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Conceptual Design Specification (CDS)

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Executive Summary

The client, Professor Philip Anderson, is searching for a design to address the needs of a specific user. Essentially, the purpose of the design is to enable the user to go from a horizontal position in his bed (0° at the horizontal) to at least 45°; this must be achieved without aid from another person. The user, who has virtually no grip strength, can exert approximately 0.60 Newtons (enough force to actuate a key on a mechanical keyboard). He has negligible strength in his arms and no use of his legs, though he is fully capable of speaking. Current common methods to aid people with similar disabilities occupy a significant amount of space, which the user does not have.

Furthermore, the design must factor in the special considerations necessitated by the user, such as his weight, 100 lbs, his restrictions on movement, and safety measures to ensure the user does not get into positions that he cannot get out of or that may damage his body. Additionally, there are other factors, such as cost and ease of implementation, that must be taken into consideration before a design can be recommended by the design team.

The design will be operated in the user's bedroom, which has dimensions of 4 × 3 metres and contains a large amount of furniture restricting the size of the design. Two power outlets are in the room, and cellular and wireless Internet coverage is available.

The design must take into consideration parties other than the user, client, and design team. These include the caretaker, the Ontario Government, and the user's neighbours. Hospitals, which are potential places of implementation, are also considered.

The idea generation process involved many brainstorming techniques, resulting in 50 design ideas. These ideas were narrowed down to three by using voting and elimination methods. The three solutions chosen comply with the client's needs, as they perform the necessary functions and adhere to constraints. The Rotating Half Mattress involves the use of a motor and pulleys to push the mattress, which in turns pushes the user, into the inclined position. The Motor and Cable System uses a motor, pulleys, and a harness to pull the user into the inclined position. The third design, the Patient Air Lift, modifies an off-the-shelf solution, an inflatable Sit-U-Up Pillow Lift, to better match the situation of the user. This design relies on the force of the device inflating to push the user to an inclined position.

The third design, the Pillow Lift, was determined to be the most suitable design as it meets the detailed requirements, with safety and compactness prioritized, and is very easy to implement, as the design can simply be added to the bed and does not modify the room. It fits well within budget and is easy to use, as it is used through the press of a button. The measure of success for the final design was based on 3 of the 8 objectives: safety, durability, and ease of use. Testing methods involved standardized tests along with tests made specifically for this implementation. For example, the ' Pillow tester' and Battery Capacity testing will be used for durability and ISO tensile testing to test the leather straps used to ensure safety. The next step for this project is preparing the design review gateway presentation, to be presented on the 13th of April.

1.0 Introduction

The client, Professor Philip Anderson, is working to develop a device to allow a disabled man to raise to an inclined position in bed without human aid. The user has no grip or arm strength and no use of his legs, although he is capable of speaking, and pushing buttons. The user lives with his mother, who serves as a caretaker, but he wishes to sit up without aid. This document will provide the client with an outline of the problem specifications as defined by the design team, along with a suitable solution.

2.0 Problem Statement

As this design is for a specific user, the projects scope is narrowed to accommodate his restrictions. The current common solution to aid people with similar disabilities, hospital beds, occupies a significant amount of space, which the user does not have. He has space for a single bed, which has dimensions of 97cm x 191cm[2], where adjustable hospital beds are typically 102cm x 215cm[3]. Therefore, the fundamental need is a compact safe design that is completely operable by the user, despite his mobility constraints. However, the design may be reset by another person[1].

3.0 Detailed Requirements

The design must assist the user in getting to an inclined position in bed, and must comply with several constraints and regulations. The design must both transport and support mass, and must do so without strength from the user.

3.1 Functions

The design must re-position the user from the horizontal to an inclined position, such that the user's back makes a 45° angle with the horizontal[1]. Helping the user back to the reposed position is outside the scope of this design[1].

3.1.1 Primary Functions

- To move a user from a reposed position to an inclined position
- To be capable of repetitive operations

3.1.2 Secondary Functions

- To support weight
- To exert force
- To be able to return to its original configuration (0˚ with respect to the horizontal), either manually or automatically.
- To indicate whether it is ready to be operated

3.2 Objectives

The objectives are given in descending order of importance, based on the user's needs. Since "compact" and "safe" directly take into consideration the circumstances of the user, they are most important[1].

Table 3.1 Objectives and corresponding goals[Appendix A]

Objective	**Goal**
Safe	Should implement several guards that reduce the likelihood of harm[1]. Should support 136 kg, the upper range of weights of offensive guards in the NFL[5]
Compact	Should have dimensions not exceeding 97cm x 191cm, the size of a "twin" mattress[2]
Easy to use	Should take no longer than 1 second to initiate operation, the estimated length of time it takes to press one button. The entire operation should be completed within one minute, as requested by the client[1]
Unintrusive	Operating noise should be under 50 dB, as loud as a refrigerator[4]
Inexpensive	Cost for the user should be kept under C$500, the lower bound of the user's budget[1]
Durable	Should last 10 years without maintenance, as per the client's expectations[1]
Easy to implement	Should be implemented within six months[1] Should not modify the room[1]
Large lift range	Should lift the user from 0° to 90°

3.3 Constraints

Several constraints have been set by the client. Most importantly, the user's lack of physical strength must be considered. Additionally, the design must:

1. Not require more than 0.60 N, the strength that is required to push a keyboard key[6]) to operate (benchmarking).
2. Lift user 45° from the horizontal, as expected by the client
3. Not exceed 97cm x 203cm, the size of a "twin XL" mattress[2]
4. Be implementable within 1 year, as expected by the client[1]
5. Allow operation cancellation
6. Adhere to certain safety standards, specifically Medical Devices Directive 93/42/EEC/[53][7][14]
7. Not require the user to pay any maintenance costs over the lifespan of the design.
8. Be able to support 45 kg, the user's weight[1]
9. Not hinder the bed's wheelchair accessibility[1]
10. Not hinder the user's sleep schedule during implementation[1]
11. Not cost more than 5000$ for the user[1]

4.0 Service Environment

The scope of this design is limited to one particular user. Hence, the service environment only considers one specific setting.

4.1 Physical Environment

The user's bedroom has dimensions of 4x3 metres, with a wooden floor. Furniture includes a bed weighing 60-70 kg[16], a bureau at one end of the bed, and a small table and television opposite. There is 30cm of clearance at the foot of the bed. Enough space is provided for the door to swing open[1].

The room has two power outlets. One at the foot of the bed; the other is near the television[1]. Appendix C contains photos of the room.

4.2 Virtual Environment

There is wireless Internet available throughout the room[12][Appendix D]. There is cellular coverage throughout the house.

5.0 Stakeholders

The stakeholders have been arranged in decreasing order of impact. The caretaker, being directly impacted in terms of providing support, is listed first. All others differ in impact and interest and are arranged accordingly[Appendix E].

