ECE 482 Project Report
Weight Shifter Design Project
Department of Electrical Engineering

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Group 4

Abstract:

In order for an aircraft to remain stable while maneuvering it must be able to shift its centre of gravity, to accomodate for the changing mass of fuel. The purpose of this project is to design a weight shifter system for a small aircraft. The system must be able to move a 12 kg mass to any location on a two meter track within two seconds, in extremis, and furthermore maintain sub-millimeter positional accuracy. A cart and roller system has already been designed. Therefore, this report provides a design for the system, primarily in its electrical aspects, including motor, brake, feedback system, wiring, battery and the overall cost of implementation.

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1. Introduction

The purpose of this report is to design a weight shifter for a small aircraft. A weight of 12 kilograms must be moved over a rail of 2 meters, on a cart. The system should track and control the precise position of the weight on the track. The weight must also be able to move across the full length of the track in no more than 2 seconds.

The cart will be propelled on a set of belts, connected to pulleys on both sides of the cart. The two pulleys should be mechanically coupled to prevent twist, undo friction, or derailment of the cart. All components on the cart must fit within its dimensions, without interfering with the cutout section.

Any motors(s) selected must supply enough torque to accelerate the mass, and be rated for a high enough speed to support the worst case movement - the aforementioned 2 meter length of the rail in 2 seconds, from a stationary position at both ends.

The acceleration of the cart can be calculated by dividing the system mass and pulley radius by the motor torque. The maximum speed the motor can accelerate to by finding the linear speed from the motor rated speed in rpm. To achieve positional control, some form of position feedback must be used, such as absolute or incremental rotary encoders, a draw cable encoder, a linear encoder, a stepper motor.

The feedback system may be implemented for CANbus communication between the plane’s computer and the weight shifter, without elaboration.

In the case of power failure, the weight shifter must maintain position, through the use of a failsafe brake.

2. Discussion

2.1 Motor

To directly power the pulleys, motor(s) on the cart must fit within an 88x50x55mm volume, at the back of tray,

To calculate the required torque and speed we use the following equations:

$$pulley\ radius\ r\ =\ Circumference/2\pi\ = 70/2\ =\ 11.1408mm$$

$$F\ =\ ma \qquad \text{(N)}$$

$$T\ =\ r * F \qquad \text{(Nm)}$$

$$N\ =\ \frac{60at}{2\pi r} \qquad \text{(rpm)}$$

$$a = \frac{v}{t}\ =\ \frac{v*r}{t}\ =\ (2\pi N/60)\ * r/t \qquad \text{(N/kg)}$$

In order for the motor to reach a maximum speed of 2m/s the rated motor speed of 1714RPM or higher and in order for the motor to accelerate the cart to accelerate through the track in two seconds, the rated torque for the motor must be greater than 0.267 Nm. However, more torque will be required to account for friction and for the motor to be able to brake so the speed is zero when it completes the track.Therefore, single motors with rated torque of 0.3 Nm and above were considered, primarily..

The following motors are the one that fit with our above criterias.

With the above design, the customer can also choose to swap out the motor for a change in system speed, weight and cost.

Motor	Length xWidth xHeight (mm)	Rated Torque (Nm)	Rated Speed (RPM)	Rated Power (W)	Encoder	Acceleration (m/s^2)	Maximum Speed (m/s)	Weight (Kg)	Price (CAD)
QBL4208-61-04-013	81x42x42	0.185	4000	52.4	Need Encoder	1.38	4.67	0.45	200
BLDC 40S40A	61x40x40	0.18	2550	48	Need Encoder	1.35	2.97	0.58	498
RPX40-250 (without encoder)	40x40x40	0.25	4075	81.6	Need Encoder	1.87	4.75	0.24	330
RPX40-250 (with encoder)	52x40x40	0.250	4075	81.6	Optical Encoder with 2048 lines	1.87	4.75	0.37	502.77
RPX40-325 (without encoder)	60x40x40	0.325	2950	100.8	Need Encoder	2.43	3.44	0.37	400

Figure 1. Table Comparison Between Motor That Meets the Minimum Requirement [1][2][3][4]

On top of moving the cart, the system should be able to hold it in place whenever there is no power. We achieved this by using a safety brake.

