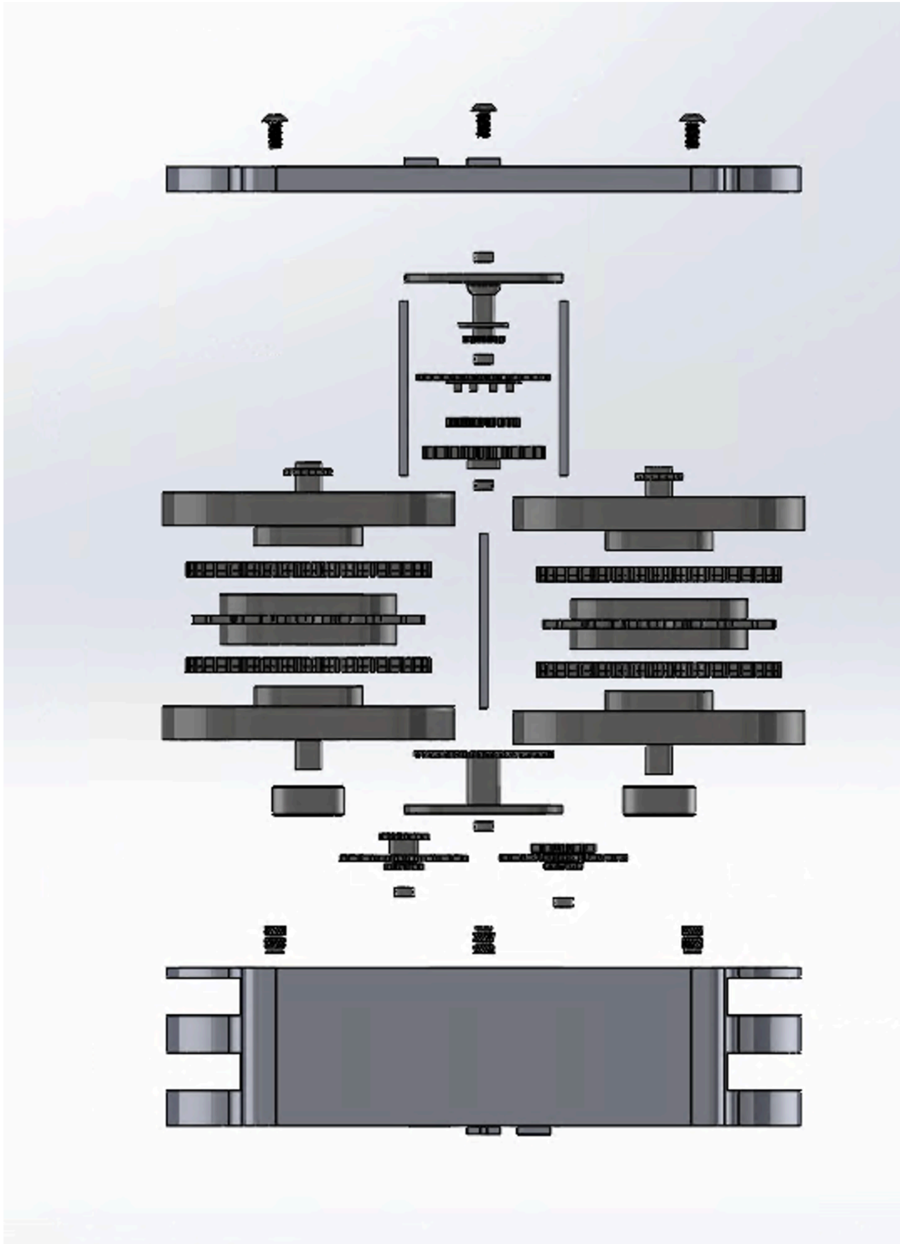

FINAL PROJECT REPORT: Handheld Math Machine

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i. Background Research

The global market for educational toys is valued at approximately $60 billion, and STEM toys are growing fast. Among these, math toys for kids aged 4–7 are especially popular because parents want their children to learn numbers early and often prefer screen-free options. Research shows that kids learn best by playing with things they can touch and manipulate, and that idea guided our design.

We found that existing toys all have drawbacks. Traditional abacuses let kids count but do not actually do calculations. Button-press toys only show pre-set answers and do not let kids try their own problems. Electronic calculators work, but they need batteries, can break, and do not show kids how numbers really work. Some advanced toys teach logic or mechanical skills but are too complicated for young children or do not focus on arithmetic.

