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Design and Fabrication of a Carbon Fiber Wheel for the Husker Motorsports Club

Benjamin Bashtovoi
University of Nebraska-Lincoln

Jordan Chapin
University of Nebraska-Lincoln

Michael Pineda
University of Nebraska-Lincoln

Caden Lind
University of Nebraska-Lincoln

Thomas Crum
University of Nebraska-Lincoln

UNIVERSITY OF NEBRASKA-LINCOLN

DEPARTMENT OF MECHANICAL & MATERIALS ENGINEERING

MECH 447H: Mechanical Engineering Design II

Team 1

Husker Motorsports Formula SAE: Carbon Composite Wheel

Post Mortem Report

Submitted to

Kurt Palik

University of Nebraska-Lincoln

By: Benjamin Bashtovoi

Team: Jordan Chapin, Michael Pineda, Tom Crum, Caden Lind

Faculty Advisor: Yuris Dzenis

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Executive Summary

Given the profound benefits of reducing unsprung mass on vehicle dynamics, including improved acceleration, handling, and braking, the Husker Motorsport team has looked to produce a carbon fiber composite wheel that weighs less than their current wheel solution and provides similar or better rigidity. Carbon composites have many stiffness and weight benefits, but because they are anisotropic they require special considerations due to their unique mechanical performance. Additionally, the manufacturing is not trivial for composites, especially when complex shapes such as a wheel are involved. The project first reviewed literature and examples of professional attempts at producing composite wheels. With this knowledge, the foundations of the project were established: problem statement, scope, deliverables, constraints, and work breakdown structure. During this process, it was concluded that the two physical deliverables of the project would be a set of wheels and a reusable mold.

> **Problem Statement:** Acceleration, handling, and braking characteristics are critical for high-performance vehicles, like the Formula-style car designed and manufactured by Husker Motorsports. This project aims to improve vehicle dynamics by reducing unsprung mass and increasing stiffness through carbon composite wheels.

Once the foundation for the project was set, the team began developing concepts which were then evaluated based on a decision matrix for the respective products. The final decision was to proceed with a one-piece composite wheel with a male mold system. After deciding on the best concepts, a model of the wheel was made referencing the geometry of the current wheel that had an interface with the car or tire. Simultaneously, analysis was done on the current wheel to extract the baseline performance criteria that the composite wheel had to outperform. ANSYS simulations were performed on the model to test its performance. From the simulation results several new iterations of the wheel were made. Once the wheel geometry was established, the mold was modeled.

By the end of the Fall 2023 semester, a final design package was created and included a drawing of the wheel, an assembly drawing of the mold, drawings for the mold part machines in-house, and the BOM of the required components. Data was also saved from multiple simulations with multiple variations of material, geometry, layer thickness, and layer distribution. This data was shared with the Husker Motorsports team to implement layup modifications depending on potential material changes when they produce a full set of carbon wheels.

The manufacturing of the wheel was delayed due to several factors relating to equipment availability and material acquisition. The Husker Motorsports team had purchased new machining equipment this year, and as such additional power had to be routed to the shop to supply more outlets to run the equipment. This process was done primarily over the winter break

but consumed some time dedicated to manufacturing. The CNC router that was installed was one of the pieces of equipment that was utilized extensively in the project for the manufacturing of the mold components. An additional delay was in the acquisition of carbon fiber from a company sponsor. Throughout the first and into the second semester, the team was guaranteed prepreg carbon fiber donations; however, due to the company's contractual obligations, this material could not actually be shared with the team. A reevaluation of the project was conducted, and a transition was made towards a wet layup manufacturing process. This transition was facilitated by a robust mold design.

Once materials were acquired, and the mold was assembled, the layup of the wheel was done. First, 180 plies were individually traced and cut by hand. Then, the mold was coated with mold release agents to ensure the part did not permanently adhere to the mold. In a nine-hour operation, the plies were applied with epoxy resin and left to cure under vacuum for 24 hours. Once the wheel had cured, the part was demolded successfully, and post-processed. A valve stem was installed and an attempt was made to mount a tire to the wheel. The finished carbon fiber wheel can be seen mounted to the 2024 competition car in Figure 1.

Figure 1.Finished carbon one-piece wheel mounted to the 2024 competition car.

