# Miniature Modular Rack Launcher Combo

**EML 4551C – Senior Design – Fall 2011**
**Concept Generation**

Team # 3

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# Table of Contents

## Introduction

This project is being sponsored by Eglin Air Force Base. The goal of this project is to build a Bomb Rack Unit (BRU) which will be used with the Tigershark UAV. The first specification of our system given is that the weight must be kept at or below 5 lbs. Another specification is that the payload must be ejected from the BRU with an ejection velocity of at least 10 ft/s; the ejection energy of the payload also must not exceed 75 ft-lbs. The system must operate within the temperature range -20°C to 60°C, and must withstand a 2G lateral load and 1G landing shock. The BRU must have safety pins that are removed before flight as well as a mechanical safety lock that is used in flight. It will only be allowed to use 28V from the aircraft, and someone must also be able to visually inspect the BRU to see if it is in “armed” mode.

To achieve these goals, the requirements have been broken into three main components. The first component is the hook system that will be used to secure the payload. The next component is the mechanical safety lock that will hold the hook in place until the system is armed. The last component is the ejection system that will be used to achieve the 10 ft/s velocity, and not exceed the 75 ft-lbs. of energy. The electrical systems will be designed later once the requirements for these systems have been found.

## Latch Systems

The latch system is the first main component that will be analyzed. This system will use a hook to hold the payload with a mechanical release mechanism to swing the hook away during the firing procedure. Several different types of release mechanisms will be considered and are outlined in the following section.

**Figure 1- Ratcheting latch design in closed position**

**Figure 2- Ratcheting latch design in open position**

The first latch system that will be considered is shown above in figures 1 and 2, in its closed and open positions, respectively. This system utilizes a torsional spring that holds the latch in the open position, and a ratcheting system to hold the latch in the closed position. During the loading procedure, the hook is ratcheted closed by a lever arm that protrudes through the front of the housing unit. The pawl of the ratchet holds the hook in the closed position against the spring force. The torsional spring stores energy that will allow the hook to spring open quickly to release the payload. During the firing procedure, the pawl on the ratchet will be moved by a linear actuator. This will release the energy in the torsional spring which will rotate the hook and release the payload.

**Figure 3- Motorized latch design in closed position**

**Figure 4- Motorized latch design in open position**

The second latch system that will be considered is shown above in figures 3 and 4. This system utilizes an electric motor attached at the pivot point of each hook. The hook used here is almost identical to the previous design, however, it does not have any spring connected to it, and there is no ratcheting action. This system uses the rotational work of the motor to hold the hook closed, and when fired, the motor provides the rotational force to spin the hook open and release the payload. This method, depending on the motor used, will not release the payload as quickly as a system designed using the stored energy of a spring to aid in turning the hook.

**Figure 5- Sliding latch design in closed position**

**Figure 6- Sliding latch design in open position**

The next system that will be considered is shown above in figures 5 and 6. This system design uses a sliding hook that is guided by channels inside the main housing unit. The movement of the hook is purely translational; a linear actuator would be used to move the hook along the channel. When the payload is locked, the linear actuator retracts and the hook holds the payload securely. When the fire signal is given, the linear actuator is activated and it slides the hook down the channel, releasing the payload. Depending on the strength of the linear actuator used, this method might also be too slow to release the payload without any drag. There also will be increased friction that would have to be overcome due to the sliding.

**Figure 7- Linear actuator design in closed position**

**Figure 8- Linear actuator design in open position**

The next design, depicted above in figures 7 and 8, uses a rotating hook. This design is similar to the previous design that used a motor connected at the pivot point, but a linear actuator would be used that is connected by a pin to a lever arm on the hook. If this method was implemented, it would have to be carefully designed because there would be some induced sideways torque on the linear actuator shaft. This could be eliminated by using a two piece linkage to connect the actuator to the hook. This method will also have trouble opening the hooks fast enough to release the payload with minimal drag.

**Figure 9-Compressed air latch design in closed position**

**Figure 10- Compressed air latch design in open position**

The final latch design that will be considered is shown above in figures 9 and 10. This design uses compressed air to provide the energy to open the latch. The hook is virtually identical to the previous design; however the linear actuator is replaced by a compressed air tank. During the firing procedure, the compressed air will be released by a valve and will push the hook into the open position, releasing the payload. This method would provide the quick impulse of energy needed to open the hook quickly so it does not drag on the payload. This system would also consume much less electrical power because the only electrical power needed is for the valve system to open the tank. This system would also be lighter weight because there is no large motor or actuator.

## Latch System Decision Matrix

| | | Designs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **1** | | **2** | | **3** | | **4** | | **5** | |
| Specifications | Weight | Score | Weight | Score | Weight | Score | Weight | Score | Weight | Score | Weight |
| Compactness | 0.1 | 2 | 0.2 | 3 | 0.3 | 3 | 0.3 | 5 | 0.5 | 5 | 0.5 |
| Weight | 0.25 | 4 | 1 | 2 | 0.5 | 5 | 1.25 | 5 | 1.25 | 5 | 1.25 |
| Strength | 0.15 | 3 | 0.45 | 4 | 0.6 | 3 | 0.45 | 4 | 0.6 | 4 | 0.6 |
| Durability | 0.1 | 3 | 0.4 | 4 | 0.4 | 2 | 0.2 | 4 | 0.4 | 4 | 0.4 |
| Operational Speed | 0.4 | 5 | 2 | 3 | 1.2 | 2 | 0.8 | 3 | 1.2 | 5 | 2 |
| Total | | **4.05** | | 3 | | 3 | | **3.95** | | **4.75** | |

**Table 1- Latch System Decision Matrix**

A decision matrix was used to analyze the different latch systems to determine the top 3 designs that will be subjected to further engineering analysis. The single-most important aspect of the latch is the operational speed. It is very important that the latch opens fast enough to eliminate the possibility of drag while releasing the payload. The weight is also an important deciding factor. From this matrix, the best designs to further analyze are design numbers 1, 4 and 5. Design 1 scored well because of its speed. It utilizes energy from a spring to snap the hook open quickly. Design 4 has a good score because of its light-weight and simplicity, but it lacks the important speed. Design 5 scored the highest because it has a compressed air energy storage system that is very lightweight, has very few moving parts, and has the ability to open the latch very quickly.

## Mechanical Safety Systems

As mentioned earlier, our product is required to have a mechanical feature that locks the hooks until the "Arm" command is given. Once the system is armed the mechanical lock will move out of the way to allow the hook to move. In order to move this feature we have decided to use a servomotor. The first design of mechanical safety system is shown below.

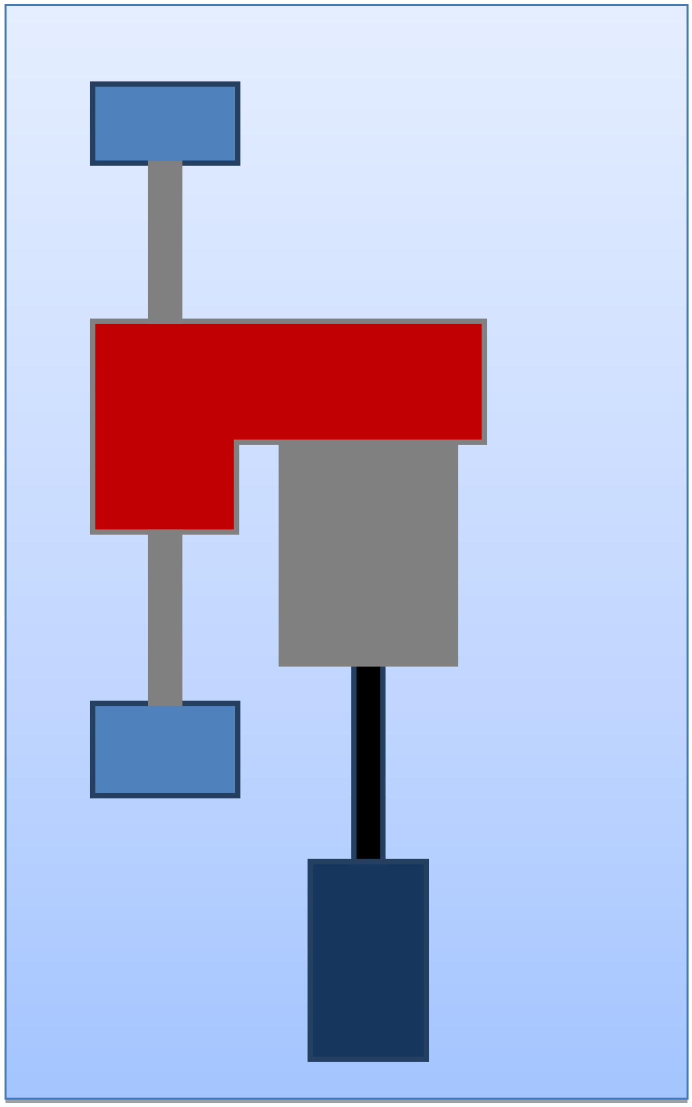


**Fig. 10 Mechanical Safety Design 1**

In this design a single servomotor placed on the side of the hook. As it can be seen in figure 10, the safety stop block, colored red, has an L-shape design. This allows the stop block to be attached more rigidly to the servomotor. The reason for the small amount of space in between the servomotor and the hook is to allow the servomotor to move with a low amount of friction. Once the system is given the "Arm" command, the servomotor moves out of the way as shown in the next figure.

