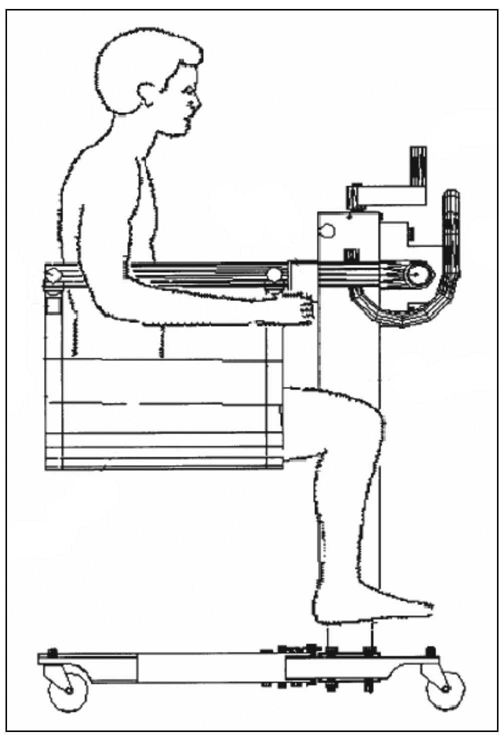

Figure 12: Compact Portable Patient Lift in use

The Compact Portable Patient Lift has several beneficial design features. It can be configured into a very compact state for storage and may be temporarily attached to the rear of a wheelchair for easy transport. The lifting point is at chest level with the person, which is especially useful in the reduced overhead room of an aircraft. Due to its stand-alone design it can be used with a variety of wheelchairs. There are some limitations which prevent its usefulness in an aircraft environment. First, there is no mechanism for positioning a passenger into the aircraft seat. The device would need to be able to approach the seat from the front. In addition the passenger would need to be first transferred to an aisle chair or remain suspended in the sling while boarding the aircraft.

2.2.2 Previous NCAT work

Ulrich Wörz, a prior graduate student working with NCAT, made great strides in developing a new method for passenger transfers. Starting with the general lifting principles used in a manual transfer, lifting at the axillae (arm-pits) and legs, an initial prototype was developed. This prototype is shown in Fig. 13.

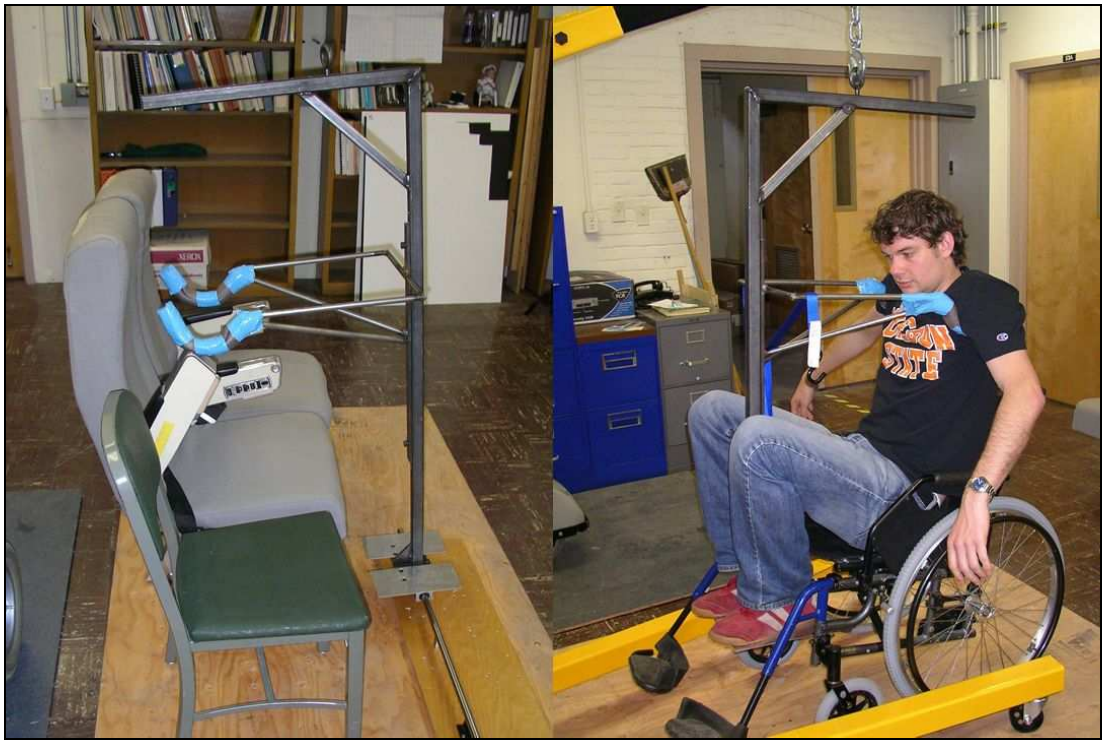

Figure 13: First prototype for transfer device unoccupied (left) and occupied (right).

The initial device had two rigid arms that were curved and padded at the ends. These curved ends were positioned under the armpits. Two plates were attached to the lower section of the device to support the feet. The lifting point was above the head of the person being lifted. This higher lifting point was chosen because it took advantage of a hydraulic engine hoist that was readily available in the NCAT lab. The lifting point could just as easily be located to a lower position to function in the confined space of an aircraft.

After several trials it was determined that about 80%-90% of the person's body weight was being supported at their axillae. This caused a great deal of discomfort and greatly increased the risk of dislocating a person's shoulders. Taking another look at the manual transfer process revealed that lifting under the legs rather than at the feet reduced the force under the axillae to about 70% of a person's body weight. It was also noticed that the agent lifting the person's torso did not just lift up under their arms, but also applied a "squeezing" force laterally at their chest.

The realization that there was also a lateral force used in lifting a person resulted in a new look at commercially available solutions. This is when the SureHands transfer device was found. One was purchased in order to evaluate its potential for aircraft transfers. The lifting mechanism proved quite effective and comfortable. However, it was too big for the aircraft environment and required that the lifting be done from above. To bring the lifting point down, and reduce the overall size, several conceptual designs were generated as shown in Fig. 14.

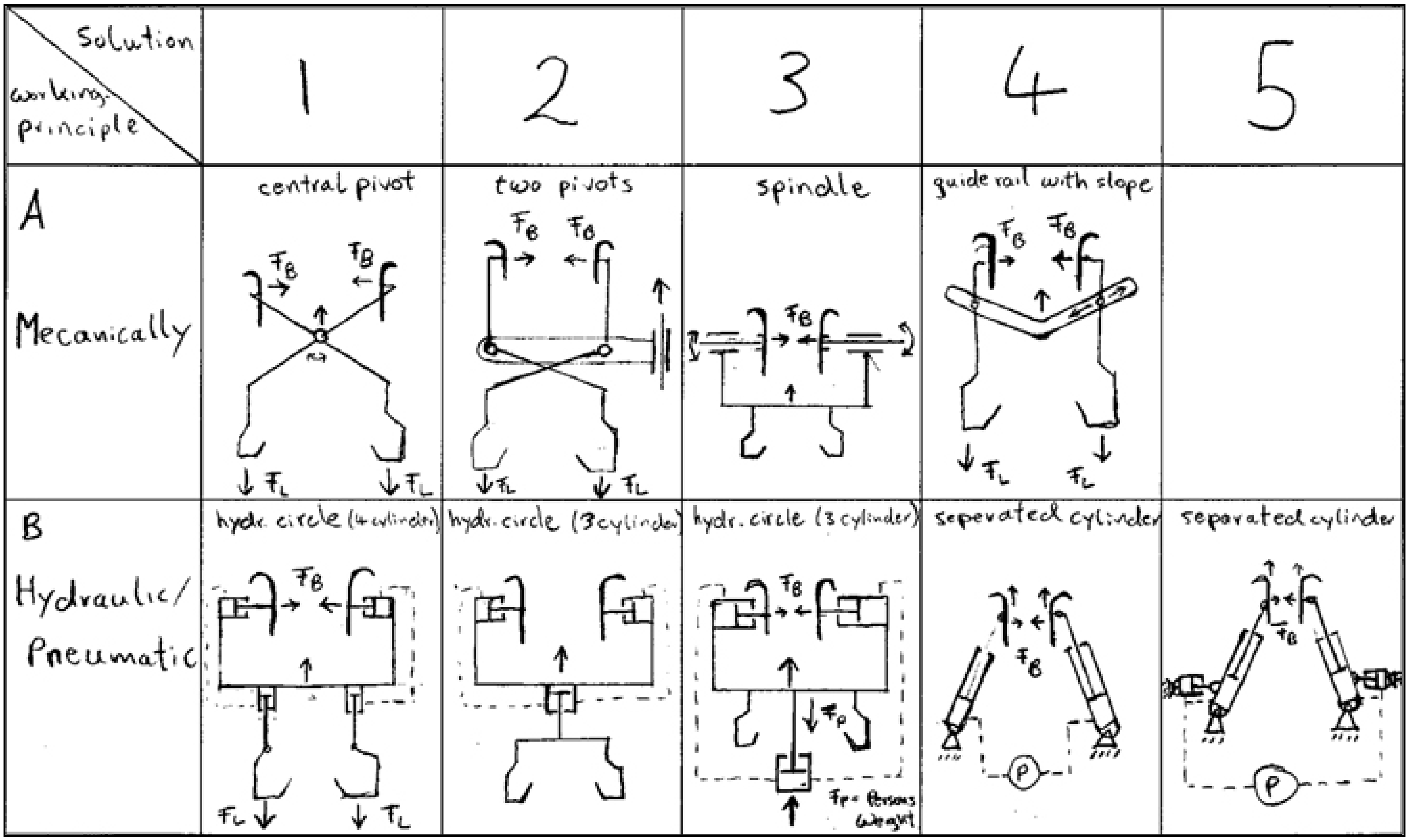

Figure 14: Conceptual designs for SureHands like device

One of the main goals in the design was to make the lateral force proportional to a person's body weight, like in the SureHands device. To accomplish this two main styles were looked at; a mechanical solution and a hydraulic/pneumatic solution. Of these a single pivot, mechanical design was selected as the most feasible for making a working prototype, a sketch of which is shown in Fig. 15. The working prototype is shown in Fig. 16.

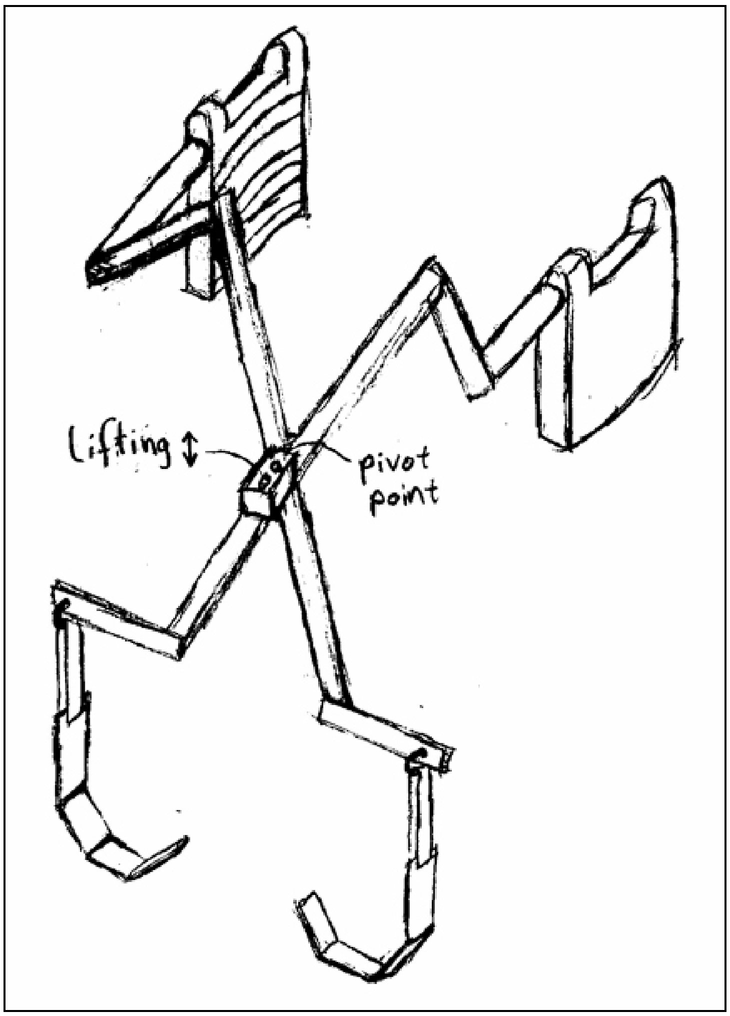

Figure 15: Single pivot, scissor style lifter sketch

Figure 16: Single pivot, scissor style lifter prototype in use

By introducing a lateral force during the lifting process the force on the underarms was greatly reduced. This increased the comfort considerably and, in turn, reduced the risk of injury. As with the initial prototype the second device was lifted from above to take advantage of the readily available hoist. It could easily be lifted from below to clear the low ceilings in an aircraft.

2.2.3 Current design

The current design of an assistive lifting device was started by using Wörz's initial design work along with some of the design elements of the SureHands device. Some of the more important design factors were that (1) the device provide a lateral force while lifting, (2) that it be possible to lift from head level or below, and (3) that it allow a substantial degree of freedom for positioning a passenger. A general design was developed where two arms would support the person, a floor mounted column would provide the lifting force, and positioning would be accomplished with an articulating arm. To evaluate whether the design warranted further effort a wooden prototype was constructed. This allowed the general design concepts and geometry to be evaluated in conjunction with a set of airline seats. The wooden prototype is shown in Fig. 17.

Figure 17: Articulating arm proof of concept

This initial prototype showed a lot of potential. Access to an aircraft seat from the aisle was possible with the articulating arm design. A working prototype was designed using the basic features from the wooden prototype. It was designed to be used in the NCAT lab so size and weight were not an issue. The main goal was to provide a foundation from which various methods could be investigated for lifting and applying lateral force. The finished working prototype is shown in Fig. 18.


Figure 18: Current working prototype

The lifting force is provided by a hydraulic jack which raises a circular sleeve along a supporting column. Attached to this sleeve is a 3-link articulating arm which allows for easy positioning. At the end of the articulating arm is the mechanism which actually contacts the passenger. Two straight arms are pinned at opposing sides of a support bar. Arm pads, borrowed from a SureHands device, are attached to the ends of the straight arms. The leg supports are also borrowed from the SureHands device. In this particular picture a strap set-up connects the leg supports to the straight arms. A clearer picture of this strap set-up is shown in Fig. 19.

Figure 19: Detail of strap setup for applying lateral force

The leg supports are connected to an aluminum bar which is attached to the lighter colored (yellow) strap at both ends. This strap drapes over both arms. A one way adjustment buckle is used to allow the strap to be tightened, adjusting the leg supports so that they are snug against a person's legs. When the device is raised a downward force is applied at the leg supports causing tension in the strap. This tension brings the arms together causing a lateral force at the person’s chest. The amount of lateral force is proportional to the person’s body weight and therefore is self adjusting. Another method for applying lateral force is with a pneumatic cylinder shown in Fig. 20.