Mass measurements after the wheel was complete were taken and proved the carbon composite wheel was lighter than the typical aluminum wheel run by the motorsports team. Further testing is needed to prove the mechanical characteristics of the wheel, but the testing rig was unfortunately damaged during the testing of the current aluminum wheels. With the wheel, mold system, and data produced in this capstone project the Husker Motorsports team can adapt the methods and data discovered to manufacture these wheels in the future as a cost-effective way to reduce unsprung mass and improve the vehicle performance.

Project Budget

The original budget put together for the project can be seen in Table 1. An estimated cost of approximately $4800 was derived based on previous carbon fiber wheel projects as well as the current cost estimated of parts derived by the Husker Motorsports team. Initially, the senior design team planned to make five wheels which was out of the club's budget. However, since the Husker Motorsports club had previously received donated carbon fiber from a local company significant costs would have been cut with company sponsorship. Unfortunately, the company was unable to sponsor the club this year, and the scope of the project was reevaluated. In addition to updating the timeline of the project a new budget was made to reflect the changes in material donations.

Table 1. Initial Budget from Fall 2023 Semester

Item	Item # / Description	Source	Qty	Cost/Unit	Total
Wheel Material					
Carbon Fiber	3K PW Fabric (5yd roll)	Royal Composites	2	$274.00	$558.00
Valve Stem	(pkg of 4)	Amazon	1	$30.00	$30.00
Honeycomb	-	Aircraft Spruce	1	$150.00	$150.00
Wheel Materials Total					**$738.00**
Mold and Manufacturing Materials					
Epoxy tooling board	EP-678 (4" Thick)	Trelleborg	3	$300.00	$900.00
Bagging	L-100	Airtech	100	$0.20	$20.00
Release Film	MR1	Airtech	100	$0.20	$20.00
Breather	Airweave-S	Airtech	100	$0.20	$20.00
Tacky Tape	AT-200Y	Airtech	1	$12.00	$12.00
Mold Release	Frekote 770	Loctite	1	$130.00	$130.00
Dowel Pins	98381A542	McMaster-Carr	4	$0.34	$1.3[illegible]
Center Bolt	92198A528	McMaster-Carr	1	$26.41	$26.41
Nut for Center Bolt	91026A036	McMaster-Carr	1	$1.73	$3.46
High Temp Foam Rings	1500N104	McMaster-Carr	2	$4.03	$8.06
Nickel Plated Hose Coupling (M)	50925K312	McMaster-Carr	1	$5.62	$5.62
Nickel Plated Hose Coupling (F)	6050T15	McMaster-Carr	1	$4.87	$4.87
Manufacturing Total					**$1151.79**
Project Total	5 Wheels and 1 Mold				**$4841.79**

The revised and final budget can be seen in Table 2. The goal of the team was to cut spending for the project to fit within the $500 support given to each senior design team by the Mechanical and Materials Engineering (MME) Department. As Table 2 shows, this was achieved, and the total spending was at around $477. The biggest cut in the budget was achieved by switching from prepreg carbon fiber to dry carbon fiber as well as a reduction in the number of wheels produced from five wheels to one. Another large cut in the budget was achieved by using a spare epoxy tooling board and epoxy that the club allowed the team to allocate for the project. All in all, not receiving material donations from a long time industry partner required a reevaluation of the project and budget which ultimately put the team slightly under budget.

Table 2. Final Project Budget.

Item	Item # / Description	Source	Qty	Cost/Unit	Total
Wheel Material					
Carbon Fiber	3K PW Fabric ($/yard)	Aircraft Spruce	6	$29.50	$195.00
Valve Stem	(pkg of 4)	Amazon	1	$30.00	$30.00
Wheel Materials Total					**$225.00**
Mold and Manufacturing Materials					
Epoxy tooling board	EP-678 (4" Thick)	Trelleborg	3	$300.00	*$900.00
Bagging	L-100	Airtech	100	$0.20	$20.00
Release Film	MR1	Airtech	100	$0.20	$20.00
Breather	Airweave-S	Airtech	100	$0.20	$20.00
Tacky Tape	AT-200Y	Airtech	1	$12.00	$12.00
Mold Release	Frekote 770	Loctite	1	$130.00	$130.00
Dowel Pins	98381A542	McMaster-Carr	4	$0.34	$1.37
Center Bolt	92198A528	McMaster-Carr	1	$26.41	$26.41
Nut for Center Bolt	91026A036	McMaster-Carr	1	$1.73	$3.46
High Temp Foam Rings	1500N104	McMaster-Carr	2	$4.03	$8.06
Nickel Plated Hose Coupling (M)	50925K312	McMaster-Carr	1	$5.62	$5.62
Nickel Plated Hose Coupling (F)	6050T15	McMaster-Carr	1	$4.87	$4.87
Manufacturing Total					**$251.79**
Project Total	1 Wheel and 1 Mold				**$476.79**

