FRICTIONLESS MOTION AIR TRACK

Andrew De La Vara, Shelby Everett, Luis Soto-Cornish, Ally Butkovich, Nathan Walek

Colorado Mesa University

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Executive Summary

This project addresses the need for a functional and portable air track system for the Physics Department at Colorado Mesa University. The department's previous air track is no longer operable and cannot be easily transported, limiting its effectiveness in classroom demonstrations. A new air track was required to help students visualize and understand key physics principles such as force displacement and simple harmonic motion in a frictionless environment.

An air track demonstrates how objects behave under only conservative forces by creating pressure between the object and the track in order to suspend it in air and eliminate friction. This allows clear observation of multiple fundamental concepts including conservation of momentum, and simple harmonic motion.

The redesigned air track consists of four primary subassemblies:

1. **Metal Base** – An 11-gauge steel sheet bent into a 90° triangular prism, featuring 3 rows of perforations for airflow.
2. **Endcaps** – 3D-printed structural components designed to feed in and hold air with air flow ports, attachment point, & adjustable feet.
3. **Tubing and Fan** – A 6HP shop vacuum fed air through a 2.5 in diameter tube to the port on the end cap.
4. **Accessories** – Two metal carts, a spring capable of stretching 75% of the track length to support harmonic motion experiments, and aluminum bumpers for added energy return.

The system is lightweight, user-friendly, & designed for classroom portability. The total cost was approximately $200, which is significantly more cost effective than commercial air tracks, costing up to thousands of dollars. This price was achieved through the assistance of sponsors, Recla metals and the Colorado Mesa Physics Club, who provided the sheet metal for the track and the carts. The final product provides a practical, cost-effective teaching tool for demonstrating frictionless motion and general force interactions.

Chapter I: Problem Definition

Problem Scope:

This paper documents the design & fabrication of an air track for the physics department to show motion & force displacement in a low friction environment. It was requested by the client to create a new air track to show simple harmonic motion & general force displacement as the old air track is no longer functional. It's important that another air track is built so the client can show students physics principles easily & without the added frustration of friction.

Technical Review:

Our client, the Colorado mesa University Physics Club, represented by Derric Loya, a graduate student & president of the physics club. The physics department as well as the club is located in Wubben Hall at Colorado Mesa University, teaching students the importance of physics in their degrees and throughout life. An air track is a tool used in physics experiments to represent frictionless motion by using a cushion of air to lift a glider, allowing it to move smoothly along the track. One purpose of the air track is to represent frictionless harmonic motion. In this idealized system, air is pushed through the track to reduce the friction between the track and the glider, where there is minimal loss of energy, allowing students to observe how forces act without the interference of friction, making the glider oscillate smoothly. The old air track that the physics department currently has is fragile & cannot be easily transported to classrooms to be used as a visual aid for the students when learning about motion and forces.

The previous air track no longer being easily transportable or functional is a significant issue because visual and physical aids are crucial for helping students understand complex physics concepts like frictionless harmonic motion. Seeing these principles in action allows students to grasp how forces interact in a controlled, low-friction environment. To provide students with an interactive tool that enhances their learning, it was important to develop a new air track. However, the client cannot implement the purchase or creation of a new air track due to the high cost, as commercial air tracks can be up to thousands of dollars, far exceeding their budget.

Design Requirements:

The client requested a functional air track that must demonstrate simple harmonic motion & general force displacement. The following are the specific requirements of the air track given by the client:

- Must have a detachable spring that can stretch at least 75% of the track length
- Must fit within the transport cart
- Must support two metal carts simultaneously
- Must be user friendly/safe
- Must have a method to fine tune the level of the track

Chapter II. Design Description

Overview:

The air track is designed to use air pressure to make carts of varying masses float and simulate a frictionless environment. The design consists of a bent sheet of metal that has a 90° angle at the top of the track. The track has a pattern of equally spaced holes cut at the top near the 90° bend. Two 3D printed end caps attach to the track and on the endcap that has a hole, the tubing connects to the opening. The tubing then attaches to the fan which provides the system with air. The following documents the design of the air track which consists of 3 subassemblies: the metal base, the endcaps, & the tubing/fan.

