Word count: 2987

Design Recommendation for a Portable Commuter Workspace for University Students in Toronto

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Appendix C: Original Design Brief

Portable Commuter Workspaces

Total word count: 1773

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Introduction

This brief outlines the development of a portable workspace designed for commuters. Many commuters struggle with working efficiently during long commutes. This is a major problem for Engineering Science students, who must balance 30+ hours of classes a week with extracurriculars. An unproductive commute makes this difficult feat of time management even less manageable. The purpose is to transform these long travel times into efficient work periods by creating a workspace that is ergonomic, portable, and safe for use on public transit. The main challenge lies in finding a way to prevent back pain from being hunched over while working and carrying a heavy workspace, while also enabling productivity. Through observation of usability and accessibility standards, this brief sets a framework from which to design.

Problem Definition, Opportunities, Stakeholders

Public transit in Toronto (primarily TTC and GO services) lacks stable surfaces to complete school work on, forcing users' to use their lap, or backpack as a work surface. This both restricts laptop and mouse use, reducing efficiency, and makes study material susceptible to the train's vibrations, forcing the users to work in hunched positions. This can pose significant health and safety issues, such as musculoskeletal injuries [24]. Existing solutions (seen later in this report) are too large or heavy to carry for 12+ hours each day or are not accessible to a wide range of users.

For engineers attempting to solve this problem, major stakeholders include transit authorities, as the solution must not pose a safety hazard for the user and other passengers and the students who will be using and carrying the product for hours. Furthermore, product designers must ensure the workspace meets safety, usability, and accessibility standards, without compromising user safety.

While commutes can be seen as wasted time, this design would enable students to utilize the time spent commuting on coursework. From an ergonomic perspective, awkward posture and poor seating can be harmful and cause long term injury. The aim to avoid musculoskeletal injuries is important to those who spend hours working on laptops or other devices. It should also be noted that, while this is designed for engineering science students, others may also benefit.

Research, Reference Designs & Standards

Portable commuter workspaces must be designed for use on soft surfaces such as Go-Train seats. Designs that resemble acceptable solutions are tables designed to work on beds, and airplane trays. These pre-existing designs act as a basis of ideas.

1. Airplane Table Trays

Closely placed airplane seats [Fig 1] resemble the limited seating room on public transit. To allow for more productive experiences for airplane users, designers built tables attached to seats.

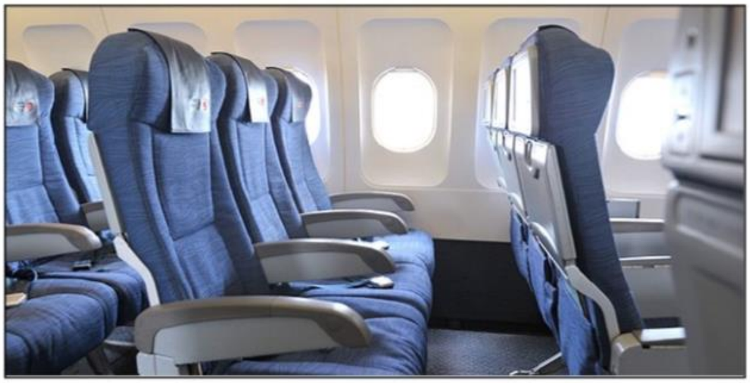

Fig 1: Air Canada economy class seats. Tightly packed seats with little room. Tray table attachment to seats when folded compactly shown [6].

All Air Canada airplane trays meet standards outlined in Canadian Aviation Regulations (CAR), which act as a basis for designing a commuter workplace (Appendix B) [4].

1. 525.561 - Outlines the maximum force seat elements (including a tray) must be able to withstand during a crash.
2. 525.789 - Details material specifications to minimize the risk of a fire.
3. 25.785 - Relates to usability, stating that seat elements such as tray tables must be easily operated by passengers to contribute to overall cabin safety [25].

Airplane tables are not portable and thus not a viable solution for a portable commuter workspace.

2. Bed Trays

Bed trays are used in medical contexts and at homes. General standards are outlined for all tables of this nature, providing a basis from which to design the opportunity. These are shown below.

Fig 3. Medical tray for home purposes making contact with the floor

Fig 2. Breakfast in bed style tables from IKEA [26]

Handbook on Human Factors Engineering for Medical Devices (Appendix B) [6]:

1. 4.3.1 - Products must be kept simple, preventing "extras getting in the way of performing basic tasks".
2. 4.4.3 - Must be designed such that it can accommodate a wide range of users.
3. 8.3.3.3. - Must be designed such that ambient lighting will not cause significant glare on the device. "Significant glare" depends upon task type.
4. 8.3.4.1 - The device should be capable of use in warm climates and colder climates, in varying temperatures and humidity extremes.
5. 8.3.4.1 - Temperature of surfaces that come in contact with device users should not exceed specific limits as can be seen in appendix A.
6. 8.3.5 - Vibration of displays should not affect user performance by a significant amount.

Furthermore, standards for tables and desks test for [8] [9] [10]:

1. Durability under environmental conditions
2. Edge durability
3. Leg Strength and Stability
4. Top Load Durability
5. Cyclic load testing (tests if tables can withstand repeated weights).

These standards provide a foundation for future creation and testing of a portable commuter workspace, however, medical tables and bed trays are not viable solutions as they are too large and not portable.

Ergonomic and Usability Factors

A portable workspace must be designed with ergonomic and usability factors in mind. Carrying the device must not harm the student, or the backpack in which it will be stored. Secondly, the design must be a functional workspace for use in trains and subways. Thus, constraints are introduced to the device.

First, the device must fit into a backpack without stretching it and be lightweight to prevent injury to the student [28]. Therefore, the material of the backpack plays a crucial role. Most backpacks are made to resist daily wear, crafted from nylon and polyester [1]. The outer material should stretch to fit the surface and protect backpack contents. The bag must also distribute weight evenly within the shoulder straps for student comfort.

Furthermore, the device's surface must fit the seats of the TTC or Go-Train. TTC seats have an average width of 17 inches, with a pitch range of 36.5-41 inches [4]. GO buses have two types of standardized seats, either a width of 17.5 or 18 inches, and pitches ranging from 29.7 to 33.5 inches. [4]. See more dimensions in appendix A. The product should thus fit within these constraints also

Figure 5. A photo of a TTC seat that the product should be able to fit in.

Design Criteria

Gap analysis shows the product must be designed with the following objectives in mind:

1. Must be compact enough to fit in the average backpack
2. Must be able to provide adequate space to fit one's study materials
3. Must provide a stable study surface the minimizes vibration
4. Must be usable by the 90th percentile man and the 10th percentile woman. Using these percentiles is standard practice in engineering and ensures that the product accommodates a wide range of users [20]
5. Must pose zero safety risk to anybody
6. Must be made of a material capable of using a mouse

Requirements and Evaluation Criteria

<table>
<tr><th>EC Identifier</th><th>Description</th><th>Verification Method</th><th>Objective & DFX</th></tr>
<tr><td>A1</td><td>When not in use, the product will have maximum dimensions of 10 x 12 x 3 inches such that it can fit into most backpacks.</td><td>Measuring tape</td><td>Objective 1 / Design for Usability</td></tr>
<tr><td colspan="4">Justification:
In inches, the average backpack's largest pouch is 10-14 wide, 12-16 long, and 3-5 deep [2]. A 10 x 12 x 3 workstation would accommodate most backpacks. These dimensions comfortably fit between a TTC seat [4].</td></tr>
<tr><td>A2</td><td>The product should have an adjustable width and height each expandable by 30% at minimum.</td><td>Measuring tape</td><td>Objective 2 / Design for Usability</td></tr>
<tr><td colspan="4">Justification:
A1 requires a maximum workstation size of 10 x 12-inch when not in use. Expandability of 30% creating a 13 x 16 workspace makes it more functional, similar to the 13 x 20-inch Breakfast in Bed tray, which holds a laptop, phone, drink and papers [19].</td></tr>
<tr><td>A3</td><td>The work platform must be able to accommodate the chest of a 10th percentile woman and a 90th percentile man.</td><td>Measuring tape</td><td>Objective 4 / Design for Accessibility and Usability</td></tr>
<tr><td colspan="4">Justification:
Ensures the working surface can accommodate a variety of people.</td></tr>
<tr><td>A4</td><td>The working surface must be adjustable at least 68 cm from the seat's back, allowing space for larger users.</td><td>Measuring tape</td><td>Objective 4 / Design for Accessibility and Usability</td></tr>
<tr><td colspan="4">Justification:
For a 90th percentile man: average waist circumference is 88 cm [24], placing the belly button 30cm from the back seat. Adding 38cm for forearm length [25], the workstation must be 68 cm from the seat for comfortable reach.</td></tr>
<tr><td>A5</td><td>Must weigh less than 5lbs.</td><td>Scale</td><td>Objective 4 / Design for Accessibility</td></tr>
</table>

			and Usability
Justification: For a 10th percentile 18-year-old female weighing approximately 108 lbs [21]. With an average backpack weighing 18.4 lbs [15], the product must be no more than 5 lbs to keep the total weight of the backpack under 20% of 108 lbs to prevent health issues [16].			
A6	The working surface must vibrate less than the train when the train experiences jolts and movements.	Testing in a virtual train environment, measuring vibrations of both the train and surface under various shocks.	Objective 3 / Design for Usability
Justification: Ensures the workspace remains stable during the commute.			
A7	The product should not require more than 200N of applied force to operate.	Test the force needed to operate the product.	Objective 4 / Design for Accessibility
Justification: Ensures product operation by 10th percentile average female grip strength, which is 200 Newtons [23].			
A8	Must be able to support a uniform load of 80lbs for an extended period of time (6 hours) when used by all users.	Product's maximum load (that it can support for six hours) must be found.	Objective 3 / Design for Usability
Justification: Assuming average weight on the workstation is the weight of an average backpack (18.4 lbs) [15], add 10 lbs for the user's arms on the workstation. Applying a factor of safety of two (standard practice in civil engineering), the critical load that must be supported is 60 lbs. Since most commutes are unlikely to exceed three hours, this time is multiplied by the safety factor, resulting in six hours.			
A9	The product must have no sharp edges. The softer the edges of the product, the better.	Visual inspection	Objective 5 / Design for Safety
Justification: The product will not injure the user in case of impact due to a train jolt.			

A10	The product must be made out of a computer-mouse-friendly material. More durability is better.	Durability material determined by testing resistance to friction (from a computer mouse)	Objective 6 / Design for Usability
Justification: Enhances usability for users on laptops.			

Conclusion:

The development of a portable commuter workspace that balances portability, usability, and safety, commuters can transform unproductive travel time into valuable work hours. This brief has outlined the problem, relevant standards, and design criteria, presenting a clear opportunity for innovation.

1. Introduction

This report recommends the Sit-On-It design—a foldable, height-adjustable table stabilized by the user sitting on its bottom brace—as a portable workspace for university students commuting on TTC and GO vehicles. The design addresses the lack of stable work surfaces in transit (see Appendix C), which often causes poor posture and musculoskeletal issues for students who work during commute [1]. Therefore, the proposed design must prioritize both the user's posture and comfort. This report reframes the original design opportunity, discusses alternative designs for commuter workspaces, and discusses the major design choices behind the final proposed design: the Sit-On-It.

2. Background

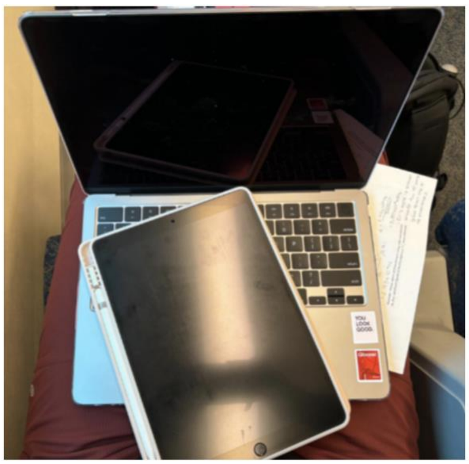

Figure 1: Lack of stable workspace for a university student to work on while commuting, forcing them to use their lap.

