Design Showcase 2 Report

University of Waterloo
Department of Systems Design Engineering

Design Team 15:
Jamie Kang - 20956456
Joel Lee - 20948926
Livia Murray - 20928120
Agam Soni - 20948293
Rylin Soto - 20942344

Date of Submission: November 26, 2021

Contents

Summary of Problem Space

Situation of Concern and Situation Impact Statement:

In the United States alone, 19 to 29% of prescribed mobility devices were abandoned by their users, with an abandonment rate of 10% for wheelchairs and 30% for crutches and walkers [1]. This statistic may be attributed to the need for these devices to be effectively operated with both hands. This restriction of the upper extremities limits users in the type of tasks they may perform and the efficiency in which they perform them. While there are pre-existing products that address this issue functionally, they struggle to achieve a universal design that accurately addresses and supports a wide range of tasks that a user may want to perform. Therefore, there exists a need for a mobility device to be developed that would enable the user population to be able to complete complex and instrumental tasks at a higher level of efficiency through removing the need for both hands to be used for movement.

Key Requirements and Constraints:

Within the quality function deployment chart (QFD), "R1. *Must be efficient*" and "R4. *Must be durable (crash testing)*" were identified as the two most important requirements [2]. However, R1 is weighted as with a higher importance since the intent behind the wheelchair modification design "You are the stick" (YATS) is to increase the efficiency of tasks for the user. Therefore, to not satisfy this requirement would cause the YATS to fail in addressing the defined problem space. The requirement, "R2. *must be durable,*" is the second most heavily weighted, as the safety of the user must be fully guaranteed when using YATS. Since YATS, as a wheelchair is a moving vehicle, the factor that collisions could happen at any time must be properly assessed and accounted for in the design. It is essential that the user will have security and assurance that they are not subjecting themselves to high or unreasonable risk of injury when operating the wheelchair.

Constraints "C4. *Must not inhibit reach, flexibility and dexterity of the upper torso*" and "C5. *Must not tip over when the user puts full weight on the backrest at a maximum possible leaning angle*" were developed from the stakeholder interviews and the engineering analysis [3][4]. "C4. *Must not inhibit reach, flexibility and dexterity of the upper torso*" is considered essential towards the functionality of YATS. This is because the YATS is meant to allow the user to use their arms and hands to perform tasks while remaining in motion, and to inhibit that freedom would significantly reduce the viability of the solution to the problem space being addressed. Likewise, the C5 constraint was determined to be essential towards the design, since in the provided stakeholder interviews, individuals clearly expressed concerns with wheelchair tipping and the overall safety for the user [4].

Basic Functions:

The objective was to design a modified wheelchair to be used by people afflicted with a disability constraining lower body control that would allow them to complete other tasks and daily activities independently using their arms while simultaneously moving. Furthermore, it must accomplish the basic functionalities of any other electric wheelchair or basic wheelchair which is to aid in the mobility of the user. Another necessary function of the system is to obtain sufficient power in order to operate the sensors and motors that are being used. However, potential overheating must be addressed, so there must be a function for a cooling system to prevent the system from damage during overheating. An essential function is for YATS to be able to support user tasks as it satisfies the most important requirement R1. regarding improving the efficiency of tasks. Furthermore, being generally weather resistant is a function that improves the accessibility of the wheelchair for a variety of user populations while also directly satisfying R5 and R8 for weather durability and user centrism [2].

Solution Approach

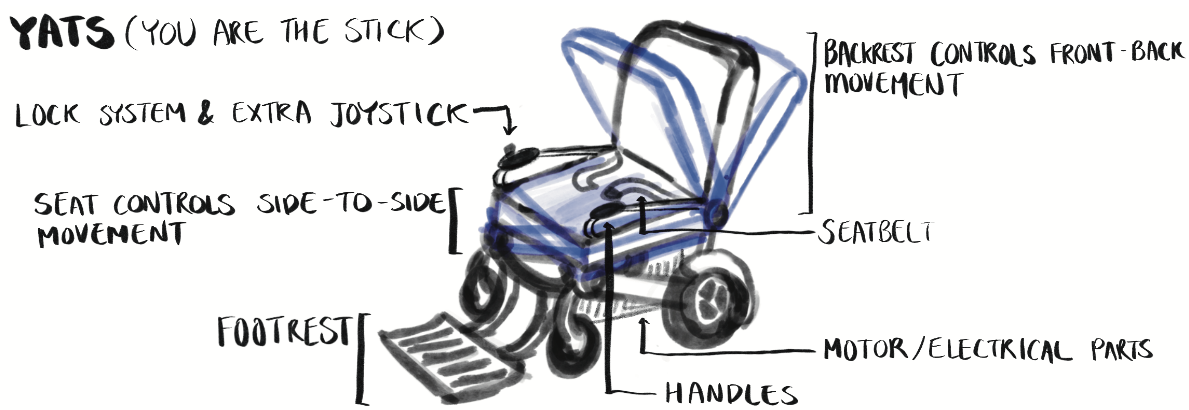
Description of Solution:

The YATS design implements the use of intuitive body-movement-based motion to create a solution utilizing a gyroscope planted in the backrest to measure and maintain orientation, while recording the backrest's angular position to determine the velocity of longitudinal movement. Pressure sensors located in the seat of the wheelchair detect notable weight shifts in the user's calibrated centre of mass which controls lateral and rotary movement, thereby rotating and turning the wheelchair accordingly. Leaning to the left and right will turn the chair in the same direction with the steepness of the turn being dependent on how much pressure is exerted by leaning. Moreover, thresholds are applied to each of the sensors to ensure that minimal shifts in body weight does not lead to any unwanted movement. Therefore, there exists a dead space in which the user's movement does not affect the movement of the chair. These thresholds can be adjusted according to the user and their unique range of motion through an initial calibration session. The YATS also has a toggle switch that will disable movement in the chair in the case that the user wants to temporarily pause/stop all movement, which could include stretching to reach something or sleeping in the chair.

