Apple Design Challenge

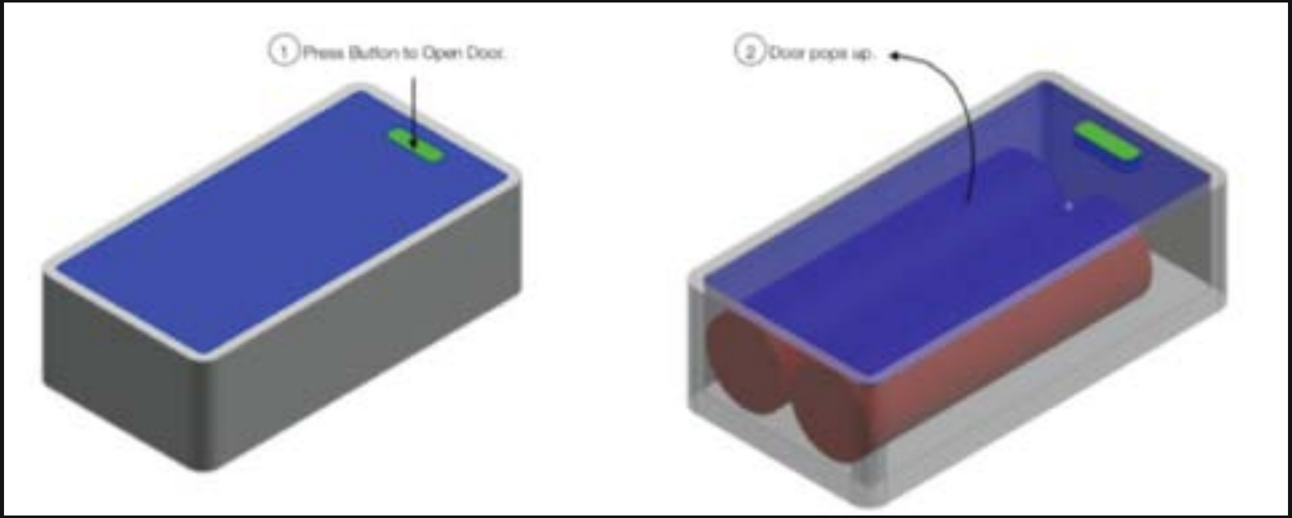
By Brandyn Nishida

Objective

Design a battery door mechanism which includes the door, release button and door latching feature to house and cover 2 AA batteries

Design Challenge as Stated

As depicted below, the door should unlock when a user presses a button, which causes the door to pop open in the opposite direction



Assumed Requirements

Standard AA battery size: 50.5mm in length by 14.5mm in diameter

Door must have an open state and a closed state

Button can be separate or integral to cover

Button push results in unlocking causing upward motion of the door

Cover must be relockable

Open Questions

What is the production QTY?

What is the life of the product?

How many cycles does the product experience?

Material constraints?

Possible Design Paths

1. Cam Latches
    a. Spring Latches
2. Mechanical Leverage
    a. Pivot Mechanism
3. Pin Mechanism
4. Electronic Latches
5. Living Hinges / Metamaterials

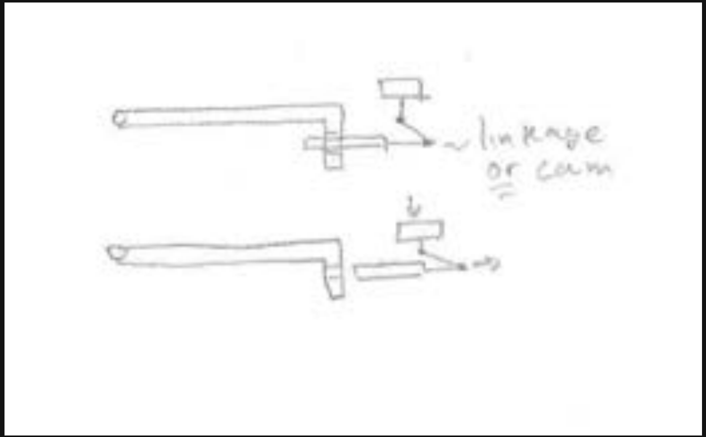
Cam Latches

- Commonly used in cabinet design
- Uses a magnet or a mechanical grabbing mechanism to secure the door
- Can use a cam path to create an “open” state and a “closed” state

Pros and Cons | Cam Latch

PROS	CONS
Button can be integral to cover	High part count
Slim profile	Greater assembly time
Clear user feedback (click)	

Locking Pin

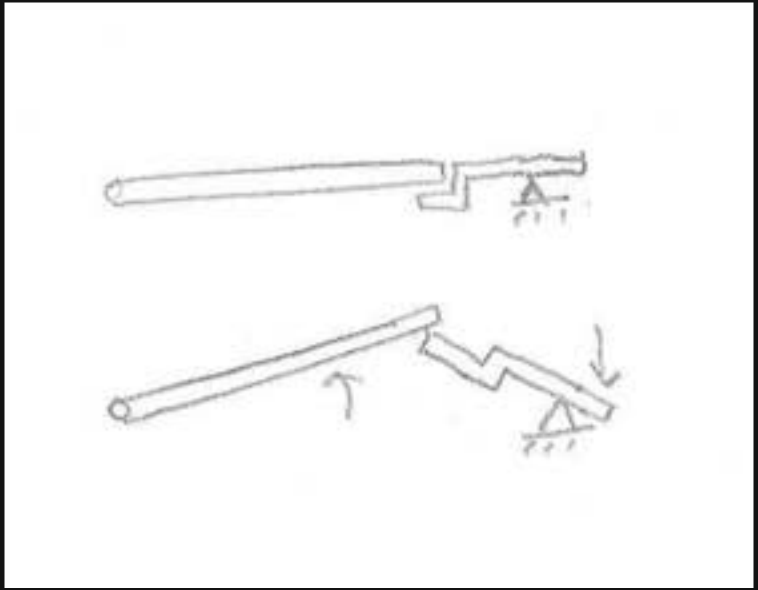


- Utilizes a “locking pin” type mechanism to secure the cover
- Downward force on button to translate in horizontal motion of the pin to disengage the cover

Pros and Cons | Locking Pin

PROS	CONS
Difficult to accidentally defeat	Button limited to being external to cover
	Button is an exposed moving part

Mechanical Leverage



- Uses a mechanical leverage to push the door open
- Door may be secured using anything from magnets to a detent to secure it in the closed state

