

Prototype: Phase II

Construction Team B1
GNG1103B – Engineering Design

Introduction

Given the importance of a space-minimizing bed and the dimensional problems with our previous design, as discussed in our previous prototyping deliverable, this document focuses exclusively on the design and analysis of a revised bed which addresses these issues. Due to scheduling difficulties, we have not had the opportunity to review our previous prototype with the client, so our only means of evaluating the suitability of the design is through our design criteria and metrics.

A number of changes have been made in this iteration (more specific details can be found throughout the document):

- The bed has been narrowed to meet the dimensional constraints of the structure
- After discussion with the water design team, the counter has been lowered to increase water pressure; it has also been extended to provide more counterspace and to accommodate a sink
- Hardware requirements and costs have been included
- Mattress weight and subassembly-specific center of gravity have been calculated to provide a more accurate estimate of latching and lifting forces

This prototype has been developed to:

- Determine whether or not the revised bed meets the dimensional constraints of the structure
- Recalculate the functional space in the structure given changes in the bed's width
- Determine hardware requirements and costs
- Calculate, with higher fidelity, the mass, center of gravity, and forces on the bed
- Ensure the dimensional consistency and alignment of all components and hardware to provide a basis for technical drawings and construction workflow (this is not included explicitly in this deliverable, but is implicit in the constrained assembly used for the CAD model and drawings presented throughout the document)

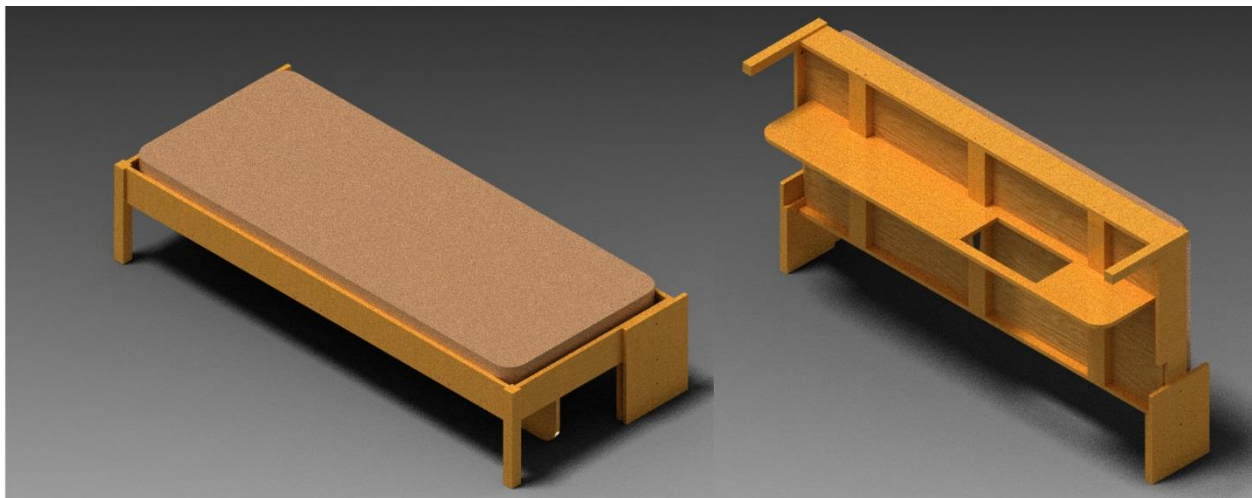


Figure 1: Isometric render of CAD model in both horizontal and upright positions

Dimensions and Functional Space

Dimensional constraints – The upper bound on the size of the bed has not changed since the previous deliverable: the interior space of the structure is still 40.25" × 88.25". However, the lower bound has been changed in order to address the dimensional concerns from our previous prototype. The bed has been redesigned to accommodate a daybed-sized mattress (30" × 74") rather than a twin-sized mattress. As shown in Figure 2, the redesigned bed satisfies both of the above dimensional constraints.