A notable feature in our design is the aforementioned calibration system, which permits individuals to regulate neutral positioning of the backrest, dead zones for static movement, and sensitivity ranges. This technology, in combination with customizable parts (footrests, backrest length, etc.) distinguishes the YATS design from its competitors by eliminating the need for multiple wheelchairs over the user's lifetime, thereby reducing expenses and reinforcing overall user-centrism.

The advantage of the YATS is that it enables the user to fully utilize their upper extremities while moving, directly addressing many of the requirements in the situation of concern. As such, tasks like vacuuming, cooking, transporting, or even playing sports become that much easier and natural for the user as YATS provides an intuitive, body-movement-based motion solution. The wheelchair is also efficient because the chair's calibration and programming responds to the movement of the user such that no unnecessary movements are made. Finally, YATS enables a diverse user population that encompasses a variety of disabilities to fully utilize their upper-extremities in the completion of tasks while remaining mobile through its assessment of generally inherent torso and balance mechanics - producing a design that thoroughly satisfies the presented situation of concern.

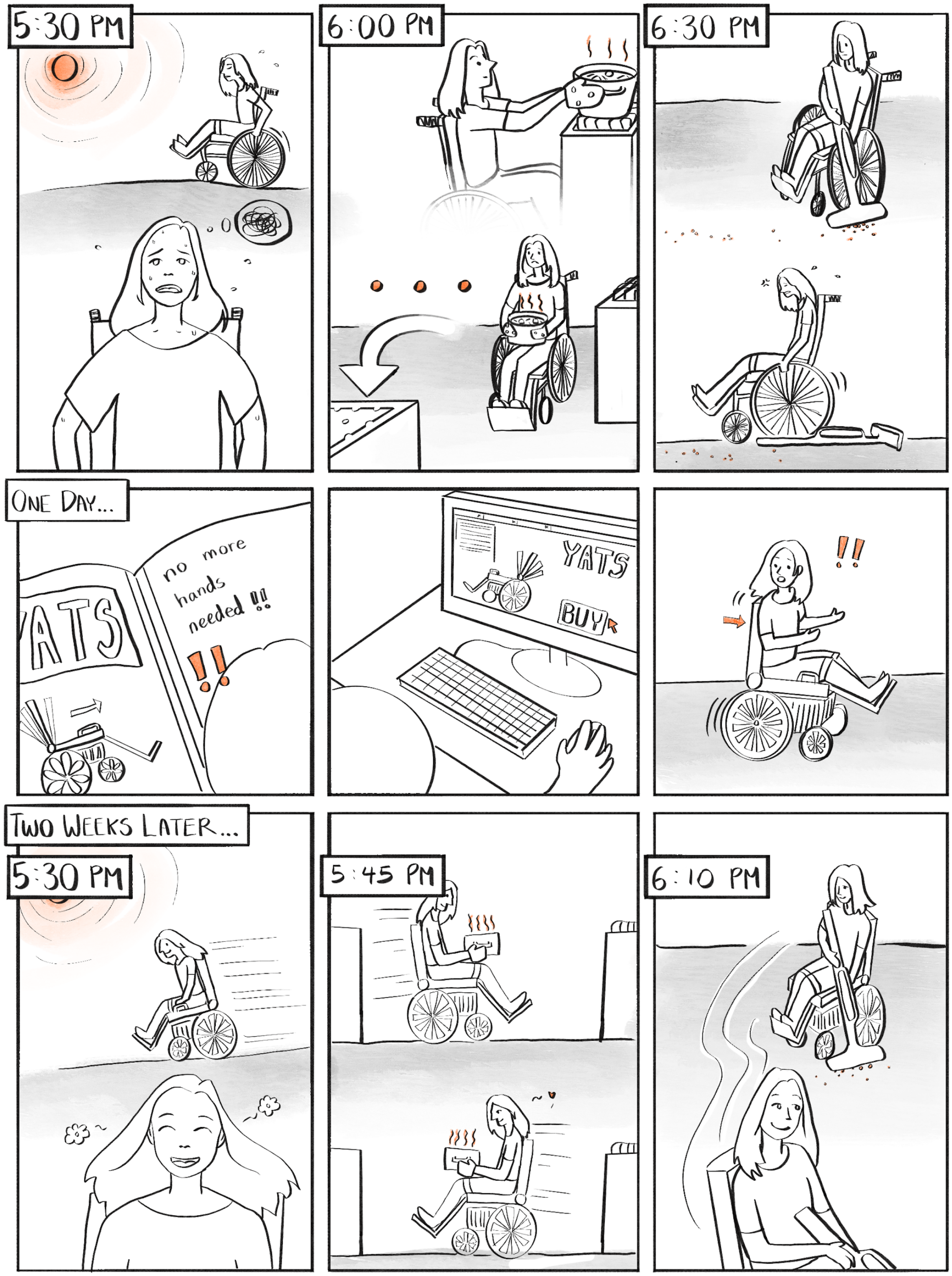
Figure 1: YATS sketch



For higher quality sketch and model of YATS (*See Appendix - Additional Sketches- Figure 3*).

Storyboard

Figure 2: YATS storyboard



Engineering Analysis

The objective of an engineering analysis is to "assess potential behaviour of the design before the prototype is built" [5], as well as predict whether the design solution will meet certain requirements of constraints previously outlined by engineers in the needs assessment phases of the design process.

