Airplane Tire Wear Reduction

Final Report

Annie Phandinh | Delaney Padgett
Nick Dermo | Emily Peters
Kyle Leitham | Param Dave
Executive Summary

The Airplane Tire Wear project, only in its second semester of development, presents the issue of excess spending to replace tires within the commercial airline industry. The goal of the project group was to extend the life of tires by mitigating the rubber loss on tires during standard landings. The solution approached by both last semester’s and this semester’s team was to pre-spin the airplane tire prior to landing to alleviate the impact and friction between the tires and the tarmac. After a failed testing of the previous prototype, a ribbed hubcap designed to collect airflow at high speeds to induce spin (Appendix A, Figure 1), the new team decided to explore a more compact mechanically driven prototype (Appendix A, Figure 2). By attaching a ring gear to the outer diameter of the hubcap and an interlocking spur gear to a motor, Prototype #2 pre-spins the tire with electricity that would be sourced from the plane itself. The team improved both the testing and design of Prototype #1, and set up a new design direction for another team to explore and better.
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1.0 Introduction

1.1 Background

The Airplane Tire Wear Team was assigned a project that tasked them to come up with a way to reduce the wear on a commercial airplane tire. The wear is caused from the high friction impacts of the tire on the runway during landings. When an airplane lands, the tires are currently at a standstill instead of being in motion like the airplane is. This causes the tires to skid down the runway creating significant wear and damage to the tire. The rubber loss causes a massive degradation of the tire’s tread forcing airlines to continuously and frequently replace the landing gear tires.

1.2 Problem Statement

In one day, the average commercial airline spends approximately $2,000,000 replacing worn aircraft tires due to the high friction created when the plane touches down on the runway. There has yet to be a feasible, cost effective solution to reducing the amount of rubber wear on a tire.

1.3 Objective

The overall objective of this project is to induce tire spin prior to landing. By inducing tire spin before the plane lands, this will decrease the amount of friction created by the tire on impact significantly. This decrease in friction will lead to overall tire life increasing and millions of dollars being saved every day. It will also decrease the amount of rubber being used for the production of new tires, therefore having a positive environmental impact.

As this is the pioneer year for this project, initial objectives will consist of gathering background research for the problem at hand from previous attempts and failures, to the logistics behind it. From there, the goal is to design and develop a preliminary prototype to begin testing and analyzing. From this initial prototype, future objectives will consist of improving, refining, and fabricating more, and better prototypes.
2.0 Design Process

2.1 Establishing Mission, Vision, Values, and Strategies

2.1.1 Mission

The Airplane Tire Wear Reduction Team will work together to test Prototype #1, an airplane hubcap, and improve the Prototype #2 design so that it will minimize tire rubber loss due to friction when landing.

2.1.2 Vision

Our final design will result in the improvement of the material used, cost effectiveness, and overall performance of the current prototype. When completed, the final design will help increase tire performance in the airline industry.

2.1.3 Values

The Airplane Tire Wear Team holds the following four values:

● We will work together to be innovative and brainstorm as many ideas as possible, providing us with many possible solutions before choosing the best one.
● We will work in an efficient manner completing all assigned tasks as fast as possible in order to keep our project on track with the projected schedule.
● We will design and create a working prototype that be reliable enough that it could be used in the commercial airplane industry.
● We will design and build our prototype in the most cost effective manner possible without compromising the quality of the materials, prototype, and airplane.

2.1.4 Strategies

In order to accomplish the goal of improving the effectiveness and aerodynamics of the previous semester’s prototype, the team used weekly meetings, email, and group messaging (GroupMe) to create a mode of open communication. The meetings are used to complete group assignments, remain up to date of the project development, and assign tasks for the coming week. The workloads will be assigned to those most capable for completing it, while also a fair distribution. Each individual is expected to complete their own work, but much of the project will be done as a group in order to have open discussion about each task performed.

Constant communication will aid the team in implementing a “Four Point System” to handle all tasks required. The “Four Point System” includes: contact, test, review, execute. Contact entails one of the team members reaching out to expert sources on topics. Testing requires testing
prototypes, expanding ideas, and gathering data. Review will be used to evaluate options moving forward or analyzing data. Lastly, execute would be the completion of the task at hand. Employing these methods will allow the team to move efficiently and thoroughly through the concept design, building, and testing of two prototypes.

