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Final Report

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Space Saving Workbench
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"I pledge on my honor that I have not given or received any unauthorized assistance on this assignment/examination."
Signatures:

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1.0 Executive Summary

The typical workbench takes up a considerable amount of space when fixed in one location. Therefore, it can be difficult for individuals with limited workspace to perform do-it-yourself (DIY) projects in their homes, garages, or other workspaces. Our team, Space Force, and our capstone project, the Space Saving Workbench, solves that problem. Using the engineering design process, our team designed a large mobile and completely collapsible workbench. Casters allow the workbench to be moved around a workspace while a unique wood and hinge-based design allows the full-size workbench (57”L X 24”W X 27”H) to be folded into a shape roughly a third of the original size. Utilizing CAD simulation and scaled-down testing, we will assemble a successful prototype of the workbench that proves the initial concepts. With future improvements, this product could be successful in the DIY market. The components of our capstone project that we will explore are:

- Market Analysis
- Problem Identification
- House of Quality
- Conceptual Design Process
- Embodiment Design Process
- Manufacturing and Process Cost Analysis
- Final Product Design Specification or "PDS"
- Prototyping & Testing
- Sustainability - Social, Economic, and Environmental Design Considerations

2.0 Market Analysis Information

Our full design was not based on any other designs, but the folding mechanism takes inspiration from a product in the March 2007 issue of magazine. The product is a large table base. It is a large structure (24 in. by 28 in. by 44 3⁄4 in.) with a wooden frame on each end with arms and panels connected by hinges to support the structure. When pushing the structure in on itself, the arms and panels fold in half and fit neatly into the end frames, creating a sandwich shape that greatly decreases the area the product takes up. Locking swivel casters are placed on the bottom of the base to provide mobility. The product can be seen below.

WORKSHOP TIPS FROM OUR READERS

edited by Tim Johnson
and Brad Holden

Folding Table Base

Want a mobile table base that provides a huge work area, holds a ton and folds up to only 7 in. thick? You can get everything you need to make the one shown here at the local home center for about $65. Build it to any size. Just make sure the folding support arms (E) and panels (F) fit inside the end frames, so the assembled table folds up completely. Screw on a top when you need a work surface and remove it when you're ready to stow the table. Hook-and-eye catches hold the folding supports open when the table is in use and keep it closed during storage.

Dick Ayers

CUTTING LIST Overall Dimensions: 24" x 28" x 44-3/4"

Part	Name	Number	Dimensions
A	Frame stile	4	1-1/2" x 3-1/2" x 21"
B	Frame rail	4	1-1/2" x 3-1/2" x 24"
C	Fixed support	4	1-1/2" x 3-1/2" x 21"
D	Hinge mounting strip	4	3/4" x 2" x 21"
E	Folding support arm	4	3/4" x 3-1/2" x 19-7/8"
F	Folding support panel	2	3/4" x 13-3/4" x 19-7/8"

Hardware: Eight 3-in. butt hinges, four 5-in. strap hinges, five hook-and-eye latches, four 3-in. locking swivel casters.

ART DIRECTION AND PHOTOGRAPHY: VERN JOHNSON

Figure 2.1: Folding Table Base from American Woodworker Magazine

Still, this product is just a table base. In order for it to be used, a table top must be screwed into the top of the table. While the folding mechanism of this product is impressive, it lacks the a folding mechanism for the tabletop. Since the top needs to be screwed, the consumer either has to create their own folding mechanism for their tabletop or be forced to use the product only in its elongated table form, defeating the purpose of the folding mechanisms in the first place. On its own, this product does not provide much use. A better product would include a tabletop that folds, similar to the support arms and panels.

To discover patents, we used https://patents.google.com/. Some terms used were “folding shelf bracket”, “collapsible table”, “folding table”, “folding workbench”, and “portable workbench”. In our search, we only found one patent similar to our design. It folds in a similar manner to our product and the product above. However, it was not exactly the same. It uses a much more complicated design, including more components, support structures, and folding directions. The patent can be found in Appendix 4.

There are five types of workbenches: workbench tables, workbench cabinets, workbenches with pegboard, portable workbenches, and wall-mounted workbenches.

Workbench tables are flat wooden or metal surfaces supported by four legs. They most popular type of workbench, due to simplicity and sturdiness. Portable workbenches include mobile and folding workbenches. Mobile workbenches move around on a surface, usually using casters. They typically provide the same sturdiness and structure as workbench tables. Folding workbenches fold to provide more space when not in use. Since they fold, they are usually smaller and lighter in weight. However, they still prove to be useful in most tasks.

Figure 2.2: Workbench Table, Folding Workbench, and Mobile Workbench

Our design combines the mechanics of portable workbenches and workbench tables. Furthermore, it utilizes both types of portable workbenches, rather than just one or the other. Therefore, it is a mobile and foldable workbench table. Consumers will prefer this product since it fits multiple purposes, rather than just one.

Mobile and foldable workbenches exist on the market, but they are made much smaller than our design. While the market for our workbench may not be huge, there is still a niche, dedicated market willing to buy the product. Searching "collapsible workbench" on Google, several results reveal do-it-yourself (DIY) projects in the same vein as our project. Make Magazine, a bimonthly magazine dedicated to DIY projects, refers to workbenches as "Some of our most popular posts here on Make." (Branwyn). Furthemore, the top 2 best sellers on Amazon in the "Workbench" category are foldable workbenches (Amazon). However, these are small foldable workbenches. No workbenches that are the size of a workbench table are

available.

3.0 Problem Identification

3.1 Problem Statement

The typical market for workbenches only considers static structures. Space Force wants to completely change how a workbench can be perceived. Space Force wants a workbench that can be portable, rigid, and compact all while maximizing the useable workspace area. Today's market has left several voids customers would desire from a workbench. A typical collapsible workbench is usually way too small or is a 2 piece system. This workbench would solve those existing problems in the market by providing a large work surface that is one total unit.

With the invention of Space Force's workbench consumers and DIY workers would be able to provide a temporary workspace that would allow for projects and work that require a workbench. With its collapsibility and storage features, users would be able to store away the workbench when it is not required allowing for other items to occupy that space. This could change the way some people view smaller work areas within their property. For example, a DIY with a small shed may not have the area to build a permanent static workbench. Therefore, he/she would not be able to have adequate space to do the job. With Space Force's workbench, he/she can use the workbench small storage space to store away when it is no longer needed.

3.2 Human Factors considerations

The workbench has several latches and pins that require the user to engage and remove to set up and store away. These latches can be a potential area that a user setting up or putting away the workbench may pinch or catch their skin in. Space Force plans in the future to develop a safer way for the user to be able to engage these latches from a potential pinch area. Another area of concern for the workbench in regard to human safety is the stability of the workbench when in the stored position. Currently, the prototype is a little unstable when in the stored position. This could cause a potential risk to younger children when near the workbench in the stored position. The Space Force team going forward would like to provide a solid base to the workbench to prevent the workbench from falling over when it's in the stored position.

4.0 House of Quality

The House of Quality is a tool used in the product planning phase that defines the customer requirements and engineering characteristics of the product and compares them to each

other using weights created by the design team. This step in the phase is essential in defining what features are necessary for the product to succeed.

Customer Requirements:

- *Unfolded Size* needs to have enough top surface area to accommodate various projects.
- *Folded Size* should be small enough to store in areas with limited space.
- *Cost* should be set at a reasonable value in comparison to similar products in the market.
- *Mobility* is important so that the customer can maneuver the device within their space.
- *Strength* should be comparable to an ordinary static workbench.
- *Durability* is important because the customer will want the product to last a long time.
- *Build Quality* should be high enough for the customer to consider it a quality product worth their investment.
- *Versatility* means that the product should be able to satisfy several of the customers needs in different ways.
- *Height* should be similar to standard workbenches, at a reasonable standing height for most people.

Engineering Characteristics:

- *Table Top Strength* describes the table top's ability to withstand forces applied.
- *Wheels* that allow for easy maneuverability around a user's workspace.
- *Collapsibility* is the qualitative amount that the product can transform from one size to another (ie. the product should be able to collapse to be 4X smaller).
- *Structural Supports* are necessary for proper stability of the product.
- *Material Strength* is determined by the internal forces within the suggested material and effects the overall strength and stability of the workbench.
- *Material Cost* is derived from the cost it takes to purchase the material and effects the overall cost of the product.
- *Weather Resistance* is important because the storage of the product is not completely predictable, some users may store it in wet, cold, or hot places.
- *Material* is an important characteristic because it affects many parts of the product interactions.

Below is the completed House of Quality.

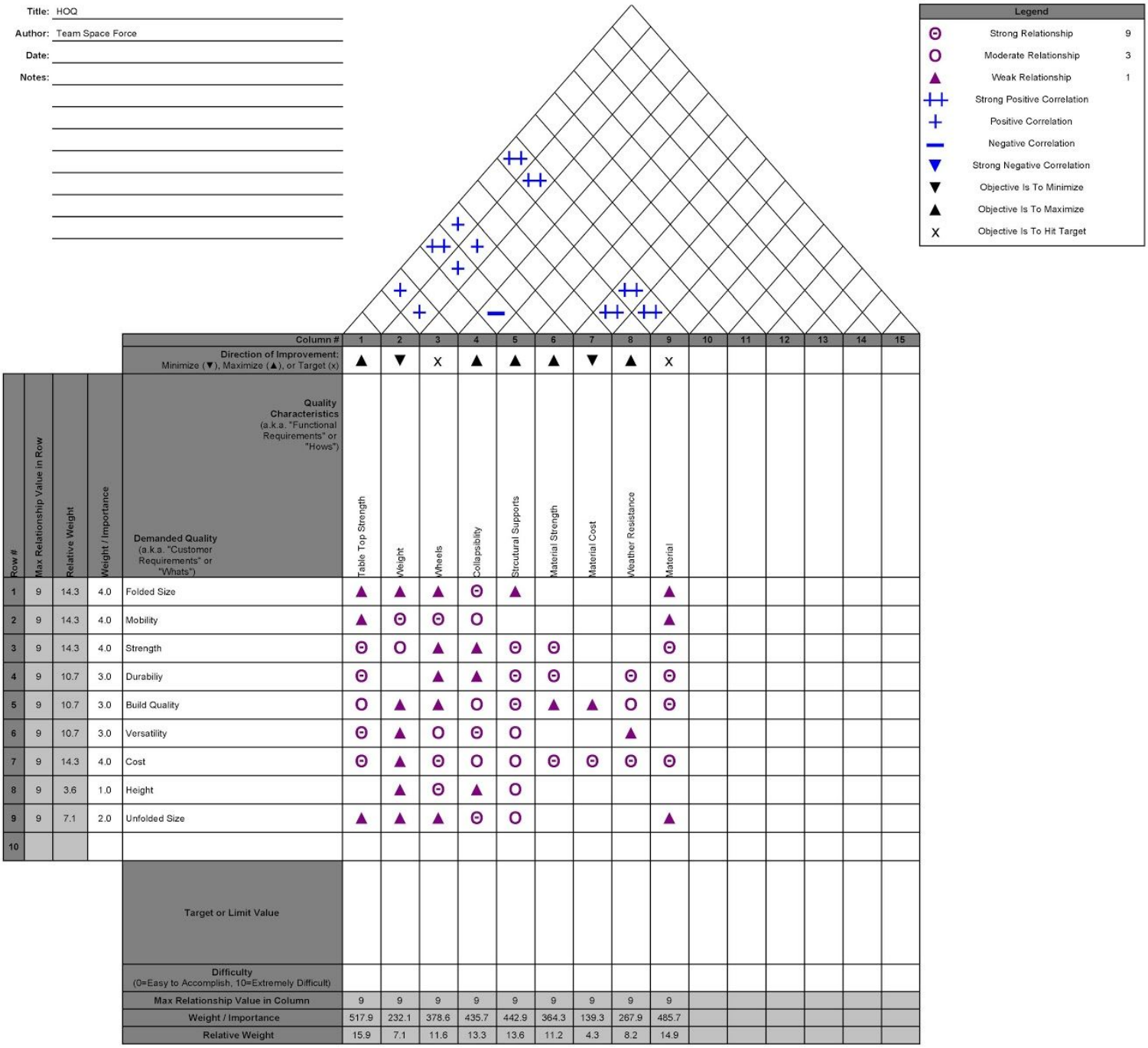


Figure 4.1: House of Quality

The results of our analysis convey that the most important engineering characteristic is tabletop strength. This result makes sense because the most important feature of a workbench is for the user to use its top surface for whatever needs they may have if the tabletop were not strong enough it would not serve its main purpose. With the strength of the tabletop being the most important characteristic, our team must work towards satisfying that need. The next highest

engineering characteristic is structural supports. Once again, this relates to the overall stability and strength that the workbench requires to satisfy the customer needs.

5.0 Conceptual Design Process

5.1 Feasible Concepts

As mentioned previously, the goal of the HOQ is to relate the product's capabilities with the needs of the customer. Using the results of the HOQ the team was able to establish a set of characteristics, that no matter how the product would be designed the team, would have to ensure that these characteristics stay consistent. A Morphological Chart is used to assist with concept generation. The team decided that the best way to use the morphological chart was to choose different designs around the sub-functions closely related to the most important quality characteristics. For example, the top quality characteristic was tabletop strength. That strength is going to be directly related to the supports we use to support the table in the middle and sides. Therefore we came up with two different ideas for supporting the table; one of which is “No support” meaning we would only have a hinge on the pieces of wood. Below is our morphological chart.

Morphological Chart				
Alternative Concepts				
Subfunctions	1	2	3	4
Locking Mechanism	Spring/ball	Barrel Lock	Extension lock	Eccentric action lock
Mobility	Casters	Solid feet	Casters with Locks	Casters with electronically controlled locks
Support	OTS Folding bracket	Custom Folding bracket	No Support	
Hinging for supports	Strap hinges	eye-hook	Butt hinge	
Material	Pine	Extruded Aluminum 80/20	Oak	
Hinging for top	Continuous hinge	Door hinge		
Scale	Full Scale	Half	Quarter	Custom
Lower Folding Mechanism	Z-Pattern 3 Support	2 Parrallel Supports with Back Brace	Telescopic Brace	

Figure 5.1: Morphological Chart

There are some blank spaces where the team could not think of a design alternative for the specific sub-function. However, the team was able to develop three different concepts that we believed were realistic. We would not choose a concept to until we used a decision making tool like AHP. At this point in the process it was still somewhat unclear how we were using all of these decision matrices for selecting the final product or the prototype. We ended up using somewhat of a combination of the two. At this point in the process there were no hard set dimensions, but we did add whether or not we would build a quarter, full, or custom scale to the morphological chart. There is an inherent inverse relationship between material cost and scale. That relationship added to the feasibility of the product.

Concept 1	Concept 2	Concept 3
Eccentric action lock	Spring/ball	Barrel Lock
Casters with Locks	Casters with electronically controlled locks	Solid feet
OTS Folding Bracket	Custom Folding bracket	No Support
Strap hinges	Butt hinge	eye-hook
Pine	Extruded Aluminum 80/20	Pine
Continuous hinge	Door hinge	Continuous hinge
Custom	Quarter	Full Scale
2 Parrallel Supports with Back Brace	Telescopic Brace	Z-Pattern 3 Support

Figure 5.2: Chosen Concepts

Black Box Function Structure

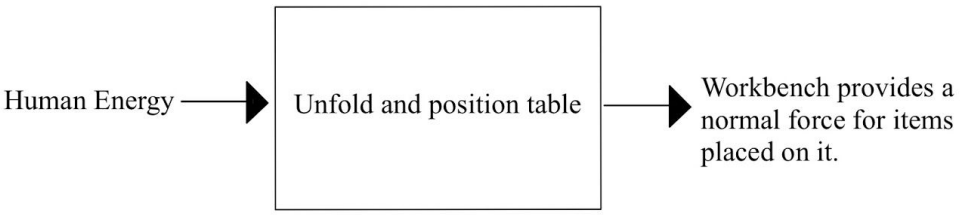


Figure 5.3: BB Function Structure

Concept 1	Concept 2	Concept 3
Eccentric action lock	Spring/ball	Barrel Lock
Casters with Locks	Casters with electronically controlled locks	Solid feet
OTS Folding Bracket	Custom Folding bracket	No Support
Strap hinges	Butt hinge	eye-hook
Pine	Extruded Aluminum 80/20	Pine
Continuous hinge	Door hinge	Continuous hinge
Custom	Quarter	Full Scale
2 Parrallel Supports with Back Brace	Telescopic Brace	Z-Pattern 3 Support

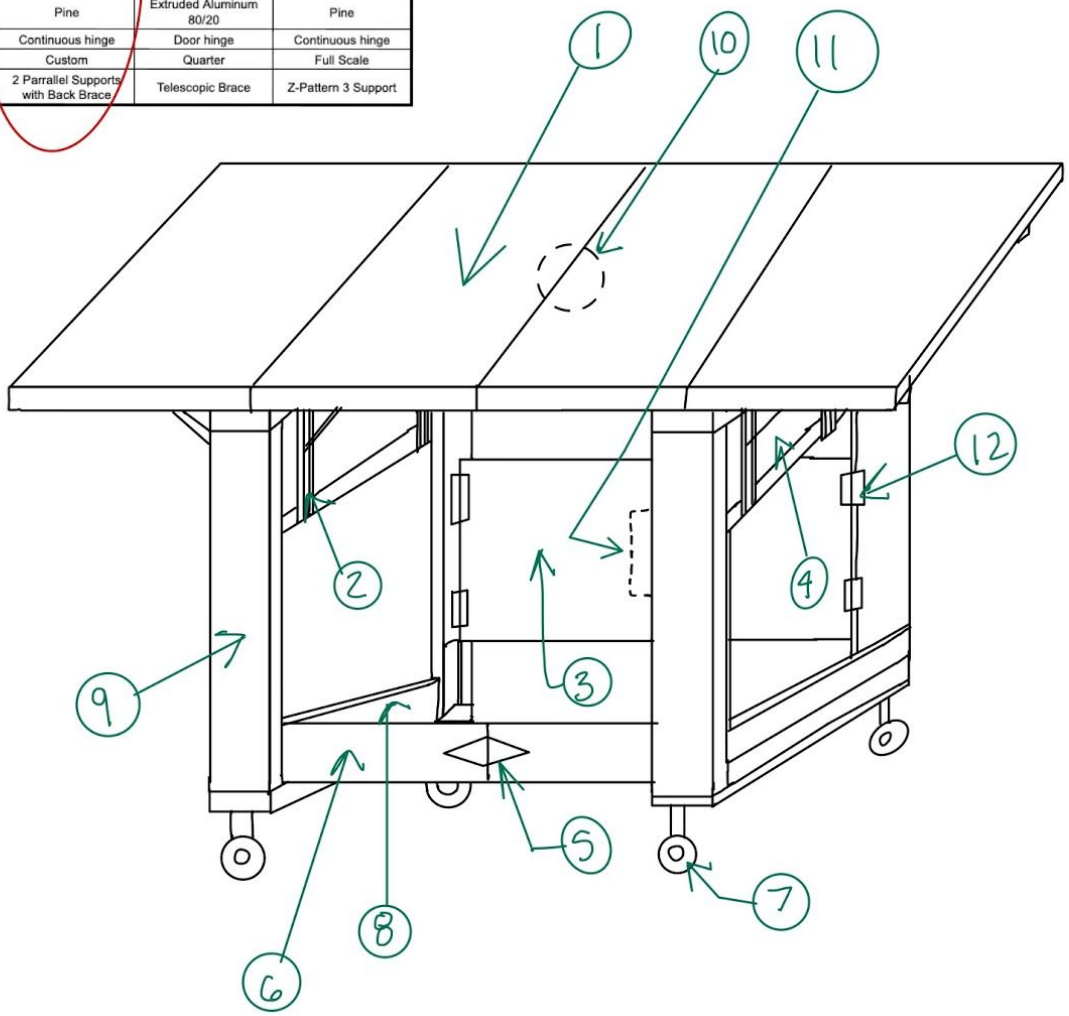


Figure 5.4: Hand Drawing Concept 1

Item Number	Item Description	Quantity
1	Table Tops	4
2	OTS Stainless Steel Supports	8
3	Plywood Support	2
4	4x4 Structural Support	2
5	Strap Hinge	1
6	1x4 Support	6
7	3 in. Caster Wheels	4
8	Cross beam support(2x4)	4
9	2x4 support(Includes All 2x4's)	12
10	Eccentric Lock	1
11	Continuous Hinge(w/ pin)	1
12	Butt Hinge	4

Figure 5.5: Concept 1 Parts List

All of the designs will function very similar, but key differences will usually relate to the cost. Concept 1 while in a collapsed position the table will be pulled apart by the user, the strap hinge(item 5) in combination with 1x4 supports(item 6), will help stabilize the product properly. Then the user will move both plywood supports(item 3) into their fully opened positions and drop in the pin into the continuous hinge(item 11). The top panels(item 1) are being held in the locked position stainless steel supports(item 2). The user will need to unlock item 2 and raise item 1 for all 4 panels(item 1). Once all four panels(item 1) are raised the user will reach under the the middle tabletop position and turn item 10 counter clockwise to lock it into position. Finally once the user has fully assembled the workbench, all four caster wheels(item 7) should be locked when the user has positioned the bench in the desired location.

Concept 1	Concept 2	Concept 3
Eccentric action lock	Spring/ball	Barrel Lock
Casters with Locks	Casters with electronically controlled locks	Solid feet
OTS Folding Bracket	Custom Folding bracket	No Support
Strap hinges	Butt hinge	eye-hook
Pine	Extruded Aluminum 80/20	Pine
Continuous hinge	Door hinge	Continuous hinge
Custom	Quarter	Full Scale
2 Parrallel Supports with Back Brace	Telescopic Brace	Z-Pattern 3 Support

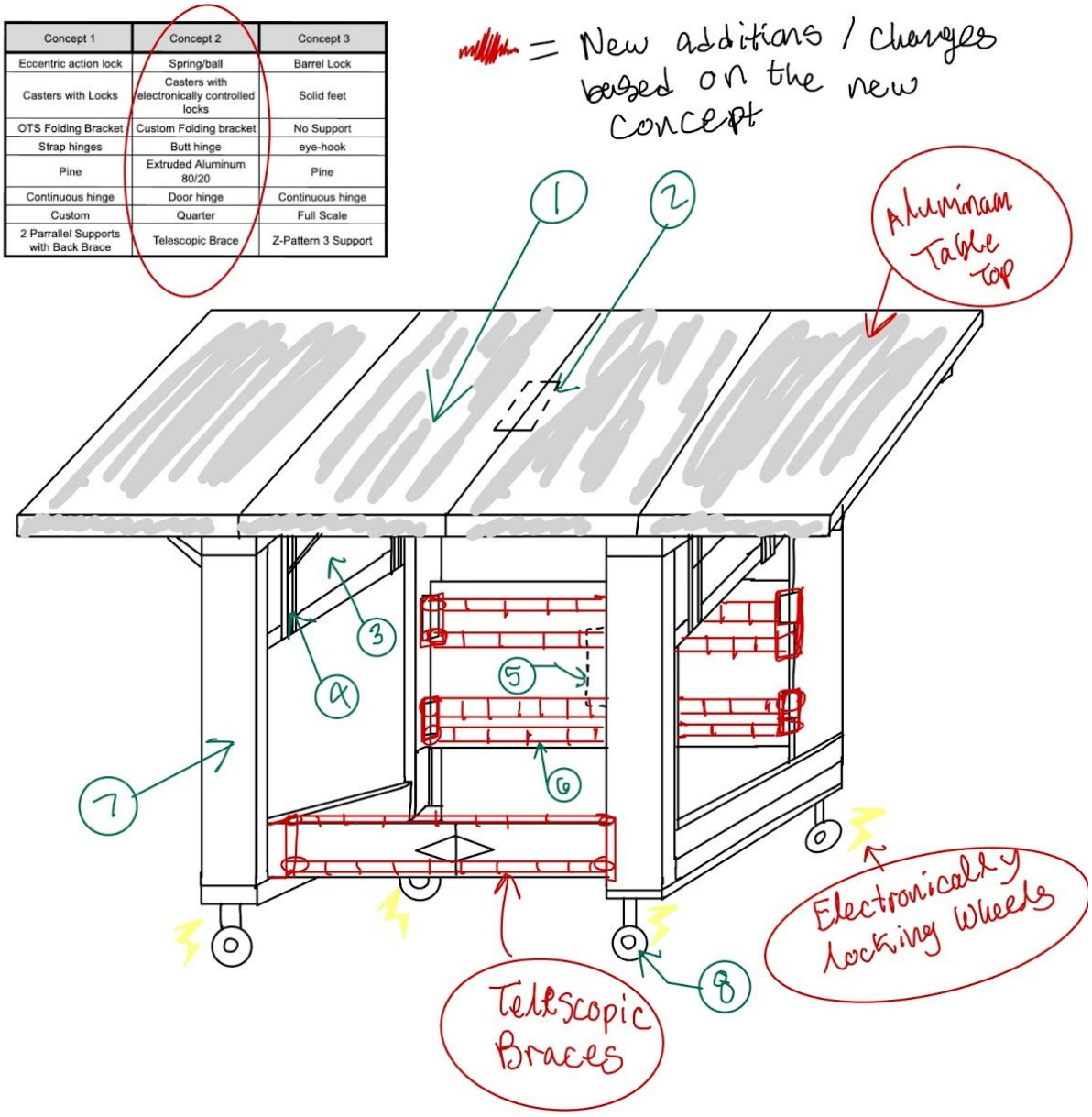


Figure 5.6: Hand Drawing Concept 2

Item Number	Item Description	Quantity
1	8020 Aluminium Table Tops	4
2	Spring Loaded Lock	1
3	4x4 Structural Support	2
4	OTS Stainless Steel Supports	8
5	N/A	N/A
6	Telescopic Brace	3
7	2x4 support(Includes All 2x4's)	12
8	Electronic Locking 3 in. Caster Wheels	4

Figure 5.7: Concept 2 Parts List

Concept 2 is supposed to represent potentially the strongest and expensive form of the workbench. The design is feasible, but isn't perfect. The design mixes aluminum and wood, but with aluminum being used as the top of the workbench with wood being used as the base. This combination is not unheard of but it is, admittedly, a little awkward. Regardless, again concept 2 is little easier to open. The user begins with sliding the two leg bases apart from each other. The leg bases are configured from (1x4), (2x4, item 7), and (4x4, item 3) supports. The top panels(item 1) are being held in the locked position stainless steel supports(item 4). The user will need to unlock item 4 and raise item 1 for all 4 panels(item 1). Once all four panels(item 1) are raised the user will reach under the the middle tabletop position and engage item 2. Finally once the user has fully assembled the workbench, all four caster wheels(item 7) will lock at the same time with the use of the controller. We never developed this idea pass that concept so we are not exactly sure how the controller and wheels would interact. Potentially we could use a simple RF transmitter and receiver, but again we did not get past the initial concept. Secondly, we assume that it would be more preferable to have as many options in the way in which the wheels locked as possible. Concept 2 definitely needs some heavy revisions if it were going to be built however the cost to produce this product would exceed the budget, and would most likely also exceed the time allotted time for completion.

Concept 1	Concept 2	Concept 3
Eccentric action lock	Spring/ball	Barrel Lock
Casters with Locks	Casters with electronically controlled locks	Solid feet
OTS Folding Bracket	Custom Folding bracket	No Support
Strap hinges	Butt hinge	eye-hook
Pine	Extruded Aluminum 80/20	Pine
Continuous hinge	Door hinge	Continuous hinge
Custom	Quarter	Full Scale
2 Parrallel Supports with Back Brace	Telescopic Brace	Z-Pattern 3 Support

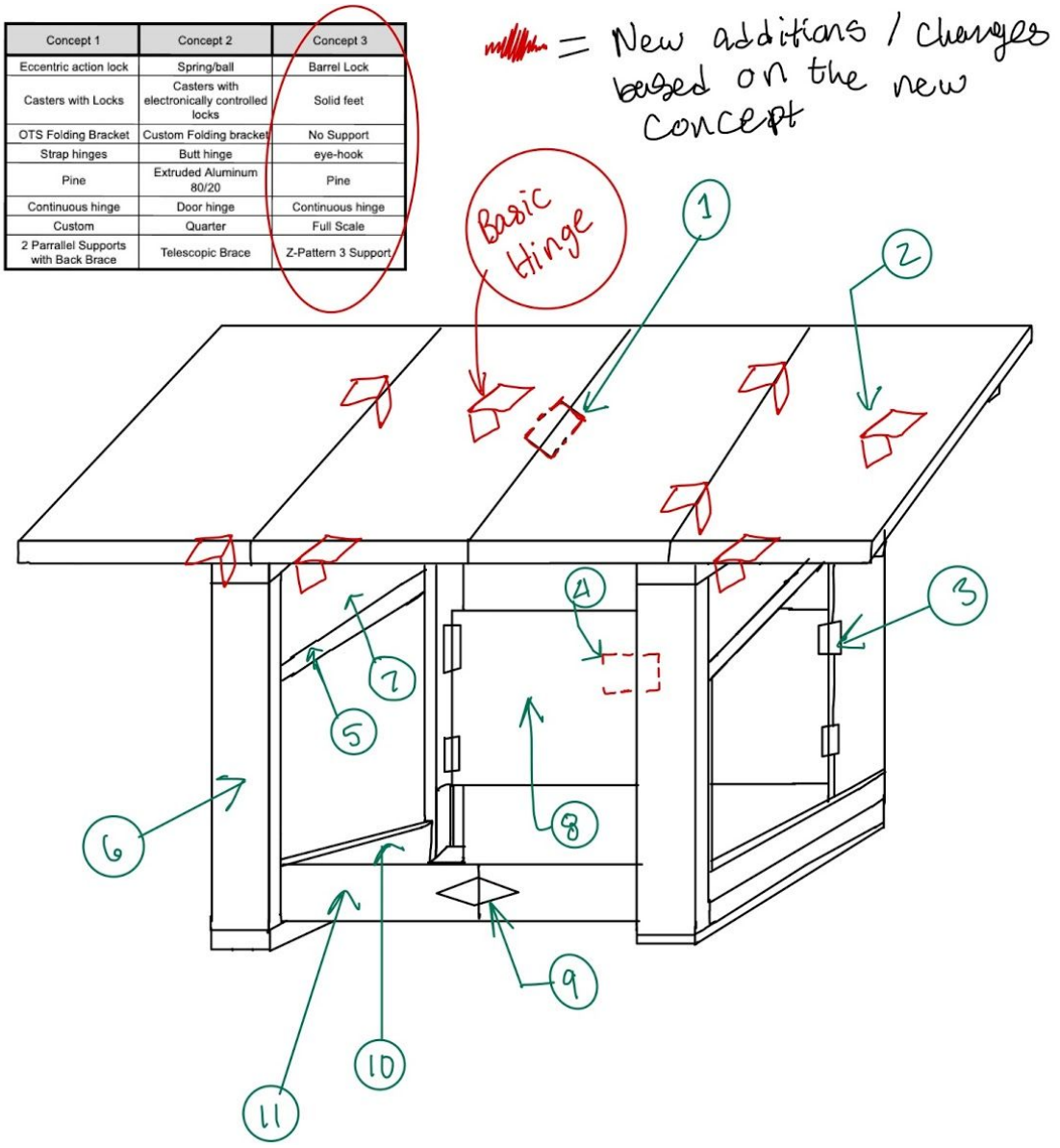


Figure 5.8: Hand Drawing Concept 3

Item Number	Item Description	Quantity
1	Barrel Lock	1
2	Table Top	4
3	Butt hinge	12
4	Eye Hook	1
5	2x4 support(Includes All 2x4's)	12
6	N/A	N/A
7	4x4 Structural Support	2
8	Plywood Support	2
9	Strap Hinge	1
10	N/A	N/A
11	1x4 Support	6

Figure 5.9: Concept 3 Parts List

The combinations from the morphological chart that form concept 3 had the focus of creating a table that could still deliver the same performance, but at the lowest cost possible. However with this design the team believes that it's pretty likely the table will not live up to our expectations. The hinges that replace all of the stainless steel supports have to be some sort spring loaded hinges that also has a 20 degrees fixed pitch angle. Overall, this design would be less likely to hold the weight necessary to be consider a workbench, potentially, even a proper table. This version also cuts wheels, which pretty much gets rid of the mobility aspect of the workbench. However, in the previous designs the wheels do act as somewhat of a limiting factor. No matter how much the workbench can hold with the 2x4 leg bases it is limited by the amount of weight the wheels can hold. Concept 3 could potentially hold more weight with better supports for the table tops.

5.2 Concept Selection Process

After narrowing down three potential concepts using the morphological chart, it was time to evaluate those concepts. We first considered using a Pugh chart to complete this evaluation but decided that using the Analytical Hierarchy Process (AHP) would result in more thorough and accurate data.

AHP's Ratings for Pairwise Comparison of Selection Criteria

Rating Factor	Relative Rating of Importance of Two Selection Criteria A and B	Explanation of Rating
1	A and B have equal importance.	A and B both contribute equally to the product's overall success.
3	A is thought to be moderately more important than B.	A is slightly more important to product success than B.
5	A is thought to be strongly more important than B.	A is strongly more important to product success than B.
7	A is thought to be very much more important than B, or is demonstrated to be more important than B.	A's dominance over B has been demonstrated.
9	A is demonstrated to have much more importance than B.	There is the highest possible degree of evidence that proves A is more important to product success than B.

The ratings of even numbers 2, 4, 6, and 8 are used when the decision maker needs to compromise between two positions in the table.

Figure 5.10: AHP's Rating for Pairwise Comparison of Selection Criteria

Criteria Comparison Matrix [C]						
	Material Cost	Manufacturing Cost	Reliability	Time-To-Produce	Mobility	Collapsibility
Material Cost	1.00	2.00	0.50	7.00	5.00	0.25
Manufacturing Cost	0.50	1.00	0.33	5.00	3.00	0.20
Reliability	2.00	3.00	1.00	8.00	7.00	0.33
Time-To-Produce	0.14	0.20	0.13	1.00	0.50	0.11
Mobility	0.20	0.33	0.14	2.00	1.00	0.13
Collapsibility	4.00	5.00	3.00	9.00	8.00	1.00
Sum	7.84	11.53	5.10	32.00	24.50	2.02

Figure 5.11 : Criteria Comparison Matrix [C]

Normalized Criteria Comparison Matrix [Norm C]							
	Material Cost	Manufacturing Cost	Reliability	Time-To-Produce	Mobility	Collapsibility	**Criteria Weights [W]**
Material Cost	0.128	0.173	0.098	0.219	0.204	0.124	0.158
Manufacturing Cost	0.064	0.087	0.065	0.156	0.122	0.099	0.099
Reliability	0.255	0.260	0.196	0.250	0.286	0.165	0.235
Time-To-Produce	0.018	0.017	0.025	0.031	0.020	0.055	0.028
Mobility	0.026	0.029	0.028	0.063	0.041	0.062	0.041
Collapsibility	0.510	0.434	0.588	0.281	0.327	0.495	0.439
Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Figure 5.12: Normalized Criteria Comparison Matrix [Norm C]

Consistency Check for {W} for Crane Hook		
Consistency Check		
{Ws} = [C]{W}1 Weighted Sum Vector	{W} Criteria Weights	{Cons} = {Ws}/{W} Consistency Vector
0.984	0.160	6.160
0.607	0.090	6.759
1.505	0.248	6.062
0.169	0.026	6.474
0.250	0.038	6.552
2.850	0.438	6.506
Average of {Cons} = λ		6.419
Consistency Index, CI = (λ − n)/(n − 1)		0.084
Consistency Ratio, CR = CI/RI		0.067
Is Comparison Consistent: CR < 0.10		**YES**

*RI = 1.25

Figure 5.13: Consistency Check for {W} for Crane Hook

RI Values for Consistency Check

# of Criteria	RI Value
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.40
9	1.45
10	1.49
11	1.51
12	1.54
13	1.56
14	1.57
15	1.58

Figure 5.14: RI Values for Consistency Check

AHP's Ratings for Pairwise Comparison of Design Alternatives

Rating Factor	Relative Rating of the Performance of Alternative A Compared to Alternative B	Explanation of Rating
1	A = B	The two are the same with respect to the criterion in question.
3	A is thought to be moderately superior to B.	Decision maker slightly favors A over B.
5	A is thought to be strongly superior to B.	Decision maker strongly favors A over B.
7	A is demonstrated to be superior to B.	A's dominance over B has been demonstrated.
9	A is demonstrated to be absolutely superior to B.	There is the highest possible degree of evidence that proves A is superior to B under appropriate conditions.

The ratings of even numbers 2, 4, 6, and 8 are used when the decision maker needs to compromise between two positions in the table.

Figure 5.15: AHPs Rating for Pairwise Comparison of Design Alternatives

Design Alternative Ratings for Material Cost

Comparison [C]					Normalized Comparison [NormC]						Consistency Check			
	Concept 1	Concept 2	Concept 3			Concept 1	Concept 2	Concept 3	Design Alternative Priorities {Pi }		{Ws} = [C]{Pi } Weighted Sum Vector	{Pi} Alternative Priorities	{Cons} = {Ws}/{P} Consistancy Vector	
Concept 1	1.00	7.00	0.50		Concept 1	0.32	0.50	0.30	0.37		1.16	0.37	3.10	
Concept 2	0.14	1.00	0.17		Concept 2	0.05	0.07	0.10	0.07		0.22	0.07	3.02	
Concept 3	2.00	6.00	1.00		Concept 3	0.64	0.43	0.60	0.55		1.73	0.55	3.12	
Sum	3.14	14.00	1.67		Sum	1.00	1.00	1.00	1.00		Average of {Cons} = λ		3.08	
											Consistency Index, CI = (λ − n)/(n − 1)		0.040	
											Consistency Ratio, CR = CI/RI		0.078	*RI = 0.52
											Is Comparison Consistent: CR < 0.10		**YES**	

Design Alternative Ratings for Manufacturing Cost

Comparison [C]					Normalized Comparison [NormC]						Consistency Check			
	Concept 1	Concept 2	Concept 3			Concept 1	Concept 2	Concept 3	Design Alternative Priorities {Pi }		{Ws} = [C]{Pi } Weighted Sum Vector	{Pi} Alternative Priorities	{Cons} = {Ws}/{P} Consistancy Vector	
Concept 1	1.00	1.00	0.25		Concept 1	0.32	0.07	0.15	0.18		0.58	0.18	3.21	
Concept 2	1.00	1.00	0.50		Concept 2	0.32	0.07	0.30	0.23		0.75	0.23	3.24	
Concept 3	4.00	2.00	1.00		Concept 3	1.27	0.14	0.60	0.67		1.85	0.67	2.76	
Sum	6.00	4.00	1.75		Sum	1.91	0.29	1.05	1.08		Average of {Cons} = λ		3.07	
											Consistency Index, CI = (λ − n)/(n − 1)		0.035	
											Consistency Ratio, CR = CI/RI		0.068	*RI = 0.52
											Is Comparison Consistent: CR < 0.10		**YES**	

Design Alternative Ratings for Reliability														
Comparison [C]					Normalized Comparison [NormC]						Consistency Check			
	Concept 1	Concept 2	Concept 3			Concept 1	Concept 2	Concept 3	Design Alternative Priorities {Pi }		{Ws} = [C]{Pi } Weighted Sum Vector	{Pi} Alternative Priorities	{Cons} = {Ws}/{P} Consistancy Vector	
Concept 1	1.00	2.00	7.00		Concept 1	0.32	0.14	4.20	1.55		5.64	1.55	3.63	
Concept 2	0.50	1.00	6.00		Concept 2	0.16	0.07	3.60	1.28		3.37	1.28	2.64	
Concept 3	0.14	0.17	1.00		Concept 3	0.05	0.01	0.60	0.22		0.65	0.22	2.98	
Sum	1.64	3.17	14.00		Sum	0.52	0.23	8.40	3.05		Average of {Cons} = λ		3.08	
											Consistency Index, CI = (λ − n)/(n − 1)		0.042	
											Consistency Ratio, CR = CI/RI		0.081	*RI = 0.52
											Is Comparison Consistent: CR < 0.10		**YES**	

Design Alternative Ratings for Time-To-Produce														
Comparison [C]					Normalized Comparison [NormC]						Consistency Check			
	Concept 1	Concept 2	Concept 3			Concept 1	Concept 2	Concept 3	Design Alternative Priorities {Pi }		{Ws} = [C]{Pi } Weighted Sum Vector	{Pi} Alternative Priorities	{Cons} = {Ws}/{P} Consistancy Vector	
Concept 1	1.00	4.00	1.00		Concept 1	0.32	0.29	0.60	0.40		1.19	0.40	2.96	
Concept 2	0.25	1.00	0.20		Concept 2	0.08	0.07	0.12	0.09		0.28	0.09	3.05	
Concept 3	1.00	5.00	1.00		Concept 3	0.32	0.36	0.60	0.43		1.28	0.43	3.01	
Sum	2.25	10.00	2.20		Sum	0.72	0.71	1.32	0.92		Average of {Cons} = λ		3.01	
											Consistency Index, CI = (λ − n)/(n − 1)		0.003	
											Consistency Ratio, CR = CI/RI		0.006	*RI = 0.52
											Is Comparison Consistent: CR < 0.10		**YES**	

Design Alternative Ratings for Mobility														
Comparison [C]					Normalized Comparison [NormC]						Consistency Check			
	Concept 1	Concept 2	Concept 3			Concept 1	Concept 2	Concept 3	Design Alternative Priorities {Pi }		{Ws} = [C]{Pi } Weighted Sum Vector	{Pi} Alternative Priorities	{Cons} = {Ws}/{P} Consistancy Vector	
Concept 1	1.00	0.50	5.00		Concept 1	0.32	0.04	3.00	1.12		3.06	1.12	2.74	
Concept 2	2.00	1.00	7.00		Concept 2	0.64	0.07	4.20	1.64		5.44	1.64	3.33	
Concept 3	0.20	0.14	1.00		Concept 3	0.06	0.01	0.60	0.22		0.68	0.22	3.04	
Sum	3.20	1.64	13.00		Sum	1.02	0.12	7.80	2.98		Average of {Cons} = λ		3.03	
											Consistency Index, CI = (λ − n)/(n − 1)		0.017	
											Consistency Ratio, CR = CI/RI		0.032	*RI = 0.52
											Is Comparison Consistent: CR < 0.10		**YES**	

Design Alternative Ratings for Collapsibility														
Comparison [C]					Normalized Comparison [NormC]						Consistency Check			
	Concept 1	Concept 2	Concept 3			Concept 1	Concept 2	Concept 3	Design Alternative Priorities {Pi }		{Ws} = [C]{Pi } Weighted Sum Vector	{Pi} Alternative Priorities	{Cons} = {Ws}/{P} Consistancy Vector	
Concept 1	1.00	0.14	2.00		Concept 1	0.32	0.01	1.20	0.51		1.39	0.51	2.72	
Concept 2	7.00	1.00	9.00		Concept 2	2.23	0.07	5.40	2.57		8.43	2.57	3.29	
Concept 3	0.50	0.11	1.00		Concept 3	0.16	0.01	0.60	0.26		0.80	0.26	3.11	
Sum	8.50	1.25	12.00		Sum	2.70	0.09	7.20	3.33		Average of {Cons} = λ		3.04	
											Consistency Index, CI = (λ − n)/(n − 1)		0.020	
											Consistency Ratio, CR = CI/RI		0.039	*RI = 0.52
											Is Comparison Consistent: CR < 0.10		**YES**	

Figure 5.16: Design Alternative Ratings [Material Cost -> Collapsibility]

Final Rating Matrix			
Selection Criteria	Concept 1	Concept 2	Concept 3
Material Cost	0.37	0.07	0.55
Manufacturing Cost	0.18	0.23	0.67
Reliability	1.55	1.28	0.22
Time-To-Produce	0.40	0.09	0.43
Mobility	1.12	1.64	0.22
Collapsibility	0.51	2.57	0.26

Figure 5.17: Final Rating Matrix

	Alternative Value
Concept 1	0.72
Concept 2	1.53
Concept 3	0.34

Figure 5.18: Final Alternative Values for Each Concept

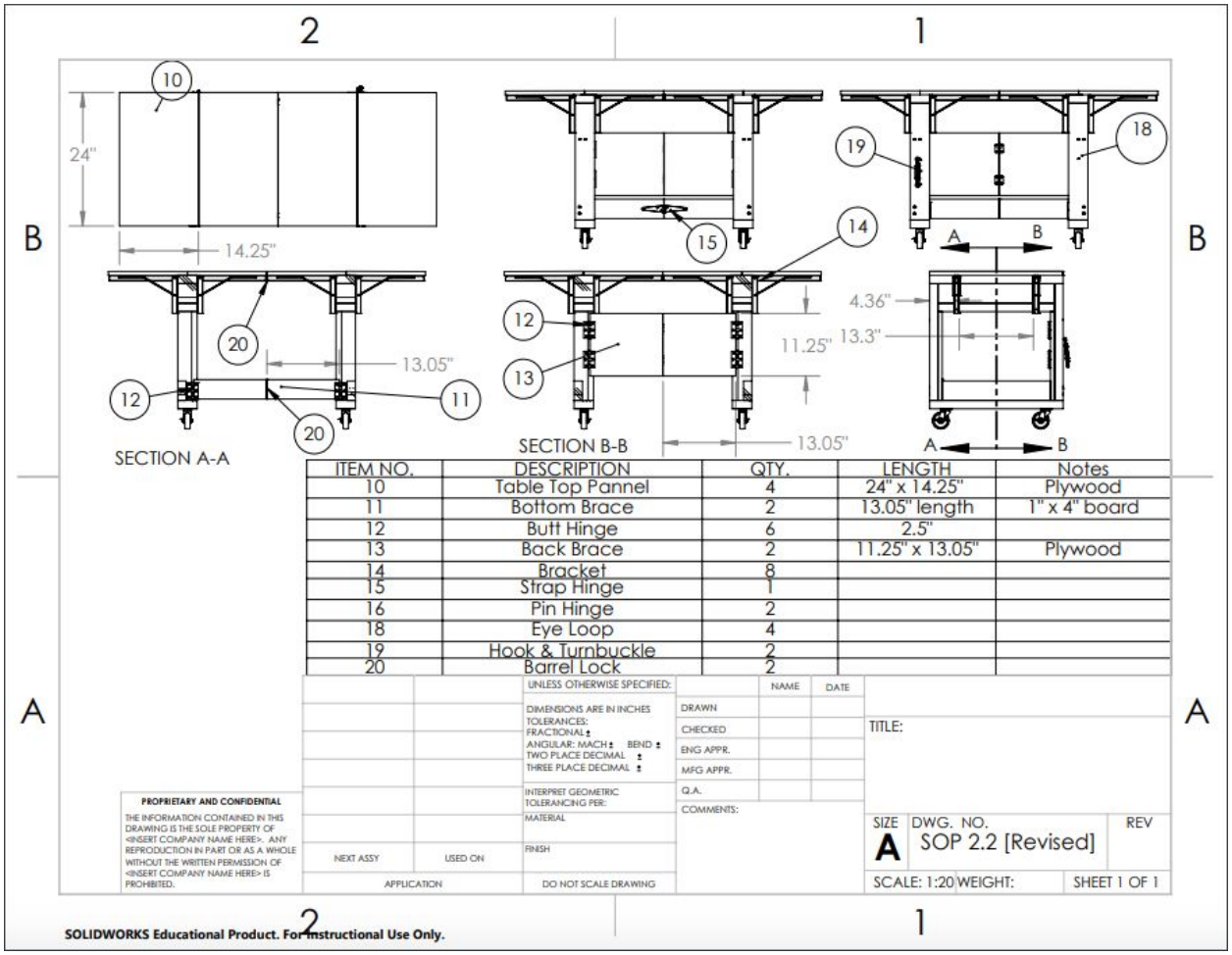
Highest Scoring Concept:	1.53	Concept 2

Figure 5.19: Highest Scoring Concept According to AHP

The team reached the conclusion that concept 2 was our most preferable design based on our weights. Design 2 would achieve our desired level of collapsibility, reliability, and mobility. Concept 2 is what we envisioned for this product. However, to actually produce concept 2 given our available time and funds would not be feasible. The reason concept 2 “won” was due to the team weighting collapsibility and reliability over cost and and production time. We believe that delivering to our customers a product that achieves the reliability expected from a normal workbench with a level of convenit collapsibility would justify a premium cost. Not to mention if produced on a higher scale their other methods and strategies to reduce cost and production time. In conclusion, concept 1 we believe reaches a better middle ground than concept 2, and overall balances our vision for the product with the realities of producing for the budget & time restrictions of capstones.

