GNG 2101 – Introduction to Product Design and Development

Design Deliverable F

Group F1.3

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5. **3.1 Identify your two most important non-functional design constraints (DFX factors) that play an important role in the development of your prototypes. Justify your reasoning**

One of the most important non-functional design constraints is usability/portability. The cane is intended for a user with mobility impairments that requires a lightweight, one-handed, and easy-to-use device. The user needs a cane that can be quickly deployed and stored, especially when using public transit, requiring a one-handing compacting mechanism. It's essential that the cane is portable and stores into a small and easy to carry from. If the design does not meet usability criteria, it won't be effective for its target users.

Another important design constraint is safety. Since the cane is a mobility aid, it must provide secure and reliable support. Ensuring a non-slip tip, sturdy structure, and stable locking mechanism is essential for preventing falls and injuries. The cane must be structurally sound and support at least 100kg with a safety factor of 1.5 to ensure no risk of failure. If the safety aspects are not properly addressed, the cane may fail under normal use conditions, putting the user at risk.

6. **3.2 For each design constraint, explain in detail what changes would need to be made to your design to satisfy the constraint (if any) or what already exists in the design to respect the constraint.**

To ensure usability and portability, several design elements have already been implemented, and additional modifications can further improve performance. The current design features a telescopic pole with a twist-to-lock. The twist locking mechanism enables quick and one-handed folding/unfolding. Additionally, a wide handle with wrist strap ensures a comfortable grip and secure handling over extended use. The wrist strap also provides a way to easily carry the cane whether it's extended or retracted. The 6063 Aluminum and ABS plastic is used to make the cane lightweight for ease of carrying, while its ability to fold down to 30% of its full length makes it convenient to store. Lastly, using a spring-loaded system enhances the ease of use when retracting the cane. However, some improvements can be made such as introducing a quick0access storage pouch would improve portability, ensuring that users can easily carry the cane when not in use.

For safety, the current design supports a maximum load of 100kg with a 1.5 safety factor, ensuring structural integrity. The non-slip rubber tip prevents slipping on various surfaces. The materials of the cane have been chosen to make the cane durable overtime and will be tested for extended use. Testing different rubber compounds and adding micro-textures to the tip can also enhance grip and longevity. Incorporating a shock-absorbing insert in the cane would minimize the vibrations from ground contact, making the cane more comfortable for extended use. Absorbing the impact forces would reduce the strain on the user making it safer for people with joint pain or reduced grip strength. Lastly, adding visibility features like a reflective strip, or small LED lights can increase user safety in low-light conditions. These improvements will ensure the cane remains safe and user friendly in all intended use cases.

7. **3.3 Provide proof (e.g. analysis, simple calculations and/or simulations, research) to demonstrate the effectiveness of your design in satisfying the constraints. Justify the process and methods you used**

To validate that the design meets these constraints, several tests should be performed. The following tables outline the testing that will be done on a prototype of the pole mechanism.

Table 1: Type of Testing

Test Number	Reason for Prototype	Evaluation	Level of Prototype
	Communication, Performance Measurement, Risk Management, Learning/Understanding	What are you testing with your concept (target measurable attributes)?	HiFi/LoFi Focused, HiFi/LoFi Comprehensive
1	Risk Managment	Load bearing capabilities of Cane Pole	HiFi Focused
2	Performance	Durability of opening/closing mechanism	HiFi Focused

Table 2: Testing Metrics

Kind of Prototype	Metrics	Test Description
Visual, Analytical, Physical	What metrics will you test?	What specifically will you test
Physical	The maximum weight the cane can hold	That the joints can sustain weight and repeated use to ensure the cane doesn't collapse.
Physical	The durability and performance of the opening/closing mechanism	Making sure the product doesn't break/deterirorate over repeated use and continues to work smoothly

Table 3: testing Analysis

Analysis Method	Results	Interpretation	Notes
Specifically how will you test, include things like duration, sequence of test, equipment, etc	Observe and record results	Pass or fail (include reason)	1. Include location of sketch, software libraries, reference materials, etc. 2. Take notes on how you can improve your next prototype 3. Other important things to remember