Pros and Cons | Mechanical Leverage

PROS	CONS
Avoids fine tolerancing	Button limited to being external to cover
Low part count	Button exposed moving part
Clear feedback on open and closed state	Lock can be overcome by user without mechanism

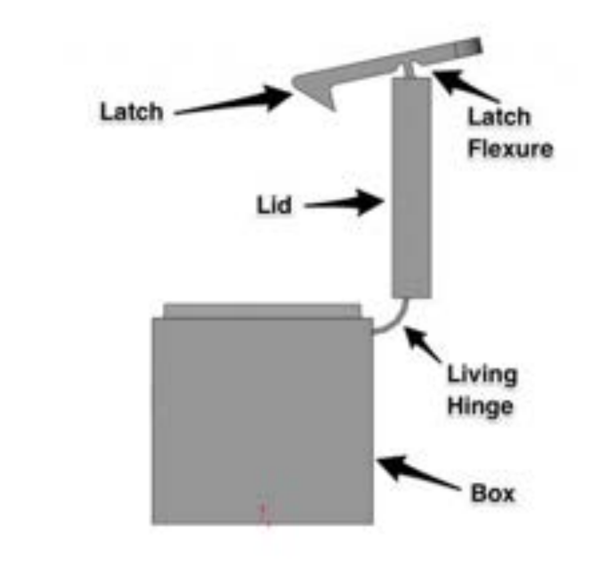
Electronic Latches

- Precise latches that can be button activated electronically
- Requires electrical power
- Available with auto relocking

Pros and Cons | Electronic Latches

PROS	CONS
Precise open/close states	Must be powered
Least user effort	Larger package size
	Expensive

Living Hinges, Metamaterials



- Can be made out of a single part
- 3D printable or injection moldable
- Depending on design, almost no assembly required

Pros and Cons | Living Hinges, Metamaterials

PROS	CONS
Least number of parts	Limited material library
Least assembly	Limited manufacturing processes
Lowest cost if injection molded at high QTY	Requires fine tolerancing
	Not serviceable

Design Path Selection

- If this is to be productized and intended for low cost mass manufacturing, the following design paths are most recommended:
  - Cam Latch
  - Mechanical Leverage
  - Locking Pin
- To ensure a secure lock that is not easily defeated:
  - Cam Latch
  - Locking Pin
- Most space efficient
  - Cam Latch

A locking pin’s mechanism must extend outward in the length of the battery

Ergonomic and Design Considerations

Push force required to activate with a finger shall be between 2.8N to 11N*

Push force required to activate with thumb/palm shall be between 2.8N and 23N*

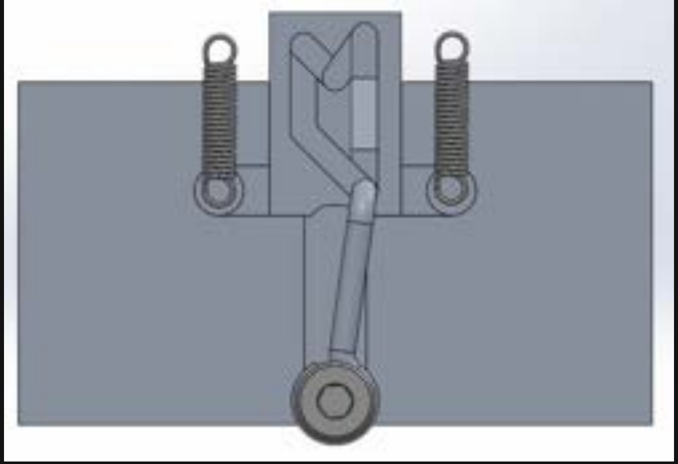
Package size shall be optimized for battery size

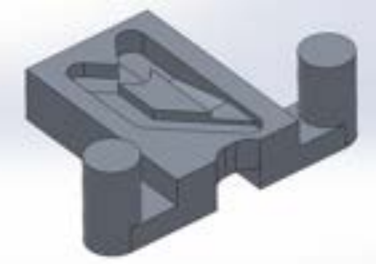
*Based on MIL-STD-1472H

Manufacturing Assumptions

- Smallest readily available end mill size: 1/32 inch (0.8mm)
- Smooth surface finishes to obtain desired coefficients of friction is achievable
- Device will not be under heavy user loads and tensile strength of M2 to M3 screws should suffice

