team 1189 gearheads

2009 Shooter Gearbox Development

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Executive Summary

This whitepaper is intended to follow the development of the custom shooter gearboxes that were used on the 2009 Lunacy robot. It also includes background on the shooter, COTS options that were explored, why custom gearboxes were used, and the process used in developing the custom gearbox. Additional learning related to the Fisher-Price gearbox that can be applied to future projects is also included. This paper is not intended to address basic manufacturing items such as measuring and hole making process nor is it intended to explore the overall design decisions of the 2009 robot.

Shooter Background

The shooter assembly for the 2009 robot consists of two wheels in an over/under configuration. The axis of these wheels are skewed 20 degrees left and right to allow different exit vectors to be created by altering the rotational speeds of the upper and lower wheels. These wheels speeds are controlled by a closed loop PID algorithm fed by quaderature encoders mounted on the wheel shafts opposite the driving motor. The original concept of the shooter had a single CIM motor direct driving each wheel shaft. This is how the shooter was prototyped.

Figure 1 Gearheads 2009 Robot

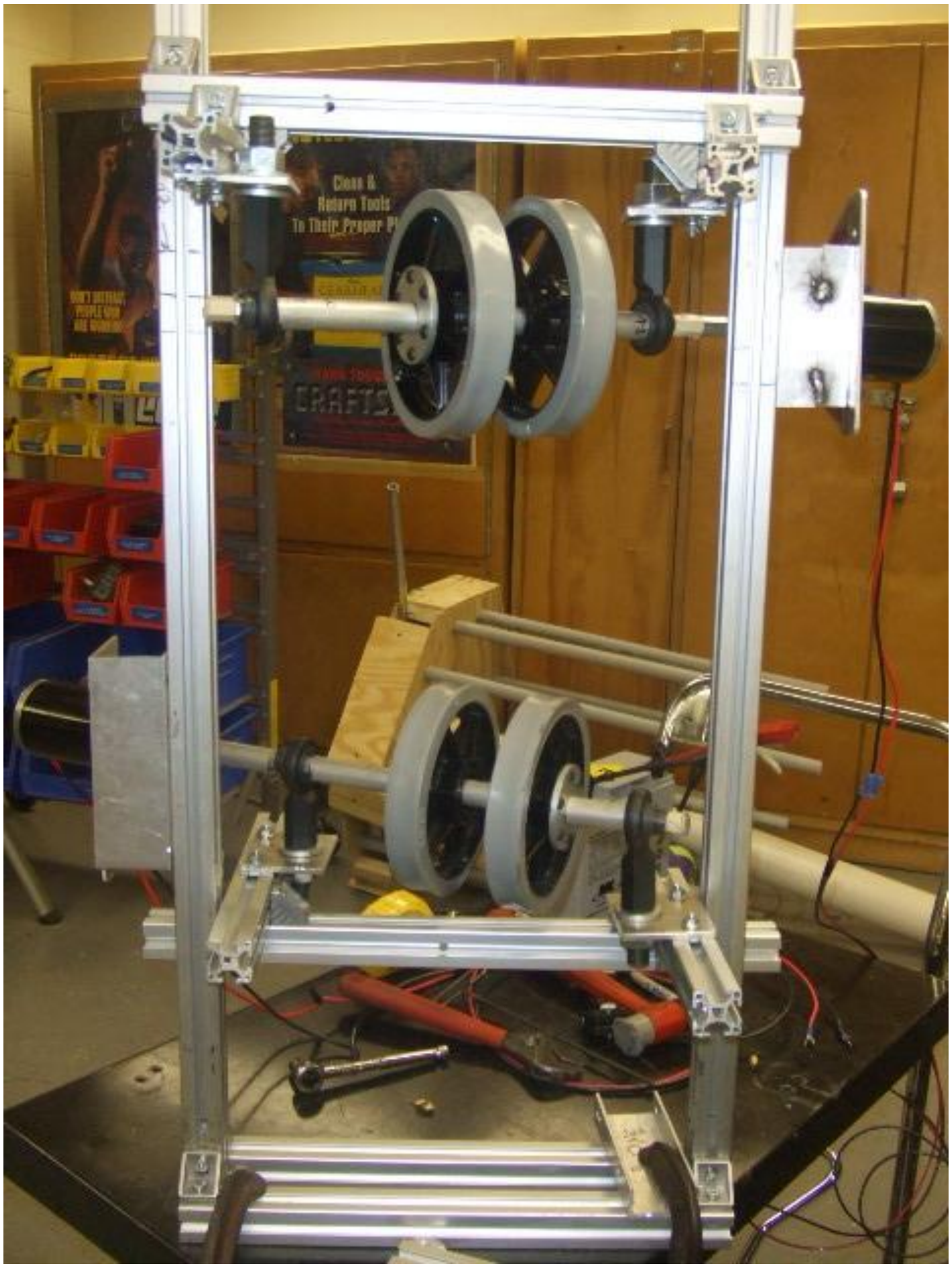


Figure 2 - Shooter Prototype with Direct Drive CIM's[1]

During later development it was determined that the torque of the CIMS was needed elsewhere on the robot and that the 2009 Fisher-Price (FP) motors would need to be used on the shooter. To compensate for the difference in motor speeds the FP's were mounted in [AM Planetary Transmissions (AM-0002)] from AndyMark, which provided a 3.67 speed reduction from the FP's 15,600 RPM. This resulted in a theoretical free speed of 4250 RPM compared to the CIM's 5310 RPM. The decrease in range resulting from the decrease in wheel speeds was determined to be an acceptable trade-off. It

[1] Photo Credit - Kara Bakowski

should be noted that there was no wheel speed data at this time. At this point, prints for the shooter were sent to a manufacturing shop for final hardware creation. After this hardware was assembled, testing began to generate an algorithm with which to drive the shooter wheel speeds based upon the distance and angle of the target. This testing would involve several hours of near constant running of the shooter mechanism.

