UCI Samueli School of Engineering | Department of Mechanical and Aerospace Engineering

UCI MAE 151B Final Design Binder
Team #10, Equitable Design Solutions

Equitable Design Solutions

Sponsor: Professor Natascha Buswell
March 22, 2024

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Executive Summary

As Team Equitable Design Solutions, we were tasked with selecting an existing product that was inaccessible to a portion of the population and redesigning it to reduce this inequity. We focused our efforts on the University of California, Irvine (UCI)'s lecture hall tablet-arm desktops. Students rotate the stowed desktop forward by 180°, then fold the desktop over the armrest. These desktops are small, unadjustable, and available in either a left- or right-handed configuration. This means that users who are left-handed must use one of the few left-handed desks available in a given lecture hall.

The proportion of left-handed seats to right-handed ones in UCI's lecture halls does not match the proportion of left-handed people to right-handed people. According to MedlinePlus, approximately 10 to 15% of the U.S. population is left-handed. Less than 5% of the seats in UCI's lecture halls are meant for left-handed students, showing a clear disregard for UCI's left-handed population.

Students that are taller or larger than average also struggle to use the current desktops. Taller students' knees may hit the desktop, making it unstable; larger students may feel constrained by the small amount of space between the end of the desk and the back of the chair.

Creating a desktop that is both large and adjustable would allow all of these students to learn more comfortably and feel looked after by their university. A survey we conducted of 11 UCI students' opinions on the current desktops corroborated this idea, showing that users would like larger desktops, adjustability, and improved stability.

To accomplish these goals, we designed a new desk that can be installed in place of the current ones. Our desk features a 20" wide fold out desktop, providing 50% more surface area than the existing one. It also features an adjustable armrest, which can be set to three preselected points, providing up to 3.5" of height adjustment and 4" of depth adjustment. These adjustments can be made easily by using our actuating handle - users can pull up on the handle to unlock the pin holding the desk in position, pull to the desired height, and then push the handle back down to relock the pin. A multi-axis swivel hinge connects the armrest to the desktop and allows the desktop to maintain the motion of the existing design. Like the current design, students can rotate the stowed desktop forward and fold it over the armrest. If students would like a larger desktop to write on, they can unfold the desktop like they would open a book.

Our redesign was dimensioned to ensure that it would fit with the geometry of the current lecture hall seating. The stowed desktop occupies the same amount of the room as the existing design. The unfolded desktop provides as much surface area as possible without interfering with neighboring desktops or other parts of the chair.

All components of the redesign are purely mechanical. There are no electronic components, meaning that the desk does not have to be connected to power in order to work. Installing our redesign would simply involve removing the old attached armrest and desktop and replacing it with our new version.

Choosing to install our successfully completed prototype in UCI's lecture halls would demonstrate UCI's commitment to accessibility and care for their student body.

Problem Definition

Objectives

Our sponsor, Professor Natascha Buswell, did not have a specific problem selected for this project. She instead gave us the freedom to choose our own issue to solve, provided that the issue and its solution fell within the realm of accessible design. An initial meeting with Professor Buswell helped us define high-level objectives for our project; ideally, we would create a product that improves inclusivity in society, addresses a need of an underrepresented population, and increases the amount of people that can use a certain product by 10%. A more detailed record of this meeting can be found in Appendix A.1.

We presented a list of potential projects to Professor Buswell, which can also be seen in Appendix A.1. Of our ideas, she was most interested in a redesign of UCI's lecture hall desks that would make them larger and more adjustable. After deciding on this topic, we conducted a survey of UCI students to see what features they would like in a new desktop. This survey is discussed further in the 'Research' section. From the survey results and further discussion with Professor Buswell, we created the following objectives:

1. The design must fit within the geometry of the existing lecture hall chair.
2. The desktop must be usable for both left- and right-handed users.
3. The design must be comfortable for users of various sizes.
4. The desktop must be stable and remain level during use.
5. The project must comply with our $400 budget.

Professor Buswell was more concerned with us creating an accessible product that functions properly than with us adhering to strict quantitative requirements. As such, the first four objectives listed above were non-negotiable and had to be met by the final prototype. The final objective was meant to prevent us from having to spend our own money on the project and to demonstrate our ability to stay within a budget.

Research

Background

The overarching goal of our project was to find an existing product that was not equitable enough and to improve the design to make it equitable. In our case, we considered different ideas in Appendix A.1, and the lecture hall desk was most appealing to our sponsor.

Professor Buswell as a sponsor was here to guide us through the project with suggestions along the way. The exact requirements and details were made by ourselves, then presented to Professor Buswell for approval during sponsor meetings.

After receiving her approval to work on the lecture hall desks, a survey was conducted of fifteen UCI students to observe their opinion on the lecture hall desks. The full results of this survey can be found here, and the corresponding bar graph is shown in Figure 1. The most common requests for improvement are larger desk size, adjustable desk position, and a more stable desktop. From these three requests, we formed our objectives (STNR).

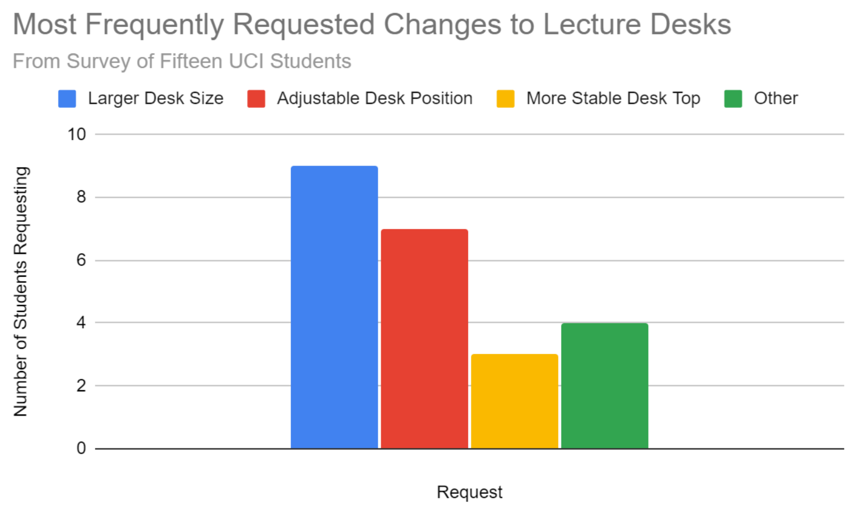


Figure 1: Results of student survey.

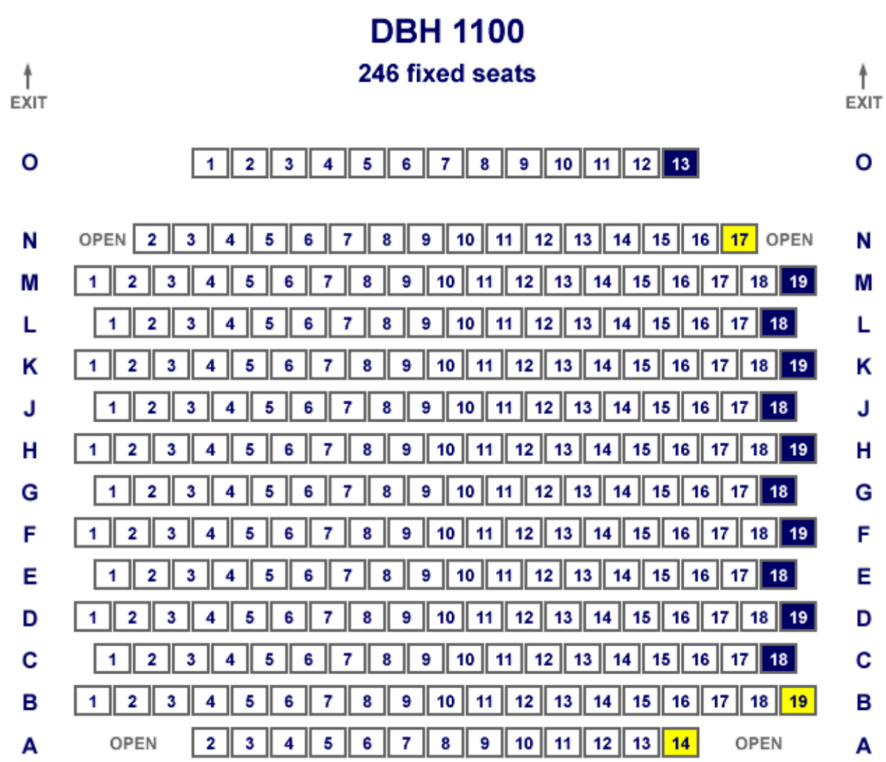


Figure 2: Layout of room 1100 in UCI's Donald Bren Hall. The seats with a dark blue background are left-handed.

Beyond the results of the survey, we found that UCI does not provide enough accessible seating to its students. In Figure 2 above, we can see a seating layout of room 1100 in Donald Bren Hall (DBH). Of the 246 seats in the classroom, only 11 of them have left-handed desks. According to MedlinePlus [1], approximately 10 - 15% of the U.S. population is left-handed. If DBH 1100 were to have enough left-handed desks to equal this ratio, 25 - 37 of the seats would have to be left-handed.

Existing Design Solutions

UCI's current solution is to provide one or two full-on desks at the front of each lecture hall for students who want to use a wider or more comfortable desktop. However, this does not solve the problems inherent to the existing desktops; it simply redirects students to a separate desk unattached from the regular lecture hall seating. For left-handed students specifically, left-handed versions of the typical tablet arm desktop are included on the left end of each row of seats, as seen in Figure 2. This limits where left-handed students can sit during lectures.

Figure 3: Some proposed solutions include an extendable surface that attaches to the desk (left) and a redesigned chair that folds a longer desk completely in front of the user (right). Our design aims to combine the flexibility and practicality of both, letting the user dictate their experience.

While there were some existing designs on the market, we wanted to design a way for students to feel comfortable and make their learning experience whatever they wanted as an individual. This desire to allow every student to find the solution that works best for them was the driving force behind our design process, and guided every decision we made. Our design attempts to combine the modularity and customization freedom of simple detachable desk expanders without putting the responsibility to be more inclusive on students. By redesigning the desks to provide increased surface area and adjustability, concepts from Figure 3 can be applied to the desks shown in Figure 4, bringing accessibility to the classrooms of UCI.

Figure 4: Current lecture hall design at UCI means left-handed students and students with accessibility or mobility needs often have little choice with where they can sit in a classroom.

Design Requirements

Requirements

Using the results from our survey and additional discussions with Professor Buswell, we came up with seven requirements that would allow us to achieve our previously stated objectives. Table 1 below shows these requirements and their corresponding objectives.

Table 1: Objectives and Requirements

Objective	#	Requirement	Ideal	Marginal
Fits within the existing geometry of the lecture hall chairs	GEO1	Armrest has same dimensions as existing design	Exact	Height can increase up to 1” (2.5 cm)
	GEO2	Desktop does not extend more than 2” beyond outer edge of armrest when stowed away	2”	1.5 - 2” (3.8-5.1 cm)
Desktop is usable for both right- and left-handed users	ACC1	50% more desktop surface area than original	50%	45 - 50%
	ACC2	Desktop extends 20” from armrest	20”	19 - 20” (48.3-51.8 cm)
Desktop is comfortable for users of all heights	ACC3	3.5” of adjustable armrest/desktop height	3.5”	3 - 3.5” (7.6-8.9 cm)
Desktop is stable and remains level	SAF1	Can bear a 100 lb load applied on the desktop without deforming	100 lb	> 90 lb (> 40.8 kg)
Complies to given budget	BUD1	Assembly meets budget constraint of $400 maximum	$400	$430 max.

The numbering system in the second column indicates what type of requirement the number is associated with. “GEO” corresponds to a geometrical requirement, “ACC” to an accessibility requirement, “SAF” to safety, and “BUD” to budget. Some of these are flexible; ACC1 and ACC2 could also be considered geometrical requirements because their upper limits were determined by the amount of space available with the current chair. Table 2 shown below contains the dimensions of the current chair/desktop.

Table 2: Chair Dimensions

Chair Measurements	Dimensions (inches)
Stowed desk	10.5
Distance between armrests	22
Edge of arm to edge of stowed table	2
Desk thickness	0.75
Distance from floor to bottom of desk	22.5
Distance from top of seat to bottom of desk	6.5
Distance from floor to top of seat	16
Distance from floor to compressed cushion	15
Distance from back of armrest to desk	8.75
Armrest length	14
Armrest width	1.5
Distance from pivot to front of arm rest	3
Depth of seat	19
Distance from chair back to the point of maximum width on desk	16

We planned to be able to install our redesign in the spot where the current armrests are. This is to ensure that installation is quick and simple, requiring only the removal of the armrest rather than the entire chair. This would allow UCI to switch out as many of the desktops as they would like rather than being forced to replace an entire row's worth of desks at a time. However, this does limit the size of our design, as it must fit in the same amount of space as the current desktop.

The dimensions in GEO1, GEO2, ACC1, and ACC2 were all determined from these limitations. The desktop cannot be made any larger without hitting the neighboring desktop. The ideal value for SAF1 was obtained by calculating the amount of force exerted by a person in the 97th percentile of weight (300 lbs or 136.1 kg) leaning down and adding a factor of safety of 2.5. BUD1 is a limitation imposed by our given budget.

Design Attributes

Objective:

- A spacious, sturdy, modular workspace suitable for both right-hand and left-hand users that comfortably accommodates a wide range of body shapes and sizes.