5.3 Final Concept Sketch and Design

The team moved forward with the design of concept 1, but for the final design we took ideas from concept 2 and 3 while adding some accessories that help with stability.



ITEM NO.	DESCRIPTION	QTY.	LENGTH	Notes
10	Table Top Pannel	4	24" x 14.25"	Plywood
11	Bottom Brace	2	13.05" length	1" x 4" board
12	Butt Hinge	6	2.5"	
13	Back Brace	2	11.25" x 13.05"	Plywood
14	Bracket	8		
15	Strap Hinge	1		
16	Pin Hinge	2		
18	Eye Loop	4		
19	Hook & Turnbuckle	2		
20	Barrel Lock	2		

Figure 5.20: Final Design Drawing

The final version of the table includes two hinges on the back brace (item 13) that separate when folded away, but with a pin that goes through both of them that keeps them together when the work bench is full assembled. The eccentric lock was removed and replaced with two barrel locks (item 20) to add the needed support under the center of the workbench. Finally two eye loops (item 18) and hook and turnbuckles (item 19) were added to add stability to the table when the collapsed position.

6.0 Embodiment Design Process

6.1 Product Architecture

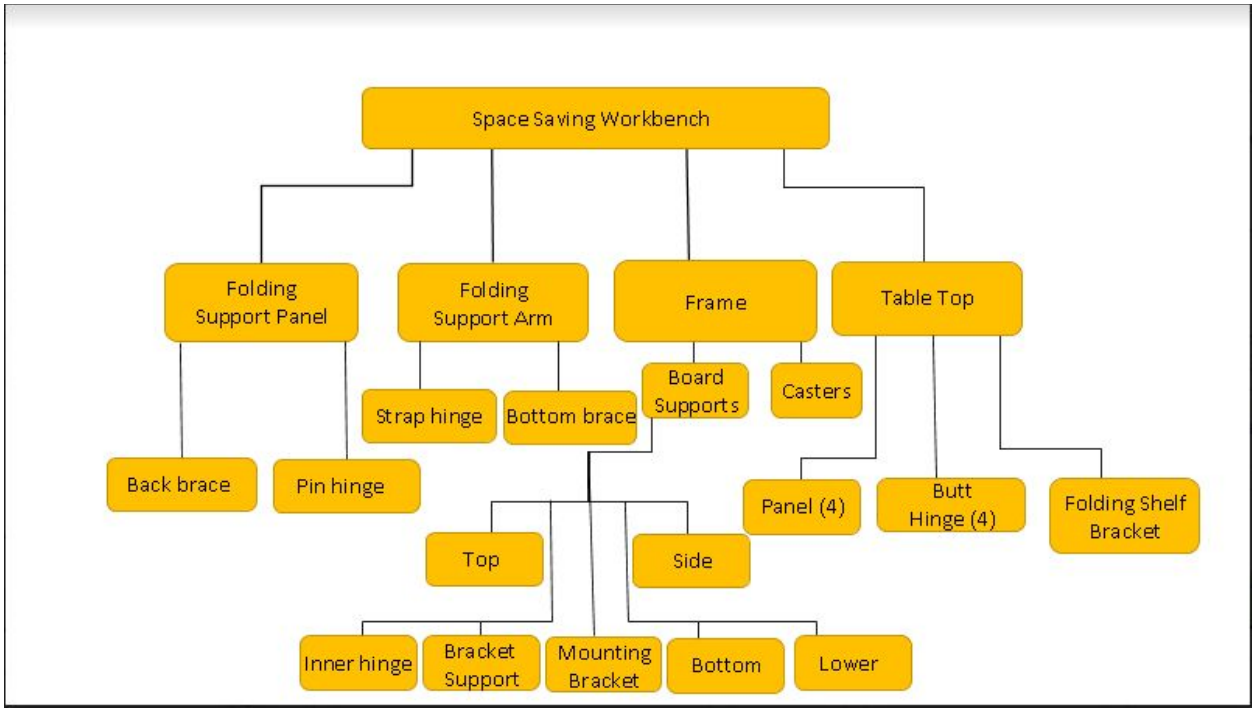


Figure 6.1: Function Decomposition

6.2 Configuration Design and Part Layout

Standard Parts:

- Stainless Steel Supports
- Caster Wheels
- Fasteners
- Glue
- Hinges
- Turnbuckle and loop
- Barrel lock

Manufactured Parts:

- Custom Sized wood
- Metal Clasp

6.3 Human Factor Analysis

The space saving work is very much designed with the human interaction in mind. The user must be able to unfolded the workbench to use initially. Once the workbench is setup it is up to the user to decide when they want to collapse it back to it's smaller size. During both these processes the team took measures to ensure that the user could easily set up or breakdown this workbench by themselves.

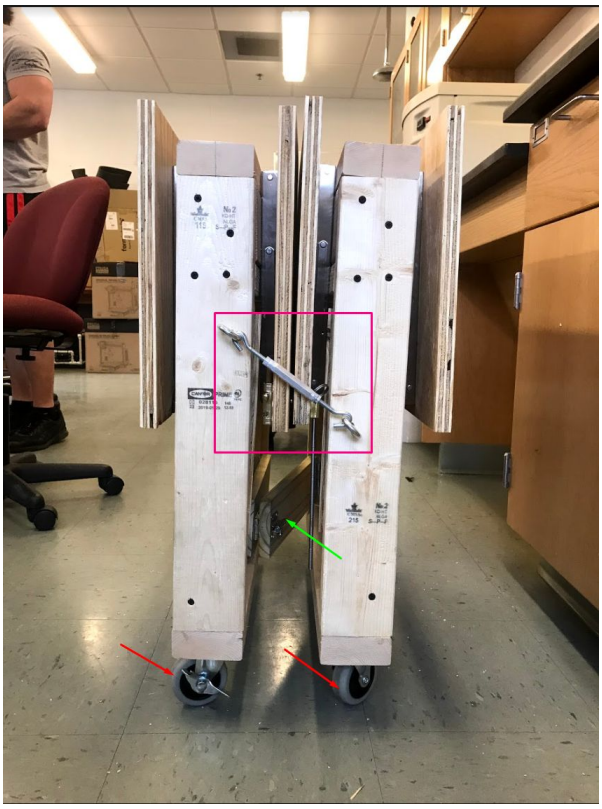


Figure 6.2: Collapsed Workbench HF Design Elements

If we look ab the pink box for figure 6.2 we'll see the loop an turnbuckle. The loop and turn buckle help the user secure the two sides of the table when collapsed. This makes it safer when users begin the process of unfolding the workbench, as well as. Makes it a lot safer when the user goes to store the workbench as it keeps the workbench stable which increases it's mobility when using the wheels. The overall weight of the table is in the range of 55-60 lbs therefore the addition of wheels allows the user to move the workbench while in both states(collapsed and uncollapsed) instead of having to pick it up which increases the single user

usability and safety. The team determined that the most dangerous interaction a human could have with the workbench itself(independent of adding extra weight) would be during the transition stage from collapsed state to uncollapse state. Looking at the 1x4 brace in figure 6.2 (identified by the red arrows) the brace doubles as a way to conjoin the two sides of the table as well as assist the user in the separation of the workbench. Once the two parts are separated the user must lift the workbench table tops. This process has the most possibility for safety concerns due to some instability, but in the future there are ways we can address these issues. In the uncollapse state the human interaction with the workbench in terms of safety risk goes down drastically outside of moving the table or preventing it's movement. For the case for which we want to prevent the movement of the workbench we added casters with locks so that the workbench could stay completely still when the user needed it to.

Figure 6.3: Table Top Clasp

One of our last minute addition to the workbench prototype was a clasp on the outside that helps with lining up the tale tops in the middle. This addition will greatly help users avoid pinching their fingers in the middle of the workbench.

6.4 FMEA

Rating for Severity of Failure

Rating	Severity Description
1	The effect is not noticed by the customer
2	Very slight effect noticed by customer; does not annoy or inconvenience customer
3	Slight effect that causes customers annoyance, but they do not seek service
4	Slight effect, customer may return product for service
5	Moderate effect, customer requires immediate service
6	Significant effect, causes customer dissatisfaction; may violate a regulation or design code
7	Major effect, system may not be operable; elicits customer complaint; may cause injury
8	Extreme effect, system is inoperable and a safety problem; may cause severe injury
9	Critical effect, complete system shutdown; safety risk
10	Hazardous; failure occurs without warning; life-threatening

Rating for Occurrence of Failure

Rating	Approx. Probability of Failure	Description of Occurrence
1	$\leq 1 \times 10^{-6}$	Extremely remote
2	1×10^{-5}	Remote, very unlikely
3	1×10^{-5}	Very slight chance of occurrence
4	4×10^{-4}	Slight chance of occurrence
5	2×10^{-3}	Occasional occurrence
6	1×10^{-2}	Moderate occurrence
7	4×10^{-2}	Frequent occurrence
8	0.20	High occurrence
9	0.33	Very high occurrence
10	≥ 0.50	Extremely high occurrence

Rating for Detection of Failure

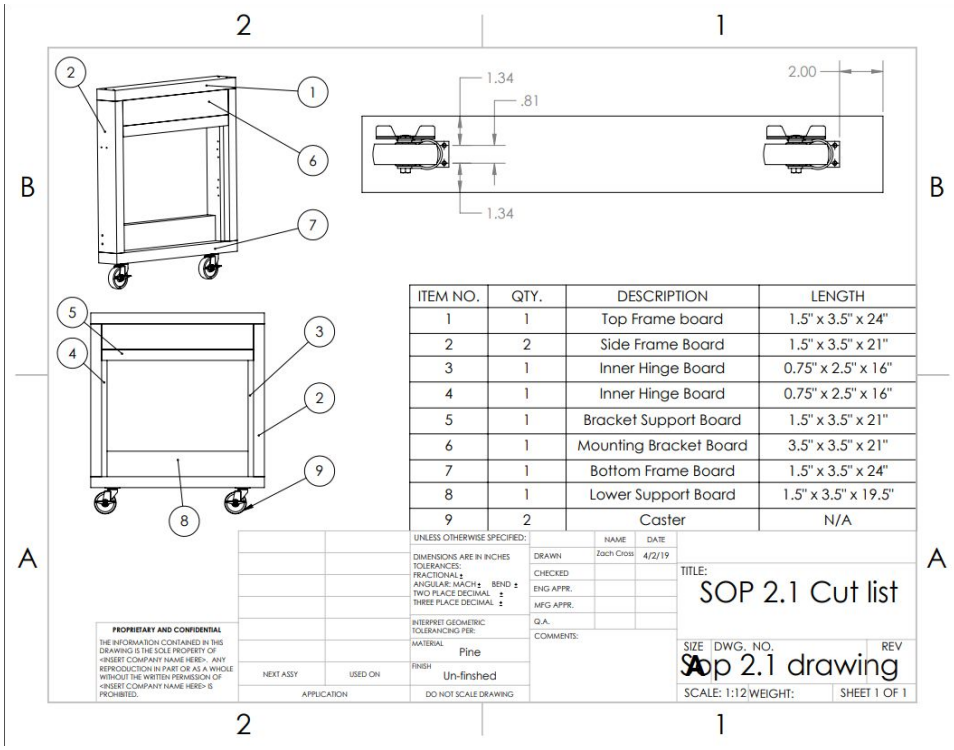
Rating	Description of Detection
1	Almost certain to detect
2	Very high chance of detection
3	High chance of detection
4	Moderately high chance of detection
5	Medium chance of detection
6	Low chance of detection
7	Slight chance of detection
8	Remote chance of detection
9	Very remote chance of detection
10	No chance of detection; no inspection

Figure 6.4 FMEA Criteria

Failure Modes and Effects Analysis		
Product name: Space Saving Workbench		
Part name: SS Hinges		
Primary Design Responsibility: Table top collapsibility		
1	Function:	1. Allows for the tabletops to fold into position.
2	Failure Mode:	High friction with its shaft
3	Effects of failure:	Jamming
4	Causes of failure:	Improper Installation
5	Detection:	Feeling of Resistance
6	Severity:	7
7	Occurrence:	5
8	Detection:	1
9	RPN:	35
10	Recommended Corrective Action:	Grease Area for less friction
11	Severity:	7
12	Occurrence:	3
13	New Detection:	1
14	RPN:	21

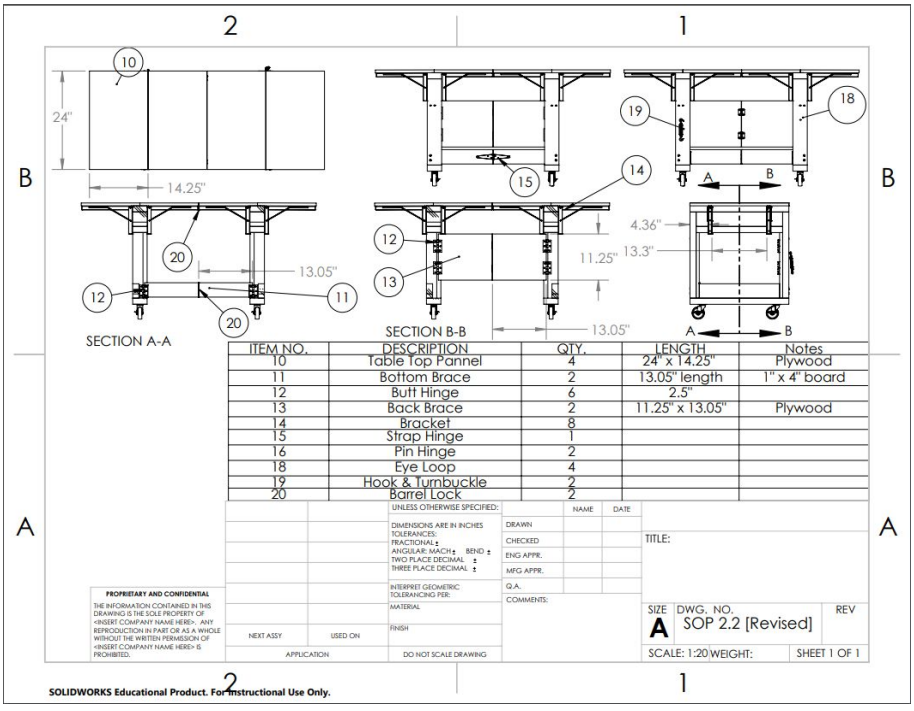
Figure 6.5 Failure Modes and Effect Analysis

6.5 Parametric Design



ITEM NO.	QTY.	DESCRIPTION	LENGTH
1	1	Top Frame board	1.5" x 3.5" x 24"
2	2	Side Frame Board	1.5" x 3.5" x 21"
3	1	Inner Hinge Board	0.75" x 2.5" x 16"
4	1	Inner Hinge Board	0.75" x 2.5" x 16"
5	1	Bracket Support Board	1.5" x 3.5" x 21"
6	1	Mounting Bracket Board	3.5" x 3.5" x 21"
7	1	Bottom Frame Board	1.5" x 3.5" x 24"
8	1	Lower Support Board	1.5" x 3.5" x 19.5"
9	2	Caster	N/A

Figure 6.6: Leg base Specs



ITEM NO.	DESCRIPTION	QTY.	LENGTH	Notes
10	Table Top Pannel	4	24" x 14.25"	Plywood
11	Bottom Brace	2	13.05" length	1" x 4" board
12	Butt Hinge	6	2.5"	
13	Back Brace	2	11.25" x 13.05"	Plywood
14	Bracket	8		
15	Strap Hinge	1		
16	Pin Hinge	2		
18	Eye Loop	4		
19	Hook & Turnbuckle	2		
20	Barrel Lock	2		

Figure 6.7: Table Top Specs.

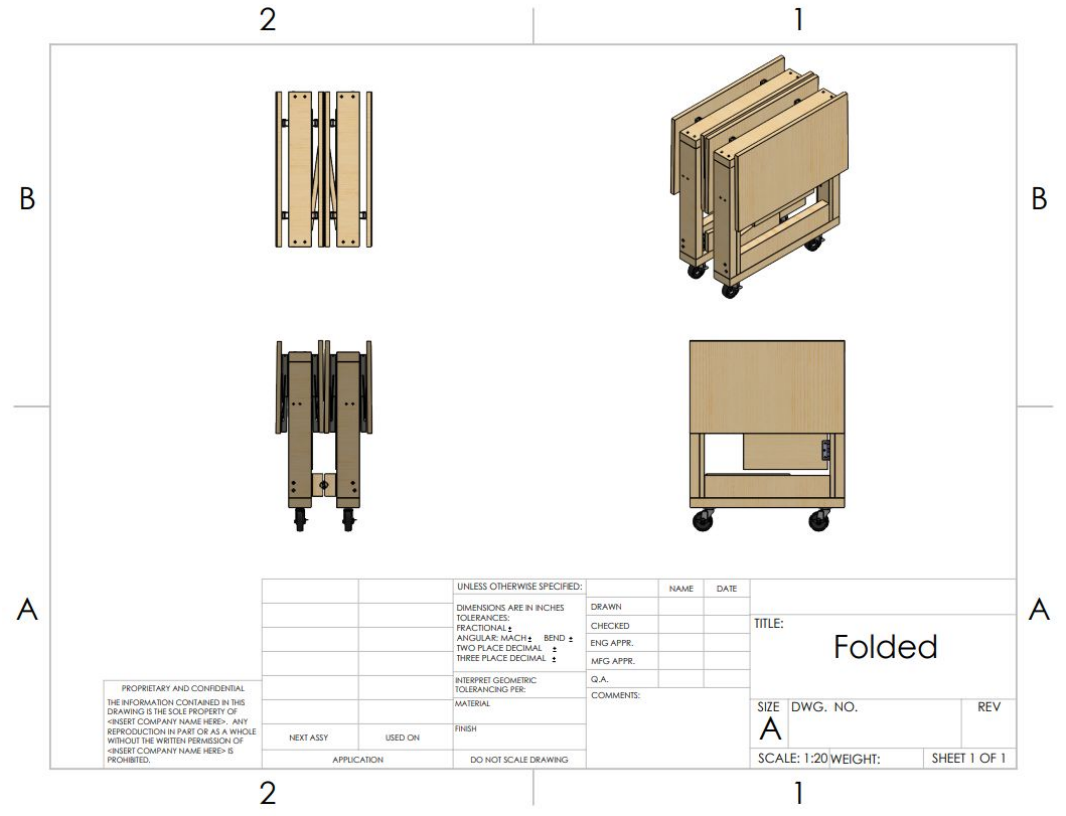


Figure 6.8: Workbench Collapsed State

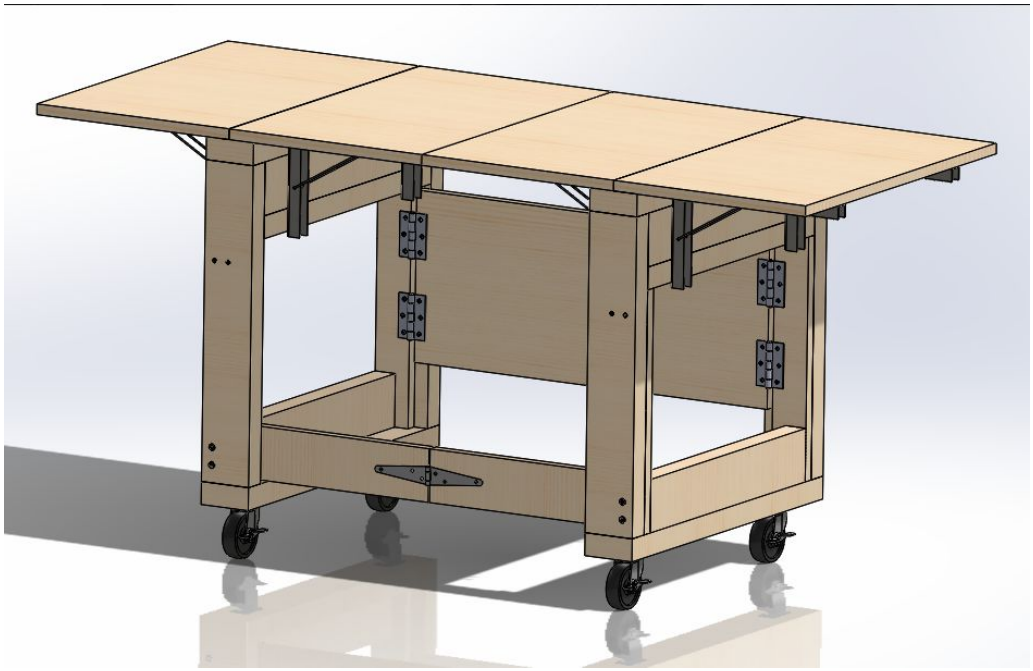


Figure 6.9: Front View - Workbench Uncollapse State

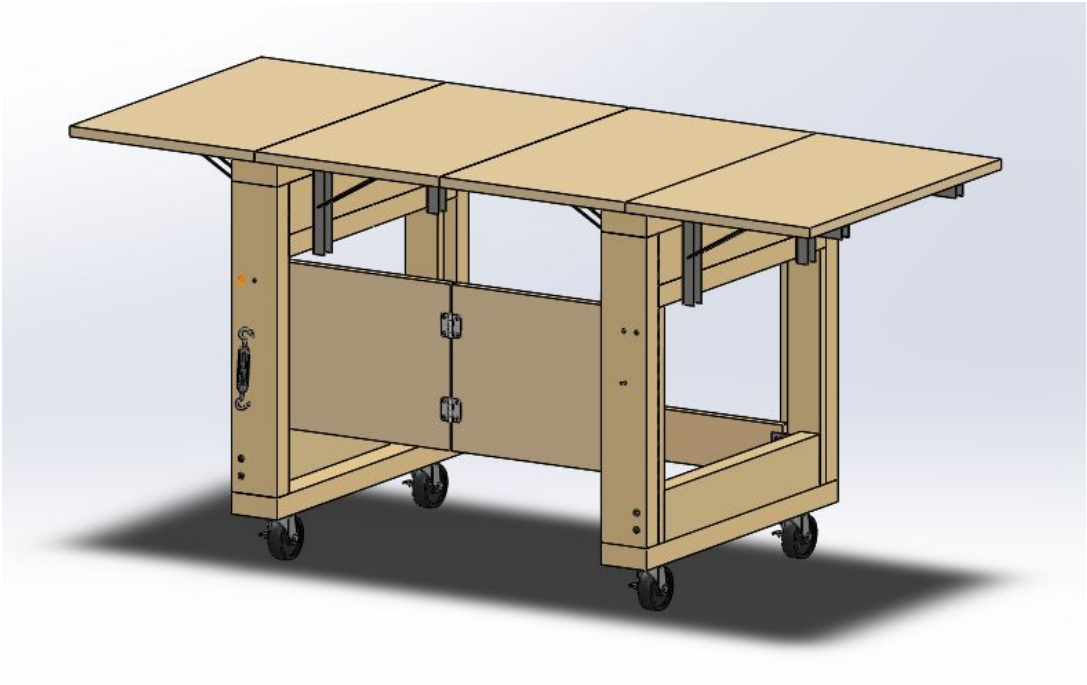


Figure 6.10: Rear View - Workbench Uncollapse State

To analyze how the workbench will react to forces applied we decided to perform various calculations by hand and using Finite Element Analysis (FEA) through ANSYS. Calculations included stress in bracket screws, stress in the casters, and stability during point load and uniform loading.

Stress in Bracket Screws

We considered one of the high stress points while using this table would be the screws that hold the main brackets to the legs of the table. We are not concerned with the brackets themselves failing as they are rated for 330 lbs, however, we are concerned that the high amount of stress in the screws would be enough to cause failure. According to the Specialty Steel Industry of North America (SSINA), the minimum yield strength our screws might possess is 30,000 psi. After discussing this scenario with our universities statics professor, Dr. Lynch, we hypothesized that the top screw would encounter the most stress. We decided to find the axial stress in the screws rather than the thread bearing stress after making the assumption that the screw would break before the threads came loose. This assumption was made from personal experience.

In addition, to make the necessary calculations we had to make the following assumptions:

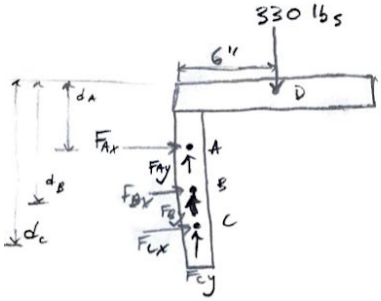
1) The diagonal support beams will transfer the energy from the force completely. Therefore, we can treat the two flat perpendicular members as a solid.
2) A force of 330 lbs is being applied in the top center of the bracket (this is the manufacturer's max loading).

Below are the calculations and assumptions we made to find the axial force and stress for each screw:

BRACKET STRESS CALCULATION AT SCREWS

Assumptions: 1) Diagonal support beam transfers all energy, therefore we can treat the two flat parts as a solid.

2) A force of 330 lbs is being applied in the top center of the bracket (this is the manufacturer's max loading).



Find: σ_A, σ_B, σ_C $\left(\sigma = \frac{F}{A} = \frac{4 \cdot F}{\pi d^2}\right)$

Known: $d = 0.21$
$d_A = 1.35''$
$d_B = 3.5''$
$d_C = 6.1$

$+\circlearrowleft \Sigma M_A = 0$

$F_{Bx}(d_B - d_A) + F_{Cx}(d_C - d_A) - 330(6) = 0$

$F_{Bx} = \frac{330(6) - F_{Cx}(d_C - d_A)}{(d_B - d_A)} = \frac{1980 - F_{Cx}(6.1 - 1.35)}{(3.5 - 1.35)}$

$\Sigma F_x = 0$

$F_{Ax} - F_{Bx} + F_{Cx} = 0$

$F_{Ax} = -F_{Bx} - F_{Cx}$

$F_{Cx} = -F_{Bx} - F_{Ax}$

$\Sigma F_y = 0$

$F_{Ay} + F_{By} + F_{Cy} - 330 = 0$

$F_{Ay} = 330 - F_{By} - F_{Cy}$

$+\circlearrowleft \Sigma M_D = 0$

$F_{Ax}(d_A) - F_{Ay}(6) + F_{Bx}(d_B) - F_{By}(6) + F_{Cx}(d_C) - F_{Cy}(6) = 0$

$+\circlearrowleft \Sigma M_C = 0$

$-330(6) - F_{Bx}(d_C - d_B) - F_{Ax}(d_C - d_A) = 0$

$F_{Ax} = \frac{-1980 - F_{Bx}(d_C - d_B)}{(d_C - d_A)}$

$F_{Cx} = -F_{Bx} - \frac{-1980 - F_{Bx}(d_C - d_B)}{(d_C - d_A)}$

$F_{Bx} = \frac{1980 - \left(-F_{Bx} - \frac{-1980 - F_{Bx}(d_C - d_B)}{(d_C - d_A)}\right)}{(d_B - d_A)}$

$F_{Cx} = -922 - 920.42$

$F_{Cx} = 0.42$ lb

$F_{Ax} = \frac{-1980 - 920(6.1 - 3.5)}{(6.1 - 1.35)}$

$F_{Ax} = -920.42$ lb

$F_{Bx} = \frac{1980(d_C - d_A) - 1980}{\left[(d_B - d_A)(d_C - d_A) - (d_C - d_A) + (d_C - d_B)\right]}$

$F_{Bx} = 920$ lb

Figure 6.11: Calculating Forces to Find Stresses

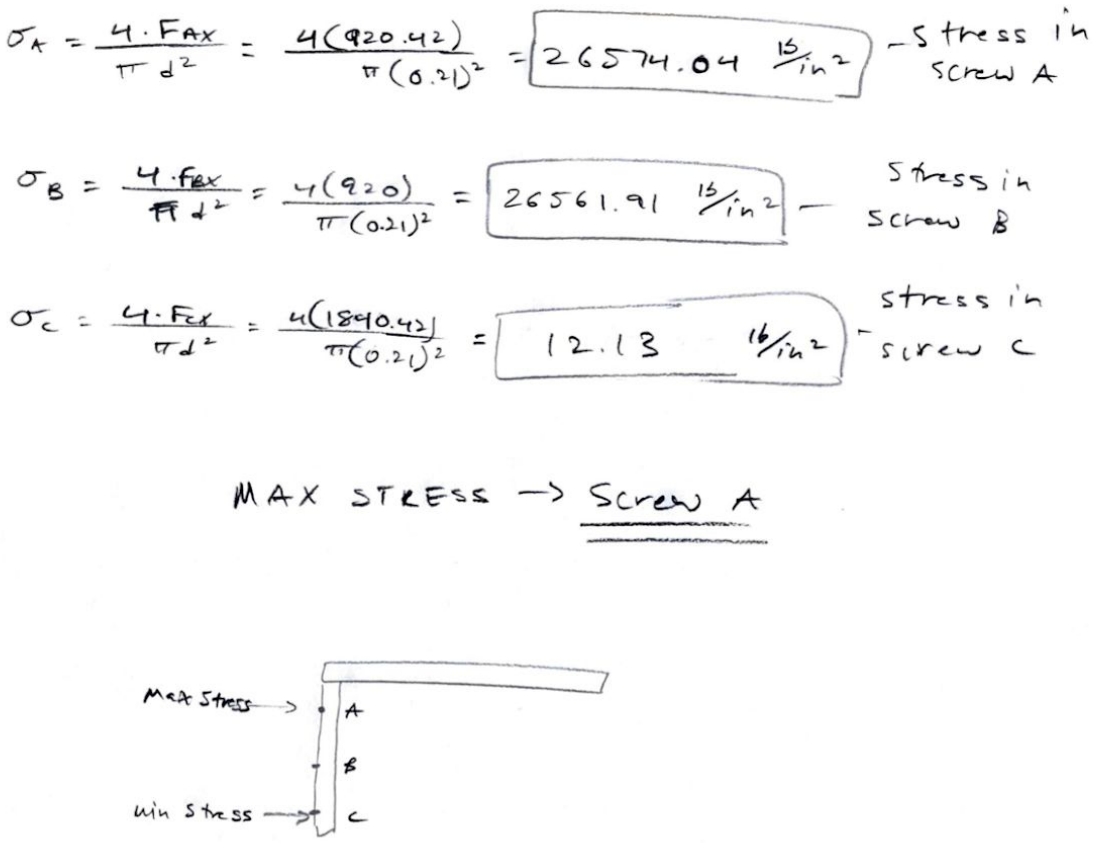


Figure 6.12: Calculation of Axial Stress for each Screw

According to our calculations the highest amount of stress will be located on the top screw which is estimated to be around 26,574 psi. This phenomenon is concurrent with our initial hypothesis. It should also be noted that this figure is below the typical yield strength of steel screws, 30,000 psi, meaning that our screws should be able to withstand the max amount of force with a factor of safety of n=1.13.

Caster Yielding Load Observation

For our prototype, two of our team's main goal was to try to exemplify as many of the core functions of the final product as possible. How much weight the workbench can hold is one of its most critical attributes and is directly tied to the how much weight the casters can hold. The casters for our prototype are three inch polyurethane casters that are rated to hold up to 110 lbs. Again, even though the other supports throughout our product are rated for higher strengths, the casters ultimately serve as a serious limiting factor. If enough normal force was applied to swivel plate of the caster, the area marked with red would begin to warp out first. The issues is currently

the team has no way to complete test that theory and no practical hand calculations can be done to analyze either. Therefore, the team is going to use FEA to try to simulate the 110 condition.

Figure 6.13: Caster Example

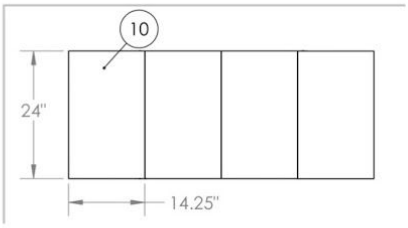
However, it would still be beneficial to see how much the casters would have to hold without the extra weight. Using the volume and density of the wooden components and the listed weight of the brackets, we were was able to determine the initial load the casters would have to support before extra weight was added for testing.

Stress & Deflection on Casters

1.) First we need to find the weight of the table w/o the casters.

Table top Pannels

* Rounding two decimal places



Volume: L: 24" W: 14.25" T: 3/4"

$V = 24in \times 14.25in \times 0.75in = 256.5in^3$

* 4 for all the pannels $\therefore V = 1026in^3$

Type of Wood = yellow pine; $\rho = 23-37 (lb/ft^3)$

$V = 256.5in^3 \times 4 = 1026in^3$

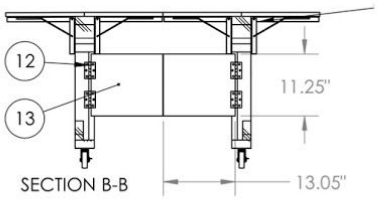
$$1026in^3 \times \frac{1^3 ft^3}{12^3 in^3} \simeq .59 ft^3$$

$$\text{Max Weight} = .59 \cancel{ft^3} \times 37 \frac{lb}{\cancel{ft^3}} = \boxed{21.97 lbs}$$

$$\text{Min Weight} = .59 \cancel{ft^3} \times 23 \frac{lb}{\cancel{ft^3}} = \boxed{13.66 lbs}$$

Weight of the four panels is between 13.66lbs - 21.97lbs

Back support pannels



Volume: L: 13.05" W: 11.25" T: 3/4"

$V = 13.05\,in \times 11.25\,in \times 3/4\,in = 110.11\,in^3$

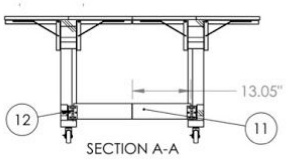
* 2x for both pieces $\therefore V = 220.22\,in^3 = 0.13\,ft^3$

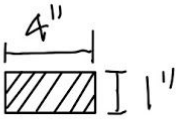
Type of Wood = yellow pine; $\rho = 23\text{-}37\ (lb/ft^3)$

$W_{max} = 0.13\,ft^3 \times 37\,\frac{lb}{ft^3} = \boxed{4.72\ lbs}$

$W_{min} = 0.13\,ft^3 \times 23\,\frac{lb}{ft^3} = \boxed{2.93\ lbs}$

Bottom Brace





V: L: 13.05" W: 4" T: 1"

$V = 13.05\,in \times 4\,in \times 1\,in = 52.20\,in^3$

* 2x for both pieces $\therefore V = 104.4\,in^3 = 0.06\,ft^3$

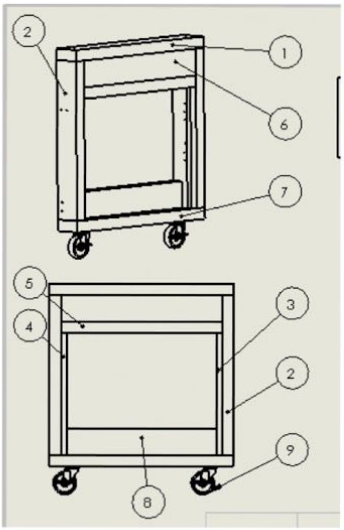
Type of Wood = yellow pine; $\rho = 23\text{-}37\ (lb/ft^3)$

$W_{max} = 0.06\,ft^3 \times 37\,lb/ft^3 = \boxed{2.22\ lbs}$

$W_{min} = 0.06\,ft^3 \times 23\,lb/ft^3 = \boxed{1.38\ lbs}$

Volume — Density — Weight of the Item

Leg Bases



* Because 2x4 piece of lumber is traditionally not exactly 2" x 4" the industry underestimates to 1.5" x 3.5". For these particular calculations I want to overestimate how much the wheels will be stressed / deflected. Overestimating gives us a better chance of ensuring the wheels will not fail. Same rule for 1"x4" and 4"x4" case.

ITEM NO.	QTY.	DESCRIPTION	LENGTH
1	1	Top Frame board	1.5" x 3.5" x 24"
2	2	Side Frame Board	1.5" x 3.5" x 21"
3	1	Inner Hinge Board	0.75" x 2.5" x 16"
4	1	Inner Hinge Board	0.75" x 2.5" x 16"
5	1	Bracket Support Board	1.5" x 3.5" x 21"
6	1	Mounting Bracket Board	3.5" x 3.5" x 21"
7	1	Bottom Frame Board	1.5" x 3.5" x 24"
8	1	Lower Support Board	1.5" x 3.5" x 19.5"
9	2	Caster	N/A

1) $V = 2in \times 4in \times 24in = 192in^3$ Type of Wood = SPF $\rho = 31\ lb/ft^3$

$W = 0.11ft^3 \times 31\ lb/ft^3 = \boxed{3.41\ lb}$

2) $V = 2in \times 4in \times 21in = 168in^3 \times 2 = 336in^3$ Type of Wood = SPF $\rho = 31\ lb/ft^3$

$W = 0.19ft^3 \times 31 lb/ft^3 = \boxed{5.89\ lbs}$

3) $V = 1in \times 2.5in \times 16in = 40in^3$ Type of Wood = yellow pine; $\rho = ^{(lb/ft^3)}23-37$

$W_{max} = \boxed{.74\ lbs}$ $W_{min} = \boxed{.46\ lbs}$

4) $V = 1in \times 2.5in \times 16in = 40in^3$ Type of Wood = yellow pine; $\rho = ^{(lb/ft^3)}23-37$

$W_{max} = \boxed{.74\ lbs}$ $W_{min} = \boxed{.46\ lbs}$

5) $V = 2in \times 4in \times 21in = 192in^3$ Type of Wood = SPF $\rho = 31\ lb/ft^3$

$W = 0.11ft^3 \times 31\ lb/ft^3 = \boxed{3.41\ lb}$

6) $V = 4in \times 4in \times 21in = 336in^3$ Type of Wood = yellow pine; $\rho = ^{(lb/ft^3)}23-37$

$W = 0.19ft^3 \times 31 lb/ft^3 = \boxed{5.89\ lbs}$

7) $V = 2\,in \times 4\,in \times 24\,in = 192\,in^3$ Type of Wood = SPF $\rho = 31\ lb/ft^3$

$W = 0.11\,ft^3 \times 31\ lb/ft^3 = \boxed{3.41\ lb}$

8) $V = 2\,in \times 4\,in \times 19.5\,in = 156\,in^3$ Type of Wood = SPF $\rho = 31\ lb/ft^3$

$W = 0.09\,ft^3 \times 31\ lb/ft^3 = \boxed{2.79\ lbs}$

Weight of equipment * Fixtures will be ignored in weight e.g. screws, washers

Brackets: $1.95\ lb \times 8 = 15.6\ lbs$

$$\text{Total Weight on 1 Caster} = \frac{\text{Weight on Casters}}{4}$$

$$\text{Max Total weight} = 21.97 + 4.72 + 2.22 + (3.41 \times 3) + (5.89 \times 2) + (.74 \times 2) + 2.79$$

$$= 55.19\ lbs$$

$$\text{Min Total weight} = 13.66 + 2.93 + 1.38 + (3.41 \times 3) + (5.89 \times 2) + (.46 \times 2) + 2.79$$

$$= 43.69\ lbs$$

$$\text{Max weight on a single caster} = 13.80\ lbs$$

$$\text{Min weight on a single caster} = 10.92\ lbs$$

Figure 6.14: Calculating weight of the table

Due to the density of wood varying depending on the wood type and also varying while in the same wood type, a range for the weight was found where we believe the true weight exists. This report is being completed pre-construction and therefore, the true weight is outside of the scope of this report. On each caster at most 13.80 lbs is being applied, leaving caster with 96.2lbs that can be added to a singular caster before reaching the predetermined threshold. Combined a

load of 384.80lbs would have to be applied to reach the threshold for the table. In future testing we will explore a 385 lb load being applied to the table.