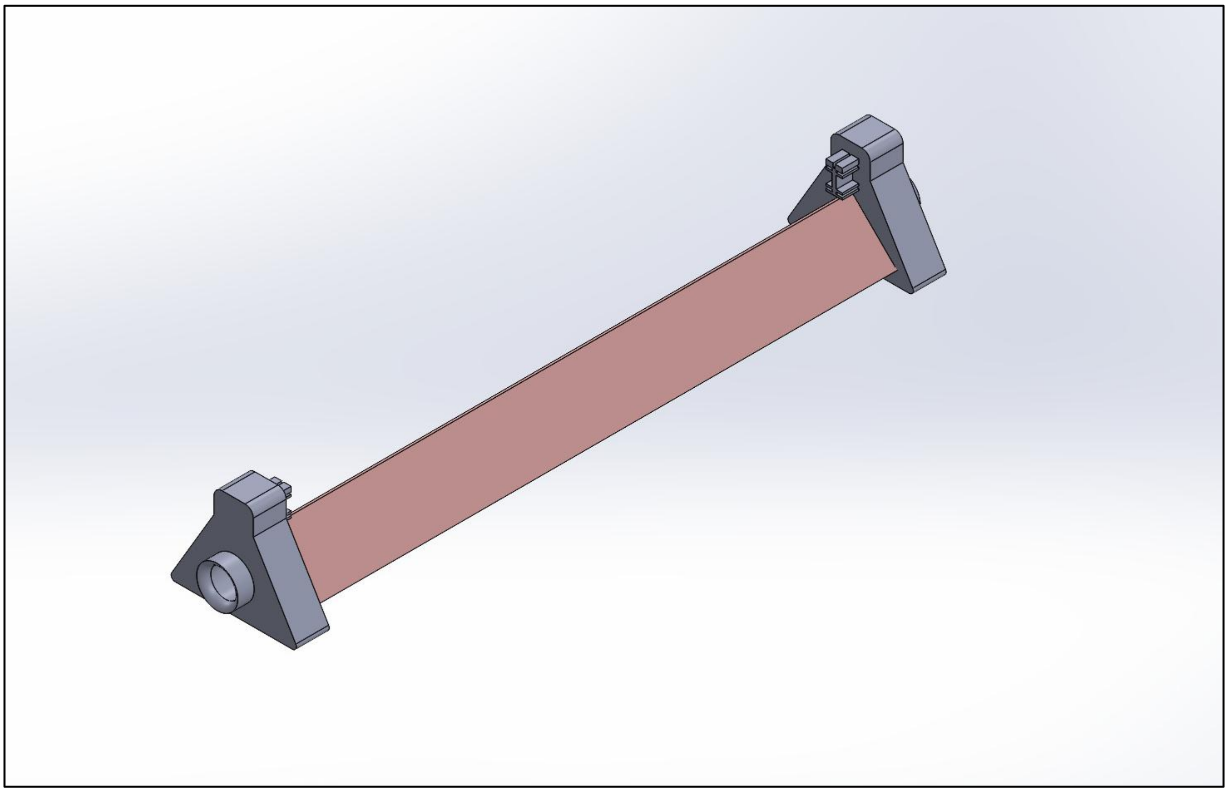


Figure 1: SOLIDWORKS rendering of Air Track

Detailed Description:

Component 1: Metal Base:

The track itself is made from a 36in x 13.65in 11-gauge hot worked steel sheet. The metal sheet is bent into a right triangle with equal side lengths of 4in. The sheet has 3 rows of perforations on each side of the 90-degree angle. These perforations are what allow the cart to experience zero friction. Recla Metals provided the metal & cut the perforation pattern.