2.2 Feedback and speed control

After finding a good motor for our application, the next step is to implement an encoder to enable feedback communication between the controller and the weight shifter. A rotary encoder is perfect for this application since they are precise, compact, and can be included without special design considerations. Within the code for controlling the system, the programmer can set up a position matrix and keep track of the motor position by looking at how many pulses the motor has when moving toward a direction.

For the speed control of the system, we selected a chopper control board, because the operation of the motor will primarily be in two modes: Full power, and very low power. In no case is over-voltage required, so other switched mode power supplies are unnecessary.

Since traversing the full length of the track will take many more than one rotation of the pulley, an incremental encoder should be used. The method to find the accuracy of the motor is as follows:

$accuracy = \frac{C}{encoder\ dimension(ppr)}$. With C being the circumference of the pulley.

2.3 Wiring

The next part of the project is wiring. The cart should be wired to the power supply, and the controller.. Since the cart is a moving part, the wiring of the system must be moveable, and have the slack required to reach the full extent of the cart's movement.

Our solution to the cable problem is to have an overhead cable carrier. The cable carrier is 13x15mm, and has a turning radius of 71mm, including the height of the duct. The carrier should lay on a chamfered ledge on the long side, to support it against sagging.

The encoder, motor, and brake cables are carried in this ducting, and the motor cables must be 10AWG (2.6mm dia) to support 18A in stranded cable, based on the peak power requirements for the motor.

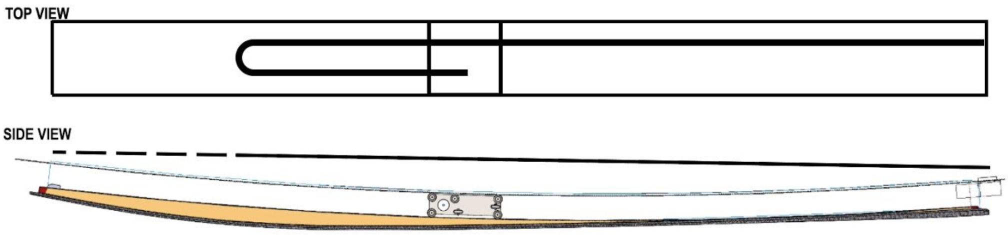

Figure 2: Weight Shifter Cable Carrier Layout

2.4 Power Consumption

Aircraft batteries generally run at 24V, and this voltage rating will be used for this. To specify a battery for this system, we must determine two more quantities: peak current, and total power consumed per flight. A safety margin of 50% will be used.

The flight duration is only around 1 hour and the system is only active for 15 minutes, only moving in very small increments in normal use.

The rated power when the motor is running at maximum torque/acceleration, and the power consumed by releasing the brakes, will be used as the basis for calculating the required capacity.

$$Rated\ Capacity\ =\ \frac{Power\ Consumed}{Rated\ Voltage} * \frac{Active\ minutes\ per\ hour}{60} = \frac{Power\ Consumed}{24V} * \frac{15}{60}$$

2.5 Metal Casting For Weight

The cart by itself is only 1Kg and we need to increase its weight to 12 Kg including the motors and brakes, with the motors occupying the back of the cart and the cut out area being reserved for the landing gear of the aircraft. Because the cart is so small, a very dense ballast must be used, in this case, cast lead, which weighs 11.4g/cm3.

Any region of the cart which is not taken by the components is eligible for ballast, for ease of manufacturing, we will attempt to limit this based on footprint, and not cast in irregular spaces.

The total weight of the metal cast should be:

$m_{metal} = 11kg - Component_{mass}$

And the volume available is:

$V_{available\ space} = 1201.6\ cm^3 - Component_{volume}$

Thus a solution is viable if:

$m_{metal} < V_{available\ space} * 11.35g/cm^3$

Another option is to use Tungsten-carbide drill scrap embedded in the lead, to increase density. Tungsten-carbide drill scrap has a density of 15.6 g/cc. Using the equations above, and assuming a space filling constant of ~0.64 (random spherical packing) we get a new density of 14.07g/cc:

$m_{metal} < V_{available\ space} * 14.07g/cm^3$

3. Design

3.1 Proposed Design

We decided to go with the RPX40-325 motor[6] without a built in encoder. This motor has a rated torque of 0.325 Nm and rated speed of 2950 rpm.the motor can accelerate the 12kg mass at 2.43 m/s^2 to a maximum speed of 3.44 m/s.