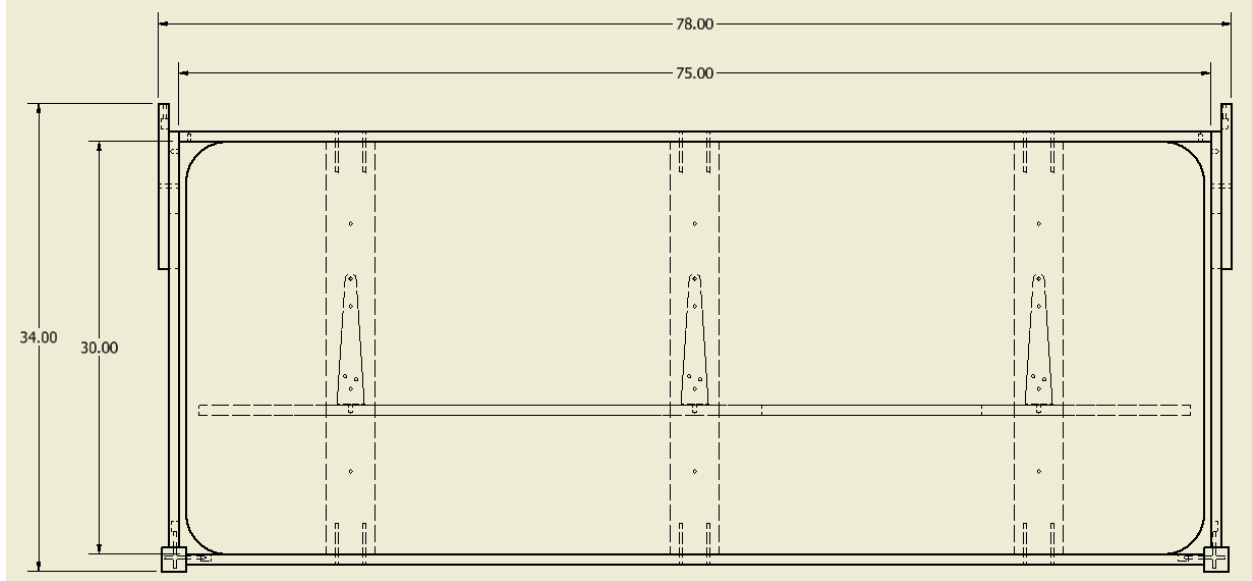


Figure 2: Base dimensions of bed (top view)

It is still necessary to ensure that the maximum projected width of the bed does not exceed the upper bound defined above. Referring to Figure 3, and performing a similar analysis as the one conducted for the previous design, the maximum projected width is

$$w_{proj} = d + \sqrt{w^2 + h^2}$$

$$w_{proj} = 6.00 \text{ in} + \sqrt{28.00^2 + 16.00^2} \text{ in} \cong 38.25 \text{ in}$$

This value is within the necessary bounds.