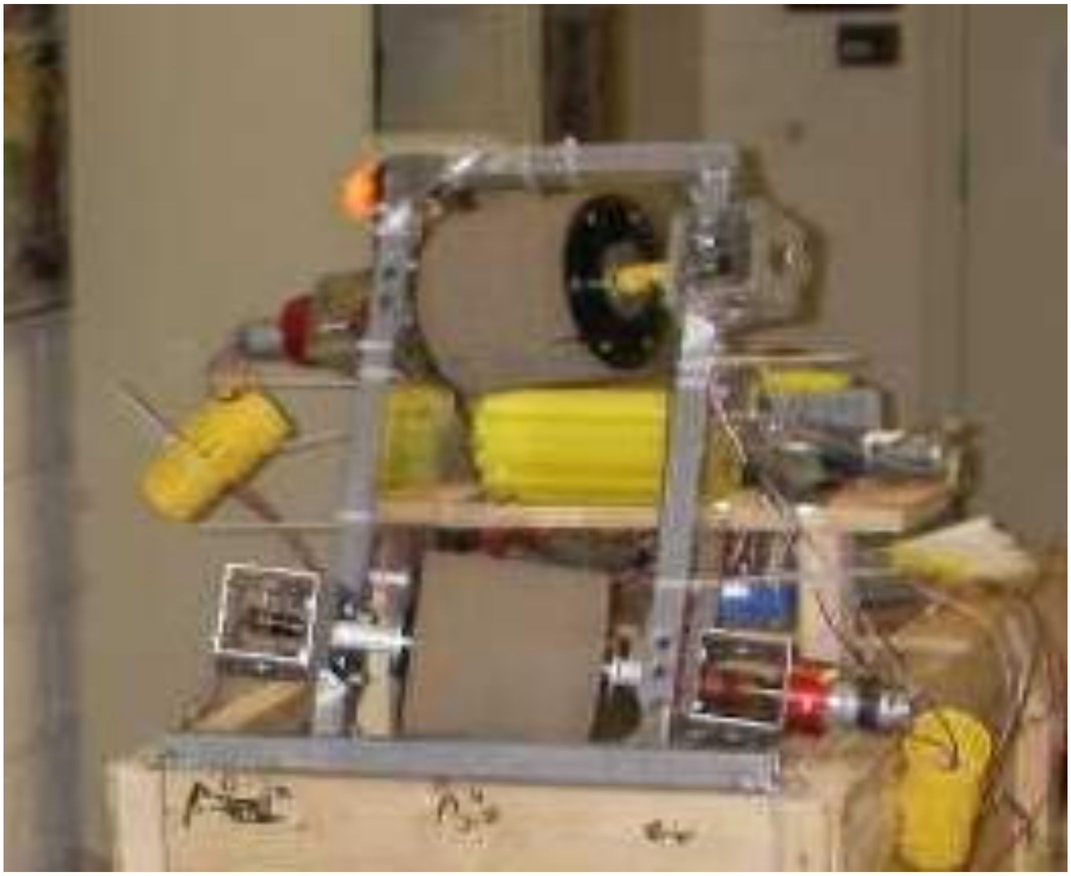


Figure 3 - Final Hardware Driven by FP Motors into AM Planetary Gearboxes

During testing it was noticed that one wheel would not go nearly as fast as the other. Upon examination there were no binding issues that could be found in the system, but it was then noticed that the internal fan blades of the FP were intermittently missing. It was speculated that this was due to damage during earlier use, prior to being assigned to the shooter. The motor was replaced and testing was continued. After a significant period of testing, 1-2 hours of continuous use, it was again noted that one of the wheels would not go as fast as the other. Binding was again suspected, but examination turned up nothing. It was noted that the motors were hot to the touch, but since they had not yet tripped their breakers it was estimated that the motors were within normal operating spec. Closer examination eventually revealed that the fan blades were again missing, indicating a motor failure. Comparison with the motor driving the other wheel showed that it too was starting to fail. It was quickly determined that a higher gearbox reduction would be needed to reduce the torque loads on the motors.

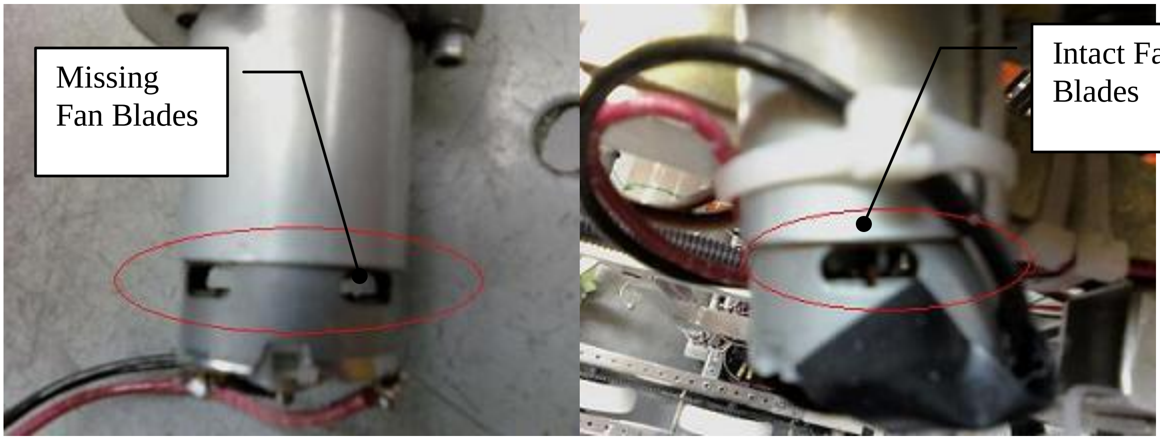


Figure 4 - Fan Blades

Gearbox Search

Based upon the testing data collected, it was determined that 1000RPM from both wheels provided a shot ~9ft down the center and 1000RPM from either wheel provided a 2.5-3ft shot to either the right or left. From this determination a desired gearbox ratio of 15.6:1 was determined (15600RPM/1000RPM). A search for a COTS gearbox was started.

Table 1 - Gearbox Options

Gearbox 1	Gearbox 2	Final Ratio
AM Planetary (3.67:1)	AM Stackerbox (3.57:1)	3.67*3.57 = 13.1:1
AM Planetary (3.67:1)	AM Toughbox (12.75:1)	3.67*12.75 = 46.8:1
AM Planetary (3.67:1)	AM GEM500 (3.67:1)	3.67*3.67 = 13.5:1
Banebot 36mm (16:1)	n/a	16:1

The Banebots 36mm planetary gearbox was determined to be the closest to the desired ratio, additionally, its cost was approximately half of the AndyMark options. Unfortunately, when an attempt was made to purchase this gearbox it was listed as 'out of stock'. At this point it was the Friday afternoon before ship and the ordering deadline for AndyMark had passed. With no way to order parts before Monday there was little chance of getting parts installed before the shipping deadline. At this point custom options became the only options.

Custom Options

The key limitation on custom gearbox options was speed; what could be assembled quickly to provide an opportunity to test and validate the shooter prior to the shipping deadline. The team has previously used DeWalt XRP gearboxes with success and with ratios of 47:1, 15:1 & 12:1; the DeWalt was within a reasonable range. Unfortunately the method for mounting and the total weight of the gearboxes (1.57lbm) exceeded acceptable limits (vs .8 for the AM planetary). The Fisher-Price gearbox was then turned to as a source of lightweight gears.

Fisher-Price Gearbox

How to Open

The FP gearbox is held together with a series of locking clips and screws. To disassemble, start by removing the screws and then, using a flathead screwdriver, pry the clips open one by one. It should be noted that the work surface should be covered with paper towel prior to opening as grease appears to be the most significant contributor to the gearbox's mass. It is common to break the locking clips during opening and the screws seem more than adequate to keep the gearbox intact once reassembled.

What's Inside

The internals of the FP gearbox are quite simple. There are four gearsets (excluding the motor) and each gearset is molded as a single piece to eliminate any chance of a coupling failure (via key etc.) In addition to the gearsets there are two 3/8" shafts that half the gearsets turn on. The remaining gearsets turn on features molding into the gearbox housing. The gears have differing pitches (sizes) that are immediately obvious to a novice, and consequently, there are a limited number of ways the gears can be engaged. Because of this the custom gearbox was limited to removing stages from the stock FP gearbox. The next step was to determine what reductions were available. The simplest way to accomplish this was by counting the number of teeth on each gear. It should also be noted that the first two gearsets (A&B) have a 3/8" hex in their center, not a cylindrical hole