To assure proper usability and safety in the design, an engineering constraint was created for the analysis of our design solution: "C5. *The wheelchair must not tip backwards when in the locked position*." With respect to this constraint, the team set about to determine a maximum required mass of the wheelchair that would allow the user to 'fall in a safe direction' when the chair's entire normal force is being applied at its back wheel directly beneath the axel. The feasibility of the result of the mathematical analysis - being the necessary mass of the wheelchair - was defined by target threshold ranges in the Quality Function Deployment Chart (QFD) [2]. In particular, these ranges were regarding "R6. *Should be light (weight)*" whose metric is mass of the wheelchair in kilograms. This engineering requirement has a user-centric nature, as a lighter wheelchair aids in the mobility of the user in terms of possible maneuvers, acceleration, and transportation. The QFD desired target was set to 75kg, which was representative of a direct competitor product weight [6]. Therefore a weight lower than our competitor would signify the fulfillment of the requirement and plausible success on the market.

By making the statement that the chair is in the locked position and therefore may be considered a 'rigid body', the principles of equilibrium in static physics may be applied. In using a statics-based analysis, it is likely necessary to simplify the potential behavior of the solution and therefore variables in the problem through making assumptions. A set of givens and assumptions were deemed reasonable in terms of our calculated results while taking into consideration a male user of weight 100kg [7]. In our taken scenarios, the front caster is just about to lift above the ground and there is no normal force occurring at the point where it would be in contact. As such, the back wheel is stationary at the point 'A', and the entire normal force resides there. In this calculation, the gravitational force accelerating the wheelchair towards earth is assumed to be $9.81 m/s^2$.

First, to find approximations and ranges in measurements and dimensions in the YATS design, the technical specifications of the *Motion Composites* Rigid Wheelchair [8] dimensions was used as the basis for the YATS wheelchair's physical structure. The weight of the wheelchair was considered a point distributed mass at the center of the wheelchair seat, excluding the weight of the backrest [9], which was independently considered as causing an opposing moment about the point where the wheel contacts the ground directly below the spoke at point 'A' (*See Appendix - Engineering Analysis - Figure 2*) where it is completely balanced and in equilibrium.

Second, there were assumptions made in order to identify extreme cases in regards to the user and their body weight distributions. The weight of the user in the calculation was previously identified through research as a reasonable maximum weight [7] for the wheelchair structure and mechanics to support. The sex of our user was strategically chosen as a greater body mass distribution percentage in upper body extremities - which is statistically more probable in males [5] - would provide the maximum amount of torque in opposition to the weight of the chair in our scenario. Therefore the head, total arm, and torso weight (93.82% of body weight) of a 100kg male was utilized in the calculation for this variable

(F_P). Finally, in terms of weight distribution the extreme was considered that the user population may include partial/full amputees and those whose disabilities limited lower body development. Therefore the lower body distribution was taken of only the thighs, indicating removal of crus, and this weight (W_P) was evenly distributed exclusively over the length of the seat of the chair - without extending past the seat's length. In reality, these values would need to be considered with more variability to regulate for the calibration/customization process and the range at which the pressure sensors located in the seat must be able to withstand.

Third, a 40 degree recline was identified as an suitable approximate maximum from the normal (vertical) line of the backrest. This angle was based on testers judging where a comfortable recline would lie, while taking into account variable core stability and exertion levels. Our team members all individually assessed where this comfort maximum angle would be, and the value of the highest recline was rounded upward in order to also determine an extraneous angle that would be unlikely to be exceeded.

From the static-based analysis, the mass of the wheelchair (W_C) must be a minimum of 71.43kg to obey the laws of equilibrium under the set of assumptions made. This means that while supporting a 100kg male with partial leg amputation at the knee with a backrest recline of 40 degrees from the normal, the chair must weigh 700.76N in order to counter the moment at (A) and allow the user to safely fall forwards. It can be determined that if that wheelchair is functional under extreme circumstances, that the behaviour and functionality of YATS can also be considered safe under less extreme circumstances.

The frame of the wheelchair will be made from stainless steel and aluminum. The aluminum will be used to make the frame of the wheelchair due to its relatively light weight which abides our light weight requirement. Aluminum is a material which requires minimal maintenance [10] and by having the aluminum clear coated to protect it from corroding [11], which will further increase the life of the wheelchair - aiding in user centrism. Furthermore, aluminum being long lasting and durable allows it to be environmentally friendly, along with being easily recyclable [10] and sustainable.

Stainless steel is utilized in making components, such as the hinges of the backrest, due to the material's relative strength, as the backrest needs to be supported with strong hinges that would not be likely to break when subjected to external and internal forces within the hinge system. Stainless steel will be also used to make the casters and the legs since stainless steel has a high tensile force, which will ensure that the base wheelchair will be able to withstand the weight of the user. Both aluminum and stainless steel can be considered viable material options for construction purposes in the medium-to-high fidelity prototyping stage and manufacturing.

To ensure that the solution be viable under the largest range of cases, a scenario was created in which the stresses and forces on the wheelchair would require for the weight to be maximized. These extremes are valid on the basis of the calculations, in order to increase the accessibility and user centrism of the solution, and thereby allow it to be viable to a greater percentile of the population. The calculation of the weight using statics-based physics principles provides a result who's given metrics are in line with the engineering requirement that "the solution should be light," with a target threshold of < 75kg. The target for a maximum withstood user weight has also been surpassed in terms of the competitor. This serves to edge out competitor products and increase user-centrism by making the user-wheelchair interface easier, for example in transporting and maneuvering.

The obvious downside to the extremes being taken into consideration during the engineering analysis is that it takes into account the lowest user percentile - say 0.1%. In this type of design, it is not always possible to compensate for such a small user population in cases where it would result in detriment to the remaining 99.9%. For example, a user need that could potentially be negatively impacted would be cost, which correlates to our existing engineering requirement, “R2. *Should be affordable by comparison*” [13]. Improvements and iterations could be implemented after the initial prototyping and user testing has been conducted in order to re-analyze the safety and functionality components of the wheelchair, while keeping in mind monetary factors, to determine whether the initial assumptions were reasonable. However, at this point in the design process a revision would not be necessary.