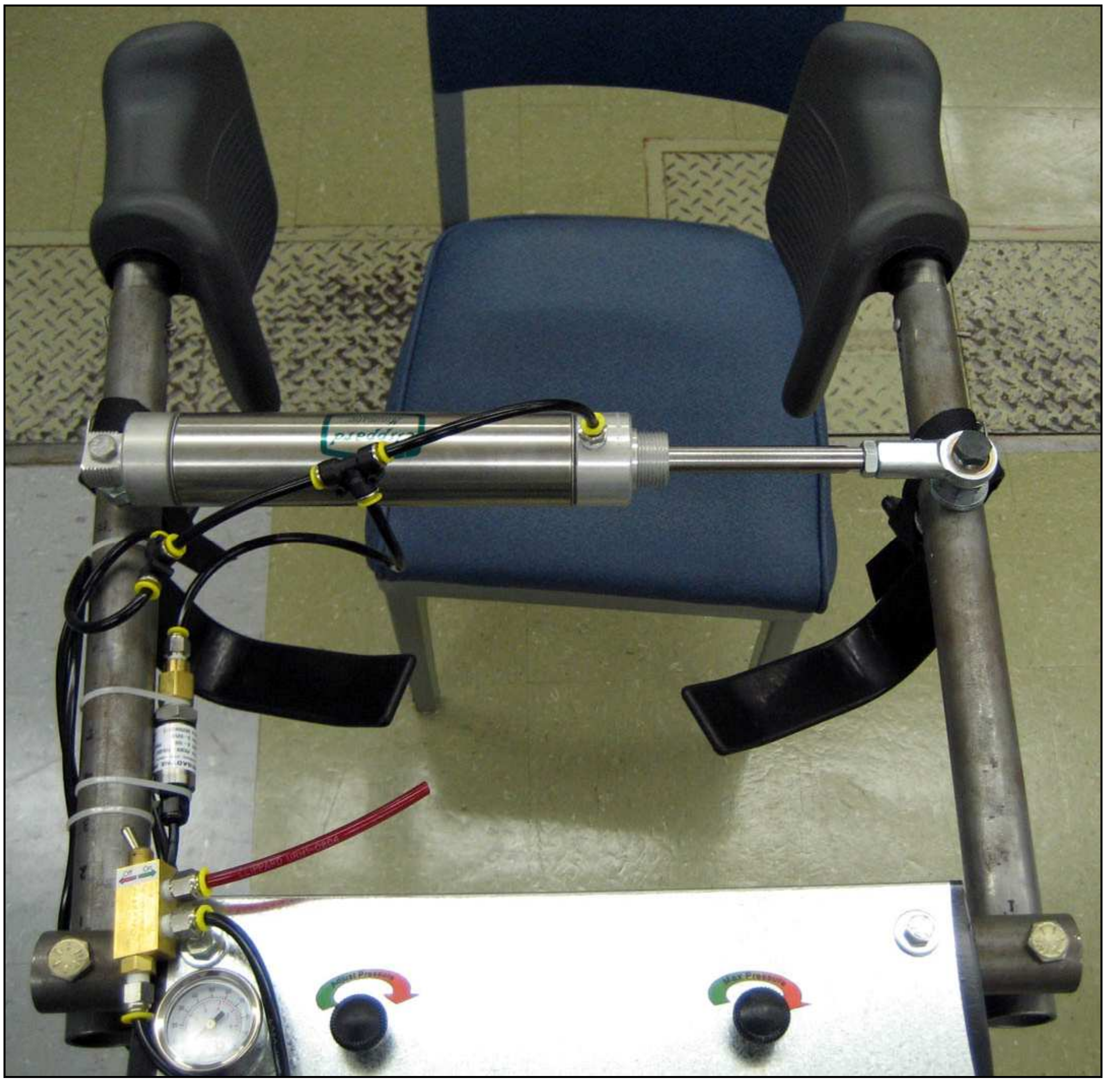

Figure 20: Detail of pneumatic setup for applying lateral force

The pneumatic setup was devised to provide an adjustable lateral force that is not dependent on a person’s weight. Overall, the setup is similar to the strap setup. The main differences are that the lateral force is provided by an air cylinder and the leg supports are directly connected to the support arms so that they do not contribute to the lateral force. A more detailed description of this setup is provided in section 3.2.

The first working prototype answered some important questions. First, it is possible to accomplish a lift similar to that of the SureHands device while lifting from below. The lateral force can be coupled to a person's body weight through the use of a strap setup connecting the leg supports. In addition, it is possible to lift a person from an aisle chair and position them into an aircraft seat with the articulating arm design.

A second working prototype was developed since the first one showed a significant amount of potential. The main goal of the second design was to reduce the size and weight of the first design so that it could possibly be tested in an aircraft setting. Attaching the lifting mechanism to an aisle chair was a natural progression in reducing the size of the device. A new design factor arose by having the ability for the lifting mechanism to move inline with the aisle chair. Before too much effort was invested in this design, a second proof of concept prototype was made. This is shown in Fig. 21.

Figure 21: Proof of concept for sliding base on second prototype

Only a sliding base needed to be constructed for this prototype. The sliding base was attached to an available aisle chair. The previous wooden prototype was used without its stationary base. It was attached to the sliding base with a wooden adapter. By combining a sliding interface between the aisle chair and the lifter, access to an aircraft seat could be accomplished with a two link articulating arm rather than requiring three links. In addition it allowed the device to be stored in a more compact state.

The hydraulic jack, sleeve, and supporting column were quite cumbersome in the first prototype. Combining these three components into one would provide a more compact, aesthetic, and efficient solution. After researching commercially available products an electrically actuated telescoping column proved to be an appropriate solution. While many of the available columns would work if the load was inline with the column the problem was finding one that would handle a 300 lb load offset up to 40 inches from the column. A D-M13 column was chosen from X2 Technology in Sweden. This column provides the lift and support needed in a single compact unit. It runs on 24 VDC and has a variable speed control to adjust the height.

An available folding aisle chair is used. It had a removable base which was easily swapped out with a custom made aluminum base so no permanent alterations were made to the chair. The chair is bolted directly to the rear of the aluminum base. The front portion of the base is connected via linear slides to allow the lifting column to move inline with the chair. The column is attached to the front of the base. Current progress of the second prototype is shown in Fig. 22.

Figure 22: Second prototype complete to telescopic column

This second prototype is only partially completed. To finish it, the designs for the articulating arm, the mechanism that applies the lateral force to the passenger, and a means of attaching these to the telescopic column need to be finalized. One of the main benefits of this design is how it naturally separates into individual components. These components are the aisle chair, sliding base, lifting column, articulating arm, and support mechanism. Work can be done to improve each component without significantly impacting the other components. This second prototype provides a platform for looking at other design aspects that affect its overall success in an aircraft environment.

2.3 Project Objectives

A major design consideration for a mechanical device that emulates a manual dependent transfer is the magnitude of the lateral force applied to a person’s chest while being lifted. In the case of manual transfers this force can be very inconsistent because it depends on the characteristics of both the passenger and the assisting agents. With the SureHands device this force is dependent on the passenger’s body weight, lateral distance between the axillae, and position of the leg supports. This is a much more consistent lifting method, but it adds complexity to the design as the lifting of the legs and upper body need to be coupled. It was also unclear if the lateral force produced by SureHands is optimal. The main objective in this experiment was to determine if there is a single comfortable range for the lateral lifting force that is appropriate for the majority of passengers.

Once a thorough understanding of how comfort is affected by the lateral force, the design can be optimized for passenger comfort. In addition, it may be possible to simplify the device. There are many benefits if a single lateral force that falls within the comfortable range for all participants is found. The device can be designed to achieve this force and avoid the need for adjustability. This would greatly reduce complexity thereby reducing cost and improving usability. Even if a single force couldn't be found, it seemed likely that a specific range of forces would be revealed. This would allow the design to target a comfortable range for the majority of passengers.

While the main goal of the study was to determine how passenger comfort was affected by the magnitude of the applied lateral force, there were two other factors of interest. It was desirable to determine the minimum lateral force required for lifting someone without them slipping. This would set the lower bound for the lateral force; any less and the person slips while being lifted, raising the potential for injury. It was also beneficial to determine a discrete value for the lateral force at which a person feels the most comfortable. This will help validate the comfort range evaluation as the most comfortable point in the comfort curve should coincide with this value. Another subjective measure related to comfort is stability. Obtaining stability information at the minimum lateral force and the most comfortable force would shed additional light on the relationship between overall comfort and lateral force.

2.4 Testing Considerations

Before a device for evaluating the effect of lateral forces could be completed two main factors needed to be investigated. The first was to insure that the device would physically fit all participants during the test. The other was to reduce the potential for serious injury as much as possible. In addition methods for measuring a participant's comfort needed to be researched.

2.4.1 Anthropometric data

The basis of the test was to mimic the action of the rear assistant lifting a person at their torso just below the arms. To accomplish this, the testing apparatus featured two molded arm pads taken from a SureHands device which are attached to steel "arms". A pneumatic cylinder was attached to these arms which in turn provide the lateral force similar to the manual lift. It was desirable to have the testing apparatus function with a wide variety of body types. Therefore, the relevant anthropometric data needed to be determined.

The position of the pads on the participant during testing was just below the axillae. This suggested that the straight line distance across the chest was the measurement data needed. The position and the length of the pads may have caused them to vary from the anterior to the posterior portion of the axilla. Two measurements needed to be determined, the anterior chest width and the posterior back width. The greater value was chosen as the design parameter. NASA's Man-Systems Integrated Standards has a section on Anthropometry that provides the necessary information. In these standards the chest width is referred to as chest breadth and the back width is referred to as interscye. The values for 5^{th}, 50^{th}, and 95^{th} percentiles on each measurement for a 40 year old American male and a 40 year old Japanese female are tabulated below.

Table 1: Measurement values of chest breadth and interscye in inches (MSIS: Vol. 1: Sect. 3, 1995)

	Dimension	5th percentile	50th percentile	95th percentile
Japanese Female	Chest Breadth	9.7	10.5	11.4
	Interscye	12.8	14.1	15.4
American Male	Chest Breadth	11.7	13.1	14.4
	Interscye	13.0	15.4	17.9

From the above data it can be seen that chest breadth varies from 9.7 inches to 14.4 inches and interscye varies from 12.8 inches to 17.9 inches. By designing for the extremes, the device was insured to work for the majority of participants. Therefore the desired separation of the pads was a minimum of 9.7 inches when in the closed position and 17.9 inches in the open position.

Much of the design was limited by the existing physical dimensions of the current prototype to be used in the tests. The anthropometric data was used to select a pneumatic cylinder with a stroke length that could produce the desired arm pad separation distances. After considering the physical dimensions of the device, the costs, and the desired arm pad distances, a cylinder with a stroke of 4 inches was chosen. An adapter was made to attach the cylinder to the arm. By adjusting the adapter the device could vary arm pad separation from 6 inches up to 21 inches. The 6 inch minimum distance helped account for some natural compressibility of the rib cage; the maximum distance of 21 inches allowed for easier ingress and egress of the largest participants.

2.4.2 Force for rib fracture

The main objective of this experiment was to determine if there is a comfortable range of lifting forces that work for all the participants. If a comfortable force can be determined it allows for optimizing the device. In testing for the comfortable force in an individual participant, it was necessary to exceed that force. This opened up the possibility of injury. To properly design the testing apparatus, the maximum force to cause injury needed to be determined.

The particular loading case in this experiment was a sustained lateral load applied to either side of the upper chest (thorax). This was a unique loading case and, as such, research on its effects was not readily available. However, there has been substantial research in impact injuries, especially in the auto industry. The Society of Automotive Engineers (SAE) has published many research papers on frontal impacts and lateral impacts, as they apply to the thorax-shoulder complex.

One report of particular interest investigated how arm position affects thoracic injuries in side impacts. In this study, 8 cadavers were used with an age range of 54 to 80. They were subjected to a lateral impact on the thoracic region, similar to that which would be experienced in a side impact crash. Two situations were examined; one where an arm was placed to protect the thorax from impact and the other where the thorax was directly impacted. Initially, the velocity of the impact was set below the expected injury value. After the first impact, the cadavers were inspected for thoracic fractures. If no fractures were detected, the impact velocity was increased by 5 km/hr. This was repeated until rib fracture occurred. The most important result of this experiment is the maximum force achieved before thoracic fracture occurred in the cases where there was no arm impact. The results showed that thoracic fracture occurs at 1750 N to 2900 N (Cesari, Ramet, & Bloch, 1994). To err on the safe side, the much more conservative value of 1750 N (393 lbs) was selected as the force resulting in rib fractures.

The selected force for thoracic fracture of 393 lbs was a very conservative value for this experiment. This value was experimentally obtained from cadaver bodies of persons 75 years or older, on which the force was generated from a mass impacting the body at approximately 20 km/hr (12.4 mi/hr). By contrast, the participants in this study were all under 40 years old and the force was applied at very low speeds with the paddles already in contact with the thorax. This essentially made it a statically applied load. Taking these observations into account, the force for fracture was a very conservative estimation. Using it to determine the maximum force provided an extra measure of safety.

2.4.3 Pain assessment research

Pain is a highly individualized and subjective event (Chambers, Giesbrecht, Craig, Bennett, & Huntsman, 1999). This makes assessing pain in any quantitative way very difficult. There are many qualitative methods to assess pain including questionnaires, mechanical visual analogies, face scales, and numerical rating scales. Substantial research has been done in the assessment of pain in children and the cognitively impaired. Considerable attention has been given to 'face scales' which show a series of faces graded in increasing pain intensity between 'no pain' and 'worst pain possible'. When using a face scale, children are asked to point to which face best illustrates how much pain they are currently experiencing (Chambers, Giesbrecht, Craig, Bennett, & Huntsman, 1999).

Studies have shown that face scales are preferred by children, parents and nurses, when compared with other assessment tools, including visual analogue scales and word descriptor scales (Chambers, Giesbrecht, Craig, Bennett, & Huntsman, 1999). Many varieties of these face scales exist, varying in the number of facial illustrations, whether the no pain case is presented with a 'smiling face' or a 'neutral face', and in style from a very basic cartoon to a realistic depiction. Three commonly used face scales are the Faces Pain Scale, Facial Affective Scale, and the Wong-Baker Scale, as shown in Fig. 23.

