ENGS 147: Ski Jumper

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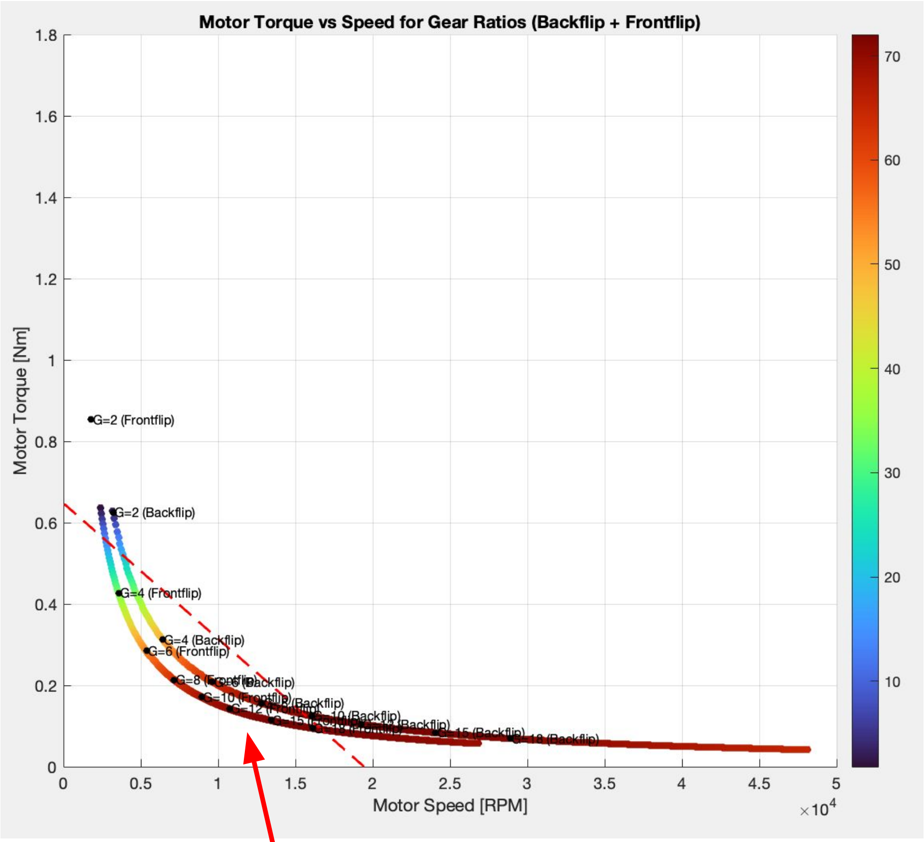
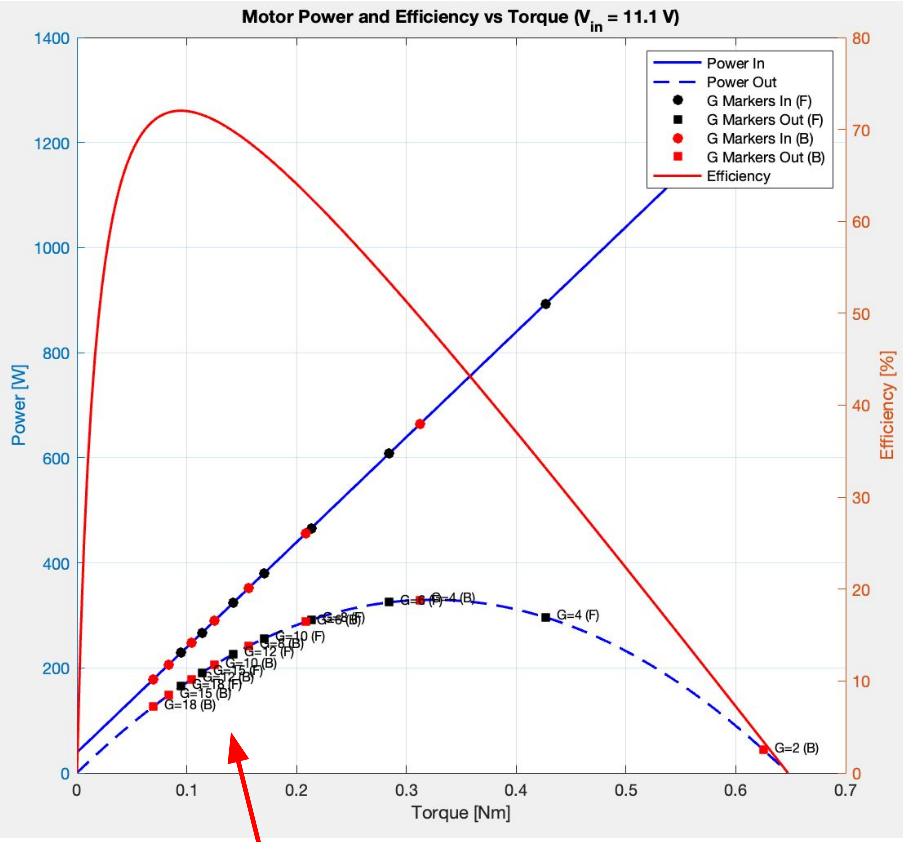
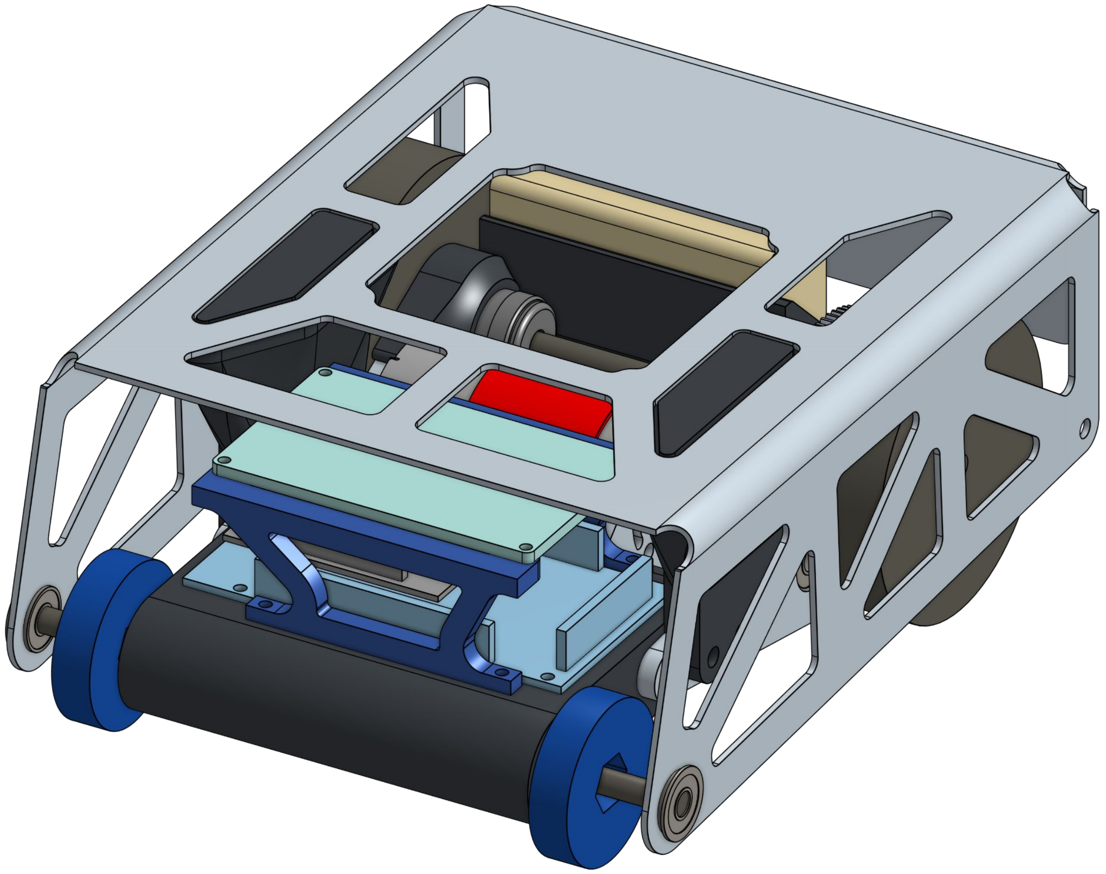
Mechanically Speaking