There is a clear gap. No toy lets kids mechanically add and subtract using any numbers they choose while still being fun and safe to play with. Mechanical calculators have existed for centuries, but they were made for adults and are now collectibles, not suitable for children. No one has made a child-friendly version before.

Our toy fills this gap. It is the first fully mechanical calculator designed for kids. Children can ask their own questions, like "What happens if I turn this wheel," and see the answer instantly. The clicking sound of the gears is satisfying and makes the learning experience fun. One side does addition and the other does subtraction, keeping play interesting.

Research in developmental psychology, particularly Jean Piaget's theory of cognitive development, shows that young children learn mathematical concepts best by physically touching and manipulating objects before they can grasp abstract numbers and symbols. Turning a wheel and watching the result helps kids understand how numbers combine or separate. They also develop fine motor skills and hand-eye coordination. The size of the toy fits comfortably in small hands, encouraging proper grip and control.

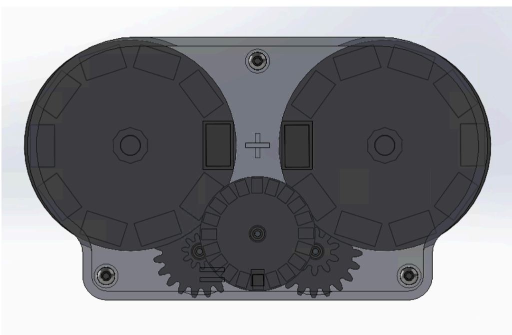
Kids can experiment with any single-digit numbers and discover math concepts themselves, like that 3 + 4 is the same as 4 + 3, or that subtraction works in reverse. They learn by exploring, not memorizing. Operating the wheels and reading the display also teaches patience and problem-solving. Parents get a screen-free toy that keeps kids engaged for a long time without batteries or electronics.

Our design draws inspiration from the lineage of Dieter Rams, who created simple, clear calculators for adults. We adapted his principles for children, much like how Apple's original iPhone calculator app drew directly from Rams' Braun ET 55 design, an electronic calculator now held in the permanent collection of MoMA. Both focus on clarity, honesty, and simplicity, and our toy brings these principles to kids learning their first arithmetic operations. It is easy to use. Two wheels provide input, and one window shows the answer, so no instructions are needed. It is quiet, safe, and built to last.

ii. Design Overview

Our design is a handheld educational toy that helps children learn addition and subtraction. The child uses two numbered input wheels (one on each side of the toy) to create an equation, with each wheel displaying digits from 0 to 9. Inside the toy, a system of gears transfers the motion of the input wheels to a central output wheel, which displays the result. Both sides of the toy operate the same way, but one side accounts for negative values. If a calculation results in a negative number, the toy displays 0.

Although the internal mechanism may appear complex at first, it is straightforward once understood. The process begins with the input wheels, each of which can rotate in only one direction due to a one-way bearing. They move only when driven thanks to a freewheel system similar to the mechanism found in bicycle hubs. This freewheel system is just another one way bearing. A detent cam ensures that each wheel always aligns precisely with one of the ten digits (0-9), preventing partial or misaligned readings.



Each full rotation of an input wheel corresponds to half a rotation of the output wheel, allowing the output to display every possible result. Motion is transferred from each input wheel to the output wheel through a gear set with the following ratios: 2.8:1.4 and 0.4:1.6 (with the 1.4 and 0.4 segments sharing a common gear). Because the two output wheels are independent, each must be linked to both input wheels. Similarly, the two input wheels are not directly connected to each other, so each requires its own gear path to the output.

A special variation occurs on the "positive" side of the mechanism: because the two wheels rotate in opposite directions, a planetary gear system is introduced. This planetary gear system acts as a differential allowing the inputs from the wheel to spin the output wheel while the other input wheel is stationary. This is achieved through an alternate reduction sequence: 2.8:1.4, 1:3, 3:1, 2:1 and then 2.8:1.4, 2:1, 2:1 for each side of the number wheel.[1]

All of these components are housed inside a sturdy enclosure secured with three bolts (though a durable one-way snap-fit system could be used for a production model). The toy is constructed from a child-safe, impact-resistant ABS plastic.

iii. Design Intent and Engineering Decisions

In modeling this device, our design intent focused on usability, safety, and durability, three qualities essential for a children's educational toy. First, we prioritized ease of use by ensuring that the input wheels rotate smoothly and consistently. The one-way bearing and detent system were modeled not only for mechanical function but also to give the wheels a satisfying, controlled feel that children can turn without excessive force.