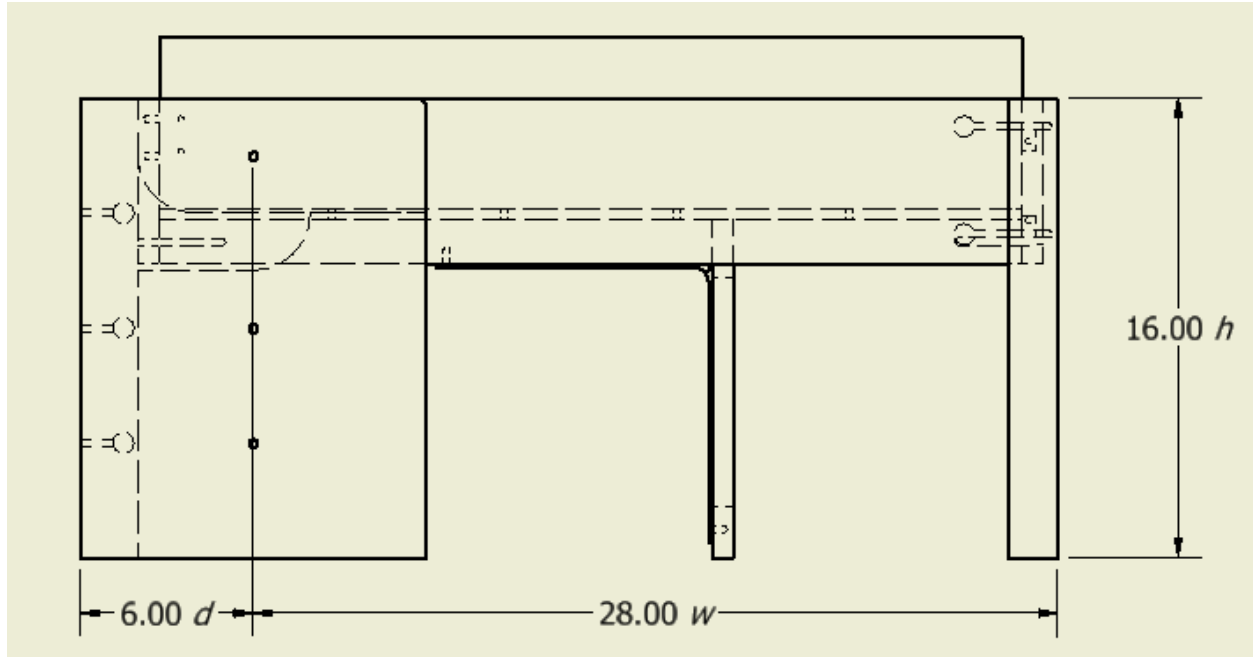


Figure 3: Relevant parameters for projected width (side view)

Functional space – Referring back to Figure 2 and the interior dimensions of the structure, the area occupied by the bed in the horizontal position is:

$$A_h = \frac{78.00 \times 34.00}{88.25 \times 40.25} \cong 74.7\%$$

This value represents a considerable improvement over the previous design (91.1%). This additional space will make it easier for the user to raise and lower the bed, as the user can now lift from the midpoint of the bed's length rather than from its end.

Referring to Figure 2 and Figure 3, the area occupied by the bed in the upright position is:

$$A_u = \frac{78.00 \times 16.00}{88.25 \times 40.25} \cong 35.1\%$$

This value is identical to the previous design as the height of the bed has remained unchanged.

Material Requirements and Cost

Methods of joining components have been explicitly considered as part of this prototype. Hardware costs have been added to Table 1, although in most cases the quantity required for the project is considerably less than what is provided in a saleable unit. Any hardware that is available, and less expensive, on a per-unit basis will be purchased as such to lower overall costs. Note also that some of this hardware may be already available in the workshop at no cost.

The lumber requirements are largely the same as that for the previous design, although a shortening of the side rails in this iteration allows us to replace one of the 1" x 6" x 8' pieces with a 6' piece instead, slightly reducing cost.

All prices in Table 1 are sourced from Rona or Home Depot:

Table 1: Summary of lumber and hardware costs

Material	Unit Cost	Quantity	Total Cost
Lumber			
Knotty pine – 1" x 6" x 8'	\$13.59	2	\$27.18
Knotty pine – 1" x 6" x 6'	\$9.99	1	\$9.99
Knotty pine – 1" x 12" x 6'	\$20.29	2	\$40.58
Spruce – 2" x 4" x 7'	\$1.84	2	\$3.68
White pine – 2" x 2" x 6'	\$5.39	1	\$5.39
Fir plywood – 3/8" x 4' x 8'	\$19.03	1	\$19.03
Hardware			
#10 x 3" wood screws (box of 7)*	\$2.49	2	\$4.98
#8 x 1" wood screws (box of 100)*	\$3.99	1	\$3.99
¼" x 3" hanger bolt (box of 25)	\$4.99	1	\$4.99
5/16" x 2" carriage bolt (box of 50)	\$9.98	1	\$9.98
#12-16 drywall anchor (pack of 20)	\$4.09	1	\$4.09
¾" corner brace (pack of 20)	\$3.49	1	\$3.49
¼"-20 hexagonal jam nut (box of 100)*	\$8.49	1	\$8.49
¼" lock washer (box of 50)*	\$2.89	1	\$2.89
10" shelf bracket	\$1.57	3	\$4.71
<i>*Hardware may be already available in workshop</i>		Subtotal	\$153.46
		Tax	\$19.95
		Total	\$173.41

