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GENERAL MOBILITY ASSISTANT

Roopak Karulkar

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by

ROOPAK KARULKAR

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ABSTRACT

GENERAL MOBILITY ASSISTANT

Roopak Karulkar, B.S. Mechanical Engineering

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Faculty Mentor: Raul Fernandez

Sitting and rising from a chair are two of the most demanding activities performed by an individual based on the muscle groups required to execute the necessary movements. As people age, their ability to sit and stand without assistance diminishes and they require external assistance. This may cause significant detriment to their lifestyle and quality of life. Currently available lifting solutions are bulky, expensive or require special operating conditions. The goal of this project was to design a portable and cost-efficient mobility assistant and give elderly individuals greater independence.

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CHAPTER 1

INTRODUCTION

The human body suffers loss of ability to perform simple motor functions with progressed age. It becomes difficult to perform necessary daily movements such as sitting and standing which require combined action of multiple muscles such as the hamstrings, quadriceps, lower back, and the core making it one of the most mechanically intensive movements [1]. A person's inability to complete this action results in a major detriment to his or her lifestyle and quality of life considering the frequency with which an average individual sits and stands in a day. This results in the person being dependent on others for simple needs. A large number of individuals do not have the choice to sit or stand on their own [2] and are therefore reliant on external assistance. The dependence may come as a shock to individuals who were previously used to an active lifestyle. This project seeks to give individuals greater independence in their advanced age by making it easier to rise out of and sit on a chair using powered assistance.

The development team, named Ascension Inc. consisting of Roopak Karulkar, Dillon Ausmus, Pate Barnes and German Bonilla aimed to create an assistive device for the elderly as a part of the Senior Design Project for the Bachelors of Science in Mechanical Engineering program. The motivation for Ascension Inc. to build a general mobility assistive device had its roots in the consideration of loved ones of the team. Members were each able to relate experiences shared by aging friends and family who, in their advanced age, experienced an overall decrease in independent locomotive capability. It was understood that these experiences are ubiquitous in a world where the average age of the population is increasing as people are able to live longer than ever. To that effect it was the desire of Ascension Inc. to improve lives by developing technology to prolong that period of freedom of individuals associated with independent mobility.

The population is currently aging as the percentage of elderly people is growing. According to the census data published in 2014, 16% of the total population of the United States will be above 65 by the year 2020 [3]. This amounts to 55 million individuals over the age of 65. With such a large number of senior citizens, there will be considerable demand for assistive devices such as the one designed for this project.

This design was developed from the ground up by the team. Development began with primary research in the form of interviews with persons facing decreased bipedal motion due to advanced age. The testimonies received in these interviews motivated Ascension Inc. to divide the needs of the market into three phases: standing and sitting, lateral movement, and semi-vertical movement including inclines and stairs. Of these, the act of standing and sitting is considered the most imperative since it preempts the other two actions. Because of this, Ascension Inc, focused on the development of a device to specifically aid in the completion of the sit-stand-sit task.

Existing assistive devices that aid sitting and standing do so adequately but they have their own drawbacks. They are bulky, heavy, expensive and static or they require certain operating conditions. The team's design is aimed to be portable, cost efficient, easy to use and safe. Current solutions confine the users to one spot in the house whereas the team's design will allow the user greater mobility.

CHAPTER 2

PRELIMINARY RESEARCH

The device the team built was technically termed a medical device; therefore, user safety and comfort were prioritized. Biomechanics and body kinematics research, to study the sitting and standing motion in humans, was conducted to ensure proper operation. The research was divided 3 ways; Ausmus researched motion capture data from game and film studios; Bonilla and Barnes conducted interviews with caregivers and elderly individuals; and Karulkar surveyed published papers. Two relevant papers were found in the *Journal of Biomechanics* titled "Analysis of the sit-stand-sit movement cycle in normal subjects" and "Sit-to-stand motor strategies investigated in able-bodied young and elderly subjects" that gave us all the necessary information about body dynamics.

In the paper "Analysis of the sit-stand-sit movement cycle in normal subjects", by researchers at the University of Nottingham, the sample set was for 25 males and 25 females between ages 20 and 78 years. Load cells were attached to the subject and the movement of the body was observed. The components of the sitting and standing movement were found to be forward lean, vertical displacement, knee angular displacement, recovery. There was much variation in movement speed based on age, which was expected, and sex. The fastest movement was seen in young males while the slowest movement was seen in elderly females. Therefore while designing for the slowest candidate, a design using the experimental data for elderly women was decided. Since elderly women are shown to have taken 2.5 seconds on an average (Figure 2.1), the suggested elevation and lowering time should be at least 5 seconds.

