UNIVERSITY OF MANITOBA

MECH 4860
Final Design Report
Team 11: Test Cart Design for StandardAero

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STANDARD AERO

UNIVERSITY OF MANITOBA

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Professor Labossiere,

Enclosed is a copy of Team 11's design report prepared for MECH 4860: Engineering Design, submitted on Dec 6th 2010. The team advisor for this course has been Vijay Chatoorgoon. The report has been written for StandardAero, Winnipeg. The report describes the redesign of StandardAero's existing Turbine Test Carts to accommodate two engine models.

To accommodate both engines models, the mounts on the original cart were modified. Also, to improve overall turnaround time during testing, the electrical, pressure, vibration, and temperature systems were redesigned.

It was determined that, through the redesign of the engine mounting system and existing measurement systems, a universal test cart created by modifying StandardAero's existing carts would be feasible.

Sincerely,
Team 11:

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Abstract

This report outlines the redesign of StandardAero Winnipeg's existing turbine test carts in order to accommodate two different engines. The primary goal of the redesign was to improve the testing time required for each engine by streamlining the test process and eliminating the need for additional carts.

Each of the two engines has different longitudinal dimensions. Our design requires replacing the base section of the engine mounts with a redesigned baseplate and carriage/rail system to accommodate either engine's dimensions.

The electrical and data acquisition systems were examined thoroughly. It was found that by updating the pressure systems we were able to significantly reduce the amount of wiring between the cart and the control room. The vibration system was improved by placing the charge amplifiers on the cart itself. This cut down on the length of wiring significantly and will increase the accuracy of the readings.

It was determined that the cart had enough space available to accommodate both of the engines' throttle control mechanisms. Redesigning the throttle controls was not necessary; both systems are to be added to the new cart in their current configuration.

The addition of baffles to the oil pan will help to dissipate the momentum of the oil developed when the dolly is moved. This will help to prevent oil sloshing out of the pan.

We were able to fulfill all the objectives determined at the start of the project. Implementing the redesigned cart will reduce the total time taken to test an engine by freeing up more space on the preparation floor and, more importantly, by significantly reducing the number of connections that must be made when setting up an engine for testing.

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1. Introduction

1.1. Background

Standard Aero functions as a complete maintenance repair and overhaul (MRO) facility for gas turbine engines. For certain maintenance operations and overhauls, the engines cannot return to the customer until the engine has passed a comprehensive test. In order to pass the testing process, the engines must meet or exceed several base requirements which are set by the engine manufacturer. These tests are performed within a test cell, which is essentially a wind tunnel equipped with a dynamometer (dyno). The engines are controlled and regulated through communication systems actuated by the operators' commands in the control room. Our project involves the test carts on which the engines are mounted during these tests. These carts contain all the required pressure tubing, electrical & vibration measuring systems, engine controls, as well as the mounting hardpoints for each specific engine model.

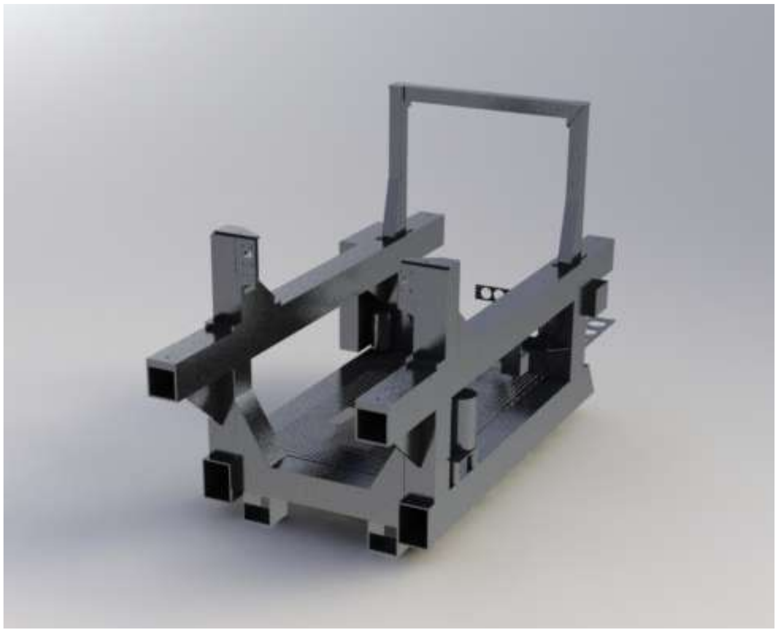


Figure 1. Original Test Cart

The test process begins when the engine arrives at the test cell. First, the engine is mounted onto a test cart (see Figure 1), which sits on a wheeled dolly. The engine is supported on the cart by three separate hardpoints. The front of the engine is supported by two hardpoints located on individual upright mounts near the front of the test cart. The front mounts are referred to as reduction gearbox (RGB) mounts as they hold the engine's transmission. The rear of the engine is supported by a third hardpoint which is mounted on a beam spanning two upright mounts near the rear of the cart. The engines are fixed to the hardpoints by bolts. Once the engines have been mounted to the cart all of the electrical, hydraulic, and pressure connections are made between the engine and cart. Engine throttle control systems are also attached to the cart. After all the connections have been made between the engine and cart, they are both wheeled into the test cell on the dolly. The cell has a large air inlet and exhaust vent to ensure proper circulation of air during testing. On one wall of the cell is a window leading into the operator control room. Next to this window are all the connections for the electrical, hydraulic, and pressure connections which must be made between the cart and the control room. A general layout of the test cell and prep area can be seen in Figure 2.

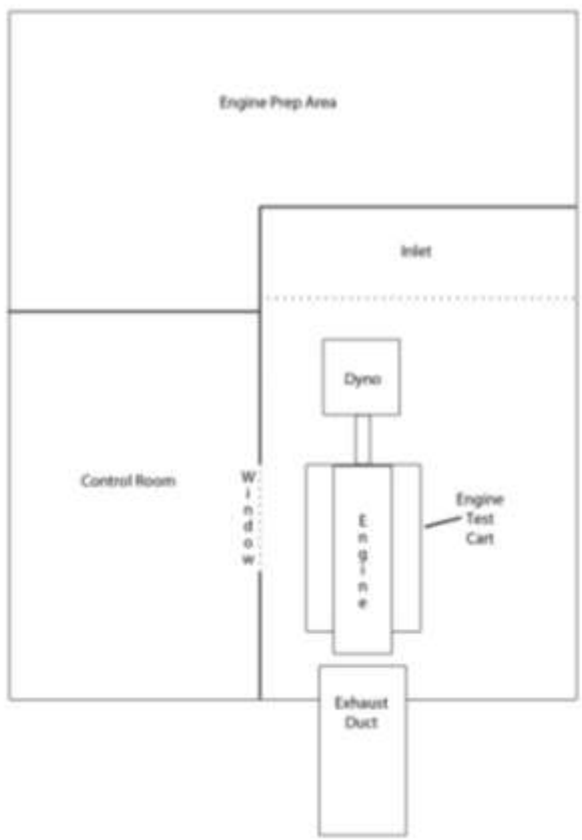


Figure 2. Test Cell Layout

The test cart is wheeled into the cell on a dolly and situated next to the dyno. A crane lifts the cart and engine off the dolly and aligns them with the dyno and exhaust vent. The operators then connect the engine to the controls and instrumentation. The engine is then fixed to the dyno, the cell doors are closed, and the testing begins. Once the tests are completed, the engine is disconnected and is wheeled out of the cell. The entire process, from the time the engine arrives until the completion of testing, can take anywhere from 2 to 5 hours depending on the operator and required tests.

1.2. Problem Statement

The West Test Cell at StandardAero currently tests multiple types of engines, used for both ground power generation and aviation applications. Our project will focus on two engine types, Engine A and Engine B (note: the engine names have been redacted due to a non-disclosure agreement).

Each engine utilizes a different configuration for mounting and interfacing with the test cell controls. StandardAero currently use different carts for each model of engine. Our team has been assigned to come up with a concept in which both engines utilize one universal cart. A shared cart would not only increase free space within the facility, but it would also cut down on rigging time for the operators.