Testing Plan

Medium fidelity prototype explanation:

The requirements chosen to assess in this stage of our design iterations are that YATS "R1. *Should be efficient*" and "R4. *Should be durable*" [13]. These particular requirements are more heavily weighted in the Quality Function Deployment chart in comparison to all the other requirements and thus must be addressed first [2]. In order to accurately assess both the efficiency and durability requirements, this medium fidelity prototype must be a simplified, life size version of our final product and must include the same motor, sensors, gyroscope and materials as in our final product while also weighing the same.

As for the efficiency requirement, it is important that the prototype has the same power, torque, sensing ability and accuracy as if we were testing with our final product in order to produce an accurate result for it's overall functionality.

To test the durability of our wheelchair, the medium prototype wheelchair must have the same weight of 71.43kg and be made of the same materials as of our final wheelchair. Moreover, a 100 kg dummy will be strapped onto the seat to mimic a user of maximum weight capacity. The connection point between the base frame and the backrest will be made of steel and the remaining components of the frame will be aluminum [14].

Since only one prototype is being made, we will not be assessing the customization aspect of YATS, as a result the created prototype will be that for an average sized male. Similarly, user comfort will not be taken into account, this means all cushioning in this medium fidelity prototype will not be the same as our final product. Finally, aspects like battery life and water resistance of the chair will not be taken into account at this time since the addition of these requirements would be costly and not having them does not alter the testing outcomes.

R1: Should be efficient - User focused testing

As outlined in our requirements table by requirement R1, YATS should be efficient. This evaluation will involve user testing, as experienced wheelchair users will give a more accurate assessment of this requirement than someone on the design team. This testing will involve reaching out to 10 manual wheelchair users, each of which will be selected to perform a timed individual task in their manual wheelchair and then again in the YATS prototype. Possible tasks will include: vacuuming or mopping their home; doing the dishes… etc. (see full list in appendix under *Figure 3)*. We encourage each participant to interpret their task how they see fit, this means they should perform their task from start to finish as they would any normal day, but they must effectively maintain consistency when performing the task in the manual wheelchair and in the YATS prototype. The efficiency will be measured as the time difference between completing the task in a manual wheelchair and in the YATS. As a result we aim to improve efficiency by decreasing the patient's time needed to perform their chosen task by 60% or more when using the YATS, as compared to their manual wheelchair.

Efficiency will be calculated using the following equation, where *Tm* is time to complete task in manual wheelchair in seconds, *Ty* is time to complete task in YATS and %*E* represents the percent efficiency of YATS compared to manual wheelchair in percent (if *E* is a negative number, there was a decrease in efficiency):

$$\%E = \frac{Tm - Ty}{Tm} \, x \, 100$$

The final product is expected to be more efficient than this prototype as a result of the following limitations. Firstly, the fact that this prototype will not be customized to each individual participant, may cause the user to perform their task slower than if they were in a YATS customized to their body type. Secondly, cushions and supports of this prototype will not match the final product, and this lack of comfort may contribute to slower times. Also, using YATS for the first time will be a learning curve for any user; there is not enough time to allow each participant to practice using the prototype for long periods of time before their timed task and this will contribute to slower times. Finally, since only one prototype will be made it will be difficult to access it with users of various heights and weights, however, we will try our best to make the prototype as general as possible in order to test a variety of body types.

R4: Should be Durable - Crash Test

To test the durability of the medium fidelity prototype, a crash test will be performed. To produce an accurate representation of the amount of force the final product can withstand, the medium fidelity prototype will have the same weight of 71.43 kg as of the final wheelchair, along with a 100 kg dummy strapped onto the seat to mimic a user of maximum weight capacity. The wheelchair will be propelled at a stable wall with a starting distance of 10 meters at its maximum speed of 10km/h **[**15**]**. This case takes the possibility for 'dangerous behavior' into consideration and the inability to always assure full user responsibility. The testing environment must be large enough to allow for a 10 meter runway as well as have smooth, level ground to reduce external forces. To carry out the test, the tester must measure exactly 10 meters from the wall and place the front wheels of the wheelchair at that point. The medium fidelity prototype must then be turned on by displacing the backrest 40 degrees from the vertical (demonstrating the extreme recognized in the engineering analysis) and utilizing the test dummy's weight to keep it in place. The wheelchair will then accelerate to 10km/h on its own towards the wall and imminently collide.

With the neglection of friction and wind resistance, the force that the wheelchair will apply onto the wall will be 66.86N by the constant acceleration equation from Kinematics and Newton's 2nd law:

$vi = 0km/h$

$vf = 10km/h = 2.78m/s$

$\Delta d = 10m$

$vf^2 = vi^2 + 2a\Delta d$

$a = (2.78)^2/20$

$a = 0.39\, m/s^2 (acceleration\ of\ the\ wheelchair\ when\ it\ makes\ contact\ with\ the\ wall)$

$Fnet = (71.34 + 100)(0.39)$

$Fnet = 66.86\, N\ (force\ that\ the\ wheelchair\ will\ apply\ onto\ the\ wall)$

As per Newton's third law, if the wheelchair crashes into the wall with a force of 66.86 N, the wall will apply an equal force onto the wheelchair. Therefore, this test will measure the durability of the wheelchair when impacted on by the opposite force of 66.86 N from the wall. The tester will take note of the effect of the force from the wall onto the wheelchair during the crash by analyzing the damage on the basis of a damage rating scale. The damage rating scale will consist of a numerical scale from 1-5, where 1 represents that the wheelchair is in good condition after the crash and 5 being that the wheelchair is in the worst condition and is no longer operable (refer to the appendix *Table 2* for the complete damage rating scale).