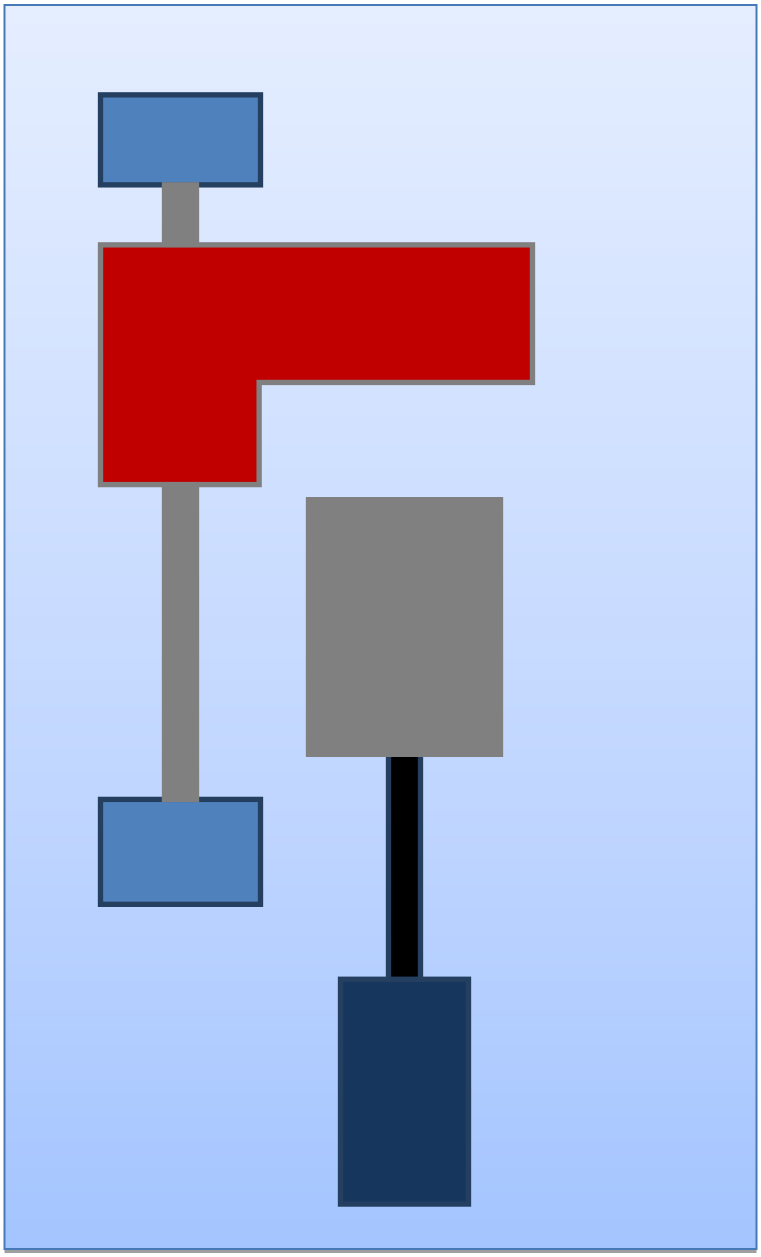


Fig. 11- Mechanical Safety Design 1 in "Armed" mode

As the above figure, figure 11, shows the servomotor moves parallel with the hook. Moving the servomotor in this way allows the stop block to be removed with a small amount of friction. One drawback of this system is that when the block is engaged with the hook, a torque will be applied to the servomotor. This puts extra stresses on the servomotor that can lead to system failure. To compensate for this torque, another servomotor can be used on the other side of the hook. This second servomotor is implemented in the next design, figure 12 shown below.

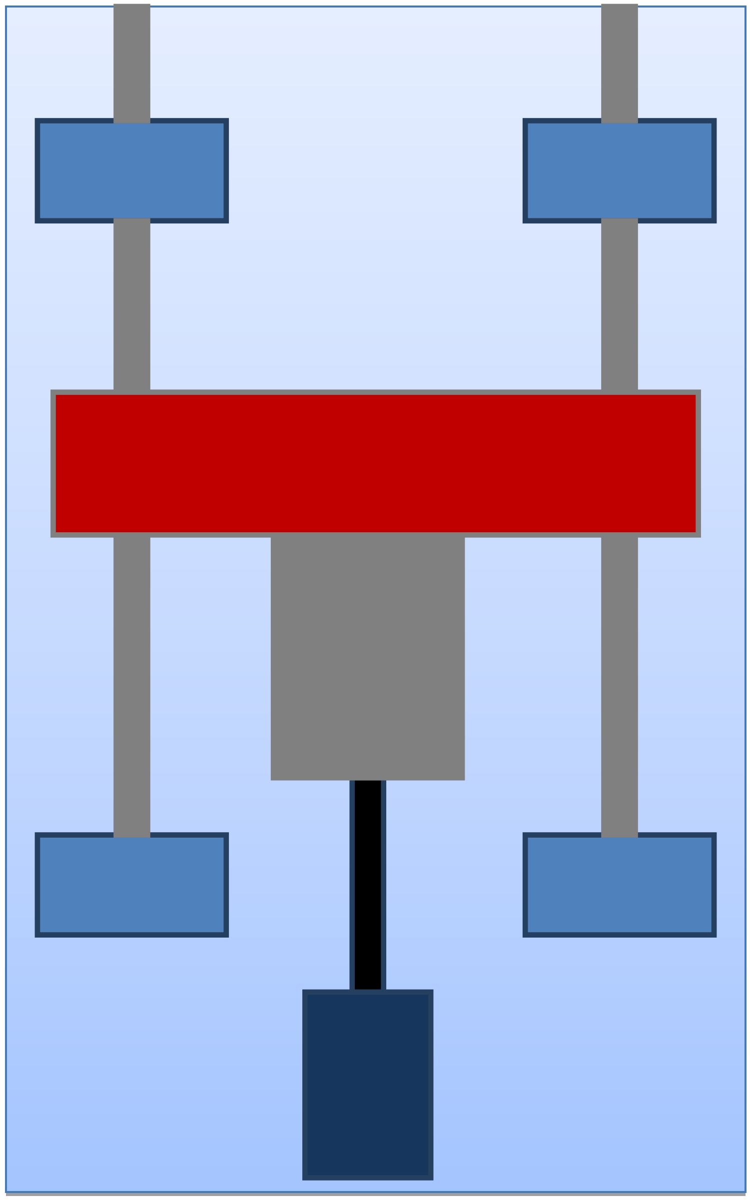
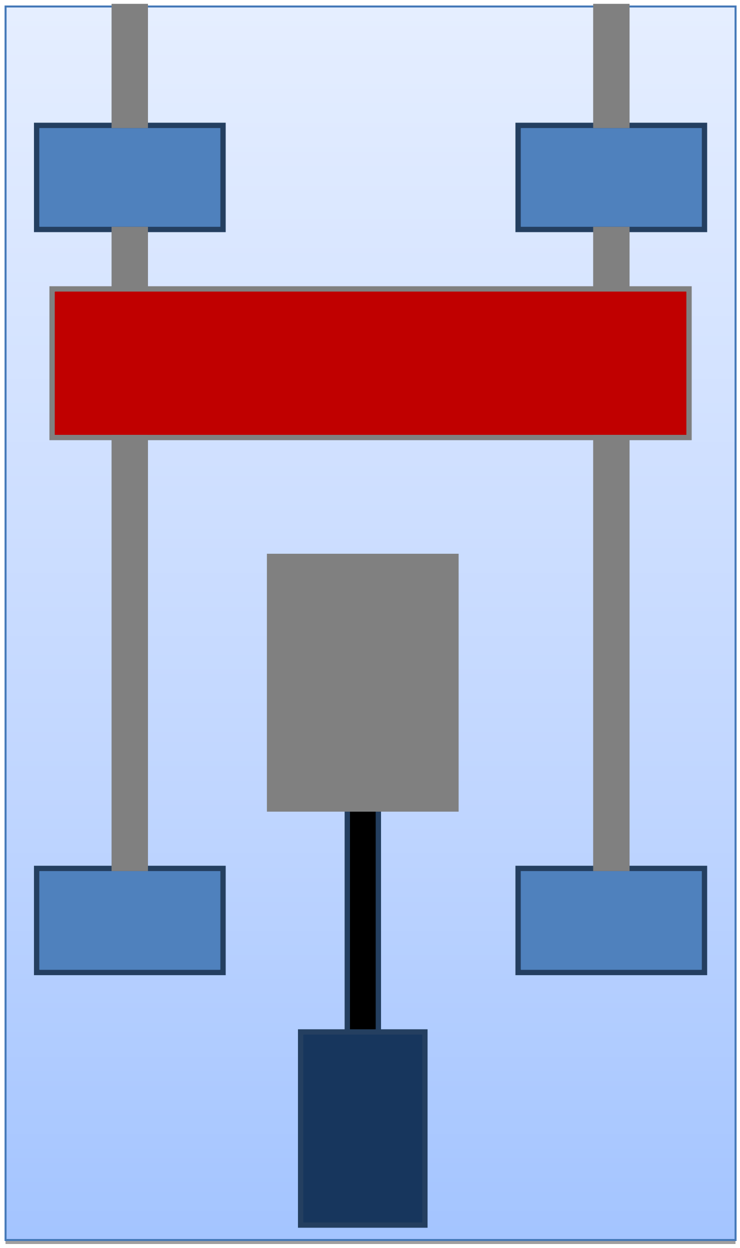