Functions:

- Allows the user to write comfortably with either hand.
- Allows for the size of the workspace to be adjusted.
- Allows for the height and distance from the chair to be adjusted.

Constraints:

- Must support the weight of a user leaning on it.
- Must not impede escape in emergency situations.
- Must not extend more than 2 inches away from the armrest when stowed.
- Must not have any exposed dangerous or sharp parts.

Means:

- Could attach and detach from the armrest.
- Could fold out to increase workable space.
- Could have height adjustment to raise the armrest.
- Sitting on the chair could allow for easier access to the previously stowed desk. (desk pops out)

System Diagrams

The following diagrams were generated using Matlab's requirements toolbox. Requirements and their implementations were tracked using a functional and physical architecture created using System Composer, as seen in Figures 5, 6, and 7.

Index	ID	Summary
SystemReq		
1	-	Ajustability
1.1	SYSTEM-REQ-01	Height
1.2	SYSTEM-REQ-02	Depth
2	-	Surface Area
2.1	SYSTEM-REQ-03	Width
3	-	Support
3.1	SYSTEM-REQ-04	Safety
3.2	SYSTEM-REQ-07	Lockout
4	-	Compatibility
4.1	SYSTEM-REQ-05	Pivot
4.2	SYSTEM-REQ-06	Stow Away
StakeholderNeeds		
2	-	Surface Area
2.1	STAKEHOLDER-02	Ambidextrous
2.2	STAKEHOLDER-03	Working Space
1	STAKEHOLDER-01	Adjustability
3	STAKEHOLDER-04	Support
4	STAKEHOLDER-05	Storage
5	STAKEHOLDER-07	Compatibility
SubSystemReq		
1	-	Position Control
1.1	POSITION-REQ-01	Linkages
1.3	POSITON-REQ-03	Locking Mech
1.2	POSTION-REQ-02	Stops

Figure 5: Requirements by category.

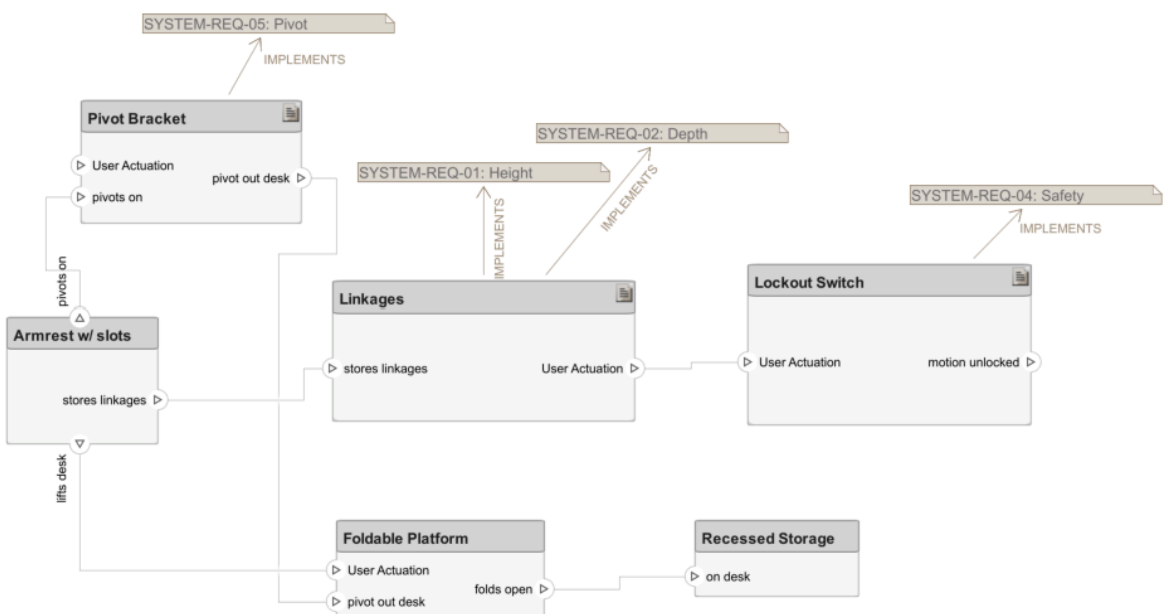


Figure 6: Physical architecture. Implementations of system requirements noted in brown.

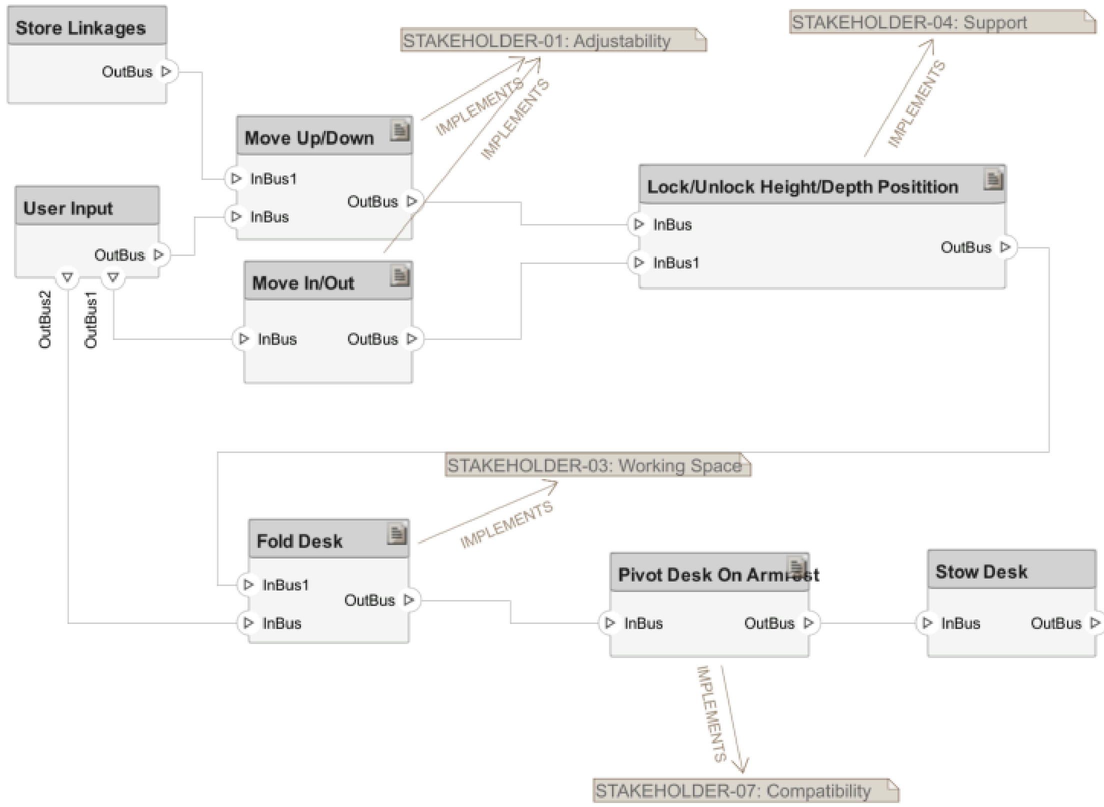


Figure 7: Functional architecture.

Work Breakdown Structure

Below is our initial work breakdown structure.

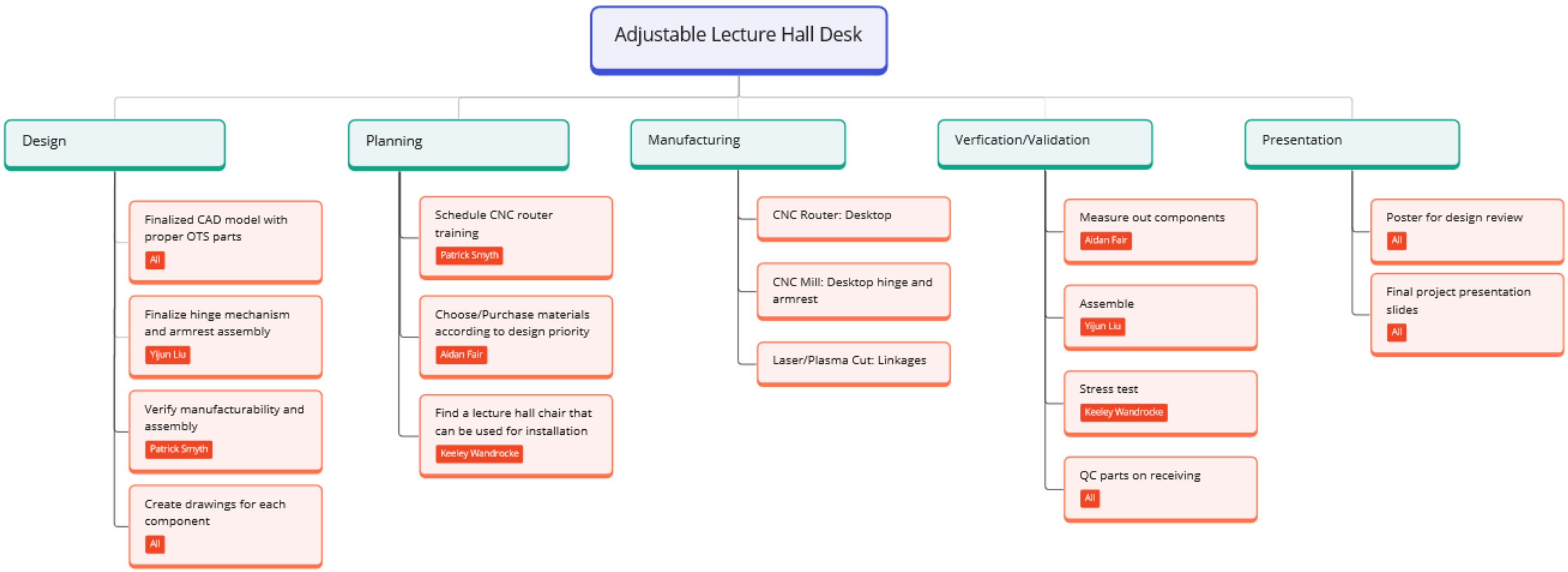


Figure 8: Initial work breakdown structure.

As we began ordering and manufacturing components, some of these tasks changed. Rather than design and manufacture our own swivel hinge, we decided it would be easier and more cost-effective to order one off the shelf. The ‘Stress test’ task within the ‘Verification/Validation’ section was changed to ‘Simulation/FEA’ due to time and budget constraints preventing us from conducting physical tests. The ‘Presentation’ section was renamed to ‘Documentation’ at the suggestion of Professor Sherif Hassaan. Within that section, the ‘Final project presentation slides’ task was replaced with the final website, and the final design binder was added. Our final work breakdown structure can be seen below. Some slight reformatting was done to make it easier to read.

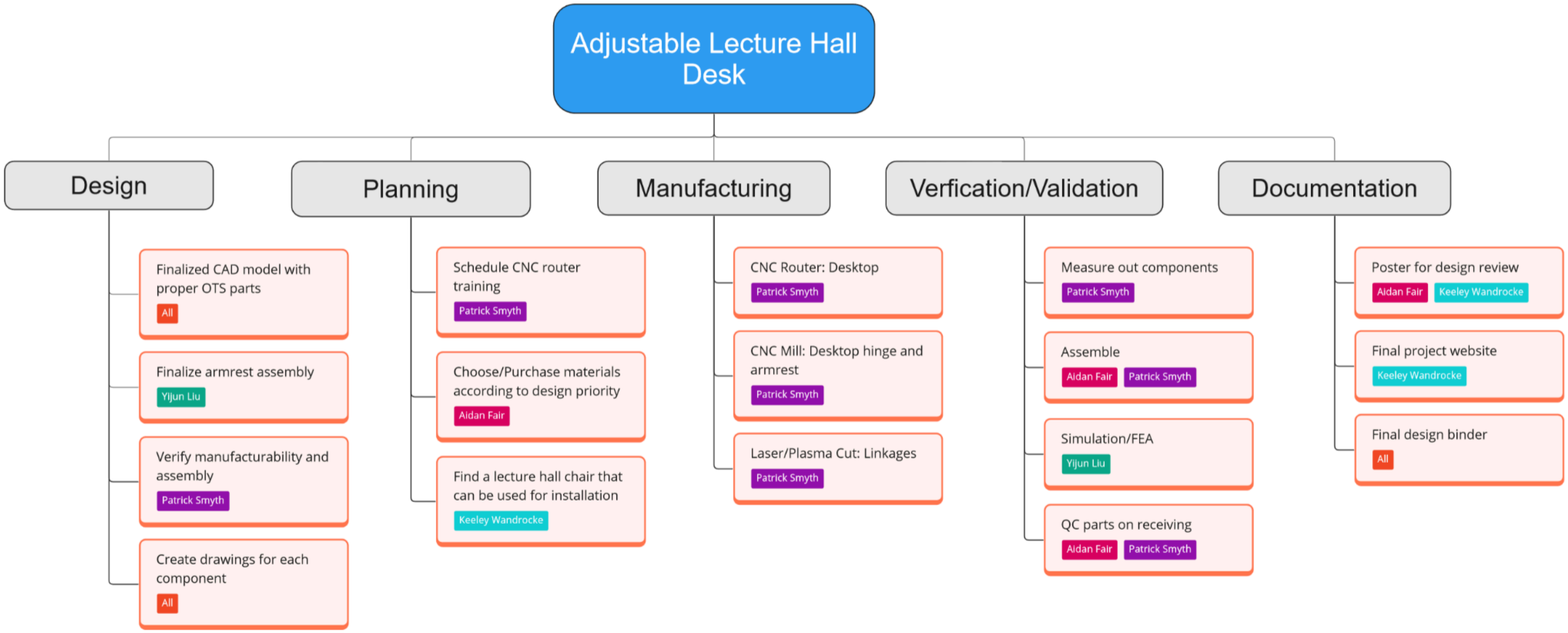


Figure 9: Final work breakdown structure.

