Ground Station 2011

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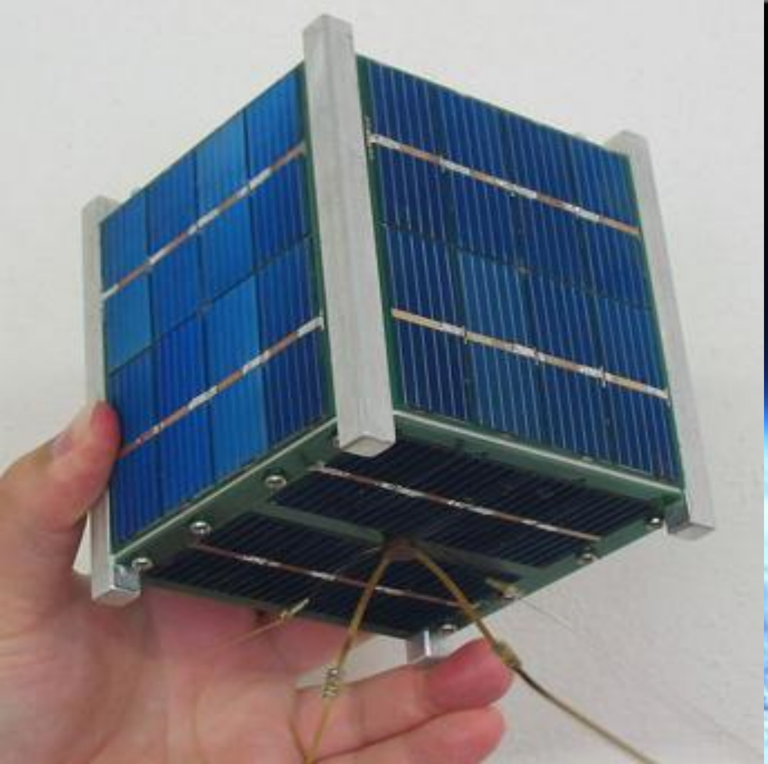
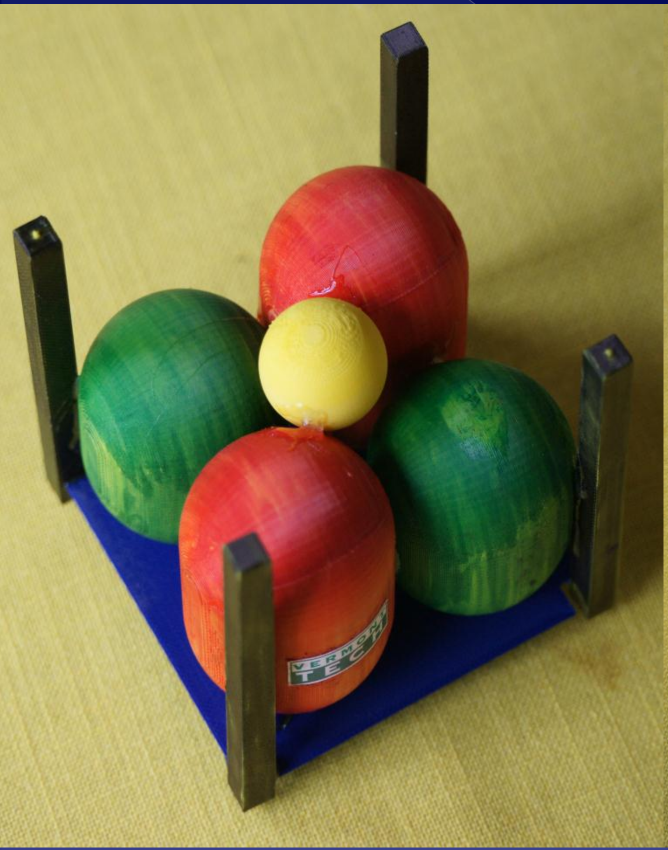
Contents

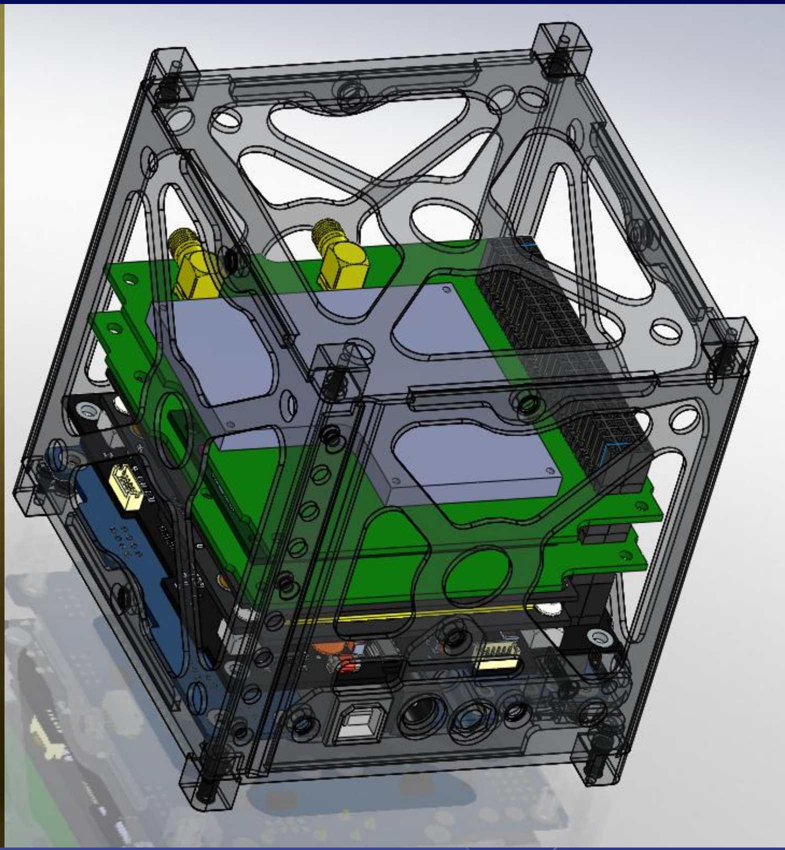
Background - CubeSat

- CubeSat is 10cm x 10cm x 10cm (10cm ≈ 3.94 inches)
- Solar Powered
- Utilizes GPS and Celestial Navigation Techniques
- Transmits Information from Sensors
    - Camera, UV/IR Spectrometer, Electron Flux



Background – CubeSat





Lunar Lander Booster 3D Solid Model of
Rapid Prototype Models CubeSat Structure

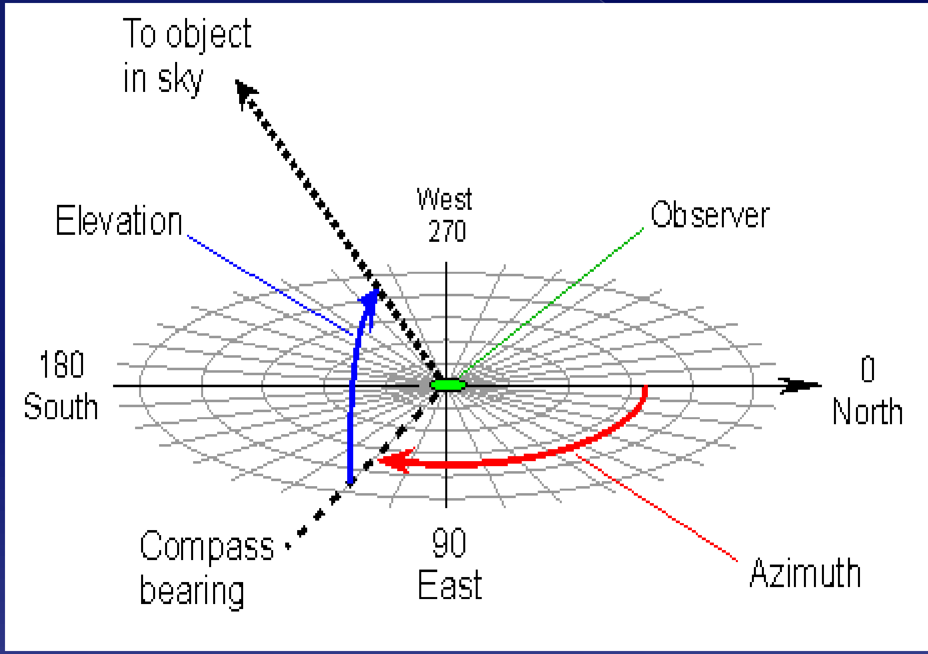
Background – Ground Station

- VTC developing CubeSat, transmits data
  - Continuing where previous groups have left off
- Have to follow CubeSat to receive data (2.4gHz)
- Existing 3-meter parabolic dish antenna
- Low orbit satellite revolves around Earth in minutes, seen for short time per orbit

Problem – Ground Station

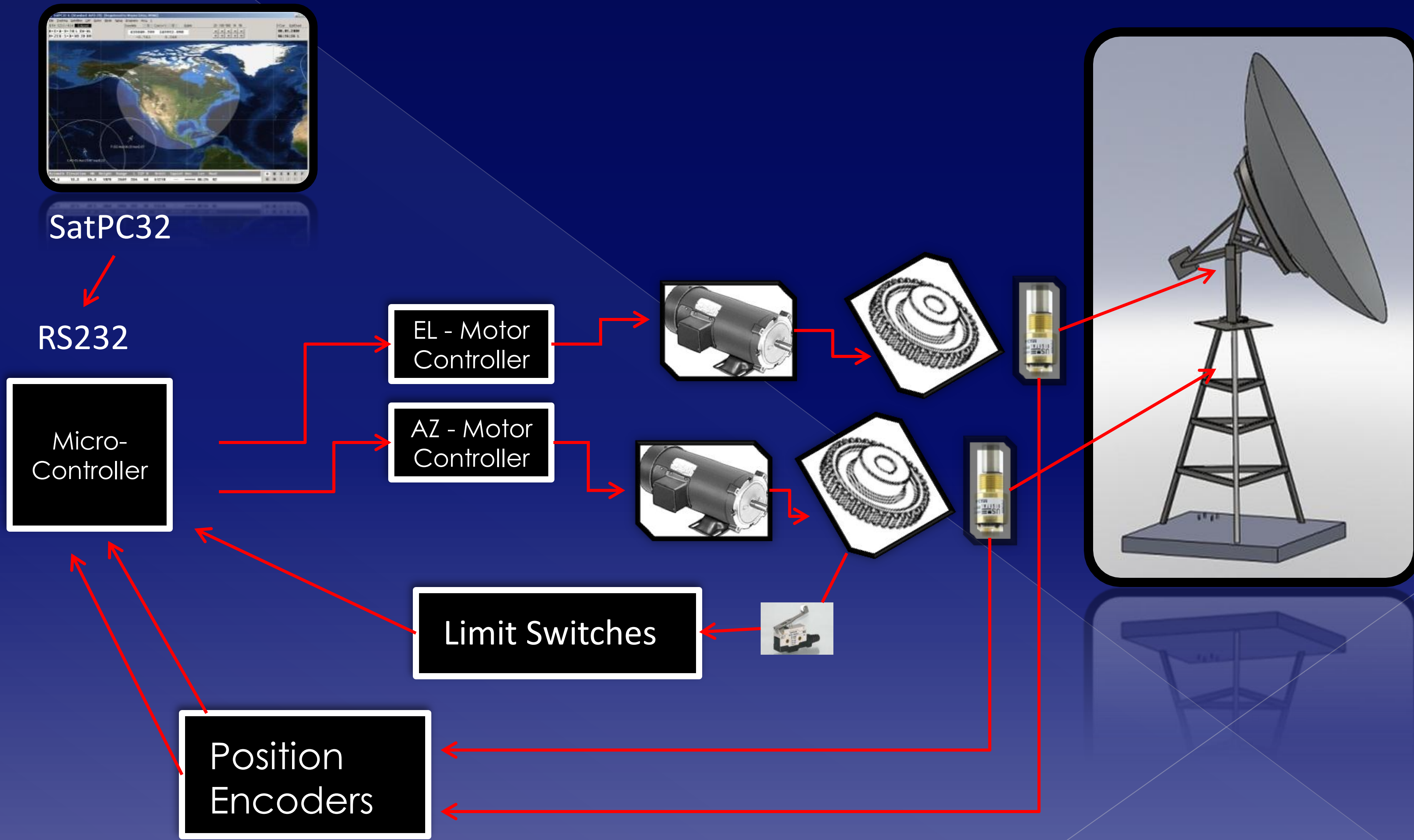
- Track a low orbit satellite such as a CubeSat from horizon to horizon in as little as 30 seconds with an accuracy of ± 0.5°
  - 180° /30 seconds=6° /sec
- Move a 3 meter satellite dish
  - 360° Azimuth (left/right)
  - 180° Elevation (up/down)
- Interface to PC running SatPC32 (Satellite Tracking Program)

Azimuth and Elevation



- Azimuth
  - A left to right angle measurement from a fixed point (north in navigation)
- Elevation
  - Angle between the flat plane and the object in the sky (satellite).