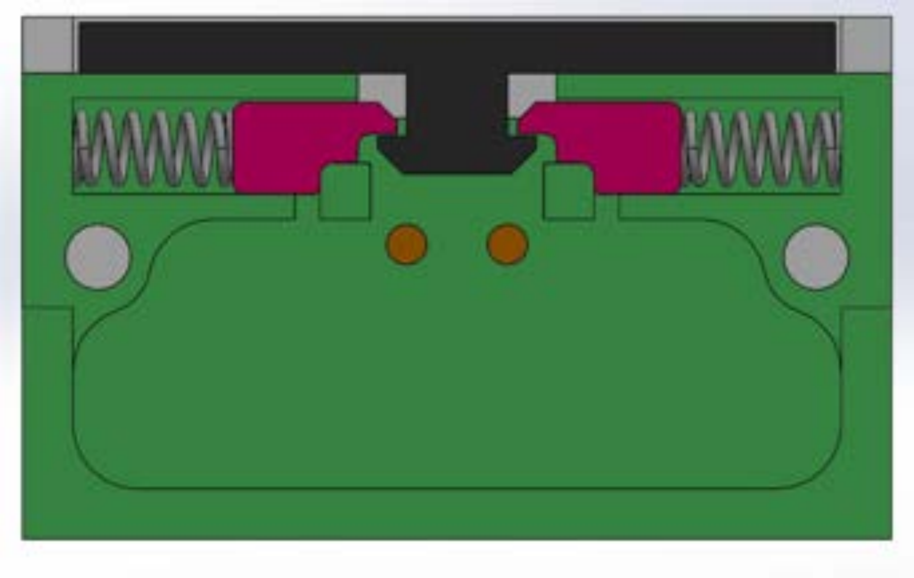
Concepts | Cam Heart Path





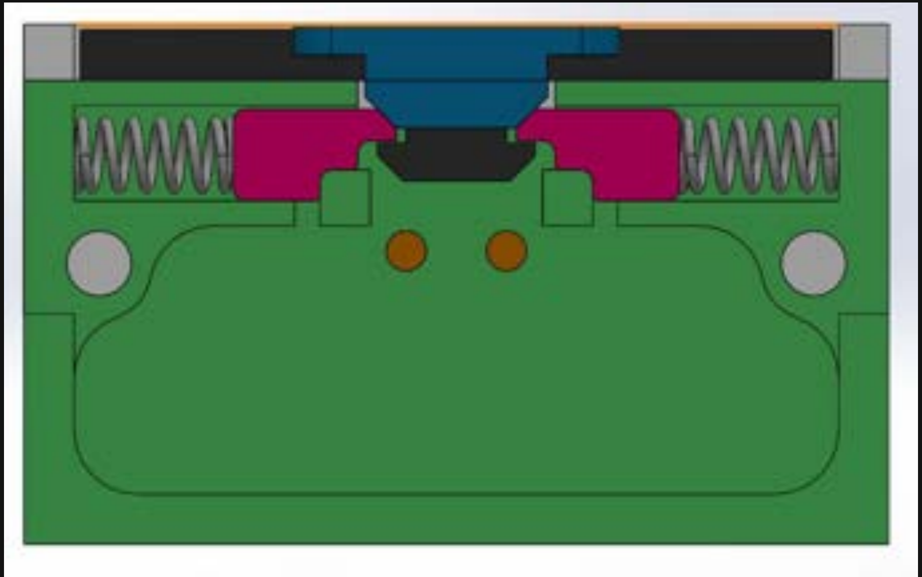
- This design uses a 3D “heart shaped” path common in push-push mechanisms to direct the cam follower clockwise
- Would have delicate parts including a wire cam follower and complex small machining for the cam path
- Height is very tall relative to the battery diameter

Concepts | Gripper Latch



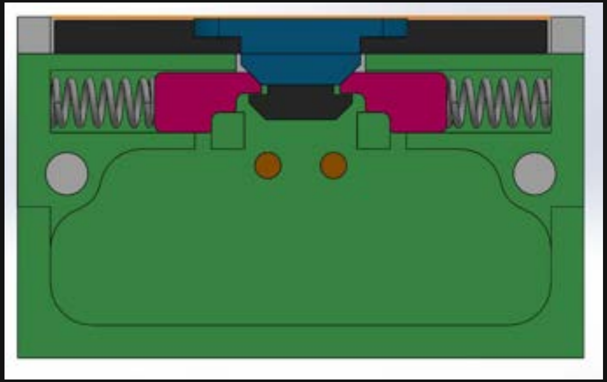
- This concept uses springs and catches to lock the cover instead and takes advantage of horizontal space
- Cam action from the tab on the cover pushes the catches away
- Springs push the catches back into place securing the cover

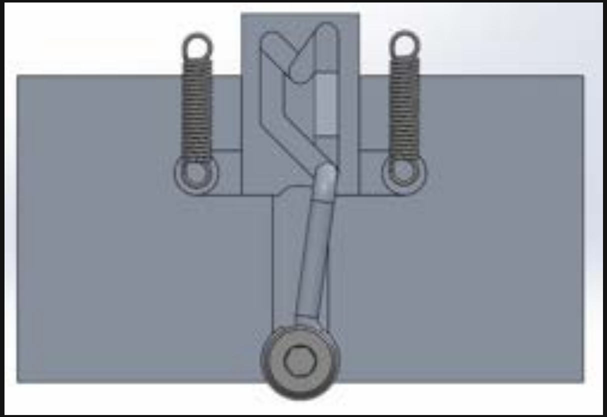
Concepts | Gripper Latch



- Having the button (shown in blue) be separate can be advantageous in this case because of how little height is given by the batteries
- Uses the same cam action as the cover

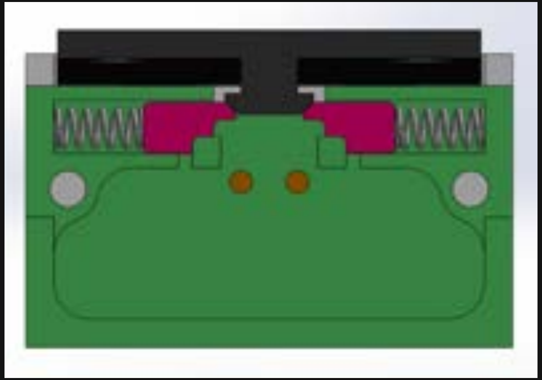
Concept Selection

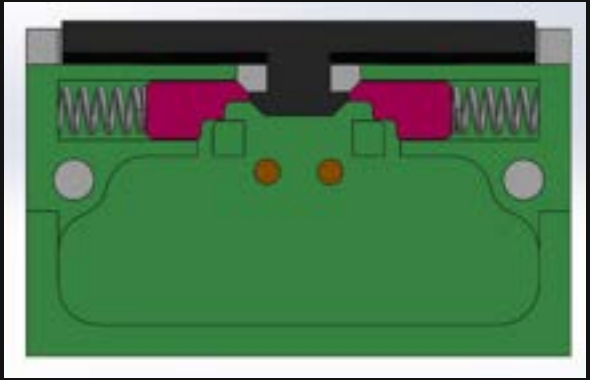


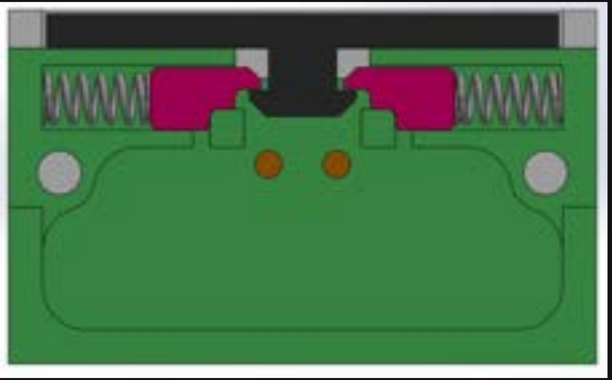


- In optimizing for space, the gripper latch is the best choice
- In optimizing for machinability, the gripper latch is also the best choice, avoiding 3D machine paths as seen with the heart shaped cam path
- Gripper latch is chosen for the final design