Each task has a tag on the bottom indicating who is responsible for it. Aidan has a magenta tag, Bill has green, Patrick has purple, and Keeley has blue. An orange tag means that all team members were assigned to work on the task.

Initial Timeline

TASK NAME	START DATE	END DATE	START ON DAY*	DURATION* (WORK DAYS)	TEAM MEMBER	PERCENT COMPLETE
Problem Definition						
Clarify objective with sponsor	10/5	10/12	0	7	All	100%
Conduct survey for user feedback	10/10	10/20	5	10	Patrick & Bill	100%
Make a gray box diagram	10/15	10/27	10	12	Patrick	100%
Derive stakeholder needs and requirements	10/5	10/20	0	15	Aidan	100%
Measure current design to find constraints	10/17	10/20	12	3	Alli	100%
Concept Generation						
Brainstorm possible solutions	10/23/2023	11/1	18	9	All	100%
Engineering sketches	10/25	11/6	20	12	Bill	100%
Decision matrix to narrow down to best concepts	10/25	11/3	20	9	All	100%
Weighted decision matrix	11/3	11/8	29	5	All	100%
System Architecture						
Model the folding desktop	11/3	11/13	29	10	Patrick	100%
Determine exact dimensions	11/6	11/15	32	9	Aidan	100%
Research best way to keep desk supported	11/6	11/13	32	7	Bill	100%
Model support and attachment	11/6	11/15	32	9	Alli	100%
Create bill of materials	11/7	11/20	33	13	Patrick	100%
Manufacturing						
Review for manufacturability	11/5/23	11/30	31	25	Alli	100%
Machine desk top on ShopSabre	11/15	12/1	41	16	Patrick	0%
Buy off the shelf components	11/6	11/27	32	21	Bill	0%
Assemble all components and verify compatibility	11/27	12/13	53	16	Aidan	0%

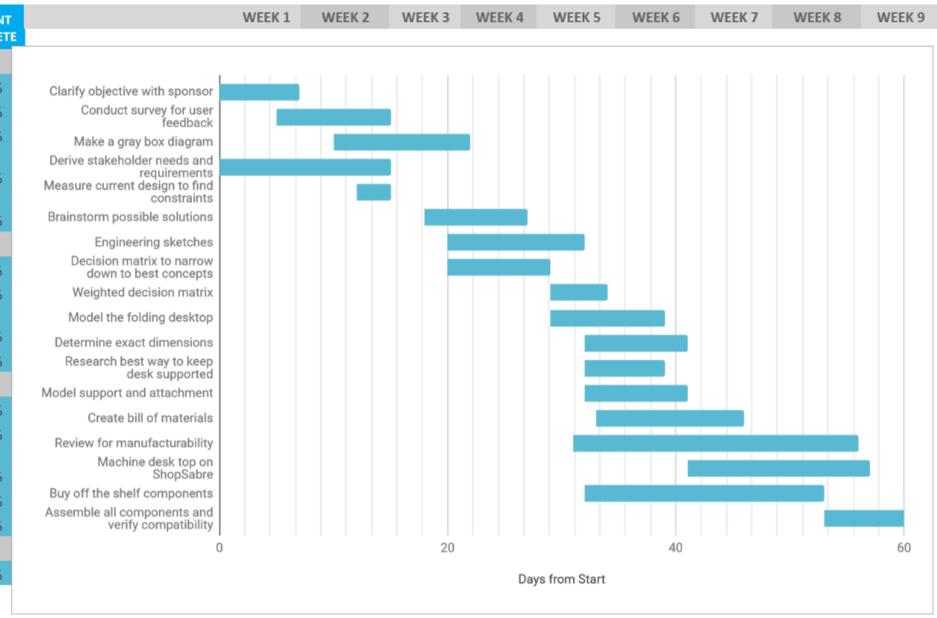


Figure 10: Initial Gantt chart for MAE151A.

The only tasks on this initial Gantt chart not completed before the end of MAE151A are the final three in the 'Manufacturing' section. No prototype of the full assembly was made; instead, a proof-of-concept assembly of the adjusting armrest was created. Photos of this model can be seen in the 'Preliminary Designs' section.

Design Process

Preliminary Designs

Desktop

In the concept generation phase, many designs were considered for both the form of the desktop and the adjustment mechanism. Some are shown below in Figure 11.

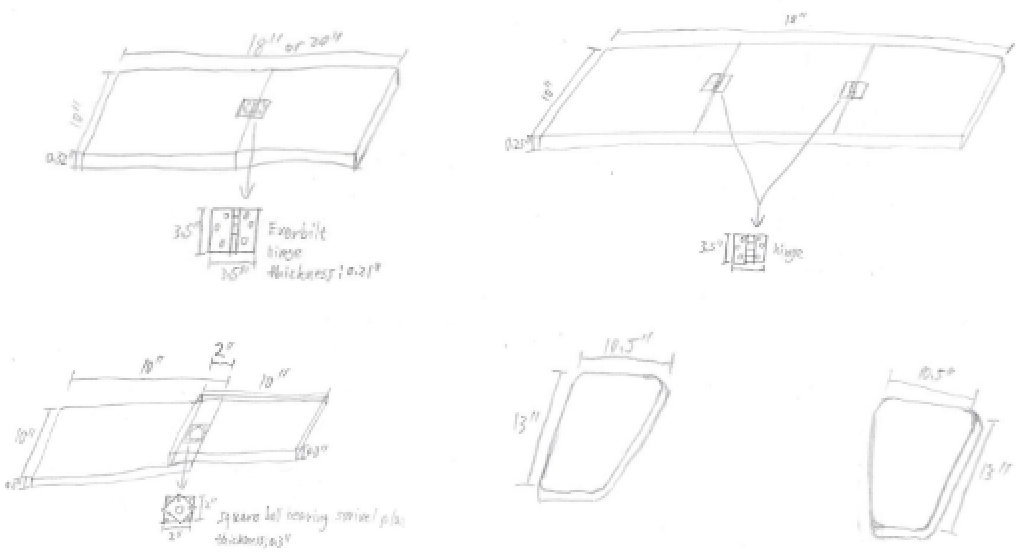


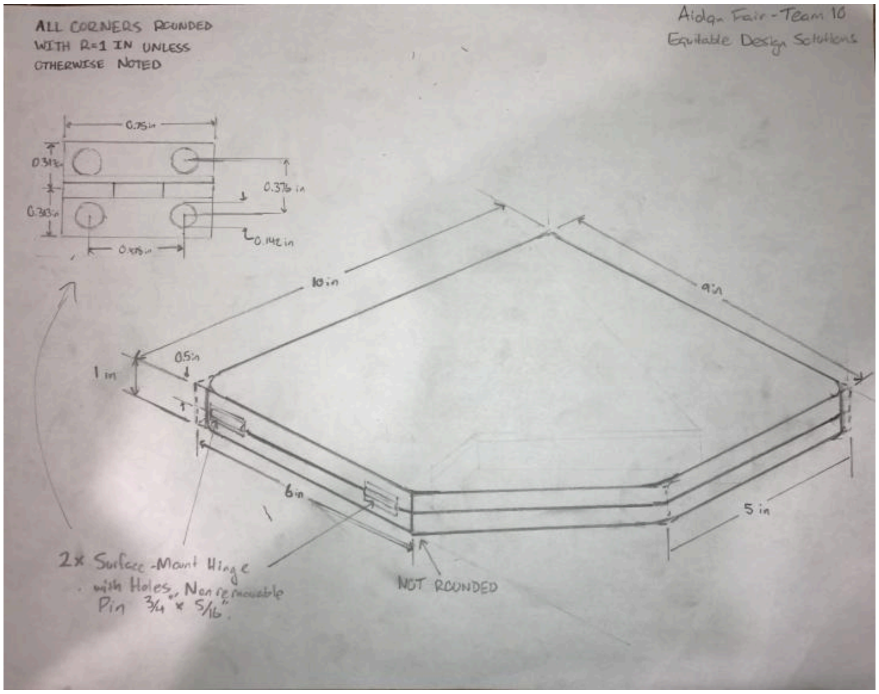
Figure 11: Preliminary sketches of concept designs that were considered. From left to right, top to bottom: single hinge, multiple hinge, hinge in plane, desk on each side.

From nine possible desktop designs, the four sketched above were selected as the strongest design concepts through both a weighted and unweighted decision matrix, as shown below in Figure 12.

	Concept Variants									
Selection Criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**REF**
Surface Area = 25%	1	1	1	1	1	1	1	1	1	0
Ease of Use = 20%	0	0	0	0	0	-1	-1	-1	0	0
Safety = 15%	-1	-1	0	-1	-1	-1	-1	-1	0	0
Stability = 15%	0	-1	0	0	0	-1	0	1	0	0
Compact Ratio = 10%	1	-1	1	1	1	1	1	-1	0	0
Strength = 10%	-1	-1	0	0	0	-1	0	1	0	0
Manufacturing = 5%	-1	-1	0	-1	-1	-1	-1	0	0	0
NET	0.05	-0.3	0.35	0.15	0.15	-0.3	-0.05	0.05	0.25	
RANK	4	5	**1**	**3**	**3**	6	4	**3**	**2**	
CONTINUE?	No	No	Yes	Yes	Yes	No	No	No*	Yes	

Figure 12: Simple and weighted decision matrices for desktop design concepts, respectively.

While the decision matrices helped rule out some inferior design choices, the final design for the desktop was decided by comparing the concepts to see how well they fit the requirements. The multiple hinge concept failed because it was too complex and introduced more failure points, the hinge-in-plane (swivel) concept failed because there would be a height difference between the two desk flat components, and the desk-on-each-side solution failed because the desktops would have to be mounted on the inside of the existing armrests, which would result in a much narrower and cramped seating experience. Because of these reasons, the single hinge design was chosen as the most viable.



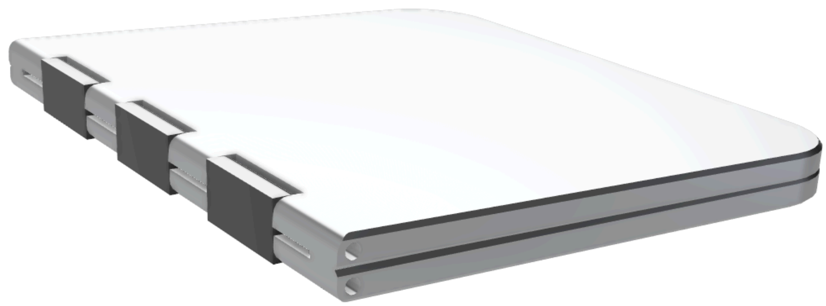


Figure 13: Early iterations of the chosen desktop design

<u>Armrest/Height Adjustment Mechanism</u>

Similarly, the adjustable armrest, which changes with the height of the desktop, underwent an iterative design process.

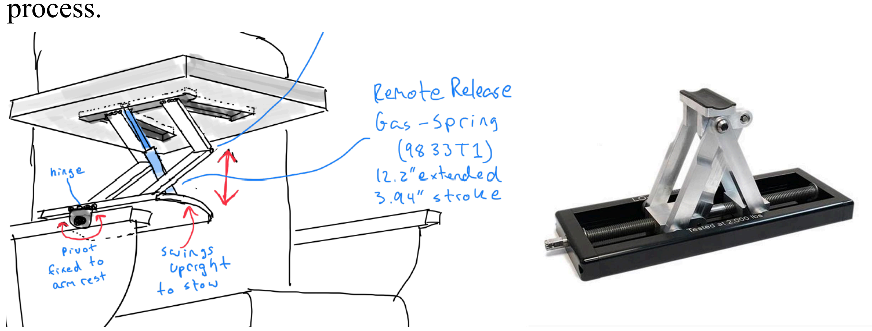


Figure 14: Early designs explored vastly different ways to adjust the height of the desk.

As seen above in Figure 14, some initial concepts featured a gas spring or would try to incorporate a threaded rod. Similarly to the desktop, different design concepts were considered and compared in a decision matrix. This is shown below in Figure 15.

Selection Criteria	Weight	Concept 1	Concept 2	Concept 3	Current Design
Ease of Use	2	-1	1	0	1
Reliability	2	-1	0	0	1
Durability	3	0	1	-1	1
Adjustability	5	1	1	1	-1
Stability	3	0	0	-1	0
Ease of Manufacturing	2	0	0	0	1
Cost	1	0	1	0	1
Safety	4	-1	-1	0	0
Comfort	2	1	1	0	-1
Space Efficiency	3	0	0	-1	1
Total		-1	9	-4	7

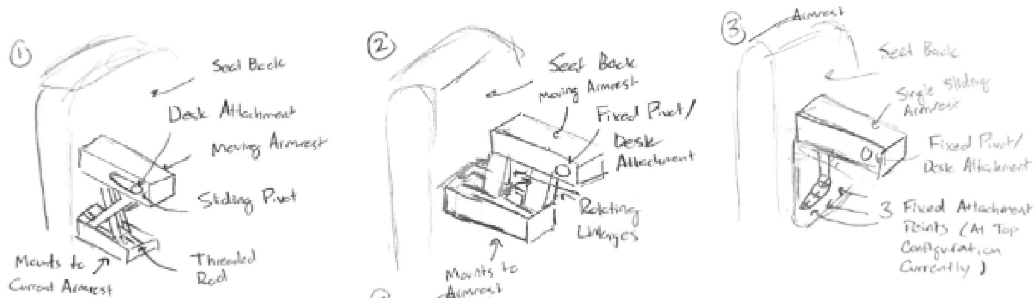


Figure 15: Concept 2 was the only option that improved on the current design.

