Custom Gear Boxes

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Bio

- FIRST
  - Founding student of 1741 (05’-08’)
  - Mentor for 1747 (08’-11’) (2013-Present)
  - Founding mentor 4272 (12’)
  - Ri3D Team Indiana (15’- Present)
- Education
  - BS Aeronautical Engineering Technology Purdue University (08’-12’)
- Industry
  - Research Engineer for Cook Research Inc. (12’-Present)

Determining Your Performance Envelope

- This is the first step
  - We decided Mecanum best suited the game so our needs were:
    - Drive 4 wheels independently
    - Still wanted to be traction limited
    - 4 inch wheels were appropriate for our application (no terrain)
  - Weight determines robot speed in a traction-limited drive
    - Because FTC has no weight limit this has significant consequences

Calculating your Desired Ratio

- To calculate your desired ratio
  - Traction Force = normal force * coefficient of friction
    - In this case, we solve for a range of weights the robot could fall into
  - Wheel shaft torque = traction force * wheel radius
  - Ratio = wheel shaft torque / total motor torque
    - You may want to consider adding some kind of safety factor by reducing the value you use for total input torque. (We typically use 80% to account for losses and provide a safety factor.)

Calculating your Desired Ratio

Weight	CoF	Traction	W Radius	W Torque	M Torque	Ratio
30	0.67	20.10	0.16	3.30	0.15	22.61
32.5	0.67	21.78	0.16	3.57	0.15	24.49
35	0.67	23.45	0.16	3.85	0.15	26.38
37.5	0.67	25.13	0.16	4.12	0.15	28.26
40	0.67	26.80	0.16	4.40	0.15	30.15
42.5	0.67	28.48	0.16	4.67	0.15	32.03
45	0.67	30.15	0.16	4.95	0.15	33.91

Selecting Gears

- Determine your diametric pitch
  - This factor is important to the strength of the gears but also determines size based on number of teeth
    - Typically FRC applications utilize 20dp or 32dp in the case of lighter loaded, higher speed situations
  - http://www.engineersedge.com/gears/gear-tooth-strength.htm
  - Pitch diameter = number of teeth / diametric pitch
    - Don't forget to look at OD of the gears to avoid interference with things outside the gear interaction
  - Pitch diameter is the contact circle where interface should occur for a given gear
  - Use convention: look at what is used in off the shelf gearboxes and implement that yourself
  - Be conservative, nobody wants to repair their drive train during competition

Selecting Gears

- Find suppliers that sell the gears in the Diametric Pitch, and shaft interface that you need
- For FRC Andymark and VexPro have a wide selection of 20 DP gears available that are reasonably affordable
- For FTC we used SDP/SI because of our need for a smaller diametric pitch
- For FRC SDP/SI should be used carefully because of cost, try and use what's available from FIRST specific suppliers, because they will likely be more cost effective

Selecting a “set” of ratios

- For FTC we wanted flexibility, so we looked at ratios that shared the same shaft spacing
  - This can be determined based on the sum of the teeth between the two gears in set
- We made a table with every 32DP gear available for purchase on SDP/SI
- For FRC your ratio will likely be much more well defined because robot weight is much less variable
- Chances are, in a drivetrain you’ll need more than one stage, but to start, we’ll just look at the middle stage because it’s the most interesting

