Engineering Analysis Package

RMTS Industries

Rocket Motor Test Stand

Program Manager Signature: ________________________

Client Procuring Officer Signature: ____________________

Acronyms

Rocket Motor Test Stand ….. **RMTS**
Engineering Analysis Package ….. **EAP**
Failure Modes and Effects Analysis ….. **FMEA**

List of Figures

Purpose

The purpose of the Engineering Analysis Package (EAP) is to analyse major failure points of the Rocket Motor Test Stand (RMTS) system, as it pertains to the Failure Modes and Effects Analysis (FMEA). Points that the FMEA determines as points of major concern will be analysed in this document.

Summary of System

The rocket motor test stand (RMTS) is a test system compatible with National Association of Rocketry (NAR) 1/8A to Class I high-power motors. It comprises 2 major systems, the control suitcase and the frame. The control suitcase acts as the user interface where tests are conducted and data extracted. The frame is made of 2 major parts, the frame with the attached ammo can, and the interchangeable lathe chuck assembly which is pictured below in figure X. In terms of safety, it must withstand the thrust of 1/8A to Class I motors, with structural components employing a 5X safety factor to ensure protection for users and surrounding property in the event of an accident.The system's total weight must not exceed 500 pounds, with individual components weighing no more than 100 pounds, and it must be able to be assembled or deployed by one person within 30 minutes and be rapidly disassembled. The RMTS must be able to operate year-round outdoors in Alaska, including temperatures as low as -40 degrees Fahrenheit (40 degrees Celsius), and has a minimum 20-year operational lifespan with minimal maintenance requirements. The RMTS can be disassembled into seven components and transported using a 6.5-foot (1.98 m) pickup truck bed or a dedicated trailer for deployment to Poker Flat Research Range (PFRR), Kodiak Pacific Spaceport Complex (PSC), and remote areas.

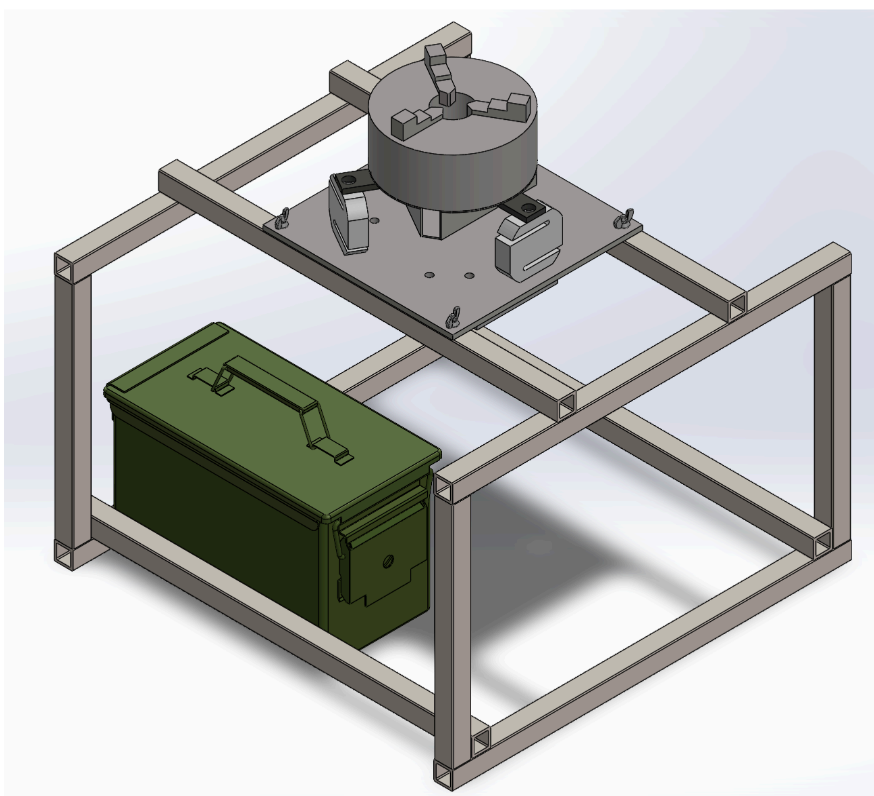


Figure X: Assembled RMTS System (50 cal ammo can model from: https://grabcad.com/library/50-cal-ammo-can-1, Hardware models from McMaster-Carr)

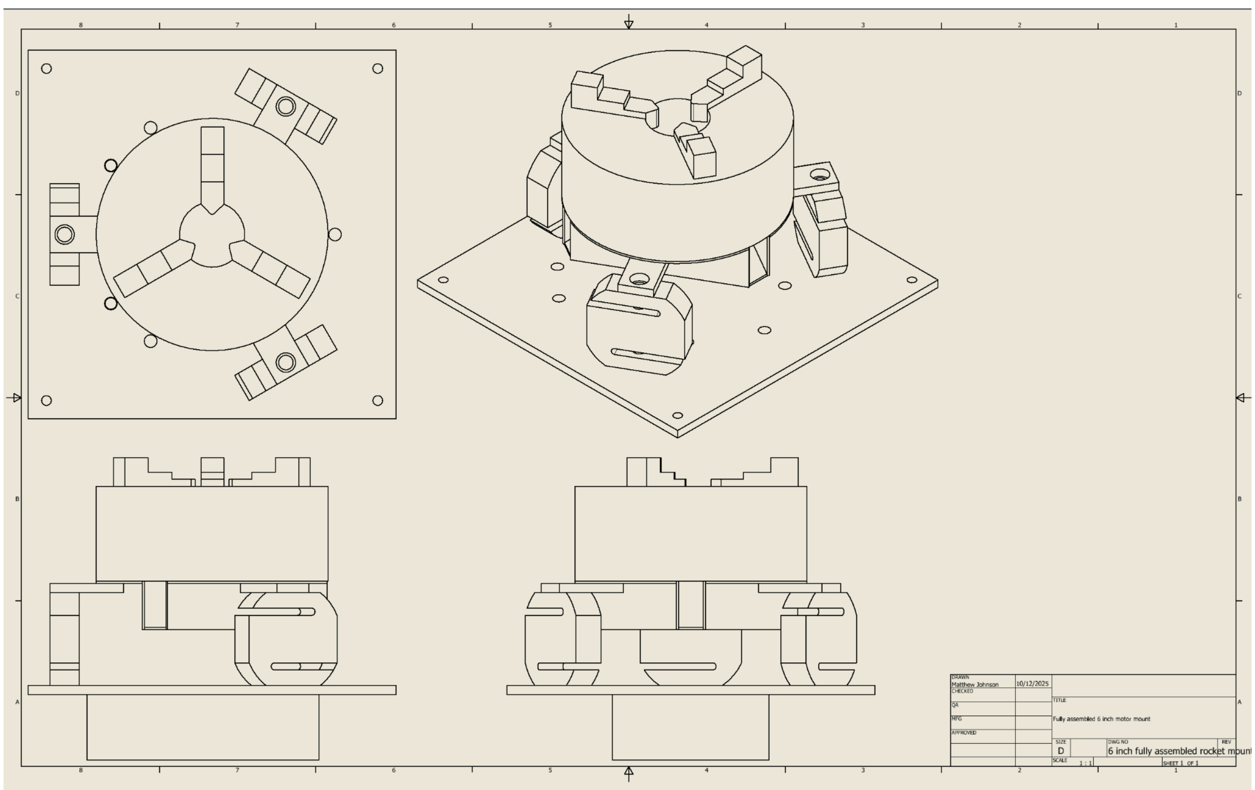
Subsystem Analysis

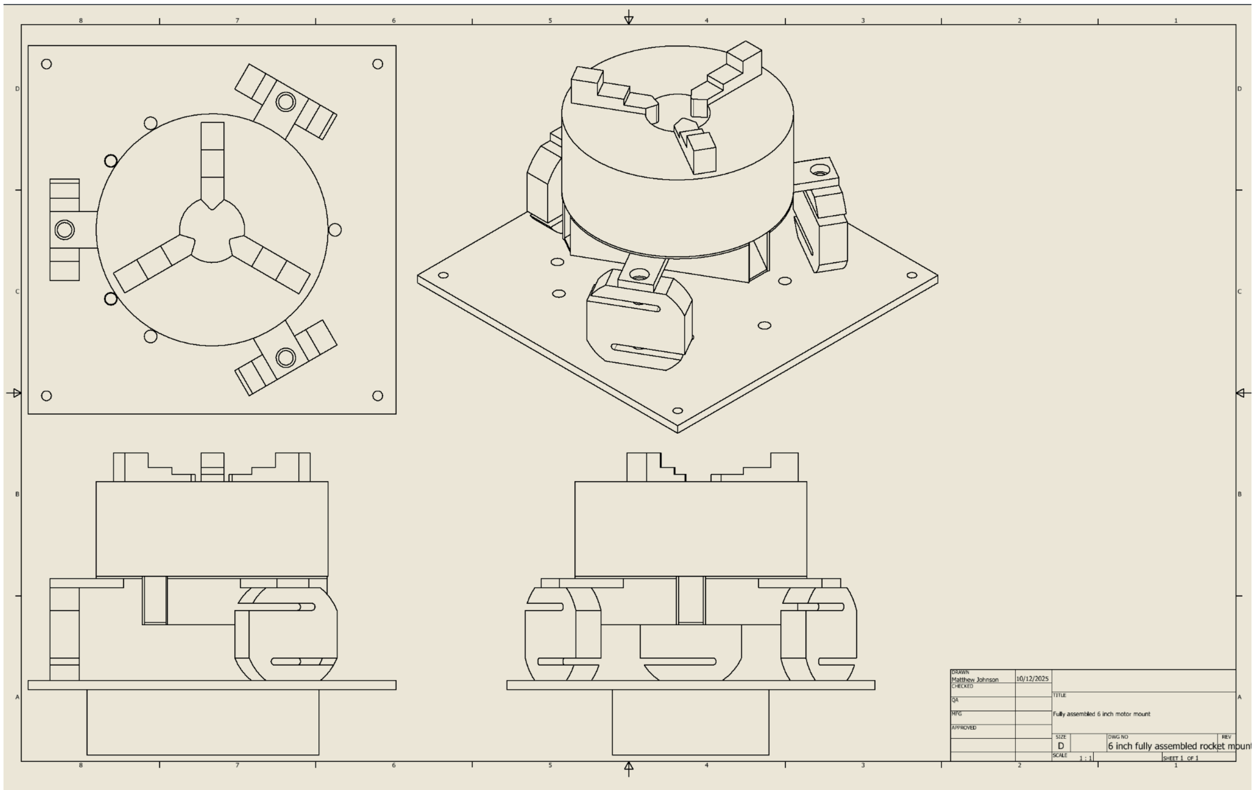
The EAP includes all design drawings. The exact dimensions are specified for all parts. The drawings are specific enough to give to another company, so that other company can produce the subsystems exactly to our intended design. The FMEA is referenced in the EAP as the main points of failure analysis.