We also shaped the overall form factor to support comfortable use. The device is approximately 5 by 8 inches, a size chosen to sit naturally in a child's lap or be held securely in both hands. This dimensioning was intentional in the CAD model to create a product that feels stable, portable for young users.

Safety was a major driver in the modeling process. All components were designed to be fully enclosed so that no loose or removable parts could be taken out by a child. One critical area we identified early was the potential pinch point where each input wheel enters the body of the toy. To eliminate this risk, we modeled the opening with rounded edges and a tight, gradually tapered fit that prevents small fingers from getting caught.

Modeling this device presented several challenges. One of the primary difficulties was designing a gear system that could reliably transfer motion from the two independent input wheels to the output wheel while maintaining accurate ratios for all possible outcomes. Because the two sides of the toy rotate in opposite directions, we had to engineer two distinct gear trains—one using an added planetary gear box as a differential to allow the rotation. Determining the appropriate gear ratios and spacing within the limited internal volume required multiple iterations and careful consideration of tolerances.

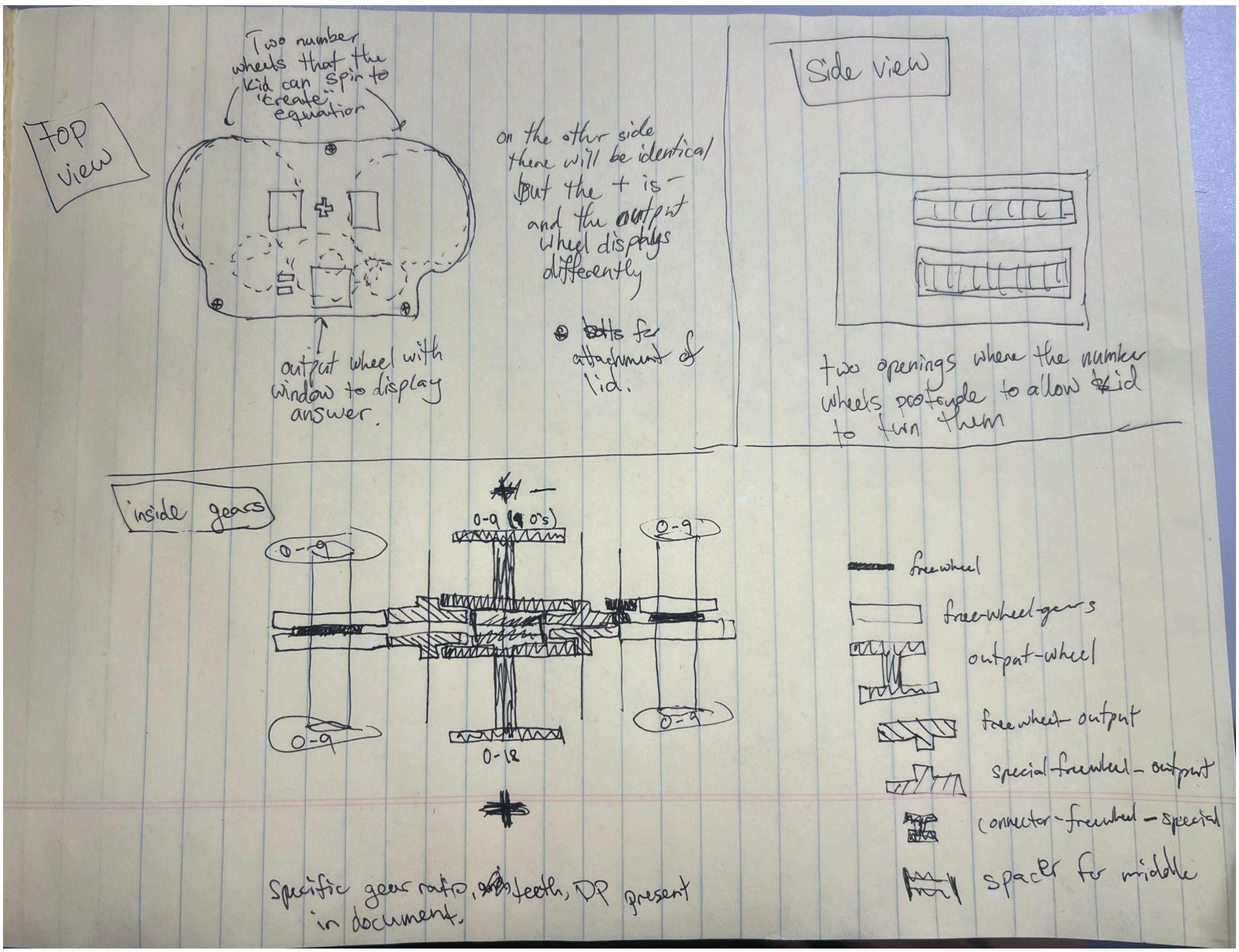
[1] See the end of document for all gear dimensions