Locking Action Illustrated

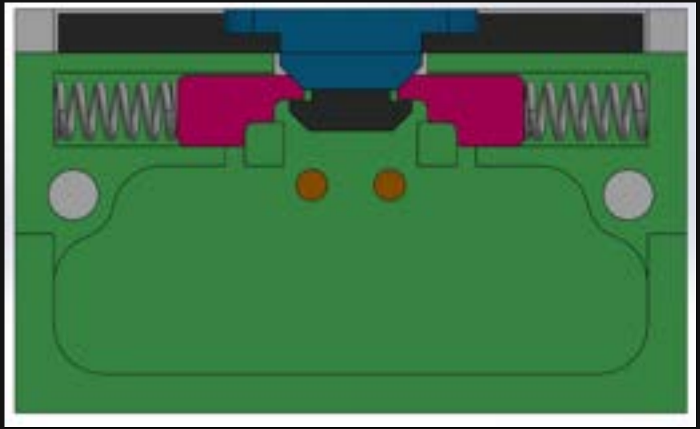


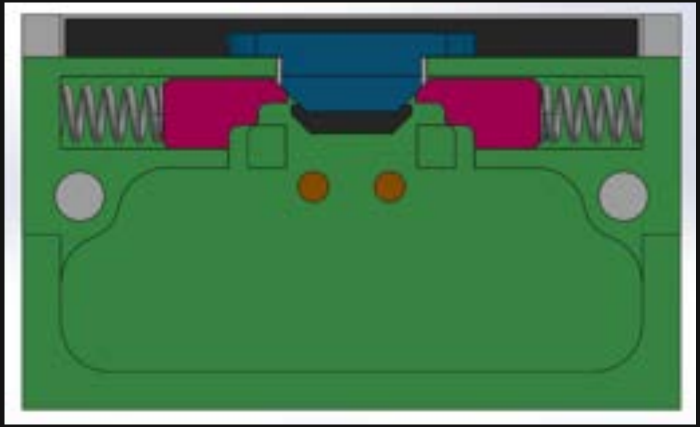




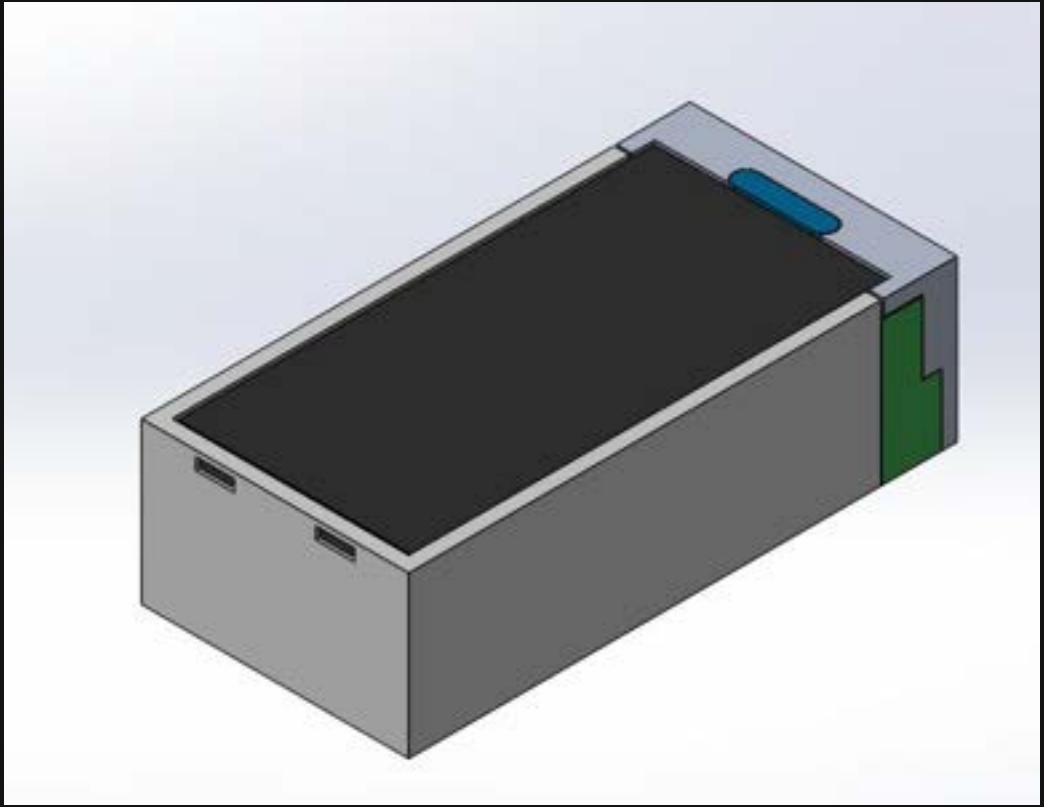
Springs are off the shelf McMaster-Carr: 9435K11