Table 5.1 Stakeholders and impact on design

Stakeholders	**Impact**
Caretaker	• Reduction in physical effort in bringing the user to an inclined position[1] • Amount of external physical assistance the design will require to operate[1] • Noise generated by the design when in operation[1]
Ontario Government	• Grants provided by the Ontario Government will cover 75% of the capital cost, as per the Assistive Devices Program[9]. Maintenance costs are not covered, but supplies could be provided[13]. The Home & Vehicle Modification Program[15] under the March of Dimes covers: ○ $15,000 lifetime maximum for home modifications • Affects the budget and allows them to provide healthcare for citizens with physical disabilities
Neighbours	• Noise generated by the design while in operation, as the user's house is semi-attached to the neighbours' houses[1]
Hospitals	• Adaptability of the design to hospital-specific conditions[1]

6.0 Alternative Designs

The idea generation process involved narrowing down 50 design ideas[Appendix F], produced through free brainstorming, to ten designs. Most of the ideas that were produced did not satisfy one or more constraints and were consequently discarded.

The remaining ideas were refined down to the final three ideas using a team voting system. The most suitable design was subsequently chosen by weighing the objectives in 3.2 and assessing the performance of each [Appendix G].

The three design solutions that were produced are the Rotating Half Mattress, the Motor and Cable System, and the Patient Airlift. All three satisfy the constraints in 3.3, and perform the necessary functions in 3.1.

6.1 Rotating Half Mattress (RHM)

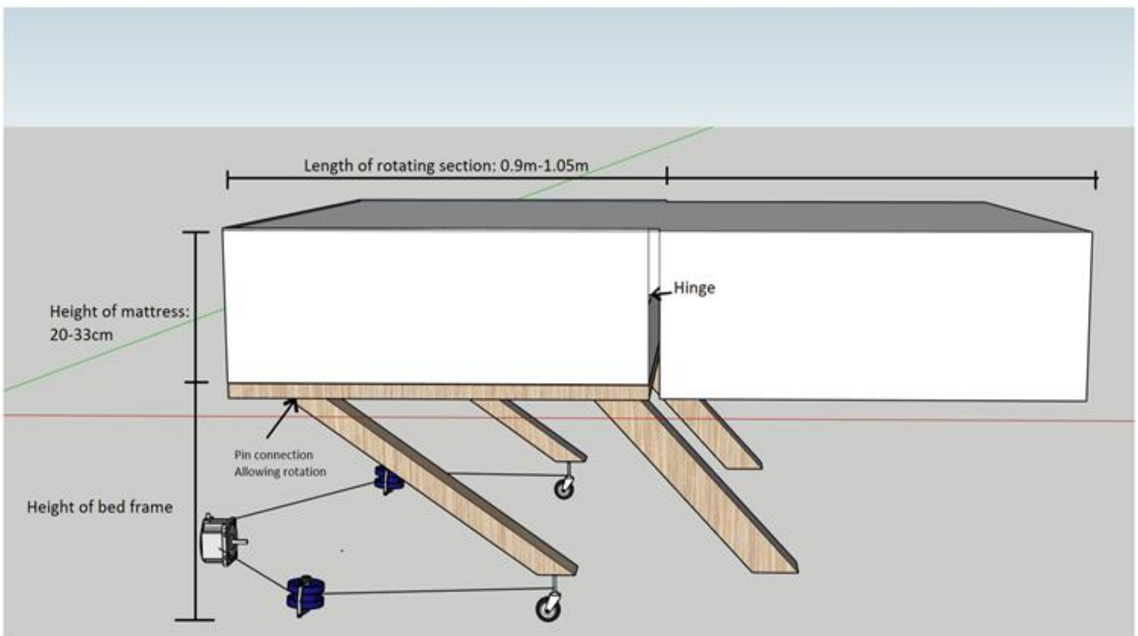

Figure 6.1 3D rendition of RHM

The mattress, along with the wood underneath, is partially split at 90~105cm, as shown in Figure 6.1. A hinge is inserted at a third of the bed's thickness (20 to 33cm)[17]. Four beams are attached to the underside of the bed frame, two of which are fixed, the other two attached to wheels. The beams attached to the rollers are connected to a 10W-motor via pulleys and cables.

Upon a button-press, the motor pulls the cables and wheels, straightening the beams and rotating the mattress and user about the hinge. This continues until the user presses the button again or the angle reaches 45˚.

The user is pushed to rotate about his pelvis for stability[Appendix H],dimensions shown in Figure 6.2, and half of the mattress rotates about the hinge.

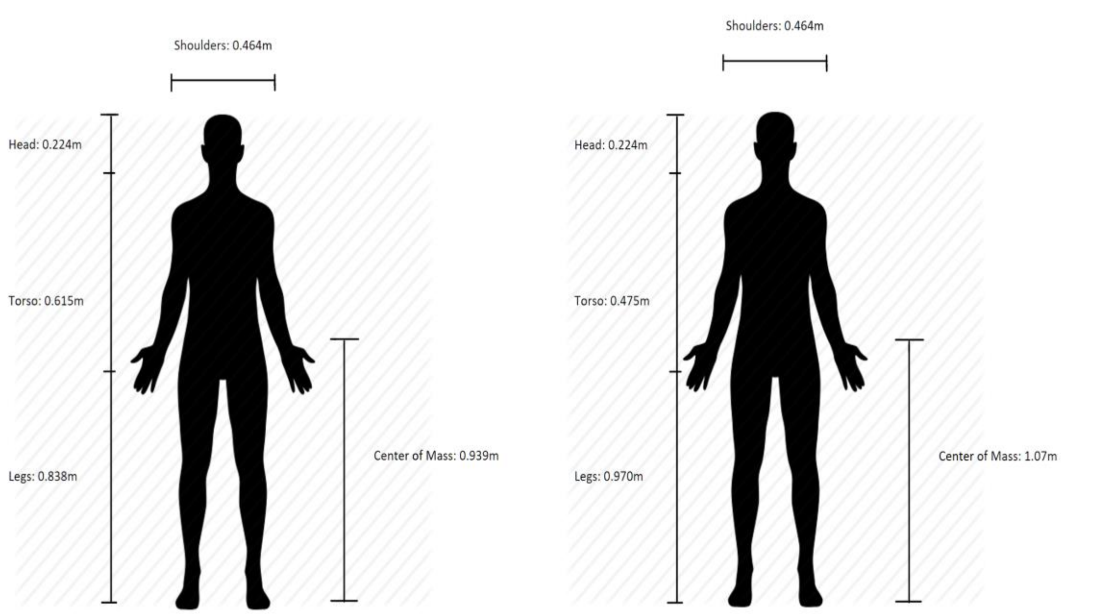

Figure 6.2: Proportions of average male[20]

6.1.1 Performance

With respect to the objectives in section 3.2, the RHM performs as follows.