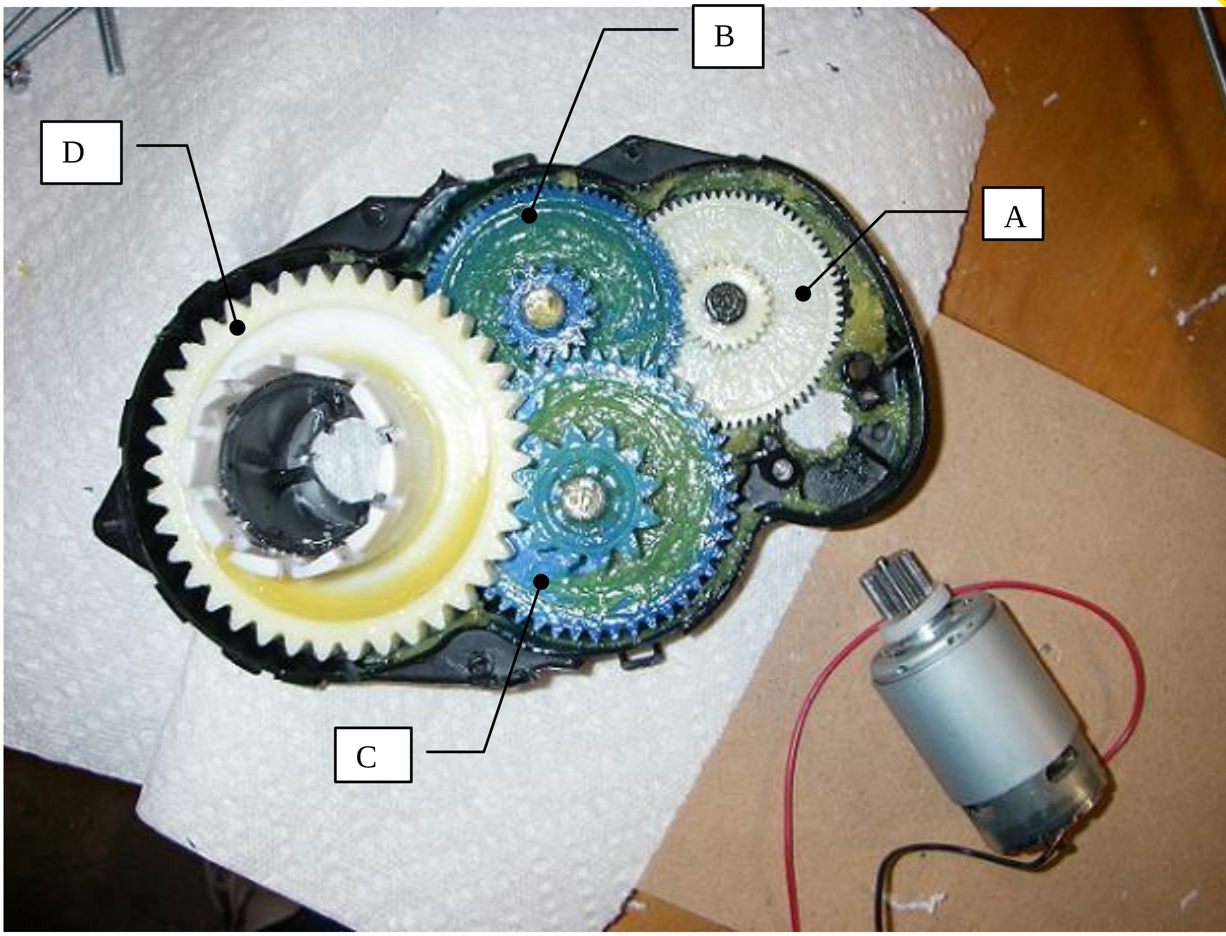


Figure 5 - FP Gearbox Internals

Table 2 - Gear Tooth Counts

Gearset	# of Teeth Small Gear (Driving)	# of Teeth Large Gear (Driven)
Motor	16	n/a
A	25	71
B	14	79
C	12	44
D	n/a	38

From these gear tooth counts the reductions can be calculated.

Table 3 – Fisher-Price Gearbox Ratios

Stage	Driving Gear	Driven Gear	Single Stage Gear Ratio	Cumulative Gear Ratio
1	Motor - 16	A – 71	4.4375:1	
2	A – 25	B – 79	3.16:1	14.0225:1
3	B – 14	C – 44	3.14:1	44:1
4	C – 12	D – 38	3.16:1	139.3:1

Center-to-center distances were also measured from the gearbox. This was done by measuring the distance between the shafts with digital calipers, with the shafts inside the measurement (inclusive). Then half of each shaft diameter was subtracted from this measurement to determine the center-to-center distance. This center-to-center distance will define the hole positions in the custom gearbox.

Table 4 – Center to Center Distances

Stage	Driving Shaft Diameter (in)	Driven Shaft Diameter (in)	Distance Between Shafts (Inclusive)(in)	Center to Center Distance(in)
1 (Motor->A)	.125	.375	1.6295	1.380
2 (A -> B)	.375	.375	2.0080	1.633
3 (B -> C)	.375	.375	2.0875	1.712
4 (C -> D)	.375	1.4885	3.1800	2.248

Based upon the information from Table 3, the closest reduction to our desired that we can achieve is ~14. This was great until it was realized that the original 16 tooth gears had been cut off when the motors were installed in the AM Planetary transmissions. The replacement motors were provided with 19 tooth gears and there was no source for the 16 tooth gears. This had significant consequences on the available gear ratios as seen in Table 5 with the closest available ratio being 11.8:1. This is significantly different from the desired 16:1, but it is what was possible in short order. If this plan did not work then the option was to order AM Stackerboxes Monday morning to put in-line with the AM Planetary for a ratio of 13.1:1.

Table 5 - Fisher Price Gearbox Ratios - Revised

Stage	Driving Gear	Driven Gear	Single Stage Gear Ratio	Cumulative Gear Ratio
1	Motor - **19**	A – 71	**3.74:1**	
2	A – 25	B – 79	3.16:1	**11.8:1**
3	B – 14	C – 44	3.14:1	**37:1**
4	C – 12	D – 38	3.16:1	**117:1**

Custom Shooter Gearbox

The custom shooter gearbox was created from materials that were on hand at the moment. As a result, these materials became the driving factor of some part dimensions. An example of this is the use of 1/2" steel hex for an output shaft. The existing 3/8" holes in the FP gearsets suggest a 3/8" output, but that was not available. Additionally, standard fasteners that were available were used, ¼-20 for the standoffs and 3/8-16 for the intermediate shaft. Screwdriver handle stock was used for spacers throughout although most plastic or metal tubing would make a reasonable substitute. Flanged bronze bearings remaining from the conveyor sub-assembly were used to support the dead end of the output shaft and manage any thrust load from the wheel axles. The source of these bushings is unknown, but they appear to be consistent with McMaster-Carr part number 6338K416. The live side of the output shaft was supported with ½" hex bore ball bearings from AndyMark part number am-0279. These bearings were on hand as a part of an earlier sample purchase and were responsible for significantly simplifying the assembly. Before mounting the gearboxes on the shooter they were run for approximately 15 minutes in 3 minute bursts to provide some assurance of robustness.