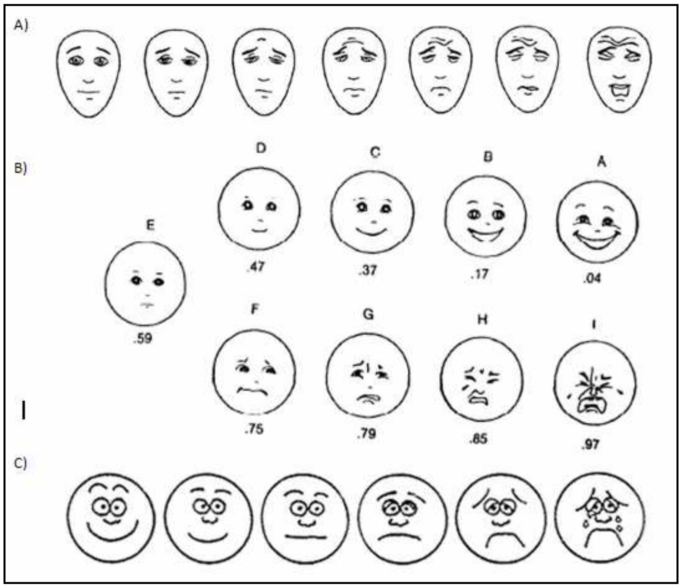

Figure 23: A) Faces Pain Scale; B) Facial Affective Scale; C) Wong & Baker Faces Pain Rating Scale (Chambers, Giesbrecht, Craig, Bennett, & Huntsman, 1999) (Goodenough, Dongen, Brouwer, Abu-Saad, & Champion, 1999)

While similar, these scales have some distinct differences. The Faces Pain Scale (FPS) is a 7-point unipolar measure of pain intensity ranging from ‘no pain’ to ‘most pain possible’. The ‘no pain’ condition features a neutral face and there are no tears present on the ‘most pain possible’ face. The Facial Affective Scale (FAS) is a 9-point bipolar measure ranging from ‘happiest feeling possible’ to ‘saddest feeling possible’ (Goodenough, Dongen, Brouwer, Abu-Saad, & Champion, 1999). The ’happiest feeling possible’ condition features a smiling face and there are tears present on the ‘saddest feeling possible’. The Wong & Baker Pain Scale (WB) is a 6-point measure ranging from ‘no hurt’ to ‘hurts worst’ (Chambers, Giesbrecht, Craig, Bennett, & Huntsman, 1999).

The differences in the face pain scales can lead to differing results. The FPS has been shown to better measure pain intensity rather than pain unpleasantness while the FAS measures pain unpleasantness better than pain intensity (Goodenough, Dongen, Brouwer, Abu-Saad, & Champion, 1999). It is possible that face scales with smiling faces may be more appropriate as measures of pain affect rather than pain intensity (Chambers, Giesbrecht, Craig, Bennett, & Huntsman, 1999).

3 MATERIALS AND METHODS

3.1 SureHands Analysis

The SureHands transfer solution emulates the manual transfer process very well and is the basis for the new prototype device. It has proven to be a successful transfer method and is generally considered to be quite comfortable. By understanding the forces produced by this device a target range for the force needed during lateral force testing can be effectively established. To accomplish this, a force and moment equilibrium analysis was done. The force distribution is shown in Fig. 24.

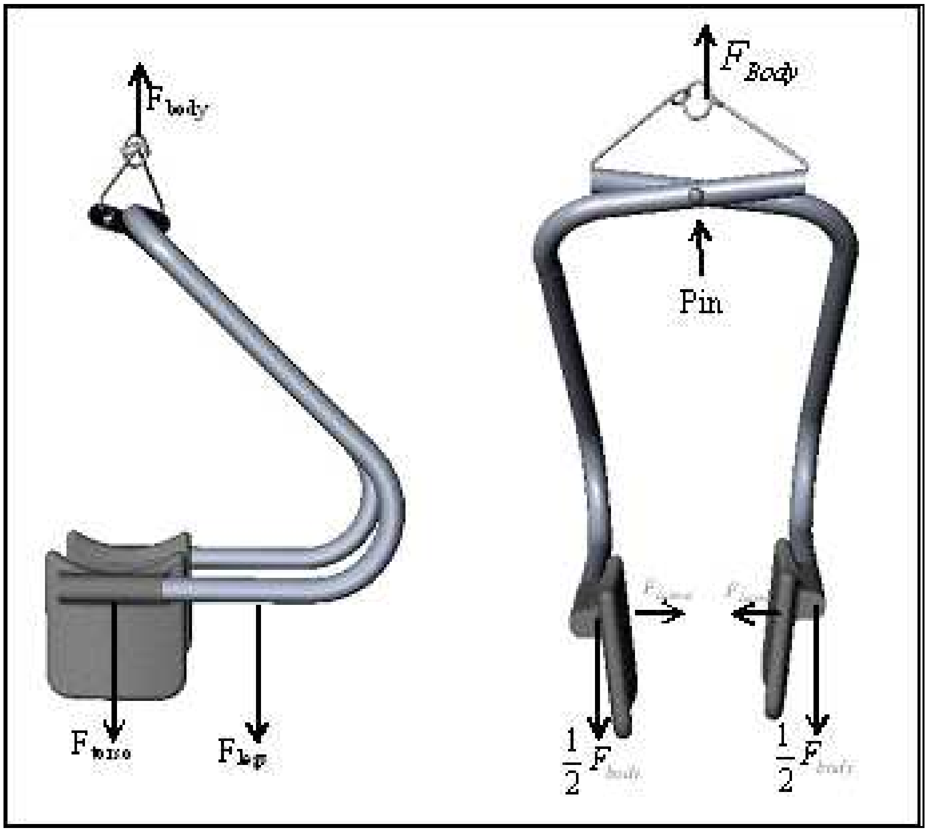

Figure 24: Side and front view of Sure Hands under hypothetical load

The total weight of a person is distributed on the device in two places; part of the weight is taken up at the arm pads and the rest is taken up by the leg supports. These two locations lie in the same plane relative to the axis of the pin. Therefore they can be considered as a single force acting at the arm pads for calculating the moment at the pin caused by a person in the device. Due to symmetry the total weight is split equally between each side. By considering the system in static equilibrium a resultant lateral force is produced at the arm pads. A relationship between the lateral force and body weight can be found by summing moments about the pin. Due to symmetry, only one side of the device needs to be analyzed as shown in Fig. 25.

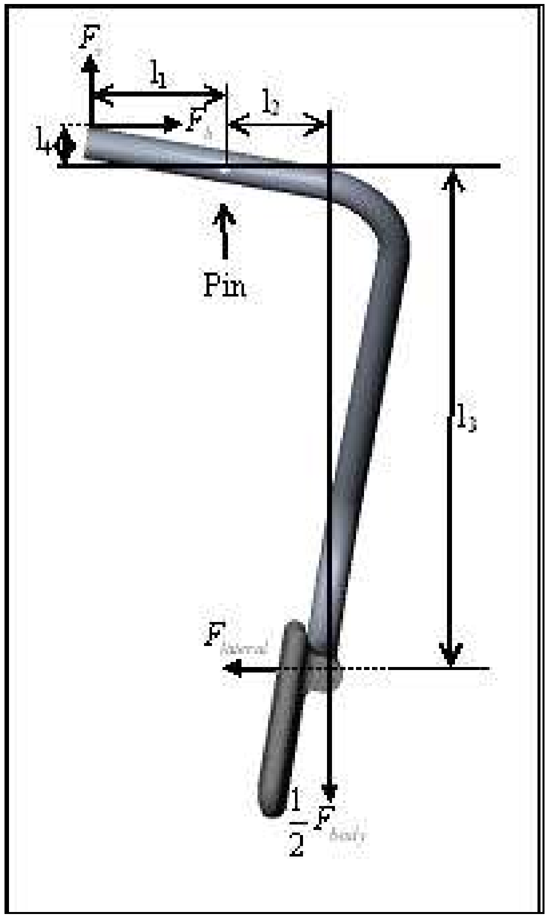

Figure 25: Front view of a single Sure Hands arm with forces and relevant dimensions indicated

The load seen by one side is equal to half of the total body weight. The relationship between lateral force and body weight varies depending on the degree of rotation of the arm about the pin as this rotation changes the lengths of the moment arms. This degree of rotation is caused by the arm pad separation distance which is caused by the physical size of the person's torso. To analyze the forces, the separation distance was calculated in 1 inch increments from 0 inches to 18 inches. The plot of lateral forces generated by SureHands for various arm pad separations is shown in Fig. 26.

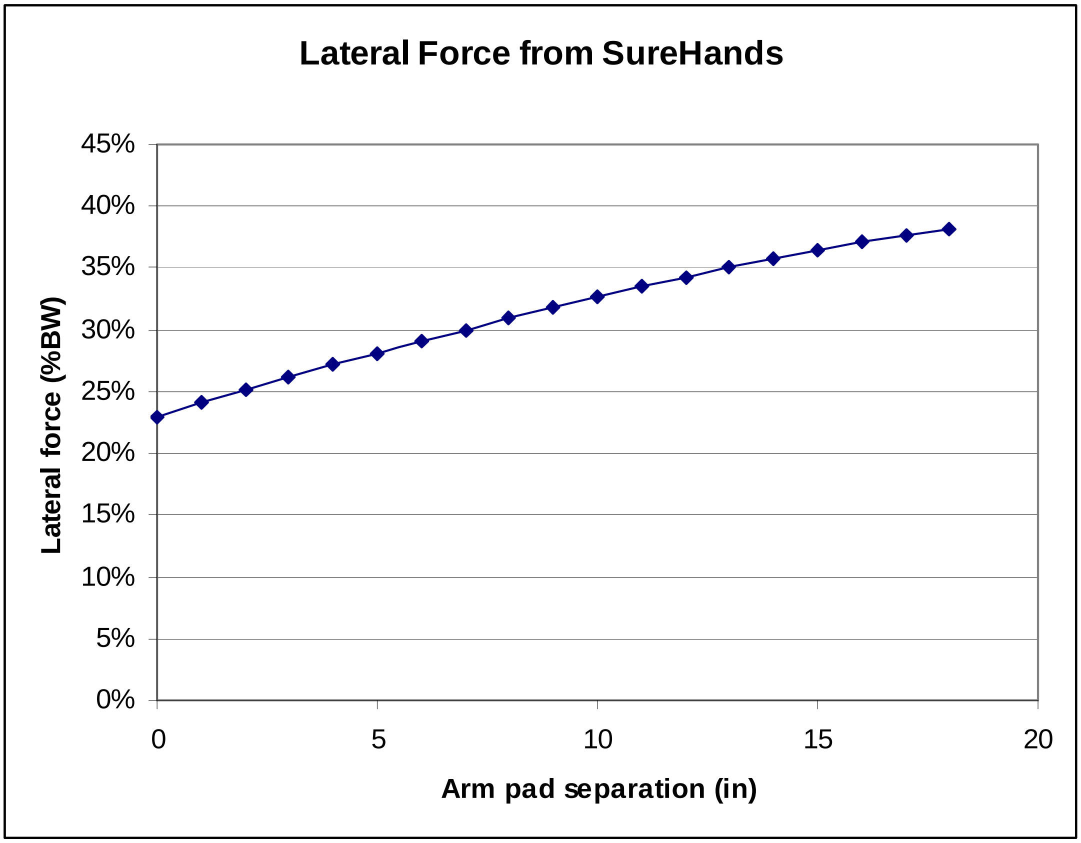

Figure 26: SureHands lateral force as a percentage of body weight

The lateral force from SureHands is proportional to a person's body weight. It is also dependent on the size of the person with more force being applied to those with larger torsos regardless of body weight. For most people roughly 30% to 38% of their body weight will be applied laterally at their chest when using the SureHands device. The calculations for the lateral force generated by SureHands can be found in Appendix A.

3.2 Experimental Setup

Several methods for applying the force were examined. The requirements of the system were that it:

- provide enough force
- measure the force
- provide incrementally adjustable force
- be easily operated
- provide emergency quick release
- be inexpensive

Among some of the methods investigated were an electric actuator, a turnbuckle, a scissor jack, a winch and pulley system, and a pneumatic system. The winch and pulley system showed some promise and a prototype was fitted to the device as shown in Fig. 27.

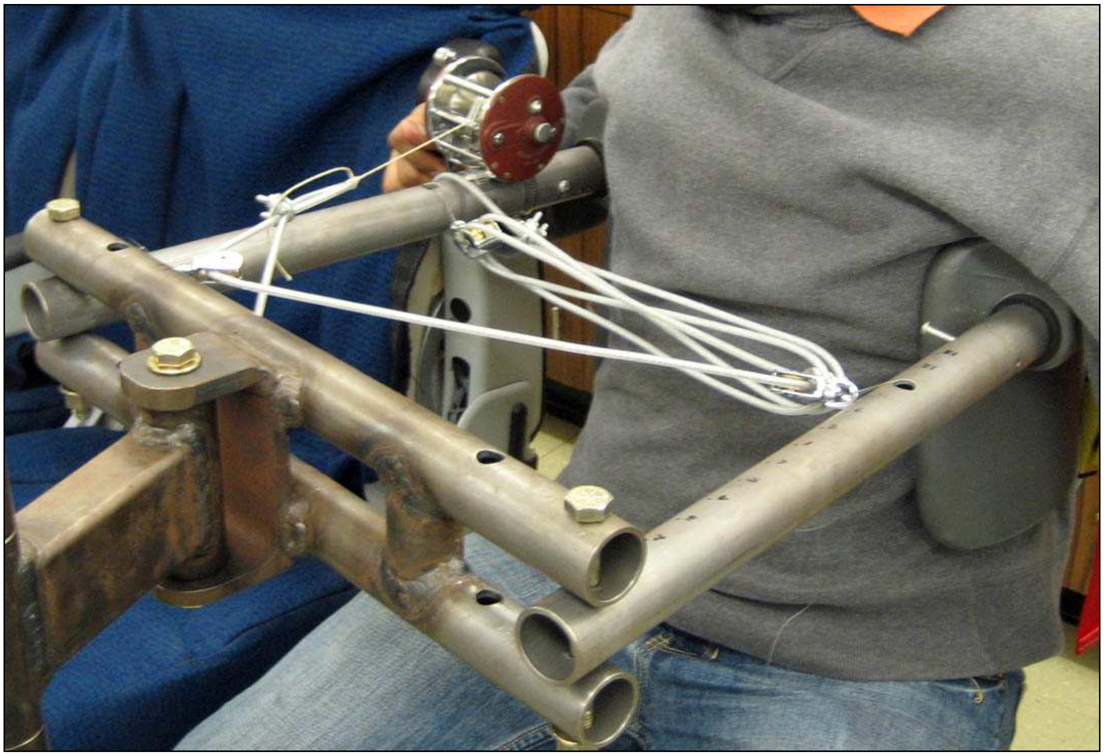
Figure 27: Winch and pulley system for applying a lateral force

While the winch and pulley system would apply a lateral force to the participant, there were many problems. First, it was not easily operated and required the participant to adjust the force. To measure the force a load cell would have needed to be placed somewhere in line with the cable. The biggest setback to this method was achieving an adequate force. From the photo it can be seen that the cable system is quite cumbersome. This particular setup only provided about half of the desired force, so to reach the correct force the cable system would have needed to be even more complex.