This motor has dual shaft output, to couple directly to both pulleys. The 3720 incremental optical encoder[5] is a through hole, hollow shaft construction, which fits onto the 6mm shaft, and its stator can be screwed into the motor casing.

The encoder has a resolution of 1024 pulses per rotation which gives the accuracy of 0.0684mm. This accuracy is less than the built in encoder of the RPX40 motors, but both sufficiently accurate for purpose, and a necessary change, because the built in encoder option is a blinld hole, and would make coupling the pulleys much more complicated.

For safety braking, we attach a BXR-025-10LE on the shaft of the motor. BXR-025-10LE is a thin spring applied brake with a diameter of 32mm and a length of 14mm. This means the brake can be mounted onto the shaft of the motor, within the constraints of the cart size, without taking up excessive space needed for ballast. This safety brake has a braking torque of 0.32 Nm. This should prevent the cart from moving due to any back and forth motion when the power is lost.

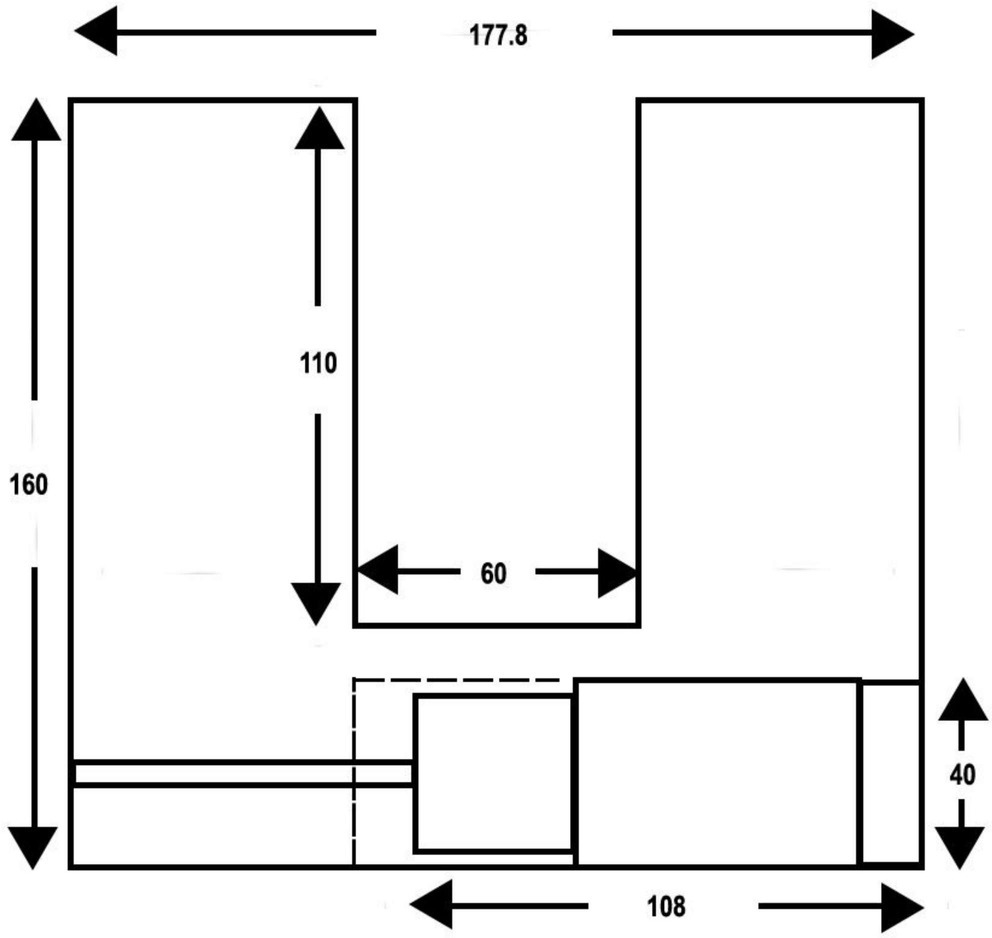

Figure 3: Cart Dimension and Location of Motor

For speed control of the system, we go with a chopper control using the motion mind 3 board, which is designed for 24V.[7]

