Final Report Regarding a Standing Aid for the Elderly and Disabled

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Executive Summary

Purpose: The purpose of this report is to present WII Solution's development of the Crutch Converted to Angled Seat, a standing aid for the elderly and disabled.

Conclusions: After conducting the design realization process, WII Solutions was able to develop a full CAD prototype as well as a much higher fidelity prototype that fully encompasses the team's engineering requirements and has the potential to compete with existing benchmark products. The performance analysis conducted on the prototype further proves this.

Process: For this report, the full development of the project that led to the final prototype is explained. The problem definition as well as the engineering requirements are first discussed. A functional decomposition was used for the concept generation and selection of the team's design. Following that, CAD designs and drawing were created to eventually develop a full physically assembly of the team's prototype, which was analyzed for both its performance and how it compared to what's currently on the market.

Discussion: The research from WII Solution's first phase motivated the creation of the team's engineering requirements for the Crutch Converted to Angled Seat. The main ones include a collapsing time of 5 seconds, $100 to purchase, a total of three leg supports, a total weight of 1.82 kg, and the ability to sustain a maximum load of 158.76 kg.

After the creation of the low-fidelity prototype during the concept generation and selection phase, the team created an improved CAD assembly that was used in developing a higher-fidelity prototype. The assembly is as follows: The device is an aluminum crutch with a curved netted seat in the center of its body. It functions as a traditional crutch as well as an angled seat. Its extended position consists of the crutch rotated 30 degrees from the horizontal supported by two support legs, which lock using a cross member and locking mechanism. The rubber tips at the end of the legs are able to bend while still having the bottom face completely touching the ground. The CAD assembly can be seen in Figure 1 and the full physical prototype can be seen in its extended state (Figure 2) and collapsed state (Figure 3).

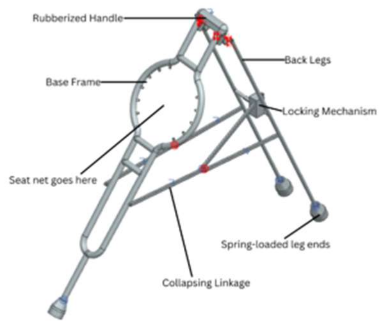


Figure 1: Full CAD Crutch Assembly

Figure 2: Physical Crutch Prototype (Extended)

Figure 3: Physical Crutch Prototype (Collapsed)

The higher fidelity prototype was evaluated with the team's most important engineering requirements. The prototype passed all these requirements with details explained in Table 1. The Bill of Materials for full scale production (60,000 annual units) yielded a total per unit cost of $26.99, which led to financial projections of 113.24% ROI and 311.15% ROR, breaking even in over 5 quarters. In terms of next steps, the team will reevaluate the dimensions and tolerances of the design based on the tolerance stack ups calculated in order to better fit the need of the product as a whole.

Requirement	Meets? (Y/N)	Details
Adjustable	Y	Seating angle adjustable. Open and closed positions with increments of angle between.
Device has 3 legs	Y	Two fixed length and one telescoping leg.
Longest width of 40.64 cm	Y	Largest width of 16 in = 40.64 cm for the seat width
Material compressive strength of 6,000 psi	Y	Aluminum tubing Ultimate compressive strength of 18,000 psi meets the requirement with safety factor of 3.

Table 1: Engineering Requirement Analysis

Table of Contents

1 – Introduction

This report's purpose is to discuss WII Solutions' project to design a solution to the prevalent issue of lower extremity injuries and disabilities, making it difficult for people to stand for long periods of time. A recent article states that 15% of emergency room visits are lower-leg injuries which eventually require the use of crutches (short term and long term). This means that 1.9% of the population has difficulty standing. Apart from this, a Timex survey shows that Americans wait about 37 billion hours each year in lines somewhere during their day. During these moments of standing in line, injured/disabled people struggle to stand without assistive devices due to their musculoskeletal issues. In fact, in the United States around 6.5 million people use crutches, canes and other assistive devices. However, the issue with crutches and canes is that while they are loading bearing, standing for long periods of time can be difficult due to minimal load bearing efficiency when stationary. Our team, WII solutions, aims to design a mechanical device that allows people with lower extremity injuries to stand for long periods of time with ease.

This report will begin with a review of the team's problem definition development, a discussion of consumer research, requirements for the project, and benchmark and patent research. These requirements will be included in the Problem Definition section that follows. The report will continue with a list of our qualitative and quantitative requirements in our problem definition. After that, the report will transition to the concept and generation and selection where we explain our functional decomposition, concept generation using a morphological chart and selection of our final concepts. Subsequently, we will describe our primary concept and compare them to our benchmarks. Next, we will introduce our bill of materials followed by a financial analysis for the development of our product. The report will then focus on our concept drawings, assembly analysis and tolerance discussion. Finally, we will end with benchmarks and performance analysis.

2 – Problem Definition Development:

The results of the Problem Definition phase for WII Solutions look hopeful. Consumer, market, benchmark, and patent research suggest a need for a standing aid product, an increasing market for it, and possible solutions to be improved upon. Consumer research found that most consumers (57%) desire a product that is shoulder width. This data was acquired by the team creating a survey targeting those with lower extremity injuries/disabilities. This, in combination with data from the National Library of Medicine, found that the product should be around 185.45mm—the average shoulder width for men. Market research found evidence for a continued market need by analyzing the trend of increasing elderly populations, as well as inspecting the percentage of hospital patients released with crutches. Both the population of elderly and the percentage of elderly in the population is expected to rise in both the US and worldwide. Not only this, the WHO predicted that "the proportion of the world's population over 60 years will nearly double from 12% to 22%." Thus, this increase in potential consumers suggests continued market need.

Benchmark research found approximate values to ascribe to qualitative requirements for later use in the HoQ. Four products addressing the problem statement were found online and their data was put into a easy-to-read chart. Patent research followed a similar line by providing ideas for potential prototypes. Again, four patents were chosen and their key data analyzed. The key ideas from this data stipulate: the optimal design has four legs, is collapsible, and has a collapsible seat rest.

The House of Quality following research found that areas of most interest were ability to support large weight, stability, low product weight, and a low cost. As WII Solutions continues with the Concept Generation and Selection phase, these requirements will prove invaluable. Finally, the problem statement was redefined with requirements in mind: "Many people with disabilities or injuries face trouble standing for longer than 30 minutes and require assistance, e.g. when in lines, on public transport, or during daily tasks." Finally, the results of this research led to the creation of the qualitative and quantitative requirements accompanying the above problem statement.

3 – Problem Definition

The results of the Problem Definition phase of the project yielded twenty engineering requirements (see below). This can subsequently be used to develop an innovative solution to the issue of the disabled and elderly having to stand for extended periods. With this data in mind, WII Solutions expects to make a 4-legged collapsible cane chair of some kind. Priorities lie on stability, strength, and weight. Thus, a design incorporating more legs, and a sturdy design will likely be chosen. Listed below are the qualitative and quantitative requirements developed by WII Solutions.

