Automatic Seeding Machine

Luis Barroso
Benjamin Bogart
Rodrigo Gonzalez
Ethan Liu

Overview

Current Situation

Plant based pharmaceutical labs use employees to place seeds into trays that are placed onto carts and then used later for various reasons. This process currently takes 10 minutes per tray using one seeding employee.

Need

This process is long and expensive; it can be more efficient using an automated machine.

Goals

To create an automated machine that can seed trays faster than the current process.

Seeder should be quick, precise and low maintenance .

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Customer Requirements

1. Retrieve a seeding tray from input cart
   Tray dimensions: 120cm x 60cm x5cm
2. Place 200 seeds on tray
   Seeds: 0.1cm sphere. Pitch: 5cm
3. Perform operation on 10 trays at a time
4. Cycle time per tray: 90 seconds
5. Stack all 10 trays on output cart

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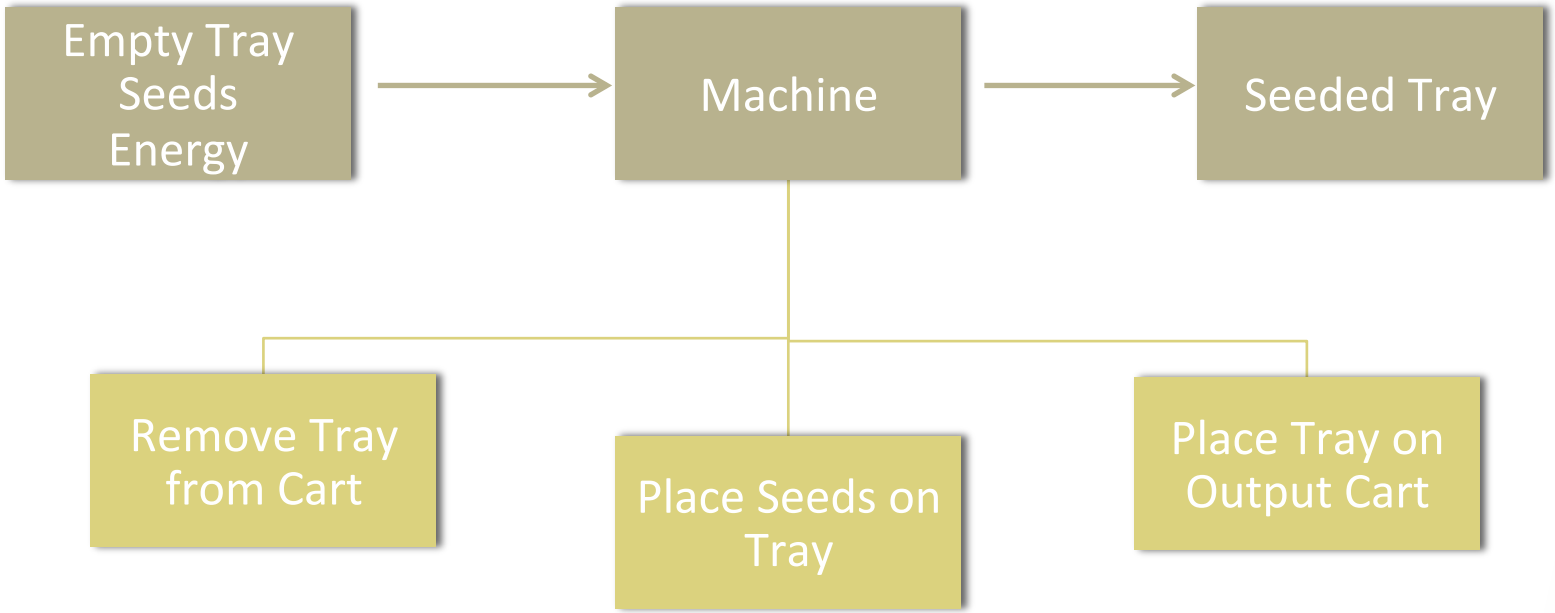
Refined Customer Requirements

- Storing:
  2 Carts (input, output)
- Seeding:
  Reliability of 95% when placing seed, variable longitudinal pitch
- Financials:
  Minimize cost and space, reduce personnel
  Maximize efficiency with 90 s per tray

Functional Decomposition



Machine Functional Requirements

- Hold trays in a 10-slot cart
- Remove trays
- Displace tray to seeding station
- Dispense seeds
- Load tray on output cart

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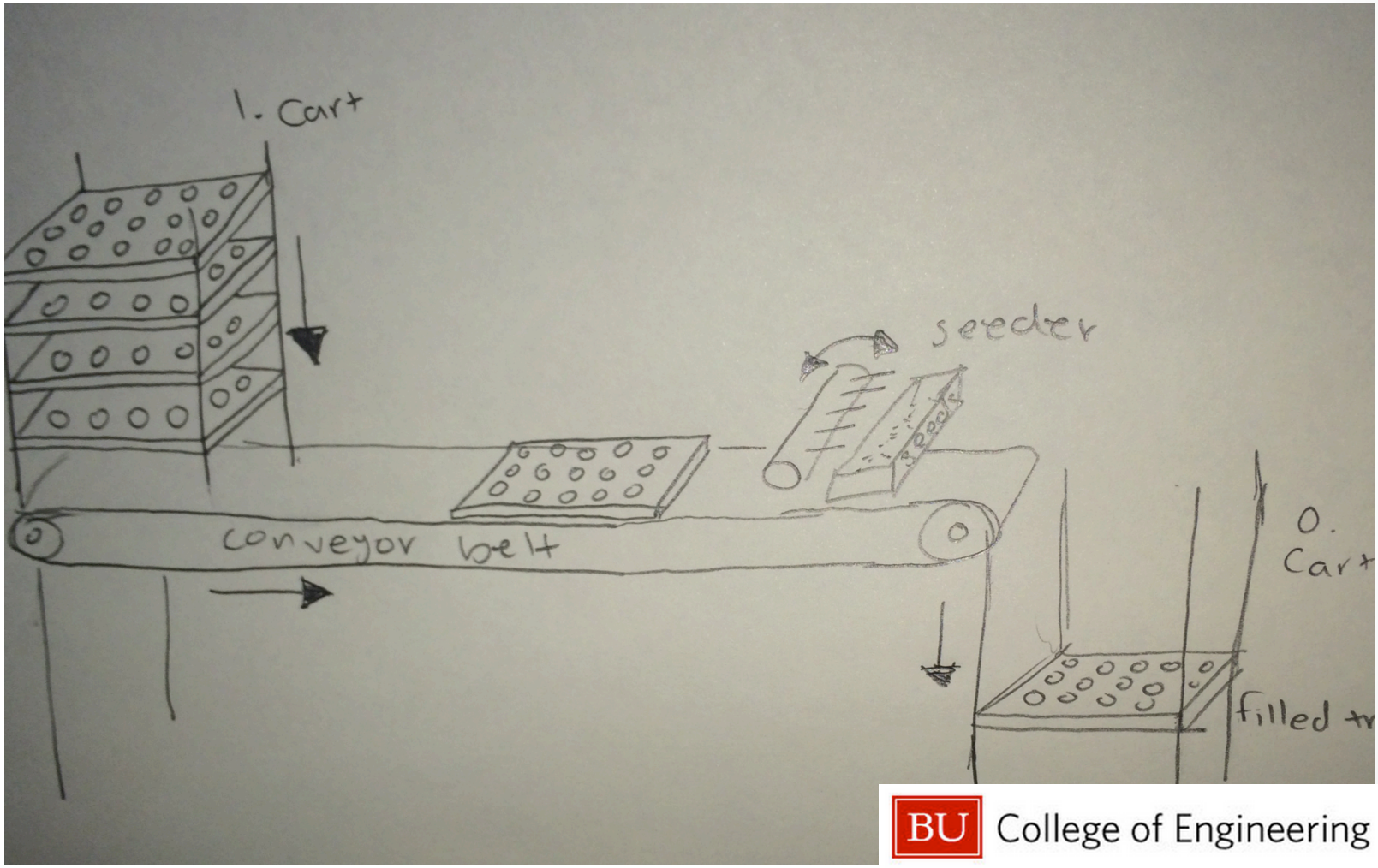
Preliminary Ideas and Sketches



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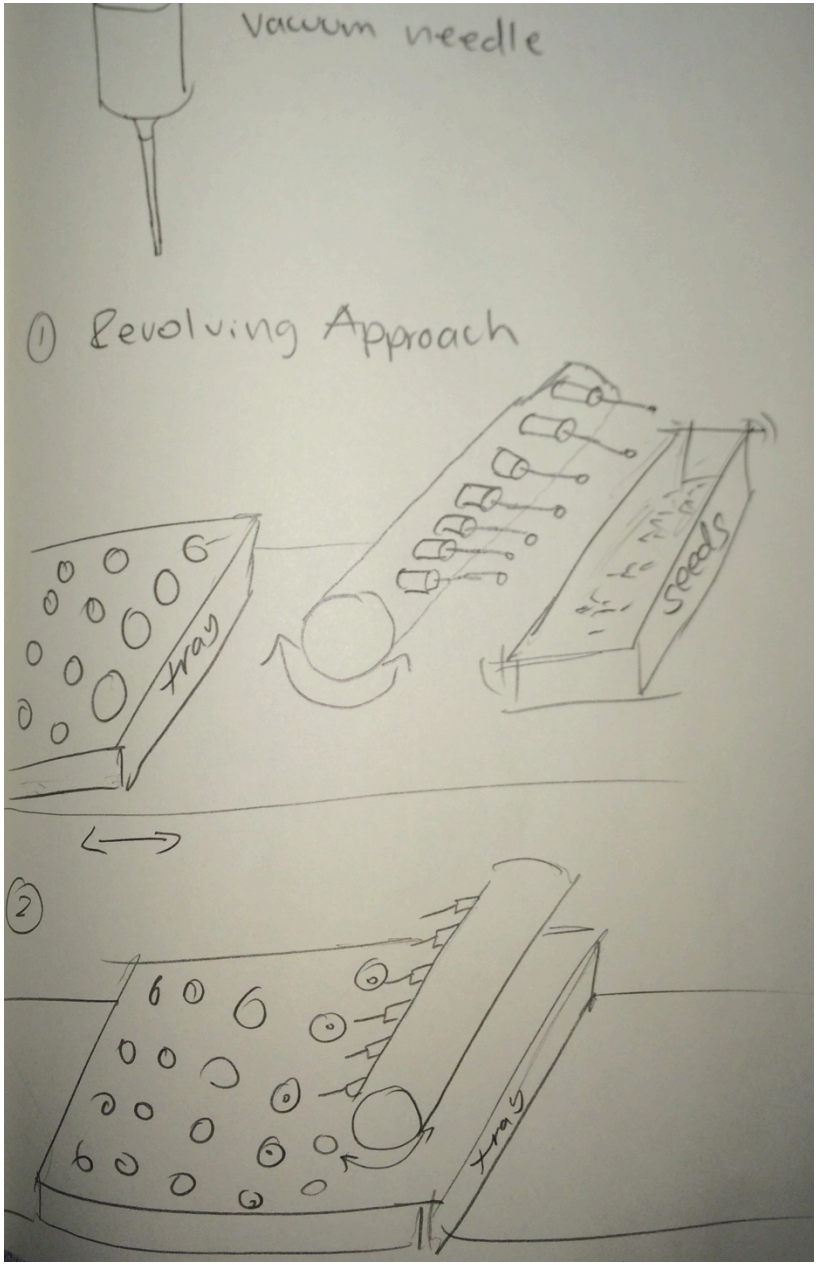
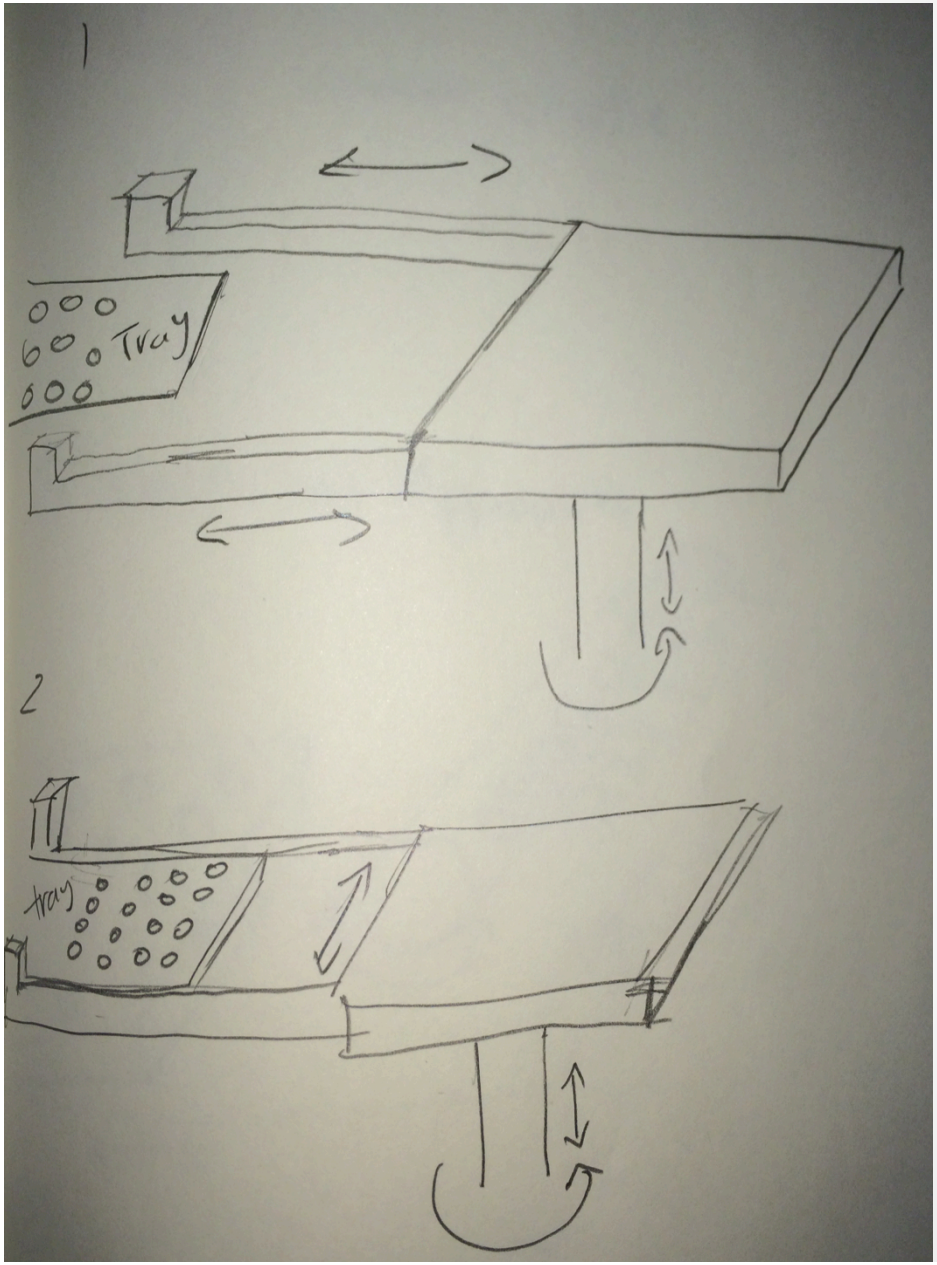
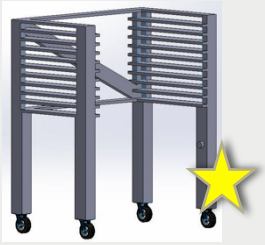
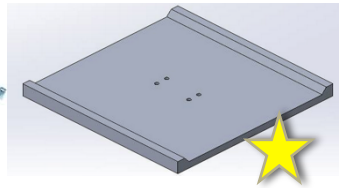
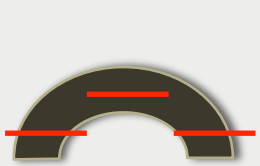
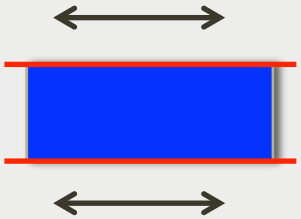
Preliminary Ideas and Sketches