A block diagram for the communications and power follows:

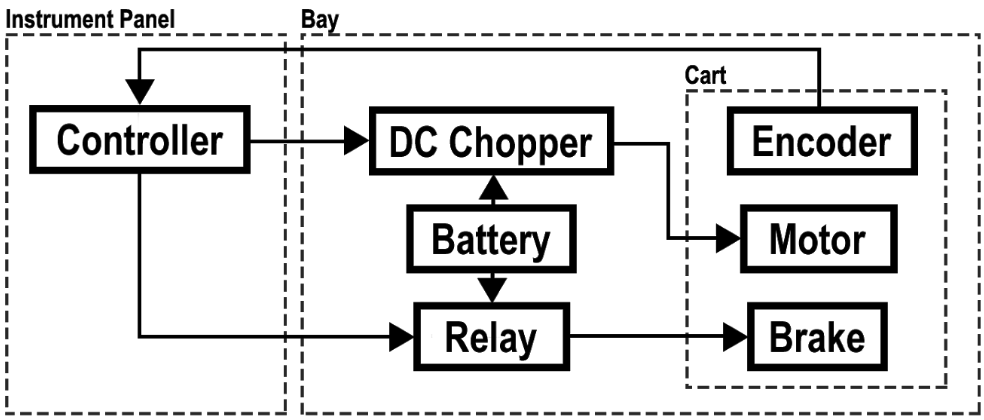

Figure 4: Weight Shifter Control Block Diagram

The power required

	Power
RPX40-325	100.8 W
BXR-025-10LE	16.5 W
Power Required (incl. safety factor)	176 W
Required rated current capacity(Ah)	1.83

Figure 5: Power Consumed by the System

Using the above number, we need a 24V battery with a current capacity of 1.83Ah to drive the system. We decided to go with the VICI Battery Razor Dirt Quad Battery for this project.[8] The battery has a voltage of 24V and a current capacity of 8 Ah. Alternatively we can power the system using the plane's electricity as the system is not very active and thus rarely consumes power.

To get the cart to the required mass, we decided to cast lead on the available volume. With our current design, we need an extra weight of around 10.45g from metal casting which can be achieved with 917 ml of lead.

Component	Weight(Kg)
RPX40-325	0.370
BXR-025-10LE	0.08
Kart	1
Encoder	0.1
Melted Lead Cast	10.45
Total	12

Figure 6: Weight of Every Component on The Kart

3.2 Total Weight and cost:

Total weight of the system :

Component	Weight(Kg)
RPX40-325	0.37
BXR-025-10LE	0.08
Cart	1
Encoder	0.1
Melted Lead Cast	10.45
Cable and Cable Carrier(Estimated)	1
Motion Mind 3	0.0454
VICI Battery Razor Dirt Quad Battery	5.9
Total Weight	18.5

Figure 7: Total Weight of the System

Total cost of the System:

Components	Price(CAD)
RPX40-325	400
BXR-025-10LE	50
Cable Tray	240
Motion Mind 3	75
3720 Encoder	100
8mm Shaft for coupling the motor	11.68
Lead Cost	17
Cable Carrier	97
Cable Cost(approximation)	10
VICI Battery Razor Dirt Quad Battery	80.33
Total	1081.01

Figure 8: Total Cost of the System

3.3 Alternative Design:

Alternatively, we can couple two motors with less torque instead of one, the two other motors in the RPX series RPX 40-125, RPX 40-250 and the BLDC 40S40A will work for this design. This will increase the acceleration of the cart while .

For our alternative design we decided to go with 2 x RPX 40-250 with a built in encoder. The built in encoder has a resolution of 2048, thus having twice the accuracy of the incremental encoder 3720 which is 0.0342 mm. However, this value of accuracy is insignificant compared to the length of the track.