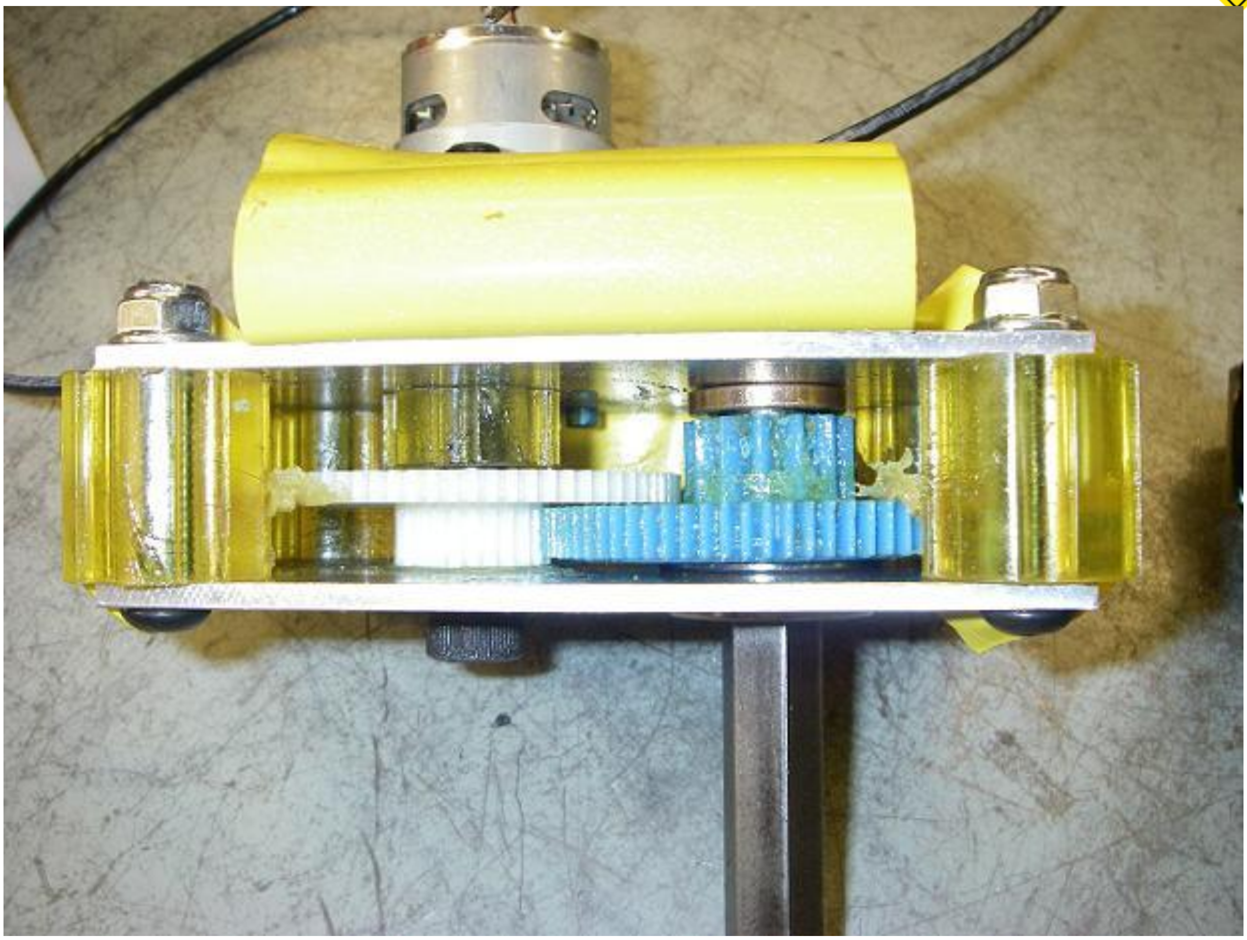


Figure 6 – Top View of Completed Gearbox

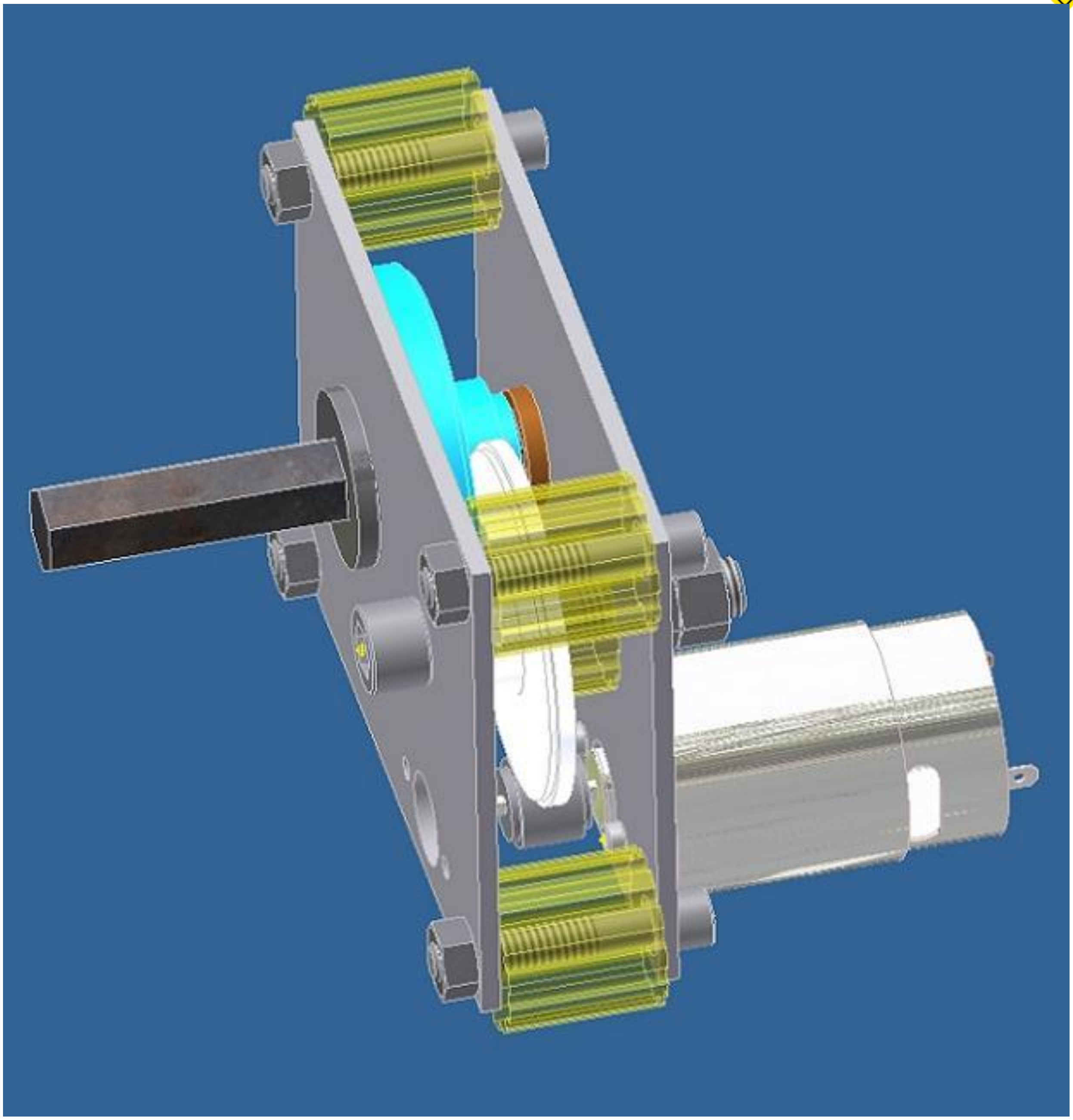


Figure 7 – View of CAD Model

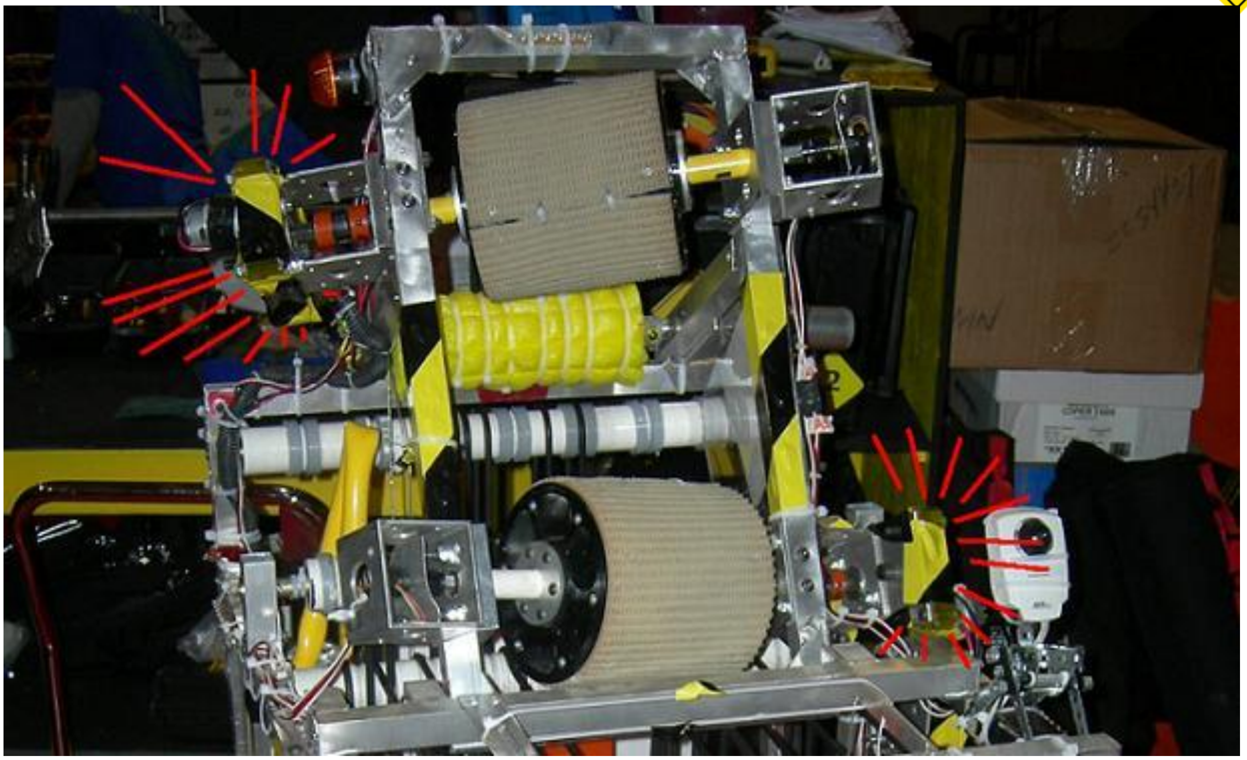
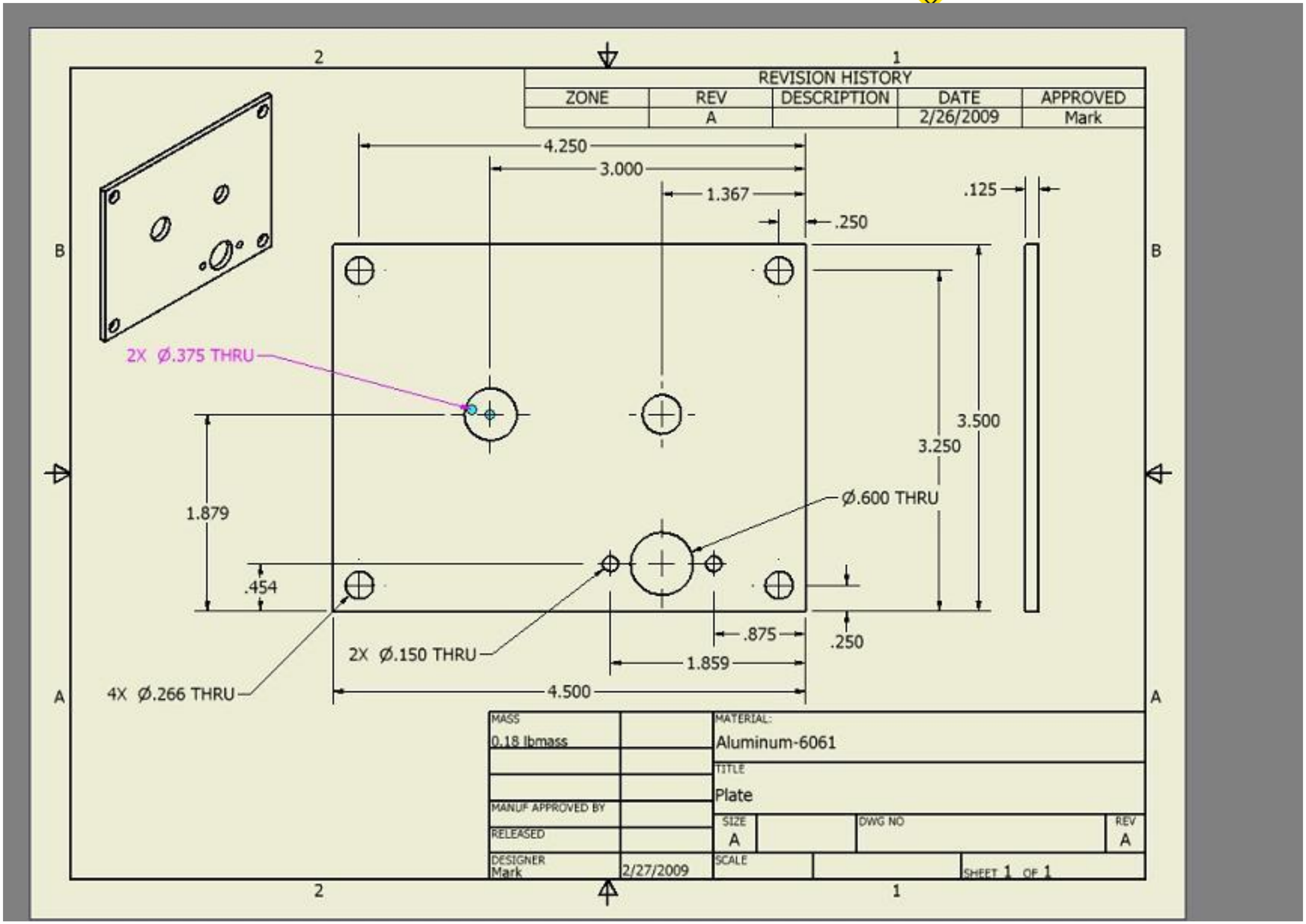


Figure 8 – Installed Gearboxes[2]

Conclusions and Comments

First of all, if nothing else was gained from this experience, I learned that the FP gearboxes are a spectacularly useful piece of equipment in the kit of parts. They are simple, robust and configurable in a variety of