Table 6.1 Performance of RHM

Objective	**Performance**
Safe	In case of emergency, the motor's operation can be stopped by a single button press on the remote Reaction force experienced by the beams and the wood underneath is reduced, due to the presence of the hinge. Thus, standards are also upheld Solid braided nylon rope, which supports 2.8 kN of weight, is used in the system[Appendix I][22] Speed of design is 0.013745m/s[Appendix J]
Compact	Has dimensions 0.615m by 0.7 m Fits within bed frame
Easy to use	A single button initiates operation Lifts user in 60 seconds[Appendix J]
Unintrusive	Design generates < 24 dB of noise, the higher end of noise generated by an electric fan[21]

Inexpensive	Total cost is approximately C$215[Appendix K]
Durable	Warranty length of the motor is 1 year[25] However, since this motor will only be used 5 times per day[1], it is expected to last much longer
Easy to implement	Modifications to the bed are required. However, implementation will take less than 6 months
Large lift range	Lifts from 0° to 45°

6.2 Motor and Cable System (MaCS)

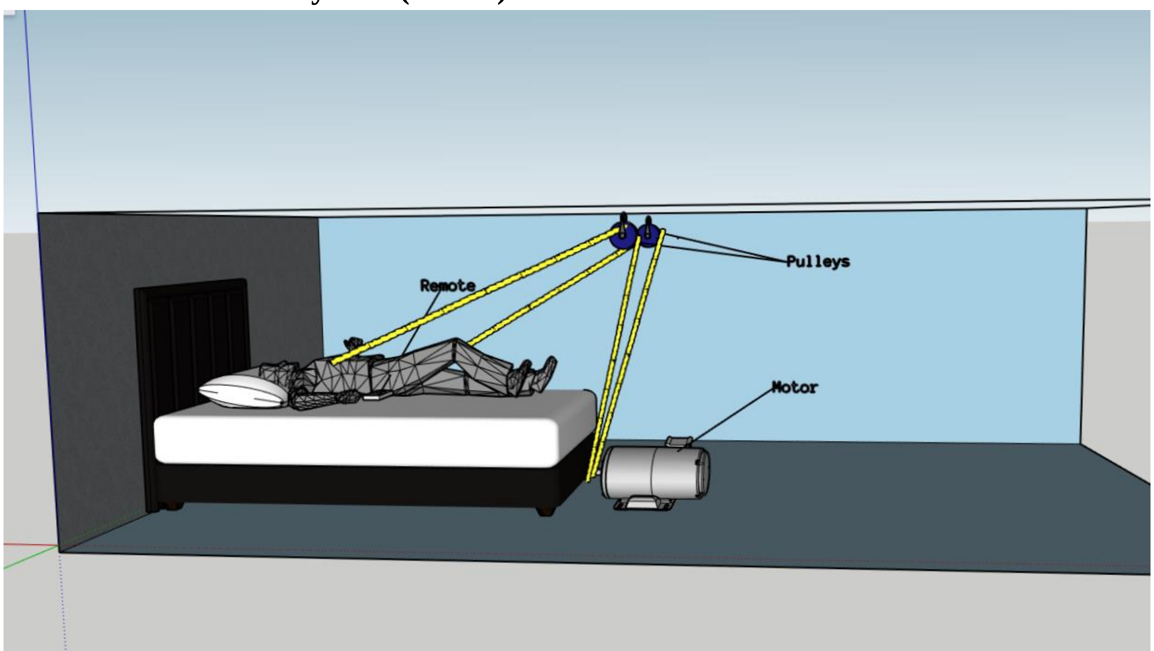

Figure 6.3 3D rendition of MaCS

Figure 6.3 depicts the configuration of the motor and cable system. A cable reel, motorized by a 10W-motor, is placed on the ground and can be turned on and off using a remote control. A cable connected to this reel splits into two, which attach to two pulleys on the ceiling, diverting the direction of the cables towards the user's bed. Hooks on the free ends of the cables connect to the user via a harness and exert a tension force on the user once the motor is activated, thereby lifting him up towards the pulleys. Once the user is at a comfortable angle, the motor can be stopped by another button on the remote and the system can immediately be reset to its original configuration.

The chest harness has two small metal rings attached around the shoulder area, one on each side. The user puts on the harness before going to bed, and the harness will not compromise the user's comfort. When the user wishes to get up from the reposed position into an upright position, he can take the hooks at the ends of the cables and slip them into the rings, allowing the cable to pull him up. No strength is required for this operation.

6.2.1 Performance

With respect to the objectives in section 3.2, the MaCS performs as follows.

Table 6.2 Performance of MaCS

Objective	**Performance**
Safe	In case a mishap arises, the motor's operation can easily be stopped by a single button press on the remote control Solid braided nylon rope, which supports 2.8 kN of weight, is used[22][Appendix I]
Compact	System only takes up space in the vertical direction, above the user's bed. Reel is at the foot of the bed and is 27.3cm by 14.6cm[23] Motor adds 16cm to the width[24]
Easy to use	Motor is activated by a single button press on the remote Lifts user in 60 seconds[Appendix L].
Unintrusive	Motor generates less than 24 dB of noise, the higher end of noise generated by an electric fan[21]
Inexpensive	Total cost is C$200[Appendix L]
Durable	Warranty length of the motor manufacturer is 1 year[25]. However, since this motor will only be used ~5 times[1] per day, it is expected to last much longer
Easy to implement	Modifications to the ceiling *are* required. However, implementation will take less than six months
Large lift range	Lifts from 0° to 90°, due to the cable's angle

6.3 Patient Air Lift (PAL)

This design works on the concept of pneumatic battery-powered technology. As shown in figure 6.4, it utilizes a modified version of an automated inflatable cushion, the "Sit-u-Up PillowLift", paired with a MicroBot pusher[Appendix M] and leather straps[28]. The PillowLift, pictured in figure 6.5, which is sewed onto the mattress of the user's current pillow-space, enables the user to achieve an inclined position by air pumped from the AirFlo Plus compressor[26].