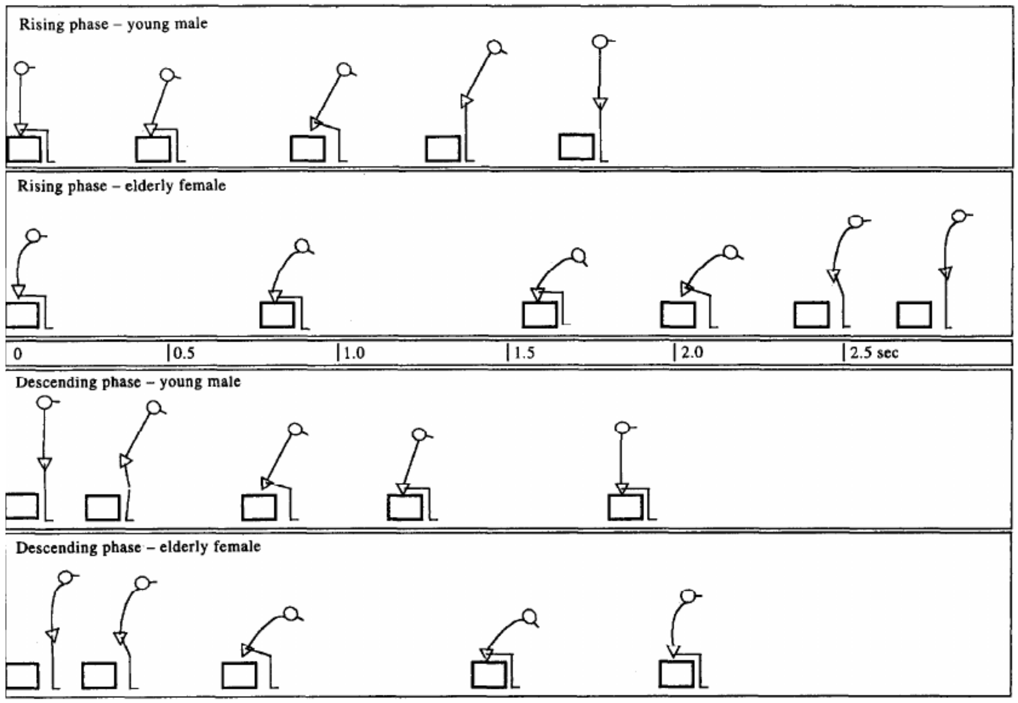

Figure 2.1: Sitting and Standing Components and the Time Taken. [4]

Variation in forward lean velocity of the center of mass was observed as well. The paper titled "Sit-to-stand motor strategies investigated in able-bodied young and elderly subjects" by researchers at the University of Sassari studied sitting and standing strategies in the elderly. It was observed by the researchers that elders would first lift themselves off the chair slightly, bring their center of mass over the support and then begin elevation.

Bonilla was responsible for conducting a patent survey. It was found that the team's design did not infringe on any patents. This device was classified as a medical device, therefore an FDA approval was deemed necessary. The device was found to be a Class II device out of a possible three classes. Class II devices require premarket notification to the FDA 90 days before the intent to market.

CHAPTER 3

DESIGN

3.1 Concepts

The team created a House of Quality, a design tool that helps determine customer requirements by assigning numerical values to the customer's wants and needs. It was decided that the device should be comfortable, quick to rise, pose no danger to the operator based on interviews with elderly individuals and the requirements highlighted by them. Therefore, the engineering requirements were fatigue life, high lifting capacity, and limiting the space taken up by the device.

Interviews with caregivers indicated that the best areas on the human body to lift were under the arms or by supporting the buttocks. Concepts were created as a team to use either or both of the lifting points for example, a scissor lift design was used to lift individuals by supporting them at the buttocks. Another design with articulating armrests was created to use the armpits as the supporting points. A design with an articulating seat powered by a linear actuator was finalized. The house of quality and the sketches of the initial designs have been included in Appendix C.

Due to significant variation in the weights of the elderly it wasn't possible to calculate an average lifting weight. Therefore, for testing purposes the chair prototype was designed to lift 250 lbs, the weight of the heaviest member of the team. A design safety factor of 1.2 was added, making the total weight to be lifted 300 lbs.

3.2 Chair Frame

The deliverable was a working prototype; therefore the following design considerations were made. The chair was designed for a life of ten years. The frame needed to be robust and easy to fabricate, so it was made out of 11-gauge 1-inch steel square tubing. The chair height was decided to be 19 inches based on the height at which the lower and upper leg of the shortest team member were perpendicular while sitting. Ease of fabrication was an important factor so the seat of an existing office chair was repurposed to fit the chair frame. The seat, actuated by a linear actuator, pivots about a hinge on the front crossbar of the frame.

Figure 3.1: Finalized Chair Design

3.3 Actuation and Control

The design of the chair was to be compact, so the actuator was placed to operate at a mechanical disadvantage (i.e., the load was placed behind the point of action of the force, effectively making the load larger). The seat used for the prototype was 14 inches deep. Modeling the chair as a Class 3 lever in which the effort is between the load and the fulcrum, the user's weight, the load of 300 lbs was estimated to act at 11 inches and the actuator was attached 5 inches from the fulcrum.

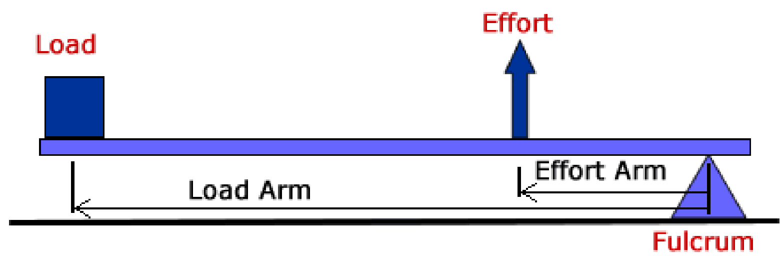

Figure 3.2: Class 3 Lever [6]

The governing equation is as follows.

$$\sum M_F = L_E \times F_E + L_L \times F_L$$

Where L_E is the effort arm, L_L is the load arm, F_E is the effort force and F_L is the load. Solving for the effort force after setting the moments about the fulcrum to zero, the hinge, the actuator was expected to lift 640 lbs. A linear actuator, PA-17, from Progressive Automation, was selected to lift the user. The actuator has a lifting capacity of 850 lbs at an extension rate of 0.66 in/sec with a stroke length of 6 inches. The preliminary research suggested that people were most stable standing up when their weight was over their feet. It was found that a seat angle of 45 degrees would be necessary to get the user's weight over their feet. Thus the 6-inch stroke was selected to achieve this angle.