This report addresses the lack of a work surface for commuting university students (see *Figure 1*) in Toronto with access to seats on TTC subways, buses, and streetcars, as well as GO trains and buses. These transit services do not have stable surfaces for university students to work on during their commute, which forces students to instead use their lap or a backpack as a work surface (see *Figure B.2,* Appendix B*)*. The lack of a work surface makes study materials susceptible to the vehicle's vibrations, which can cause discomfort (see *Figure B.4*).

3. Stakeholder Needs

The key stakeholders in this design are commuting university students in Toronto, including the authors of this report, and other passengers on local and regional transit. The report is scoped to Toronto because a 2019 survey in the Greater Toronto-Hamilton Area found that 60% of university students use regional or local transit, mainly from the University of Toronto and Toronto Metropolitan University [27]. The University of Toronto states that local transit in Toronto consists of TTC subways, buses, and streetcars while regional transit consists of GO trains and buses [5].

The proposed design must address usability and accessibility. Survey feedback from Engineering Science students highlights the need for a stable work surface to reduce discomfort from poor posture and transit vibrations (*Figures B.3, B.4, B.6*). Given the variation in student height and weight, height adjustability is crucial for accessibility. Furthermore, the surface must be lightweight to avoid exceeding the recommended weight limit of 15% of a student's body weight in addition to the 14.7-lbs average weight of a backpack [29].

To avoid disturbing other passengers, the design must fit within the dimensions of a single seat. The seat width is 17 inches on TTC vehicles and 18 inches on GO transit vehicles. The minimum distance between two seats on a GO bus is 33.5 inches [2] and given that the 99th percentile male has a 13-inch elbow-wrist length, this leaves around 20.5 inches of space to the back of the seat in front of him [19].

4. Design Requirements

The following tables outline the requirements for the design opportunity based on design goals.

Table 1 (top), Table 2. (middle), Table 3 (bottom): Columns going left to right show objectives, metrics, with requirements and evaluation criteria, and justifications, in that order, and are listed for the goals of designing for (1) usability, (2) accessibility, and (3) safety. Objectives are labelled "Obj.", requirements "Req.", and evaluation criteria "EC.", all referenced as such in other sections of the report.

4.1 Goal 1: Design for Usability			
Objective	Metric		Justification
	Requirement	Evaluation Criteria	
Obj. 1: Workspace should fit in an average backpack.	**Req. 1:** Shall have maximum dimensions of 10" x 12" x 3" when folded.	**EC. 1:** The smaller the folded dimensions of the workspace, the better.	To ensure portability, the workspace must fit in a backpack, with the largest pouch typically measuring 10-14" wide, 12-16" long, and 3-5" deep (see Appendix C).
Obj. 2: Workspace should fit on one seat when used.	**Req. 2:** Shall have maximum dimensions of 17" x 20.5" in the horizontal directions when in use.	**EC. 2:** The greater the area of the unfolded work surface, the better.	As mentioned in Section 3, the smallest seat width is 17" and a person has at least 20.5" of space in front of them when sitting down.
Obj. 3: Workspace should be lightweight.	**Req. 3:** Shall weigh less than or equal to 4 lbs.	**EC. 3:** The lighter the workspace, the better.	As described in Section 3, the average backpack weighs 14.7 lbs, and should not weigh more than 15% of a person's body weight [29] For an average 18-year-old female, lighter than the average male, weighing1 25 lbs, her backpack should weigh no more than 18.7 lbs., leaving a maximum weight difference of 4 lbs for the workspace [11].
Obj 4: Workspace should not vibrate due to vehicle movement and vibrations.	**Req 4: S**hall have a natural frequency greater than 100 Hz.	**EC. 4:** The higher the natural frequency of the workspace, the better.	Transit vehicles experience ground-borne vibrations of 1-100 Hz [20]. If the workspace has a higher frequency, vehicle vibrations will be damped via energy absorption [21].

4.2 Goal 2: Design for Accessibility			
Objective	Metric		Justification
	Requirement	Evaluation Criteria	
Obj. 5: Workspace should have a surface high enough for comfortable use. Ideally, this height is adjustable to accommodate various users.	**Req. 5:** Height of the surface above the seat shall be between 8.2” and 13.7”. If adjustable, at least one setting must be in this range.	**EC. 5:** The greater the adjustable height range of the surface, the better. The range will be measured as a percentage of the shortest height setting.	The surface should be at least waist-level while sitting to prevent awkward posture. The minimum sitting waist height for a female is 8.2", and the maximum for a male is 13.7" [19].

4.3 Goal 3: Design for Safety			
Objective	Metric		Justification
	Requirement	Evaluation Criteria	
Obj. 6: Workspace should be able to support the objects a user would place on its surface.	**Req. 6:** Shall consistently support a uniformly distributed load of 49 lbs on the surface when in use.	**EC. 6:** The greater the maximum load the surface can support, the better.	The workspace must support the weight of an average backpack (14.7 lbs [8]), the user's arms (14 lbs, *Table A.5* in Appendix A) and its own weight (4 lbs max. from Req. 5). With a safety factor of 1.5 [9], the critical load should be at least 49 lbs.

5. Initial Design Space and Diverging Process

To explore and exhaust the design space for portable commuter workspaces within the constraints defined by Section 4, three diverging tools were employed:

1. Brainwriting (see Appendix E.1): The team developed and modified fifteen design ideas and then merged nine that were similar. Four designs were selected for further improvement of which three are covered in Section 6: Sit-On-It, FoldX, and DeskPack.
2. Reverse Brainstorming (see Appendix E.2): This tool helped the team identify previously overlooked issues, such as vibrations from public transport, that needed to be addressed, as seen in Appendix B, *Figure B.4*.
3. Morph Chart (see Appendix E.3):
    a. This chart expanded the design space for individual functions. Mechanisms like the folding mechanism in FoldX and height adjustability in Sit-On-It and DeskPack were incorporated. A new design, BriefDesk, was developed by combining two main mechanisms: a handle for portability and a rotatable axis.

b. A solution to the vibration issue identified through Reverse Brainstorming was selected from the damping mechanisms in the chart, leading to the first key design decision.

This decision uses damping thickness practices employed in plate vibration damping to achieve the same energy-damping effects in the workspace [28].

A Pairwise Comparison (Appendix E.4) was used to evaluate the uniqueness and performance of five designs based on the requirements (*Tables 1, 2, 3*). One design was discarded due to mechanisms susceptible to crushing under load, leaving four viable designs in Section 6.

KEY DESIGN DECISION 1: All connection points to the workspace surface must have a 5/8-inch layer of neoprene for damping (EC. 4).

6. Four Alternative Designs

6.1. Sit-On-It

The Sit-On-It (SOI) design is a two-way foldable table. The top flaps (see *Figure 2*) fold up to form the work surface, supported by hinges (see *Figure 3*). The bottom folds outward like the top flaps to create space for the user's legs, while the middle section includes a height extension mechanism (see *Figure 4*) for adjustability. A demonstration of the Sit-On-It can be found here.

Figure 2: Compact dining table with two sides on hinges that fold out to form a wide table surface [24].

Figure 3: Shelf hinge designed to be foldable and support a heavy load when locked at a right angle [22].

Figure 4: Extension tube commonly used in tripods. The rod can be locked at any location in its adjustable range by tightening the buffer—thick part of the rod [32].

6.2. FoldX

The FoldX surface uses accordion-style folding (see *Figure 6*), with a walking stick mechanism (see 20 in *Figure 5*) connecting the folds to snap into place. The legs are extendable with a telescopic design for adjustable height (see *Figure 8*). When fully assembled, a cross support forms underneath the surface, providing stability. The cross is made of solid bars with ball-and-socket joints at the table corners (see *Figure 7*), connected by a four-way connector (see *Figure 9*). A demonstration of the FoldX can be found here.

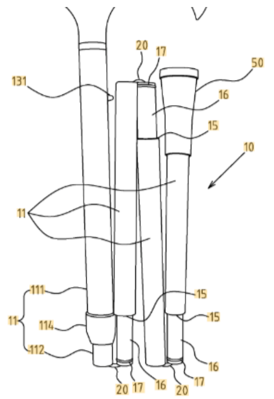

Figure 5: Folded walking stick labelled with different components. Number 20 indicates a mechanism that allows for the walking stick to snap into place at the connection [22].

Figure 6: Folding table with the accordion-style folding mechanism for different segments of the top surface [4].

Figure 7: Mechanical ball and socket joint, allowing the rotation of a connected mechanism, such as the extended screw shown [13].

Figure 8: Telescopic leg with adjustable height that can lock in any position in its range [14].

Figure 9: Four-way connector with slots of equal radii fitting up to four rod-like objects [6].

6.3. BriefDesk

The BriefDesk design features a handle that frames the folded tabletop. When rotated outward and locked, the handle acts as a support for the user to place between their legs while sitting. The surface is a tri-fold design, with two sections unfolding for a wider table similar to *Figure 11*. The connection to the handle allows for complete 360º rotation and the surface can be locked at any angle (see *Figure 10*). A demonstration of the BriefDesk can be found here.

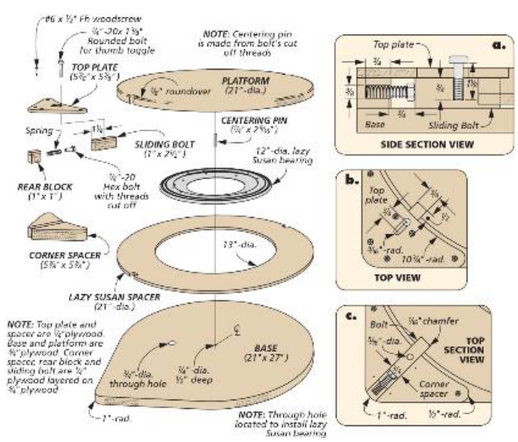

Figure 10: Image of a Lazy Susan mechanism employed for rotating the base of saws. The image shows a locking mechanism, which can stop the plate from rotating in various positions along the disk [16].

Figure 11: Two images showcasing a tri-fold mirror, which is extendable via hinges placed between axles of rotation [26].

6.4. DeskPack

The DeskPack design can be carried similar to a backpack by wearing straps connected to the workspace. A table surface connects to extendable rods with socket joints (see *Figure 13*), which are then connected to the straps, allowing the surface to be pulled out for use. When not needed, the DeskPack can be detached from the straps. The straps are adjustable through buckles (see *Figure 12*), which allow the user to slide the workspace up and down their torso as needed.

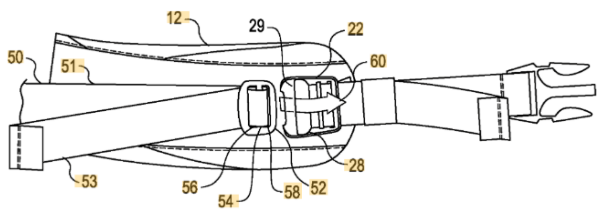

Figure 12: Backpack buckle on a strap, buckle labelled as object 52. Arrows 54, 56, and 58 show the components that allow the buckle to slide up and down the strap, as shown by arrow 60, allowing for adjustable lengths [7].

Figure 13: Rod connected to a socket joint, allowing for rotation about the connection point [30].

Figure 14: Sketch demonstrating the DeskPack's features and how it should be used.

7. Comparing Alternative Designs

Four different testing methods were used to quantify the properties of the four viable designs and then comparison tools were used to differentiate them.

7.1. Testing Methods

Both physical and mathematical testing methods were used to evaluate the properties and performance of prototypes.

7.1.1. Dimensions and Weight Testing

To-scale cardboard prototypes (see videos in Section 6) were made for each design to compare dimensions and weights, test the folding mechanisms, and ensure they met dimension requirements (Req. 1 and Req. 2). A demonstration of physical dimensions testing can be found here. The prototypes' volumes were calculated (see Appendix D.3.), and their weights compared using an arbitrary constant (ρ) to represent material densities that would be selected in future design iterations (Req. 3).

7.1.2. Adjustable Height Testing

To compare the adjustable height mechanisms of DeskPack, FoldX, and BriefDesk, existing designs that employed the same mechanisms were referenced. For Sit-On-It design, the prototype was created with a testable extension mechanism for adjustable height measurements. The adjustability was measured as described in EC. 5, allowing proportional application to all four designs.