Assuming that the system are accelerating and decelerating with rated torque under no friction, here are their speed vs time characteristics when the cart moves 2 meters:

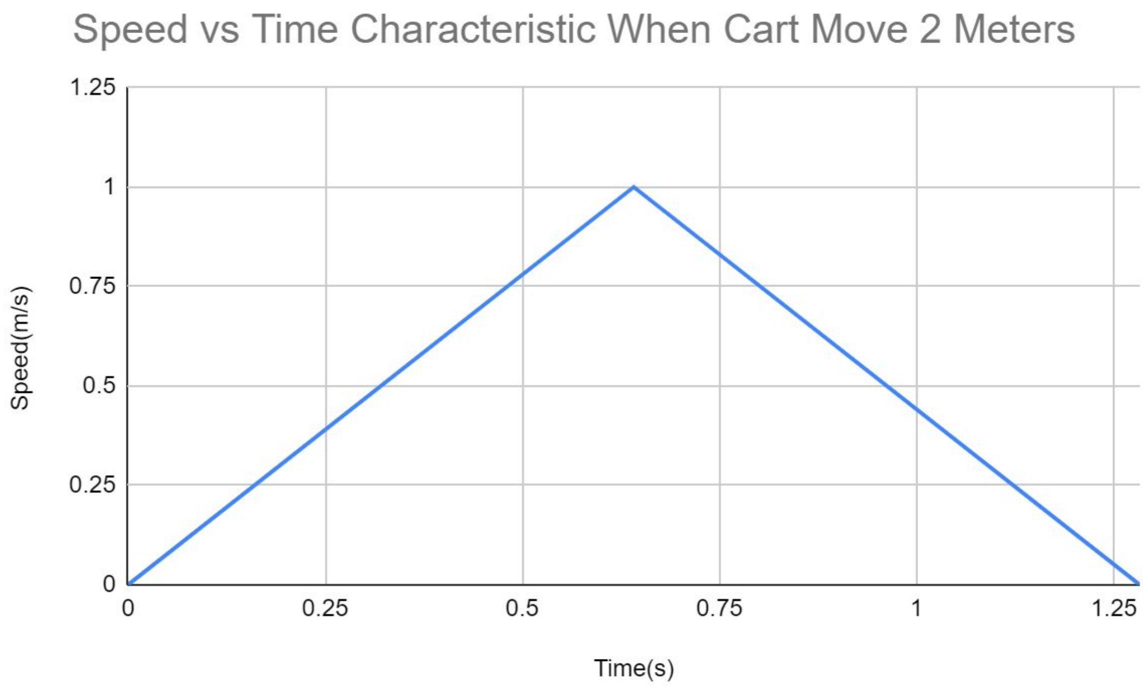

Figure 9a: Speed Time Characteristic When the Cart Moves 2 Meters Using the Proposed Design