The chair was designed to be operated with two buttons to go up and down, so an Arduino board was used by Karulkar to control the actuator and monitor button states. The actuator operates at 12VDC and draws 20A which the Arduino cannot supply. Therefore an external power supply and H-bridge motor driver were used in the design. The Arduino detects button presses and commands the H-bridge using Pulse Width Modulation (PWM) to extend or retract the linear actuator based on the user's preference. The Simple-H H-Bridge motor driver by Robot Power was used for the design. It provides a current monitoring feature to monitor system performance. The output of this port was processed using the following formula

$$I = 0.075/V_c$$

I is the current being drawn by the actuator, *Vc* is the voltage measured at the current sensing port, and 0.075 is the proportionality constant provided in the H-bridge documentation provided by the manufacturer. The code for the Arduino, written by Karulkar, is supplied in Appendix A.

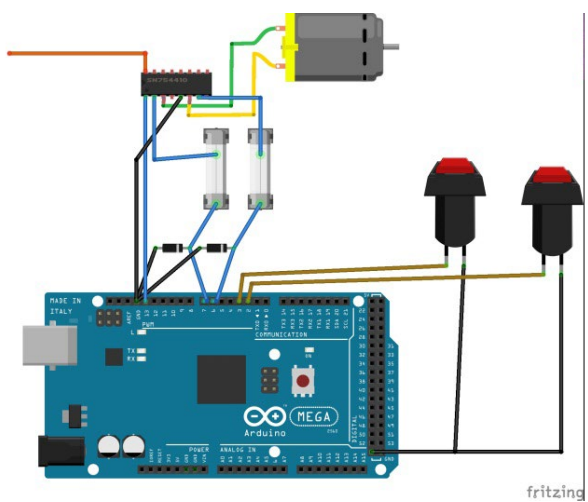

Figure 3.3: Arduino Circuit Layout

The H-Bridge does not have any protection circuitry so a simple protection circuit was designed using a Zener diode rated at 5.1V and a 100mA fuse. One end of this circuit was connected to the connections from the Arduino to the H-bridge and the other end was connected to the ground. The Zener diode acts like a resistor when the voltage across is below 5.1V and acts like a conductor when the breakdown voltage is reached. The Arduino operates at 5V at full duty cycle so the breakdown voltage should not be reached under normal operating conditions. The Zener diode shorts to ground through the fuse upon breakdown. This causes the fuse to blow and breaks the circuit effectively protecting the low voltage circuitry on the Arduino.

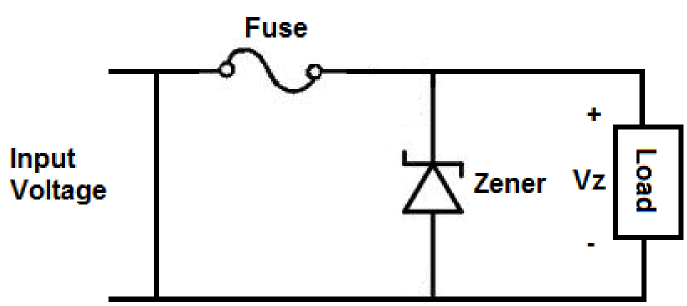

Figure 3.4: Overvoltage Protection Circuit [7]

The total cost of the prototype is $700 in material cost which can be brought down during mass production. This way we can market the device for $1200 - $1500, thereby making it a very cost-effective device.

CHAPTER 4

ANALYSIS

4.1 Structural Analysis

It is important to check whether the design performs according to the requirements before moving on to fabrication. Therefore, structural analysis is necessary to analyze the design using software tools. A model of the chair was made using SolidWorks and analyzed by Karulkar using ANSYS into two configurations: one where the actuator was fully extended and one where the actuator was fully retracted. The model was analyzed for both Static and Fatigue loading. The frame is designed to have a life of ten years. The user is assumed to sit and stand ten times a day, thereby reaching 36500 cycles in ten years.

4.1.1 Analysis with Actuator Fully Extended

The loading configuration of the chair with 300 lbs is shown in Figure 4.1. The user's weight is shown to be acting straight down in the scenario that there is no other support for the user. The chair was imported as a parasolid assembly into ANSYS for this analysis. The frame is made of structural steel and the mounting brackets are made of aluminum.

