USDA Subsurface Banding Poultry Litter Implement

Preliminary Design Report

Corp_10

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Abstract:

Corp_10 was formed early in the 2010 Fall semester to work with the USDA-ARS National Soil Dynamics Laboratory on improving an implement designed to apply beneficial nutrients to the soil. Two main problems with the current design of the implement were identified by the USDA. The first deals with the nutrient application phase, and the second focuses on the soil recovery phase. Each problem requires a unique set of engineering abilities to appropriately solve.

To improve the nutrient application process, a redesign of the implement walls was proposed. Working with the industrial sponsor, an appropriate design was selected. The design bends the steel walls of the implement outward to remedy a pinching problem currently experienced. Additionally, a low-friction, protective coating may be used on the implement to reduce the likelihood of the deposited nutrients backing up and clogging the system.

In the soil recovery phase, an adjustable dirt scooping system is proposed to aid the current press-wheel system. The design is simple and low-maintenance, while being very effective. Presented in this preliminary design report is a complete outline detailing the work done in coordination with the USDA, including the generation of feasible concepts, appropriate engineering analysis, validation of the design, and future plans for the project.

As the design progresses, so do the requirements and expectations. As is such, the design process is one that requires multiple iterations. The work presented in this report is the best available at this time; however, the expectations of the group are that the concepts will continue to evolve with the project.

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Introduction

Our sponsor, the USDA-ARS National Soil Dynamics Laboratory, has identified two problems encountered during normal use of an implement designed to supply beneficial nutrients to the soil. The implement, coined for the project purposes as a "poultry litter trencher", was designed and patented as an "Applicator System and Method for the Agricultural Distribution of Biodegradable and Non-Biodegradable Materials" [US Patent 7,721,662 B2]. The problems encountered include material bending in the litter depositing stage, and ineffective recovery in the soil restitution phase. Our task is to improve the design of the implement (shown below in Figure 1) to remedy these problems.

Figure 1- Subsurface Banding Poultry Litter Implement [Way, T. (2010) - Improvement of Soil Trenchers for a Subsurface Banding Poultry Litter Implement (6)]

Problem Specifications-

1) During the litter depositing stage, the force of the soil is causing inward bending of the 1/8th inch thick steel walls, leading to backup of the litter. The design chosen to fix this must be able to withstand the force from the soil (determined by implementing a force testing system) while allowing the poultry litter to travel unaffected to the soil. Considerations of the design include:

    - Weight
    - Manufacturability
    - Interface with existing components
    - Cost
    - Durability in rugged and caustic environment
    - Reliability
    - Accessibility

2) During the soil restitution phase, the current closing wheel system is not effectively recovering the dirt spread by the plowing portion of the implement. The result of this is a rut being formed as the implement travels. The goal of the design is to augment the current system, or design a replacement for it altogether. The design chosen will be more effective in recovering the soil, and will more accurately cover the litter band, ensuring a rut is not formed. Design considerations for the soil recovery system are:

    - Durability
    - Strength
    - Manufacturability
    - Cost
    - Reliability
    - Adjustability

Presented in the following report is a comprehensive study of the derived engineering specifications (both from test data, and conceptual analysis), concepts generated, evaluation, and the proposed solution(s) to the problems stated above.

Mission Objective(s):

Litter Application Component-

To improve or redesign the walls of the poultry litter implement so that litter can be more effectively distributed to the soil, mitigating the clogging that currently occurs under normal operation while

- Minimizing environmental impact
- Increasing the wall strength
- Providing reliable operation
- Being easily manufactured

Recovering Dirt Component-

To improve or replace the current press-wheel system used on the implement for dirt recovery so that the extricated soil is more effectively replaced over the deposited litter band. This must be accomplished considering

- Durability of the system
- Environmental impact
- Manufacturabiliy
- Effectiveness

Architectural Design and Development:

Feasible Alternatives- Litter Application Component

<u>Straight Wall</u>

Advantages

- Simple design
- Same as currently installed

- Moves no extra soil away from trench

Disadvantages

- Bends inward under soil pressure

Circular Bend

Advantages

- Allows for deflection without inhibiting litter flow

Disadvantages

- Complicated to manufacture
- Tills up soil contrary to sponsor needs
- Not easily fitted to current design

Angled Bend

Advantages

- Allows for deflection without inhibiting litter flow
- Fairly easily manufactured

Disadvantages

- Tills up soil contrary to sponsor needs
- Moves soil farther away from trench, making recovery more difficult

Front Flared

Advantages

- Releases force from trencher walls, thereby eliminating deflection

Disadvantages

- Tills up soil contrary to sponsor needs
- Complicates current design
- Moves soil farther away from trench, making recovery more difficult

Angled Wall

Advantages

- Allows for deflection without inhibiting litter flow

Disadvantages

- Complicated to manufacture and fit to current trencher design
- Tills soil contrary to sponsor needs
- Moves soil farther away from trench, making recovery more difficult
- Likely will need supports or rebending from time to time

* See Appendix A for sketches of designs

Feasible Alternatives- Recovering Dirt Component

<u>John Deere Model</u>

Advantages

- Two rows of collectors provides redundancy
- Rigid and sturdy design
- Simple and easily repairable
- Maintains position along ground

Disadvantages

- Large and fairly cumbersome
- Not adjustable to various widths
- Not easily fitted to current trencher design
- Likely to pull stalk debris into trench with dirt, allowing for erosion
- Does not adjust to various terrain heights

<u>Trapezoidal Scoop Model</u>

Advantages

- Simple and cost effective design
- Convenient mounting for current trencher
- Adjusts to various terrain heights
- Easily manufactured

Disadvantages

- Flimsy design
- Likely to pull stalk debris into trench, allowing for erosion
- Likely will bounce if hard or uneven terrain is encountered

Self Adjusting Scoop

Advantages

- Adjusts very well to changing terrain
- Sturdy design

Disadvantages

- Complicated to manufacture and assemble
- Difficult to fit to current trencher design
- Likely to till soil and be environmentally unfriendly
- Maintenance and purchase relatively costly

Two Bar Collector

Advantages

- Simple design
- Easily produced and fitted to current design
- Easily manufactured
- Adjusts to changing soil height
- Can be adjusted for varying trench widths

Disadvantages

- Possibility of being flimsy
- Will require additional weight to hold near ground

Two Hinge Scoop

Advantages

- Adjusts to changing terrain height
- Simple and easily manufactured
- Easily fitted to current trencher design

Disadvantages

- Flimsy design
- Likely to bounce when rough terrain is encountered

* See Appendix A for sketches of designs

Requirements:

Trencher (System)

- Apply litter band to soil at desired depth
- Work in corrosive environment
- Perform with little or no maintenance
- Minimize damage to environment during operation
- Perform under various soil conditions
- Must be affordable for eventual manufacture and market (approximately $25,000 for the implement)
- Be reliable in operation
- Must be adjustable to different terrain
- Needs to operate safely

Trencher Walls

- Prevent clogging of poultry litter during application to soil
- Withstand pressure from soil
- Work in corrosive environment
- Perform with little or no maintenance
- Minimize damage to environment during operation
- Perform under various soil conditions
- Be compatible with current trencher design
- Must be affordable

Soil Recovery System

- Recover soil displaced by leading edge and trencher walls
- Support or replace current press-wheel system
- Operate reliably under different soil conditions
- Avoid interference with crops
- Minimize environmental impact of trencher
- Require minimal maintenance
- Cost effective
- Needs to be easily manufacturable

In order to quantify some of the requirements of the trencher implement, engineering analysis was performed on select areas of the project. The first undertaking was to measure the force exerted on the trencher walls by the soil. To complete this task, it was decided that a testing rig be created. The final design of the force testing rig uses four pressure transducers mounted to a plate of 1/8th inch steel sheet metal with a recess machined for each transducer, as shown in Figure 2.