Qualitative Requirements:

1. Adjustable
2. Comfortable

Quantitative Requirements:

1. Longest Width of 40.64cm
2. Cost in USD of $250 to purchase
3. Collapsed width of 12.7cm
4. Collapsing time of 5 seconds
5. Foam comfort thickness of 2.54cm
6. Grip materials coefficient of friction is 0.7
7. Structural material's Compressive strength is 6,000 psi
8. Range of seat heights is 2.54cm (Highest-Lowest)
9. Device has 3 legs
10. Supports maximum load of 158.76 kg
11. Total weight of 1.82 kg
12. Grip material roughness of 15.24 micrometers
13. Leg bottom coefficient of friction of 0.7

14. 1 Collapse fold
15. Base area of 2129.03 square centimeters
16. 1 second moving to stationary time

It is also important to note that with the production cost at $26.98, an annual production of 60,000 units is expected.

4 – Concept Generation and Selection

To generate initial concepts for our design we began with a function tree to identify and analyze all the subfunctions we wanted our solution to perform (Figure 4). After identifying our functions and subfunctions, a morphological chart was used to brainstorm potential designs to address each subfunction. Using this chart, four initial sketches were created. Each sketch was made by selecting the best or most appropriate solution for each function. This way, each sketch was a combination of one solution from each row and the best potential solutions could be compared directly.

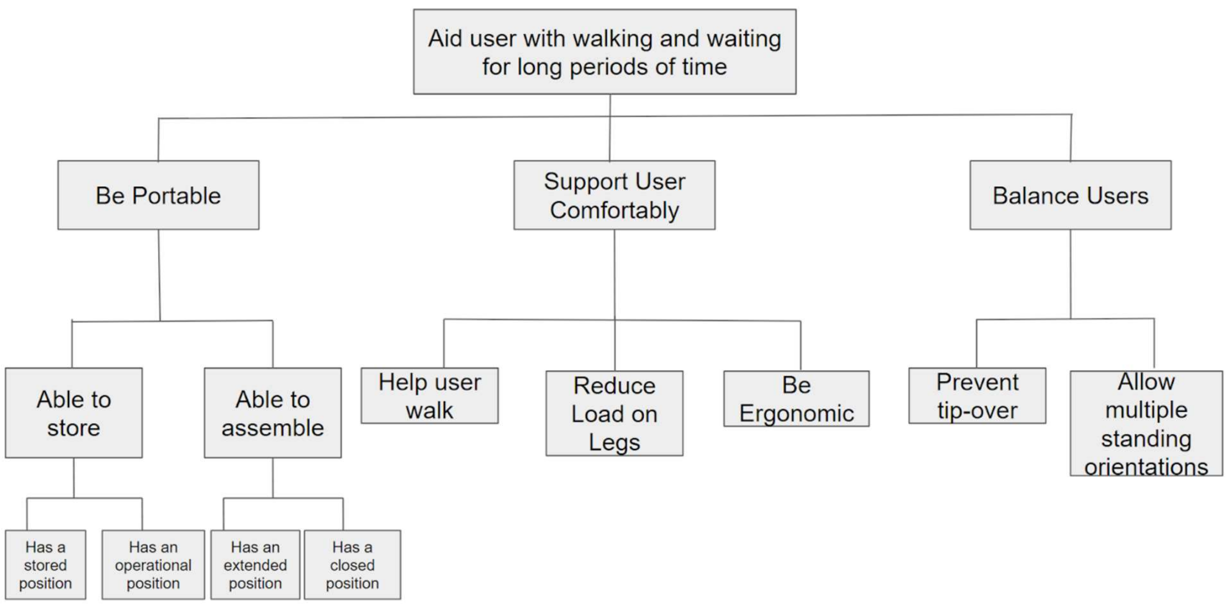


Figure 4: Functional Decomposition

Following this, WII Solution began a comparison of the four potential best designs through a Decision matrix (see Figure 5). This was accomplished by looking at how the Sling Seated Crutch (a current market product and the datum) meets the stated customer requirements, each of the four concepts were judged against the benchmark. Weights for customer requirements were assigned based on their importance to customers.

To determine the advantages of the "Crutch converted to Angled Seat" WII Solutions compared it against the datum. The advantages it holds over the datum, "Sling Seated Crutch," is as follows:

1. The device has a lower collapsing time due to less time needed to get up
2. The device is able to support greater weight due to more supports and a stronger base
3. The device is more durable than the sling seated crutch due to less force applied on the mesh, and spring-loaded base
4. The device is more stable due to sling seated crutch and more supports than the Sling Seated Crutch
5. The device is also more adjustable than the datum due to the use of telescoping tubes
6. The device reduces the load on legs when getting up as the user will not be completely sitting down like in the datum

These clear advantages over the datum caused WII Solutions to select the design. The Sling Seated Cane design follows a lot of the advantages of the already existing Sling Seated Crutch design but improves upon them in many areas. Thus, it has been proved to yield a higher weighted score against other potential designs.

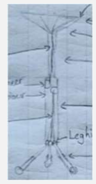
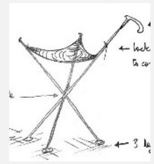
		Concepts				
Customer Requirements	Weights (1-10)	Crutch Converted to Angled Seat 	Tensioner extending cane seat 	Sling Seated Cane 	Curved End Crutch with back support 	DATUM (sling seated crutch) 
Device handle at waist height	7	0	0	0	0	0
Device is shoulder width or smaller	6	0	0	0	0	0
Low Cost	5	0	0	1	-1	0
Low setup time	2	0	0	0	1	0
Low closing/collapsing time	4	1	0	0	1	0
Lightweight	8	0	0	0	-1	0
Portable	6	0	1	1	-1	0
Able to support large weight	5	1	0	0	1	0
Durable	5	1	-1	0	1	0
Low load on legs when getting up	10	1	0	0	1	0
Stable (prevent tip over)	9	1	0	0	1	0
Adjustable	3	1	0	0	0	0
Comfortable when standing	5	0	0	0	0	0
Comfortable when waiting	5	0	0	0	0	0
Easy to store	7	0	0	0	-1	0
	Total +	6	3	6	5	0
	Total -	0	-1	0	-4	0
	Overall Total	6	2	6	1	0
	Weighted Total	38	3	13	10	0

Figure 5: Decision Matrix

5 – Operational Description

The team's device is a crutch with a curved center containing a net seat in the center of its body consisting of aluminum rods (see Figure 6). The user uses it as a traditional crutch when walking, however when having to conduct a standing task or wait in line for prolonged periods of time the user can switch to its extended position. Its extended position consists of the crutch rotated 30 degrees anticlockwise (if the users facing toward the right) supported by two stands that rotate through the mechanism of a button system. These stands then lock using a cross member and locking mechanism. The rubber tips at the end of the legs are able to bend while still having the bottom face completely touching the ground. The user can sit in an angled manner on the net on the crutch to reduce the strain on their legs. The user can switch from the crutches operational (walking) position to its extended position by bringing the crutch under their arm and opening the stand with their arms. The user then shifts the crutch from under their arm and sets it behind them. The user will have to balance on their uninjured leg for a second during this switch. After using the crutch in its extended position, to switch back the user will stand up using their uninjured leg, and then pull the crutch to their side while removing the lock for the stands with a sliding switch mechanism. They will then close the stands in the same manner they opened it. After this, the user is ready to use the crutch for walking again.