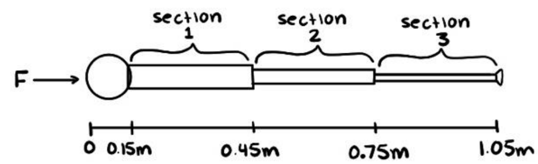
Stress test the prototype by adding more and more weight to the cane, until it breaks or surpasses the maximum load of 100kg + a 1.5 safety factor.	Record the weight that breaks the cane	Pass: it doesn't break before it reaches the needed weight capacity + safety factor Fail: It breaks before reaching the required load	1. Sketch location: Solid Works Test Location: MakerSpace 2. Adding the handle to more closely mimic the final product for more thorough testing. 3.
Stress test the prototype by rapidly opening/closing the cane. Repeat 500 times or until the mechanism deteriorates (gets harder to open/close, gets stuck/jammed, gets weaker)	Record how the experience of opening/closing the cane changes overtime.	Pass: The opening/closing remains smooth after 500 consecutive trails. Fail: The structural integrity of the cane weakens during the stress tests.	4. Sketch location: Solid Works Test Location: MakerSpace 5. Adding the handle and tip to more closely mimic the opening/closing motions for more thorough testing.

The first test ensures that the cane is safe while the second test validates the usability. To further prove that the design is safe, detailed calculations have been performed to ensure that the selected materials can safely withstand the applied load. Additionally, an analysis was conducted to determine the minimum required lip width for the telescopic sections, to make sure the locking mechanism securely holds the cane in place during use. These calculations provide essential proof that the design meets the safety constraints.

Figure 1-2: Safety Calculations

One-Handed Foldable Cane Calculations

Given Parameters



user weight = 100 kg

safety factor = ± 1.5

Givens from McMaster-Carr;

Section 1: inner diameter = 0.035 m outer diameter = 0.038 m

Section 2: inner diameter = 0.032 m outer diameter = 0.035 m

Section 3: inner diameter = 0.029 m outer diameter = 0.032 m

6063 Aluminum for Poles

Yield strength = 36000 Psi = 2.48×10^8 Pa

Tensile strength = 40000 Psi = 2.76×10^8 Pa

modulus of Elasticity = 10 000 000 Psi = 6.89×10^{10} Pa

Density = 2.7 g/cm³ = 2700 kg/m³

ABS (3D-Print) for lip and locking mechanism

Yield strength = 6000 Psi = 4.14×10^7 Pa

Tensile strength = 7500 Psi = 5.18×10^7 Pa

modulus of Elasticity = 2000 000 Psi = 1.38×10^{10} Pa

Density = 1.04 g/cm³ = 1040 kg/m³

shear stress = 3×10^5 Pa

Calculating Maximum force on Cane

$$F_{max} = mg$$

$$= (\text{safety factor}) \cdot (\text{user weight}) \cdot (g)$$

$$= (1.5)(100)(9.81)$$

$$\boxed{F_{max} = 1471.5 \text{ N}}$$

Calculating if 6063 aluminum can hold the load

compressive stress = $\sigma = \frac{F_{max}}{A}$ where A = cross sectional area

$$= \frac{\pi}{4}(d_{out}^2 - d_{in}^2)$$

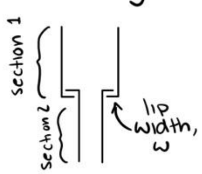
$$\sigma = \frac{F_{max}}{A} \qquad = \frac{\pi}{4}\left((0.032)^2 - (0.029)^2\right)$$

$$= \frac{1471.5\ N}{\frac{\pi}{4}(1.83\times10^{-4})} \qquad = \frac{\pi}{4}(1.83\times10^{-4})$$

$$\sigma = 1.024\times10^{7}\ Pa$$

$\boxed{\text{Since } 248\ MPa\ (2.48\times10^{8}\ Pa) > 1.024\times10^{7}\ Pa\text{, the aluminum tube will not fail.}}$