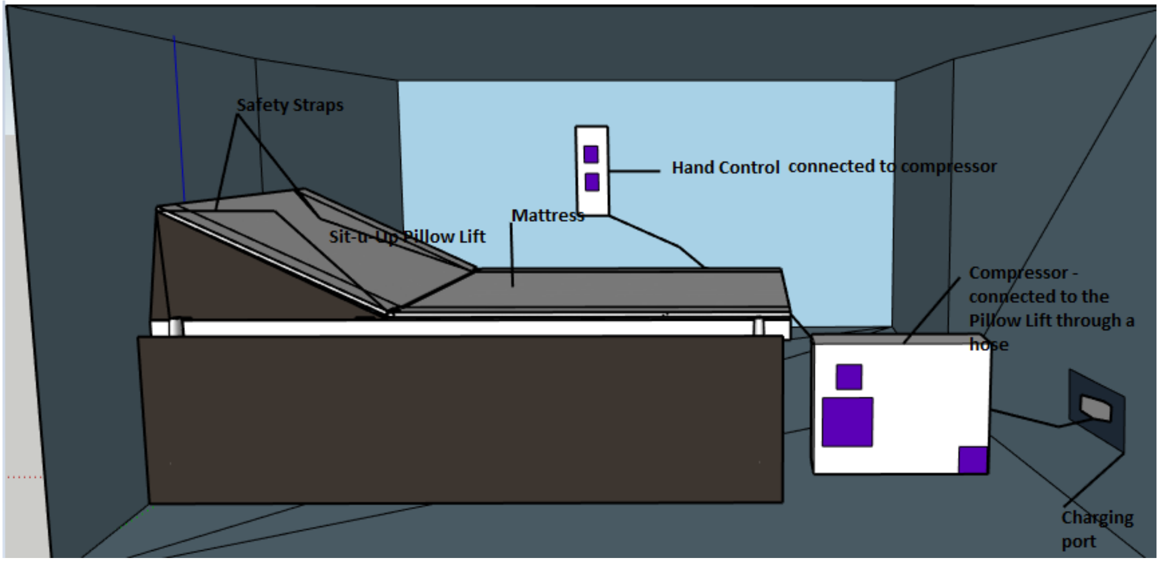

Figure 6.4 3D rendition of PAL

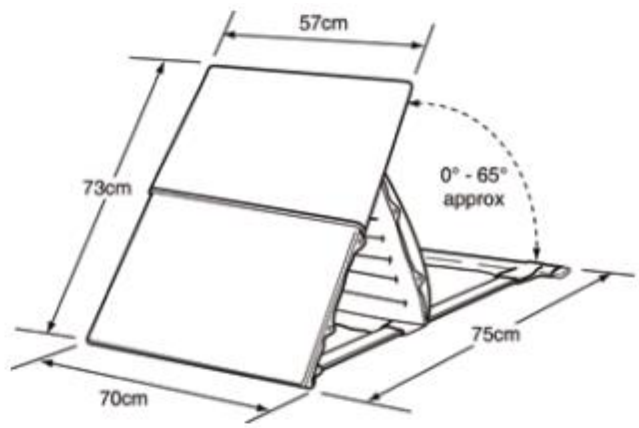

Figure 6.5 Representation of Pillow Lift[34]

This process starts with the user slipping his arms into the straps and touching a button on his phone screen, after which the MicroBot pushes a button on the hand control until the final angle is reached.

The AirFlo compressor[30] is connected to the pillow lift by a hose. It runs on battery and uses LEDs to indicate power levels[30]. As the battery life decreases, the compressor must be charged. The caretaker's assistance is required when the compressor is being charged[26].

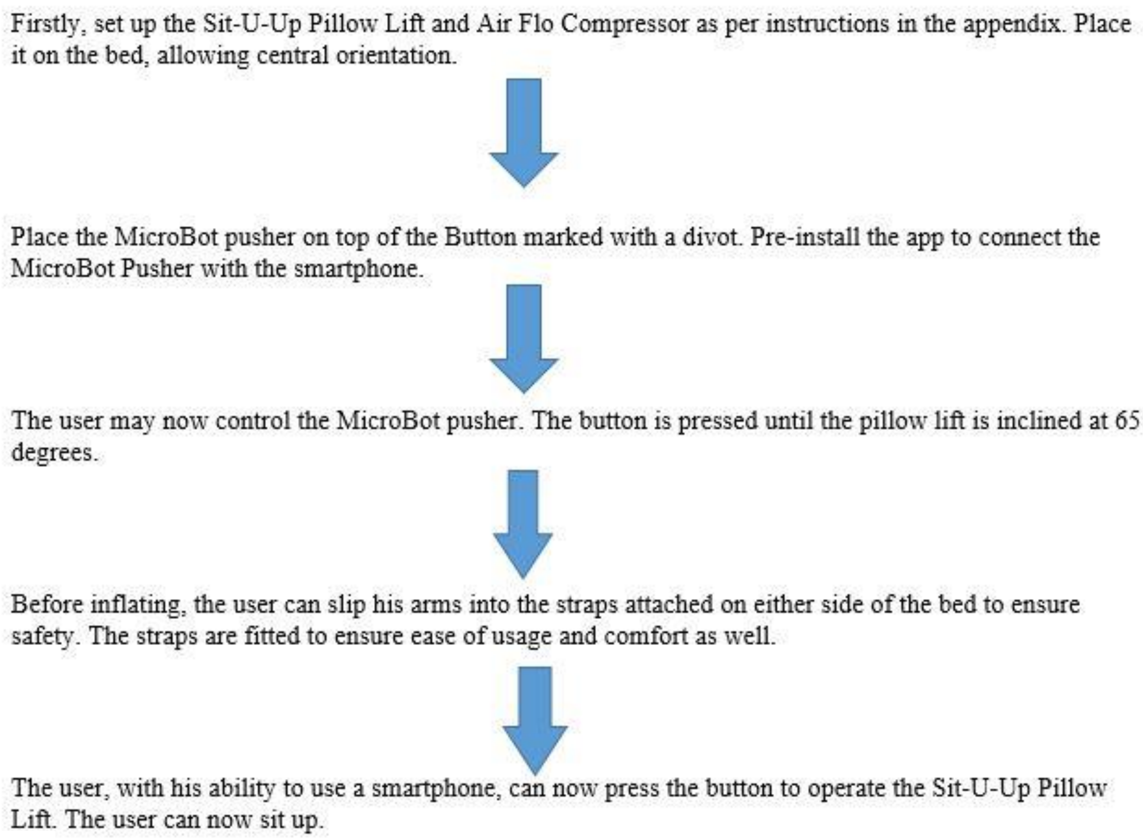

Figure 6.6 Flow chart of PAL

6.3.1 Performance

With respect to the objectives in section 3.2, the PAL performs as follows.

Table 6.3 Performance of PAL

Objective	**Performance**
Safe	Supports up to 152.41 kgs[26] Byhands Webbing Backpack Straps[28] of length 0.475 - 0.615 meters[Appendix H] are attached to the PAL on either side to ensure stability during inflation. The straps are attached to the PAL with Permatex Plastic Epoxy Adhesive[51] Equipped with anti-slip pillow holder[34] Speed is 0.0561 m/s[Appendix O]
Compact	Dimensions of 75cm x 70cm[26]

Easy to use	Single button press to initiate operation Lifts in 15 seconds[Appendix O]
Unintrusive	Generates 41 dB of noise[29]
Inexpensive	Costs C$987.57[Appendix P]
Durable	Expected to last more than 5 years, but has a warranty of 5 years[31][Appendix Q]
Easy to implement	The design makes use of existing technology, linking an existing air cushion and a smartphone. Hence, implementation time will be less than 6 months as minimal modifications are required.
Large lift range	Lifts from 0^o to 65^o

7.0 Proposed Conceptual Design

PAL is a more appropriate solution than the RHM or the MaCS[Appendix G]. It uses off-the-shelf solutions, including the PillowLift and the MicroBot, ensuring the implementation process is easy and the design has been thoroughly tested.

The user needs to be able to sit upright in bed without help from his caretaker. The PAL is able to complete this task, and is able to do so without any downsides of the other two designs. For instance, in order to be implemented, the MaCS requires modifying the room (i.e., drilling through the ceiling), and the RHM requires splitting the bed in half and adding a hinge, a task which may hinder the user's sleep schedule.