In the end a pneumatic system was chosen to apply the lateral force. There were several benefits with this setup. The system could continuously vary the force. This force could be readily measured via an inline pressure sensor. In case of an emergency, the force could be quickly released by simply exhausting to the atmosphere. In addition, the NCAT laboratory had a steady supply of compressed air at 100 psi. A schematic of the pneumatic system is shown in Fig. 28.

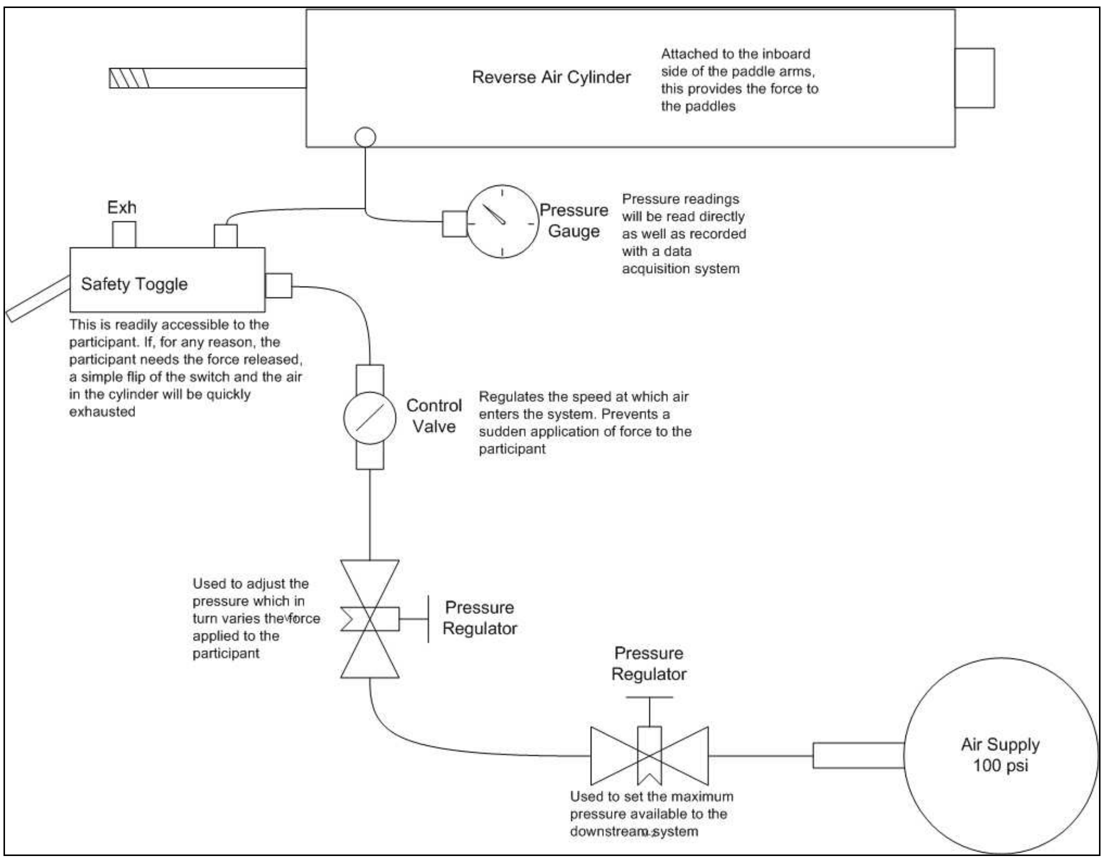

Figure 28: Schematic of pneumatic system developed for test

The system was connected to a 100 psi air supply. This then went through two pressure relieving regulators. One regulator was used as a safety to set the maximum allowed pressure; the other was used to adjust the pressure during the test. Since they were pressure relieving regulators the pressure in the system could be actively reduced. Next in line was a control valve which limited the speed at which the air entered the system. This prevented the arm pads from suddenly closing on the participant, reducing the chance of impact injury. Then there was a three-way pneumatic toggle switch. This served two purposes. First it was used to activate the system and began applying force to the arm pads. Second it acted as the primary safety release. By flipping the switch off, the supply air would be cut off and the air in the cylinder quickly exhausted. During the experiment, the switch was held by the participant, giving them control of when to start applying force, or in case of an emergency to quickly release it. As a backup safety measure, any of the connecting hoses could be severed by one of the observers with readily accessible cutters. Downstream of the switch the air line split in two directions. One branch went to the air cylinder which converted the air pressure into a lateral force. The other branch went to both a mechanical and an electrical pressure sensor. These sensors provided the pressure reading in the cylinder which was later converted into a lateral force. The actual pneumatic system is shown in Fig. 29.

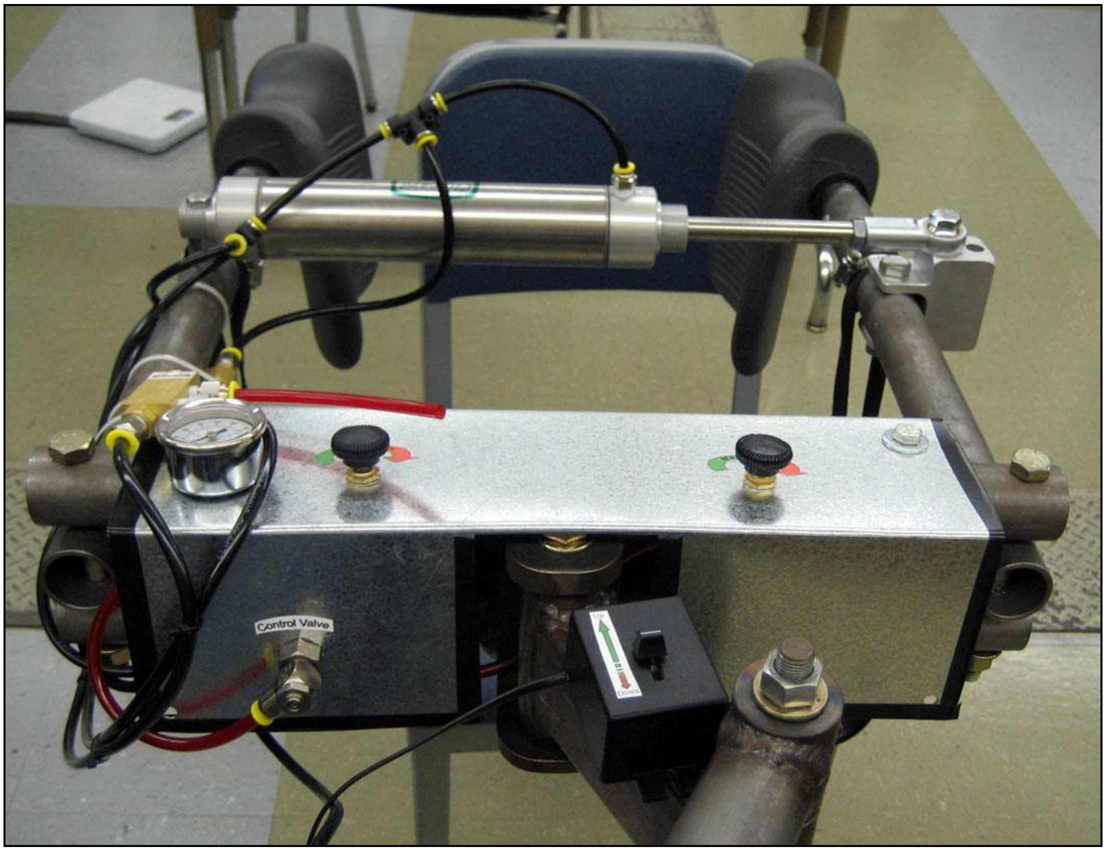

Figure 29: Pneumatic system with labels

3.3 Force Applied by Device

The independent variable in this experiment was the lateral force applied to a participant’s chest. This lateral force was achieved through the use of a pneumatic cylinder. It was necessary to verify that the system could provide the needed range of forces while not exceeding the force required for injury. A schematic of the test setup is shown in Fig. 30.

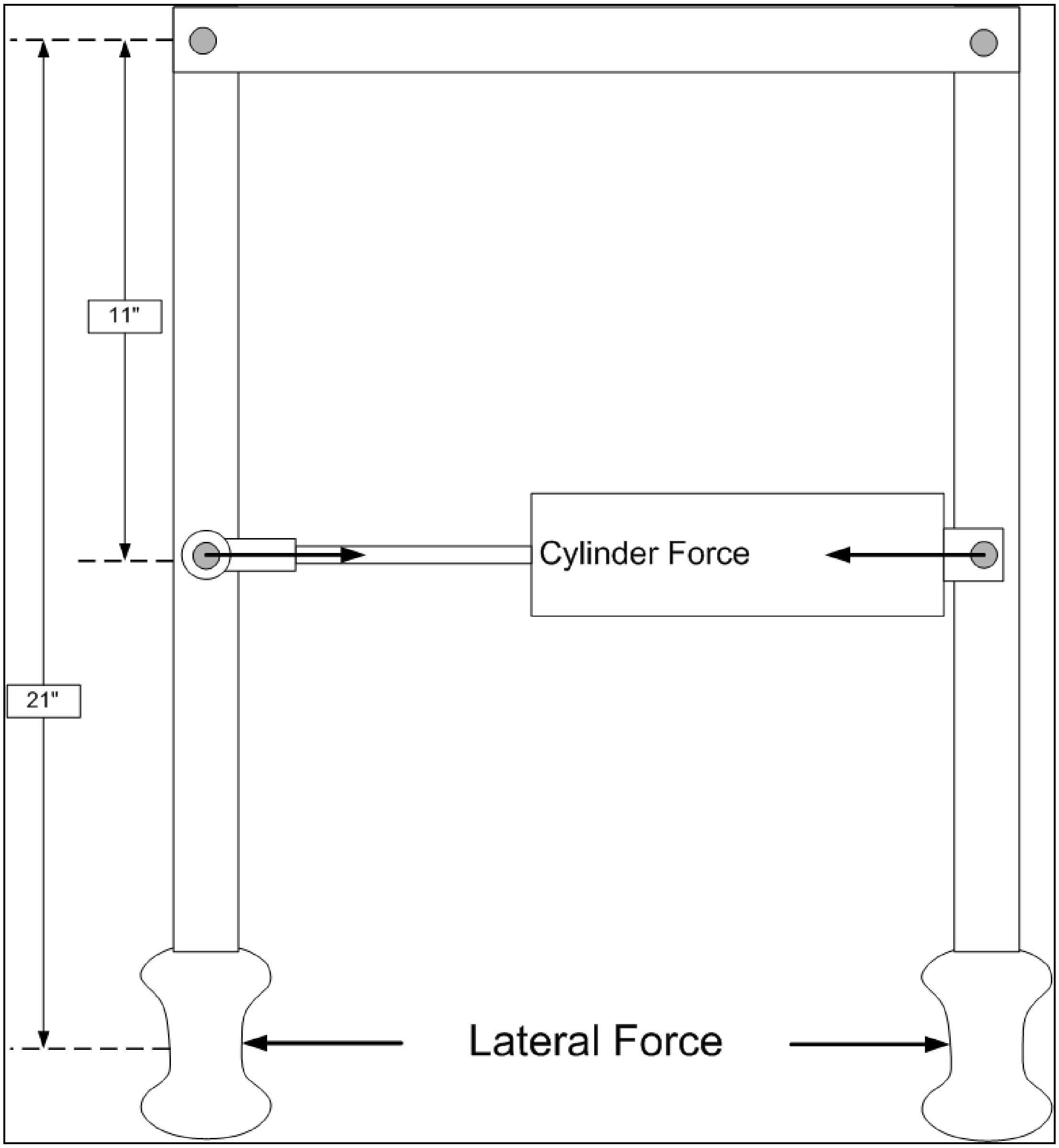

Figure 30: Schematic of lateral force applied by device

It was a relatively straightforward procedure to determine the lateral force produced at the arm pads. First, the cylinder force needed to be determined. This was done by multiplying the air pressure in the system by the effective area of the cylinder. The air pressure was directly measured from a pressure sensor inline with the cylinder. Since the selected cylinder was a reverse acting style, the effective area was found by subtracting the cross-sectional area of the rod from the cross-sectional area of the bore. The force analysis can be found in Appendix B. The relationship between the lateral force at the arm pads and the air pressure in the cylinder is shown in Fig. 31.

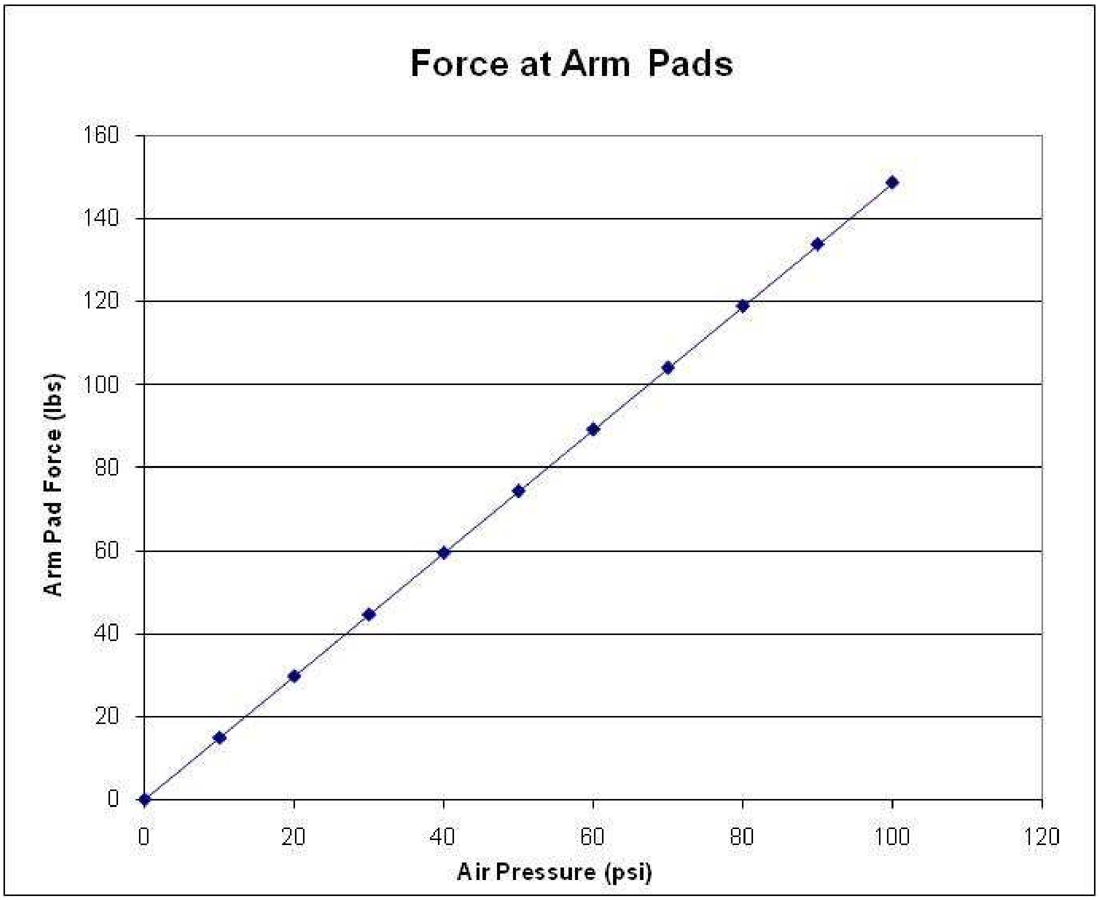

Figure 31: Effective lateral force at the arm pads based on air pressure in the system

For the supply air pressure of 100 psi the device provided a wide range of lateral force, from 0 lbs to 150 lbs, with a continuous adjustment. Considering the lateral force of 38% of a person's body weight from

SureHands, the high end of this range is equivalent to that required for lifting a person weighing 395 lbs with SureHands.