Solution


SatPC32
RS232
Micro-Controller
EL - Motor Controller
AZ - Motor Controller
Limit Switches
Position Encoders

Mechanical Areas of Interest

- Axis orientation (EL/AZ or AZ/EL)
- Weight of dish and Center of Mass
- Moment of Inertia of the dish
- Torque needed to spin/flip the Dish

Choosing a Mount Design

Choosing a Solution:

- Two choices: Fork Mount and Equatorial mount

- Equatorial is accurate
- Fork is versatile

Axis Mounting Design

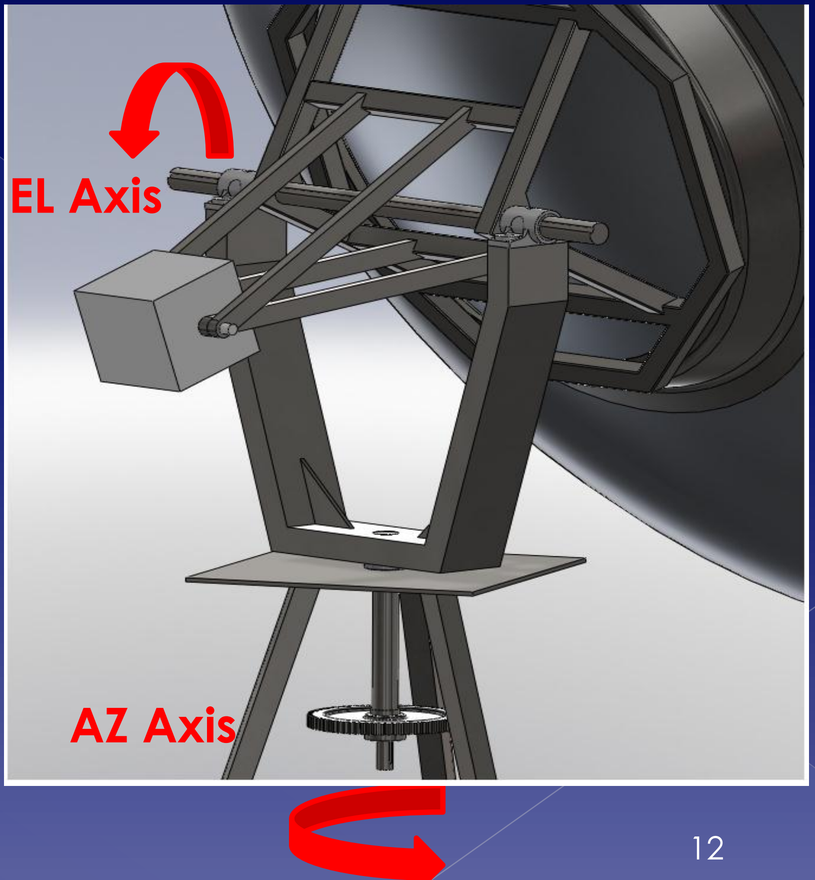
- Equatorial Mount:
  - The movement of the Azimuth (here the Declination Axis) makes an arc in the sky.

  - The Elevation (a) is set parallel to the earths axis of rotation.

This system is much more accurate than the Fork and needs a much less complicated control system.

Axis Mounting Design

- Fork Mount
  - Simple left-right/up/down characteristics
  - Allows the dish to go over backwards if it needs to.
  - Dish can track large range of orbit paths.

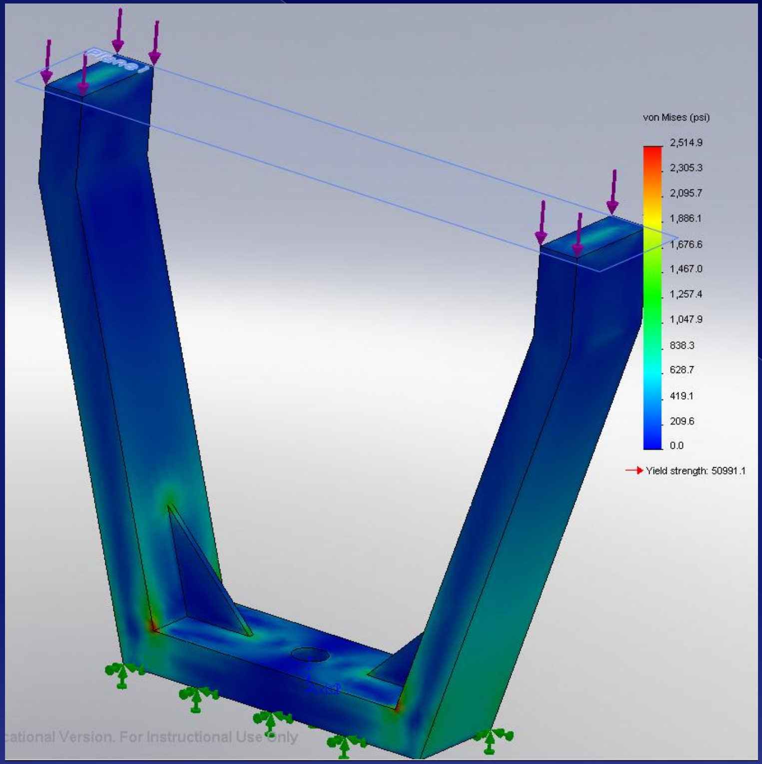


We chose this configuration because of the versatility in what we can track

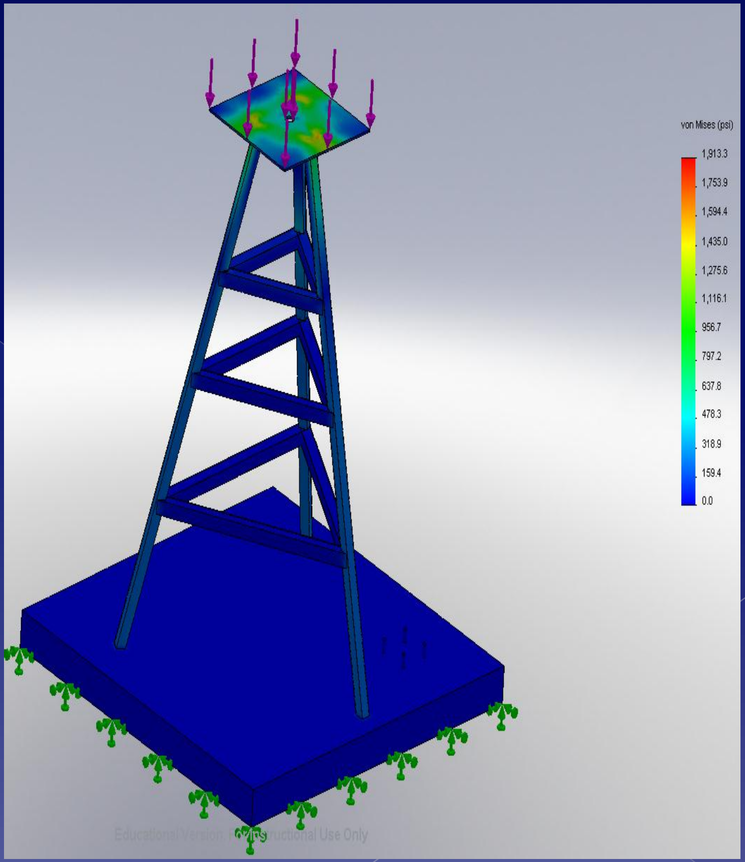
Final Proposed Design

- 180 degree EL Motion
- 360 degree AZ Motion
- Approx weight: 1100 lbs

Finite Element Analysis (FEA)