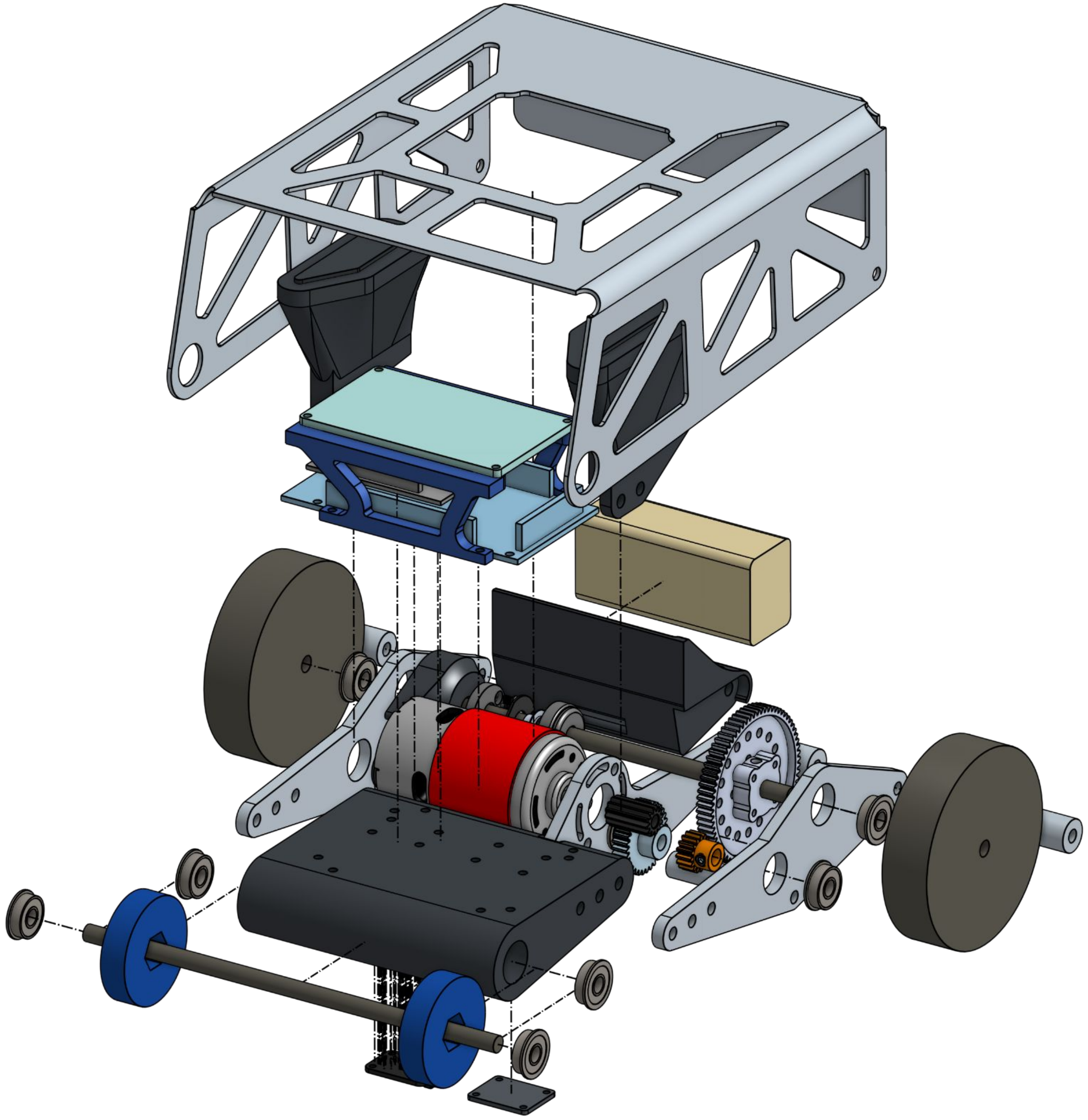
Motor Selection



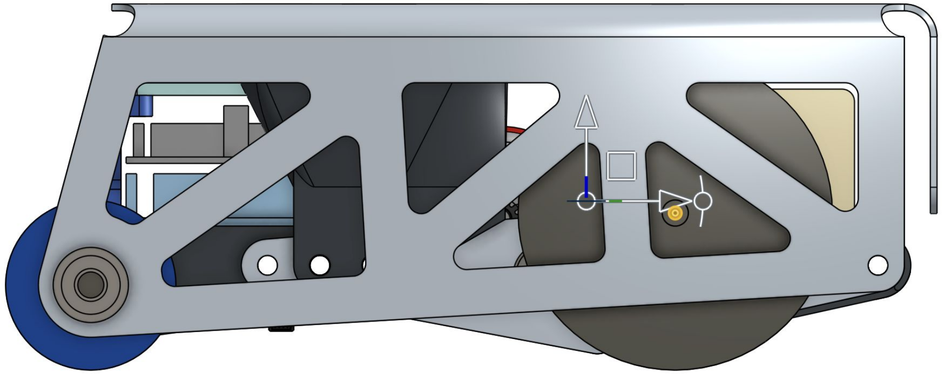


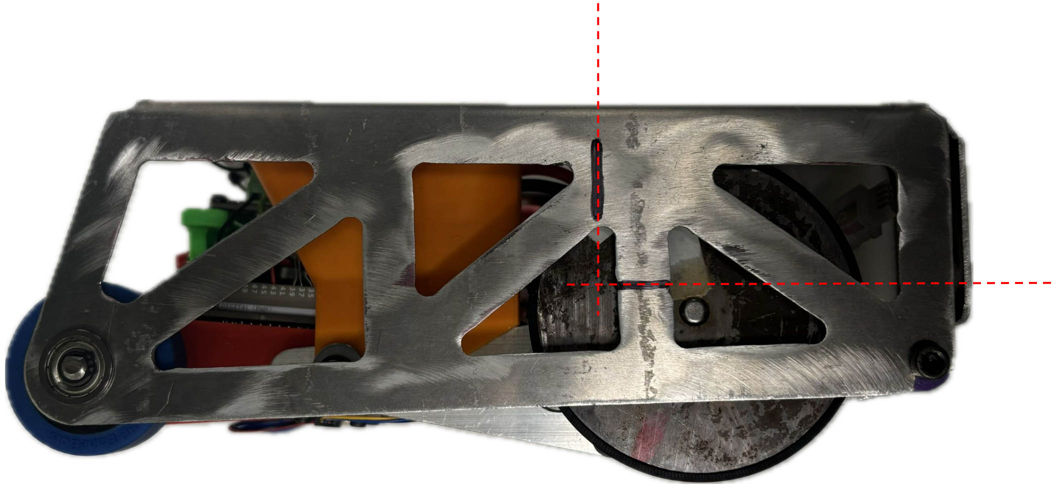
Gear Ratio = 12 (front flip)