WII Solutions created a 3D CAD model for reference (see Figure 6). Figure 6 displays the crutch in its closed, locked position. Refer to Figure 6 to see the crutch in its open, locked position. In this position, it is ready for the user to sit on it. Additionally, refer to Figure 6 to see how the rear telescoping legs provide adjustability to the height.

The product body is made up of aluminum rods welded together at key points. The shoulder brace and hand grip are constructed out of rubber, and the mesh is a polyester material. The cross-member lock (one to hold the crutch in the sitting position) and the telescoping legs locks are made out of steel.

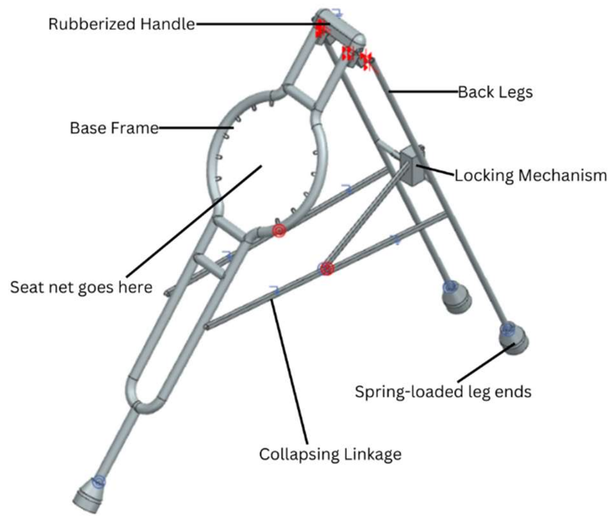


Figure 6: Crutch Converted to Angled Seat

6 – Bill of Materials (BOM) / Materials Selection / Materials Fabrication

WII Solutions created a BOM to estimate the unit cost at full scale production (Table 3). This was created after finalising a conceptual design and identifying the primary features which would be incorporated. The required parts were then listed and sources for each part were identified, and their prices listed. Any other processes were added, such as machining or assembly costs.

The costliest parts are the seat nets, U pipes and crutch cushion tops. This is because these are unique parts that are not as widely manufactured and distributed as, for example, the external threaded rod. Although the production scale has significantly reduced the unit cost for these items, a larger yearly production quantity would motivate lower per unit cost due to the increased effect of economies of scale.

Item No.	Part No.	Part Name	Units	Qty	Material/ Description	Source	Catalog No.	Unit Cost ($)	Unit Processing Cost ($)	Assembly Cost ($)	Line Total Cost ($)
2	M1	Body Aluminum Rods	ft	12	1.25" body rods	Online Metals	7003	0.5	-	-	6
3	M2	Leg aluminum rods	ft	3	1.25" leg rods	Online Metals	7003	0.833333	-	-	2.500
13	M3	Thread support ends	threads	2	Thread support legs to accept rod ends	-	-	-	0.5	-	1
14	M4	Seat net tying points	clips	4	Machine and weld on clips	-	-	-	0.5		2
4	A1	Body Rod assembly	-	2	Bending body rods to fit seat shape	-	-	-	-	1	2
5	A2	Pipe, leg, and body assembly	-	1	Welding of legs and body to U- connecter	-	-	-	-	1.2	1.2
1	P1	U - shaped pipe	pcs	2	1.25" connecting rod	Architectural Iron Designs	293-6	1	-	-	2
6	P2	Spring Loaded Crutch Tip	pcs	3	The bottom rubber tip of the crutch with a spring in the middle for better stability	Fetterman Crutches	942GT	0.5	-	-	1.5
7	P3	Crutch Cushion Top	pcs	1	Underarm Crutch Pad Cushion Top	Amazon	B0CLR24LRJ	0.96	-	-	0.96
8	P4	Crutch Hand Grip	pcs	1	Soft Rubber Crutches Handle Grip	Amazon	B09872TVZL	0.2475	-	-	0.2475
9	P5	Folding leg bracket	pcs	2	Zinc Plated steel set of 2	McMaster-Carr	1571A12	0.930625	-	-	1.8613
10	P6	Seat net	pcs	1	6.5'x9.8' Polyseter net to be cut to size	Amazon	B09P8KWHZ8	2.661875	2	-	4.662
11	P7	External threaded rod	pcs	2	Zinc-Plated Carbon Steel 1/2" outer thread	McMaster-Carr	4749T14	0.52	-	-	1.04
12	P8	Leg bracket screws	pcs	4	Stainless 82 Deg countersink 1/2" thread	McMaster-Carr	91771A128	0.003725			0.0149
									Total Purchased Parts $		12.286
*A = Assembly *P = Purchased *M = Manufactured									Total Custom Manufactured Parts $		11.500
									Total Assembly Cost $		3.2
									Total Cost $		26.986
									Yearly Production cost $		1619132

Table 3 - Bill of Materials for Full Scale Production Unit Cost

7 – Drawings

After designing and producing each of our manufactured parts in the CAD software NX, the team was able to create a full assembly of our Crutch Converted to an Angled Seat. Following the full assembly, we were able to develop a drawing that can be used to manufacture the part. The drawing can be seen in Figure 7. We'd like to add a note that drawings for each of the parts listed in the table of Figure 7 can be found in the Appendix (Section 12).