For additional safety, the pressure regulator for setting the maximum pressure available to the system was set at 90 psi. This corresponds to 134 lbs of lateral force, or roughly one third of the 393 lbs determined for thoracic fracture. In the event of a failure with this regulator, the maximum supply pressure of 100 psi would only result in a lateral force of 150 lbs; still well below the force required for serious injury.

3.4 Comfort Scale

A standardized rating scale was chosen to determine a participant's comfort level. It features 7 hand drawn faces depicting an increasing degree of pain. The anchor point for the "no pain" case is a smiling face, which has been shown to better capture the affective aspect of pain (Chambers, et al., 1999), (Goodenough, et al., 1999). It was thought that the affective judgment of pain would best represent the overall feeling of comfort which is the desired measure for the experiment. The chosen pain scale is shown in Fig. 32.

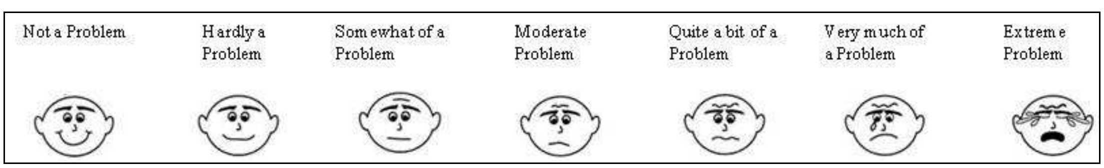

Figure 32: Comfort Rating Scale

One of the main objectives of the experiment was to determine the participant's comfort level for three critical cases. To establish a base comfort rating for each participant they were asked their initial comfort level upon first sitting in the chair. They were then asked about their comfort level when lifted with the minimum lateral force. The minimum lateral force was established as the force required to hold a participant so that the arm pads no longer slipped into their axillae as they were being lifted. After determining the minimum lateral force, the force at which the participant said they felt most comfortable was to be determined. This was done by lifting the participant with a pressure of 10 psi more than that at the minimum lateral force and then adjusting the pressure until they found the point which was most comfortable for them. Once this stated most comfortable force was found they were asked to indicate their comfort level.

3.5 Stability Scale

Another measure of interest was how secure the participant felt while being lifted. Again, this is a highly subjective measure. To evaluate it, a rating scale was created depicting a computer drawn chair in various degrees of tipping. This tipping chair scenario was chosen as the model of security because many people can relate to it. It ranges from an inevitable fall to being "rock solid" on the floor. Having the best and worst conditions of stability reversed from the conditions of the comfort rating is an attempt to gain a separate evaluation of a participant's sense of security. Therefore, a quick glance at the scales would not suggest that being stable only happens when the participant is comfortable. The stability rating scale is shown in Fig. 33.

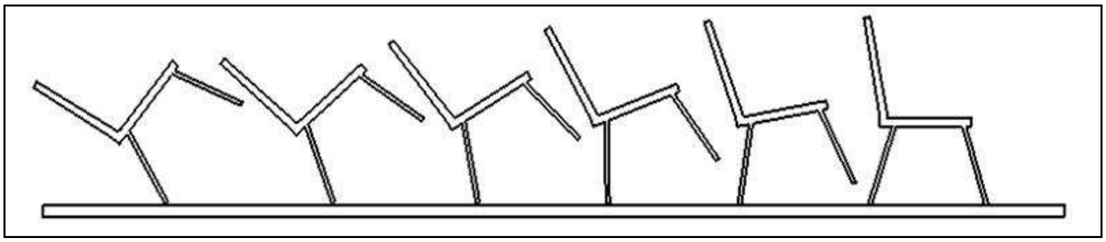

Figure 33: Stability Rating Scale

As with the measure of comfort the measure of stability was taken at two points during the experiment; after being lifted with the minimum lateral force and after reaching the stated most comfortable force. It was predicted that a participant will feel the least secure at the minimum lifting force.

3.6 Comfort Range

Arguably the most important objective of the test was to determine a range of applied lateral forces that are capable of lifting the participant while still being considered comfortable. The comfort rating scale, mentioned earlier, was used as the basis for this measurement. The grid for recording the comfort range is shown in Fig. 34.

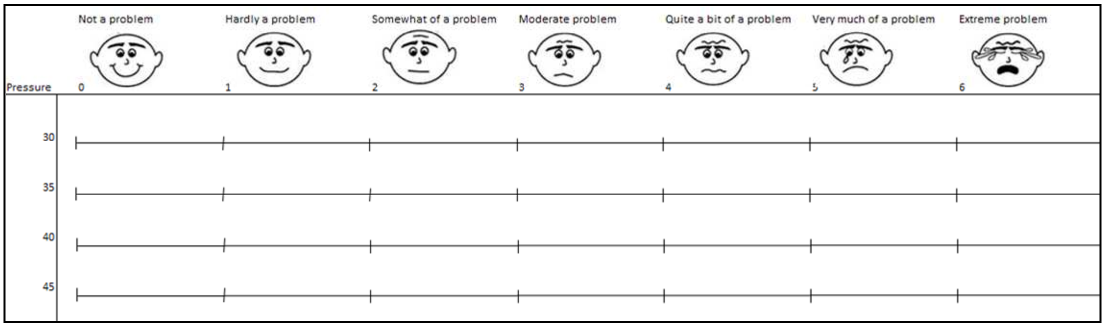

Figure 34: Comfort Range Grid

A numerical value from 0-6 was added to each facial depiction. This allowed the participant to indicate their comfort level on a continuous 0-7 scale. Below the comfort rating scale is a set of continuous lines, one for every 5psi increment between 30 and 90 psi. Once the pressure was adjusted to the appropriate setting the participant was asked to indicate their current comfort level on the corresponding line. The force was then incremented to the next setting where they were asked to indicate their comfort level again. This was repeated until the participant ended the test due to discomfort, or because the maximum pressure of 90 psi was reached. After a maximum pressure was reached the pressure was then reduced back to the stated most comfortable pressure. The pressure was then reduced in 5 psi increments with the participant indicating their comfort level until the minimum pressure of 30 psi was reached.

It was hypothesized that the comfort level would improve from the minimum lateral force to the most comfortable force. As the lateral force was increased beyond the most comfortable point it was expected that participant comfort would get worse. While it was considered to be highly likely that the location of the general comfort level would vary from participant to participant, it was expected that a general trend would emerge. This would reveal a range of lateral forces where the majority of participants experience the highest level of comfort.

3.7 Participant Selection

A sample size of approximately 50 adult participants was required for the study. There were no restrictions on who could volunteer other than those required to insure participant safety during the experiment. Due to the risk of injury during testing, as well as the increased risk due to participant age, only adults between the ages of 18 to 40 were allowed to participate. In addition, individuals who reported heart problems, respiratory problems, osteoporosis, or those taking drugs or medications that impair physical or mental function were excluded. To prevent gender effects from skewing the results a similar number of men and women were to be enrolled in the study with neither sex comprising more than 60% of the participants. Qualifying participants were selected in the order in which they made an appointment to be tested, subject to the upper limits on the number of participants of each sex.

Prior to testing, qualified participants were given an informed consent document which detailed the experiment, risks, benefits, and their rights as a participant, which they were to sign acknowledging that everything was explained to their satisfaction. A copy of the informed consent document can be found in Appendix C. After signing the informed consent, participants were asked to fill out a short health history questionnaire, which can be found in Appendix D. This questionnaire was used to identify existing conditions that could have increased the risk of injury during the experiment.

4 RESULTS

4.1 Example Results

After a participant was finished, the data recorded during the experiment was put into an Excel work sheet as shown in Table 2. The cells highlighted in light green are where the data was entered. The un-highlighted cells are values calculated from the inputted data.

Table 2: Example spreadsheet for a single participant

Participant #	018
Age	24
Gender	M
Height (in)	74
Weight (lbs)	175
Initial Comfort Level	0
Minimum Lateral	
Pressure (psi)	30.0
Force (lbs)	44.55
Force (%BW)	25.46%
Comfort	2.0
Stability	2.0
Most Comfortable	
Pressure (psi)	52.0
Force (lbs)	77.21
Force (%BW)	44.12%
Comfort	2.0
Stability	1.0

Comfort Range			Raw	Zeroed
Pressure (psi)	**Force (lbs)**	**%BW**	**Comfort**	
30	44.547	25.46%	3.7	1.7
35	51.9715	29.70%	3.5	1.5
40	59.396	33.94%	3.0	1.0
45	66.8205	38.18%	2.3	0.3
50	74.245	42.43%	2.0	0.0
55	81.6695	46.67%	2.0	0.0
60	89.094	50.91%	2.3	0.3
65	96.5185	55.15%	2.7	0.7
70	103.943	59.40%	3.2	1.2
75	111.3675	63.64%	3.5	1.5
80	118.792	67.88%	4.0	2.0
85	126.2165	72.12%	4.5	2.5
90	133.641	76.37%	5.5	3.5

The independent variable adjusted during the experiment was the air pressure in the system. This air pressure was used to calculate the applied lateral force on the participant. The lateral force was then used to calculate the equivalent force as percentage of each participant's body weight. A comfort rating was recorded for each pressure reading. To maintain consistency across all participants the comfort curve was normalized so that the most comfortable point became a zero rating on the scale. A comfort curve from a single test is shown in Fig. 35.

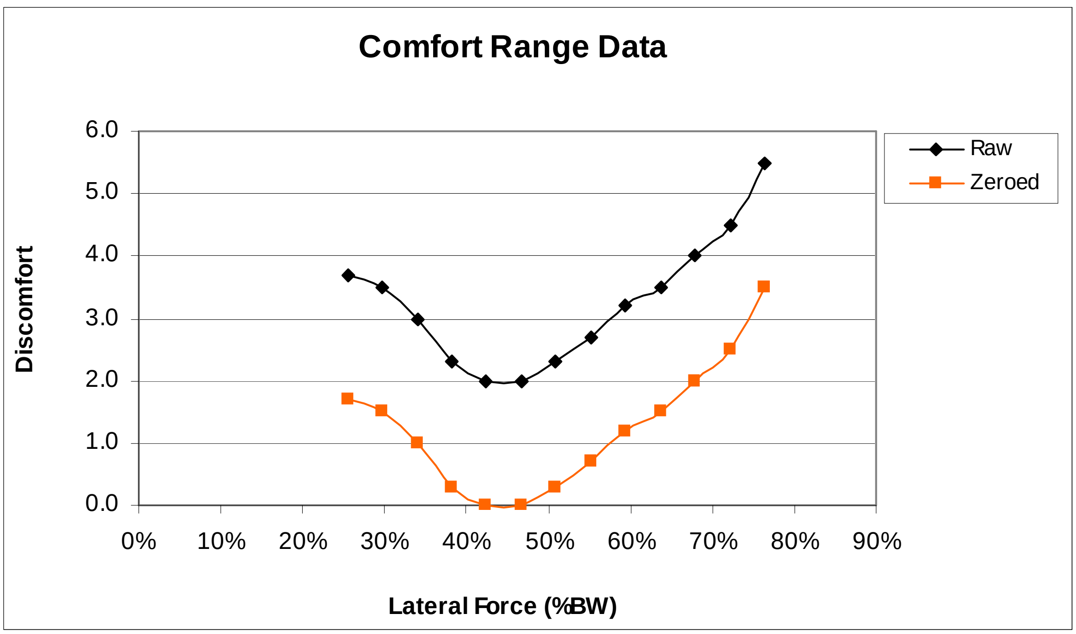

Figure 35: Individual participant comfort ratings

The comfort range data is plotted as discomfort versus applied lateral force as a percentage of body weight. The minimum point in the curve represents the most comfortable force.

4.2 General Statistics

Overall demographic data was calculated from all of the participants. Data for age, gender, height, and weight were all recorded. From this the average, standard deviation, minimum value, and maximum value were constructed as shown in Table 3.

Table 3: General demographic statistical information

General Statistics	Avg	Stdev	Min	Max
Gender	50 total		21 F	29 M
Age	23.24	3.34	18	35
Height (in)	67.43	3.97	60	80
Weight (lbs)	152.96	33.15	82	245

Participants ranged from 5' to 6' 8" tall and 82 lbs to 245 lbs. The average participant was 23 years old, 5' 7" tall, and weighed 153 lbs. This is expected with the sample population consisting mostly of college students. Of the 50 participants 29 were male and 21 were female. This met the goal of not having more than 60% of participants of only one gender.

4.3 Minimum Lateral Force

Based on each participant's evaluation of the minimum lateral force to lift them without slipping resulted in the average, standard deviation, and 95% confidence intervals for minimum lateral pressure, force, percentage of body weight, and corresponding comfort and stability. Table 4 shows these values.

Table 4: Minimum lateral force statistical information

Minimum Lateral Force	Avg	Stdev	95% CI
Pressure (psi)	30.56	5.53	1.53
Force (lbs)	45.38	8.21	2.28
Force (%BW)	30.31%	5.39%	1.49%
Comfort	1.32	0.79	0.22
Stability	1.01	0.79	0.22

The average minimum lateral force (MLF) is 30% of a person's body weight with a 95% confidence interval of (28.8%, 31.8%). This gives a fairly specific value at which the lateral force must be to prevent the arm pads from slipping into a person's arm pits and causing discomfort and potential injuries. The average comfort rating is a 1.32 or "hardly a problem" and the participants felt secure with a 1.01 rating or the slightly tipped chair.

4.4 Stated Most Comfortable Force

Participant's determination of the stated force that was most comfortable resulted in the average, standard deviation, and 95% confidence intervals for minimum lifting pressure, force, percentage of body weight, and corresponding comfort and stability. Table 5 shows these values.