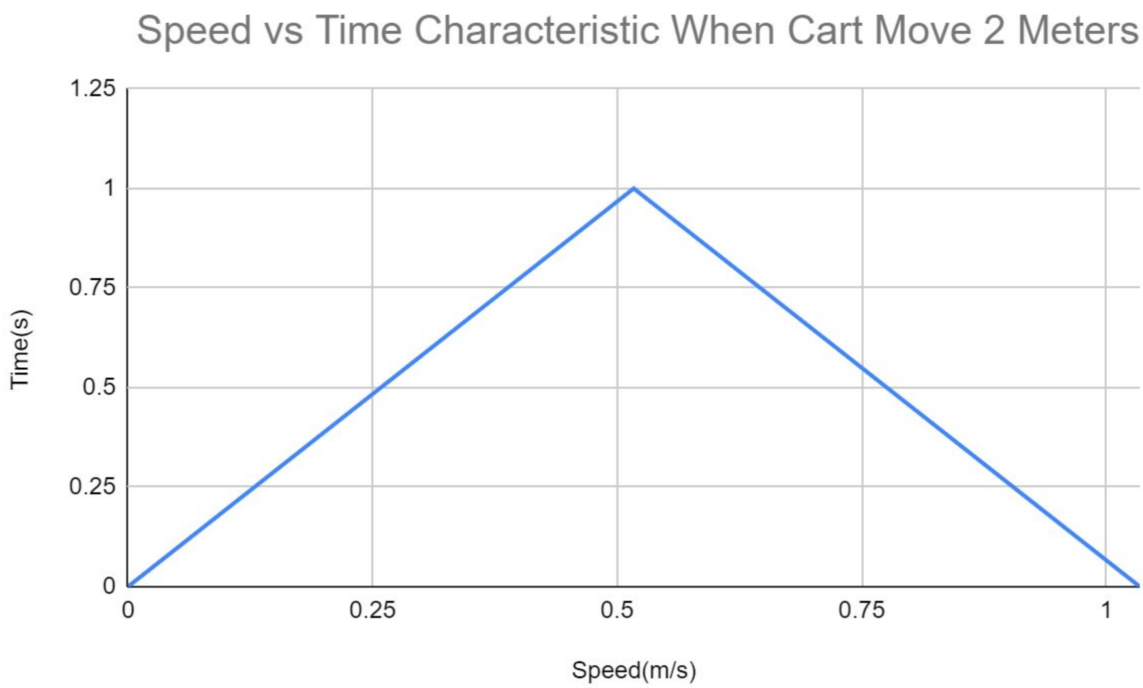

Figure 9b: Speed Time Characteristic When the Cart Moves 2 Meters Using the Alternative Design

As shown in the above figure, The proposed design can complete the track in 1.3

second, RPX40-250 can complete the track in 1.31 and the alternative design can complete the track in around 1 second. When accounting for friction, these two systems would still be more than enough.

When using this alternative design, on top of needing 2x motors, we also need 2x brakes(one for each motor) and we potentially need 2x the amount of cable. We would also have less volume on the cart to solve our weight problem. With the two motors occupying the backside of the cart, we only have 117.8x110x55 mm which is 712.69 ml.

The mass we need from the metal casting is $m = 11 -$0.48 - 0.16-1-0.1 = 10.26.

$$m_{metal} = 15.6V_{tungsten\ drill\ scrap} + 11.34V_{lead} = 10.26\ Kg$$

$$V_{metal} = V_{tungsten\ drill\ scrap} + V_{lead} = 721.69\ ml$$

With the above equations, get V(tungsten drill scrap) = 487.33ml and V(lead) = 234.36 ml.

Component	Weight(Kg)
2x RPX40-250	0.48
2x BXR-025-10LE	0.16
Kart	1
Encoder	0.1
Melted Lead Cast	4.398
Tungsten Carbide Scrap	7.602
Total	12

Figure 10: Weight of Every Component on The Kart(alternative design)

Here is the calculated total cost of this alternative system:

Components	Price(CAD)
2x RPX40-325	1005
2x BXR-025-10LE	100
Cable Tray	240
Motion Mind 3	75
8mm Shaft for coupling the motor	11.68
Lead Cost(487.33ml)	7.03
Tungsten Carbide Scrap(234.36ml)	0
Cable Carrier	97
Cable Cost(approximation)	10
VICI Battery Razor Dirt Quad Battery	80.33
Total	1626.04

Figure 13: Total Cost of the System(alternative design)

Since we are using the same cart weight as our proposed design, there should be little to no weight difference aside from an increase in the amount of wiring.

Here is a table that compares the 2 systems by looking at power usage, speed, price, total weight and accuracy.

Design	Cost(CAD)	Time needed to complete the track(s)	Rated Current Needed(Ah)	Accuracy(mm)	Total Weight(Kg)
Proposed	1081.01	1.31	1.83	0.0684	18.9
Alternative	1626.04	1	3.07	0.0342	19.9

Figure 14: Comparison Table Between The Proposed and Alternative Design

Our alternative design provides us with more speed and accuracy but it is 50.4% more expensive than the proposed design which already far exceeded the minimum acceleration needed to accelerate the mass. Furthermore this alternative design is a bit heavier and consumes more power compared to the proposed design.

4. Conclusion:

In conclusion, we base our final design on the RPX40-325 motor due to its high torque to be able to accelerate the mass all by itself. Our design includes an encoder and a shaft that couple the two pulleys.

To keep the cart in place, we implemented a BXR-025-10LEbrakes and the shafts of each motor. We use a motion mind 3 DC control board for speed control of the system. For our wiring, we lay our cable carrier on a chamfer ledge to prevent the cable from causing damage when the cart is moving back and forth. We estimate the total weight of our system to be 18.5 Kg and the total cost to be 1081.01 CAD.