Ideally, multiple engines should be rigged and prepped for testing while another is being tested in the cell. Since the carts are currently model-specific, bottlenecking occurs if three or more engines of the same type are delivered in a row. Due to lack of carts the third cannot be rigged until the first is finished testing; this is an inefficient use of the operators' time and of the space within the facility.

The creation of a universal cart would solve this bottlenecking, since it would allow for a total of three carts per engine within the facility instead of two. A universal cart should have a simple way of being reconfigured to test either engine with minimal set up time. The cart must also incorporate either engine's pressure systems, electrical systems, data acquisition systems, as well as the engine control interface for both of the engines.

1.3. Project Objectives

The primary objective of this project is to reduce the time required to run tests on Engine A and Engine B. Currently, both Engine A and Engine B are tested in the same cell but using different carts. There are currently three carts on the floor; two carts for Engine A and one for Engine B. There are plans to add an additional cart for Engine B, making for a total of four carts. Having four carts takes up a lot of valuable floor space. Our objective is to have a design requiring only three carts, all of which are compatible with either Engine A or Engine B. This would allow one engine to be prepped for testing on a cart while another engine is being tested in the cell and a final engine is being dismounted from its cart after testing.

The current interface between the engines and the carts will need to be modified. The primary goal in modifying the carts is to accommodate both engines, but an attempt will be made to streamline test preparation time as the overall goal of the project is to make the test process more efficient.

There are numerous connections between each engine and its cart. These connections include fuel and oil lines, pneumatic lines, pressure sensor connections, and thermocouple wires. Engine A and Engine B both utilize different connections. Our design will accommodate both.

Currently, connections made to the top of the engine are hung from a boom suspended in the test cell. This design leaves cables and wires too exposed in the testing chamber. Using the current design, there is a risk of wires and hoses coming in contact with moving parts and damaging the engine. These connections will be rerouted to reduce the risk of contact with the engine.

Engine B uses a full authority digital engine control (FADEC) system while Engine A uses a mechanically controlled throttle. The new cart will be compatible with both control systems; it will accommodate the mechanical throttle used by Engine A while not impeding the mounting of Engine B and vice versa.

Engine A and Engine B both have hardpoints for mounting the engine to the cart but they are in different locations. The cart needs to be modified to accommodate either engine's hardpoints while ensuring proper alignment with the dynamometer, which is fixed in the cell.

The steering system will be examined to determine if any improvements can be made. The current design has problems with the cart shifting when it is steered from a stationary position.

Each cart has four hooks so it can be lifted into the test cell by a crane. These hooks must remain in the final design.

The design will make use of existing components as much as possible. The goal is to modify the existing carts, not completely redesign them. Ideally, all modifications will be capable of being completed at StandardAero Winnipeg.

1.4. Concept Creation and Selection

Numerous processes were employed to develop candidates for the final redesign. These processes included brainstorming, concept screening, concept scoring, and client input.

As an example, during the design of the adjustable hardpoint system the above processes were used to develop two rail system concepts. This included a round rail type system, and a C rail type system. Four mount fixing options were developed. The use of bolts, pins, clamps, and lead screws were considered as fixture options. These concepts were reduced and integrated into a single final redesign using concept screening and concept scoring.

The first step of the concept generation process was brainstorming. During the brainstorming process, team members generated a number of designs. The process yielded the above mentioned concepts. Sketches of the designs were displayed amongst the team. Through discussion, the team thoroughly analyzed the feasibility, advantages, and disadvantages of each concept. A concept screening table and a concept scoring table were developed to help select superior concepts. The 'C' shaped monorail concept was chosen, and the lead screw and pin mount fixing options were chosen for further consideration. Additional selection criteria and analysis are discussed in detail in Appendix A: Concept Evaluation.

2. Details of the Design

The additions/modifications that were made to the original test cart have been divided into twelve major components.

- Rail/carriage system for moving the mounts
- Front RGB mounts
- Rear upright mounts
- Mount alignment and fixing system
- Dry pressure measurement system
- Wet pressure measurement system
- Vibration system
- Temperature measurement system
- Wire management
- Oil drip pan modifications
- Electrical matchplate
- Data acquisition and space allocation
- Steel grate modifications

Each major component will be discussed in detail in the following sections.

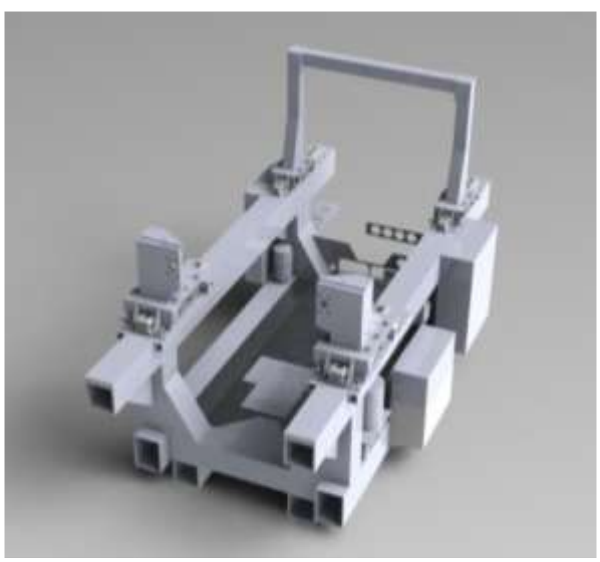


Figure 3. Redesigned Test Cart

2.1. Rail/Carriage System

In order to allow the mounts to move longitudinally along the cart base a system utilizing linear rails with mobile carriages was incorporated into the design. The rail and carriage models were chosen from the Schaeffler Group's INA brand [1]. These rails were suggested by StandardAero and are already used at StandardAero Winnipeg. Two models were selected, the RUE65-E and the RUE100-E-L, based on the required dimensions of the mounts, and the required load.

The RUE series are composed of a mobile carriage and a C channel rail. The carriage moves along the rail smoothly by use of four lines of roller bearings. The carriages are designed to carry very high loads and undergo minimal deflection, making them ideal for our design.

Engine A and Engine B require different front and rear mount locations. The lengths from the front of the test cart to the front mount base are:

i. Engine A – 635 mm (25 inches)
ii. Engine B - 457.2 mm (18 inches)

The length from the rear mount base to the back of the test cart is:

i. Engine A - 177.8 mm (7 inches)
ii. Engine B - 355.6 mm (14 inches)

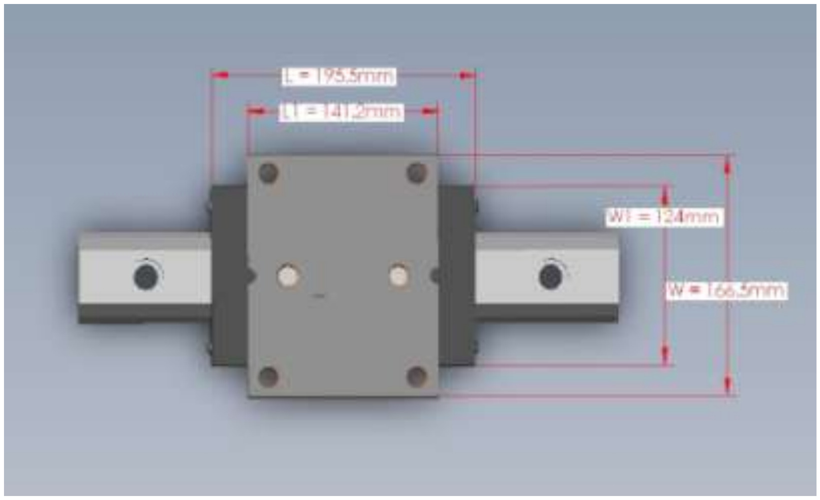


Figure 4. RUE65-E (Rear Carriage/Rail)

These measurements give us clear information on where the railing blocks should be located with respect to the dynamometer alignment. Therefore, an allowable sliding distance of 177.8 mm (7 inches) should be allotted between the two locations. To satisfy these criteria, our design consists of four rails measuring 635mm each. Extra length was added to accommodate the length of the carriage and mounts.