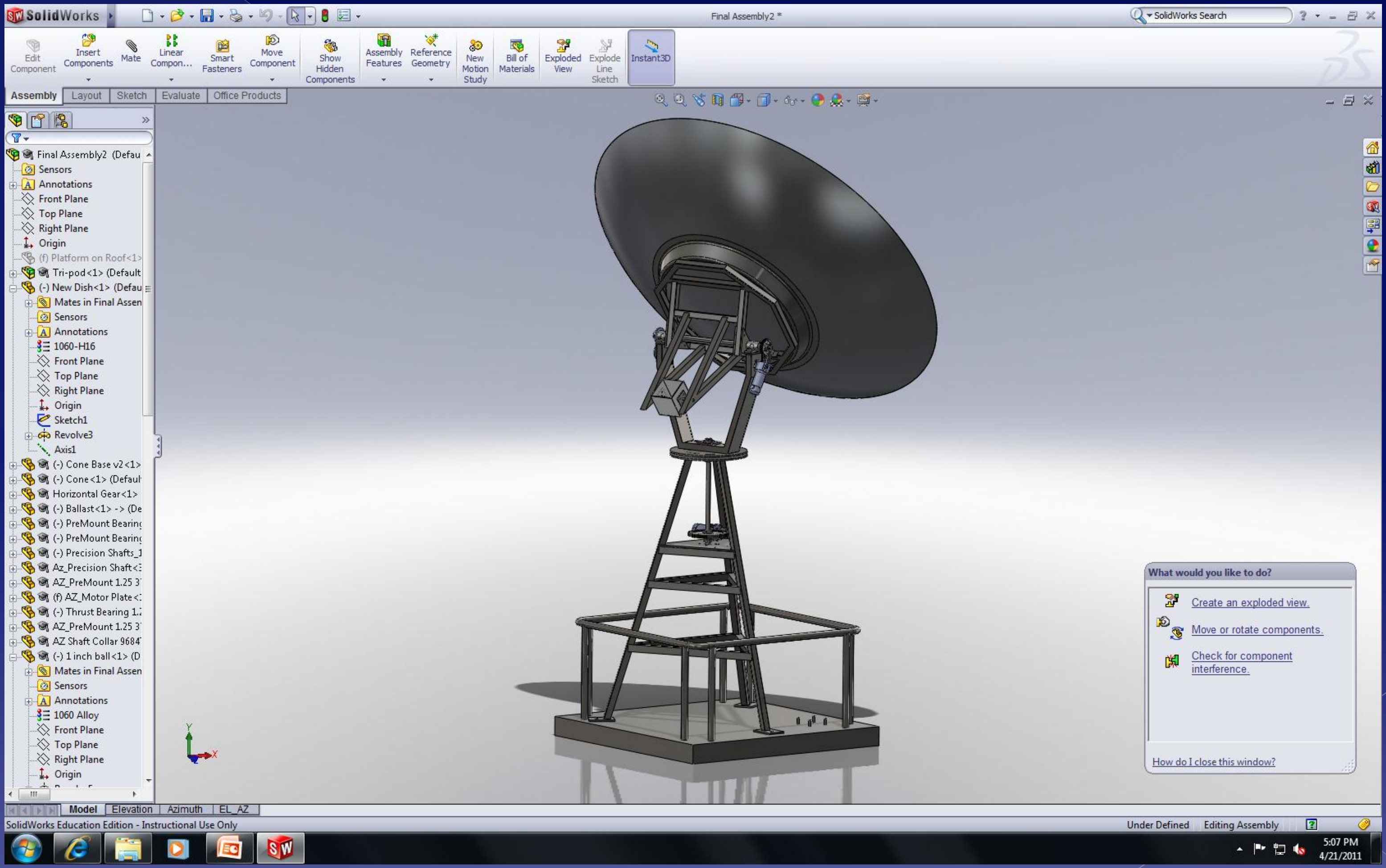


Tripod stand FEA



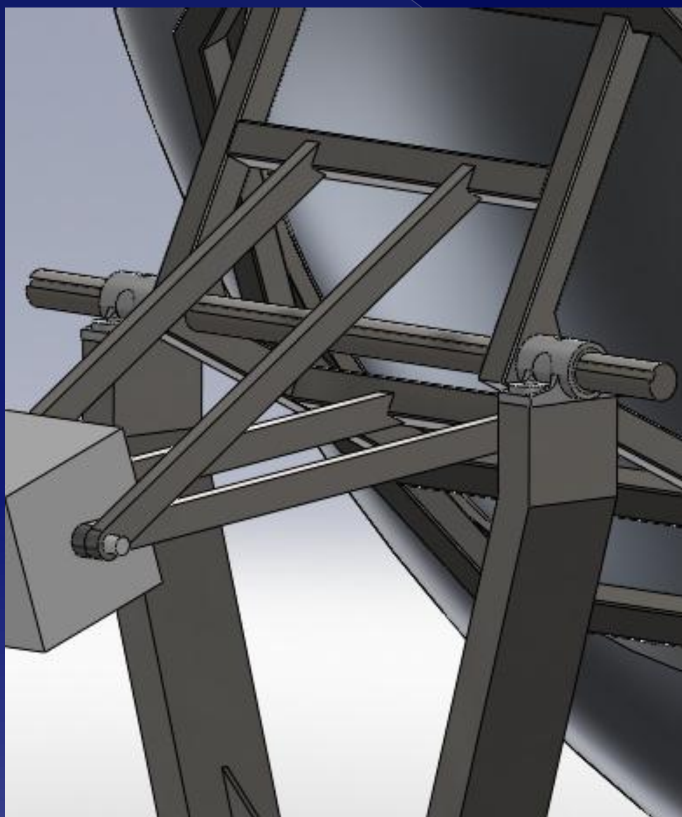
Fork design FEA

Motion Study in Solidworks

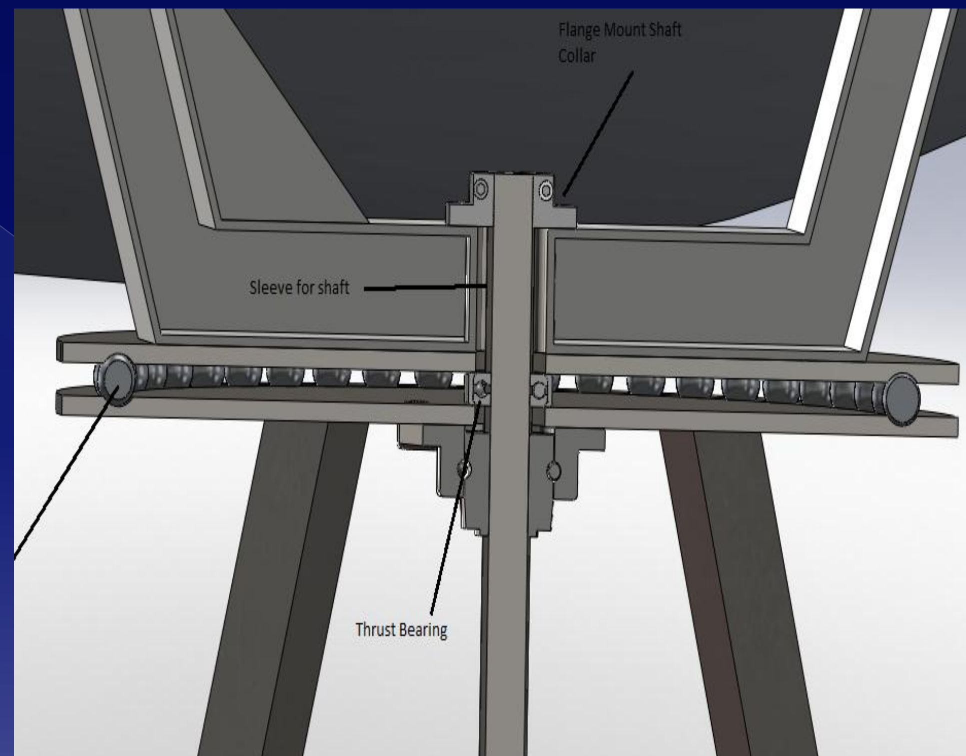


Elevation Axis

Azimuth Axis

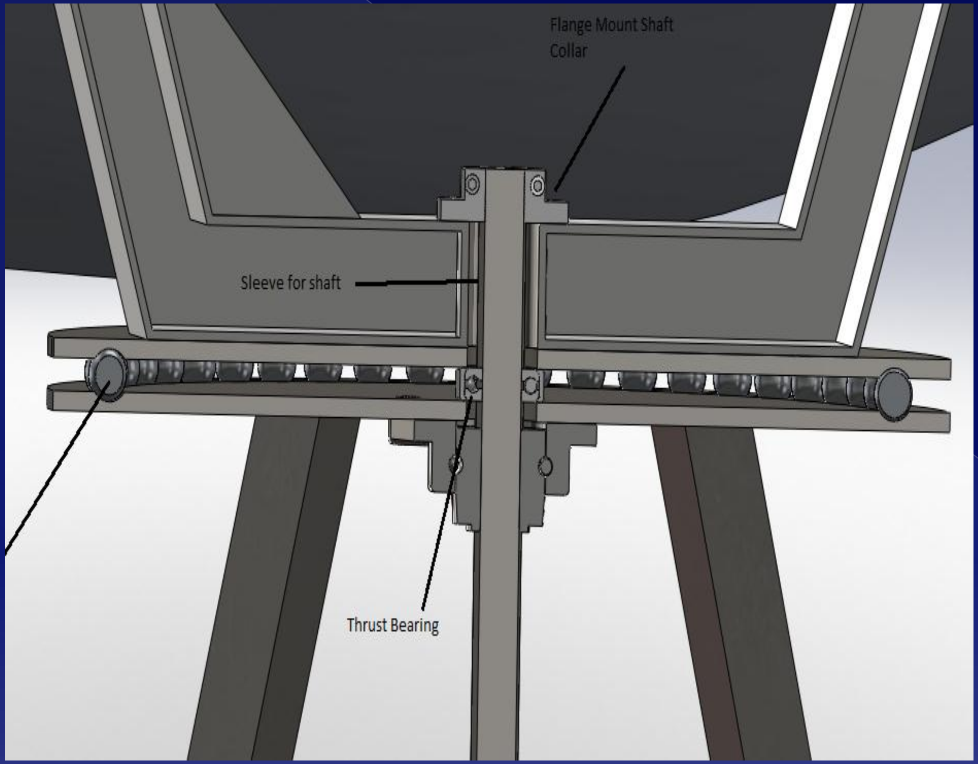


Simple shaft and Bearing setup



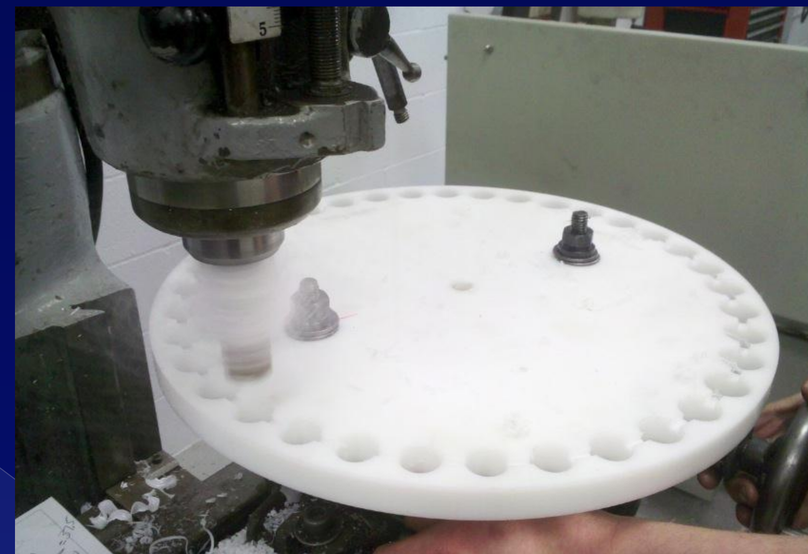
Load bearing Thrust and Ball Bearing setup

Azimuth Axis



Load bearing Thrust and Ball Bearing setup

Bearing Manufacturing



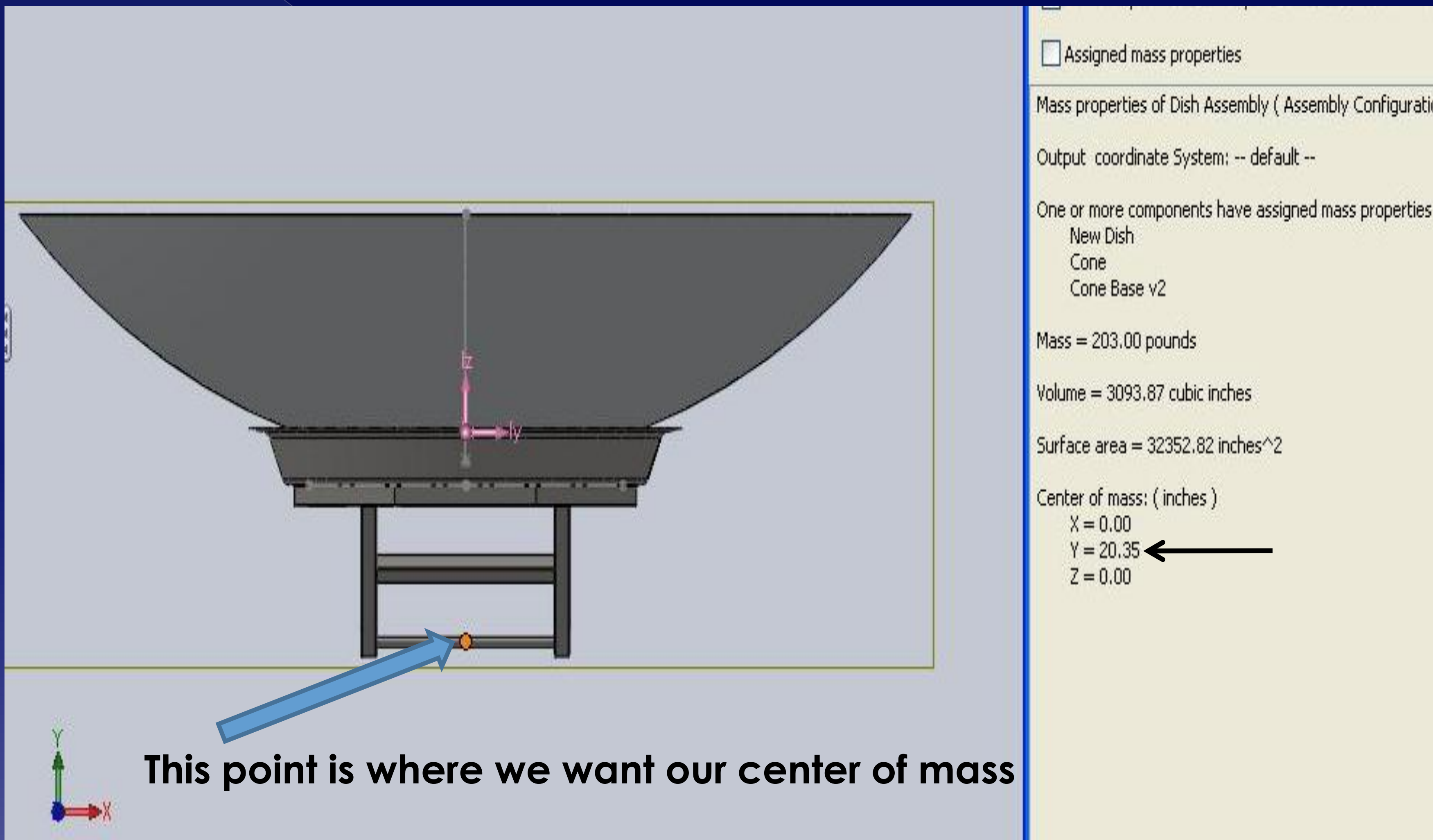
Mechanical Design

Statics and Dynamics:

Key Points of Interest:

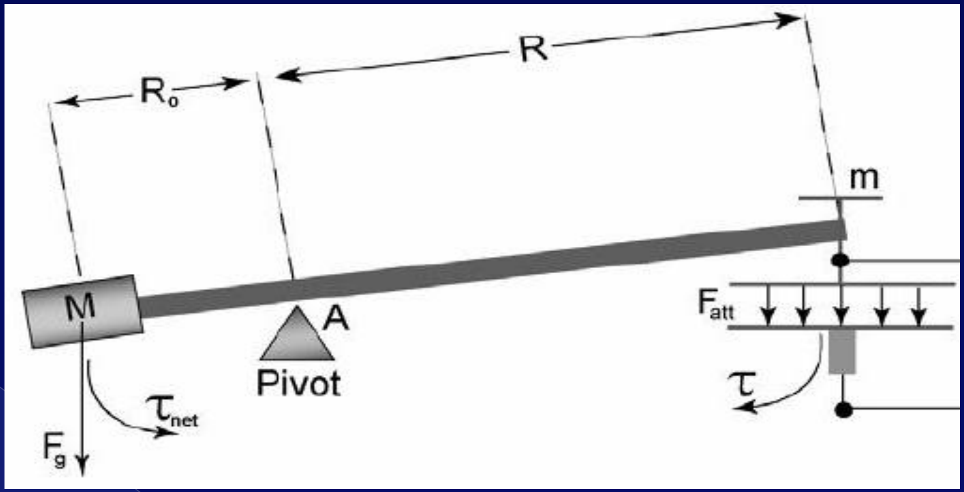
- **Center of Mass-** The mean location of all system masses.
- **Moment of Inertia-** A measure of an object's resistance to changes to its rotation. It is the inertia of a rotating body with respect to its rotation.
- **Dynamic Torque-** The torque encountered by a system that is not only in motion, but accelerating.
- **Static Torque-** The torque produced at constant velocity (rest or running).