Release Action Illustrated

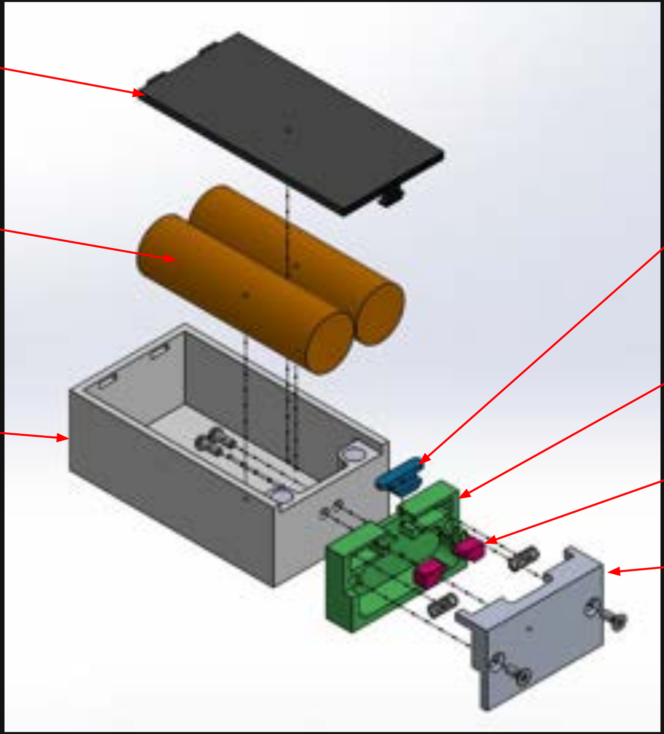




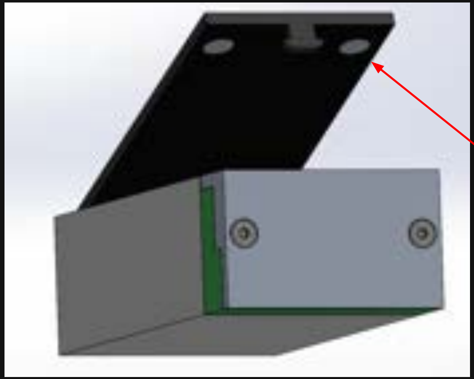
Design | Overall Package

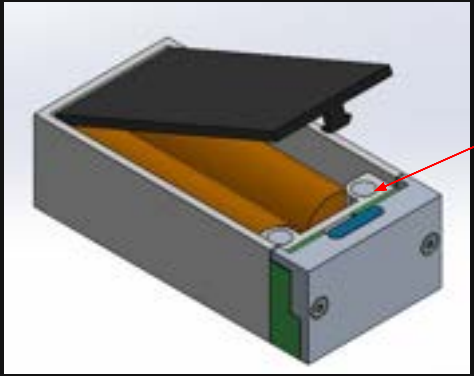


Assembly



Lift Action





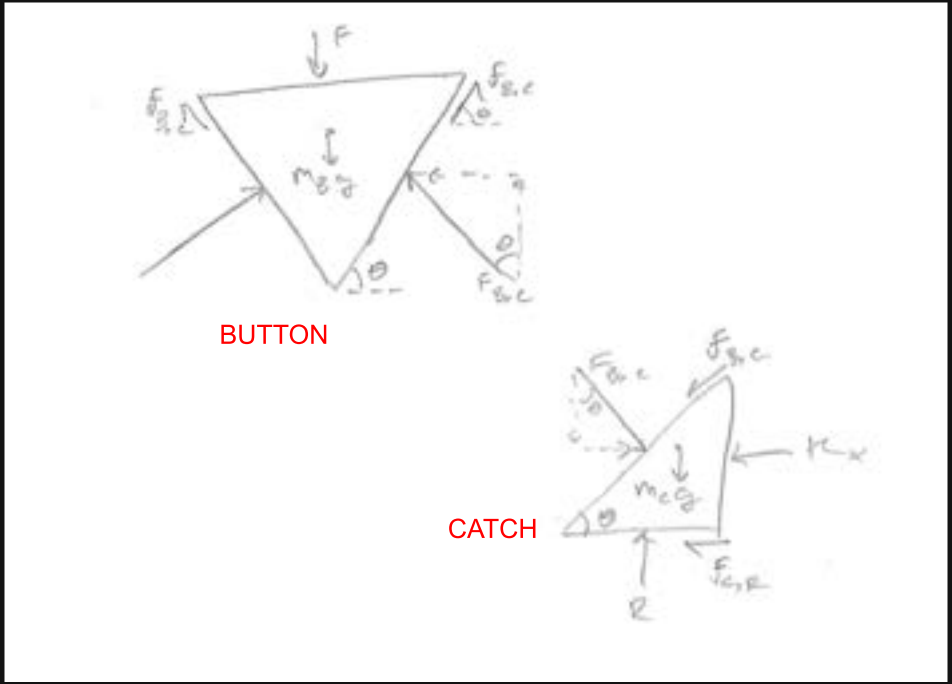
- Magnets used for their repelling ability to lift the cover upon release
- Magnets were chosen as they are easily integratable as press fit or adhered into the cover and the box
- Allows cover to be fully removable as torsion springs require a hinge
- Uses off the shelf KJ Magnetics: D31-N52
- **Design Variable:** Magnets in the box may use thicker magnets for more opening force

Material Specs / Fabrication Method

Component	Material	Mass	Fabrication
Cover	Delrin, PC-ABS	5.21g (Delrin)	CNC, Injection Mold
Button	Delrin, PC-ABS	0.18g (Delrin)	CNC, Injection Mold
Magnet	Neodymium	0.212g	OTS
Catch	Aluminum	0.17g	CNC
Latch Plate	Delrin, PC-ABS	2.72g (Delrin)	CNC, Injection Mold
Box	Delrin, PC-ABS	16.53g (Delrin)	CNC, Injection Mold
Rear Cover	Delrin, PC-ABS	3.10g (Delrin)	CNC, Injection Mold
Springs	Stainless Steel	0.06g	OTS

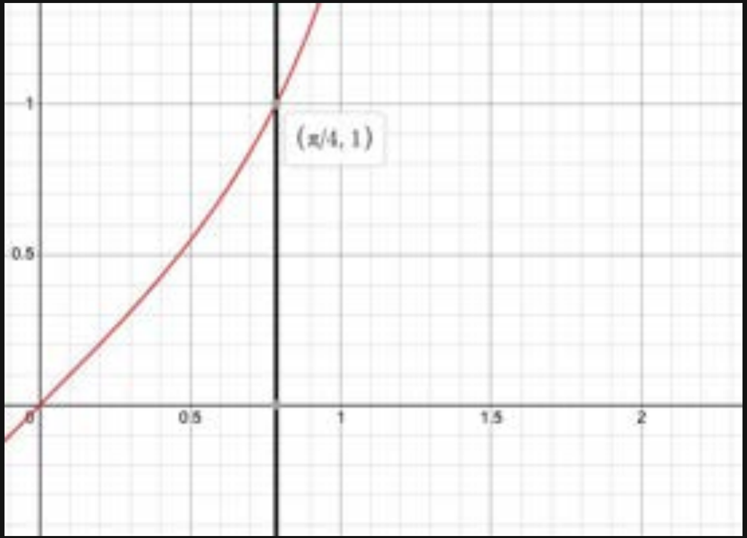
Injection molding may require design edits for uniform wall thickness and adding radii