Table 5: Most comfortable force statistical information

Stated Most Comfortable	Avg	Stdev	95% CI
Pressure (psi)	49.41	12.40	3.44
Force (lbs)	73.37	18.41	5.10
Force (%BW)	48.75%	10.87%	3.01%
Comfort	1.23	0.80	0.22
Stability	0.57	0.65	0.18

The average stated most comfortable force (SMC) is 49% of a person's body weight with a 95% confidence interval of (45.74%, 51.76%). There is a wider range for this measurement because it is a subjective rating on comfort rather than an evaluation on whether the arm pads slipped or not. The average comfort rating is a 1.23 or "hardly a problem" and the participants felt very secure with a 0.57 rating or the slightly tipped chair.

4.5 Revealed Most Comfortable Force

During the comfort range test a participant's comfort was evaluated at specific pressure increments which resulted in a comfort curve similar to the one shown previously in Fig. 35. The minimum of this comfort curve (the most comfortable force) did not always coincide with the SMC. This minimum in the comfort curve resulted in a new, "revealed" force which was the most comfortable for each participant. The average, standard deviation, and 95% confidence interval for this force as a percentage of body weight and corresponding comfort is shown in Table 6.

Table 6: Revealed most comfortable force statistical information

Revealed Most Comfortable	Avg	Stdev	95% CI
Force (%BW)	43.30%	7.55%	2.09%
Comfort	0.75	0.78	0.22

The average revealed most comfortable force (RMC) is 43% of a person's body weight with a 95% confidence interval of (41.21%, 45.39%). The average comfort rating is a 0.75 or "not a problem". This comfort rating was taken from the initial participant evaluations and not from the normalized comfort data. Stability was not evaluated during the comfort range test.

4.6 Comparison

A graphical representation of the averages for the three different lateral forces, plotted as a percentage of body weight versus comfort rating, is shown in Fig. 36.

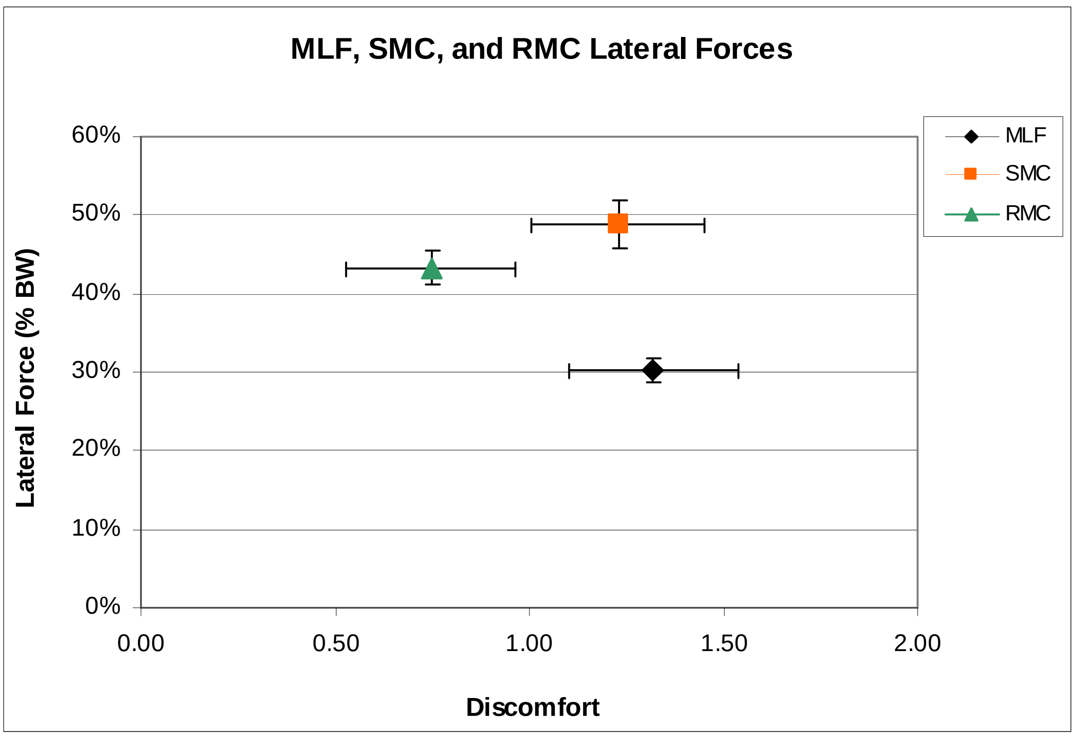

Figure 36: Lateral force as a percentage of body weight vs. discomfort. (x and y error bars are 95% CI for the average of discomfort and force as %BW respectively)

From the graph the three forces are easily compared. The MLF is by far the smallest at 30% BW and there is a slight difference between the SMC and

RMC at 49% BW and 43% BW respectively. The revealed force appears to be the most comfortable, but there seems to be little difference between the minimum force and the stated force.

A graphical representation of the MLF and SMC plotted as a percentage of body weight versus stability rating is shown in Fig. 37.

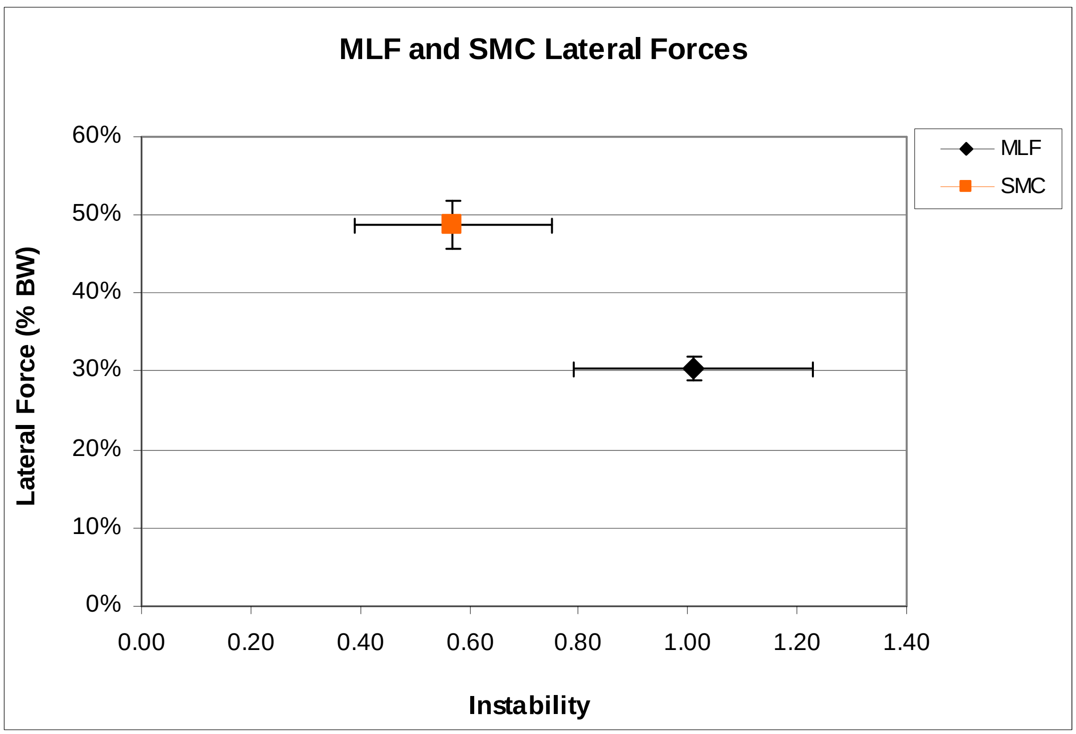

Figure 37: Lateral force as a percentage of body weight vs. stability

From the graph the stability ratings for the MLF and the SMC are easily compared. On average, participants seem to feel more secure when at the SMC. Since stability was not evaluated during the comfort range test the RMC is not included in this plot.

To determine if these differences in means are statistically significant a two sample t-test was done comparing each force for the average %BW and comfort rating. In addition the stability ratings were compared for the MLF and the SMC forces. These tests can be found in Appendix E. A summary for the calculated p values is shown in Table 7.

Table 7: p values from two sample t-tests comparing the means

	MLF vs SMC	**MLF vs RMC**	**SMC vs RMC**
Lateral Force (%BW)	1.25411E-16	5.1175E-16	0.0045
Comfort	0.5728	0.0004	0.0030
Stability	0.0029	**NA**	**NA**

All of the differences between the forces are statistically significant except there is no statistical difference between the comfort rating for the MLF and the SMC.

4.7 Comfort Range

The average comfort rating was calculated for each pressure increment. The corresponding force, calculated as a %BW, for each pressure increment was also averaged. The average comfort ratings were then plotted versus the average %BW forces. This is shown in Fig. 38.

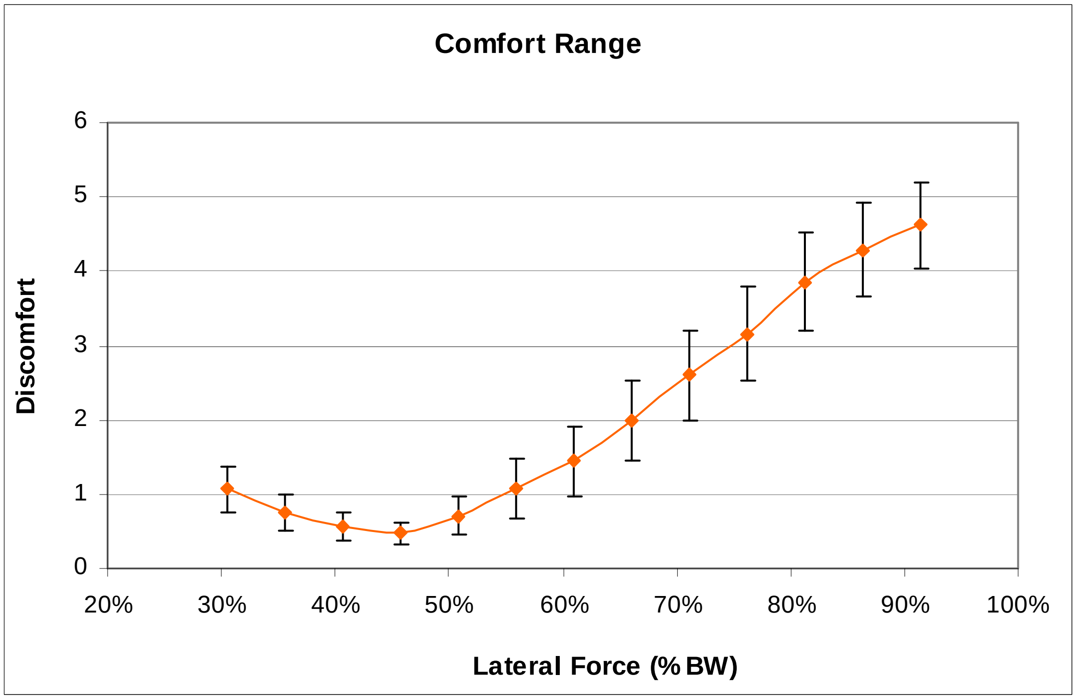

Figure 38: Average comfort range based on average force as %BW

The plot shows a clear trend relating comfort to the applied lateral force. As the force increases from the MLF the comfort improves until it reaches the most comfortable point at a force of 46% BW. Discomfort increases steadily as the force is increased beyond the most comfortable point. This backs up the initial hypothesis very well. The y-error bars are the 95% confidence intervals for the mean comfort ratings. The tightest interval is at the most comfortable point which further strengthens its validity as a target value for the applied lateral force.

4.8 Correlations

In the previous results the applied lateral force is expressed as a percentage of body weight. This assumes that the lateral force is correlated with a person's weight. To confirm this and to determine if any other relationships exist between the factors recorded from the experiment, a correlation analysis was done. The overall correlation analysis table can be found in Appendix F. A reduced version showing those factors with strong correlations highlighted is shown in Table 8.

Table 8: Correlation analysis

	Age	*Gender*	*Height*	*Weight*	*Initial Comfort*	*Min Force*	*Min Comfort*	*Min Stability*	*Stated Force*	*Stated Comfort*	*Stated Stability*
Age	1										
Gender	0.4423	1									
Height	0.4399	0.6966	1								
Weight	0.4209	0.5299	0.7279	1							
Initial Comfort	0.4402	0.0135	0.3869	0.3559	1						
Min Force	0.2504	0.3831	0.4494	0.6025	0.1486	1					
Min Comfort	-0.0376	-0.1965	0.1093	0.2151	0.2480	0.0635	1				
Min Stability	-0.1022	-0.2756	-0.2136	-0.0388	-0.0900	-0.2010	0.3411	1			
Stated Force	0.3958	0.3916	0.3508	0.5593	0.1898	0.6268	-0.1527	-0.1000	1		
Stated Comfort	-0.0020	-0.2125	0.0512	0.0552	0.3228	0.0853	0.6719	0.1580	0.0119	1	
Stated Stability	-0.0174	-0.0652	-0.0347	-0.0013	-0.0364	-0.1738	0.2156	0.5909	-0.0259	0.2532	1

Although the age of the participants does not seem to correlate strongly with anything, it should not be ruled out because only people between 18 and 40 years old could participate. Age could possibly play a role outside of this range. Gender correlated with height and weight, which is to be expected, but doesn't seem to affect much else. The height of a participant was highly correlated to their weight, which is again expected, but nothing else stands out. The weight of a participant is correlated with the MLF and their SMC. This confirms that the magnitude of the lateral force should be related to a person's weight. The initial comfort level had no effect on the other factors. The MLF is strongly related to the SMC, but this can be attributed back to the person's weight. Comfort at the MLF is correlated with comfort at the SMC. Likewise, stability at the MLF is correlated with stability at the SMC. However comfort and stability are not correlated.

5 DISCUSSION

5.1 Importance of Forces

The MLF is particularly important as it is the force at which the arm pads no longer slip into a person's axillae. If the arm pads slip then there is an increase in the load that must be supported by a person's under arms. This increases the likelihood of dislocating the arms and other injuries such as bruising. The MLF obtained during testing was found to be 30% of the body weight (30% BW).

The SMC and RMC forces are essentially the same force although they were obtained using a slightly different measurement method. The most comfortable force, taken as the average of the SMC and RMC forces, was 46% BW. This also happens to be the minimum point in the comfort range curve. The majority of participants felt the most comfortable with this lateral force. Being the most comfortable it can be assumed that this force would also cause the least amount of injuries.

5.2 Role of Comfort and Stability

The main goal of the study was to determine how a person's comfort was affected with various lateral forces. This was recorded by using two subjective rating scales; one for how comfortable the participant felt and one for how secure they felt. There was essentially no difference between the comfort ratings for the MLF and the SMC; however, there was a significant difference in how secure a participant felt.

The comfort range measurement revealed a force that was significantly more comfortable than the MLF or SMC forces. This could be due to the fact that small increments of force were rated relative to the previous force. As the lateral force increased from the most comfortable force it became less comfortable. This is intuitive because the higher the force the more constricting it is going to be. However, as the lateral force was reduced from the most comfortable force it also became less comfortable. This was likely due to two factors. One was that as the force was reduced a person felt less secure. The other was that a person began to slip as the force was reduced and the arm pads began to push against their under arms.