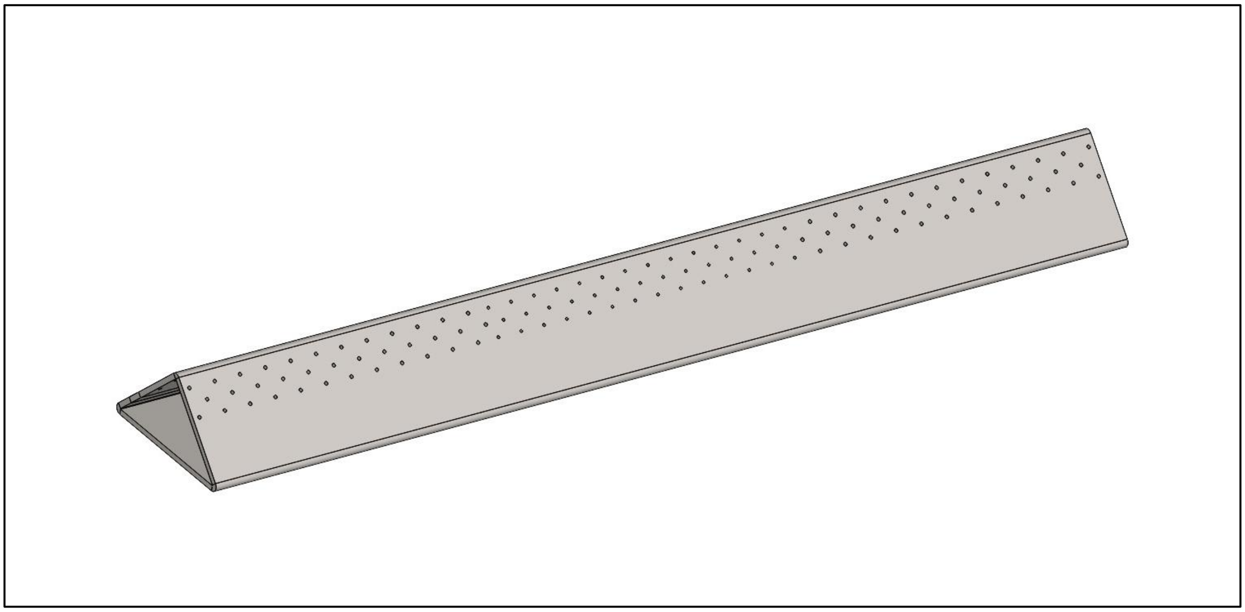


Figure 2: Metal base rendering with perforations for air flow

Component 2: Endcaps:

The endcaps are 3D-printed from PLA filament and include triangular components to support sealing. One endcap is fully enclosed to seal one end of the air track, while the other features a 2.5-inch diameter port designed to accommodate an external air source. Tubing connects directly to this port using clamps, forming a secure and airtight fit for the airflow system. To help maintain a level surface, there are holes at the bottom of each endcap to accommodate adjustable feet, allowing the entire track to be leveled as needed. The endcap ensures that air is directed through the perforations on the top of the track, preventing leaks and enabling smooth, frictionless motion for the glider. The length of the metal track and the end caps included fit the criteria for the length of the cart which is 3 feet.