	14	16	18	20	22	24	26	28	30	32	34	36	40	42	48	50	52	54	56	60	64	70	72	75	76	80	88	90	92	96	100	110	112	120	124	128	130	132
14	28	30	32	34	36	38	40	42	44	46	48	50	54	56	62	64	66	68	70	74	78	84	86	89	90	94	102	104	106	110	114	124	126	134	138	142	144	146
16	30	32	34	36	38	40	42	44	46	48	50	52	56	58	64	66	68	70	72	76	80	86	88	91	92	96	104	106	108	112	116	126	128	136	140	144	146	148
18	32	34	36	38	40	42	44	46	48	50	52	54	58	60	66	68	70	72	74	78	82	88	90	93	94	98	106	108	110	114	118	128	130	138	142	146	148	150
20	34	36	38	40	42	44	46	48	50	52	54	56	60	62	68	70	72	74	76	80	84	90	92	95	96	100	108	110	112	116	120	130	132	140	144	148	150	152
22	36	38	40	42	44	46	48	50	52	54	56	58	62	64	70	72	74	76	78	82	86	92	94	97	98	102	110	112	114	118	122	132	134	142	146	150	152	154
24	38	40	42	44	46	48	50	52	54	56	58	60	64	66	72	74	76	78	80	84	88	94	96	99	100	104	112	114	116	120	124	134	136	144	148	152	154	156
26	40	42	44	46	48	50	52	54	56	58	60	62	66	68	74	76	78	80	82	86	90	96	98	101	102	106	114	116	118	122	126	136	138	146	150	154	156	158
28	42	44	46	48	50	52	54	56	58	60	62	64	68	70	76	78	80	82	84	88	92	98	100	103	104	108	116	118	120	124	128	138	140	148	152	156	158	160
30	44	46	48	50	52	54	56	58	60	62	64	66	70	72	78	80	82	84	86	90	94	100	102	105	106	110	118	120	122	126	130	140	142	150	154	158	160	162
32	46	48	50	52	54	56	58	60	62	64	66	68	72	74	80	82	84	86	88	92	96	102	104	107	108	112	120	122	124	128	132	142	144	152	156	160	162	164
34	48	50	52	54	56	58	60	62	64	66	68	70	74	76	82	84	86	88	90	94	98	104	106	109	110	114	122	124	126	130	134	144	146	154	158	162	164	166
36	50	52	54	56	58	60	62	64	66	68	70	72	76	78	84	86	88	90	92	96	100	106	108	111	112	116	124	126	128	132	136	146	148	156	160	164	166	168
40	54	56	58	60	62	64	66	68	70	72	74	76	80	82	88	90	92	94	96	100	104	110	112	115	116	120	128	130	132	136	140	150	152	160	164	168	170	172
42	56	58	60	62	64	66	68	70	72	74	76	78	82	84	90	92	94	96	98	102	106	112	114	117	118	122	130	132	134	138	142	152	154	162	166	170	172	174
48	62	64	66	68	70	72	74	76	78	80	82	84	88	90	96	98	100	102	104	108	112	118	120	123	124	128	136	138	140	144	148	158	160	168	172	176	178	180
50	64	66	68	70	72	74	76	78	80	82	84	86	90	92	98	100	102	104	106	110	114	120	122	125	126	130	138	140	142	146	150	160	162	170	174	178	180	182
52	66	68	70	72	74	76	78	80	82	84	86	88	92	94	100	102	104	106	108	112	116	122	124	127	128	132	140	142	144	148	152	162	164	172	176	180	182	184
54	68	70	72	74	76	78	80	82	84	86	88	90	94	96	102	104	106	108	110	114	118	124	126	129	130	134	142	144	146	150	154	164	166	174	178	182	184	186
56	70	72	74	76	78	80	82	84	86	88	90	92	96	98	104	106	108	110	112	116	120	126	128	131	132	136	144	146	148	152	156	166	168	176	180	184	186	188
60	74	76	78	80	82	84	86	88	90	92	94	96	100	102	108	110	112	114	116	120	124	130	132	135	136	140	148	150	152	156	160	170	172	180	184	188	190	192
64	78	80	82	84	86	88	90	92	94	96	98	100	104	106	112	114	116	118	120	124	128	134	136	139	140	144	152	154	156	160	164	174	176	184	188	192	194	196
70	84	86	88	90	92	94	96	98	100	102	104	106	110	112	118	120	122	124	126	130	134	140	142	145	146	150	158	160	162	166	170	180	182	190	194	198	200	202
72	86	88	90	92	94	96	98	100	102	104	106	108	112	114	120	122	124	126	128	132	136	142	144	147	148	152	160	162	164	168	172	182	184	192	196	200	202	204
75	89	91	93	95	97	99	101	103	105	107	109	111	115	117	123	125	127	129	131	135	139	145	147	150	151	155	163	165	167	171	175	185	187	195	199	203	205	207
76	90	92	94	96	98	100	102	104	106	108	110	112	116	118	124	126	128	130	132	136	140	146	148	151	152	156	164	166	168	172	176	186	188	196	200	204	206	208
80	94	96	98	100	102	104	106	108	110	112	114	116	120	122	128	130	132	134	136	140	144	150	152	155	156	160	168	170	172	176	180	190	192	200	204	208	210	212
88	102	104	106	108	110	112	114	116	118	120	122	124	128	130	136	138	140	142	144	148	152	158	160	163	164	168	176	178	180	184	188	198	200	208	212	216	218	220
90	104	106	108	110	112	114	116	118	120	122	124	126	130	132	138	140	142	144	146	150	154	160	162	165	166	170	178	180	182	186	190	200	202	210	214	218	220	222
92	106	108	110	112	114	116	118	120	122	124	126	128	132	134	140	142	144	146	148	152	156	162	164	167	168	172	180	182	184	188	192	202	204	212	216	220	222	224
96	110	112	114	116	118	120	122	124	126	128	130	132	136	138	144	146	148	150	152	156	160	166	168	171	172	176	184	186	188	192	196	206	208	216	220	224	226	228
100	114	116	118	120	122	124	126	128	130	132	134	136	140	142	148	150	152	154	156	160	164	170	172	175	176	180	188	190	192	196	200	210	212	220	224	228	230	232
110	124	126	128	130	132	134	136	138	140	142	144	146	150	152	158	160	162	164	166	170	174	180	182	185	186	190	198	200	202	206	210	220	222	230	234	238	240	242
112	126	128	130	132	134	136	138	140	142	144	146	148	152	154	160	162	164	166	168	172	176	182	184	187	188	192	200	202	204	208	212	222	224	232	236	240	242	244
120	134	136	138	140	142	144	146	148	150	152	154	156	160	162	168	170	172	174	176	180	184	190	192	195	196	200	208	210	212	216	220	230	232	240	244	248	250	252
124	138	140	142	144	146	148	150	152	154	156	158	160	164	166	172	174	176	178	180	184	188	194	196	199	200	204	212	214	216	220	224	234	236	244	248	252	254	256
128	142	144	146	148	150	152	154	156	158	160	162	164	168	170	176	178	180	182	184	188	192	198	200	203	204	208	216	218	220	224	228	238	240	248	252	256	258	260
130	144	146	148	150	152	154	156	158	160	162	164	166	170	172	178	180	182	184	186	190	194	200	202	205	206	210	218	220	222	226	230	240	242	250	254	258	260	262
132	146	148	150	152	154	156	158	160	162	164	166	168	172	174	180	182	184	186	188	192	196	202	204	207	208	212	220	222	224	228	232	242	244	252	256	260	262	264