Free Body Diagram | Button



Since the design is symmetrical, only one side is modeled

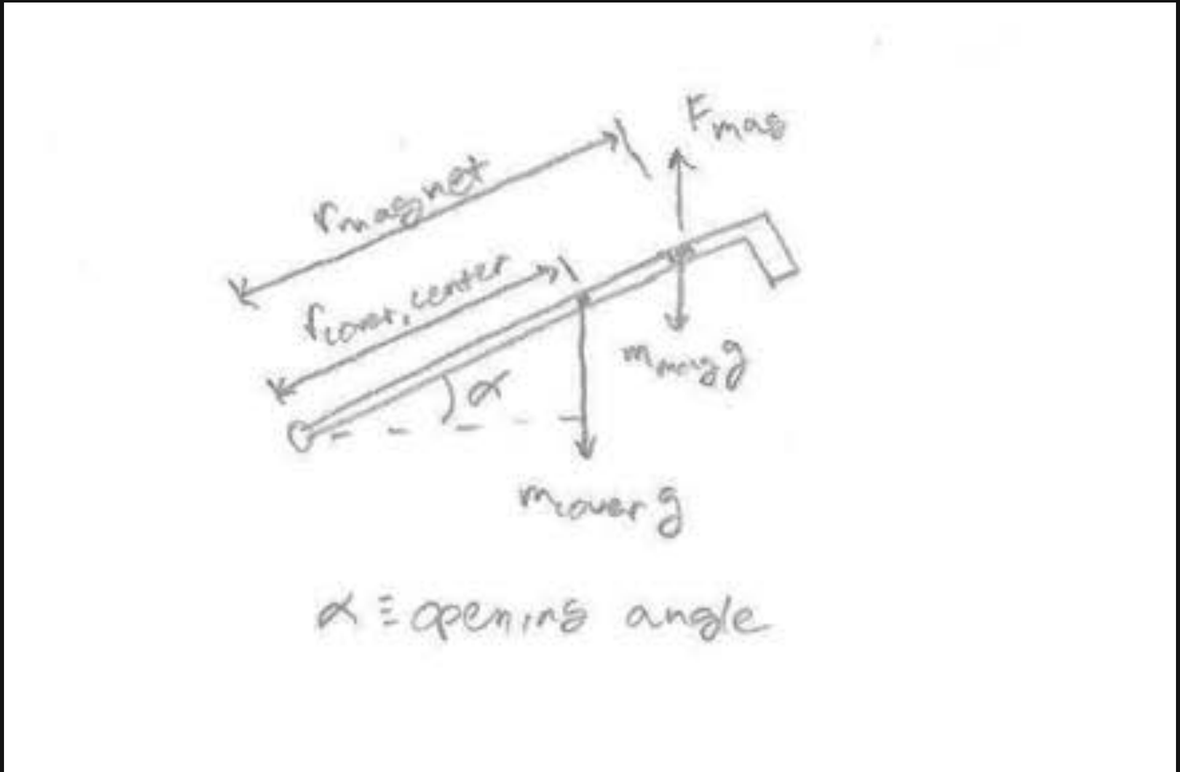
CAM Mechanism | Optimization



The cam motion ratio of downward movement of the button over horizontal movement of the catch is given by *tanθ*.

A 45 degree angle for the cam offers a simple 1:1 ratio for translating motion and strikes a balance with mechanical advantage

Free Body Diagram | Cover Hinge Point



Analysis | Edge Cases, Overcome Friction

$$F_{B,C} = \frac{1}{2}(F + m_B g)(\cos\theta + \mu\sin\theta)^{-1}$$
$$R = F_{(B,C)}(\cos\theta + \mu\sin\theta) + m_c g$$
$$kx = F_{(B,C)}(\sin\theta - \mu\cos\theta) - \mu R$$

Using the balancing equations, first is to check that the push force plus the mass of the button is enough to overcome static friction between the button and catch with the maximum 11N of push force

In which static friction coeff. μ = 0.325 (See Additional Resources for constants)

Case: Pass, plugging in max force and static friction, we find that there is a positive spring displacement (x > 0)

Analysis | Edge Cases, Opening

$$F_{B,C} = \frac{1}{2}(F + m_B g)(\cos\theta + \mu \sin\theta)^{-1}$$
$$R = F_{(B,C)}(\cos\theta + \mu \sin\theta) + m_c g$$
$$kx = F_{(B,C)}(\sin\theta - \mu \cos\theta) - \mu R$$

Using the same balancing equations, we have this edge case in which the spring has been pushed to its required extent to open.

In which dynamic friction coeff. = 0.2

Solving we require a force greater than 8.6N. We have an 11N max according to the MIL-STD

Case: Pass

Analysis | Edge Cases, At Open

$$m_{cover} g r_{cover,center} \cos\alpha + 2 m_{magnet} g r_{magnet} \cos\alpha \leq 2 F_{magnet} r_{magnet} \cos\alpha$$

For this, a 6.35mm opening was targeted. Solving for the angle, we have a 6 deg opening.

Solving using the relevant mass properties and magnet forces from the KJ Magnetics page at the specified distance, this cover should stay open

Case: Pass

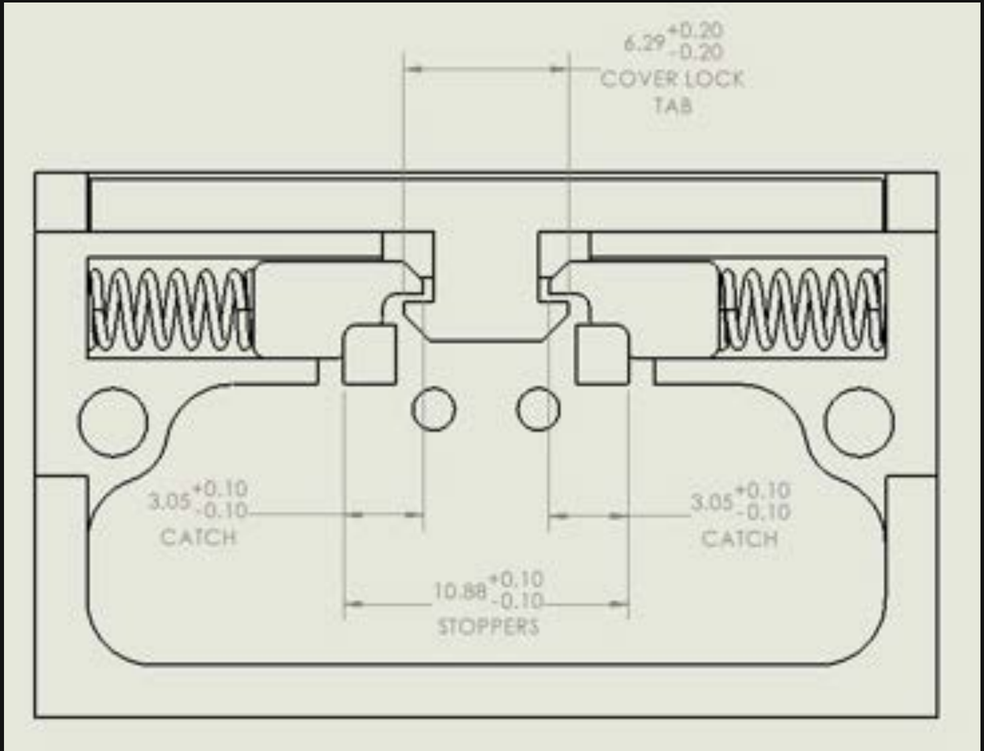
Analysis | Edge Cases, Closing

$$F_{close} r_{close} \geq -g(m_{cover} r_{cover,center} + 2 m_{magnet} r_{magnet}) + 2 F_{magnet} r_{magnet} + F_{overcomespring} L_{cover}$$

To close, the force required is aided by the mass of the cover and magnet. However, it must overcome the repelling force of the magnet and force to overcome the springs (8.6N). Solving, we require a force of 15N at the edge of the cover which is less than the 23 N limit for a palm or thumb. We can also apply 23 N as far away as 20mm from the latch end.