Based on the decision matrix, the chosen design featured a separated armrest that would rotate nearly 90° from its lowest position to its highest, as seen below. This came with the downside of height and depth not being able to be adjusted individually, but allowed for the desk to be adjusted much easier. An early representation of the system is shown below. This solution also allowed for the locking mechanism to be accessed easier, with the implementation of an ergonomic handle.

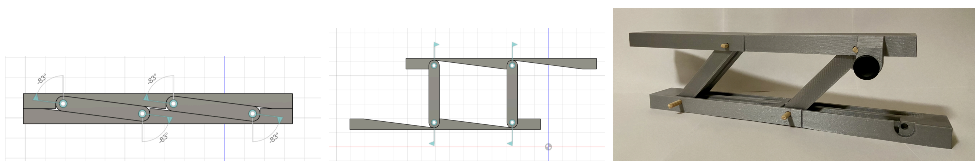


Figure 16: The geometry for the linkages of the height-adjustment mechanism and a proof-of-concept prototype verified that the height adjustment functionality met our requirements.

Critical Design

Component Analysis & Testing

There were four major components in the assembly. An individual component analysis was conducted on each component. They included the desktop, the height adjustment mechanism, the hinge, and the locking mechanism.

Desktop

The desktop was partially inspired by airplane fold-out desks like the ones shown below in Figure 17. These were chosen because they have a similar application in that they mounted to the side of the user, folded out when in use, and had a thin form factor.

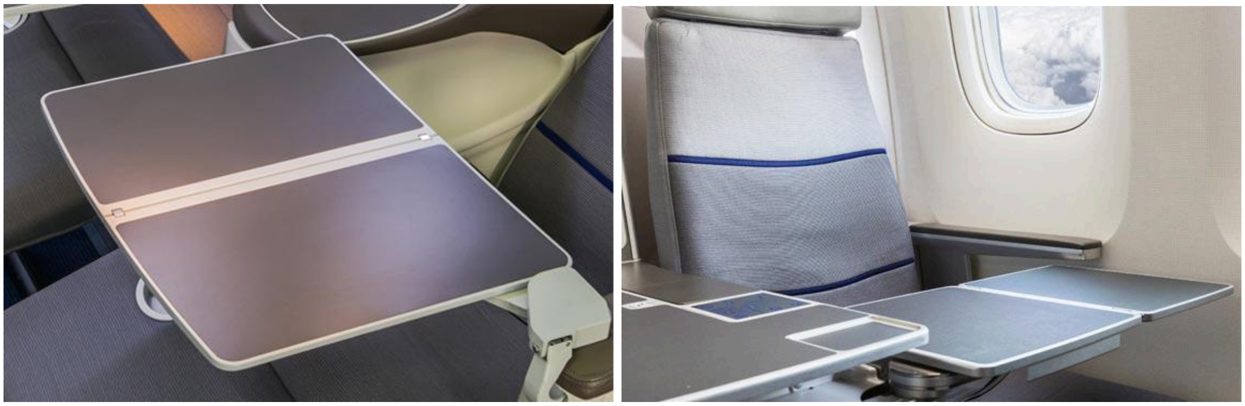


Figure 17: Modern airplane desks often fold out from the side and hinge in the middle, offering a compact yet sturdy user experience.

Figure 18 shows the results of the FEA simulation that was performed on the CAD model of the desktop to simulate a load of 100 pounds (45.4 kg) applied, exerting the largest moment possible at the left unsupported edge. This value was derived from the force exerted by a person in the 97th percentile of weight (300 lbs) leaning on the desk, with a factor of safety of 2.5 applied. This factor of safety was taken from other similar applications, as it is often utilized in furniture testing.

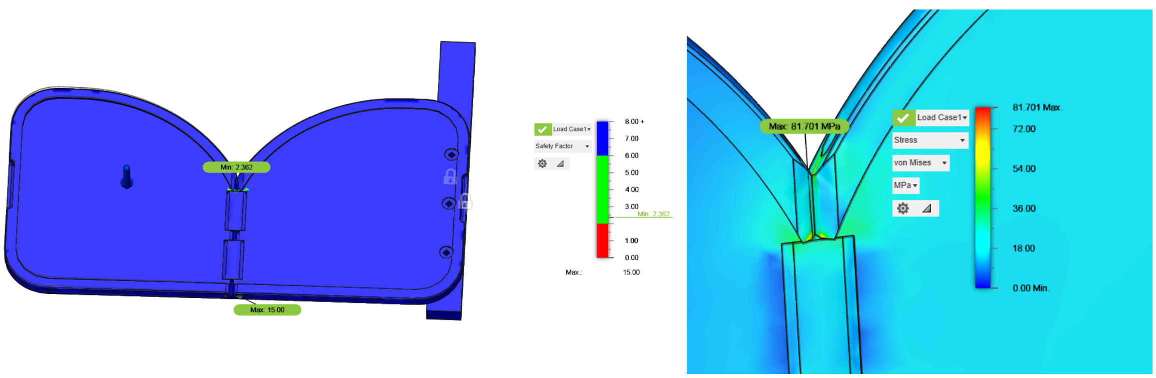


Figure 18: FEA shows that the max stress under the worst-case loading occurs at the hinge between the two desktop flats.

Height-Adjustment Mechanism

The height-adjustment mechanism was partially inspired by standing desks. This two-linkage design had minimal pinch points and offered a reliable way to adjust the height of the desk while remaining stable. Another important factor in this choice was space efficiency, as this method would fit within the required dimensions, not extending more than two inches beyond the outside edge of the current armrest.

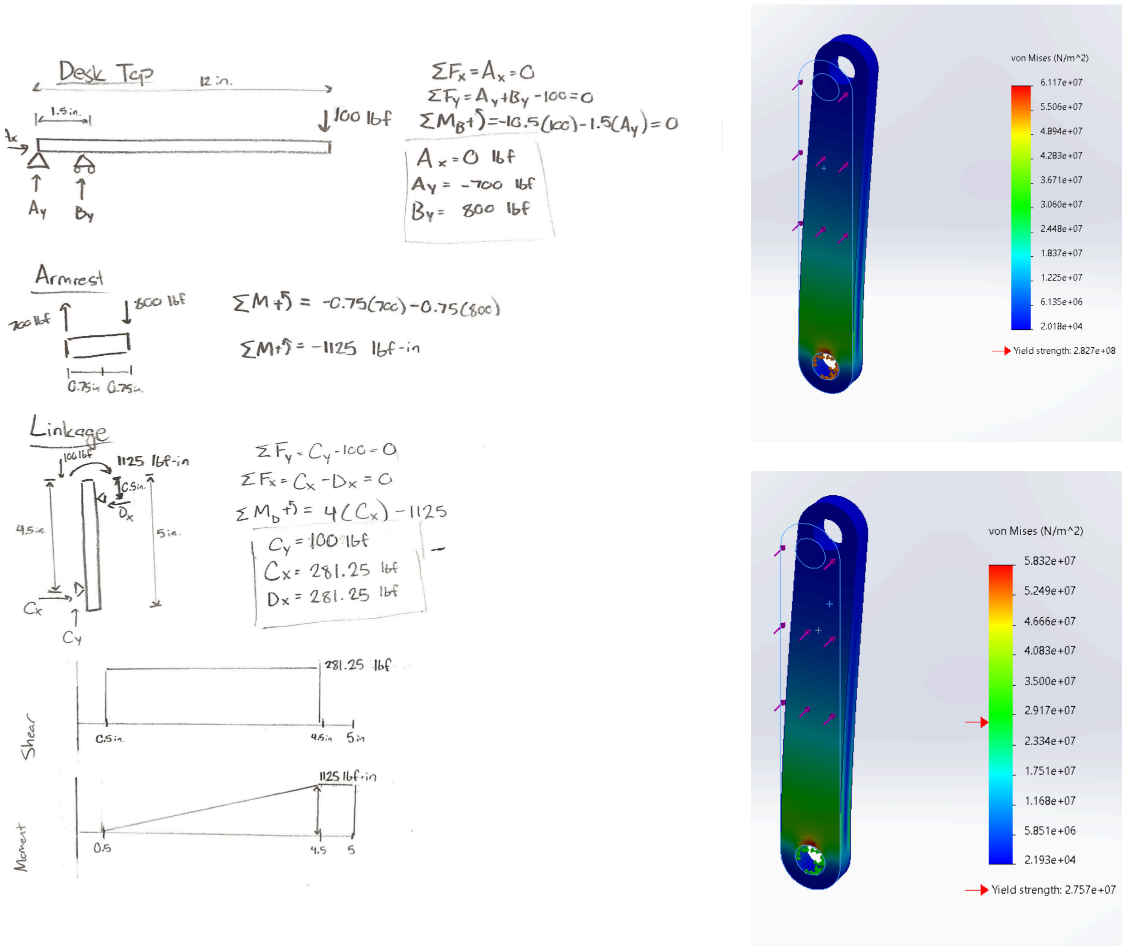


Figure 19: The desktop was modeled as a simple beam to simulate the load experienced by the linkages. The expected maximum load (with a factor of safety of 2.5 applied) was then applied in SolidWorks to find the maximum deformation of hypothetical linkages made of aluminum and steel.

The results of the analysis in Figure 19 suggest that wood would not be a strong enough material for the linkages. Both solid steel and aluminum should support the expected load, and further analysis on the moments of inertia of a solid aluminum bar and rectangular hollow-section (RHS) steel tubing would be carried out to determine the best way to optimize both strength and weight. The design was also iterated upon from this point to go from four narrower linkages to two thicker linkages, with analysis and reasoning shown below in Figure 20.

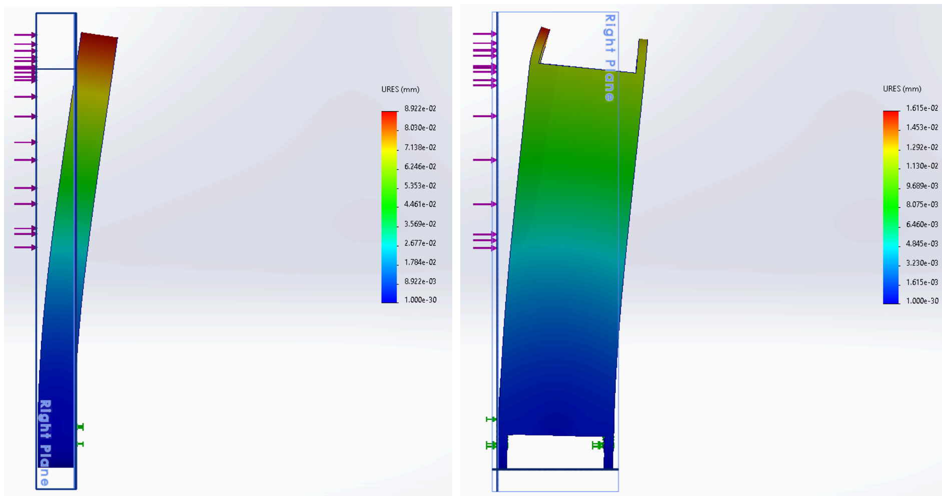


Figure 20: Hollow-section tubing deforms less than narrower solid bars, even when the force difference between two and four linkages is accounted for.

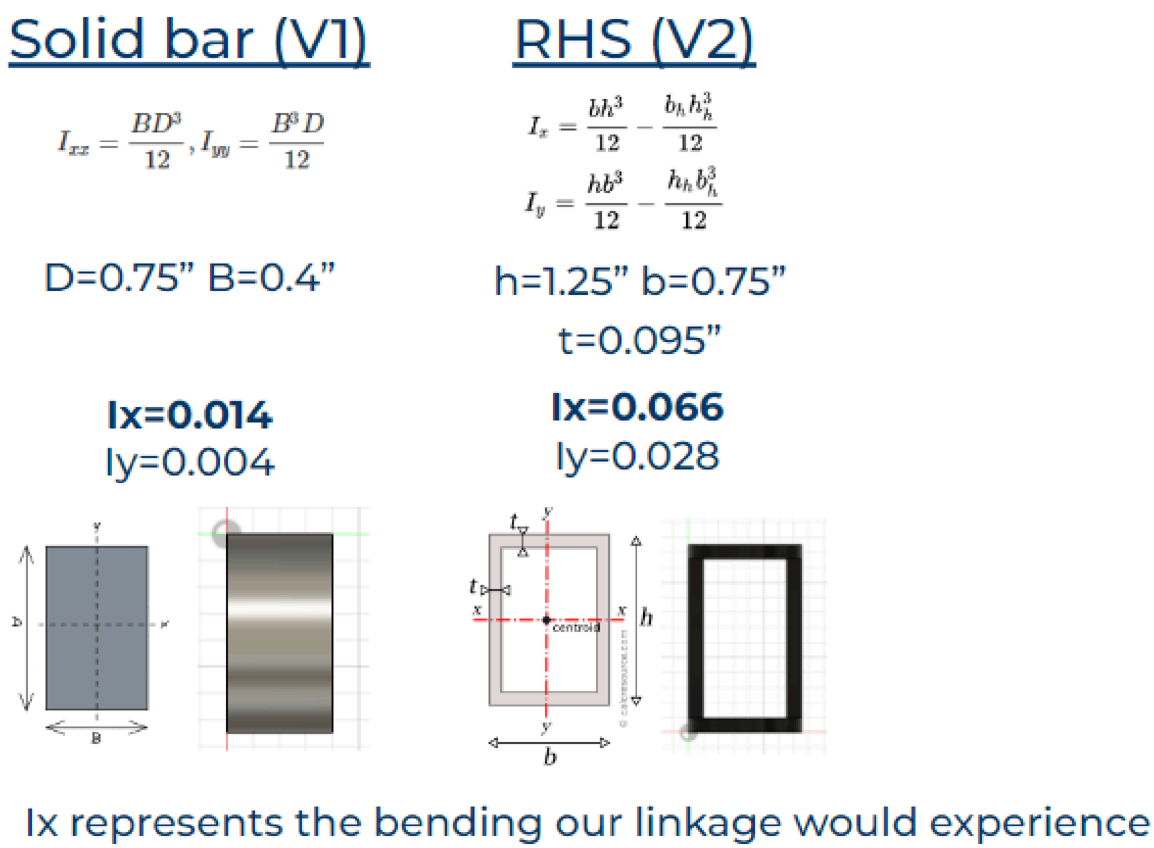


Figure 21: Moment of inertia calculations show that both solid aluminum (left) and rectangular hollow-section tubing (right) would be sufficient, but the lower weight and higher rigidity of the RHS made it the best choice when manufacturing linkages.