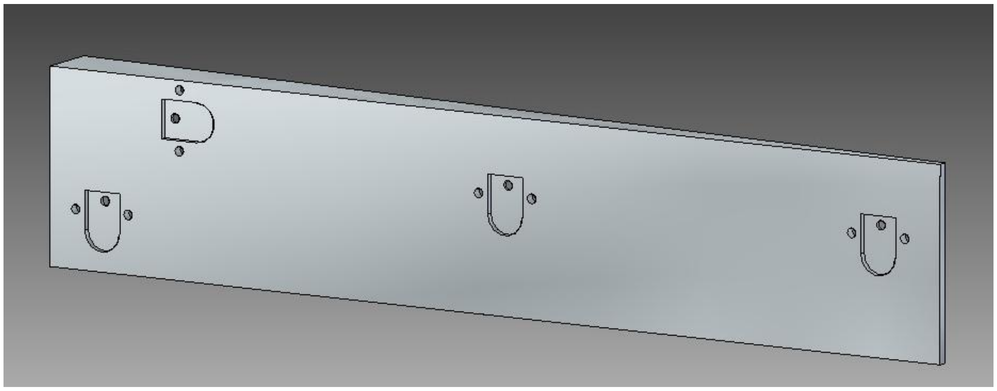


Figure 2- CAD Drawing of Force Testing Rig

The pressure transducers were mounted flush to the surface of the steel so that the reading will be accurate and the transducers will be protected from the soil. The force test rig was mounted in a configuration as close to the actual configuration of the bent trencher walls. As shown in Figure 3, this was done by mounting the rig to a straight trencher wall, using triangular spacers to achieve the desired angle.

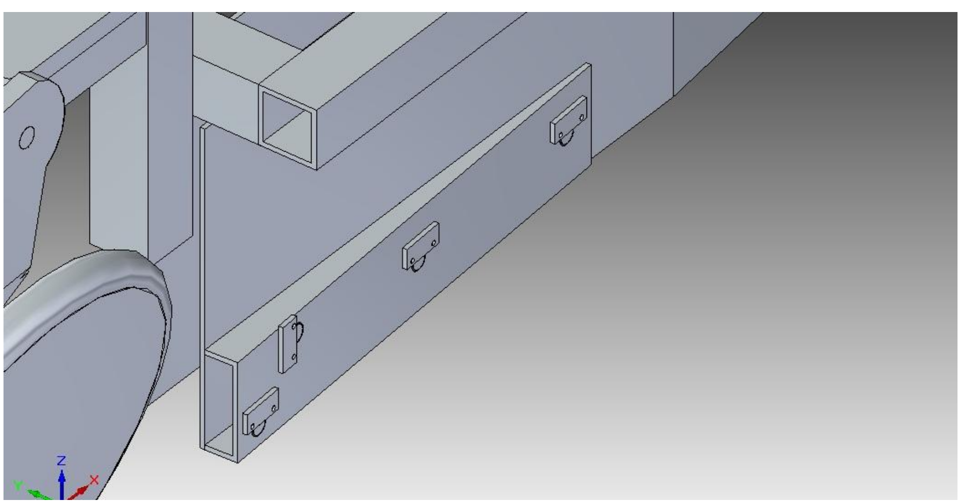


Figure 3- CAD Drawing of Assembled Force Testing Rig

After mounting the force test rig to the trencher, a small tractor will pull it through the soil. Data for each pressure sensor will be recorded along with the depth of the trencher at each data set. This will give an accurate measurement of the pressure on the trencher walls, the results of which will be used in a finite element analysis (ANSYS) of the deflection of the walls. Preliminary testing with an estimated force show that increasing the thickness of the trencher walls drastically reduces the deflection. The results of this, and a sample of the deflection in the trencher walls, are shown in Figures(s) 4-5.