Besides weekly meetings, the “Four Point” system, and constant messaging, the team created a Gantt Chart (Appendix B, Figure 1) to ensure that the project would be completed on time.

Since the project requires the use of power tools and machines, each team member is required to get Learning Factory certified. Additionally, the team will use local hardware stores, Amazon, CAD SolidWorks modeling, and 3D printing to acquire and build the prototype.

2.2 Concept Generation

Last semester’s team left the new team with a 3-D printed and untested hubcap tire fin (Appendix A, Figure 1). Before generating new concepts, the new team decided to test the fin in the undergraduate fluid lab’s wind tunnel. A small mount adapter was constructed in the learning factory to hold the wheel on a ⅜” axle (Appendix A, Figure 2). Under the guidance of Teaching Assistant Peter Ingram, the wheel failed to spin successfully under wind speeds of 90 mph. Suspecting weight was the problem, the team decided to remove the hubcap from the tire and test it on its own. The lone hubcap spun rapidly.

Keeping these new discoveries in mind, the team decided to review and expand on other concepts generated by the previous team. Such thoughts ranged from an axle-mounted motor to a fin over the top half of the tires to redirect wind. The team proceeded to look to experts for advice.

Luckily, the team did not have to look far for such experts. Emily’s band director, a private pilot, suggested incorporating the failed fin into a fairing (Appendix A, Figure 4). Fairings are commonly used to reduce drag over the non-retractable landing gear of small planes. In addition, Delaney’s father, a commercial pilot, suggested a mechanical system to be integrated with the cockpit altimeter. The design would consist of two gears that can engage and disengage with a motor to pre-spin the tire to a specified speed at a certain altitude (Appendix A, Figure 3). Using these concepts, the team moved to the selection phase.

2.3 Concept Selection

There were multiple concerns that the new team wanted to address with their new design. The criteria for Prototype #2 were improving the materials used, cost effectiveness, feasibility for the prototype to be integrated into the commercial airline industry, and overall performance. These four criteria were used to come up with three possible design options.
Concept A built off of the design from last semester, Prototype #1. This concept involved a fin but used hinges to make it collapsible. This would design would make it more feasible to be integrated into the commercial airline industry. When the landing gear is retracted into the belly of the plane, they fold tightly into a space that does not leave room for any attachments. The Boeing 737 for example, has a hole cut into the gear door to allow for the landing gear tires to protrude from the belly of the airplane due to the lack of expendable space inside. Even if Prototype #1 had worked, it would not have been realistic to implement into the commercial airline industry. Concept A would improve Prototype #1 by eliminating the space issue with its collapsible feature. Unfortunately, because Concept A would still involve a fin, this prototype would be very costly. This design idea would improve the overall performance of the prototype and could be feasible in the commercial airline industry, but would not improve the materials used thus making it cost ineffective.

Concept B is comparable to concept A as it is built off of Prototype #1. This idea involved attaching a fairing to the wheel in order to funnel wind directly to the tire fin hubcap. While this would better control the wind tunneling into hubcap, it poses an issue similar to that in Concept A: there is no extra room in the belly of the airplane for such an attachment. Concept B would not improve the materials used, cost effectiveness, or be feasible in the industry. However, it would improve the overall performance of Prototype #2.

Concept C was a completely new idea. This concept makes use of a motor placed in-between the landing gear tires, a pinion gear, and an internal gear ring. A small pinion gear would be attached to the motor, which starts at rest. An internal gear ring will be placed on the hub of the tire. This setup would work in conjunction with the airplane’s radar altimeter. First the landing gear are put down, then when the plane reaches a certain distance above the ground, the radar altimeter tells the motor with the pinion gear engage the internal gear ring. This setup will pre-spin the tire as the plane continues its descent. As the plane gets closer to the runway, the radar altimeter again signals the motor, but this time to disengage the internal gear ring. This concept allows for the tire to be spinning without adding any additional extremities to the outside of the tire. Concept C meets all four design criteria and makes vast improvements from Prototype #1.
After carefully analyzing the pros and cons of each design concept, as well as taking the Prototype #1 test results into account, the team decided to move forward with Concept C. This design eliminated the need for a fin, improving the materials needed and reducing the cost. It would be feasible for the airline industry to implement, as it will work with the current landing gear wheel well size. The other design concepts required wind to spin the wheel, which is an uncontrollable and unreliable source. By using the motor, Concept C eliminates any uncertainties.