ways. These modifications are relatively easy, which makes them quickly implemented for either prototyping efforts or final hardware. I strongly suspect that if not for the FP gearboxes, Team 1189 would not have had a running shooter at its first competition. Those that understand gearing will be able to take advantage of this resource and those that do not will be left wondering what to do next.

[2] Photo Credit - Jim Creighton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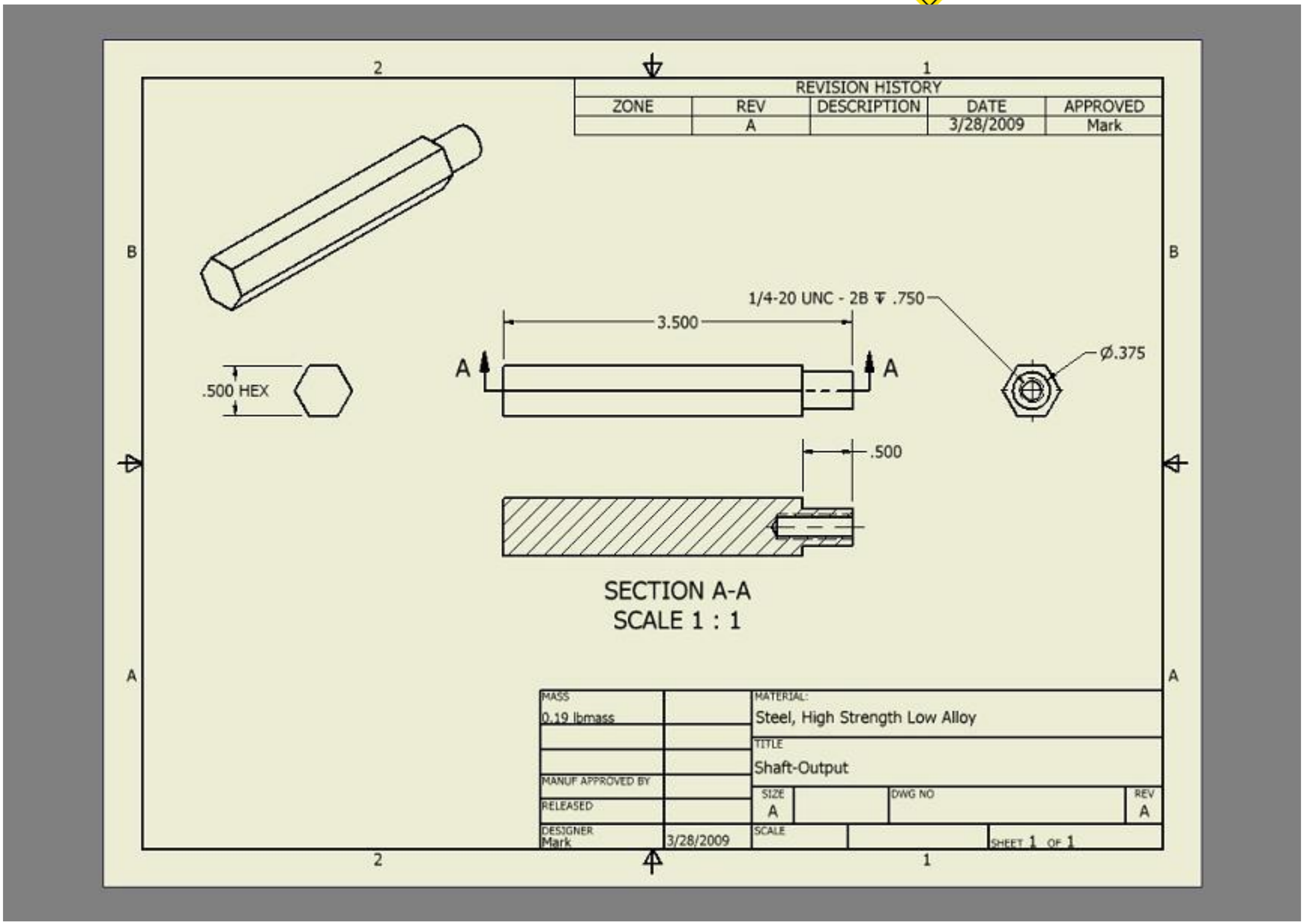