Project Timeline

The initial timeline that was developed for this project is seen in Figure 2. Since this project must align with the timeline for the Husker Motorsports Formula SAE team, some of the project deadlines such as completion and carbon layups are determined by the overarching FSAE timeline. Our first timeline was broken into five major categories: wheel modeling, wheel simulation, mold design, manufacturing, and testing. The timeline in Figure 2 shows much of the wheel and mold design being done simultaneously at the beginning of the Fall semester, and machining would start in the late fall. The manufacturing of the wheels would then be completed after the winter break before the car completion date of March 12th. Several unforeseen problems changed this timeline. In the design sections, the steep learning curve with the ANSYS software delayed some deadlines by a small amount. The biggest delays were the machine availability and material acquisition. As such a new timeline was created.

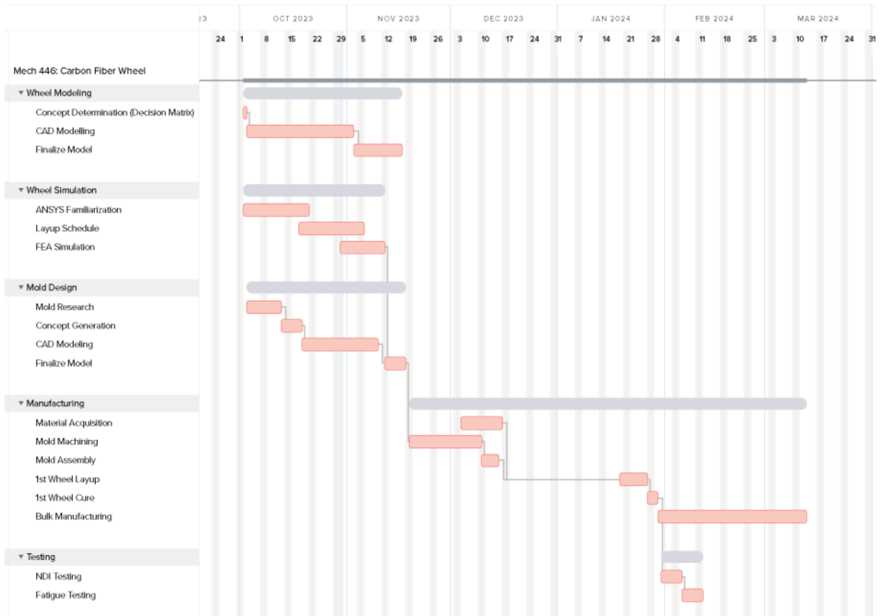

Figure 2. Initial Project Timeline

During the project reevaluation meeting in the spring semester, a new Gantt chart was created to reflect the new goals of the team which can be seen in Figure 3. In this new timeline, time was dedicated to the setup and reorganization of the new machine in the Husker Motorsports shop, as well as the additional time needed to source new carbon fiber that fulfilled the project goals and was cheaper than prepreg carbon fiber.