Physical Properties and Function

Mass – The mass of the bed has been determined in a similar manner as that for the previous design. However, the mass of the rotating subassembly has been calculated separately from that of the entire bed, and we have included a simulated mattress made of polyurethane (i.e. memory foam) to provide a more accurate estimate.

Using densities from the material libraries built into Autodesk Inventor, the mass-equivalent weights are:

$$m_{\text{total}} = 72.6 \text{ lbs}$$

$$m_{\text{subassembly}} = 66.1 \text{ lbs}$$

Latching force – Given the changes in the bed's dimensions, it is necessary to recalculate the forces applied to the latching mechanism. In this analysis, the following simplifying assumptions are made:

- There are two latching mechanisms which are level with each other and positioned near the top of the bed
- A distributed load on the table is equivalent to a single load applied along its width

With reference to Figure 4, and assuming $F_{load} = 100$ lbs, the maximum force applied to either latch is:

$$2F_{latch}(27.12 \text{ in}) = (100 \text{ lbs})(8.80 \text{ in}) + (66.1 \text{ lbs})(2.20 \text{ in})$$

$$F_{latch} = 18.9 \text{ lbs}$$

This force is more than that for the previous design (18.9 lbs versus 14.6 lbs) given the shorter moment arm for the latch force, but this value still falls within reasonable bounds for commonly available latching hardware. Note that we have not yet decided on a latching mechanism. However, given that the bed's overall construction is not contingent on this mechanism, it can be determined at a later time.

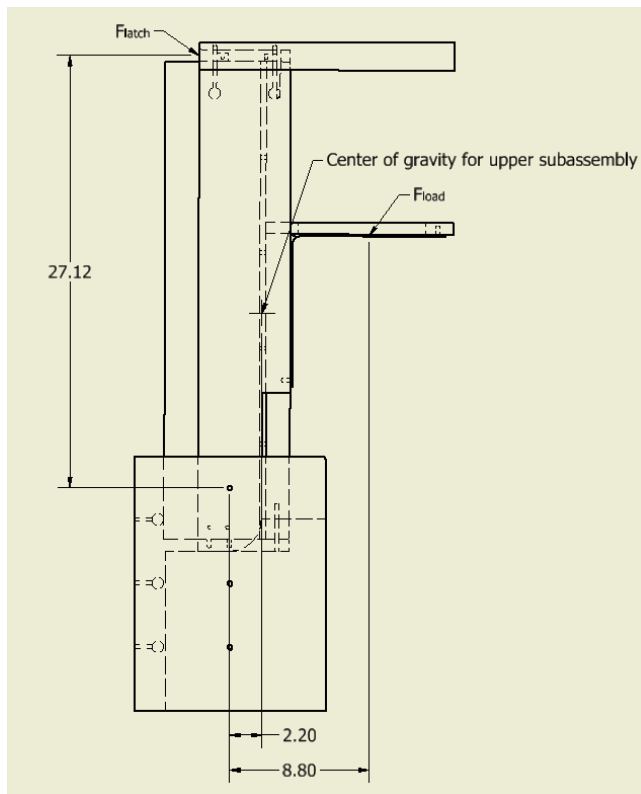


Figure 4: Forces applied about pivot axis (upright position)

Lifting force – The changes in the dimensions of the bed also make it necessary to recalculate the lifting force required to raise the bed. As the mass and center of gravity of the subassembly have been explicitly determined, only one simplifying assumption is made in this analysis. Namely, the force applied by the individual is applied immediately next to the supporting leg, and the force is parallel to the leg throughout the entire range of motion.