The ACTUAL Table

Input Gears \ Output Gears	14	16	18	20	22	24	26	28	30	32	36	42	48	56	60	64	72	76	96	100	110	120	124	128
14		1.14	1.29	1.43	1.57	1.71	1.86	2	2.14	2.29	2.57	3.00	3.43	4.00	4.29	4.57	5.14	5.43	6.86	7.14	7.86	8.57	8.86	9.14
16	0.88		1.13	1.25	1.38	1.50	1.625	1.75	1.88	2.00	2.25	2.63	3.00	3.50	3.75	4.00	4.50	4.75	6.00	6.25	6.88	7.50	7.75	8.00
18	0.78	0.89		1.11	1.22	1.333	1.44	1.56	1.67	1.78	2.00	2.33	2.67	3.11	3.33	3.56	4.00	4.22	5.33	5.56	6.11	6.67	6.89	7.11
20	0.70	0.80	0.90		1.1	1.20	1.30	1.40	1.50	1.60	1.80	2.10	2.40	2.80	3.00	3.20	3.60	3.80	4.80	5.00	5.50	6.00	6.20	6.40
22	0.64	0.73	0.82	0.91		1.09	1.18	1.27	1.36	1.45	1.64	1.91	2.18	2.55	2.73	2.91	3.27	3.45	4.36	4.55	5.00	5.45	5.64	5.82
24	0.58	0.67	0.75	0.83	0.92		1.08	1.17	1.25	1.33	1.50	1.75	2.00	2.33	2.50	2.67	3.00	3.17	4.00	4.17	4.58	5.00	5.17	5.33
26	0.54	0.62	0.69	0.77	0.85	0.92		1.08	1.15	1.23	1.38	1.62	1.85	2.15	2.31	2.46	2.77	2.92	3.69	3.85	4.23	4.62	4.77	4.92
28	0.50	0.57	0.64	0.71	0.79	0.86	0.93		1.07	1.14	1.29	1.50	1.71	2.00	2.14	2.29	2.57	2.71	3.43	3.57	3.93	4.29	4.43	4.57
30	0.47	0.53	0.60	0.67	0.73	0.80	0.87	0.93		1.07	1.20	1.40	1.60	1.87	2.00	2.13	2.40	2.53	3.20	3.33	3.67	4.00	4.13	4.27
32	0.44	0.50	0.56	0.63	0.69	0.75	0.81	0.88	0.94		1.13	1.31	1.50	1.75	1.88	2.00	2.25	2.38	3.00	3.13	3.44	3.75	3.88	4.00
36	0.39	0.44	0.50	0.56	0.61	0.67	0.72	0.78	0.83	0.89		1.17	1.33	1.56	1.67	1.78	2.00	2.11	2.67	2.78	3.06	3.33	3.44	3.56
42	0.33	0.38	0.43	0.48	0.52	0.57	0.62	0.67	0.71	0.76	0.86		1.14	1.33	1.43	1.52	1.71	1.81	2.29	2.38	2.62	2.86	2.95	3.05
48	0.29	0.33	0.38	0.42	0.46	0.50	0.54	0.58	0.63	0.67	0.75	0.88		1.17	1.25	1.33	1.50	1.58	2.00	2.08	2.29	2.50	2.58	2.67
56	0.25	0.29	0.32	0.36	0.39	0.43	0.46	0.50	0.54	0.57	0.64	0.75	0.86		1.07	1.14	1.29	1.36	1.71	1.79	1.96	2.14	2.21	2.29
60	0.23	0.27	0.30	0.33	0.37	0.40	0.43	0.47	0.50	0.53	0.60	0.70	0.80	0.93		1.07	1.20	1.27	1.60	1.67	1.83	2.00	2.07	2.13
64	0.22	0.25	0.28	0.31	0.34	0.38	0.41	0.44	0.47	0.50	0.56	0.66	0.75	0.88	0.94		1.13	1.19	1.50	1.56	1.72	1.88	1.94	2.00
72	0.19	0.22	0.25	0.28	0.31	0.33	0.36	0.39	0.42	0.44	0.50	0.58	0.67	0.78	0.83	0.89		1.06	1.33	1.39	1.53	1.67	1.72	1.78