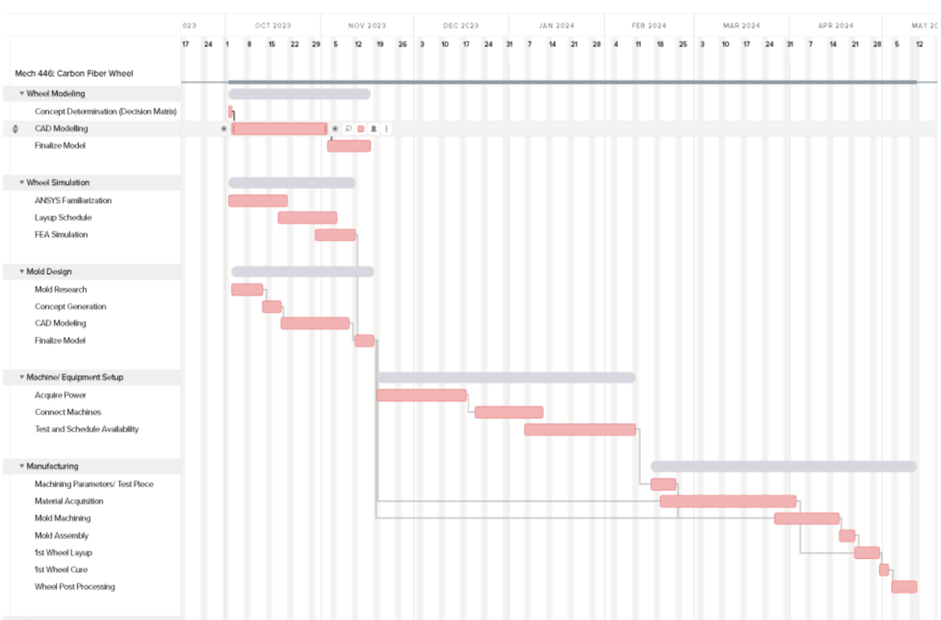

Figure 3. Final Project Timeline

A reflection of the project revealed several key areas where time was lost. Many of these time sinks were due to unforeseen events, but analysis of the events and strategies to overcome them is beneficial for future teams. Some time was lost in the design portion of the project due to the learning curve associated with ANSYS software to develop a functional FEM model of the carbon fiber wheel. This is a complex process that no one on the team had prior experience with, so it took longer than expected. Another timeline risk was the status of the Husker Motorsports manufacturing shop. The team rearranged and installed new equipment, so the manufacturing capabilities of the shop were limited at the scheduled manufacturing time. This prevented the team from pursuing any manufacturing tasks over the winter break as planned. The last time risk was the initial reliance on an industry partner that was ultimately unable to support the team. This resulted in several weeks of redesign and finding new solutions for material acquisition.

While there were a variety of timeline risks, some float time was built into the manufacturing portion of the project timeline. The meeting to reevaluate the project was very beneficial in addressing the unexpected events that prevented the current plan from being implemented. During the meeting, a “Remaining Tasks” spreadsheet was created which divided top priority tasks between members and assigned strict deadlines. This method allowed the project to quickly shift gears from a prepreg design to a wet layup design while remaining on budget and on time.

Measure of Success

According to the initial goals of the team, the project was not successful; however, the changes in the project over the year allowed the team to readjust those goals in line with the expectations of the Husker Motorsports team. With these new goals in place, I believe the project was very successful in demonstrating a robust manufacturing method and providing the tools to replicate the process. The mold system performed well above expectations, and because its design took autoclave temperatures into consideration it could be used with prepreg in the future if the team secures more material. The mold system was designed to be reusable, and only minimal damage was accumulated on the mold during the demolding process, so this metric was achieved per the original deliverables. The weight of the final wheel was lighter than the current aluminum wheels by 0.5 lbs and it was cured as a single piece which was a significant achievement for the manufacturing, strength, weight, and stiffness of the wheel. Further testing of the wheel was not possible due to the testing rig breaking during the testing of the aluminum wheels, so analysis of the mechanical characteristics is not possible to compare to the performance deliverables of the wheel.

Discussion

At the end of the Fall semester, the team had made good progress on the project, and the team was about to transition from the design phase to manufacturing. The foundation of the project had been set, but several improvements could be made in the project and design to make sure the project kick-off in the Spring semester would be successful.

Project Improvement

Some of the observations as the t=Team Lead last semester were that the quality and timeliness of work could be improved upon, especially considering the project was slightly behind schedule due to ANSYS training. Since I believed the two issues were related, I recommend a couple of solutions to help mitigate the problems. First, I suggested starting work on assignments earlier, so that there would be enough time to edit and revise them. This would improve the quality of the work submitted, but also motivate the team to work on tasks in a more timely manner. This was also combined with opportunities to work on the task individually and shorter meeting times. While all of these strategies were implemented, they were not done so in a structured fashion. Shortening meeting times and allowing team members to work on their tasks individually did decrease the amount of distraction, but it also limited accountability. I believe the net gain was positive, but a better solution would also integrate a way for the team leader to check in on the progress being made. The team still struggled with timeliness, as the car became a priority over the wheel at certain points during the project.