Although RHS was the absolute best choice, logistical and budgetary constraints led us to use solid aluminum in the final design, as we were not able to source the RHS tubing. Luckily, these prior calculations from Figure 21 validated this design choice as well, although the design would be more stable if hollow steel tubing was utilized instead.

Hinge

The hinge was an off-the shelf component that was integral to the entire design. Because of our budget and time constraints, we decided an off-the-shelf part would be the best choice. However, the smallest off-the-shelf dual axis hinge we could source was wider than our desired half-armrest design of 0.75 inches (1.905 cm). Because of this, the armrest design was thickened to 1.25 inches (3.175 cm), which allowed for the off-the-shelf hinge to be attached to the top armrest, where the desktop would rest upon.

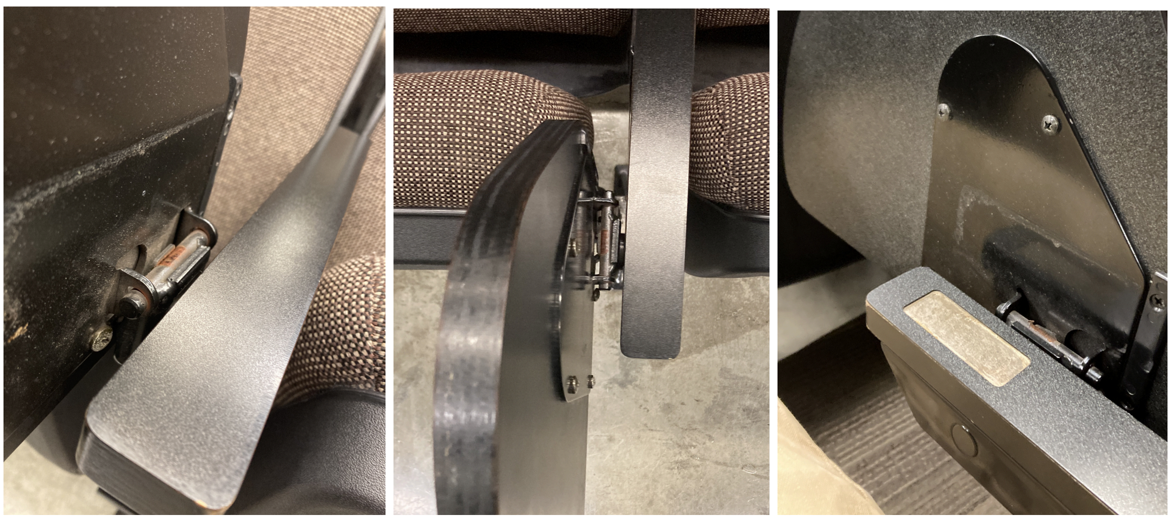


Figure 22: The current hinge design allows for the desk to rotate in two perpendicular axes, so the desk can be efficiently stowed when not in use.

Initially, attempts were made to contact facilities management and the desk manufacturers, but the hinges seen in FIgure 22 are custom parts that are out of production. We briefly discussed making a custom hinge, but decided to focus our efforts on other components, ordering the hinge from Mcmaster-Carr.

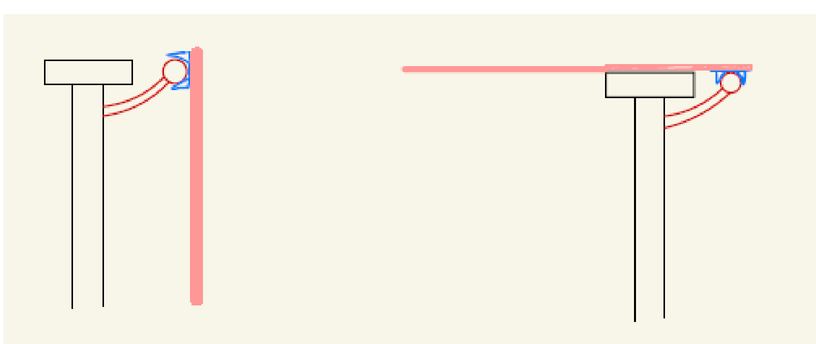
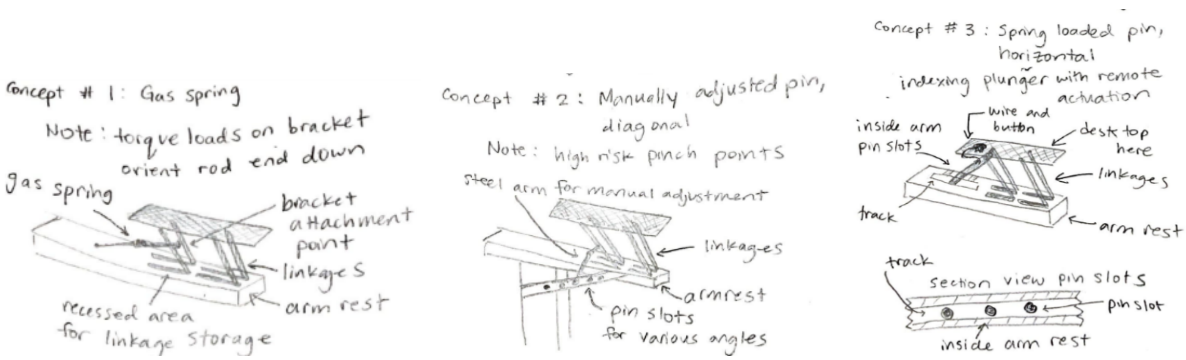


Figure 23: A ball joint swivel was briefly considered, but the lack of stability and complicated manufacturing process led to alternative decisions.

<u>Locking Mechanism</u>

Much like the height-adjustment mechanism, a simple decision matrix (shown in Figure 24) was used to determine the most viable design concept.



	Concept Variants			
Selection Criteria	**1**	**2**	**3**	**REF**
Reliability = 25%	-1	0	0	0
Safety = 20%	0	-1	0	0
Ease of Use = 15%	1	0	1	0
Accessible = 15%	1	1	1	0
Compact Ratio = 10%	0	-1	0	0
Remote Actuation = 10%	1	0	1	0
Manufacturing = 5%	-1	-1	-1	0
NET	0.1	-0.2	0.35	
RANK	2	3	**1**	
CONTINUE?	No	No	Yes	

Figure 24: Concept 3 had the benefits of being easy to use and remote-actuated, with its main downside being the manufacturing difficulty.

The chosen design featured an indexing plunger to easily lock and unlock the desk, although this would be transformed in the final design. Three discrete heights are selected by inserting the indexing plunger into one of three holes, two of which are on the linkages, with the third position being selected by locking the plunger into the bottom armrest.

Testing Protocols

The following tests have not been conducted. They are included as a suggestion if future work is to be done on the project.

Desktop Loading

- **Test**:
  Load a 100 pound mass (45 kg) on the desktop prototype when unfolded and observe displacement of desktop flats.
- **Risks**:
  - Components may be damaged as a result of testing.
  - Tests should be conducted indoors. Weather conditions should not affect the results.
- **Test procedure:**
  1. Unfold desktop flats.
  2. Mount prototype on table or other flat surface (armrest should be held down and secured on surface).
  3. Measure the vertical distance between the far edge of the desktop and the plane of the surface the prototype is mounted on using a metric ruler.
  4. Load 100 pound mass (45 kg) on the desktop edge furthest from the armrest.
  5. Measure the vertical distance between the far edge of the desktop and the plane of the surface the prototype is mounted on. Note if any displacement has occurred as a result of the loading. If the edge of the desktop is touching the surface, either adjust the height of the armrest or place thick, flat objects (such as books or planks of wood) under the armrest until the edge no longer touches the surface. If this is done, make sure to retake the initial distance measurement without any loading.
- **Purpose of results**:
  If the desktop undergoes great displacement (greater than 13 mm or 0.5 inches) when loaded, it may not be comfortable or stable enough for continuous use. The desktop material may have to be changed to a stiffer one or supports may have to be added near the armrest.

Usability and Comfort Testing

- **Test**:
  Have a random selection of UCI students use the prototype. Note any issues the user encounters while using the desk and armrest. Have users evaluate the comfort and usability of the prototype through a survey delivered after they have used the desk.
- **Risks**:
  - Components may be damaged as a result of testing.
  - Test volunteers may injure themselves while using the desk. To prevent this, make users aware of all moving parts and intervene if the user attempts to use the prototype improperly.
  - Test volunteers may be uncomfortable with having their height measured and recorded. Fully inform all potential volunteers of what the testing involves prior to selecting them for the test to insure this is not the case.
  - Tests should be conducted indoors. Weather conditions should not affect the results.
- **Test procedure:**

1. Assemble a group of UCI students. These students can be solicited through a mass email or through UCI-affiliated social media platforms, such as subreddits or Discord groups. Make sure to fully inform the students on what the testing will entail.
2. Measure the height of each student and note whether they are left-handed, right-handed, or ambidextrous.
3. Mount the prototype on the armrest of a chair. The UCI lecture hall chairs would be ideal, but if these are unavailable, any chair on campus with an armrest that the prototype can be properly mounted on is acceptable. Mounting can be done with zip ties. Make sure that the desktop is fully stowed away before user testing begins.
4. Have the user take out and unfold the desktop. Record how long this process takes.
5. Ask the user to adjust the armrest height to all three of our preselected heights. Initially, do not tell them how to do this. See if they can figure it out by observing the prototype. If they cannot, tell them how. Allow them to then choose the height that feels most comfortable for them and have them set the height to that point.
6. Provide the user with a pencil and notebook. Have them write a few sentences to see if the experience is comfortable. Example sentences may include "I am testing Equitable Design Solutions' desktop redesign. The prototype is excellent and will surely get them a fantastic grade." Allow the user to readjust the height of the desktop if they believe a different height will be more comfortable. Record this adjustment if it occurs. (Which height did they adjust from? Which height did they adjust to?)
7. Retrieve the pencil and notebook from the user.
8. Provide the user with a laptop. Have them type a few sentences into the Notepad application. The same sentences as before may be reused. Allow the user to readjust the height of the desktop if they believe a different height will be more comfortable. Record this adjustment if it occurs. (Which height did they adjust from? Which height did they adjust to?)
9. Retrieve the laptop from the user.
10. Have the user fold up the desktop and stow it away. Record how long this process takes.
11. Have the user return the armrest height to its lowest position if it is not already there. Record how long this process takes.
12. Issue a survey to the user through Google Forms. Here is a list of questions which may be included:
    - How comfortable did you find the new desk? (Answer format is a scale from 1 to 5, with 1 being 'Very uncomfortable' to 5 being 'Very comfortable')
    - How comfortable do you find the existing desk? (Answer format is a scale from 1 to 5, with 1 being 'Very uncomfortable' and 5 being 'Very comfortable')
    - How could the desk be made more comfortable for you? (Answer format is a text box)
    - How easily were you able to use the new desk? (Answer format is a scale from 1 to 5, with 1 being 'With great difficulty' and 5 being 'With great ease')
    - How easily are you able to use the existing desk? (Answer format is a scale from 1 to 5, with 1 being 'With great difficulty' and 5 being 'With great ease')
    - How could the new desk be made easier to use? (Answer format is a text box)

- What changes or additions would you make to the new desk to make it ideal for you? (Answer format is a text box)

- **Purpose of results**:
  If our design is unintuitive, an instructional sticker explaining how to use the desk will be made and applied to the armrest of our product. If the design is uncomfortable or difficult to use, we may have to redesign certain components to better meet our goal of accessibility.