The dimensions of the front and rear mount bases are 152.4 mm (6 inches) by 431.8 mm (17 inches) and 101.6 mm (4 inches) by 260.35 mm (10.25 inches) respectively. The selected monorail system dimensions for both the front and rear mounts are shown in Figure 4 and Figure 5.

The rear mounts will each be fixed on the RUE65-E blocks and likewise the front mounts on the RUE100-E-L. Engine A and Engine B have a mass of 1125 kg and 771 kg respectively. The load directions are shown in Figure 6, and loading carrying capacity for each block is shown in TABLE I.

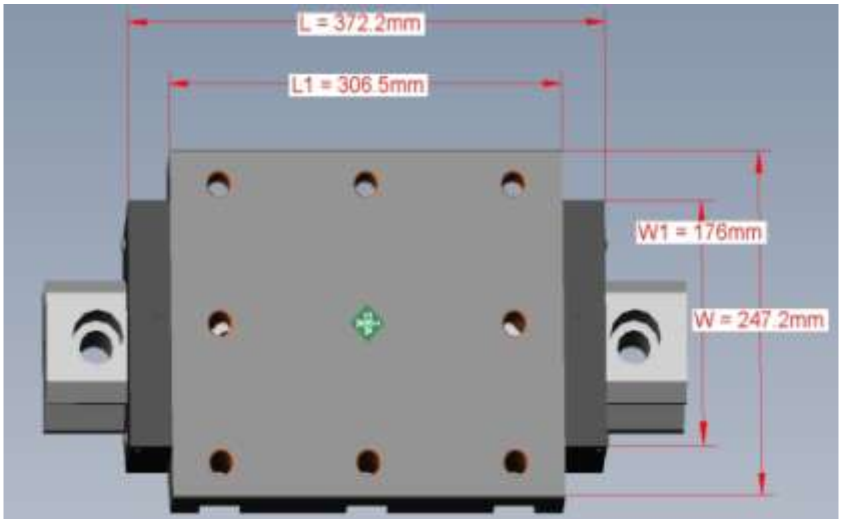


Figure 5. RUE100-E-L (Front Carriage/Rail)

Those ratings show that the vertical loading capacity of one block is more than enough to withstand the weight of the full engine. In our design, the weight of either engine will be shared by four blocks; two RUE65-E and two RUE100-E-L mounts. Also, the vibration and lateral force on the mounts are small compared to the vertical load, and the moment ratings are large enough to withstand the applied load with a significant margin of safety.

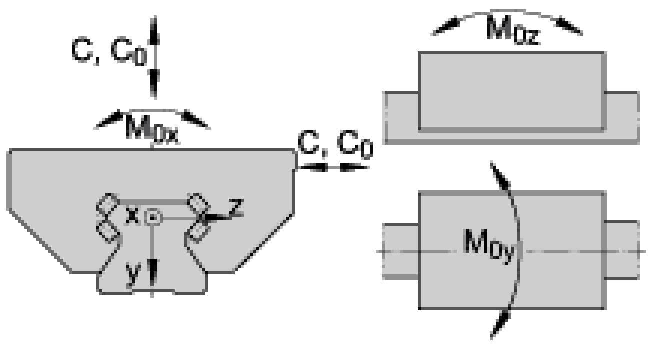


Figure 6. Load directions [2]

TABLE I – LOAD CARRYING CAPACITY [2] [3]

	Load Carrying Capacity				
	Basic load ratings		Moment ratings		
Model	**C/N**	**C_0/N**	**M_{0x}/Nm**	**M_{0y}/Nm**	**M_{0z}/Nm**
RUE65-E	200000	435000	5450	12100	10900
RUE100-E-L	630000	1490000	33780	80250	72280

The monorail system facilitates the accommodation of both Engine A and Engine B on the same test cart. Once the operators know which engine is going to be tested, they can slide the mounts to their specific locations and lock them into place using locating pins (discussed in detail below). The engine can then be mounted to the cart.

TABLE II: RAIL/CARRIAGE COST ANALYSIS

Item	Quantity (Per Cart)	Cost (Each)	Total
RUE65-E with Rail	2	2953.01	5,906.02
RUE100-E-L with Rail	2	5097.67	10,195.34
			$16,101.36

2.2.Front RGB Mounts

The first step in developing a functional universal test cart was to re-evaluate the current RGB mounts and develop a solution to meet the project goals. The design methodology for creating a practical solution followed these criteria:

- Match the existing mount positions exactly in the lateral and vertical position relative to the cart

- Integrate the new design with the chosen rail systems and ensure a practical solution is proposed
- Modify the original RGB mount geometry
- Ensure no detrimental effects are inherently built into the proposed design

It was realized that the need for a reduction in height and a re-designed base plate was needed to meet the necessary criteria. As the base plate influences the mount, the design of the plate and RGB mount itself were simultaneous processes. The proposed base plate is seen in Figure 7. A 0.5'' steel plate with fastening locations corresponding to the RUE-100-E-L carriage will be welded to a support assembly located at the rear and front of the carriage (see Figure 7). This support assembly serves as a robust structure to transfer any longitudinal loads through the carriage and into the cart through the means of locating pins. It should be mentioned that no significant longitudinal loads are expected and the design is simply for added robustness to ensure no lateral motion is ever seen during test. This structure acts as the hard points for pin location and is main interface between the monorail assembly and the cart; see Section 2.4 for mount fixture and alignment details.

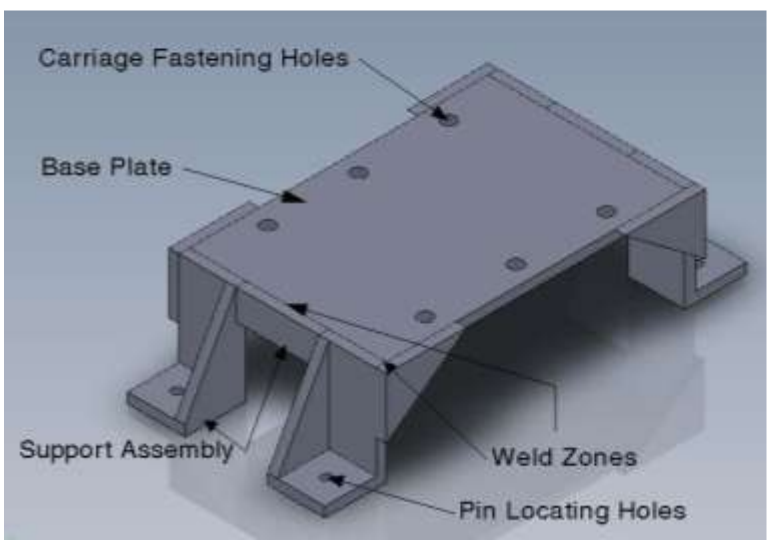


Figure 7. Base Plate Assembly

The base plate is designed to be fixed to the RUE-100-E-L by six ANSI metric 14 M hex bolts. These bolt sizes are specified by the carriage manufacturer. An exploded view can be seen in Figure 8 of the proposed assembly. Engineering drawings can be found in Appendix B: Design Drawings.