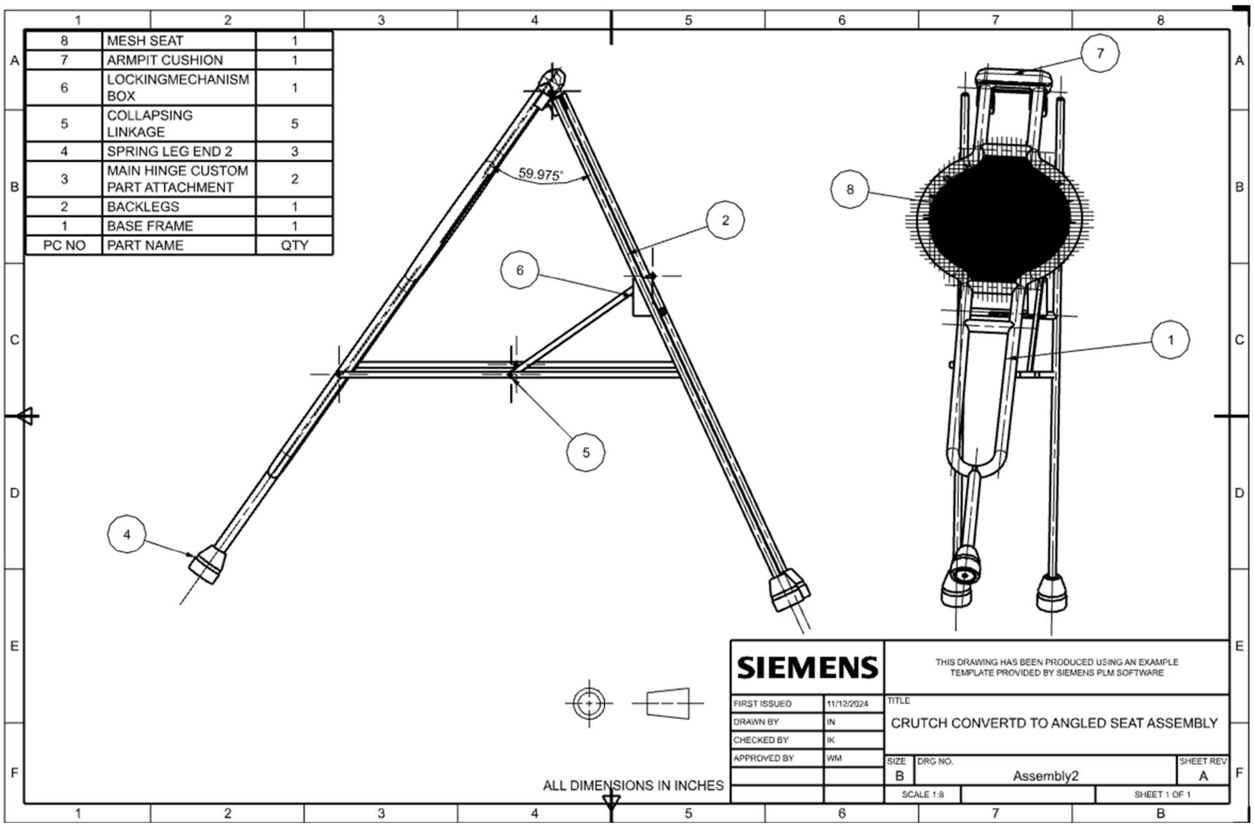


Figure 7: Assembled Drawing

8 – Assembly and Tolerance Discussion

1.Base frame is the start of the assembly on which everything is assembled.

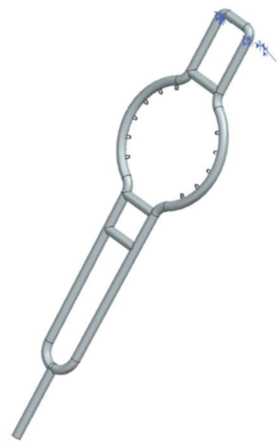


Figure 8: Assembly 1

2.The mesh seat, main hinge custom part attachment, are attached. The worst-case scenario is that the custom part attachment will not fit the tube by 0.006 inches. 49.87% of the custom part attachment will fit given by the normal distribution of radii.

Figure 9: Assembly 2

3.Next the main hinge and armpit cushion are assembled on to the frame.

Figure 10: Assembly 3

4.After this, the back legs are attached to the main hinge.

Figure 11: Assembly 4

6.Next the locking mechanism is added to the back legs.

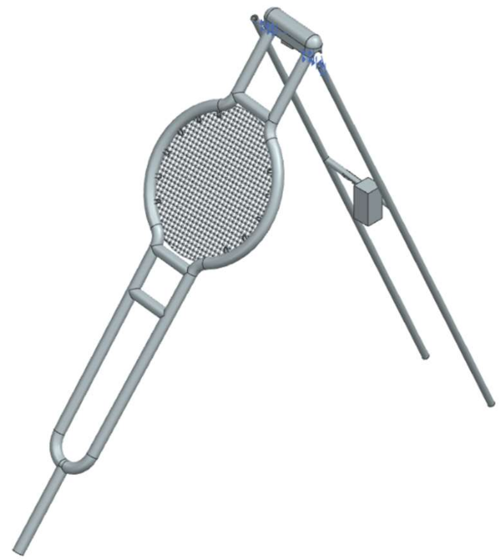


Figure 12:Assembly 5

7.Finally connect the 6 collapsing linkages between the back legs, base frame, and locking mechanism, and add the 3 spring leg ends. The worst-case scenario is that the spring leg ends will not fit the tube by 0.015 inches. 49.87% of the spring leg ends will fit given by a normal distribution.

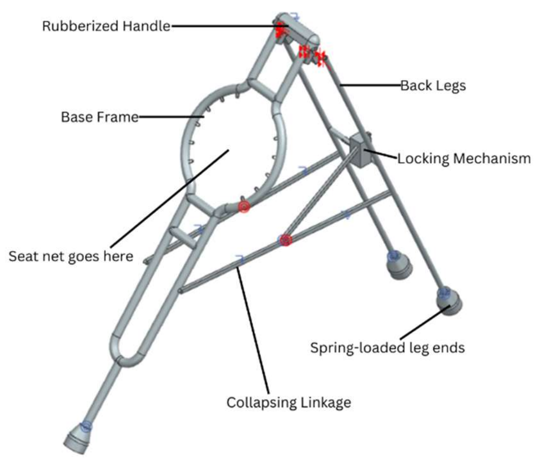


Figure 13: Final Assembly

9 – Benchmarks and Performance Analysis

The prototype was evaluated on critical engineering requirements, detailed in table 4. The prototype was judged to have met all requirements, and a justification was provided for each requirement.

Requirement	Meets? (Y/N)	Details
Adjustable	Y	Seating angle adjustable. Open and closed positions with increments of angle between.
Device has 3 legs	Y	Two fixed length and one telescoping leg.
Longest width of 40.64 cm	Y	Largest width of 16 in = 40.64 cm for the seat width
Material compressive strength of 6,000 psi	Y	Aluminum tubing Ultimate compressive strength of 18,000 psi meets the requirement with safety factor of 3.

Table 4: Key engineering requirements met

Furthermore, engineering models were created to conduct performance analysis on the engineering requirements stipulated.

Firstly, a model was created to analyze whether the crutch would first slip or tip under increasing load. The model used a rigid body static equilibrium as shown by the Free-Body Diagram (FBD) in Figure 14. Key assumptions of the model were as follows. The coefficient of static friction between the rubber end tips and the ground was 0.85. The angle ϴ of the crutch was 30° and both legs are equal in length. All components have negligible mass. See appendix 12 for further details.

After conducting calculations on the FBD, it was determined that slipping will always be the failure point of the crutch, with the stated assumptions in mind. This suggests that to be stable under load, the crutch must not slip when in regular operation.

