Pre-Denting Can Crusher

EML 3362 Final Mechanism Design Project: Group 13

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Parts I&II. Clarify and Ideate:

Empty soda cans take up a lot of space, so when recycling them, it is advantageous to crush the empty cans to improve the packing factor. Aluminum beverage cans are remarkably strong along their vertical axis due to two factors: their cylindrical shape and pressurized contents. The shape evenly distributes forces around the circumference, while the internal pressure prevents the walls from buckling. Once emptied, the can loses this internal pressure support, making the walls vulnerable to buckling, but the can's shape still resists crushing. Our prototype aims to tackle this even-force-distribution by designing a device that will pre-dent the cans before crushing them. Pre-denting the can at a point along its vertical axis solves this problem by weakening the reactionary axial forces during crushing. When force is applied to crush the can, this pre-dent will cause a cascading effect as further denting occurs, and gives the aluminum sides somewhere to fold into. By creating this initial weak point, the force needed to crush the can is reduced, helping individuals who might lack the strength to crush undamaged cans.

We have tools like SolidWorks for design, and materials like aluminum and wood available for fabrication. We used tools like a Dremel to cut the aluminum bar stock and a sensitive drill press to make connecting points on each link for fastening bolts. The input to the mechanism will be a manual upward push and downward pull on the lever arm handle. The output variables we measured include the reduced amount of input force, and the range of motion for the output sliding link. Samuel created the first CAD prototype of a dual-action can crusher with several iterations of the pre-denting arm assembly. Ross worked on the initial graph and analysis of the prototype, which was reviewed and signed by the professor, so we began development of the first cardboard prototype. This allowed us to analyze link dimensions and joint placements, and adjustments to the mechanism’s assembly were led by Thais. These modifications allowed us to increase input range of motion and minimize the crushing capability of the mechanism. An updated graph was then needed with the modified prototype design, with graph analysis completed by Natalia for updated approval from the professor. The entire group utilized tools and materials on campus, such as the DFX lab and Samuel’s research and development lab, to develop the final prototype. Ross gathered all building material including wood block, aluminum bar stock, bolts, washers, and Nyloc nuts. The group collaborated very well and maintained communication throughout the design and development stages.

Our prototype is a dual-action can crusher designed to reduce the amount of input force by first creating a horizontal indentation before completing the vertical crush. It uses a 6-bar linkage system that enables two distinct motions. Pushing the handle forward causes the angled links to apply a horizontal force that partially deforms the can. Then, pulling the handle down will drive the sliding link downwards to complete the vertical crush, which becomes easier thanks to the initial indentation. We designed the prototype in SolidWorks and planned to manufacture it using a combination of sheet metal and wood, easy materials to work with that are ideal for thin and parallel moving links against a sturdy base structure.

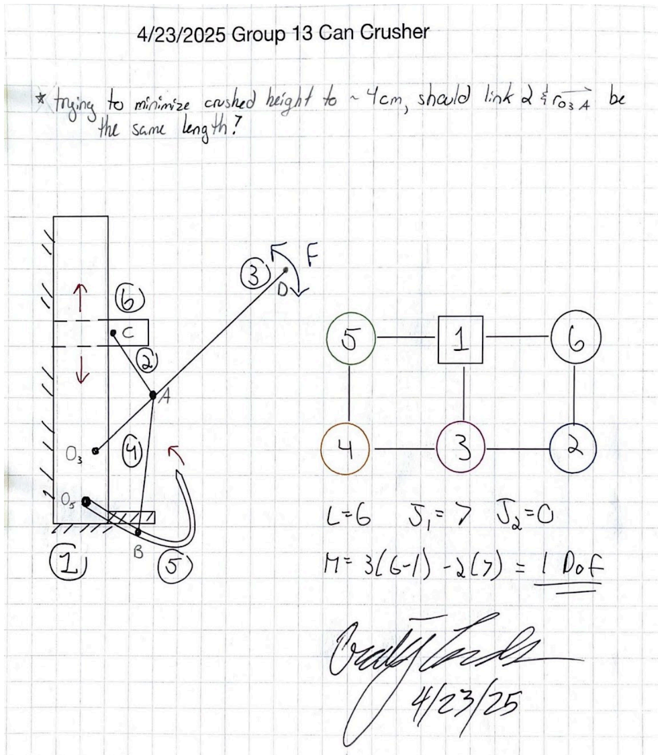


Figure 1: Skeleton Diagram and Graph

Part III. Develop

Using the signed skeleton diagram and the motion graph as references, we created a detailed sketch of the mechanism in CAD.