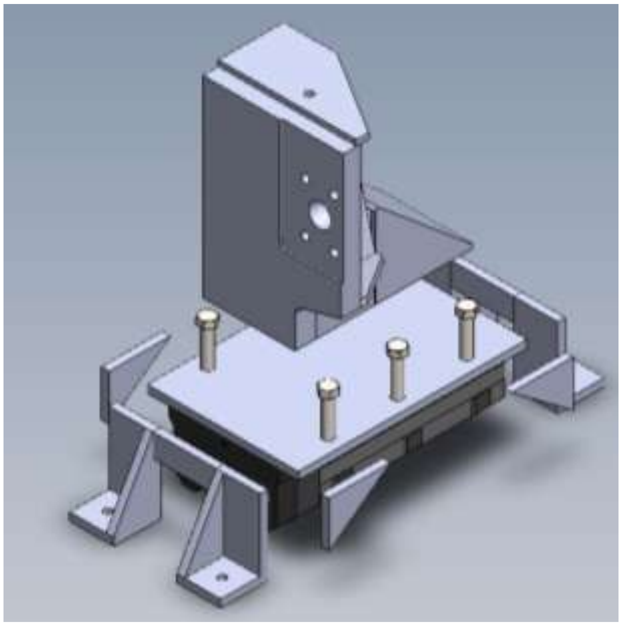


Figure 8. Exploded View of Front RGB Mount Assembly

The front RGB mounts require that the five fastening points on the prop shaft be perfectly aligned with the dyno. Adding our components changed the overall height, and thus an adjustment of geometry in the mounts was necessary. This was achieved by redesigning the existing mounts. An overall FEA analysis of the new mounts can be seen in Section 2.2.1. The tolerances used when designing the mount were kept to .01” for most components, while the location of the five fastening holes was retained to 0.001”. This feature was also evident when using the drawings provided by StandardAero and was also incorporated within our work to maintain consistency. As mentioned above, specifics of the proposed RGB mount geometry can be seen in Appendix B.

2.2.1. Finite Element Analysis

The modified front RGB mounts required a stress analysis regarding the influences of the proposed geometric alterations. To ensure that the proposed design does not cause any detrimental changes to the front mount's performance, a relative comparison between the original mount and the newly designed mount was made. This enabled a qualitative evaluation between the two designs, and comparisons were made between deflection and stress distribution. The FEA also provides the client with a design insight for changes that may be made in future cart designs.

2.2.2. Finite Element Model

Using SolidWorks CAD models and the embedded Cosmos software found within the student edition of SolidWorks, a load case scenario was developed. Each CAD model incorporated several small parts built into an assembly where the proposed design had the geometric alterations described in section 2.2. Within the assembly, individual components were modeled as perfectly glued wherever a weld would be present. This was assumed to be a valid approximation, as the stress was not expected to be high enough to deform the welded joints. This assumption was also used to describe the boundary conditions applied to the RGB Mount assembly; the assembly was assumed to be perfectly glued to the base plate, which was also assumed to be perfectly fixed in space. This means that the base plate is either firmly fastened to the cart, as was the case in the original design, or the base plate is firmly fastened to the monorail system. Both of the above mentioned assumptions are reasonable and are supported by the performance of the existing carts.

The client could not provide data regarding each engine's wet weight (weight including fuel and oil), although the client did provide engine dry weights. For simplification, the provided dry weights were used to describe the loading conditions at each bolt-hole in a single RGB mount. With this design being a universal test cart, the weight of the heavier engine that will be in service is all that is of concern for analysis. Engine A's weight was estimated at 12 000 N and is assumed to be distributed evenly between the front mounts and the rear uprights. This leaves

3000 N to be carried by a single RGB mount, where the weight is distributed between four bolts and an alignment fixture. Using the ratio of the total surface area and the surface area covered by an individual bolt we can find the percentage of force that would be distributed to that area. The alignment fixture will take approximately 41% of the load while an individual bolt will take 14.75% of the overall load. The corresponding load cases were then applied as parabolic bearing loads to each individual support. We were unable to obtain the specific material used on the current test carts as the original specs were not available. It was decided that standard plain carbon steel chosen from within the SolidWorks material library would be used.

2.2.3. Finite Element Analysis Results

Stress distributions and deflection will be observed and discussed. Figure 9 illustrates the complete redesign of the RGB mounts. Figure 10 and Figure 11 show the original RGB Mount and the modified RGB mount from the front and side views. The stress distribution in Figure 10 shows that the high stress zones are located at the lower arm radial corner and at the bottom of each fastening hole. This is an anticipated result as stress concentrations are thought to be located at corners/radiuses and high stress zones are expected at the lower half of load bearing circular cross sections.

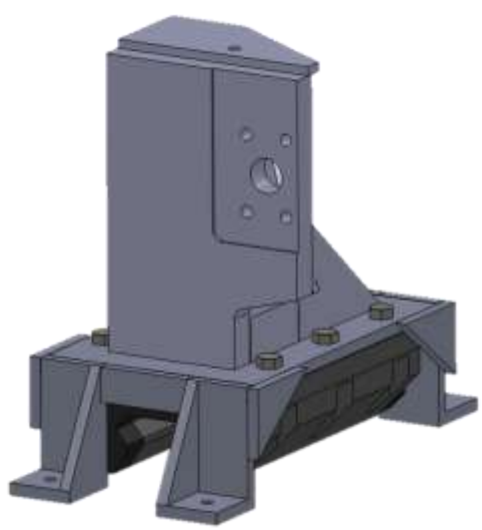


Figure 9. RGB Mount

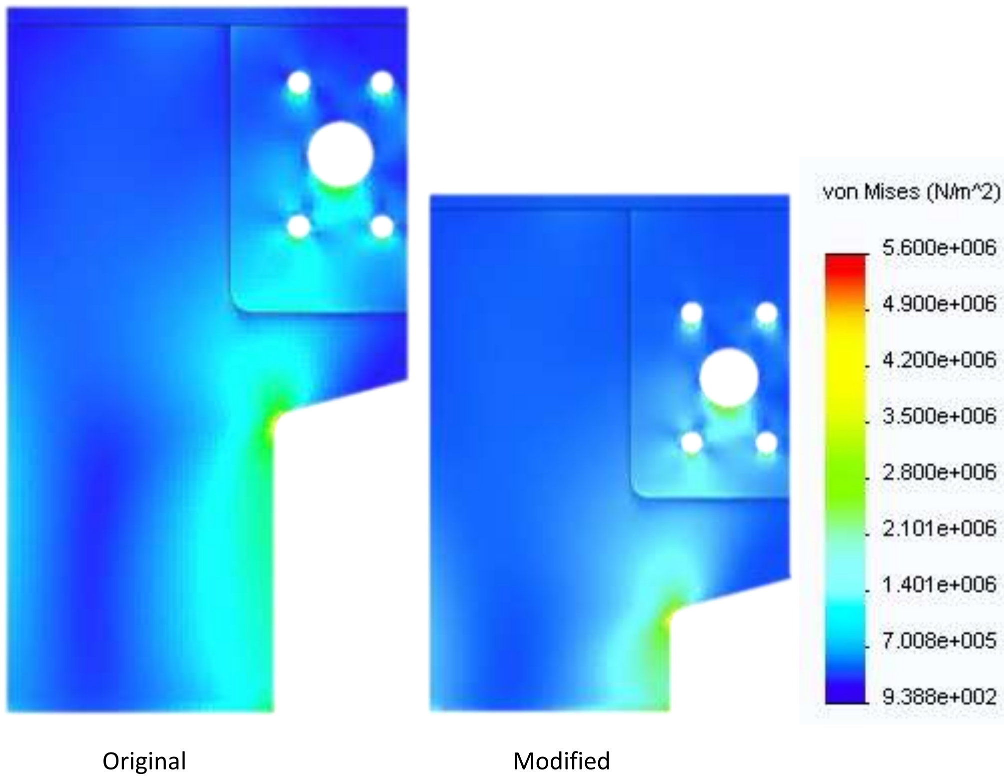
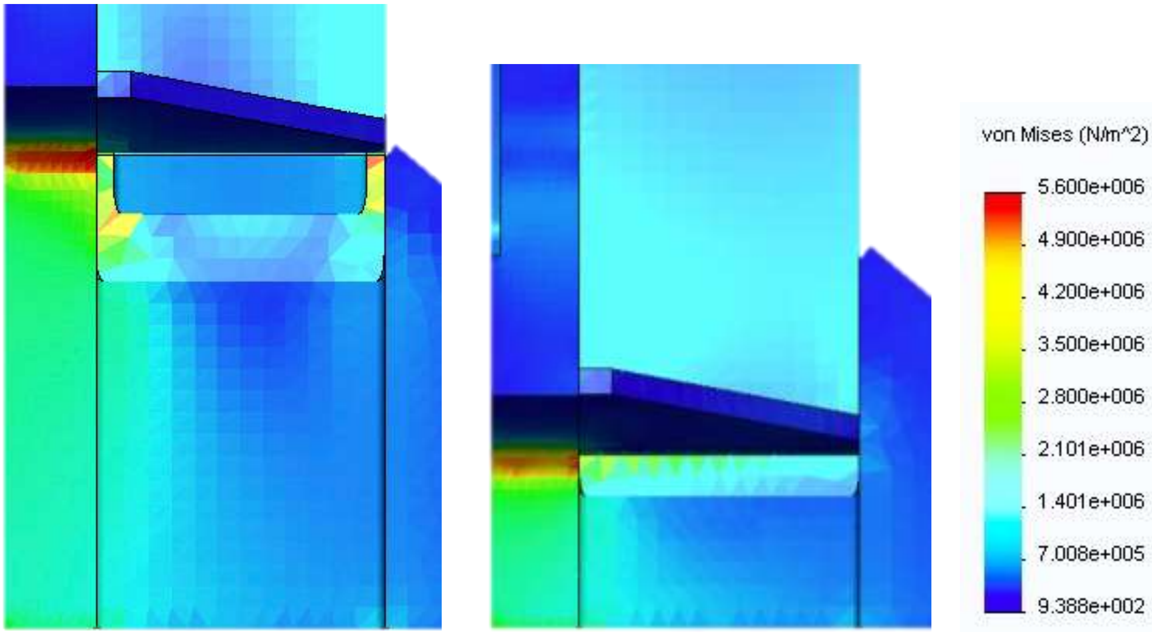