Fig. 12- Mechanical Safety Design 2

Along with the added servomotor, the stop block is a rectangular piece that connects to both servomotors. This design removes the torque from the servomotors, as well as adding more force to the safety system. This allows for two smaller servomotors to be used to hold the stop block in place. One of the disadvantages to this system is the extra weight added with the extra servomotor and mounting system. Another disadvantage to this design is the added cost of the extra servomotor and mounting system. When the "Armed" command is given to the system, the servomotors move parallel to the hook like the first design as shown below.



**Fig, 13- Mechanical Safety Design 2 Safety in "Armed" mode**

As with the first design, the stop block moving away from the hook as shown in the above figure, allows for low friction in the system. A drawback with both of the first two designs is that the stop blocks are mounted on top of the servomotors. This adds a shear stress to the mounts between the stop block and the servomotors. Another drawback of these systems is that the stop blocks do not touch the bottom of the hooks. This could allow a hook that rotates to open prematurely. The next design, shown below, takes away these problems by changing the direction of motion and rotating the motor 90° to have the top of the servomotor facing the hook.

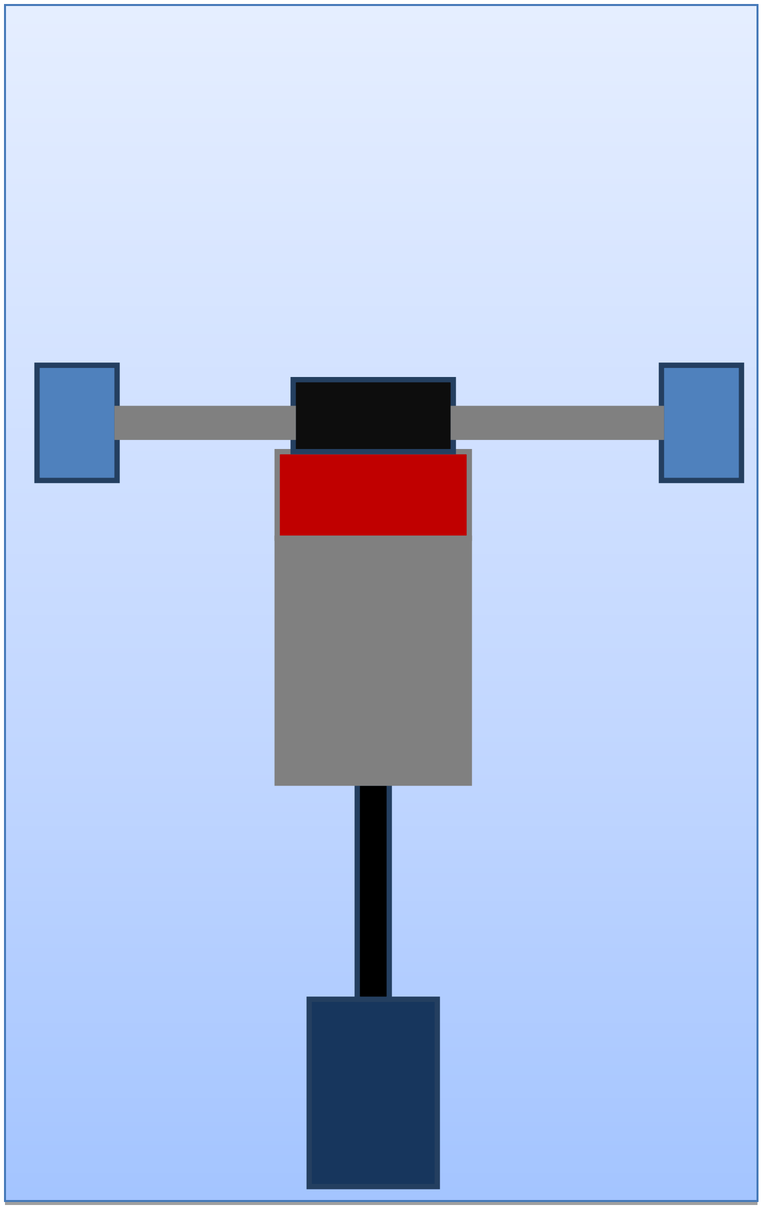


**Fig. 14 - Mechanical Safety Design 3**

As it is shown in the above figure, figure 14, the servomotor moves perpendicular to the hook. This system is beneficial because the stop block is smaller than the other design blocks, saving weight on the system. The next figure shows the system in “Armed” mode.