7.1.3. Loading Testing

The workspace's maximum load for EC. 6 was determined by analyzing failure modes of the tabletop and legs, including material yielding and global buckling (see Appendix D.2 for calculations). For the tabletop, maximum stress due to load P was calculated using the formula

$\sigma_{stress}$$\sigma stress$

= My/I. For the legs, failure due to yielding and buckling was evaluated, and the lower force between the two was used. A design's maximum load is the minimum of the three calculated loads.

7.1.4. Vibration Testing

To address EC. 4, the test determined the vibration frequency after damping to prevent resonance with transit vehicle vibrations (see Appendix D.1 for calculations). After researching appropriate materials, Key Decision 2 was established:

KEY DESIGN DECISION 2: Elastomers were chosen as damping materials, in connection to Key Design Decision 1, due to their effective polymer network composition for vibration damping [23]. Neoprene was selected for its low density [15] which reduces the device's weight (EC. 3).

Thus, the calculations used the lowest available Young's Modulus of an elastomer: 1.4 MPa (see *Figure A.5* in Appendix A), to find the minimum vibrational frequency of the workspace. This was compared to the 1-100 Hz range of transit vibrational frequencies [20].

7.2. Measurement Matrix

Table 4: The measurement matrix comparing the four designs listed in Section 6. The criteria are based on the EC.'s in *Tables 1, 2, 3,* as mentioned in the "Relevant EC" column. The EC to be prioritized when comparing designs using the Pugh Charts are labelled "High Priority" in the "Relevant EC" column.

Relevant EC	Measurements	BriefDesk	Sit-On-It	DeskPack	FoldX
EC. 1	Folded Dimensions ($in.^3$)	5.5 × 11.8 × 2.4	11.8 × 7.7 × 1.8	9.6 × 11.4 × 0.2	10 × 3.5 × 3.0
EC. 2 *(High Priority)*	Open Surface Dimensions ($in.^2$)	13.0 × 11.8	16.4 × 11.8	9.6 × 11.4	17.5 × 10
EC. 3	Weight (lbs)	ρ * 21.1 in^3	ρ * 161.5 in^3	ρ * 7.81 in^3	ρ * 43.6 in^3
EC. 4	Vibration frequency (Hz)	1041.5	1039.7	1040.7	1040.1
EC. 5 *(High Priority)*	Height Adjustability (% increase from shortest to tallest setting)	0%	93%	83% [12]	49% [31]
EC. 6	Maximum loading (Newtons)	951 * σ_{stress}	77.3 * σ_{stress}	14.49 * σ_{stress}	15.77 * σ_{stress}

EC. 2 and EC. 5 are "High Priority" as they enhance usability and accessibility as per stakeholder needs. Adjustable height addresses neck pain from hunching, an issue outlined in Appendix B, *Figure B.3*, while increased surface area aligns with the smallest standard desk dimensions of 40 x 24 inches [17] to meet stakeholder needs (Appendix B, *Figure B.6*).

7.3. Representative Pugh Chart

Table 5: Pugh Chart comparing the four designs from Section 6 based on the ECs in *Tables 1,2,3*. Rows compare EC. 1 through EC. 6, with Sit-On-It as the reference design ("DATUM"). Other designs are marked with '+' for better performance or '-' for worse performance compared to Sit-On-It. The total number of '+' and '-' for each design is shown in the bottom row.

EVALUATION CRITERIA	BriefDesk	Sit-On-It	DeskPack	FoldX
EC 1: The smaller the folded dimensions, (in.^{3}), the better	+	D	+	+
EC 2: The larger the open surface dimensions (in.^{2}), the better	-	A	-	-
EC 3: The less the weight, the better	+	T	+	+
EC 4: The larger its frequency of vibration (Hz), the better	+	U	+	+
EC 5: The more height adjustability (% increase from shortest to tallest setting), the better	-	M	-	-
EC 6: The more load it can hold, the better	+		-	-
Total	4+ 2-	0	3+ 3-	3+ 3-

Other Pugh Chart iterations are shown in Appendix F; however, the Pugh Chart in *Table 5* best displays the motivation behind the final recommendation of the Sit-On-It, as it showcases the design outperforming the alternatives in the high priority ECs (see *Table 4* and Section 7.2).

8. Final Design Recommendation

The final recommended design is the Sit-On-It, due to its outstanding performance in usability and accessibility. As shown in *Table* 5, Sit-On-It excels in usability, with the largest workspace area of 16.4 × 11.8 in^{-2} (EC. 2), and accessibility, offering the highest adjustable height range of 93% (EC. 5). While it slightly underperforms in vibration frequencies (see *Table* 4), its natural frequency is still over ten times higher than vehicle vibrations and within a comparable range. Additionally, Sit-On-It features the second-highest load capacity (77.3 * σ_{stress}, EC. 6). However, its weight (ρ * 161.5 in^3, EC. 3), requires improvement, which can be achieved through material and dimensional optimization.

To address these limitations, material exploration was conducted prioritizing low density and high yield stress, leading to Key Design Decision 3:

KEY DESIGN DECISION 3: Carbon fiber will be used for the workspace due to its low density and high strength [18], improving weight (EC. 3) and load capacity (EC. 6).

This material choice, combined with Sit-On-It's design features, ensures an exceptionally usable and accessible workspace while addressing performance gaps in weight and strength.

9. Conclusion

The final recommended design for a portable workspace for university students in Toronto to use on TTC and GO vehicle seats is the Sit-On-It, because it prioritizes usability and accessibility. The absence of stable work surfaces on transportation services often hinders students' productivity due to poor posture and disruptive vibrations. The diverging process yielded four viable alternative designs: Sit-On-It, FoldX, DeskPack, and BriefDesk. Upon comparing the alternative designs, the Sit-On-It was shown to outperform the others with its larger workspace surface area and highest adjustable height range. Maximizing usability and accessibility, the Sit-On-It ensures a more comfortable and productive commute for university students.

10. References

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Appendix A: Source Extracts

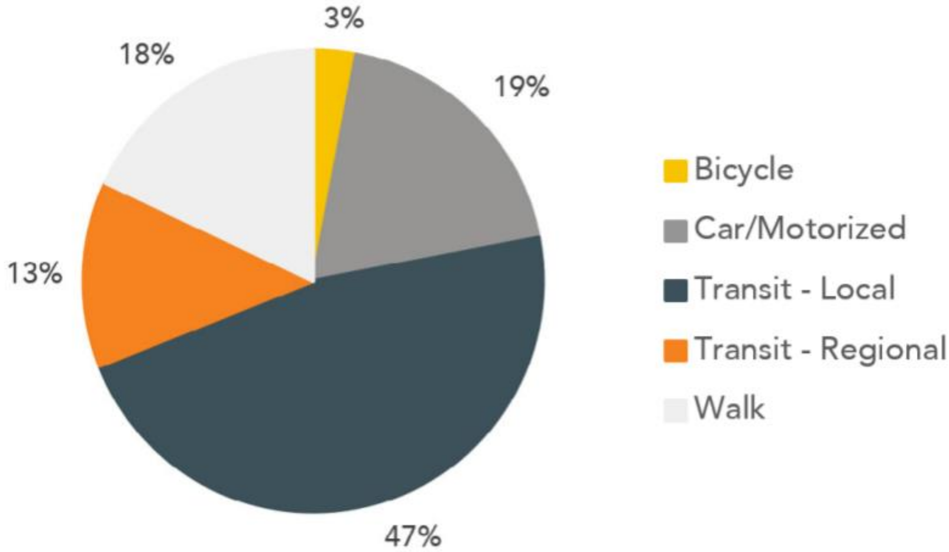


Figure A.1: Mode of transport for Home to Campus/Campus to Home trips [27].

	# of Students*	# of Responses	Response Rate	% of All Responses
Centennial College	25,454	1,153	5%	6%
Durham College	14,026	1,167	8%	6%
McMaster University	38,474	1,706	4%	9%
Mohawk College	40,000	657	2%	4%
OCAD University	4,788	422	9%	2%
Ontario Tech University	10,390	714	7%	4%
Ryerson University	47,296	3,968	8%	22%
Sheridan College	29,108	1,139	4%	6%
University of Toronto	60,000	5,289	9%	29%
York University	58,271	2,298	4%	12%
Total	**327,807**	**18,513**	**6%**	**100%**

Table A.1: Share of responses by university [27].

	Model 1 OR (95% CI)	Model 2 OR (95% CI)
Low-back pain *n* = 1758		
1. Standing in the same place	1.05 (0.82–1.34)	0.97 (0.75–1.25)
2. Back strongly bent or frequent twisting/turning of the back	**1.47 (1.18–1.83)**	**1.38 (1.09–1.74)**
3. Arms at or above shoulder height	1.01 (0.82–1.25)	0.93 (0.75–1.16)
4. Repetitive arm movement	**1.26 (1.02–1.56)**	1.08 (0.86–1.35)
5. Squatting or kneeling	0.99 (0.80–1.23)	1.03 (0.82–1.28)
6. Pushing/pulling or lifting/carrying	1.19 (0.96–1.47)	1.01 (0.81–1.26)
Neck-shoulder pain *n* = 1635		
1. Standing in the same place	1.08 (0.84–1.39)	1.07 (0.82–1.39)
2. Back strongly bent or frequent twisting/turning of the back	**1.42 (1.12–1.79)**	**1.29 (1.01–1.64)**
3. Arms at or above shoulder height	1.15 (0.92–1.43)	1.05 (0.83–1.32)
4. Repetitive arm movement	**1.38 (1.10–1.72)**	1.02 (0.80–1.30)
5. Squatting or kneeling	1.01 (0.81–1.27)	1.07 (0.85–1.36)
6. Pushing/pulling or lifting/carrying	1.19 (0.95–1.48)	1.06 (0.84–1.34)

Table A.2: Odds ratios for physical work demands among workers with region-specific musculoskeletal disorders [1].

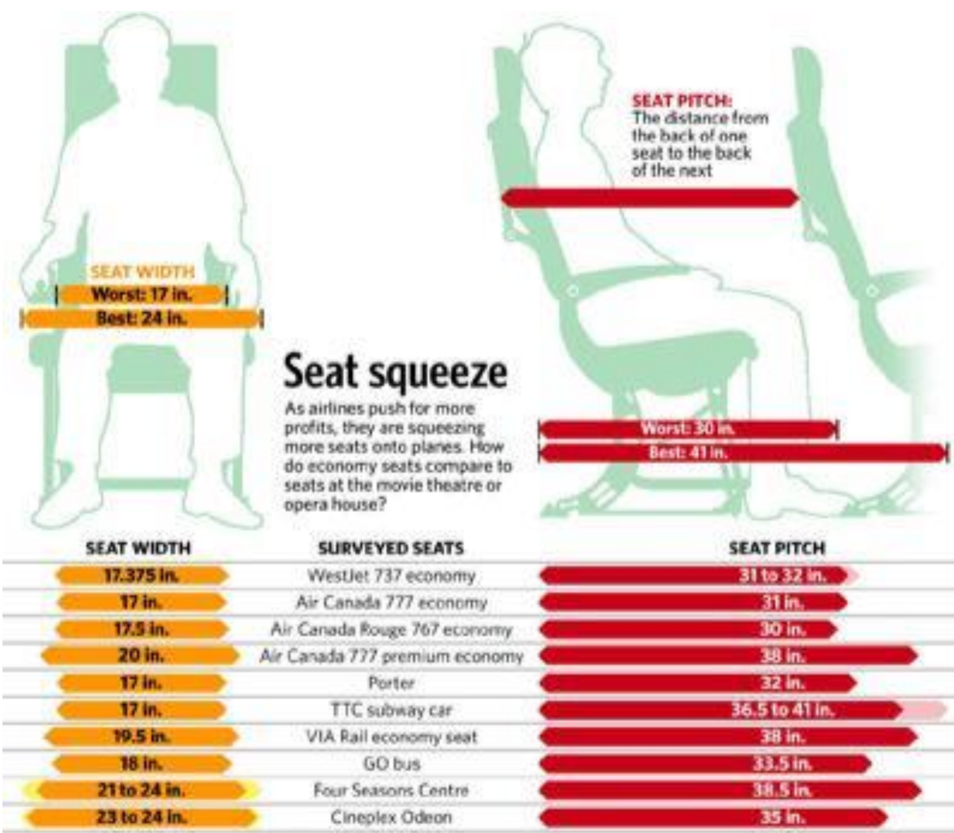


Figure A.2: Standard seat widths and pitches for some Canadian companies [2].

