Optimization of a high-speed rotational blade for use in combat robotics

Achira Cataldi

Mentored by Ms. Julie Foresta, Dr. Sean Gart, Mr. Ian Michel-Tyler, Dr. Jesse Milzman, Mr. Long Quang, Ms. Virgina To

SMA Science and Mathematics Academy

ARL

Introduction

In combat robotics, the goal is to critically damage the opposing robot by disabling its weapon or drivetrain using an active weapon or demonstrating significant control of the robot. Weapon types include horizontal spinners, vertical spinners, grabbers and hammers. Horizontal spinners are one of the most common type of weapons and is commonly used in beginner kits. Aside from combat robotics, horizontal blades have real life applications such as lawn mower blades, circular saws and food processor blades.

An optimal high-speed rotational blade exerts a large force over one moment in time during a collision. Tooth bite is defined as the distance that the teeth of the spinner damages on the opposing robot. Maximizing the tooth bite maximizes the damage output of the weapons system. Rectangular beams and circular disks are the two main shapes of horizontal blades. Circular disks have a higher moment of inertia and have less stressful impacts while delivering an impact to another robot. However, a spinning disk is subjected to higher stress when struck by an out of place force. Creating a hybrid between a rectangular blade and a disk can optimize the advantages of each type of shape while helping to reduce the weight (Meggiolaro, 2009).

The goal of this project was to optimize blade geometry for a horizontal spinner for use on a combat robot in the 3 lb category.

Methods and Materials

Five blades were designed in Fusion 360 and plasma cut out of A36 3/16 in. steel as this was a common readily available steel. Each of five blade geometries were evaluated for damage output, angular acceleration, durability, weight and cost. A pendulum impact hammer inside a testing enclosure was constructed and used for the project (Figure 2). For damage testing, each blade struck 15 plastic beams (Figure 4) attached to a linear rail guide to simulate an elastic collision.