76	0.18	0.21	0.24	0.26	0.29	0.32	0.34	0.37	0.39	0.42	0.47	0.55	0.63	0.74	0.79	0.84	0.95		1.26	1.32	1.45	1.58	1.63	1.68
96	0.15	0.17	0.19	0.21	0.23	0.25	0.27	0.29	0.31	0.33	0.38	0.44	0.50	0.58	0.63	0.67	0.75	0.79		1.04	1.15	1.25	1.29	1.33
100	0.14	0.16	0.18	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.36	0.42	0.48	0.56	0.60	0.64	0.72	0.76	0.96		1.10	1.20	1.24	1.28
110	0.13	0.15	0.16	0.18	0.20	0.22	0.24	0.25	0.27	0.29	0.33	0.38	0.44	0.51	0.55	0.58	0.65	0.69	0.87	0.91		1.09	1.13	1.16
120	0.12	0.13	0.15	0.17	0.18	0.20	0.22	0.23	0.25	0.27	0.30	0.35	0.40	0.47	0.50	0.53	0.60	0.63	0.80	0.83	0.92		1.03	1.07
124	0.11	0.13	0.15	0.16	0.18	0.19	0.21	0.23	0.24	0.26	0.29	0.34	0.39	0.45	0.48	0.52	0.58	0.61	0.77	0.81	0.89	0.97		1.03
128	0.11	0.13	0.14	0.16	0.17	0.19	0.20	0.22	0.23	0.25	0.28	0.33	0.38	0.44	0.47	0.50	0.56	0.59	0.75	0.78	0.86	0.94	0.97	

Pinion Table

	22	24	26	28	30	32	36	42	48	56	60	64	72	76	96	100	110	120	124	128
11						2.91	3.27	3.82	4.36	5.09	5.45	5.82	6.55	6.91	8.73	9.09	10.00	10.91	11.27	11.64
12						2.67	3.00	3.50	4.00	4.67	5.00	5.33	6.00	6.33	8.00	8.33	9.17	10.00	10.33	10.67
13					2.31	2.46	2.77	3.23	3.69	4.31	4.62	4.92	5.54	5.85	7.38	7.69	8.46	9.23	9.54	9.85
14					2.14	2.29	2.57	3.00	3.43	4.00	4.29	4.57	5.14	5.43	6.86	7.14	7.86	8.57	8.86	9.14
15				1.87	2.00	2.13	2.40	2.80	3.20	3.73	4.00	4.27	4.80	5.07	6.40	6.67	7.33	8.00	8.27	8.53
16				1.75	1.88	2.00	2.25	2.63	3.00	3.50	3.75	4.00	4.50	4.75	6.00	6.25	6.88	7.50	7.75	8.00
17			1.53	1.65	1.76	1.88	2.12	2.47	2.82	3.29	3.53	3.76	4.24	4.47	5.65	5.88	6.47	7.06	7.29	7.53
18			1.44	1.56	1.67	1.78	2.00	2.33	2.67	3.11	3.33	3.56	4.00	4.22	5.33	5.56	6.11	6.67	6.89	7.11
19		1.26	1.37	1.47	1.58	1.68	1.89	2.21	2.53	2.95	3.16	3.37	3.79	4.00	5.05	5.26	5.79	6.32	6.53	6.74
20		1.20	1.30	1.40	1.50	1.60	1.80	2.10	2.40	2.80	3.00	3.20	3.60	3.80	4.80	5.00	5.50	6.00	6.20	6.40
21	1.05	1.14	1.24	1.33	1.43	1.52	1.71	2.00	2.29	2.67	2.86	3.05	3.43	3.62	4.57	4.76	5.24	5.71	5.90	6.10
22		1.09	1.18	1.27	1.36	1.45	1.64	1.91	2.18	2.55	2.73	2.91	3.27	3.45	4.36	4.55	5.00	5.45	5.64	5.82