FEMALE N = 2208			MALE N = 1774		
Centimeters		**Inches**	**Centimeters**		**Inches**
32.88	**Mean**	12.94	36.00	**Mean**	14.17
1.77	**Std Dev**	.70	1.79	**Std Dev**	.70
41.30	**Maximum**	16.26	43.60	**Maximum**	17.17
23.70	**Minimum**	9.33	29.30	**Minimum**	11.54
	Percentiles			**Percentiles**	
29.93	1st	11.39	32.26	1st	12.70
29.35	2nd	11.56	32.64	2nd	12.85
29.63	3rd	11.67	32.89	3rd	12.95
30.02	5th	11.82	33.23	5th	13.08
30.63	10th	12.06	33.78	10th	13.30
31.04	15th	12.22	34.16	15th	13.45
31.37	20th	12.35	34.47	20th	13.57
31.66	25th	12.47	34.75	25th	13.68
31.92	30th	12.57	35.00	30th	13.78
32.17	35th	12.66	35.24	35th	13.87
32.40	40th	12.75	35.47	40th	13.97
32.62	45th	12.84	35.70	45th	14.05
32.84	50th	12.93	35.92	50th	14.14
33.06	55th	13.02	36.15	55th	14.23
33.29	60th	13.10	36.39	60th	14.33
33.52	65th	13.20	36.63	65th	14.42
33.77	70th	13.29	36.89	70th	14.52
34.04	75th	13.40	37.18	75th	14.64
34.34	80th	13.52	37.50	80th	14.76
34.69	85th	13.66	37.87	85th	14.91
35.15	90th	13.84	38.35	90th	15.10
35.84	95th	14.11	39.06	95th	15.38
36.29	97th	14.29	39.51	97th	15.55
36.64	98th	14.42	39.83	98th	15.68
37.20	99th	14.64	40.33	99th	15.88

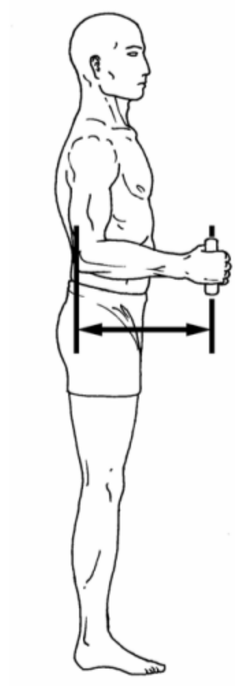


Figure A.3: Data for elbow-center of grip length [19].

Table A.3: Height and weight of males aged 13-20 [11].

Height to Weight for Male Teens 13 - 20 Years		
Age	**Weight**	**Height**
13 Years	100.0 lb. (45.36 kg)	61.5" (156.2 cm)
14 Years	112.0 lb. (50.8 kg)	64.5" (163.8 cm)
15 Years	123.5 lb. (56.02 kg)	67.0" (170.1 cm)
16 Years	134.0 lb. (60.78 kg)	68.3" (173.4 cm)
17 Years	142.0 lb. (64.41 kg)	69.0" (175.2 cm)
18 Years	147.5 lb. (66.9 kg)	69.2" (175.7 cm)
19 Years	152.0 lb. (68.95 kg)	69.5" (176.5 cm)
20 Years	155.0 lb. (70.3 kg)	69.7" (177 cm)

Table A.4: Height and weight of females aged 13-20 [11].

Height to Weight for Teenage Girls 13 - 20 Years		
Age	Weight	Height
13 Years	101.0 lb. (45.81 kg)	61.7" (156.7 cm)
14 Years	105.0 lb. (47.63 kg)	62.5" (158.7 cm)
15 Years	115.0 lb. (52.16 kg)	62.9" (159.7 cm)
16 Years	118.0 lb. (53.52 kg)	64.0" (162.5 cm)
17 Years	120.0 lb. (54.43 kg)	64.0" (162.5 cm)
18 Years	125.0 lb. (56.7 kg)	64.2" (163 cm)
19 Years	126.0 lb. (57.15 kg)	64.2" (163 cm)
20 Years	128.0 lb. (58.06 kg)	64.3" (163.3 cm)

Waist Height, Sitting (Natural Indentation)

	FEMALE N = 2208			MALE N = 1774	
Centimeters		Inches	Centimeters		Inches
27.95	**Mean**	11.01	28.73	**Mean**	11.31
2.14	**Std Dev**	.84	1.66	**Std Dev**	.65
36.00	**Maximum**	14.17	34.70	**Maximum**	13.66
20.08	**Minimum**	8.19	23.10	**Minimum**	9.09
	Percentiles			**Percentiles**	
22.81	1st	8.98	24.79	1st	9.76
23.48	2nd	9.24	35.31	2nd	9.96
23.88	3rd	9.40	25.63	3rd	10.09
24.42	5th	9.61	26.04	5th	10.25
25.22	10th	9.93	26.66	10th	10.50
25.75	15th	10.14	27.06	15th	10.65
26.16	20th	10.30	27.37	20th	10.78
26.52	25th	10.44	27.64	25th	10.88
26.84	30th	10.57	27.88	30th	10.98
27.14	35th	10.69	28.10	35th	11.06
27.42	40th	10.80	28.30	40th	11.14
27.70	45th	10.90	28.51	45th	11.22
27.97	50th	11.01	28.70	50th	11.30
28.24	55th	11.12	28.90	55th	11.38
28.51	60th	11.23	29.11	60th	11.46
28.80	65th	11.34	29.32	65th	11.54
29.10	70th	11.46	29.55	70th	11.63
29.42	75th	11.58	29.79	75th	11.73
29.78	80th	11.73	30.07	80th	11.84
30.20	85th	11.89	30.41	85th	11.97
30.72	90th	12.09	30.84	90th	12.14
31.46	95th	12.39	31.58	95th	12.40
31.92	97th	12.57	31.95	97th	12.58
32.25	98th	12.70	32.29	98th	12.71
32.73	99th	12.89	32.85	99th	12.93

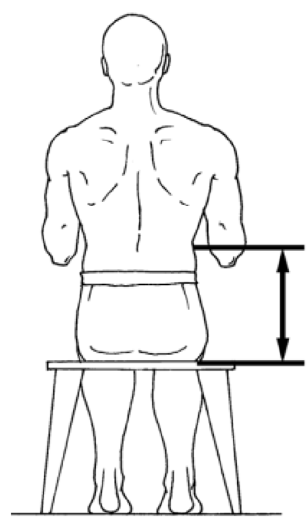


Figure A.4: Data for natural sitting waist height [19].

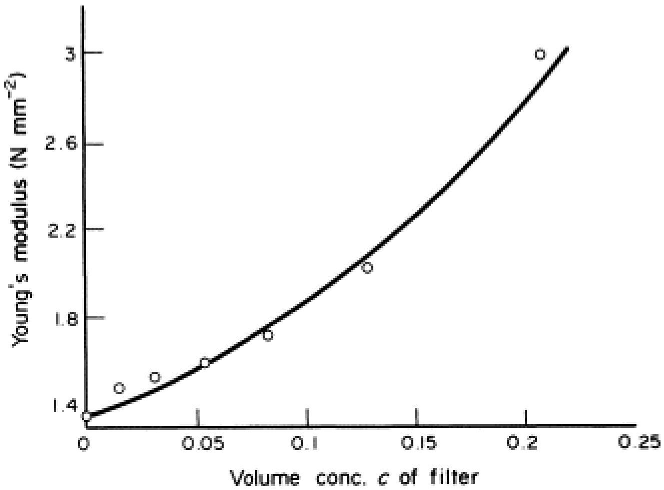


Figure A.5: Graph of Young's modulus of elastomers, showing a minimum of 1.4Nmm^{-2} [10].

Segment Weights as Percentages of Total Body Weight

	Men N = 35		Women N = 100	
One segment	Mean	SD	Mean	SD
Hand	0.65%	0.06%	0.5%	0.026%
Forearm	1.87	0.2	1.57	0.1
Upper arm	3.25	0.49	2.9	0.32
Foot	1.43	0.13	1.33	0.02
Shank	4.75	0.53	5.35	0.47
Thigh	10.5	1.21	11.75	1.86
Whole trunk	55.1	2.75	53.2	4.64
Head and neck	8.26		8.2	
Thorax	20.1		17.02	
Abdomen	13.06		12.24	
Pelvis	13.66		15.96	

Table A.5: Different weights of the parts of the human body, both male and female, listed as a percentage of total body weight. The upper arm and forearm percentages from this figure are applied to the average 18-year-old male body weight of 147.5 lbs from *Table A.3* [3].

Appendix B: Survey Results

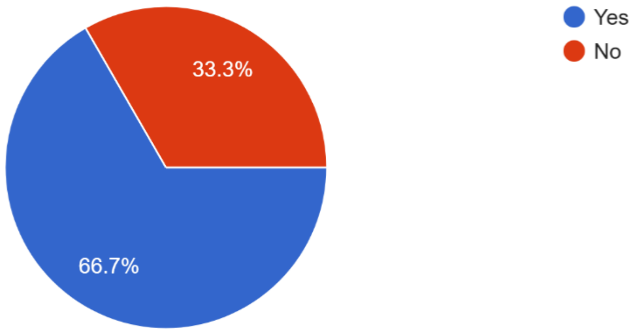


Figure B.1: Responses to “Do you work during your commute?”

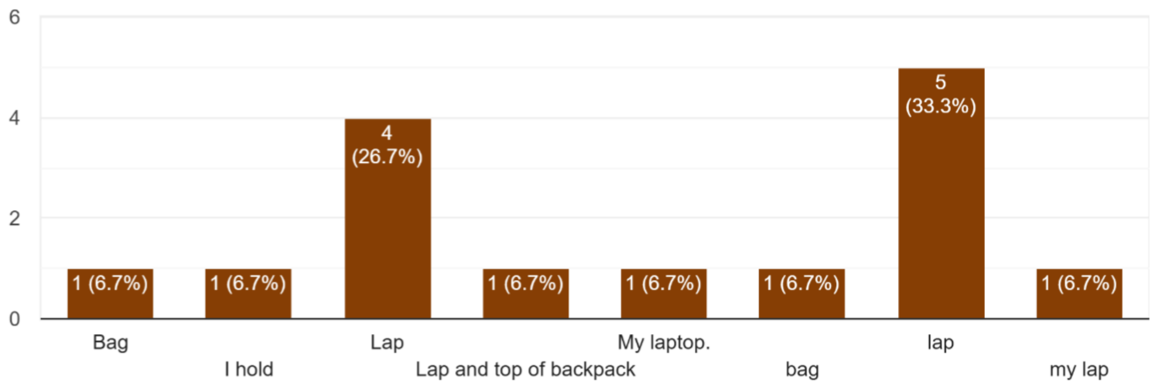


Figure B.2: Responses to “What do you use as your surface to place your study materials?”