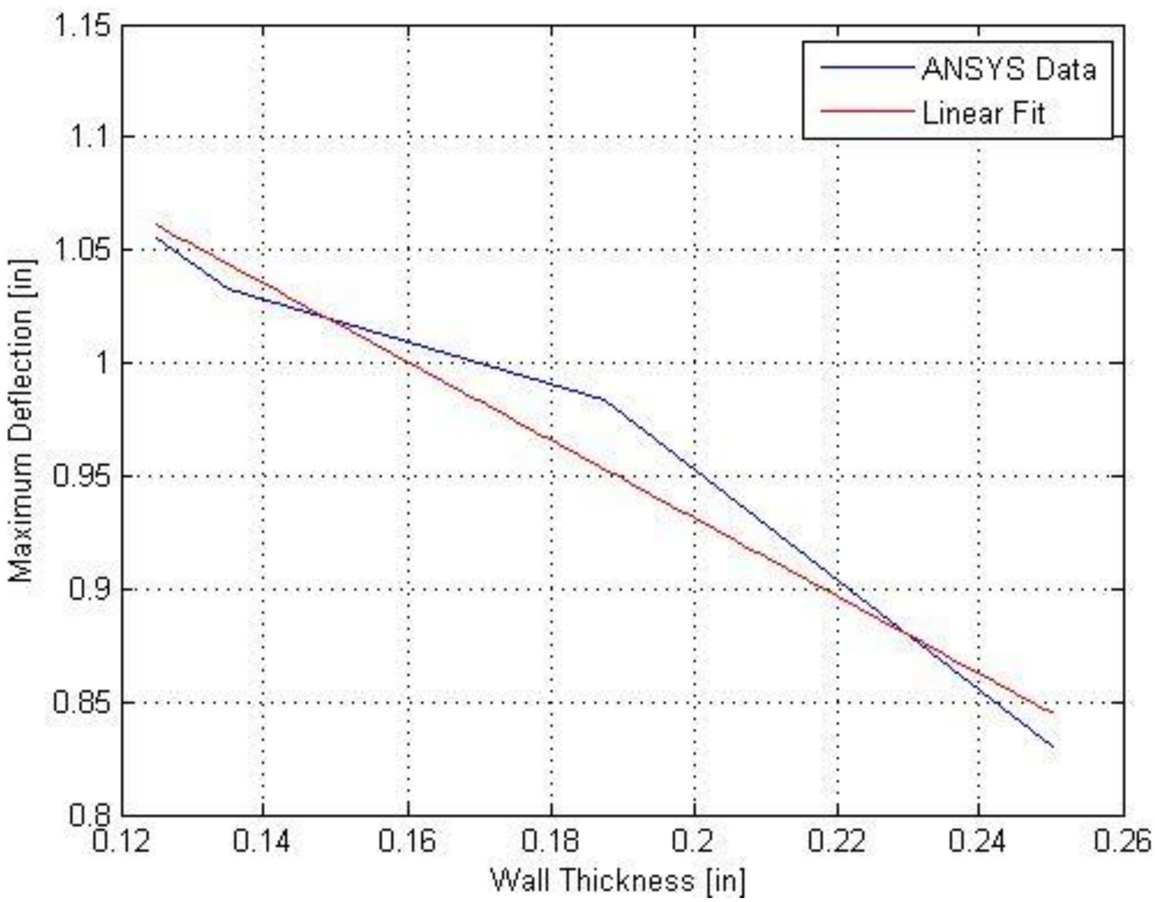


Figure 4- Deflection in the Trencher Walls vs. Wall Thickness

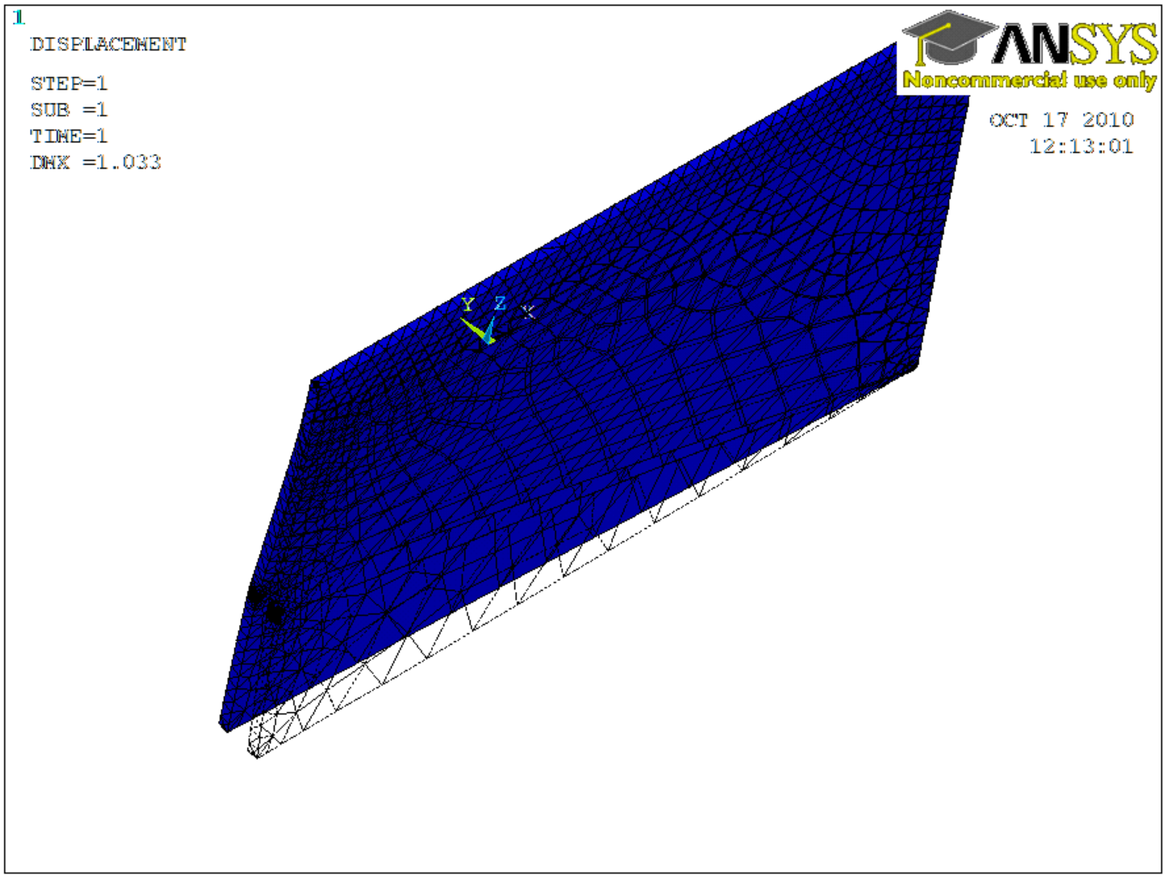


Figure 5- Sample Deflection in Angled Bend Trencher Wall

Additionally, to determine the impact that adding a soil recovery device would have on the trencher implement, and to help size components, a generic MATLAB program was created (see Appendix B for code). The program determines the minimum effective weight of the soil recovery device, the shear in the pivoting parts under differing conditions, and the additional force experienced by the trencher. The results of this analysis help to determine the durability, reliability, and weight requirements of the soil recovery device.

Based on the requirements set forth, and the analysis completed, a weighted evaluation was performed by the group. The results of the evaluation are presented on the next page in Table(s) 1-2.

Requirement	Importance	Straight Wall	Circular Bend	Angled Bend	Front Flared	Angled Wall
No Bending	**9**	8	8	8	9	8
Cost	**5**	8	4	6	6	7
Reliability	**8**	6	6	6	6	6
Environmental Impact	**7**	10	7	8	2	7
Maintenance	**7**	8	8	8	8	8
Effectiveness	**9**	5	8	8	6	8
Weight	**4**	6	6	6	5	6
Manufactuability	**7**	10	3	7	3	6
Compatibility	**9**	8	8	8	4	8
Total Scores (% of max)		76.46%	66.77%	73.69%	55.38%	72.31%

Table 1 – Structured Evaluation of Trencher Wall Concepts

Requirement	Importance	John Deere	Trapezoidal Scoop	Self Adjusting	Two Bar	Two Hinge
Cost	**7**	3	7	6	8	8
Durability	**8**	8	7	7	7	5
Reliability	**8**	9	7	6	7	6
Environmental Impact	**6**	7	7	9	7	7
Maintenance	**6**	9	8	7	8	8
Effectiveness	**10**	6	7	8	7	6
Weight	**4**	5	6	6	6	7
Manufactuability	**8**	10	7	7	8	9
Compatibility	**7**	0	8	6	8	8
Adjustability	**8**	2	7	7	7	7
Total Scores (% of max)		59.58%	72.36%	70.28%	74.44%	71.39%

Table 2 – Structured Evaluation of Soil Recovery Concepts

In both evaluations, multiple concepts performed well. For the trencher walls, a straight wall redesign (thickening of the walls) was chosen initially, but after a meeting with the industrial sponsor, it was decided to pursue a design similar to the angled bend to ensure the poultry litter would not clog under normal operation. The two bar collector was chosen for the soil recovery phase; however, further design iterations look to incorporate the best of all of the alternative components.