The design implements appropriate safety measures through the use of straps that secure the user to the design. Since the design is secured to the bed, there is virtually no way for the user to change position while he is being lifted. This provides the most security out of the three designs, as the other two allow slight movement.

The PAL is the most compact out of the three, being about a third of the mattress size. It is activated by a button press, with a response time of less than one second and a completion time of 15 seconds, far shorter than the RHM or MaCS.

Additionally, the design comes assembled, so the only implementation procedure is to attach the PillowLift to the bed and plug the compressor into the wall outlet.

Although the price of this design is not the lowest of the three, subsidies provide C$15,000; hence, the budget is met. The manufacturer of the PillowLift offers a 5 year warranty, longer than the warranties offered on the other designs. Furthermore, the PAL can lift the user up to 65^o, larger than the RHM.

Due to the compact nature of the PAL, as well as its low margin of error for safety concerns, the design matches the clients priorities as well as possible.

8.0 Measure of Success

This section addresses the effectiveness of the proposed design (PAL) by performing standardized tests that will measure its success in meeting the main criteria specified by the client: safety, durability and ease of use. Other criteria such as compact, inexpensive and unintrusive do not need standardized testing as they are absolute values. Due to the the fact that our design already exists, the design has already been proved feasible.

8.1 Testing Against Criteria

The evaluation methodologies for the PAL with respect to key objectives are outlined below.

8.1.1 Safety

The design will be tested against the requirement for class 1 devices of the Medical Devices Directive 93/42/EEC, this is an internationally recognized standard that meets the client's safety specifications[32]. As it has been certified and tested against this standard, the design will pass this test.

8.1.2 Strength of Leather Straps

The PAL will be tested according to the ISO 3376:2011 standard test, this test will determine the tensile strength as well as the elongation by applying certain loads on the recommended leather straps[33], the leather straps are expected to pass this test as they are made from genuine cowhide leather, which normally has a tensile strength of 8-25 N/mm^2[52].

8.1.3 Ease of Use

To test this objective the following can be performed:

- The user weighs 45 kg. Therefore, 90 kg was picked for the maximum mass the design will ever need to carry for this particular user
- 90 kg will be positioned on the design prototype. The design will be activated while measuring the time it takes to complete the operation in comparison to the client objective. The design has been tested to withstand upto 152.41 kgs of force, thus passing this test [26].
- The design will be initialized using an application on the user’s phone; since his phone is equipped with WiFi, the operation initialization duration can be assumed to be less than 1 second.

8.1.4 Durability

Durability of the design is measured by Battery Capacity testing. There are Full String Tests or Single Cell tests to determine the longevity of battery life. The battery is subjected to a constant current load while measuring the individual voltages and string overall voltage. It can be calculated by the formula: Capacity= T_{actual} / T_{final} *100%
If the battery capacity is greater than 80%, then it passes the test[49]. This design will

pass the test because similar nickel-based batteries to the ones used - the 1 x 12v - 2200 mAh Ni-MH battery Pack - can deliver around 300 to 500 cycles before capacity drops below 80%. [30] [54].

Durability of the PAL can also be tested by “The Pillow Tester”[50]. It is a standardized test performed by Pikolin ™ to test the durability of pillows. A thirty kilogram weight is placed on the center of the pillow 10000 times, after which it is checked for any signs of wear and tear or loss of thickness and support. This simulates the use of the pillow during the span of its entire life. The material is checked for deformation. Since the pillow is made of foam, it passes this test because pillow foam scores a value between 20 - 40 Indentation Load Deflection (ILD) in the 25 percent compression test, meaning it can withstand “The Pillow Tester” and will pass it [31][55].

8.2 Demonstration of Feasibility

Since our design exists and is being sold, we have no need for simulations. Live-action experiments have been conducted and we can use those to analyse the operations and any shortcomings. Further analysis can be conducted to determine the strengths and weaknesses of the design.

9.0 Conclusion

Through the development of this design, the user will be self-sufficient with regards to reaching an inclined position in bed, which will positively impact the quality of life of both the user and his caretaker. The design team assessed the functional requirements of any solution, and took into consideration the attributes of the user’s bedroom as well as of potential stakeholders (the neighbors, for example). From considering three original design ideas, the Patient Air Lift was determined to be more suitable than the other two, and its performance and testing methodologies were examined. The next step for this project is preparing the design review gateway presentation, to be presented on the 13th of April.

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Appendix A: Pairwise Comparison of Objectives

Table A.1 Objective legend

1	Inexpensive
2	Durable
3	Compact
4	Easy to implement
5	Large lift range
6	Easy to use
7	Unintrusive
8	Adjustable
9	Versatile
10	Safe

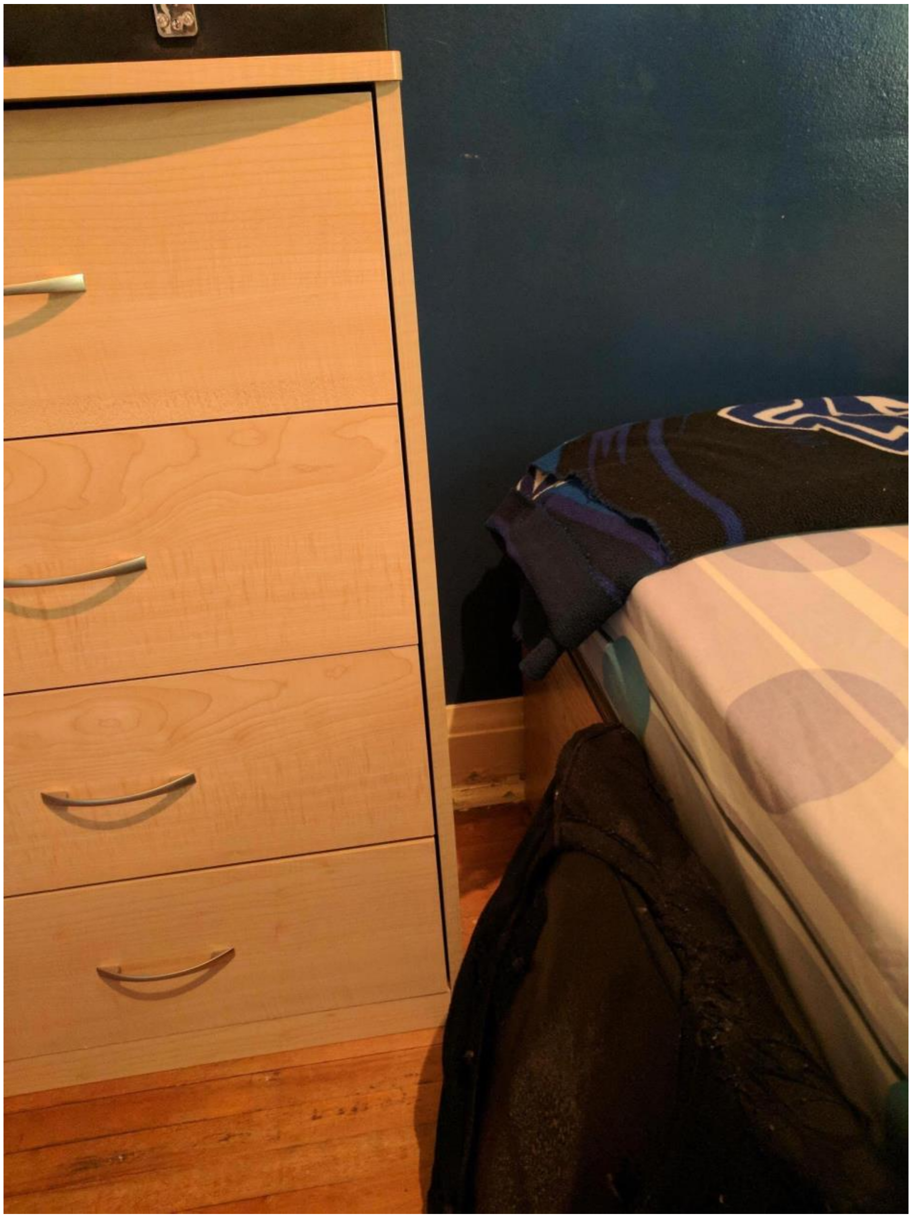
Table A.2 Pairwise comparison of objectives