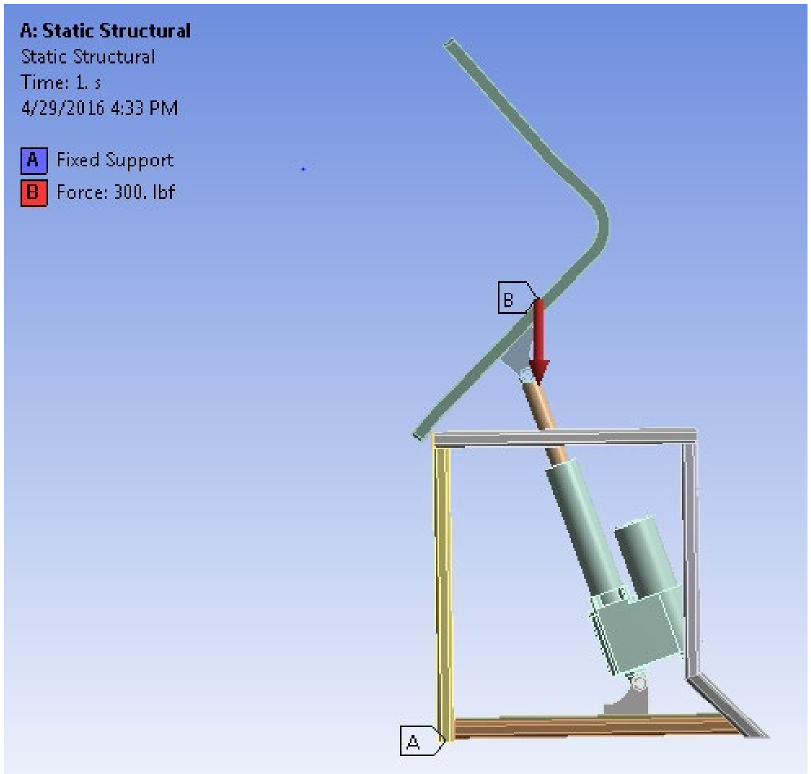

Figure 4.1: Loading Condition – Extended Configuration

The chair was analyzed for Equivalent Stress (Von Mises). The maximum stress seen was 26000 psi at the hinge. This was within the safety margin as shown in Figure 4.2. This configuration was also tested for deformation which was 0.0094 inches at the bottom of the back rest. All additional analysis images are included in Appendix B.

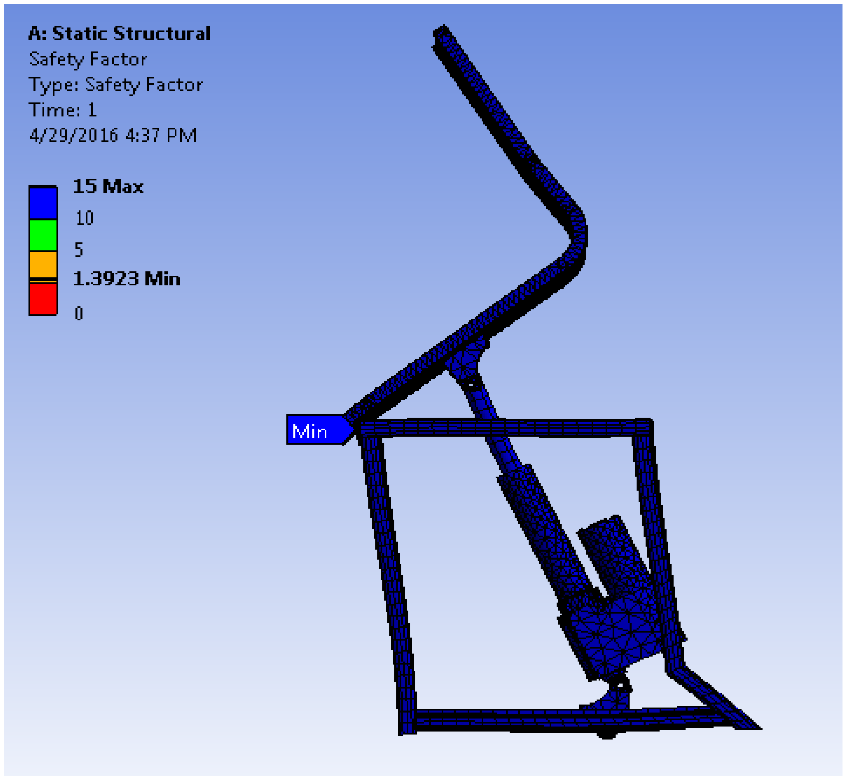

Figure 4.2: Safety Factor for Static Loading – Extended Configuration

Fatigue load analysis showed the model to be capable of lasting up to 38000 cycles with the weakest component being the hinge.

4.1.2 Analysis with Actuator Fully Retracted

The loading configuration of the chair with 300 lbs is shown in Figure 4.3. The user's weight is shown to be acting straight down assuming the user is supported solely by the chair. The chair was imported as a parasolid assembly into ANSYS for this analysis. The frame is made of structural steel and the mounting brackets are made of aluminum.

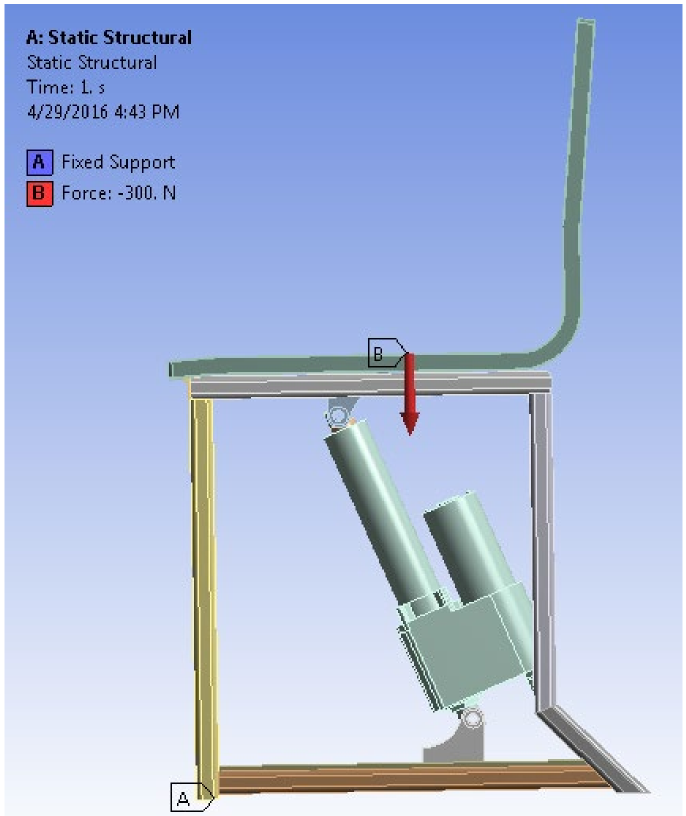

Figure 4.3: Loading Condition – Retracted Configuration

The chair was analyzed for Equivalent Stress (Von Mises). The maximum stress seen was 3660 psi at the upper mounting bracket for the actuator. This was within the safety margin as shown in Figure 4.4.