Functions	Solutions/means				
Storing Tray	Vertical Cart 	Horizontal Cart 	Hollow Cart 		
Handling Tray	Arms grab tray from underneath 	Side Pressure from arms slides 	Platform Holds Tray 	Cart with sliding arms 	
Transporting Tray	Conveyor Belt 	Platform Linear Drives 	Half Ferris Wheel 	Sliding arms 	Robot arms 
Placing Seeds	Vacuum system 	Dispenser system	Push through resistive opening	Gravity release mechanism (latch)	
Linear Movement	Linear Drive 	Pistons 	Linear Lifting 	Scissor Lift 	

Holding Trays

Criteria	Weight	Vertical Cart	Horizontal Cart	Hollowed Vertical Cart with rails
Cycle time	4	0	-1	0
Cost	1	0	0	+1
Maintainability	2	0	-1	+1
Weight	1	0	0	-1
Space	1	0	0	-1
Complexity	3	0	0	0
Total		0	-6	+1

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Retrieving and Delivering Trays

Criteria	Weight	Push system	Arm system	Linear drive systems
Cycle time	4	0	-1	0
Cost	1	0	-1	+1
Maintainability	2	0	0	+1
Weight	1	0	0	-1
Space	1	0	0	-1
Complexity	3	0	-1	0
Total		0	-8	+1

Seeding Mechanism

Criteria	Weight	One row seeder	Entire tray loader
Cycle time	4	0	+1
Cost	1	0	-1
Maintainability	2	0	0
Weight	1	0	1
Space	1	0	-1
Complexity	3	0	0
Total		0	+1

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Ground Horizontal Movement

Criteria	Weight	Rack and pinion	Belt	Ball Screw
Cycle time	4	0	0	+1
Cost	1	0	+1	-1
Maintainability	2	0	-1	0
Weight	1	0	+1	-1
Space	1	0	0	-1
Complexity	3	0	0	0
Total		0	0	+1

Linear Drive for Seeder

Criteria	Weight	Rack and pinion	Belt	Ball Screw
Cycle time	4	0	0	+1
Cost	1	0	+1	-1
Maintainability	2	0	-1	0
Weight	1	0	+1	-1
Space	1	0	0	-1
Complexity	3	0	0	0
Total		0	0	+1

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Vertical Actuator for Seeder

Criteria	Weight	Rack and pinion	Belt	Piston (pneumatic cylinder)	Ball Screw
Max load	3	0	+1	+1	-1
Max stroke	2	0	0	+1	0
Precision	2	0	-1	+1	-1
Acceleration	1	0	-1	+1	-1
Max velocity	1	0	0	-1	0
Cost	1	0	+1	0	-1
Maintainability	2	0	0	+1	0
Weight	1	0	0	0	-1
Space	1	0	+1	+1	-1
Complexity	3	0	0	+1	0
Total		0	0	+13	+1

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Tray Holder Vertical Movement

Criteria	Weight	Rack and pinion	Belt	Ball Screw Linear Lift
Max load	4	0	-1	+1
Max stroke	3	0	0	0
Precision	1	0	-1	-1
Acceleration	2	0	0	0
Max velocity	1	0	0	-1
Weight	1	0	+1	-1
Complexity	3	0	0	0
Total		0	-4	+1

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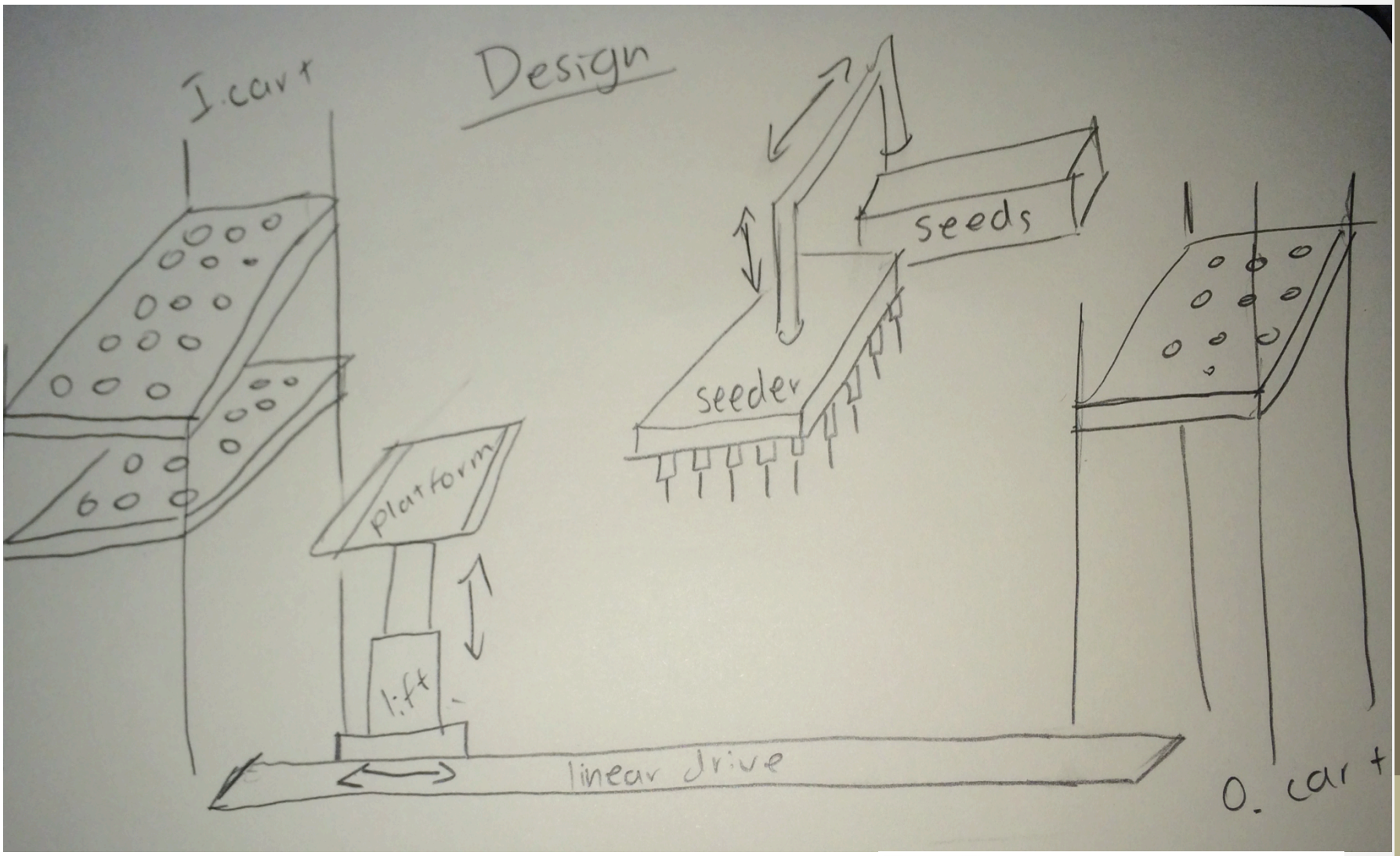
Final Design Sketch



Finalized Idea

Functions:

1. Hold trays in a 10-slot cart
2. Remove trays
3. Displace tray to seeding station
4. Dispense seeds
5. Load tray on output cart

Means:

- Hollow cart with rails for input and output cart
- Linear lifting unit on horizontal linear ball screw lifts tray from underneath and places into seeding position
- Linear drive and piston move to bring seeder to pick up position and then to drop off position
- Linear lift comes in from above into the output cart and drops to let go of tray.

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PDR

Time Breakdown

Process 1: Tray Movement

Time	Process
8	Lifting Column goes up to just above tray location
9.5	Horizontal Drive moves tray out of cart
8	Lifting Column brings tray down
9.5	Horizontal drive moves tray to seeding location
9.5	Horizontal Drive moves tray next to output cart
8	Lifting Column takes tray up to output location
9.5	Horizontal drive moves tray into output cart
8	Lifting Column comes down
20	Horizontal drive brings lifting column back to initial position

Total Time Allotted: 90s

Total Time: 90s

Process 2: Seeder Movement

Time	Process
4	Pneumatic cylinder brings seed needles down (into bucket)
4	Pneumatic cylinder brings seed needles up
22	Seed needle drive brings seeds to seeding location
4	Pneumatic cylinder brings seed needles down (seeding)
4	Pneumatic cylinder brings seed needles up
22	Seed needle drive brings seeds to seed bucket

Total Time: 60s

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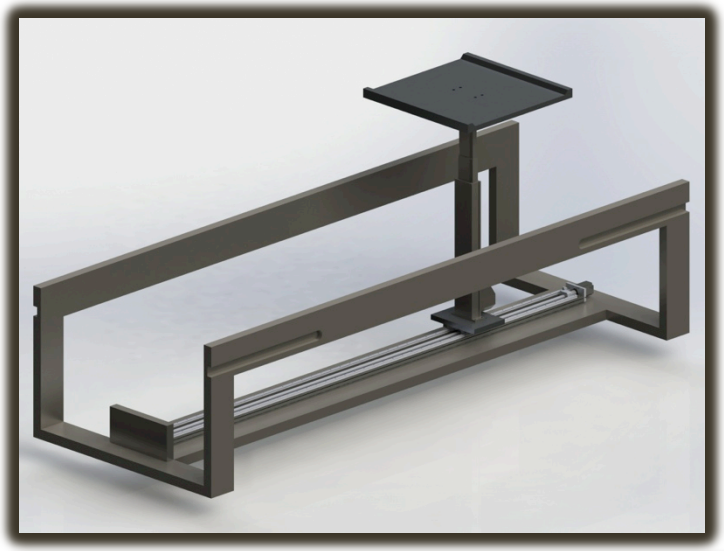
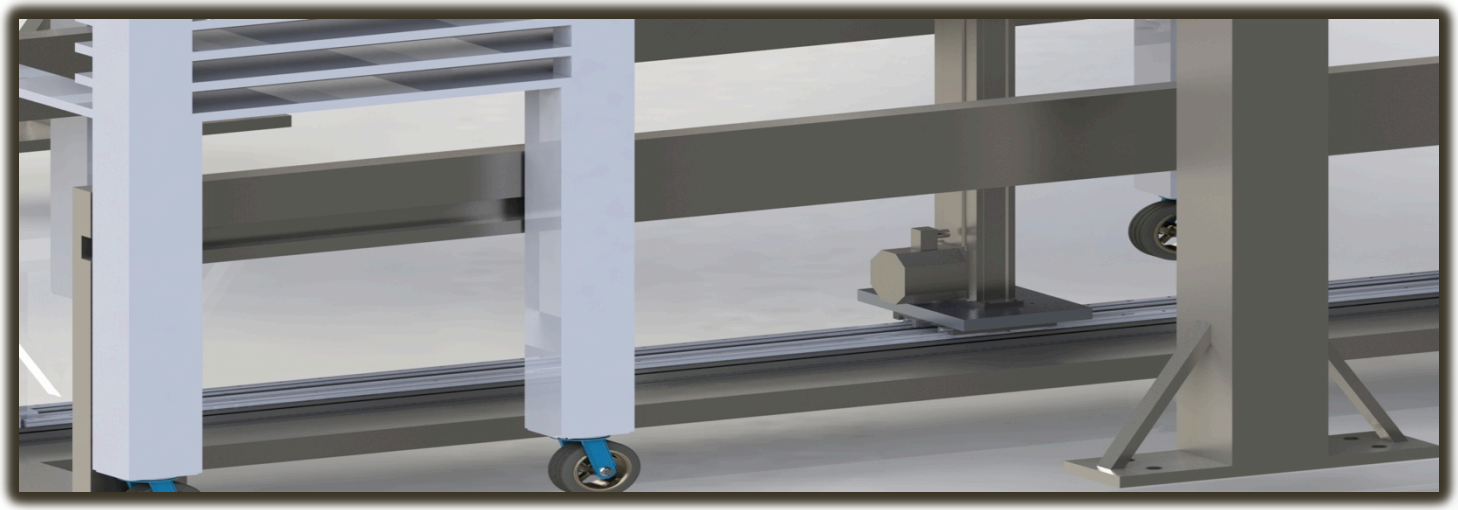
Lower Half of Seeding Apparatus