Referring to Figure 5:

$$F_{lift}(26.25 \text{ in}) = (66.1 \text{ lbs})(12.08 \text{ in})$$

$$F_{\text{lift}} = 30.4 \text{ lbs}$$

This required force is almost identical to that for the previous design (a difference of 0.2 lbs). Moreover, the additional space provided by the narrowing of the bed, discussed above, allows the user to raise the bed from a more ergonomic position. With these considerations in mind, the team has decided not to implement any lift-assistance mechanism. Not only is the required lifting force well within the physical capabilities of an expected user, any such mechanism would add considerable cost and complexity to the design.

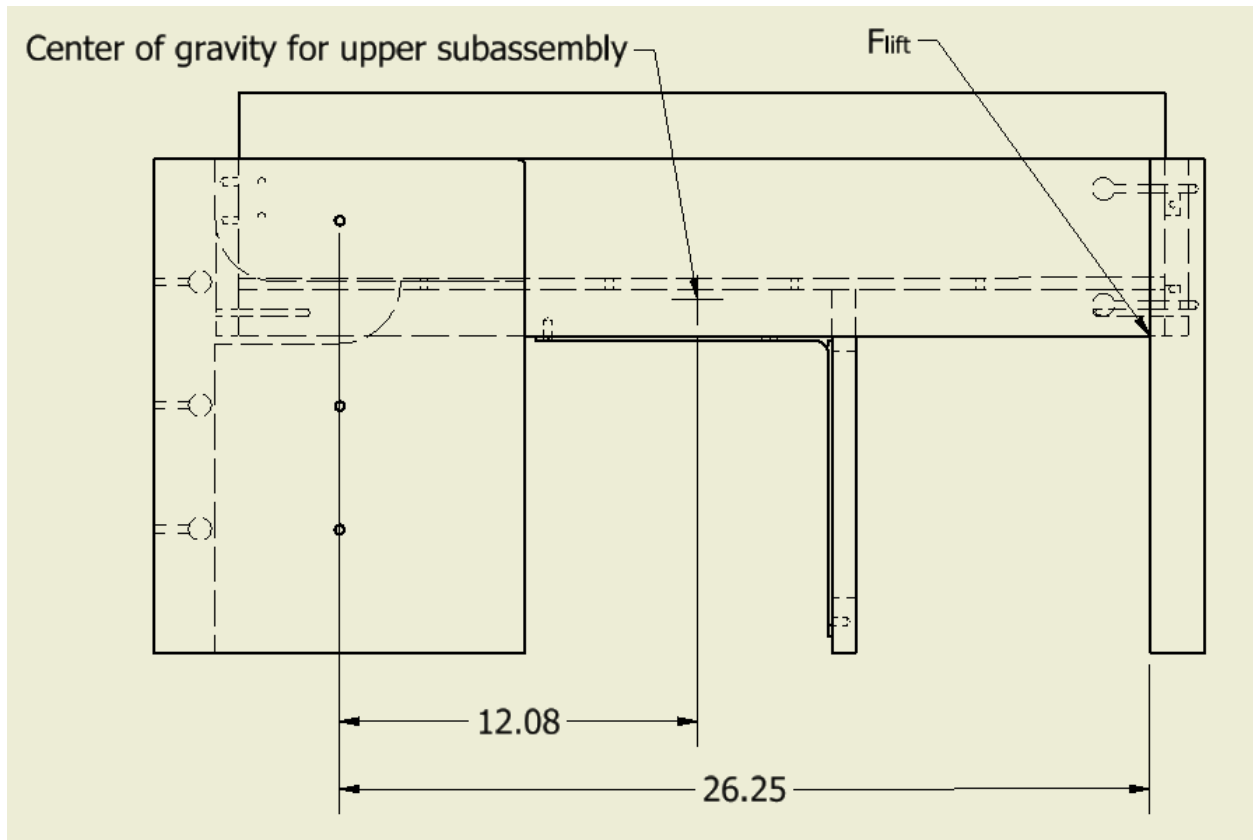


Figure 5: Forces applied about pivot axis (horizontal position)