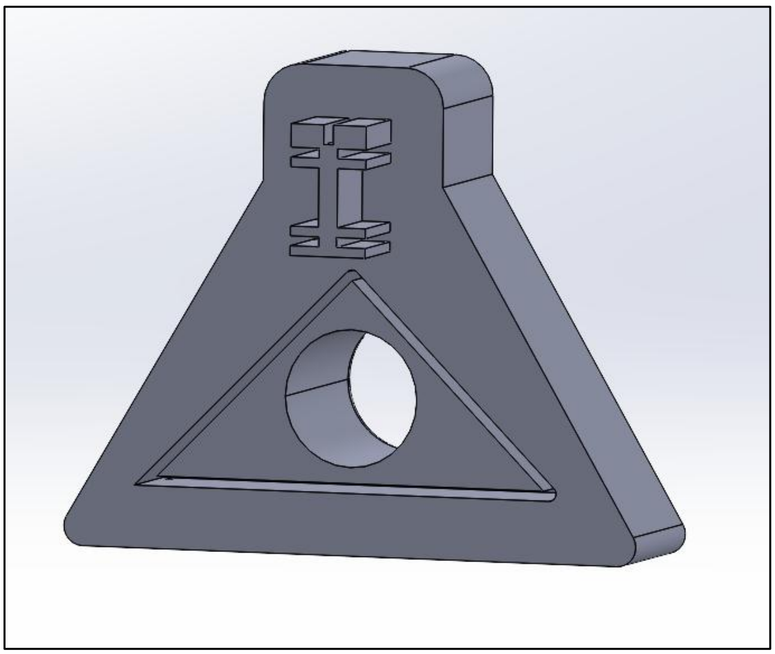


Figure 3: End cap design

Component 3: Tubing/Shop-Vac:

The flexible 2.5-inch diameter PVC tubing was purchased from a local hardware supply store, while the shop vacuum was ordered online. This tubing connects to one end cap at the end of the air track and is secured with clamps at both the vacuum and the end cap to ensure a tight seal and prevent air leakage. The shop-vac used is an 8-gallon, 6-horsepower Hart vacuum with adjustable speed settings. Operating at just 32 dB, it is quiet enough not to cause distractions during demonstrations and fits directly underneath the cart. The shop-vac is attached to an adapter, which then connects to the tubing, allowing airflow to be directed through the system effectively.

Figure 4: Shop-Vac that was purchased

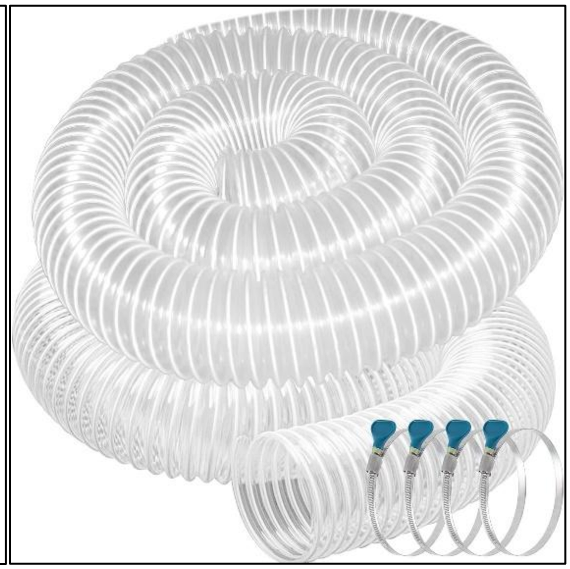


Figure 5: Tubing that was purchased

Bill of Materials:

The cost of materials can be seen below, with the materials, quantity, and costs. The most expensive items were the fan and the metal carts with them being $58 and $42 each respectively. The cost of two items, the metal carts and the aluminum sheet, were not included as sponsors are paying for them, which has greatly helped reduce the overall cost and fit within the $250 budget.

Table 1: Materials and respective costs with the total cost at the bottom

Item	Cost	Quantity	Total
Measuring Tape	$ 8	2	$ 16
Double sided tape	$ 10	2	$ 20
36inx36inx.02in Aluminum Sheet	$ -	1	$ -
Fan/Shop Vac	$ 58	1	$ 58
Spring	$ 6	1	$ 6
10/24 in Screws	$ 10	1	$ 10
Adjustable Feet	$ 6	1	$ 6
3D Printing Film	$ 25	1	$ 25
Compressed air tubing systems	$ 25	1	$ 25
Metal Carts	$ -	2	$ -
Mini Leveler	$ 6	1	$ 6
Hex Nuts	$ 2	4	$ 6
Total Cost (before tax)			$ 178
Final Cost (8% tax)			$ 192.24

Use:

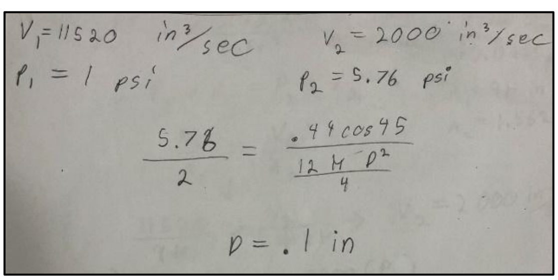
The air track is utilized by teachers to visually show the concepts of forces, motion, & momentum. The spring attachment when the carts are pulled back, pull the cart to the other end of the track and should keep oscillating which shows the idea of simple harmonic motion. Another experiment shown could be if one cart was at rest on the air track and the teacher slid a second cart towards it. They could then see how energy transfers between the first and second cart, which could be vital to helping the students understand the concepts in addition to seeing equations on a whiteboard.