Case: Pass

Tolerancing | Catch Mechanism

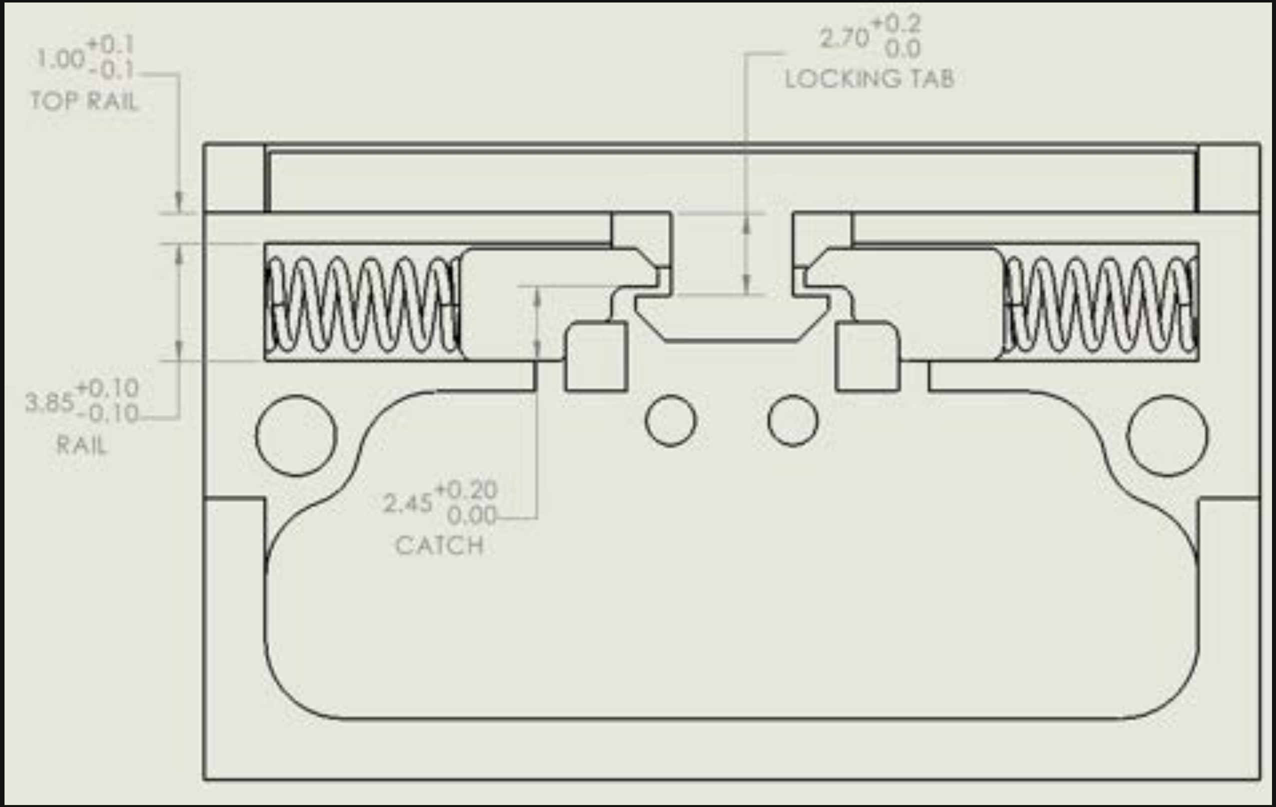


Tolerancing | Catch Mechanism

COVER LOCKING TAB	6.49MM
	6.09MM
STOPPERS	10.98MM
	10.78MM
CATCH	3.15MM
	2.95MM

- For the locking mechanism to work, the cover locking tab must always be wider than the distance from catch edge to catch edge
- Catch edge to catch edge distance is calculated to be 4.48mm to 5.08mm which falls into the range

Tolerancing | Catch Mechanism

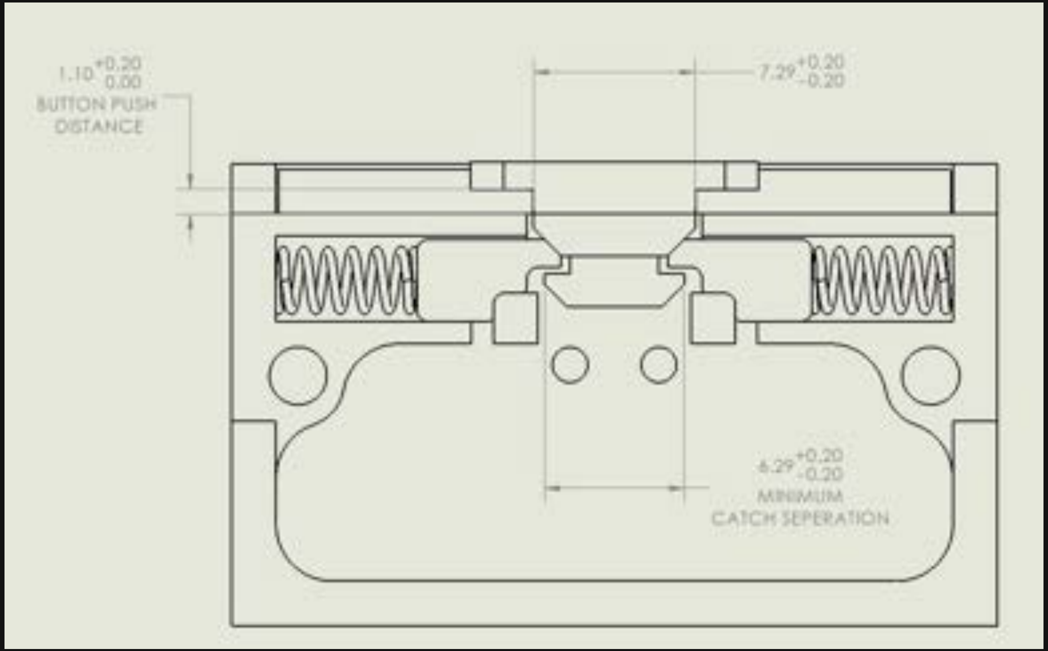


Tolerancing | Catch Mechanism

TOP RAIL	1.10MM
	0.90MM
RAIL	3.95MM
	3.85MM
CATCH	2.65MM
	2.45MM
LOCKING TAB	2.90MM
	2.70MM

- We must also check that the tab can reach deep enough
- Calculating the furthest depth of the bottom of the tip of the catch, the distance the locking tab must reach is 2.1mm to 2.6mm, which is within tolerance band