RMTS Motor Mount

The RMTS motor mount is 2 separate mounting systems designed for 2 different rocket ratings. There is a 6 inch version and a 5 inch version which both refer to the size of the lathe chuck mounted on top. For each mount there are 3 unique machined parts, 5 total machined parts, and 3 from seller parts.

Pictured below are the 5 and 6 inch versions respectively. Starting from the top the parts are the 3 jaw lathe chuck, the ejection catch, the load cell spacers, the load cells, the base plate, and the load cell junction box.





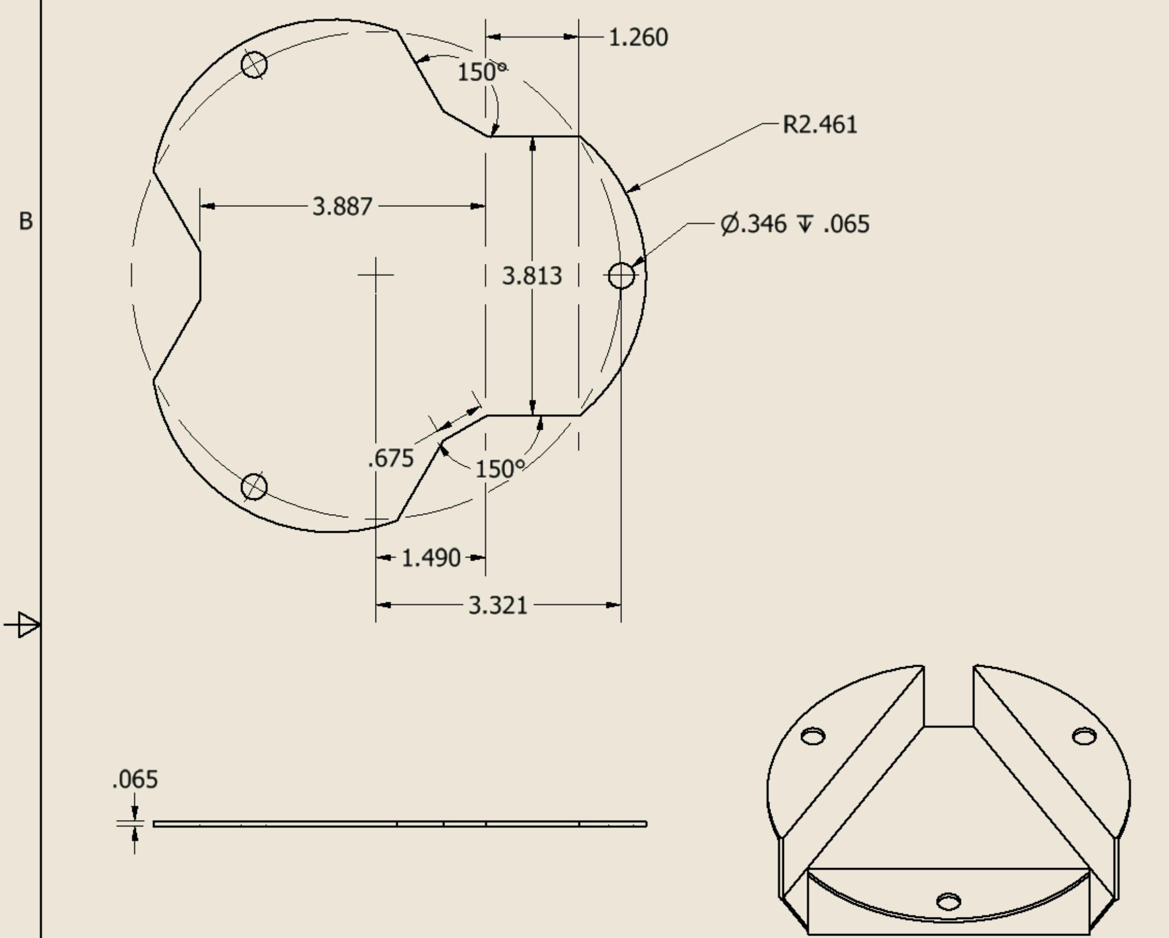
3 Jaw Lathe Chucks

The lathe chucks will be purchased through an online realtor such as Amazon. The 2 lathe chucks needed for the motor mounts are the K11-160 and the K11-125 which are the 6 and 5 inch chucks respectively. The chucks were tested by placing a rocket motor in the jaws and applying force to the motor and seeing if a slip occurs or if damage to the motor is done by the lathe jaws. In testing it was concluded the lathe jaws are capable of securing the rocket motors as motors were weighted with the testers full body weight and the motor did not yield. It was also concluded that the Estes rocket motors are strong enough to withstand the clamping force behind the lathe jaws.

Ejection Catch

The ejection catch is designed to shield the load cells from the ejection charge of model rocket motors. The ejection catch is machined out of either 16 gauge or 1.5 mm sheet steel then manually bent into the appropriate shape. The only analysis that will be done on the ejection catches is how the fair in test motor fires. The 5 and 6 inch ejection catches are pictured below

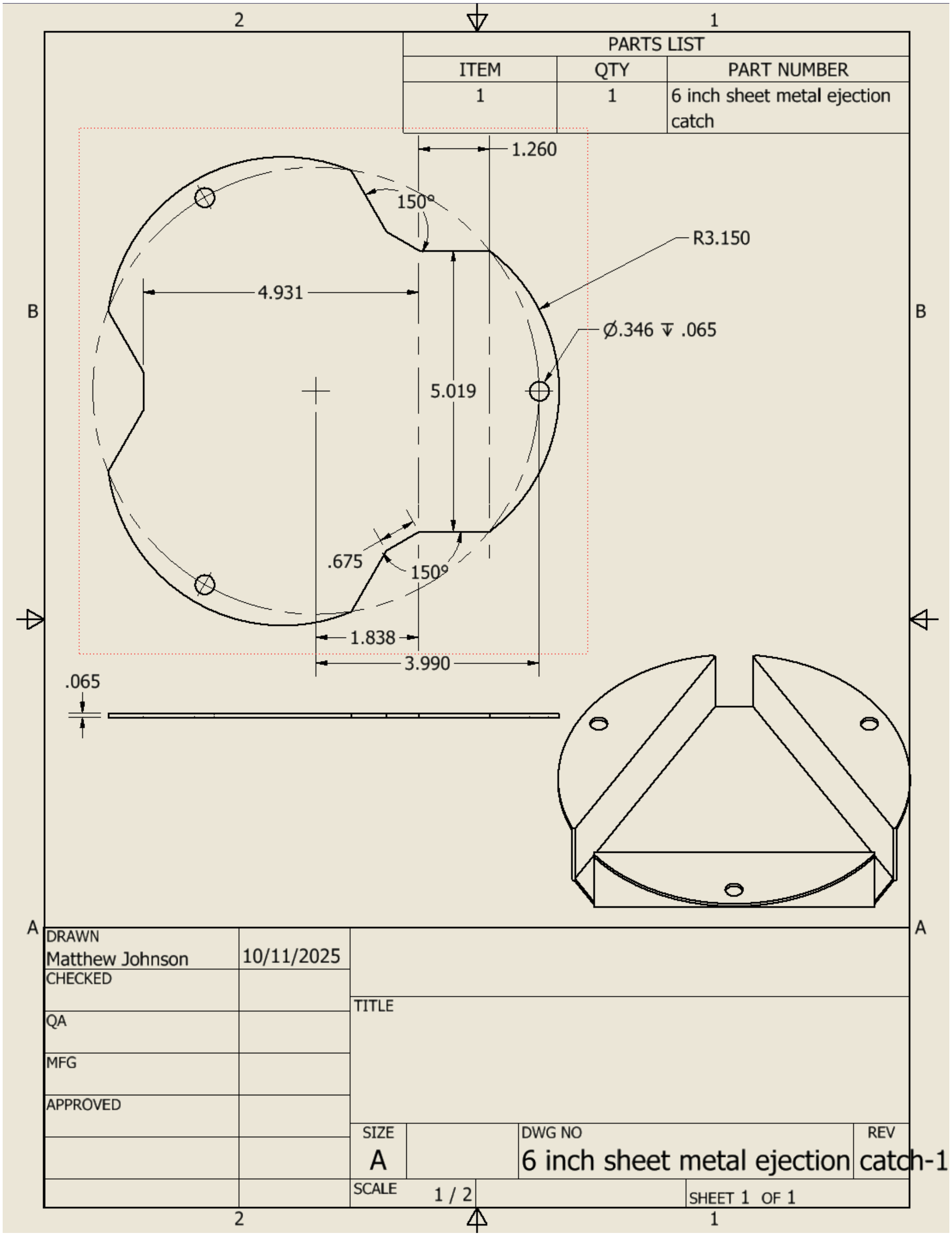
PARTS LIST		
ITEM	QTY	PART NUMBER
1	1	5 inch sheet metal ejection catch