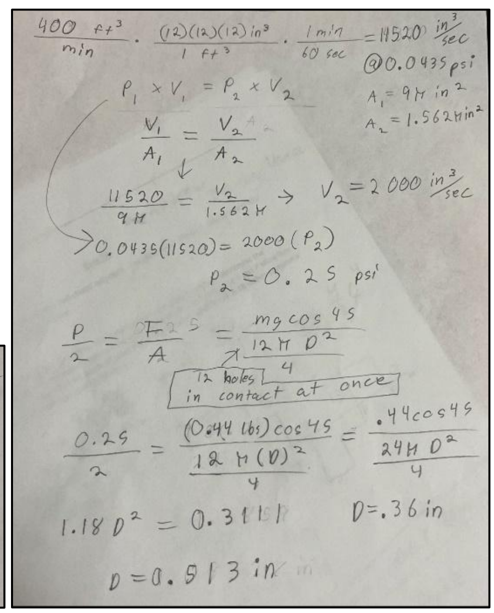
Chapter III. Design Evaluation

Purpose of Evaluation:

Air Pressure:

Calculations to determine the required air pressure (psi) needed to lift the carts and assess whether the chosen fans and air flow design would be suitable. The conclusion that forces normal to the cart provided for the most reliable air flow was made through an understanding of fluid dynamics. The calculations shown in Figure 6 indicated that 5–6 psi would be necessary to make the carts float if the holes were 0.1 inches in diameter. Figure 7 presents the analysis which eliminated a tube fan configuration as a possibility and guided us toward the decision of a shop vac air system. The results showed that this fan configuration could generate sufficient air pressure to lift the carts, but only if the hole diameter was 0.513 inches. This diameter created too much overall surface area for the rated flow rate of the fan to be sufficient.

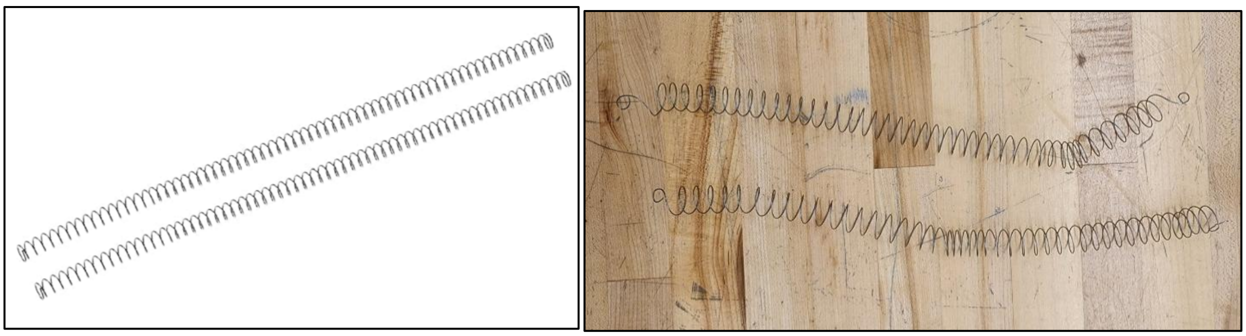




Figures 6 & 7: Calculations finding psi needed & fan option that wouldn't work

Detachable Spring:

To determine the best type of spring to use, it was important to first find a spring that could stretch at least 2 feet since that was almost 75% of the track length. The original springs that were purchased were 12” compression springs. When they were tested out on the track, the springs ended up not compressing or extending that well, so they were scrapped, & two new springs were introduced. The new springs were on the final product & they extended way better. Although they extended well, they did not compress well, which caused issues of them slowing the cart down.