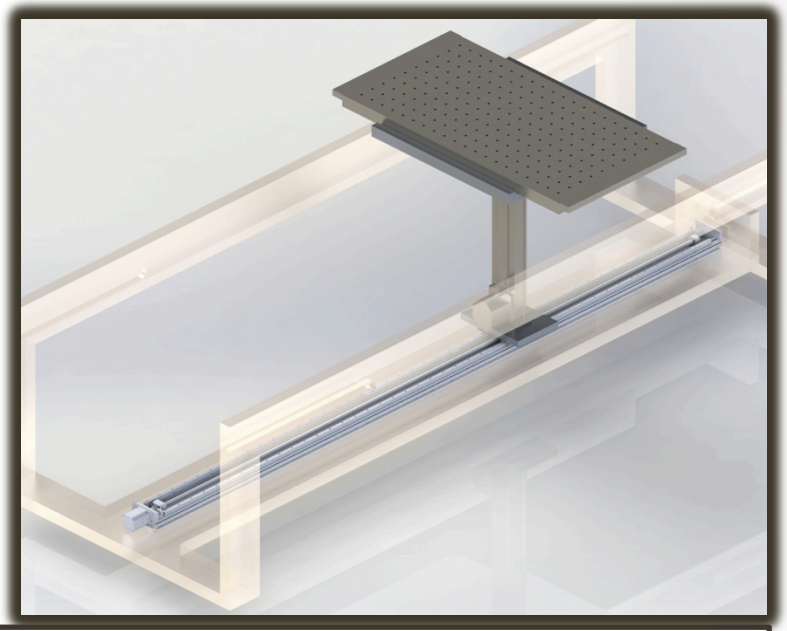


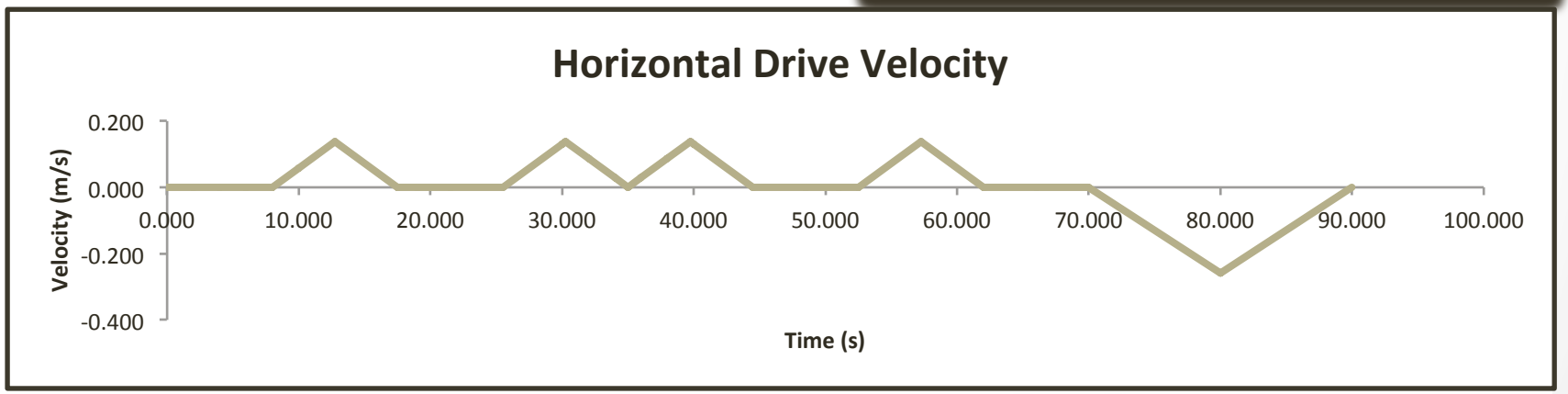
- Lower linear drive controlling lateral position of tray holder
- Frame has custom guide paths for carts to dock
- Linear lifting unit mounted to platform on the lower linear drive



Horizontal Linear Drive

- Linear drive responsible for carrying a platform, linear lifting unit, tray holder, and a single tray of seed/soil





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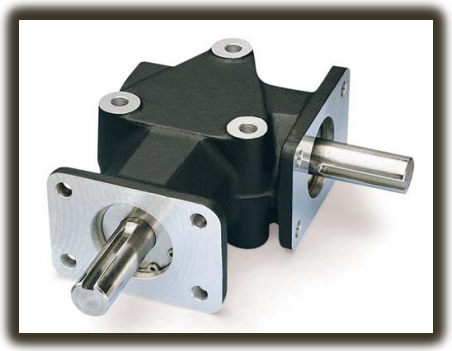
Lifting Column Unit

- Implementation of a telescopic linear lifting unit
- Design based off of the Rose-Kreiger Lambda Cologne
- Motor is AeroTech BM200
- Internal gearbox to transmit torque 90 degrees upwards
- Gearbox model: zero-max.com Model # C208806



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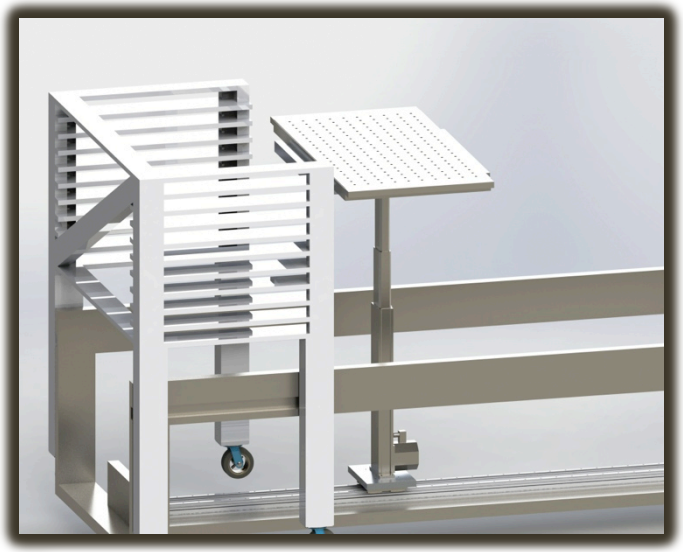
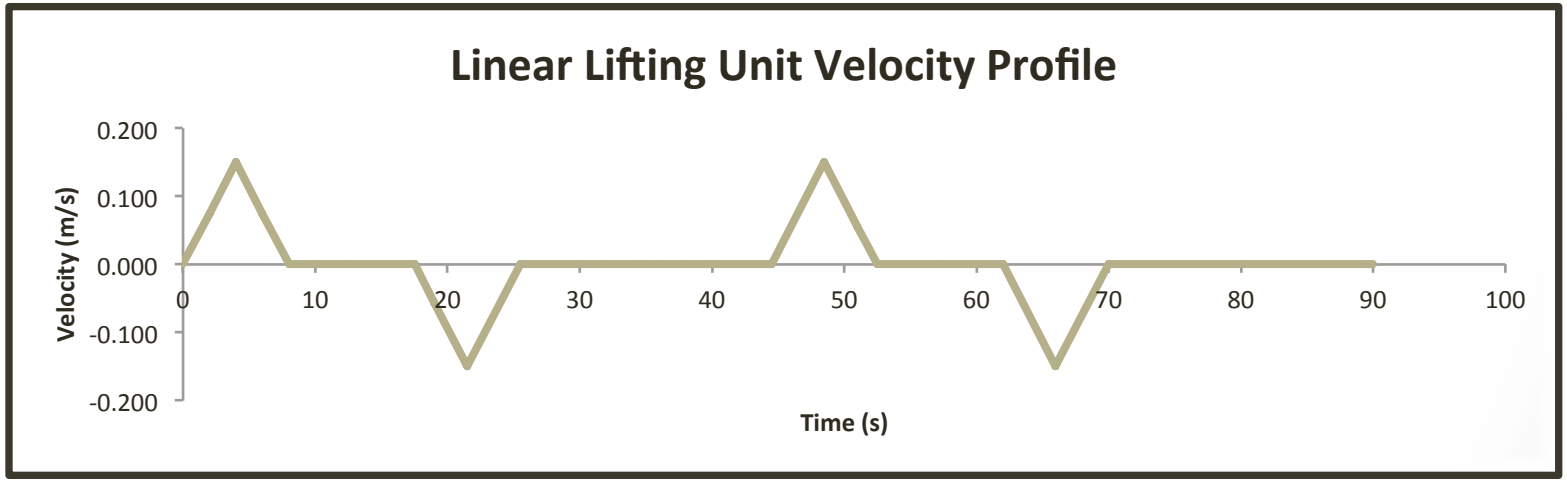
Lifting Column Unit



- Fully extended length of the linear lifting unit capable of reaching top tray
- Linear lifting unit responsible for carrying weight of the tray holder and tray of seed/soil



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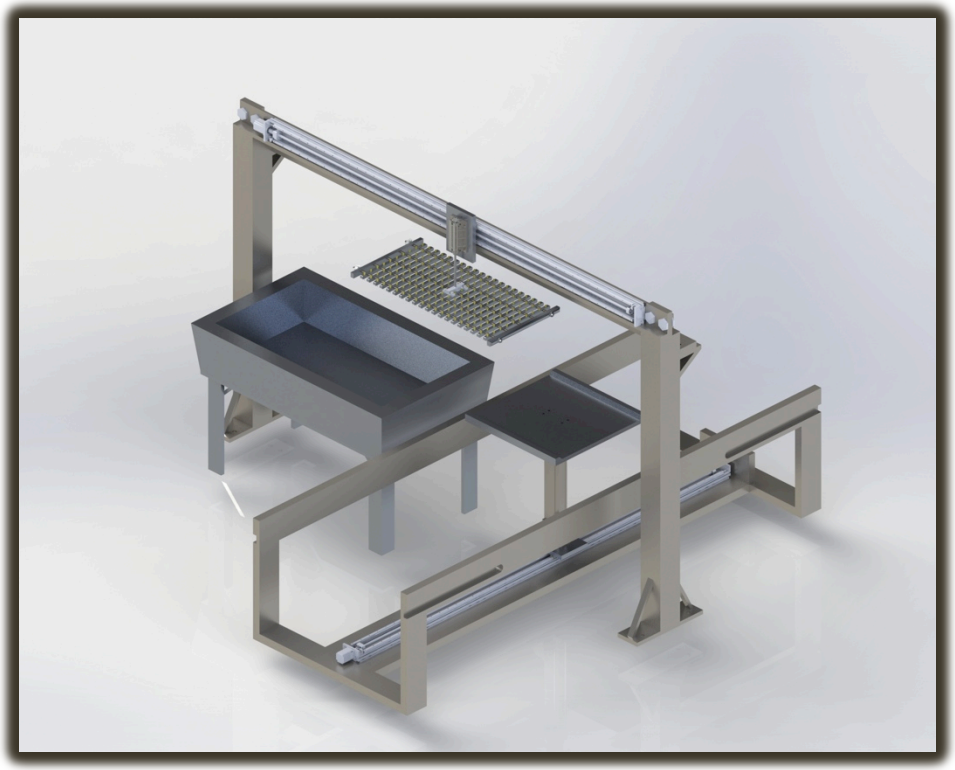
Upper Half of Seeding Apparatus

- Upper linear drive attached to overhanging stand, oriented perpendicular to the lower linear drive
- Structural support bears the weight of the linear drive, the piston, the seeding tray, and the two compressors