Inertial Model Validation



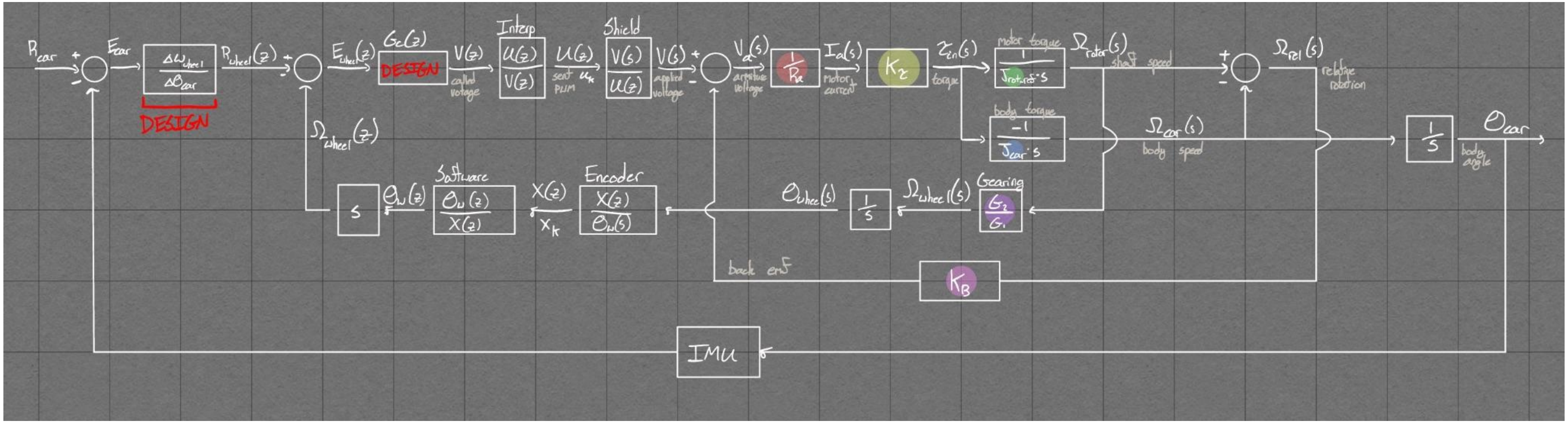


m_{CAD} = 2.829 kg

m_{true}= 2.803 kg

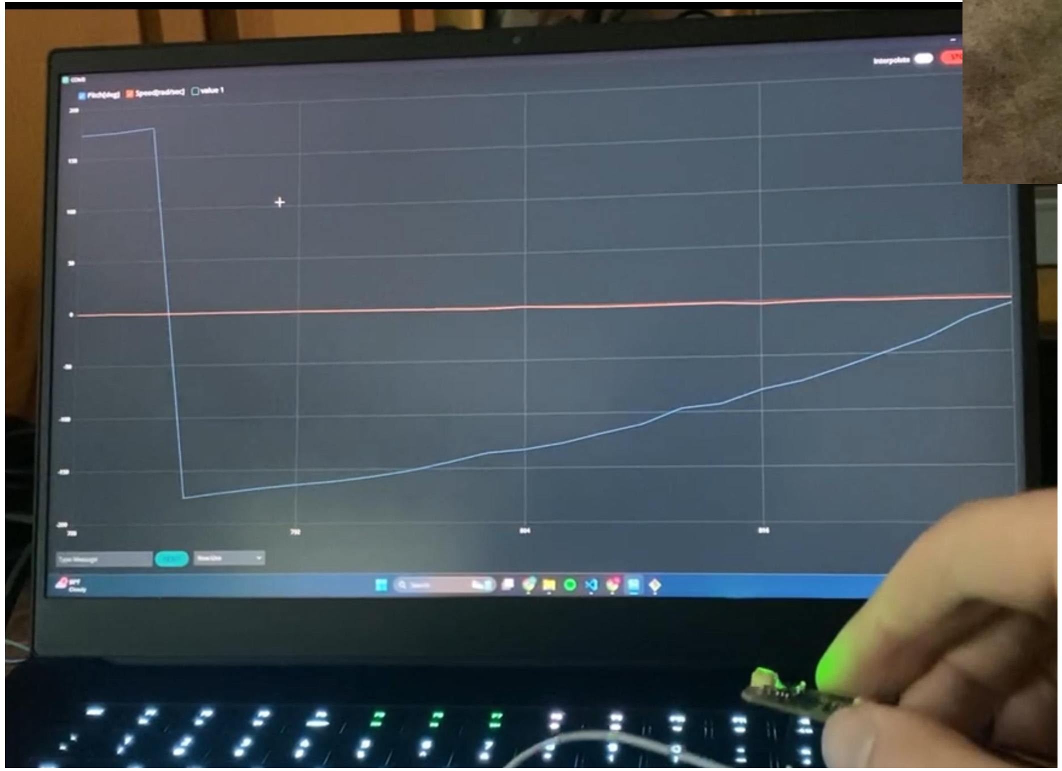
The Process