DRAWN
Matthew Johnson 10/12/2025
CHECKED
QA
MFG
APPROVED

TITLE
5 inch sheet metal ejection catch

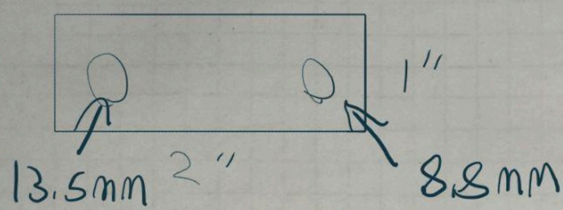
SIZE A
DWG NO 5 inch sheet metal ejection catch-1
REV
SCALE 1 / 2
SHEET 1 OF 1


PARTS LIST
ITEM
QTY
PART NUMBER
1
1
6 inch sheet metal ejection catch
1.260
150°
R3.150
4.931
Ø.346 ↧ .065
5.019
.675
150°
1.838
3.990
.065
DRAWN
Matthew Johnson
10/11/2025
CHECKED
QA
MFG
APPROVED
TITLE
SIZE
A
DWG NO
6 inch sheet metal ejection catch-1
REV
SCALE
1 / 2
SHEET 1 OF 1

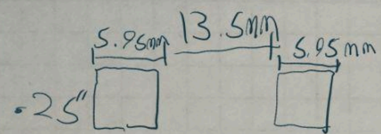
Load Cell Spacer

The load cell spacers are designed to make it possible to rigidly fix the lathe chuck to the load cells. They are required due to only being able to thread into the load cells from the top and the lathe chuck from the bottom. They are a very simple machined part made out of ¼ inch sheet steel. A shear analysis was conducted to find the factor of safety under a 1000 Newton load on the 6 inch load cell spacer. The analysis was conducted on this spacer due to it having a larger bolt hole and larger rated max thrust. The analysis and the 5 and 6 inch spacers are pictured below. The spacers were designated as the weakest point on the motor mount due to taking all the force of the rocket motors and much weaker than the base plate due to less total area for shear. However, the load cell spacers achieved a very high 29.8 factor of safety.

Strength of load cell spacers



$\sigma_y = 36{,}000$ psi

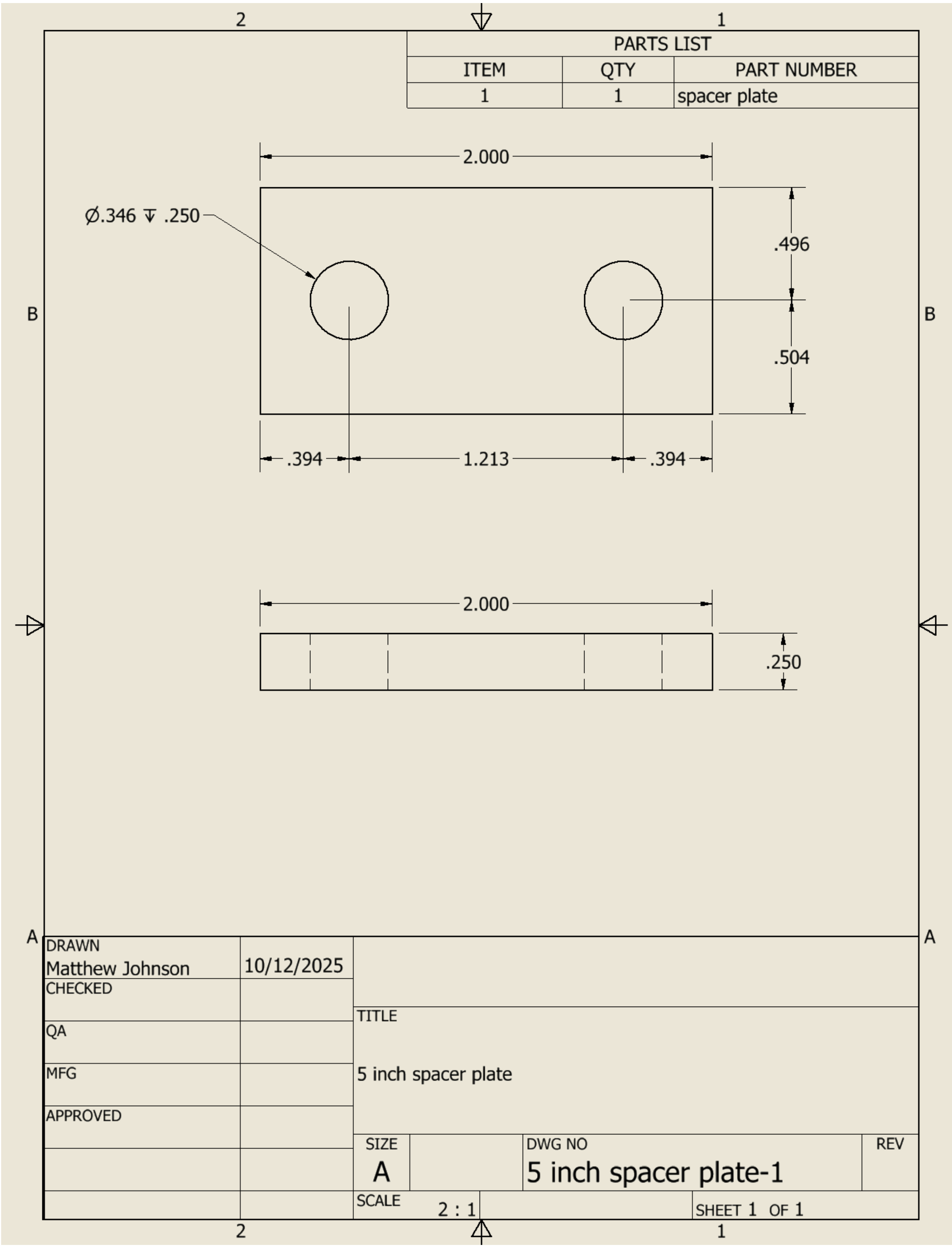


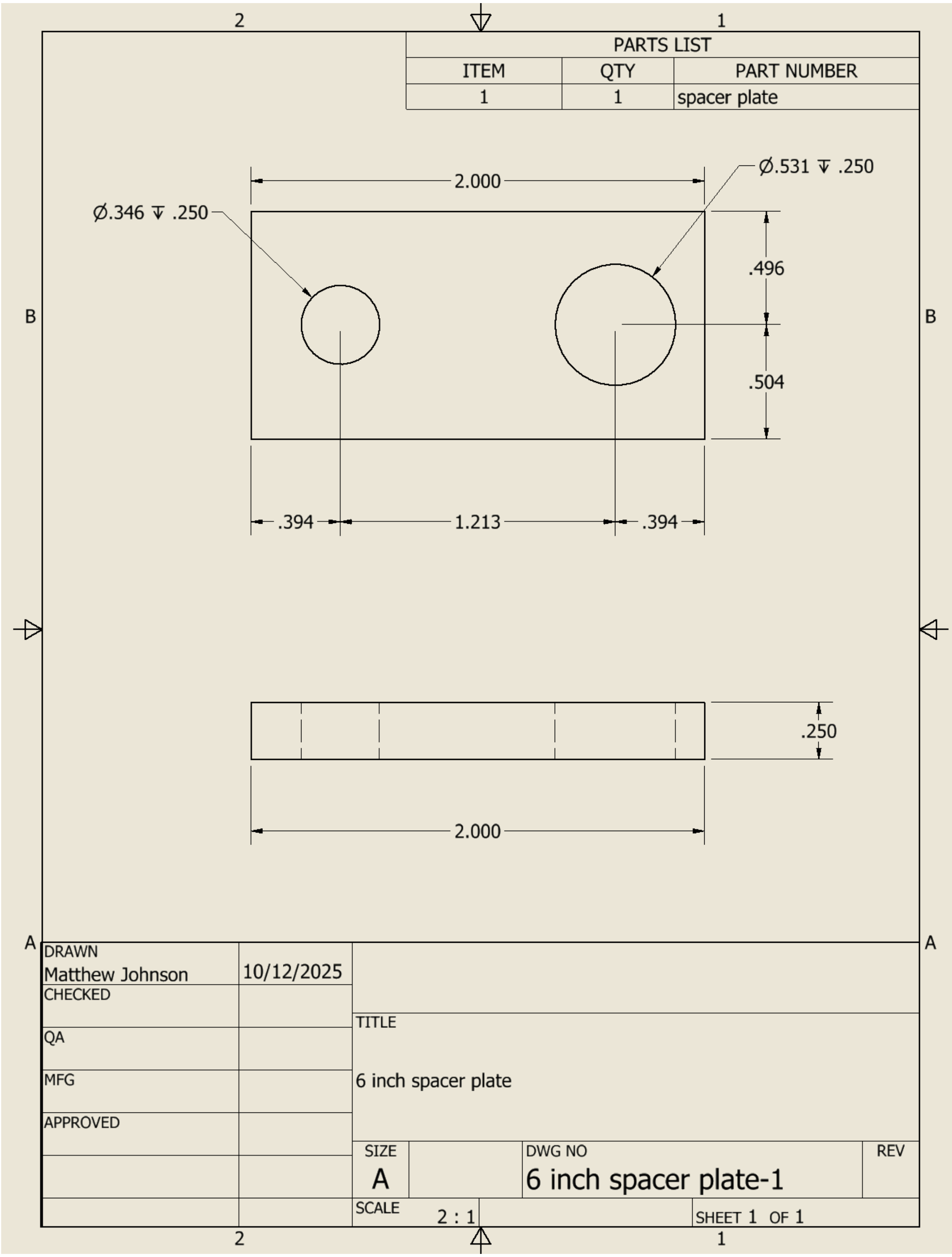
$A = 3 \cdot .25'' \cdot (10.9/25.4) = 0.3219\ in^2$