Figure 10. Contour Plot of von Mises Stress Distribution Front View (Deformation Scale 1:1)

The proposed design has a very similar stress distribution with one major difference being the 2.8-3.5 MPa range stress zone located at the lower right radial corner. The modified mount shows an arcing stress distribution from the radius of the arm to the bottom right corner of the base. This distribution is much like the original design, although due to a shorter height the stress distribution has effectively been scaled down. This is to be expected and the resulting stress distribution is reasonable. Comparing the overall magnitude of stress located at the fastening holes, very similar values and distribution occurs in both models. This indicates that the proposed redesign has a negligible effect on the stress seen at the bolt holes. When comparing the stress distribution along the depth of the lower radial corner, seen in Figure 11, it can be seen that the proposed design distributes the stress over the supporting plates more effectively. This produces an overall reduction in the magnitude of the stress seen along the length of the corner. The high stress regions located at the corner radius in Figure 12 are expected as the corner acts as a stress concentration.



Original Modified

Figure 11. Contour Plot of von Mises Stress Distribution Side View (Deflection Scale 1:1)

In regards to the resulting displacements, we can see in Figure 12 that the highest resultant displacements in the modified RGB mount are approximately half the magnitude of the original design. It should be mentioned that a reduction in deflection was expected, as by reducing the distance of the load to the base plate there would be a corresponding reduction in the bending moment near the bottom joint. These results are reasonable approximations and do give us an insight into the advantages of the re-designed RGB mount geometry. Although the displacements are relatively small, compared to the acceptable tolerances used in the manufacturing of these components, there is always room for improvement.

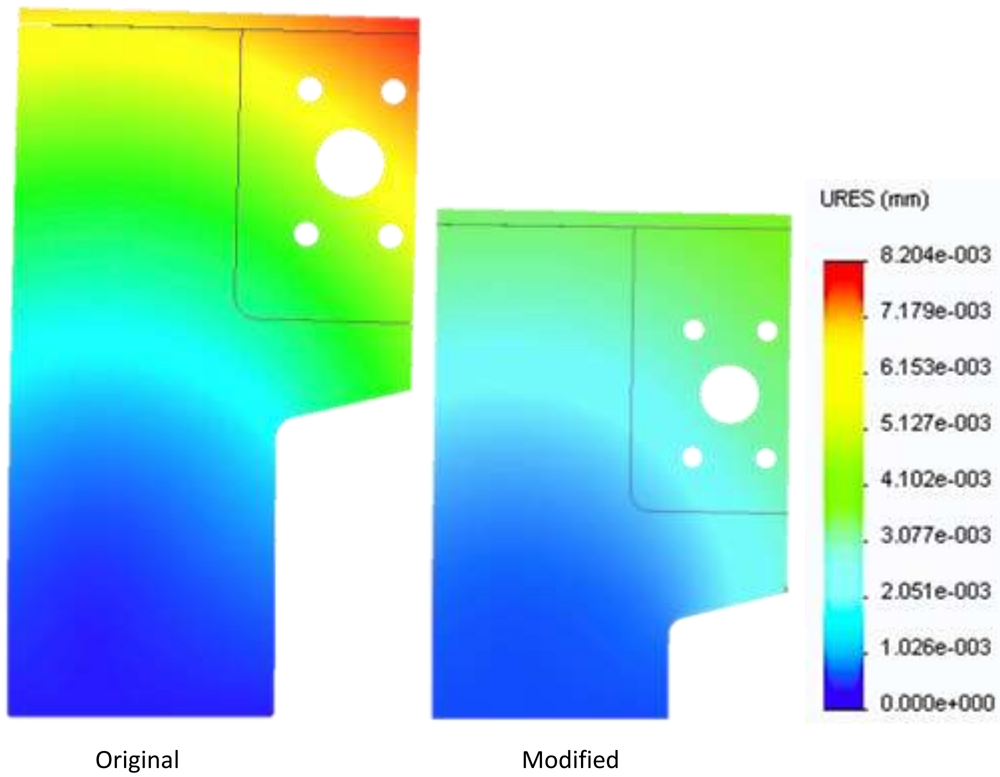


Figure 12. Contour Plot of Resultant Displacement (Displacement Scale 1000:1)

2.3. Rear Upright Mounts

The engines use a three point mounting system. Two hardpoints are located near the front of the engine, and one is located at the rear. During operation, these hardpoints would be fixed to the aircraft or the ground generator stand (depending on application). During testing, they are fixed to the test cart. The rear hardpoint is centred laterally and faces up from the engine, mounting to a horizontal cross bar supported by two upright mounts.

For Engine A, the crossbar can be removed from the upright columns. To mount the engine to the cart the crossbar is lifted by a crane and aligned with the engine. The crossbar is then mounted to the engine and both the engine and crossbar are lifted onto the cart. The crossbar is then attached to the upright mounts by bolts.

Engine B's cart has a fixed crossbar. The engine is lifted by a crane and aligned with the crossbar, which is already fixed to the upright mounts.

Figure 13 shows a model of the original rear engine mounts and the redesigned mounts, including the upright columns and the crossbar. The hardpoint is located on the underside and in the centre of the crossbar. Note that on the original mounts the mount base plates are fixed to the cart base by bolts.

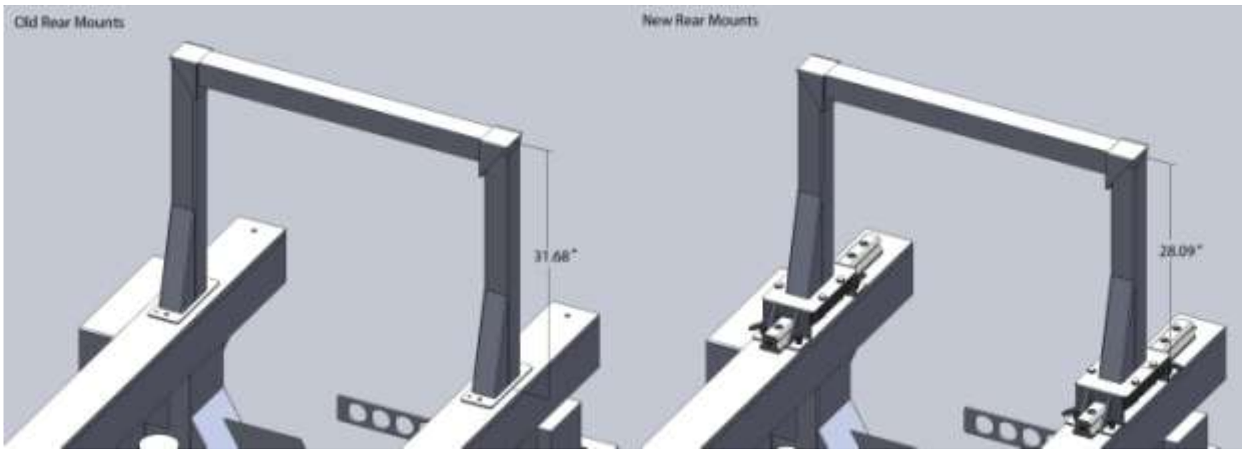


Figure 13. Rear Mount Original and Redesign

The primary purpose in redesigning the rear mounts was to accommodate the dimensions of the carriage and rail without compromising the structural integrity of the mounts. The rail and carriage add an additional 3.59 inches (91.2 mm) to the total height of the rear mounts. To ensure proper alignment with the hardpoints, the redesigned mounts must be lowered by 3.59 inches (91.2 mm).