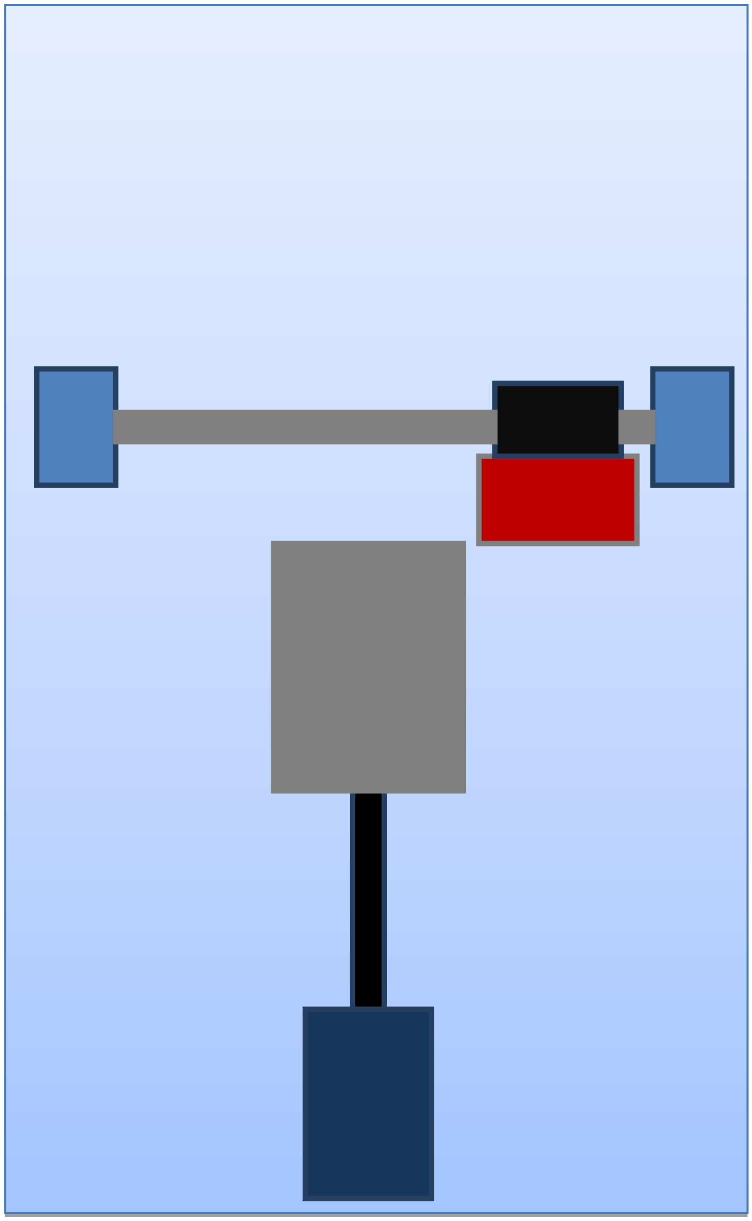


**Fig. 15- Mechanical Safety Design 3 in "Armed" Mode**

As it can be seen in the figure, the stop block is moved to the right to allow the hook to freely move and release the payload. A slight disadvantage to this system is the added friction to the system from the way that the stop block disengages with the hook. The next design changes the direction of motion again by moving vertically. As shown below, this design incorporates a larger stop block and two servomotors.

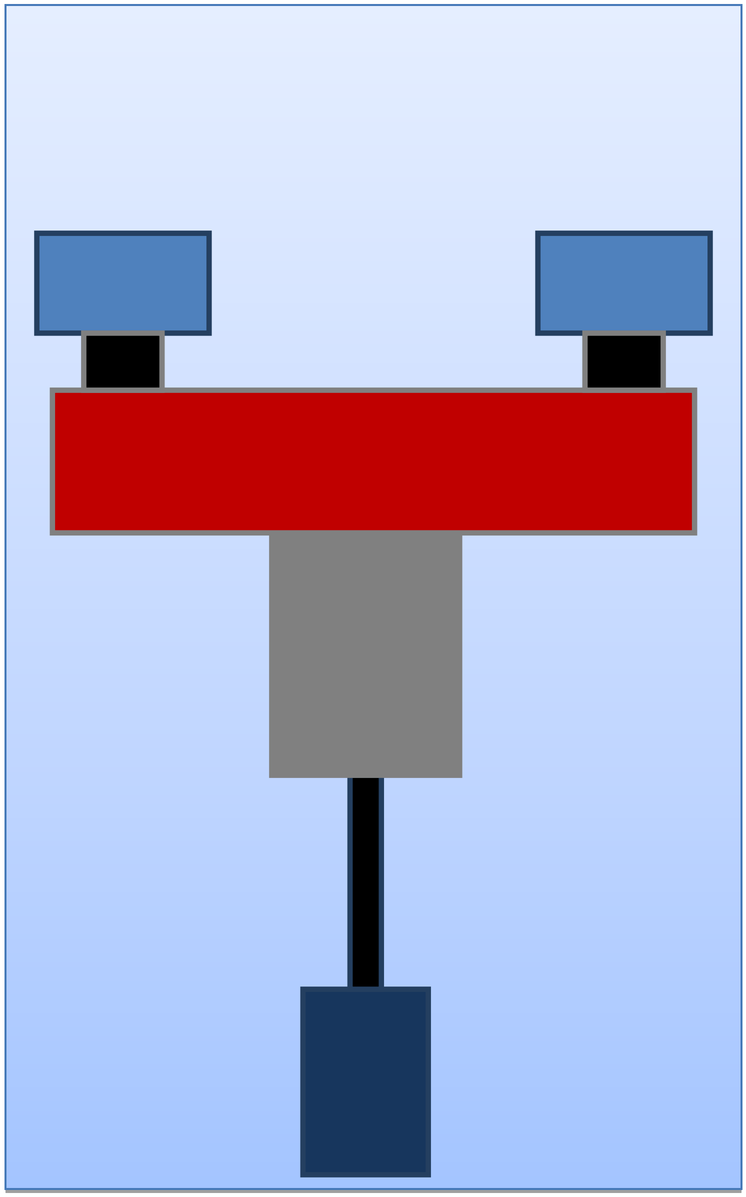
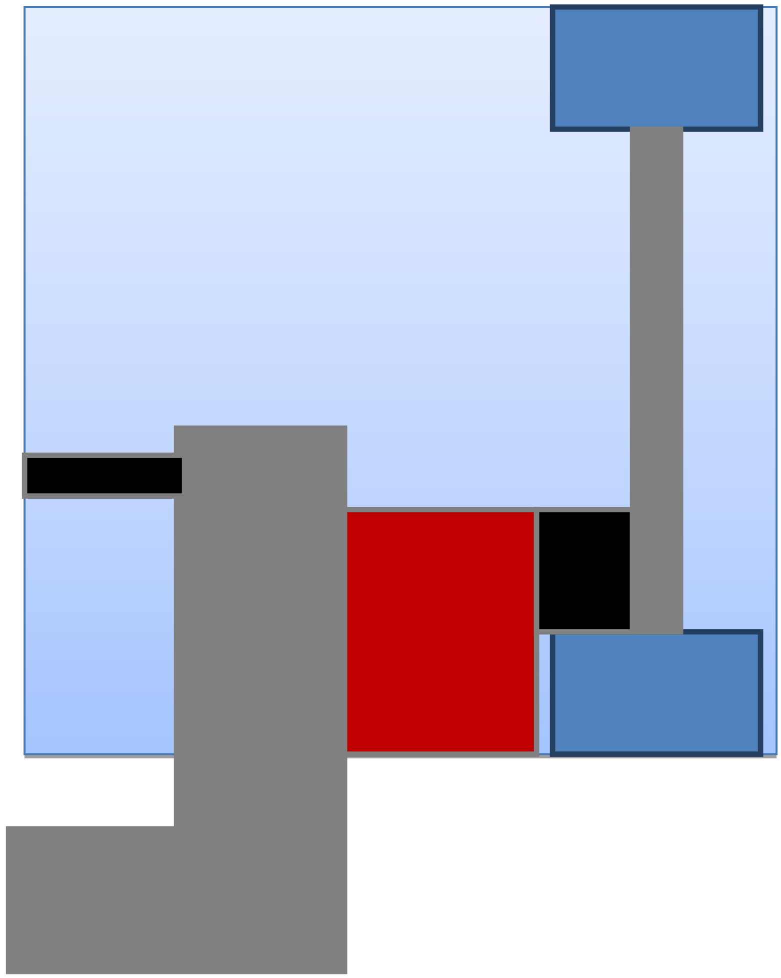


Fig. 16- Mechanical Safety Design 4

As it can be seen, this design has the two servomotors placed on opposite sides of the hook. This takes away any torque from the hook. The side view, shown below, shows how the stop block will work when engaged with the hook.



**Fig, 17 – Side view of Mechanical Safety Design 4**

Like the previous design, design 3, this design has the servomotor mounted behind the stop block instead of under it. The block is twice as big as the servomotor to not allow the hook to move at all. This system adds more weight to the system by having the stop block larger than the others. Once the “Armed” command is given, the block will move out of the way as shown below.