Since, the weight of the prototype and test dummy as well as the speed at which it hits the wall have all been maximized, if the crash test is deemed a 1 or 2 on the damage rating scale, this medium fidelity prototype may be considered safe, usable and durable in all other allowable conditions with reasonable confidence.

The limitations with the medium fidelity prototype testing are that this test is focused on a specific scenario in which the wheelchair hits an object straight up, but there can be various scenarios in which the wheelchair can crash differently into other objects. For example, if the wheelchair had crashed into the same wall at a different angle then the force being impacted on the wheelchair could vary and result in different damage ranking according to the damage rating scale. Moreover, by having a dummy in place of a real user, the test is focused on a scenario in which there is no user reaction or attempt to change the direction of the wheelchair when it moves towards the wall. If there was a real user on the wheelchair, there remains the cause to assume that the user could have safely maneuvered the wheelchair into a different or more optimal position for collision to protect themselves or the chair. It is impossible to predict the outcome of every infinite variation of incidents affecting variables within collisions. If the wheelchair were in collision with another object, it could have resulted in a difference in force and location of impact, resulting in a singularly independent set of damages suffered to the wheelchair. It is never entirely possible to predict all possible outcomes and user reactions, and it is not plausible to use various crash test scenarios to test the durability of the wheelchair with our medium fidelity prototype due to monetary and safety concerns. Therefore, it is the best possible practice of the engineering team to apply the knowledge gained in the head on collision scenario to minimize potential risk, being what is probable in terms of the "occurrence of a hazard causing harm and degree of severity of the harm" [16] to the user in a high fidelity or manufacturing level prototype, and reduce that risk whenever possible until considered low risk. This may be done by assessing possible redundancy, warning, and failure options.

Iteration Plan:

Changes to solution or design process:

From the engineering analysis we discovered that the minimum weight required to prevent the chair from tipping in the most extreme scenario was approximately 71.43 kg, therefore a possible change that can be made is to the requirement "Should be lightweight" which initially outlined the range for the wheelchair's weight as 50 kg to 115kg [13]. The requirement's metric should be modified to 71.43 kg to 115 kg. This should also be reflected on the QFD table as well underneath the minimum weight for the wheelchair.

Future Work:

From this point in the project, future work would include actually implementing our design in a low, medium, high fidelity prototype range. Additionally, it would become necessary to utilize user testing in the iterative design process - bringing in primary persona type users to test the engineering requirements against user functions and needs. This would assist us in developing an idea of how user centric our design is at directly addressing a primary person type user's goals, desires and pains. Moreover, in order to satisfy requirements like "R.2 *should be affordable by comparison*," cost should be constantly compared with competitor products like the omeo [6], which results in a more detailed understanding of how YATS can be further optimized for cost and the goals for what the cost should be. Additional testing for the break time of YATS should be conducted as the break time is essential in avoiding hazardous scenarios including crashes and potentially hazardous material. The testing process for the break time would be as simple as measuring the time needed to break with the independent variable being different weights supported by the wheelchair. The wheelchair should come to a stop in under 2 seconds [13].

While the established testing plan outlines the process for how the efficiency and durability of YATS will be assessed, other requirements that pertain to the user like comfort and user centricity are neglected. Therefore, additional testing could include implementing the testing process for comfort, user centricity and accessibility. While these requirements are not weighted as heavily as the efficiency and durability of the YATS, it still enables the team to be able to draw conclusions in order to enhance the user experience. Testing for comfort can be done by letting a primary persona type user to use YATS for a 2-3 week period. Then once the 2-3 week period has passed, the user would fill out a survey (*see Appendix - Additional questions for user testing - Figure 4)*. Testing for user centricity can be done in a similar way by providing a survey after the 2-3 week period with a likert scale to determine the user's perception on the YATS' ability to fit to their personal abilities (*see Appendix - Additional questions for user testing - Figure 5)*.

Conclusion

As per our situation impact statement we set out to design an affordable modified wheelchair to be used by people afflicted with a disability constraining lower body control and movement to relieve them from using their upper extremities - thereby allowing them to complete other tasks and daily activities independently while simultaneously moving [17].

This statement can be broken down into its components: the general solution (affordable modified wheelchair), the primary user (people afflicted with a disability constraining lower body control and movement) and the task as well as the benchmark (perform daily activities whilst relieving the user from needing to use their upper extremities to control the modified wheelchair); each of which will be assessed in the following paragraphs.

Beginning with the general solution, which was to design an affordable modified wheelchair. The final price of YATS came out to be an estimated $10,000 - $15,000 which may or may not be a reasonable purchase on an individual user basis. If the user is transitioning from a manual or electric wheelchair to YATS, they will more than likely have to pay more than what they paid for their current wheelchair. However, wheelchairs on the market that are similar to YATS, in that no upper extremities are required to control the wheelchair, are considerably more expensive sitting at about $21,000 [6]. There is the clear intention to keep the cost within the identified range, in order to satisfy the requirement which is to be affordable in comparison to other competitor solutions. Because of this we deem YATS affordable and thus a success in fulfilling this requirement.

Next, our primary user outlined in the situation impact statement is a person afflicted with a disability constraining lower body control and movement. Unfortunately, it is not rational that our solution encapsulates the entire possible user population, and it was determined that a reasonable maximum weight that the wheelchair must support is 100kg (225lbs). In addition, the user must have reasonably strong core/abdominal muscles to be able to work YATS, this may exclude some potential users from being able to purchase YATS. Considering the fact that the user's core muscles will strengthen over time while using YATS, much like how arm muscles strengthen when using a manual wheelchair, we believe we are able to include enough of our desired population in order to deem this aspect a success.