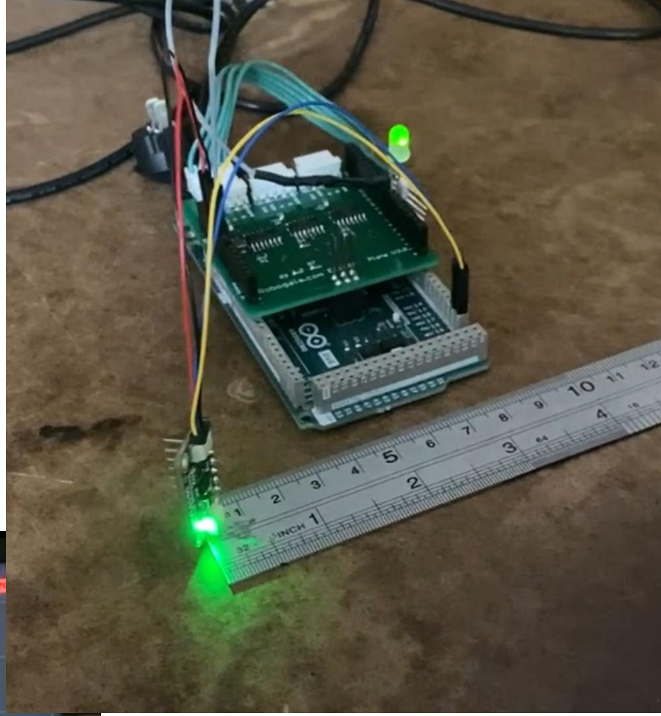
System Model



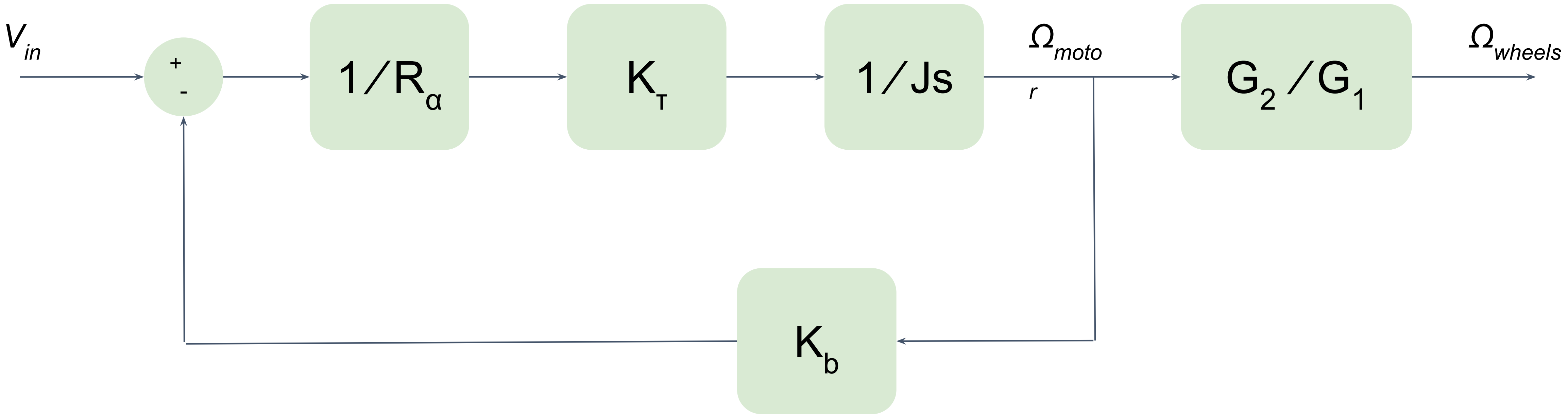
Sensors and States

- ToF Library issues
- Absolute Orientation
- No State Machine
    - Watchdog timers