$\tau_y = \frac{\sigma_y}{\sqrt{3}} = 20785$ psi

$F_{max} = \tau_y \cdot A = 6691\ lbs = \boxed{29{,}834\ N}$

$\boxed{F.S = 29.8}$


PARTS LIST
ITEM
QTY
PART NUMBER
1
1
spacer plate
2.000
Ø.346 ↧ .250
.496
.504
.394
1.213
.394
2.000
.250
DRAWN
Matthew Johnson
10/12/2025
CHECKED
QA
MFG
APPROVED
TITLE
5 inch spacer plate
SIZE
A
DWG NO
5 inch spacer plate-1
REV
SCALE
2 : 1
SHEET 1 OF 1


PARTS LIST
ITEM
QTY
PART NUMBER
1
1
spacer plate
2.000
Ø.346 ↧ .250
Ø.531 ↧ .250
.496
.504
.394
1.213
.394
.250
2.000
DRAWN
Matthew Johnson
10/12/2025
CHECKED
QA
MFG
APPROVED
TITLE
6 inch spacer plate
SIZE
A
DWG NO
6 inch spacer plate-1
REV
SCALE
2 : 1
SHEET 1 OF 1

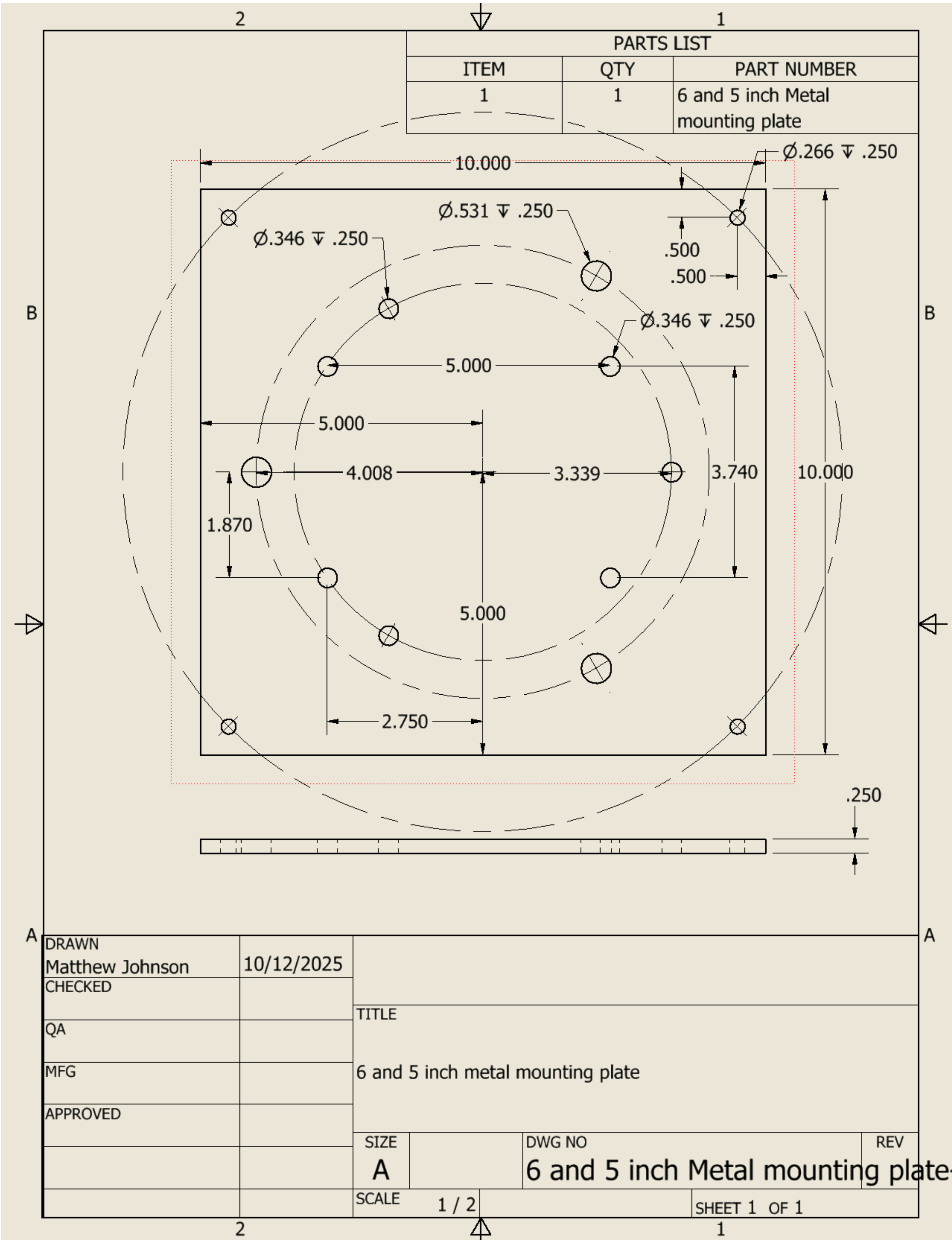
Load Cells

The load cells will be purchased from ATO and are the ATO-LC-S02 in the 10 and 50 kg versions. These load cells are slightly different sizes which is part of what is attributed to needing 2 separate motor mounts. An analysis was done on the error, max measurable load and max tolerable load of each configuration and is tabulated below. The load cells are the point of failure with the lowest factor of safety on the RMTS rocket motor mount with a factor of safety of 2.1 for the 6 inch mount. This low factor of safety was unavoidable due to the accuracy required of the load cells and the accuracy of a load cell being directly related to its maximum rated load.

Load Cell Rating (kg)	Number of Cells	Safety Overload	Accuracy	Weight of System (N)	Max Measurable Thrust (N)	Max Safe Load (N)	Error (N)
50	3	150%	0.03%	85	1387	2122	0.255
10	3	150%	0.03%	53	242	389	0.051

Base Plate

The base plate is where everything gets attached to; the load cells, load cell splitter, and frame all directly interface with the base plate. The base plate is universal so it works with both the 5 and 6 inch motor mounts. The base plate is machined out of ¼ inch steel. The base plate is pictured below.


PARTS LIST
ITEM QTY PART NUMBER
1 1 6 and 5 inch Metal mounting plate
10.000
Ø.266 ↧ .250
Ø.531 ↧ .250
Ø.346 ↧ .250
.500
.500
Ø.346 ↧ .250
5.000
5.000
4.008
3.339
3.740
10.000
1.870
5.000
2.750
.250
DRAWN
Matthew Johnson
10/12/2025
CHECKED
QA
MFG
APPROVED
TITLE
6 and 5 inch metal mounting plate
SIZE
A
DWG NO
6 and 5 inch Metal mounting plate-
REV
SCALE 1 / 2
SHEET 1 OF 1

Load Cell Junction Box

The load cell splitter combines the 3 load cells in parallel so only 1 amp and 1 external detachable connector is needed. The splitter is purchased from ATO under the SKU ATO-LCBOX-10I. No analysis will be performed on the load cell junction box.

Frame Analysis

The RMTS frame will act as the mounting surface for the rocket motor mount as well as the electrical box that will be affixed to the frame. This means the frame must be designed to handle the forces produced by I-class rocket motors and provide stability in case of off axis burn. The design of the frame is pictured below.