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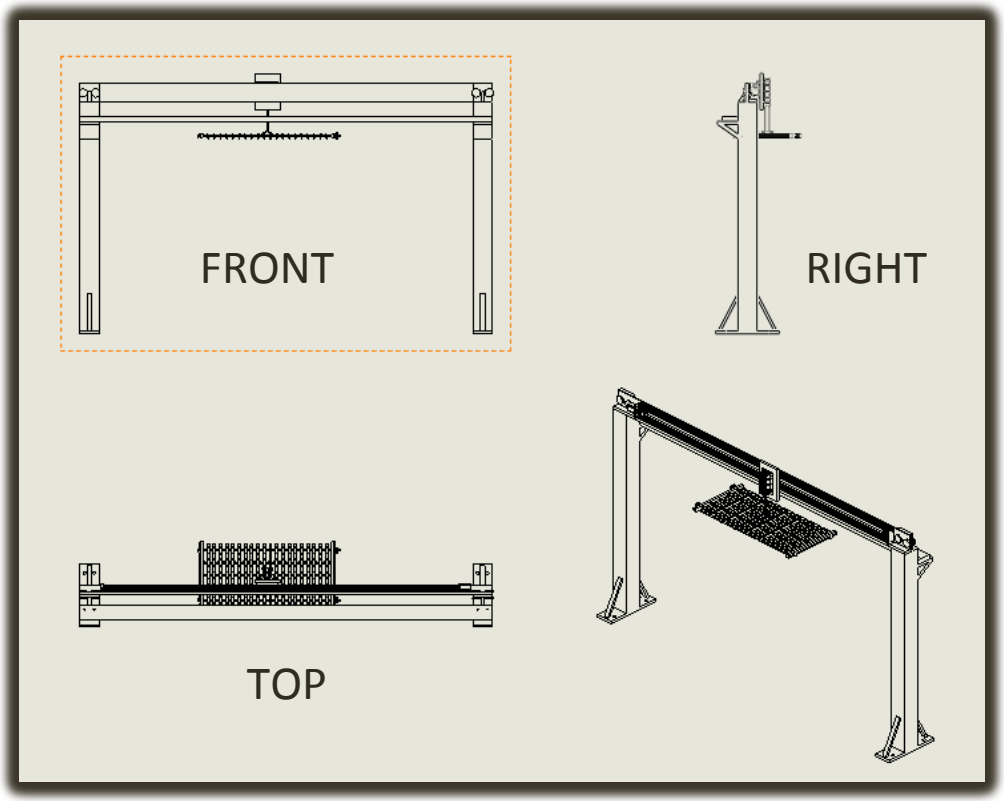
Upper Linear Drive

- Responsible for translating the weight of the piston and the seeding frame



Motor requirement results

Component	Required Torque (Nm)	Max. Angular Velocity (RPM)	Chosen motor torque (Nm)	Chosen motor angular velocity (RPM)	Critical Angular Velocity of Screw (RPM)	Notes
Lifing column drive	0.905	1800	1.2	4000	5805.4	One end fixed, one end free
Horizontal tray drive	0.001362	3233	0.55	4000	9085.4	Manufacturer claim
Horizontal seeder drive	8.14E-05	3006	0.55	4000	9085.4	Manufacturer claim

AeroTech BM200
AeroTech BM75

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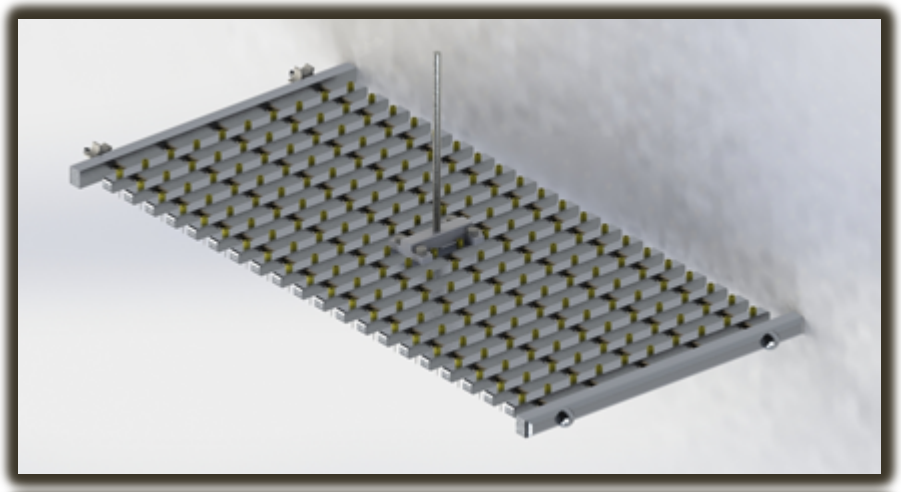
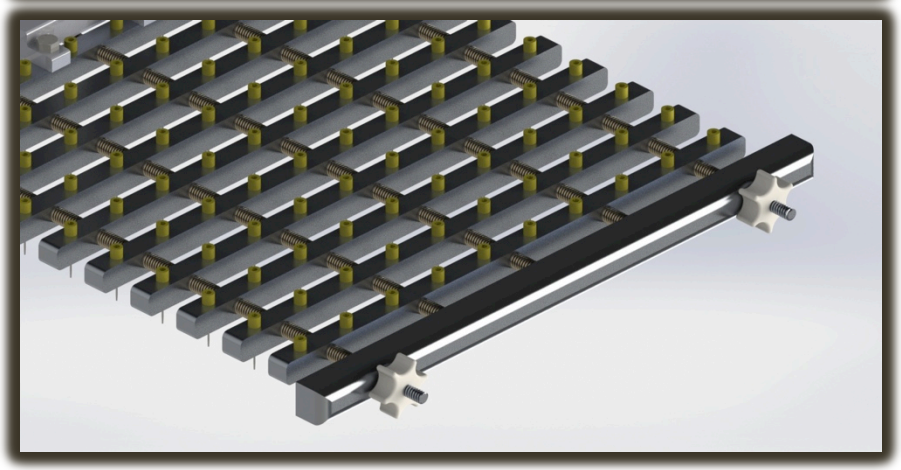
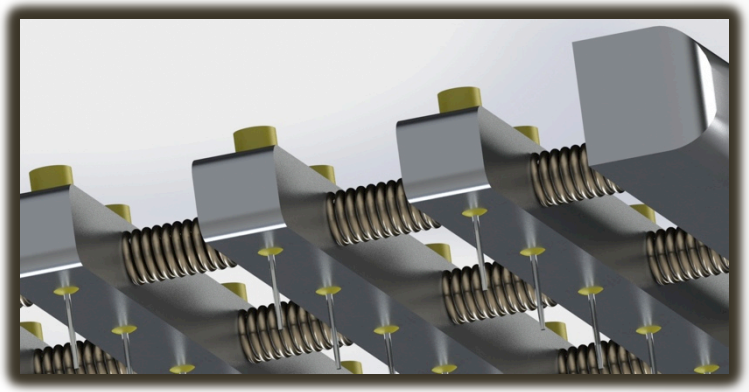
Seed Dispensing Mechanism





- Tubes attached to the top of each individual hole, which is fed into a compressor. This creates a suction force to pick up seeds from the vibrating bucket.



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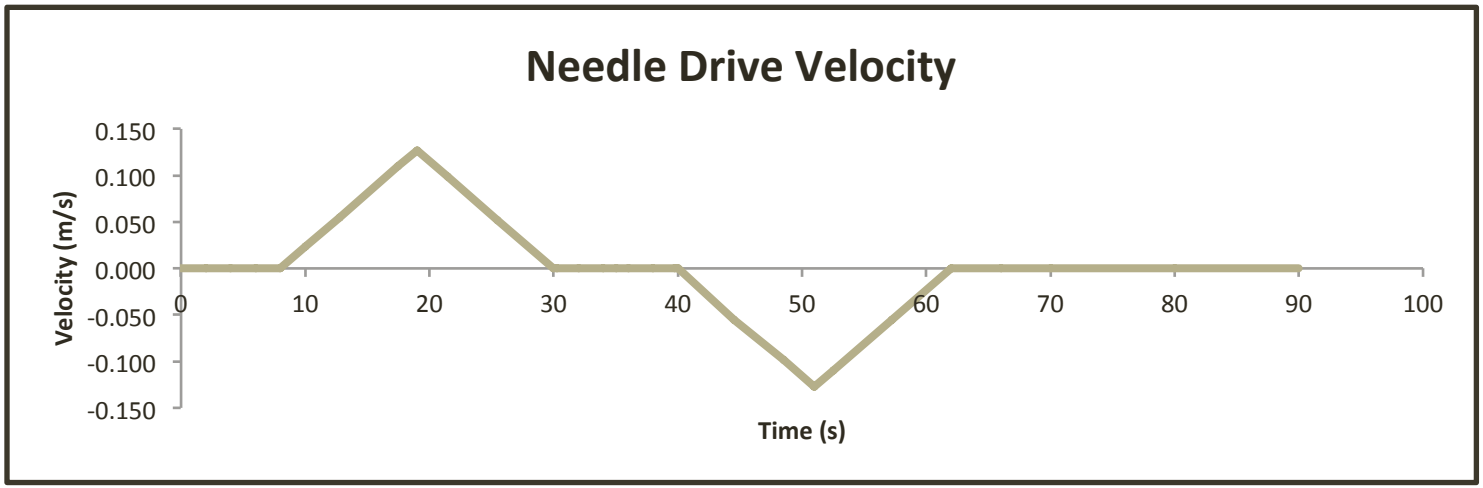
Needle Linear Drive Calculations



- The linear drive travels from bucket to seeding station at time 10-30 sec.
- The linear drive returns back to the bucket at time 40-60 sec.

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Piston Actuator

- Attached to Upper Linear Drive, which brings Seeder up and down to pick up seeds from bucket & place them on tray
- Binary movement ensures accuracy while placing seeds
- Compressor attached to Frame Support
- Parker P1D-S100MS-0320

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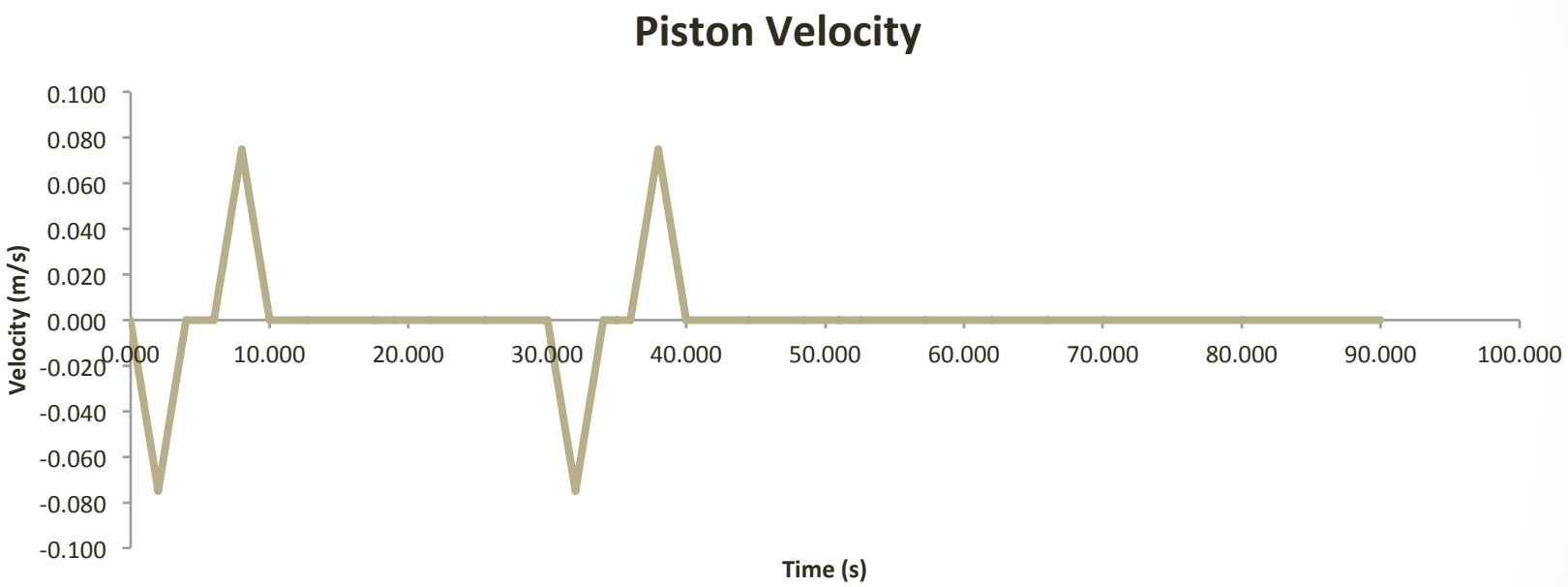
Piston Velocity Profile



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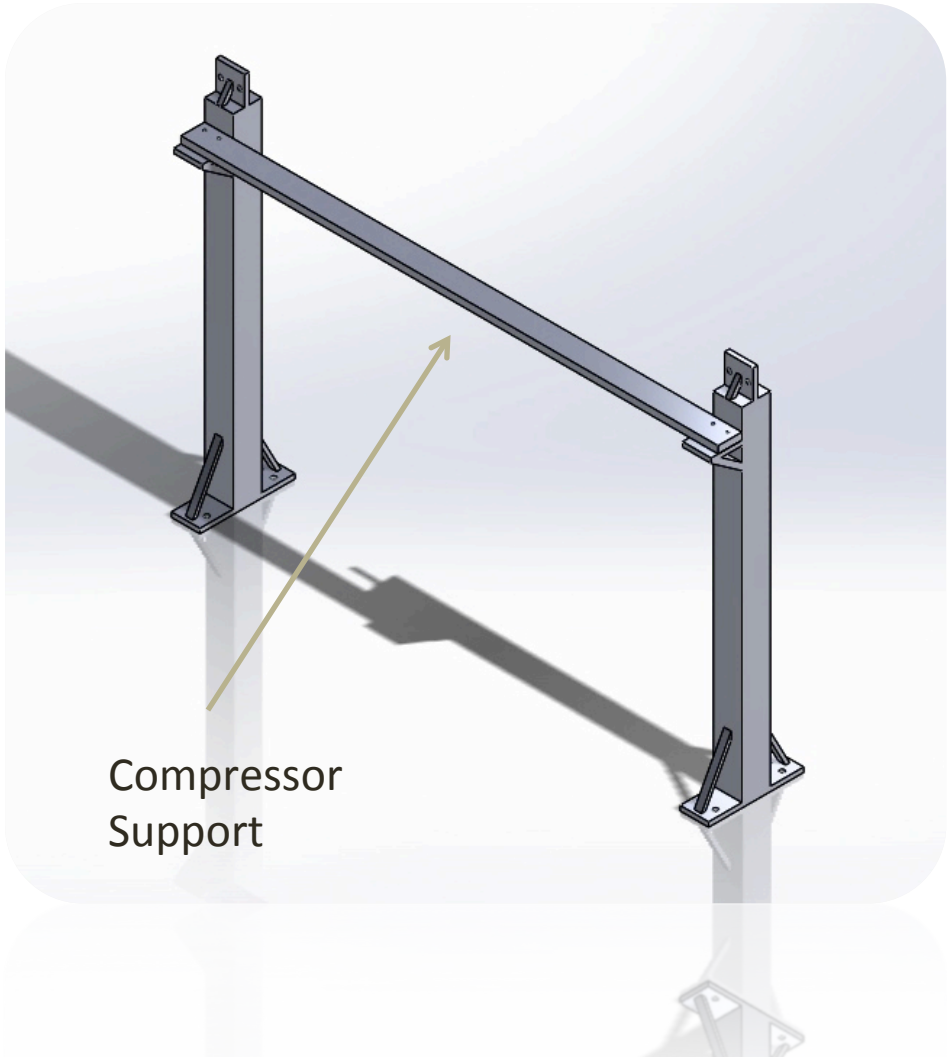
Seeder Frame Support