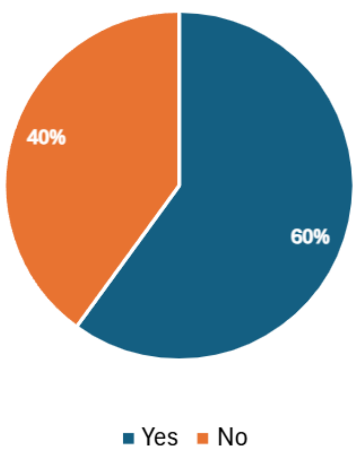
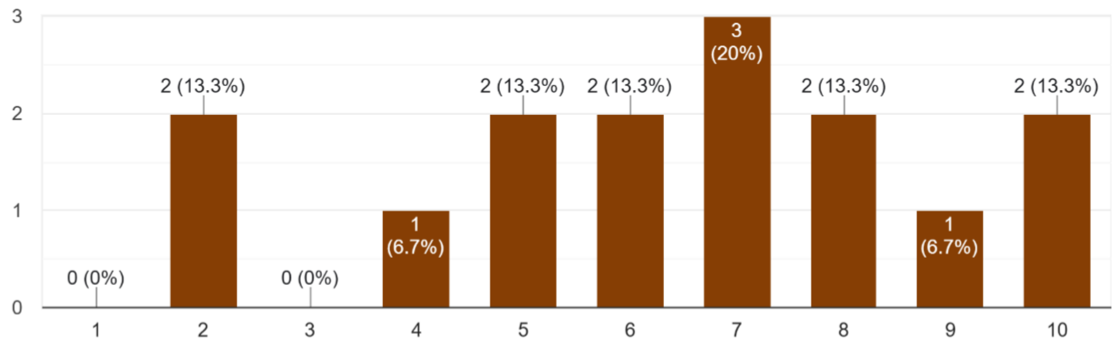


Figure B.3: Responses to “Do you ever feel pain in your back or neck due to working while commuting?”



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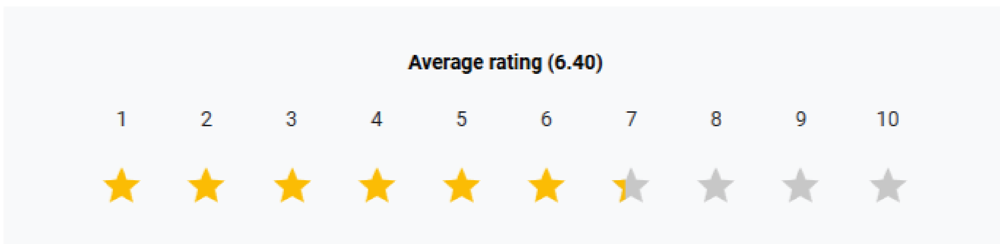


Figure B.4: Responses to “How much of an issue would you say vibrations of the vehicle are when working on a scale of 1 to 10? (1 - Not an issue at all; 10 - Can't get any work done because of it)”

I walk, so I can't safely do anything other than listen to stuff.

n/a

when i'm on the go train, sometimes people get mad at me for putting my feet on the seats in front of me (or i can't because someone's sitting in front of me), and so I have to rest my laptop on my knees, and then i have to write (i use pen and paper) on my laptop keyboard, and it's alright, (i've gotton used to it, and it's not terrible), but depending on the amount of pressure I put on my laptop, a key accidentally gets pressed, or the arrows get pressed, moving the laptop a bit). Basically, very small space you have to manage with.

Not too big, but it can also get a bit tiring, and if you're in shorter commutes (ex. when I am on the subway, my commute's 7ish minutes or if I miss my go train, and have to wait 20 minutes, it's a hassle opening it, working and then putting it away for a few minutes when my go train arrives. CONTACT ME FOR MORE INFORMATION IF NECESSARY.

Figure B.5: Some responses to “What makes working on commute inconvenient?”

Something to place the laptop on

some kind of desk space

NA

Some sort of desk

- pull out desk

A foldable tray table option

table

Better Wi-Fi

TABLES IN GO BUSSES!!!

Figure B.6: Some responses to "Anything you wish you had to make working while commuting easier?"

Appendix C: Original Design Brief

Portable Commuter Workspaces

Total word count: 1773

Table of Contents

Introduction

This brief outlines the development of a portable workspace designed for commuters. Many commuters struggle with working efficiently during long commutes. This is a major problem for Engineering Science students, who must balance 30+ hours of classes a week with extracurriculars. An unproductive commute makes this difficult feat of time management even less manageable. The purpose is to transform these long travel times into efficient work periods by creating a workspace that is ergonomic, portable, and safe for use on public transit. The main challenge lies in finding a way to prevent back pain from being hunched over while working and carrying a heavy workspace, while also enabling productivity. Through observation of usability and accessibility standards, this brief sets a framework from which to design.

Problem Definition, Opportunities, Stakeholders

Public transit in Toronto (primarily TTC and GO services) lacks stable surfaces to complete school work on, forcing users' to use their lap, or backpack as a work surface. This both restricts laptop and mouse use, reducing efficiency, and makes study material susceptible to the train's vibrations, forcing the users to work in hunched positions. This can pose significant health and safety issues, such as musculoskeletal injuries [24]. Existing solutions (seen later in this report) are too large or heavy to carry for 12+ hours each day or are not accessible to a wide range of users.

For engineers attempting to solve this problem, major stakeholders include transit authorities, as the solution must not pose a safety hazard for the user and other passengers and the students who will be using and carrying the product for hours. Furthermore, product designers must ensure the workspace meets safety, usability, and accessibility standards, without compromising user safety.

While commutes can be seen as wasted time, this design would enable students to utilize the time spent commuting on coursework. From an ergonomic perspective, awkward posture and poor seating can be harmful and cause long term injury. The aim to avoid musculoskeletal injuries is important to those who spend hours working on laptops or other devices. It should also be noted that, while this is designed for engineering science students, others may also benefit.

Research, Reference Designs & Standards

Portable commuter workspaces must be designed for use on soft surfaces such as Go-Train seats. Designs that resemble acceptable solutions are tables designed to work on beds, and airplane trays. These pre-existing designs act as a basis of ideas.

1. Airplane Table Trays

Closely placed airplane seats [Fig 1] resemble the limited seating room on public transit. To allow for more productive experiences for airplane users, designers built tables attached to seats.

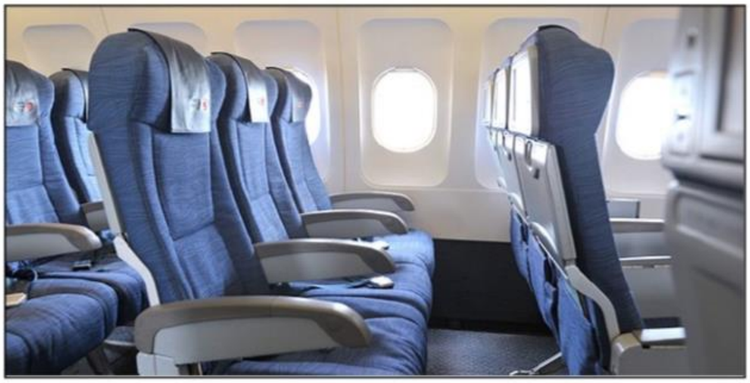


Fig 1: Air Canada economy class seats. Tightly packed seats with little room. Tray table attachment to seats when folded compactly shown [6].

All Air Canada airplane trays meet standards outlined in Canadian Aviation Regulations (CAR), which act as a basis for designing a commuter workplace (Appendix B) [4].

1. 525.561 - Outlines the maximum force seat elements (including a tray) must be able to withstand during a crash.
2. 525.789 - Details material specifications to minimize the risk of a fire.
3. 25.785 - Relates to usability, stating that seat elements such as tray tables must be easily operated by passengers to contribute to overall cabin safety [25].

Airplane tables are not portable and thus not a viable solution for a portable commuter workspace.

2. Bed Trays

Bed trays are used in medical contexts and at homes. General standards are outlined for all tables of this nature, providing a basis from which to design the opportunity. These are shown below.

Fig 3. Medical tray for home purposes making contact with the floor

Fig 2. Breakfast in bed style tables from IKEA [26]

Handbook on Human Factors Engineering for Medical Devices (Appendix B) [6]:

1. 4.3.1 - Products must be kept simple, preventing "extras getting in the way of performing basic tasks".
2. 4.4.3 - Must be designed such that it can accommodate a wide range of users.
3. 8.3.3.3. - Must be designed such that ambient lighting will not cause significant glare on the device. "Significant glare" depends upon task type.
4. 8.3.4.1 - The device should be capable of use in warm climates and colder climates, in varying temperatures and humidity extremes.
5. 8.3.4.1 - Temperature of surfaces that come in contact with device users should not exceed specific limits as can be seen in appendix A.
6. 8.3.5 - Vibration of displays should not affect user performance by a significant amount.

Furthermore, standards for tables and desks test for [8] [9] [10]:

1. Durability under environmental conditions
2. Edge durability
3. Leg Strength and Stability
4. Top Load Durability
5. Cyclic load testing (tests if tables can withstand repeated weights).

These standards provide a foundation for future creation and testing of a portable commuter workspace, however, medical tables and bed trays are not viable solutions as they are too large and not portable.

Ergonomic and Usability Factors

A portable workspace must be designed with ergonomic and usability factors in mind. Carrying the device must not harm the student, or the backpack in which it will be stored. Secondly, the design must be a functional workspace for use in trains and subways. Thus, constraints are introduced to the device.

First, the device must fit into a backpack without stretching it and be lightweight to prevent injury to the student [28]. Therefore, the material of the backpack plays a crucial role. Most backpacks are made to resist daily wear, crafted from nylon and polyester [1]. The outer material should stretch to fit the surface and protect backpack contents. The bag must also distribute weight evenly within the shoulder straps for student comfort.

Furthermore, the device's surface must fit the seats of the TTC or Go-Train. TTC seats have an average width of 17 inches, with a pitch range of 36.5-41 inches [4]. GO buses have two types of standardized seats, either a width of 17.5 or 18 inches, and pitches ranging from 29.7 to 33.5 inches. [4]. See more dimensions in appendix A. The product should thus fit within these constraints also

Figure 5. A photo of a TTC seat that the product should be able to fit in.

Design Criteria

Gap analysis shows the product must be designed with the following objectives in mind:

1. Must be compact enough to fit in the average backpack
2. Must be able to provide adequate space to fit one's study materials
3. Must provide a stable study surface the minimizes vibration
4. Must be usable by the 90th percentile man and the 10th percentile woman. Using these percentiles is standard practice in engineering and ensures that the product accommodates a wide range of users [20]
5. Must pose zero safety risk to anybody
6. Must be made of a material capable of using a mouse

Requirements and Evaluation Criteria

<table>
<tr><th>EC Identifier</th><th>Description</th><th>Verification Method</th><th>Objective & DFX</th></tr>
<tr><td>A1</td><td>When not in use, the product will have maximum dimensions of 10 x 12 x 3 inches such that it can fit into most backpacks.</td><td>Measuring tape</td><td>Objective 1 / Design for Usability</td></tr>
<tr><td colspan="4">Justification:
In inches, the average backpack's largest pouch is 10-14 wide, 12-16 long, and 3-5 deep [2]. A 10 x 12 x 3 workstation would accommodate most backpacks. These dimensions comfortably fit between a TTC seat [4].</td></tr>
<tr><td>A2</td><td>The product should have an adjustable width and height each expandable by 30% at minimum.</td><td>Measuring tape</td><td>Objective 2 / Design for Usability</td></tr>
<tr><td colspan="4">Justification:
A1 requires a maximum workstation size of 10 x 12-inch when not in use. Expandability of 30% creating a 13 x 16 workspace makes it more functional, similar to the 13 x 20-inch Breakfast in Bed tray, which holds a laptop, phone, drink and papers [19].</td></tr>
<tr><td>A3</td><td>The work platform must be able to accommodate the chest of a 10th percentile woman and a 90th percentile man.</td><td>Measuring tape</td><td>Objective 4 / Design for Accessibility and Usability</td></tr>
<tr><td colspan="4">Justification:
Ensures the working surface can accommodate a variety of people.</td></tr>
<tr><td>A4</td><td>The working surface must be adjustable at least 68 cm from the seat's back, allowing space for larger users.</td><td>Measuring tape</td><td>Objective 4 / Design for Accessibility and Usability</td></tr>
<tr><td colspan="4">Justification:
For a 90th percentile man: average waist circumference is 88 cm [24], placing the belly button 30cm from the back seat. Adding 38cm for forearm length [25], the workstation must be 68 cm from the seat for comfortable reach.</td></tr>
<tr><td>A5</td><td>Must weigh less than 5lbs.</td><td>Scale</td><td>Objective 4 / Design for Accessibility</td></tr>
</table>

			and Usability
Justification: For a 10th percentile 18-year-old female weighing approximately 108 lbs [21]. With an average backpack weighing 18.4 lbs [15], the product must be no more than 5 lbs to keep the total weight of the backpack under 20% of 108 lbs to prevent health issues [16].			
A6	The working surface must vibrate less than the train when the train experiences jolts and movements.	Testing in a virtual train environment, measuring vibrations of both the train and surface under various shocks.	Objective 3 / Design for Usability
Justification: Ensures the workspace remains stable during the commute.			
A7	The product should not require more than 200N of applied force to operate.	Test the force needed to operate the product.	Objective 4 / Design for Accessibility
Justification: Ensures product operation by 10th percentile average female grip strength, which is 200 Newtons [23].			
A8	Must be able to support a uniform load of 80lbs for an extended period of time (6 hours) when used by all users.	Product's maximum load (that it can support for six hours) must be found.	Objective 3 / Design for Usability
Justification: Assuming average weight on the workstation is the weight of an average backpack (18.4 lbs) [15], add 10 lbs for the user's arms on the workstation. Applying a factor of safety of two (standard practice in civil engineering), the critical load that must be supported is 60 lbs. Since most commutes are unlikely to exceed three hours, this time is multiplied by the safety factor, resulting in six hours.			
A9	The product must have no sharp edges. The softer the edges of the product, the better.	Visual inspection	Objective 5 / Design for Safety
Justification: The product will not injure the user in case of impact due to a train jolt.			