Moving forward towards the final product the team would definitely replace the current casters for larger and higher rated casters. However, the team realizes that the workbench will never reach its full potential reallying on casters as a bases. During design ideation the team proposed a "convertible system" either automatic or manual that would allow the table to adjust from using the casters as a base to using the floor and the legs in conjunction as a base. This would allow the table to maintain its mobility while not sacrificing its strength. The only issue was budget. Every option we discussed would be too costly and time consuming for the scope of the project. In addition to the cost, the team foresaw integrating the convertible system into our collapsible design would be very time consuming as well. We found that the best option was to postpone that piece of construction until a potential prototype three that would allow us to implement this new system if we had the appropriate time and resources.

Stability

An important calculation for the workbench is the stability. In this case we need to find out the expected amount of weight that will cause the table to become unstable and start to tip. For this calculation we were to determine how much of a point load it would take on a side table top flap to cause instability. To do this it was determined that a force acting on the farthest edge on the table top would cause the largest moment with the force to be applied. At the point the moment produced by the force was equal to the moment produced by the weight of the table. In order to find this the distance from the table leg to the force was multiplied by the applied force, F. The components on the opposite side of the applied force were all broken down and analyzed separately according to their weight and distance from the table leg. A simplification was made for calculations, that being the density for the materials was constant throughout. This will allow for the use of the center of gravity of material to be in the middle of the materials, which in turn allows the moment to be calculated from the center of gravity.

The calculations below show the forces that are required to cause instability, with both a point load and uniform load. The calculations show that a point load of 87.6 lbs on the edge of the table will be the threshold for tipping. Additionally, a uniform load of .51 pounds per square inch distributed uniformly across the tabletop side flap will be the threshold for instability. The determination of the uniform load rating was determined by consolidating the uniform distribution into one resultant force, then using the same moment balance that was used for a single force. After the resultant force was determined, it was then divided by the area of the tabletop side flap.

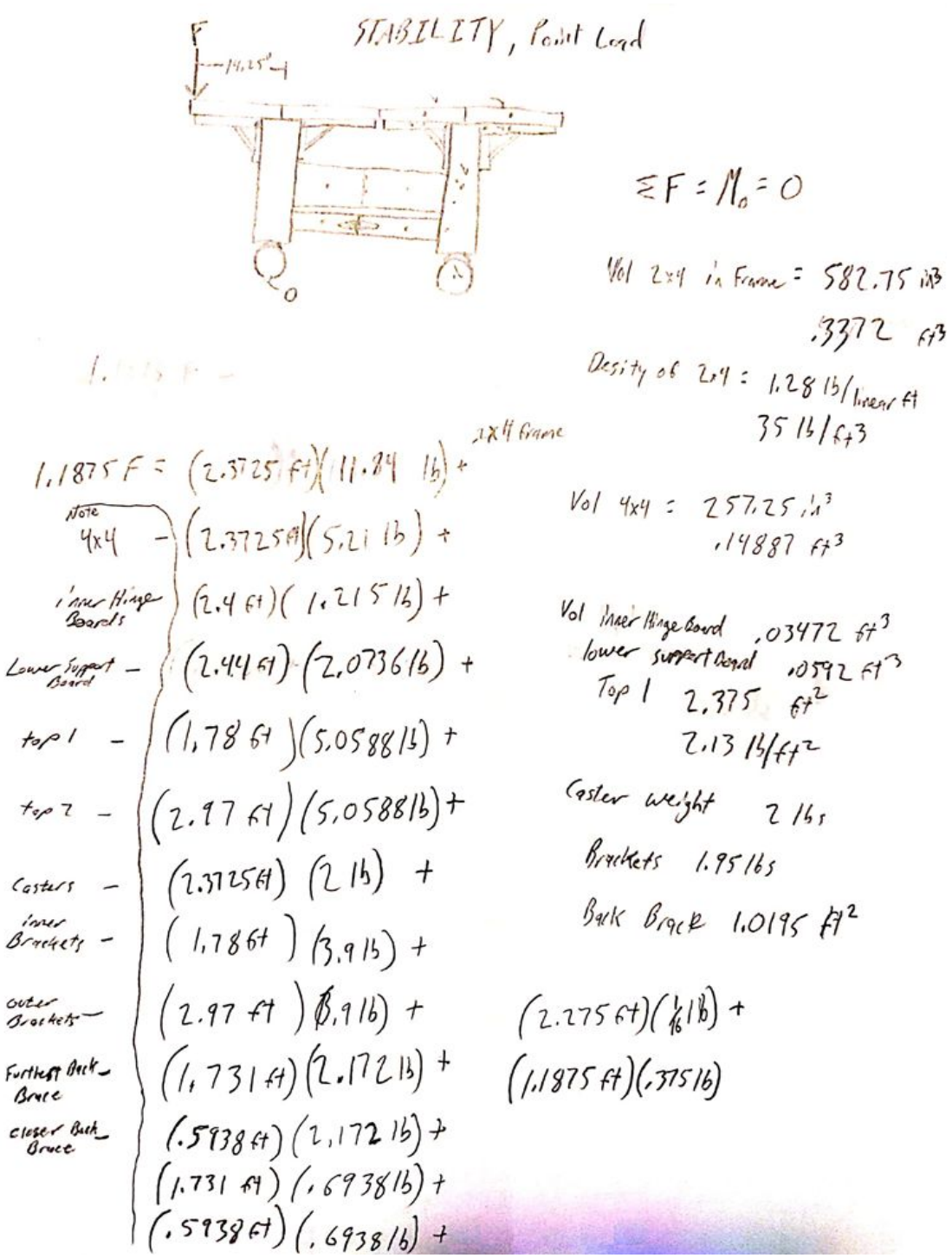


Figure 6.15: Hand calculation stability point load

$\Sigma M_0 = 0 \Rightarrow 1.1875F = 102.976 \text{ ft·lb}$

$F = 86.7 \text{ lb}$

Figure 6.16: Hand calculation stability point load

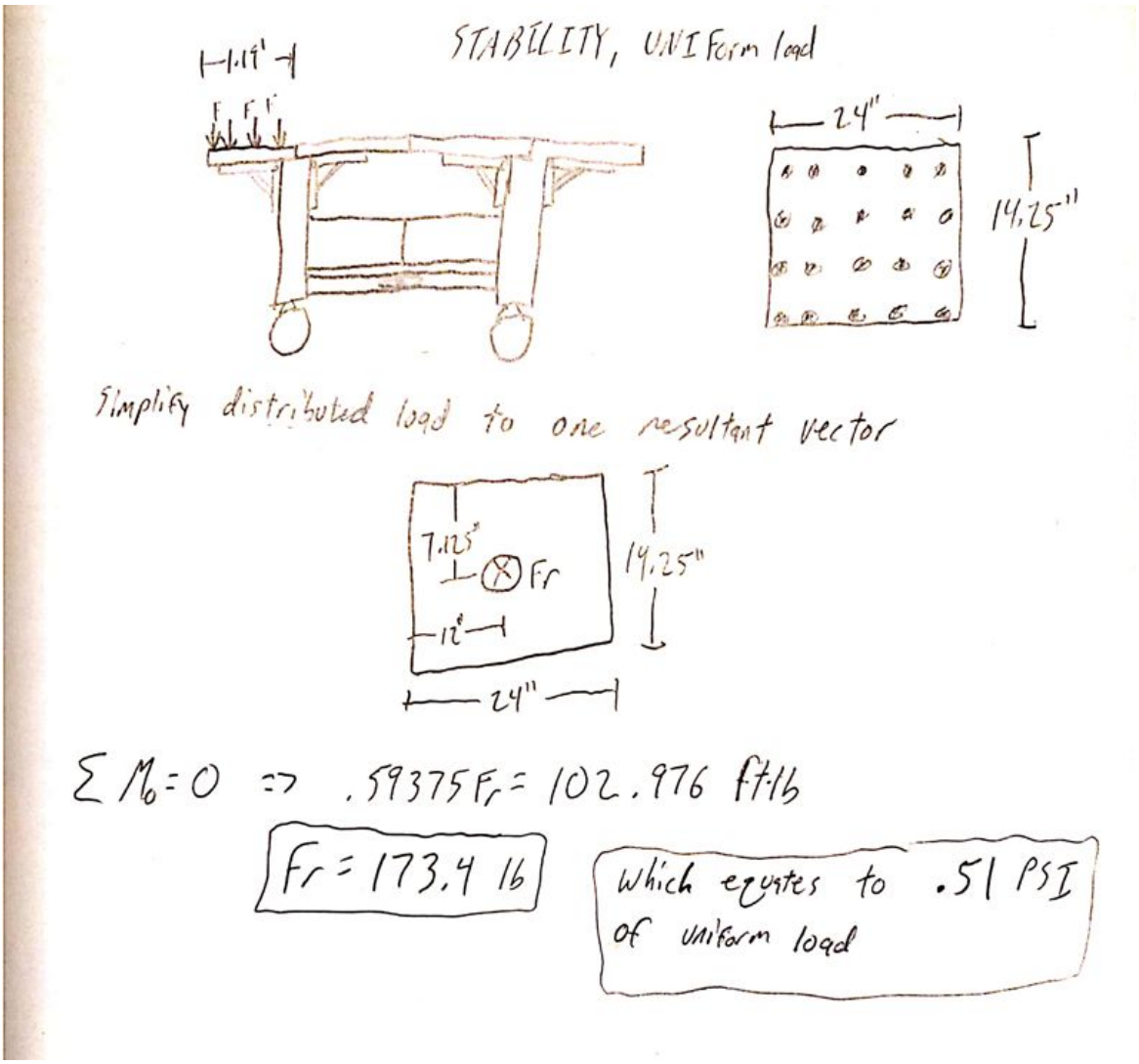


Figure 6.17: Hand calculation stability uniform load

6.6 Finite Element Analysis

In figure 6.18 there is a 660 lb uniform load applied top of the leg base. The goal of this test is to see how the stress is distributed throughout the leg base. Figure 6.19 shows that the stress gets focused into the casters. Stress focuses around the welded edge of the caster at close to the top. It the maximum point of stress is represented with the symbol “Max”. The max stress experienced by the caster is 17210 psi. This part of the caster is made of stainless steel and therefore has a yield strength of 31200. Therefore at this weight the caster should not yield. The goal of figure 6.20 is to show the total deformation after a 660 lb uniform load is applied to a single table top. The 660 lb load is double the rating for all the stainless steel brackets, and a point of measure the team thought would properly exemplify the strength of the table. The total deformation of the table was 0.11471 in at the edge of the table. This amount is an acceptable range for the products expectations. The final image, figure 6.21, shows 2.671e5 psi of stress in the screws connecting the brackets to the table. This is area is where we believe the product would most likely fail. In a future design these screws would be replaced with bolts to ensure the screws would not rip off.

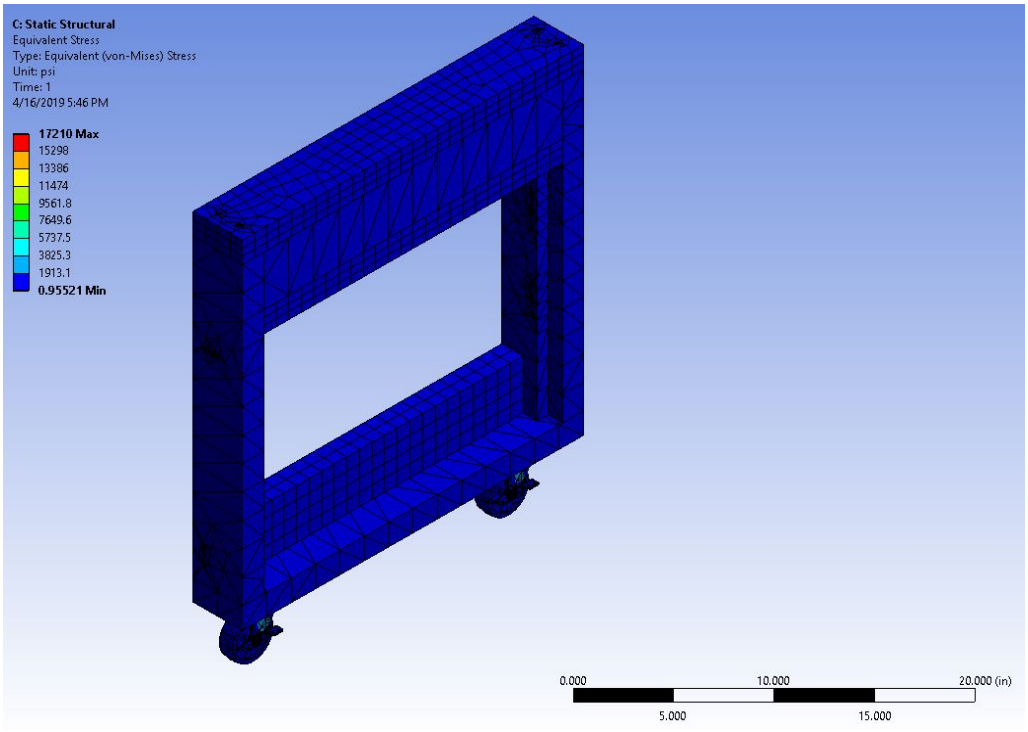


Figure 6.18: 660 lbs of force uniform load applied to the top of the leg base

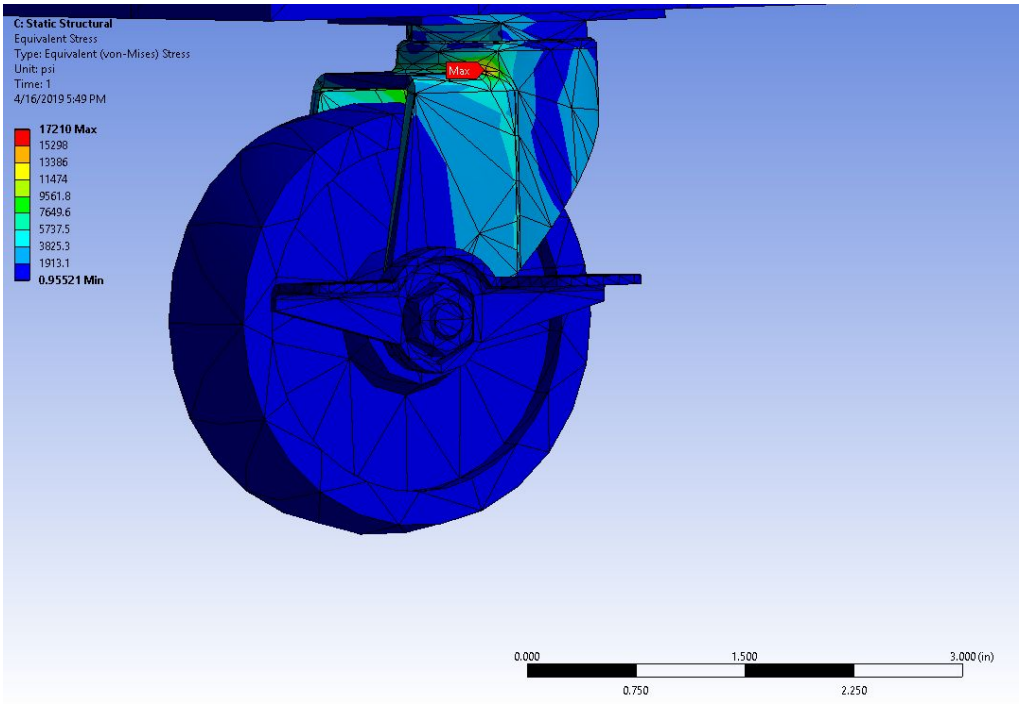


Figure 6.19: Stress in Casters after 660 lbs of force applied

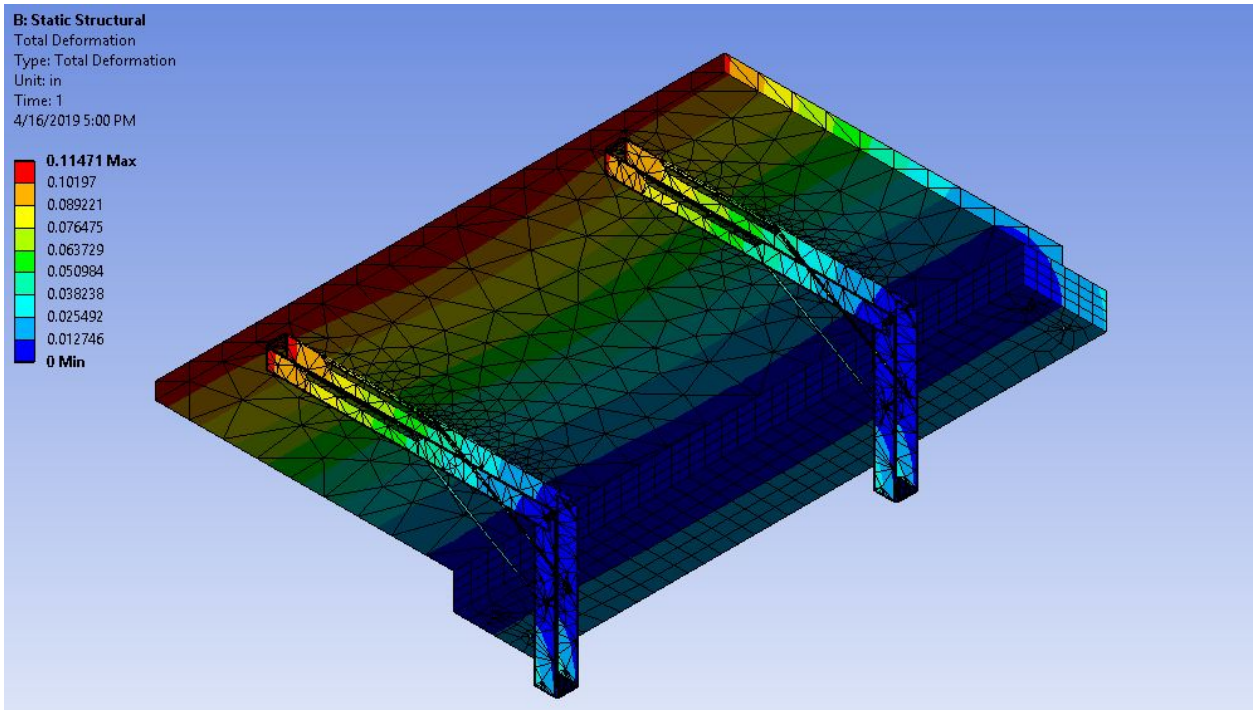


Figure 6.20: Total Deformation after 660 lbs uniform load applied table top

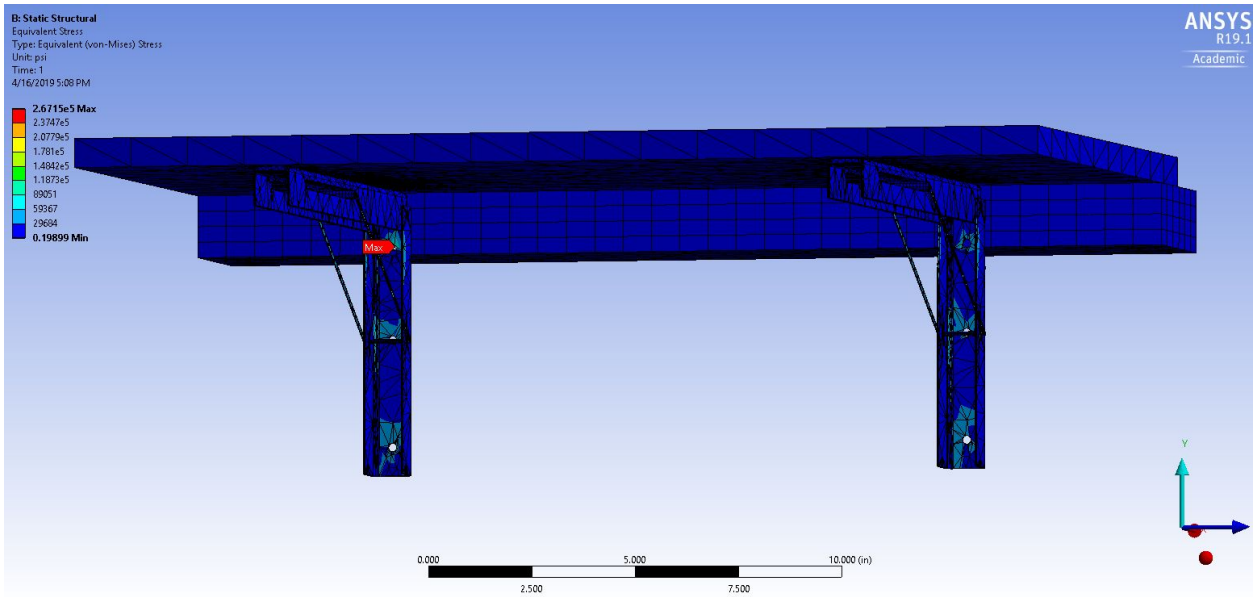


Figure 6.21: Total Deformation after 660 lbs uniform load applied table top

6.7 Design for Manufacturing & Assembly

Manufacturing. When it comes to the design for manufacturing and assembly the team unfortunately did not have the time to layout a preliminary strategy for the manufacturing and assembly of the product. However, the team understands how imperative DFM and DFA are to creating a product. For the final product the team believes that replacing the wooden pieces of the base for a 80/20 based aluminium bottom would provide stronger stability and significantly reduced the weight. On top of that the plywood table top would be replaced for a lighter, stronger, and better surface quality wood. The team believes pinewood could be a potential solution to this problem. The issue with this change is obviously the increased cost. The team believes that price increase can be made up for by reducing cost as much as possible in areas like manufacturing and assembly. Therefore the design for manufacturing will center around manufacturing the aluminium and the pine wood.

Wood is a challenge to work with due to its knots, cracks, and discoloration, but pine wood has historically been an easier wood to work with in terms of manufacturing. This is due to the wood being durable, but soft, is easier stained, and usually sells at an affordable rate. However, the secondary process selected for pine would still need to prioritized surface quality of the wood and an acceptable range on the tolerance. Low tolerances could impact assembly times dramatically, due to the wood panels not fitting properly on the brackets. Regardless of the process there would need to be a focus on quality control when it comes to wood.

Aluminium in general is a lot easier to manufacture and control the quality. The advantages of 80/20 aluminum in particular is its modularity, due to its T-slot structural framing. 80/20 aluminium is also available as OTS(off-the-shelf) purchase. The quality of the manufacturing process that exist right now for 80/20 aluminum is at a satisfactory level for the price. The design at it's core would not change dramatically, but things about how the legs interact with the folding mechanism would have to change to properly incorporate the 80/20 aluminium. This change in design and weight would also change where the c.g. exist for the product, but many of these changes will adjust the calculations needed for the product. Additionally, the leg base could be made out of other types of custom aluminum parts, but that case has yet to present itself. The benefits that the product gains from switching to an 80/20 aluminium design is again the modularity. There is an entire market of accessories that would automatically integrate with this product, boosting its appeal to customers.

Assembly. The story when it comes to assembly is not as straightforward. Currently, the team believes the leg bases could definitely be developed using automation. A lot of that assumption comes from the industry's ability to overall maintain quality when producing metal products with automation. However, automation in the wood product industry may not meet the

accuracy needs for the product. This will cause the company to incur high labor fees to build this product to scale. However, using the Boothroyd-Dewhurst DFA method for manual assembly, the team believes that labor cost can be compensated with decreased assembly times. Currently however, the team cannot determine a precise assembly time for the final design.

7.0 Manufacturing and Process Cost Analysis

The benefit of our product is that the parts used to manufacture are easily obtained and modified as needed for assembly. All the hardware required for the product come directly off the shelf with no modifications required for the product. The structure also comes from off the shelf goods, however the wood must be cut to the proper dimensions.

The first part of the assembly process would be to cut the material to the proper length. Once the parts are the proper size, assembly of the frame will begin. Jigs would be beneficial to the assembly of the frame, so that the pieces could be easily placed and assembled while reducing the amount of error that could be introduced by movement of flexion. Also the use of adhesive with the fasteners will make further enhance the strength of the final product.

Our prototype material cost was approximately two hundred fifty dollars, for the final design we would have better quality material which would add some cost, however we could also utilize material in a slightly different configuration, using leftover scrap for another unit, as well as bulk discount pricing for materials. The estimation for cost for the final product will use a material cost of one hundred sixty dollars, a labor cost of seventy five dollars (one laborer at twenty five dollars an hour for three hours), and an overhead rate of sixty four dollars. With a

profit margin of thirty percent. Using these values, and an estimated monthly fixed cost of one thousand five hundred dollars, the calculation of break even is as follows. The equation we will use is;

$$Z = PQ - (Qv + f)$$

At the break-even point, $Q = Q_{BEP}$ and $Z = 0$

$$Q_{BEP}(P - v) = f \qquad \text{Therefore, } Q_{BEP} = \frac{f}{P - v}$$

Using f = 3500, P = 390, and v = 235. We arrive at a break even point at approximately twenty three units. If we extrapolate this to a yearly break even we arrive at a break even at approximately two hundred seventy one units.

A basic initial design life cycle calculation is carried out below. This is based on a smaller scale operation that would have less associated cost, but also a lower potential for mass production of units.

	Year					
	1	2	3	4	5	6
Sales Price		390	385	380	380	380
Unit Sales		500	750	1000	750	500
Net Sales		195000	288750	380000	285000	190000
Unit Cost		300	290	285	285	285
Cost of Product sold		150000	217500	285000	213750	142500
Gross Margin($)		45000	71250	95000	71250	47500
Gross Margin(%)		0.230769231	0.246753247	0.25	0.25	0.25
Development Cost	50000	30000	25000	25000	25000	25000
Marketing		5000	5000	5000	5000	5000
Other		5000	5000	5000	5000	5000
Total Operating Expense	50000	40000	35000	35000	35000	35000
Operating Income	-50000	5000	36250	60000	36250	12500
Op Income		0.025641026	0.125541126	0.157895	0.127193	0.065789
Cumulative Op Income	-50000	-45000	-8750	51250	87500	100000

Cumulative Sales	1338750
Cumulative Gross Margin	330000
Cumulative Op Income	135000
Ave % Gross Margin	0.245504496
Avg % Op Income	0.100411869

Figure 7.1: Sales Projections

8.0 Final Product Design Specification or "PDS"

PDS for Workbench

Product Design Specification: Space Force's space saving workbench

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Product Identification
- The Space Saving Workbench

Special Features
- Integrated collapsing table top and frame
- Adjustable work space sizes
- Portability with rollable casters
- Compact storage size
- Impact resistant

Key Performance Targets
- Able to fold and unfold reliabally
- Maximize work surface area
- Minimize size when collapsed
- Ability to withstand most user applications

User Training Required
- User manual with assembly instructions and basic safety information
- Entry-level building knowledge

Service Environment
- Indoor 40 to 80℉
- Outdoor -20 to 120℉
- Dry conditions only

Logistics
- Shipping:
  - Pre-cut structural pieces
  - Some pre-assembled sections
  - Hardware included

Key Project Deadlines
- March 8th, 2019: Interim Report 1
- April 15th, 2019: Interim Report 2
- February 18th, 2019: Team Contract
- February 18th, 2019: Patent Search
- April 17th, 2019: Last day to print posters
- April 26th, 2019: Present to FSU Board
- May 3th, 2019: FSU Symposium
- May 4th, 2019: Final Paper Due
- May 9th, 2019: UMD Design Day
- May 10th, 2019: Final Poster

Physical Description

- 57”L X 24”W X 27”H Unfolded
- 15”L X 24”W X 27”H Folded
- 4 Casters attached on bottom
- 304 stainless steel brackets
- Plywood table top
- Pine structure
- Zinc brackets and straps

Manufacturing Specifications

- All wood framing and cutting will be manufactured in house
- OFT 304 stainless steel brackets, hinges, screws, straps, and casters
- Suppliers: TBD

Market Identification

- Beginner to Expert DIY with limited garage space
- Initial Retail location: Online
- Initial production units: 1000 tables
- Brand name: Space force

Financial Requirements

- Concept Budget: $250
- Service Budget: $185
- Theoretical Manufacturing Cost: $300
- Theoretical Product Cost: $390
- Warranty Policy: 2 year limited

Life Cycle Targets

- Useful life: 20+ years
- Maintenance: Lubricate support brackets every 6 months and re-torque caster and bracket nuts
- End of life strategy: Workbench wood and metal components are recyclable

Social, Political, and Legal Requirements

- Exemplifies the academic excellence of University of Maryland and Frostburg State University
- Infringes upon no copyrighted patents
- Safety:
  - Support 1000 lbs
  - Lock when unfolded
  - Complies with OSHA standards
  - Does not require extraneous effort to operate

9.0 Prototyping & Testing

The final prototype demonstrates the proof of concept that we intend. It is not made from the exact size or material as the final product would be. The scale is a custom scale, i.e. not 2:1 or any variation. We had to sacrifice some intended elements of the final design due mainly to budget constraints. The budget hampered the ability of our team to create a full scale model which would have some other materials used. The final product would have a higher quality integrated tabletop, likely a sealed hardwood. We would also incorporate heavier duty hardware to enhance strength and stability. We built our final prototype from plywood, stock pine boards, hinges and fasteners. No special processes were needed building our prototype, other than cutting the wood to size and using drills for assembly.

The physical testing of our prototype was performed by loading it with weight at various locations to test if it can hold the weight, and also to measure the deflection. The first test loaded weight in the middle of the prototype to test the capability of both inner flaps being engaged. The figures below describe the results for deflection.

Deflection with Weight in Middle	
Weight (Lbs)	Deflection(in)
Initial	0
50	3/16
100	1/4
150	1/4
200	5/16
250	5/16

Figure 9.1: Deflection of Weight in Middle

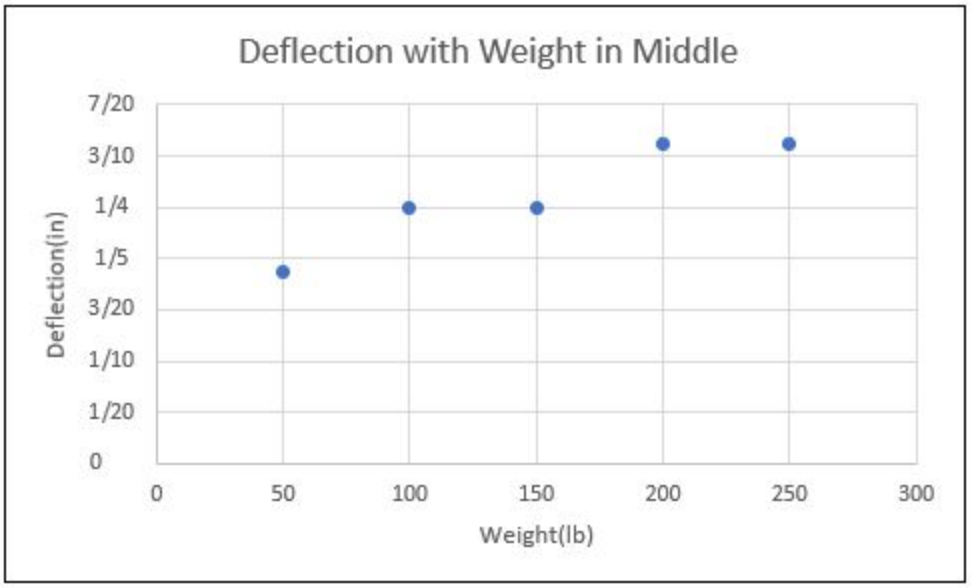

Figure 9.2: Deflection Chart

Figure 9.3: Weight Test

Figure 9.4: Weight Test Front View

The second test performed to test the capability when one inner table top flap is engaged with the load. The test results are shown below.

Deflection with Weight on One inner Flap	
Weight(lb)	Deflection(in)
Initial	0
50	1/16
100	3/16
150	3/16
210	1/4

Figure 9.5: Inner Flap Deflection

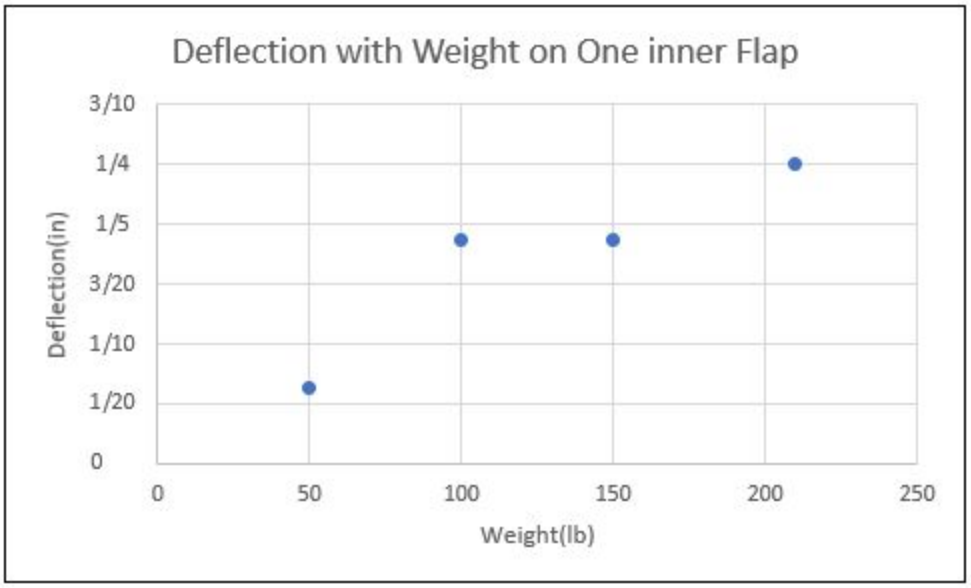

Figure 9.6: Inner Flap Deflection Chart

The third test was performed on the capability of one other flap. This was performed by loading the weight on the outside flap, while also counter balancing the table to prevent flipping. The results of this test are as follows.

Deflection With Weight on Side Flap	
Weight(lb)	Deflection(in)
Initial	0
50	1/16
100	1/8
150	3/16

Figure 9.7: Side Flap Deflection

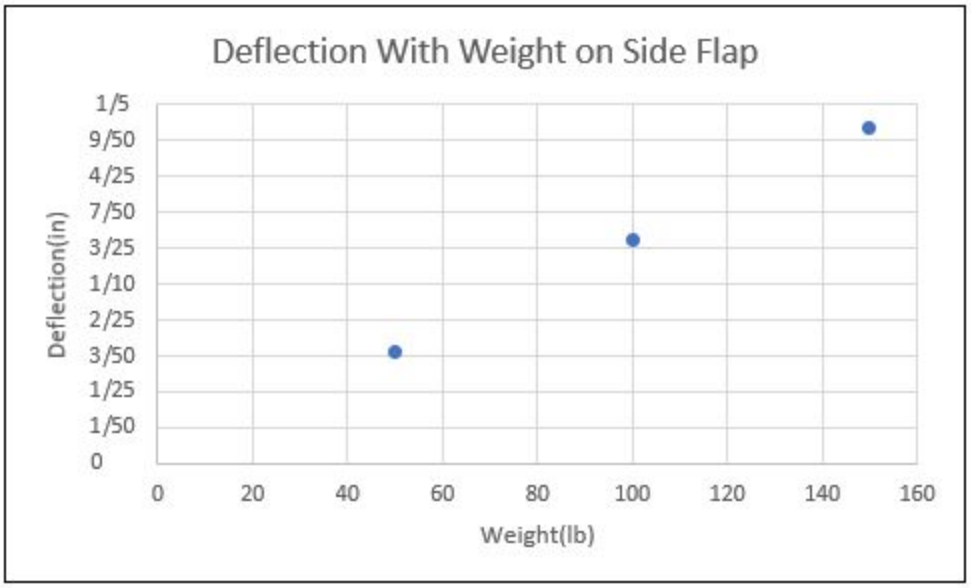

Figure 9.8: Slide Flap Deflection Chart

The last test performed was to test for stability. It was calculated that a weight of 86.7 pounds point loaded at the edge on the table would cause the table to start tipping. The testing confirmed this as a great calculation of this result. The table was loaded near the edge and the weight was slowly increased to find the tipping point. As expected from the calculation the table was stable when 85 pounds was loaded, however began to tip when 90 pounds was loaded shortly afterward.

Figure 9.9: Weight Test on Side Flap

For our prototype the testing showed that the table would be effective under anticipated normal working conditions. The shortfall of the testing was that we were unable to test the prototype to the full potential. This is due to multiple factors. Firstly, we did not want to load the prototype to failure at this time, because we will need it to be fully functional during our presentations. We were also limited by the amount of weight that was available for our use. This was more impactful to testing the side flap than any other test, due to the need to counterbalance the table while performing this test.

10.0 Sustainability

It is our responsibility to consider our products impact on our society, economy and environment. The following steps are recommended to reduce the impact that a product has on the environment:

1. Use waste as a resource
2. Diversify and cooperate to fully use the habitat
3. Gather and use energy efficiently
4. Optimize rather than maximize
5. Use material sparingly

6. Don't foul nests
7. Don't drawdown resources
8. Remain in balance with the biosphere
9. Run on information
10. Shop locally

Of course we would implement many of these in various ways but one of the easiest factors to predict is the first; use waste as a resource. Due to the construction of our product, many of our assembly items are commercial-off-the-shelf products. However, our design also heavily relies on the use of pine wood. We can implement the first strategy by purchasing our wood in bulk and then recycling any wood that is wasted due to cutting or sanding. Wood is a very easy raw material to recycle, we could either invest in the equipment to recycle it ourselves or turn the waste over to a company that will recycle the wood.

Other environmental considerations lie within the manufacturing and acquisition process. The manufacturing and assembly done in-house would not have a heavy environmental impact as we are not using power intensive equipment, hazardous materials, or producing air pollution. While our in-house production will not be an issue, it is also important to consider the processes that take place before the raw materials and parts are received by our manufacturing team. These considerations include cutting down trees to acquire the wood, the mining that goes into the steel brackets and hinges, and pollution caused by the transportation of these materials.

We do not predict any environmental issues at the end of life cycle of our product as it is made up of easily reusable and/or recyclable materials such as wood and steel.

11.0 Conclusions on Designed Product

11.1 Project Results

Overall, our team is satisfied with the results of the final design in relation to our initial conception of this product. The inspiration for our design can be seen in Figure 6.1 as well as in many other similar products in the market. The key distinction that we sought to accomplish in our design was to subvert the idea of having a separate solid tabletop that would have to be stored additionally. This resulted in the design decision to have a folding center and outer tabletops. The result of this divergence from the existing product architecture provides users with more versatility and ease of storage. Having no additional parts that need to be stored means that the user will be less averse to folding and storing the workbench. Additionally, having the two side flaps allows the user to customize their surface area to meet their specific needs.

Some of the key design phases that greatly affected our product are: House of Quality (HOQ), Finite Element Analysis (FEA), and Prototyping. Producing the HOQ allowed us to

realize the key characteristics of our product and gave us a particular factor to focus towards. During the embodiment design phase we conducted FEA which was crucial to our understanding of the physics of the workbench and allowed us to key in on aspects that may need redesigning and aspects that were projected to perform well. Arguably the most impactful stage in our design was prototyping. During the design phase and even while modeling the workbench in CAD and FEA we gained inside on the potential performance of the product, however, it was not until building and testing the prototypes that we were able to get a full scope on the successes and failures of our design. Prototyping allowed us to see the real-world outcomes of every single previous design choice and it served as an extremely useful learning tool.

11.2 Future Design Goals

The most obvious weakness in our design was discovered after assembling the final prototype. This design weakness is the low structural stability when transforming from the folded to unfolded configuration and vice versa. This flaw is derived from our decision to have only one permanent connection between the two sides of the table which in turn was a result of needing more interior folding space for the two main table tops. Having the main table top fold down results in less space for interior supports such as those seen in Figure 6.1. We can improve on this flaw by using a semi-permanent connection between the two sides of the center table top. A fully permanent solution is not possible because when fully folded down a simple hinge would not be able to reach both flaps due to its folding angle. However, if we were able to develop a hinge that was solid when in the unfolded position but then can extend and maybe rotate while the workbench is folding then it would allow the two sides to have another connection point to provide more stability during transformation.

Some other design aspects worth mentioning are the table top material and caster functions. The tabletop of the final prototype is made of low quality plywood. Clearly this would not satisfy customers needs and we envision a final product having a table top either made of a more solid and higher quality wood or an equivalent alternative. For the casters there are two design changes we would make. First, we would replace two of the swivel casters (on the same end) with fixed casters to make movement simpler and easier. Secondly, we would like to implement casters that can be manually disengaged so that the table would then be sitting flat on the ground; providing more strength and stability while in use.

Figure 11.1: Casters are engaged

Figure 11.2: Casters are disengaged

11.3 Design Process Reflection

One of the main weaknesses of the design process that our team followed was the ambiguity of whether or not we should be focusing on our "ideal" product or the prototype we would be physically creating. As a result of this being both a class and a design project, some phases were focused on our prototype (Hand calculations, FEA) while some were focused on the product that we would produce if capable (AHP, Morphological chart). While this did prove to be confusing at the time, we are all aware that during an actual design phase our main focus

would that of the final product and the prototype would simply supplement our efforts in reaching a successful final product.

One example of this conflict is the AHP. We conducted the AHP in conjunction with what we would consider our "ideal" final product, however, after reviewing the results it was clear that we would not be able to accomplish a prototype based off of the concept's required features. Therefore, we acknowledged that the empirically best solution was determined by the AHP but we would use features of a different concept to build our prototype as it would be far cheaper.

As a result of this design process we were able to gain insight on the importance of following the process and how doing so will make each sequential step much easier.