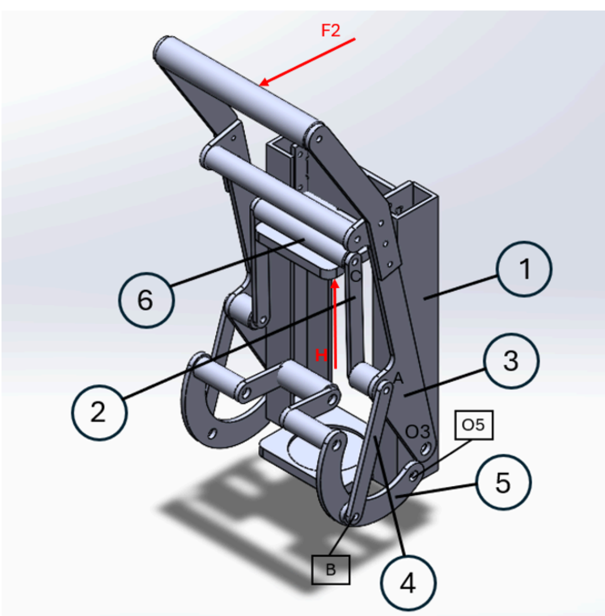


Figure 2a: Horizontal Crushing Motion

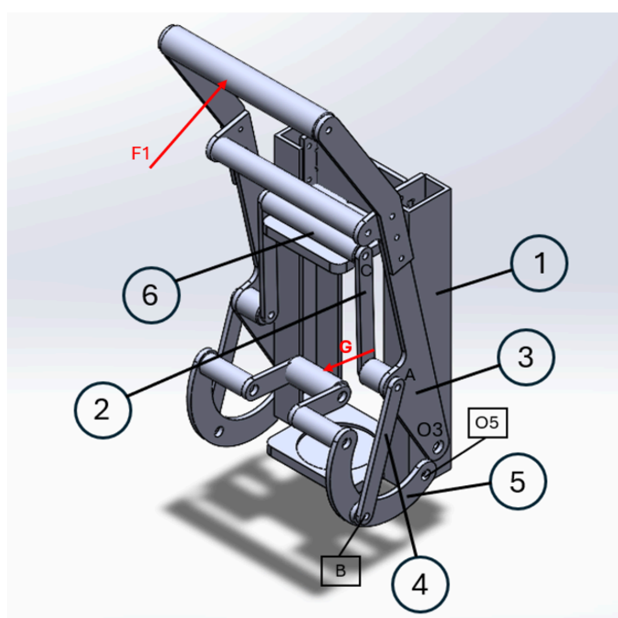


Figure 2b: Vertical Crushing Motion

Table 1: List of Mechanism Links and Pin Joints

Name	Description
1	The ground link is fixed to the wall and used to hold the can.
2	Coupler Link
3	Input link of the entire mechanism
4	Coupler Link
5	The output link for the Horizontal crushing action.
6	The output link for the vertical crushing action.
O3	The pin connecting the ground to link 3
O5	The pin connecting the ground to link 5
A	The pin connecting links 2, 3, and 4
B	The pin connecting links 4 and 5
C	The pin connecting links 2 and 6
F1	Input force for the horizontal crushing motion.
F2	Input force for the vertical crushing motion
G	Output force for the horizontal crushing motion
H	Output force for the vertical crushing motion

<u>Narrative</u>

The mechanism has six links and seven lower pairs, so there is only one degree of freedom. The input for this degree of freedom is link 3, the mechanism's lever arm. The mechanism operates as a watt-chain, with one vector loop responsible for each of two outputs, denting the can and crushing the can. To dent the can, the input link rotates counterclockwise (viewed from the left) until it is parallel with link 1. This will also rotate links 4 and 5 counterclockwise, until a horizontal output force from link 5 dents the can at a point along its vertical axis. To crush the can, link 3 rotates clockwise causing link 2 to rotate counterclockwise, this will pull link six downwards and decrease its distance relative to the mechanism's ground link. The largest mechanical advantage occurs when link three becomes parallel with link 1 along either the x or y axis. This means that as the lever arm approaches link 1, either through denting or crushing, the mechanical advantage will increase. This is crucial because additional input force is required once the mechanism begins to crush the can, so mechanical advantage must be maximized.