Unlike the front mounts, there is no geometry in the rear mounts that would conflict with the shortening of the upright beams. Shortening these beams was determined to be the simplest way to accommodate the additional height of the carriage and rail.

The base plate for the rear mounts was altered to accommodate the bolt pattern for the rear carriages as it differed from the original pattern for mounting directly to the cart base.

Again, due to the non disclosure agreement, limited load and weight information for the engines was available to the team. A thorough stress analysis was therefore not possible. Unlike the front mounts, no major changes in geometry were made to the rear mounts except for the height of the uprights. It was therefore deemed unnecessary to perform a relative analysis comparing the stress distribution between the original design and new design. The only change in the redesign will likely be a decrease in lateral deflection, as the height of the uprights has been reduced.

The horizontal crossbar was unchanged in the redesign and is only bolted onto the current upright mounts. It can therefore be reused on the new carts, without any modifications.

The original upright mounts are welded to the bottom brace and base plate. Thus the whole rear mount assembly must be remanufactured to suit the shortened height and new base plate.

2.4. Mount Alignment/Fixing System

The operators must be able to quickly align the mounts to fit either engine. They must be fixed with a high level of precision to ensure proper alignment with the dyno.

Locating pins will be used to align each mount in its required position. The pins, shown in Figure 14, are essentially smooth bolts fitted with a retractable ball bearing. Running through the centre of the pin is a shaft. This shaft holds the ball bearing in place until the button is depressed. Pressing the button aligns a depression in the internal shaft with the ball bearing, allowing the ball bearing to recess into the shaft. This releases the pin, or allows the pin to be inserted.

Figure 14. Locating Pin [4]

The major advantage of using a locating pin, as opposed to a bolt, is the speed at which it can be removed and inserted. Removing and rethreading bolts continuously would be far too labour intensive, slow, and would require the bolts to be replaced periodically due to deformation of the threads.

The locating pins will be used to fix the mount to the top of the cart base. Each of the baseplates fixed to the top of the carriages have four holes drilled through them. On the cart base, a matching hole will be drilled. To align the mounts, the pin is passed through the hole in the baseplate and into the hole in the cart base.

The hole in the cart base is drilled once the engine and cart are in the test cell and aligned with the dyno. This ensures proper alignment for that specific type of engine. The engine is loaded onto the cart, moved into the cell, and connected to the dyno. Then the alignment holes in the cart base can be drilled. This is performed for both Engine A and Engine B, resulting in a different set of alignment holes in the cart base for each engine.

The pins will also serve as a means to fix the mounts in place. The carriages are free to slide along the length of the rail. INA provides a hydraulic braking system, but hydraulics would not be practical for the redesigned cart as there would be no continuous source of high pressure oil as the cart is being moved into the cell. This means the engine would be free to slide along the rails while the cart is being moved.

JEGS manufactures and sells 0.5 inch quick release pins which are rated to a double shear load of 31,160 lbs [4]. There is minimal longitudinal force acting on the mounts during testing as the engines are not designed to produce thrust, only torque on the shaft. Four bolts rated to 31,160 lbs on each mount will be adequate for testing, and will provide additional strength in the event that the cart undergoes any rapid acceleration, such as a collision during transport from the rigging area to the cell.

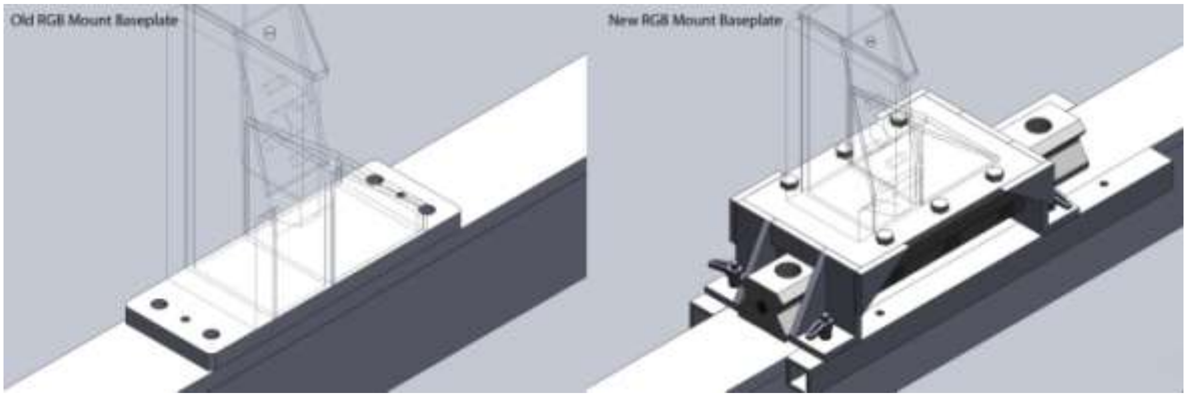


Figure 15. Front Baseplate Comparison

The pins will be fixed to the carriage through a redesigned base plate. A bracket was added to each side of the base plates. These brackets ride just above the surface of the cart base and have half inch holes for the pins to pass through. Figure 15 and Figure 16 show the redesigned front and rear mount base plates.

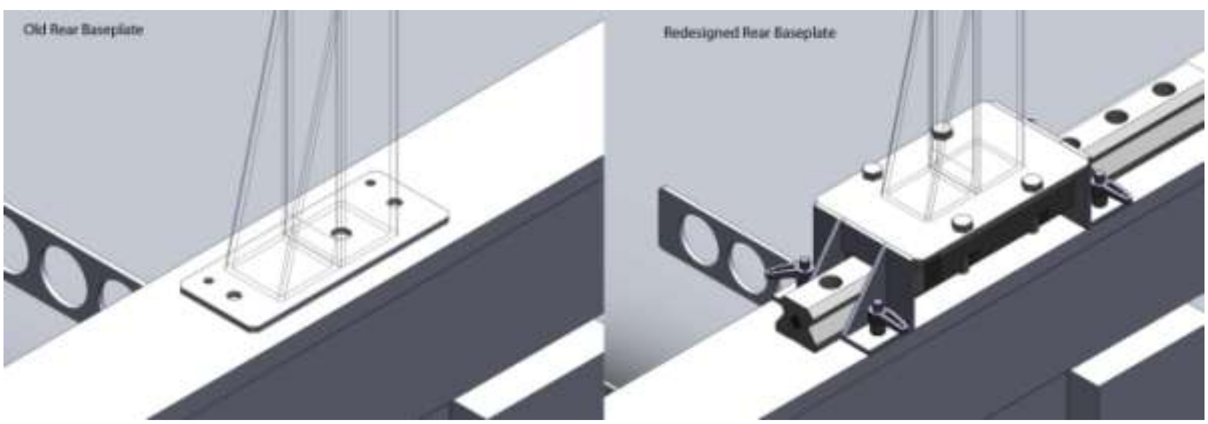


Figure 16. Rear Baseplate Comparison

The base plates already require remanufacturing to accommodate mounting on the rails. The fixing pins were incorporated into the base plates, as opposed to creating a separate fixture, to eliminate the need for machine additional components. This will reduce the overall cost of converting the carts.