Calculating the width of lip between pole sections



shear stress = $\tau = \frac{F}{A}$ where; $A = \omega \cdot C$

$$= \omega\ 2\pi r_{in}$$

$$\tau = \frac{F}{\omega 2\pi r}$$

$$\Rightarrow \omega = \frac{F}{\tau 2\pi r}$$

section 1 and 2

$$= \frac{(1471.5)}{(3\times10^5)2\pi(0.035)}$$

$$= 0.022\ m$$
$$= 2.2\ cm$$

Section 2 and 3

$$= \frac{(1471.5)}{(3\times10^5)2\pi(0.032)}$$

$$= 0.024\ m$$
$$= 2.4\ cm$$

$\boxed{\text{Therefore the 3D-Printed Lips between poles must be } \geq 2.4\ cm}$

8. **Prototype 2**

9. **4.1 Summarize any new client feedback that you have received or any new testing results and clearly state what needs to be changed or improved in your design. Update your detailed design accordingly.**

Key Client Feedback & Required Changes

✓ Folding Efficiency: Concerned about the time required to collapse each section. Prefers an internal locking mechanism over visible clips.

✓ Thigh-Activated Folding: Likes using her thigh to shorten the cane. Prefers a fast, one-button compacting system.

✓ Locking System Customization: Wants adjustable locking points for custom height settings.

✓ Weight Concern: Telescopic sections may become too heavy. Prefers lightweight materials like carbon fiber over aluminum.

✓Handle & Strap Preferences: Prefers a thicker ergonomic grip and a ski-style wrist strap for better control.

Required Design Improvements:

- Modify the locking mechanism to ensure it can be released without fully letting go of the cane. Consider a spring-loaded push-button or groove-based system instead of manual clips.
- Optimize material choices to reduce weight while maintaining strength (aluminum or carbon fiber for segments).
- Redesign the handle to improve ergonomics and add a wrist strap for better grip security.
- Adjust segment proportions to balance weight distribution, preventing the cane from becoming too top-heavy.

10. **4.2 Define the most critical product assumptions that you have not yet tested. Explain which of your DFX factors from Project Deliverable B this assumption(s) relates to.**

As we move forward with refining our one-hand folding cane, we have identified three critical assumptions that require validation through testing. These assumptions directly impact the usability, safety, and overall performance of the product. Each assumption is linked to key Design for X (DFX) principles outlined in Project Deliverable B to ensure our design meets the intended functional, structural, and ergonomic requirements.

Assumption 1: The Modified Locking Mechanism Will Function Efficiently with One Hand

One of the most important aspects of the cane's design is ensuring that the user can collapse and extend the cane using only one hand. The locking mechanism should be fast, secure, and easy to engage/disengage without requiring excessive force or complex actions. The client has expressed a preference for using their thigh as leverage while collapsing the cane, which means the mechanism must function reliably in this context.

Challenges & Uncertainties:

- Force Required – Will the user be able to unlock the cane with minimal effort?
- Locking Speed – Can the mechanism be operated within a few seconds?
- Stability – Will the cane remain stable while being collapsed without causing imbalance?

Reliability Over Time – Will the locking system hold up after repeated use without becoming loose or ineffective?Impact on Design:

- The locking mechanism's placement and actuation method must be optimized to allow quick and intuitive operation.

- If the current design is too stiff or requires two hands, we may need to redesign the mechanism

Related DFX Factor: Design for Usability – The mechanism should be intuitive and effortless to use, allowing individuals with limited dexterity to operate the cane smoothly.

Assumption 2: The Cane Will Maintain Structural Stability While Remaining Lightweight

Description:
The cane must be strong enough to support at least 100 kg of user weight while also being lightweight enough for easy carrying and handling. A balance must be struck between structural integrity and weight reduction to meet both safety and portability requirements.

Challenges & Uncertainties:

- Material Selection – Will aluminum or carbon fiber tubing provide sufficient strength while keeping the total weight under 0.8 kg?
- Joint and Connection Strength – Will the telescopic joints and locking system withstand repeated stress without becoming weak?
- Impact of Tube Thickness – How thin can we make the tubes while maintaining load-bearing capacity?
- Effect of Repeated Use – Will the cane remain structurally sound after prolonged use (e.g., after 10,000 extension/contraction cycles)?