Product Hierarchy

The project consists of two objectives: the trencher wall redesign, and the soil recovery component. As the trencher walls are considered a part in the trencher subsystem, there is no particular need for a product hierarchy. However, physically the trencher walls provide the exterior structure of the trencher implement. The walls separate and hold back the soil, and allow poultry litter to be deposited in the division. The walls have a physical interface with the trencher skeleton, and utilize welds to fix their position.

The soil recovery subsystem of the trencher implement has two further subsystems: the linkage bar, and the recovery scoops, as shown in Figure 6.

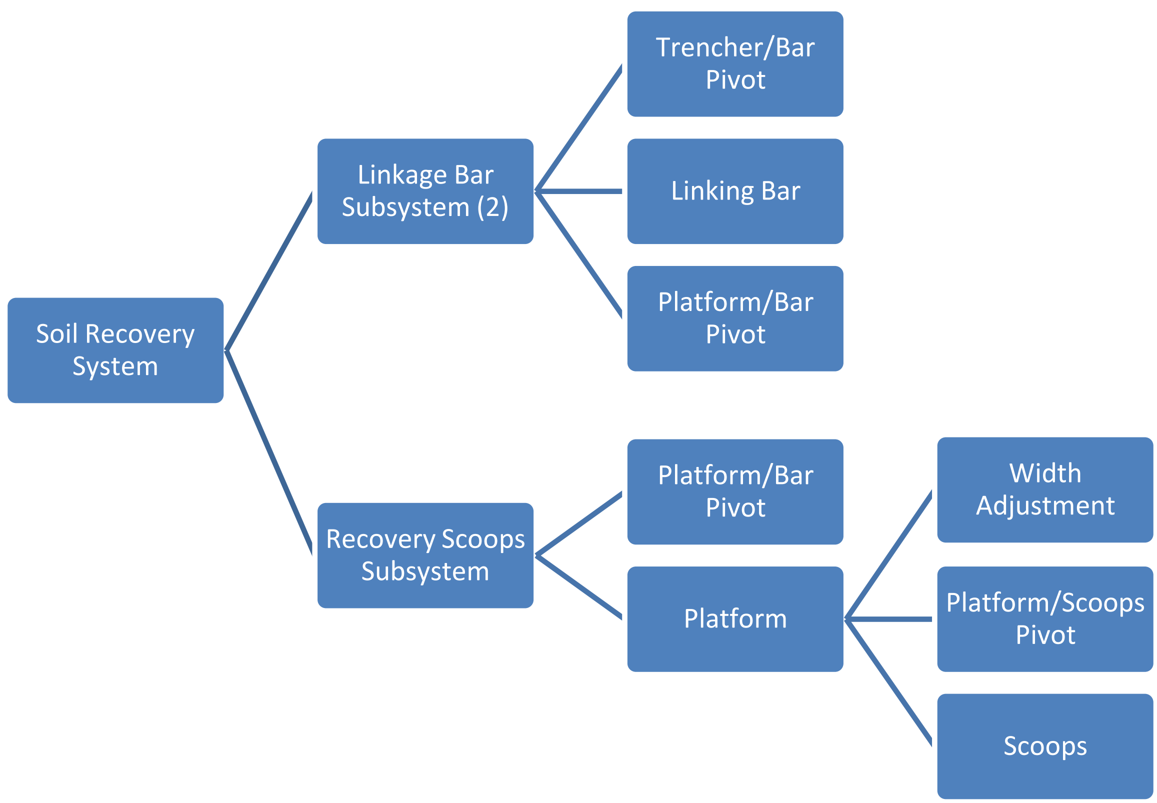


Figure 6- Product Hierarchy of the Soil Recovery Subsystem

The components of each linkage bar subsystem are two pivots, likely machine bolts, and a linking bar which will span between the trencher and recovery platform. The recovery platform will serve as the location for width adjustment of the scoops, and to connect the scoops with the linking bar. The components of the recovery scoop subsystem are as follows: a pivot connecting the linking bar to the recovery platform, the recovery platform, a lockdown component that fixes the position of scoops, a pivot that connects the scoops to the platform, and the actual scoops themselves. The soil recovery system is located between the tailing edge of the trencher walls and the press-wheel system. The soil recovery system will be designed so that it cannot interfere with any other systems in the implement.

Bill of Materials

The tentative Bill of Materials for the soil recovery system is presented in Table 3 below.

Materials	Quantity	Unit Cost	Notes
Steel Bar	2	$11.07	1x12x1/4"
Steel Plate	1	$40.31	6x6x1"
Steel Flat Bar	2	$56.68	5x18x1/4
Zinc Plated Bolt	8	$0.08	1/4" – 20, @1 and 1/2" length Priced individually from pack of 100
Zinc Plated Nut	6	$0.03	1/4" - 20 Priced individually from pack of 100
Zinc Plated Wing Nut	2	$0.10	1/4" - 20 Priced individually from pack of 100
Labor	1	$35.00	http://www.bls.gov/oco/ocos223.htm
	Total	**$225.15**	

Table 3- Bill of Materials for Soil Recovery System

Concept of Operation

The subsurface banding poultry litter implement, as the name implies, delivers poultry litter from a hopper to a trench dug by the implement between rows of crops. There are a series of four implements, known as trenchers, attached to a main structure. The system is pulled behind a farm tractor and hydraulic power is provided by a pump located within the tractor.

Upon the main structure sits the hopper that distributes the poultry litter to the four trenchers via a series of conveyor belts. The belts are propelled by a series of motors powered by the aforementioned hydraulic system. For each trencher, a coulter produced by Yetter (2995 Series Coulter) breaks the soil surface [1]. The coulter is attached to the main structure by a four-bar mechanism [not shown] that allows the trencher to travel in the vertical direction with changing soil height or obstacles. Also attached to the four-bar mechanism and located directly behind the coulter is an expansion wedge [2]. The wedge, composed of sheet metal, spreads the broken soil to the necessary width for the trench. It is supported on the bottom by a plastic insert that keeps unwanted dirt from entering the wedge.