- Supports Upper Linear Drive
- Compressors for both vacuum needles and piston are placed here on the frame

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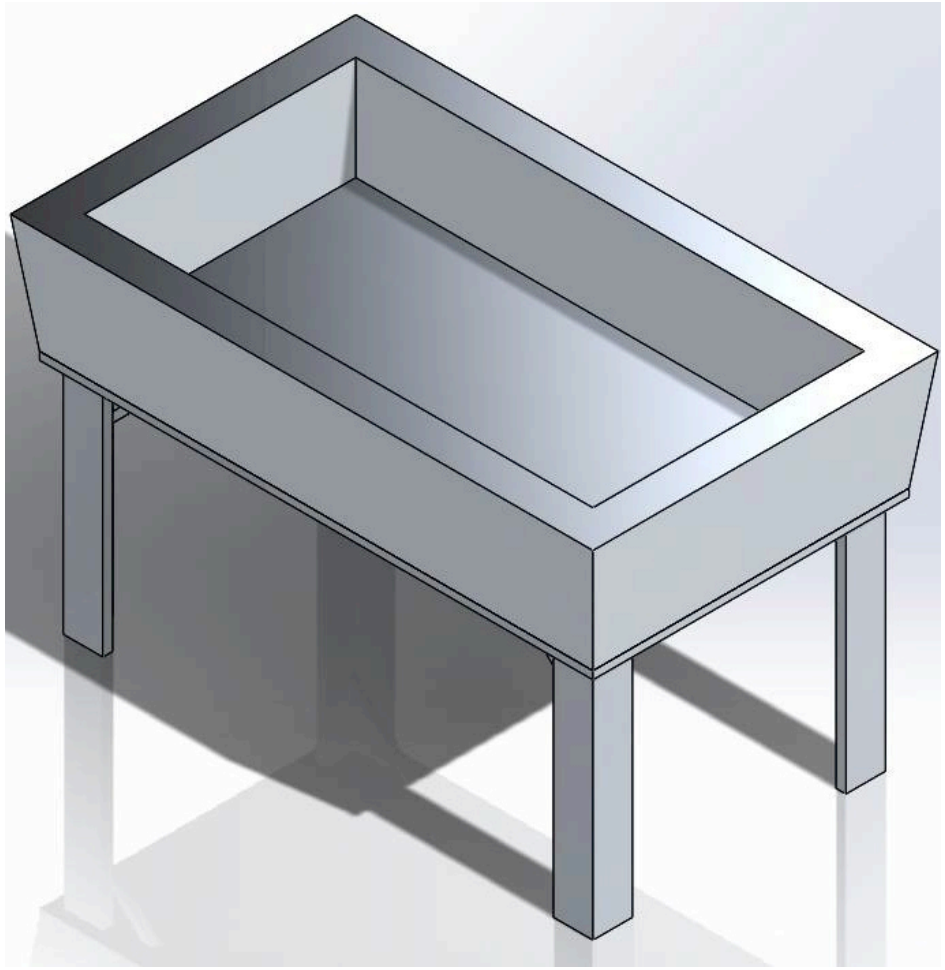
Seed Bucket



- Holds seeds
- Vibration Motor makes seeds jump around. This facilitates vacuum needle performance

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Sensors

Required Feedback

1. Carriage arriving at ends of linear drive
2. Seeder Arriving at bucket & seeding station
3. Vertical position of tray holder relative to trays

Selected Sensor

1. Inductive Proximity Sensor (x2)
2. Inductive Proximity Sensor (x2)
3. Absolute Encoder

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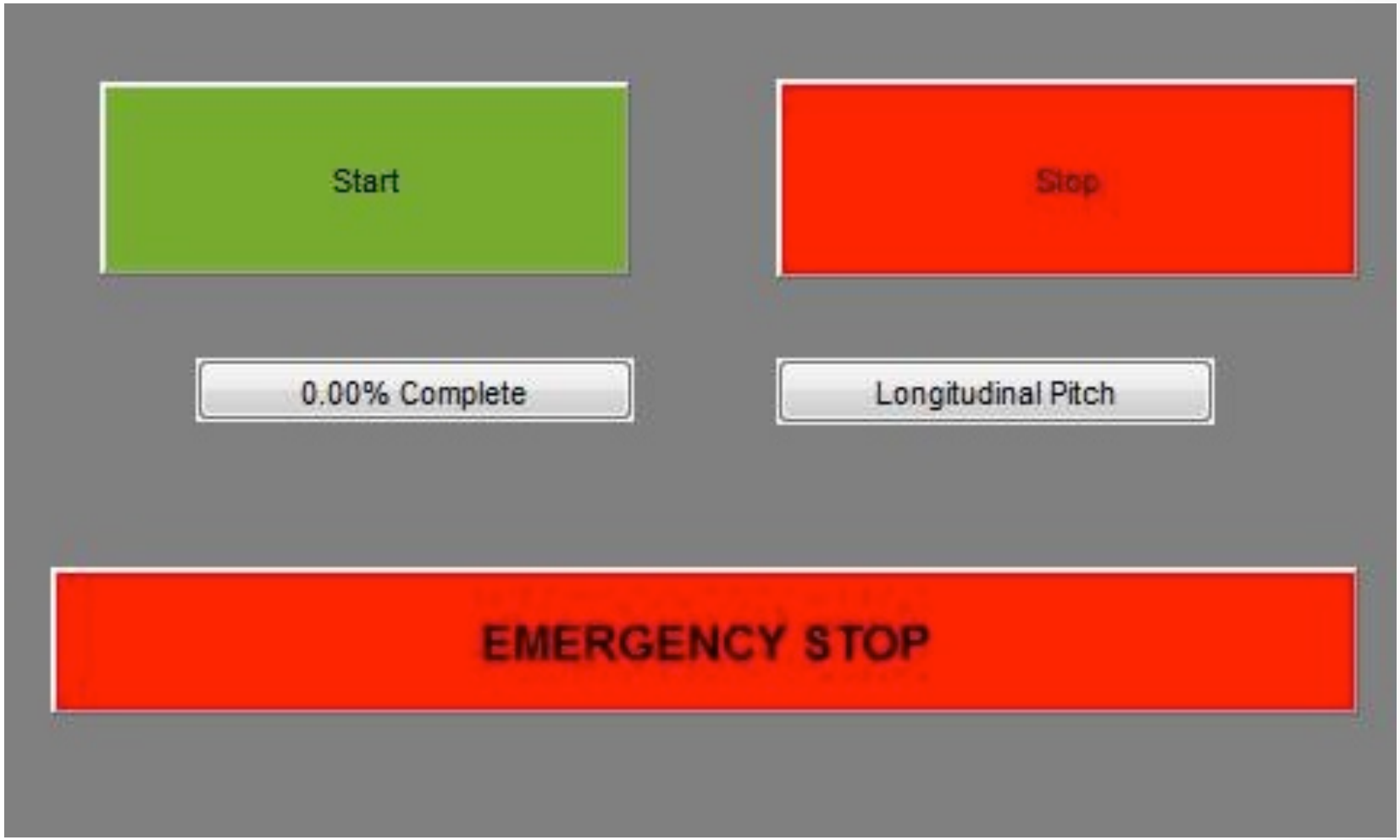
User Interface



Bill Of Materials

Custom Part	Material	Weight (lb.)	Qty.	Cost	Manufacturing
Tray Holder	1060 Alloy	80	1	$87	$174
Seeding Tray	AISI316 SS	161	10	$3,010	$6020
Lifting Column	1060 Alloy	178	1	$1500	$3000
Moving Platform	1060 Alloy	10.12	2	$22	$44
Cart	1060 Alloy	276	2	$300	$600
Base	AISI316 SS	2613	1	$4,713	$10,426
Seed Bin	1060 Alloy	636	1	$693	$1,386
Stands	AISI 316 SS	827	2	$2,982	$5,964
Connector	AISI 316 SS	193	1	$345	$690
Compressor stand	AISI 316 SS	282	1	$507	$1014
Threaded Rod	1060 Alloy	6.53	5	$700	$1400
Needle top	ABS Plastic	0.05	200	$100	$200
Needle	AISI 316 SS	0.1	200	$500	$1000
Needle Holder	1060 Alloy	1.05	20	$400	$800
Rod End Cap	1060 Alloy	2.71	2	$200	$400
Springs	1023 Carbon Steel	0.031	190	$500	$1000

Purchased Items

Purchased Part	Manufacturer	Model	Quantity	Cost
Lifting Column Motor	AeroTech	BM200	1	$200
Gearbox	Zero-Max	C208806	1	$200
Linear Drive	SMI4Motion	XLA15-T110-BS.100	2	$5,170
Linear drive Motor	AeroTech	BM75	2	$188
Pneumatic Cylinder	Parker	P1D-S100MS-0320	1	$165
Directional Control Valve	Festo	550170	2	$110
Seeding Compressor	Ingersoll Rand	TS4N95	1	$700
Vibration Motor	Tinsley Company	BE-1980-48	1	$200
Proximity Sensor	OMRON	E2EX2MF1-M1	5	$400
Encoder	Allen-Bradley	842A	1	$110

Financial Justification

Current Situation	Seeding Machine	Development
1 operator: 1 tray every 10 min.	1 operator needed. 90 s per tray.	2 engineers. 1 year of work for $80,000 base salary
17,520 trays per year. (8 hr. work day)	116,800 trays per year	Cost of materials and manufacturing ~ $50,000
Salary of operator: $50,000/year	Saves 5 operators	Developmental costs: $210,000
	Labor savings: $250,000	Maintenance: $10,000 per year

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Financial Justification

year		0	1	2	3	4	5
Development cost		-$210,000.00					
labor savings			$250,000.00	$250,000.00	$250,000.00	$250,000.00	$250,000.00
maintenance			-$10,000.00	-$10,000.00	-$10,000.00	-$10,000.00	-$10,000.00
annual cash flow		-$210,000.00	$240,000.00	$240,000.00	$240,000.00	$240,000.00	$240,000.00
cumulative cash flow		-$210,000.00	$30,000.00	$270,000.00	$510,000.00	$750,000.00	$990,000.00
NPV cash flow			$218,181.82	$198,347.11	$180,315.55	$163,923.23	$149,021.12
R	0.1						
Net Present Value		$699,788.82					
Payback Period		0.875	years into year 1				