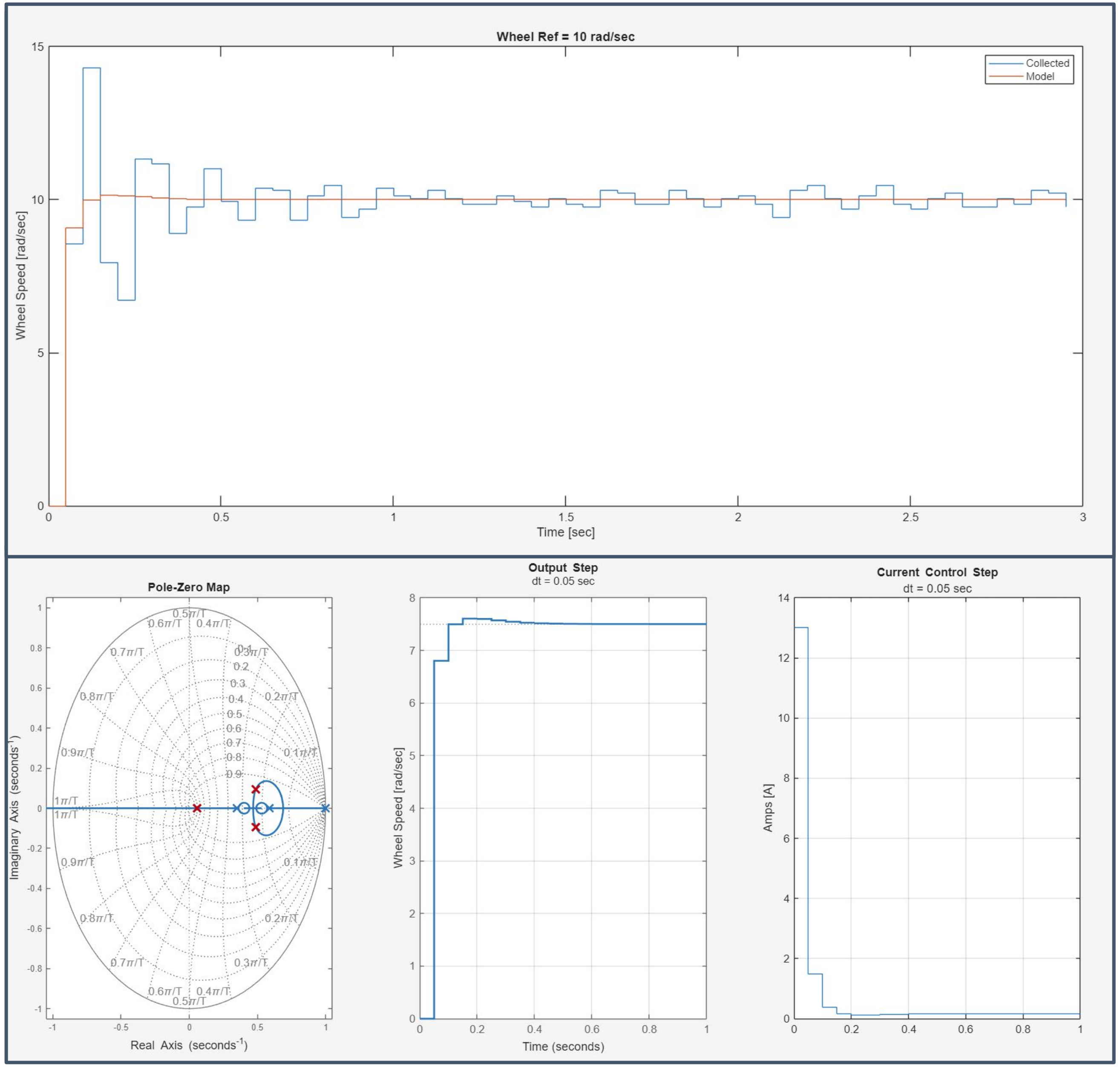


Motor Model (Static)

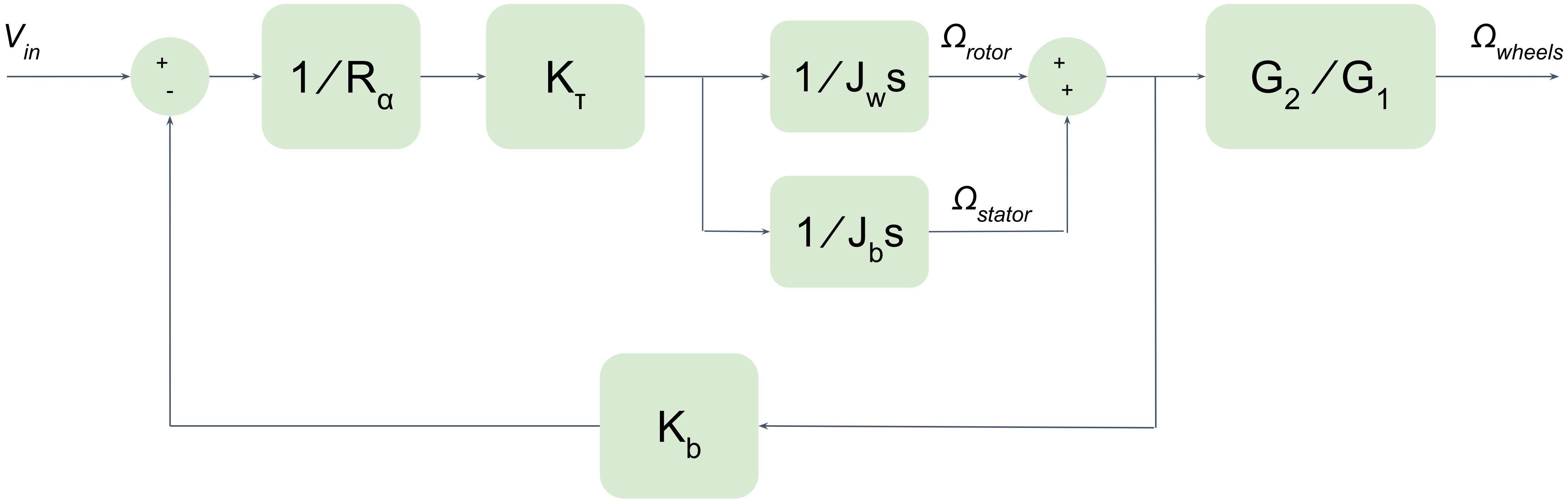


Drivetrain

- Update J_{wheel} and K_b with fixed body step
  - Designed speed controller
  - Control limits