Figures 8 & 9: The original springs tested & the final springs used, respectively

User Friendly:

To enhance user accessibility, several design considerations were implemented in the development of the air track. The structure was engineered for durability to withstand moderate use and incidental impacts. All welded edges were thoroughly sanded to eliminate the risk of cuts or metal splinters. The setup process was intentionally simplified to reduce the likelihood of user error, requiring only a screwdriver and access to a standard electrical outlet. The integrated on/off switch on the shop vacuum further facilitates straightforward operation. If the hose has been detached for storage, it can be easily reconnected to the appropriate ports using the provided clamps. The most technically involved aspect of the setup involves securing the springs to the carts, a process that typically takes one to two minutes.

Fine Tuning:

To have the ability to fine tune the level of the track, there are 2 magnetic bubble levelers on each side of the track, making 4 in total. Using those, you can determine if the track is level & if you need to adjust so the carts don't slide to one side when the fan is turned on. Magnetic bubblers seemed like the most efficient option to see if the track was level since they are movable & can be taken on or off easily. In addition to the bubble levelers, there are 2 adjustable feet at the bottom of both endcaps. The feet were planned to screw into the bottom of the endcaps, but not from the 3D print. The holes in the bottom of the endcaps were expanded using a Dremel tool in order to fit the adjustable feet into them. Using the feet, you can adjust the height of the track & can fix the different sides to be level in case the surface it's used on is unlevel.

Figures 10 & 11: Magnetic bubble levelers that were purchased & adjustable feet that were used

Test Methods/Results & Discussion:

In the initial test, a circular metal bar from the bottom of a desk chair that had 4 small holes was used to observe how air behaved with periodic escape points. The goal for this test was to see if the air was evenly distributed and if the concept of making “floating carts” was a reality with perforated holes. This functionality test was conducted using a shop vac, air compressor, and inline duct fan with the air compressor producing the most even pressure. Each air system was tested a second time once the track had been welded shut. The inline duct fan produced insufficient pressure for the track’s design. The air compressor produced sufficient even pressure but was ruled out due to noise levels. The shop vac produced sufficient pressure and the desirable volume, so it was selected as the final air system.

Table 2: Different fans used and how well they worked

Type of Fan	Positive results	Negative Results
Air Compressor	produced sufficient even pressure	Very loud
Incline Duct Fan	Quietest fan system	Did not produce sufficient pressure
8 Gallon 6 HP Shop Vac	-Produced sufficient even pressure -Sufficient noise level	Largest footprint

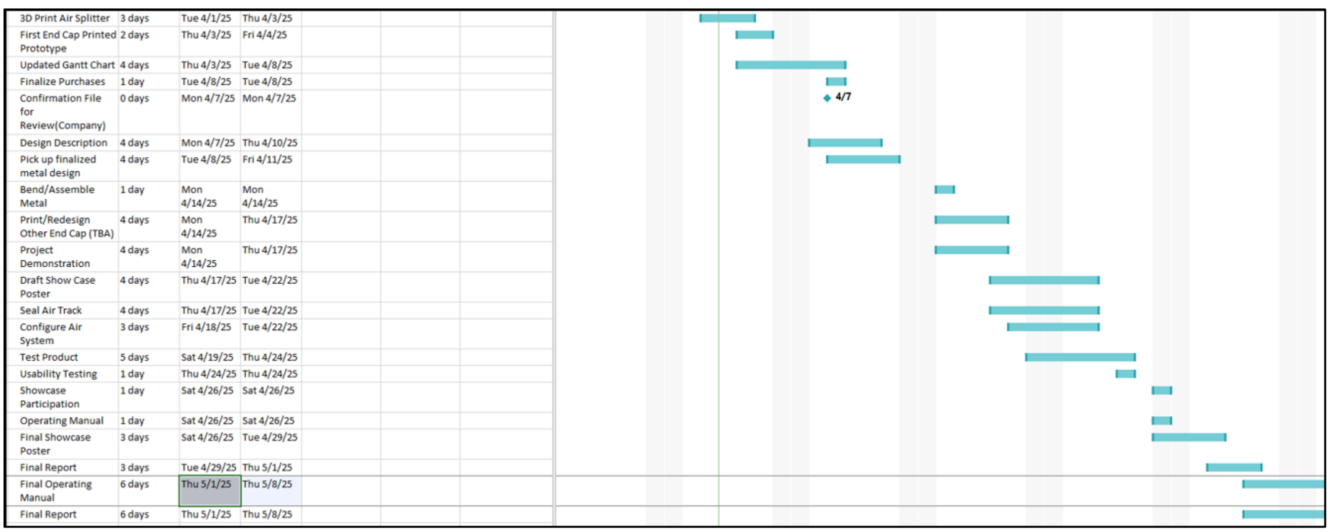
Validation:

The initial iteration of the prototype that was made of cardboard housed the idea of releasing the air through a slit on top of the metal. Once some people in the shop and the client were consulted, it was decided that the slit was a little risky. It could output too much air and cause the cart to wobble or fall off if the air distribution was off. Then the design switched to have rows of perforations along both sides of the metal. The second iteration of the prototype was a test of how well the air would be distributed if there were holes along the length of the metal and only had air coming through one area by using a metal ring with 4 holes spread out. The air pressure was good, so the plan continued on. Finally, the last iteration had 3 rows of holes that were offset to make sure the carts always covered the same amount of holes no matter where it was on the track.

Chapter IV. Team Performance

The team dynamic throughout the project started as distributing the work and then everyone went out and achieved their goals for the class period. It was quickly learned that that didn't work well as many times there would be 2 or 3 people left not doing anything or just helping on small things for most of the class period. The plan was then changed & it was decided to start doing team meetings at the beginning of every class period so everyone could all decide who was doing what for that day. There were usually 1-2 people working on each task and if someone finished their task or needed something else to do then they could assist with anything else that needed to be completed that day.

The project was organized by assigning tasks to members according to their individual strengths, maximizing efficiency in both design and construction. Weekly roles were designated and maintained throughout each week, with a rotating team lead assigned to conduct check-ins and ensure progress stayed on track. A shared notebook was used to document all planning activities. For major tasks, specific team members were appointed as leads to oversee their completion. Prototypes for the design were also shared to other members outside of the group for constructive feedback.



3D Print Air Splitter	3 days	Tue 4/1/25	Thu 4/3/25
First End Cap Printed Prototype	2 days	Thu 4/3/25	Fri 4/4/25
Updated Gantt Chart	4 days	Thu 4/3/25	Tue 4/8/25
Finalize Purchases	1 day	Tue 4/8/25	Tue 4/8/25
Confirmation File for Review(Company)	0 days	Mon 4/7/25	Mon 4/7/25
Design Description	4 days	Mon 4/7/25	Thu 4/10/25
Pick up finalized metal design	4 days	Tue 4/8/25	Fri 4/11/25
Bend/Assemble Metal	1 day	Mon 4/14/25	Mon 4/14/25
Print/Redesign Other End Cap (TBA)	4 days	Mon 4/14/25	Thu 4/17/25
Project Demonstration	4 days	Mon 4/14/25	Thu 4/17/25
Draft Show Case Poster	4 days	Thu 4/17/25	Tue 4/22/25
Seal Air Track	4 days	Thu 4/17/25	Tue 4/22/25
Configure Air System	3 days	Fri 4/18/25	Tue 4/22/25
Test Product	5 days	Sat 4/19/25	Thu 4/24/25
Usability Testing	1 day	Thu 4/24/25	Thu 4/24/25
Showcase Participation	1 day	Sat 4/26/25	Sat 4/26/25
Operating Manual	1 day	Sat 4/26/25	Sat 4/26/25
Final Showcase Poster	3 days	Sat 4/26/25	Tue 4/29/25
Final Report	3 days	Tue 4/29/25	Thu 5/1/25
Final Operating Manual	6 days	Thu 5/1/25	Thu 5/8/25
Final Report	6 days	Thu 5/1/25	Thu 5/8/25