TABLE III: QUICK RELEASE PINS COST ANALYSIS

Item	Quantity (Per Cart)	Cost (Each)	Total
Quick Release Pins	16	$19.99	$319.84
		Total	**$319.84**

Figure 17 and Figure 18 show the entire rear and front mount assemblies. Note that on the front mounts the base plate extends beyond the sides of the cart base. The only carriage available that could accommodate the load and dimensions of the front RGB mounts, the RUE100-E-L model, was as wide as the original top beam of the cart base. In order to accommodate the locating pins additional square hollow shafts must be added to the sides of the cart base. These shafts provide a location for the pins to lock into, and are to be welded to the cart base.

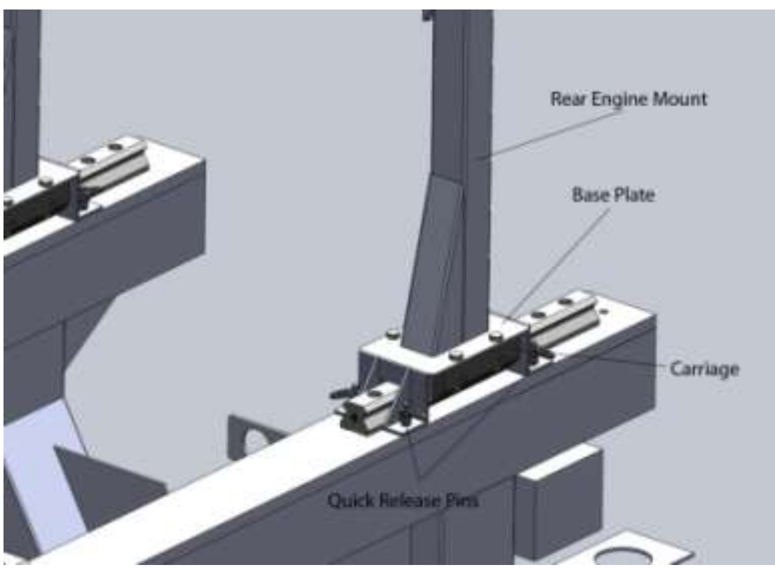


Figure 17. Rear Mount Redesign

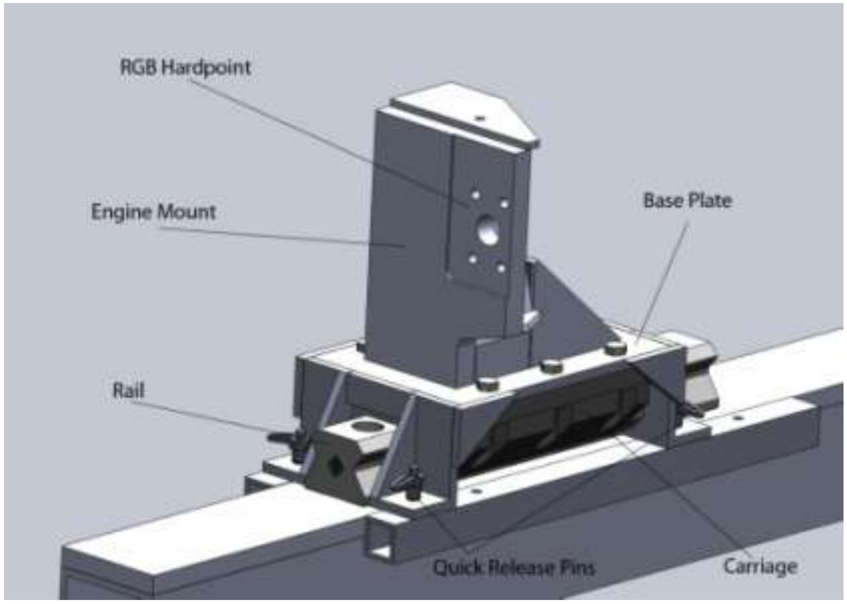


Figure 18. Front Mount Redesign

2.5. Data Acquisition Systems

The data acquisition system involves the wet pressure measurements, dry pressure measurements, vibration systems, temperature systems as well as the electrical components involved with these systems. The West Test Cell currently uses an outdated data acquisition system. It is difficult to troubleshoot, frequently causes problems, and the outdated components are affecting precision of engine measurements. We were asked to develop concepts for a new data acquisition system. This new system will incorporate as much of the old system as possible, while adding new technologies and improving the system's accuracy at the same time.

2.5.1. Dry Pressure System

The West Test Cell currently uses Honeywell Precision Pressure Transducers [5] (PPTs) for dry pressure analysis. This system has been in place since the original West Test Cell design, but it has many disadvantages. The Honeywell PPTs work by taking an input pressure and translating it into an electrical signal. This signal is then transported to the control room where it is converted into a digital pressure reading. Between Engine A and Engine B there are over 40 dry pressures measurements. Each of these measurements currently requires an individual PPT which is situated in a cabinet on the wall of the test cell. All PPTs require a power supply from the control room, a pressure source off the engine, a data cable running to the control room, and an ambient pressure reference source. Considering there are over 40 of these transducers, the total system requires over 160 connections running into the cabinet. The multitude of connections results in an overly complicated system, which can take an extensive amount of time to troubleshoot. We were tasked with simplifying the pressure reading system and thus improve the troubleshooting process and reduce downtime in the cell.

Figure 19. Esterline Dry Pressure Brick [6]

The selected replacements for the Honeywell PPTs are the Esterline [6] aerospace pressure bricks. Each of these bricks can measure up to 16 dry pressure channels with equal or better accuracy than the existing system. This will reduce the number of pressure units from 40 PPTs to just 3 pressure bricks. Each brick requires one power source, up to 16 pressure inputs, and one Cat5 data cable output. This will reduce the wires running to and from the control room by a factor of 16. As a result, it will simplify the troubleshooting and reduce downtime significantly. In addition to wire management, the Esterline bricks' pressure analysis is performed directly within the brick instead of transferring the signal to the control room for analysis. This will also reduce the amount of computer hardware needed in the control room, eliminating another source of error in the pressure signals. The pressure bricks will be mounted directly onto the cart. This will minimize pressure tubing running from the engine to the cart and will minimize the opportunity for kinks or holes in the pressure tubing.

Figure 20. ATP Pneumatic Tubing [7]

For the pressure connections to the brick, the engines will connect to 0.125 inch nylochem nylon tubing, shown in **Error! Reference source not found.**, which has a working pressure of up o 420 psi [7]. Due to its vulnerability to high temperature, this tubing must be kept away from the hot sections of the engine at all times. This will require a 12 inch piece of stainless steel tubing to be attached as a barrier between the hot sections of the engine and the nylon tubing. Since they are static pressure readings, this will ensure that enough heat is dissipated before the air reaches the nylon tubing. To ensure proper sealing at the tube ends, compression fittings will be used. On the engine side the fittings must correspond to the appropriate AN fitting size so that the tubing can be removed several times without damaging the seal, a feature which is not available using compression fittings.

At the electrical box interface, a Twintec BH threaded port series quick connect (**Error! eference source not found.**) will be used. Each quick disconnect is capable of connecting 16 dry pressures, which will match up with the 16 channels available on each brick. This will create a simple operator interface for attaching each bundle of dry pressure hoses to each brick. Using barbed fittings with these quick connects will ensure a permanent connection and prevent any leaks. The space allocated for the dry electrical box can be seen in Figure 30.

Figure 21. Twintec Pneumatic Quick Disconnect [8]

Figure 22 illustrates the layout of the dry pressure measurement system.