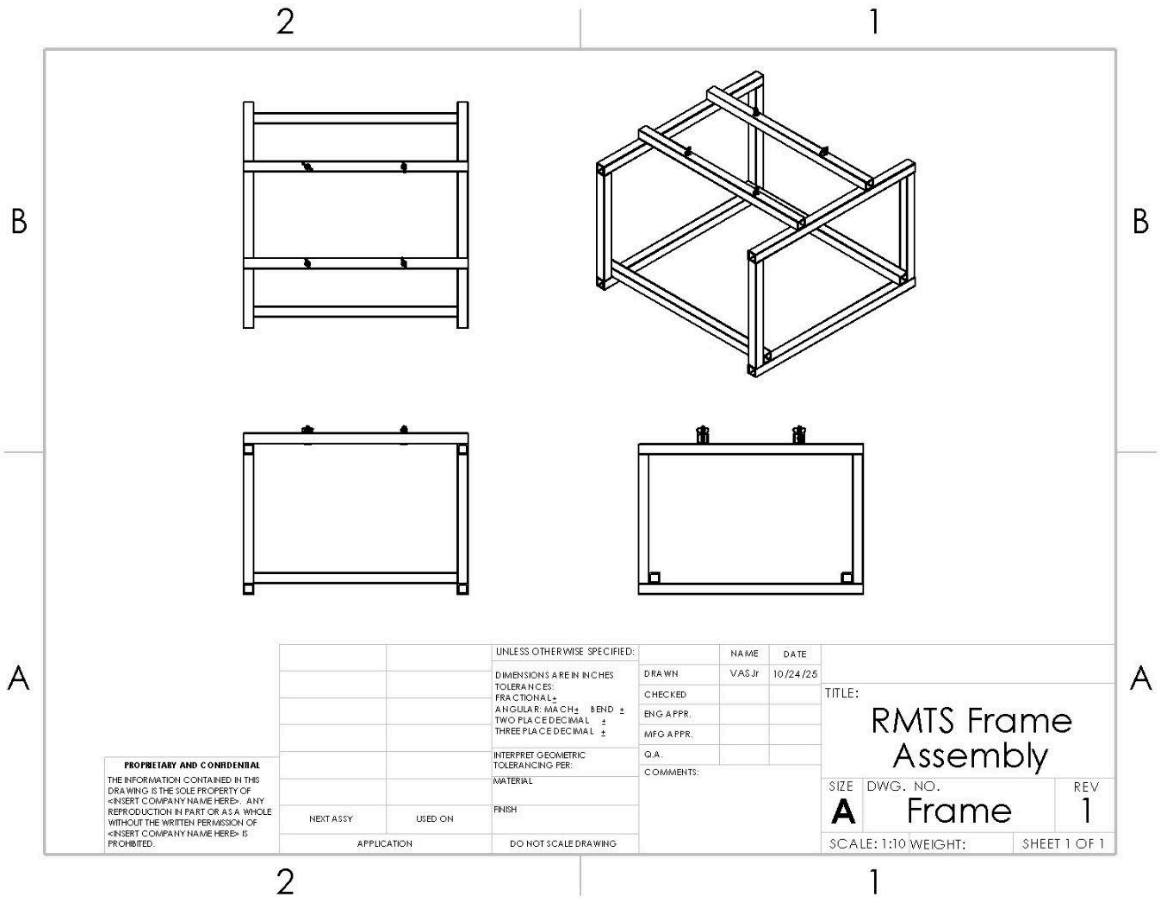


Figure X: Drawing of frame assembly

Frame Components

The frame is assembled from three main components, 1”x1”x1/8” square steel tube cut to 12 in length or cut to 21 in length. The third component is a modified version of the 21 in tube with mounting holes drilled out for attaching the RMTS Motor Mount. The following are the drawings of each component.

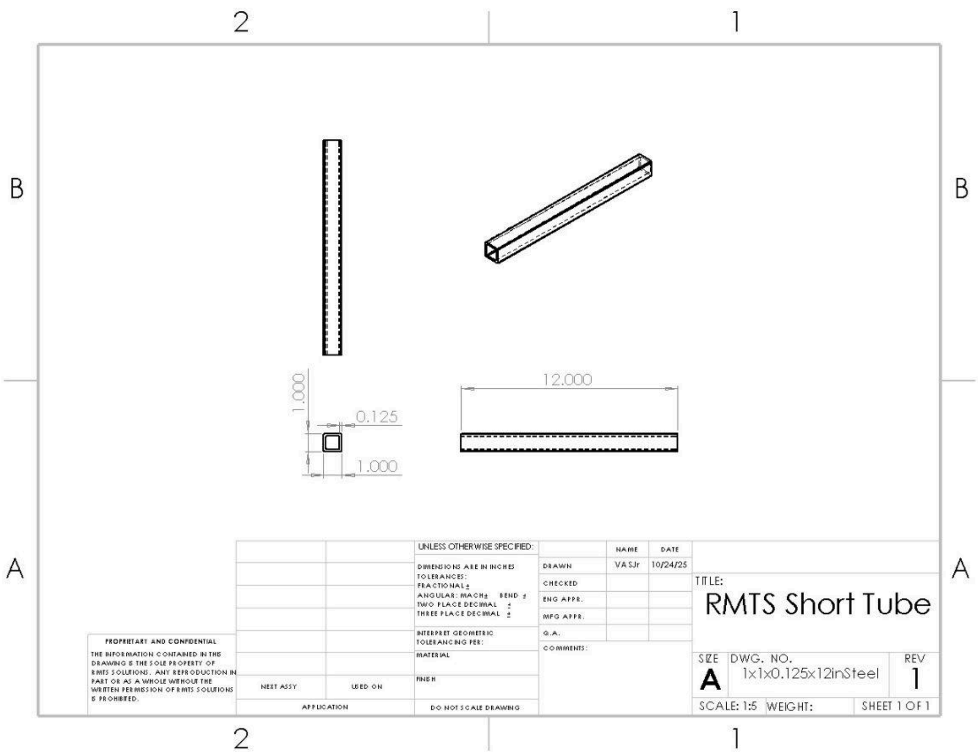


Figure X: Drawing of 1”x1”x1/8” square steel tube cut to 12 in

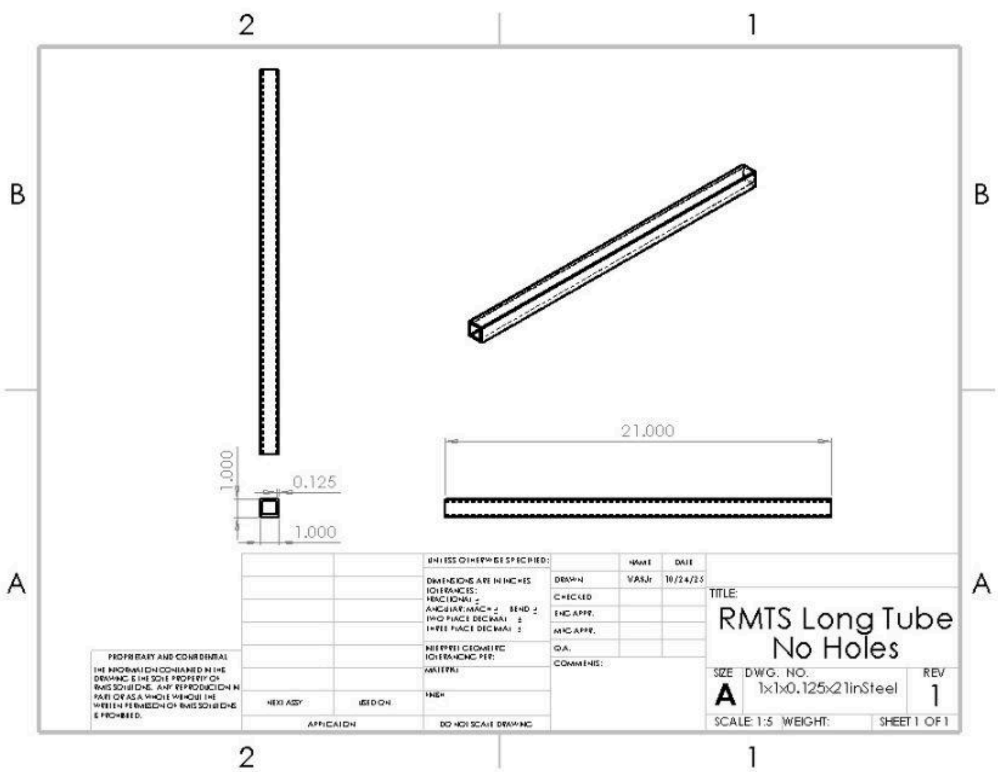


Figure X: Drawing of 1”x1”x1/8” square steel tube cut to 21 in

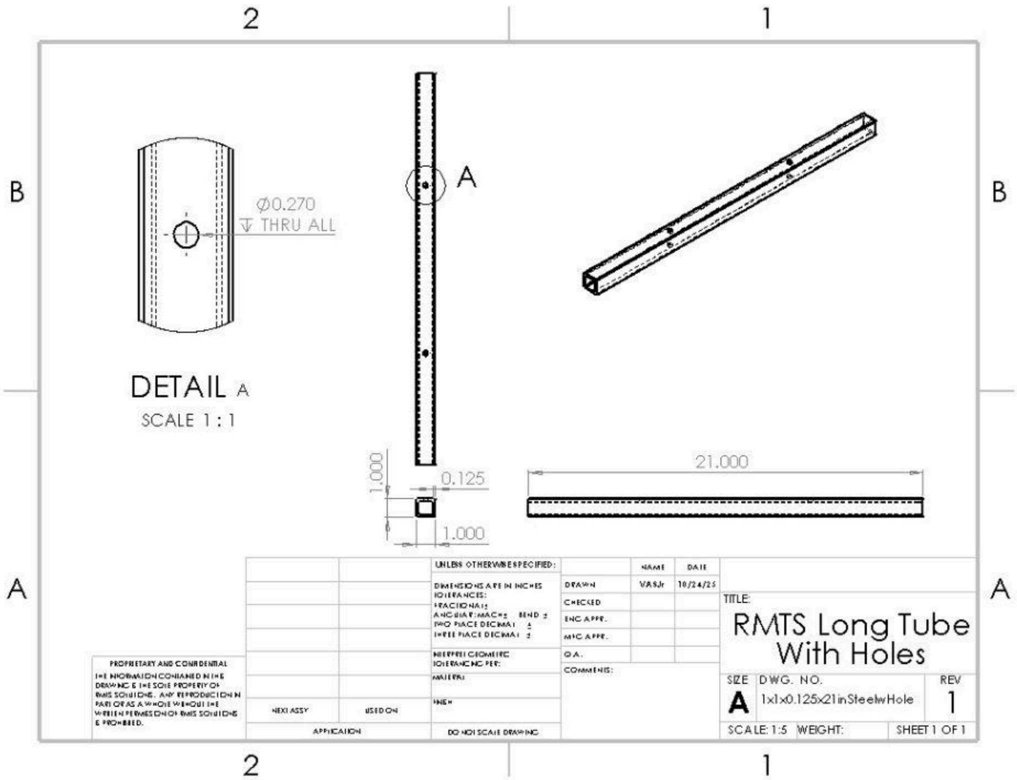


Figure X: Drawing of 1”x1”x1/8” square steel tube cut to 21 in with mounting holes

Frame Structural Analysis

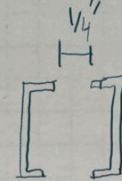
The identified weak points of the frame are on the top two 1”x1”x1/8” steel bars that the rocket motor mount is mounted to. Specifically the location of the through holes for mounting the motor mount and the welds to the rest of the frame were investigated as they were most likely to contain high stress concentrations. Pictured below is the hand calculation on the shear and bending stress in both of those points. A yield strength of 36 ksi was assumed for the steel tube and a max motor force of 1000 Newtons was assumed. The analysis into the shear strength shown below yielded a factor of safety of 139x. The frame is much weaker in bending than in shear, but still is plenty strong enough with factor of safeties of 17.4x and 36.7x at the wall and mounting location respectively.