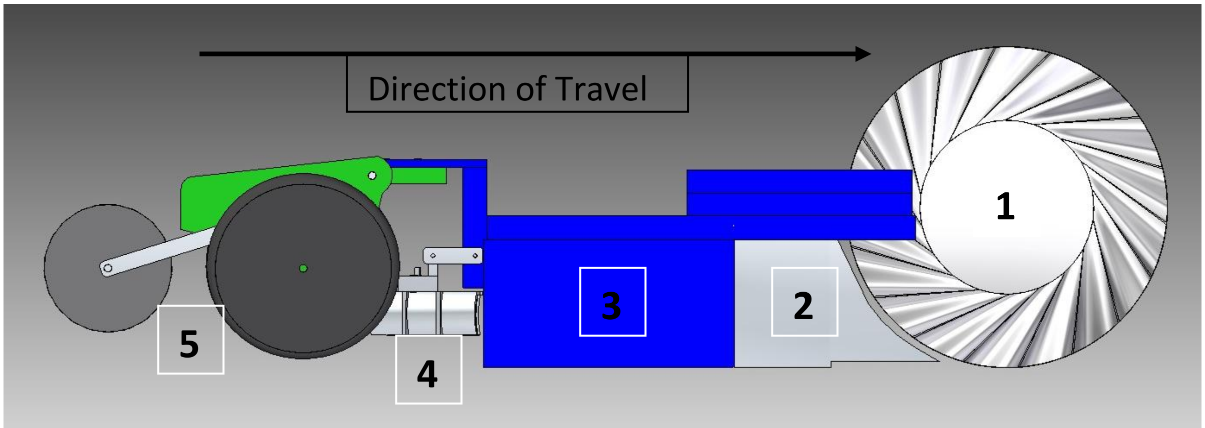


Figure 7- CAD Drawing of Poultry Litter Trencher

Sheet metal welded to the rear edge of the wedge serves as the trencher walls [3]. Between these parallel walls, the poultry litter can be deposited to the trench. The trencher walls are bent out at a slight angle towards the rear of the wall to prohibit pinching of the walls together. This type of pinching would constrict the flow of litter and create clogging. Behind the trencher walls is a two-bar mechanism that serves to collect the dirt pushed aside by the coulter and wedge [4]. Moreover, the collector’s goal is to move the dirt inwardly so that a John Deere closing disk assembly may place it in the trench. The collector component is shown in more detail in Figure 8.

The closing disk assembly, from a John Deere Pro-Series XP Row Unit, is connected to the trencher structure and pivots on a spring assembly that allows for vertical translation with changing elevation and obstacles. Attached to the disk assembly is a set of wheels that compact the soil once it has been returned to the trench [5]. The compaction occurs solely under the weight of the wheels so as not to overly compress the soil.

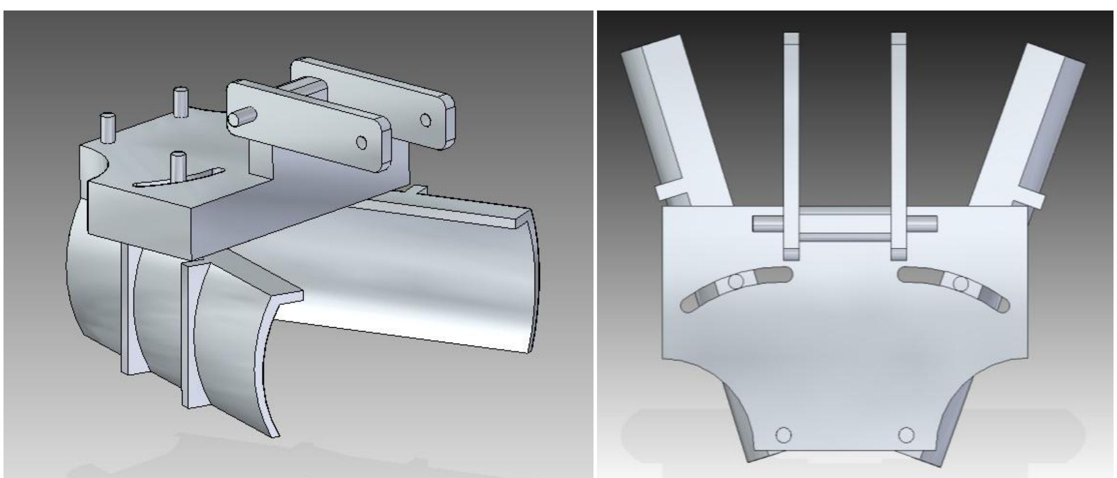


Figure 8- CAD Drawing of Soil Recovery Component

Validation and Verification:

To verify that the redesigned implement is meeting the requirements set forth, simple tests will be performed in conditions that simulate those found in the operating environment. The trencher will be run in various soil types, and at various soil depths to ensure the poultry litter is depositing without problem. At the same time, the recovery implement will be checked for effectiveness in guiding the loose dirt back over the trench.

The testing plan for system validation is also quite simple. The redesigned trencher will be placed in the original system, run under various soil conditions, and compared with the original trencher based on performance, environmental impact, effectiveness, and maintainability. No interfacing problems are expected as the redesigned trencher will mount using the same connections.

Interfaces and ICD:

The interfaces found in this system are strictly mechanical, as shown in Figure 9 below.

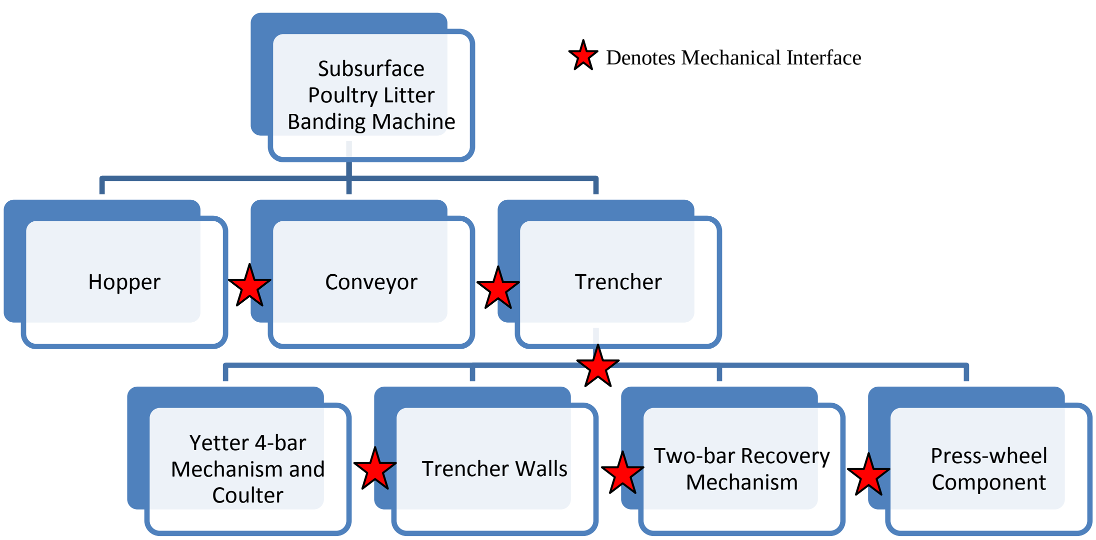


Figure 9- Interfaces and Operational Boundaries of System

The interfaces that are of importance to the project are mainly at the component level. Little is expected to change in the mechanical interface between the trencher and Yetter 4-bar mechanism and coulter. The same is true with the press-wheel component. The trencher walls are expected to change in shape, but the same technique for mounting (namely welding) is expected to be employed, and connection points will remain in relatively the same location. The two-bar recovery mechanism will mount to the trencher by use of pivot. It is thought that a simple bolt will provide the means for the pivoting action. The bolt will be sized according to a "worst-case" force analysis performed on the two-bar mechanism; however, preliminary results show that the shear forces will be small, and no additional support will need to be added to the trencher structure.