Figure 12: Gantt Chart used during the span of the project

Chapter V. Conclusions

This project presented numerous challenges, but we ultimately achieved our primary objective: constructing a functional air track. In the end, we successfully built a portable and cost-effective system that meets all client specifications. The air track effectively demonstrates essential physics principles such as simple harmonic motion, force-displacement relationships, conservation of momentum, and energy transfer between two objects in a low-friction environment. However, it is not without flaws. While the air does lift the carts off the track, the system is not entirely frictionless. The springs do not compress as smoothly as desired, leading to additional friction that slows the carts more quickly than expected. Additionally, the bumpers do not produce perfectly elastic collisions; instead, they cause the carts to launch forward unexpectedly. We hope that future improvements can address these issues to enhance the quality of the demonstration.

Chapter VI. Recommendations

Improvement/Additional Testing

Some things that could be done to improve the air track and the experiments even more could be redesigning the bumpers on the endcaps to be lower down. The original design was made for a 200g cart that was bigger but when the carts arrived, they ended up both being 100g, so the bumpers were a bit too tall, but they still worked. Some additional testing that would be good is testing more springs and how well they compress and extend. The spring was difficult to get correct as the first spring tested was too stiff and wouldn't extend or contract at all. The next spring after that extended well but wouldn't compress well, it would just move out of the way. If there were more testing on which springs can compress and extend well, then it would make a significant difference when doing the experiments that require them.

Harmonic Motion Demonstration

While the track minimizes friction, its motion is not perfectly continuous due to the limitations of the springs used. The springs were hand-stretched and do not produce a perfectly linear or elastic force, reducing overall system efficiency. As a result, gliders eventually come to a stop. A perfectly elastic string that compresses linearly to extend the cart's oscillation duration for more effective demonstrations.

Another potential improvement for the harmonic motion system is to use bungee cords in place of traditional springs.

Bumper Design

The bumpers between the carts and the end caps do not simulate elastic collisions effectively. The bumpers cause the carts to have motion in the vertical direction which causes the carts to rub against the track resulting in friction making the system inefficient. Due to the bumpers as the carts collide, they do not experience a proper conservation of energy since so much energy is lost in the form of motion other than horizontal. The bumpers are far too rigid to display elasticity and collisions in the system.

To fix this change the bumpers from the bent aluminum segments and swap them with magnets which would provide gradual resistance and zero contact display of collision.

End Cap Design

The endcaps can be more securely fastened to the track to enhance durability. Creating a secure connection between the track and endcaps would eliminate the need for electrical tape, which currently covers the hot glue, and would result in a cleaner, more professional appearance. Additionally, the adjustable feet on the bottom of the track could be replaced with longer, more user-friendly alternatives for easier adjustment.

Normal/Additional Uses

Package transportation

One of the main demonstrations for the air track is to show simple harmonic motion, where you connect one spring from the cart to an endcap & pull the cart past the spring's equilibrium. When you release the cart, it contracts to the unstretched length and then stretches back out past equilibrium to where the cart was released from. The second main demonstration is to show force displacement using 2 carts. If you slide one cart towards a second cart that's at rest, some of the velocity from the first cart transfers into the second cart. An additional part to the main experiments could be talking about the conservation of energy and momentum when in a frictionless environment. Since there's no nonconservative forces acting upon the carts, the energy and total momentum are almost the same before and after the collision. Another addition to the spring experiment could be connecting a spring to both sides of the cart & connecting them to the endcaps. Then, the cart oscillates between the two springs, stretching past equilibrium of one at a time and going back to the unstretched lengths continuously.

References

- Kyle Fanning: ktfanning@mavs.coloradomesa.edu-referenced for fluid dynamics calculations involving theoretical pressures
- Robert W. Wilson: rwwilson@coloradomesa.edu- referenced for fabrication techniques and recommended air supplies

Sponsors

- Recla Metals: 479 30 Rd, Grand Junction, CO 81504- Supplied and perforated steel for the body of the track