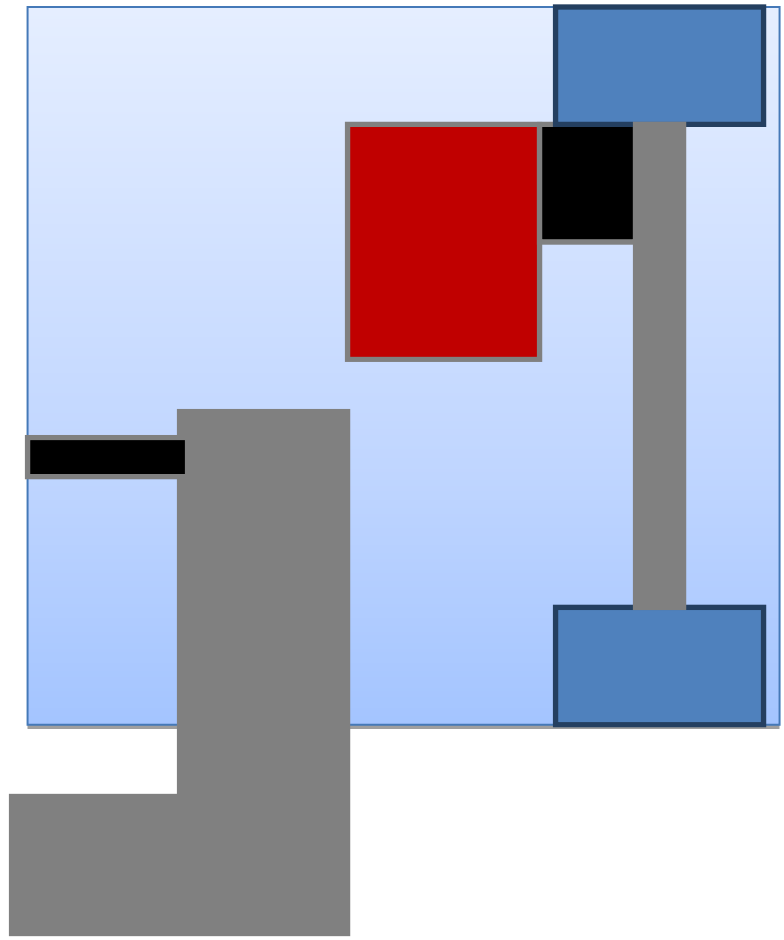
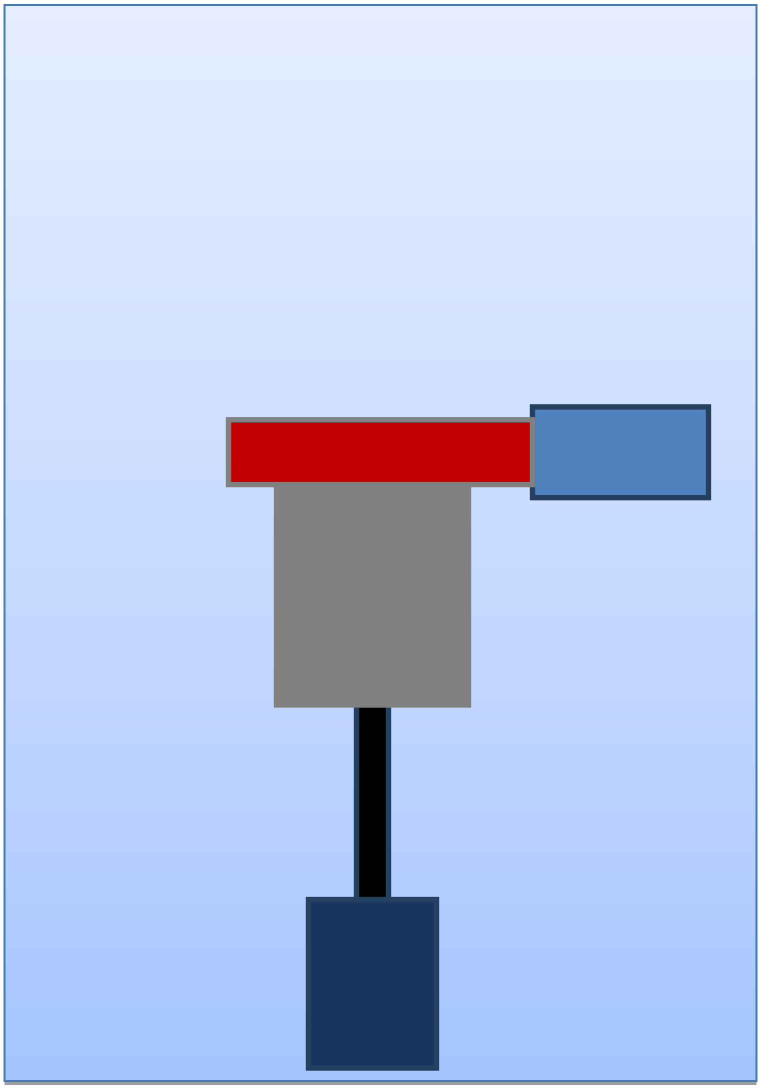


**Fig. 18- Mechanical Safety Design 4 in "Armed" Mode**

As it can be seen, the stop block is moved high enough to allow for the hook to move freely.  As with the previous design, the stop block has more friction on it when disengaged from the hook.  The last to designs put more compressive strain on the servomotors if the arming sequence fails.  If this happens multiple times, the servomotor could be crushed and have to be replaced.

The previous four designs use a servomotor that move linearly in some orientation to the stop block.  The next designs of the Mechanical Safety will employ a servomotor that rotates a stop block out of the way instead of using linear motion.  Below is figure 19 showing the design of this type of system.



As figure 19 shows, this system is much more compact than the designs using linear servomotors. The next figure is a side view of this design showing how the servomotor is connected to the mounting blocks.

**Fig. 19- Mechanical Safety Design 5**

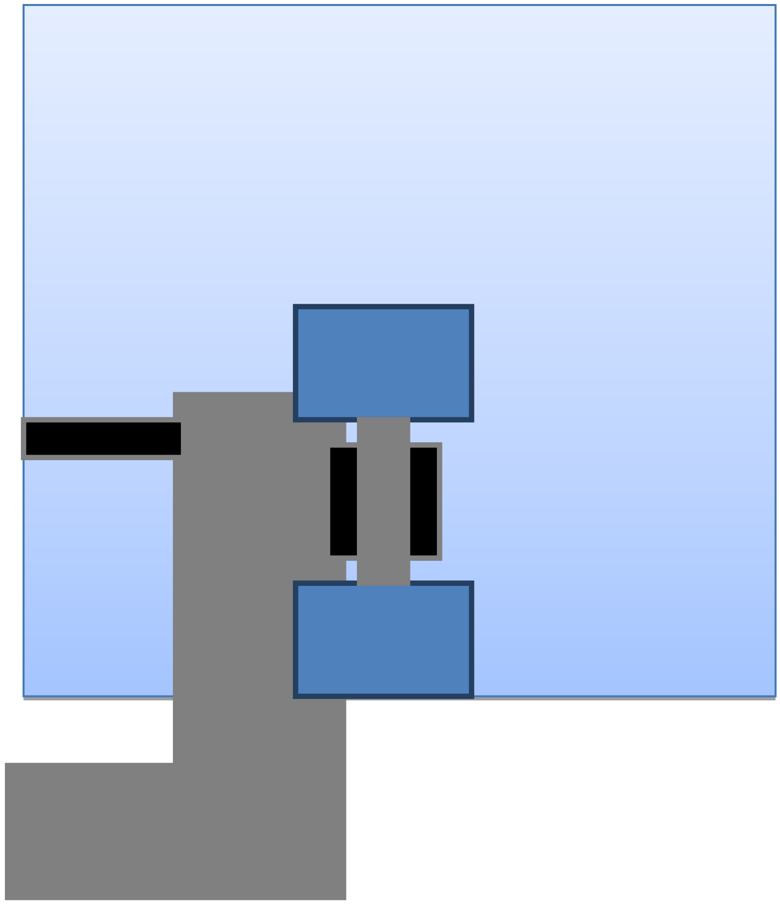
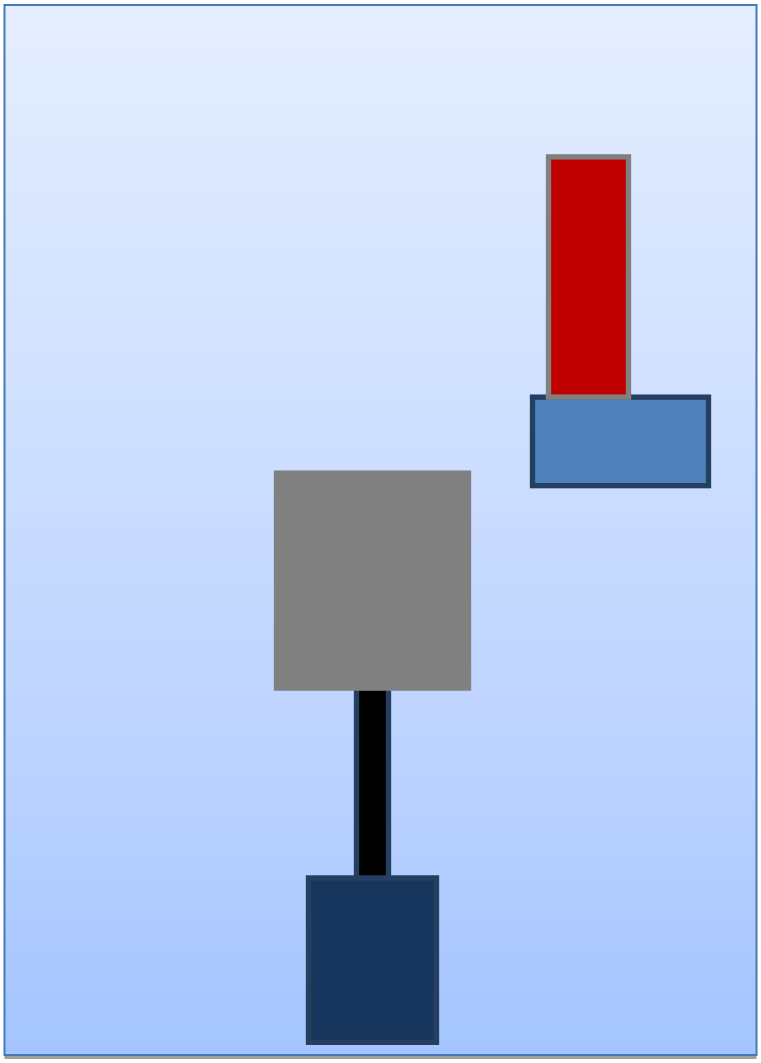