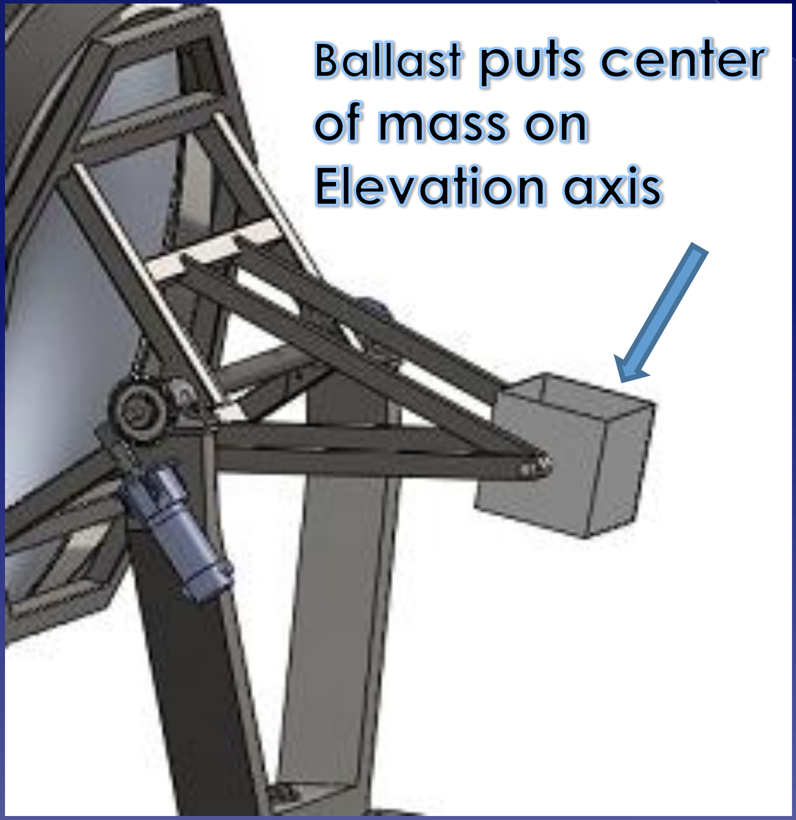
Center of Mass: Solid Works



Forces and Foot Pounds

Having a balanced mass is very important in a motion system

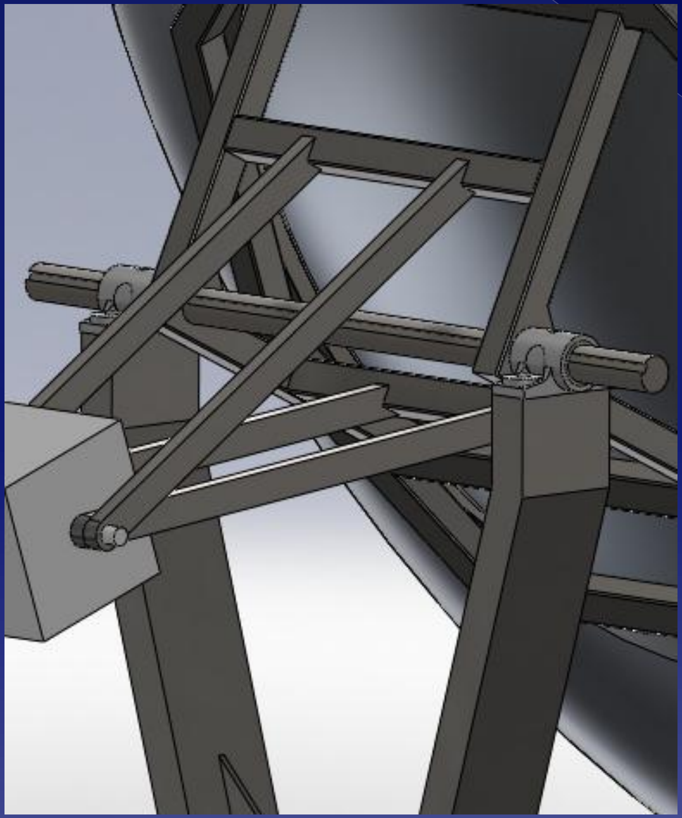




Balance ($R_oM = Rm$)

Reduces driving torque that the motor has to produce

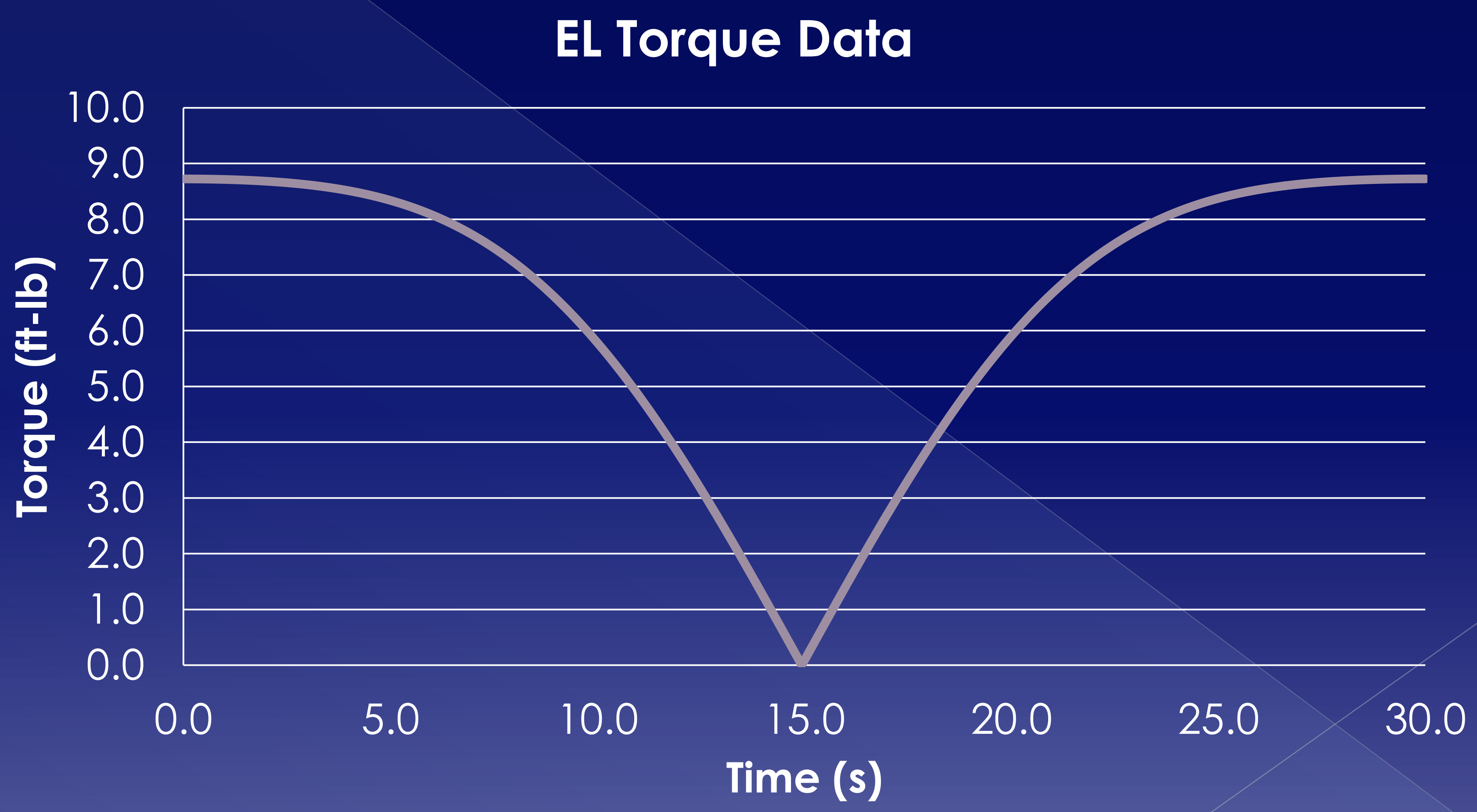
Ballast Manufacturing



Simple shaft and Bearing setup

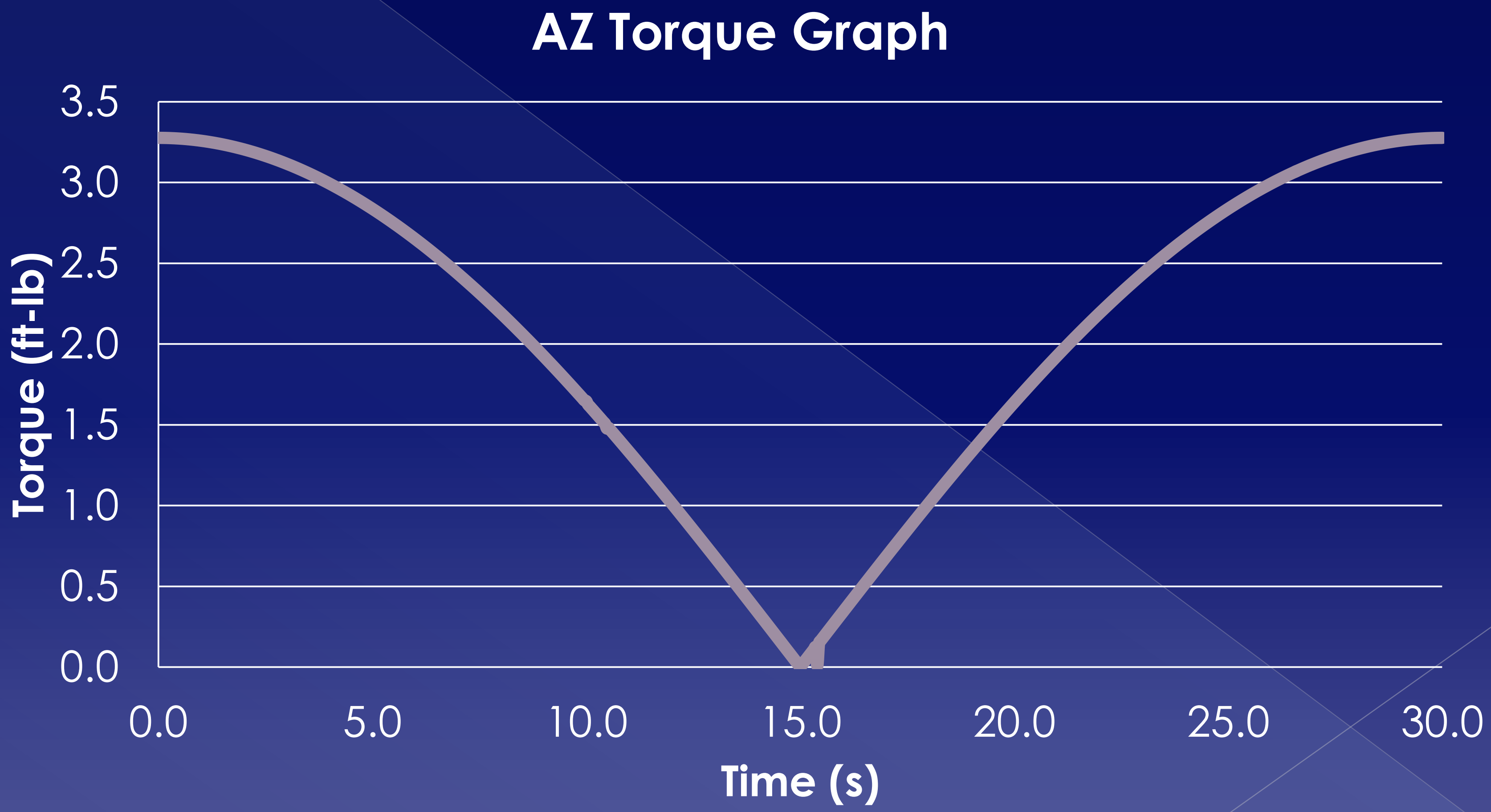
Dynamic Torque Curve (Elevation)