Tolerancing | Button



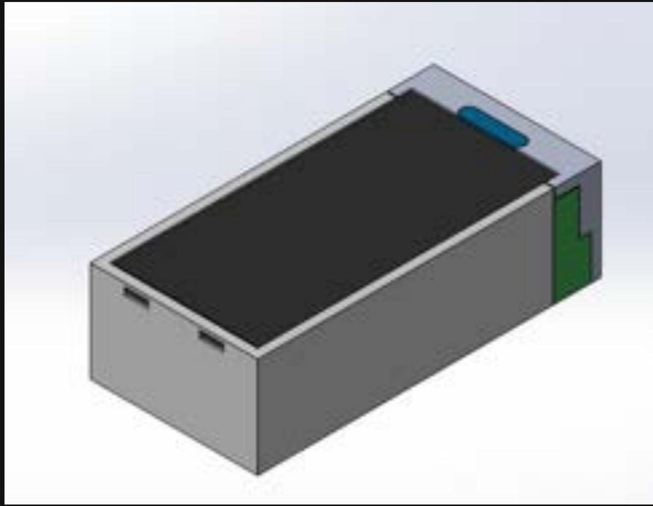
- For the button to work the width must wider than the locking latch on the door
- From the tolerances shown, this case will pass

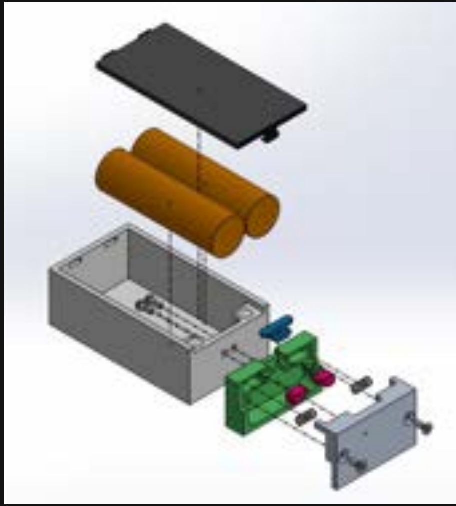
Tolerancing | Button

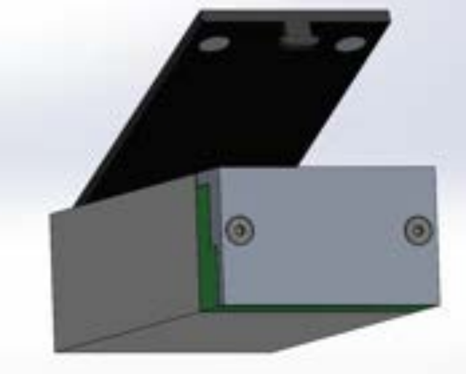
MINIMUM SEPARATION (LATCH WIDTH)	6.49MM
	6.09MM
CATCH END-TO-END	5.08MM
	4.48MM
CALCULATED TOTAL ENGAGEMENT	2.01MM
	1.01MM
ENGAGEMENT PER CATCH	1.01MM
	0.51MM

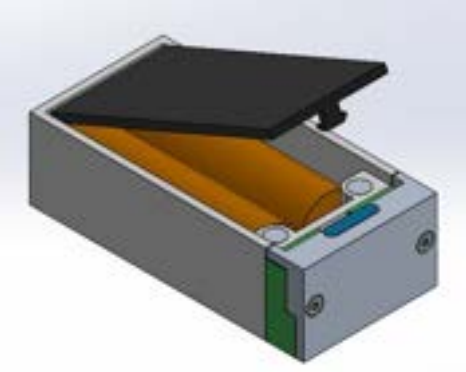
- From the cover latch width tolerance and the end-to-end catch tolerance, we can find the range of engagement for the lock
- Dividing by 2 (for 2 catches) we can find engagement per catch
- For the button to work, the amount to push down must be equal given the one-to-one ratio of depth of the button to horizontal movement of the catch
- The lowest range of push is 1.1mm, for the button, therefore passing

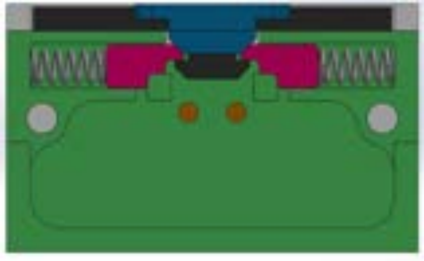
Summary

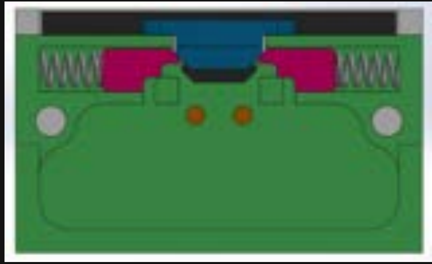












Information Resources

Smallest End Mill Size:

https://www.fictiv.com/articles/fillets-when-to-use-em-when-to-lose-em

Coefficient of Friction Approximations:

https://www.tribology-abc.com/abc/cof.htm

Images

https://www.biscoind.com/Southco-R4-EM-21-161/p?utm_source=google&utm_medium=cpc&utm_campaign=southco-pmax-upgraded-smart&utm_term=&gclid=Cj0KCQjwlPWgBhDHARIsAH2xdNc0AT733_cWx4JEVuR8gKCFksFdeR3EpzY0XyANPaDKf3tgZgZdC8QaAnbcEALw_wcB

https://markforged.com/resources/blog/mmf-living-hinges-3d-printed-part

https://www.walmart.com/ip/Boyt-Harness-83001-Black-12-25-Personal-Vault-w-Keypad-Hidden-Manual-Overide/37242563

https://www.amazon.com/Touch-Latch-Brown-Standard-overall/dp/B001DT1600

https://www.amazon.com/Magnetic-Touch-Push-Latch-Black/dp/B07DNJNDGV/ref=asc_df_B07DNJNDGV/?tag=hyprod-20&linkCode=df0&hvadid=309763090755&hvpos=&hvnetw=g&hvrand=13838903270973367731&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9031944&hvtargid=pla-573575520691&psc=1

OTS Sources

https://www.kjmagnetics.com/

https://www.mcmaster.com/