Finally, the team took on a more general approach to the problem space by not specifying a task. Instead, our benchmark for success is to enable the user to perform daily activities whilst relieving them from needing to use their upper extremities to control the modified wheelchair. YATS will be essentially replacing the user's current wheelchair and as such the user will be able to perform all the same tasks, if not more, in YATS that they can perform in their current wheelchair. The overall dimensions and maneuverability are the same as the average manual wheelchair, the only difference being that YATS likely weighs more at 71.43 kg. Thus, if the user can perform a task in their current wheelchair they will indeed be able to perform it using YATS. Addressing the situation impact statement and overall goal of the wheelchair modification - being that the user should be able to control YATS without using their upper extremities - was also a success, as the user simply needs to lean or move their core in the direction they wish to go. The only time the user would need to use their hands would be to change the wheelchair to the locked position or vice-versa, even so we also believe this aspect of the situation impact statement to be a success.

Overall we believe YATS to be a success in addressing the problem space; since it is affordable, reaches enough of the desired population and enables the user to perform daily activities whilst relieving them from needing to use their upper extremities to control the modified wheelchair.

References:

[1] J. Howcroft, "BME161 - Fall 2021 - Situation of Concern," September 2021. [Online]. Available: https://learn.uwaterloo.ca/d2l/le/content/709103/viewContent/3958790/View [Accessed September 2020].

[2] Jamie Kang, Joel Lee, Livia Murray, Agam Soni, Rylin Soto. BME 161, "Quality Function Deployment Chart". Department of Systems Design Engineering, University of Waterloo, Waterloo, Canada, October 29, 2021.

[3] Jamie Kang, Joel Lee, Livia Murray, Agam Soni, Rylin Soto. BME 161, "Constraints Table". Department of Systems Design Engineering, University of Waterloo, Waterloo, Canada, October 29, 2021.

[4] J. Howcroft. BME161. Class Lecture, Stakeholder Interviews: "Connection Library - Jeremy - Wheelchair User - BME Cut." Biomedical Engineering, University of Waterloo, Waterloo, Canada, Sept, 26 2021. Available: https://learn.uwaterloo.ca/d2l/le/content/709103/viewContent/3983869/View [Assessed September 29 2021].

[5] J. Howcroft. BME 161. Class lecture, Engineering Analysis, "Engineering Analysis information session." Systems Design Engineering, University of Waterloo, Waterloo, Canada, November 8, 2021.

[6] K. Halsall, "Omeo Technical Specifications," *Omeo Technology*, February 10 2021. [Online]. Available: https://omeotechnology.com/omeo-technical-specifications/ [Accessed October 15 2021].

[7] Redman Power Chair, "Do Wheelchairs Have a Weight Limit?" Redman Power Chair, 2021. [Online]. Available: https://www.redmanpowerchair.com/do-wheelchairs-have-a-weight-limit/ [Accessed November 17, 2021].

[8]. Motion Composites, "Technical Specifications," Motion Composites, 2021 [Online]. Available: https://www.motioncomposites.com/en_ca/products/rigid-wheelchairs/apex-c#technical-specifications [Accessed November 17, 2021].

[9] Future Mobility Products, "Lunar Basic," Future Mobility Products, 2021 [Online]. https://www.futuremobility.com/wheelchair-back-lunar-basic / [Accessed November 17, 2021]

[10] Sierra Joslin, "8 Benefits of Aluminum in Construction and Design," gb&d, June 21, 2021. [Online]. Available: https://gbdmagazine.com/benefits-of-aluminum/ [Accessed November 25, 2021].

[11] The Aluminum Association, "Infinitely Recyclable," The Aluminum Association. [Online]. Available: https://www.aluminum.org/Recycling [Accessed November 25, 2021].

[12] Metals Warehouse, “Aluminium VS. Stainless Steel: What are the Main Differences?” Metals Warehouse. [Online]. Available: https://www.metalswarehouse.co.uk/aluminium-vs-stainless-steel-what-are-the-main-differences/ [Accessed November 25, 2021].

[13] Jamie Kang, Joel Lee, Livia Murray, Agam Soni, Rylin Soto. BME 161, “Requirements Table”. Department of Systems Design Engineering, University of Waterloo, Waterloo, Canada, October 29, 2021.

[14] MobilityBasics, “Manual Wheelchair Frames” *MobilityBasics*, 2021. [Online]. Available: https://mobilitybasics.ca/wheelchairs/frames [Accessed November 23, 2021].

[15] K.Nunez, (2018, August) “Does Your Jogging Speed Feel Right?” *Healthline.* [Online] Available: https://www.healthline.com/health/average-jogging-speed. [Accessed September 26 2021].