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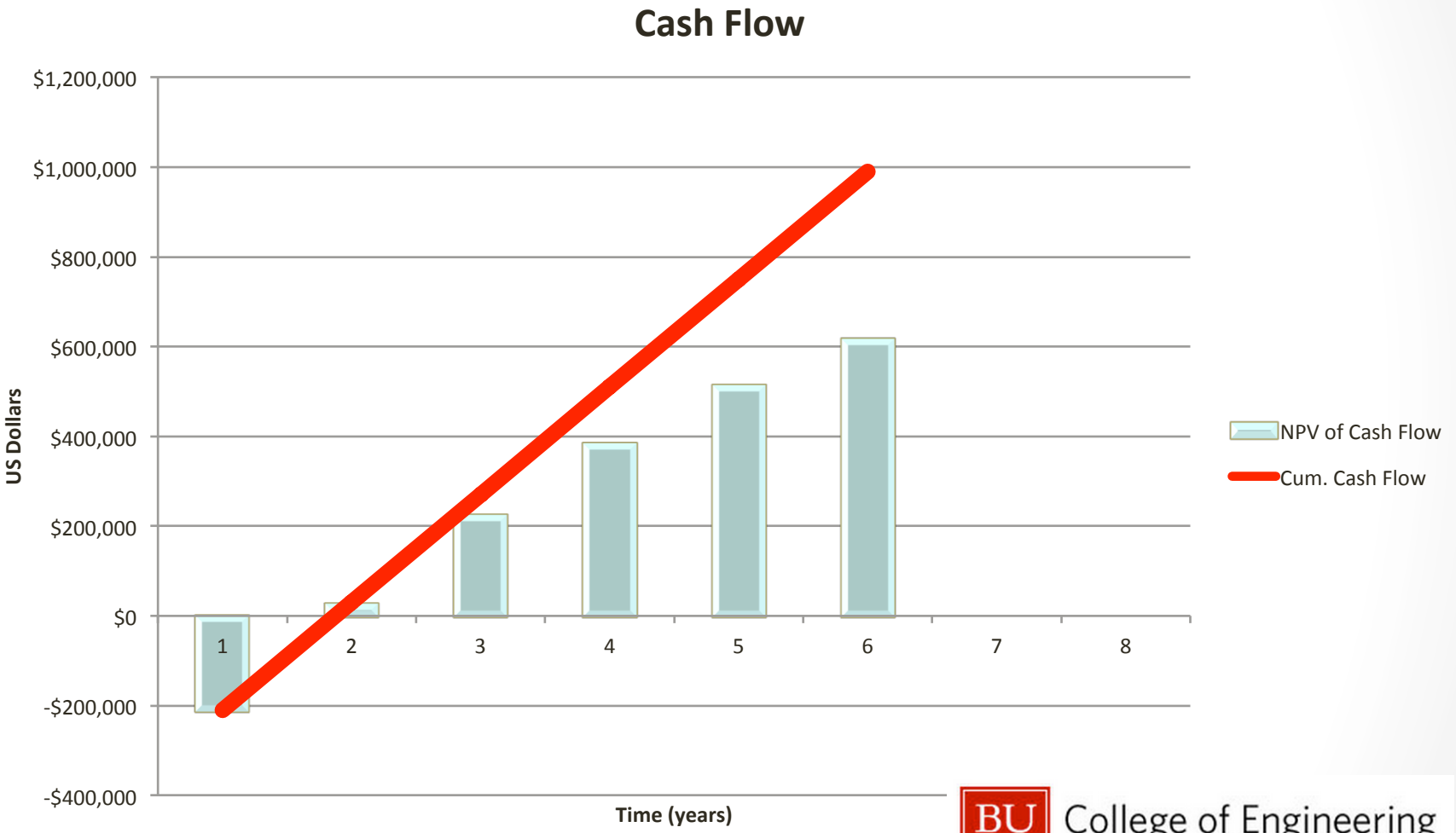
Financial justification



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Thank You

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CAD Resources

- www.smi4motion.com
- rose-kreiger.partcommunity.com
- www.gradcad.com

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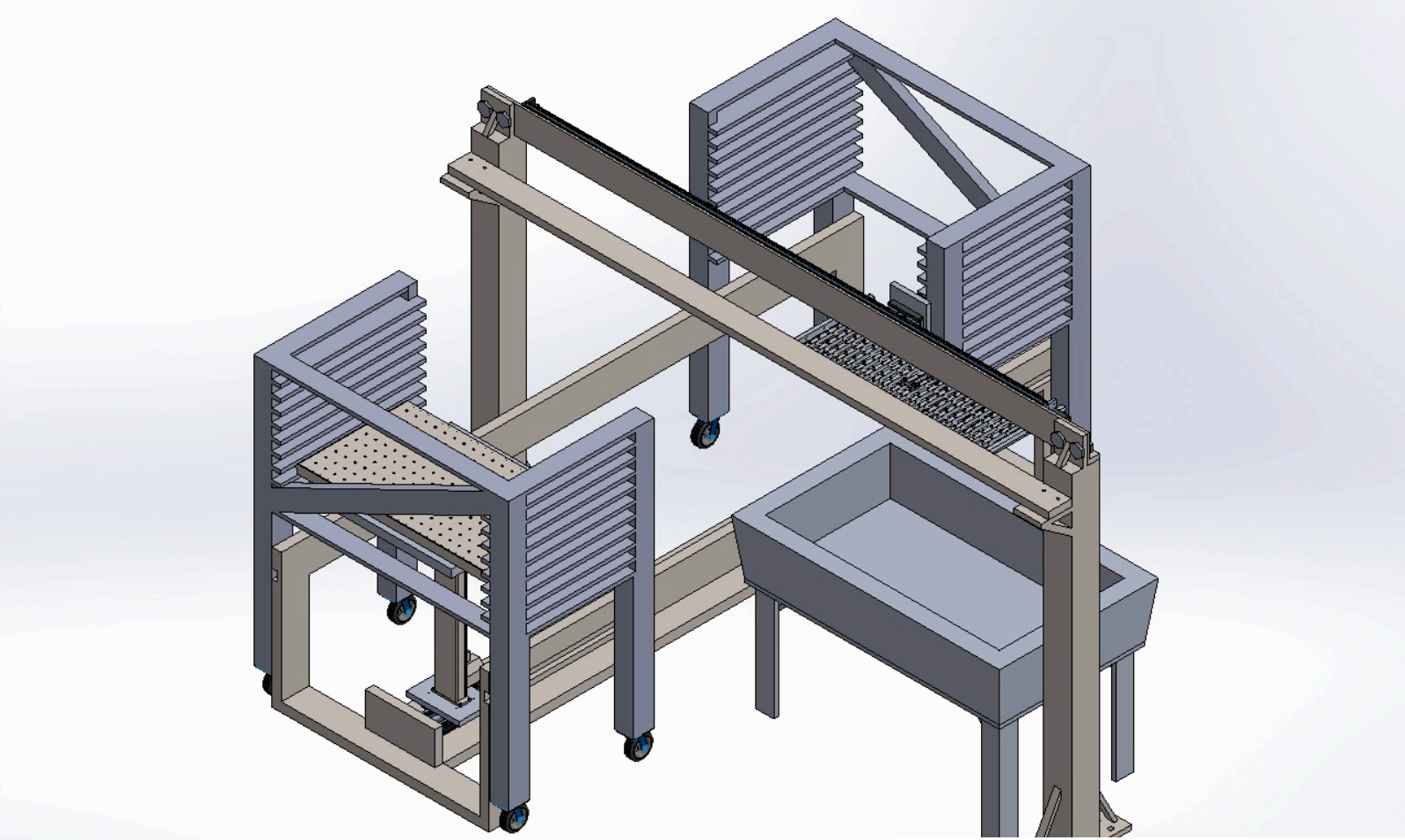
Appendix



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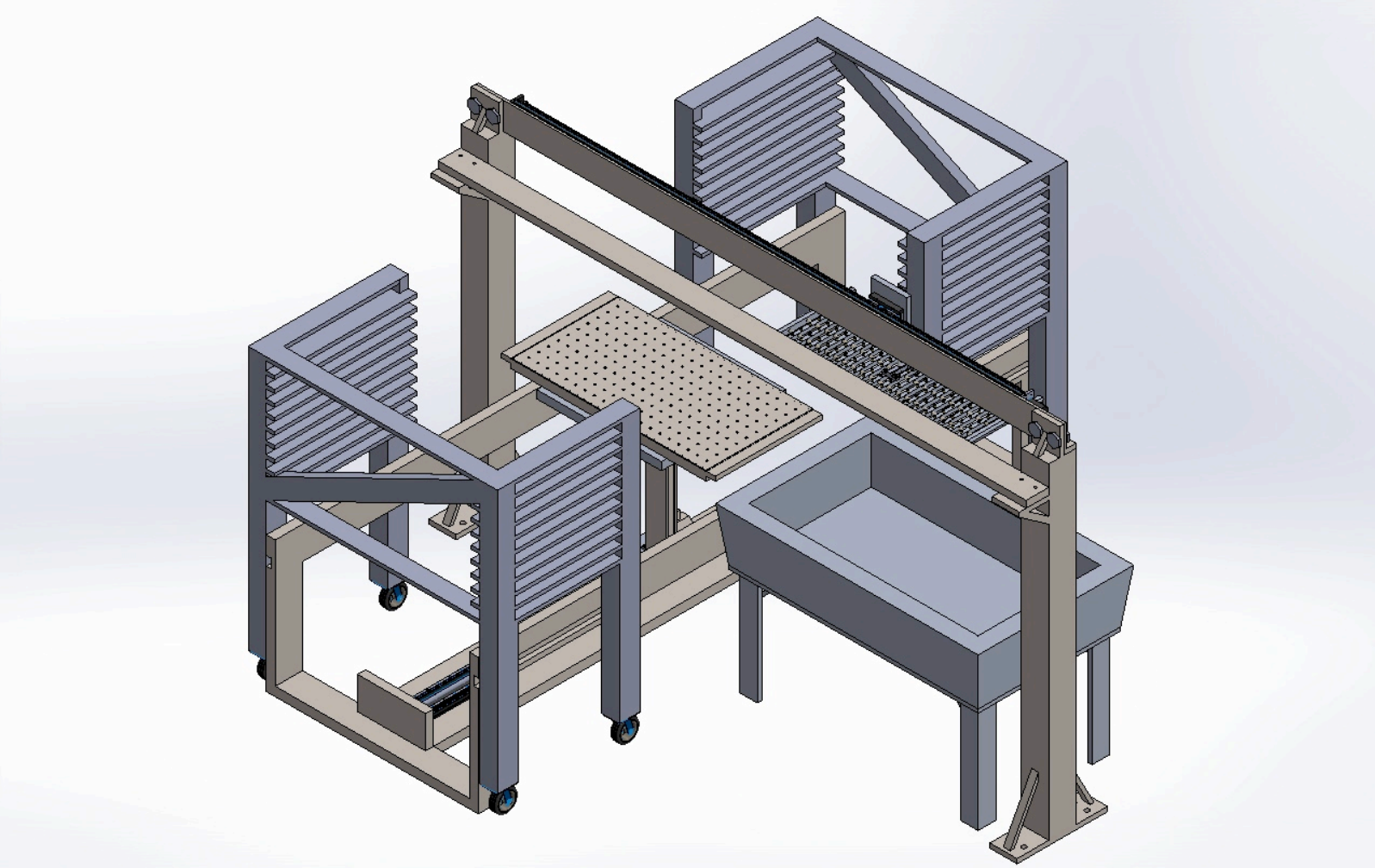
Tray retrieval from input cart



Tray placement on seeding station

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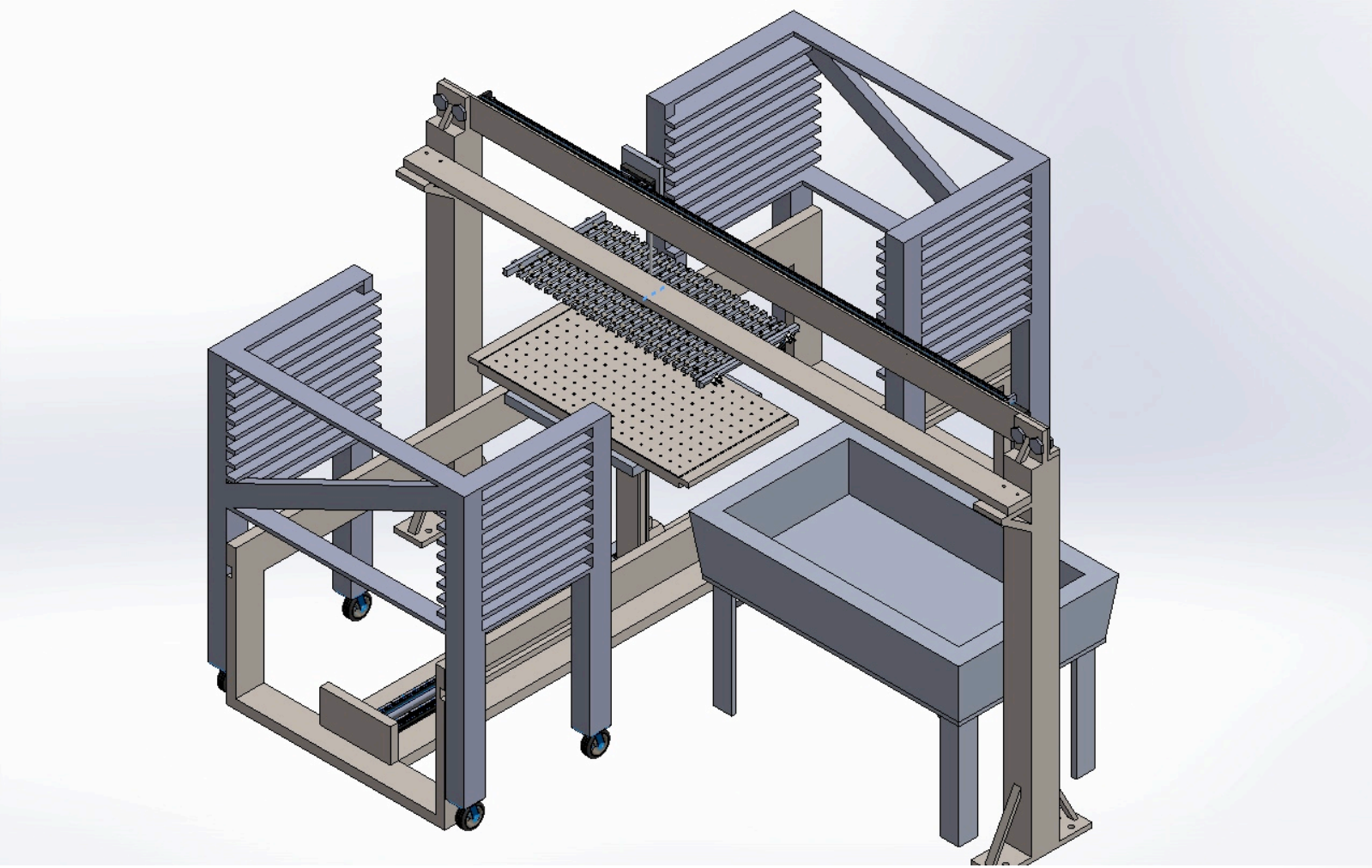