A10	The product must be made out of a computer-mouse-friendly material. More durability is better.	Durability material determined by testing resistance to friction (from a computer mouse)	Objective 6 / Design for Usability
Justification: Enhances usability for users on laptops.			

Conclusion:

The development of a portable commuter workspace that balances portability, usability, and safety, commuters can transform unproductive travel time into valuable work hours. This brief has outlined the problem, relevant standards, and design criteria, presenting a clear opportunity for innovation.

Appendix D: Calculations

D.1. Mathematical Modeling for Vibration

Finding the approximate frequency of vibration:

$$\omega^2 = \frac{k}{m}\ ; k = Fx$$

$$\mathrm{E} = \frac{F/A}{\Delta L/L}$$

$$FL = \frac{EA}{L} = k$$

$$\mathrm{f} = \frac{\omega}{2\pi} = \frac{\sqrt{k/m}}{2\pi} = \frac{\sqrt{EA/Lm}}{2\pi}$$

Design	Sit on it	Fan	Backpack	Cross
Area of dampening (in^2)	6x1	0.393701 x 0.393701	1.9685 x 0.11811 x2	0.46500093 in^2
Area of dampening (m^2)	0.00387	0.000100	0.000300	0.0003
Neoprene mass (kg)	m= 0.00800kg	m=0.000206kg	m=0.000619kg	M=0.0120kg
Frequency of vibration	1039.7 Hz	1041.5 Hz	1040.7 Hz	1040.6 Hz

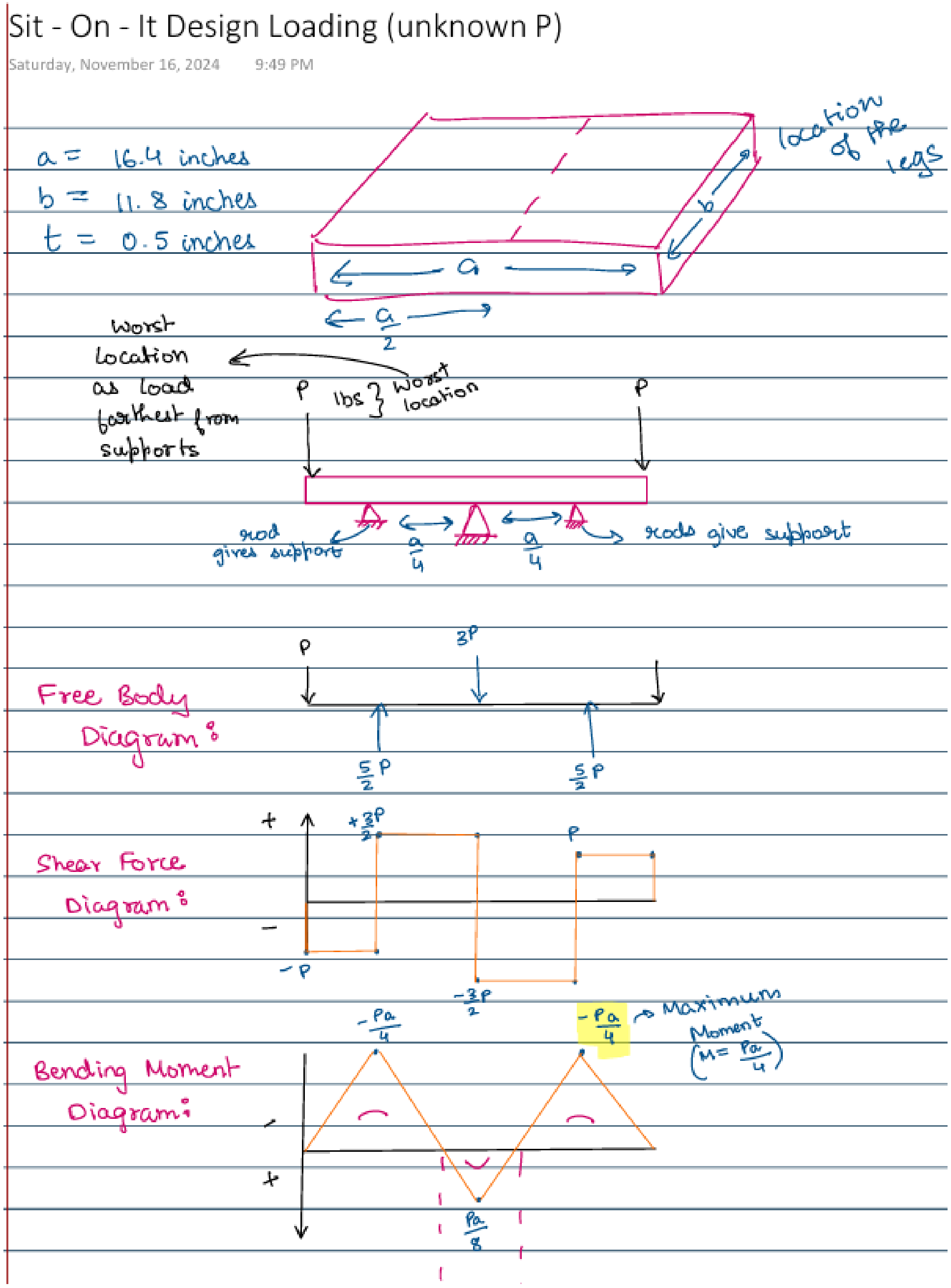
E=1.4*10^6 N/m^2

L= 5/8 inches = 0.015875m

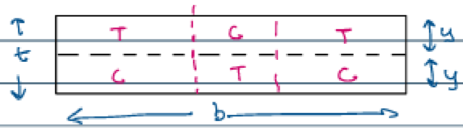
$$\mathrm{f} = \frac{\omega}{2\pi} = \frac{\sqrt{k/m}}{2\pi} = \frac{\sqrt{EA/Lm}}{2\pi}$$

D.2. Loading Calculations for Viable Designs

D.2.1. Sit-On-It



Cross-Section:
(T = Tension,
C = Compression)



Second Moment of Area, $I = \frac{b t^3}{12}$

Maximum stress, $\sigma_{max} = \frac{My}{I} = \frac{\frac{Pa}{4} \times \frac{t}{2}}{\left(\frac{bt^3}{12}\right)} = \frac{3}{2} \times \frac{Pa}{bt^2}$
(both Tension and Compression)

Tabletop will fail if σ_{yield} of material chosen $= \sigma_{max}$

So, $\sigma_{yield} = \frac{3}{2} \times \frac{Pa}{bt^2} \Rightarrow P = \frac{2}{3} \frac{bt^2}{a} \times \sigma_{yield}$

$P = 77.3 \times \sigma_{yield}$ N

D.2.2. FoldX

leg:

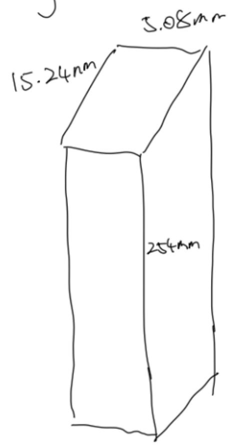
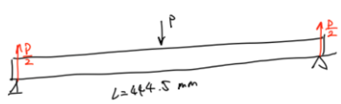
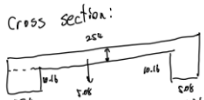


table:



Cross section:



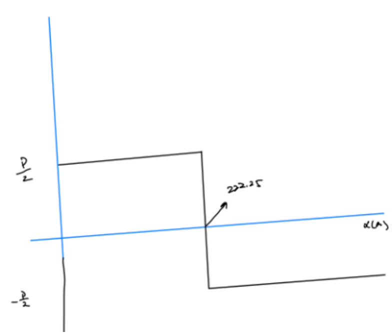
$$\bar{y} = \frac{(254)(5.08)(12.7) + (10.16)(5.08)(5.08) + (10.16)(25.4)(5.08)}{(25.4)(10.16) + (10.16)(5.08) + (254)(5.08)}$$

$= 11.43$ mm

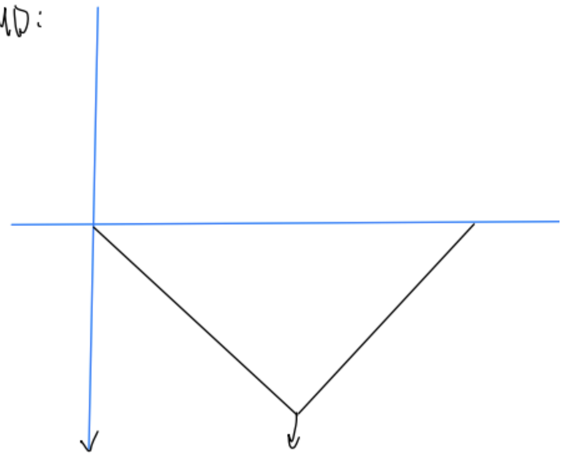
$$I = \frac{(10.16)^3(254)}{12} + (10.16)(25.4)(11.43-5.08)^2 + \frac{(5.08)^3(254)}{12} + (5.08)(254)(12.7-11.43)^2 + \frac{(10.16)^3(5.08)}{12} + (10.16)(5.08)(6.35)^2$$

$= 20007\ mm^4$

SFD :



BMD:



$$\sigma_c = \frac{My}{I}$$

$$= \frac{(3.81)(111P)}{20007} = \sigma_{yield}(c)$$

$$\Rightarrow P = 47.3 \cdot \sigma_{yield}(c)$$

$$\sigma_t = \frac{My}{I} = \frac{(11.43)(111P)}{20007} = \sigma_{yield}(t)$$

$$P = 15.77 \cdot \sigma_{yield}(t)$$

Compression in legs:

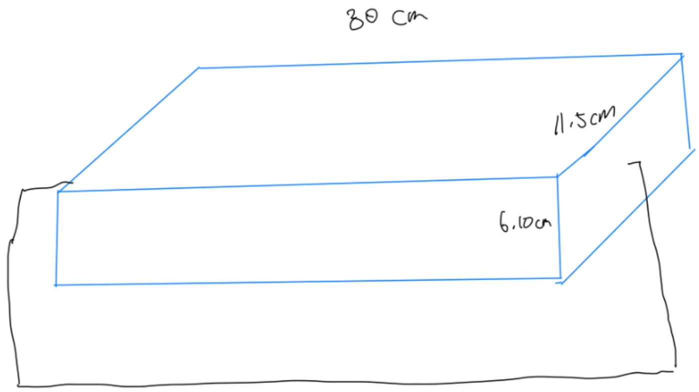
$$\sigma_{comp} = \frac{P}{4(5.08)(15.24)} = \frac{P}{310}$$