Max Torque needed = 8.7 ft lbs

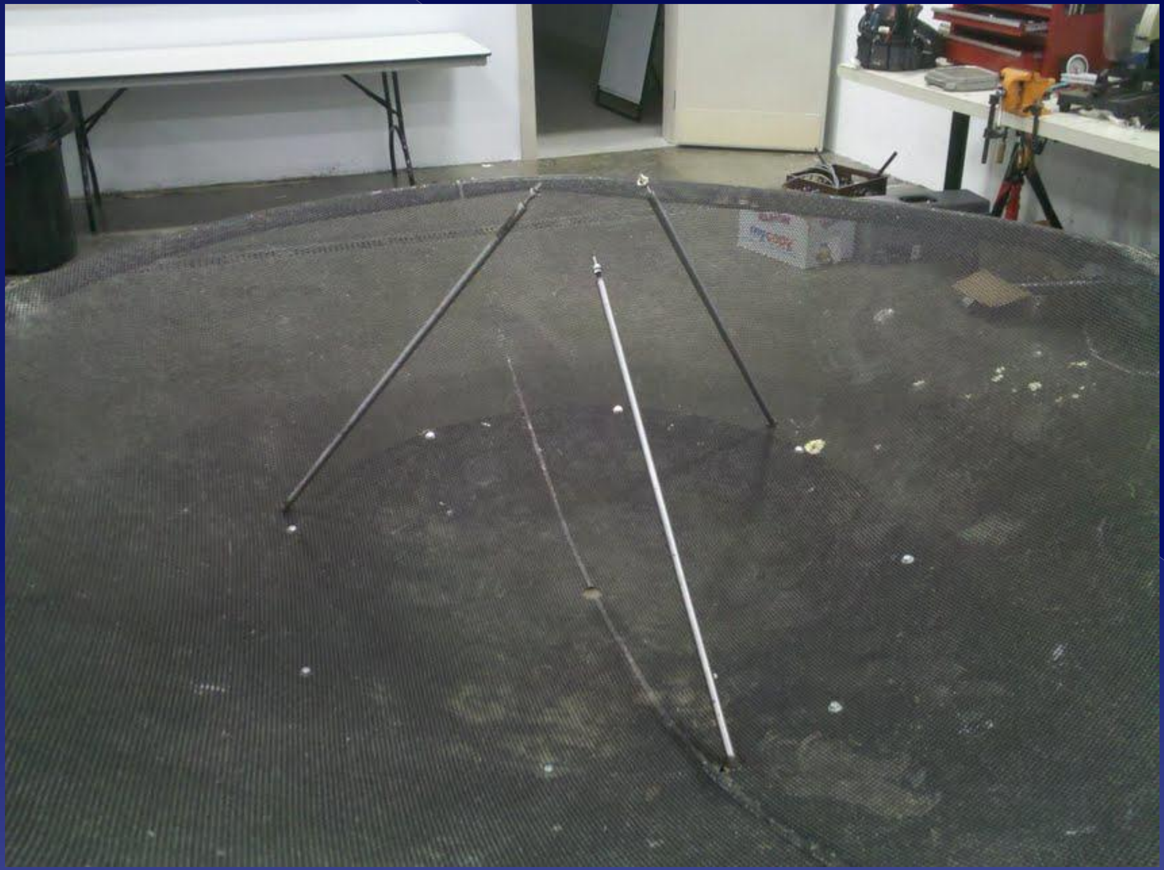


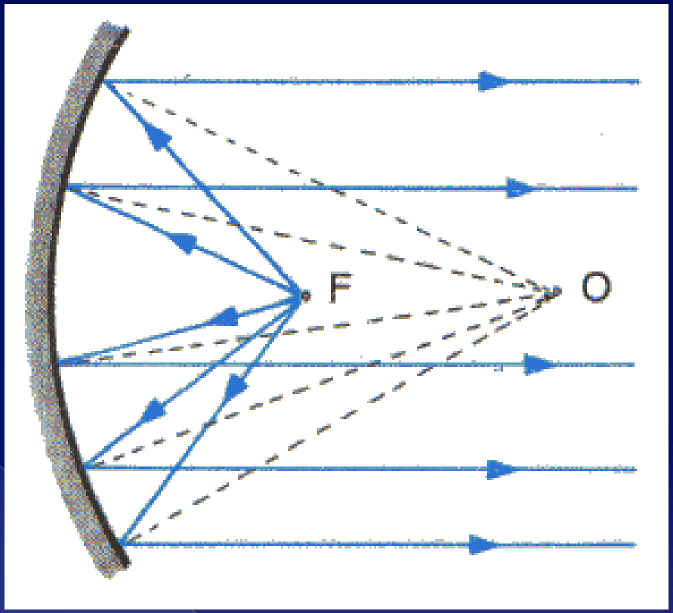
Dynamic Torque Curve (Azimuth)

Max Torque Needed = 3.3 ft lbs



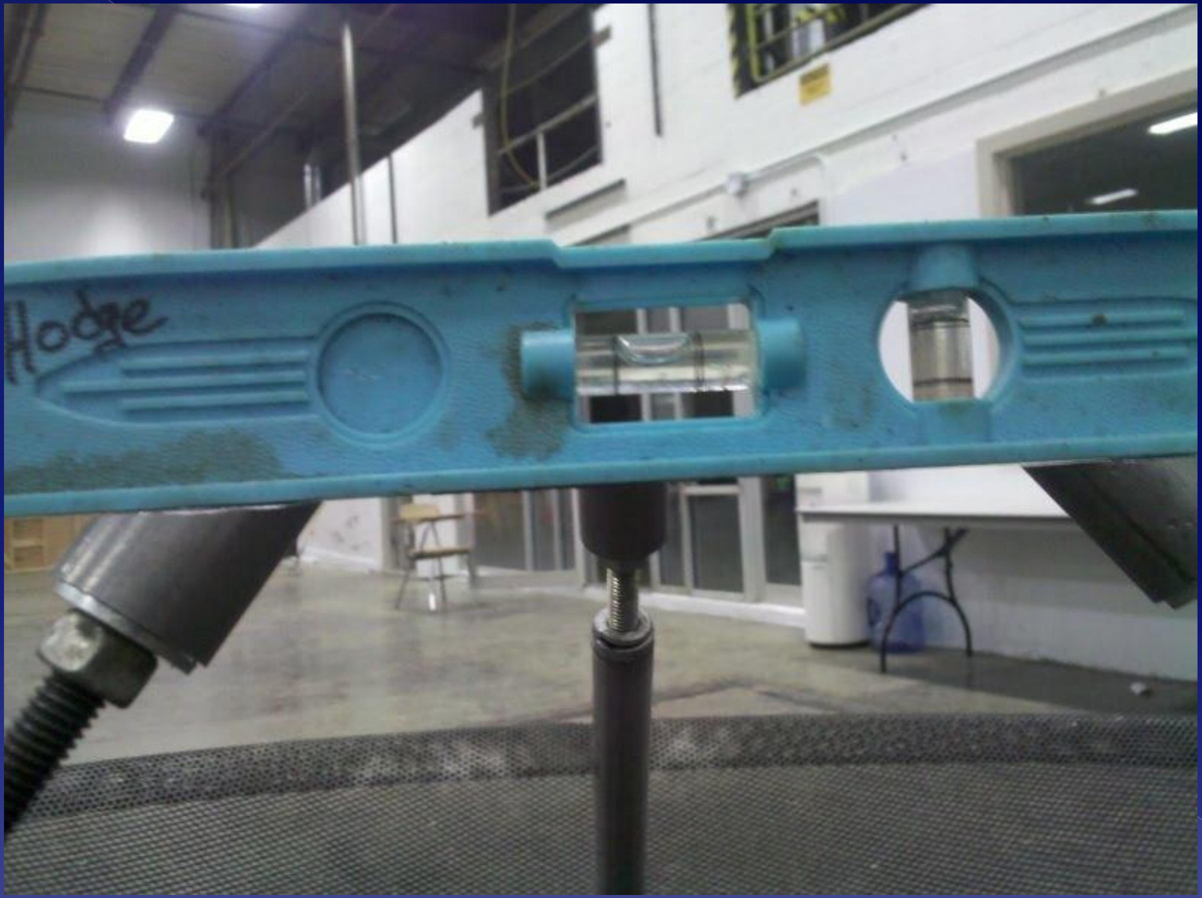
Focal Point





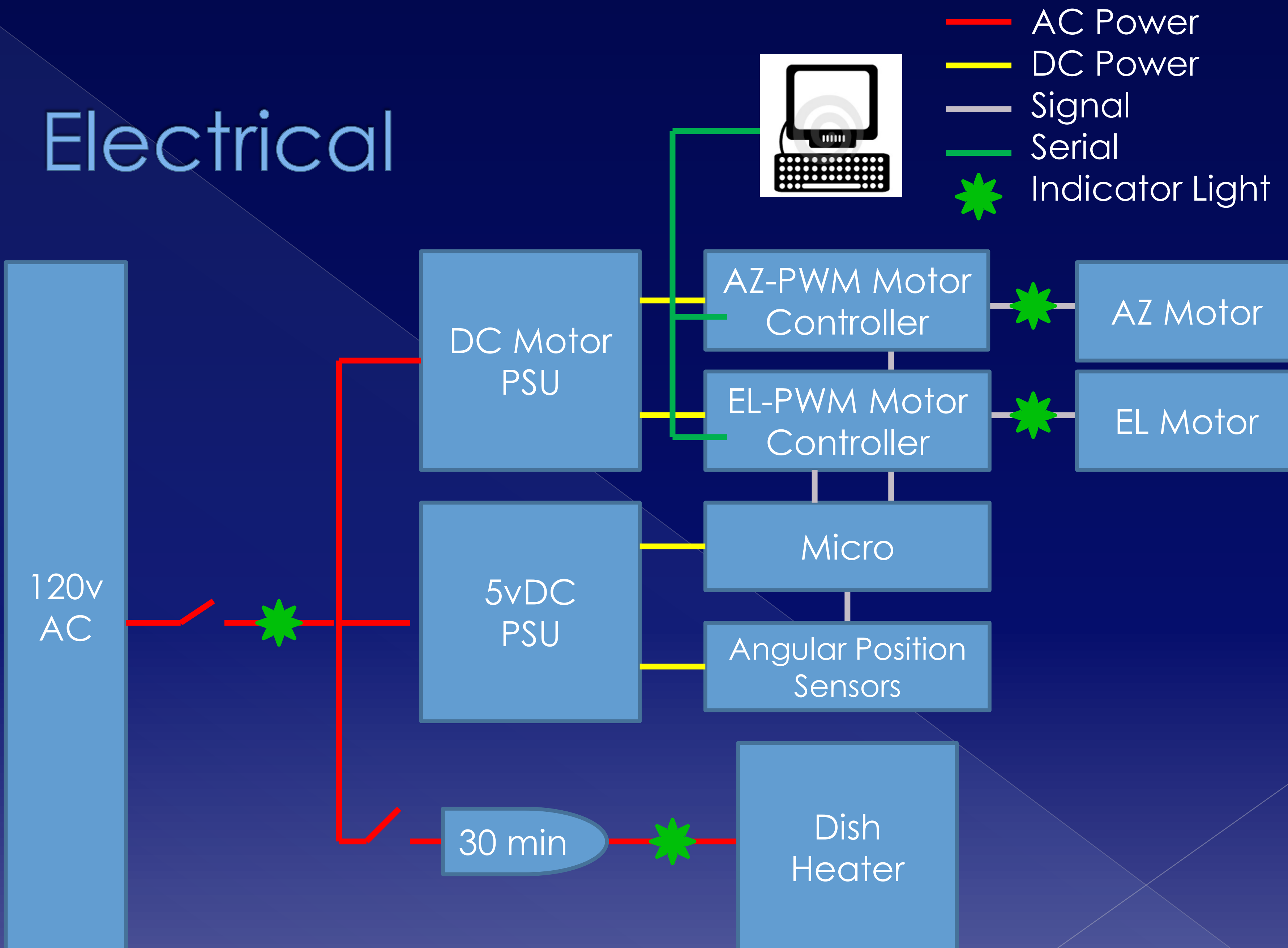
Focal point calculated to be 37.5 inches from vertex of dish
with a tolerance within 0.150" – 0.300"

Focal Point



Transceiver Mount Must be Level

Electrical


AC Power
DC Power
Signal
Serial
Indicator Light
120v AC
DC Motor PSU
5vDC PSU
AZ-PWM Motor Controller
EL-PWM Motor Controller
AZ Motor
EL Motor
Micro
Angular Position Sensors
30 min
Dish Heater