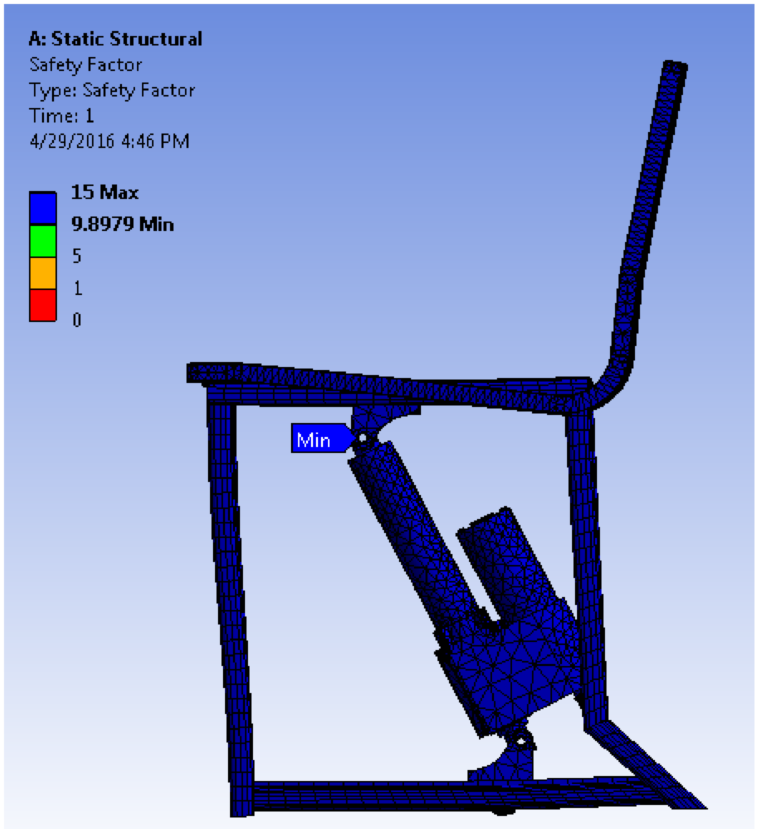

Figure 4.4: Safety Factor for Static Loading – Retracted Configuration

4.2 Kinematic Analysis

Kinematic Analysis was also performed on the model to make sure it was rising at an appropriate rate. The chair was modeled by Karulkar in AutoDesk ForceEffect Motion as shown in Figure 4.5 and the appropriate actuator characteristics were included. In Figure 4.6, this analysis showed that the actuator extended completely to the desired final position in 8.5 seconds with fits within the acceptable range of time to ensure fast enough movement.

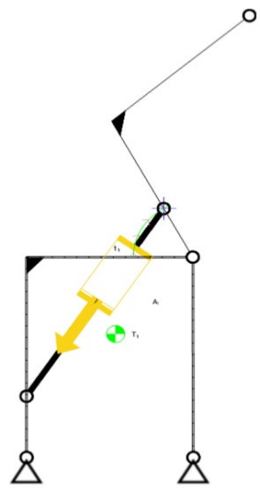

Figure 4.5: Kinematic Model

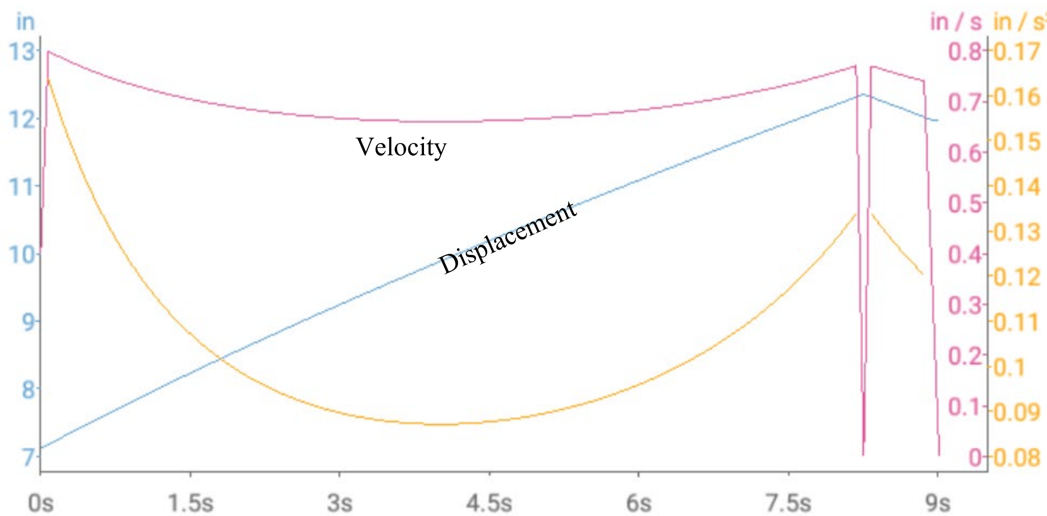

Figure 4.6: Displacement and Velocity

CHAPTER 5

CONCLUSION

Ascension Inc. has achieved the goal of creating a safe, portable and cost-efficient assistive device. The analysis shows that the device will have a long operating life with daily use. This meets all the goals set by Ascension Inc. for the project. Future work on this project may involve making the device mobile so the user does not face any physical exertion while moving it around the house, optimizing actuator configurations, or upgrading the control system.