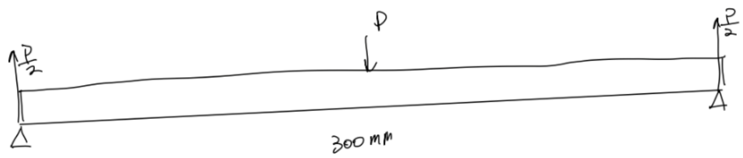
$$P = 310\,\sigma_{yield}(c)$$

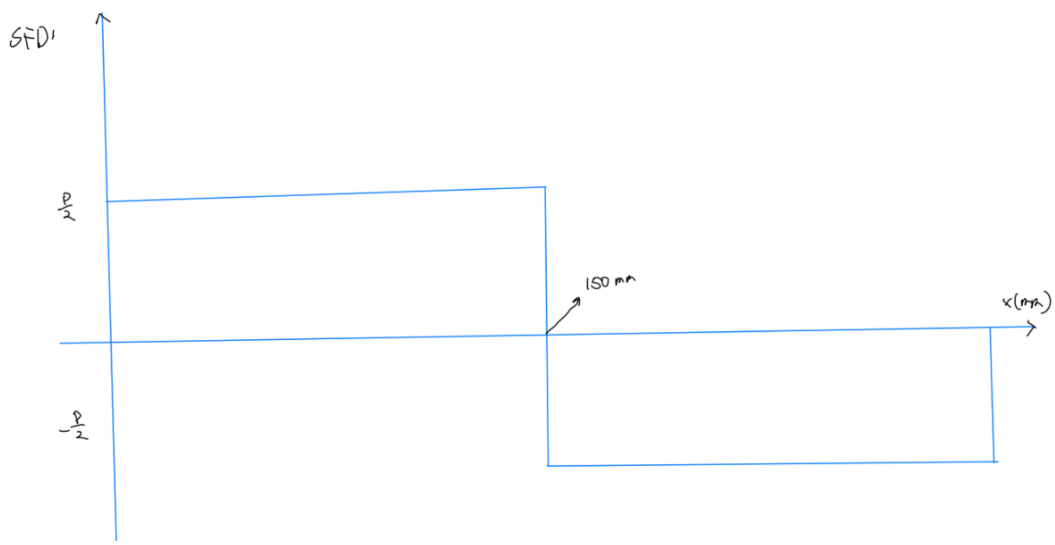
buckling:

$$P_{crit} = \frac{\pi^2 I E}{L^2} = 3.06E$$

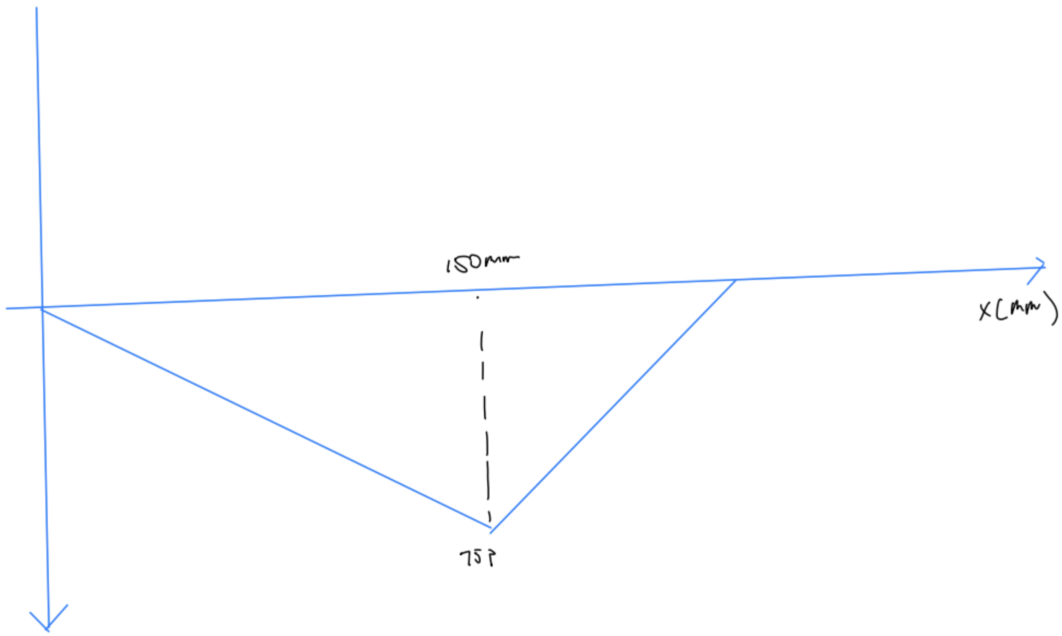
D.2.3. BriefDesk







BMD:



Cross section:

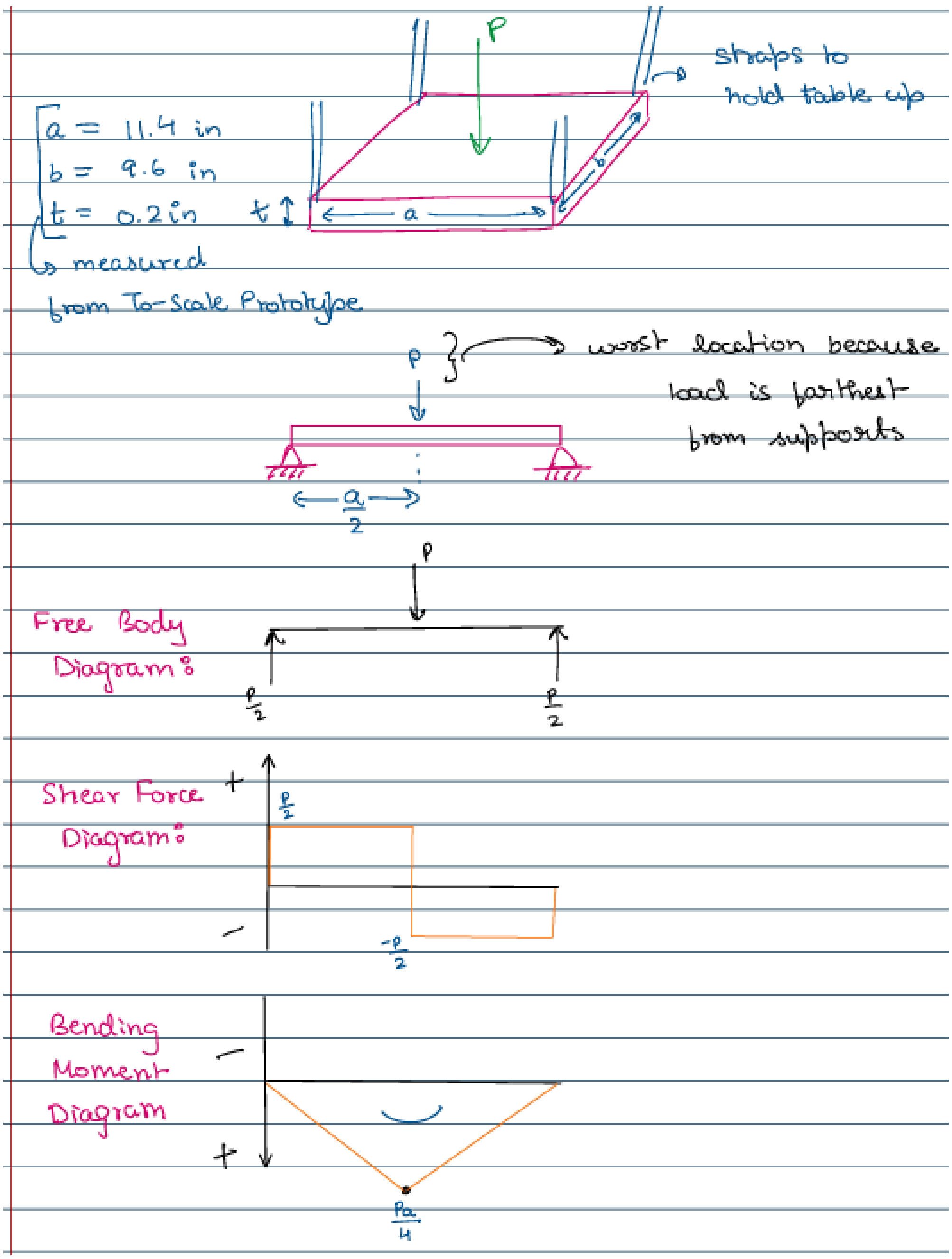
$y = 30.5\text{mm}$

$$I = \frac{(61^3)(115)}{12} = 2.175\times10^6 \text{ mm}^4$$

$$\sigma = \frac{My}{I} = \frac{(75)(30.5)P}{2.175\times10^6} = \sigma_{yield}$$

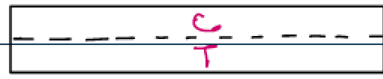
$$P = 951\times\sigma_{yield}$$

D.2.4. DeskPack



Cross-Section:

(T = Tension,
C = Compression)



Second Moment of Area, $I = \frac{b t^3}{12}$

Maximum stress, $\sigma_{max} = \frac{My}{I} = \frac{\left(\frac{Pa}{4}\right) \times \frac{t}{2}}{\left(\frac{bt^3}{12}\right)} = \frac{3}{2} \times \frac{Pa}{bt^2}$

(both Tension and Compression)

Tabletop will fail if σ_{yield} of material chosen $= \sigma_{max}$

So, $\sigma_{yield} = \frac{3}{2} \times \frac{Pa}{bt^2} \Rightarrow P = \frac{2}{3} \frac{bt^2}{a} \times \sigma_{yield}$