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8.0 Appendix

Weighted Decision Matrix

	(1-5)		Workbench		Therapy Sensor		Pot Stirrer		Fire Pit Generator		Portable Laundry Basket		Easy Eye Glass Cleaner	
Criteria	Weight		Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating
Price	5		4	20	2	10	2	10	1	5	5	25	3	15
Time to complet	3		4	12	2	6	2	6	1	3	4	12	3	9
Feasibility (diffic	4		5	20	2	8	3	12	2	8	4	16	2	8
Market Feasibilit	1		2	2	4	4	4	4	4	4	3	3	4	4
Originality	2		3	6	5	10	4	8	5	10	3	6	5	10
Comprehensiver	4		2	8	5	20	5	20	5	20	1	4	4	16
Background Info	2		4	8	2	4	1	2	2	4	3	6	3	6
Manufacturabilty	1		4	4	4	4	3	3	3	3	5	5	3	3
Interest	2		5	10	4	8	2	4	2	4	4	8	4	8
Total				90		74		69		61		85		79

Gantt Chart (Through Phase 2)

WBS NUMBER	TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION	PCT OF TASK COMPLETE
1.0	PHASE ONE: IDEATION					
1.2	Brainstorming	All	1/28/19	2/1/19	5	100%
1.3	Decision Matrix	All	2/4/19	2/6/19	3	100%
1.2	Approval to move forward with first idea	All	2/6/19	2/6/19	1	100%
1.3	Patent Research	All	2/11/19	2/15/19	5	100%
1.4	Start Preliminary Principle Design	All	2/7/2019	2/12/19	6	100%
2.0	PHASE TWO: INTIAL DESIGN AND START REPORT					
2.1	Principal Design(Table Design)	ZC,MB,DZ,DM	2/18/19	2/27/19	10	100%
2.2	Accessories Design(Storage)	DM,AS,ZC	2/18/19	2/22/19	5	100%
2.3	PD Testing	All	2/27/19	3/4/19	6	100%
2.4	White Paper Completion(Error)	DM,AS,DZ	02/23/2019	3/1/2019	7	100%
2.5	White Paper Completion(progress)	All	3/1/2019	4/5/2019	36	100%
2.6	Prototype 1	All	03/08/2019	03/08/2019	1	100%
2.7	Post-Prototype 1 Discussion	ZC,MB,DZ,DM	03/11/2019	03/11/2019	1	100%
3.0	PHASE THREE: ANALYSIS, FINAL DESIGN, AND REPORT COMPOSITION					
3.1	Finish Principal Design	ZC	03/25/2019	04/06/19	11	100%
3.2	Revised Report	DZ	03/25/19	03/29/19	4	100%
3.3	Prototype 1 Description	MB	03/25/19	03/29/19	4	100%
3.4	SOP 2.1 draft 1	DM,ZC	03/28/19	03/29/19	1	100%
3.5	Poster Production	AS	03/25/19	04/16/19	21	100%
3.6	SOP 2.1 Final	DM,ZC	04/01/19	04/05/19	4	100%
3.7	SOP 2.2 Final	DZ,MB	04/01/19	04/05/19	4	100%
3.8	Hand Calcs/Research and Completion	All	04/08/19	04/19/19	11	100%
3.9	White Paper Intial Deliviery	All	04/08/19	04/08/19	0	100%
3.10	White Paper Revisions	AS,DZ			0	100%
3.11	FEA Analaysis	ZC,MB,DM	04/08/19	04/19/19	11	25%
3.12	Report 2 Due	All	04/15/19	04/15/19	1	100%
4.0	PHASE FOUR: CONSTRUCTION AND PRESENTATION PRACTICE					
4.1	Poster 1 Due		4/17/19	4/17/19		100%
4.2	Assembly	All	4/17/19	4/19/19	2	100%
5.0	PHASE FIVE: PHASE FIVE: POLISH, PRESENTATIONS AND FINALIZE REPORT					
5.1	Poster Presentation for Advisory Board	All	4/26/19	4/26/19	1	0%
5.2	Poster 2 Due	All	4/29/19	4/29/19	1	75%
5.3	SOP: Improvements	ZC	4/22/19	4/22/19	1	0%
5.4	Adding Improvements	All	4/24/19	4/24/19	1	0%
5.5	SOP: Testing	MB	4/23/19	4/23/19	1	80%
5.6	Testing	All	4/25/19	4/25/19	1	0%
5.7	Prorate Analysis	AS	4/22/19	4/22/19	1	0%
5.8	Presentation Outline	DM,DZ	4/22/19	4/23/19	1	0%
5.9	Presentation practice	All	4/24/19	4/25/19	1	0%
5.10	FSU Symposium	All	5/3/19	5/3/19	1	0%
5.11	Final Paper Due	All	5/4/19	5/4/19	1	0%
5.12	UMD Design Day	All	5/9/19	5/9/19	1	0%

Team Contract

Team Name: Space Force - We Save Your Space
Team Members: Matthew Beall, Zach Cross, Demetrick McDonald, Andrew Saku, Devon Zollinhofer

Code of Conduct

As a project team, we will:

1. Work proactively, anticipating potential problems and working to prevent them
2. Keep other team members informed of information related to the project
3. Focus on what is best for the whole project team
4. See the team project through to completion

Participation

We will:

1. Be honest and open during all project activities
2. Encourage diversity in teamwork
3. Provide the opportunity for equal participation
4. Be open to new approaches and consider new ideas
5. Have one discussion at a time
6. Let the team know well in advance if a team member has to miss a meeting or may have trouble meeting a deadline for a given task
7. Upon inclement weather meet via the best form of communication

Communication

We will:

1. Decide as a team on the best way to communicate various information
2. Focus on solving problems, not blaming people
3. Present ideas clearly and concisely
4. Meet and communicate frequently to discuss project progress
5. Arrange additional meetings, as needed
6. Keep discussions on track
7. Honor meeting time frames

8. Read communications (emails, meeting log, group messaging, etc.) from each other
9. Respond to each other in a timely manner (i.e., within 24 hours)

Problem Solving

We will:

1. Encourage everyone to participate in solving problems
2. Only use constructive criticism
3. Strive to build on each other's ideas
4. Hold each other accountable for meeting the aforementioned

Team Roles

Principle Design:

- Lead: Zach Cross
    - Matthew Beall
    - Devon Zollinhofer
    - Andrew Saku
    - Demetrick McDonald

Structural Analysis:

- Lead: Matthew Beall
    - Zach Cross
    - Demetrick McDonald Jr.
    - Devon Zollinhofer

Project Manager:

- Lead: Demetrick McDonald Jr.
    - Andrew Saku
    - Devon Zollinhofer

Drafting & Animations:

- Lead: Devon Zollinhofer
    - Demetrick McDonald

Subsystem Design:

- Lead: Demetrick McDonald Jr.
    - Andrew Saku
    - Devon Zollinhofer

Report and Poster Board

- Lead: Andrew Saku
    - Devon Zollinhofer
    - Demetrick McDonald Jr.
    - Zach Cross
    - Matthew Beall

Engineering Design Specification - Space Saving Workbench

Product Identification

- Workbench

Special Features

- Integrated collapsing table top and frame
- Adjustable work space sizes
- Casters

Key Performance Targets

- Able to fold and unfold reliabally
- Maximize work surface area
- Minimize size when collapsed
- Ability to withstand most user applications

User Training Required

- User manual with assembly instructions and basic safety information

Logistics

- Shipping
    - Pre-cut structural pieces
    - Some pre-assembled sections
    - Hardware included

Key Project Deadlines

- **Thursday March 8th, 2019**: Interim Report 1
- **Thursday April 15th, 2019**: Interim Report 2
- **Monday February 18th, 2019**: Team Contract
- **Tuesday February 18th, 2019**: Patent Search
- **Wednesday April 17th, 2019**: Last day to print posters for free
- **Friday April 26th, 2019**: Poster Presentation for Advisory Board
- **Friday May 3th, 2019**: FSU Undergraduate Symposium
- **Monday May 4th, 2019**: Final Paper Due
- **Tuesday May 5th, 2019**: Ethics Essay
- **Friday May 10th, 2019**: UMD Design Day(potentially)
- **Friday May 10th, 2019**: Final Poster

Physical Description

- 36”L X 12”W X 18”H

Market Identification

- Beginner to Expert DIYers with limited garage space

Financial Requirements

- Concept Budget: $250
- Service Budget: $185
- Theoretical Manufacturing Cost: <$400
- Theoretical Product Cost: <$424

Life Cycle Targets

- Multiyear use, in storage or actively used
- User reparable since its user assembled

Social, Political, and Legal Requirements

- Exemplifies the academic excellence of University of Maryland and Frostburg State University
- Infringes upon no copyrighted patents

Constraints

- Safety
    - Support 1500-2000 lbs
    - Lock when unfolded
    - Complies with OSHA standards
    - Does not require extraneous effort to operate
- Manufacturability
    - Requires several cuts
    - User assembled
- Cost
    - <$425
- Design
    - Fold and unfold reliably
    - Folded position must take the minimum space possible
- Material
    - Lightweight
    - Inexpensive
    - Rigid

US 20090000522A1

(19) **United States**

(12) **Patent Application Publication**

Collins et al.

(10) **Pub. No.: US 2009/0000522 A1**

(43) **Pub. Date: Jan. 1, 2009**

(54) **FRAME ASSEMBLY FOR A FOLDING WORKBENCH**

(75) Inventors: **Matthew Spencer Collins**, Meppershall (GB); **Matthew Robert Blaylock**, Tunbridge Wells (GB)

Correspondence Address:
BAINWOOD HUANG & ASSOCIATES LLC
2 CONNECTOR ROAD
WESTBOROUGH, MA 01581 (US)

(73) Assignee: **FREEFORM DESIGN & INNOVATION LIMITED**, Shefford (GB)

(21) Appl. No.: **12/133,196**

(22) Filed: **Jun. 4, 2008**

Related U.S. Application Data

(63) Continuation of application No. PCT/EP2006/069398, filed on Dec. 6, 2006.

(30) **Foreign Application Priority Data**

Dec. 8, 2005 (GB) 0525053.5
Mar. 2, 2006 (GB) 0604173.5

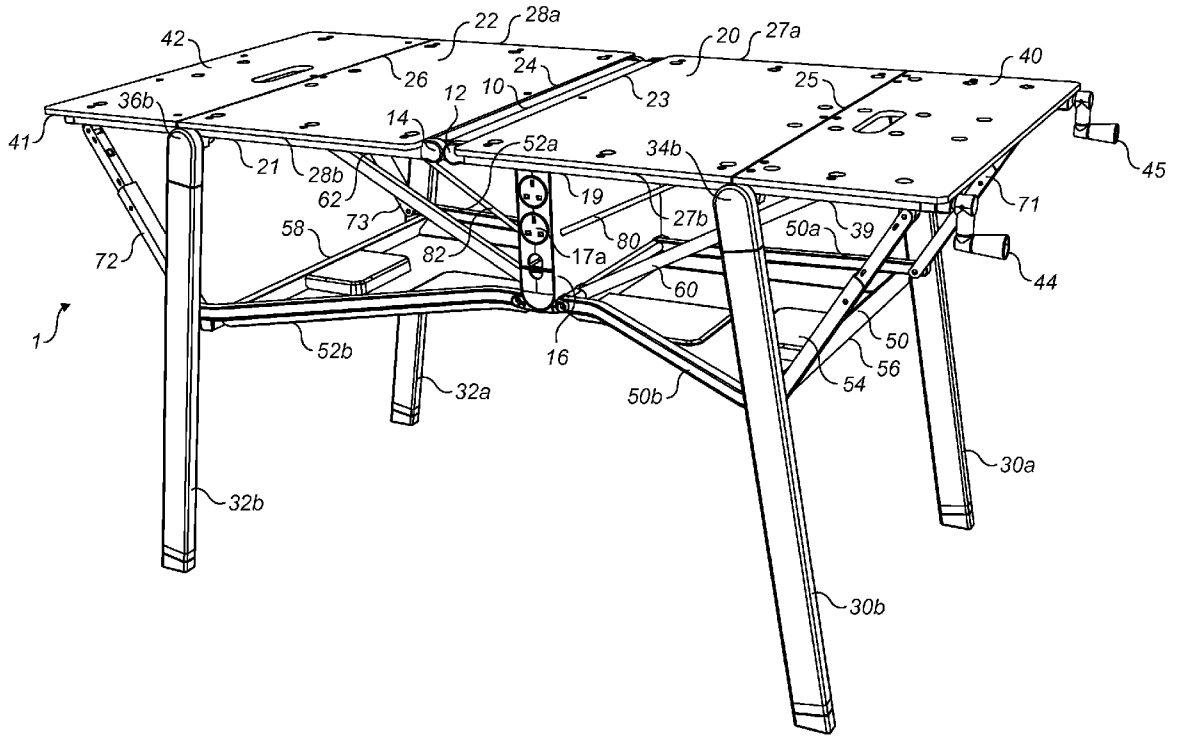
Publication Classification

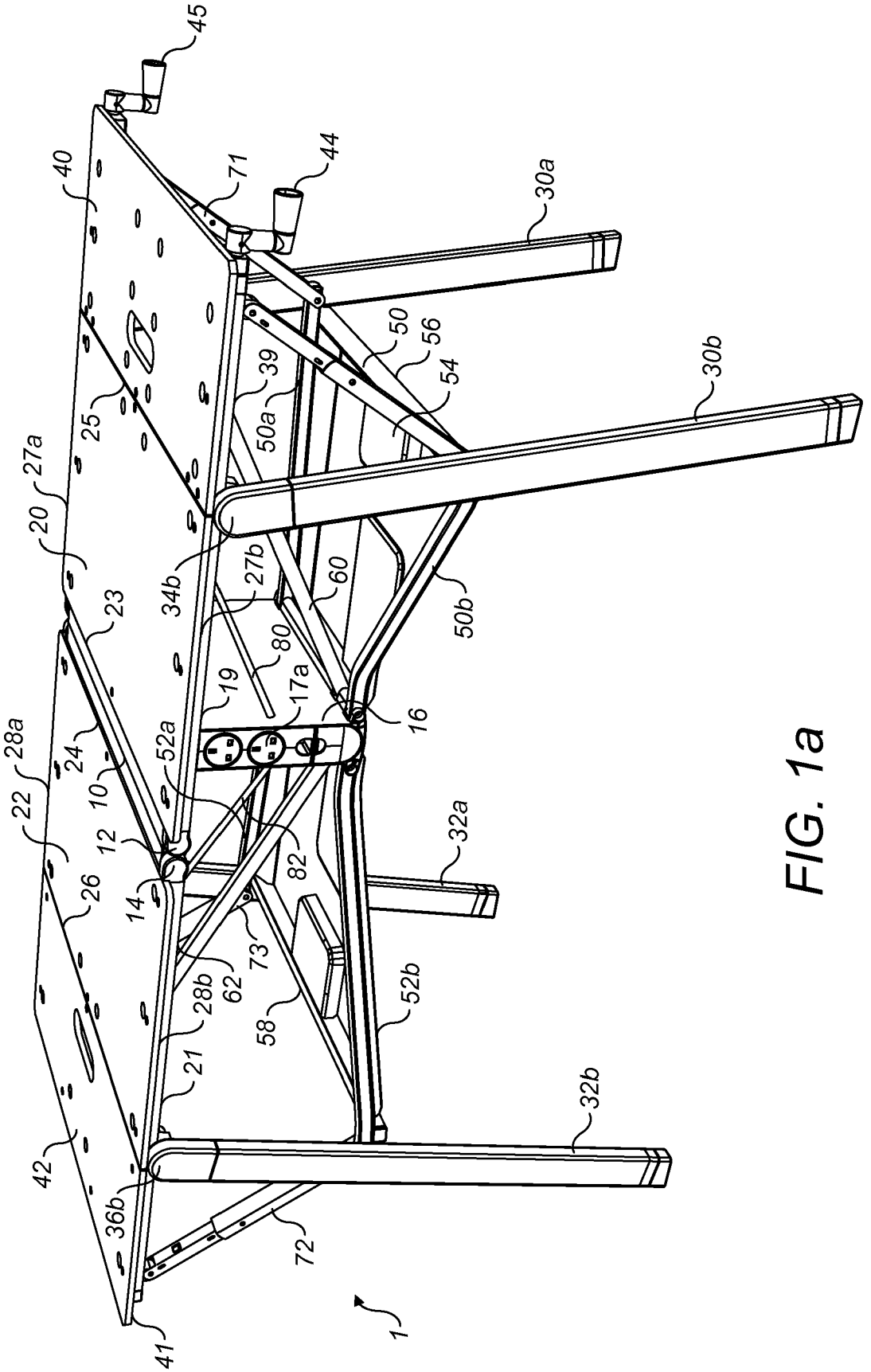
(51) **Int. Cl.**
B25H 1/04 (2006.01)
B25H 1/14 (2006.01)

(52) **U.S. Cl.** **108/12**; 108/115; 108/170; 108/50.02; 108/161

(57) **ABSTRACT**

There is provided a frame assembly for a foldable workbench comprising a frame assembly for a workbench that is reversibly foldable from an in-use to a folded configuration comprising a central spine; first and second primary work surface frames, each work surface frame having an inner edge, an outer edge and two side edges, wherein each said inner edge thereof hingedly mounts to the central spine such that the primary work surface frames are foldable towards each other; and first and second opposing pairs of legs, each leg pivotally mounting to one end of an outer edge of the first and second primary work surface frames, such that the legs of each opposing pair are foldable towards each other. The inner edge of each of the first and second primary work surface frames hingedly mounts to the central spine by a distinct hinge mounting such that in the folded configuration, opposing side edges of the respective first and second primary work surface frames are brought parallel with each other and each of the legs is brought parallel with a side edge thereof.

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17a
16
28a
24
52a
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72
41
1

FIG. 1a

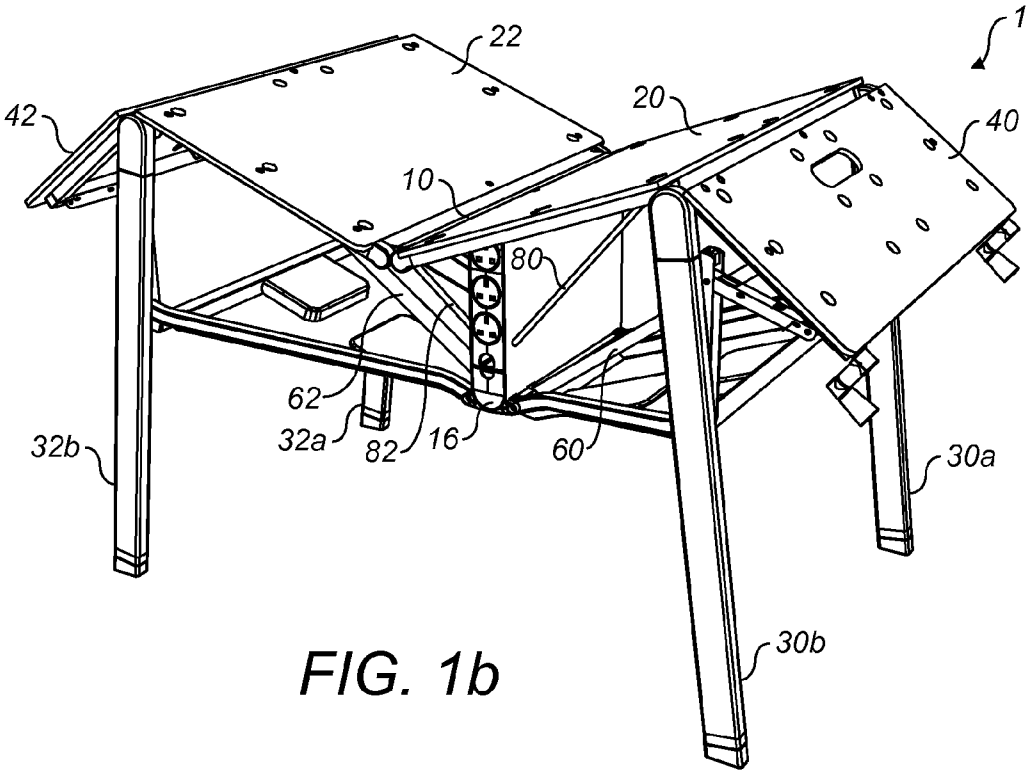
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FIG. 1b

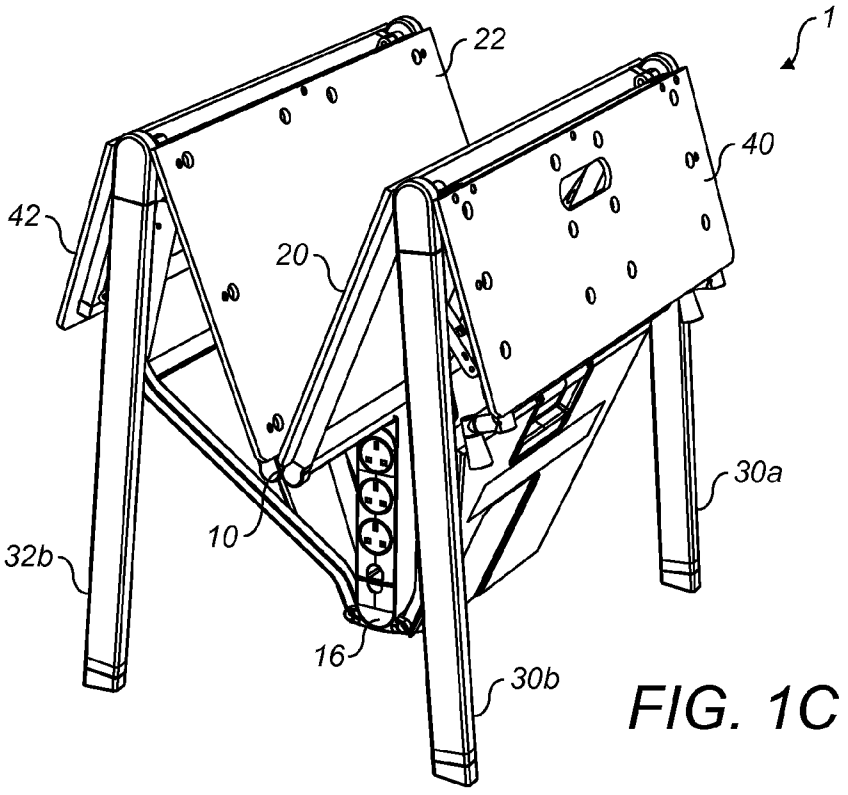
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FIG. 1C

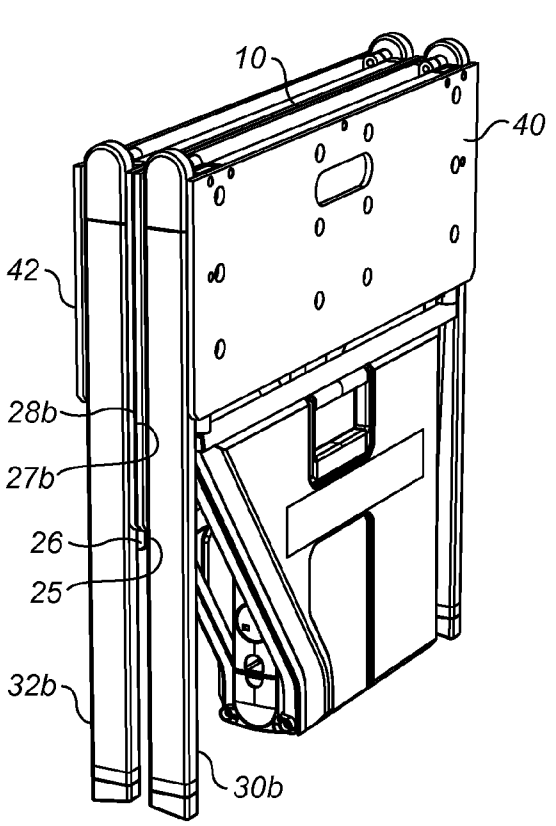
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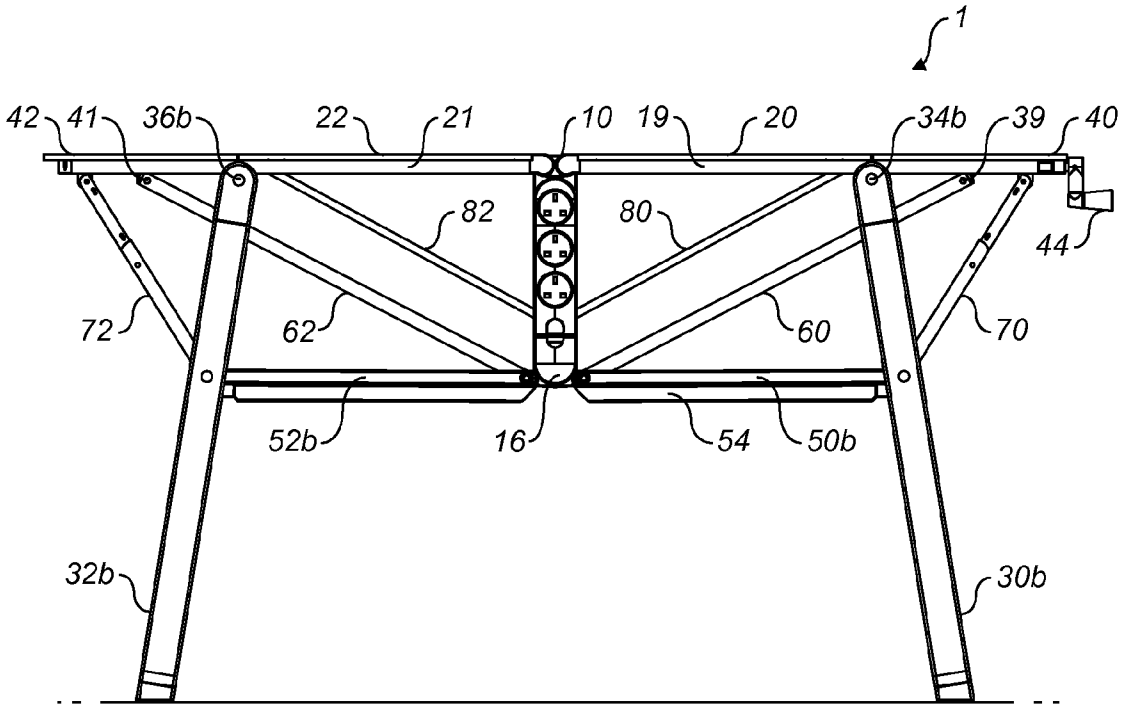
FIG. 1d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50b
32b
30b

FIG. 2a

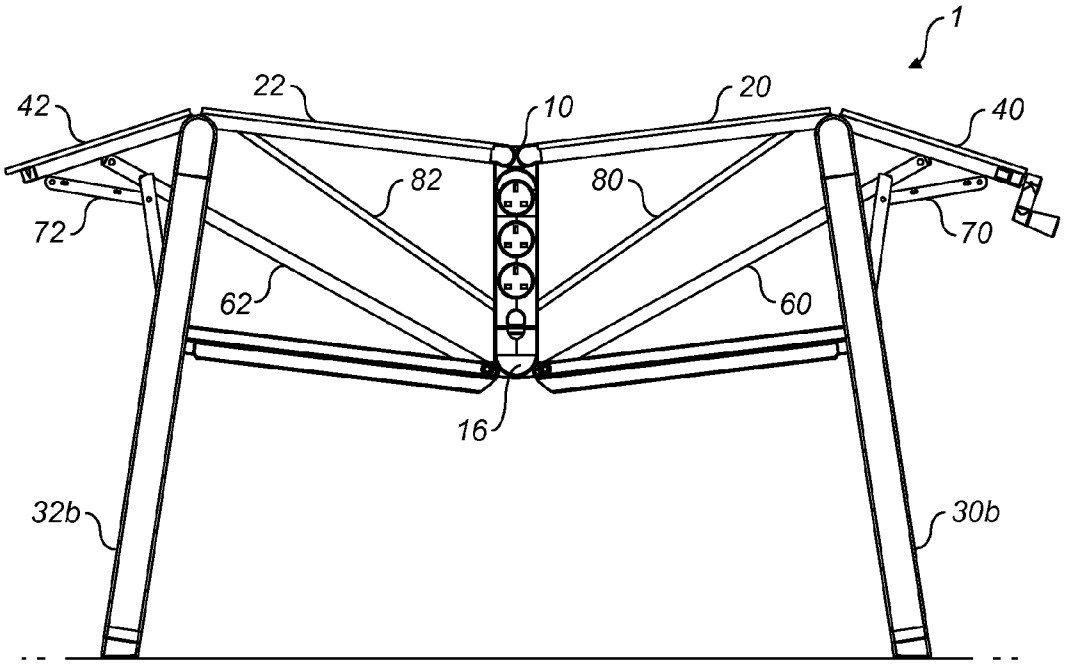
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FIG. 2b

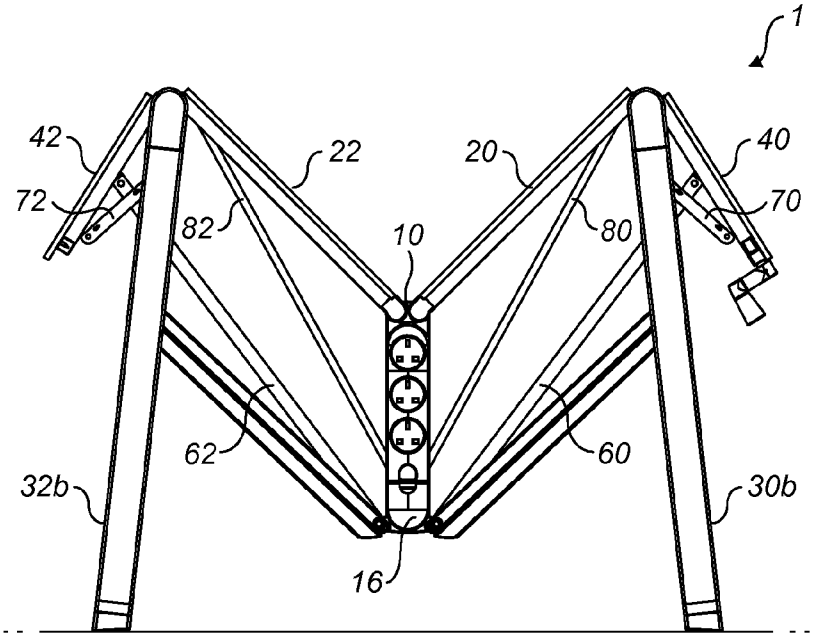
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FIG. 2c

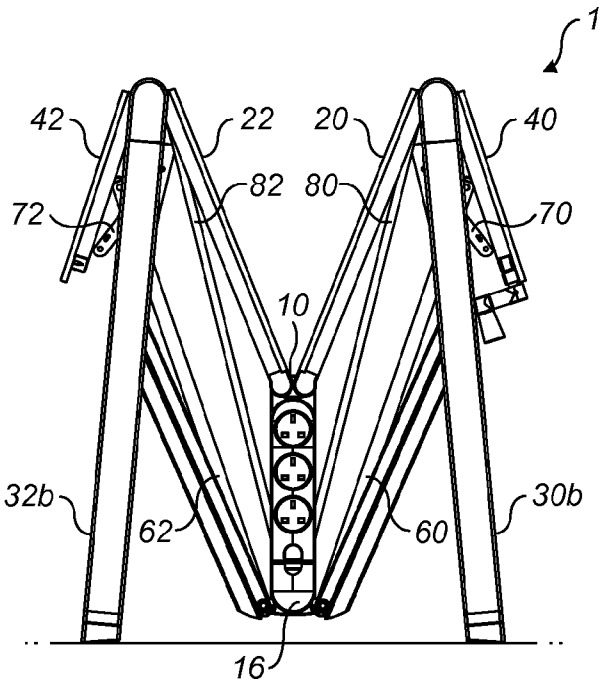
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FIG. 2d

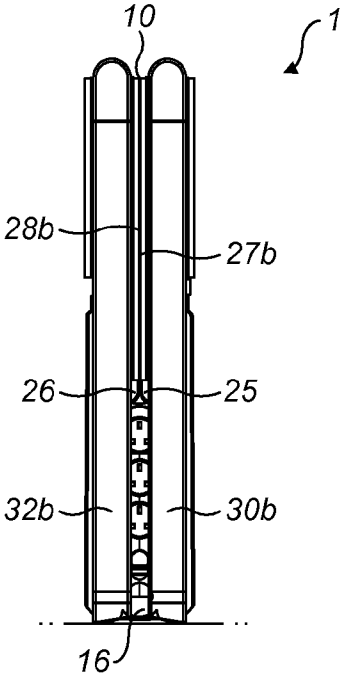
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FIG. 2e