APPENDIX A

ARDUINO CODE

```
const int upPin = 3; // Button to raise
const int downPin = 4; //Button to collapse
const int motor1Pin = 5;    // H-bridge leg 1
const int motor2Pin = 6;    // H-bridge leg 2
const int enablePin = 7; //Enable H-bridge
const int ledPin = 8;
const int currPin = A0; //Measure current sensor voltage
float Vc = 0;
float currVal = 0;

void setup()
{
 // Pin setup
 pinMode(upPin, INPUT_PULLUP);
 pinMode(downPin, INPUT_PULLUP);

 pinMode(motor1Pin, OUTPUT);
 pinMode(motor2Pin, OUTPUT);
 pinMode(enablePin, OUTPUT);
 pinMode(ledPin, OUTPUT);

 digitalWrite(enablePin, HIGH);
}

void loop()
{
 // Main code
	if(digitalRead(upPin) == HIGH && digitalRead(downPin) == LOW)
	{
		digitalWrite(motor1Pin, HIGH);
		digitalWrite(motor2Pin, LOW);
	}
	else if(digitalRead(upPin) == LOW && digitalRead(downPin) == HIGH)
	{
		digitalWrite(motor1Pin, LOW);
		digitalWrite(motor2Pin, HIGH);
	}
	else
	{
		digitalWrite(motor1Pin, LOW);
		digitalWrite(motor2Pin, LOW);
	}

	Vc = analogRead(currPin);
	currVal = Vc/0.075;
```

```
if (currVal > 25.0) //Lights warning LED if the current draw is too high
	{
		digitalWrite(ledPin, HIGH);
		delay(100);
	}
	else
	{
		digitalWrite(ledPin, LOW);
		delay(100);
	}
}
```