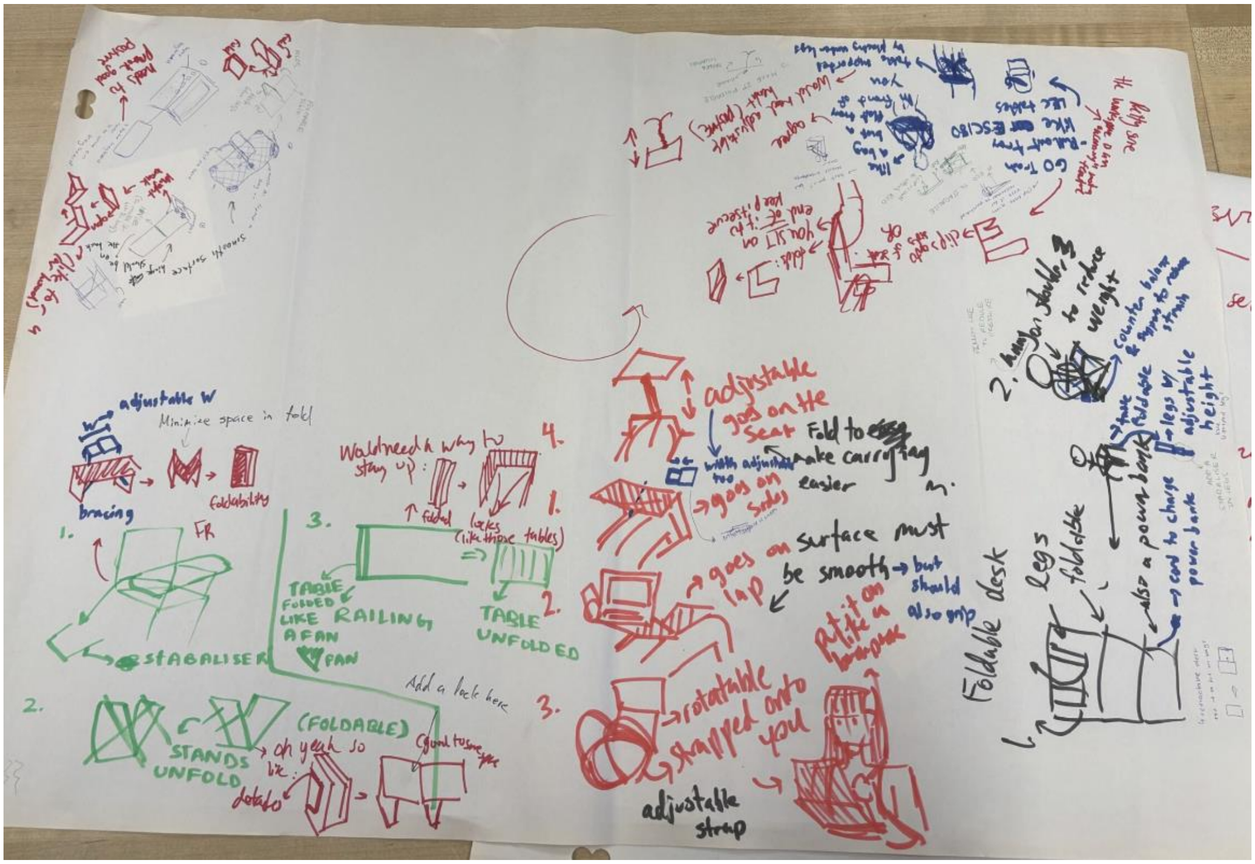
$P = 14.49 \times \sigma_{yield}$ N

D.3. Volume Calculations for Viable Designs

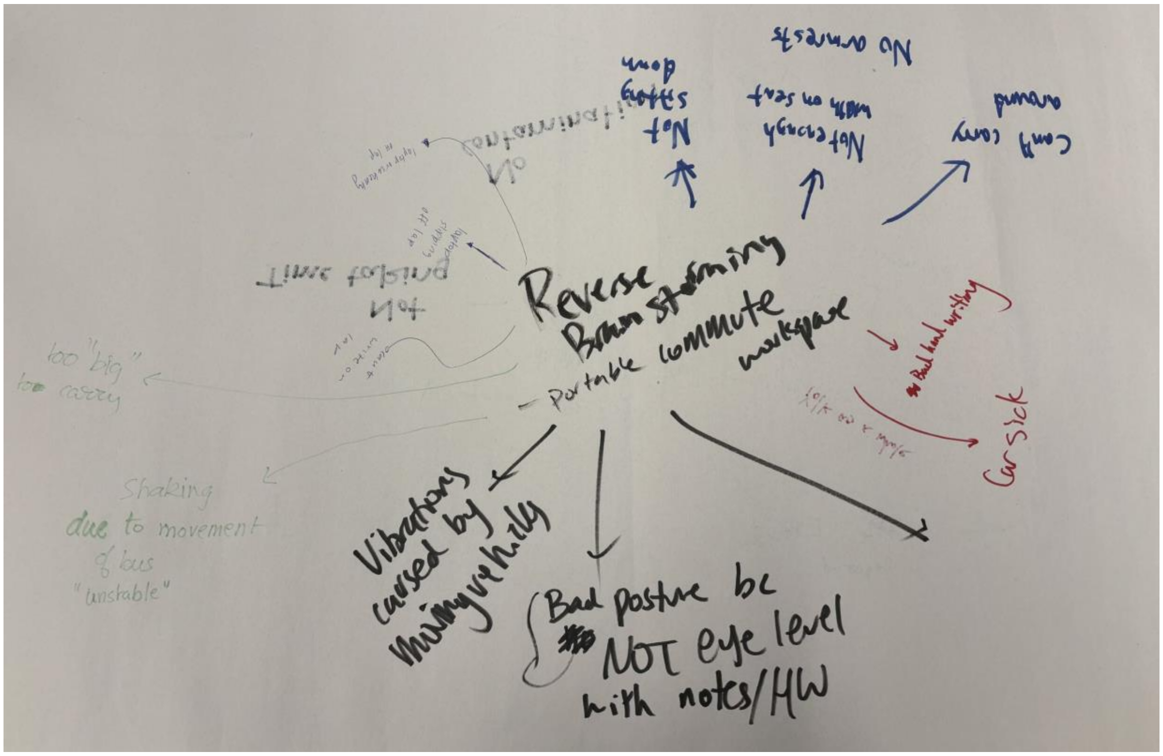
Design	Sit on it	Fan	Backpack	Cross
Total Volume	30×19.6×4.5 cm = 2646 cm^3	28×11.5×1cm + 30×4×0.2 = 322 + 24 = 346cm^3	29×24×0.2 = 139cm^3	Total volume = 42.16 inch^3 + 1.2 inch^3 = 43.36 inch^3 = 710.543095 cm^3

Appendix E: Diverging and Converging Process Evidence

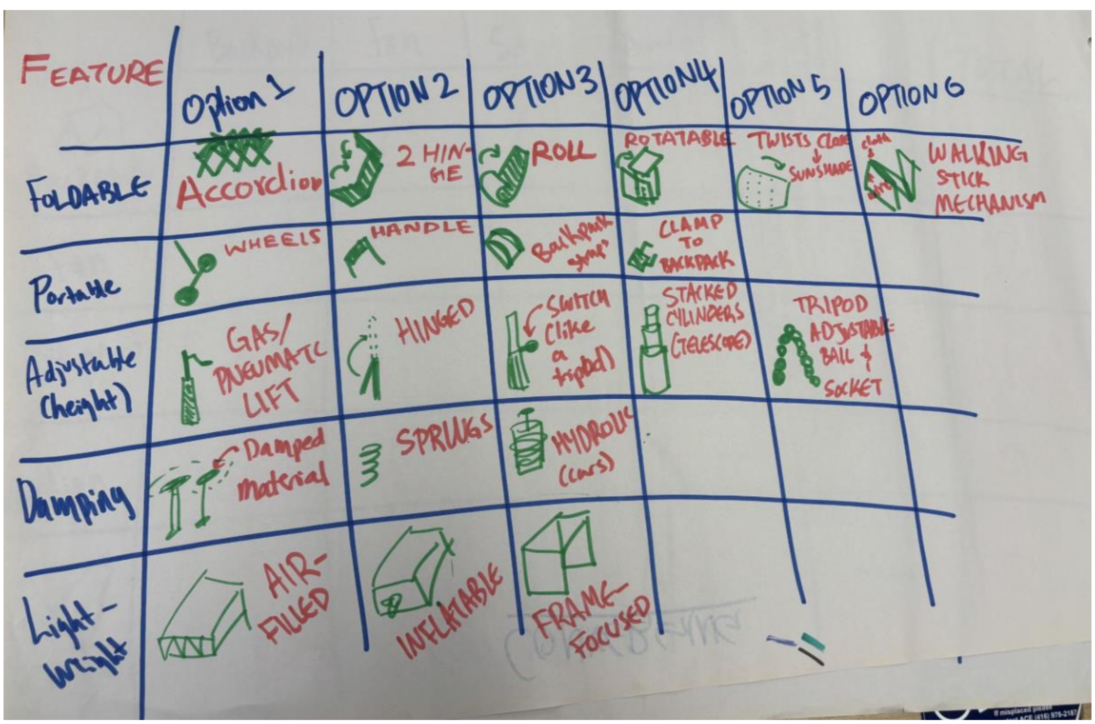
E.1. Brainwriting



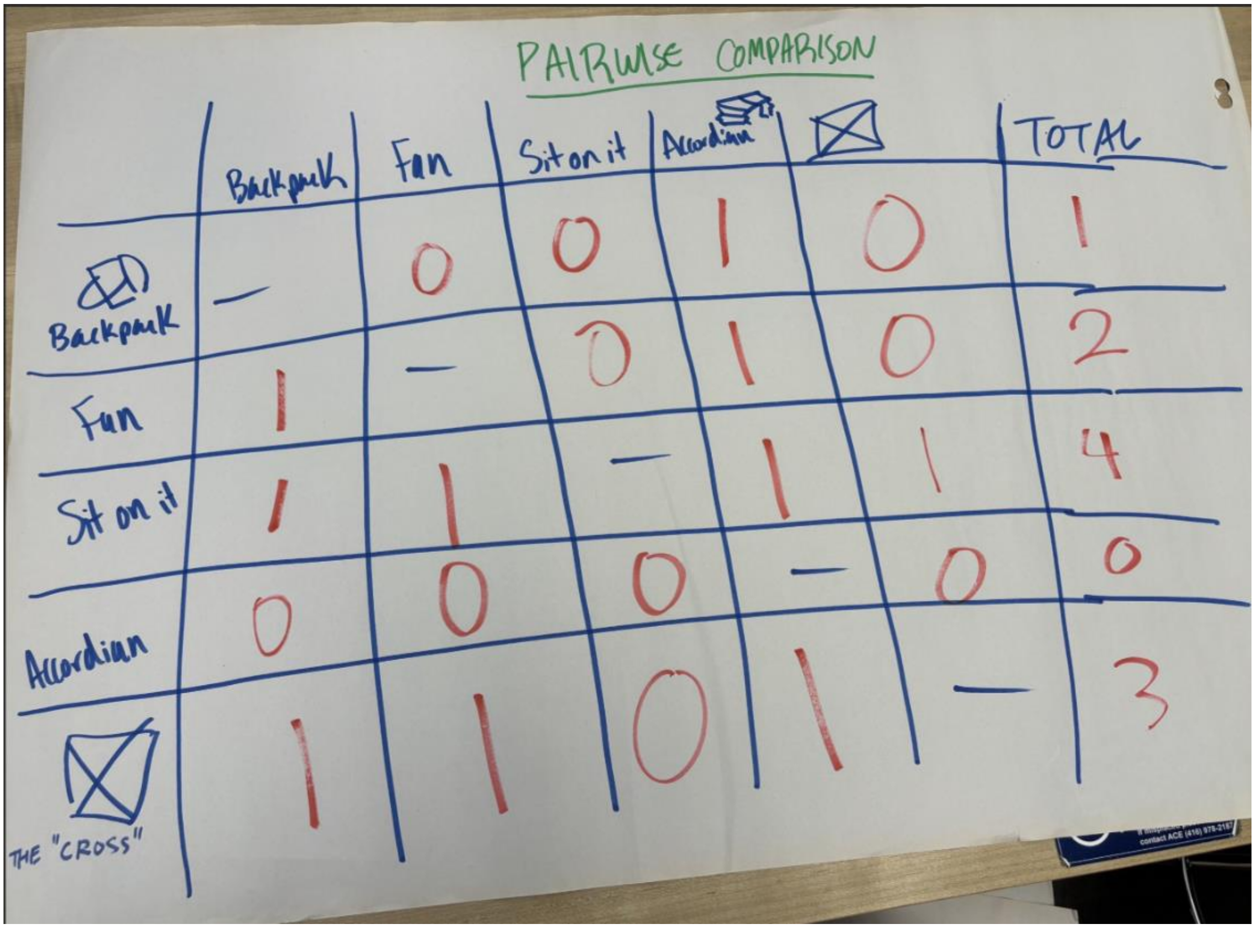
E.2. Reverse Brainstorming



E.3. Morph Chart



E.4. Pairwise Comparison Chart



Appendix F: Additional Pugh Charts

F. 1. Pugh Chart 1

EVALUATION CRITERIA	BriefDesk	SOI	DeskPack	FoldX
The smaller the folded dimensions, (in.^{3}), the better	D	-	+	+
The larger the open surface dimensions (in.^{2}), the better	A	+	-	+
The less the weight, the better	T	-	+	+
The larger its frequency of vibration (Hz), the better	U	-	-	-
The more height adjustability (% increase from shortest to tallest setting), the better	M	+	+	+
The more load it can hold, the better		-	-	-
Total	0	2 + 4-	3+ 3-	4+ 2-

F. 2. Pugh Chart 2

EVALUATION CRITERIA	BriefDesk	SOI	DeskPack	FoldX
The smaller the folded dimensions, ($in.^3$), the better	-	-	D	-
The larger the open surface dimensions ($in.^2$), the better	+	+	A	+
The less the weight, the better	-	-	T	-
The larger its frequency of vibration (Hz), the better	+	-	U	-
The more height adjustability (% increase from shortest to tallest setting), the better	-	+	M	-
The more load it can hold, the better	+	+		+
Total	3 + 3-	3+ 3-	0	2+ 4-

F. 3. Pugh Chart 3

EVALUATION CRITERIA	BriefDesk	SOI	DeskPack	FoldX
The smaller the folded dimensions, (in.^{3}), the better	-	-	+	D
The larger the open surface dimensions (in.^{2}), the better	-	+	-	A
The less the weight, the better	+	-	+	T
The larger its frequency of vibration (Hz), the better	+	-	+	U
The more height adjustability (% increase from shortest to tallest setting), the better	-	+	+	M
The more load it can hold, the better	+	+	-	M
Total	3+ 3-	3+ 3-	4+ 2-	0