5.3 Design Considerations

By taking into account how a person's comfort is affected by the applied lateral force, further designs of the device can be optimized to maximize passenger comfort. The applied lateral forces are highly dependent on a person's body weight. Therefore the device should apply a lateral force that is proportional to a passenger's body weight. The results from the study show that there is an optimum lateral force of 46% BW that the design should apply to insure passenger comfort.

An acceptable range for the applied lateral force also emerged from the results. A device capable of applying a lateral force between 35% BW and 50% BW would adequately address passenger comfort as these forces achieved average comfort ratings (with 95% confidence) less than one. There are also clear limits to acceptable forces. The device should be restricted from applying a force less than 30% BW or more than 55% BW.

While a single value for the optimum applied lateral force was found, it was directly proportional to an individual's body weight. The device will still need to provide a range of forces to accommodate the majority of passengers. For a 5th percentile Japanese female passenger the most comfortable applied lateral force would need to be 40 lbs and it would need to be 100 lbs for a 95th percentile American male. When considering a larger passenger, up to 300 lbs, the device would need to apply a lateral force of 140 lbs. The device should automatically adjust the lateral force appropriately considering the passenger's weight. A small adjustment range of about 40% BW to 50% BW could be provided so that the lateral force can be tailored to maximize an individual passenger's comfort without placing them at risk of too little or too much force.

6 CONCLUSION

6.1 Limitations of the Study

While the study proved to be quite successful there are still several limitations that should be noted. First, the participants of the study were not from the intended user population. The participants were mostly college students who were between the age of 18 and 40 and were in good health. This was necessary to insure a relatively safe and consistent testing of the lateral forces. The effects of bone strength and upper/lower body mobility were not examined. There were a large percentage of Indian and Asian participants in the study. The effects of cultural and racial differences were also not evaluated in this study.

There were also a few limitations related to the testing apparatus and procedure. The effect of the position of the leg supports was not examined. In addition the orientation of the arm pads was fixed. There was no adjustability for different body shapes and therefore some participants experienced differing pressure points which could have affected the results. In many cases the participant remained suspended in the device for an extended period of time to evaluate each pressure increment. The effect of the duration at which a participant was suspended was not evaluated. In addition, each participant was only tested once. There was no evaluation on the repeatability of the most comfortable force for each participant.

6.2 Suggestions for Future Studies

After using the initial prototype for some time it has been noticed that the position of the leg supports plays a significant role in overall comfort during a transfer. The current study tried to standardize the position of the leg supports for every participant by having them placed mid-thigh. Now that a comfortable force has been determined with the constant position of the leg supports the role of the position of the leg supports can be investigated. A new measure of comfort can be determined by keeping the applied lateral force at the revealed comfortable value of 46% of a person's body weight and varying the position of the leg supports.

There are two extensions to the original test which may provide additional validity to the results. The first is to examine the repeatability of the measurements, specifically with the lateral force at which an individual participant feels the most comfortable. One method to do this would be to have a participant select the most comfortable lateral force for them and then repeat the same evaluation one week later. The second extension would be to determine if the most comfort force of 46% BW is applicable to the intended user population. Now that a range of comfortable lateral forces has been determined an additional study can be done; evaluating comfort versus applied lateral force, with participants who have disabilities.

6.3 Suggestions for Future Designs

One of the more important design considerations is stability of the device. By incorporating the aisle chair and lifter in one device the second prototype is quite stable fore and aft. Lateral stability is another story. Something needs to be designed so that the device will not tip over while a passenger is positioned to the side of the device. In addition, the stabilizing mechanism needs to be compact enough so that the aisle chair can be maneuvered through the aircraft.

Maneuverability of the device is another design challenge. The second prototype was designed with regards to size and weight considerations. Its ability to maneuver tight spaces was not considered. This is a very important design aspect especially directly after first entering the aircraft.

Improvements to the arm pad design are also possible. During comfort testing many participants mentioned that the current pads created uncomfortable pressure points and did not adequately fit their body. Designing the pads so that they automatically adjust to apply force across their entire area would not only increase comfort, but also reduce the chance of injury.

6.4 Overall Project Summary

Aircraft accessibility is an area that offers many opportunities for improvement. Developing a method that improves how passengers with disabilities get from their wheelchair and into an aircraft seat is one such opportunity. The current method is hazardous, cumbersome, and undignified. While some alternatives exist, there is still room for improvement.

One device currently under development in the NCAT lab at OSU mimics the manual transfer method. It grasps a person about the chest and legs while lifting, without being prone to inconsistencies passengers may experience from one set of assistants to another. It also reduces the need for close physical contact. One of the main concerns in the design of this device is to make sure the passenger is as comfortable as possible.

The study covered in the previous sections looked at how a person’s comfort is affected by various lateral forces applied to their chest while being lifted. The results showed that the minimum lateral force needed while lifting a person without slipping and the force at which the person felt the most comfortable were strongly dependent on their weight. It was found that the lateral force needs to be about 30% of the person’s body weight to prevent slipping and they were the most comfortable at a force of about 46% of their body weight. This provides strong goals on what lateral force future iterations of the device should apply to maximize passenger comfort.

By no means are the results of this study or the overall goals for improving the transfer process limited to air travel accessibility. There are many other settings in which a compact, maneuverable transfer device can be readily put to use. Patient care in hospitals, assisted living centers, and personal homes can be greatly improved. Injuries, resulting from repeatedly transferring a patient from one position to another, can be significantly reduced for nurses and assistants. In addition the process would be less intrusive and more pleasurable for the patients.

BIBLIOGRAPHY

Americans With Disabilities: 2002. (2006, May). Retrieved April 11, 2007, from U.S. Census Bureau: http://www.census.gov/prod/2006pubs/p70-107.pdf

Cesari, D., Ramet, M., & Bloch, J. (1994). Influence of Arm Position on Thoracic Injuries in Side Impact. In S. Backaitis, *Biomechanics of Impact Injury and Injury Toerances of the Thorax-Shoulder Complex* (pp. 893-919). Warrendale: Society of Automotive Engineers, Inc.

Chambers, C., Giesbrecht, K., Craig, K., Bennett, S., & Huntsman, E. (1999). A comparison of faces scales for the measurement of pediatric pain: children's and parent's ratings. *Pain , 83*, 25-35.

Ergonomic Guidelines for Manual Material Handling. (2007). Retrieved June 19, 2007, from CDC/NIOSH: http://www.cdc.gov/niosh/docs/2007-131/

Goodenough, B., Dongen, K., Brouwer, N., Abu-Saad, H., & Champion, D. (1999). A comparison of the Faces Pain Scale and the Facial Affective Scale for children's estimates of the intensity and unpleasantness of needle pain during blood sampling. *European Journal of Pain , 3*, 301-315.

MSIS: Vol. 1: Sect. 3. (1995, July). Retrieved January 7, 2007, from NASA: Man-Systems Integration Standards: http://msis.jsc.nasa.gov/sections/section03.htm

Nondiscrimination on the Basis of Disability in Air Travel. (2003, July). Retrieved April 10, 2007, from U.S. Department of Transportation: http://airconsumer.ost.dot.gov/rules/382short.pdf

Pavol, M., Welsch, L., & Higginson, B. (2006). *Risk Factors For Injury During Dependent Transfers On An Aircraft.* Corvallis, OR.

Products: Eagle 2. (n.d.). Retrieved April 15, 2007, from Haycomp: http://www.haycomp.com.au/default.cfm?id=82

Safe Patient Handling and Movement. (2005). Retrieved June 19, 2007, from VISN 8 Patient Safety Center of Inquiry: http://www.visn8.med.va.gov/patientsafetycenter/safePtHandling/default.asp

The Americans With Disabilities Act of 1990. (n.d.). Retrieved April 10, 2007, from Federal Transit Administration: http://www.dotcr.ost.dot.gov/Documents/ycr/ADA1990.htm

BIBLIOGRAPHY (Continued)

XP Equipment: XP BoardingChair. (n.d.). Retrieved April 15, 2007, from Xpiration B.V.: http://www.xpiration.com/pages/xp-boardingchair.html

Zografopoulos, K. (2005, September 9). TRAVELERS WITH DISABILITIES: THE AMERICAN MARKET. Athens, Greece: Open Doors Organization.

APPENDICES

APPENDIX A. SureHands Lateral Force Analysis

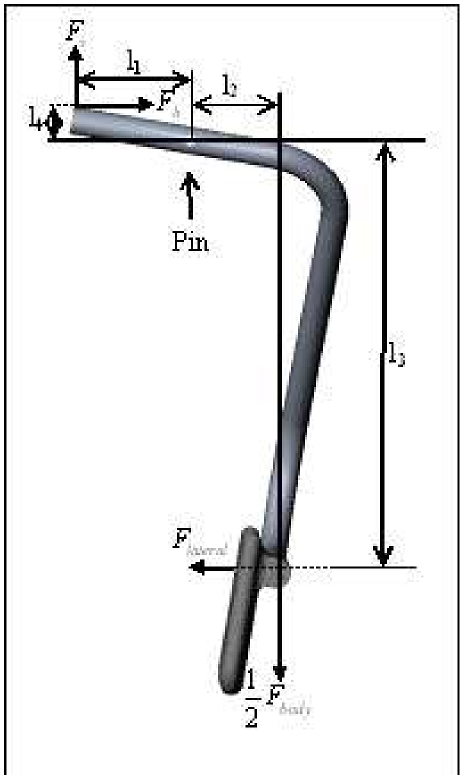

Figure A.39: Front view of a single Sure Hands arm with forces and relevant dimensions indicated

The moment equilibrium equation is:

$$\sum M_{pin} = 0 = -\frac{1}{2}F_{body} * l_2 - F_{lateral} * l_3 - F_v * l_1 - F_h * l_4$$

Where:

$$F_v = \frac{1}{2}F_{body}$$

$$F_h = \frac{F_v}{\tan(\alpha+\theta)} = \frac{F_{body}}{2 * \tan(\alpha+\theta)}$$

The equilibrium equation can be reduced as follows:

$$\sum M_{pin} = 0 = -\frac{1}{2}F_{body} * l_2 - F_{lateral} * l_3 - \frac{1}{2}F_{body} * l_1 - \frac{F_{body}}{2 * \tan(\alpha+\theta)} * l_4$$

$$\sum M_{pin} = 0 = -\frac{1}{2}F_{body} * \left(l_1 + l_2 + \frac{l_4}{2 * \tan(\alpha+\theta)} \right) - F_{lateral} * l_3$$

$$F_{lateral} * l_3 = -\frac{1}{2} F_{body} * \left(l_1 + l_2 + \frac{l_4}{2 * \tan(\alpha + \theta)} \right)$$

$$F_{lateral} = -\frac{1}{2 * l_3} * \left(l_1 + l_2 + \frac{l_4}{2 * \tan(\alpha + \theta)} \right) * F_{body}$$

The following coefficient shows how large $F_{lateral}$ is compared to F_{body}.

$$Coefficient = \frac{1}{2 * l_3} * \left(l_1 + l_2 + \frac{l_4}{2 * \tan(\alpha + \theta)} \right)$$

Where:

$l_1 = L_1 Cos(\theta)$

$l_2 = L_2 Cos(\theta) - L_3 Sin(\theta)$

$l_3 = L_3 Cos(\theta) + L_2 Sin(\theta)$

$l_4 = L_1 Sin(\theta)$

$\theta = 0^{\circ} to 20.5^{\circ}$

The physical dimensions of SureHands are:

$L_1 = 6.5 in$

$L_2 = 9 in$

$L_3 = 24 in$

$\alpha = 15^{\circ}$

The resulting lateral force based on arm pad separation is below:

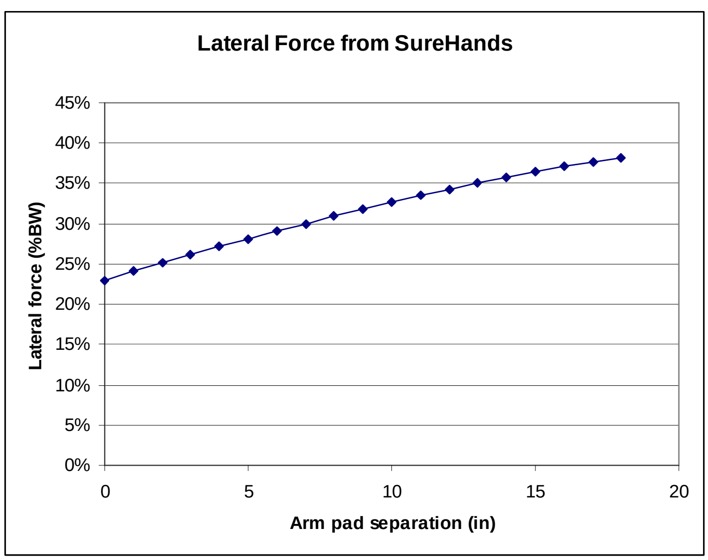

Figure A.40: SureHands lateral force as a percentage of body weight

APPENDIX B. Force Applied by Device

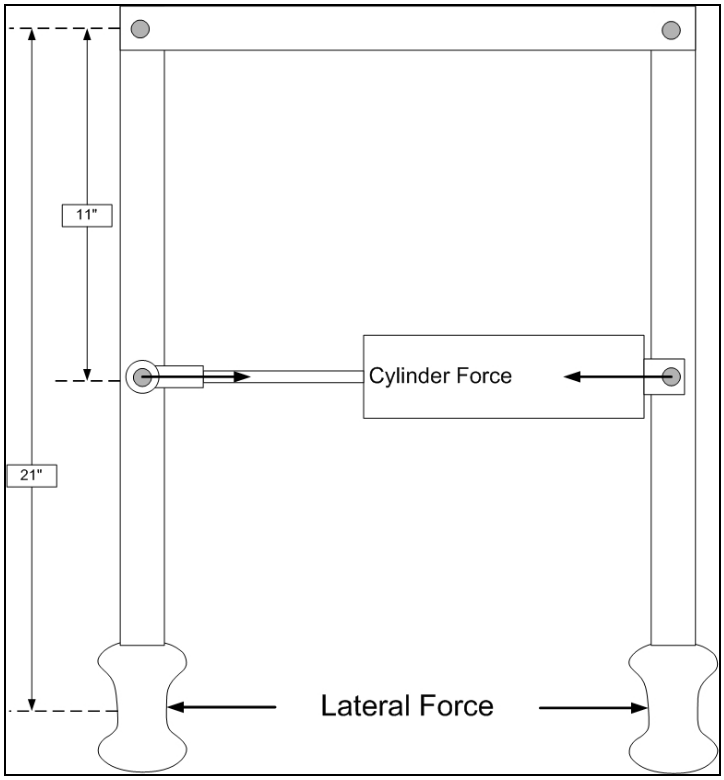

Figure A.41: Schematic of lateral force applied by device

The force generated by the air cylinder is given as:

$$CylinderForce = A * P_{air}$$

Where:

$$A = A_{bore} - A_{rod} = \left(\pi * \frac{d_{bore}^{\ 2}}{4}\right) - \left(\pi * \frac{d_{rod}^{\ 2}}{4}\right) = \left(\pi * \frac{2^2}{4}\right) - \left(\pi * \frac{0.63^2}{4}\right) = 2.83$$

Therefore:

$$CylinderForce = 2.83 * P_{air}$$

The resulting lateral force at the arm pads is:

$$LateralForce = \frac{11}{21} * CylinderForce = \frac{11}{21} * 2.83 * P_{air}$$

Therefore:

$$LateralForce = 1.48 * P_{air}$$

The lateral force is roughly 1.5 times the air pressure in the cylinder.