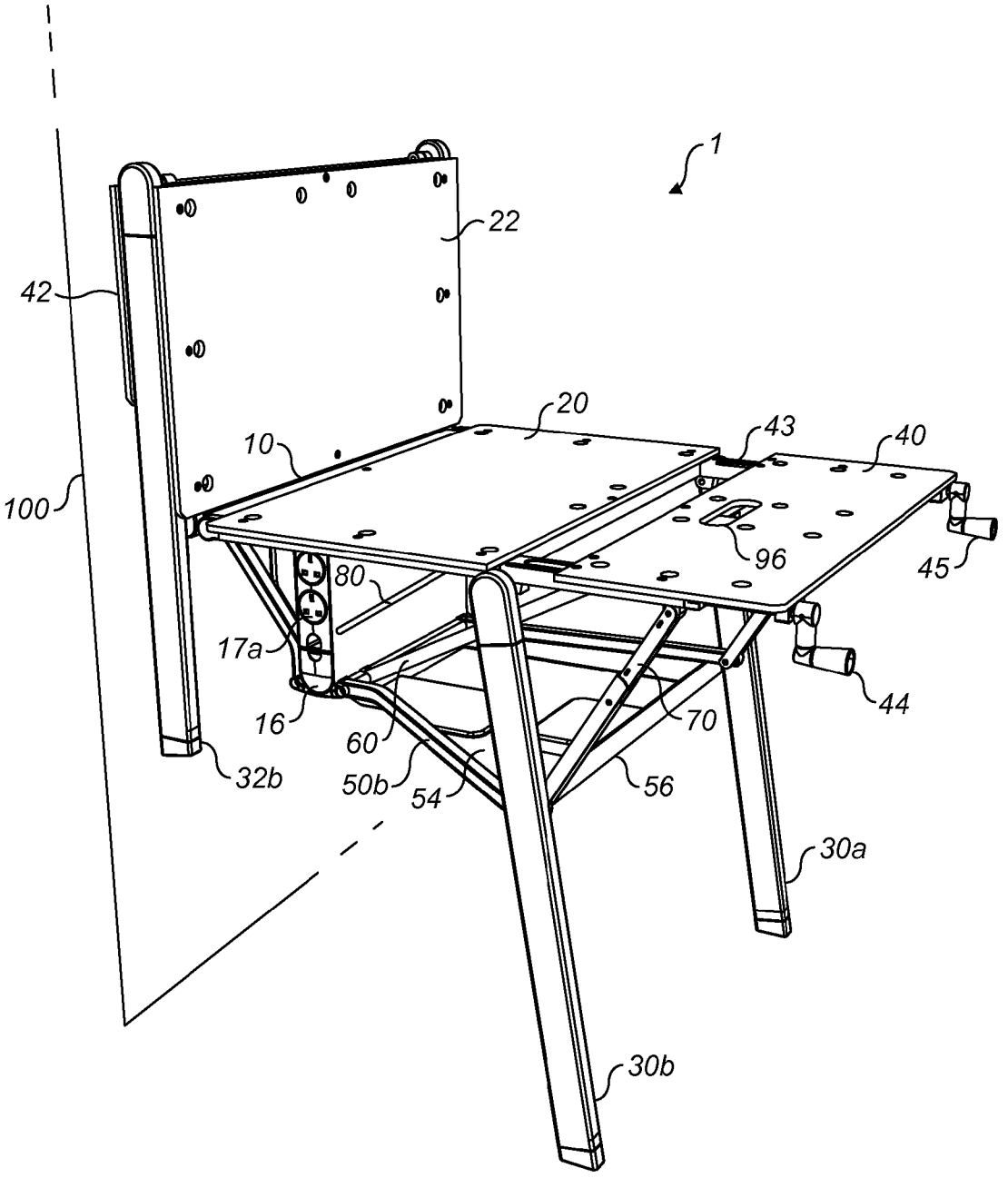

FIG. 3a

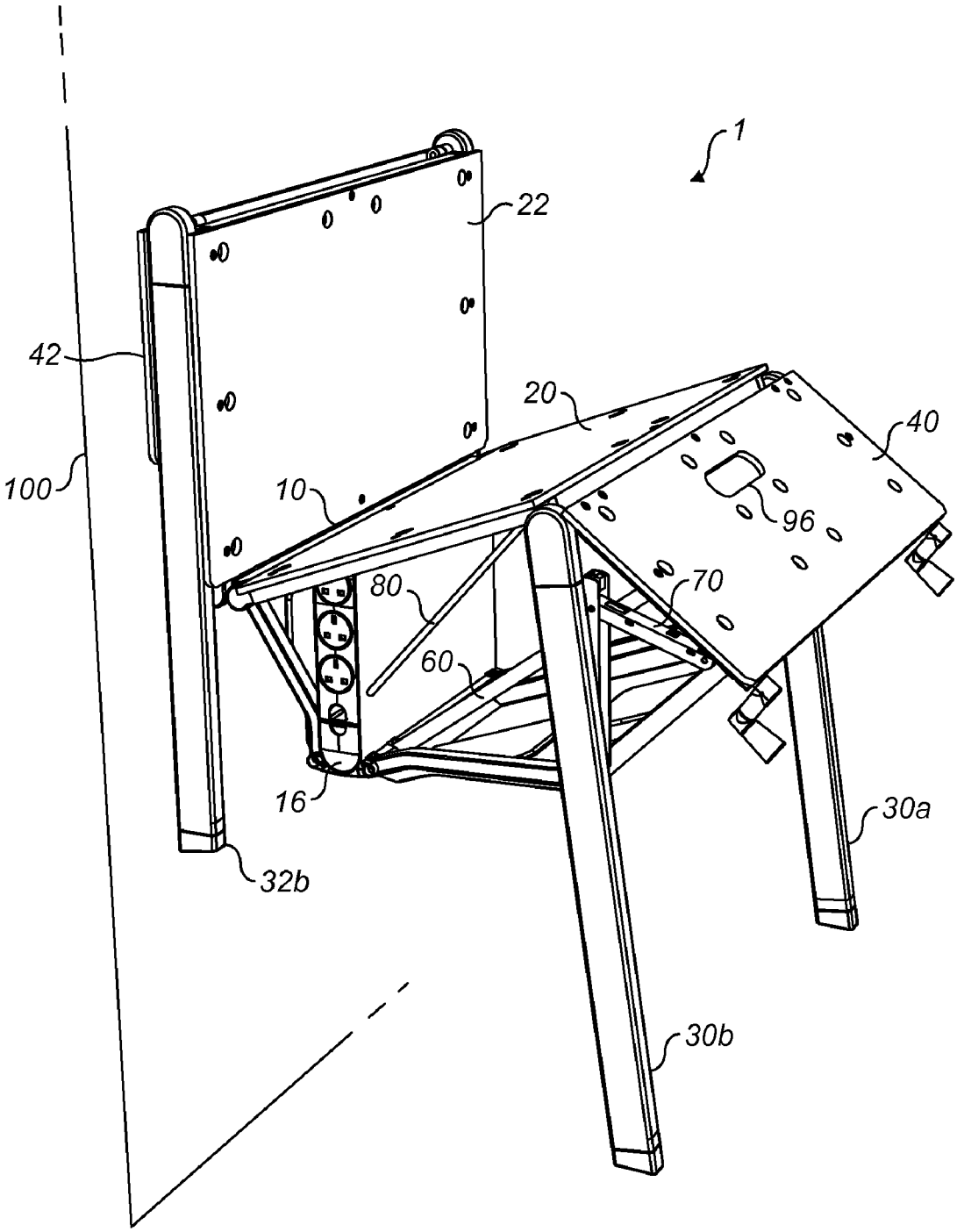

FIG. 3b

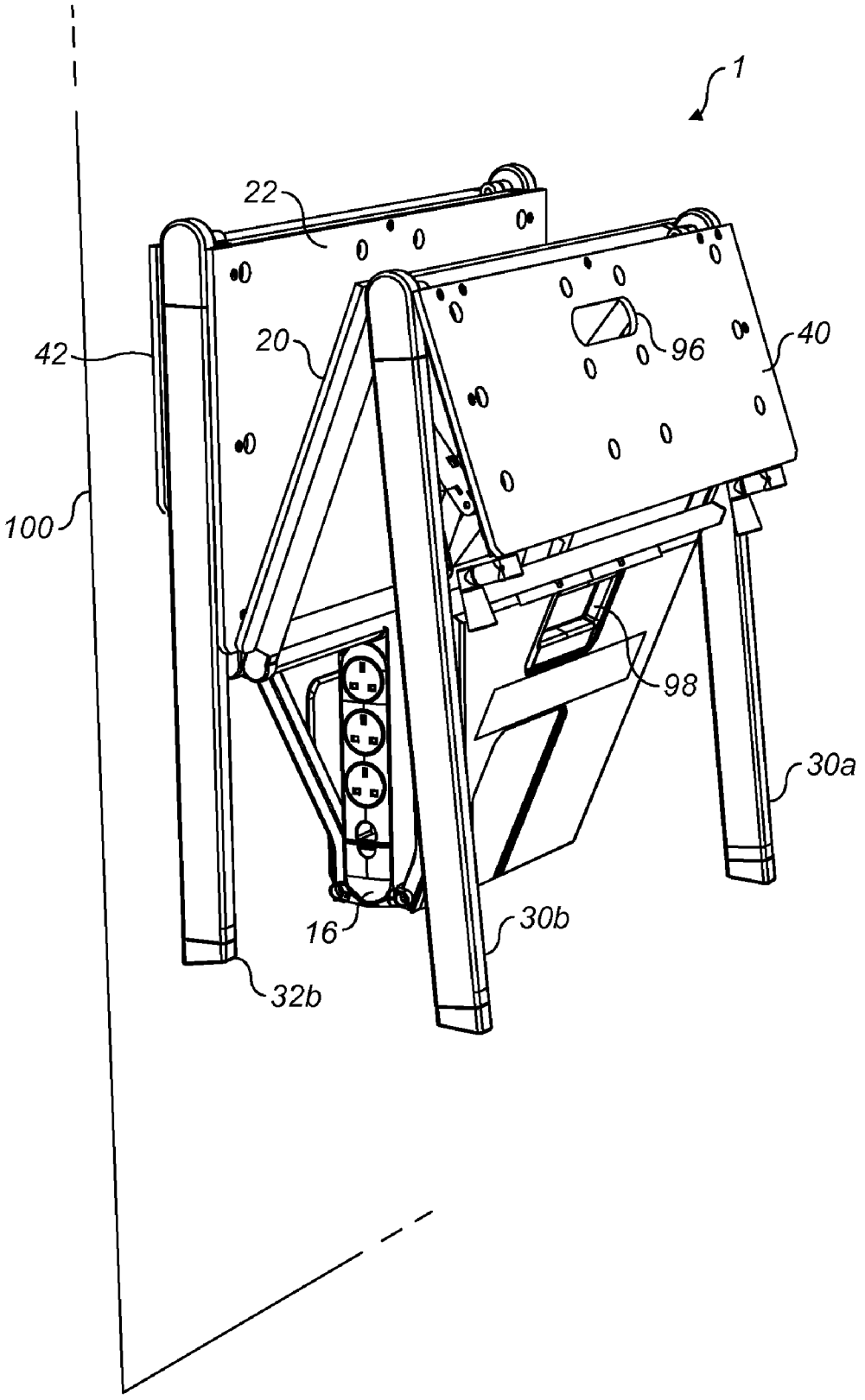

FIG. 3c

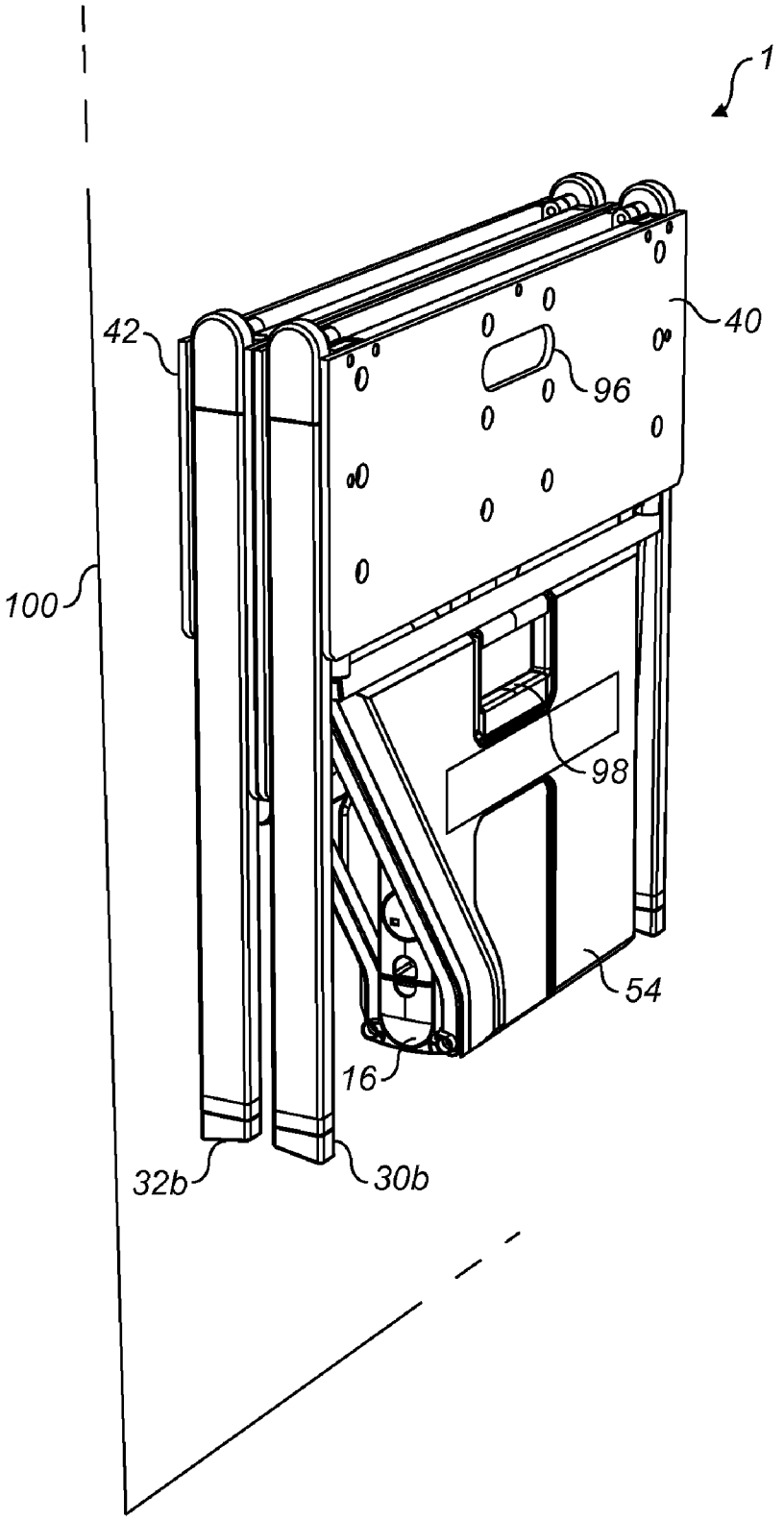

FIG. 3d

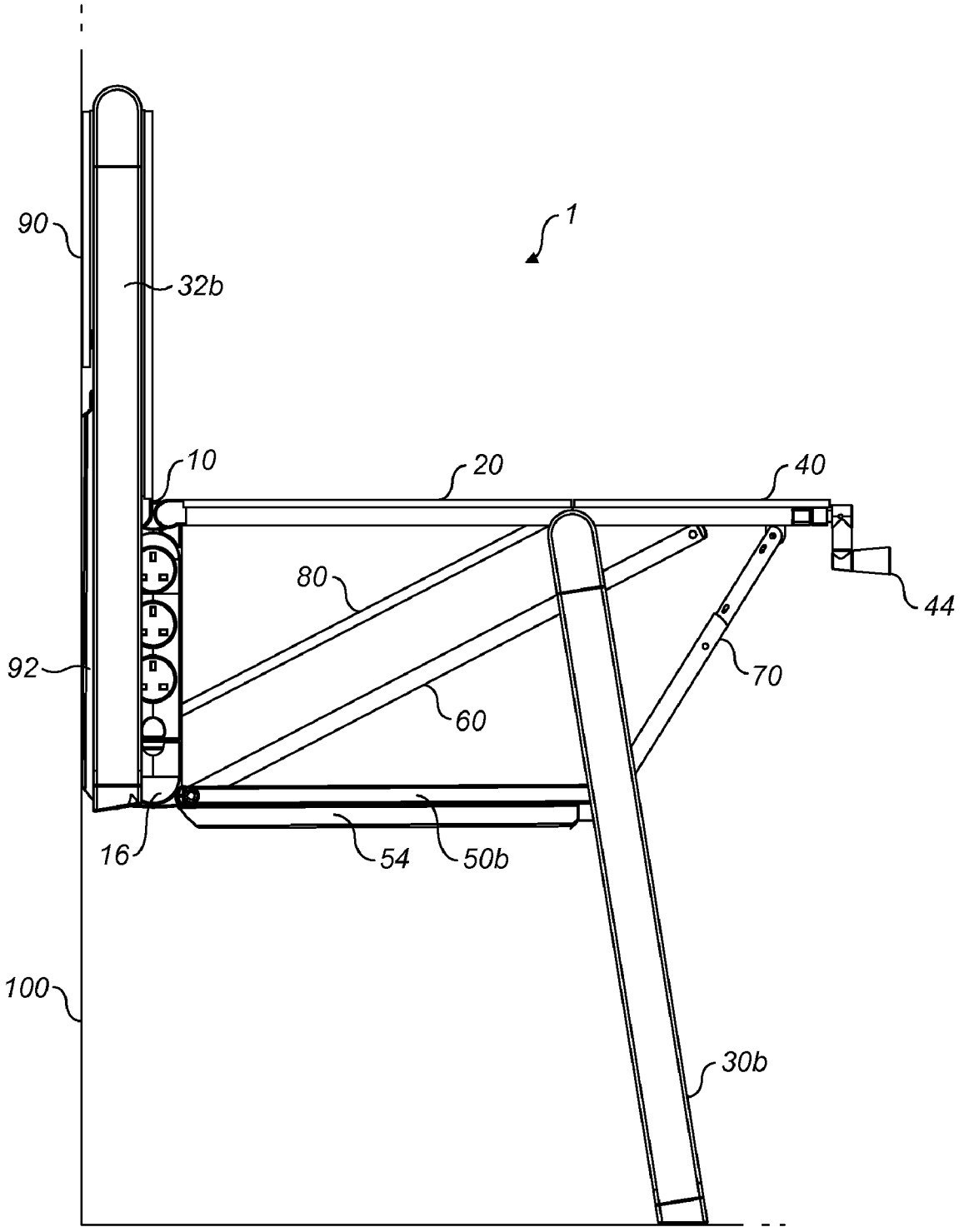

FIG. 4

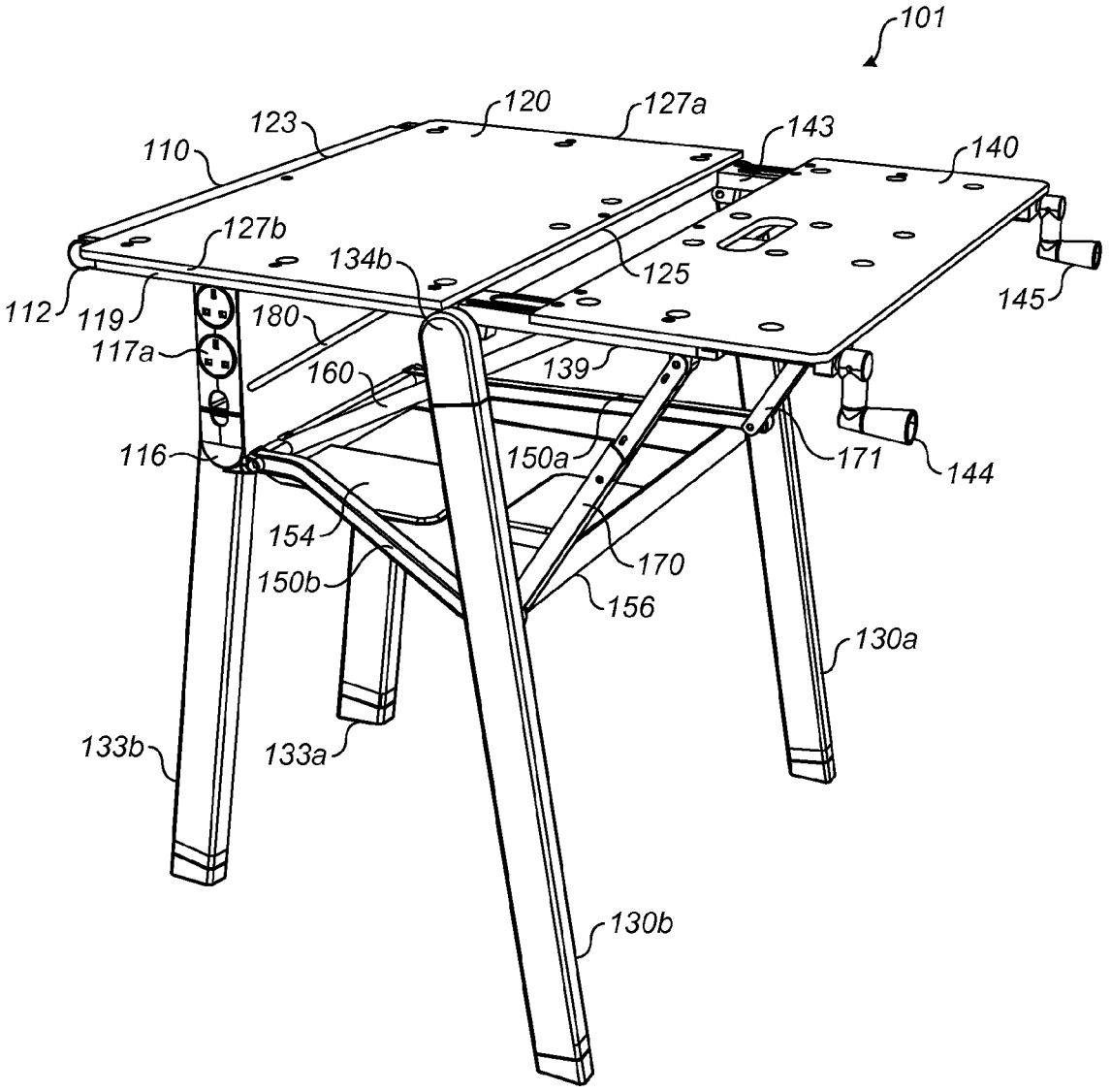
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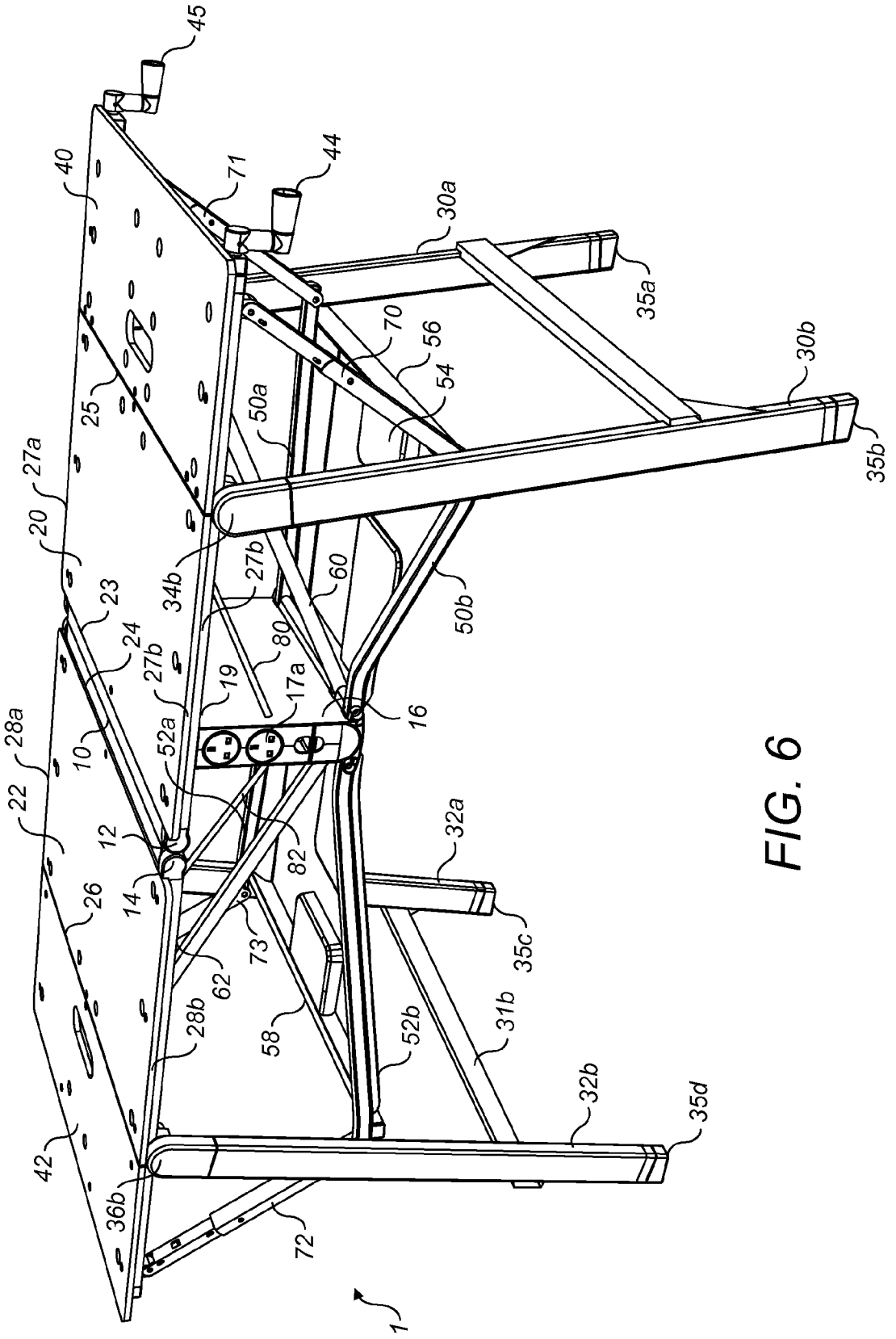
FIG. 5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32a
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FIG. 6

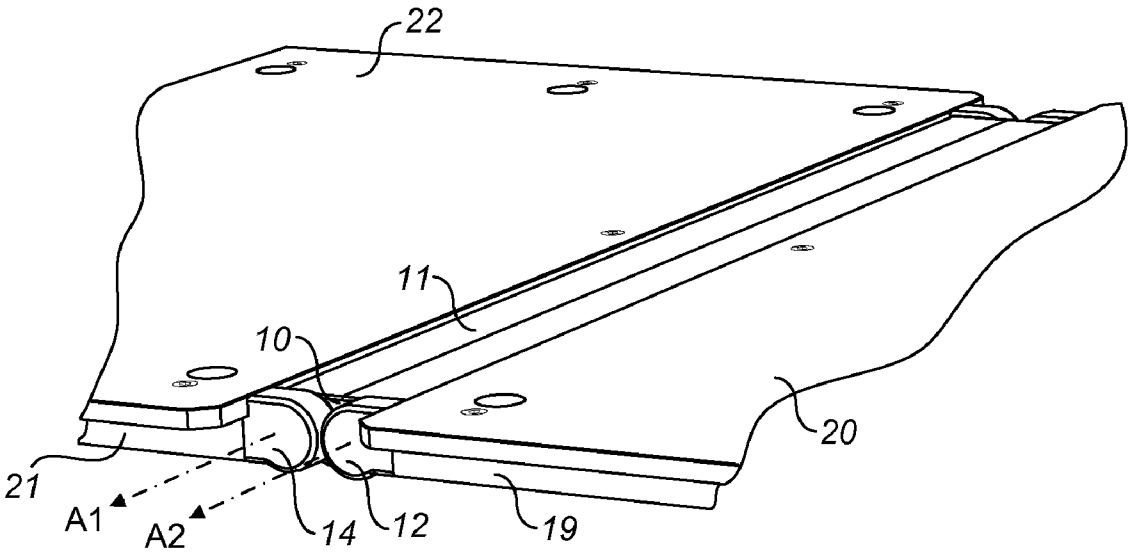

FIG. 7a

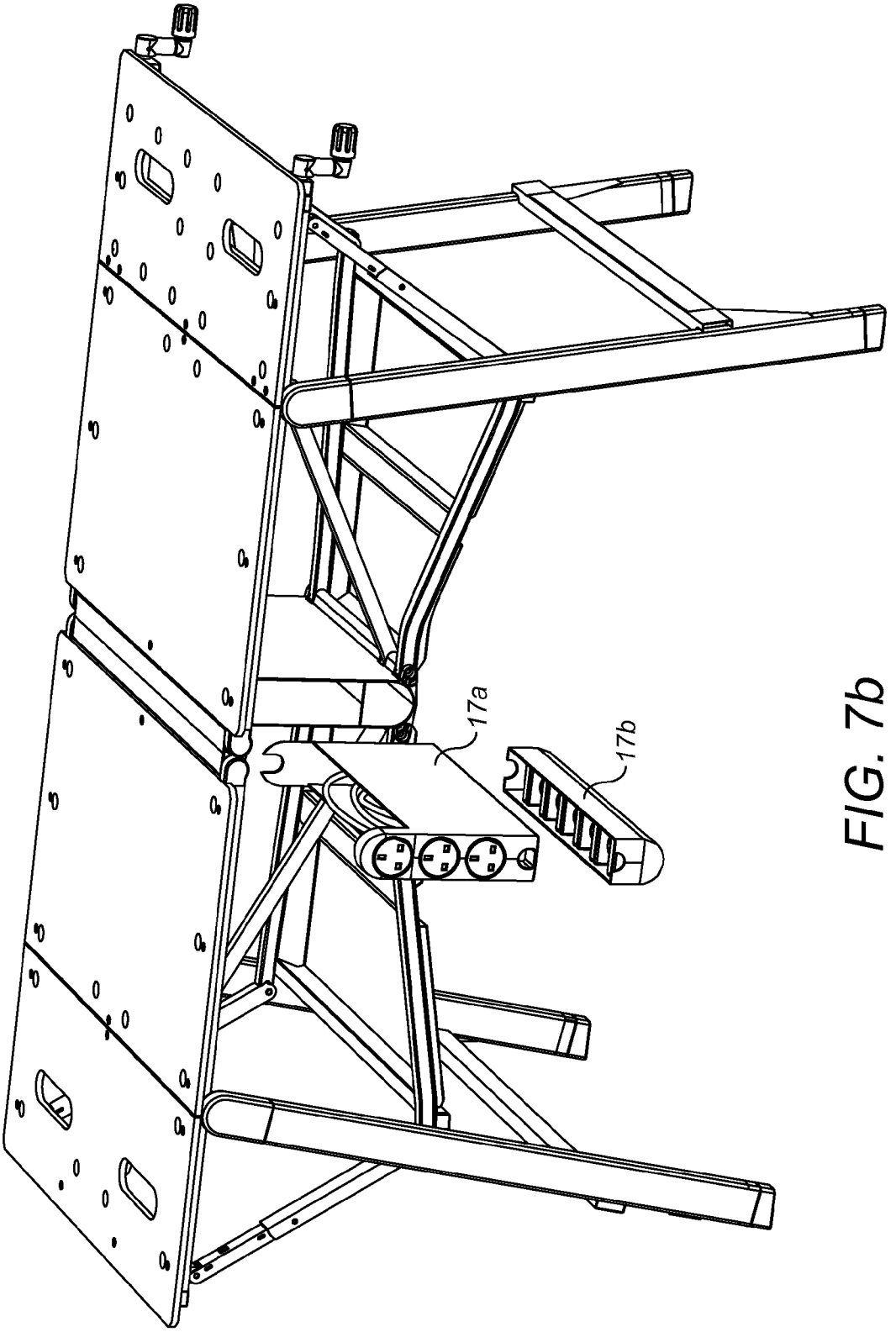

FIG. 7b

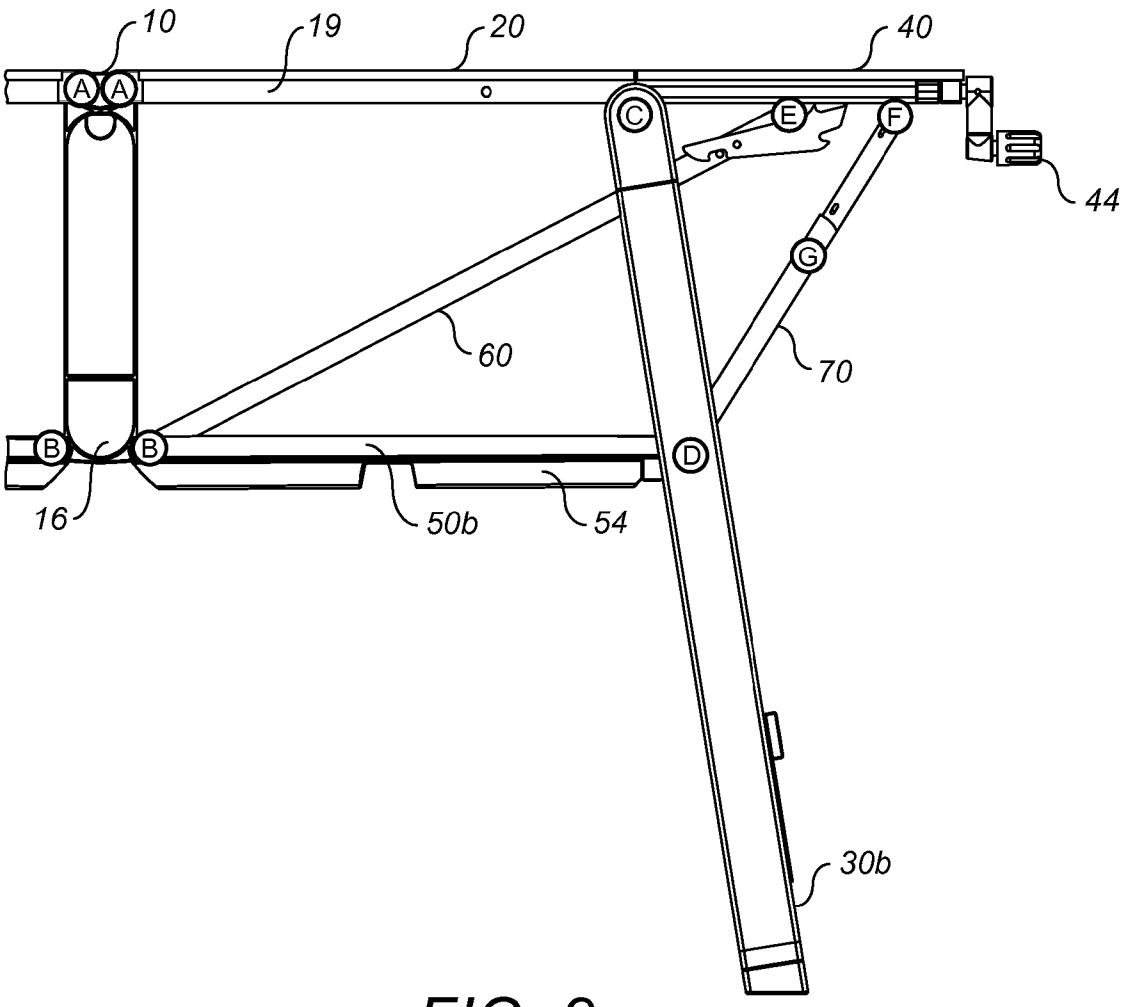

FIG. 8a

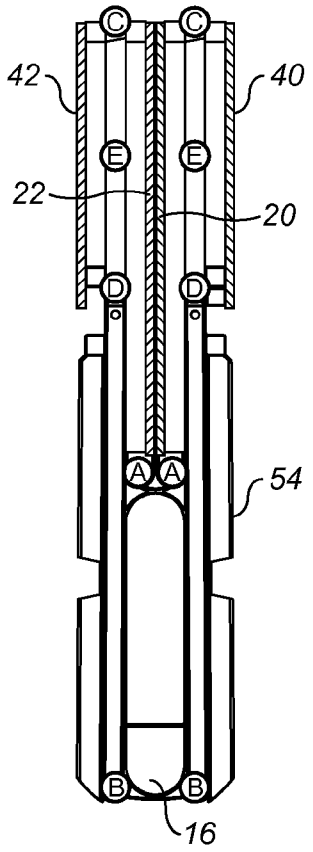
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FIG. 8b

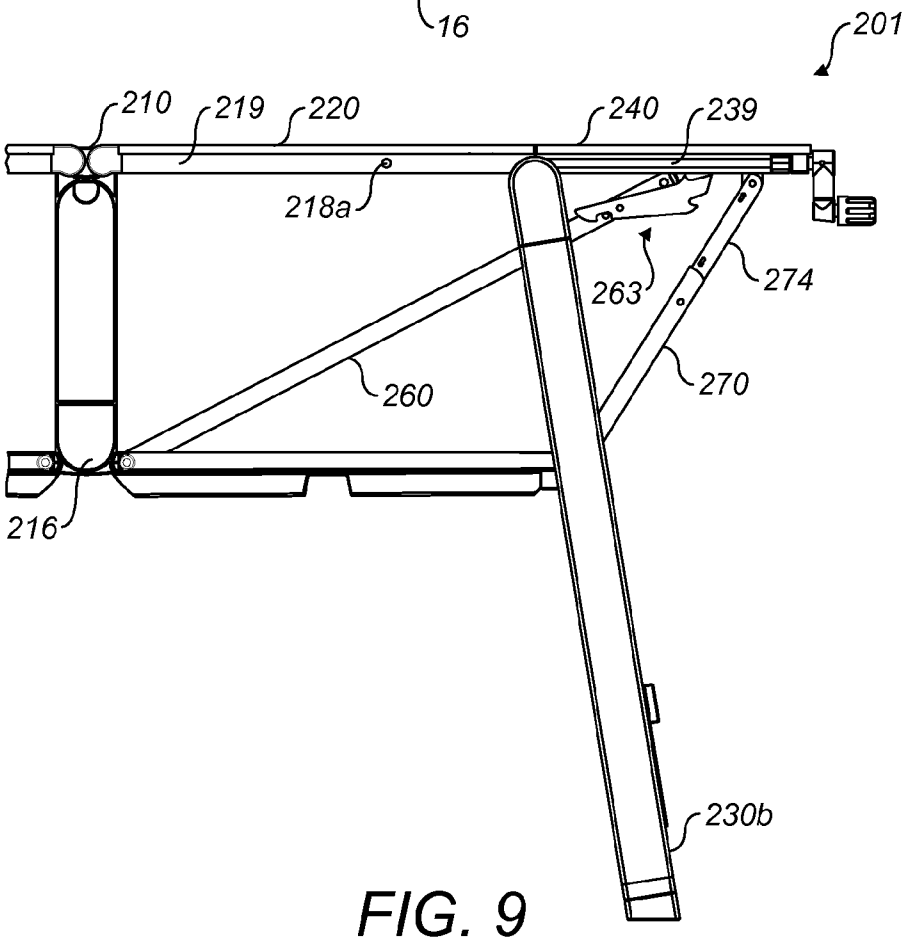
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FIG. 9