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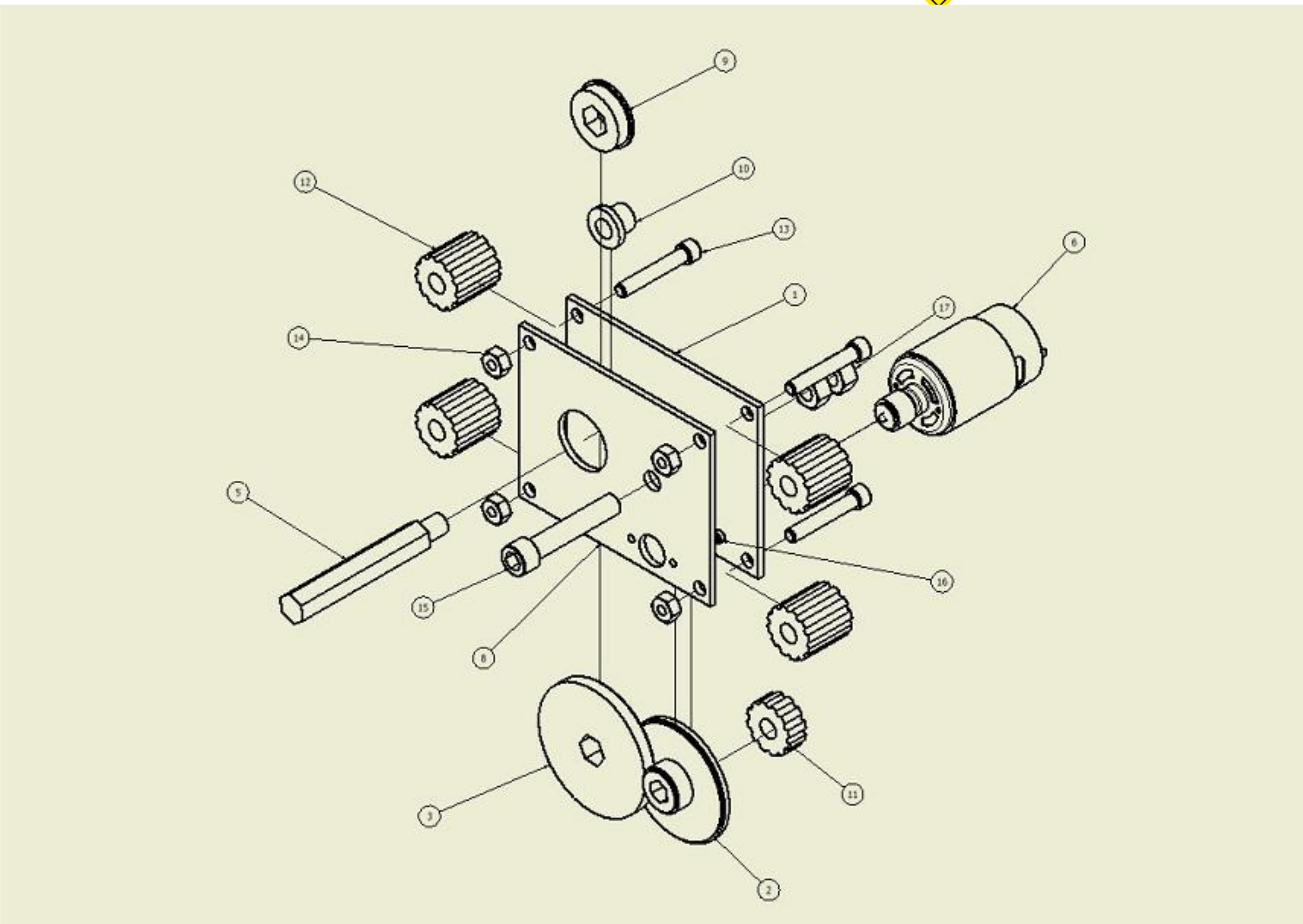

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Part List

Item	Part Number	QTY	Description	Mass	Material
1	Plate	1		0.182 lbmass	Aluminum-6061
2	FP Gear A	1		0.031 lbmass	Nylon Composite (Nylon, molybdenum disulphide)
3	FP Gear B	1		0.060 lbmass	Nylon Composite (Nylon, molybdenum disulphide)
5	Shaft-Output	1		0.193 lbmass	Steel, High Strength Low Alloy
6	FisherPriceMotor	1		0.088 kg	Steel, Mild
7	FP Motor Pinion	1		0.004 lbmass	Default
8	Plate-Output	1		0.173 lbmass	Aluminum-6061
9	Flanged Bearing-Hex	1		0.071 lbmass	Stainless Steel, 440C
10	Bushing	1		0.024 lbmass	Bronze, Soft Tin
11	Spacer-Idler Shaft	1		0.012 lbmass	Polyaryletherketone Resin
12	Spacer-Plate Standoff	4		0.029 lbmass	Polyaryletherketone Resin
13	91251A546	4	SHCS-.250-20x1.5	0.027 lbmass	Steel
14	90499A029	4	nut-hex-250	0.008 lbmass	Steel, High Strength Low Alloy
15	SHCS-.375-16x2.0	1		0.010 lbmass	Default
16	SHCS-M3x0.5-6	2		0.000 lbmass	Default
17	nut-hex-375-16	2	nut-hex-250	0.018 lbmass	Steel, High Strength Low Alloy

Additional Fisher-Price Gearbox Techniques

During the course of the custom gearbox construction a number of additional methods for using the FP gearboxes were discovered. I have collected them here for future use and to prevent their loss. Your mileage may vary.

Mounting Stock Gearbox

Gearbox can be easily mounted onto a piece of tube stock with a shaft passing through it. The gearbox aligns on the shaft has it's rotation constrained by the tube stock. A few zip ties would be all that is required to retain the gearbox, but in many orientation even that is not needed. The back of the gearbox may be drilled out as needed to facilitate passing the shaft through. Keep in mind that the output gear pilots on its ID so some care is required to prevent removing this constraining feature completely. Up to ~1.125" diameter seems acceptable in most cases, but be sure to check the specific gearbox that you are working on prior to modification.