Impact on Design:

- If aluminum tubing is too heavy, we may consider switching to carbon fiber or a hybrid design to reduce weight.
- Finite Element Analysis will be required to simulate stress distribution in different parts of the cane.
- Load testing will help determine whether telescopic joints or connectors need reinforcement to prevent failure under weight.

Related DFX Factor: Design for Safety – Ensuring that the cane remains structurally stableunder load and does not bend, break, or fail unexpectedly.

Assumption 3: The Adjusted Handle Design Will Improve Comfort and Security

Description:
The handle and wrist strap play a crucial role in ensuring that the cane is comfortable and secure to use for extended periods. Since the client relies on a single hand to operate the cane, the grip

should be ergonomic, reducing strain on the hand and wrist. Additionally, the wrist strap should prevent accidental drops and allow for easy retrieval.

Challenges & Uncertainties:

- Grip Comfort – Will the handle shape minimize hand fatigue during prolonged use?
- Wrist Strap Effectiveness – Will the wrist strap provide sufficient security without limiting mobility?
- Handle Material – Does the handle material offer a non-slip surface while remaining comfortable to hold?
- Size and Weight Distribution – Is the handle proportional to the overall cane design, or does it make the cane feel unbalanced?

Impact on Design:

- The handle should be shaped to reduce pressure points and improve grip stability.
- A rubberized or foam-coated grip may be needed for better comfort and non-slip performance.
- The wrist strap length and attachment should be tested to ensure that it does not interfere with normal use.

Related DFX Factor: Design for Usability – Ensuring that users experience comfort and security while using the cane for extended periods.

11. **4.3 Define the tests that you must perform to assess the assumption(s).**

Test 1: Usability Test for Locking Mechanism

Objective: Ensure that the locking system can be operated with one hand and collapsed quickly.
Procedure:

- Have users extend and collapse the cane five times using only one hand.
- Measure the time required and force needed to operate the mechanism.
- Gather feedback on ease of use and comfort.

Success Criteria: The mechanism should allow full operation within 5 seconds, with an ease-of-use rating of at least 8/10.

Test 2: Load-Bearing and Weight Test

Objective: Ensure that the cane supports 100 kg while staying under 0.8 kg.
Procedure:

- Weigh the fully assembled cane.
- Apply a gradual vertical load up to 100 kg and observe any bending or deformation.

Success Criteria: No structural failure or noticeable bending should occur under 100 kg of force.

Test 3: Ergonomics and Comfort Assessment

Objective: Validate the handle design and wrist strap comfort over prolonged use.
Procedure:

- Have users hold and walk with the cane for at least 30 minutes.
- Ask for feedback on grip comfort, wrist strap security, and overall feel.

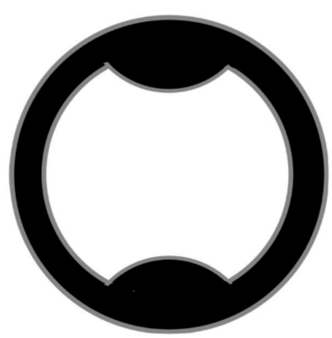
Success Criteria: At least 80% of users should report comfort with the handle and strap after extended use.

12. **<u>4.4 Develop a second set of prototypes that will test the critical product assumptions and help you to create your final prototype along the way.</u>**

The second prototype will be focused on assumptions one and two, making sure the design for the locking mechanism can be used with one hand and can support the weight of the user. This test will determine if the proposed design is efficient enough to be used in the final prototype.

13. **4.5 Document your latest prototype(s) using as many sketches/diagrams/pictures as required and explain the purpose and function of your prototype(s).**

Our latest prototype consists of two 3D printed pieces that resemble section 2 of the pole and the locking system that prevents the first pole from collapsing into each other. The aim of this prototype is to test if the conceptualized design is sufficient and can withstand the average force exerted [~130 N (30 lbs)] on the walking stick without collapsing.