Electrical - Sensors

Absolute Magnetic Shaft Encoder

- 1° step size = at least nine bit resolution

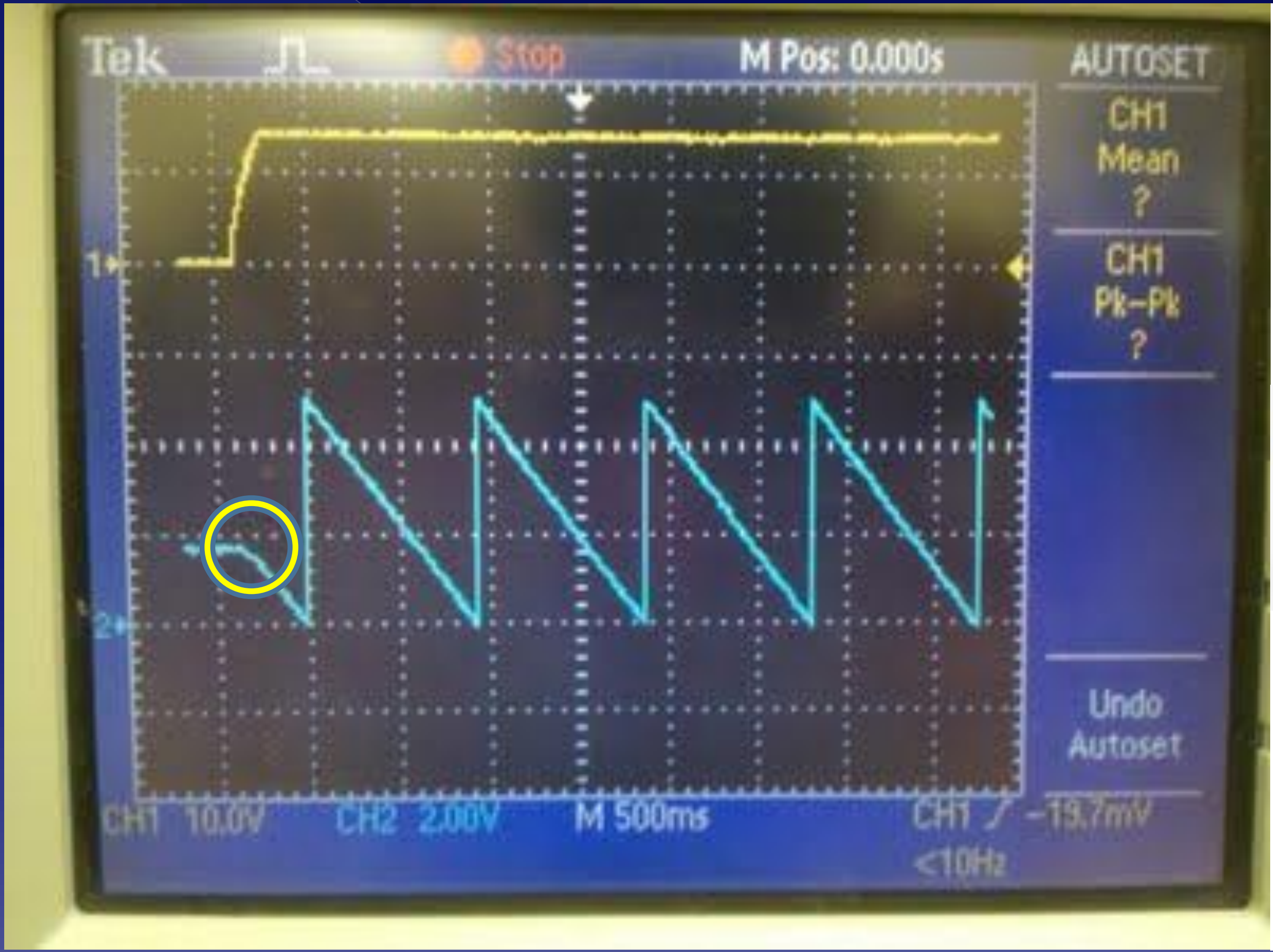
  2^9 = 512 steps 360 deg/512 steps = .7 deg/step

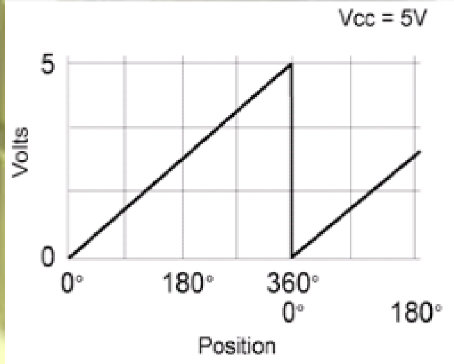
- 6°/sec = 1 rpm

  180°/30sec=6°/sec=360°/60sec

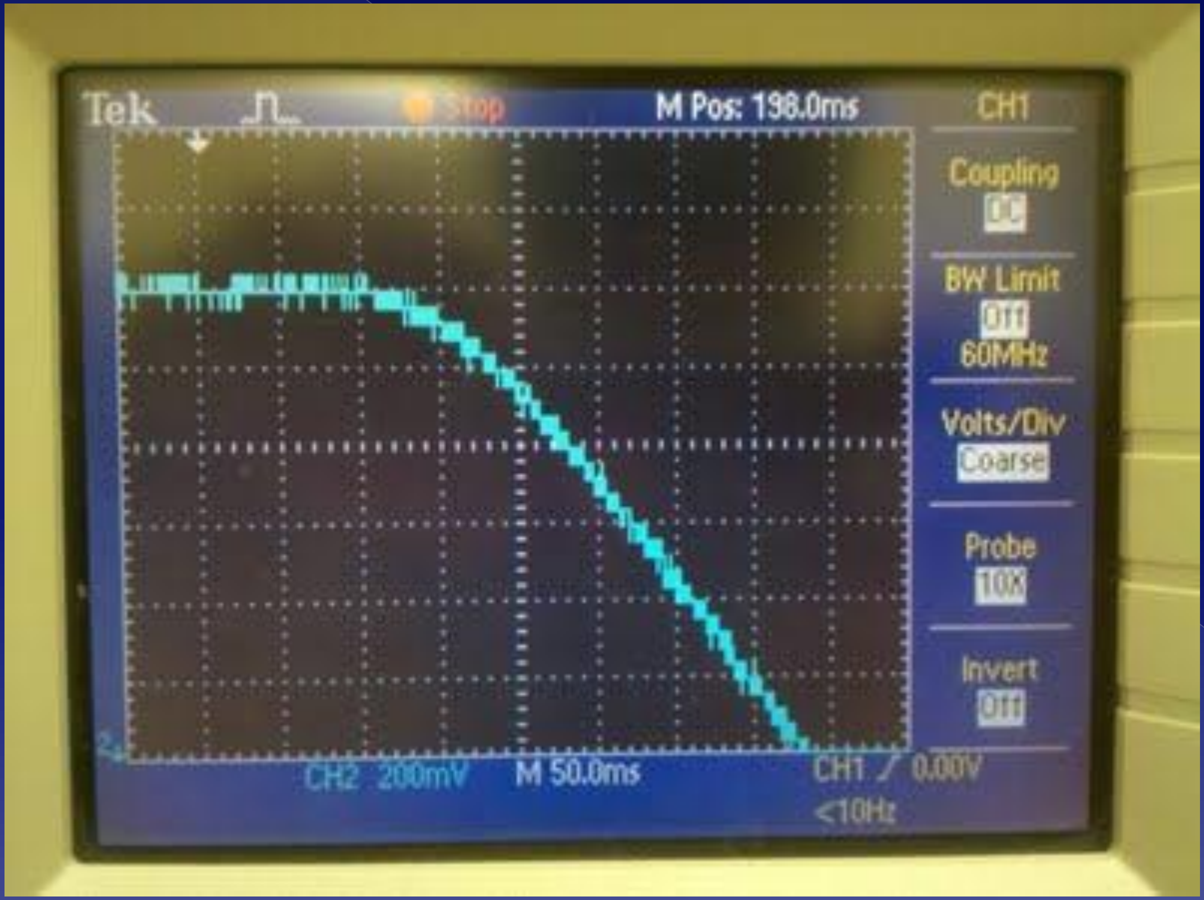
- Magnetic shaft encoder
  - Max 15,000 rpm
  - Absolute position sensing
  - Small size, large operating temperature range
  - Analog output from 10-bit DAC
    - 1024 steps or .35° /step

Electrical – Motor Modeling





Electrical – Motor Modeling

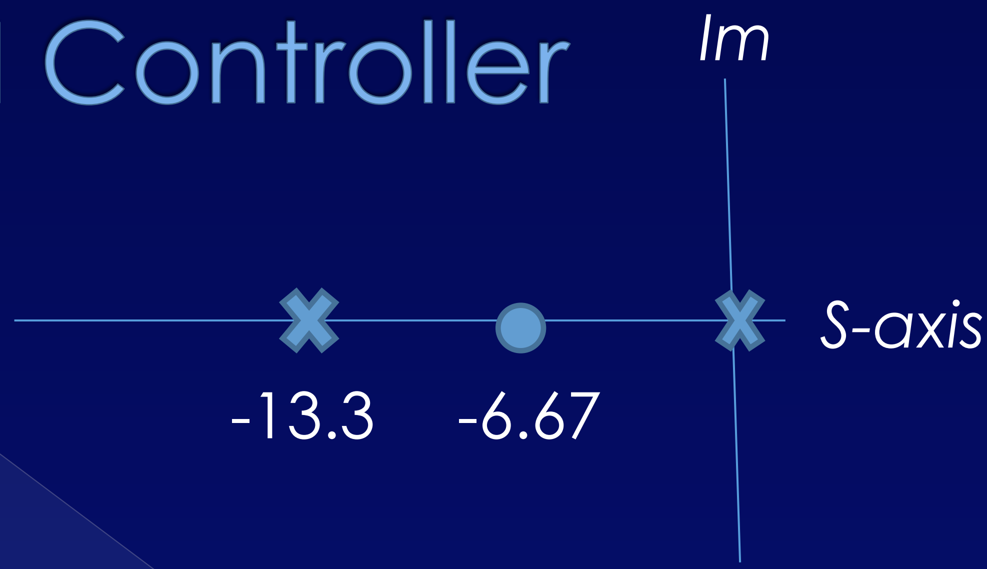


Time Constant – 67ms

Software – PI Controller

Pole-Zero Diagram:

$$G_s(s) = (PI)\left(\frac{1}{.075(s+13.3)}\right)$$



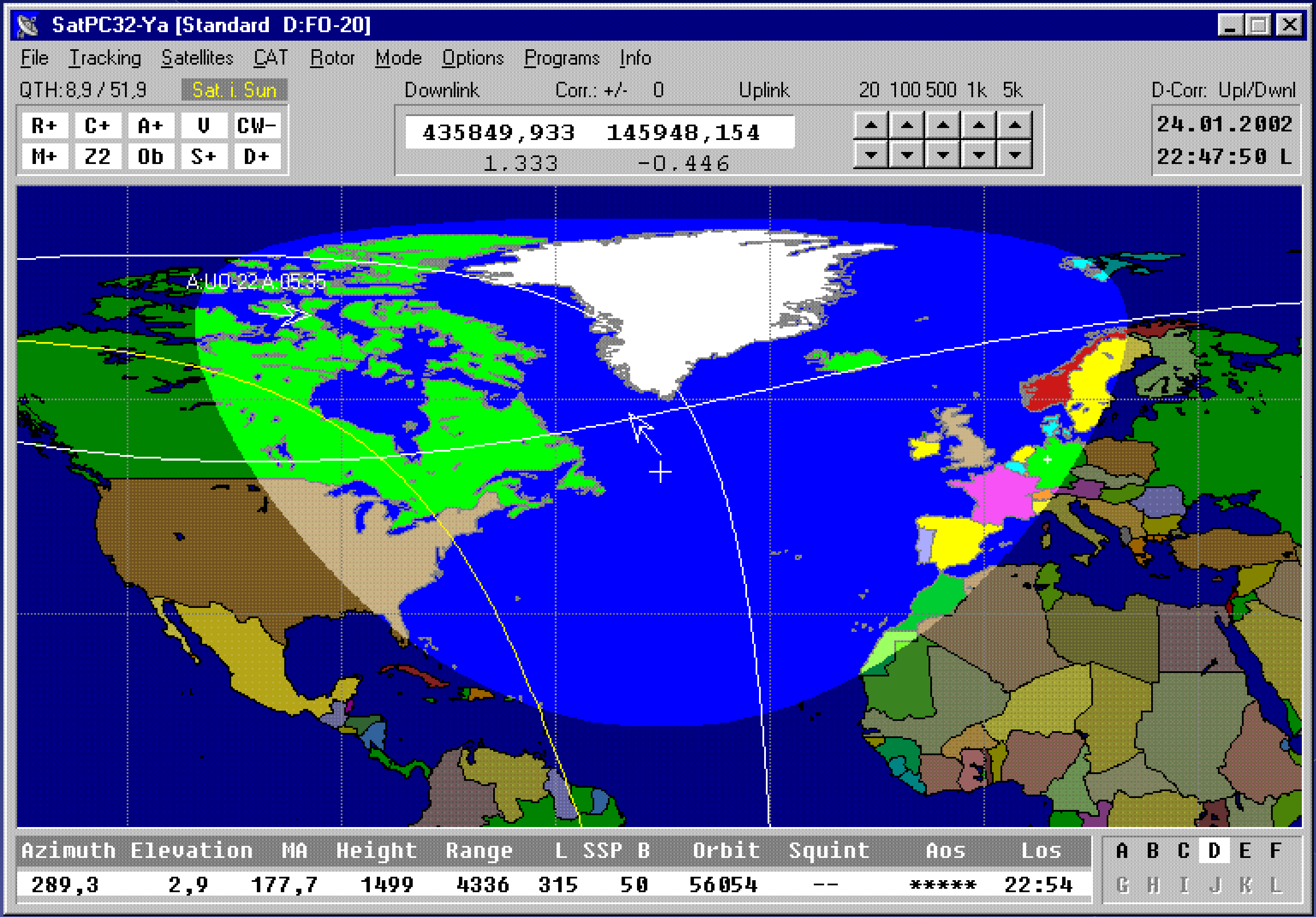
Z- Transform Equation:

$$G_c(z) = \frac{7.4669z - 7}{z - 1}$$

Difference Equation:

$$Y_c(n) = 7.4669X_c(n) - 7X_c(n-1) + Y_c(n-1)$$

Software – SatPC32: Video



Software – Serial Communication

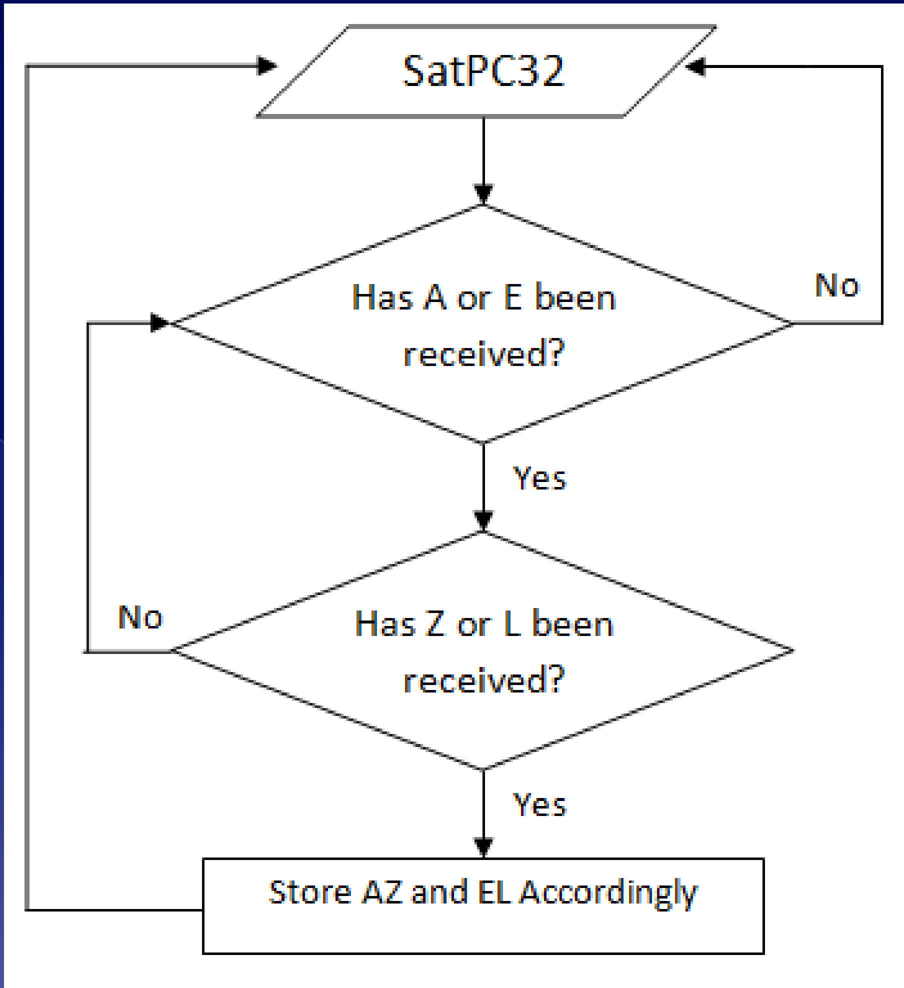
Time (sec)	Logic Placer	AZ Value	EL Value	Azimuth	Elevation	CR
0	0	0	0	AZ000.0	EL000.0	
1	1	8	4	AZ008.0	EL004.0	
2	0	8	4	AZ008.0	EL004.0	
3	0	8	4	AZ008.0	EL004.0	
4	0	8	4	AZ008.0	EL004.0	
5	1	16	8	AZ016.0	EL008.0	
6	0	16	8	AZ016.0	EL008.0	
7	0	16	8	AZ016.0	EL008.0	
8	0	16	8	AZ016.0	EL008.0	
9	1	24	12	AZ024.0	EL012.0	
10	0	24	12	AZ024.0	EL012.0	
11	0	24	12	AZ024.0	EL012.0	
12	0	24	12	AZ024.0	EL012.0	
13	1	32	16	AZ032.0	EL016.0	
14	0	32	16	AZ032.0	EL016.0	
15	0	32	16	AZ032.0	EL016.0	
16	0	32	16	AZ032.0	EL016.0	
17	1	40	20	AZ040.0	EL020.0	
18	0	40	20	AZ040.0	EL020.0	
19	0	40	20	AZ040.0	EL020.0	
20	0	40	20	AZ040.0	EL020.0	

Desired Track Time	180	Sec
Desired AZ Displacement	360	Degrees
Desired EL Displacement	180	Degrees
Divisor Value	4	Sec to hold
AZ Increment Value	8	Degrees/Divisor
EL Increment Value	4	Degrees/Divisor

Be sure to copy ONLY AZ, EL AND CR fields into HyperTerm

Software – Serial Communication

- Transmitted Format
  - AZ360.0 EL180.0
- Serial Transmit Rate
  - 1 Data point/Second



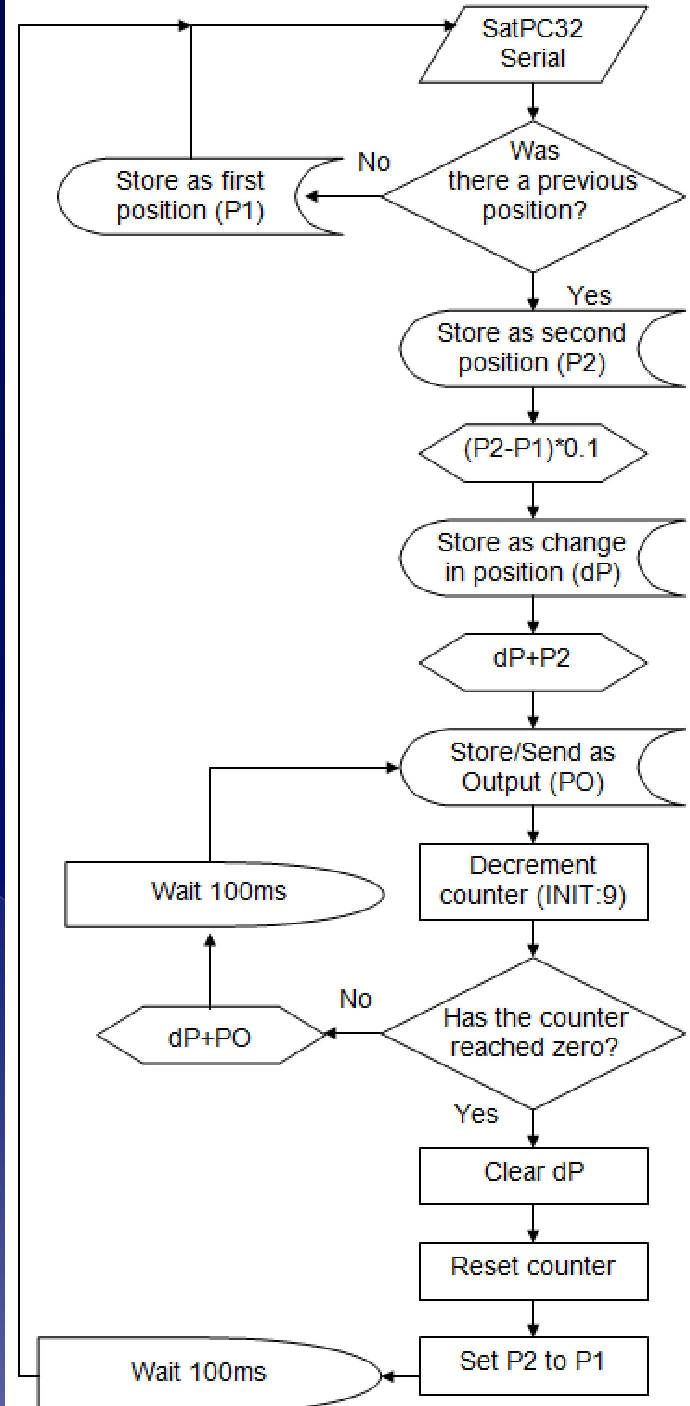
Software – Serial Communication

```
void check_serial(void){
  CALLcheck_serial=0;
  switch(Serial_State){

     case 3:

       if (Serial_Error == ERR_OK){
        if (Buffer_In == 'A'){           //Look for 'A'
          Serial_State = 4;
        }
        else {
          Serial_State = 3;
        }
       }
        break;
```

```
if (store_serial_AZ==1){

      store_serial_AZ=0;

      for (i=NumPos-1; i>0; i--){
        Serial_AZ[i]=Serial_AZ[i-1];
      }

      /*Pull Float from Incomming, put into Serial_AZ[0]*/
      Serial_AZ[0]=0;
      Serial_AZ[0]=(float)((
        ((Incomming[0]-48)*100)+ //convert from ASCII to decimal, 100's place
        ((Incomming[1]-48)*10 )+ //convert from ASCII to decimal, 10's  place
        ((Incomming[2]-48)*1  )+ //convert from ASCII to decimal, 1's   place
        //Incomming[3] = decimal point
        ((Incomming[4]-48)*.1 )+ //convert from ASCII to decimal, .1's  place
        ((Incomming[5]-48)*.01)+0.48));//convert from ASCII to decimal, .01's place
      /*Pull Float from Incomming, put into Serial_AZ[0]*/

       //ADD TO THE TIMER ARRAY TOO
      for (i=NumPos-1; i>0; i--){
        Serial_AZ_TIME[i]=Serial_AZ_TIME[i-1];
      }
      Clock_Error=Clock_GetTimeMS(&current_time);
      Serial_AZ_TIME[0]=(((float)(current_time))/1000);
      //ADD TO THE TIMER ARRAY TOO

      CALLcheck_interpolate=1;
      Serial_State = 3
```

Start Interpolating

Software Serial Interpolation



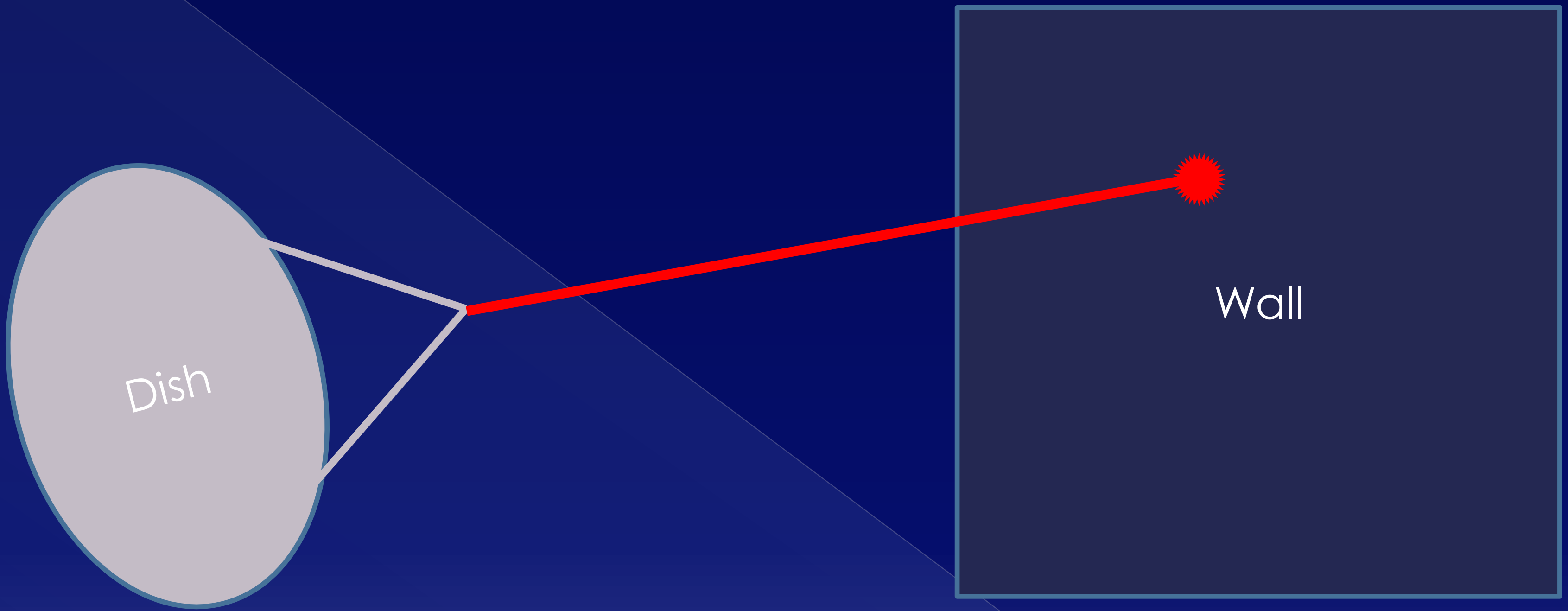
Software – Interpolation

```
void interpolate_serial(void){

   switch(interpolate_state){
       case 0:

       if (Serial_AZ[1] > 0){
         dP = (Serial_AZ[0] - Serial_AZ[1]) * 0.1f;     //DEFINE CHANGE IN UNIT TIME HERE
         interpolate_out = dP + Serial_AZ[0];
         interpolate_state = 1;
       } else interpolate_state = 0;
    break;

      case 2:

       interpolate_clock_GetTimeMS(&interpolate_time);
       if (interpolate_time >= INTDELAY){
        interpolate_time = 0;
        interpolate_clock_Reset();
        interpolate_count--;
        interpolate_out = dP + interpolate_out;
        interpolate_state = 1;
       } else interpolate_state = 2;

    break;
```