- This table uses pinion gears from Actobotics compatible with the Neverest motor series from AM as well as a selection of gears from SDPSI.
- Some of the available gears from SDPSI were omitted due to usefullness of ratios.

Final Drive (Pulley Reduction)

- We settled on an AM 42 tooth pulley on each wheel, so we calculated against SDP/SI options here as well

	42
12	3.5
14	3
15	2.8
16	2.625
17	2.470588
18	2.333333
19	2.210526
20	2.1
22	1.909091
25	1.68
28	1.5
29	1.448276

Putting it all together

- Multiply ratios together to get your total reduction
  - (Output1/Input1)*(Output2/Input2)*(Output3/Input3)….
- Typically achieving a similar reduction through each stage is preferred.
- Center Bore
  - Hex is best, keyed is okay, but set screws suck.
  - Hex broaches in 500 hex and 375 hex are available, but check to see if another local team and is willing to share before you buy
- Bearings
  - These are important, select them carefully
  - Remember than a bearings may be thicker than your gearbox plate and may interfere with your motor mounting

Our Final Drive Table

M RPM	Gears/Sprockets						Ratio	Circ.	Spd. Loss	Raw	W/loss	M Trq.	W Rad.	W Trq.	Trq. Loss	W Frc.	CoF	Weight	Speed
6600	14	72	30	60	12	42	36.0	1.0	0.8	3.1	2.5	0.2	0.2	6.6	0.9	36.0	0.7	53.7	2.5
6600	14	72	30	60	14	42	30.9	1.0	0.8	3.7	2.9	0.2	0.2	5.6	0.9	30.9	0.7	46.1	2.9
6600	14	72	30	60	15	42	28.8	1.0	0.8	3.9	3.1	0.2	0.2	5.3	0.9	28.8	0.7	43.0	3.1
6600	14	72	30	60	16	42	27.0	1.0	0.8	4.2	3.4	0.2	0.2	4.9	0.9	27.0	0.7	40.3	3.4
6600	14	72	30	60	17	42	25.4	1.0	0.8	4.5	3.6	0.2	0.2	4.6	0.9	25.4	0.7	37.9	3.6
6600	14	72	30	60	18	42	24.0	1.0	0.8	4.7	3.8	0.2	0.2	4.4	0.9	24.0	0.7	35.8	3.8
6600	14	72	30	60	19	42	22.7	1.0	0.8	5.0	4.0	0.2	0.2	4.1	0.9	22.7	0.7	33.9	4.0
6600	14	72	30	60	20	42	21.6	1.0	0.8	5.2	4.2	0.2	0.2	3.9	0.9	21.6	0.7	32.2	4.2
6600	14	72	30	60	22	42	19.6	1.0	0.8	5.8	4.6	0.2	0.2	3.6	0.9	19.6	0.7	29.3	4.6
6600	14	72	30	60	25	42	17.3	1.0	0.8	6.6	5.2	0.2	0.2	3.2	0.9	17.3	0.7	25.8	5.2
6600	14	72	30	60	28	42	15.4	1.0	0.8	7.3	5.9	0.2	0.2	2.8	0.9	15.4	0.7	23.0	5.9
6600	14	72	30	60	29	42	14.9	1.0	0.8	7.6	6.1	0.2	0.2	2.7	0.9	14.9	0.7	22.2	6.1

Spacing

- Pitch Diameter = Teeth / Diametric Pitch
- Shaft Spacing = PD1 + PD2 + Gear Allowance
  - For most FIRST application .002” gear allowance is appropriate.
- The easiest way to build these boxes is with advanced manufacturing
- They can be built with a sharpie, a set of calipers, a sharp set of drills, and a decent drill press
  - Match drill these plates: stack two and drill both at the same time

Questions?