The mechanism works by using the slots as guides to prevent the rods from twisting upon retraction and extension. The locking mechanism works by twisting the block piece into the horizontal slot, which prevents the rod from retracting and allows the user to place force on the rod without fear.

14. **4.6 Carry out prototype testing, analyze and evaluate performance compared to the updated target specifications first developed in Project Deliverable C and document all your testing results and prototype specifications. Present your testing in an organized, tabular format that shows expected versus actual results (i.e. compare your measured prototype specifications to your target specifications by including both in a similar table to the one your developed for Project Deliverable C).**

Since we are using 3D-printed PLA pieces tpo replicate aluminum, the equivalent force that it is able to withstand is much lower, therefore using the aluminum cross-sectional area of 223.7 mm^2 and a maximum force of 100N, it can be calculated with yield strength and force that the PLA equivalent force is 36.5 N.

Gym weights equivalent of 1kg (10N) were placed on the extended locked mechanism. The table below shows the pass/fail chart.

Equivalent Force on Aluminum	Force on PLA	Pass/Fail
26.9N	10N	Passed
54.8N	20N	Passed
82.2N	30N	Passed
109.6	40N	-NA-

15. **4.7 Outline what your team intends to present to your client(s) and what information you would like to gather at your next client meeting**

At the next client meeting, the team will be presenting a second prototype of the product, along with plans for future prototyping and building a finalized product, The client will be able to see part of the design process that led to the prototype being designed and manufactured the way it has, and the specifications that the product adheres to (ex. maximum weight, height, etc.). A CAD model of the design will be shown to demonstrate how the cane can be operated, along with any physical prototypes made at that point. It is important at this stage to present the information in a way that conveys the engineering of the product, while still ensuring that the information is digestible for the client.

Upon presenting the prototypes, it would be ideal to gather the client's likes and dislikes about the design. It would also be beneficial to address any concerns she may have, and learn how we can make the cane more optimal for her before the final prototype is designed. Other necessary information includes her height, the terrain in which she intends to use the cane, how tall she would like the cane to be, and whether she wanted a cane that clearly indicates she is disabled (as mentioned in the first client meeting).

16. **Project Plan Update**

PD F: Design constraints	**12 days**	**Sun 25-02-16**	**Sun 25-03-02**	
PD F.1: Design constraints	5 days	Mon 25-02-17	Fri 25-02-21	Alex
PD F.2: Prototype 2	2 days	Tue 25-02-18	Wed 25-02-1	Jennifer
PD F.2: Testing	2 days	Tue 25-02-18	Wed 25-02-1	Anjali
F.2.1-2.3	5 days	Mon 25-02-1	Fri 25-02-21	Armand
F2.4-2.6	5 days	Mon 25-02-1	Fri 25-02-21	Jennifer
F.2.7	5 days	Mon 25-02-1	Fri 25-02-21	Emily
PD F quality check	2 days	Thu 25-02-20	Fri 25-02-21	Emily
PD F projet plan update	2 days	Thu 25-02-20	Fri 25-02-21	Anjali
Client meet 3			Tue 25-02-25	
PD G: Economic and IP considerations	**12 days**	**Sun 25-03-02**	**Sun 25-03-16**	
PD G.1: Economics report	11 days	Mon 25-03-03	Sat 25-03-15	Alex
PD G.2: IP report	11 days	Mon 25-03-0	Sat 25-03-15	Emily
PD G quality check	2 days	Fri 25-03-14	Sun 25-03-16	Jennifer
PD G projet plan update	2 days	Fri 25-03-14	Sun 25-03-16	Anjali
PD H: Design day	**10 days**	**Sun 25-03-16**	**Thu 25-03-27**	
Final prototype	9 days	Mon 25-03-1	Thu 25-03-27	Anjali
Design day presentation	9 days	Mon 25-03-17	Thu 25-03-27	Emily
PD H quality check	3 days	Tue 25-03-25	Thu 25-03-27	Armand
Design Day	0 days	Thu 25-03-27	Thu 25-03-27	Jennifer