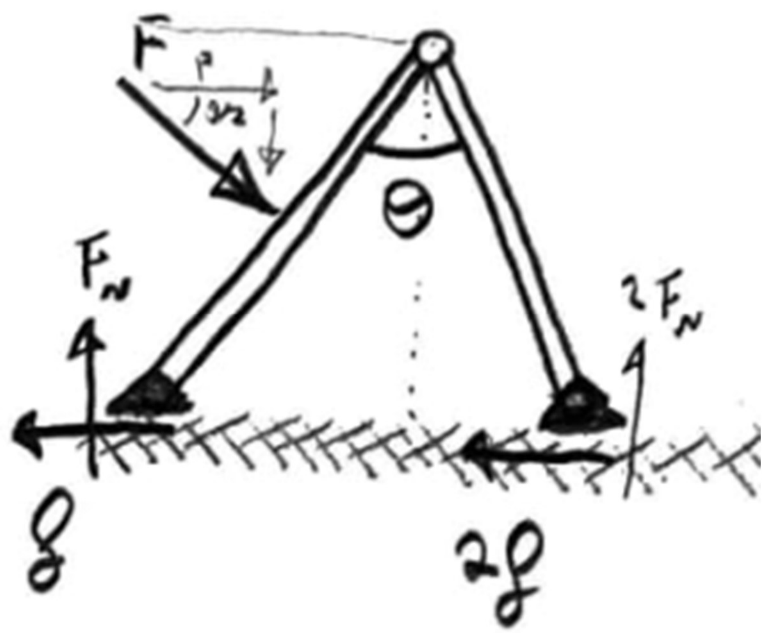


Figure 14: Tip vs Slip model static equilibrium FBD

10 – Conclusion

The Problem Definition Phase for WII Solutions laid a solid groundwork for developing a standing aid product, driven by insights from consumer, market, benchmark, and patent research. With the growing elderly population and increasing demand for mobility aids, the need for a shoulder-width, collapsible product with a seat rest became evident. The Concept Generation and Selection Phase continued this development by the generation of potential concepts through morphological modeling as well as the creation of the low fidelity prototype. During the Design Realization Phase, the Bill of Materials (BOM) of the crutch was updated to reflect more realistic costs, resulting in a total per unit cost of $26.97. The team then continued with the design of the product by creating CAD models of all the components of the crutch. These models included drawings with dimensions and tolerances. A full CAD assembly of the crutch was developed, which involved both engineering analysis and tolerance stack-up calculations. Based on this, the team evaluated the assembly by making sure it met all the engineering requirements, which it in fact did. The device has three legs (two fixed and one telescopic), an adjustable seat angle, a maximum width of 40.64 cm, which is located at the seat, and a compressive strength of 18,000 psi for the aluminum tubing with a factor of safety of 3.

In terms of the future steps for this project, there needs to be a full verification of the design, dimensioning, and tolerancing of the product in order to make sure all measurements are accurate and reasonable. Following that, full-sized physical prototypes should be fabricated that closely matches the final product specifications. Once the fabrication process is complete, physical testing and validation of the manufactured product should be conducted, including load testing for the compressive strength of the design as well as ensuring all components function properly and meet ergonomic requirements. Once the product has been tested and validated, it can be ready for production.

11- References

[1] "Ageing and Health." *World Health Organization*, Oct. 2022,

[2] Department of Economic and Social Affairs, Population Division, United Nations. *World Population Prospects*, 2024, www.population.un.org/wpp/Graphs/DemographicProfiles/Line/900.