**Fig. 20. Side View of Mechanical Safety Design 5**

The side view of design 5 shows the rotational servomotor mounted in between the two mounting blocks. As it can be seen in the side view, this design is more compact because it does not have to move along its shaft. As with the first two designs, this system may allow for a rotating hook to prematurely open since it does not meet near the bottom of the hook. The next figure shows how the stop block is rotated out of the way to allow for the hook to move freely.



As the above figure shows, figure 21, the stop block is rotated 90° to allow the hook to move freely. This system has a low amount of friction from how it is disengaged from the hook. The next design uses this same type of system, but rotates along the vertical instead of the horizontal axis.

**Fig. 21- Mechanical Safety Design 5 in "Armed" Mode**

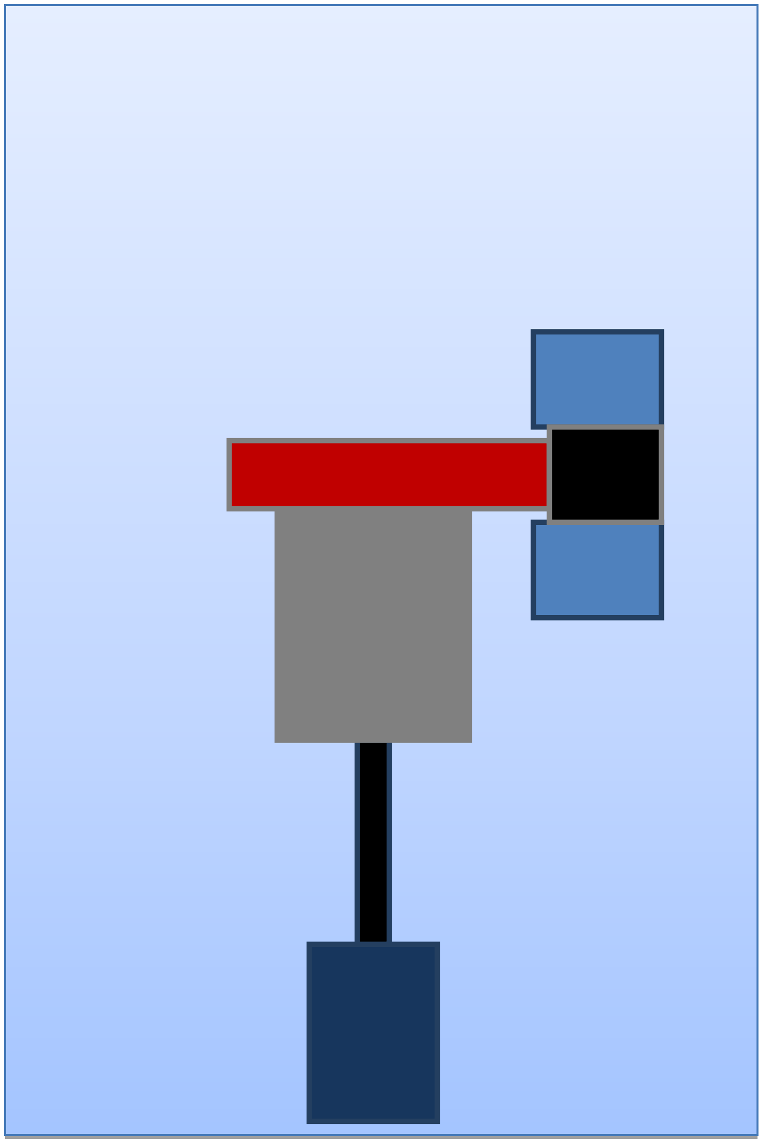


**Fig. 22- Mechanical Safety Design 6**

As the above figure shows, this design is essentially Design 5 rotated 90°. This will take the torque on the motor out its axis of motion. This will cause the servomotor to have a shear stress when engaged with the hook. This will also allow the stop block to make contact at the bottom of the hook, not allowing any motion. A benefit of this system is its compactness. Like the previous design, this system has a small mounting space. The difference is that this design takes up less space when moved into "Armed" mode. Since design #5 moves along the length of the BRU, considerations have to be made to allow for this motion. As it is shown in the figure below, figure 23, this design takes a small amount of space up in the vertical direction.

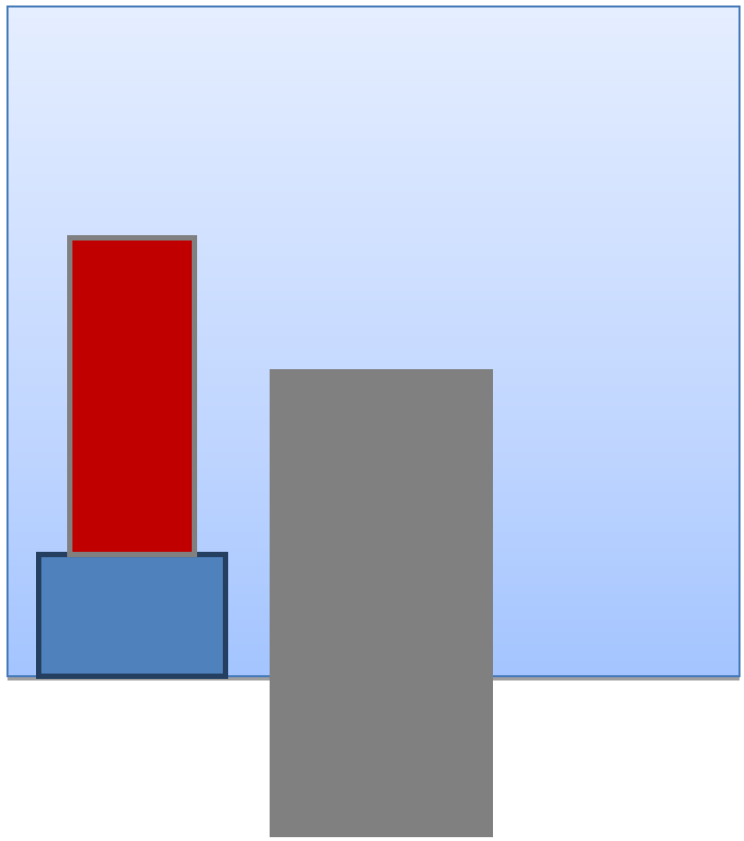


**Fig. 23- Front view of Mechanical Safety Design 6 in “Armed” mode**

The front view of Design 6 shows how the stop block could be moved into “Armed” be saved that can be used for mounting other systems onto the BRU. As it was discussed earlier, removing the stop block in the vertical direction adds more friction on the system when disengaging from the hook.