Mission Environment:

Our mission environment is very corrosive. The chemicals from the chicken feed, compounded with the occasional dampness of the soil, make for a rough environment for steel (as of now the main metal of the system). Our goal is to reduce the effects of the corrosion on the material (either by choosing a new, more corrosion resistant metal, or applying a corrosion resistant coating), while at the same time ensuring we don't add any harmful materials (mainly from any coating) to the environment.

Risk Management:

During normal operation, the trencher poses little risk to the operator and/or onlookers. More important to consider in this application is the risk due to mechanical or other failure. Presented in Table 4 is an outline describing the potential failures of the system, their severity, and possible solutions to remedy the problem.

Rank	Risk Title	Risk Exp.	Action	Risk Type	Status
1	Component separation from trencher system	Likelihood: Low Consequence: Mod	Watch	Technical	Redesign fasteners, components, or subsystems
2	Clogging of trencher walls	Likelihood: Mod Consequence: Mod	Watch/ Research	Technical/ Program	Redesign of trencher walls
3	Soil not sufficiently collected by soil recovery subsystem	Likelihood: Low Consequence: Mod	Watch/ Research	Technical	Adjust recovery device
4	Damage to crops by soil recovery subsystem	Likelihood: Low Consequence: Low	Watch	Technical/ Program	Adjust soil recovery subsystem
5	Soil over-tilled by soil recovery subsystem	Likelihood: Low Consequence: Low	Watch	Technical/ Environmental	Adjust soil recovery subsystem
6	Deformation of trencher walls	Likelihood: Mod Consequence: Mod	Research	Technical/ Program	Redesign of trencher walls
7	Soil over-tilled by trencher walls	Likelihood: Low Consequence: Mod	Watch/ Research	Technical/ Environmental	Redesign of trencher walls
8	Damage to crops by trencher walls	Likelihood: Low Consequence: Mod	Watch	Technical/ Program	Redesign of trencher walls

Table 4- Risk Management Structure

Configuration Management:

Please see the website for information regarding how the configuration is managed.

Subsystems Design Engineering:

The structure of this project has two main branches: the trencher walls, and the soil recovery device. Each subsystem must not only be able to complete its assigned task, but also interface with the entire system. To ensure that each subsystem would function on its own, and in the context of the whole system, careful methodology in systems engineering was employed.

This began in the Pre-Phase A stage, where the mission objectives and concepts were generated. Each mission objective was treated as its own entity, and the focus of concept generation was solely on completing the objective. Multiple concepts were generated for both subsystems.

In Phase A, the requirements for the entire system were formed. A trade study of the materials and methods available for use in fabrication was completed as well. The generated concepts were discussed with the industrial sponsor, and the focus of the project was narrowed to one concept for each subsystem. This allowed the group to move forward to Phase B.

In Phase B, the subsystem level requirements were formed. For the trencher walls, it was determined that the mission environment needed to be quantified, specifically in determining the force exerted on the walls by the soil. To accomplish this, a pressure testing rig was designed and fabricated in coordination with the industrial sponsor. Finite element analysis was performed on the trencher wall concept to determine if it was suited for the environment. For the soil recovery device, the requirements were easier to obtain. Simple proof-of-concept mock-ups were created, and the soil recovery design was tested for effectiveness.

Project Management:

The project management structure is based on the strengths of the individual team members. As is such, there is some overlap within the structure, and the completion of a task is rarely performed by one member; however, the basic management structure is presented below in Figure 10.

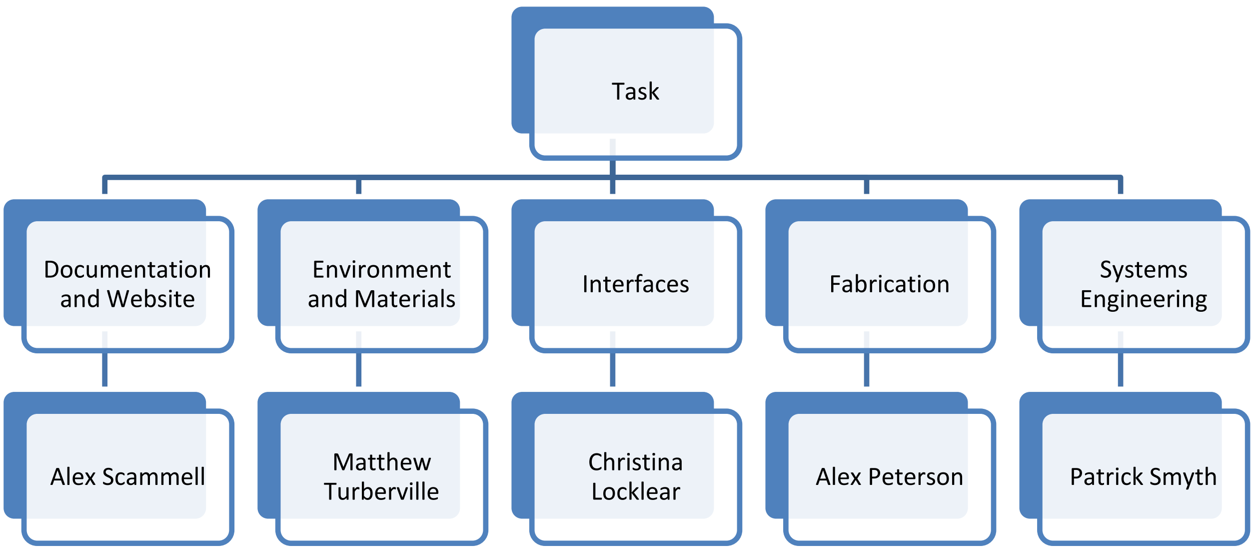


Figure 10- Project Management Structure

For the upcoming concept design review, the focus of the group is on researching, sizing and validating components. Once the appropriate analysis has been performed, the group will perform the detailed design necessary for the project. It is expected that most of the parts will be fabricated in the USDA's machine shop, so drafts will need to be created. Additionally, the interfaces will be checked in accordance with the systems engineering process. Deliverables are expected to include drafts, interfaces, and verification of parts and components.

The project is managed by using a series of milestones, presented in a Gantt chart. Due to size constraints, the Gantt chart is available in Appendix D.