2.4 Manufacturing Process

After having a long and thorough discussion with Delaney’s father, Professor Gary Gray and Evan who worked on the same project last semester, the team decided to go with the design consisting of a mechanical system with two gears that will be able to engage and disengage with a motor to pre-spin the tire to a specified speed at a certain altitude. The materials used in our manufacturing process include:

- Wires
- Alligator clips
- Connectors
- 4.5 inches Tire
- DC 12V 2000RPM Torque Double Shaft Magnetic Gear Box Electric Motor
- Wood
- Screws
- Epoxy
- Steel Axle
- 3D Printed Gears
- Metal Brackets
The team used the wood primarily to build the mount and the tire was attached to the mount using a steel axle. The system of gears was attached to the tire and the motor was used to rotate the tire. The motor was connected to the gears using electric wires, alligator clips and connectors.

2.5 Testing

2.5.1 Prototype #1 Testing

The previous group tested their prototype and determined that the design was successful. The reason for this untrue result was the way in which they tested it. The team used a leaf blower and angled the air coming out of it to only contact the bottom half of the hubcap. Without any airflow to hitting the top, the prototype was able to spin at a high RPM, and they thought their design was a success. But, this semester’s team determined that this was an unrealistic way to test the functionality of the prototype.

The current team wanted a more realistic test to determine if the prototype would actually work, so they consulted Peter Ingram, head of the undergrad fluids lab, who allowed the team to use the wind tunnel in the lab. When tested in the wind tunnel with wind speeds of 90 MPH, the prototype had no to minimal spin, and the prototype proved unsuccessful in a more realistic setting.

Figure 2.5.1a: The current team tests last semester’s prototype in the undergrad fluids lab’s wind tunnel

2.5.2 Prototype #2 Testing:

During prototype #2 Testing, the group encountered issues that would make it impossible to get reliable testing results. First, the gears that were attached to the motor and the inside of the wheel were not perfectly aligned, so grinding and stripping of the gears became much more likely. It was impossible to place the motor on the constructed “motor holder” without the assistance from one of the group members. So, the lack of preciseness during construction cost the team reliable testing result. When held by one of the group members, the motor did perform very well. The gears engaged and the wheel spun at a high RPM.
Before actual data could be collected, the team ran into another issue. Unaware of the cause, the team discovered that the speed controller no longer worked, so gathering data became nearly impossible. Without the speed controller, the motor would be taking on the direct current from the battery, which would make the motor instantly spin at its maximum RPM. This would not be a safe way to test the prototype. Instead, to simply demonstrate the theory and process behind our idea, the team acquired a smaller battery that would supply less direct current and make the wheel spin much slower. Because of the setbacks, the team did not get a chance to gather final data to compare to their theoretical data. The battery, charger, and motor are all still functional, but the speed controller will not work and prevents the team from reaching their goal. Suggestions for improvements and making data gathering possible are found in the next section of the report.

3.0 Future Work

As mentioned previously in the report, last semester’s team left this year’s team with a hubcap idea that was designed to catch the air and spin the tire before landing. Testing proved the prototype to be a failure, so the team’s immediate reaction was to redesign the hubcap. The team had the ideas of reducing the number of fins on the hubcap and shaping the fins to be more cup-like rather than at a 90 degree angle with the tire. In addition to these ideas, as recommended by the previous team, they also thought of designing a fender that would block the wind from hitting the top half of the hubcap so that all of the wind would be directed at the bottom, spinning the wheel to maximum speed. These were all good ideas that would potentially make the wheel spin more successfully when testing in the wind tunnel, but when talking to a commercial pilot, the team determined that the design was not practical.

The project’s purpose is to design a way to help the commercial airline industry save money by reducing the frequency of maintenance on tires. Unless the description changes to smaller aircraft, the hubcap idea will not work for commercial airplanes. Delaney’s father, a commercial pilot, informed the team that the wheel wells are very small, and some of them barely even fit the landing gear alone. Attachments to the outside of the wheel will cause problems when trying to fit the landing gear into the wheel well, and as a result of the impracticality of this design, the current team decided to move forward.
If the following group wishes to improve upon the current’s group motor idea, they should lean towards designing a simpler model that eliminates the need for a motor inside each wheel. To do this, much more in depth research would need to be completed on the structure of the wheel well and the power supply of the airplane. The power needed to spin the wheels would come from the airplane’s main power source, the wheels would all be spun together to the desired RPM, and then the gears would disengage so that each tire would spin freely on its own in preparation for touchdown. Also, because of the current team’s trouble with the speed controller, more research would have to be done on the wiring, power supply, and speed control. Dedicating more time to this instead of just one or two weeks could make the project more successful. So, improvements on the current design should include making the system simpler by implementing devices that would perform the tasks mentioned.