Calibration Techniques – True AZ and EL

- Azimuth
  - Align one leg of tripod to true north
- Elevation
  - Inclinometer (Shown here)

Calibration Techniques - Repeatability



- Mount laser on transceiver location
- Point to given spot and record location
- Attempt to recreate position
- Adjust accordingly


HERCULINER

LINER
CAT
CASE

Subsystem Videos

Ground Station Budget

Item: Description	Quantity	Price Per	Total
High-Speed Cast Iron Mounted STL Ball Bearing Square-Flange Mount, for 1-1/4" Shaft Diameter	2	$103.82	$207.64
Extra-Grip Two Piece Clamp-on Shaft Collar 1-1/4" Bore, 2-1/2" Outside Diameter, 5/8" Width	2	$9.69	$19.38
Partially Keyed Steel Drive Shaft 1-1/4" OD, 1/4" Keyway Width, 36" Length	1	$60.26	$60.26
E52100 Alloy Steel Ball 1" Diameter, Grade 25	5	$13.05	$65.25
One-Piece Steel Thrust Ball Bearing for 1-1/4" Shaft Diameter, 2-11/32" OD, Shielded	1	$22.35	$22.35
Mounting Flange One-Piece Shaft Collars 1-1/4" Bore, 2-1/4" Collar OD, 1" Overall Width	1	$43.98	$43.98
Cast Iron Base-Mounted Babbitt-Lined Bearing Solid, for 2" Shaft Diameter	2	$82.60	$165.20
Two-Piece Clamp-on Shaft Collar Steel, 2" Bore, 3" Outside Diameter, 11/16" Width	4	$11.32	$45.28
Fully Keyed 1045 Steel Drive Shaft 2" OD, 1/2" Keyway Width, 48" Length	1	$146.06	$146.06
Steel Needle-Roller Bearing Double Sealed for 3/4" Shaft Dia, 1" OD, 3/4" Width	2	$10.34	$20.68
Hardened Precision Steel Shaft 3/4" Diameter, 12" Length	1	$9.60	$9.60
Black Polyurethane Sheet 1/4" Thick, 12" X 12", 90A Durometer	1	$53.99	$53.99
Step-Up Clamp-on Shaft Adapter 5/8" Bore, 7/8" Shaft Outside Diameter	1	$54.91	$54.91
Two-Piece Clamp-on Shaft Coupling Steel, with Keyway, 3/4" X 5/8" Bore, 1-1/2" OD	1	$82.12	$82.12
Fully Keyed 1045 Steel Drive Shaft 3/4" OD, 3/16" Keyway Width, 3" Length	1	$8.48	$8.48
Extra-Grip Two Piece Clamp-on Shaft Collar 1" Bore, 2-1/4" Outside Diameter, 5/8" Width	1	$9.13	$9.13
Steel Ball Bearing--ABEC-1 Dbl Sealed Bearing NO. R16 for 1" Shaft Dia, 2" OD	2	$11.36	$22.72
Threaded-Stem Caster W/Total Lock, 5" X 1-1/4" Rubber Whl, 1/2"-13 Stem	3	$20.25	$60.75
Type 416 Stainless Steel Key Stock 3/16" X 3/16", 12" Length	1	$11.20	$11.20
5/8 inch needle bearings	2	$2.76	$5.52
7/8 needle bearing	1	$2.83	$2.83
7/8 keyed shaft (3/16 keyway) 9" length	1	$20.82	$20.82
3/4 needle bearing	1	$2.83	$2.83
3/4 inch diameter keyed shaft (3/16 keyway) 9" length	1	$19.16	$19.16
1.25x3/4x3/8 Roller Flat Sealed Track Roller	3	$23.43	$70.29
Two-Piece Clamp-on Shaft Collar Steel, 1-1/4" Bore, 2-1/16" OD, 1/2" Width	2	$5.17	$10.34
Dayton DC Motor (50 RPM)	1	$347.23	$347.23
Dayton DC Motor (94 RPM)	1	$347.23	$347.23
2"x2"x3/16"x 24' Square Tubing	3	$82.00	$246.00
2'x2'x.5" Plate	3	$75.00	$225.00
6"x2"x3/16" x12' Rect. Tube	1	$105.00	$105.00
8"x 8" x 1/4" Plate	5	$9.50	$47.50
Waterjet Cutting for Brackets and Mounts	1	$230.00	$230.00
Waterjet Cutting for Gears for Encoders	1		
Vinal Coated Nylon Tarp (Black)	3	$58.50	$175.50
Vinal Adhesive	1	$18.75	$18.75
CASE,RACKMNT,19 ,88.1mmX250mm	1	$51.95	$51.95
Woods 59007 Decora Style 30-15-10-5 Minute Preset Wall Switch Timer, White, 30-Minute	1	$13.39	$13.39
CA-MIC3-SH-NC 3-Pin Micro / Unterminated Shielded Cable (20ft)	2	$26.30	$52.60
MA3 Miniature Absolute Magnetic Shaft Encoder	4	$45.40	$225.55

Total
$3326.47

Ground Station Timeline (1.05)		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Mechanical									**Mechanical**							
Design																
	Space (Roof) Requirements	Y														
	Physical Characteristics	Y														
	Torque Requirements		Y													
	Fork Mount		Y	Y												
	Balast		Y	Y												
	Small Scale Test				Y	Y										
	Gears					Y										
	Sensor Mounts				Y											
	Motor Selection and Mounts					Y										
	Preliminary Budget					Y										
Construct																
	Move to Building	Y														
	Small Scale Test					Y	Y									
	Fork Mount					Y	Y									
	Balast						Y			Y						
	Ballast Support on Cone Dish						Y	Y								
	Elevation Shaft (Take down to 1" for gear)						Y									
	Water Jet Parts (Taps and Fitting)						Y	Y								
	Misc Machining (Keyweys, shafts)						Y									
	Gears							Y	Y							
	Sensor Mounts						Y	Y	Y	Y	N					
	Motor Mounts							Y	Y							
	Final Assembly							Y	Y	Y	Y	Y				
	EL Shaft Mounted on Fork							Y	Y							
	1" Groove on AZ Bearing Setup							Y	Y							
	Tripod Legs						Y									
	Tripod Assembly							Y	Y							
Electrical									**Electrical**							
	Power Supply		Y													
	Sensors		Y													
	Motor Controller				Y		Y									
	Microcontroller			Y	Y	Y	Y									
	RS232 Communications			N	Y	Y	Y									
Software									**Software**							
	SatPC32 Research	Y	Y			Y	Y	Y								
	Serial Communication Test						Y									
	Serial Code										Y	Y	Y	Y		
	Encoder Code			N	Y	Y				Y	Y	Y	Y	Y		
	Motor Controller Code			N	N	Y			Y	Y	Y	Y	Y	Y		
	Interpolation Code	Y	Y	Y	Y	Y				Y	Y	Y	Y	Y		
Misc.									**Misc**							
	Group Meeting	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		
	Brandon Meeting	Y			N			N			Y			Y		
	Presentation					Y					Y				######	
	Calibrate													Y		
	System Tests											Y	Y	Y		
Milestones						DESIGN	MOTOR	SMALL			SYSTEM		ALLCOMP			CAL

Remaining Tasks

- Mechanical
  - Weatherization
  - Calibration
- Electrical
  - Hardware User Interface Box
- Software
  - Further (Redundant) Control Algorithm Testing

Areas of Responsibility

- Hodge (300+ Hours)
  - CAD and FEA
  - Torque Calculations/Measurements
  - Ballast Implementation
  - Motor Specifications
- Lyford (300+ Hours)
  - Sensors and Electrical
  - Fork Design w/ Motors
  - Drive Mechanisms and Implementation
  - Material Manager / Budget
- Schreiber (300+ Hours)
  - Project Manager
  - Mechanical Analysis and FEA
  - Interpolation Implementation
  - Communications
  - Motor Controllers

Special Thanks

Vermont Technical College Staff

John Kidder - Use of Catamount Building Space
Bryan Carroll - Use of Catamount Building Space
Carl Wolf - FEA, General Project Guidance
Andre St. Denis - Software Support, General Project Guidance
John Murphy - Controller Development, Software and Hardware Support
Ingred Van-Steamburg - Ordering Parts, Budget Allocation, Financial Assistance
Preston Allen - Supplying Tools and Machinery, Assembly and Construction Assistance
Joan Richmond-Hall - Materials Safety Precautions
Roger Howes - CNC Support
Mike Wright – Machine Shop Assistance
Scott Sabol - Green Structural Building Analysis
Sam Colwell - LCD Software Support

Vermont Technical College Students

Aaron Minard - Briefing from previous years
Ben (Student in Design Comm. Class) - Solidworks Models of Motors

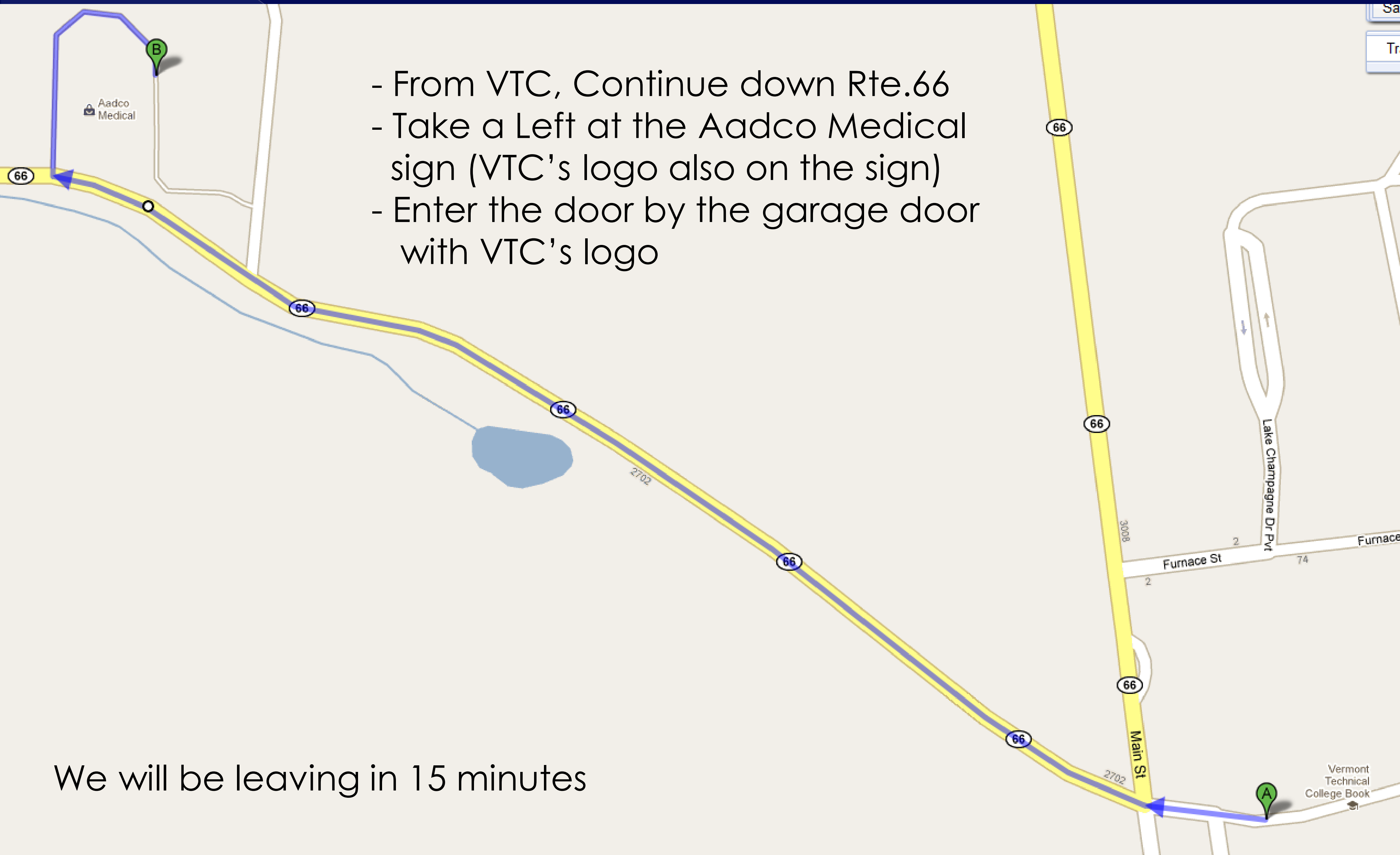
Outside Vermont Technical College

David Durgin of Mainly Metals - Water-jet parts
K BeBee Plumbing - Supplying Free Material
Vermont Wireform - CNC/Machine Shop and Machine Time
Mark Schreiber of Granite City Electric - Delivering Material, Providing Dish Heater

Questions?

Join us at the Catamount building for a live demonstration

- From VTC, Continue down Rte.66
- Take a Left at the Aadco Medical sign (VTC's logo also on the sign)
- Enter the door by the garage door with VTC's logo



We will be leaving in 15 minutes