12- Appendices

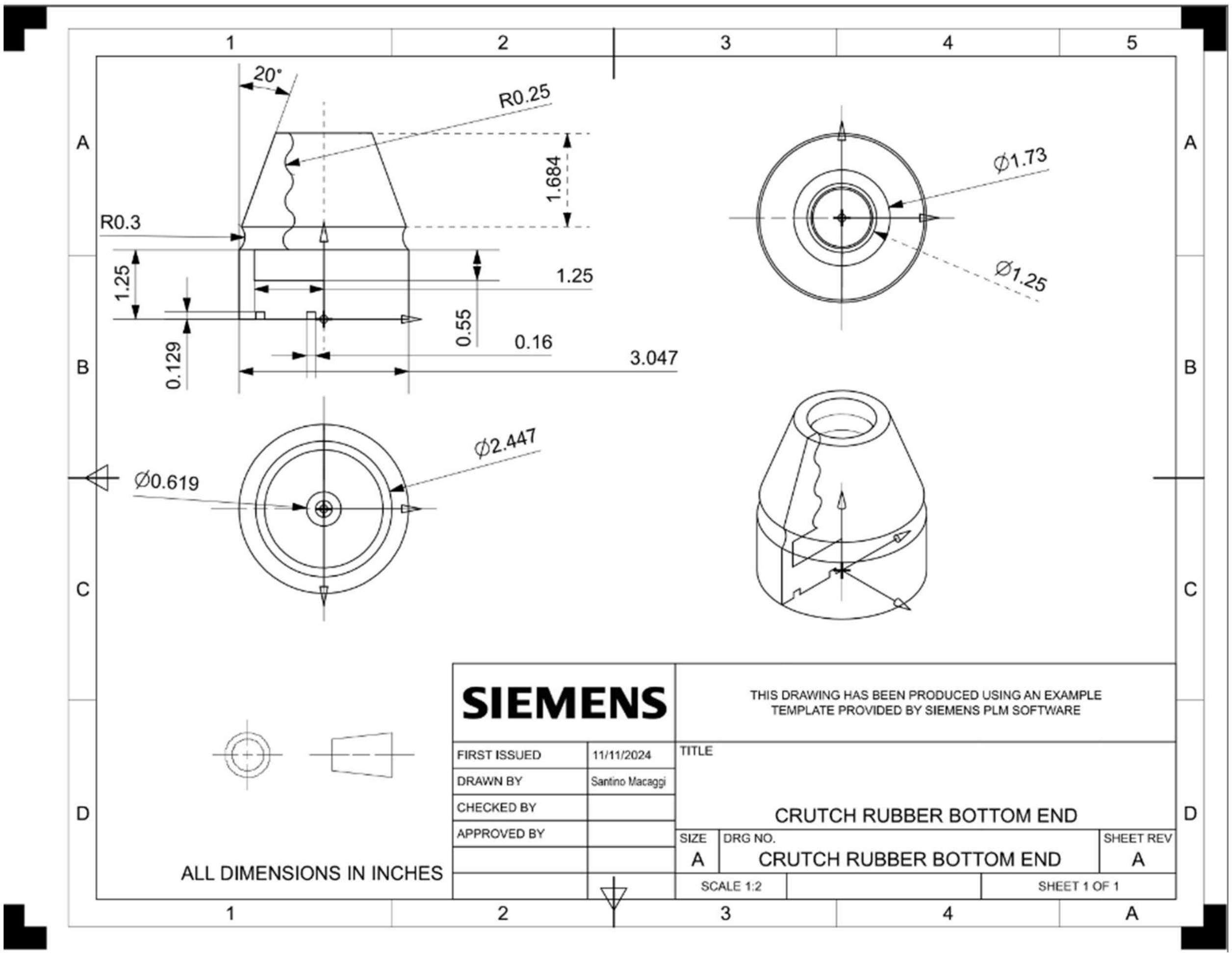


Figure 15: Crutch Rubber Bottom End Drawing

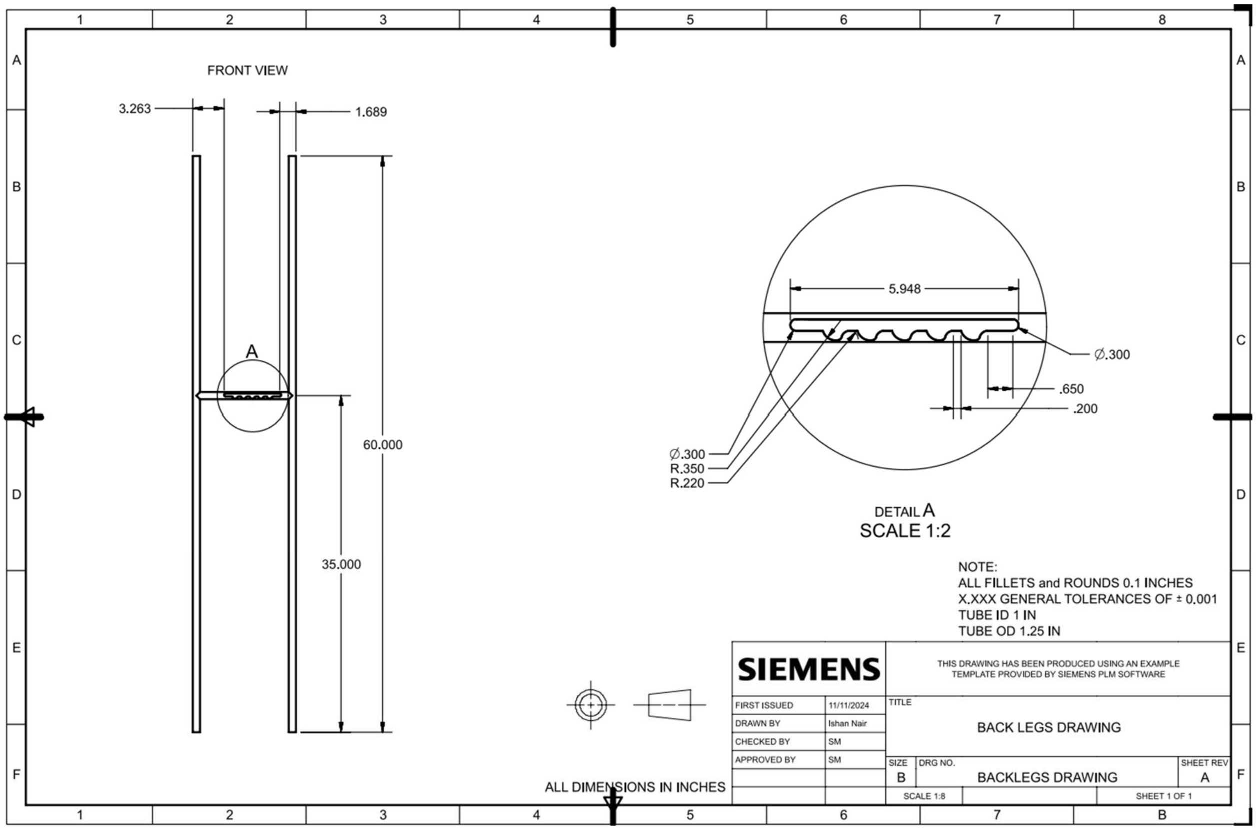


Figure 16: Back Support Legs Drawing

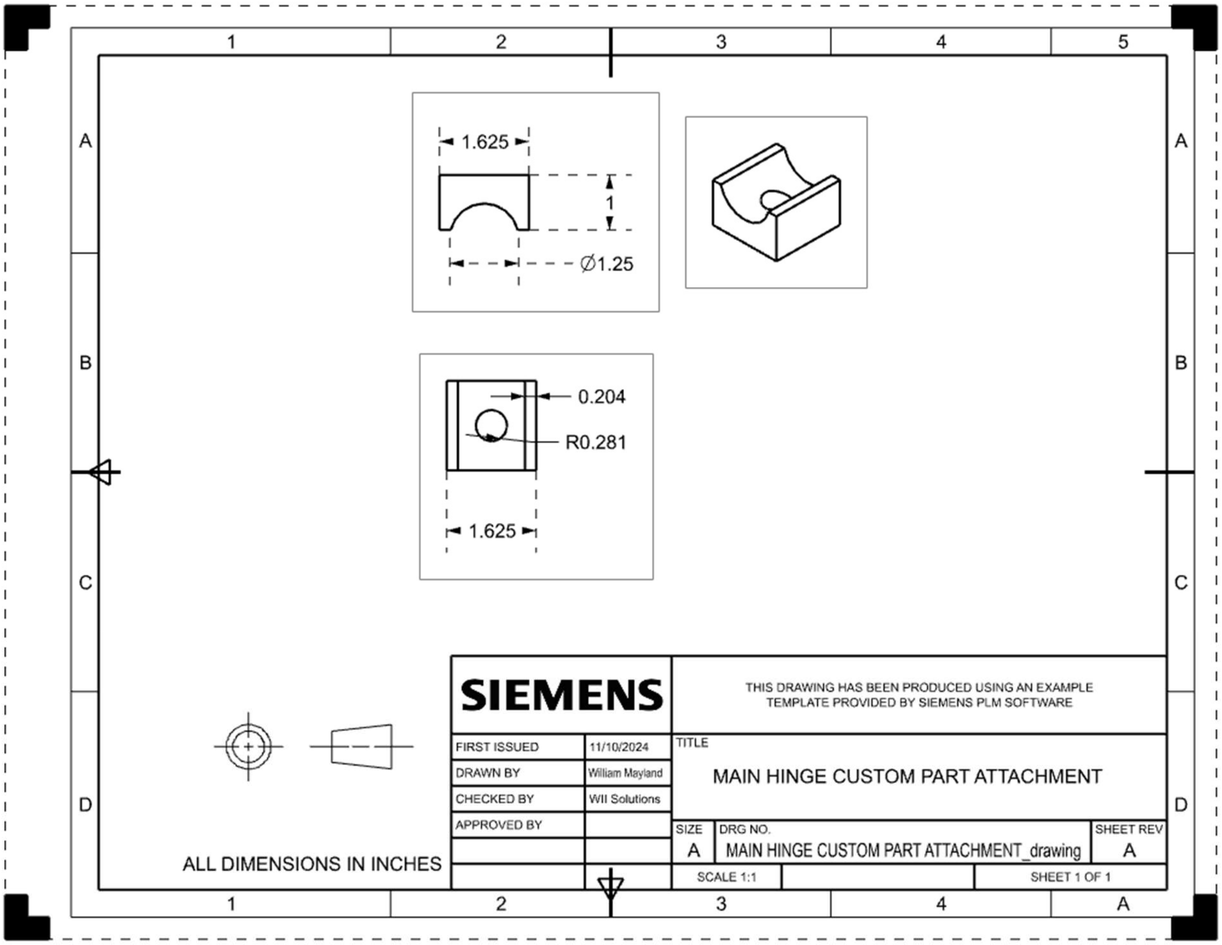


Figure 17: Main Hinge Custom Part Attachment Drawing

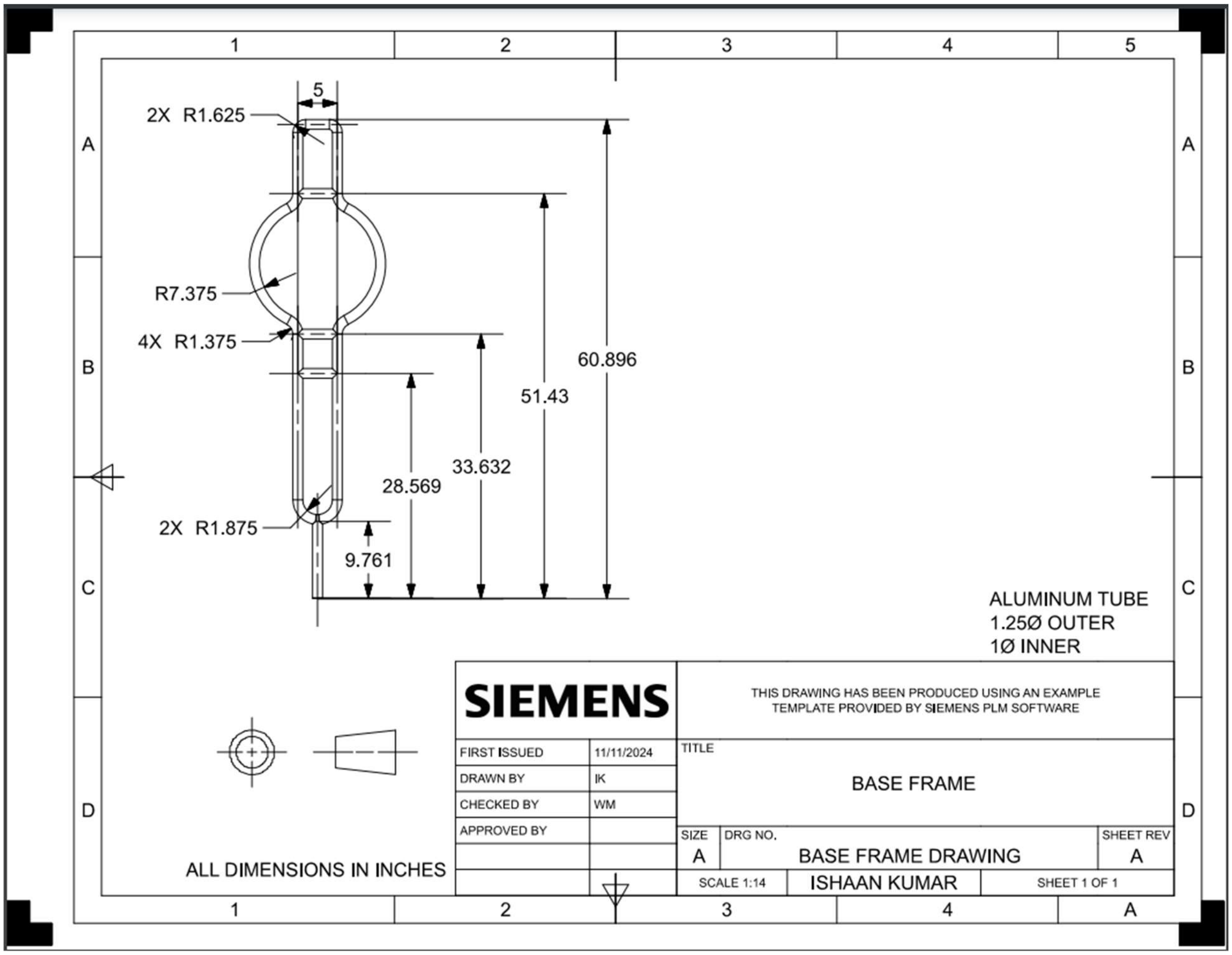
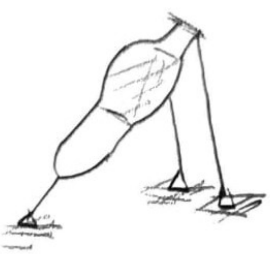
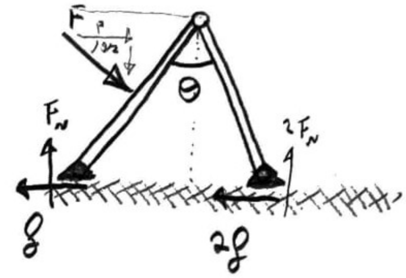


Figure 18: Main Crutch Base Frame Drawing

Assumptions

- rigid body
- static equilibrium
- coefficient of static friction $\mu = 0.85$, as found online between rubber and dry concrete