## Mechanical Safety System Design Decision Matrix

In order to make an accurate decision on which Mechanical Safety will work best for our system. From this decision matrix the top three systems will be selected for further review. One of the reasons for this is that the best Mechanical Safety can only be chosen after the hook system is chosen. This will give the strongest system for that style of hook system, and ultimately making this system the safest it can be. The features that will be analyzed with the decision matrix are the compactness, weight, strength, durability, and operational speed of each design.

| | | **Mechanical Safety System Designs** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | |
| Specifications | Weight | Score | Weight | Score | Weight | Score | Weight | Score | Weight | Score | Weight | Score | Weight |
| Compactness | 0.2 | 3 | 0.6 | 2 | 0.4 | 3 | 0.6 | 2 | 0.4 | 4 | 0.8 | 5 | 1 |
| Weight | 0.2 | 3 | 0.6 | 2 | 0.4 | 4 | 0.8 | 2 | 0.4 | 5 | 1 | 5 | 1 |
| Strength | 0.3 | 3 | 0.9 | 5 | 1.5 | 4 | 1.2 | 5 | 1.5 | 4 | 1.2 | 4 | 1.2 |
| Durability | 0.2 | 3 | 0,6 | 5 | 1 | 2 | 0.4 | 3 | 0.6 | 4 | 0.8 | 3 | 0.6 |
| Operational Speed | 0.1 | 4 | 0.4 | 5 | 0.5 | 2 | 0.4 | 3 | 0.3 | 5 | 0.5 | 4 | 0.4 |
| Total | | 3.1 | | **3.8** | | 3.4 | | 3.2 | | **4.3** | | **4.2** | |

**Table 2- Mechanical Safety Decision Matrix**

From the decision matrix the top three designs for the Mechanical Safety System are Design numbers 2, 5, and 6. The next step for these designs is to undergo an analysis to find which one will work best with the type of hook system used or this project.

## Sway Bracing

Sway bracing is a critical design feature on the BRU, and is used to prevent the store from moving laterally or vertically during flight. The store could experience lateral forces of up to 2G during a turn. The sway brace must be able to resist this force and keep the store steady. Below are two designs for the sway brace.

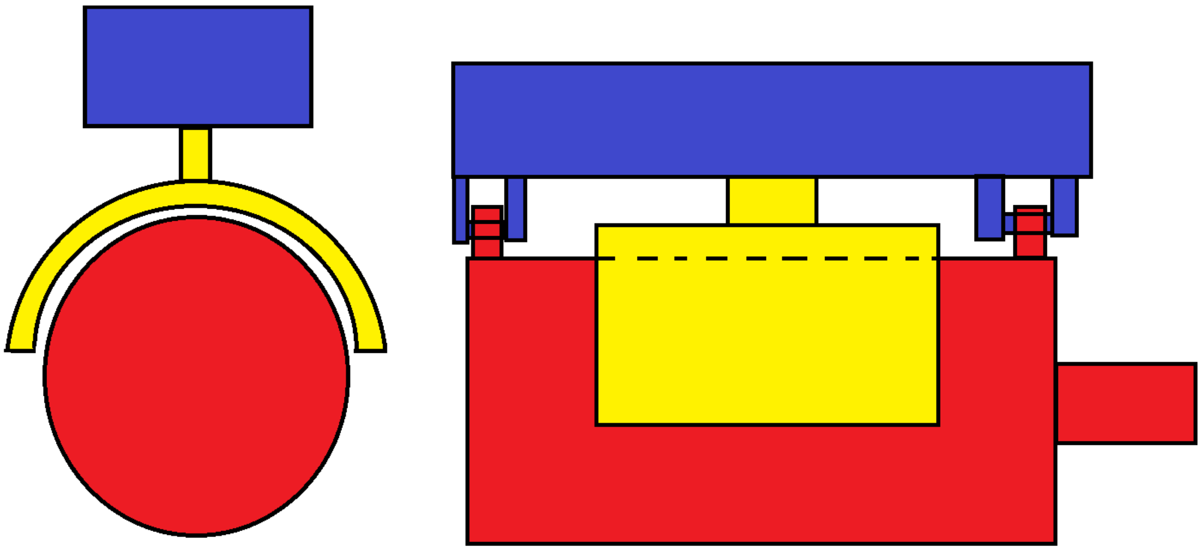


**Fig. 24- Sway Brace Design 1**

Design 1, shown above, illustrates one design for the sway bracing needed to keep the store steady in flight. This design uses a stationary sway brace (yellow) fixed to the BRU (blue). The store (red) will fit inside the radius of the sway brace. When in a turn, the store will push up against the sides of the brace preventing lateral motion. Pitching, vertical motion, of the store will also be limited by this design.

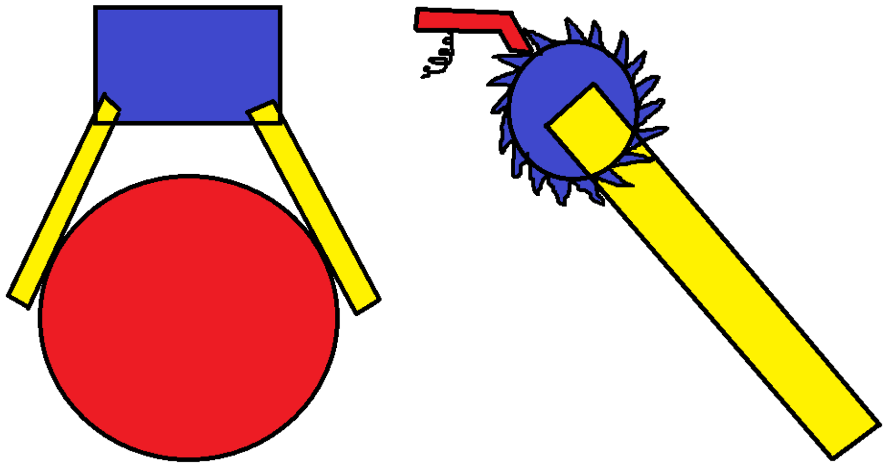


**Fig.25- Sway Brace Design 2**

The second design for sway bracing is illustrated above. There are 4 arms located near the corners of the BRU (blue box on left). Once the store (red on left) is locked into the hooks, the arms will be manually lowered and will self lock with a ratchet-paw system. Each arm (yellow) is attached to a ratchet gear (blue gear on right). The arms will lightly pinch the store preventing its movement. A manual release will be used to disengage the paw (red on right) so the arm can be raised and reset.

## Sway Brace Decision Matrix

In order to select which sway brace will be better for the BRU the following decision matrix has been assembled. Six categories with assigned weights are used to aid in the selection process. The most important factor for the sway brace is weight. As the BRU will have lots of important parts, the weight needs to be kept low. The next important deciding factor is the brace's load carrying capability. The sway brace will need to withstand lateral forces of up to 2 Gs as well as keeping the store from moving in flight. Store Size Flexibility looks at how easily the sway brace can adapt to changes in the size/shape of the store. Durability looks at how well the brace can withstand repeated loadings/releases. Ease of Use refers to how easily ground crews can set the sway brace up so it is ready for flight. Finally, Simplicity focuses on how simply the sway brace can be implemented to the BRU.

| | | **Sway Brace Concepts** | | | |
|---|---|---|---|---|---|
| | | 1 | | 2 | |
| Specifications | Weight | Score | Weight | Score | Weight |
| Weight | 0.3 | 2 | 0.6 | 4 | 1.2 |
| Load carrying | 0.3 | 5 | 1.5 | 3 | 0.9 |
| Store Size Flexibility | 0.15 | 1 | 0.15 | 5 | 0.75 |
| Durability | 0.1 | 4 | 0.4 | 2 | 0.2 |
| Ease of Use | 0.1 | 5 | 0.5 | 4 | 0.4 |
| Simplicity | 0.05 | 5 | 0.25 | 2 | 0.1 |
| Total | | 3.4 | | 3.55 | |

**Table 2- Sway Brace Decision Matrix**

As you can see both designs have similar totals, further calculation and design will be needed to select a definite sway brace to be used on the BRU. Other considerations with regard to the ejection mechanism could affect the final decision.

## Store Ejection

When the "Release" signal is given from the aircraft, the hooks release the store. This causes the store to fall entirely due to gravity. This free fall is too slow and an ejection method is required. The store will need to leave the BRU at a minimum velocity of 10 ft/sec and cannot be forced down with more than 75 ft-lbs of energy. Below are four designs for the store ejection.