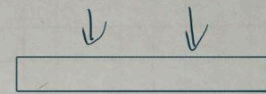
Known: $1'' \times 1'' \times 1/8''$ $\sigma_y = 36$ ksi 2 beams

Find: saftey factor of 5x in shear and bending

Solution:

$\tau_y = \frac{\sigma_y}{\sqrt{3}} = 20.78$ ksi

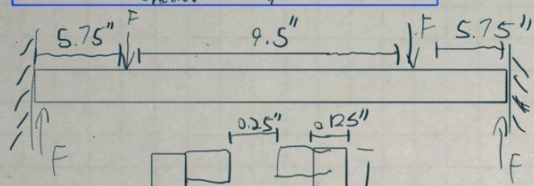


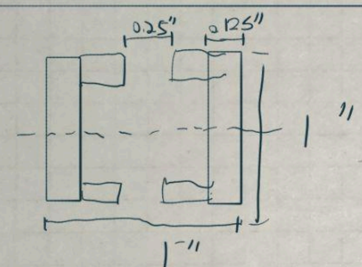


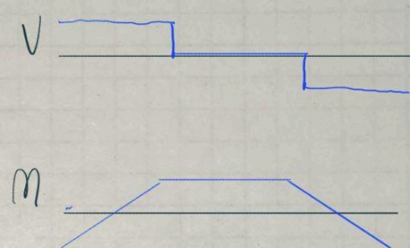
$A = ((1)^2 - (1 - 2\cdot 0.125)^2) - (2\cdot 0.25\cdot 0.125)) \cdot 4 = 1.5\ in^2$

$F_{max} = \tau_y \cdot A = 31170$ lbs $= 138{,}990$ N

$F.S. = \frac{F_{max}}{F_{expected}} = \frac{138{,}990}{1{,}000} = 138.99$







$F = \frac{1}{2}$ load

$I_{5.75} = 2 \cdot 0.04492 = 0.08984\ in^4$ $c = 0.5''$ $E = 29 \times 10^6$ psi

Using Super position

$M_{5.75} = F \cdot \frac{5.75^2 \cdot 15.25^2}{21^3} = F \cdot 1.66$

$\rightarrow 1.57F$

$M_{5.75} = \frac{F \cdot 5.75^3}{21^3}(3 \cdot 15.25 + 5.75) - \frac{F \cdot 15.25 \cdot 5.75^2}{21^2} = -0.08613 \cdot F$

$M_{wall} = -F\left(\frac{5.76 \cdot 15.25^2}{21^2} + \frac{15.25 \cdot 5.75^2}{21^2}\right) = -4.176 \cdot F$

$\sigma_{y_{5.75}} = \frac{M_{5.75} \cdot c}{I_{5.75}} = 8.737 \cdot F \rightarrow$ $F_{max} = 4120.2$ lbs $\rightarrow 18372$ N

$\sigma_{y_{wall}} = \frac{M_{wall} \cdot c}{I} = 18.445 \cdot F \rightarrow$ $F_{max} = 1951.7$ lbs $\rightarrow 8703$ N

17406 N Max load

Finite Element Analysis (FEA) was performed on the structure as a hole as depicted below:

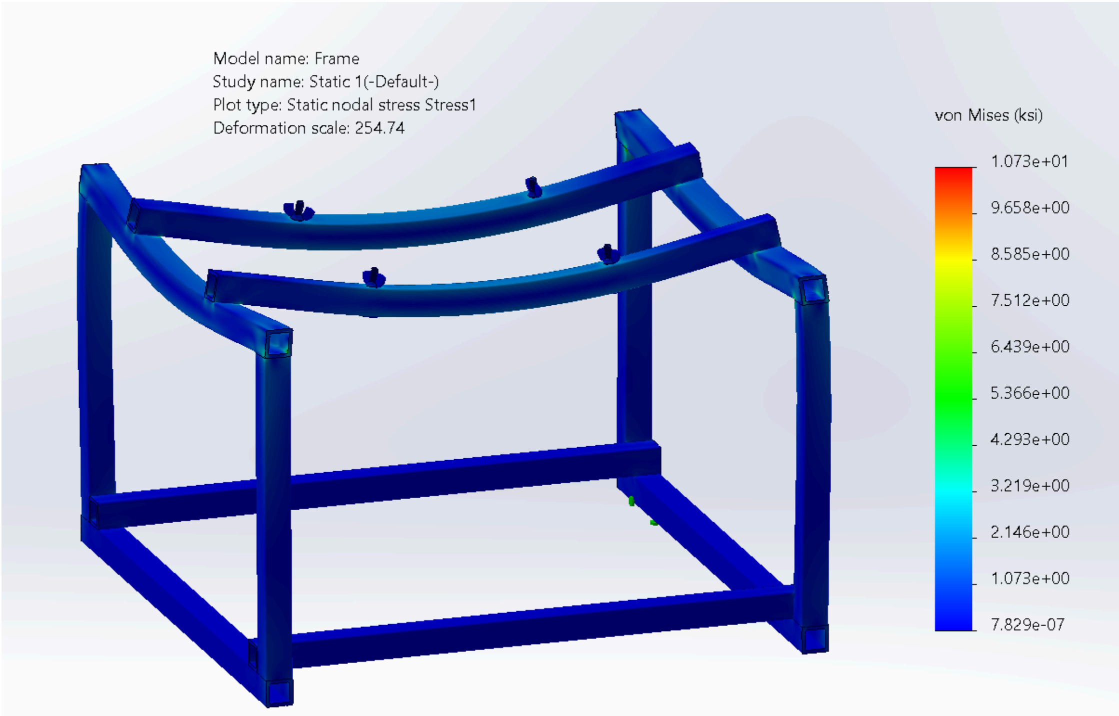


Figure X: FEA of Frame assembly with a max stress of 10.73 ksi

Although the FEA indicated a higher stress than expected, in closer examination, this maximum stress is at the joints as depicted in the figure X below.

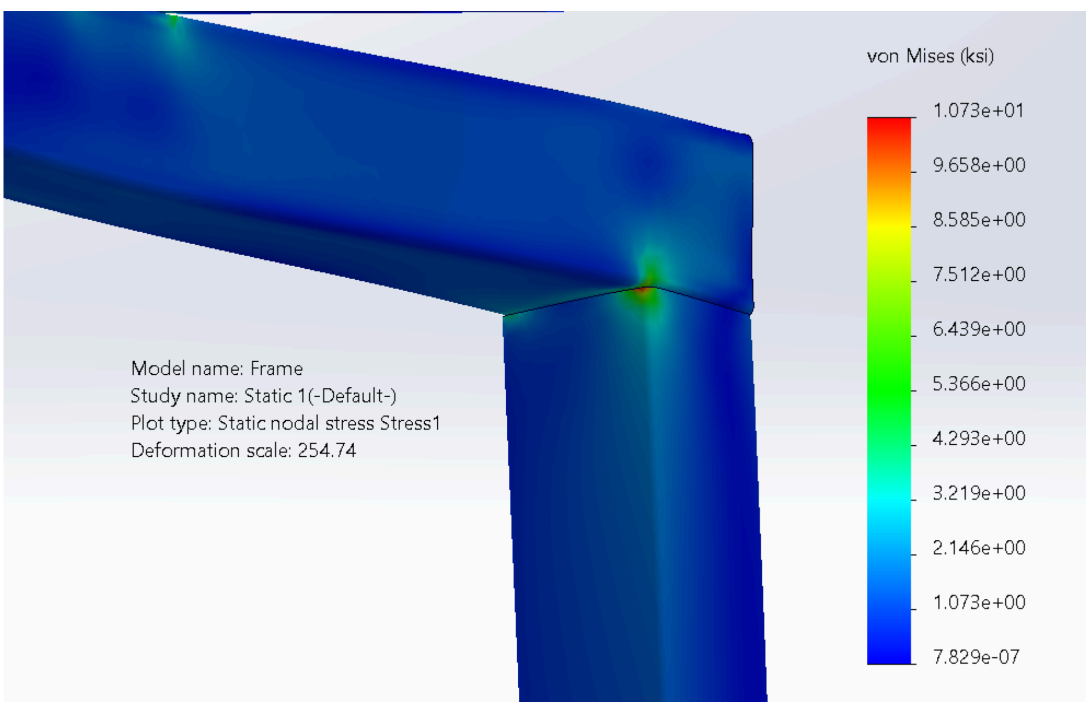


Figure X: Point on frame with highest stress, on upper corner of 21 in bar and 12 in bar

The areas indicated with the highest stress are where there are intended to be weld joints, which is not accurately reflected in the FEA. Therefore, these stresses may be ignored from this simulation. When comparing the stress at other points of the frame, the highest is around 6 ksi, a factor of safety of 6.