Another suggestion for future research or design is to stray away from the “pre-spinning idea” and focus more on the material of the tire. Neither the current team nor the previous group looked into the properties of the material that makes up a commercial airplane tire, and doing research on this may lead to something that could potentially reduce the wear of the tires regardless of their RPM. Also, research could be done on retreading tires and how the airline industry utilizes treads to reduce expenses.

4.0 Leadership Lessons

Throughout the course of this semester, the team has learned many valuable lessons. Given the group's limited expertise in this particular subject, the team learned the value of asking for help. Consulting experts when it came to make decisions proved to be extremely helpful and saved our group a lot of time and worrying. In order to be efficient, you need to make use of the available
resources. Being that everyone in the group are students of Penn State, there were plenty of professors available that were happy to meet with the team and discuss what the best options were.

The team also found that proper scheduling and communication were essential to having a smooth running project. Early on, the team realized that there were a lot of conflicting class schedules. In order to overcome this, the meetings had to be meaningful and straight to the point. Agendas were crucial to keep the meetings focused and on task. A group message app was used to keep communication going outside of meeting times which proved to be very useful. To keep all of the project work in one accessible spot, the team used a google drive. In the event that certain team members couldn’t meet up in person, they were able to input work remotely.

Proper planning and management were key assets in bringing the project to fruition. The team started out by identifying the scope of the project, which allowed them to make a list of tasks that needed to be accomplished. From there, the time to complete each task could be estimated and the task dependencies could be established. With this information, the team constructed a Gantt chart which was maintained throughout the semester. The chart visualized the team’s progress and changes were made if the project began to run behind schedule. Having the chart made it incredibly easy for the group to keep on track and finish the project within the specified time frame.

5.0 Conclusions

In exploring the previous prototype and the team’s new idea, the team found that this problem may not have a solution in terms of attaching something to the tire. The wheel well doesn’t permit much room for add ons since the well barely has room for the landing gear alone. This puts a huge constraint on the size of the design. Attaching a physical piece to the tire also creates another part that can malfunction. This would lead to another item that needs to be maintenance and could potentially cost the airlines more money.

As far as which design would be more effective at getting the tire up to speed, the team has come to the conclusion that the motor would do a more sufficient job. The fins weren’t able to catch enough of the airflow to overcome the inertia of the tire. That being said, the team never tried an alternate fin design. Alternative fin designs are a plausible road for future teams to delve into. The motor concept on the other hand just relies on the power of motor. If the motor is strong enough, the tire is guaranteed to get up to the landing speed. The team is assuming here that the closer the speed of the wheel gets to the approach speed, the less wear will occur on landing.

Another thing to consider is that, upon research, the group found that spinning tires make the plane act in unpredictable ways during the landing that can cause more problems than they solve. It may be that spinning the wheel is not a viable solution. Future groups should definitely research and explore other options.
6.0 Acknowledgments and References

6.1 Acknowledgements

We would like to thank Mike Erdman, Matt Krotowski, Previous Group Members: Oron and Evan, Gary Gray, Del Padgett, Nhan Phandinh, Peter Ingram, LOWES and all of their kind and helpful employees.

6.2 References

https://www.jupitor.co.jp/pdf/michelin_aircraft.pdf
http://www.howacarworks.com/basics/how-the-starting-system-works
http://www.csgnetwork.com/tirerevforcecalc.html

7.0 Appendices

7.1 Appendix A

Figure 1: Ribbed hubcap, 3D printed with ABS plastic, bolted to a wheel barrow tire
Figure 2: Motor and interlocking gears attached to a wheel barrow tire

Figure 3: Solidworks model of tire and gears
Figure 4: Concept - Combine the failed fin and fairing
Figure 5: Tire model

Figure 6: Pinion gear model
Figure 7: Internal gear ring model

7.2 Appendix B
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Figure 1: The project Gantt Chart used to maintain on schedule with tasks for the class and project.

Figure 2: Internal gear ring drawing
Figure 3: Tire drawing
Figure 4: Pinion gear drawing