APPENDIX B

ADDITIONAL STRESS ANALYSIS RESULTS

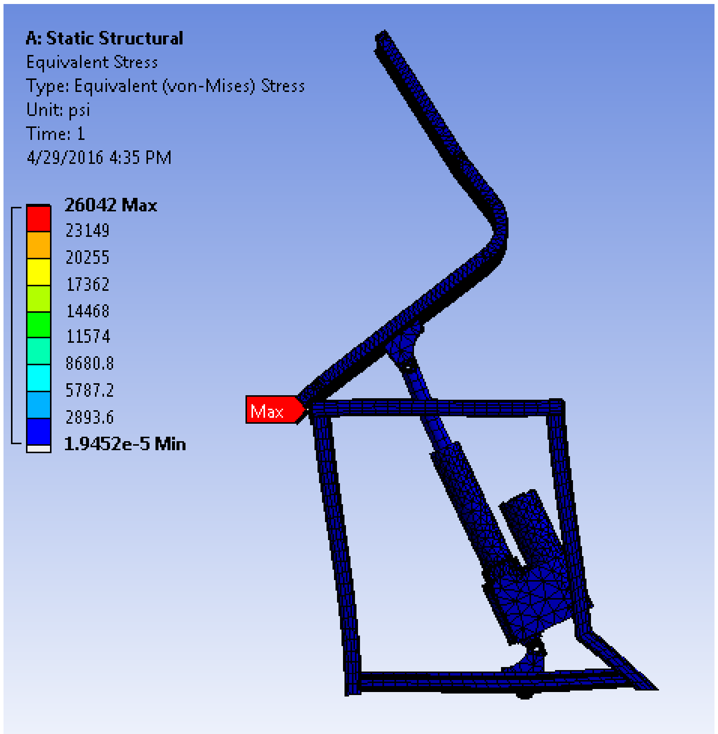

Figure B.1: Stress – Extended Configuration

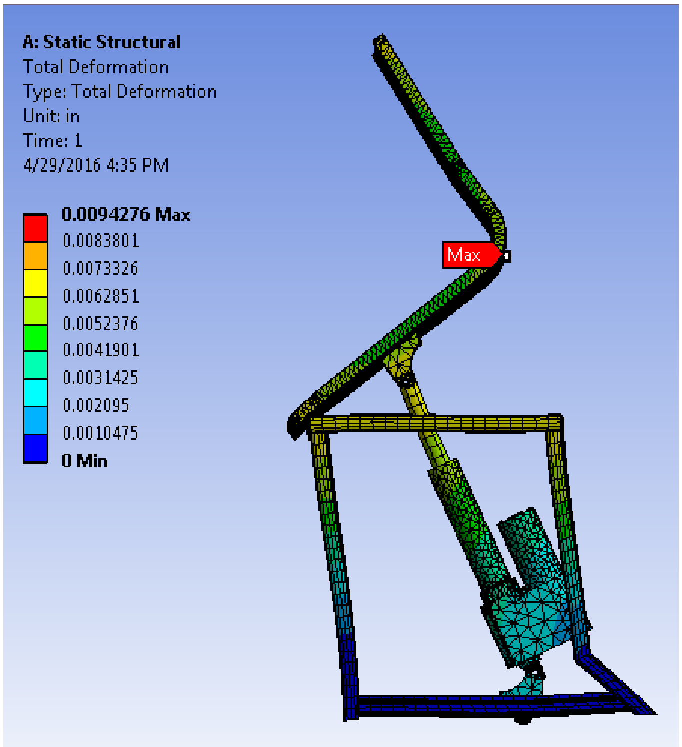

Figure B.2: Deformation – Extended Configuration

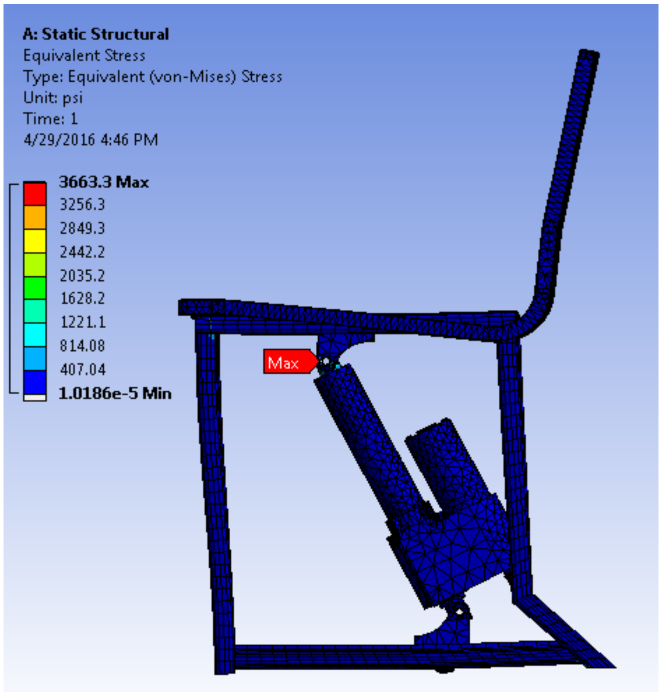

Figure B.3: Stress– Retracted Configuration

APPENDIX C

INITIAL DESIGNS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	Improvement Direction		↓	↑	↔	↑	↓	↑	↓	↓	↑	↓	↓	↔	↔	↑	↑	↓	↓	↓		
2	Units		lb	lb HP	sec	lb/(in*N)	$	lb/in	°F	Btu/(ft^2*h) W/m^2	%	ft^3	decibel	inch	lb/in	in/lb	HP/ft^3	time constant/ settling time	N	sec	inch/inch	bits
3		Importance Weight Factor	weight	lift weight/power?	time to complete cycle	fatigue life	cost	stiffness of hardware	temperature	heat flux	completion probability	size	loudness	loose/close/intermediate fit	stretchability of support	softness of support	efficient	responsive control	number of parts	time to install	forgiving/sensitivity	resolution
4	safe	5	3	3	3	9			3	3	9			3	3			3				
5	easy to use	5									3							9		3		
6	easy to set up	3	9									9							9	9		
7	cheap	4		3		1	9															
8	comfortable	5		1	1		3	3	9	9				3	9	9						
9	reliable	5		3	1	3					9						3	3	1			
10	long life	4				9					3					3			1			
11	quiet	2	3	3	3		1	1					9	1			1					
12	compatible (works w/chair/cane)	4	1									3										
13	quick	3	1	9	9						3							3				
14	non-obtrusive	4	3	1					3	3		9	3	3	9					1		
15	*RAW SCORE(1134)*		67	84	58	100	53	17	72	72	126	75	30	44	96	57	17	84	36	46		
16	RELATIVE WEIGHT %		5.9	7.4	5.1	8.8	4.7	1.5	6.3	6.3	11.1	6.6	2.6	3.9	8.5	5	1.5	7.4	3.2	4.1		
17	RANK ORDER		7	4	8	2	10	15	6	6	1	5	14	11	3	9	15	4	13	11		