Frame Stability Analysis

As mentioned prior, the stability of the RMTS comes from the frame. The stability of the frame was analyzed in 3 different methods to correlate to different use configurations. Method one was stability in the x and y axis of the frame with no stabilization bars, method 2 was stability in the x and y axis with the 5 foot stabilization bars, and method 3 was a diagonal stability analysis of the frame with stability bars as the diagonal in this case is the least stable. The hand stability calculations are pictured below. No stabilization bars gives enough stability for a 22.8 degree off axis burn assuming the frame is on level ground and the rocket motor used is the maximum thrust of 1000 Newtons. The stand only becomes more stable if a smaller rocket motor is used, so 1000N was used for all calculations. A 22.8 degree off axis burn is extremely unlikely, however if more stability is desired the 5 foot stabilization legs can be attached then the frame can achieve a 53.3 degree off axis burn in the x and y axis and has an absolute worst case scenario off axis burn limit of 49.1 degrees in the diagonal axis.

Stability of frame with stability legs

frame height - 15''

Motor mount max height - 17''

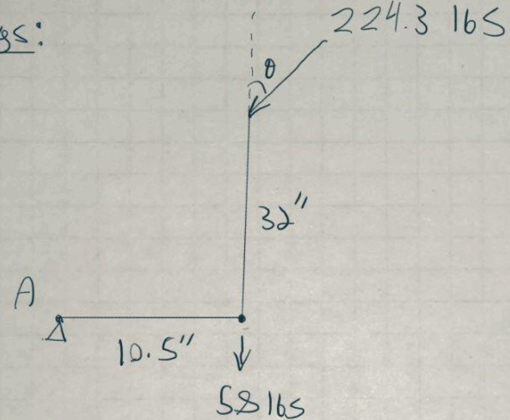
frame weight - 26 lbs

Motor mount weight - 32 lbs

assuming 1000 N max rocket force → 224.3 lbs

legs Width - 60''

Solution - no legs:

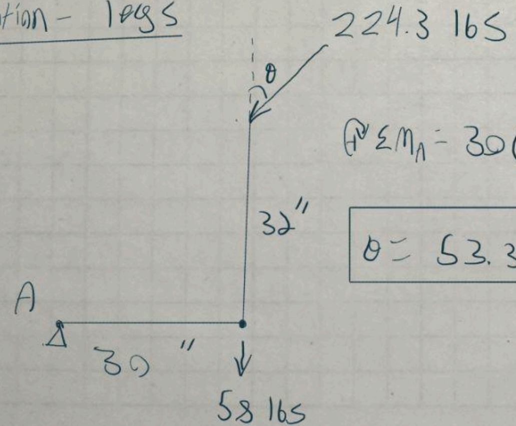


$$\circlearrowleft^{+} \Sigma M_A = 0 = 10.5 \cdot 58 + 10.5 \cdot 224.3 \cdot \cos(\theta) - 32 \cdot 224.3 \cdot \sin(\theta)$$

$$0 = 609 + 2355.15 \cdot \cos(\theta) - 7177.6 \cdot \sin(\theta)$$

$\boxed{\theta = 22.79^\circ}$ before loss of stability

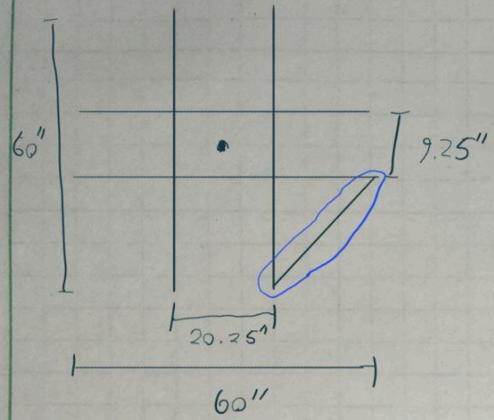
Solution - legs

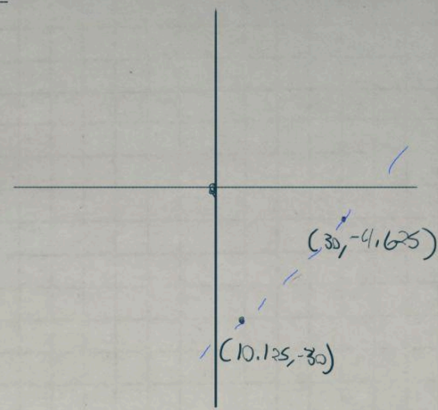


$$\circlearrowleft^{+} \Sigma M_A = 30(58 + 224.3 \cdot \cos(\theta)) - 32 \cdot 224.3 \cdot \sin(\theta)$$

$$\boxed{\theta = 53.34^\circ}$$

Solution - diagonal leg case





Find: eq of the line and length of perpendicular line to origin

Solution:

$y = mx + b$

$m = \dfrac{-4.625 + 30}{30 - 10.125} = 1.2167$ $\quad b = -30 - m \cdot 10.125 = -42.927$

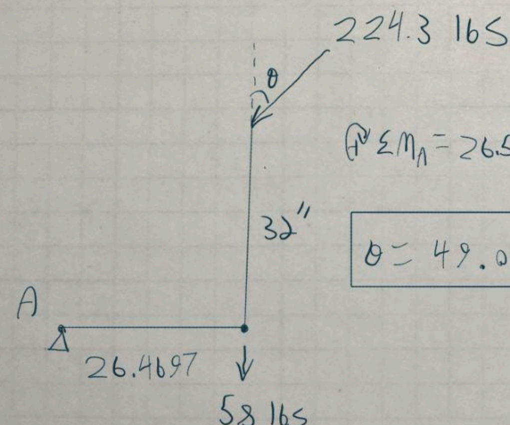
$m_{perp} = -\dfrac{1}{m} = -0.78325$

$y = m \cdot x + b$

$y = m_{prep} \cdot x$

$x_{sol} = \dfrac{b}{(m_{prep} - m)} = 20.8385$ $\quad$ line length $= L = \sqrt{x^2 + y^2} = \boxed{26.4697}$

$y = m_{prep} \cdot x_{sol} = -16.3218$



$\curvearrowleft \Sigma M_A = 26.5(58 + 224.3 \cdot \cos(\theta)) - 32 \cdot 224.3 \cdot \sin(\theta)$

$\boxed{\theta = 49.0833^\circ}$

Electrical Analysis

Figures X and X below show the RMTS electrical subsystems.