Compliance Table

Table 3: Requirements Compliance

Requirement	Compliant/Non-compliant (C/NC)	Verification	Notes
Armrest has same dimensions as existing design	NC w/ ideal, C w/ marginal The top armrest slat has a height of 31.8 mm (~1.25”). Ideally, it would be 19 mm (~0.75”).	Initially with Fusion360 model by Aidan Fair. Further confirmed with physical prototype by Patrick Smyth.	Our sponsor approved this exception due to a lack of available OTS swivel hinges with dimensions appropriate for mounting on a 19 mm thick slat.
Desktop does not extend more than 2” beyond outer edge of armrest when stowed away	C	Initially with Fusion360 model by Aidan Fair. Further confirmed with physical prototype by Patrick Smyth.	
When unfolded, desktop has at least 50% more surface area than existing design	C	Initially with Fusion360 model by Aidan Fair. Further confirmed with physical prototype by Patrick Smyth.	
When unfolded, desktop extends at least 20”	C	Initially with Fusion360 model by Aidan Fair. Further confirmed with physical prototype by Patrick Smyth.	
3.5” of adjustable desktop height	C	Initially with Fusion360 model by Aidan Fair. Further confirmed with physical prototype by Patrick Smyth.	
Can bear a 100 lb load applied on the desktop without deformation	NC	Verified with SolidWorks simulation by Patrick Smyth.	Due to time and budget constraints, no loading tests were conducted on

			our physical prototype. FEA simulations indicate that minimal deformation would occur.
Total cost meets budget constraint of $400	NC w/ ideal, C w/ marginal	Final BOM by Keeley Wandrocke	See BOM.

Risk Analysis

The following Failure Modes and Effects Analysis (FMEA) table does not have any columns dedicated to detectability or current process controls. This is because our design includes only mechanical components. We have no plans to add electronic components.

Table 4: FMEA

Function	Potential Failure Mode	Potential Effect(s) of Failure	S	Potential Cause(s) of Failure	O	CRIT	Recommended Actions
Desktop position adjusts	Desktop position does not adjust Desktop position changes when user does not want or expect it to (falls during use)	User is uncomfortable User is annoyed User is injured by moving parts	8	Indexing plunger does not fully extend or retract Improper hardware installation Desktop overloaded (linkages may deform) Linkages stuck Linkages slide away from locking mechanism Actuation handle broken	5 2 5 3 4 4	40 16 40 24 32 32	Make sure that the plunger's pin is fully in place before using the desk. You may need to jiggle the armrest slightly to line up the pin and the hole on the linkage. Make sure that there is not too much weight on the desktop. Try adjusting the position without anything on the desk. Visually inspect the parts of the desk and armrest that you can see. If anything looks broken or if the desk continues to not adjust, let your professor know or contact Facilities Management.

Desktop unfolds	Desktop does not unfold	User is uncomfortable User is annoyed	6	Desktop folding hinge is stuck Desktop flats are stuck together	3 1	18 6	Inspect the visible part of the folding hinge to make sure nothing is gumming it up. Run something long and thin (like a ruler) between the desktop flats to make sure that they are not sticking together.
Desktop swivels up from stowed position	Desktop does not swivel	User is unable to use desktop User is annoyed	9	Swivel hinge is stuck An object is in the desk's path of motion	1 3	9 27	Check that nothing is gumming up the swivel hinge. Check that nothing is blocking the desk's movement.

Final Design

Component Details

All engineering drawings of custom components can be found in Appendix A

Desktop

Figure 25: Extended desktop viewed from the front, facing the chair.

Desk

Overall desktop space was increased by over 50%, providing 20” (50.8 cm) of deskspace crosswise. In order to fit the space constraints of the existing desktop, the new desktop is half the thickness of the old. The two ½” (1.3 cm) surfaces fold together via a custom made hinge.

Figure 26: Folded desktop viewed from the rear.

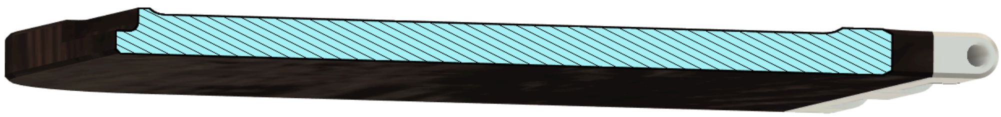


Figure 27: Cross section view of desk recess.

In response to the initial surveys done on what improvements students would like to see, one of the main features of the desk was a recessed surface to keep objects from rolling off the edge. A pocket was added on each end to make opening the desk easier.

Red oak was the chosen material for the desk as it provides high strength and is easily machined. Initially, the design was to be manufactured in aluminum. After closer looks at the FEA of the desktop, the high risk area was at the hinge rather than along any portion of the desktop. Aluminum was kept for the hinge portion, but wood proved to be a comparable replacement for the desktop and provided better aesthetics and easier production. Each desk was CNC machined individually, final radial dimensions sit within ~0.005” (0.013 cm) and axial within ~0.01” (0.025 cm). Mounting holes for the hinge were drilled in a mill to ensure that the hinges sat along the same axis. Dowel pins were used to hold the hinge in place while tightened..

Figure 28: Hinge mounting points. Four M4 bolts and three ⅛” dowel pins.

Hinge and Links

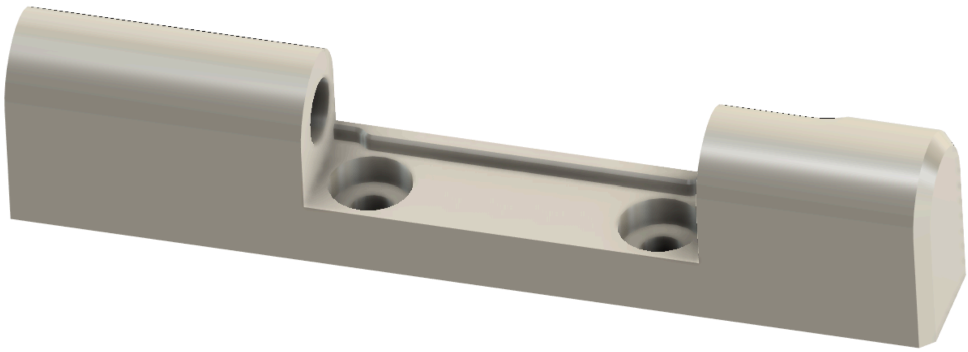


Figure 29: One of the hinge components. Uses ¼” shoulder bolts as axles and M4 bolts for mounting

Given the custom dimensions of the desk and a design goal of keeping the hinge point flat, we custom machined hinges that fit the profile of the desk while also providing the support needed to keep the desk from over extending when folded out with weight applied. For ease of manufacturability, the hinge mech for each side was split into two pieces. Each piece required 4 different setups in the CNC mill to machine the smaller details that allow it to work. This process can be seen below.

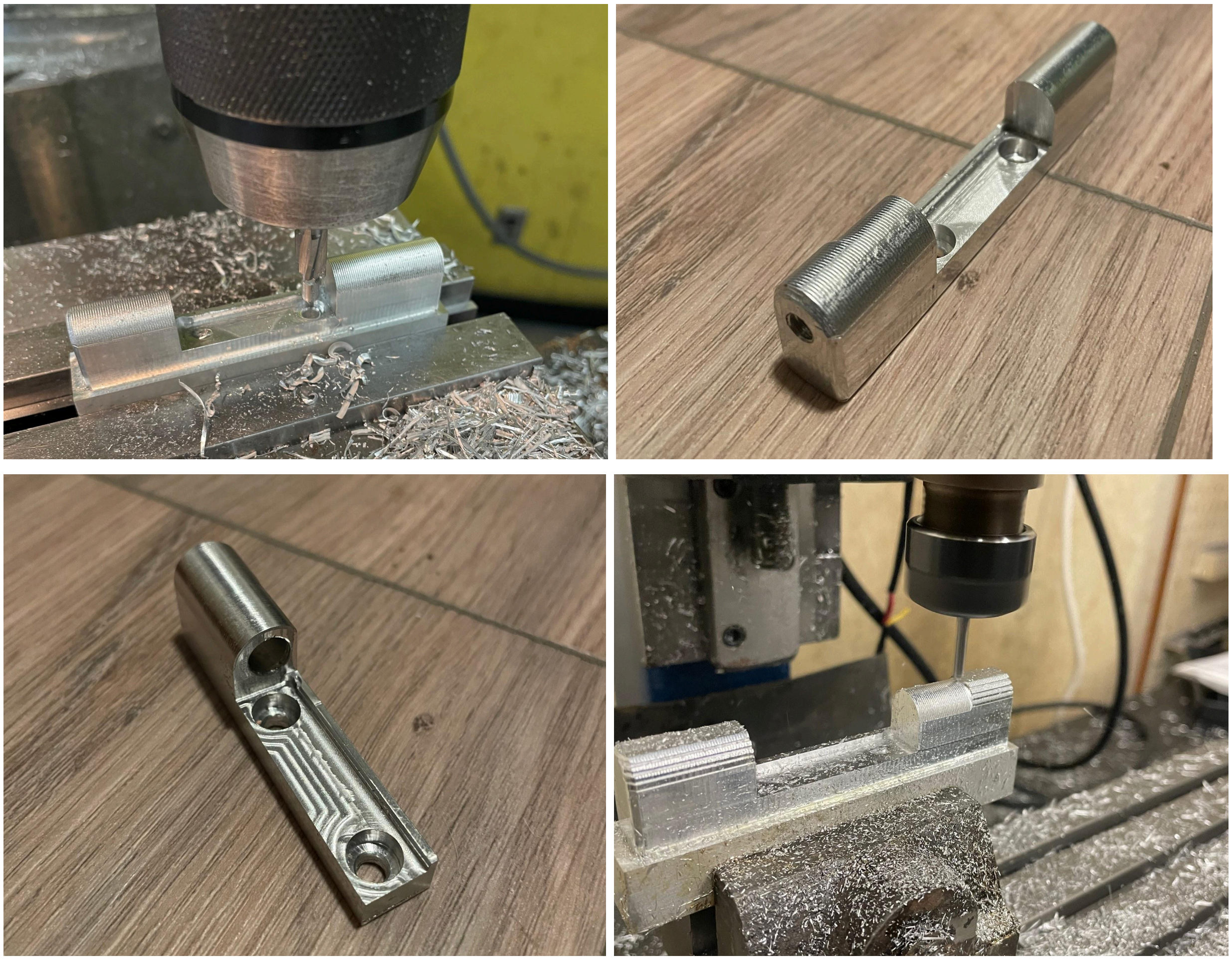


Figure 30: Machining process of the loner hinge component. Multiple 3D CAM programs and setups were used to create the eccentric part.

The links seen in Figure 30 are fairly easily machined components that incorporate bushings to smoothen the folding motion and decrease wear on the axles. The links and hinge are designed around each other to maximize surface contact when the desk is fully opened, dispersing the force across the link and hinge. The hinge also has a stop for when the desk folds, as seen in the sectioned view of the assembly. The cuttaway portion of the hinge is fit to the radius of the link to create the flattest surface possible across the desktop when fully extended.

It was crucial that these components be done in aluminum as they experience the highest stress of the components in the desk portion.

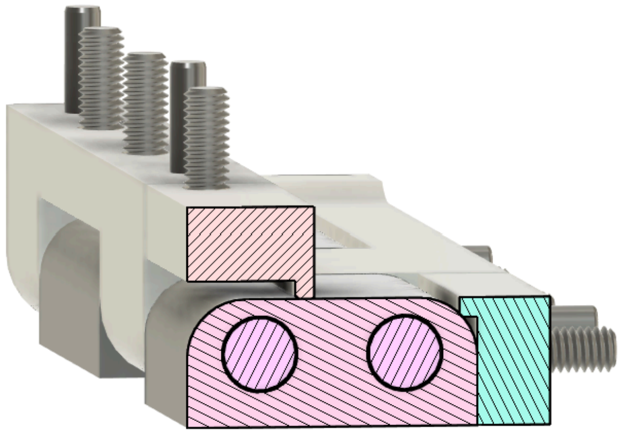


Figure 31: Hinge and link interface. Tight tolerances are required to ensure that no stress risers or extended moment arms were created.

For larger production, the components could easily be cast or machined in quantity with a proper fixture. An improvement on the design could incorporate bushings into the hinges, like what was done in the links. The hinges could attach to the desktop simply with wood screws rather than bolts and threaded inserts. The design was intended to be bolted to an aluminum desktop, a material that is easily drilled and tapped. Using a wood desktop would remove the need for the counterbores and would instead work better with countersinks. In our case, the hinges were already produced by the time we decided to use wood. Threaded adapters were used to allow the use of bolts but left a less than ideal surface for the hinges to bolt to.

A final addition to the desktop was a ¼” (0.635 cm) spacer that keeps the desk horizontal when laid across the armrest. This is similar to the original desk but slightly more compact. The part was simply plasma cut with little post processing to clean up the finish.

Figure 32: Plasma cut ¼" aluminum plates make up the structural part of the armrest and the spacer for the desktop to sit square to the armrest.

Figure 33: Exploded view of the desktop assembly.

Armrest

Frame

Like the desktop, the constraints and functions of the armrest required a completely custom design. The armrest fulfills the height and depth extension requirements while staying within the dimensions of the original armrest.

The armrest was the most iterated design due to issues with available material and timeframe. Despite the setbacks, the final version had no compromise in the overall strength of the assembly. The most significant change was moving from a 2 piece CNC milled aluminum body to a 3 part assembly consisting of a 3D printed center "sandwiched" in between two aluminum plates. Upon closer analysis of the armrest, it was found that the center portion played no role in the structural integrity of the arm rest. The ¼” (0.635 cm) axles of the linkages were supported solely by the outside sections.