APPENDIX C. Informed Consent Document

Informed Consent Document

Project Title:	Determination of optimum compression force when mechanically emulating a two person transfer.
Principal Investigator:	Joe Zaworski, Ph.D., Mechanical Engineering.
Co-Investigator(s):	Jon Mast, Mechanical Engineering. Sushim Koshti, Mechanical Engineering.

PURPOSE

You are being invited to take part in a research study designed to determine the minimum, maximum and most comfortable squeezing force that should be used when lifting a person by the chest and legs. The results will be used in designing a Human Transfer Device to aid the transfer of people from wheelchairs to an aircraft seat and back. This is currently done manually by airline staff and is a major source of injury to both the passenger and airline staff. This project is studying the design of a device to reduce the risk of injury to both staff and passengers during onboard transfers.

This consent form gives you the information you will need to help you decide whether to be in the study or not. Please read the form carefully. You may ask any questions about the research, the possible risks and benefits, your rights as a volunteer, and anything else that is not clear. When all of your questions have been answered, you can decide if you want to be in this study or not.

You are being invited to take part in this study because you are a healthy adult between 18 and 40 years of age and have a good health history. If you have Osteoporosis, you are not allowed to participate in the study. The study can cause serious injury to people with Osteoporosis. Approximately 50 subjects will participate in this study.

PROCEDURES

If you agree to participate, your involvement will last for one session of approximately 45-60 minutes. You will not be asked to return later for a subsequent session. The following procedures are involved in this study.

The lifting device we are testing includes a paddle on each side of the chest and a lifting support under each leg. This mimics the way two people would move a person from a wheelchair to an aircraft seat.

Health History and Bone Health Questionnaire: You will record your general health history and bone health on a questionnaire. This will take approximately 5 minutes to complete. It is possible that we may ask you not to participate in this study as a result of the information you provide on this questionnaire.

Explanation of your role: We will familiarize you with the various parts of the device and how it works. The device basically consists of a pair of arms which will be positioned on the side of your chest and lifting supports, one of which will be positioned under each leg. A linkage of 3 bars connects the arms to a vertical column and the vertical column has an electrically driven mechanism to lift you up. We will also show you the safety features available in case of an emergency. You will have control of the safety devices. Finally, you will be shown a list of questions to answer at different points of during the experiment. The questions are about your current experience with the device.

Actual experiment When the actual experiment starts you will be asked to remove all outer clothing such as sweaters and jackets before proceeding. The experiment consists of 3 parts as follows:

1. *To find the minimum force required to hold a person for the purpose of being lifted up. (Note: It is anticipated that the average minimum lifting force will occur at 30psi (53lb).)*

   You will be seated on the chair and asked to respond to the *Comfort Rating Scale*. The paddles will then be positioned appropriately on the sides of your chest. The examiners will use a foam spacer of approximately 1 inch width to ensure that the top of the paddles are placed well below your arm pits. The leg supports will then be put in place. After you are comfortable and have been given the ‘emergency release’ switch, a force will gradually be applied to the paddles. An initial pressure of 20psi (35 lbs) will be applied and you will be lifted up just until the chair is no longer bearing your weight. If this pressure is not enough to hold you as you are being lifted, the pressure will be increased by 5psi (8.6 lbs) and lifting will be attempted again. This will be repeated until the pressure at which you can be lifted is reached. Once you are lifted up, you will be asked to respond to the *Comfort Rating Scale* and the *Stability Scale*. It should be noted that since you are only just above the chair, you cannot slip through a great distance and thus no serious injuries are expected to occur. You will then be lowered the remaining distance to the chair and you can step away from the device.

2. *To find the force that the participant considers best for the purpose of being lifted.*

   You will be seated in the chair and the paddles and leg supports will be positioned in place. A pressure of 40psi (70 pounds) will be applied. You will be lifted just until you are no longer in contact with the chair. Once you are being supported by the device, the examiners will increase or decrease the pressure in 5psi (8.6lb) increments at your direction until the you are completely satisfied that the optimum comfort level has been achieved You will then be asked to respond to the *Comfort Rating Scale.* After you have been lowered you can step away from the device.

3. *To find the comfort range of the applied force for the purpose of being lifted up.*

   Once you are ready, you will be seated in the chair and the paddles and leg supports will be positioned in place. The pressure recorded previously as the most comfortable will be applied and you will be lifted up until you are no longer in contact with the chair. If you feel you can bear more force without undue discomfort, the examiners will increase the force in steps of 5psi (8.6 lbs). At each increment in force, your response to the C*omfort Range Scale* will be recorded. The force will be increased either until you indicates that it is becoming uncomfortable or the maximum possible force of 90psi (155lb) is reached. You will be lowered back to the chair and the force will be removed and you can step away from the device.

RISKS

The possible risks and/or discomforts associated with the procedures described in this study are as follows:

- During the experiment you may experience some discomfort and a little pain around the chest. One aim of the experiment is to find the force which causes pain and discomfort. But it will not have any long term consequences. The maximum force reached in this experiment will be less than 160 lbs. The force required to fracture ribs in a similar load arrangement is about 425 lb. (Cesari et al., *SAE International* 1994;893-919).
- It is possible that you may experience a little pinching of skin due the paddles on the arms. This may cause minor bruising on the skin.
- You may experience difficulty in breathing during the experiment.

At any time during the experiment you will have an emergency release switch to remove all pressure on the paddles. If you experience unbearable pain, please alert us immediately and withdraw from the study. Adequate safety measures have been taken to ensure your safety.

BENEFITS

There are no direct benefits of this study to the participants. Those who may ultimately benefit from this study will primarily be travelers with disabilities and the airline personnel who perform dependent transfers. The ultimate aim of this study is to partially automate dependent transfers for boarding and disembarking an aircraft, thereby removing one of the deterrents to air travel by people with disabilities.

COMPENSATION

You will not get any compensation for being in this research study.

CONFIDENTIALITY

Records of participation in this research project will be kept confidential to the extent permitted by law. It is possible that these records could contain information that personally identifies you. To preserve your anonymity and confidentiality, your data will be identified only by an assigned subject code, and not by name. Only the researchers will have knowledge of your name and code number. Any documents that include your name will be stored in a locked filing cabinet in the NCAT Laboratory and will be accessible only to the research staff of this study. In the event of any report or publication from this study, your identity will not be disclosed. Results will be reported in a summarized manner in such a way that you cannot be identified.

RESEARCH RELATED INJURY

In the event of research related injury, compensation for medical treatment is not provided by Oregon State University.

VOLUNTARY PARTICIPATION

If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any benefits or rights you would normally have if you choose not to volunteer. You can stop at any time during the study and still keep the benefits and rights you had before volunteering.

You will not be treated differently if you decide to stop taking part in the study. You are free to skip any question that you would prefer not to answer. You are free to withdraw from this project at any time before it ends. If you choose to do so, the researchers may keep information that has already been collected about you and this information may be included in study reports.

QUESTIONS

If you have any questions about this research project, please contact:
Dr. Joe Zaworski: 541-737-9695, joe.zaworski@oregonstate.edu
Jon Mast: 541-737-7032, mastjo@onid.orst.edu
Sushim Koshti: 541-737-7032, koshti@engr.orst.edu

If you have questions about your rights as a participant, please contact the Oregon State University Institutional Review Board (IRB) Human Protections Administrator, at (541) 737-4933 or by email at IRB@oregonstate.edu.

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Participant's Name (printed):

____

_______________________________ (Signature of Participant)

__________________ (Date)

APPENDIX D. Health Questionnaire

Participant Code: ____________________

OREGON STATE UNIVERSITY
NCAT LABORATORY

Health History Questionnaire

Sex: ____ Male ____ Female

Height: _________

Age: _______

Weight: _________

Have you ever had:	Yes	No
Diabetes		
Heart trouble/heart attack		
Disease of the arteries		
High blood pressure		
Epilepsy		
Lung disease		
Asthma		
Surgeries/Operations of the Chest region		
Chronic lung disease		
Vitamin D Deficiency		

Cushing’s disease		
Multiple sclerosis		
Rheumatoid arthritis		

Do you take these medicines:	**Yes**	**No**
Oral glucocorticoids (steroids)		
Thyroid medicine		
Antiepileptic medications		
Gonadal hormone suppression		
Immunosuppressive agents		

If female, are you pregnant?	**Yes**	**No**

APPENDIX E. Two Sample t-tests

To determine if the differences means are statistically significant a two sample t-test was done comparing each force for the average %BW and comfort rating. These tests are shown in Tables A.1 to A.6.

Table A.9: Difference in means for the minimum lifting force and the stated most comfortable force as a percentage of body weight

	Min %BW	*Stated %BW*
Mean	0.3031	0.4875
Variance	0.0029	0.0118
Observations	50.0000	50.0000
Hypothesized Mean Difference	0.0000	
df	72.0000	
t Stat	-10.7532	
P(T<=t) one-tail	0.0000	
t Critical one-tail	1.6663	
P(T<=t) two-tail	0.0000	
t Critical two-tail	1.9935	

Table A.10: Difference in means for the minimum lifting force and the revealed most comfortable force as a percentage of body weight

	Min %BW	*Revealed %BW*
Mean	0.3031	0.4330
Variance	0.0029	0.0057
Observations	50.0000	50.0000
Hypothesized Mean Difference	0.0000	
df	89.0000	
t Stat	-9.9014	
P(T<=t) one-tail	0.0000	
t Critical one-tail	1.6622	
P(T<=t) two-tail	0.0000	
t Critical two-tail	1.9870	

Table A.11: Difference in means for the stated and revealed most comfortable forces as a percentage of body weight

	Stated %BW	*Revealed %BW*
Mean	0.4875	0.4330
Variance	0.0118	0.0057
Observations	50.0000	50.0000
Hypothesized Mean Difference	0.0000	
df	87.0000	
t Stat	2.9141	
P(T<=t) one-tail	0.0023	
t Critical one-tail	1.6626	
P(T<=t) two-tail	0.0045	
t Critical two-tail	1.9876	

Table A.12: Difference in means for comfort ratings of the minimum lifting force and the stated most comfortable force

	Min Comfort	*Stated Comfort*
Mean	1.3200	1.2300
Variance	0.6200	0.6450
Observations	50.0000	50.0000
Hypothesized Mean Difference	0.0000	
df	98.0000	
t Stat	0.5658	
P(T<=t) one-tail	0.2864	
t Critical one-tail	1.6606	
P(T<=t) two-tail	0.5728	
t Critical two-tail	1.9845	

Table A.13: Difference in means for comfort ratings of the minimum lifting force and the revealed most comfortable force

	Min Comfort	*Revealed Comfort*
Mean	1.3200	0.7470
Variance	0.6200	0.6117
Observations	50.0000	50.0000
Hypothesized Mean Difference	0.0000	
df	98.0000	
t Stat	3.6508	
P(T<=t) one-tail	0.0002	
t Critical one-tail	1.6606	
P(T<=t) two-tail	0.0004	
t Critical two-tail	1.9845	

Table A.14: Difference in means for comfort ratings of the stated and revealed most comfortable force

	Stated Comfort	*Revealed Comfort*
Mean	1.2300	0.7470
Variance	0.6450	0.6117
Observations	50.0000	50.0000
Hypothesized Mean Difference	0.0000	
df	98.0000	
t Stat	3.0466	
P(T<=t) one-tail	0.0015	
t Critical one-tail	1.6606	
P(T<=t) two-tail	0.0030	
t Critical two-tail	1.9845	

To evaluate the difference in stability ratings between the minimum lifting force and the stated most comfortable force another two sample t-test was done. The results of which are shown in Table A.7.

Table A.15: Difference in means for stability ratings of the minimum lifting force and the stated most comfortable force

	Min Stability	*Stated Stability*
Mean	1.0100	0.5700
Variance	0.6172	0.4185
Observations	50.0000	50.0000
Hypothesized Mean Difference	0.0000	
df	95.0000	
t Stat	3.0572	
P(T<=t) one-tail	0.0015	
t Critical one-tail	1.6611	
P(T<=t) two-tail	0.0029	
t Critical two-tail	1.9853	

APPENDIX F. Correlation Analysis

Table A.16: Correlation

	Age	Gender	Height	Weight	Initial Comfort	Min Force	Min %BW	Min Comfort	Min Stability	Stated Force	Stated %BW	Stated Comfort	Stated Stability	Revealed %BW	Revealed Comfort
Age	1														
Gender	0.4423	1													
Height	0.4399	0.6966	1												
Weight	0.4209	0.5299	0.7279	1											
Initial Comfort	0.4402	0.0135	0.3869	0.3559	1										
Min Force	0.2504	0.3831	0.4494	0.6025	0.1486	1									
Min %BW	-0.2553	-0.2427	-0.3805	-0.5577	-0.2077	0.2904	1								
Min Comfort	-0.0376	-0.1965	0.1093	0.2151	0.2480	0.0635	-0.0948	1							
Min Stability	-0.1022	-0.2756	-0.2136	-0.0388	-0.0900	-0.2010	-0.1696	0.3411	1						
Stated Force	0.3958	0.3916	0.3508	0.5593	0.1898	0.6268	-0.0193	-0.1527	-0.1000	1					
Stated %BW	-0.0285	-0.0851	-0.3107	-0.3415	-0.1319	0.1053	0.5418	-0.3082	-0.1060	0.5656	1				
Stated Comfort	-0.0020	-0.2125	0.0512	0.0552	0.3228	0.0853	0.1158	0.6719	0.1580	0.0119	0.0258	1			
Stated Stability	-0.0174	-0.0652	-0.0347	-0.0013	-0.0364	-0.1738	-0.1341	0.2156	0.5909	-0.0259	-0.0301	0.2532	1		
Revealed %BW	-0.0276	-0.2548	-0.3411	-0.3955	-0.0575	0.0500	0.5051	-0.1124	-0.1494	0.1532	0.5511	0.0367	-0.1042	1	
Revealed Comfort	0.1356	0.0726	0.2147	0.3707	0.1520	0.2901	-0.1680	0.3578	0.3297	0.2045	-0.1378	0.3691	0.3554	0.0990	1