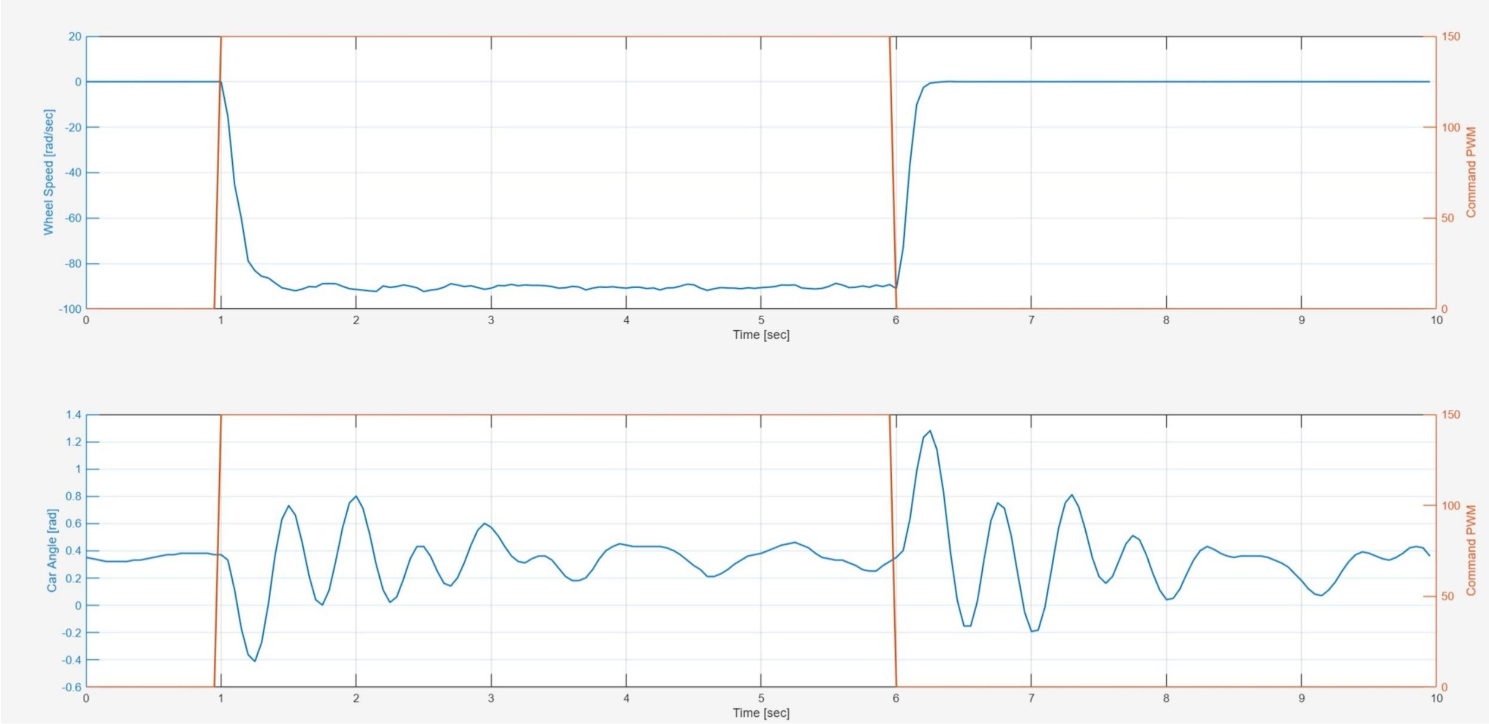


Motor Model (Floating Body)

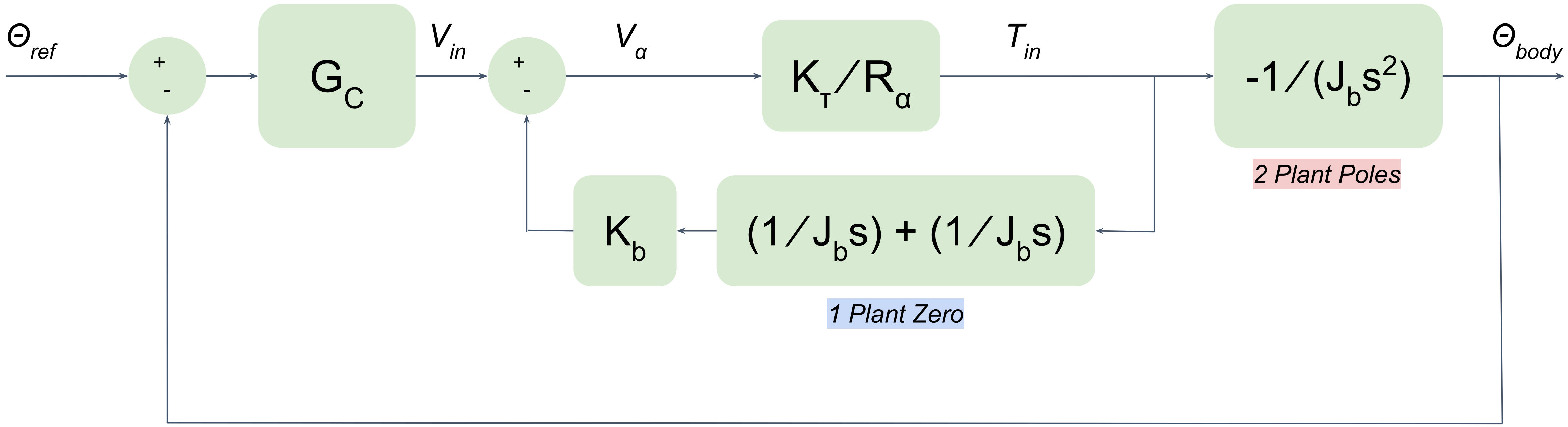


Hanging System

- Characterizing our kick
- Brake was a significant non-linear component
- Could not rotate around center of mass