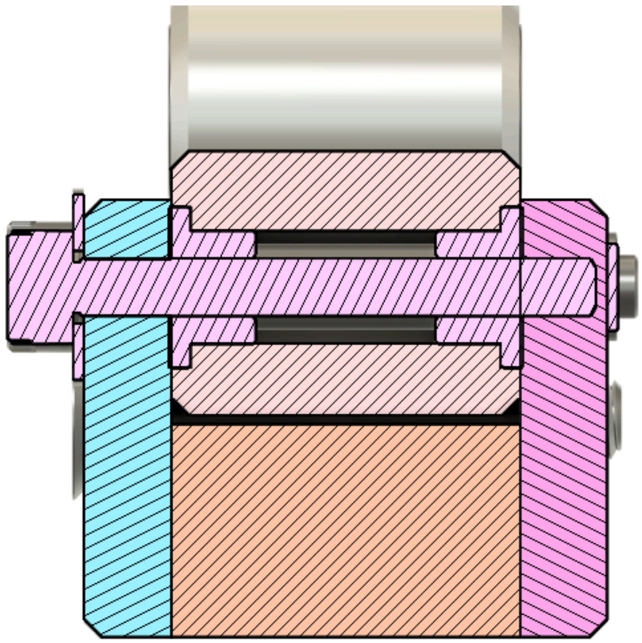


Figure 34: Section view of the armrest. Blue and purple sections are ¼” aluminum plates which guide and support the ¼” axle through the linkage (pink). Orange component is the center of the armrest, bearing no serious loads, the component can be printed or cut from wood.

An improvement would be to use wood or injection molding for the center. The one important role of the center is to line up the two aluminum plates. Machined wood or molded parts will allow the sides to align far better than a 3D printed part which deforms during the printing process. Without proper alignment, the linkages will bind or sit off the axis.

Figure 35: Side plates of the armrest as arranged for generating tool paths for plasma cutting.

Linkages

The linkage component underwent various revisions due to material constraints. Given the high stress application of the linkages, there could be no compromises in the production of the part. The ultimate design is the strongest of the iterations but also the heaviest and the most expensive. Having to use aluminum stock instead of rectangular drawn tubing did allow us to machine high precision linkages with pressfit pockets for the bushings.

The switch to aluminum stock linkages also required a redesign of the component responsible for the indexed positions. The part was machined rather than simply plasma cut, and was bolted to the linkage instead of welded.

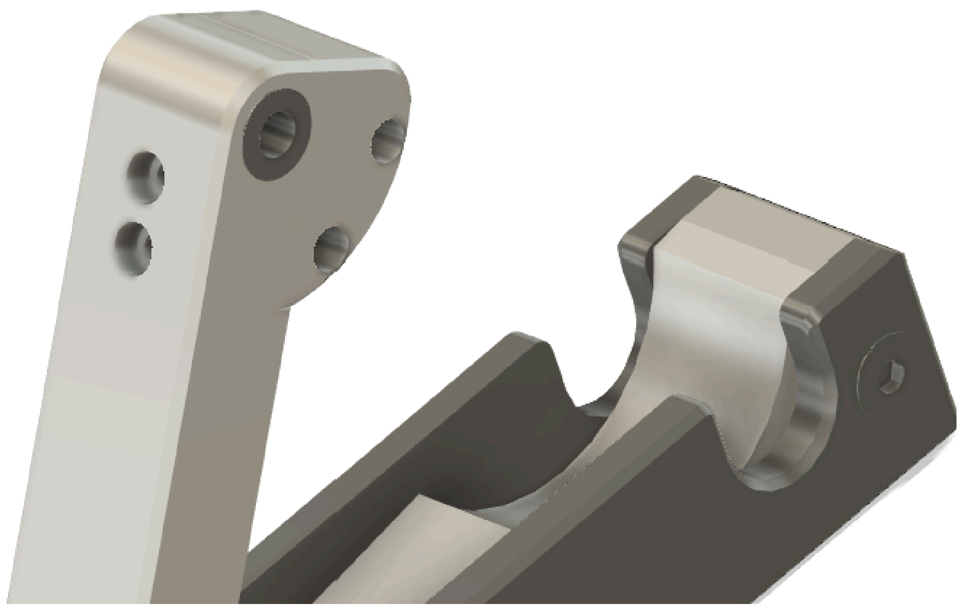


Figure 36: Linkage with attached locking block. Bolted with two M4 bolts

Locking Mechanism

The armrest was designed to lockout in three different positions, providing three different height and extension settings. Spring loaded locking pins (seen in Figure 37) are used to lock into the holes of the linkage. The pins are actuated by a cam. In order to integrate the locking mech, mounts were machined and bolted to the outside plates.

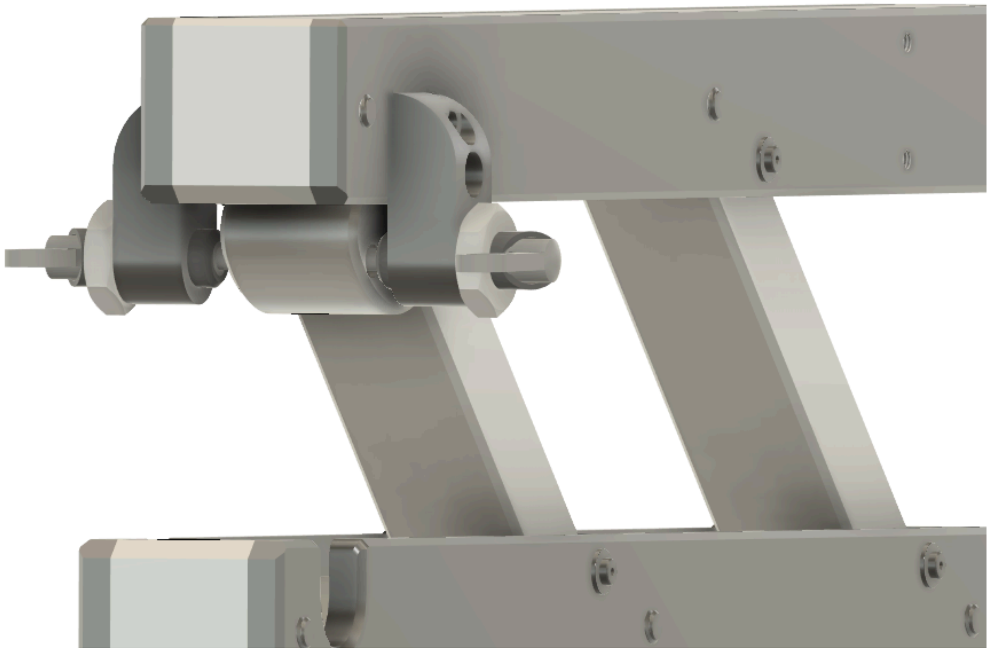


Figure 37: Locking plungers fit the holes on the locking block, providing three indexed positions.

Figure 38: CNC machined locking mech mounts. Bolts to armrest plates via two M4 bolts.

In order to make lifting the armrest easier, a handle (seen in Figure 39) was designed to simultaneously actuate both cams and provide greater leverage. The handle was 3D printed on an FDM printer but due to its shape and need for supports, injection molding or powder bed fusion printing would be ideal.

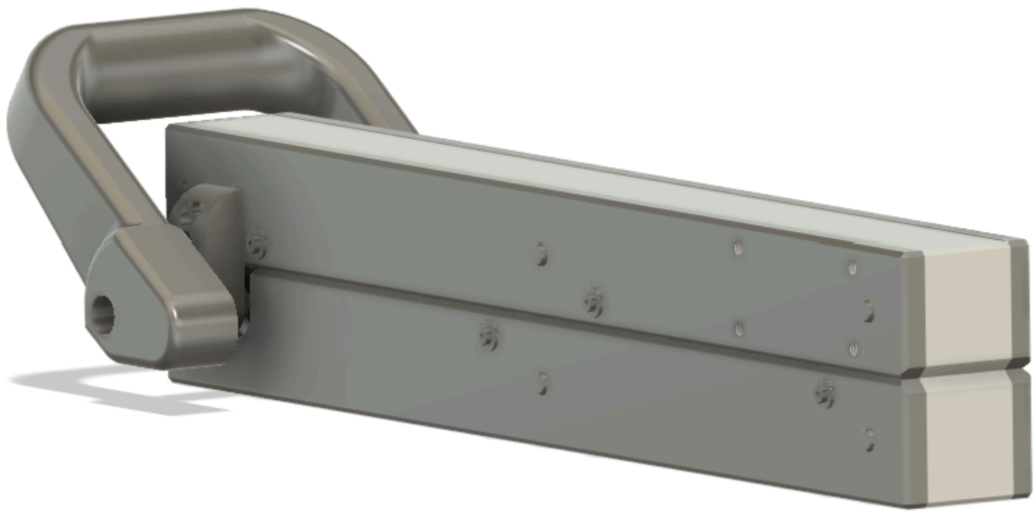


Figure 39: Armrest with actuating handle. The four bolt pattern on the right is where the purchased swivel hinge attaches.

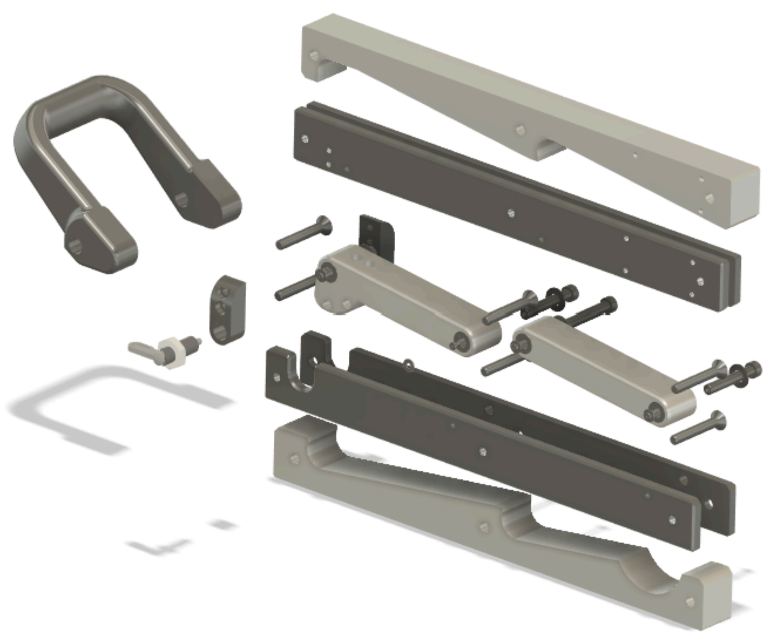


Figure 40: Exploded view of the armrest assembly.

Figure 41: Exploded view of desktop and armrest attachment.

Figure 42 below contains photos of our completed physical prototype in various states, including stowed and unstowed and at various height levels.

Figure 42: Photographs of physical prototype.

BOM & Cost Analysis

Figure 43 below shows our final Bill of Materials (BOM). The full sheet can be accessed here. Please note that the BOM does not include any labor costs, only material costs.

MAE151B

Bill of Materials Template (modified from propelplm.com)

PRODUCT NAME Stowable Lecture Hall Desk
DESCRIPTION
TEAM NUMBER 10
TEAM MEMBER NAMES Aidan Fair, Patrick Smyth, Yijun Liu, Keeley Wandrocke
PART COUNT 43
TOTAL COST $423.75
SHIPPING + TAX $48.81

Level	Item Number	Description	Category	Revision	Quantity	Lifecycle Phase	Notes	Source (shop/distributor)	Distributor Part Num	Cost (ea.)	Cost (tot,)	Link (distributor, g-drive drawing/file, etc)
		Desktop										
2	D001	Desktop Flats	MTS		2	Production	Oak hardwoo	Wood from Ganahl Lumber,	-	$ 15.00	$ 30.00	https://drive.google.com/file/d/15wMTEQ6bqthG
3	D002	Desktop Hinges	MTS		2	Production	Aluminum	UCI Machine Shop	-		$ -	https://drive.google.com/file/d/1FHAOipsUcsxJD
3	D003	Desktop Axle Mounts	MTS		4	Production	Aluminum	UCI Machine Shop	-		$ -	https://drive.google.com/file/d/1Ow6H_AsgVvU8
		Plunger										
1	P001	Indexing Plunger w/ cam actuation	OTS		2	Production		Zoro	K0637.1050410	$ 24.39	$ 48.78	https://www.zoro.com/kipp-cam-action-indexing-
1	P002	Plunger Handle	MTS		1	Production	ABS	Fabworks	-		$ -	
		Swivel Hinge										
1	S001	Multi-Axis Friction Hinge	OTS		1	Production		McMaster-Carr	2332N11	$ 53.33	$ 53.33	https://www.mcmaster.com/2332N11/
		Height Adjustment Mechanism										
2	H001	Bottom Armrest	MTS		1	Production	ABS	Fabworks	-	$ 1.36	$ 1.36	https://drive.google.com/file/d/1EjhVG_gCatTF5
2	H002	Top Armrest	MTS		1	Production	ABS	Fabworks	-	$1.36	$ 1.36	https://drive.google.com/file/d/1_pnsrMGdjH2rHF
2	H003	Aluminum flat bar - 1.75" x 2" x 36"	OTS		1	Production	For armrest re	Online Metal Supply	6063FBT1.75W2L36	$76.17	$ 76.17	https://onlinemetalsupply.com/1-75-x-2-x-36-606
2	H004	Aluminum flat bar - 0.75" x 1.25" x 36"	OTS		1	Production	For linkages	Online Metal Supply	60616FBT0.750W1.25L36.1	$32.78	$ 32.78	https://onlinemetalsupply.com/0-750-x-1-25-x-36
		Miscellaneous										
3	M001	M4 Bolt 12mm (qty 50)	OTS		1	Production		McMaster	93070A103	$ 10.79	$ 10.79	https://www.mcmaster.com/catalog/130/3552/93
3	M002	4-40 Bolt 3/16" (qty 10)	OTS		1	Production		McMaster	92220A313	$ 13.21	$ 13.21	https://www.mcmaster.com/catalog/130/3552/92
3	M003	Internal threaded shoulder 1.5" 4-40	OTS		4	Production		McMaster	96655A115	$ 9.21	$ 36.84	https://www.mcmaster.com/catalog/130/3532/96
3	M004	Shoulder screw 1/4"dia, 5"lg	OTS		2	Production		McMaster	91259A425	$ 14.77	$ 29.54	https://www.mcmaster.com/catalog/130/3528/91
3	M005	1/8" Dowel pins 5/8" length (qty 50)	OTS		1	Production		McMaster	98381A472	$ 9.30	$ 9.30	https://www.mcmaster.com/catalog/130/3528/91
3	M006	316 Stainless steel washers (qty 100)	OTS		1	Production		McMaster	90107A005	$ 3.72	$ 3.72	https://www.mcmaster.com/catalog/130/3668/90
3	M007	18-8 Stainless steel washers for size 14 screw (qty 100)	OTS		1	Production		McMaster	92141A223	$8.00	$ 8.00	https://www.mcmaster.com/catalog/130/3668/92
3	M008	High load sleeve bearing 1/4" shaft	OTS		8	Production		McMaster	60695K1	$1.86	$ 14.88	https://www.mcmaster.com/catalog/130/1430/60
3	M009	High load oil-embedded sleeve bearing 1/4" shaft	OTS		8	Production		McMaster	2938T1	$0.61	$ 4.88	https://www.mcmaster.com/catalog/130/1436/29

Figure 43: Bill of materials.