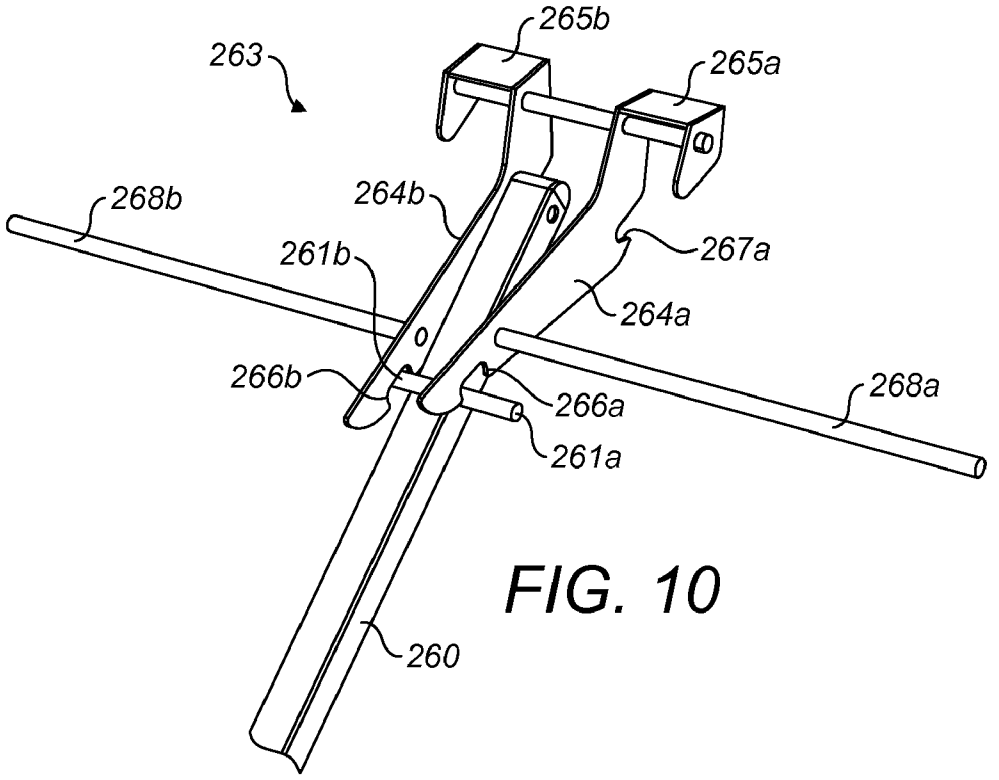

FIG. 10

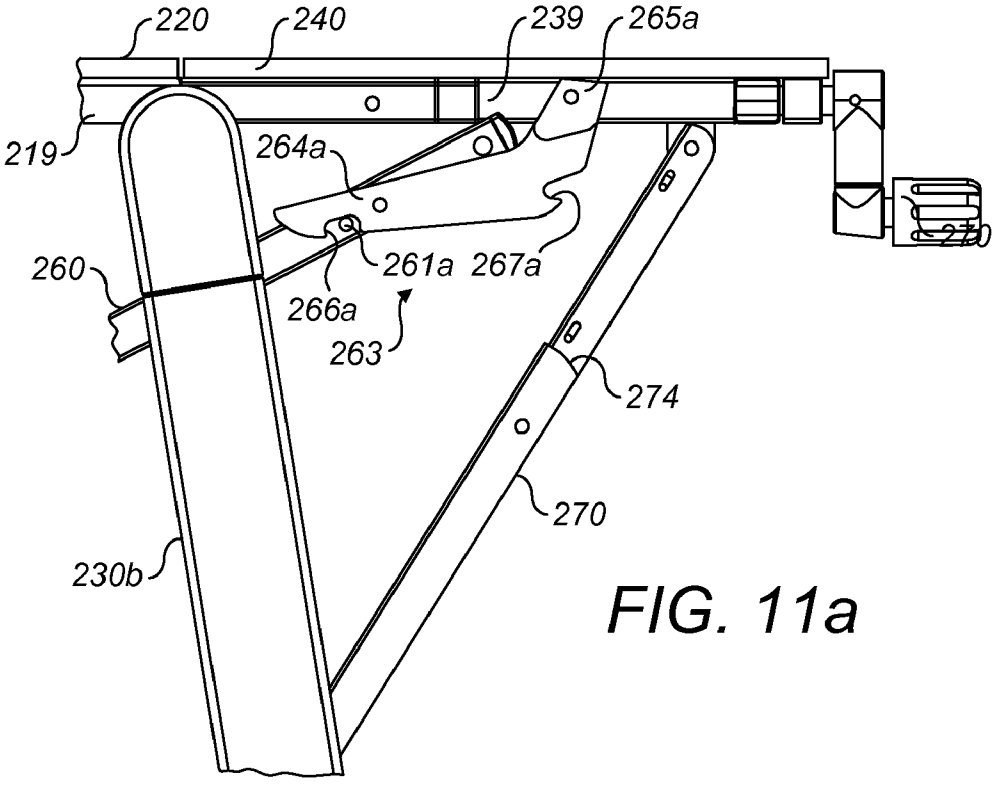

FIG. 11a

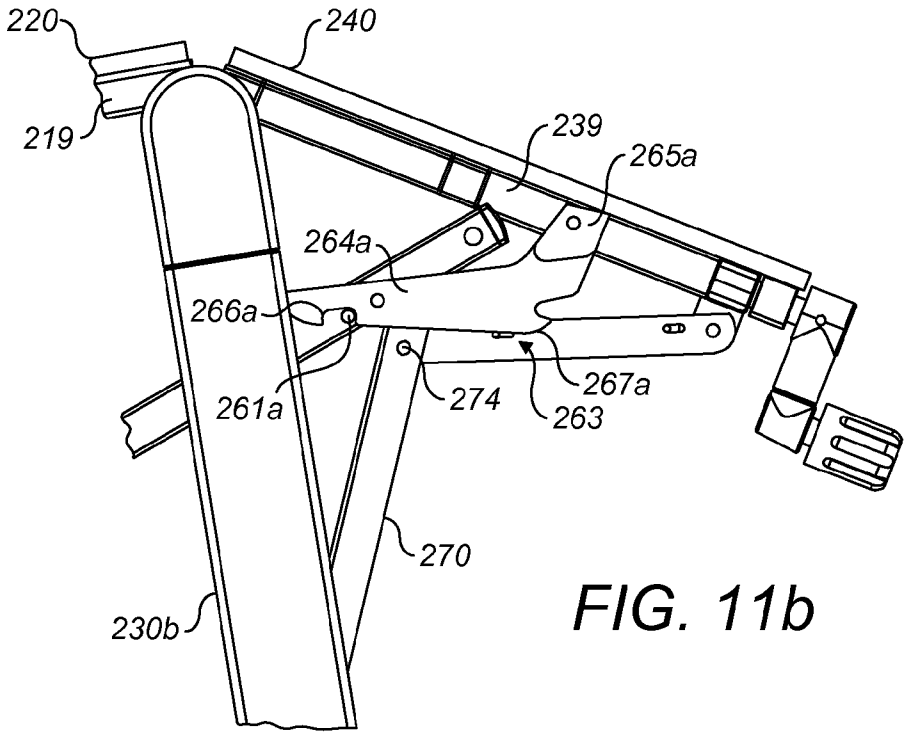

FIG. 11b

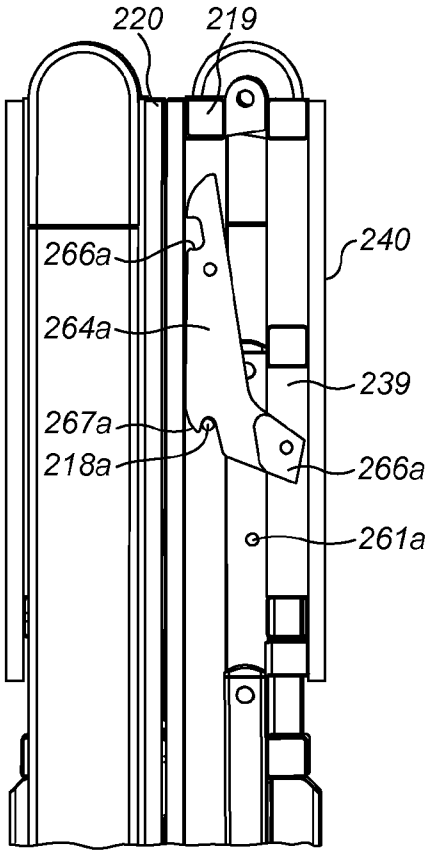

FIG. 11c

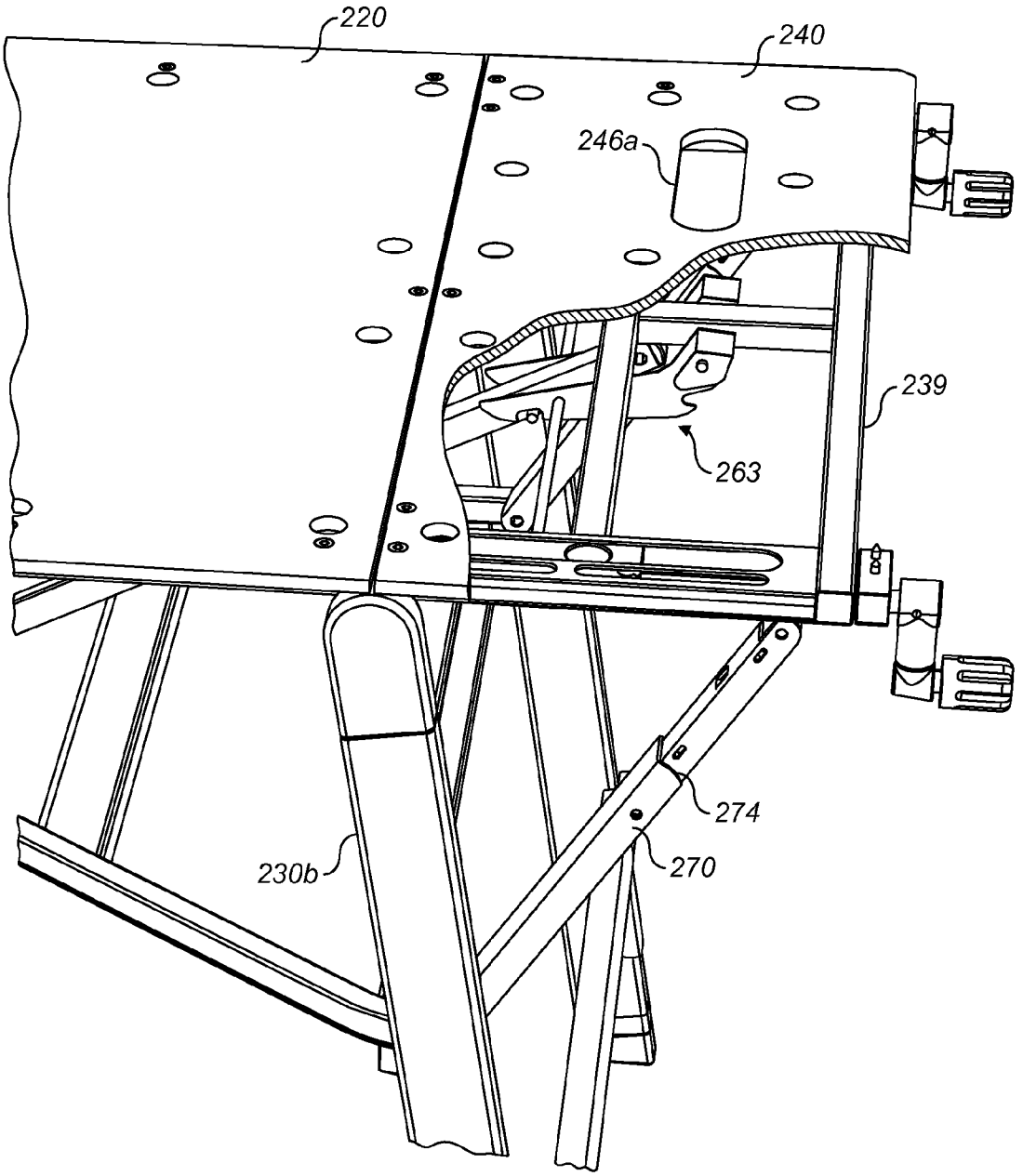

FIG. 12a

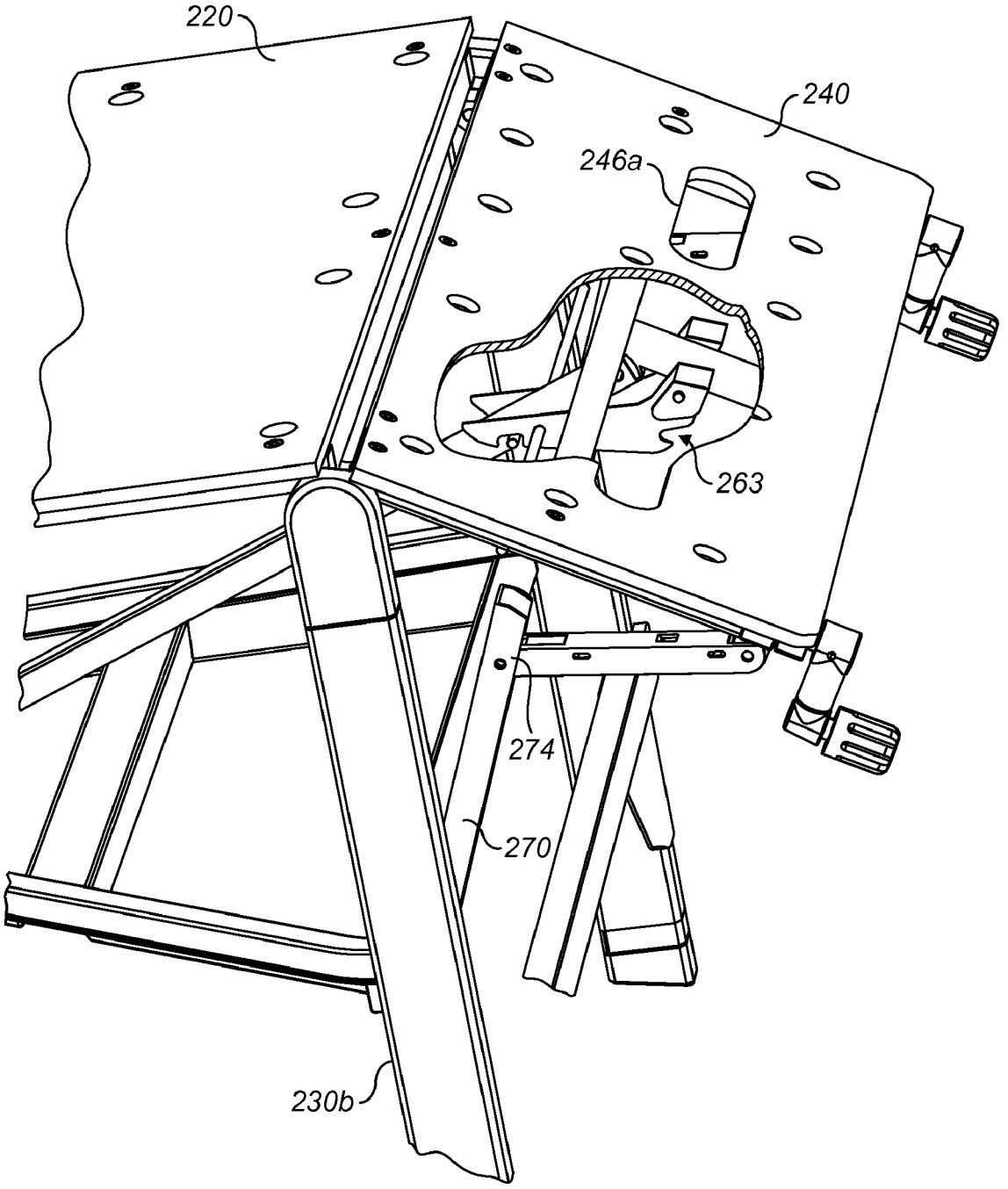

FIG. 12b

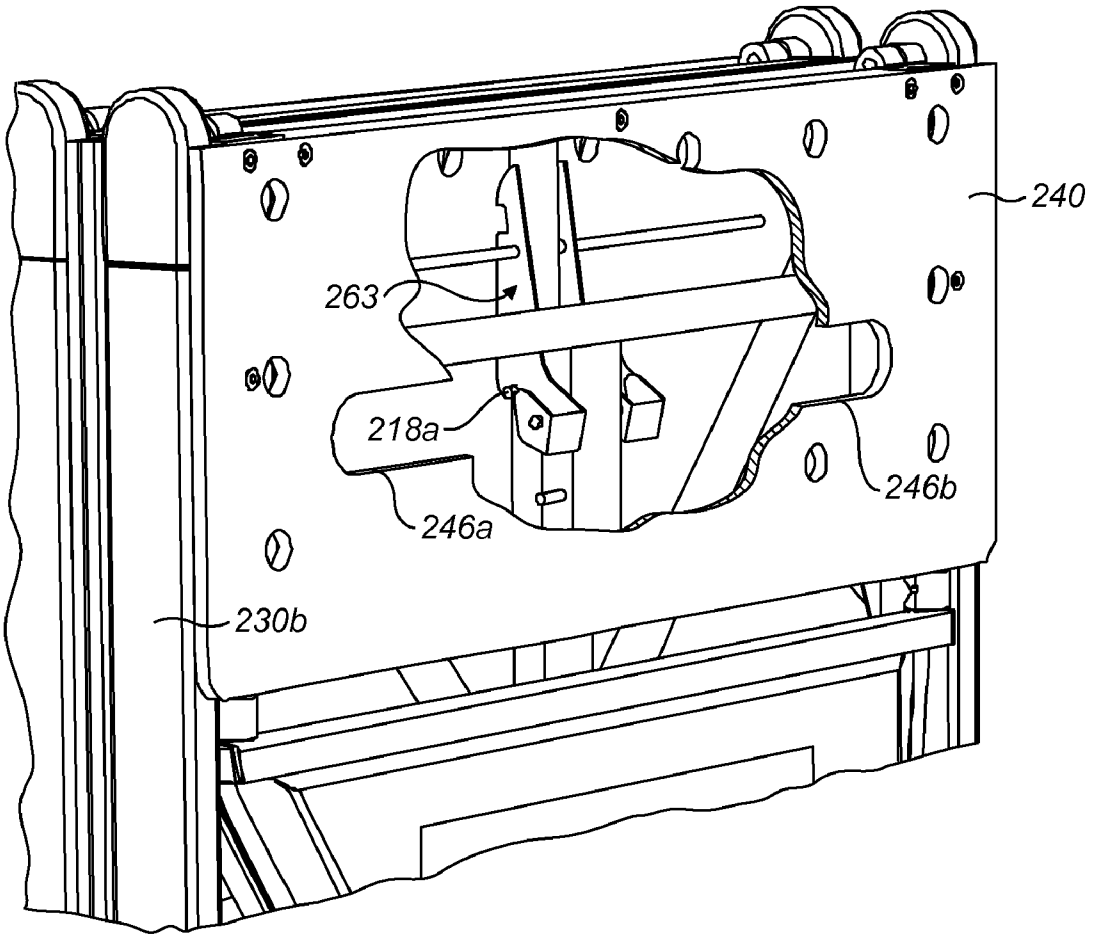

FIG. 12c

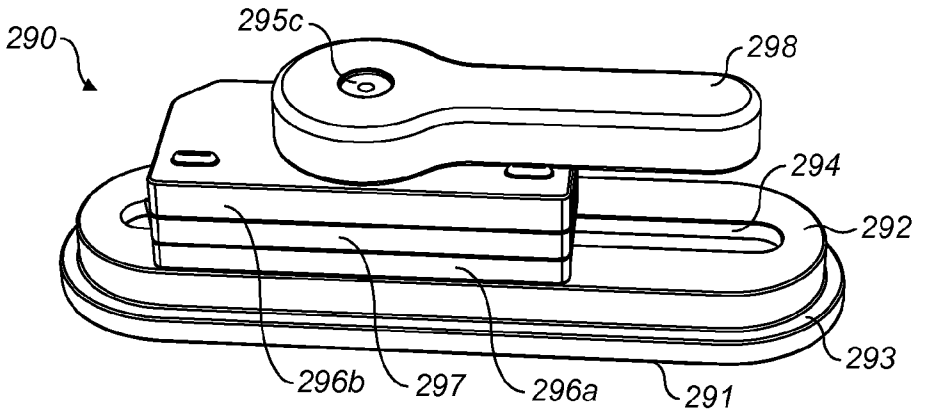

FIG. 13

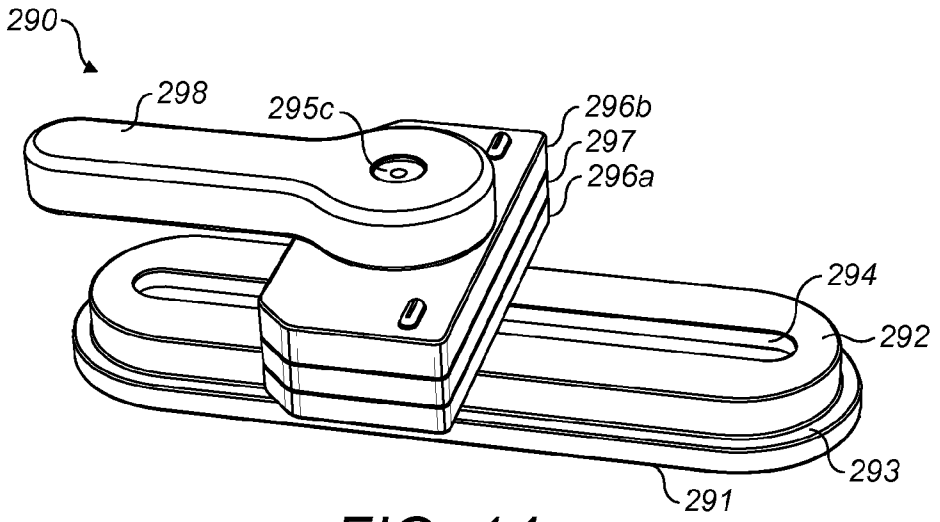

FIG. 14a

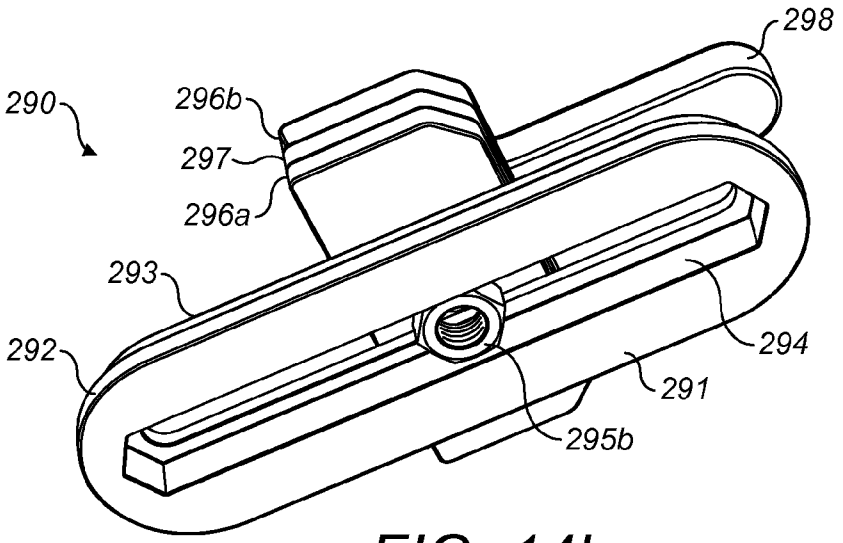

FIG. 14b

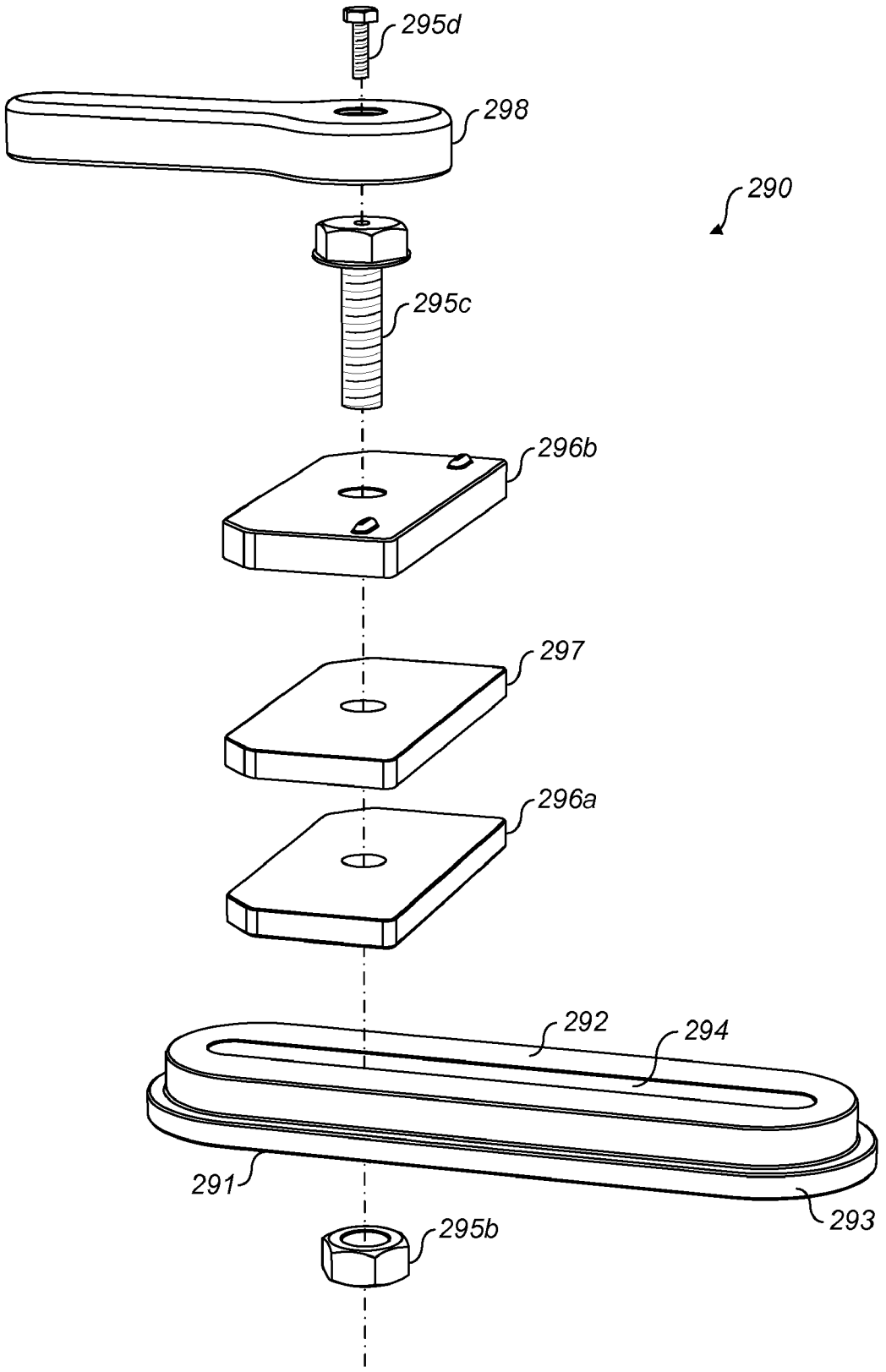

FIG. 15

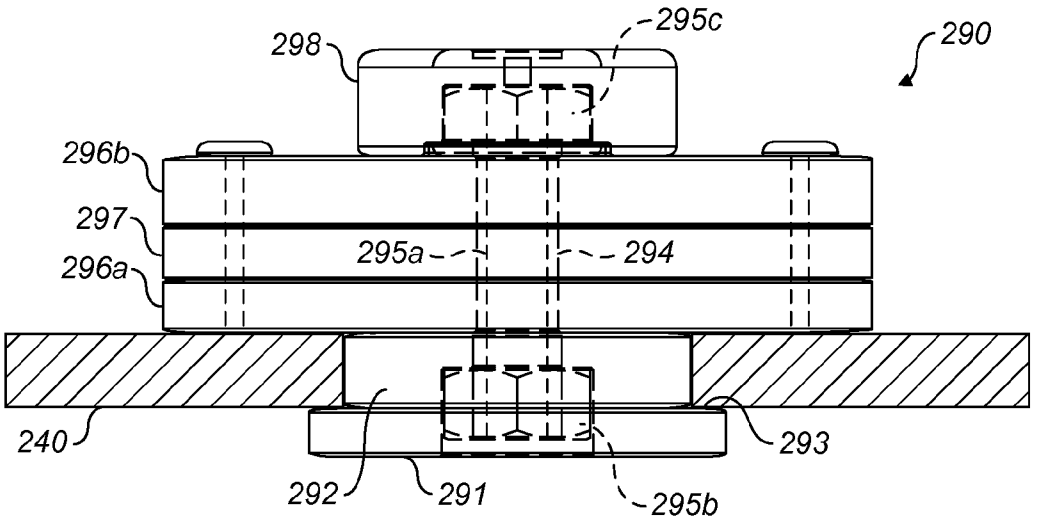

FIG. 16

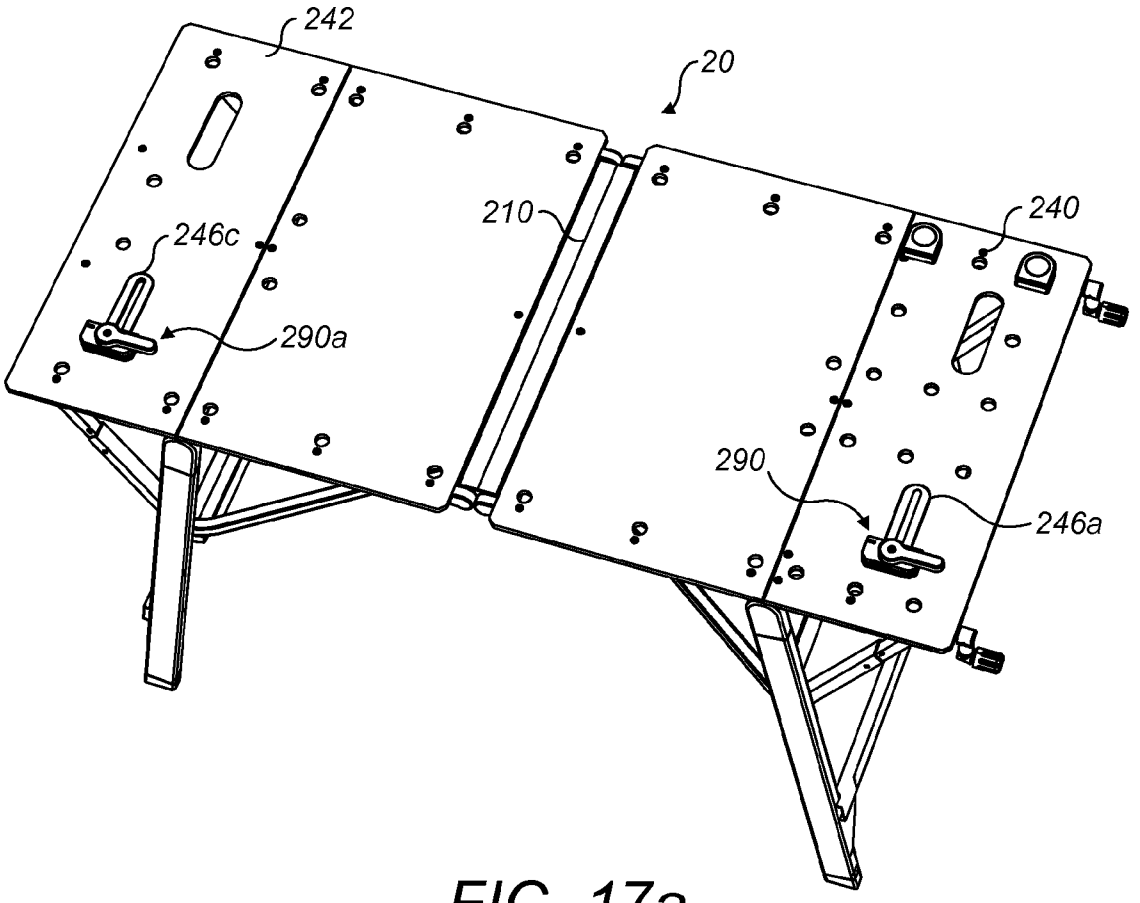

FIG. 17a

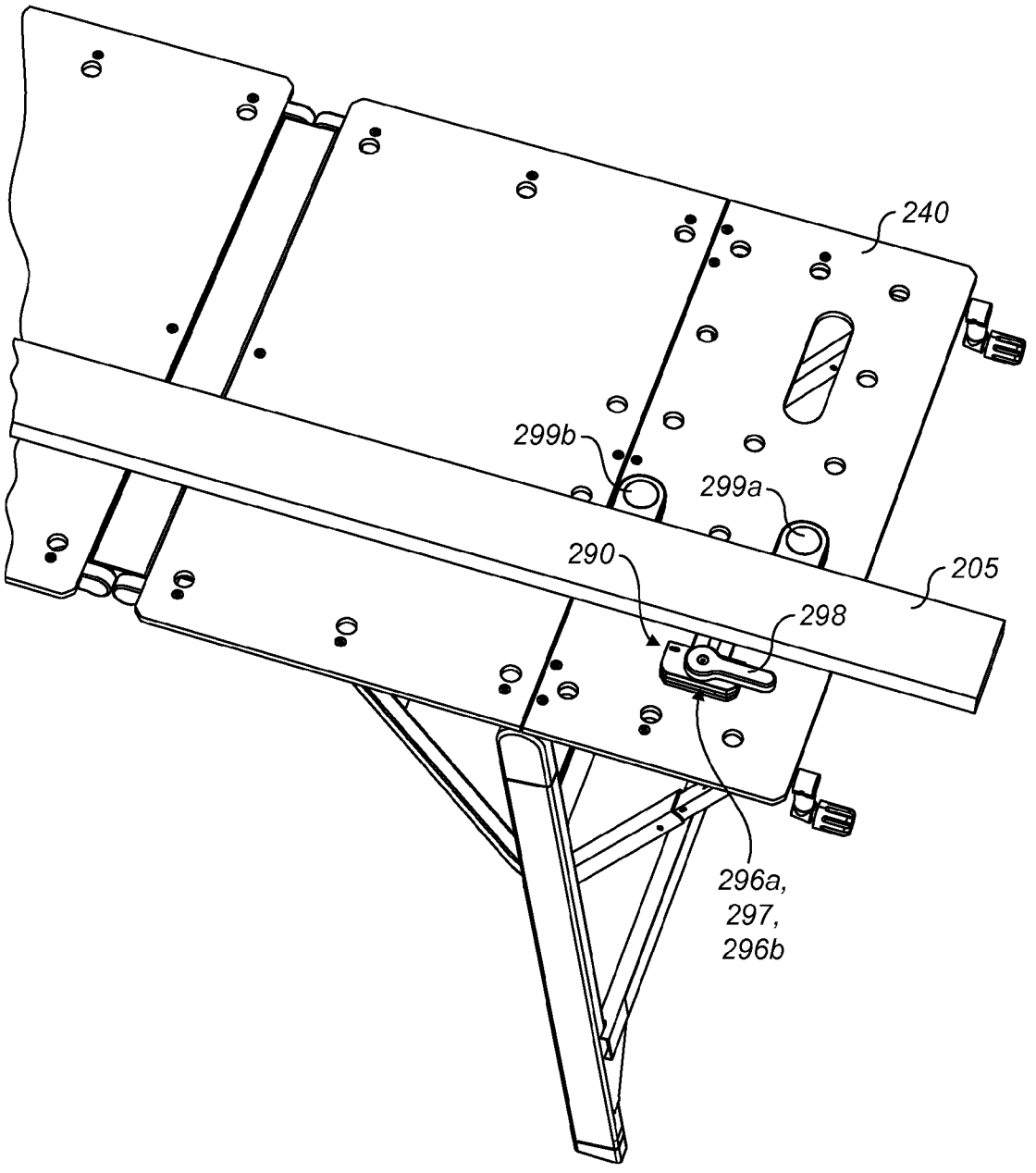

FIG. 17b

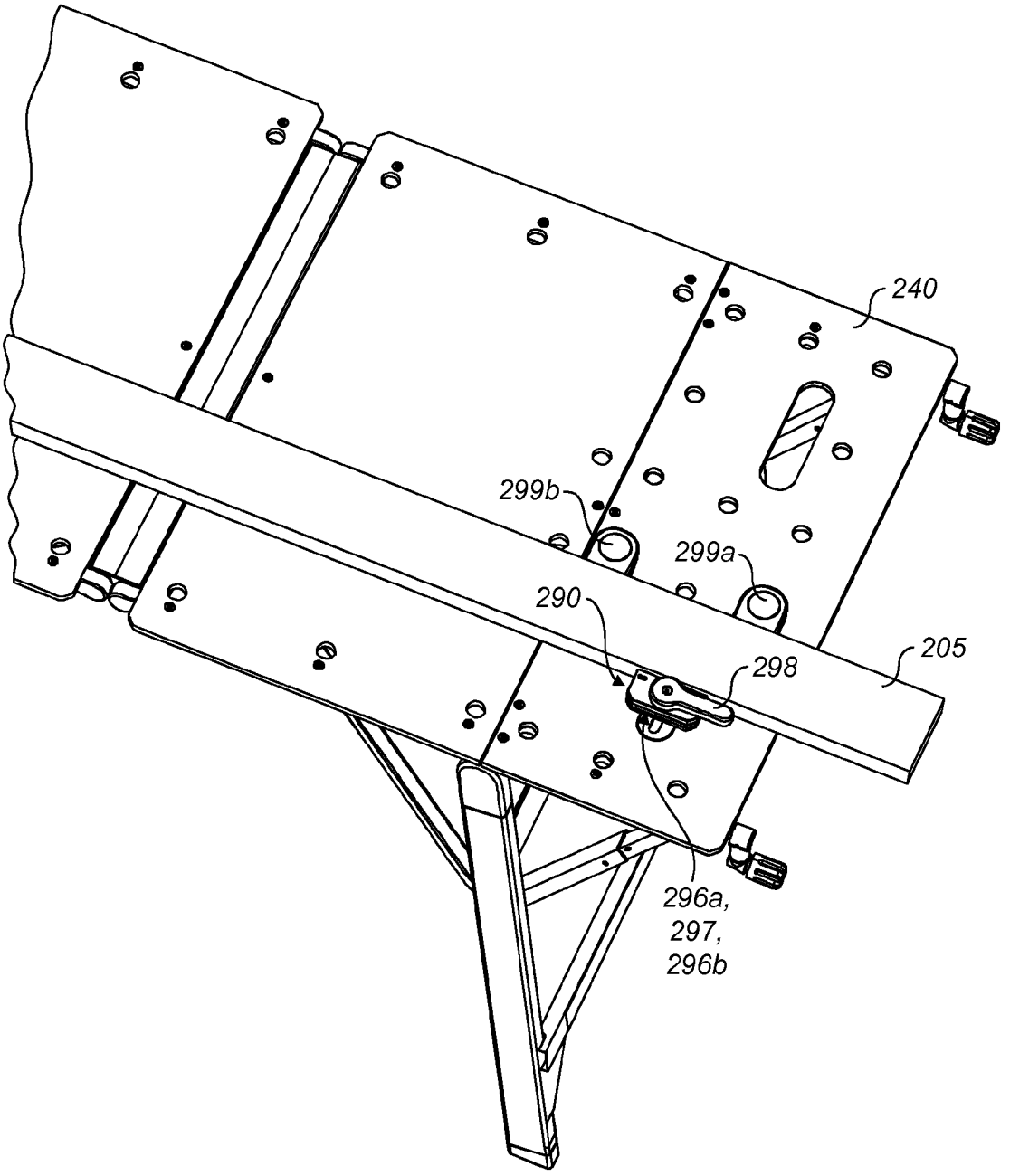

FIG. 17c

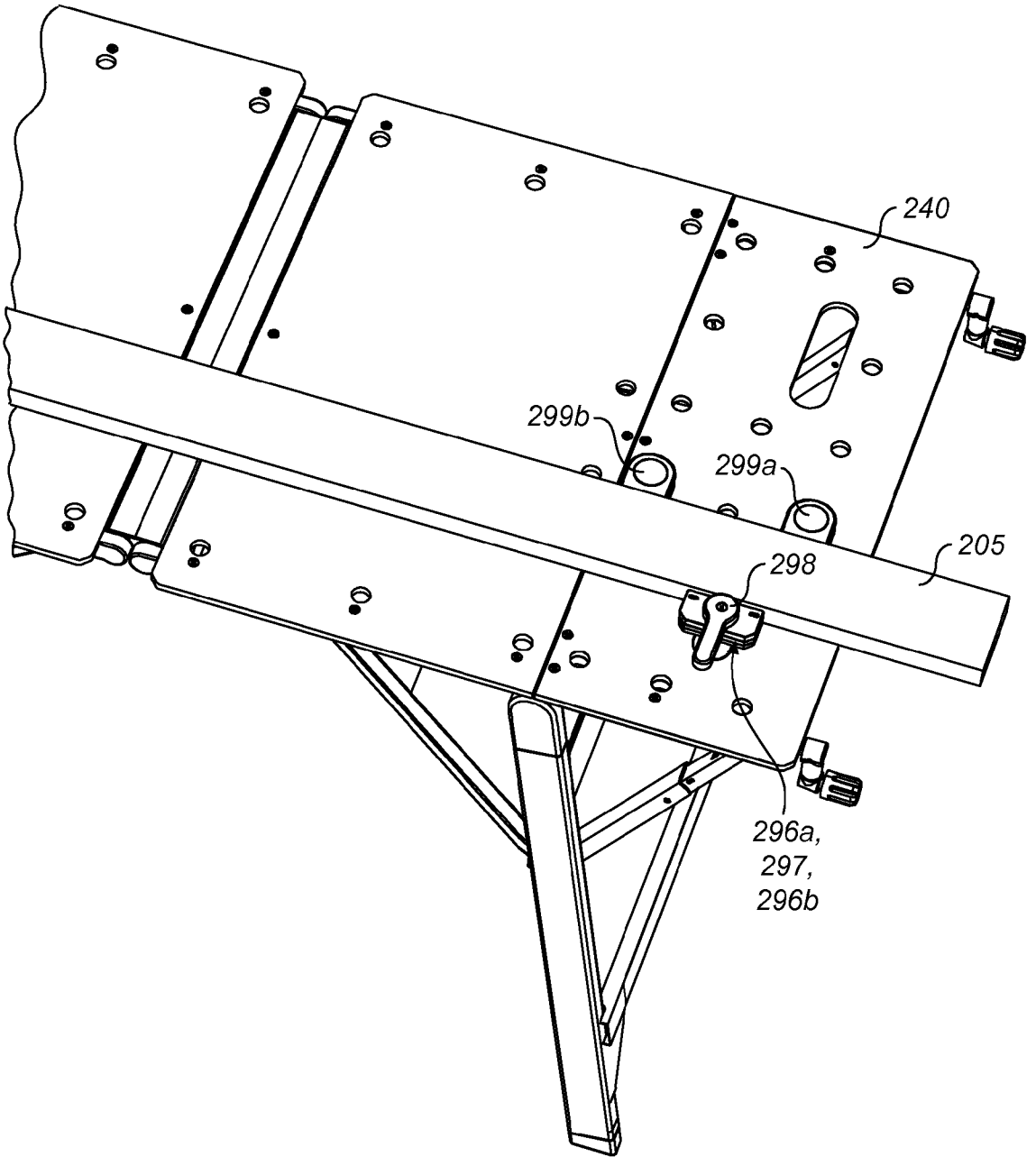

FIG. 17d

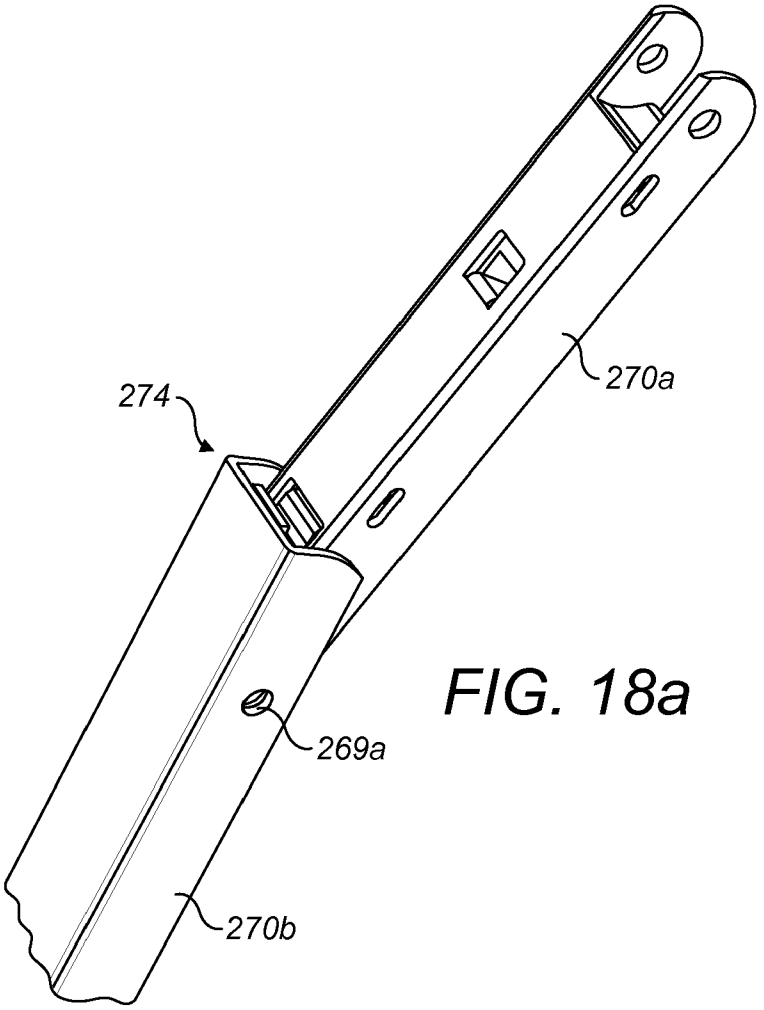

FIG. 18a

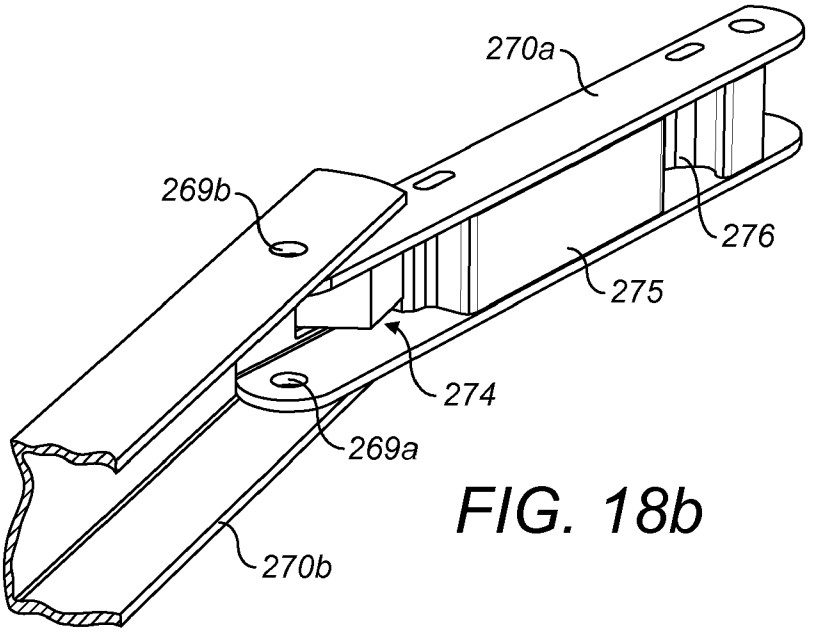

FIG. 18b

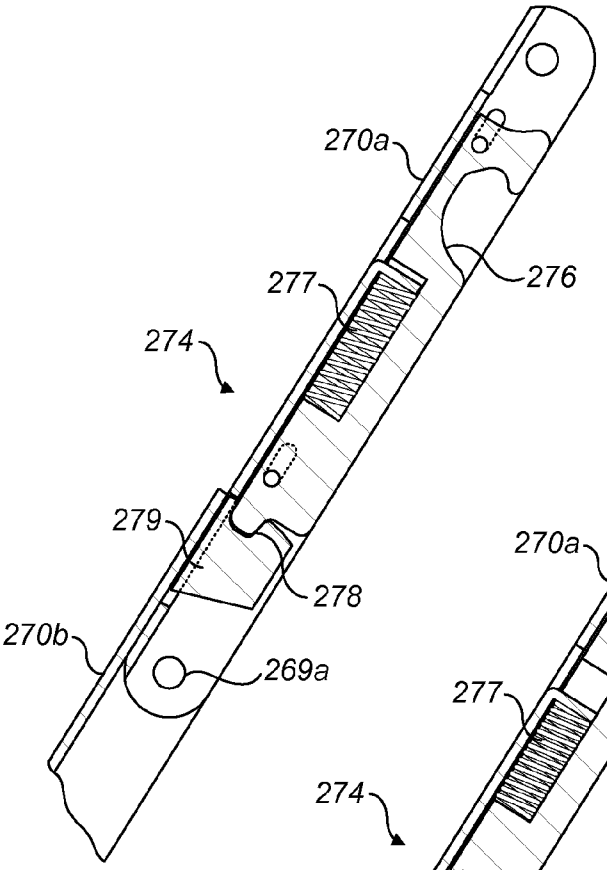

FIG. 19a

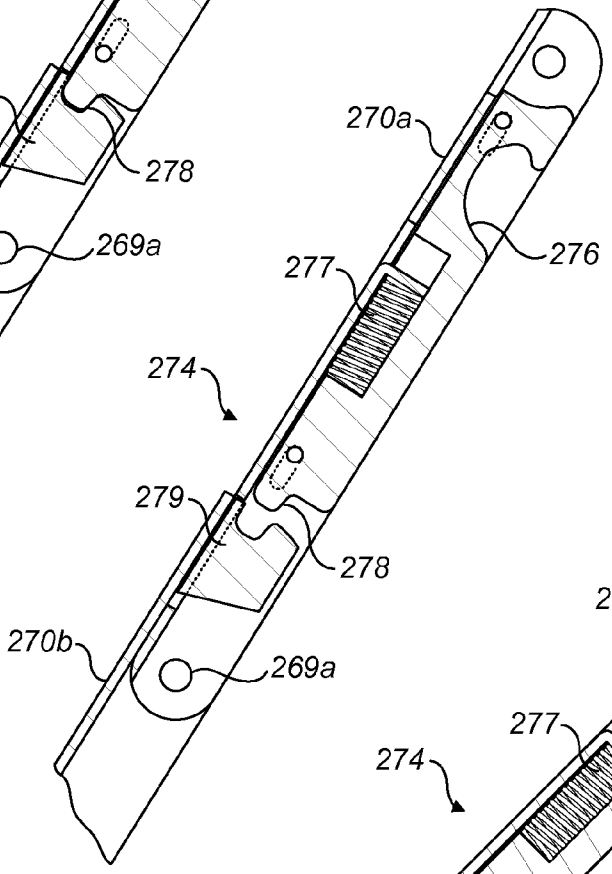

FIG. 19b

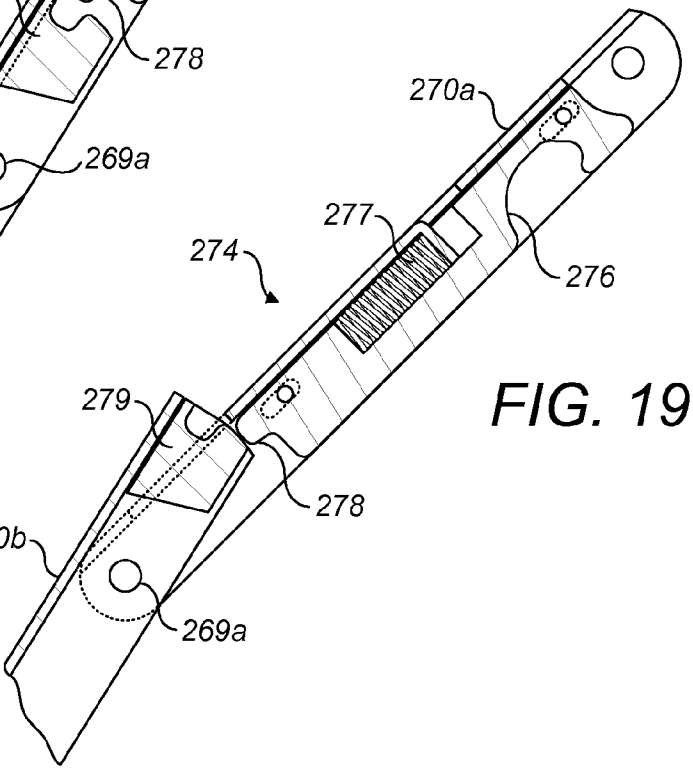

FIG. 19c

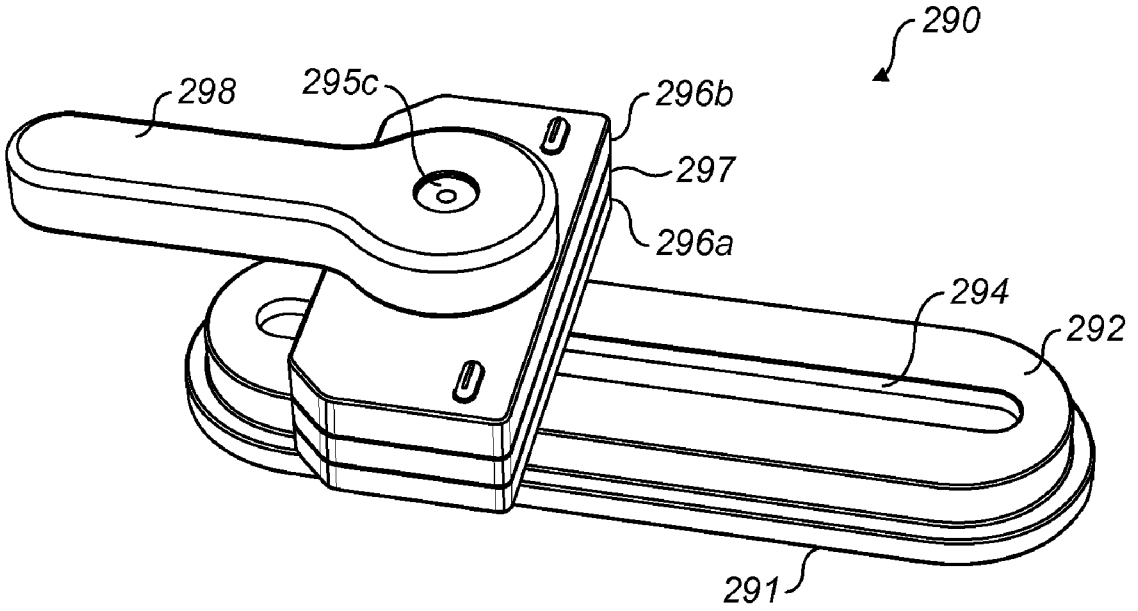

FIG. 20

FRAME ASSEMBLY FOR A FOLDING WORKBENCH

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This patent application claims priority to International Application Number PCT/EP2006/069398 filed on Dec. 6, 2006 which claims priority to GB Patent Application No. 0525053.6 filed on Dec. 8, 2005, and to GB Patent Application No. 0604173.5 filed on Mar. 2, 2006, the contents and teachings of which are hereby incorporated by reference in their entirety.

FIELD

[0002] The present invention relates to a folding workbench and frame assembly therefor, which is readily and reversibly foldable from an 'in-use' configuration to a compact 'folded' configuration.

BACKGROUND

[0003] When performing woodworking, metalworking or other 'do it yourself' tasks it is common to make use of a workbench that provides a relatively large, but also sturdy work surface. Since such workbenches are typically not required for daily use it is desirable for them to be stowable in disassembled or folded-up form. It is also desirable that the stowed form is as compact as possible and that the time and effort required to translate the workbench from its stowed to in-use position be minimized.

SUMMARY

[0004] The Applicant has now devised a folding workbench that is stowable in highly compact form yet readily and safely unfolds with the minimum of time and effort to provide a relatively large and sturdy work surface. This workbench further allows for the accommodation of useful additional features such as a storage tray, housing for electrical equipment and integral vice feature(s).

[0005] The Applicant's workbench employs a central spine to which first and second primary work surface frames hingedly mount such that the primary work surface frames hingedly mounts to the central spine by a distinct hinge mounting with each hinge mounting typically spaced horizontally from the other. In the folded configuration, the outer edges of the respective first and second primary work surface frames rest parallel with each other and each of the legs of the workbench rests parallel with a side edge thereof.

[0006] An additional feature of the Applicant's workbench is that it may be used in an asymmetrical mode of operation in which half of the workbench is mounted to a wall and the other half extends from the wall. Thus, additional flexibility of use is provided, which makes the workbench particularly amenable to usage in conditions of restricted space.

[0007] It is an object of the present invention to provide a workbench that provides a relatively large work surface but that is also conveniently and safely stowable in highly compact form.

[0008] According to one aspect of the present invention there is provided a frame assembly for a workbench that is reversibly foldable from an in-use to a folded configuration comprising:

[0009] a central spine;

[0010] first and second primary work surface frames, each work surface frame having an inner edge, an outer edge and two side edges, wherein each said inner edge thereof hingedly mounts to the central spine such that the primary work surface frames are foldable towards each other; and

[0011] first and second opposing pairs of legs, each leg pivotally mounting to one end of an outer edge of the first and second primary work surface frames, such that the legs of each opposing pair are foldable towards each other,

[0012] wherein the inner edge of each of the first and second primary work surface frames hingedly mounts to the central spine by a distinct hinge mounting such that in the folded configuration, opposing side edges of the respective first and second primary work surface frames are brought parallel with each other and each of the legs is brought parallel with a side edge thereof.

[0013] The present invention relates to a frame assembly for a workbench that is readily and reversibly foldable from an in-use to a folded configuration. The frame assembly is desirably supplemented with one or more bench and/or utility features such as to provide the full workbench.

[0014] The frame assembly comprises a central spine. The central spine is suitably rigid and locates about the central folding axis of the frame assembly. In embodiments, the central spine has an elongate rectangular (e.g. box form), elongate open rectangular (e.g. open box form) or elongate cylindrical (e.g. tubular) form. For compactness of folding, the distinct hinge mountings preferably locate inboard of the central spine (e.g. within the space defined by planes defined by the lateral extent of the central spine). Suitably, the central spine defines a rectangular top surface (e.g. a plate), which in the in-use configuration preferably defines a central part of the work surface of the workbench.

[0015] The frame assembly further comprises first and second primary work surface frames suitable for receipt and/or definition of first and second primary work surfaces. In one aspect, the first and second primary work surfaces are separately provided to their primary work surface frames, to which they are secured by suitable securing means (e.g. screw mounting, bracket fixing or slide/track mounting). In another aspect, the first and second primary work surface frames actually define the first and second primary work surfaces (i.e. integral frame structure).

[0016] Each work surface frame suitably has an inner edge, an outer edge and two side edges. Typically, the dimensions of the first and second work surfaces frames and edges thereof are selected to match each other. Each inner edge of the first and second work surface frames hingedly mounts to the central spine such that the primary work surface frames are foldable towards each other (i.e. as in the folded configuration).

[0017] The frame assembly is provided with at least two (i.e. first and second) opposing pairs of legs. Each leg pivotally mounts to one end (typically, the outer end) of an outer edge of the first and second primary work surface frames such that the legs of each opposing pair are foldable towards each other. In the in-use configuration, the legs extend generally downwards to typically provide a four leg supporting structure for the first and second primary work frames.

[0018] For additional stability, adjacent pairs of legs (i.e. those pairs of legs which mount to an identical outer edge of either the first or second primary work surface frames) are provided with a cross-brace. Preferably, both pairs of adjacent legs (of the four leg supporting structure) are cross-braced. Suitably, the ends of the legs are provided with feet. Feet comprised of rubber or of a similar flexible or rubber-like material are preferable.

[0019] The inner edge of each of the first and second primary work surface frames hingedly mounts to the central spine by a distinct hinge mounting such that in the folded configuration, the side edges of the respective first and second primary work surface frames (i.e. opposing side edges) are brought parallel with each other and each of the legs is brought parallel with a side edge thereof. Preferably, in the folded configuration the (top surfaces of the) primary and second work surfaces rest flush with each other and the legs rest flush with the underside thereof.

[0020] Each primary work surface frames mounts to the central spine by a distinct (i.e. separate) hinge mounting. The distinct first and second hinge mountings are suitably arranged (e.g. in parallel fashion to each other) about the central spine such as to define first and second hinge axes that are parallel to and spaced apart slightly from each other. The relative spacing of the axes of the hinge mountings is selected to allow for compact folding of the frame assembly and in particular, for flush accommodation of the first and second primary work surfaces in the folded configuration. Typical hinge axis spacing may be from 5 to 500 mm, preferably from 10 to 100 mm (e.g. 30-40 mm) apart. In embodiments, the first and second hinge axes lie below the central spine, for example below the rectangular top surface of the central spine.

[0021] In one example, for a hinge spacing of say 40 mm, the first hinge locates on a first axis that is laterally spaced 20 mm from but parallel to the central axis defined by the central spine and the second hinge locates on a second axis that is laterally spaced 40 mm from the first axis, but also 20 mm laterally from and parallel to the central axis defined by the central spine (i.e. one on either side of the central spine). Alternatives and equivalents to hinge mountings are envisaged herein including arrangements (e.g. series arrangements) of pivot mountings and other mechanical arrangements capable of providing hinge-like functionality. The spaced hinge mountings may either comprise separate hinges or alternatively, the hinges may be coupled in some way (e.g. by a coupling arm or geared link) including for example, by a compass type hinge.

[0022] Where the central spine defines a rectangular top surface (e.g. a plate) having major and minor rectangle edges, the hinge mountings preferably locate inboard of (i.e. within the leading edges, which is to say major edges, of) that rectangular top surface.

[0023] Suitably, the frame assembly additionally comprising first and/or second subsidiary work surface frames, each respective subsidiary work surface frame pivotally mounting to an outer edge of the first and second primary work surface frames. Suitably, in the folded configuration, each respective subsidiary work surface frame is brought parallel with its primary work surface frame. Suitably, in the folded configuration, each respective subsidiary work surface frame is brought parallel with the legs.