There are two outputs, the distance between link 5 and ground in order to dent the can, and the distance between link 1 and link 6 in order to crush the can. If the greatest length between ground link 1 and slider link 6 were not limited, then the output range of motion is determined by link 5, the denting arm. The output range of motion begins at full pre-denting, when the lever arm is fully pushed upwards with the end point of link 5 an equal distance to ground as sliding link 6 (r_6 = 2.5cm). The range of motion ends when the lever arm is fully pulled downwards and link 5 makes contact with the supporting wall or surface (collinear with ground link 1), resulting in a range of motion of 180.49° for the denting output.

However, the shortest distance possible between sliding link 6 and ground link 1 is still the main parameter used to determine the mechanism's effectiveness. Determined through CAD analysis and the consideration of the range of motion for link 5, the total range of motion for sliding link 6 relative to ground link 1 is 23.98 cm. The can crusher's maximum crushing width of an aluminum can is 0.46 cm, although this value is also an ideal measure and dependent on the can's total volume and thickness. The table below analyzes how changing any link length in the mechanism will affect each of three outputs. Output rotation range is the total range of pre-denting link 5, output distance range is the total distance traveled by sliding link 6, and maximum crushing width is the shortest distance from sliding link 6 to ground link 1, which will determine the mechanism's ability to crush a can.

Table 2: Effect of Changes to Mechanism Link Lengths

Parameter (nominal value)	Parameter change (% change from nominal)	Effect on output rotation range, (% change from nominal)	Effect on output distance range, (% change from nominal)	Effect on maximum crushing width (% change from nominal)
r1= 5cm	Δr1x = +.5cm (10%)	189.23° (4.8%)	23.67 cm (1.29%)	0.77 cm (67.4%)
	Δr1x = -.5cm (10%)	172.22°(4.6%)	24.17 cm (0.79%)	0.26 cm (43.5%)
r2=11.2cm	Δr2 = +.5cm (4.46%)	180.49°(0%)	23.06 cm (3.8%)	1.88 cm (308.7%)
	Δr2 = -.5cm (4.46%)	142.19°(21.2%)	21.11 cm (11.9%)	2.83 cm (515.2%)
r3=13.5cm	Δr3 = +.5cm (3.7%)	135.23°(25%)	21.88 cm (8.76%)	2.88 cm (526%)
	Δr3 = -.5cm (3.7%)	180.49°(0%)	21.07 cm (12.1%)	2.97 cm (545.6%)
r4=11.2cm	Δr4 = +.5cm (4.46%)	180.49°(0%)	23.26 cm (3%)	1.29 cm (180.4%)
	Δr4 = -.5cm (4.46%)	178.82°(0.93%)	24.22 cm (1%)	0 cm (100%)
r5= 4.5cm	Δr5 = +.5cm (11%)	180.49°(0%)	24.33 cm (1.46%)	0.15 cm (67.4%)
	Δr5 = -.5cm (11%)	180.49°(0%)	23.32 cm (2.75%)	1.04 cm (126.1%)
r5b = 8cm	Δr5b= +.5 cm (6.25%)	177.45°(1.68%)	23.89 cm (0.37%)	0.46 cm (0%)
	Δr5b= -.5 cm (6.25%)	183.7°(1.78%)	24.04 cm (0.25%)	0.46 cm (0%)
r6= 2.5cm	Δr6 = +.5cm (20%)	177.16°(1.84%)	22.59 cm (5.79%)	1.77 cm (284.8%)
	Δr6 = -.5cm (20%)	145.57°(19.3%)	21.67 cm (9.63%)	2.83 cm (515.2%)

<u>Significance to Design Purpose</u>

The purpose of the can crusher is to minimize input force with increased input motion, and maximize output force for a decreased output motion. The determining factor for success of the mechanism is how much an aluminum can will be compacted, so changes to the maximum crushing width is the most important factor to consider. To increase the success of the mechanism, the output rotation range should be maximized (increased in value) while the maximum crushing width should be minimized (decreased in length). When analyzing the effect of changes to each link, we found that decreasing the length of coupler link 4 resulted in the smallest crushing width while also increasing the range of motion. Most other changes would increase the crushing width, making it less efficient. The output range of sliding link 6 only needs to accommodate varying can sizes and therefore does not need to be further maximized beyond the existing range. Another consideration to maximize mechanical advantage is extending the input lever arm beyond its joint location; this addition ensures over 90 degrees of motion and a parallel alignment with the ground link. This will also maximize the mechanical advantage while driving the lever arm downwards.Using equivalent coupler link lengths for links 2 and 4 will create a parallel mechanism model, allowing for more compaction with less force input.