Conclusions:

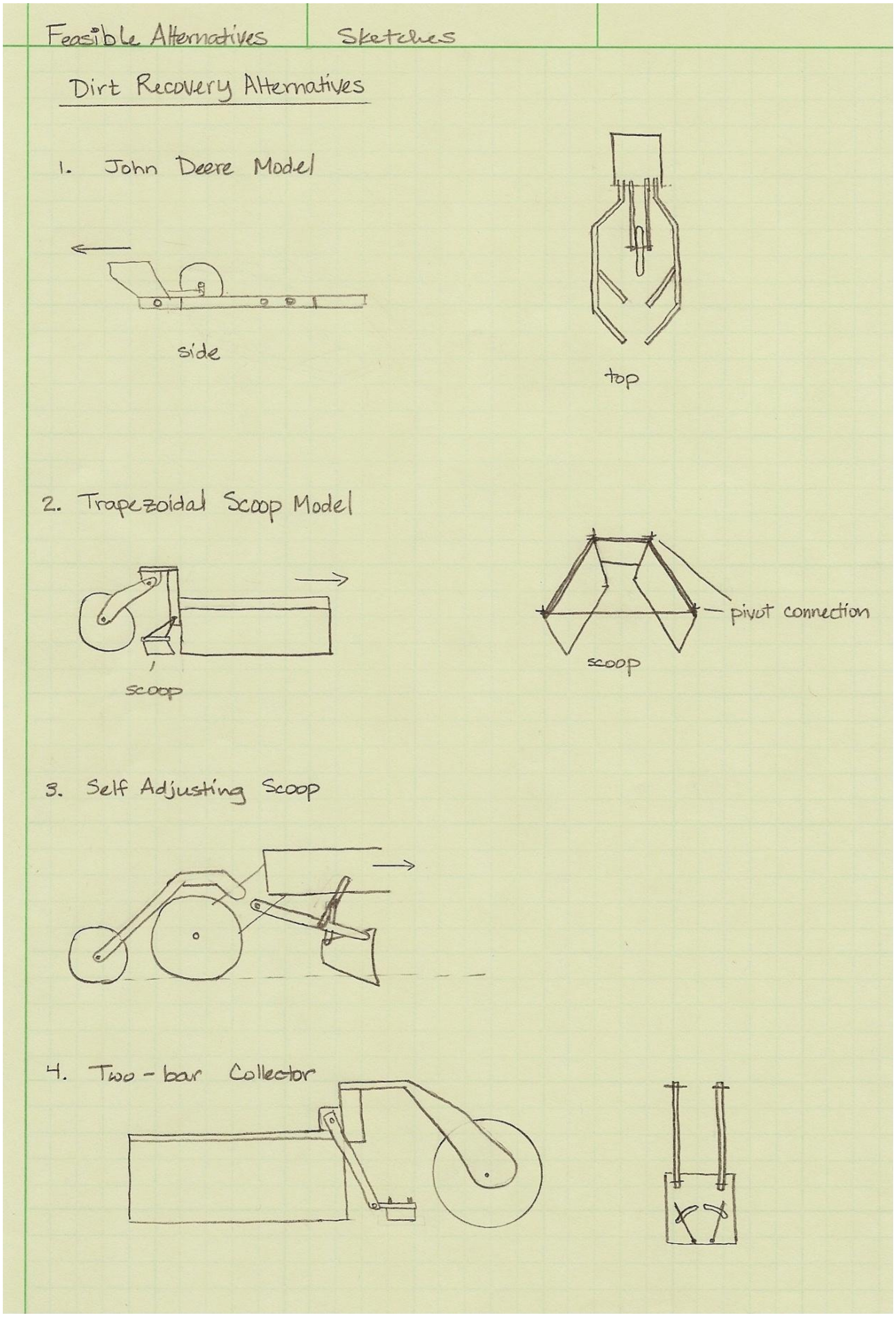
Throughout the project, the desire of Corp_10 has been to effectively complete the mission objectives while utilizing the simplest design possible. This is due to the nature of the project. The end user for the implement, the farmer, does not need or desire an overly complicated piece of machinery. Rather, the user requires a device that will perform reliably in all circumstances, while needing little maintenance and keeping costs down. This mentality has provided the group a chance to experience practical engineering.

Using the structured evaluation, deductive reasoning, and our sponsor's input, it was decided to pursue an angled bend design for the trencher walls. This will eliminate pinching in the walls, which previously caused poultry litter backup. What remains is determining the thickness of the walls, which will be decided when the results of the force testing are completed. It is believed that the design will meet or exceed all of the requirements set forth.

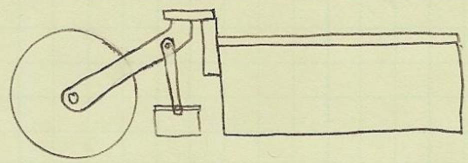
For the soil recovery device, it was decided to use a two bar linkage system that will ride behind the trencher, but in front of the press-wheel system. It is thought that the simple design will augment the effectiveness of the press-wheels and meet the requirements set forth. The preliminary design is complete for this subsystem; however, some work remains in designing the final component. Parts will need to be sized and bought or fabricated.

Overall, the project appears to be on-schedule for completion by the culmination of the spring semester of 2011. Our corporate sponsor has been instrumental in ensuring this is a learning experience for the group, and each member of Corp_10 has been able to further their engineering knowledge thus far. The expectation is that this will continue as the project progresses.

Appendix A: Feasible Alternatives



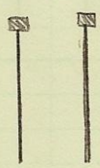
5.



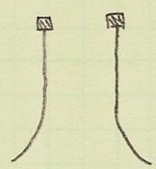
Two Hinge Scoop

Trencher Wall Alternatives

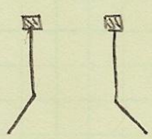
1. Straight Wall



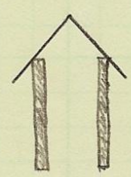
2. Circular Bend



3. Angled Bend



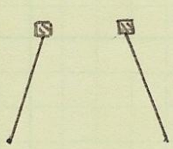
4. Front Flared.