Design Improvement

Two design improvements were identified in the MECH 446H Post Mortem report: elimination of the form insert needed for bridging carbon fiber and producing a mold out of a single piece rather than joining separate pieces. Neither of these improvements were implemented into the project, due to the additional time and reevaluation of the simulations needed for the foam elimination and the cost of the single-piece mold. The foam center ring that was eventually converted to a 3D printed part was not implemented, because, at the beginning of the semester, ANSYS simulations still took a lot of time to complete. However, at the time of manufacturing the team member who performed the simulations had become proficient enough that a new simulation could have been made. Further, tire mounting was not deemed possible due to the bridging material. That said, the project priorities and time did not allow this recommendation from being adopted, but if it were implemented it would have likely improved the project's success. The recommendation to machine the mold pieces out of one piece of stock was an ideal case scenario and would have made assembly of the mold easier. However, after reviewing the budget as well as the matching process for the mold parts, a single piece of aluminum stock for the mold would likely be a very costly and risky change for minimal improvement. Overall, neither suggestion was implemented due to the constraints of the project, and only removing the core material would have significantly improved the project.

Team Interaction

The two improvements recommended last semester for team interaction involved establishing an accountability system as well as improving the communication strategy. The accountability system was proposed as a way to also improve the quality and timeliness of work for the group, and it incorporated a partner within the team that would "check in" on another member to see if they needed help with a task. The improved communication strategy was simply a way of making sure the leader knew everyone received his message and had an opportunity to bring up concerns. Similar to the project improvements these suggestions were implemented loosely. Accountability of tasks was often done on an individual basis rather than at team meetings like in the last semester, but there were no scheduled times to check in on someone. The communication this semester was better, but I believe further improvements could be made by using a different forum for messaging. Text messages were used to communicate, but an app geared toward project planning and management may have been better to make sure everyone was on the same page.

Reflection

Analysis of Success

All in all, the project was successful in demonstrating single-piece carbon composite wheels could be manufactured with a reusable mold system, and that they were lighter than the current wheels used. Further testing is needed to verify the viability of the wheels under race conditions. I believe the additional time spent in the design phase making sure everything was up to specifications paid dividends in the long run and gave the team flexibility when challenges with material and machining arose. The mold in particular was robust enough that no significant design changes were needed, and it was quickly adopted for wet layup. When the project was behind schedule and material donations became an issue the team held an emergency meeting to reevaluate the project. This meeting and the updated materials that came out of it were also very beneficial to the project.

Recommendations

Throughout the project, several recommendations for the Husker Motorsports team were documented. These recommendations included advice on the areas of mold design, wheel design, sponsor reliance, and software training.

Design

While the demolding of the wheel went very well, there were some opportunities to improve the process. The geometry and size of the wheel make demolding awkward. During the demolding process, drilling holes and installing handles was suggested as a way to make the process easier for the operator. With the addition of handles the mold would also likely see less wear which would improve the lifetime of the mold. Integration of a handle on either half of the mold would facilitate better grip on the mold to pull them apart as well as allow torque to be applied to break the pieces free.

The wheel itself could also see some improvements. Namely, the bridging material should be removed or lowered to allow a tubeless tire to be mounted. Luckily, this change does not change the mold in any way which speaks to the design of the mold.

Project Management

Much of the trouble in the middle of the project was due to the assumption that material would be donated by an industry partner. Since it had been promised in the first semester and only taken away in the second semester limited time was used to find a remedy. It is recommended that limited reliance should be put on industry partners, and if a partnership is necessary look into several options simultaneously even if the first choice is very reliable. The largest amount of uncertainty in this project came from communication with the composites manufacturer that the team relies on for both layup materials and autoclave time.

From the beginning of this project, it was known that traditional FEA software, such as SolidWorks, would not be appropriate for conducting stress analyses on the wheel due to its carbon fiber construction. ANSYS is one of a few software suites specializing in carbon fiber simulations. The team recommends that individuals familiarize themselves with the program as early as possible in the design process, as the software has a steep learning curve. Additionally, having multiple team members knowledgeable in ANSYS will help verify each others' work. In general, any knowledge gap in the team should be addressed as soon as possible, and multiple people should be trained within the group.

Conclusion

Husker Motorsport's request for a lightweight carbon fiber wheel comes from a desire to address an area of untapped performance potential. The carbon fiber wheel project is currently projected to meet these needs. The final wheel design has a theoretical FOS and maximum deflection within the original design requirements, with weight just above the original target. The design constraints set out at the start of the project have been taken into consideration in every step of the project. The production of prototype wheels at the end of the project demonstrates the robustness of the mold design, as well as a repeatable manufacturing process. Given future funding for the Husker Motorsports club, the team is excited to see the potential for one-piece carbon composite wheels being integrated into future competition cars.