Finally, the limited 5-by-8-inch form factor created spatial challenges. We had to make decisions about gear placement, particularly how large we could make them. Since the larger the gear the more tolerance there is during manufacturing, it was imperative for us to fit as large of gears inside the enclosure as possible. This involved sketching multiple gear trains with different sizes to ensure full utilization of the space that we had.

Overall, the modeling process required continuous trade-offs between mechanical complexity, user experience, safety, and durability, leading us to make thoughtful engineering decisions at every stage.

iv. Freehand Sketch and Diagram of the Original Concept

Image Showing Initial Concept



v. Factor of Safety

The only part where the safety factor was calculated for was the box. The box is the outermost component and would take any force imparted on the toy. The initial calculations were done by hand in a simple compressive scenario. The assumption was that the force of the kid would be distributed evenly across the walls of the structure. Below is the image showing the calculations.

Stress and Safety Factor Calculation

The maximum allowable compressive stress for ABS plastic was taken as:

$$\sigma_{max} = 7ksi$$

The area of the component under compression is approximately:

$$A = 1.5in^2$$

Using the normal stress equation:

$$\sigma = \frac{F}{A}$$

The maximum allowable compressive force is:

$$F_{max} = \sigma_{max} \cdot A$$

$$F_{max} = (7{,}000psi)(1.5in^2)$$

$$F_{max} = 10{,}500lb$$

Factor of Safety

The factor of safety is defined as:

$$SF = \frac{\sigma_{max}}{\sigma_{applied}}$$

Assuming a conservative applied load of:

$$F_{applied} = 100lb$$

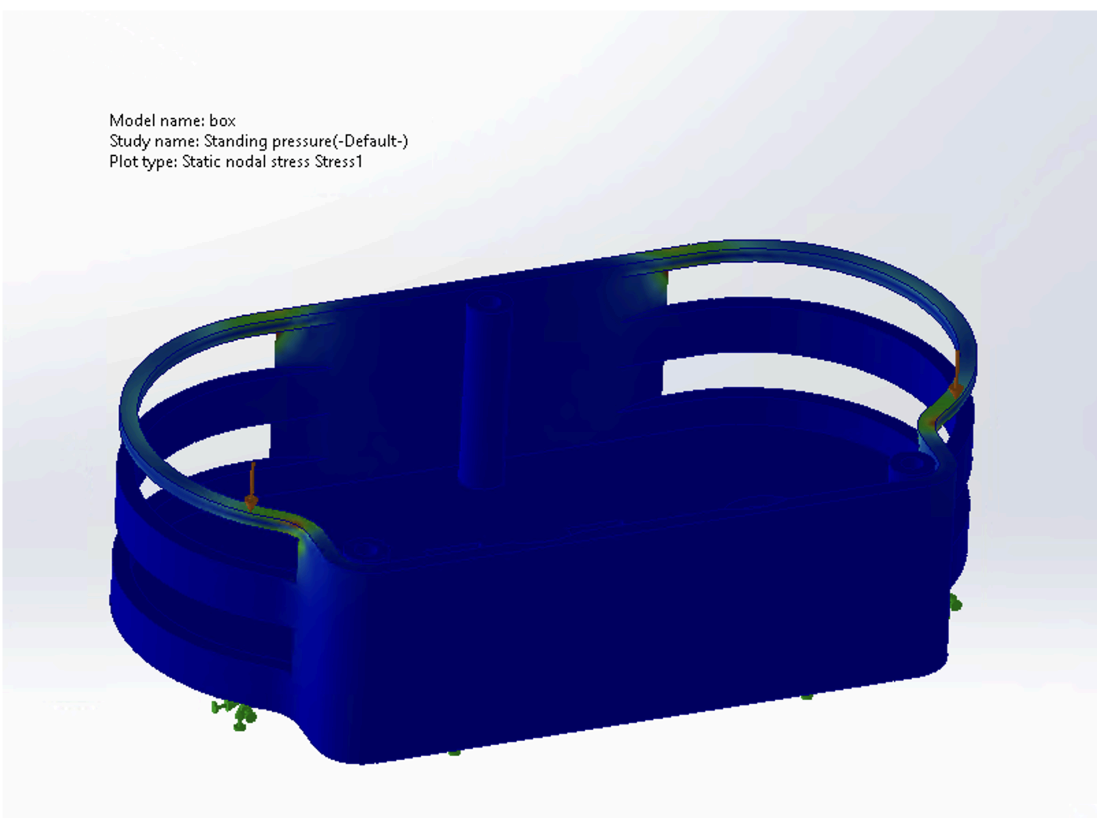
The applied stress is:

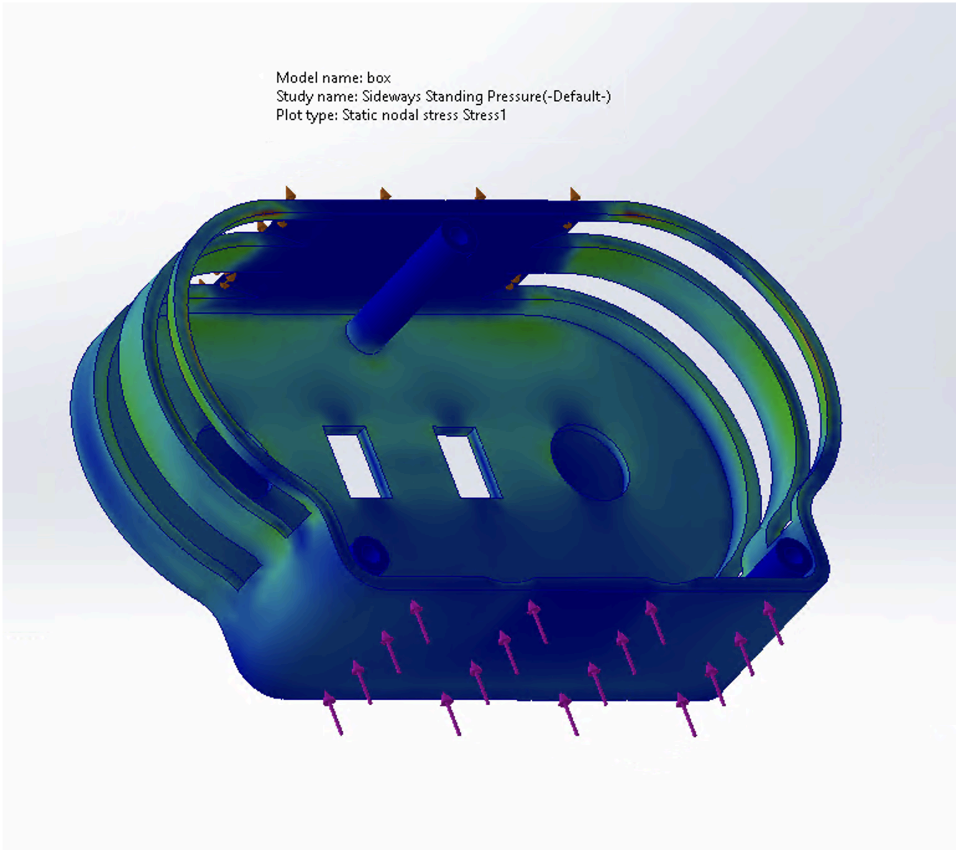
$$\sigma_{applied} = \frac{100}{1.5} = 66.7psi$$

Thus, the factor of safety is:

$$SF = \frac{7{,}000}{66.7} \approx 105$$

This was then followed up with two simulations testing the same thing but in different orientations. Below are the images showing the von Mises stress distribution throughout the part.





The factor of safety from the simulations was 32.87 which was significantly less than the hand calculations, but still within an order of magnitude. There was a warning about a large deformation, which makes sense given that all the conditions of gears in between were not in the simulation. Overall there is definitely a sufficient safety factor to ensure the toy does not break under normal conditions.

Table of Gears

Diameter (in) [Gear Name/Location]	Teeth	DP	Pressure Angle (degree)	Face Width (in)
2.8 [freewheel]	40	14.2857	20	0.07
1.4 [intermediary]	20	14.2857	20	0.07
0.4 [intermediary]	10	25	20	0.07
1.6 [output wheel]	40	25	20	0.07
.5 [to outer carrier]	10	20	20	0.07
.666 [to outer ring]	10	15	20	0.07
1.5 [Outer Carrier]	30	20	20	0.07
1.333 [Outer Ring]	20	15	20	0.07
.91 [Ring]	40	44	20	0.10
.45 [Sun]	20	44	20	0.10
.23 [Planet]	10	44	20	0.10