Seed placing by seeder

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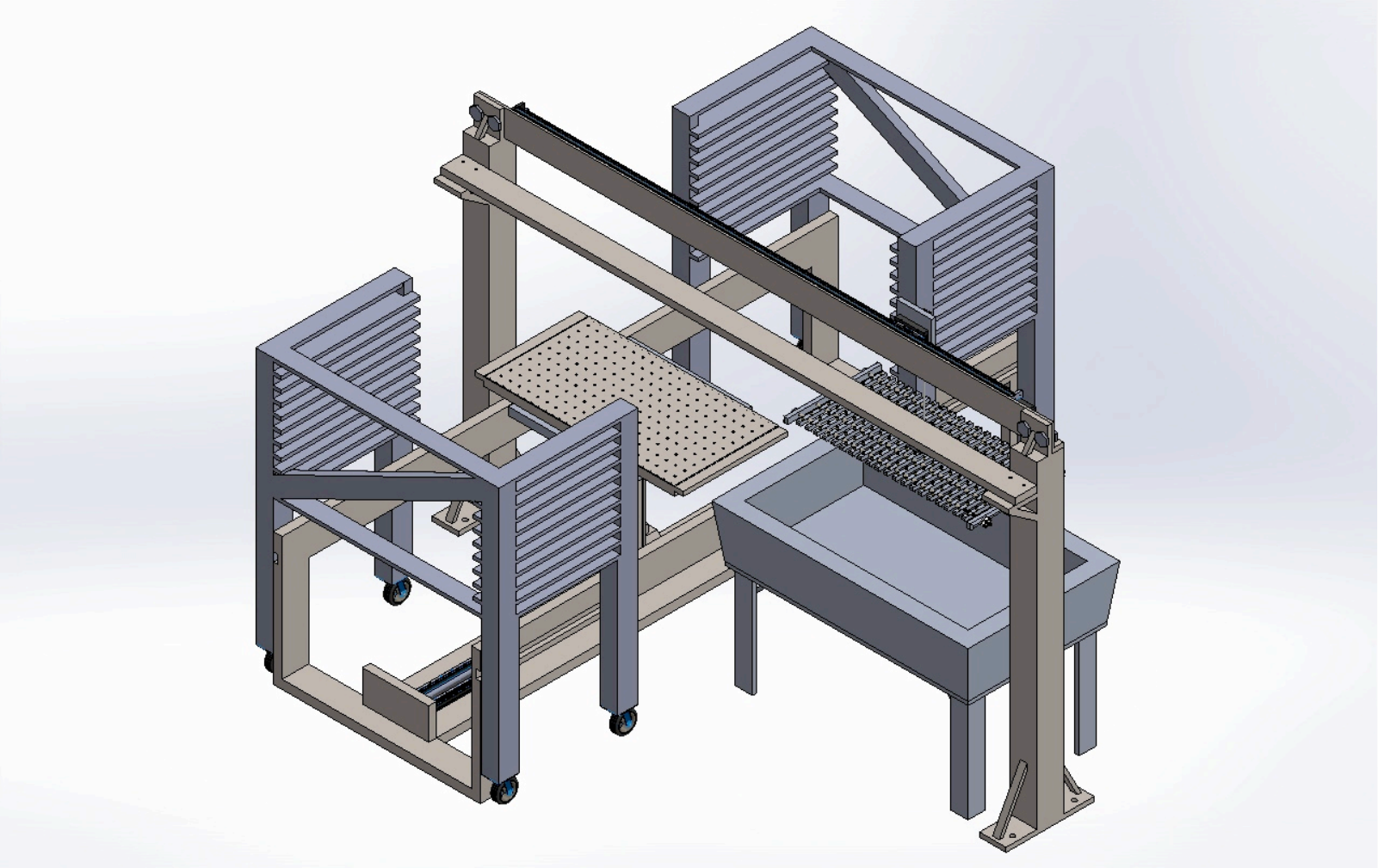

Seeder returns to bucket

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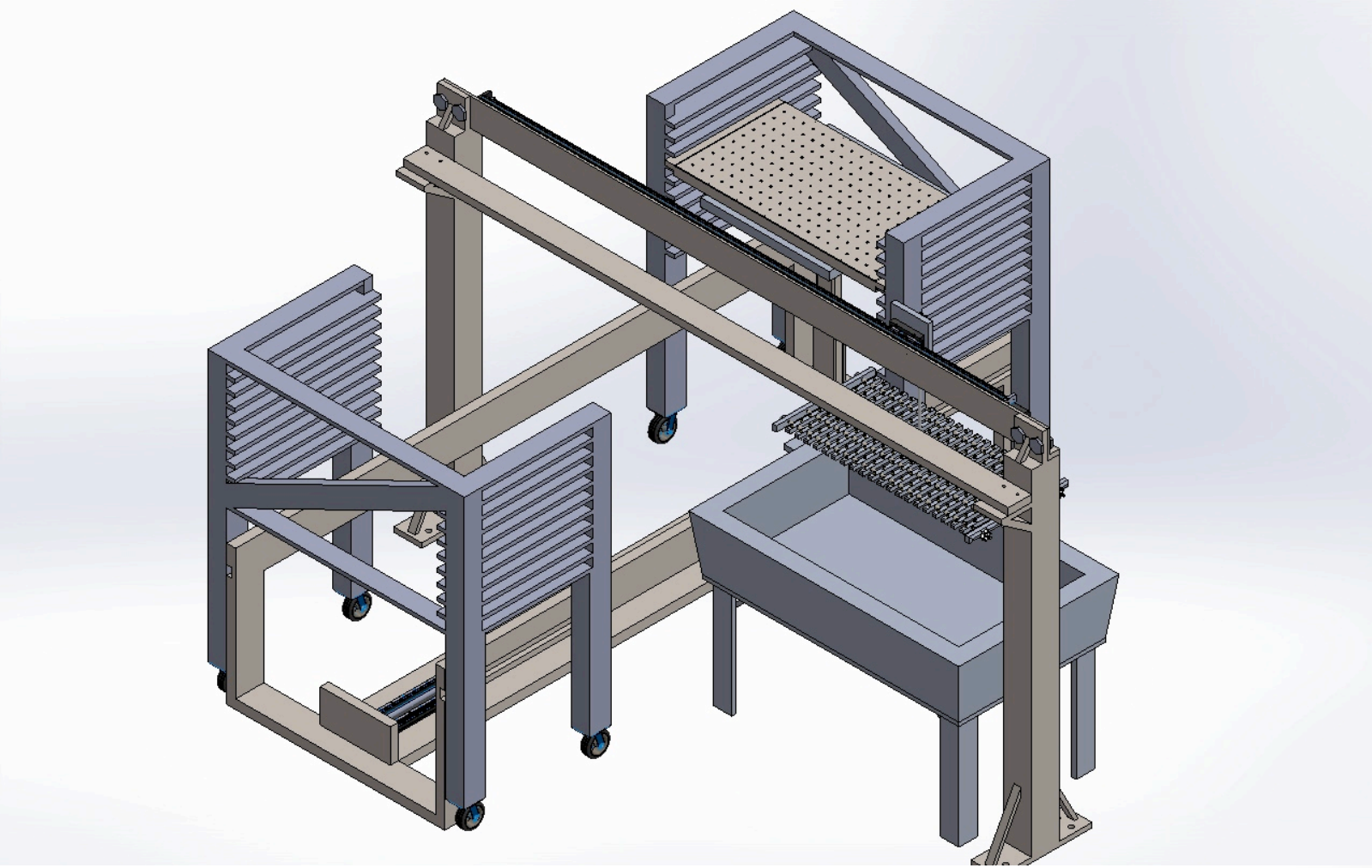

Tray drop off in output cart

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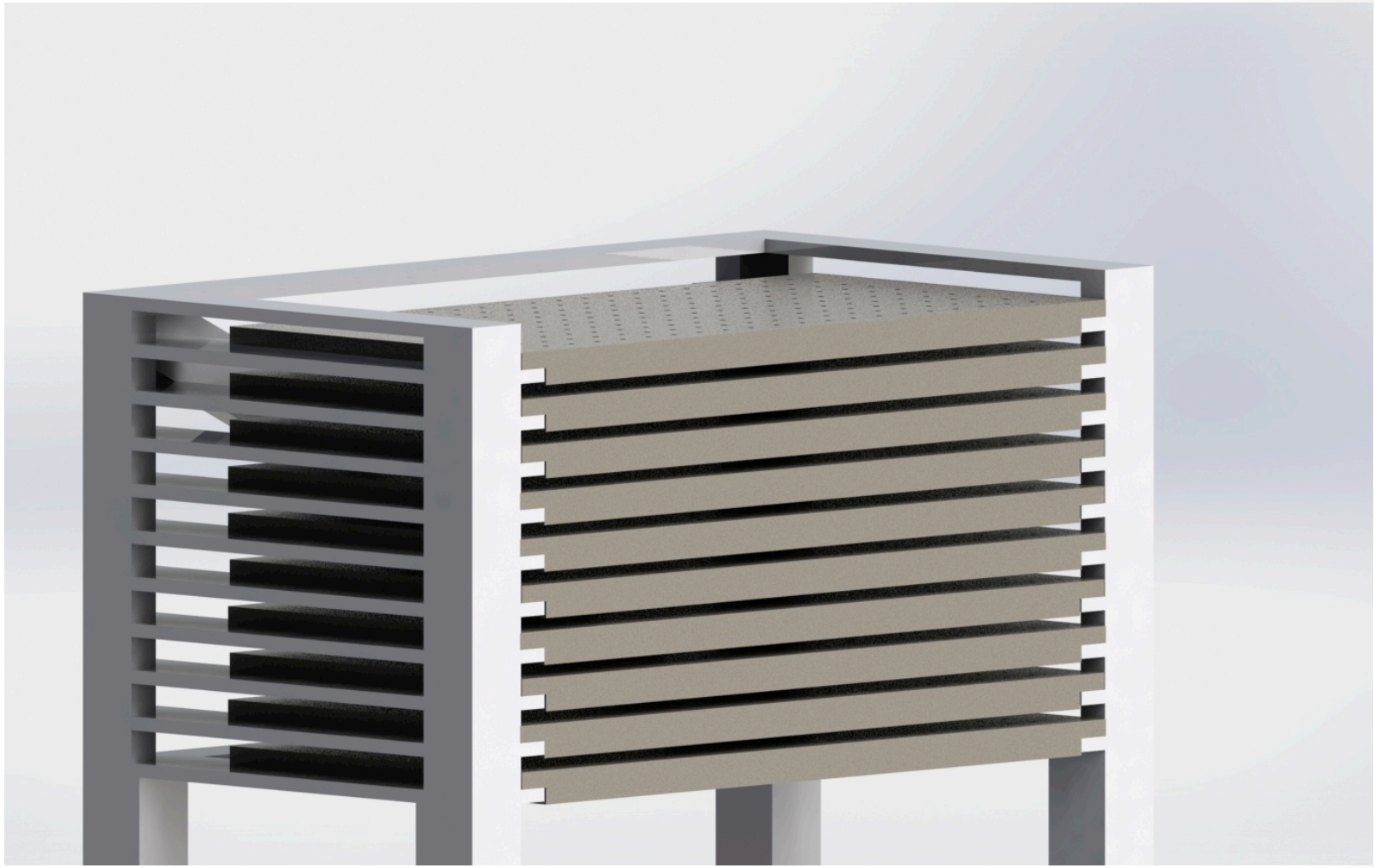

Fully Loaded Cart

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Sample Calculation: Required Torque for Lifting Column

The linear acceleration is calculated from: $x = \frac{1}{2}at^2$

$$a = \frac{2({}^{x}/_{2})}{({}^{t}/_{2})^2} = \frac{2({}^{.60\ m}/_{2})}{({}^{8.0\ s}/_{2})^2} = 0.038\ {}^{m}/_{s^2}$$

The required force (P) for this acceleration is calculated from: $\sum F = P - mg = ma$

$$P = m(a+g) = (115.5\ kg)\left(0.038 + 9.81\ {}^{m}/_{s^2}\right) = 1137.4\ N$$

The required torque (τ_l) is calculated from:

$$\tau_l = {}^{PL}/_{2\pi\eta} = {}^{(1137.4\ N)(0.005\ \frac{m}{rev})}\Big/_{(2\pi\ \frac{rad}{rev})(0.9)} = 0.905\ Nm$$

The angular acceleration is:

$$\alpha = {}^{2\pi a}/_{L} = {}^{(2\pi\frac{rad}{rev})\ (0.038\ \frac{m}{s^2})}\Big/_{0.005\frac{m}{rev}} = 47.12\ \ {}^{rad}/_{s^2}$$

The moment of inertia for the screw is calculated as:

$$I_L = \frac{1}{2}\rho\left(\frac{d}{2}\right)^4 l = 0.5\left(7500\ {}^{kg}/_{m^3}\right)\left({}^{0.06\ m}/_{2}\right)^4(0.66\ m) = 0.0063\ \text{kg}\,m^2$$

The torque required to rotate the motor and lead screw is found from:

$$\tau_m = (I_l + I_m)\alpha = (0.0063 + 0.0005\ \text{kg}\,m^2)\left(47.12\ \ {}^{rad}/_{s^2}\right) = 0.00025\ Nm$$