Part IV. Implement:

A. To decide the dimensions of the mechanism, we first created a CAD design. This helped us to visualize the overall size and estimate the amount of material we would need for the prototype. Based on the CAD model, we built our first prototype out of cardboard to test whether the design worked and determine the final product's optimal dimensions. After testing with the cardboard model, we realized that some dimensions from the original CAD design needed to be adjusted to improve the mechanism’s performance. Once we finalized the dimensions through the cardboard testing, we moved on to constructing the actual mechanism. Using the updated measurements, we completed the design and assembly of our fully functional prototype.

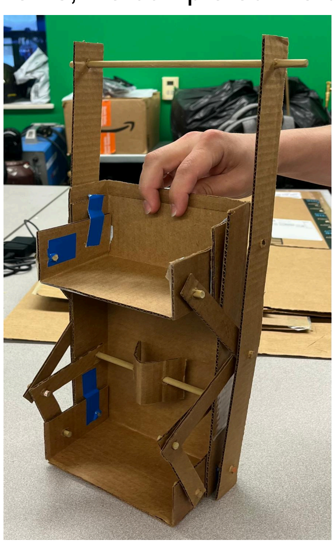


Figure 3a: Cardboard Prototype

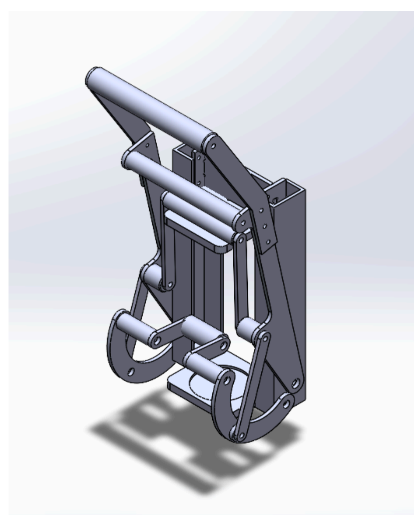
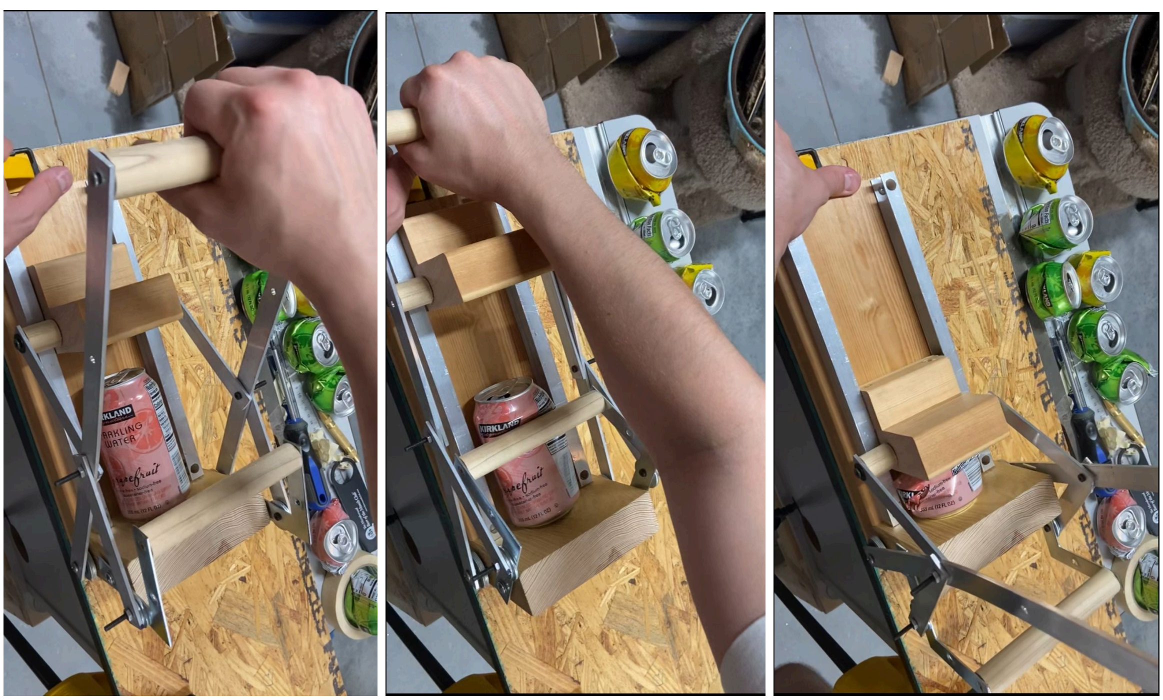