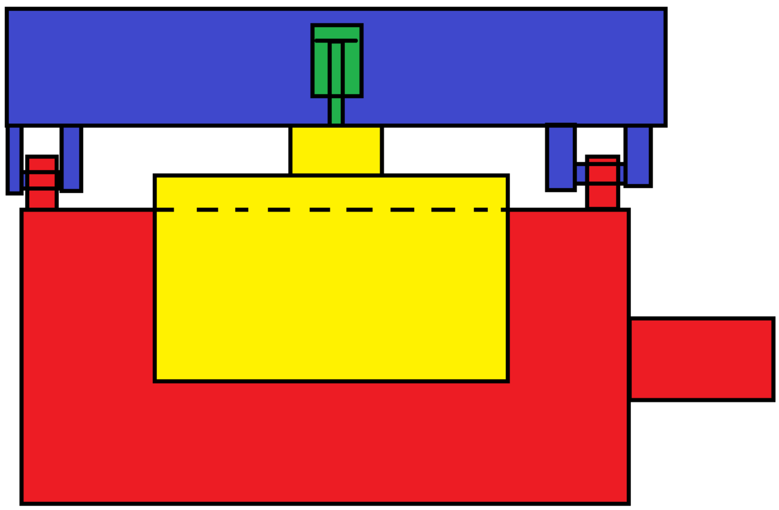


**Fig. 26- Store Ejection Design 1**

Design 1 above uses a pneumatic piston (green) to eject the store (red). The piston will push the store down when the "Release" signal is given. A pneumatic canister will be filled preflight on the ground and installed into the BRU (not shown). The fixed sway brace can be used as a "foot" attached to the piston. When the piston fires it forces the sway brace down at a high velocity, ejecting the store.

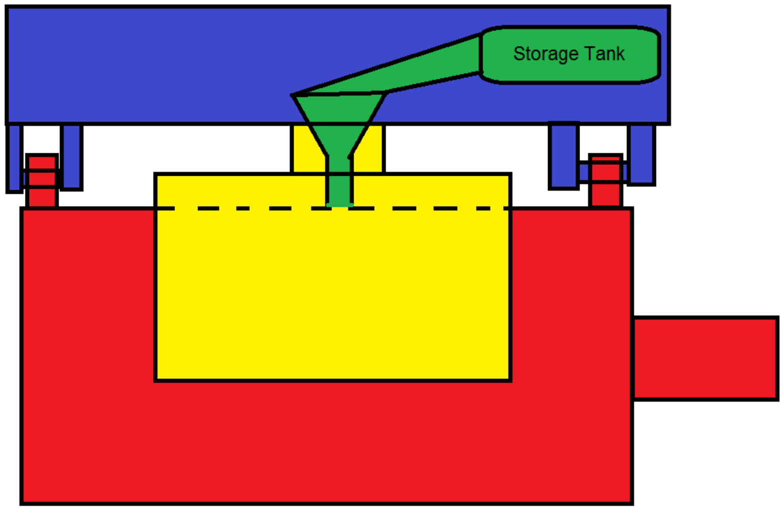



**Fig. 27- Store Ejection Design 2**

Design 2 uses compressed air to eject the store. A compressed air canister (green) will be filled on the ground and inserted into the BRU during ground operations. When the “Release” signal is given the air will be released and forced through a nozzle directed toward the store pushing it down away from the aircraft.

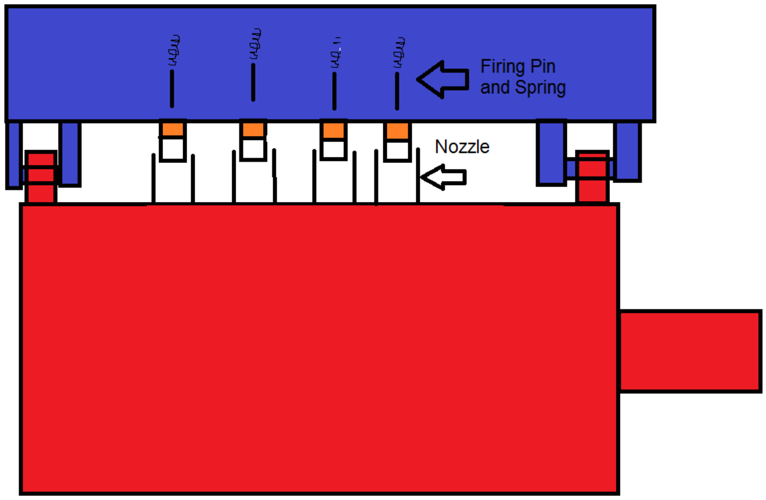



**Fig. 28- Store Ejection Design 3**

Design 3 above uses pyrotechnics to eject the store away from the aircraft. The pyrotechnics involved will use gun powder (orange) from a bullet to create a controlled explosion to force the store down and away from the aircraft. As shown in the illustration, multiple explosives can be arraigned to create enough ejection force. To set off the explosive, a firing pin is attached to a spring, which will be compressed in flight for safety reasons, when the "Release" signal is given the spring will be released forcing the firing pin into the bullet. The pin hits the primer igniting the propellant creating a controlled explosion which will force the store down away from the aircraft.

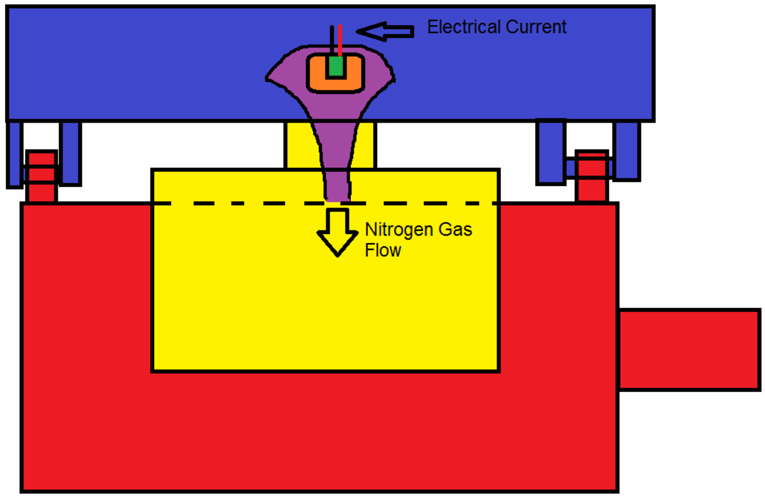



**Fig. 29- Store Ejection Design 4**

The final ejection design uses the same technology that is used in air bags in cars. When the car experiences a crash, an electrical signal is sent to the bag and sets off an extremely violent chemical reaction that combines sodium azide ($NaN_3$) with potassium nitrate ($KNO_3$). The product of this reaction is nitrogen gas. An air bag can deploy in one-twenty-fifth of a second, faster than a person can blink an eye. As an ejector for the BRU, a nozzle (purple) will funnel the nitrogen gas directly onto the store. The strong pressure created by the reaction will push the store away from the aircraft.

## Decision Matrix

The following decision matrix does a simple comparison of how the designs fare with regard to the design criteria.

| | | Ejector Designs | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3 | | 4 | |
| Specifications | Weight | Score | Weight | Score | Weight | Score | Weight | Score | Weight |
| Weight | 0.25 | 2 | 0.5 | 3.5 | 0.875 | 5 | 1.25 | 2.5 | 0.625 |
| Size | 0.15 | 3 | 0.45 | 4 | 0.6 | 5 | 0.75 | 2 | 0.3 |
| Cost | 0.1 | 2 | 0.2 | 3 | 0.3 | 4 | 0.4 | 2 | 0.2 |
| Safety | 0.2 | 4.5 | 0.9 | 4 | 0.8 | 1 | 0.2 | 2 | 0.4 |
| Ease of Use | 0.2 | 3 | 0.6 | 3 | 0.6 | 4 | 0.8 | 3 | 0.6 |
| Simplicity | 0.1 | 3 | 0.3 | 3 | 0.3 | 2 | 0.2 | 4 | 0.4 |
| Total | | 2.95 | | **3.475** | | **3.6** | | 2.525 | |

**Table 4- Ejection System Decision Matrix**

As you can see, designs 2 and 3 have the greatest score. However further design review and calculations are required to determine the viability of the designs.

## Conclusion

The main focus of our design is the integration of all these components into one cohesive system. To do this a mechatronic system will have to be constructed, most likely with an intervalometer, to organize a sequence of events for the payload to be released. Once an analysis of each system is completed, a better understanding of the mechatronic system needed to control this system will be known. After this has been completed a final design can be made, and the entire system can be constructed and tested.

## References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