The total torque is the sum of the the torque required to accelerate the mass and to rotate the motor and screw:

$$\tau = \tau_l + \tau_m = 0.905 + 0.00025\ Nm = 0.90525\ Nm$$

System Parameters	
Time (t)	8.0 s
Max Extension (x)	0.6 m
Lead (L)	0.005 m
Screw length (l)	0.66 m
Screw diameter (d)	0.06 m
Motor Intertia (I_m)	0.0005 kgm^2
Ball screw eficiency (η)	0.9
Total Mass (m)	115.5 kg

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Sample Calculation: Required Torque for tray linear drive

The linear acceleration is calculated from: $x = \frac{1}{2}at^2$

$$a = \frac{2({}^{x}/_{2})}{({}^{t}/_{2})^2} = \frac{2({}^{.65\ m}/_{2})}{({}^{9.5\ s}/_{2})^2} = 0.029\ {}^{m}/_{s^2}$$

The required force (P) for this acceleration is calculated from: $\sum F = P = ma$

$$P = m(a+g) = (116\ kg)\left(0.029\ {}^{m}/_{s^2}\right) = 3.36\ N$$

The required torque (τ_l) is calculated from:

$$\tau_l = {}^{PL}/_{2\pi\eta} = \left.\frac{(3.36\ N)(0.00254\ \frac{m}{rev})}{(2\pi\ \frac{rad}{rev})(0.9)}\right. = 0.00135\ Nm$$

The angular acceleration is:

$$\alpha = {}^{2\pi a}/_{L} = \left.\frac{(2\pi \frac{rad}{rev})\ (0.029\ \frac{m}{s^2})}{0.00254\ \frac{m}{rev}}\right. = 71.26\ {}^{rad}/_{s^2}$$

The moment of inertia for the screw is calculated as:

$$I_L = \frac{1}{2}\rho\left(\frac{d}{2}\right)^4 l = 0.5\left(7500\ {}^{kg}/_{m^3}\right)\left({}^{0.016m}/_{2}\right)^4(2.794\ m) = 0.00013\ \text{kg}\ m^2$$

The torque required to rotate the motor and lead screw is found from:

$$\tau_m = (I_l + I_m)\alpha = (0.00013 + 0.0005\ \text{kg}\ m^2\ )\left(71.26\ \ {}^{rad}/_{s^2}\right) = 1.829E-5\ Nm$$

The total torque is the sum of the the torque required to accelerate the mass and to rotate the motor and screw:

$$\tau = \tau_l + \tau_m = 1.829E-5 + 0.00135\ Nm = 0.00136\ Nm$$

System Parameters	
Time (t)	9.5 s
Max travel length (x)	0.65 m
Lead (L)	0.0254 m
Screw length (l)	2.794 m
Screw diameter (d)	0.016 m
Motor Intertia (Im)	0.0005 kgm^2
Ball screw eficiency (n)	0.9
Total Mass (m)	116 kg

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Sample Calculation: Pressure for Pneumatic Cylinder

The acceleration is calculated from: $x = \frac{1}{2}at^2$

$$a = \frac{2(^{x}/_{2})}{(^{t}/_{2})^2} = \frac{2(.32\ ^{m}/_{2})}{(4.0\ ^{s}/_{2})^2} = 0.08\ ^{m}/_{s^2}$$

The required force is calculated as: $F = ma = (14\ kg)(0.08\ ^{m}/_{s^2})$ = 138.5 N

The required pressure is calculated from:

$$P = {}^{F}/_{A} = {}^{138.5\ N}/_{0.00785\ m^2} = 17629\ Pa$$

System Parameters	
Time (t)	4 s
Max travel length (x)	0.32 m
Total Mass (m)	14 kg
Piston Area (A)	0.00785 m^2

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Sample Calculation: Pressure for Seeder Needle Vaccuum

The acceleration is calculated from: $x = \frac{1}{2}at^2$

$$a = \frac{2({}^{x}/_{2})}{({}^{t}/_{2})^2} = \frac{2({}^{.32\ m}/_{2})}{({}^{4.0\ s}/_{2})^2} = 0.08\ {}^{m}/_{s^2}$$

The required force is calculated as: $F = ma = (14\ kg)(0.08\ {}^{m}/_{s^2})$ = 138.5 N

The required pressure is calculated from:

$$P = {}^{F}/_{A} = {}^{138.5\ N}/_{0.00785\ m^2} = 17629\ Pa$$

In order to move the seeds the minimum pressure required was calculated.
The total mass for 200 seeds, assuming a mass m is:

$$M = Nm = (200\ seeds)\left(0.0005\ \frac{kg}{seed}\right) = 0.1\ kg$$

The force required to hold the seeds is: : $F = ma = (0.1\ kg)(9.81\ {}^{m}/_{s^2})$ = 0.981 N

The total suction area of the seeder is:

$$A = Na = (200\ needles)(5.03\text{E-}7\ m^2) = 0.0001\ m^2$$

The minimum vacuum pressure is:

$$P = {}^{F}/_{A} = {}^{0.981\ n}/_{0.0001\ m^2} = 9758\ Pa\ (vacuum)$$

System Parameters	
Number of seeds (N)	200
Mass of single seed (m)	0.0005 kg
Radius of needle opening	0.0004 m
Area of a single needle (a)	5.03E-7 m^2

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Looking Ahead

- Compressor hook up in Solidworks
- Gearbox hook up in Solidworks
- Add screws, nuts, bolts

- Order parts and materials
- Manufacture custom parts
- Build it!

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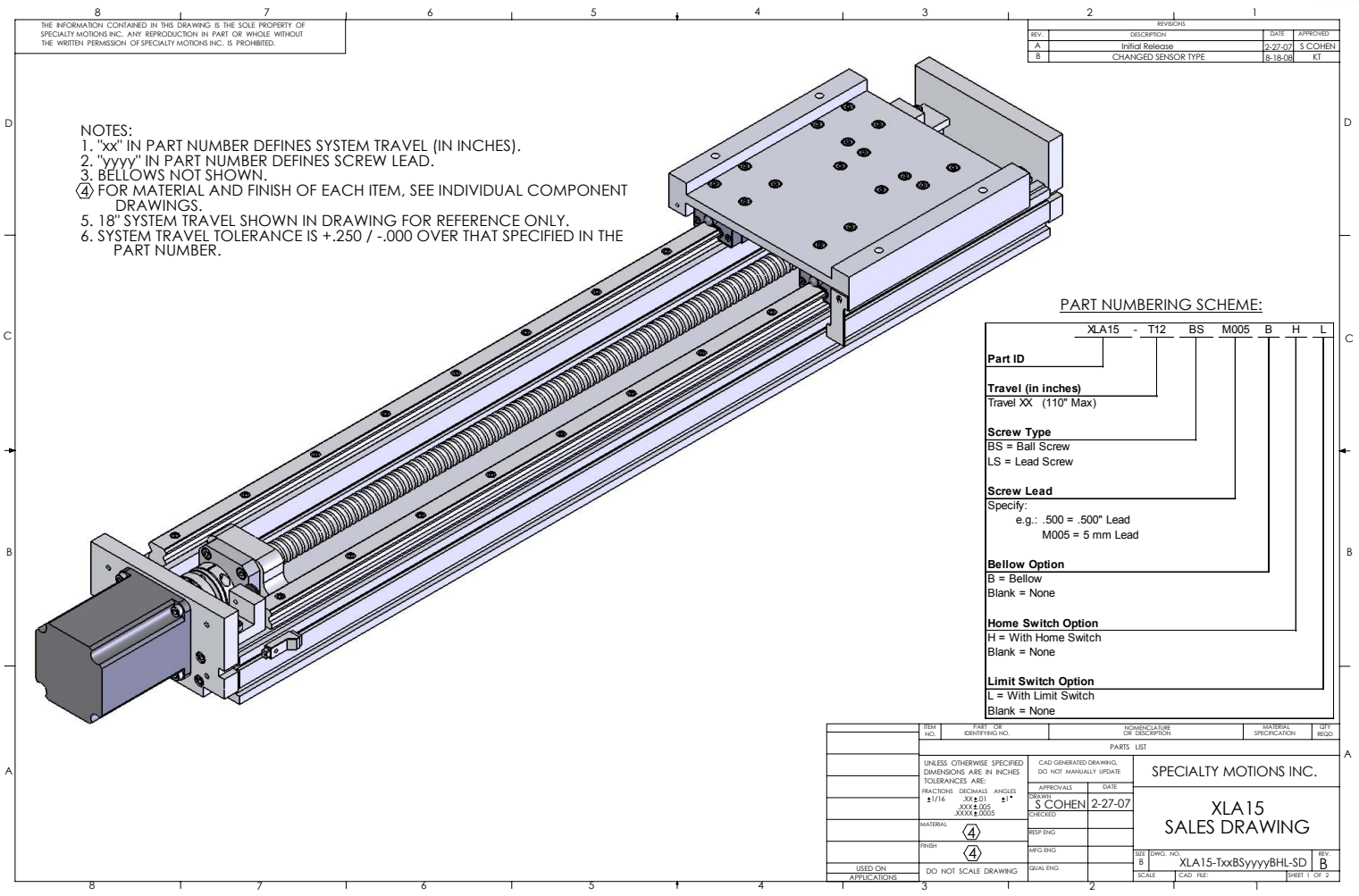
Linear Drive Websites

- Linear Actuation Selection Guide: http://www.duffnorton.com/productmenu.aspx?id=7952

- Travel length of 110'' or 9.166'
  http://www.smi4motion.com/smi2/atuators/profile-rail-linear-actuators/xla-15-multi-axis-linear-actuator.html

Linear Drives



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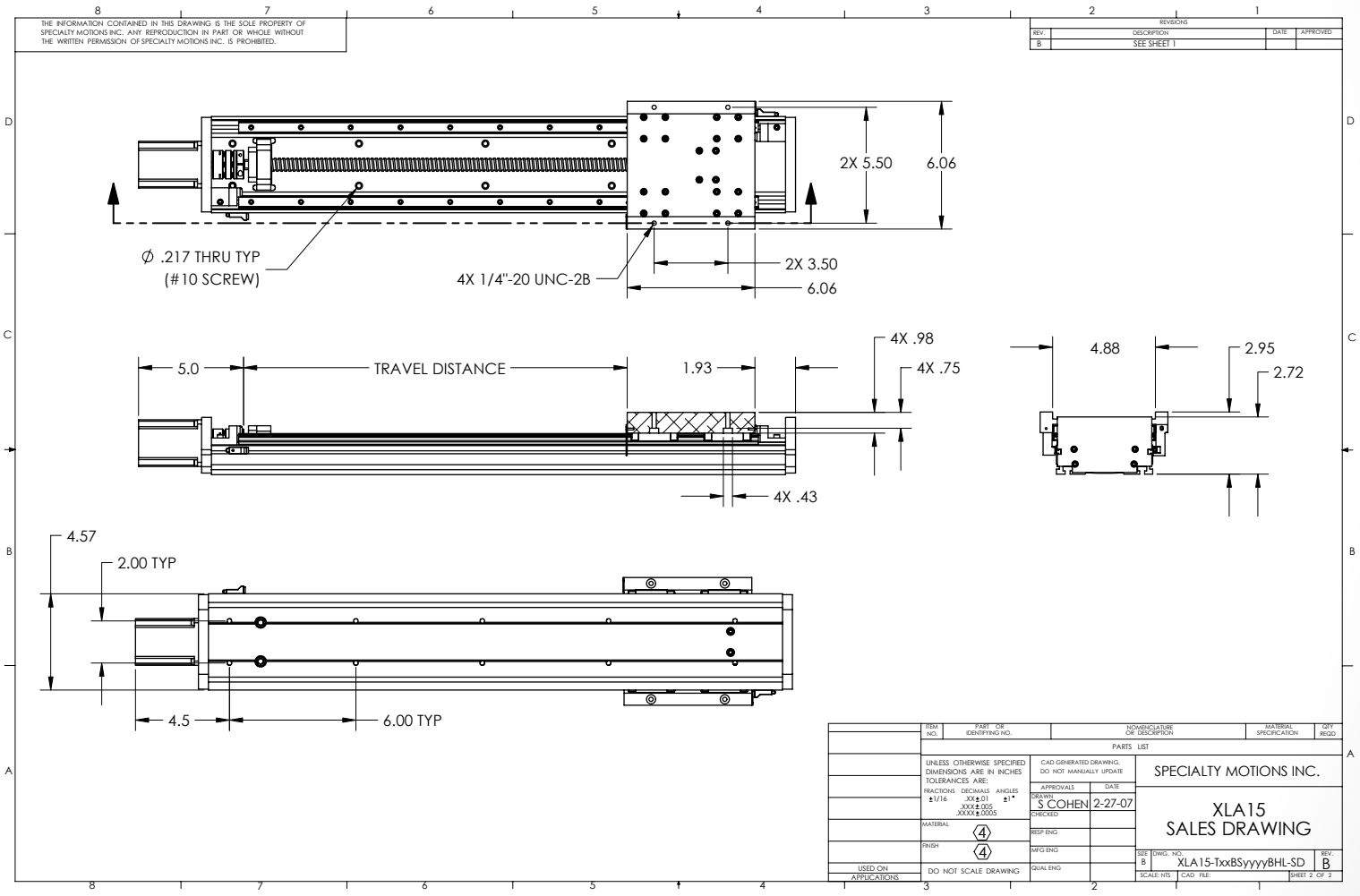
Linear Drives



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Miscellaneous Info

- Gearbox at zero-max.com model C208806 (3/4’ shaft)
  1:1 ratio

- Material Pricing:
- AISI 316 SS: $3,975/2,204 lbs.
  -MEPS.co.uh
- 1060 Aluminum Alloy: $2,400/2,204 lbs.
  -Alibaba.com (Average of Various Prices)

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