Figure 3b: CAD design

B. In both the CAD model and the prototype, our mechanism had one degree of freedom actuated by lever arm link 3, where the user first pushes forward/upward to pre-dent the can and then pulls backward/downward to fully crush it. In the initial CAD design, the pre-denting arm was curved, but after building the cardboard prototype, we realized it would work better at a 70-degree angle, as shown in the images above. In the CAD design, the mechanism had some limitations regarding how far it could crush the can vertically and how much it could move forward during the pre-dent stage. These issues were mainly caused by interference between certain parts of the linkage system, which restricted the overall motion and prevented the mechanism from reaching its full range of movement due to link overlap. To address this in our physical prototype, we added spacers between links 2 and 6, 3 and 1, and 4 and 5. These spacers helped eliminate the collisions that were happening between links, especially during the transition between pre-denting and crushing. We also adjusted the lengths of some of the links to give the mechanism more clearance and flexibility. These small changes made a noticeable difference in how well the mechanism performed. The motion became much smoother, and the overall can-crushing process felt more controlled, efficient, and consistent. The figures below show the final prototype at three different stages of operation: initial position before any crushing takes place, intermediate position during the horizontal pre-dent motion, and a final position after the vertical crushing is complete.



Initial Position | Intermediate Position | Final Position

Figure 4: Use of the final prototype

C. In general, the mechanism worked almost exactly as we would expect for a planar rigid-body system. The motion we observed in the prototype was very close to what we laid out in the skeleton diagram, designed in CAD, and tested in the cardboard prototype. All the components moved as expected, and the sequence of movement transitioned smoothly from pre-denting to crushing. After construction of the final prototype, it was observed that bending or loosening occurred at pin joint locations and frictional resistance occurred between the sliding channel and crushing link. These effects did not significantly alter the prototype's performance and were minimized by implementing washers at each pin location and grease along the metal bearings and sliding channel. Even though there were some secondary effects, such as minor deflection of the structure, they didn't interfere with the operation of the mechanism. One thing we did notice was that the aluminum lever arm bent slightly when a significant amount of force was applied. This happened because aluminum isn't very stiff under high loads, especially in longer parts like the lever arm. You can see this in the image below, where the lever arm shows a small but visible deformation after multiple uses of the mechanism.However, even with that small flexing, the mechanism still completed the pre-dent and the full crushing stages without any problems. So, while some practical considerations changed the motion slightly from the ideal model, they were not significant and did not change how the device operated.

Figure 5: Deformed Lever Arm

D. The prototype was able to perform exactly as we wanted, which shows that the concept behind the design was correct. We were trying to reduce the amount of force needed to crush the can by pre-denting it horizontally first, and the prototype accomplished that. To test this, we used both a mechanical and electrical force gauge to measure the amount of force required to crush a can with and without the pre-denting process. Without the horizontal pre-dent, it required about 36 pounds of force to crush the can completely. The force was reduced to about 21 pounds when the pre-denting stage was included. This demonstrated a significant 40% decrease of input force, supporting that our two-stage motion design does reduce input forces required and makes crushing a can easier and more efficient. These results guarantee that the design concept works and operates as intended and designed.

E. One thing we would recommend to improve the prototype's quality is to change the material used for the lever arm and coupler links. Right now, these links are cut from flat aluminum stock, which is ideal for ease of use and lightweight construction, but our lever arm did undergo permanent bending deformation when a significant amount of force was applied. While our mechanism still operated as intended during the final project showcase, the resulting bend meant not all of the input force was transferred to our desired output and crushing became slightly more difficult to accomplish. If a stronger material like flat steel stock material is used instead, the lever arm would be much less prone to deformation and the transfer of force between our input and output links would be maximized. Improving the quality of material used would create a more efficient and reliable prototype that can withstand prolonged use or higher input forces, resulting in an improved mechanism overall.

Conclusion:

Through completion of this project, our group gained valuable insight into the design and fabrication processes of real-world mechanical systems. The biggest take-away from this experience has been an appreciation for the time and input required to create even a “simple” mechanism such as a can crusher. Using SolidWorks helped us visualize the motion of our prototype with accurately scaled dimensions, but it was only through prototype construction and testing (even if only on a cardboard model) that we could identify and improve our mechanism’s function and actuation. Each aspect of building a mechanism, from material selection and changes to link lengths, even to incorporating small washers onto fastening bolts, can greatly impact its performance and functionality. As engineering students, seeing the results of our project was incredibly gratifying—especially when we were able to measure a clear decrease in the required input force after implementing our pre-denting link arm. It validated both our design concept and our ability to develop a reliable product. This project bridged the gap between classroom learning and hands-on experience, highlighting how iteration, teamwork, and testing are all essential components of the engineering process.