[0024] The first and/or second subsidiary work surface frames are suitable for receipt and or definition of first and second subsidiary work surfaces. In one aspect, the first and second subsidiary surfaces are separately provided to their subsidiary work surface frames, to which they are secured by suitable securing means (e.g. screw mounting, bracket fixing or slide/track mounting). In another aspect, the first and second subsidiary work surface frames actually define the first and second subsidiary work surfaces (i.e. integral frame structure).

[0025] A preferred configuration includes both first and second subsidiary work surface frames; although a less preferred configuration including only one subsidiary work surface frame is envisaged.

[0026] Suitably, a trunk extends downwards from the central spine to define a trunk cavity. That is to say, the central spine is provided with a trunk having trunk walls that extends downwards (i.e. towards the floor) from the central spine, and generally a trunk base. The trunk typically reaches only partways to the floor when the workbench is in the 'in use' position. The trunk may extend downwards across the full length of the central spine or only from a part length thereof. In embodiments, the trunk has a box form or an open box form. In embodiments, the trunk is integrally formed with the central spine. Use of a trunk extending to only a part length of the central spine is preferable to allow for accommodation of the user's legs when seated at the workbench.

[0027] Suitably, the distinct hinge mountings locate inboard of the trunk (i.e. within the space defined by planes defined by the downwardly extending walls of the trunk). In embodiments, the first and second hinge axes of the distinct hinge mountings lie within the upper part (i.e. that part closest to the central spine and furthest from the trunk base) of the trunk.

[0028] Suitably, in the folded configuration the trunk locates directly underneath the first and second primary work surfaces and frames. This assists with compact stowage of the trunk.

[0029] Suitably, the width of the trunk approximates to the combined thickness of the first and second primary work surface frames, and their respective first and second work surfaces, when brought together in the folded configuration. Again, this assists with compact stowage of the trunk. Suitably, the length of downward extent of the trunk added to the length of one of the side edges of the first and second primary work surface frames equates to less than or approximately equal to the length of one of the legs.

[0030] Most preferably, in the folded configuration the trunk locates directly underneath the first and second primary work surface frames and the combined length of these elements is roughly equal to (i.e. only slightly more than or less than) that of the legs. Thus, in essence, the length of the legs defines the maximum extent of the compact folded configuration and the width thereof is only slightly greater than the combined width of the opposing legs and thicknesses of the work surfaces (as lie side-by-side each other).

[0031] Suitably, the frame assembly is provided with struts that pivotally connect the lower part (i.e. closest to the floor) of the trunk to each of the respective legs such that in the in-use configuration the struts define a tray framework for receipt of a tray. That is to say, in the in-use configuration the struts preferably define a flat/level framework suitable for optional receipt of a tray or other flat surface.

[0032] Suitably, leg cross-struts are also provided to adjacent legs, each leg cross-strut running parallel to the outer edge of one of the first and second primary work surface frames. Suitably, the leg cross-struts further define the framework for receipt of a tray.

[0033] The trunk is suitably shaped to define an inner trunk cavity for storage of tools and/or receipt of utility equipment (e.g. electrical plug socketry or cable storage).

[0034] Suitably, the frame assembly additionally comprises first and second couplings that act to respectively couple said trunk to the underside of each of the first and

second subsidiary work surface frames. Preferably, each of said first and second couplings acts such as to move (e.g. push and/or pull) the respective underside of each of the first and second subsidiary work surface frames parallel with the respective underside of each of the first and second primary work surface frames on folding of the frame assembly from the in-use to the folded configuration. Preferably, also each of said first and second couplings acts such as to push each of the first and second subsidiary work surface frames to their in-use position on unfolding of the frame assembly from the folded to in-use configuration. Most preferably, the couplings provide both push and pull function. Suitably, each of said couplings comprises a coupling arm, preferably a rigid strut. Suitably, each of said couplings shares a common pivot with the trunk mounted pivot of the trunk to leg strut.

[0035] In embodiments, each of said couplings is provided with a safety catch, which acts to prevent uncontrolled (or e.g. accidental) folding of the frame assembly of the workbench.

[0036] Suitably, for each coupling the safety catch comprises a latch arm, which pivotally mounts to the underside of the relevant subsidiary work surface frame (or in alternatives, to the underside of the relevant subsidiary work surface itself); said latch arm provided with at least a first latch element (e.g. a cutaway portion or slot) for latching interaction with a first latch pin provided to the coupling when the workbench is in the in-use configuration. In embodiments, that latching interaction is also enabled when the workbench is in a part-folded configuration, and the latching interaction must be broken to enable full folding of the workbench.

[0037] In embodiments, the latch arm is additionally provided with a second latch element (e.g. a cutaway portion or slot) for latching interaction with a second latch pin provided to the underside of the relevant primary work surface frame when the workbench is in the folded configuration.

[0038] In embodiments, a pair of such latch arms is provided, each of which pivotally mounts to the underside of the relevant subsidiary work surface frame (or in alternatives, to the underside of the relevant subsidiary work surface itself). Preferably, the pair of latch arms pivotally mounts about a common pivot mounting axis.

[0039] In embodiments, the or each latch arm is provided with an actuator arm (e.g. in the form of a horizontally extending rod), which actuator arm is arranged for ease of latching/delatching by the user. Where a pair of latch arms, each with an actuator arm is present, the pair of actuator arms preferably shares the same axis when the pair of latch arms is in the latched and/or fully unlatched positions. The actuator arms are movable independently.

[0040] Suitably, the frame assembly additionally includes one or more supports, which are provided to support either the first or second subsidiary work surface frames. Suitably, the one or more supports extend in supporting fashion to the first and/or second subsidiary work surface frames from one or more of the legs or from any leg cross-struts provided thereto. Preferably, each of the one or more supports comprises a snap-link (e.g. rod with snap-linkage or sliding latch) provided with a lock for locking said link in a rigid position.

[0041] Suitably, one support pivotally connects to each of the legs (i.e. for a four-legged frame assembly there are also four supports, preferably one extending to each corner of the unfolded workbench).

[0042] Suitably, that support-to-leg pivotal connection is shared (i.e. in common with) the strut-to leg pivotal connection that connects the aforementioned struts to their respective legs. As described above, the struts extend to a lower part (i.e. closest to the floor) of the trunk to define a tray framework.

[0043] Suitably, the frame assembly additionally comprises first and second sprung couplings, which act to respectively couple said trunk to the underside of each of the first and second primary work surface frames. The sprung couplings act such as to provide a degree of resistance to folding (and hence control and safety) when the workbench is folded up and provide a degree of spring assist when the workbench is unfolded.

[0044] Suitably, the frame assembly is symmetrical about the central spine. For strength and compactness symmetry is generally preferable in the overall frame assembly structure and in the arrangement of the component parts (e.g. work surfaces, couplings, struts and supports). Suitably however, the frame assembly also provides for an asymmetric mode of operation, in which one half of the workbench is folded and wall-mounted and the other half extended.

[0045] According to another aspect of the present invention there is provided a workbench comprising a frame assembly as described hereinabove; and first and second primary work surfaces provided to the first and second primary work surface frames.

[0046] Suitably, the workbench additionally comprises first and/or second subsidiary work surfaces provided to the first and/or second subsidiary work surface frames. In one particular aspect, at least one of the first and/or second subsidiary work surfaces mounts to its subsidiary work surface frame by a slide track mounting such that the subsidiary work surface is movable (laterally and along the slide track) relative to its subsidiary work surface frame (e.g. to form a clamping vice).

[0047] Suitably, the central spine defines a rectangular top surface (e.g. a plate), that in the in-use configuration preferably rests essentially co-planar with (or slightly below) the first and second primary work surfaces to define a central work surface of the workbench.

[0048] Preferably, the width of the minor edge of the rectangular top surface of the central spine corresponds essentially to the combined width of the first and second primary work surface frames and their respective first and second work surfaces, when brought together in the folded configuration. In other words, the width of the minor edge of the rectangular top surface of the central spine defines the flush, folded width of the first and second primary work surface frames and their respective first and second work surfaces.

[0049] On folding, the first and second primary work surface frames are suitably brought towards each other, passing over the central spine (e.g. top surface thereof) and meeting essentially flush alongside the central axis defined by the central spine, thereby providing maximum compactness of the folded configuration.

[0050] Preferably, in the folded configuration the (top surfaces of the) first and second primary work surfaces rest essentially flush with each other, and preferably the legs rest flush with the underside (i.e. bottom surfaces) of the first and second primary work surfaces. Preferably, in the folded configuration, the legs rest flush with the underside of the first and second primary work surfaces. In embodiments, the first and second subsidiary work surfaces are provided with an access hole to enable the user to access (and thereby, actuate) the actuator arm(s) of any latch arm(s) provided to the underside thereof.

[0051] In embodiments, the workbench is provided with a clamp for use in securing a workpiece, which is typically arranged for use with one or more dogs. In embodiments, the clamp and dogs are provided to any of the first and/or second primary work surfaces and/or the first and/or second subsidiary work surfaces. The clamp described herein may be used in conjunction with any suitable workbench, and thus comprises another aspect of the present invention.

[0052] In embodiments, the clamp comprises a base defining an upper plug sized and shaped for receipt within an access hole of a subsidiary work surface of the workbench. In embodiments, the base is provided with a flange, which in-use seats against the subsidiary work surface (in embodiments, the underside or topside thereof) when the plug portion seats within the access hole. In other embodiments, no flange is present. In embodiments, the plug includes a lateral slot arranged for receipt of a securing bolt, which is used to secure a sequential arrangement of a lower jaw; compressible (e.g. rubber) block; and upper jaw to the base. Suitably, a securing nut associates with the securing bolt to allow reversibly securable receipt of the arrangement of lower jaw; compressible (e.g. rubber) block; and upper jaw within the slot. One or more stops may be provided (e.g. to the upper jaw) to prevent the handle from turning more than a set amount (e.g. 1800) and thereby being overtightened or inadvertently undone.

[0053] In embodiments, a handle is received by the head of the securing bolt. Suitably, a handle-retaining bolt is used to secure the handle to the head of the securing bolt. In use, the handle is turned in a first rotational sense to cause a loosening of the securing bolt, which enables the jaw and block arrangement to be moved laterally within the slot. Suitably, the handle requires only to be turned in a reverse rotational sense through 90° (i.e. a quarter turn) relative to the base to allow for securing of the jaw and block arrangement at a particular lateral position within the slot of the base. As a result of such securing, the compressible (e.g. rubber) block is compressed and expands outwardly to exert a clamping force to secure a workpiece.

[0054] Suitably, the workbench additionally comprises an optional tray provided to the tray framework.

[0055] The frame assembly and workbench herein may be supplied fully assembled or in any suitable kit of parts form. There is also provided the use of the workbench herein in its folded and/or in-use configuration.

[0056] In one particular use configuration, one half of the work bench mounts to an external vertical surface (e.g. a wall) in folded configuration and the other half of the work bench is unfolded to its in-use configuration. Thus, the workbench may also be supplied as a kit of parts with an optional wall mounting.

[0057] The frame assembly and workbench herein has been described in relation to embodiments comprising both first and second primary work surface frames. A less preferred configuration comprising only 'one half' of the present workbench, and thus comprising only one primary and subsidiary work surface frame (and typically, one pair of legs associated therewith) is however, also envisaged. It will be appreciated that in one embodiment such 'one half' configuration would be suitable exclusively for use in the wall-mounted configuration. In another embodiment supporting legs (e.g. permanent, bolted on or flipped down) are provided to the underside of the trunk of the 'one half' configuration such that in use, the 'one half' workbench would be supported by these trunk-mounted legs (i.e. instead of the wall-mounting) and the pair of legs associated with the one primary and subsidiary work surface frame.

BRIEF DESCRIPTION OF THE DRAWINGS

[0058] Embodiments of the present invention will now be described with reference to the accompanying drawings in which:

[0059] FIGS. **1***a* to **1***d* show perspective views of a first folding workbench herein in various stages as the workbench is folded up from the normal 'in-use' configuration (FIG. **1***a*) to the 'folded' configuration (FIG. **1***d*);

[0060] FIGS. **2***a* to **2***e* show side views of the first folding workbench herein in various stages as the workbench is folded up from the normal 'in-use' configuration (FIG. **2***a*) to the 'folded' configuration (FIG. **2***e*);

[0061] FIGS. **3***a* to **3***d* show perspective views of the first folding workbench herein in various stages as the workbench is folded up from the wall-mounted 'in-use' configuration (FIG. **3***a*) to the wall-mounted 'folded' configuration (FIG. **3***d*);

[0062] FIG. **4** shows a side view of the first folding workbench herein in the wall-mounted 'in-use' configuration;

[0063] FIG. **5** shows a perspective view of a second folding workbench herein in the 'in-use' configuration;

[0064] FIG. **6** shows a perspective view of a third folding workbench herein in the normal 'in-use' configuration;

[0065] FIG. **7***a* shows a perspective view of a detail of the central spine part of the first folding workbench of FIGS. **1***a* to **2***e* with the first primary work surface shown ghosted for ease of view;

[0066] FIG. **7***b* shows a perspective view of the first folding workbench of FIGS. **1***a* to **2***e*, with an exploded view of an inner cavity for receipt of electrical socketry.

[0067] FIGS. **8***a* and **8***b* show schematic end views of the arrangement of pivots of one half of the first folding workbench respectively in the in-use and folded configurations (and shown absent its legs in FIG. **8***b* for clarity of view);

[0068] FIG. **9** shows a side view of one-half of a fourth folding workbench herein with a safety catch feature as shown in the normal 'in-use' configuration;

[0069] FIG. **10** shows a perspective view of the safety catch feature of the fourth folding workbench of FIG. **9**;

[0070] FIGS. **11***a* to **11***c* show side views of details of the fourth folding workbench with safety catch feature of FIG. **9**, as respectively shown in the normal 'in-use', part-folded and folded configurations;

[0071] FIGS. **12***a* to **12***c* show perspective views (with part of the first primary work surface shown in cut-away view) of details of the fourth folding workbench with safety catch feature of FIG. **9**, as respectively shown in the normal 'in-use', part-folded and folded configurations;

[0072] FIG. **13** shows a perspective view of a clamp for use with a workbench herein shown in a storage position;

[0073] FIGS. **14***a* and **14***b* respectively show perspective views of the top and underside of the clamp of FIG. **13** as shown in the clamp closed position;

[0074] FIG. **15** shows an exploded view of the clamp of FIG. **13**;

[0075] FIG. **16** shows a sectional side view of the clamp of FIG. **13**;

[0076] FIGS. **17***a* to **17***d* show perspective views from the top of sequential steps in securing a plank of wood to a fifth workbench herein, which incorporates the clamp of FIG. **13**;

[0077] FIGS. **18***a* and **18***b* respectively show perspective views from the top and underside of a snap-link coupling for use in a workbench herein as shown in its unsnapped position;

[0078] FIGS. **19***a* to **19***c* show sectional views from the side of the snap-link coupling of FIGS. **18***a* and **18***b*, as respectively shown in the locked, unlocked and unsnapped positions;

[0079] FIG. **20** shows a perspective view of the top of a clamp that is a slight variant of the clamp of FIGS. **13** to **17***d*, as shown in the clamp closed position.

DETAILED DESCRIPTION

[0080] Referring now to the drawings, in FIGS. **1***a* to **1***d*; and FIGS. **2***a* to **2***e* there is shown a first folding workbench **1** herein in various stages as the workbench is folded up from a normal 'in-use' configuration (FIGS. **1***a* and **2***a*), in which the workbench rests on the floor, to a normal 'folded' configuration (FIG. **1***d* and **2***e*). For simplicity of reference, not all Figures are labelled with all number labels.

[0081] In more detail, and with further reference to FIG. **7***a*, the workbench **1** comprises a rigid central spine **10**, defining first and second spaced hinge mountings **12**, **14** arranged in parallel fashion. First and second primary work surfaces **20**, **22** attached to first and second primary work surface frames **19**, **21** (see FIG. **7**) hingedly mount to the central spine **10** via said first and second hinge mountings **12**, **14**. The central spine **10** is provided with a top surface **11** in the form of a rectangular plate, which in this (i.e. in the in-use) configuration is essentially co-planar with the top surfaces of the first and second primary work surfaces **20**, **22**. It will be noted that the hinge axes A1, A2 defined by the hinge mountings **12**, **14** are parallel to each other and to a central axis defined by the central spine **10** and lie below the plane of the rectangular plate **11**.

[0082] Each work surface frame has an inner edge **23**, **24**, an outer edge **25**, **26** and two side edges **27***a*, **27***b*; **28***a*, **28***b*. It may be seen that it is the inner edge **23**, **24** of each primary work surface frame **19**, **21** that hingedly mounts to the central spine **10** such that the primary work surface frames **19**, **21** (and their respectively supported work surfaces **20**, **22**) are foldable towards each other.

[0083] As a point of detail, it is noted that each hinge mounting **12**, **14** for the primary work surface frames **19**, **21** locates approximately 20 mm away from the centre line of the workbench **1** to allow the frame **19**, **21** to rotate clear of the central spine **10** and allow the primary work surfaces **20**, **22** to meet flush along the centre line.

[0084] The workbench additionally comprises two opposing pairs of legs **30***a*, **30***b*; **32***a*, **32***b*. Each leg **30***a*, **30***b*; **32***a*, **32***b* mounts via pivot mounting **34***b*, **36***b* to one end of the outer edge **25**, **26** of the first and second primary work surface frames **19**, **21** such that the legs of each opposing pair **30***a*, **30***b*; **32***a*, **32***b* are foldable towards each other.

[0085] The workbench **1** also includes first and second subsidiary work surface frames **39**, **41**, which support first and second subsidiary work surfaces **40**, **42**. Second subsidiary work surface frame **41** pivotally mounts directly to outer edge **26** of the second primary work surface frame **21**. First subsidiary work surface **40** mounts via slide track mounting to first subsidiary work surface frame **39**, which then pivotally mounts to outer edge **25** of the first primary work surface frame **19**. The first subsidiary mount surface **40** is movable on its slide track mounting by the action of turn handles **44**, **45**. It may also be seen that trunk **16** extends downwards from the central spine **10**. The trunk **16** defines an inner cavity for receipt of electrical socketry **17***a* and also cabling, tools etc., as shown in more detail in FIG. **7***b*, and a storage drawer **17***b*.

[0086] As a point of detail, it is noted that the exact positioning of the pivot mountings for the subsidiary work surface frames **39**, **41** lies about 10 mm below the corresponding edge of the frame **39**, **41**.

[0087] Struts **50***a*, **52***a*, **50***b* **52***b* pivotally connect the underside of the trunk **16** to each of the respective legs **30***a*, **30***b*; **32***a*, **32***b* such that in the in-use configuration the struts **50***a*, **52***a*, **50***b* **52***b* define a tray framework for receipt of storage tray **54**. Leg cross-struts **56**, **58** are also provided to adjacent legs **30***a*, **30***b* and **32***a*, **32***b* respectively, each leg cross-strut **56**, **58** running parallel to the respective outer edge **25**, **26** of one of the first and second primary work surface frames **19**, **21**. The leg cross-struts **56**, **58** provide further support for the tray **54**.

[0088] The workbench **1** also comprises first and second coupling arms **60**, **62** that act to respectively couple trunk **16** to the underside of each of the first and second subsidiary work surface frames **39**, **41**.

[0089] As may be seen with particular reference to FIGS. **1***b*-**1***c* and **2***b*-**2***d*, during folding the first and second couplings **60**, **62** act such as to pull the respective underside of each of the first and second subsidiary work surface frames **39**, **41** parallel with the respective underside of each of the first and second primary work surface frames **19**, **21**.

[0090] Two supports **70**, **71** are provided to support the first subsidiary work surface frame **39** in the in-use configuration. These two supports **70**, **71** extend upwards from adjacent pair of legs **30***b*, **30***a*. Similarly, two supports **72**, **73** are provided to support the second subsidiary work surface frame **41** in the in-use configuration. Again, these two supports **72**, **73** extend upwards from adjacent pair of legs **32***b*, **32***a*.

[0091] Each of the supports **70**-**73** comprises a snap-link provided with a lock for locking said link to provide rigid support when the first and second subsidiary work surface frames **39**, **41** are in the in-use configuration.

[0092] First and second sprung couplings **80**, **82** act to respectively couple trunk **16** to the underside of each of the first and second primary work surface frames **19**, **21**. These sprung couplings **80**, **82** act such as to provide a degree of resistance to folding (and hence control and safety) when the workbench **1** is folded up and provide a degree of spring assist when the workbench **1** is unfolded.

[0093] Referring in particular to FIGS. **1***d* and **2***e* it may be seen that in the folded configuration the outer edges **25**, **26** of the respective first and second primary work surfaces **20**, **22** rest flush with each other and each of the legs **30***b*, **32***b* (only two visible in FIGS. **1***d* and **2***e*) rests flush with a side edge **27***b*, **28***b* (again, only two visible in FIGS. **1***d* and **2***e*) thereof.

[0094] Also, in the folded configuration, each respective subsidiary work surface frame **39**, **41** rests parallel with its primary work surface frame **19**, **21** and flush with the relevant legs **30***a*, **30***b*, **32***a*, **32***b*. The trunk **16** locates directly underneath the first and second primary work surfaces **20**, **22**. It may be seen that the combined length of the trunk **16** add to the length of one of the side edges **27***b*, **28***b* of the first and second primary work surfaces **20**,**22** amounts to just less than the length of one of the legs **30***b*, **32***b*.

[0095] It may be appreciated that the overall form of the workbench **1** is generally symmetrical about the central spine

10. Such symmetry is desirable from the standpoint of ease and stability of use, particularly during folding and unfolding of the workbench **1**.

[0096] It is however, also a feature of the workbench **1** herein that it may be used in an asymmetrical mode of operation in which it is used in combination with a wall mounting suitable for mounting one half of the workbench in its folded configuration whilst the other half is in the in-use configuration. FIGS. **3***a* to **3***d* and **4** show the workbench **1** herein in various stages as the workbench **1** is folded up from the wall-mounted 'in-use' configuration (FIG. **3***a* and FIG. **4**) to the wall-mounted 'folded' configuration (FIG. **3***d*).

[0097] Referring now to FIGS. **3***a* to **3***d* and FIG. **4**, the general features of the workbench **1** and mode of operation thereof are identical to those already described with reference to FIGS. **1***a* to **1***d*; and FIGS. **2***a* to **2***e*. For succinctness, features already described with reference to the earlier drawings are not described further hereinafter.

[0098] In one embodiment, the left hand-side of the workbench **1** mounts to the wall **100** via mounting brackets **90**, **92** provided to the wall that engage with mounting slots **96**, **98** provided respectively to the top of the second subsidiary work surface frame **41** and the underside of the tray **54**. These mounting slots **96**, **98** are visible in FIG. **3***d*, but in respect of the unmounted half of the workbench **1**. First subsidiary work surface **40** mounts to its first subsidiary work surface frame **39** by a slide track mounting **43** and is movable thereon by the action of turn handles **44**, **45** to form a 'vice' like feature.

[0099] The wall-mounted mode of operation is particularly suitable for use in restricted spaces and where the full extent of the workbench top surface is not required.

[0100] FIG. **5** shows a second workbench herein that may be appreciated to be a variation of the first workbench of FIGS. **1***a* to **4**, which in essence comprises only 'one half' of the first workbench **1** together with an additional pair of supporting legs **133***a*, **133***b* provided to the underside of the trunk **116** thereof.

[0101] In more detail, the second workbench **101** comprises a rigid spine **110** provided with first hinge mounting **112** arranged in parallel fashion thereto. First primary work surface frame **119** hingedly mounts to the spine **110** via said first hinge mounting **112**. The primary work surface has an inner edge **123**, an outer edge **125** and two side edges **127***a*, **127***b*. It may be seen that it is the inner edge **123** of the primary work surface **120** that hingedly mounts to the spine **110** such that the primary work surface **120** (and its respective supporting frame **119**) is foldable up.

[0102] The workbench **101** comprises first pair of legs **130***a*, **130***b*. Each of these legs **130***a*, **130***b* mounts via pivot mounting **134***b* to one end of the outer edge **125**, of the first primary work surface frame **119** such that the legs **130***a*, **130***b* are foldable in.

[0103] The workbench **101** also includes first subsidiary work surface **140**, which mounts via slide track mounting **143** to first subsidiary work surface frame **139**, which then pivotally mounts to outer edge **125** of the first primary work surface **120**. The first subsidiary mount surface **140** is movable on its slide track mounting by the action of turn handles **144**, **145**. It may also be seen that trunk **116** extends downwards from the spine **110**. The trunk **116** defines an inner cavity for receipt of electrical socketry **117** and also cabling, tools etc. The underside of the trunk **116** is further provided with an additional pair of supporting legs **133***a*, **133***b*.

[0104] As a point of detail, it is noted that the exact positioning of the pivot mounting for the subsidiary work surface frame **139** lies about 10 mm below the corresponding edge of the frame.

[0105] Struts **150***a*, **150***b* pivotally connect the underside of the trunk **116** to each of the legs **130***a*, **130***b* such that in the in-use configuration the struts **150***a*, **150***b* define a tray framework for receipt of storage tray **154**. Leg cross-strut **156** is also provided to adjacent legs **130***a*, **130***b*, the leg cross-strut **156** running parallel to the outer edge **125** of one of the first primary work surface **120**. The leg cross-strut **156** provides further support for the tray **154**.

[0106] The second workbench **101** also comprises first coupling arm **160** that acts to couple trunk **116** to the underside of the first subsidiary work surface frame **139**.

[0107] As with first workbench **1**, during folding of the second workbench **101** the first coupling **110** acts such as to pull the underside of the first subsidiary work surface frame **139** parallel with the underside of the first primary work surface frame **119**.

[0108] Two supports **170**, **171** are provided to support the first subsidiary work surface frame **139** in the in-use configuration. These two supports **170**, **171** extend upwards from adjacent pair of legs **130***b*, **130***a*. Each of the supports **170**, **171** comprises a snap-link provided with a lock for locking said link to provide rigid support when the first subsidiary work surface frame **139** is in the in-use configuration.

[0109] First sprung coupling **180** acts to couple trunk **116** to the underside of the first primary work surface frame **119**. This sprung coupling **180** acts such as to provide a degree of resistance to folding (and hence control and safety) when the workbench **101** is folded up and provides a degree of spring assist when the workbench **101** is unfolded.

[0110] FIG. **6** shows a third folding workbench that is identical to the first folding workbench shown at FIGS. **1***a* to **1***d* and **2***a* to **2***e* hereinbefore other than that it further includes leg cross-bracing and rubber feet. Thus, all other labelled features of the third folding workbench are generally identical (except that storage tray **54** is moulded to fit around and behind leg cross-brace **31***a*, **31***b*) to those of the first folding workbench of FIGS. **1***a* to **1***d* and **2***a* to **2***e*, and the description of these is not repeated.

[0111] Whilst FIG. **6** shows the third folding workbench in the normal 'in-use' configuration, it will be appreciated that its folding action is identical to that of the first folding workbench of FIGS. **1***a* to **1***d* and **2***a* to **2***e*.

[0112] FIG. **6** shows the additional features of the third folding workbench, namely that respective adjacent pairs of legs **30***a*, **30***b* and **32***a*, **32***b* are each provided with a respective cross-brace **31***a*, **31***b*. The presence of the cross-braces **31***a*, **31***b* adds to the stability of the workbench. Rubber feet **35***a-d* are also provided to each leg **30***a*, **30***b*, **32***a*, **32***b*.

[0113] FIGS. **8***a* and **8***b* show schematic end views of the arrangement of pivots of one half of the first folding workbench **1** of FIGS. **1***a* to **2***e* respectively in its in-use and folded configurations. The workbench **1** is shown absent its legs and with its tray **54** in ghosted view in FIG. **8***b* for clarity of view. Other than the now-labelled pivots A to G, all other labelled features are identical to those of the first folding workbench of FIGS. **1***a* to **2***e*, and the description of these is not repeated.

[0114] In more detail, and with particular reference to FIG. **8***a*, pivots A, B, C and D may be seen to adopt the form of a parallelogram frame, and with the identical pivot arrangement of the other half of the workbench (not shown in FIG.

8*a*, but see FIGS. **1***a* to **2***d*) therefore adopt an overall back-to-back parallelogram frame arrangement that is symmetrical about the trunk **16**. This back-to-back parallelogram structure provides the workbench **1** with strength, and assists with ease of folding/unfolding.

[0115] The pair of pivots A may be seen to lie equally spaced about the central spine **10**, inboard thereof and also inboard of the walls defining the trunk **16**. The pair of pivots B are also equally spaced, but with spacing greater than that of pair of pivots A and lying outboard of the walls defining the trunk **16**.

[0116] Now referring to FIG. **8***b*, when the workbench **1** is in the folded-up configuration, pivots A remain spaced and side-by-side and pivots C, E, D and B may be seen to line up approximately in a straight line. Overall, it will be appreciated that the arrangement of pivots A to G is selected to maximise the compactness of the folded-up configuration and to enable ease of its transition to and from the in-use configuration.

[0117] As has been described in relation to the previous figures, the workbench **1**; **101** herein suitably comprise coupling arms **60**, **62**; **160** that act to respectively couple trunk **16**; **116** to the underside of each of the first and second subsidiary work surface frames **39**, **41**; **139**. In embodiments, each of the coupling arms **60**, **62**; **160** is provided with a safety catch, which acts to prevent uncontrolled (or e.g. accidental) folding of the frame assembly of the workbench. One such embodiment is now described with particular reference to FIGS. **9** to **12***c*.

[0118] Thus, FIG. **9** shows one-half of a fourth folding workbench **201** herein with a safety catch feature **263** provided to a coupling arm **260** thereof. As before, the coupling arm **260** acts such as to couple trunk **216** to the underside of first subsidiary work surface frame **239**. The workbench **201** also includes supports **270** (only one visible) to support the first subsidiary work surface frame **239** in the in-use configuration. Second latch pins **218***a* (only one visible) are provided to the primary work surface frame **219**. The supports **270** extend upwards from adjacent pair of legs **230***b* (only one visible). Each of the supports **270** comprises a snap-link lock **274** (see also FIGS. **18***a* to **19***c*) for locking said link to provide rigid support when the first subsidiary work surface frame **239** is in the in-use configuration. Other details of the workbench **201** including first primary work surface frame **219**; first primary work surface **220**; and first subsidiary work surface **240**; are generally identical in form to those already described in relation to the first to third workbenches herein (other than that the number of access holes **246***a*, **246***b* has changed from one to two).

[0119] FIG. **10** shows more details of the safety catch feature **263**, which comprises first and second latch arms **264***a*, **264***b*, which pivotally mount to the underside of the first subsidiary work surface frame **239** by means of pivot mountings **265** *a*, **265***b*. It will be appreciated that both latch arms **264***a*, **264***b* share a common axis of pivot mounting **265***a*, **265***b*. Each latch arm **264***a*, **264***b* is provided with a first latch element **266***a*, **266***b* in the form of a cutaway portion for latching interaction with first latch pins **261** *a*, **261***b* provided to the coupling arm **260** when the workbench is in the in-use configuration (see also FIGS. **11***a* and **12***a*) and a part-folded configuration (see FIGS. **11***b* and **12***b*). Each latch arm **264***a*, **264***b* is provided with a second latch element **267***a* (second latch element of second latch arm **264***b*, not visible) in the form of a cutaway portion for latching interaction with the second latch pins **218***a*, **218***b* when the workbench is in the folded configuration (see also FIGS. **11***c* and **12***c*).

[0120] Each latch arm **264***a*, **264***b* is further provided with an actuator arm **268***a*, **268***b* in the form of a horizontally extending rod, which actuator arm **268***a*, **268***b* is arranged for ease of latching/de-latching by the user. It will be appreciated that the actuator arms **268***a*, **268***b* share the same axis when the latch arms **264***a*, **264***b* are both latched in the in-use (see FIGS. **11***a*, **12***a*) and/or folded (see FIGS. **11***c*, **12***c*) configurations of the workbench **201**.

[0121] Further details of the latch arm **264***a*, **264***b* action may be understood by reference to FIGS. **11***a* to **11***c* and **12***a* to **12***c*.

[0122] Referring now to FIGS. **11***a* and **12***a*, the workbench **201** is shown in the in-use configuration. The snap-link lock **274** of the supports **270** (only one visible) is locked in place, and folding up of the first subsidiary work surface frame **239** is therefore not possible. The first latch elements **266***a* (only one visible) of the latch arms **264***a* (only one visible) rest firmly on the first latch pins **261** *a* (only one visible) of the coupling arm **260** as a result of the latching arms **264***a*, **264***b* being sprung about their pivots.

[0123] Referring now to FIGS. **11***b* and **12***b*, the snap-link lock **274** of the support has now been unlocked and folding up of the first subsidiary work surface frame **239** (and hence, workbench **201** as a whole) is in progress. The coupling arm **260** is however still latched into its position, and the workbench **201** may not be folded up further without first unlatching the latch **263**. That unlatching is achieved by the user reaching through access holes **246***a*, **246***b* to pull up on the actuator arms **268***a*, **268***b* and to thereby manipulate the latch arms **264***a*, **264***b* to unlatch first latch elements **266***a*, **226***b* from the first latch pins **261***a*, **261***b* of the coupling arm **260**. Once so-unlatched the coupling arm **260** may be moved freely to the fully folded position of FIGS. **11***c* and **12***c*, in which the second latch elements **267***a*, **267***b* latch onto their respective second latch pins **218***a* (only one visible). During this further folding the coupling arm **260** acts such as to pull the underside of the first subsidiary work surface frame **239** flush with the respective underside of the first primary work surface frame **219**.

[0124] In a subtle aspect, and with particular reference to FIG. **12***b*, it may be noted that for the full folding action to occur the user must first reach through the access holes **246***a*, **246***b* with both hands thereby, ensuring that both of the user's hands are free of the folding action. The user's hands are also in the correct position to take the weight of the workbench **201** as it closes. This therefore provides a safety benefit in that any accidental crushing of the user's hands is prevented because the hands are safely located within the access holes **246***a*, **246***b* during the folding action. The actuator arms **268***a*, **268***b* are again used by the user in similar fashion as described to unlock the workbench **201** from the fully folded position of FIGS. **11***c* and **12***c* and to enable unfolding thereof.

[0125] The workbench **1**; **101**; **201** herein is in embodiments, provided with a clamp **290** for reversible clamping of a wooden plank or other item to be worked on. The clamp **290** is now described in particular relation to its use with the fourth workbench **201** herein (see FIGS. **17***a* to **17***d*), although it may be appreciated that its form makes it amenable for use with any of the workbenches **1**; **101**; **201** described herein.

[0126] Referring now to FIGS. **13** to **16**, there is shown a clamp **290** comprising a base **291** defining an upper plug **292** portion sized and shaped for receipt within an access hole **246***a*, **246***b* of a subsidiary work surface **240** of the workbench **201**. The base **291** is provided with a flange **293**, which in-use seats against the underside of the subsidiary work surface **240**, **242** when the plug portion **292** seats within the access hole **246***a*, **246***b*. The plug **292** includes a lateral slot **294** arranged for receipt of securing bolt **295** *a*, which is used to secure a sequential arrangement of lower jaw **296***a*; compressible rubber block **297**; and upper jaw **296***b* to the base **291**. It will be seen that securing nut **295***b* associates with securing bolt **295***a* to allow reversibly securable receipt of the arrangement **296***a*, **297**, **296***b* within the slot **292**.

[0127] It will also be seen that handle **298** is received by the head **295***c* of the securing bolt **295***a* and that handle-retaining bolt **295***d* is used to secure the handle **298** to the head **295***c* of the securing bolt **295***a*. It will be appreciated that in use, the handle **298** is turned to cause a loosening of the securing bolt **295***c*, which enables the jaw and block arrangement **296***a*, **297**, **296***b* to be moved laterally within the slot **294**.

[0128] FIG. **13** shows the clamp **290** in an unsecured position, in which the shank of the handle **298** and jaw and block arrangement **296***a*, **297**, **296***b* are lined up with the base **291**. FIGS. **14***a* and **14***b* show the clamp **291** in a secured position, in which the jaw and block arrangement **296***a*, **297**, **296***b* has been turned through 90 D and the handle **298** has been turned through a further 90 D (i.e. a quarter turn) relative to the base **291** to allow for securing of the jaw and block arrangement **296***a*, **297**, **296***b* at a particular lateral position within the slot **294** of the base **291**.

[0129] Referring now to FIGS. **17***a* to **17***d*, which show sequential steps in securing a plank of wood to clamps **290**, **290***a* provided to a workbench **201** herein.

[0130] At FIG. **17***a*, it may be seen that a first clamp **290** has been secured within an access hole **246***a* of first subsidiary work surface **240**, and a second clamp **290***a* has been secured within an oppositely-located access hole **246***c* of second subsidiary work surface **242**. Both clamps **290**, **290***a* are in the loosened position, in which the handle **298** thereof is orthogonal to the central axis defined by the central spine **210** of the workbench **201**. The jaw and block arrangement **296***a*, **297**, **296***b* lines up with the handle **298**.

[0131] At FIG. **17***b*, dogs **299***a*, **299***b* have been provided to the first subsidiary work surface **240**, and are received in holes provided thereto. The dogs **299***a*, **299***b* locate in line with each other and spaced from the jaw and block arrangement **296***a*, **297**, **296***b* of the clamp **290** such that wooden plank **205** may be received therebetween.

[0132] At FIG. **17***c*, the jaw and block arrangement **296***a*, **297**, **296***b* has been moved within the slot **294** of the clamp **290** towards the wooden plank **205** such that the edges of the wooden plank **205** sandwich snugly between the dogs **299***a*, **299***b* and the jaw and block arrangement **296***a*, **297**, **296***b* of the clamp **290**.

[0133] At FIG. **17***d*, the clamp **290** has been tightened by turning the handle **298** through 90° (i.e. a quarter turn) relative to its base **291**. This tightening results in securing of the jaw and block arrangement **296***a*, **297**, **296***b* at the selected lateral position within the slot **294** of the base **291**. The tightening also results in a slight compression of the rubber block **297** within the first **296***a* and second blocks **297***a*, thereby causing the rubber block to bulge slightly, which bulging results in tight gripping of the wooden plank **205**.

[0134] It will be appreciated that untightening and removal of the wooden plank from the clamp **290** may be achieved by carrying out the steps of FIGS. **17***a* to **17***d* in reverse order.

[0135] A variant of the clamp **290** of FIGS. **13** to **17***d* is shown at FIG. **20**. This variant is identical to the earlier clamp in all aspects other than that the flange **293** of the earlier clamp **290** is not present.

[0136] As has been described in relation to the previous figures, the workbench **1**; **101**; **201** herein suitably comprise support arms **70-73**; **170-171**; **270** that are provided to support the first and/or subsidiary work surface frames **39**, **41**; **139**; **239** in the in-use configuration. In embodiments, each of the **70-73**; **170-171**; **270** comprises a snap-link lock **274** for locking thereof to provide rigid support when the first and/or subsidiary work surface frames **39**, **41**; **139**; **239** are in the in-use configuration. Details of one such snap-link lock **274** are now described with particular reference to FIGS. **18***a* to **19***c*.

[0137] Referring initially to FIGS. **18***a* and **18***b*, there is shown first and second **270***a*, **270***b* halves of support, which pivot mount relative to each other at pivot points **269***a*, **268***b*, and are provided with snap-link lock **274**.

[0138] The mechanism of the snap-link lock **274** may be better understood by reference also to FIGS. **19***a* to **19***c*. Thus, first support half **270***a* is provided with slide mounted latch **275**, which includes finger-accessible release element **276** (in the form of a recess).

[0139] As shown at FIG. **19***a*, the latch **275** is biased by spring **277** such that a lock finger **278** thereof is biased into latching engagement with a notched element **279** of the second support half **270***b*. The supports **270***a*, **270***b* are thereby, locked into engagement with one another.

[0140] As shown at FIG. **19***b*, the user has pulled back on the release element **276** to slide the latch **275** back against the biasing force of the spring **277** such that the lock finger **278** has become disengaged from the notched element **279**. The support halves **270***a*, **270***b* are thereby, unlocked from their engagement with one another, and the support halves **270***a*, **270***b* may be 'snapped open' by relative movement about the pivots **269***a*, **269***b* to the unsnapped position of FIG. **19***c*.

[0141] It will be appreciated that return of the support halves **270***a*, **270***b* to the locked position may be readily achieved by carrying out the steps of FIGS. **19***a* to **19***c* in reverse order. In aspects the opening action of the workbench **201** and springs **277** automatically put the snap-links **274** into the locked position with the user merely having to do a quick visual inspection to ensure that all snap-links **274** are locked.

[0142] For the avoidance of doubt, it is noted that wherever reference herein is made to 'pivot mounting', 'pivotally mounting', pivotally connecting' and the like, what is envisaged is both classic pivot forms typically comprising pivot pins and associated bushes and washers, and any functional equivalents thereto such as pivot assemblies that comprise interlocking parts that provide the required pivot movement.

[0143] It is noted that wherever reference herein is made to 'hinge mounting', 'hingedly mounting', hingedly connecting' and the like, what is envisaged is both classic hinge forms and any functional equivalents thereto such as hinge assemblies that comprise interlocking parts that provide the required hinge movement.

What is claimed is:

1. A frame assembly for a workbench that is reversibly foldable from an in-use to a folded configuration comprising:

a central spine;

first and second primary work surface frames, each work surface frame having an inner edge, an outer edge and two side edges, wherein each said inner edge thereof hingedly mounts to the central spine such that the primary work surface frames are foldable towards each other; and

first and second opposing pairs of legs, each leg pivotally mounting to one end of an outer edge of the first and second primary work surface frames, such that the legs of each opposing pair are foldable towards each other,

wherein the inner edge of each of the first and second primary work surface frames hingedly mounts to the central spine by a distinct hinge mounting such that in the folded configuration, opposing side edges of the respective first and second primary work surface frames are brought parallel with each other and each of the legs is brought parallel with a side edge thereof.

2. A frame assembly for a workbench according to claim **1**, additionally comprising first and/or second subsidiary work surface frames, each respective subsidiary work surface frame pivotally mounting to an outer edge of the first and second primary work surface frames, wherein in the folded configuration, each respective subsidiary work surface frame is brought parallel with its primary work surface frame.

3. A frame assembly for a workbench according to claim **2**, wherein in the folded configuration, each respective subsidiary work surface frame is brought parallel with the legs.

4. A frame assembly for a workbench according to claim **1**, wherein the central spine locates about the central folding axis for the frame assembly.

5. A frame assembly for a workbench according to claim **1**, wherein the distinct hinge mountings locate inboard of the central spine.

6. A frame assembly for a workbench according to claim **1**, wherein the central spine defines a rectangular top surface.

7. A frame assembly for a workbench according to claim **6**, wherein in the in-use configuration said rectangular top surface defines a central work surface of the frame assembly.

8. A frame assembly for a workbench according to claim **6**, wherein the distinct hinge mountings locate inboard of the rectangular top surface.

9. A frame assembly for a workbench according to any of claim **1**, wherein the distinct hinge mountings are in parallel fashion to each other such as to define first and second hinge axes that are parallel to and spaced apart relative to each other.

10. A frame assembly for a workbench according to claim **9**, wherein the relative spacing of the axes of the hinge mountings is selected to allow for compact folding of the frame assembly.

11. A frame assembly according to claim **9**, wherein said first and second hinge axes lie below the central spine.

12. A frame assembly for a workbench according to claim **1**, wherein a trunk extends downwards from the central spine.

13. A frame assembly for a workbench according to claim **12**, wherein the distinct hinge mountings locate inboard of the trunk.

14. A frame assembly for a workbench according to claim **1**, wherein:

the distinct hinge mountings are in parallel fashion to each other such as to define first and second hinge axes that are parallel to and spaced apart relative to each other;

a trunk extends downwards from the central spine; and

the first and second hinge axes of the distinct hinge mountings lie within an upper part of the trunk.

15. A frame assembly for a workbench according to claim **12**, wherein in the folded configuration the trunk locates directly underneath the first and second primary work surface frames.

16. A frame assembly for a workbench according to claim **12**, wherein the length of downward extent of the trunk added to the length of one of the side edges of the first and second primary work surface frames is less than or approximately equal to the length of one of the legs.

17. A frame assembly for a workbench according to claim **12**, wherein struts pivotally connect a lower part of the trunk to each of the respective legs such that in the in-use configuration the struts define a tray framework for receipt of an optional tray.