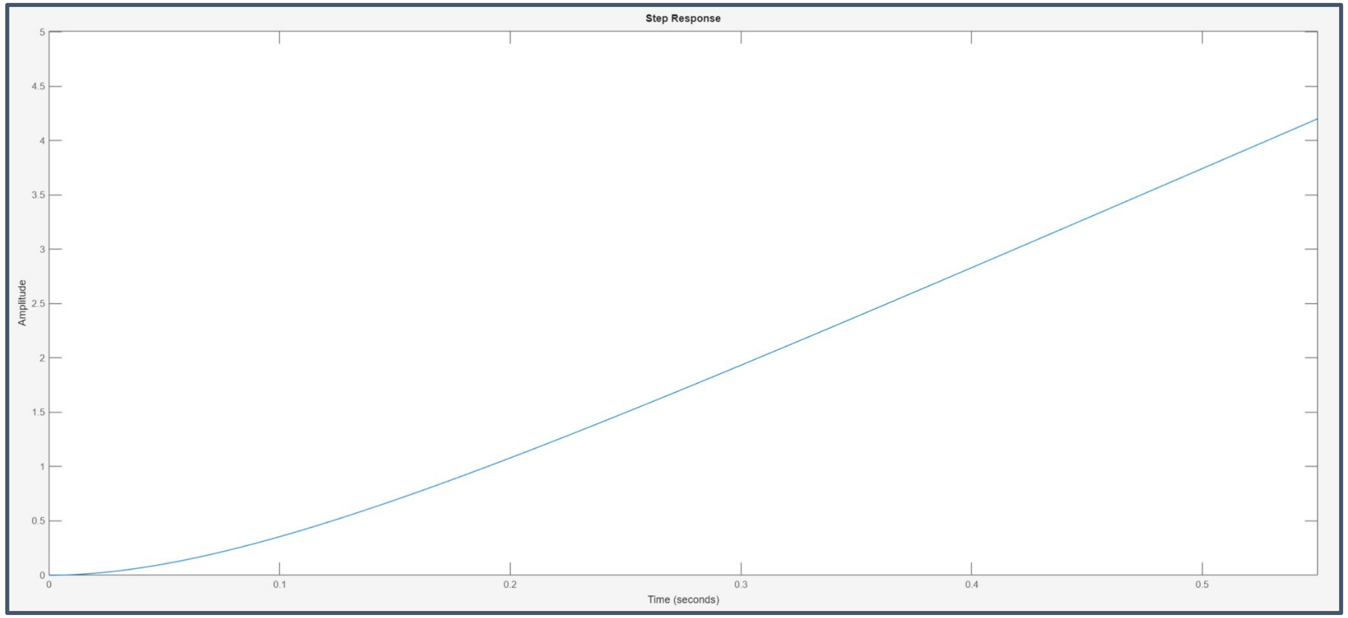


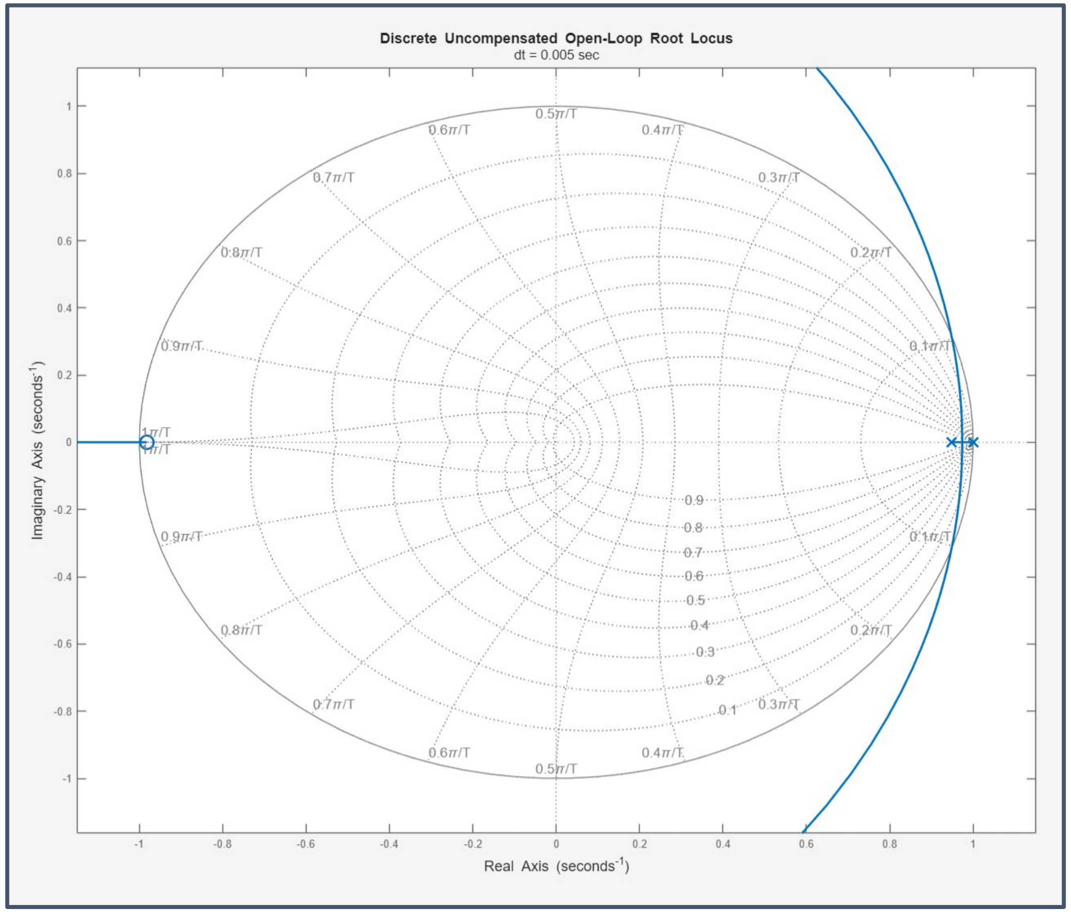
Synthesized System Model



Free Model

- Ignores ICs and Brake





Hardware Tuning

- Most success with proportional control

Done in prod_playground.ino

DT [ms]:	Angle Ref:	B_E0:	B_E1:	B_E2:	B_U1:	B_U2:	PWM Ramp:	Ramp up time [ms]:	Max Air Time [ms]	Worked:	Behavior:	Notes:	Test #
50	-PI	10	0	0	0	0	160	900	550	☐	Did a flip then held a nose dive		
10	-PI	10	0	0	0	0	160	900	550	☐	Overshot (to full flip) but did try to reverse		
10	-PI	5	0	0	0	0	160	900	550	☐	Overshot (full flip) - basially same as previous		
10	-PI	1	0	0	0	0	160	900	550	☐	Switched at proper orientation, braking power was too much		
5	-PI	0.5	0	0	0	0	160	900	550	☐	Basically same as above, but too slow		
5	N/A	0	0	0	0	0	160	900	550	☑	Open loop response, running motor is air --> rotated backwards		
5	N/A	0	0	0	0	0	160	900	550	☑	Open loop response, turning motor off once in air --> rotates forward onto back		
5	-PI	30	0	0	0	0	160	900	550	☐	Overshot, landed quite well though		
5	-2PI	30	0	0	0	0	160	900	550	☐	Flip and a half		
5	-2PI (+ PI/2)	30	0	0	0	0	160	900	550	☑	Flipped and landed, some overshoot		
5	-2PI (+ PI/2)	10	0	0	0	0	160	900	550	☐	Double flip, but questions of code		
5	-2PI (+ PI/2)	30	0	0	0	0	160	900	550	☑	See two above		
5	-PI (+ PI/2)	30	0	0	0	0	160	900	550	☑	Got to orientation, held (sightly overshot other way)		
5	-PI (+ PI/2)	10	0	0	0	0	160	900	550	☑	Held upside down, perfect		
5	PI/2 (+ PI/2)	10	0	0	0	0	160	900	550	☐	Backflip, overshot by PI/2		
5	PI/2	10	0	0	0	0	160	900	550	☐	Steady state error too high, no overshoot though		
5	PI/2	20	0	0	0	0	160	900	550	☐	High goal, then overshot on fix		
5	PI/2	15	0	0	0	0	160	900	550	☐	Hit goal, less oscillation		
5	PI/2	30	0	0	0	0	160	900	550	☐	Too much braking correction		
5	0	10	0	0	0	0	120	500	550	☐	Brake too powerful		
5	0	1	0	0	0	0	120	500	550	☐	Lame		
5	0	5	0	0	0	0	120	500	550	☐	Nose dive		
5	-2PI	524	-471.6	0	0.3	0	160	1000	550	☐			
5	-2PI	20	-17.4	0	0.6	0	160	1000	550	☐	Overshoot of pi/2		
5	-2PI	15	-13.05	0	0.6	0	160	1000	550	☐	Raif says: "not great"		
5	-2PI	22	-19.8	0	0.2	0	160	1000	550	☐			
5	0	22	-19.8	0	0.2	0	160	1000	550	☐	Overshoot		
5	0	22	-19.8	0	0.2	0	160	1000	550	☐		Now we give it an initial error and input	
5	-PI (+ PI/2)	10	0	0	0	0	160	900	550	☐	Works well, but unstable	Now IMU before	
5	-PI	10	0	0	0	0	160	900	550	☐	Bad	Now IMU before	
5	PI/2	15	0	0	0	0	160	900	550	☐	Overshoot of pi/2	Now IMU before	
5	-2PI	22	-19.8	0	0.2	0	160	900	550	☐	Slightly too much overshoot	Now IMU before	