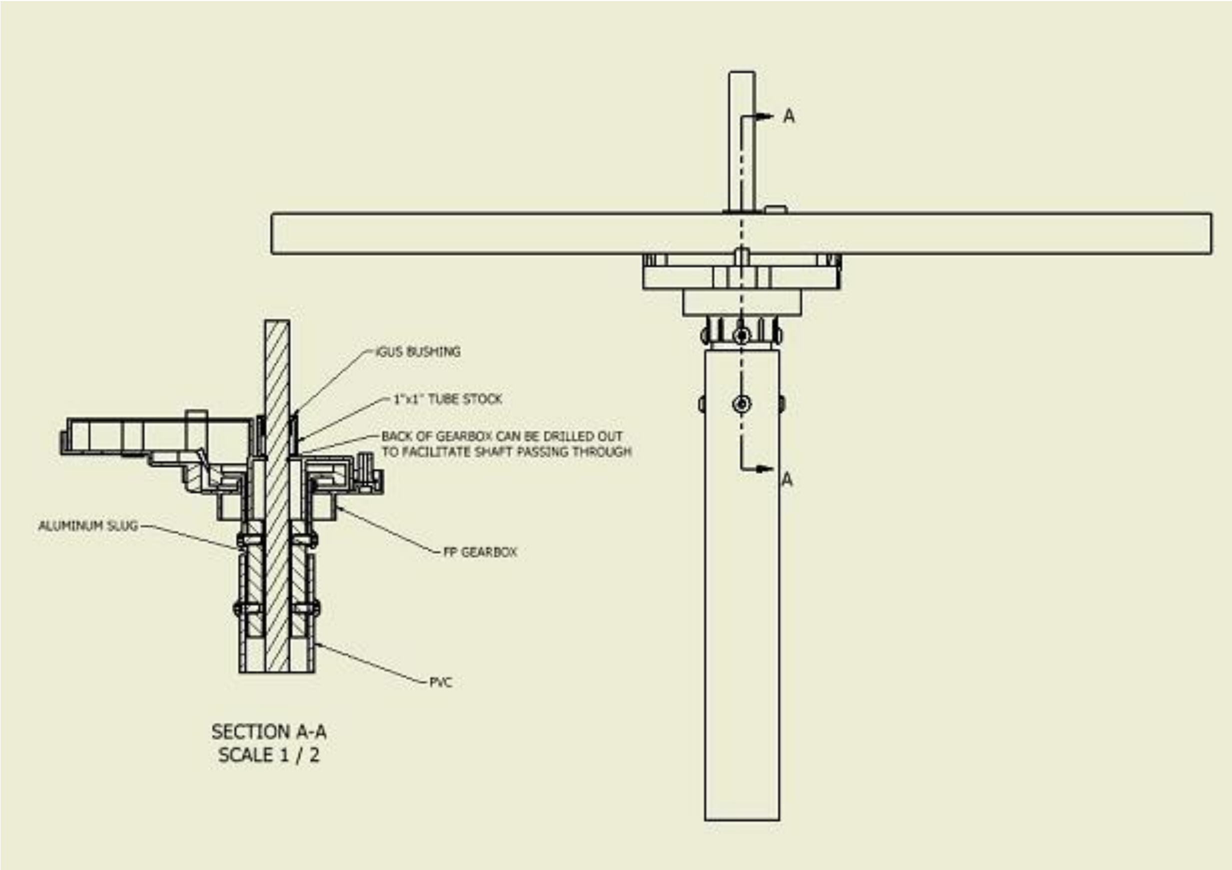

Figure 9 – Gearbox Mounting Option

Mating to Stock Gearbox Output

Fisher-Price Coupler

Not surprisingly, Fisher-Price manufactures a coupler for the output of their gearboxes. p/n: 74460-2249 - It can be useful in robot construction, but is not particularly space efficient. It can be purchased from - http://www.householdappliance.com/power_wheels_gearboxes.html ~$4.25

Figure 10 – FP Wheel Driver[3]

[3] Photo from www.householdappliance.com

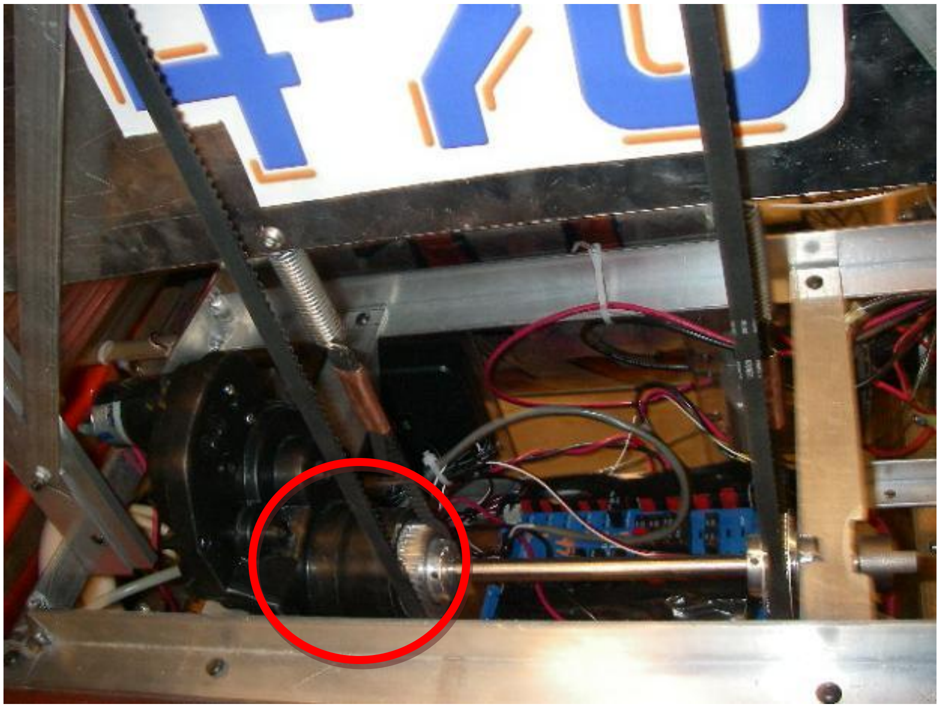

Figure 11 – FP Wheel Driver – FRC470 (2009)[4]

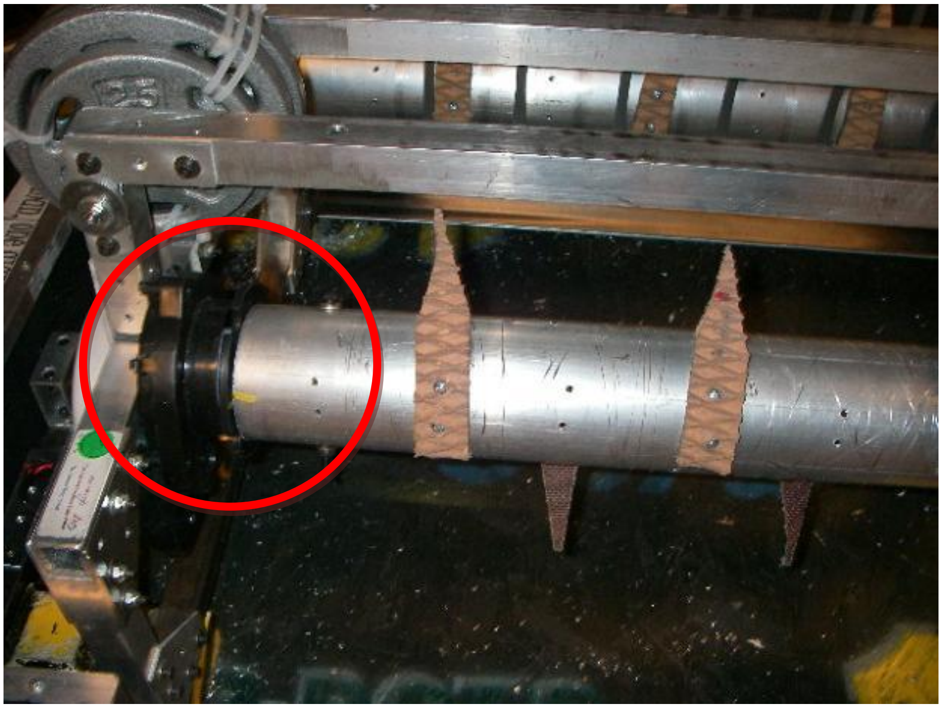

Figure 12 – FP Wheel Driver – FRC1250 (2009)[5]

[4] Photo Credit – Tito Huffman
[5] Photo Credit – Tito Huffman

Gearheads Coupler (2007)

An alternate in-house creation by Matt Veryser was based upon the design of the FP coupler, but with a lower profile design to aid in packaging. The decreased amount of material suggests that this only be attempted in aluminum. As an additional bonus, this custom coupler can be created with whatever mating feature is required for your secondary attachment. (keyed hole, hex, bolt circle, etc)