18. A frame assembly according to claim **17**, wherein leg cross-struts are provided to adjacent legs, each leg cross-strut running parallel to the outer edge of one of the first and second primary work surface frames.

19. A frame assembly according to claim **18**, wherein said leg cross-struts further define said framework for receipt of an optional tray.

20. A frame assembly according to claim **12**, wherein said trunk defines a trunk cavity for receipt of electrical equipment and/or tools.

21. A frame assembly for a workbench according to claim **1**, additionally comprising:

first and/or second subsidiary work surface frames, each respective subsidiary work surface frame pivotally mounting to an outer edge of the first and second primary work surface frames, wherein in the folded configuration, each respective subsidiary work surface frame is brought parallel with its primary work surface frame;

a trunk extending downwards from the central spine; and

first and/or second couplings that act to respectively couple said trunk to the underside of each of the first and/or second subsidiary work surface frames.

22. A frame assembly for a workbench according to claim **21**, wherein the or each of said first and/or second couplings acts such as to move the respective underside of each of the first and/or second subsidiary work surface frames parallel with the respective underside of each of the first and/or second primary work surface frames on folding the frame assembly from the in-use to the folded configuration.

23. A frame assembly for a workbench according to claim **21**, wherein the or each of said couplings comprises a coupling arm.

24. A frame assembly for a workbench according to claim **21**, wherein the or each of said couplings is provided with a safety catch.

25. A frame assembly for a workbench according to claim **24**, wherein said safety catch comprises a latch arm, which pivotally mounts to the underside of the relevant subsidiary work surface frame, said latch arm provided with at least a first latch element for latching interaction with a first latch pin provided to the relevant coupling when the workbench is in the in-use configuration.

26. A frame assembly for a workbench according to claim **25**, wherein the latch arm is additionally provided with a second latch element for latching interaction with a second latch pin provided to the relevant primary work surface when the workbench is in the folded configuration

27. A frame assembly for a workbench according to claim 25, wherein the safety catch comprises a pair of the latch arms.

28. A frame assembly for a workbench according to claim 27, wherein said pair of latch arms pivotally mount about a common pivot mounting axis.

29. A frame assembly according to claim 25, wherein the or each latch arm is provided with an actuator arm.

30. A frame assembly for a workbench according to claim 2, wherein one or more supports are provided to support either the first and/or second subsidiary work surface frames.

31. A frame assembly for a workbench according to claim 30, wherein said one or more supports extend from one or more of the legs or from any leg cross struts provided thereto.

32. A frame assembly for a workbench according to claim 30, wherein each of the one or more supports comprises a snap-link provided with a lock for locking said link rigid.

33. A frame assembly for a workbench according to claim 12, additionally comprising first and second sprung couplings act to respectively couple said trunk to the underside of each of the first and second primary work surface frames.

34. A frame assembly for a workbench according to claim 1, wherein the frame assembly is symmetrical about the central spine.

35. A frame assembly for a workbench according to claim 12, wherein the frame assembly adopts a back-to-back parallelogram frame arrangement that is symmetrical about the trunk.

36. A frame assembly for a workbench according to claim 1, wherein adjacent pairs of legs are provided with a cross-brace.

37. A workbench comprising a frame assembly that is reversibly foldable from an in-use to a folded configuration, the frame assembly having:

a central spine;

first and second primary work surface frames, each work surface frame having an inner edge, an outer edge and two side edges, wherein each said inner edge thereof hingedly mounts to the central spine such that the primary work surface frames are foldable towards each other; and

first and second opposing pairs of legs, each leg pivotally mounting to one end of an outer edge of the first and second primary work surface frames, such that the legs of each opposing pair are foldable towards each other,

wherein the inner edge of each of the first and second primary work surface frames hingedly mounts to the central spine by a distinct hinge mounting such that in the folded configuration, opposing side edges of the respective first and second primary work surface frames are brought parallel with each other and each of the legs is brought parallel with a side edge thereof, further comprising

first and second primary work surfaces provided to the first and second primary work surface frames.

38. A workbench according to claim 37, additionally comprising first and/or second subsidiary work surface frames, each respective subsidiary work surface frame pivotally mounting to an outer edge of the first and second primary work surface frames,

wherein in the folded configuration, each respective subsidiary work surface frame is brought parallel with its primary work surface frame and additionally comprising first and/or second subsidiary work surfaces provided to the first and/or second subsidiary work surface frames.

39. A workbench according to claim 37, wherein the central spine defines a rectangular top surface that in the in-use configuration defines a central work surface of the workbench.

40. A workbench according to claim 39, wherein the width of said rectangular top surface corresponds essentially to the combined width of the first and second primary work surface frames and their respective first and second work surfaces, when brought together in the folded configuration.

41. A workbench according to claim 37, wherein in the folded configuration the first and second primary work surfaces rest flush with each other.

42. A workbench according to claim 37, wherein in the folded configuration, the legs rest flush with the underside of the first and second primary work surfaces.

43. A workbench according to claim 38, wherein in the folded configuration, the legs rest flush with the underside of the first and second subsidiary work surfaces.

44. A workbench according to claim 38, wherein the first and/or second subsidiary work surfaces are provided with an access hole to enable the user to access an actuator arm of any safety catch provided to the underside thereof.

45. A workbench according to claim 38, wherein at least one of the first and/or second subsidiary work surfaces mounts to its subsidiary work surface frame by a slide track mounting.

46. A workbench according to claim 37, additionally including a clamp.

47. A workbench according to claim 46, wherein said clamp is provided to the first and/or second primary work surfaces and/or the first and/or second subsidiary work surfaces.

48. A workbench according to claim 46, wherein the clamp comprises a base defining a plug sized and shaped for receipt within an access hole of a subsidiary work surface of the workbench.

49. A workbench according to claim 48, wherein said base is provided with a flange, which in-use seats against the subsidiary work surface when the plug seats within the access hole.

50. A workbench according to claim 48, wherein said plug includes a lateral slot arranged for receipt of a securing bolt for securing an arrangement of a lower jaw;

compressible block; and upper jaw to the base.

51. A workbench according to claim 50, wherein said securing bolt is provided with a head, which is arranged to receive a handle.

52. A workbench according to claim 51, wherein turning movement of said handle causes a loosening of the securing bolt, which enables the jaw and block arrangement to be moved laterally within the slot.

53. A workbench according to claim 52, wherein a reverse turning movement of the handle relative to the base allows for securing of the jaw and block arrangement at a particular lateral position within the slot of the base.

54. A workbench according to claim 53, wherein said reverse turning movement of the handle compresses said compressible block, which expands outwardly to exert a clamping force.

55. A workbench according to claim **51**, wherein the clamp is additionally provided with one or more stops to prevent overtravel of the handle.

56. A workbench according to claim **17**, additionally comprising a tray provided to the tray framework.

57. A workbench according to claim **36** in kit of parts form.

58. Kit of parts comprising a:

workbench having a frame assembly that is reversibly foldable from an in-use to a foldable configuration, the frame assembly having:

a central spine,

first and second primary work surface frames, each work surface frame having an inner edge, an outer edge and two side edges, wherein each said inner edge thereof hingedly mounts to the central spine such that the primary work surface frames are foldable towards each other, and

first and second opposing pairs of legs, each leg pivotally mounting to one end of an outer edge of the first and second primary work surface frames, such that the legs of each opposing pair are foldable towards each other,

wherein the inner edge of each of the first and second primary work surface frames hingedly mounts to the central spine by a distinct hinge mounting such that in the folded configuration, opposing side edges of the respective first and second primary work surface frames are brought parallel with each other and each of the legs is brought parallel with a side edge thereof, further comprising

first and second primary work surfaces provided to the first and second primary work surface frames; and

a wall mounting suitable for mounting one half of the workbench in its folded configuration whilst the other half is in the in-use configuration.

* * * * *

Course/Project name:			**Categories**							
Collapsable Workbench			1 = casters							
Date:			2 = hinges							
4/22/19			3 = wood							
Instructor/Supervisor Name:			4 = fastners							
Jamil Abdo			5 = OTS supports							
Project Student members:			6 = PLA				=Complete			
Devon Zollinhofer							=Incomplete			
Matt Beall										
Zach Cross										
Demetrick McDonald										
Andrew Saku										
Purchased Items					**Purchasing Budget:**				**$250.00**	Link
Quantity	**Unit**	**Cat. No.**	**Descritption**	**Vendor**	**Unit Cost**	**Usage**	**Ext. Cost**	**Shipping**	**Total**	
3	Pair	2	3" Narrow Butt hinge	Lowes	$2.98	100.00%	$9.48	$0.00	$9.48	https://www.lowes.com/pd/Gatehouse-3-in-Zinc-Mortise-Door-Hinge-2-Pack/50041814
1	N/A	2	4" Strap hinge	Lowes	$2.98	100.00%	$3.16	$0.00	$3.16	https://www.mcmaster.com/1526a51
1	lb	4	Wood Construction Screws	Lowes	$6.98	55.26%	$4.09	$0.00	$4.09	
4	N/A	5	SS supports	Amazon	$25.99	100.00%	$110.20	$9.51	$119.71	https://www.amazon.com/YUMORE-Folding-Shelf-Brackets-Load/dp/B07F3RBFXC
			*** When ordering for P2, order 1 less PAIR of brackets -> Buy total of 3 pairs							
2	in	3	2x4x12' Long Pine	Lowes	$5.31	100.00%	$11.26	$0.00	$11.26	https://www.lowes.com/pd/Top-Choice-2-x-4-x-12-ft-Spruce-Pine-Fir-Lumber-Common-1-5-in-x-3-5-in-x-12-ft-Actual/1000464217
1	in	3	4X4x8' Long Pine	Lowes	$12.98	100.00%	$13.76	$0.00	$13.76	https://www.lowes.com/pd/Severe-Weather-Common-4-in-x-4-in-x-6-ft-Actual-3-5-in-x-3-5-in-x-6-ft-2-Treated-Lumber/4745827
1	in	3	1x4x8' Pine	Lowes	$4.97	100.00%	$5.27	$0.00	$5.27	https://www.lowes.com/pd/Severe-Weather-Common-x-8-ft-Actual-0-75-in-x-3-5-in-x-8-ft-Appearance-Treated-Lumber/4745763
1	in	3	Table & Back(Plywood 23/32"x4'x8')	Lowes	$10.64	100.00%	$11.28	$0.00	$11.28	https://www.lowes.com/pd/Plytanium-23-32-CAT-PS1-09-Pine-Plywood-Sheathing-Application-as-4-x-8/1000068939
2	N/A	2	Removeable pin hinge	Lowes	$2.88	100.00%	$6.11	$0.00	$6.11	https://www.rosebrand.com/product2623/Rose-Brand-Loose-Pin-Hinge.aspx?tid=3&info=Slip%2BHinge
1		4	Gorilla Glue	Lowes	$3.98	25.00%	$1.05	$0.00	$1.05	
1	Pack	4	Washers	Lowes	$6.88	64.00%	$4.67	$0.00	$4.67	
4		1	3" Caster wheels locking	Lowes	$7.58	100.00%	$32.14	$0.00	$32.14	https://www.lowes.com/pd/Waxman-3-in-Rubber-Swivel-Caster/1000596097
2	Pack		2" Barrel Lock	Lowes	$2.78	100.00%	$2.95	$0.00	$5.90	https://www.lowes.com/pd/Gatehouse-2-in-Zinc-Steel-Barrel-Bolts/50088770
4	Pack		Zinc eye-loop	Lowes	$0.68	100.00%	$0.72	$0.00	$2.88	https://www.lowes.com/pd/National-Hardware-Zinc-Plated-1-Count/1000362349
2	Pack		Hook and Turnbuckle	Lowes	$1.78	100.00%	$1.89	$0.00	$3.78	https://www.lowes.com/pd/National-Hardware-1-4-x-7-1-2-Aluminum-Steel-Hook-And-Hook-Turnbuckle/1000422515
							0.00		$0.00	Use 1/2" plywood and/or 2" casters if expenses too close
							0.00		$0.00	
							0.00		$0.00	
							0.00		$0.00	
					Purchased Total				$234.52	
					Remaining Balance				$15.48	
In Kind Service					**In Kind services Budget**				**$185.00**	
			Descritption				Hours	Rate	Total	
BAM							0	18.5	$0.00	
Machine Shop			Wood Cutting	Machine Shop			10	18.5	$185.00	
					In Kind Service Total				$185.00	
					In Kind Budget Balance				$0.00	

A. JAMES CLARK
SCHOOL OF ENGINEERING

FROSTBURG
STATE UNIVERSITY

SOP 2 - Shop Procedure

ENME 472
Spring 2019

Project Name:
Space Saving Workbench
Team Name:
Space Force - We Save Your Space

Team Members:
Matthew Beall
Zachary Cross
Demetrick McDonald
Andrew Saku
Devon Zollinhofer

Team Member Signatures:

_____

_____

_____

Advisor Signature:

_____

Shop Signature:

_____

I. Introduction

- **Objective**: Cut raw materials into required dimensions.
- **Date**: Tuesday 4/16/2019
- **Location**: Compton 108
- **Attendees**: Mr. Fearon

II. Procedure

1. Devise cut list for shop to follow.
2. Purchase and pick up required material.
3. Store material in room 108 for easy access by Mr. Fearon.
4. Attend consultation with Mr. Fearon to discuss cut list and subsequent SOP requirements.
5. Receive cut material from Mr. Fearon.

III. Cut List

Materials:

- Two 2” x 4” x 12’ Pine wood
- One 4” x 4” x 6’ Pine wood
- One 1” x 4” x 8’ Pine wood
- One 4’ x 8’ x ¾’’ Plywood

Instructions:

REFERENCE DRAWING 1 (attached) FOR THE FOLLOWING CUTS.

---

1. Remove rounded edges by rip cutting ½” off each side of boards used.
2. Select one (1) 2” x 4” x 12’ to use for steps 3-5
3. Cut two(2) 24” length boards corresponding to **ITEM NO.’s 1 and 7**.
4. Cut three(3) 21” length boards corresponding to **ITEM NO.’s 2 and 5**.
5. Cut one(1) 19.5” length board corresponding to **ITEM NO. 8**
6. **Repeat steps 3-5** using the second 2” x 4” x 12’ for the cuts.
    a. You should have two pieces of scrap wood left over totalling 27” or about 13.5” a piece.

For directions 7-8 the quantities on the drawings will not match the total amount of cuts. The quantity of cuts have been doubled in order to construct two sets of the table’s rolling leg base. This need was addressed for the earlier parts though part 6.

7. Using the 1” x 4” x 8’ Pine wood, cut four(4) 16” length boards corresponding to **ITEM NO.’s 3 and 4**.
    a. The reaming wood from this cut will be used in the next section.
8. Using the 4” x 4” x 6’ Pine wood, cut two(2) 21” length boards corresponding to **ITEM NO. 6**.
    a. There should be about 30’’ left over.

REFERENCE DRAWING 2 (attached) FOR THE FOLLOWING CUTS.

---

1. Remove rounded edges by rip cutting ½” off each side of boards used.
2. Select the 4’ x 8’ x ¾’’ Plywood to use for steps 3-4
3. Cut four(4) 24” x 14.25” panels corresponding to **ITEM NO. 1**.
4. Cut two(2) 11.25” x 13.05” panels corresponding to **ITEM NO. 4**.
5. Using the reaming 1” x 4” x 8’, cut two(2) 13.05” length boards corresponding to **ITEM NO. 2**.

Notes:

1. Though the team focused on scrap conservation sometimes it was cheaper to go with more wood than we needed.
2. **We will require an SOP for all procedures taken place.**

A. JAMES CLARK
SCHOOL OF ENGINEERING

FROSTBURG
STATE UNIVERSITY

SOP 3 - Prototype 2 Build Day 1

ENME 472
Spring 2019

Project Name:
Space Saving Workbench
Team Name:
Space Force - We Save Your Space

Team Members:
Matthew Beall
Zachary Cross
Demetrick McDonald
Andrew Saku
Devon Zollinhofer

Team Member Signatures:

_____

_____

_____

Advisor Signature:

_____

Shop Signature:

_____

I. Introduction

- **Objective**: Begin assembly of prototype 2, complete both side frames.
- **Date**: Wednesday 4/17/2019
- **Time**: 5:30PM-8:30PM
- **Location**: Compton 109
- **Attendees**: Zach Cross, Demetrick McDonald

II. Safety

In the lab, we must follow the laboratory safety policies of Frostburg State University, the Physics and Engineering department, and the Chemical Hygiene Plan. Due to safety, we are not allowed to operate some machinery without supervision, permission, and completed safety protocols. Safety glasses must be used at all times in the lab.

Potential hazards include pinching and crushing from assembling and operating the product.

In case of an emergency or injury, we will call 911, local emergency number (such as Frostburg State Campus Police or Frostburg City Police), or local health care center, including the Frostburg Medical Center and the Western MD Regional Medical Center. Thereafter, we will contact faculty assigned to our project to file an injury report form. Mr. Fearon MUST be present to begin construction.

III. Materials

1. 2 ea. 24”L x 3.5”W x 1.5” H(A): **ITEM NO.’s 1 and 7**
2. 3 ea. 21”L x 3.5”W x 1.5” H(B): **ITEM NO.’s 2 and 5**
3. 1 ea. 21”L x 3.5”W x 3.5” H(C): **ITEM NO. 6**
4. 2 ea. 16”L x 2.5”W x 0.75”H(D): **ITEM NO.’s 3 and 4**
5. 1 ea. 19.5”L x 3.5”W x 1.5”H(E): **ITEM NO. 8**
6. 1 ¼ wood screws
7. 12 ea. ½” wood screws
8. 1 bottle of Gorilla Wood Glue

IV. Tools (continued on next page)...

1. Large clamps
2. Sand paper
3. Tape measure
4. Right angle square
5. M12 Fuel Milwaukee cordless driver

6. Phillips-head driving bit attachment
7. $\frac{7}{64}$ ” drill bit

V. Procedure (continued on next page)...

Make notes on any changes in procedure throughout the process

Refer to drawing 1 (attached)

1. Gather and equip safety gear (as listed above). Receive all pieces from Mr. Fearon and gather screws
2. Gather M12 Fuel Milwaukee cordless driver and phillips-head driving bit attachment.
3. Lay Item #7 on the table so its widest side is laying flat against the table surface.
4. Align (2) Item #2 boards perpendicular to Item #7 board so they from a 90 degree square.
5. Allow a small gap between the boards to apply wood glue to the mating surface and apply clamps to the joints.
6. Before attaching any screws, align Item #1 board to the top of the unfinished 90 degree square. At this point you should have a square with 90 degree angles, wood glue applied to each mating joint, and clamps that allow for the wood glue to cure.
7. Position Item #6 directly underneath Item #1 so it is positioned between the two both item #2 vertical boards. Make sure space is left to apply the glue.
8. Apply glue to the top, left, and right faces fitting under the square made from the previous steps. Apply a clamp horizontally for positive clamping force between item’s #2 and item #6.
9. Directly underneath board (C) place another board (B) in the same orientation as board (C)
10. Apply glue to each end of board (B) and apply clamps to allow for positive clamping force on the joint.
11. At this point make sure the square is still 90 degrees in all 4 corners.
12. Directly parallel to the 2 vertical boards in Step 5, place board (D) on the inside edge of board (B). Repeat this process for the other side of the square.
13. Apply wood glue to the back side of board (D) and apply clamps so that boards (D) and (B) are sandwiched together.
14. Above board (A) in step 4, place board (B) on top of board (A) so that it sits on its 1.5” side.
15. Apply wood glue along board (B) mating surface and apply a clamp.
16. At this part, make sure the square you have constructed has not shifted from 90 degrees in each of the 4 corners. If it has, reposition the joints as needed to allow for 90 degree angles in each of the 4 corners.
17. On the bottom side of board (A) place (board (A) from step 4) place a caster 2” from each end of the board (A). Make sure the casters are positioned on centre.

18. Apply (8) screws to securely fasten the casters to board (A)
19. At this point, apply screws in all the areas noted within the drawing to allow for the glue to properly cure. Make sure after applying the screws that your angles within the square have not changed.
20. Remove the clamps and allow the wood glue to completely dry.
21. Repeat this process to mirror the other side of the workbench build.

A. JAMES CLARK
SCHOOL OF ENGINEERING

FROSTBURG STATE UNIVERSITY

SOP 4 - Prototype 2 Build Day 2 [Revised]

ENME 472
Spring 2019

Project Name:
Space Saving Workbench
Team Name:
Space Force - We Save Your Space

Team Members:
Matthew Beall
Zachary Cross
Demetrick McDonald
Andrew Saku
Devon Zollinhofer

Team Member Signatures:

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Advisor Signature:

Shop Signature:

I. Introduction

- **Objective**: Assemble the remaining items involved with prototype 2.
- **Date**: 4/18/19
- **Time**: 6:00PM-8:30PM
- **Location**: Compton 109
- **Attendees**: Devon Zollinhofer, Matthew Beall, Andrew Saku

II. Safety

In the lab, we must follow the laboratory safety policies of Frostburg State University, the Physics and Engineering department, and the Chemical Hygiene Plan. Due to safety, we are not allowed to operate some machinery without supervision, permission, and completed safety protocols. Safety glasses must be used at all times in the lab.

Potential hazards include pinching and crushing from assembling and operating the product.

In case of an emergency or injury, we will call 911, local emergency number (such as Frostburg State Campus Police or Frostburg City Police), or local health care center, including the Frostburg Medical Center and the Western MD Regional Medical Center. Thereafter, we will contact faculty assigned to our project to file an injury report form.

III. Materials

1. 4 ea. 24”L x 14.5”W x 23/32”H *Plywood* : **ITEM NO. 10**
2. 2 ea. 13.05”L x 4”W x 1”H *Pine*: **ITEM NO. 11**
3. 6 ea. 2.5” *Butt Hinge* : **ITEM NO. 12**
4. 2 ea. 11.25”L x 13.05”W x 23/32” *Plywood* : **ITEM NO. 13**
5. 8 ea. *Folding Brackets* : **ITEM NO. 14**
6. 1 ea. *Strap Hinge* : **ITEM NO. 15**
7. 1 ea, *Pin Hinge* : **ITEM NO. 16**
8. 16 ea. ½” *screws* (included with bracket purchase)
9. 16 ea. 1¼” *screws* (included with bracket purchase)
10. 4 ea. 3” Swivel Casters
11. **4 ea. Zinc eye-loop ITEM NO. 18**
12. **2 ea. Hook and Turnbuckle ITEM NO. 19**
13. **2 ea. 2” Barrel Lock (Includes (6) ½” *screws)* ITEM NO. 20**

IV. Tools (continued on next page)...

1. Clamps
2. Sand paper
3. Tape measure
4. Right angle try square
5. M12 Fuel Milwaukee cordless driver
6. Phillips-head driving bit attachment
7. $\frac{7}{64}$ ” drill bit

V. Procedure (continued on next page)...

Make notes on any changes in procedure throughout the process

Refer to Drawing 1 for Items #1-9 and Drawing 2 for Items #10-16 (attached)

1. Lay two boards of Item #10 flat on the table with the top facing down, make sure that the long edges are parallel. Create a small gap between the table tops.
2. Place the square support (made during SOP 2.1) upside down and perpendicular to the length on top of the joint between two of Item #10 so that the frame has an equal amount of both boards touching it. Be sure that the inside (which features the cut 1 x 4 inside the frame) is facing towards the center of the table length.
3. Place four of Item #14 onto both of Item #10 with two on each side of the square frame with the short edge touching the square frame.
4. Space them as indicated in Drawing 2.
5. Mark the holes from Item #14 onto Item #10 and Item #6, remove Item #14 and drill pilot holes where marked.
6. Align Item #14 with pilot holes driven in previous step, drive 2 ½” screws into Item #10 and two 1¼” screws into Item #6.
7. Repeat Steps 1-6 for the other half of the table.
8. Lay the assembly on its side so the the square frame and the table tops make a T shape.
9. Lay a scrap piece of 2 x 4 between the two sides, this will serve as a support when drilling Item #13.
10. Place both sides Item #13 in place, be sure that there is enough room above it to clear Item #14 as well as Item #11 which will be in place below.
11. Place two of Item #12 on both ends of Item #13 as indicated in Drawing 2.
12. Mark and drill pilot holes after the proper fitting of Item #13.
13. Fasten Item #12 using the screws included with their purchase to Item #13 and Item #3
14. Secure the center of Item #13 using both of Item #16, equally spaced in the vertical direction.
15. Next, place both of Item #11 flat on the table, secure them together (with a small gap in between) using Item #15 and the screws included in its purchase.

16. Flip the entire assembly over so that Item #13 is now the highest vertically.
17. Place the assembly of the two Item #13s in place as indicated on Drawing 2. Scrap 2 x 4 may be used to support the weight of these items.
18. Align two of Item #12 in the proper locations on both ends according to Drawing 2.
19. After checking that the length is correct, mark and drill pilot holes into Item #2 and Item #11.
20. Drive the screws included with Item #12 into Item #2 and Item #11.
21. Lay the entire assembly upside down.
22. Place Item #17 in place according to Drawing 1.
23. Mark the hole locations, remove the item, drill pilot holes.
24. Return Item #17 to the location and secure by driving screws into the pilot holes
25. **Place the table upside down, so the tabletop surface is lying flat against work surface.**
26. **Place (1) Item #20 directly centered between the gap of item #10 (The two inner-middle top panels). Place (6) ½" screws in item #20 to securely fasten to item #10**
27. **Fully extend item #15 to its most horizontal position. Directly on the opposite side of item #15, place (1) item #20 centered between the gap.**
28. **Place (6) ½" screws into item #20 to securely fasten it to the back side (opposite) side of item #15.**
29. **Turn the table upright, so it is fully extended and in the correct orientation.**
30. **Screw in by hand item #18 into item #2. Item #18 should be positioned in the middle of item #2. (equal distance from the top/bottom and left/right)**
31. **Repeat this for the other three leg post. The table should have (2) item # 18 on the front and (2) item #18 on the back.**
32. **Attach (1) item #19 to the left, front side of item # 18 by placing the hook of item #19 into the loop of item #18.**
33. **Attach the second item #19 to the left, back side of item # 18 by placing the hook of item #19 into the loop of item #18. (There will be one item #19 on the front side of the table and one on the back side of the table)**

A. JAMES CLARK
SCHOOL OF ENGINEERING

FROSTBURG STATE UNIVERSITY

SOP 5 - Prototype 2 Build Day 3 [Revised]

ENME 472
Spring 2019

Project Name:
Space Saving Workbench
Team Name:
Space Force - We Save Your Space

Team Members:
Matthew Beall
Zachary Cross
Demetrick McDonald
Andrew Saku
Devon Zollinhofer

Team Member Signatures:

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Advisor Signature:

Shop Signature:

I. Introduction

- **Objective**: Finish the assembly of prototype 2.
- **Date**: 4/19/19
- **Time**: 10:00AM-12:00PM
- **Location**: Compton 109
- **Attendees**: Devon Zollinhofer, Matt Beall, Andrew Saku, Demetrick McDonald, Zach Cross

II. Safety

In the lab, we must follow the laboratory safety policies of Frostburg State University, the Physics and Engineering department, and the Chemical Hygiene Plan. Due to safety, we are not allowed to operate some machinery without supervision, permission, and completed safety protocols. Safety glasses must be used at all times in the lab.

Potential hazards include pinching and crushing from assembling and operating the product.

In case of an emergency or injury, we will call 911, local emergency number (such as Frostburg State Campus Police or Frostburg City Police), or local health care center, including the Frostburg Medical Center and the Western MD Regional Medical Center. Thereafter, we will contact faculty assigned to our project to file an injury report form.

III. Materials

1. 4 ea. 24”L x 14.5”W x 23/32”H *Plywood* : **ITEM NO. 10**
2. 2 ea. 13.05”L x 4”W x 1”H *Pine*: **ITEM NO. 11**
3. 6 ea. 2.5” *Butt Hinge* : **ITEM NO. 12**
4. 2 ea. 11.25”L x 13.05”W x 23/32” *Plywood* : **ITEM NO. 13**
5. 8 ea. *Folding Brackets* : **ITEM NO. 14**
6. 1 ea. *Strap Hinge* : **ITEM NO. 15**
7. 1 ea, *Pin Hinge* : **ITEM NO. 16**
8. 16 ea. ½” *screws* (included with bracket purchase)
9. 16 ea. 1¼” *screws* (included with bracket purchase)
10. 4 ea. 3” Swivel Casters
11. **4 ea. Zinc eye-loop ITEM NO. 18**
12. **2 ea. Hook and Turnbuckle ITEM NO. 19**

13. **2 ea. 2” Barrel Lock (Includes ½” *screws)* ITEM NO. 20**

IV. Tools (continued on next page)...

1. Clamps
2. Sand paper
3. Tape measure
4. Right angle try square
5. M12 Fuel Milwaukee cordless driver
6. Phillips-head driving bit attachment
7. $\frac{7}{64}$ ” drill bit

V. Procedure (continued on next page)...

Make notes on any changes in procedure throughout the process

Refer to Drawing 1 for Items #1-9 and Drawing 2 for Items #10-20 (attached)

1. Evaluate progress completed in the previous day.
2. Finish all necessary steps.
3. Refine previous progress and ensure quality construction.

A. JAMES CLARK
SCHOOL OF ENGINEERING

FROSTBURG
STATE UNIVERSITY

SOP 6 - Test Procedure

ENME 472
Spring 2019

Project Name:
Space Saving Workbench
Team Name:
Space Force - We Save Your Space

Team Members:
Matthew Beall
Zachary Cross
Demetrick McDonald
Andrew Saku
Devon Zollinhofer

Team Member Signatures:

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Advisor Signature:

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Shop Signature:

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I. Introduction

- **Objective**: Test prototype 2 for load capabilities.
- **Date**: Thursday 4/25/2019
- **Time**: 5:00PM - 7:00PM
- **Location**: Home weight lab
- **Attendees**: Matt Beall

II. Safety

Procedures outlined in this SOP must be followed to ensure proper loading of test, and to limit exposure to injury. Loading must be performed in an incremental manner to ensure overloading potential is reduced. Potential hazards for this test include crushing due to loading weight during test. In the event of emergency emergency medical personnel will be contacted. Thereafter, we will contact faculty assigned to our project to file an injury report form.

III. Materials

- Bench prototype 2
- Three 45 lb weights
- Two 35 lb weights
- Two 25 lb weights
- Two 10 lb weights
- Two 5 lb weights

IV. Procedures

1. Setup workbench in the operational position, fully opened and all braces locked.
2. Place a 45 lb weight on table top; make observations on any deflection, noise or potential failure.
3. Repeat step 2 for each weight until the maximum test weight is achieved, deflection is becoming too large, or until the procedure is deemed too unsafe to continue.

ENME 472 Spring 2019
Project Name: Space Saving Workbench
Team Name: Space Force
Members: Matt Beall, Zach Cross, Demetrick McDonald, Andrew Saku, Devon Zollinhofer
Advisor: Dr. Jamil Abdo

The typical workbench takes up a considerable amount of space when fixed in one location. Therefore, it can be difficult for individuals with limited workspace to perform do-it-yourself (DIY) projects in their homes, garages, or other workspaces. Our capstone project, the Space Saving Workbench, solves that problem. Our solution is a large mobile and completely collapsible workbench. Casters allow the workbench to be moved around a workspace while a unique wood and hinge-based design allows the full-size workbench (57”L X 24”W X 27”H) to be folded into a shape roughly a third of the original size. Utilizing CAD simulation and scaled-down testing, we will assemble a successful prototype of the workbench that proves the initial concepts. Following the design process we have completed the following tasks:

- Problem identification
- Established customer needs.
- Research and gathering of information.
- Concept generation and rating using a morphological chart and AHP.
- Construction of an initial prototype.

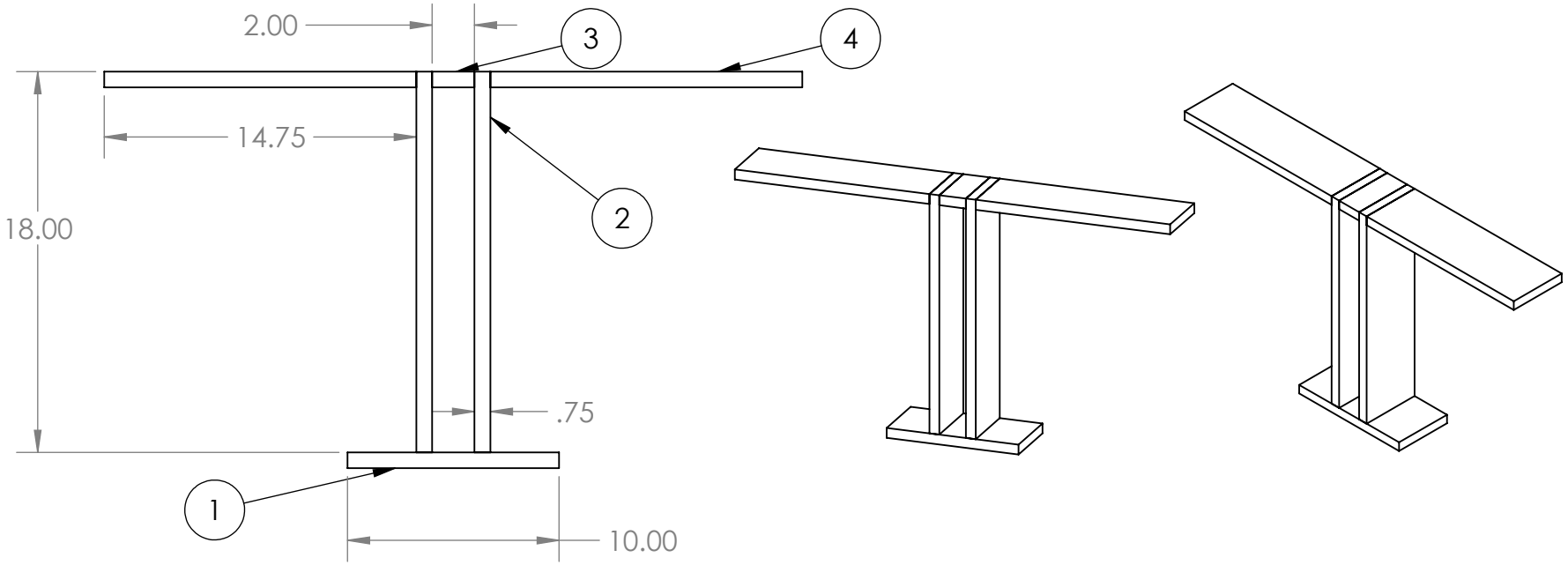
Following the engineering design process, we will:

- Analyze the structural integrity and stability using hand calculations and FEA software.
- Create a scale-down prototype as close to our envisioned product, within the means of our budget.
- Complete testing of our final prototype to understand its full capabilities.

In order to complete these tasks, we will need:

- Occasional supervised access to rooms 108 and 109 of the Compton Science Center.
- Frequent access to CAD programs on campus.
- Access to drills, screws, and other woodworking materials in the laboratory.
- Raw material cut to size by Mr. Fearon.
- Ability to purchase materials not available on campus, including wood, hinges, and screws.

If this project is approved to move forward, our efforts will result in the completion of a final prototype to display our proposed products feasibility. In doing all of this we will be certain to follow safety rules and guidelines accompanied with particular rooms, tools, or processes.



The thickness of all cuts are $\frac{3}{4}$" thick unless specified

All cuts need to be flat. (90 degree)

ITEM NO.	QTY.	DESCRIPTION	LENGTH
1	1	Base Plate	10" L x 4.8125" W
2	2	Side Plate	18" L x 4.8125" W
3	1	Top Plate	2" L x 4.8125" W
4	2	Side Flap	14.75" L X 4.8125" W

NEXT ASSY	USED ON	
APPLICATION		DO NOT SCALE DRAWING

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Pine wood

FINISH

	NAME	DATE
DRAWN	Zach Cross	3/5/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
Cut List

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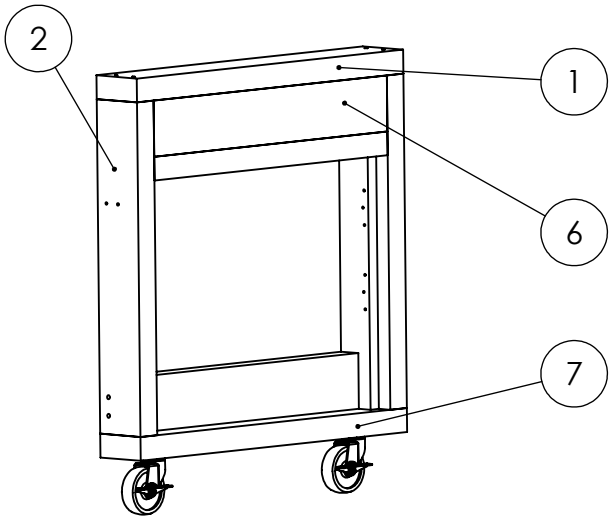

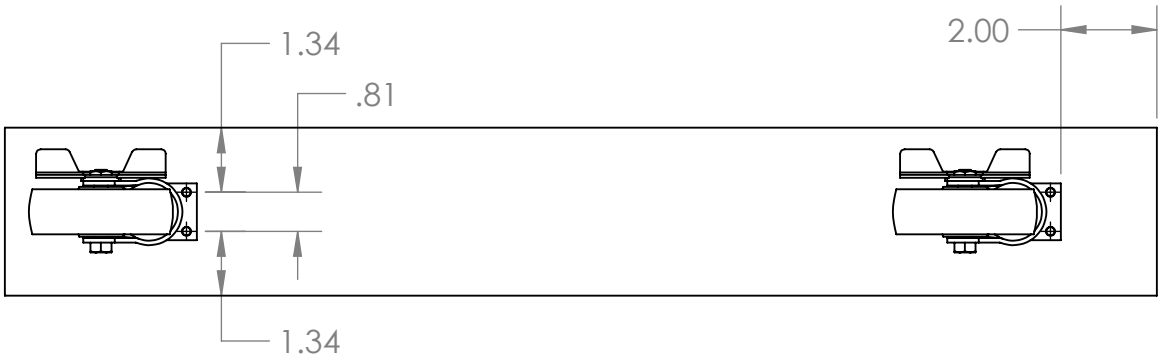

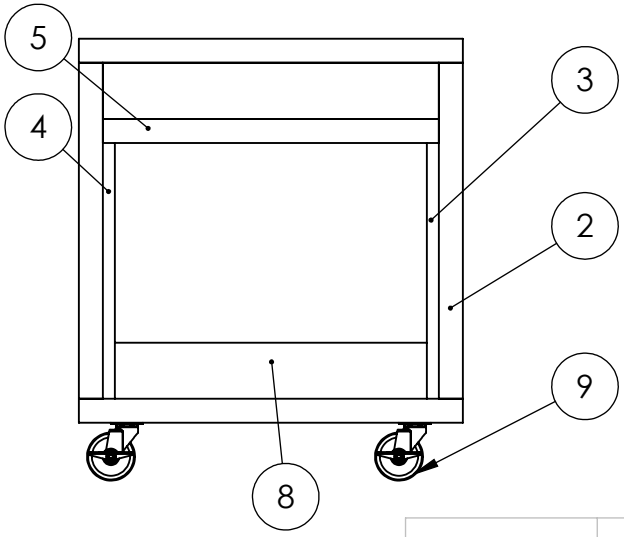

ITEM NO.	QTY.	DESCRIPTION	LENGTH
1	1	Top Frame board	1.5" x 3.5" x 24"
2	2	Side Frame Board	1.5" x 3.5" x 21"
3	1	Inner Hinge Board	0.75" x 2.5" x 16"
4	1	Inner Hinge Board	0.75" x 2.5" x 16"
5	1	Bracket Support Board	1.5" x 3.5" x 21"
6	1	Mounting Bracket Board	3.5" x 3.5" x 21"
7	1	Bottom Frame Board	1.5" x 3.5" x 24"
8	1	Lower Support Board	1.5" x 3.5" x 19.5"
9	2	Caster	N/A

		UNLESS OTHERWISE SPECIFIED:		NAME / DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	Zach Cross 4/2/19
			CHECKED	
			ENG APPR.	
			MFG APPR.	
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.	
		MATERIAL: Pine	COMMENTS:	
NEXT ASSY	USED ON	FINISH: Un-finshed		
APPLICATION		DO NOT SCALE DRAWING		

TITLE:

SOP 2.1 Cut list

SIZE	DWG. NO.	REV
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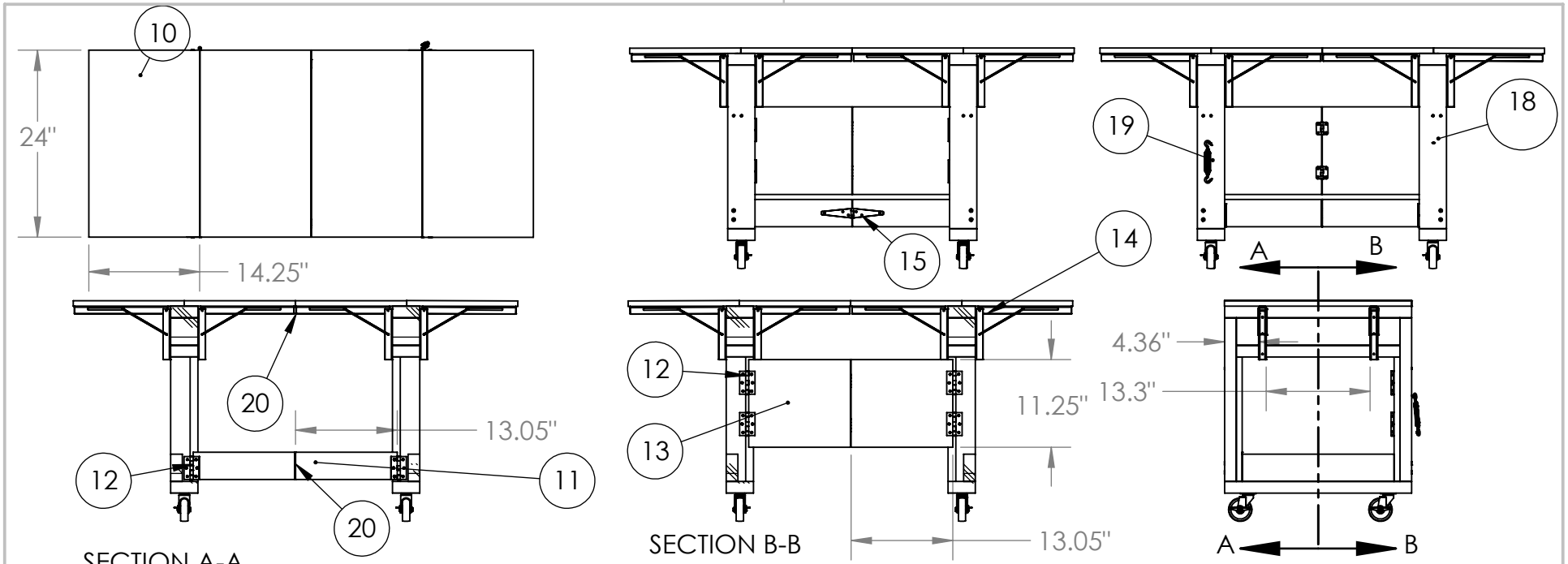
SCALE: 1:12	WEIGHT:	SHEET 1 OF 1



SECTION A-A

SECTION B-B

ITEM NO.	DESCRIPTION	QTY.	LENGTH	Notes
10	Table Top Pannel	4	24" x 14.25"	Plywood
11	Bottom Brace	2	13.05" length	1" x 4" board
12	Butt Hinge	6	2.5"	
13	Back Brace	2	11.25" x 13.05"	Plywood
14	Bracket	8		
15	Strap Hinge	1		
16	Pin Hinge	2		
18	Eye Loop	4		
19	Hook & Turnbuckle	2		
20	Barrel Lock	2		

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

SIZE	DWG. NO.	REV
A	SOP 2.2 [Revised]	
SCALE: 1:20	WEIGHT:	SHEET 1 OF 1