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Score**
1	-	1	0	1	1	0	0	1	1	0	5
2	0	-	0	1	1	0	0	1	1	0	4
3	1	1	-	1	1	1	1	1	1	0	8
4	0	0	0	-	1	0	0	1	1	0	3
5	0	0	0	0	-	0	0	1	1	0	2
6	1	1	0	1	1	-	1	1	1	0	7
7	1	1	0	1	1	0	-	1	1	0	6
8	0	0	0	0	0	0	0	-	1	0	1
9	0	0	0	0	0	0	0	0	-	0	0
10	1	1	1	1	1	1	1	1	1	-	9

Appendix B: Safety Standards[48]

In this scenario, the design must comply with certain safety standards issued by the ISO and Government of Canada. The codes used for this standard is the one issued by the European commission specifically the requirements for Class 1 devices(which the design falls under) of the Medical Devices Directive 93/42/EEC/

Appendix C: Photograph of the User's Room



Appendix D: Correspondence with Client

"Hi
"I'm pretty sure he has wifi. I think the speed is on the higher end, but not sure. City is Toronto. Pictures show side of bed with him partly in the picture, and a space at the end of the bed. Sorry, all I have so the rest I'll have to relate to you as best I remember.
"PA"

Received February 6, 2018 at 9:50PM

Appendix E: Stakeholder Analysis

Table D.1 Analysis of the impact on stakeholders

	High Influence	Low Influence
High Interest	Caretaker	Neighbours
Low Interest	Ontario Government	Hospitals

Appendix F: Design Ideas

1. Magnetic related stuff: electromagnet embedded in a bed that turns on once client wishes for operation, and then lift the bed (using magnetic repulsion) until desired angle of inclination is achieved, and then attached into a hook, and stop lifting. Reset by: 1) physically doing something with the hook, and 2) reversing magnetic polarity of the electromagnet to bring it down.
2. Rollers on mattress to ensure compact aspect
3. Voice command to initiate operation
4. Patient Lifts
5. Portable Lifts
6. Analogy: gym equipment. Handle or lifting mechanism automatically is pulled down; and when firmly attached to user, weights are added and weights pull person up.
7. Adjusting current bed
8. Pay someone to get him out of bed everyday
9. Cure the client of his illness
10. Create a Robot that will do it
11. Get the client a bigger house to allow a hospital bed
12. Pulleys
13. Rollers + ramp
14. Metal bilayer
15. Springs
16. Wrap him in a cocoon-like structure that inflates
17. Robotic ants that can raise him up
18. Air cannon that inflates
19. Make a giant magnetic field between the bed and the ceiling

20. Modifying hospital beds with less features(mainly to incline the user)
21. Inflatable mattress
22. Inflate an airbag
23. Open a series of folded steps to bring him to the inclined position he desires
24. Robots that function as a lifting crank
25. Divide the mattress in two - basically two individually sewn and stuffed mattress parts. Place a mechanical/robotic lift (springs, crankshaft) inside the part of the mattress where the head and spine is placed and this can be operated to lift up the user to an incline.
26. Look up small-sized electrical hospital beds and consider modifying to fit dimensions of the room.
27. Use a spring operated electrical system underneath the mattress/ modify it to fit in the mattress.
28. Use a water bed , but one that is divided into two parts and then fill an increased amount of water into the first part of the bed and then that raises the user.
29. Part of mattress that moves up and down (little square to push his back)
30. Robotic arm that he holds
31. Rope at end of bed that attached to hand
32. Super strong core muscles prosthetic arms
33. Mattress rolls up the wall
34. Hospital bed without side safety
35. Expanding pillow
36. Inflatable pyjamas
37. Hoverboard repulsion technology
38. Magnetic velcro
39. Robotic exoskeleton
40. Metallic spinal cord attachments that allow movement to become inclined
41. Air force with straps
42. Air force with guide rails
43. Push with straps to keep to device
44. Push with guide rails if user falls
45. Pull with ropes attached to straps
46. Pull with ropes attached to harness
47. Pull with guide rails if user falls

Table F.1 Morphological chart

Apply force	Air	Pushing	Pulling
Keep user stable	Straps	Harness	Guide rails

Appendix G: Weighted Decision Matrix

Table G.1 Weighted decision matrix of objectives

Objective	**Weight**	**RHM**	**MaCS**	**PAL**
Safe	25%	80% (Allows immediate operation cancellation, but hinge makes injuries possible.)	60% (Allows immediate operation cancellation, but contains no guards against hazards, e.g snapping of rope.)	100% (Uses safety straps on either side of the lifting cushion that will prevent dislocation of the patient when the design is functioning. Design is also attached to the bed)
Compact	20%	100% (Has dimensions < 0.97 by 1.91 m)	90% (Reel has approximate dimensions of 30cm by 30cm, but pulleys take up space in the vertical direction)	100% (Has dimensions < 0.97 by 1.91 m)
Easy to use	15%	100% (<1 second) (~1 min)	80% (Initiates operation with single button press, motor is powerful enough to lift 90 degrees in one minute, but user must set up system before initializing)	80% (Initiates operation with a sensor touch on user's smartphone; compressor is battery powered and can hence, be charged when required; however, user must set up system before initializing)
Unintrusive	15%	100% (Noise is under 24 dB)	100% (Noise is under 24 dB)	100% (Noise is under 41 dB)
Inexpensive	10%	100% (Costs C$215) Due to subsidies available, no price is paid by the user.	100% (Costs $200) Due to subsidies available, no price is paid by the user.	100% (Costs C$988) Due to subsidies available, no price is paid by the user.
Durable	5%	40% (1 year warranty but	40% (1 year warranty,	50% (As 5 year warranty is

		expected to last longer)	but expected to last longer)	provided)
Easy to implement	5%	75% (50%, implementation time is < 6 months) (25% for internal modifications)	60% (10% for internal modifications) (50% is implementation time is < 6 months)	95% (50% for implementation within 6 months+ 45% for minimal changes)
Large lift range	5%	50% (Max lift is 45˚ instead of 90˚)	100% (Lifts from 0 to 90 degrees)	72.22% (limited lift range- supports inclination of 65^{o})
Total	**100%**	**88.25%**	**80.00%**	**92.86%**