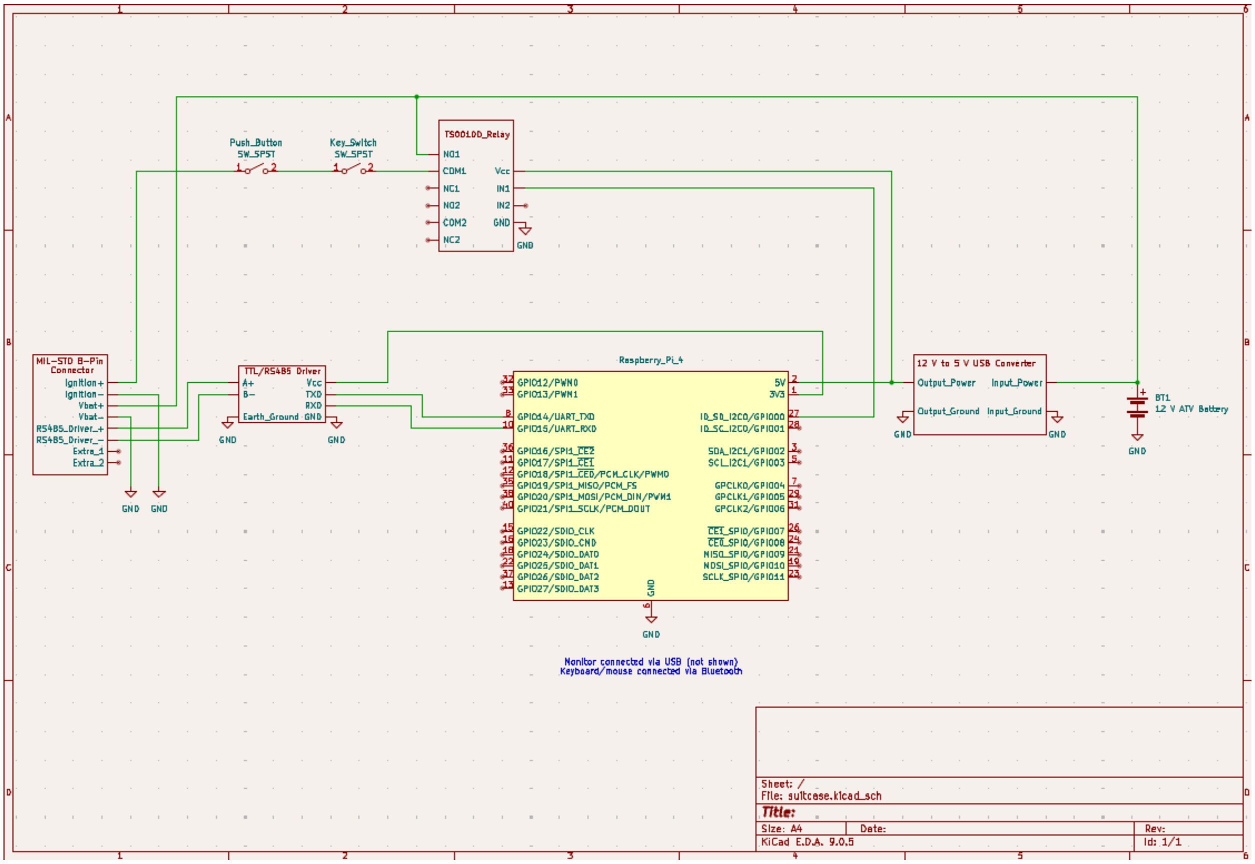


Figure X: Control Case Electronics Schematic

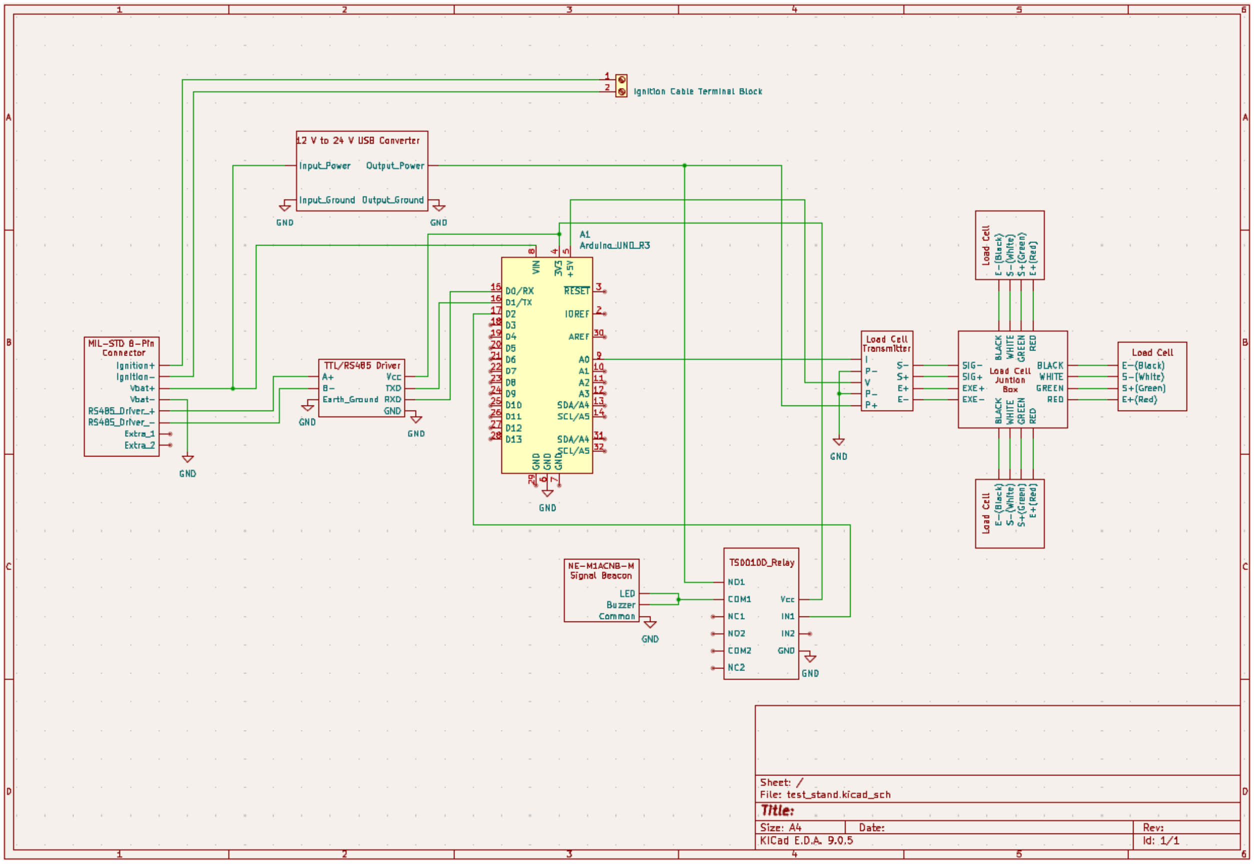


Figure X: Test Stand Electronics Schematic

1. Ignition

The key components of the ignition system are the initiator, key switch, push button, cable bundle, and battery.

The RMTS will use disposable initiators from the manufacturer of the rocket motor for ignition. The initiators will be connected to screw terminal blocks that are part of a specific ignition circuit that is controlled by the user at the RMTS control case (shown in Figure X). The initiators available for this class require a minimum of 6 V and a maximum of 2 A.

Figure X: Screw Terminal Blocks for Initiators

Rocketry safety guidelines require a physical interlock that disconnects the ignition circuit until the user is ready to fire the motor. The key switch component was included in the circuit to satisfy this requirement. The key switch purchased is single pole, single throw, and capable of handling up to 24 V and 8 A of direct current (DC). Until the key is turned, the battery will not be connected to the ignition system. After the key is turned a push button will be used to ignite the rocket after a countdown. The push button can handle a maximum DC voltage of 28 V and maximum DC current of 10 A.

The voltage and current for the ignition circuit will be carried to the RMTS over two 14 American Wire Gauge (AWG) wires within the cable bundle, with a dedicated positive and negative wire to prevent any surges or power fluctuations for the rest of the electronics.

The same All Terrain Vehicle (ATV) 12 V battery will be used to ignite the rocket motor as is powering the rest of the RMTS electronics.

2. Data Sampling

The load cell circuit consists of three parallel load cells connected to a central hub that splices the connection into a single wire. This is then fed into a load cell amplifier which will output a voltage between 0 and 5 V-DC. This voltage signal will be fed to the arduino for sampling.

The Arduino Uno R4 integrated within the test stand will do the data sampling using its 14-bit analog to digital converter to take voltage measurements from the load cell amplifier. The Arduino Uno R4 uses a Renesas R7FA4M1AB3CFM#AA0 chip, which theoretically has a maximum 14-bit sample conversion time of just 1.22 microseconds. Discussions on Arduino user forums indicate that a maximum sampling rate in realistic projects is between about 30 and 45 kHz, which is still far greater than the 100 Hz sampling requirement.

The amount of data gathered during a rocket motor test might be significant, depending on how long the rocket motor burns. For example, if 14-bit force measurements are taken for 30 seconds at a 100 Hz rate, 42,000 bits of data will be created. The Arduino's serial port can only transmit 8 bits at a time, so each 14-bit measurement will be split into two 8-bit numbers written to the serial port, with 48,000 bits transmitted over 6,000 one byte writes to the serial port.

The TTL to RS485 driver boards purchased for the RMTS automatically detect if data is being transmitted so the same half-duplex connection can be used to both transmit and receive. User reviews suggest this automatic switching leads to data integrity issues if the boards are used to transfer data faster than one megabit per second. This shouldn't be an issue, however, because the maximum serial baud rate of the Arduino and Raspberry Pi 4 commonly used in hobbyist applications is 115,200 bit per second. At this rate, it would take about 0.417 seconds for the Arduino to transmit the data to the Raspberry Pi, assuming no break between each byte being transmitted.

3. Control Case

The RMTS will be controlled via a control case housing many of the electrical components, including the Raspberry Pi 4 and the key switch and push button for igniting the rocket motor. Most of the ignition components are in the control case to allow the user to safely and securely initiate the rocket following relevant guidelines. Locating the Raspberry Pi 4 in the control case will allow the user to connect its peripherals and view rocket motor thrust data immediately after the test is completed. The 12 V battery will be with the user at a safe distance from the rocket, and the control case also acts as a distribution hub for the battery's power.

4. Cable

The control case and test stand will be connected via a 125 ft cable bundle containing wires for several different circuits. The test stand power circuit and the ignition circuit will both be connected to the control case with 14 AWG wire, with separate ground wires for both. 14 AWG wire was chosen for its low cost and ability to carry large amounts of current without a large voltage drop over long distances. The separate ground wires were added to avoid any preventable power fluctuations when the rocket motor is initiated. The Raspberry Pi 4 and Arduino Uno R4 will communicate with two TTL to RS485 drivers transmitting signals over Cat 6 ethernet cables. This communication method was chosen because the UART ports on both microcontrollers may struggle to reliably transmit data over 125 feet, while RS485 low voltage differential signaling was designed for distances up to 1000 m. Each driver is only half-duplex, so two will be used to enable the Raspberry Pi 4 and Arduino Uno R4 to both transmit data simultaneously. Both communication circuits require two wires for differential signaling, so four of the Cat 6 wires will be used. The two ends of the cable bundle will be tipped with male Amphenol connectors that pair with female Amphenol connectors integrated into the control case and test stand electronics box so a weather-proof connection can be made reliably. The 14 AWG wires and the Cat 6 cable will be zip tied or fastened periodically along their length so they can be easily rolled and unrolled together when setting up and tearing down the RMTS.

5. Power Budget

    The power budget of the RMTS will be tight because of all the integrated electrical components. Within the control case, the Raspberry Pi 4, two TTL to RS485 driver boards, portable monitor, keyboard with integrated mouse, and dual relay module will all consume power and within the test stand the Arduino Uno R4, two TTL to RS485 driver boards, load cell amplifier/transmitter, flasher/siren, and ignition circuit will need power. The biggest current hogs will be the Raspberry Pi 4, which is expected to need about 2.5 A, the portable monitor, which is expected to need about 2 A, and the ignition circuit, which will need about 2 A when igniting the rocket. The expected maximum current the battery will need to supply for all these electronics is about 6.46 A. Further details and a breakdown of the power budget can be found in the project Failure Modes and Effects Analysis document.

Subsystem Compatibility Analysis

- Paragraph on size of components and how they can fit in a case for shipping
- Primary mechanical-electrical interface is the load cells - maybe add a short paragraph on them?

Other Analysis

- 5x safety factor URD

References

FMEA

Appendix