We came up with an alternative design that can achieve more speed while having more accuracy than the proposed design but it is significantly and consumes more power.

5. Learning Outcome:

Learning out comes:

- This project helps us learn how to refine our internet searches, especially when it comes to filtering out components that we needed for a specific problem.
- This project helps us understand a real world world application of a drive system, in this case it is to maintain the center gravity of an airplane.
- This project helps us learn how to apply physical concepts that we learn in school such as acceleration, torque, angular velocity,etc when looking through drive machines specification.
- This Project introduces us to the CAN BUS protocol and its effectiveness in transportation systems like cars and airplanes.

Challenge:

- One of the challenges we encountered was figuring out how to wire a moving motor to its battery, microcontroller, the airplane control system without the cable causing trouble.
- It was difficult to find a small enough safety brake for this application.
- Figuring out the math behind specification data provided by devices data sheet.
- Understanding the scope of the project.

6. Reference:

(1) https://www.electrocraft.com/pdf.php?pdf=files/downloads/Datasheets/bldc/RPX40-DataSheet-US.pdf
(2) https://www.digikey.ca/product-detail/en/nmb-technologies-corporation/BLDC40S40A/BLDC40S40A-ND/5967622
(3) https://www.digikey.ca/product-detail/en/trinamic-motion-control-gmbh/QBL4208-61-04-013/1460-1087-ND/4843438
(4) https://www.radwell.ca/en-CA/Buy/ELECTRO%20CRAFT/ELECTRO%20CRAFT/RPX40-325V24-100-X
(5) https://www.kuebler.com/en/products/measurement/encoders/product-finder/product-details/3720?fbclid=IwAR2bE2drC_RGek5ovGjD3drKWCQCuvnStvj0WD79d0XrxoqIq5ez8bBrZ1E
(6) https://www.mikipulley.co.jp/EN/Products/ElectoromagneticClutchesAndBrakes/SpringActuatedTypeBrakes/BXR-LE/index.html
(7) http://www.solutions-cubed.com/products-page/motor-controller/motion-mind-3/
(8) https://www.amazon.com/Razor-Dirt-Quad-Battery-Replacement/dp/B00C6CK9SS/ref=sr_1_1?dchild=1&keywords=24v+battery&qid=1584963172&sr=8-1
(9) https://www.mcmaster.com/wire-routers?fbclid=IwAR01R5TJ-GPLQ_2P_8iAGSrhLnr7DttggPz4k1pn_BdmpXbINB9zhJqLdqg
(10) https://www.mcmaster.com/wire-trays

7. Gantt Chart:

Airplane Weight Shifter

Group Number: 4
Minh Dai Tran, Connor Wiebe

Project Start: Fri, 2-28-2020

Display Week: 1

TASK	ASSIGNED TO	PROGRESS	START	END
Research				
Draft preliminary dimensions	Connor	0%	2-28-20	2-28-20
Calculate minimum motor specs	Connor	0%	2-28-20	2-29-20
Research available motors	Connor + Minh	0%	3-1-20	3-6-20
Braking modes	Connor + Minh	0%	3-4-20	3-5-20
Power supply (Regulator/Invertor/Modulator)	Minh	0%	3-6-20	3-8-20
Preliminary feedback system	Minh	0%	3-7-20	3-8-20
Design				
Preliminary BOMs (weight/cost)	Minh	0%	3-8-20	3-9-20
Component layouts	Minh	0%	3-10-20	3-13-20
Wiring diagrams	Connor	0%	3-10-20	3-12-20
Communications diagram	Connor	0%	3-12-20	3-13-20
Model feedback systems	Minh	0%	3-13-20	3-14-20
Analysis				
Analyze systems and select a preferred system	Connor + Minh	0%	3-15-20	3-17-20
Final drawings	Connor	0%	3-18-20	3-20-20
Final report	Connor + Minh	0%	3-16-20	3-22-20

Unfortunately, this schedule does not describe the real efforts of the team.
Rather, the research for the motor was done in the allotted time, and the wiring system was determined early on, but feedback was done only very late, and review in the final days revealed our initial design was invalid, and required changes.