viewed from top

↑ direction of travel

5. Angled Wall



Appendix B: Analysis

```
% Senior Design
% Force on the soil recovery device
% Corp_10

clear all
close all
clc

% Knowns
g = 32.2; % f/s^2
p_steel = 0.284; % lb/in^3 (Structural Steel A36, Hibbeler- Back Cover)
p_soil = 110/(12^3); % lb/in^3 (http://www.concrete-
catalog.com/soil_compaction.html)
V_soil = 5*1.75*4; % in^3 max displaced by trencher
u = 0.3;

Fsoil = [-V_soil*p_soil,0,0]; % lbs

% Wcs = 12.5;
acx = .88; % ft/s^2 0-3mph in 5 seconds
syms Rgs F21xs F21ys FT2xs FT2ys Wcs real

ac = [acx,0,0];
F21 = [F21xs,F21ys,0];
Wc = [0,-Wcs,0];
FT2 = [FT2xs, FT2ys,0];
R = [0,0,0]; % Assume min weight when ground doesn't provide any reaction
Ff = [-u*R(2),0,0];
m1 = -Wc(2)/g;

equ = Wc + R + F21 + Ff + Fsoil - m1*ac;
equ1 = equ(1);
equ2 = equ(2);

rT = [0,0,0];
rM = [-1.5,-5,0];
rC2 = (rT + rM)/2;
rC2T = rT-rC2;
rC2M = rM-rC2;
rTM = rM-rT;
V_2 = hypot(rTM(1),rTM(2))*1.5*.25*2; % Volume of Steel in linkage (quarter
inch, by 1.5 inches)
m2 = V_2*p_steel;
G2 = [0,-m2,0];

% Linkage

equ_B = -F21 + FT2 + G2 - m2*ac;

equ3 = equ_B(1);
equ4 = equ_B(2);
```

```
equ5z = cross(rC2T,FT2) + cross(rC2M,-F21);
equ5 = equ5z(3);

sol = solve(equ1,equ2,equ3,equ4,equ5);
F21x = eval(sol.F21xs);
F21y = eval(sol.F21ys);
FT2x = eval(sol.FT2xs);
FT2y = eval(sol.FT2ys);
WC = eval(sol.Wcs);

F21 = [F21x, F21y, 0]
FT2 = [FT2x, FT2y, 0]
WC = [0,WC,0]

Q1 = hypot(F21x,F21y)
Q2 = hypot(FT2x,FT2y)
```

Appendix C: Trade Study

Possible Metals

Wear-Resistant Air-Hardened D2 Tool Steel

Versatile high-carbon/high-chromium tool steel that has great wear and abrasion resistance. Offers high hardness and is commonly used for long-run dies and blanking, as well as shear blades, burnishing tools, and gauges.

Easy-to-Weld Aircraft-Grade 4130 Alloy Steel

Very similar to 4140, but has a lower carbon content, giving it better weldability and formability while retaining good fatigue, abrasion, and impact resistance. Use it when military specifications must be met and for your most demanding structural applications.

Super-Corrosion-Resistant Stainless Steel (Type 316)

Higher molybdenum content provides better corrosion resistance than Type 304. Low carbon chromium-nickel (austenitic). Good weldability and temperature resistance. May become slightly magnetic. Not heat treatable. Maintains corrosion resistance up to 800° F.

General-Purpose Low-Carbon Steel

1006 to 1035 carbon steel. Easy to cold form, bend, braze, and weld.

Multipurpose Nickel (Alloy 400)

Also known as Monel 400, this nickel-copper alloy provides excellent corrosion resistance, good weldability and formability, and high strength.

High-Strength Super-Corrosion-Resistant Aluminum (Alloy 5083)

The strongest of the marine-grade alloys. Offers high strength in addition to excellent corrosion resistance and good weldability. Typically used in saltwater applications. Not heat treatable. Nonmagnetic.

Ultra-Corrosion-Resistant Architectural Aluminum (Alloy 6063)

Superb corrosion resistance. Perfect for outdoor applications.

Corrosion-Resistant High-Strength Aluminum (Alloy 7075)

Exceptionally strong but still lightweight, this aircraft alloy has better corrosion resistance than Alloy 2024 due to the addition of zinc. Use for aircraft frames, keys, gears, and other high-stress parts.

Multipurpose Aluminum (Alloy 6061)

Most widely used aluminum alloy due to combination of strength, good corrosion resistance, and machinability.

Possible Coatings

- **Nox-Rust 3100 (X-110) Heavy Duty Corrosion Control Temporary Coating**

  Proven VCI temporary heavy duty outdoor barrier corrosion protection coating provides 1 to 5 years corrosion protection to bare metal parts or painted surfaces. Apply to clean or rusted metal surfaces to give superior VCI protection, including water and salt spray resistance.

  Dries to a firm dry to touch clear corrosion protective coating. Can be removed with many common water based degreasers. Provides requirements of Mil C-161793 Rev E. Class 1 Grade 4 and Mil PRF-16173 Rev E. Grade 4

  Package: 5 gallons or 55 gallon drums ($237.45 - $828.82)

- **Nox-Rust 5100 Petroleum Outdoor Corrosion Inhibitor**

  Corrosion protective coating designed to protect metals when exposed to outdoor weather conditions and for general purpose preservation, indoor or outdoor, with or without cover, for domestic and overseas shipment where a "dry to touch" film is required. Can be removed with a degreasing wash, steam or common industrial wax remover.

  Black color dry to touch temporary coating Salt Spray 336 hours; humidity cabinet 1200 hours
  Package: 5 gallons or 55 gallon drums ($245.17 - $980.68)

- **VCI-8500 Clear Permanent Coating for Outdoor Corrosion Protection**

  Water-based, air-dry, permanent, hard barrier coating that provides extended outdoor protection for multi-metals. Available in colors and as clear coat. Average performance results 168 hours, ASTM B-117 Salt Spray Test @ 1-2 mil DFT (Dry Film Thickness) Low VOC 0.75 lbs/gallon

  This Daubert Corrosion Coating provides up to three times the protection of similar water based VCI coatings. Package: 5 gallons (19 liters) and 55 gallons (208 liters) ($192.00 - $768.00)

- **<u>Nox Rust 9900 Aqueous Clear Outdoor/indoor Barrier Corrosion Coating</u>**

  Environmentally safe <u>water based barrier</u> VCI <u>coating</u> for bare metal parts or industrial finishes to provide corrosion protection. Water based easy to use metal corrosion control available in 5 gallons or 55 gallons. Very thin, very clear coating. Dries to a dry, non-tacky finish. Removable.

  ($181.75 - $727.00)

ALL PREVIOUS FOUND AT: http://www.corrosionvci.com/coatings.htm

- **Cold Zinc Galvanize #958**
  Cold Zinc Galvanize prevents corrosion and rust creepage on metal surfaces where rusting has occurred. After curing, the protective coatings can be painted over to restore the original look of the surface or to bring it new life. Easily bonds to metal and electrically re-coats corroded areas. Clogging is eliminated due to a special valve used on the product. Provides an unmatched, blemish free film because of our formula's extremely stable unique zinc suspension. Meets many U.S. military specifications and is authorized by the USDA for use in meat and poultry plants. Useful anywhere rust and corrosion are a nuisance.

- **Rust Exterminator #965**
  Stops rust and corrosion by converting corroded surfaces to a tough, black chemical resistant film ie: protective coatings . Can be used as a primer to stop rust prior to painting. Quickly neutralizes existing rust while preventing the formation of new corrosion. A convenient, one-step aerosol that allows product application in hard to reach areas and eliminates the need for extensive clean up or major surface preparation.

ALL PREVIOUS FOUND AT: http://www.interstateproducts.com/coating.htm

- **Ultra High Molecular Weight Polyethylene**
  The highest abrasion resistance. Outstanding impact strength even at low temperatures. Excellent sliding material due to low coefficient of friction. Self-lubricating. Easily machined with common woodworking tools
    - http://www.ptreeusa.com/uhmwproducts.htm
    - 1/4" X 4" X 48 " Sheet = $11.99

Appendix D: Gantt Chart