Appendix H: Body Calculations and Dimensions of the User

Given his height, that is, 1.67 meters, the possible length of his legs would be from 0.838m to 0.970m[19], as the range of the the leg-to-upper body ratio is 1.0-1.4. The average ratio of center of mass(measured from legs) to height in males is approximately 0.560. From these ratios and calculations the center of mass of the user is between 0.94m and 1.07m from the legs. [35][36][37][43]

It has also been stated that the center of mass is usually found to be 10 cm below the navel.[.]. This information matches for the case$h_{\square\square\square}$=0.838 from the ground, giving the COM to be at 0.56 x 1.67 = 0.93 m, that is 0.1+0.83 as well. Thus, for the case$h_{\square\square\square}$=0.97, the COM becomes approximately (maximum) 1.07 m.

Client stated user is about 5’’6’. 1 head is then about 8.8 inches. The back and head is about 4 heads. So the back is about 3 heads, 26.4 inches.

Appendix I: Nylon Rope Specifications

Nylon rope is resistant to abrasion and withstands contaminants such as mildew or oils[22]

Appendix J: Motor Speed Calculations for RHM

Power of motor required = (Weight lifted * distance to lift) / (time to lift * efficiency)/By making the assumption that the force that the design applied on the user is at most equal and opposite to the combined weight of both the user and half of the mattress: A standard twin mattress weighs 20.41 kgs; half of this weighs 10.205 kgs. [18].

= (546N * 0.8247m) / (60 * 0.8)

= 9.381 W

(assuming that the motor is 80% efficient)

Appendix K: Cost analysis for RHM

Cost analysis:

Installation of pins is negligible price.
Plywood: upper limit of C$100[38]
Wheel: upper limit of C$50 [39]
Motor: upper limit of C$50 [40]
Pulley: upper limit C$10[41]
Rope: C$50 per 500 inches [42] * approximately 50 inches (length of rotating section + 10 inches) = C$5

Appendix L: Analysis of MaCS

Table F.1 Cost breakdown of system

Item	**Cost**
10W torque motor	C$42 [24]
Cable reel	C$28 [23]
Nylon rope	C$50 per 500 inches [22] * 400 inches = C$40
2 ceiling mounted pulleys	C$8.50 [44.]
Chest harness	C$55 [45]
Remote control and receiver	C$9 [46] + C$6.50 [47] = C$15.50
Miscellaneous supplies (nails, etc.)	C$10
Total	C$200

Power of motor required = (user's weight * distance to lift) / (time to lift * efficiency)
= (450N * 1m) / (60s * 0.8)
= 9.375 W
(assuming that the motor is 80% efficient)

Appendix M: MicroBot Pusher[27]

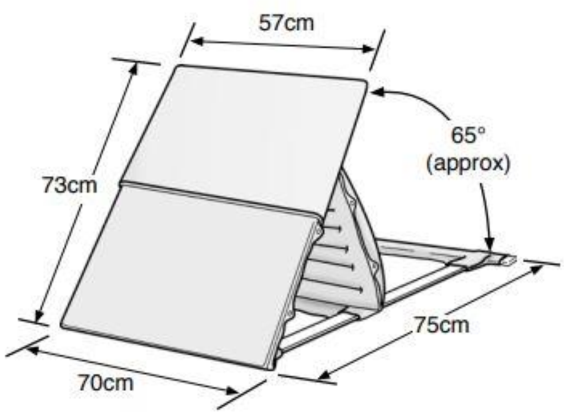
Pair
Install the MicroBot Push app and pair with the device

Attach
Use the included double-sided adhesive tape

Use
Press the button remotely or automatically

Process
This Microbot pusher will be paired to the smartphone using WiFi that is available in the house. This mocrobot will then be attached to the hand control of the PAL using an adhesive tape. Upon activating the microbot through a sensory touch on the smartphone screen, it will facilitate pressing of the button on the hand control. This initiates the compressor to begin pumping air into the inflatable cushion. The PAL is inflated and it rises to an inclined position, thereby, completing the process of moving the user from a reposed position to an inclined position

Appendix N: Detailed description of working of PAL[48]



Specifications

Rated Load:	150kg (24st)
(Use with heavier persons will not damage the product, but full lift may not be achieved)	
Weight:	4.8kg
Air hose length:	1.8m
Maximum inlet pressure:	0,35 bar (5psi)
Max. temperature:	50°C

Representation of PAL connected to compressor [26]

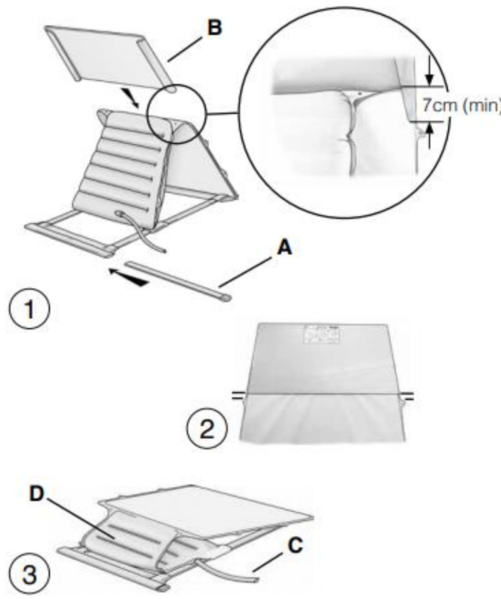
Additional Information on PAL
The inflatable cushion is portable and lightweight. It is easy to assemble because the hose is easily connectable and labels are easy to read[26]. Moreover, the AirFlo compressor is battery operated and is therefore, easy to use.