As can be seen, we exceeded our budget by $23.75. This still places us within our marginal budget of $430, but is nevertheless unideal. We used $30 of the $150 gift card provided to us by Ganahl Lumber to purchase wood for the desktop flats. If we subtract this value from the total money spent, we are left with $393.75, which is within our ideal budget maximum of $400.

Estimating the labor needed to create our product is a bit of a challenge. Patrick works in UCI's machine shop, leading him to complete all of the machining work necessary for our custom components. Patrick estimates that remaking the prototype with all of his current knowledge would take him approximately 60 to 80 hours. The machine shop charges $65/hour. If we were to make our product using only the machines and labor available at UCI, it would cost between $3900 and $5200 for the labor alone. This is far more expensive than would be practical if we wanted to sell this product.

If we were to mass manufacture the desktop, certain manufacturing processes would likely change. The swivel hinge was an expensive OTS component, so we may try to design and manufacture our own to keep costs down. All custom aluminum parts would be manufactured with die casting rather than milling, cutting down on production times and therefore costs.

Producing in bulk would also bring certain OTS component costs down. Many of the components in the 'Miscellaneous' section of the BOM offered lower individual unit prices if more than a certain amount were purchased at a time. Bulk purchasing would also reduce shipping costs.

Process Flowcharts

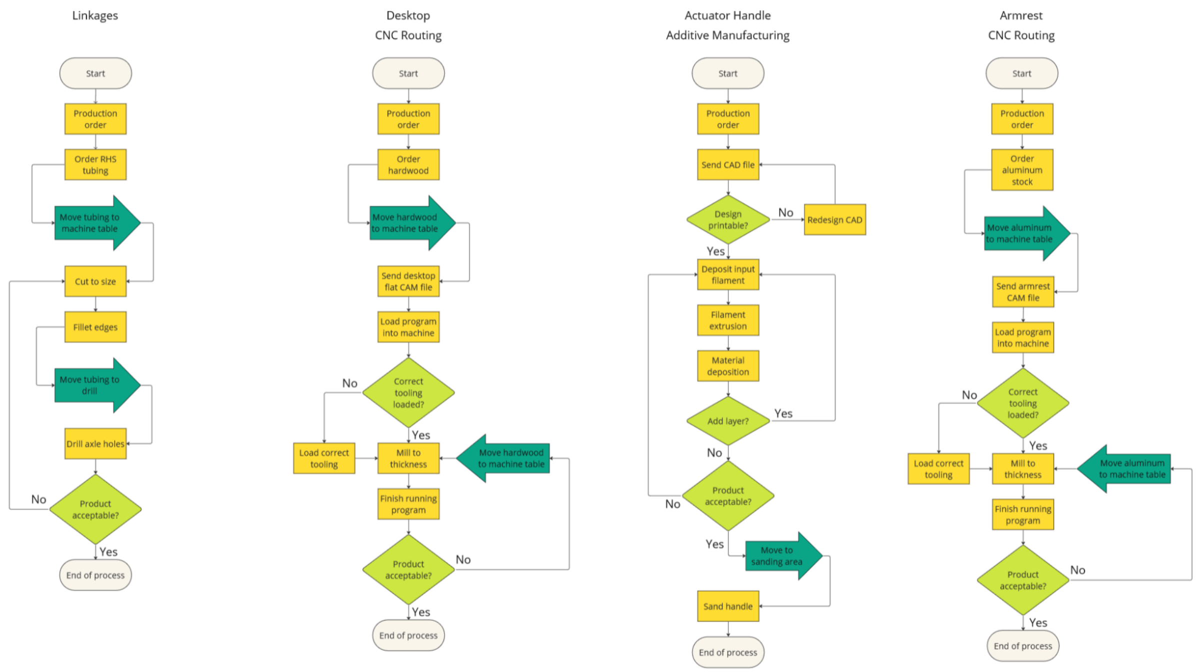


Figure 44: Manufacturing flowcharts for ideal prototype.

Figure 44 above contains the manufacturing flowcharts for our four main designed components in our ideal prototype. Below, Figure 45 shows the flowcharts for the processes used in our real final prototype.

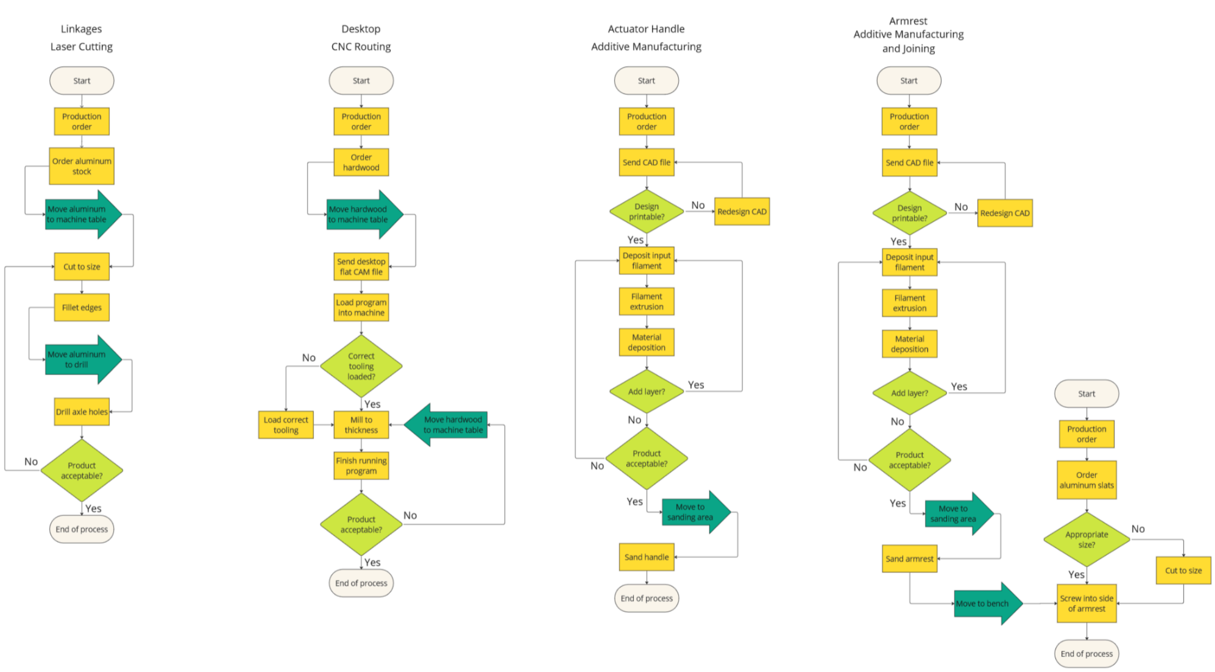


Figure 45: Manufacturing flowcharts for final prototype.

Due to time constraints and a lack of available RHS, we used solid aluminum for the linkages rather than RHS. The manufacturing process for the armrests changed quite significantly. Rather than using the CNC router on aluminum stock, we 3D printed the main body of the armrest slats and reinforced the sides with long pieces of aluminum. This was due to time and budget constraints.

Ideally, the manufacturing process would follow the first set of flowcharts. More detailed manufacturing methods are discussed above in the 'Component Details' section.

Conclusions

We successfully achieved our goal of creating a more accessible lecture hall desktop. Our final prototype's wide desktop can be used by both right- and left-handed users. Our height adjustment mechanism allows for combined height and depth adjustment, making the product more comfortable for users who are tall and/or large. All swivel points within the design rotate with the correct range of motion. Our prototype fits within the geometry constraints of the current lecture hall chair. All of our initially stated objectives were satisfied by our final prototype.

If future work were to be done on the project, we would like to conduct user testing and loading tests. The protocols for these tests were discussed earlier in the 'Testing Protocols' section. We would also like to try and separate height adjustment and depth adjustment, making the desktop's position even more customizable. Improving the safety of our product would also be a crucial goal, as extremities and clothing may get caught in between the slats of the armrest when in a raised position. Making this pinch point inaccessible would reduce potential injury.

If we had the opportunity to restart this project with our current knowledge, we would put more effort into effectively managing our time. Getting started sooner, checking the class schedule well ahead of time, and asking for help if expectations are unclear or if tasks start to go wrong would help produce a product more in line with our concept and reduce stress within the team. We would also pay closer attention to the availability of chosen OTS components. We wanted to make the linkages within the armrest out of 1.25" (3.175 cm) by 0.75" (1.905 cm) RHS tubing, but tubing with those dimensions was in short supply. All of the vendors we checked were sold out by the time we sent in an order. In contrast, 1.25" (3.175 cm)by 1" (2.54 cm) tubing was easy to find in stock. Slightly changing our design to accommodate this tubing size would have prevented us from having to alter it so far into the quarter. The swivel hinge connecting the desktop to the armrest was also an issue. Only two vendors sold a hinge of an appropriate size and the price from both was over $50, meaning that this single component cost over an eighth of our total budget. Designing and manufacturing our own swivel hinge would likely have been a challenge but it may have freed up space in our budget for other materials or components.

Despite these issues, we are proud of the design and prototype we were able to produce. We hope that UCI continues work on our project to make it more suitable for the classroom. The demand for accessibility is there; at the Annual Design Review, many of the people who visited our poster expressed their desire to see our design in the lecture halls, with some even asking when the new desktops were going to be installed. Making the lecture halls more accessible is a way of showing that UCI cares for their entire student body and sees their ability to learn in comfort as a priority. We would be honored if UCI decides to keep this project alive, and even if they choose not to, we at least hope that Equitable

Design Solutions helped raise awareness of accessibility and human-centered design, inspiring the next engineer to consider it in their future work.

Final Timeline

TASK NAME	START DATE	END DATE	START ON DAY*	DURATION* (WORK DAYS)	TEAM MEMBER	PERCENT COMPLETE
Presentations						
Problem Redefinition and Updated Milestones	1/15	1/17	0	2	All	100%
Critical Design Review	1/22	2/4	7	13	All	100%
Prototype B Presentations/Demonstrations	2/15	3/1	31	15	All	100%
Annual Design Review prep	3/8	3/15	53	7	All	100%
Critical Design Review						
Stress Analysis/ deflection test	1/22	1/29	7	7	Patrick	100%
Risk Analysis	1/25	2/1	10	7	Aidan	100%
Establish improvements	1/25	2/4	10	11	All	100%
Prototype B						
Risk Analysis	2/5	2/21	21	16	Keeley	100%
Write protocols for future tests	2/21	2/26	37	6	Keeley	100%
Complete Protoype B	2/23	2/23	39	1	All	100%
Final Demonstration						
Purchase order and update BOM	1/15	3/4	0	49	Bill	100%
Finalized design and parts ordered	3/4	3/4	50	1	All	100%
Annual Design Review poster	2/23	2/27	39	5	All	100%
Project website	2/24	3/1	40	8	All	100%
Finalize assembly	2/26	3/8	42	11	Patrick	100%
Final design binder	3/1	3/22	47	22	All	100%
Complete final prototype	3/15	3/15	59	1	All	100%

Figure 46: Final Gantt chart.

Above, Figure 46 displays our final timeline for MAE151B. The redlines and orange diamonds are milestone markers. In order, these three milestones are completing our second prototype, ordering all the materials and components for the final prototype, and completing the final prototype.

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Appendix

If you are unable to access the content linked below, please e-mail kwandroc@uci.edu.

A.1 Project Ideas

A.2 Engineering Drawings

A.3 Custom Component STL Files

A.4 Meeting Agendas and Minutes

A.5 Past Reports

A.6 Project Website

A.7 Component Analysis Documents

A.8 Final Prototype Photos