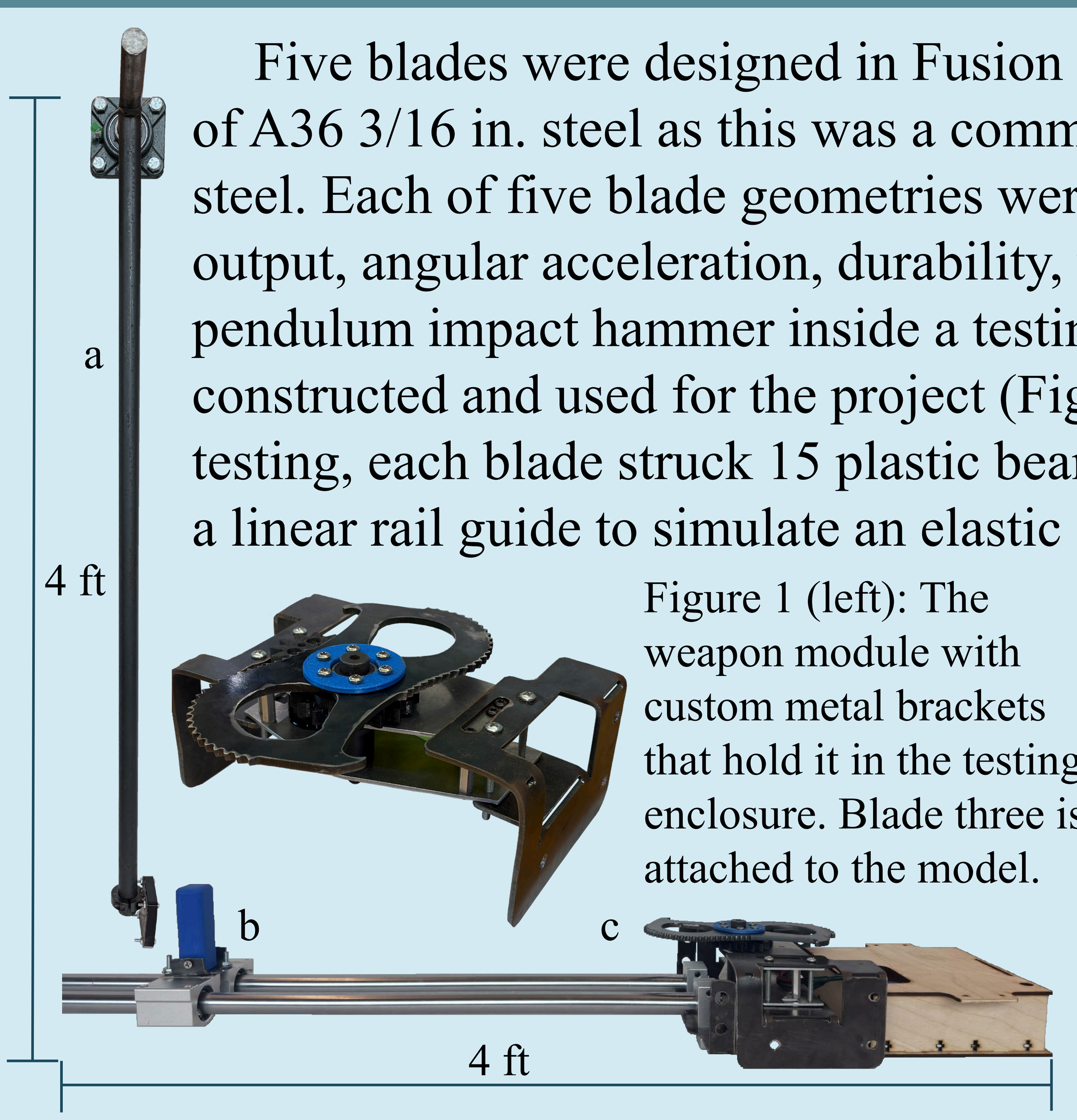


Figure 1 (left): The weapon module with custom metal brackets that hold it in the testing enclosure. Blade three is attached to the model.

Figure 2 (left, below): The internal components of the testing enclosure. For damage output testing, the pendulum hammer (a) strikes the linear rail guide (b) sending the plastic beam (Figure 4) towards the weapon module (c) to be struck by the blade.

Methods and Materials (continued)

The tooth bite was measured on each blade by measuring the horizontal distance the blade damaged on the plastic beam. For angular acceleration, the blade was recorded using a slow-motion camera at 240 FPS and then was analyzed in Kinovea. For durability, each blade was run under a dynamic event simulation with expected forces from a combat robot fight in Fusion 360 and the max stress (MPa) was recorded. For cost, the compound perimeter of the shape was recorded from Fusion 360 as compound perimeter directly relates to metal fabrication costs (Cuesta, 1998). Additionally, the cost per blade cut out of A36 3/16 in. steel was $11–$30 depending on the blade geometry. Finally, the weight of the blade in A36 3/16 in. steel was also recorded.

Figure 3 (below, left): The five different blades that were tested in this project. Each blade had a diameter of 6.5 in. and was spun in a clockwise direction.

Figure 4 (below, right): A plastic beam (1.5 in. × 1.5 in. × 2.5 in.) that is used to measure the damage output.