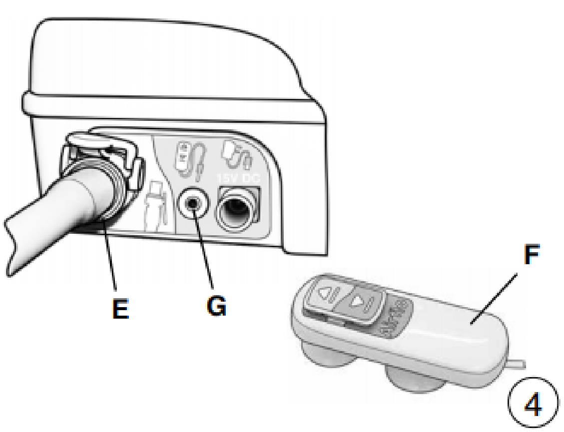
Setting up PAL
The process of setting up the PAL is the same as that of setting up **'Sit-u-up'** as mentioned earlier. However, leather straps will be attached to the PAL in order to increase safety of user.[48]

Fitting

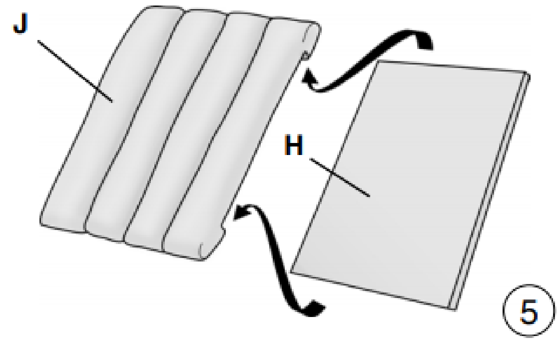
- Insert the spreader bar (**A** fig.1).
- Slide the headrest (**B** fig.1) as far down the backrest as it will go, ensuring that the bottom edge of the headrest is a minimum of 7cm down from the top of the backrest (detail fig. 1) and an equal distance from the tab on each side as indicated (Fig. 2).
- Place the Sit-u-Up on the bed with the spreader bar positioned against the headboard. Lead the air hose (**C** fig.3), to the side of the bed where the Airflo compressor is to be placed and fold the strut (**D** fig.3) towards the headboard.

FOR YOUR SAFETY: Ensure that the Airflo compressor, air hose and hand control lead are kept tidy.



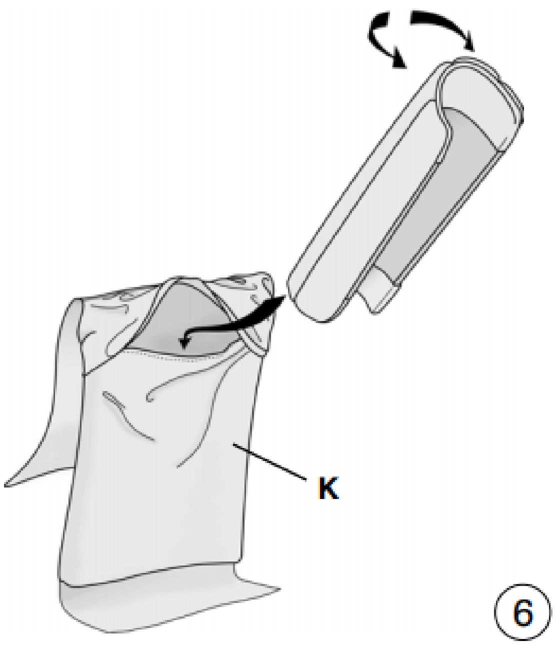


- Connect the air hose from the Handy Pillow Lift to the compressor air outlet socket (**E** fig. 4).
- Connect the Push Button Hand Control (**F**) to the socket (**G**).
- Place the Airflo by the side or under the bed, in an out of the way position.
- Inflate the Sit-u-Up by pressing 'up' ▲ on the hand control (see separate Airflo compressor instructions).



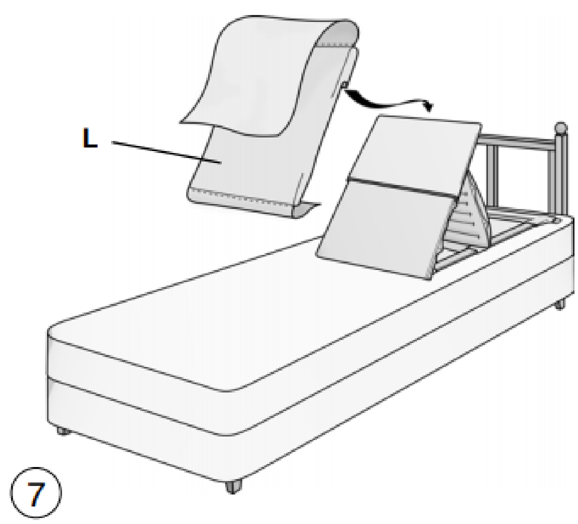
Assembling the overlay

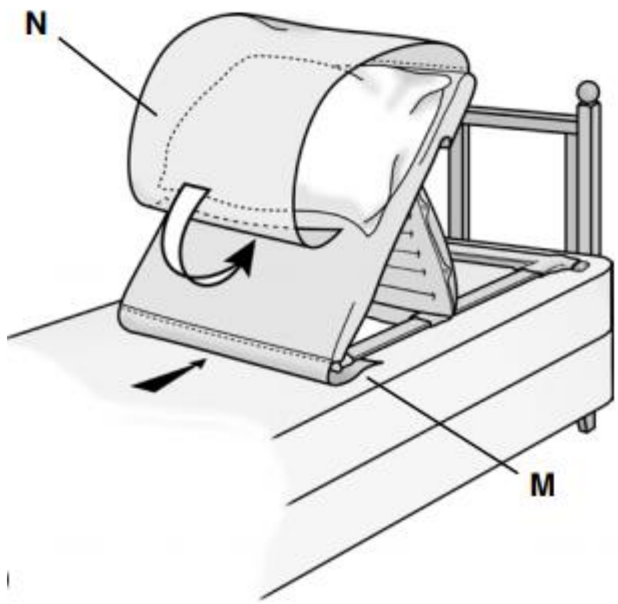
- Insert the foam (**H** Fig.5) into the quilt (**J**) as indicated.



- Fold the quilt and foam as indicated (Fig.6) and insert them into the cover (**K**).

- Fit the assembled overlay (**L** fig.7) to the Sit-u-Up by sliding it over the top of the headrest.
- Tuck the lower flap (**M** fig.8**)** underneath the Sit-u-Up.
- Position your pillow on the Sit-u-Up as indicated (fig.8) and wrap the flap (**N**) completely around the pillow to hold it in place.





Operating
To raise the PAL, the MicroBot presses 'up' on the hand control

Appendix O: Speed of PAL

The motor[30] has an input power of P=V*I=110*0.5=55. Assuming the efficiency is as low as 50%. We know that P(out)=*F**v, and F is m*g. The mass of the user is 45 kgs and the mass of the PillowLift is not more than 5 kgs[26]. Thus the velocity is ~0.056065m/s. Since the distance the to be covered is maximum 0.824668 meters, time taken is 14.7 seconds~ 15 seconds.

Appendix P: Cost of PAL

The cost of design 3 is calculated s stated below:

- Sit-u-Up PillowLift[26] - $479
- % Year Extended Warranty - $ 161.45
- Compressor = $ 200.00

- MicroBot Push 2nd Generation[27] = $ 49.99
- 25mL 5 Minute Plastic Epoxy Adhesive = $10.99
- Byhands webbing Backpack Strap with Genuine Leather = $36.15

Total = $ 987.57

Appendix Q: Durability of PAL

Sit-U-Up Pillow Lift warranty - 2 years (warranty is available for 5 years)
Battery Warranty - 1 year
MicroBot Pusher - Upto 1 year Battery Life