Figure C.1: House of Quality

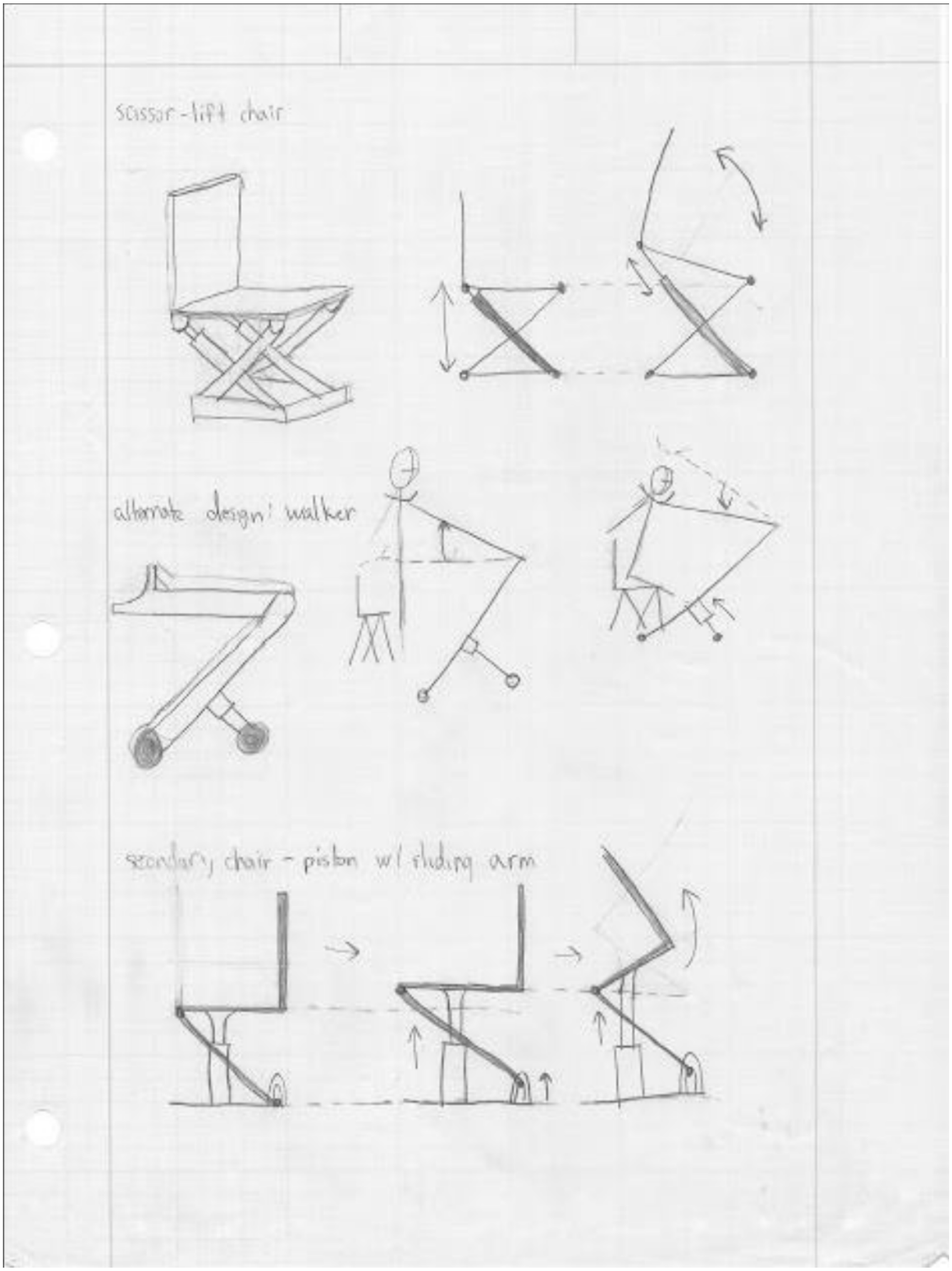

Figure C.2: Design Concept 1

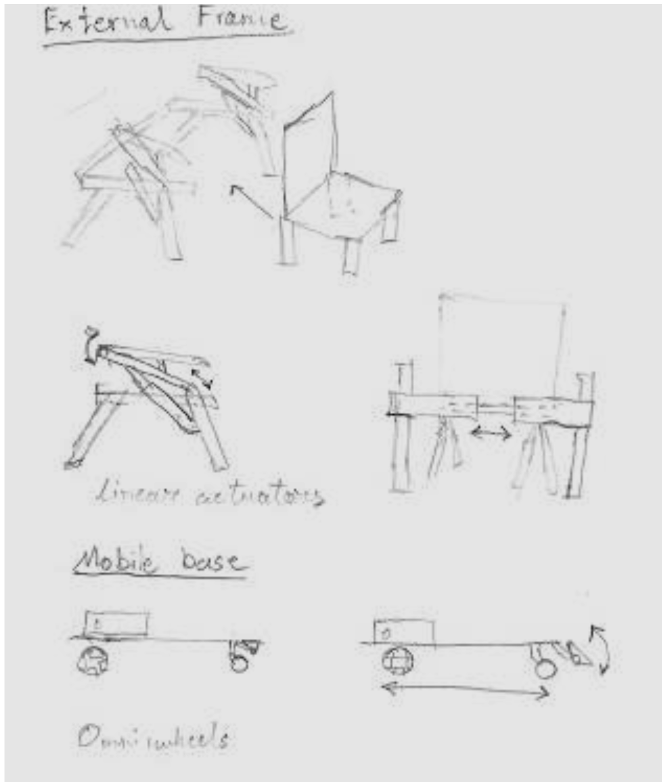

Figure C.3: Design Concept 2

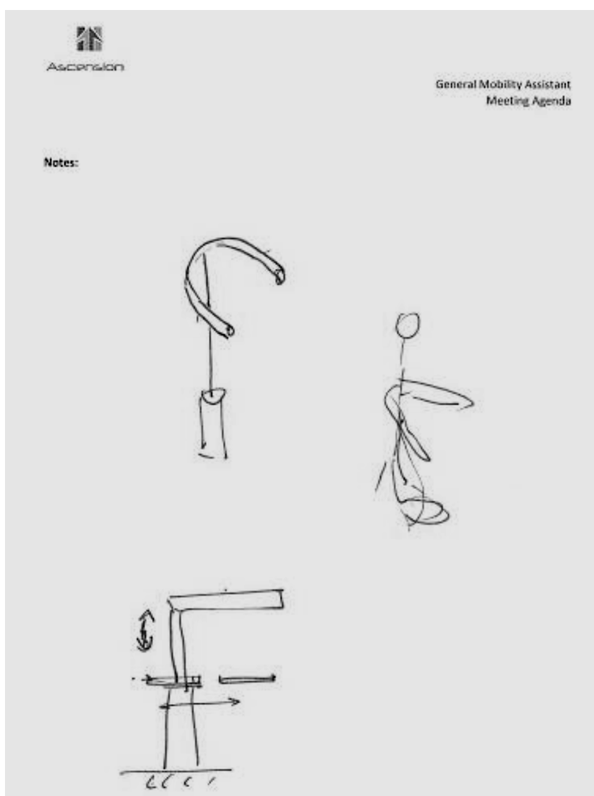

Figure C.4: Design Concept 3

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BIOGRAPHICAL INFORMATION

Roopak Karulkar will graduate in May 2016 with an Honors Bachelor of Science in Mechanical Engineering from the University of Texas at Arlington. After graduation, he plans to conduct research in graduate school. His research interests are automation and control.

Karulkar received an Undergraduate Research Fellowship from the Honors College during Summer 2015. He is also the recipient of several prestigious scholarships including the Igor Fraiberg Scholarship, the Stephen T. Kugle Scholarship, and the President’s Charter Scholarship.

He served as the president of the UTA chapter of the American Society of Mechanical Engineers in 2015 and is a member of the Tau Beta Pi Engineering Honors Society.