- $\theta = 30^\circ$
- legs are equal length, massless





Find / will the cutch slip or tip first when a certain load F is applied?

Solution /

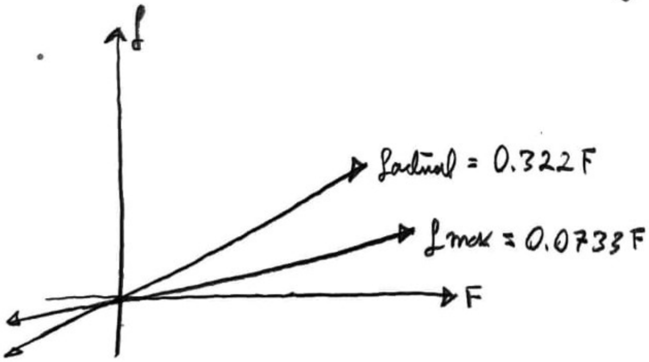
$$\sum F_x = F\cos\theta/2 - 3f_{actual} \rightarrow f_{actual} = \frac{F\cos\theta/2}{3} \qquad f_{max} = \mu_s F_N$$

$$\sum F_y = -F\sin\theta/2 + 3F_N \rightarrow F_N = \frac{F\sin\theta/2}{3} \qquad f_{max} = \frac{\mu_s F\sin 15^\circ}{3}$$

$$f_{actual} = \frac{\cos 15^\circ}{3}F = 0.322F$$

$$f_{max} = \frac{0.85\sin 15^\circ}{3}F = 0.0733F$$

∴ $f_{actual} > f_{max}$ and the cutch will always slip first.