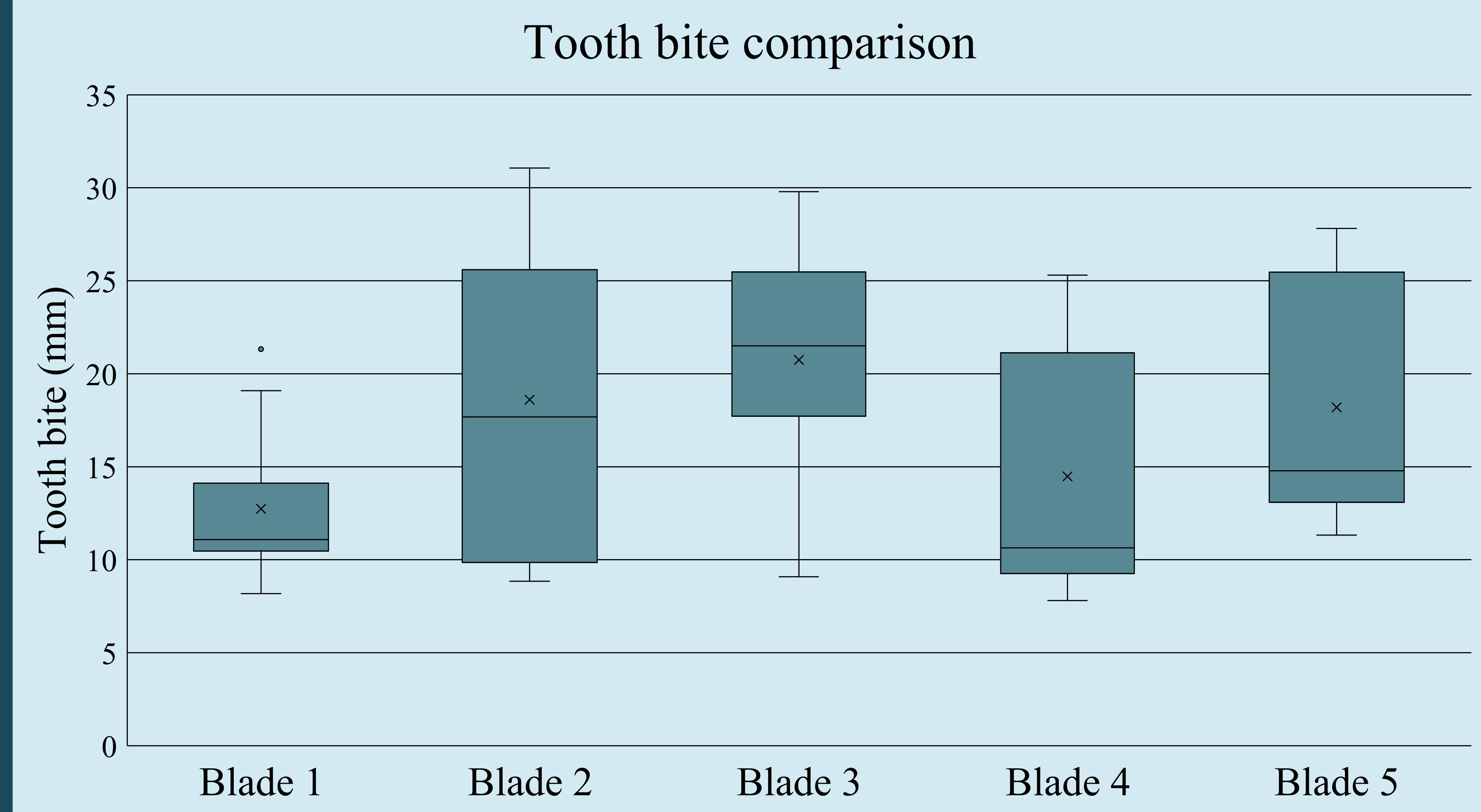
Results

Blade	Average tooth bite (mm)	Angular acceleration (rad/sec^2)	Compound perimeter (mm)	Max stress (MPa)	Weight (g)
1	12.74	63.6	655	236.3	157.2
2	18.60	59.6	1225	59.48	410.4
3	20.74	62.6	1072	181.4	246.5
4	14.49	72.8	542	421.0	124.7
5	18.20	64.1	807	152.7	225.1

Table 1 (above): A table showing the results from the five tests conducted on each of the five different blade geometries.

A one-way ANOVA revealed that there was a statistically significant difference in tooth bite (mm) by blade 1 (M = 12.74, SD = 3.8), blade 2 (M = 18.60, SD = 8.1), blade 3 (M = 20.74, SD = 5.8), blade 4 (M = 14.49, SD = 6.5) and blade 5 (M = 18.20, SD = 6.2) which revealed there is a significant effect of blade geometry on tooth bite on a plastic beam, [$F(4, 70) = 4.10$, $p = .005$].

Results (continued)



Graph 1 (above): A box and whisker plot comparing the mean tooth bite (mm) for each blade.

Conclusion

The goal of the project was to determine the optimal geometry for a high-speed rotational blade that could be used in combat robotics with focus on a combat robot in the 3 lb category. Additionally, no studies like this one has evaluated the effectiveness of a weapons system for combat robotics yet. This study had to develop new methods for evaluating the blades based on damage output, durability, angular acceleration, cost and weight. Future studies could use the developed methods from this project and analyze more blade geometries. The chosen blade geometry was blade 3 due to its high average tooth bite which correlates to high damage output. While high cost and weight may be unideal for mass producing blades, the geometry of blade 3 was chosen as the most effective blade for combat robots. The final blade was produced in AR500 steel, a more durable, impact resistant and more expensive steel as most combat robotics utilize AR500 steel for their weapon systems.

References

Cuesta, E., Rico, J. C., Mateos, S., & Suarez, C. M. (1998). Times and costs analysis for sheet-metal cutting processes in an integrated CAD/CAM system. *International Journal of Production Research*, *36*(6), 1733–1747. https://doi.org/10.1080/002075498193255

Meggiolaro, M. A. (2009) *RioBotz combat tutorial*. RioBotz. https://www.riobotz.com/riobotz-combot-tutorial