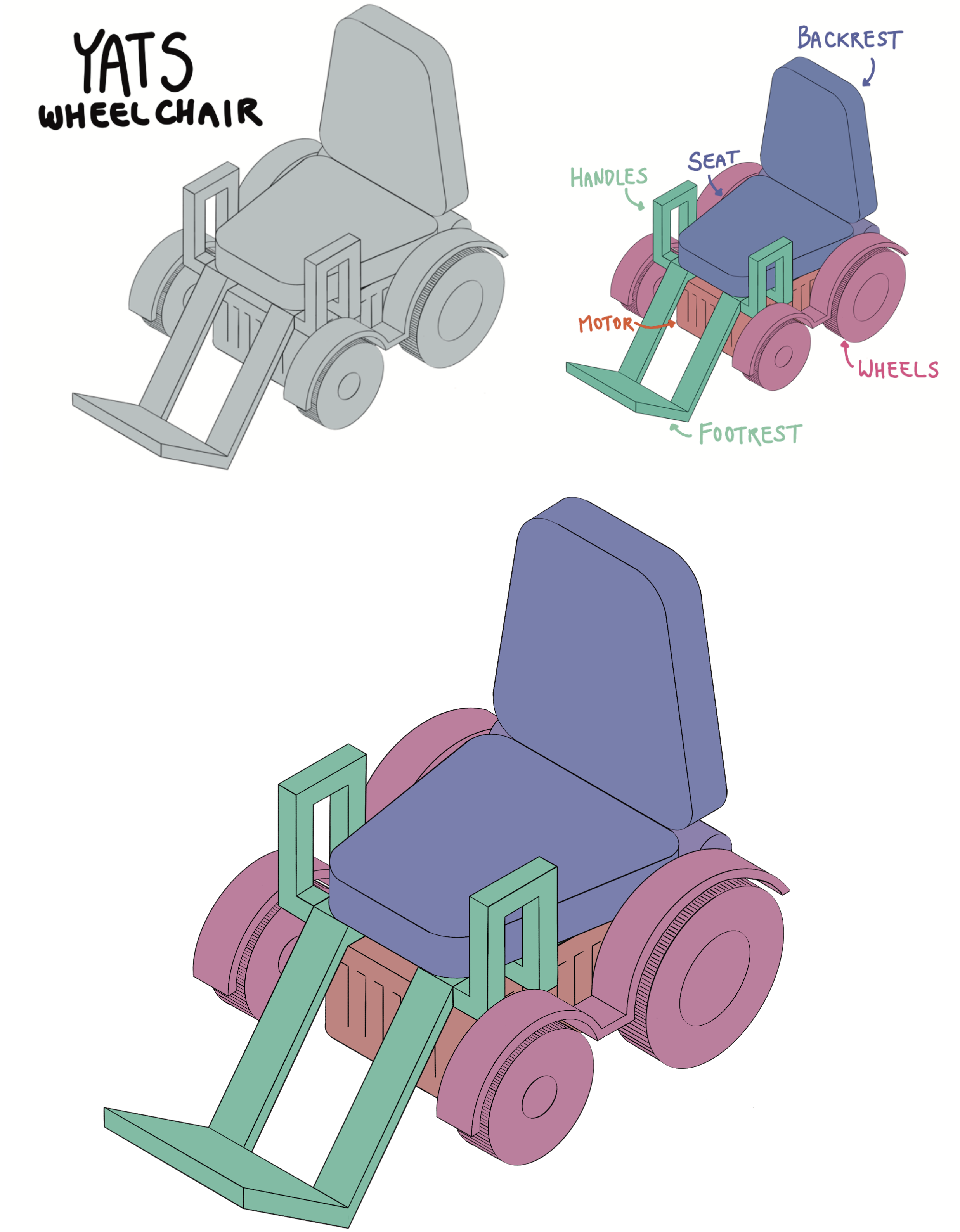
[16] J. Howcroft. BME 161. Class lecture, Risk Analysis, “BME161 - Wk11 - Risk Analysis.” Systems Design Engineering, University of Waterloo, Waterloo, Canada, November 15, 2021.

[17] Jamie Kang, Joel Lee, Livia Murray, Agam Soni, Rylin Soto. BME 161, “Situation Impact Statement”. Department of Systems Design Engineering, University of Waterloo, Waterloo, Canada, October 29, 2021.

Appendix:

Additional Sketches:

Figure 3: High quality YATS sketch



Engineering Analysis:

Related constraint:

Table 1: Constraint 5

C5	The wheelchair must not tip backwards in a locked position.	Weight of wheelchair (kg)	Have test dummies ranging from min weight(33kg) to max weight (115kg) lean backwards at max angle when the wheelchair is in the locked position.	The weight of the wheelchair must not exceed a maximum weight of 113kg when compensating for the tipping of the wheelchair.

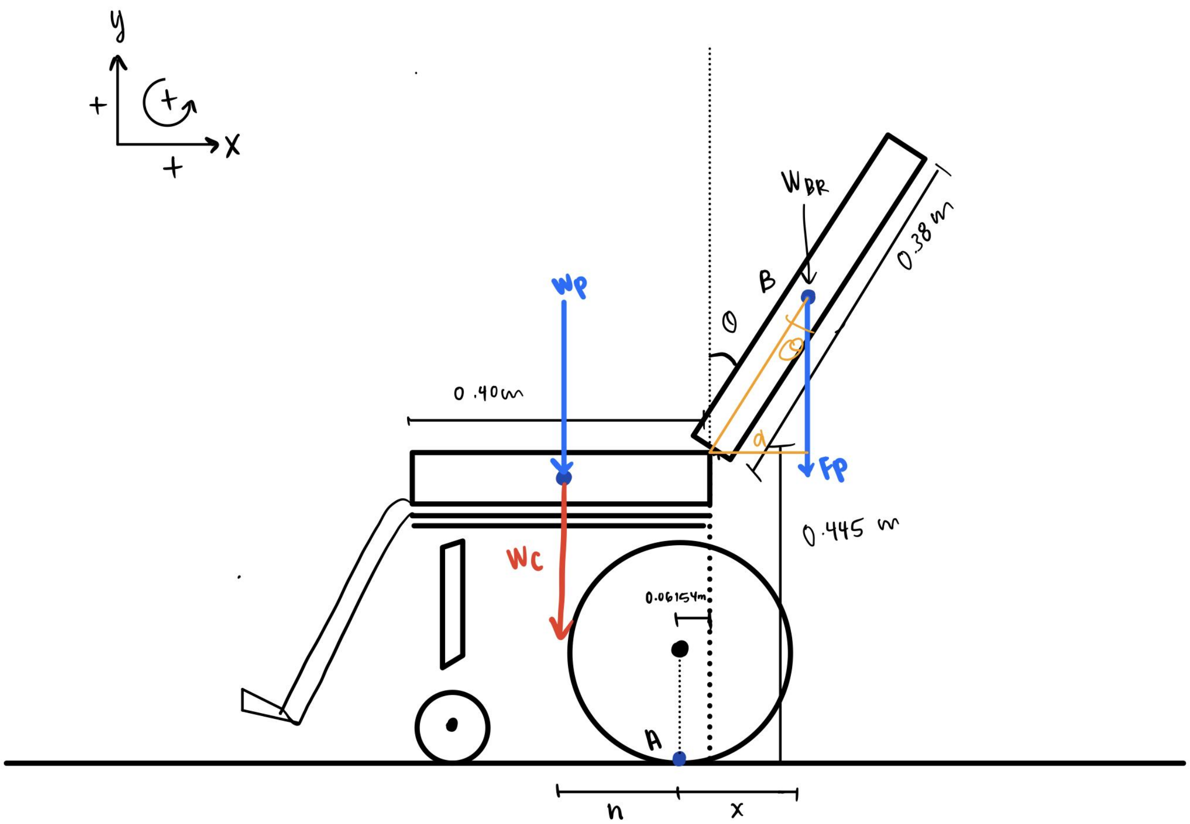
Objective:

Solve for the minimum overall weight of the wheelchair to prevent it from tipping when the backrest is locked at a 40 degree angle.

The following assumptions were made during the engineering analysis:

1. Assume the most extreme case - calculate with conditions that would make the most amount of force to make the wheelchair topple over.
    a. User is at the maximum weight capacity of 100 kg [7]
    b. Assume heaviest upper body (male, high upper body proportion, etc).
    c. Assume lightest lower body (amputee, no shanks or feet).
2. Assume the wheelchair is in a locked position to allow for static calculations and that the user is leaning backwards at the maximum angle allowance.
    a. Backrest is at an angle of 40 deg from the vertical.
3. Assume that the chair is on the verge of tipping backwards.
    a. No normal force required on the front wheel.
4. Weight and dimensions of wheelchair:
    a. Weight of backrest = 3lb [9] or 1.36078kg
    b. Height of backrest = 0.38m [8]
    c. Distance between rear spoke and seat to backrest joint = 0.06154m [8]
    d. Width of seat = 0.4m [8]
    e. Height from floor to seat = 0.445m [8]

Free body diagram:
Figure 2: Free body diagram of YATS



Calculations:
Solve of weight of wheelchair, Wc and mass of wheelchair, Mc:

$\theta = 40^{o}$

$\phi = 50^{o}$

$\mu = 0.40$

$a = 0.19 sin\theta$

$x = (a + 0.06154) = 0.1837\, m$

$n = (0.2 - 0.06154) = 0.1385\, m$

Body weight distribution without leg/shank and feet = 93.82% [5]

F_p = Portion of the weight of the user acting on the backrest includes:

Weight of user's head, whole trunk and total arms = 69.06% of 93.82% [5]

$=> \frac{69.06}{93.82} \times 100\, kg = 73.609\, kg$

$F_P = 73.609\, kg\, (9.81 m/s^2)$

$= 722.10429\, N$

W_P = Portion of weight of the user acting on the seat

$=> 100kg - 73.609kg = 26.391kg$

$$W_P = 26.391kg\,(9.81m/s^2)$$
$$= 258.89571\,N$$

W_{BR} = Force of backrest

$$W_{BR} = 1.36078kg\,(9.81m/s^2)$$
$$= 1.3349N$$

$$\Sigma M_A = 0$$
$$0 = F_P(x) + W_{BR}(x) - W_P(n) - W_C(n)$$
$$= 722.10429N(0.1837m) + 1.3349N(0.1837m) - 258.89571N(0.1385m) - W_C(0.1385m)$$
$$W_C = \frac{722.10429N(0.1837m) + 1.3349N(0.1837m) - 258.89571N(0.1385m)}{0.1385m}$$
$$W_C = 700.759\,N$$
$$M_C = \frac{W_C}{9.81m/s^2}$$
$$M_C = 71.43\,kg$$

Additional Questions for user testing:

<u>Testing - Requirement 1:</u>

Figure 3: List of user tasks

1. Vacuum home
2. Mop home
3. Do the dishes
4. Do laundry
5. Cook dinner
6. Mow lawn
7. Do morning routine
8. Do nightly routine
9. Shoveling show
10. Raking leaves

Table 2: Durability Damage Rating Scale

Damage Rank	Damage Description
1 (Good Condition/No Damage)	No dents or scratches on the frame, and the wheelchair is fully functional, usable, and safe.

2	Small dents or scratches on the frame, however the wheelchair is still functional, usable, and safe.
3	Major dents to the frame leading to the frame deforming, other components such as gyroscope, legs rests are damaged. The wheelchair is slightly functional, but not safe.
4	The seat is broken and the frame is half deformed, along with the damage to the motor and sensors. Highly unsafe and not functional.
5 (Worse Condition/ Fully Damaged)	The frame of the wheelchair is fully deformed, the battery is damaged, and the rest of the wheelchair is fully damaged. The wheelchair is neither safe nor stable and is in the condition to be disposed of.

<u>Iteration Plan - Survey 1:</u>
Figure 4: Comfortability User Questions
Rate on a scale of 1-10: *1 - not comfortable at all & 10 - extremely comfortable*

- Q1. Comfortability of seat cushion
- Q2. Comfortability of head rest
- Q3. Comfortability of foot rest
- Q4. Comfortability of back rest
- Q5. Overall comfort

<u>Iteration Plan - Survey 2:</u>
Figure 5: User centrism Ranting
Rate on a scale of 1-5: *1 - not well at all & 5 – exceptionally well*

- Q. Rate how well you feel that our solution has addressed your personal needs, wants, hopes and desires