Slipping will always be the failing point. Design the cutch ends with slipping in mind.

Figure 19: Slip vs Tip engineering model

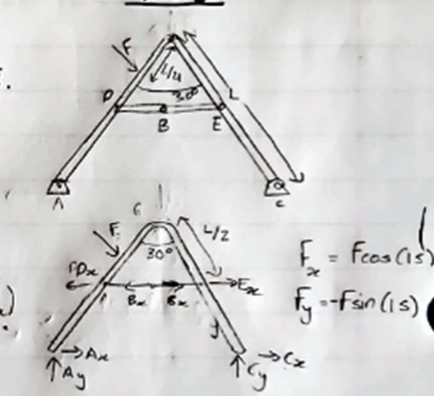
Assumptions:

1) Rigid Body
2) μ_s of 0.85 (BD/BE)
3) $\theta = 30°$
4) All joints & members have negligible weight
5) Cross members or central joint B will fail before any other joints / members
6) All joints/members analysed are Aluminum 6061-0 alloy, Ultimate tensile strength of: 45 ksi, " compressive " " : 18 ksi
7) Members are 1.25" OØ. 1" IØ, hence Area = 0.442 in^2
8) Factor of Safety of 3
9) Legs same length
10) Static Equilibrium
11) Cross member at L/2

Objective:

Determining load force F required to be unsafe for Cross members. (Axial stress > $\left(\frac{UTS}{3}\right)$ or $\left(\frac{UCS}{3}\right)$) BD, BE.

FBD:



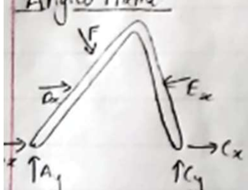
Calculations:

$\Sigma F_x = 0 = F\cos(15) - D_x + E_x + A_x + C_x$ ①

$\Sigma F_y = 0 = -F\sin(15) + A_y + C_y$ ②

$\Sigma M_B = 0 = F\sin(15)\left(\frac{L\sin(15)}{4}\right) - F\cos(15)\left(\frac{L}{2} - \frac{L\cos(15)}{4}\right) + \left(\frac{L\sin(15)}{2}\right)(A_x + C_x)$
$+ \left(\frac{L\cos(15)}{2}\right)(C_y - A_y)$ ③

Angled Frame:



$\Sigma F_x = 0 = F\cos(15) + D_x - E_x + A_x + C_x$ ④

$\Sigma F_y = 0 = -F\sin(15) + A_y + C_y$ ⑤ = ②

$\Sigma M_A = 0 = C_y 2L\sin(15) + \frac{L\cos(15)}{2}(E_x - D_x) - F\sin(15)\left(\frac{3L}{4}\sin(15)\right) - F\cos(15)\left(\frac{3L}{4}\cos(15)\right)$ ⑥

From two force members BD & BE: $D_x = B_x = E_x$ ⑦, ⑧

⑦, ⑧ into ⑥ → $C_y 2\cancel{L}\sin(15) - F\sin(15)\left(\frac{3\cancel{L}}{4}\sin(15)\right) - F\cos(15)\left(\frac{3\cancel{L}}{4}\cos(15)\right) = 0$

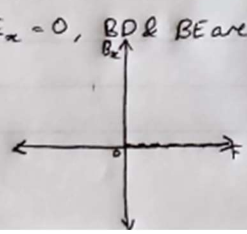
$8C_y\sin(15) - 3F\left(\sin^2(15) + \cos^2(15)\right) = 0 \rightarrow C_y = \frac{3F}{8\sin(15)} = 1.449F$ into ⑤ or ②

$A_y = F\sin(15) - 1.449F = -1.19F$ into ③ → $\frac{FL}{4}\sin^2(15) - \frac{F\cos(15)L}{2} + \frac{FL\cos^2(15)}{4} + \frac{L\sin(15)}{2}(A_x + C_x) + \frac{0.259L\cos(15)}{2} = 0$

$\frac{F}{4} - \frac{F\cos(15)}{2} + \frac{\sin(15)}{2}(A_x + C_x) + 0.125 = 0$

$(A_x + C_x) = \frac{2(0.233F - 0.125)}{\sin(15)} = 1.8F - 0.966$

Since $D_x - E_x = 0$, BD & BE are zero force members in this case of F.



→ Member exists to support other loads and maintain 30° angle when lateral forces applied to both outer legs.

→ Therefore, in regular use, cross member operates within range.

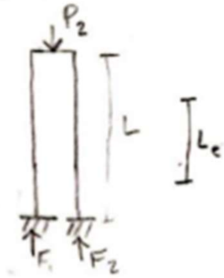
Appendix 20: Failure of cross members engineering model

Deliverable 16: Modeling	Santino Macaggi	11/19/2024

Purpose: Determine the maximum load P just before the support legs buckle

Assumptions:
- Aluminum compressive strength of 18,000 psi (allowable psi of 6000)
- Factory of Safety equal to 3
- Crutch is placed on flat surface
- User' weight is evenly distributed across the meshed seat
- Assume the load P on the seat is the same as the load at the top handle ($P_1 = P_2$)
- Assume the support legs evenly split the applied load
- Assume Fixed-Fixed boundary conditions

FBD:



Knowns:

Outer Diameter (d): 31.75 mm

Thickness (t): 3.175 mm

Length (L): 1.524 m

Effective Length (L_e): $0.5L = 0.762$ m

Factory of Safety (FS): 3

Young's Modulus (E): 69 GPa

Acceleration due to gravity (g): 9.81 m/s²

Solution:

$$P_{critical\ load} = \frac{\pi^2 E I}{(0.5L)^2}$$ ← Euler's buckling load

$$P_{cr,overall} = 2 \cdot P_{cr}$$

$$I = \frac{\pi}{4}\left(\left(\frac{d}{2}\right)^4 - \left(\frac{d}{2} - t\right)^4\right)$$

$$P_{cr,overall} = 69{,}081.22\ N$$

$$I = 2.945 \times 10^{-9}\ m^4$$

$$P_{cr} = \frac{\pi^2 (2.945 \times 10^{-9})(69 \times 10^9)}{0.25\ L^2}$$

$$FS = 3$$

$$P_{allow} = \frac{P_{cr,overall}}{3}$$

$$P_{cr} = \frac{80{,}223.2}{L^2}$$

$$P_{allow} = 23{,}027.08\ N$$

$$P_{cr} = 34{,}540.61\ N$$ (For one leg)

Weight = P_{allow} = mg $\quad m = \frac{P_{allow}}{g}$

Maximum mass allowed: 2,347.31 kg

TOPS

Appendix 21: Buckling of Support Rod Aluminum Tubing