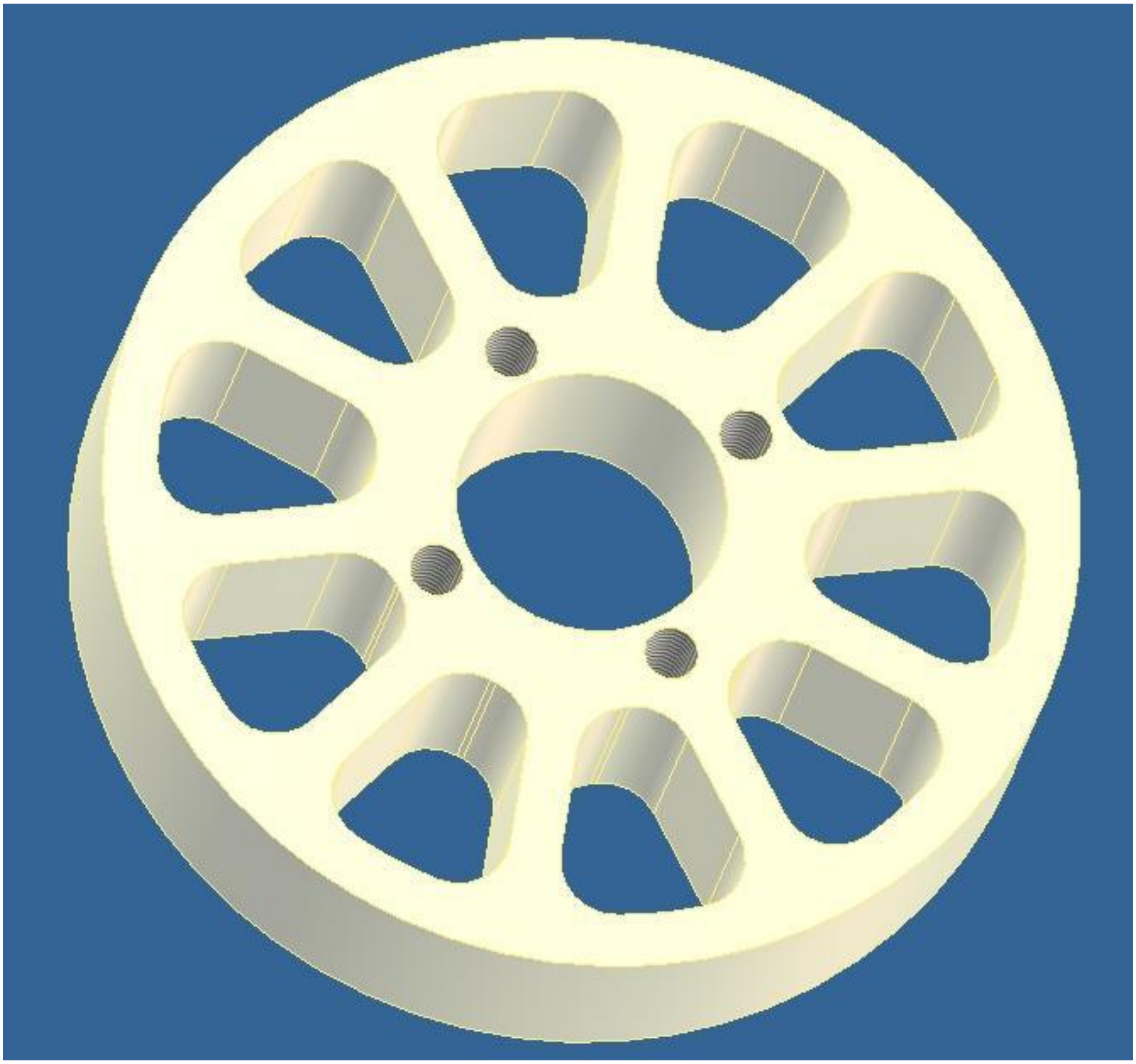

Figure 13 – Gearheads Coupler (2007)

Cylindrical Slug

A simple slug of material is all that is required to mate with the Fisher-Price output. Select a nominal stock size of aluminum that nearly fits into the output of the gearbox and then drill through the tabs of the FP output and tap into the slug. The compliance of the tabs can accommodate a significant amount of clearance between the parts, at least .020". This slug and be drilled out to allow a guide shaft to pass through or have a hex broached into it to allow a smaller drive shaft. This is my preferred method.

Figure 14 – Cylindrical Slug – FRC1260 (2009)[6]

[6] Photo Credit – Tito Huffman

Octagon Slug

An alternate slug construction is possible if a suitable size of octagon stock is available. The octagon slug is placed into the output of the FP gearbox and simply secured with a hose clamp. The slug may be drilled/broached as in any of the above methods. While this is the simplest method I have not been able to find a source for octagon bar stock in the relevant size.

Figure 15 – Octagon Slug – FRC201 (2009)[7]

[7] Photo Credit – Tito Huffman

Alternate Motor Mounting

While it cannot be guaranteed in all of the FP gearboxes, in many of them the first two gearset (A & B) have the same size (diametral pitch and pressure angle) which allows the stock motor pinion to be remounted to engage the second gearset directly. This effectively removes one stage of the gearbox (resulting in a ~4.4 increase in output speed with the 2009 gearbox) for the price of three simple holes.

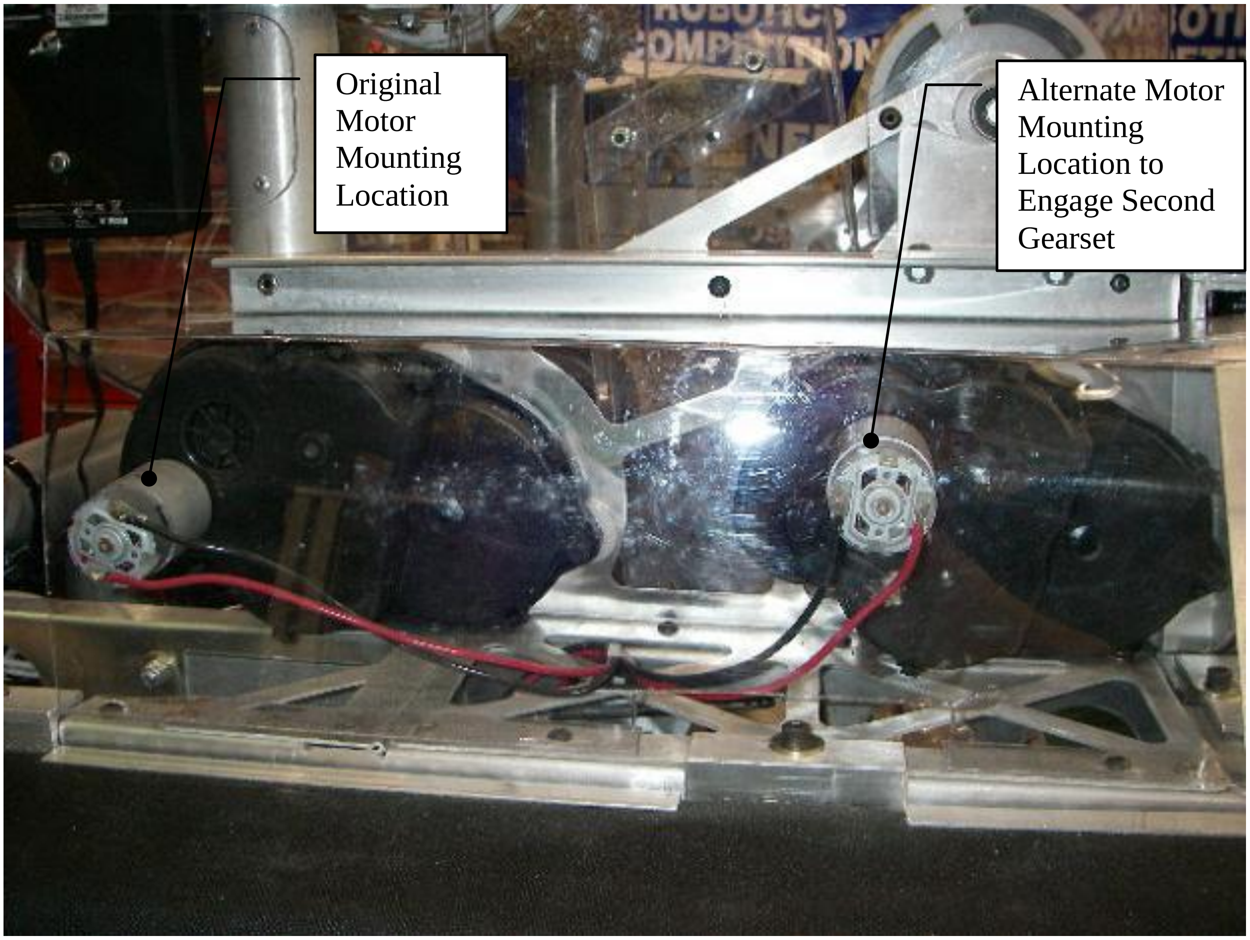

Figure 16 – Alternate Motor Mounting Location – FRC67 (2009)

Acknowledgements

Thanks go out to Kara Bakowski & Jim Creighton for capturing the progress of the shooter in photos during the season. These photos made this paper possible. Thanks to Tito Huffman & Nathan Troscinski for reviewing this paper and keeping my thinking on this subject process in line. I must also thank Tito for his consistent traipsing around at events and scrounging up new ways to do things as well as his ever present guidance.

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http://www.chiefdelphi.com/forums/member.php?&u=1282
Chief Delphi Post by Paul Copioli -
http://www.chiefdelphi.com/forums/showpost.php?p=440972&postcount=13
Chief Delphi Discussion
http://www.chiefdelphi.com/forums/showthread.php?t=61315

Gearhead Forums – Shooter Prototyping Discussions