5	-0	22	-19.8	0	0.2	0	160	900	550	☐	Slightly too much overshoot	Now IMU before	
5	-PI	10	0	0	0	0	160	900	550	☐			
5	-PI + 2	10	0	0	0	0	160	900	550	☐			
5	-2PI + (PI/2)	10	0	0	0	0	160	900	550	☐	Double flip(?)		
To Demo:													
5	-PI + 2	10	0	0	0	0	160	900	550	☑	Goal: Nose-dive, complete		#1
Code: flip_and_land													flip_and_land
5	PI	10	0	0	0	0	160	900	550	☑	Goal: back flip		#2

Documentation of design decisions

Mechanical Requirements

Technical Requirement	*MoSCoW*	*Method*	*Metric/Units*	*Criteria*	*Justification*	*Accomplished?*
Moment of inertia (car)	S	CAD modeling	$kg\ m^2$	**$I_{xx} < I_{yy}$ & I_{zz}** or $I_{xx} > I_{yy}$ & I_{zz}	Minimize I_{xx} to reduce control effort & avoid intermediate-axis instability.	Yes
Moment of inertia (wheels)	M	CAD modeling	$kg\ m^2$	$I_{xx} \cong 0.00045$	Sufficiently large $I_{xx,\ wheel}$ reduces required $\Delta\omega_{wheel}$ to achieve a given $\Delta L_{chassis}$ via conservation of angular momentum.	Yes
Motor torque capability	M	Motor curve analysis	Nm	T > 0.155 Nm	According to simulation, ~0.155 Nm torque max required to produce desired axial acceleration	Yes
Unit test mounting point	M	CAD modeling	mm	Within 1mm of COM	Unit test mounting point must be near COM in order to accurately model robot rotation	Close

Electrical Requirements

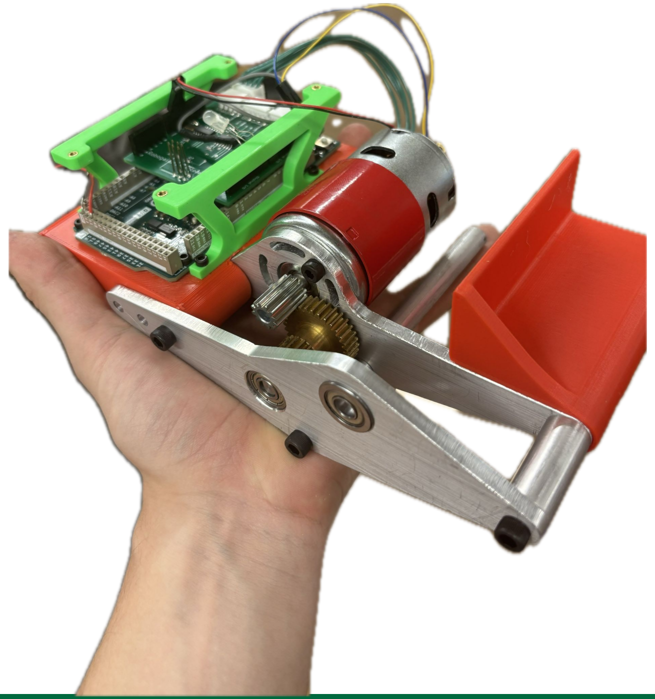
Technical Requirement	*MoSCoW*	*Method*	*Metric/Units*	*Criteria*	*Justification*	*Accomplished?*
Peak Current	M	Ammeter through Motor Controller	Amps	~20A cont. 30A peak	Necessary to deliver simulated torque, subject to motor controller	Cont: Yes Peak: Exceeded
Distance Accuracy	S	Serial print along test positions (ruler)	Meters	+/- 0.5 cm	Need for general state changes, but not pinpoint accuracy (on ground, not distance to ground)	Yes
Orientation Accuracy	S	Serial print along test positions (protractor)	Radians	+/- 0.125 rad	Control does not care too much about steady-state error regardless. Goal impact being off is still upright	Yes
Motor Speed Accuracy	M	High speed camera and Serial print	Percentage	+/-5%	Need to have accurate approximation for torque, max sim = 6000 rpm	Yes
Time of Flight I2C Communication	C	Serial Prints of Variables	ms	< 25ms	Straight serial takes time - we do not have to sample Time of Flight every cycle	Yes

Key Takeaways

1. Intensive up-front mechanical analysis for component selection was imperative

2. Frontloading development of a (mostly) comprehensive CAD model was worthwhile

3. Control is easier in simulation



THANK YOU!

Robot Demo

THANK YOU!

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