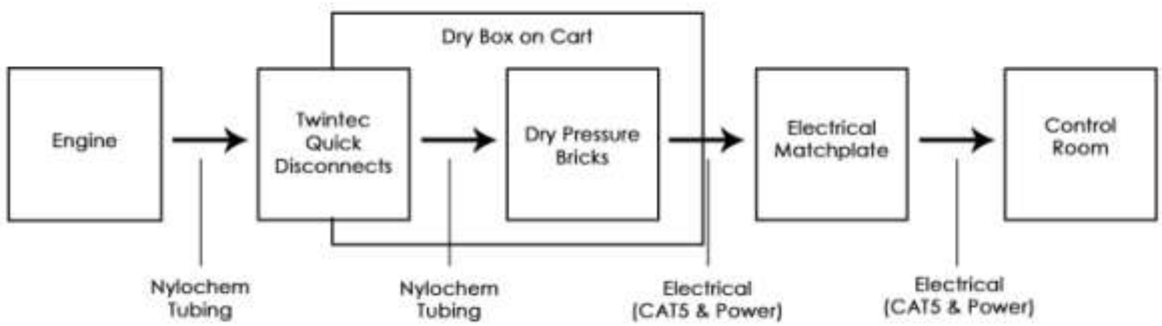


Figure 22. Dry Pressure System Layout

Below is a cost analysis for the dry pressure system. ScaniValve dry pressure bricks were considered as well. The ScaniValve bricks were approximately the same cost as Esterline bricks. StandardAero already uses Esterline bricks in their other test cells and were therefore selected for use in the West Test Cell.

TABLE IV: DRY PRESSURE COST ANALYSIS

Item	Quantity (Per Cart)	Cost (Each)	Total
Esterline 9116 Dry Pressure Brick (16 Channels)	3	$6, 970	$20, 910
Nylon Tubing	250 ft.	$35	$35
Swagelok Compression Fittings	Varies	-	$1500 (approx.)
Twintec BH Series 16-Port Quick Connects	3	$60	$180
Barbed Fittings	10 Packs	$12 / 5 Pack	$120
		Total	**$22, 745**

2.5.2. Wet Pressure System

The current wet pressure system in the West Test Cell utilizes General Electric pressure drucks [9]. Similar to the dry pressure system, these input a static wet pressure signal and convert it to an electrical output. The signal is then sent to the control room where it is analyzed and converted into the appropriate pressure measurement. Since each pressure requires an individual druck, the same large amount of wiring is needed as with the dry Honeywell PPTs. The customer requested that we investigate replacing or simplifying the wet pressure system.

The replacements selected for the current wet pressure system are Esterline wet pressure bricks. Wet pressure bricks will allow us to measure up to 12 pressure signals on a single brick, cutting our connections to the control room by a factor of 12. Although they still require individual pressure transducers, the power and data analysis is supplied directly from the brick which eliminates lengthy wire runs. Shortening the wire runs will simplify troubleshooting and, as a result, reduce downtime for the cell.

Figure 23. Esterline Wet Pressure Brick & Transducer [6]

As with the dry pressure system, the wet pressure bricks must be in an electrical cabinet as well to protect them from spilt oil and other elements. They must be placed in a separate cabinet than the dry pressure bricks in case a leak occurs in the wet pressure hoses.

Figure 24. Staubli Quick Connect Plate [10]

For a quick change over within the cell, the existing Staubli quick connect plates (**Error! eference source not found.**) are to be used at the wet electrical box interface on the cart. This will facilitate the operator's changeover between Engine A and Engine B, and reduce rigging times. The allotted space for the wet electrical box on the cart can be seen in Figure 30.

Figure 25 illustrates the layout of the wet pressure measurement system.

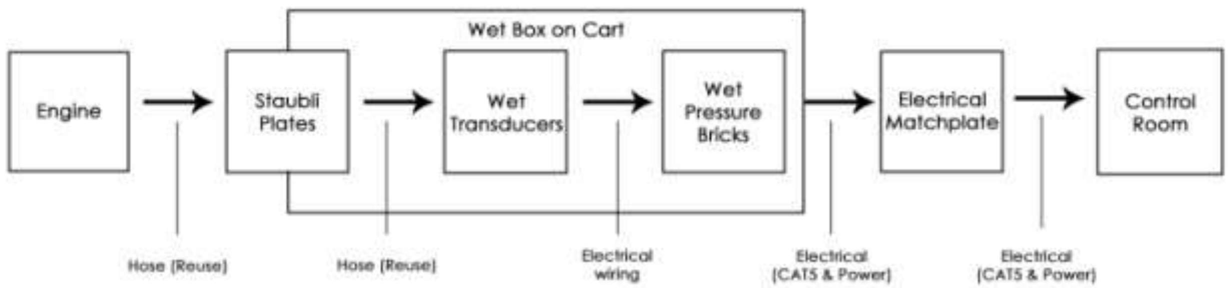


Figure 25. Wet Pressure System Layout

Below is a cost analysis for the proposed wet pressure system. As with the dry pressure system, Esterline was chosen over ScaniValve.

TABLE V: WET PRESSURE COST ANALYSIS

Item	Quantity	Cost (Each)	Total
Esterline 9022 Wet Pressure Brick (12 Channels Each)	2	$5,110	$10,220
Esterline Transducer	20	$100	$2,000
Cable (Pack of 12)	2	$364	$728
Hose	Use Existing/ Modify	-	$300 (approx.)
Staubli Plate	2	Use Existing	$0
		Total	**$13, 248**

2.5.3. Vibration Systems

The vibration system currently used is sufficient, although the setup does not optimize the accuracy of vibration readings. The signal from the vibration amplifiers runs from the engine over an electrical boom and into the electrical box charge amps located on the cell wall. The long length of the vibration cables results in significant electrical interference, which decreases the accuracy of the vibration signal. Since vibrations are an important part of engine testing, it is required that the vibration signals be as accurate as possible. The customer requested that we should design a system to improve accuracy.

A potential solution to improving this accuracy is to move the charge amps onto the test cart. This will reduce the amount of wire running from the transducers to the charge amps from 30 to on average 5 feet. This will minimize electrical interference and improve the accuracy of vibration readings. The charge amplifiers for the vibration system will also be mounted in the dry electrical box, shown in Figure 30.

No additional components are required to implement this redesign. The only cost involved would be the labour required to reposition the charge amps.

Figure 26 illustrates the layout of the vibration measurement system.

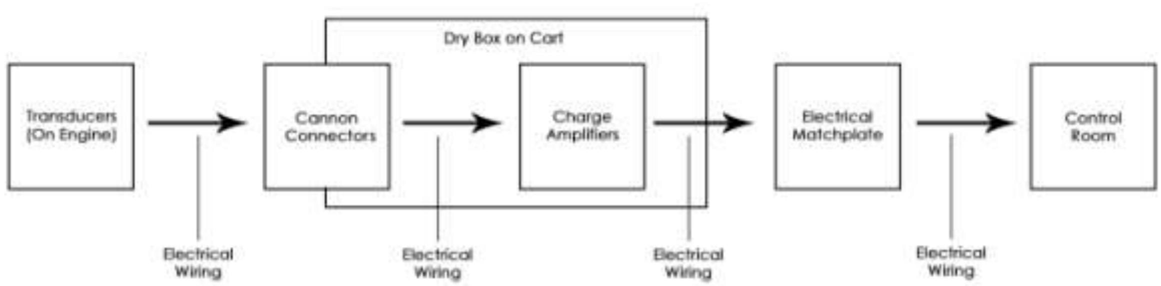


Figure 26. Vibration System Layout

2.5.4. Temperature Systems

Currently, the engine temperatures are measured using lengthy runs of thermocouple cables. Modifications have been made to the original design to add extensions and intermediate connections. These connections have caused accuracy issues and can result in misinterpreted signals.

The engine thermocouple systems in the West Test Cell will also be replaced by Esterline aerospace thermocouple bricks. These bricks are similar to that of the wet and dry pressures. They will not only cut down on the amount of wires running to the control room by a factor of 16, but they will also reduce troubleshooting and downtime in the cell.

TABLE VI: TEMPERATURE COST ANALYSIS

Item	Quantity	Cost (Each)	Total
Esterline 9046 Temperature Brick (16 Channels)	2	$5, 495	$10, 990
		Total	**$10, 990**

The thermocouple bricks are to be placed in the dry electrical box on the cart, alongside the vibration and dry pressure components. This dry electrical box can be seen in Figure 30.

Figure 27. Esterline Temperature Brick [6]

The allowances for the temperatures on the cart are for the individual thermocouple connections only. These thermocouples currently run over the boom. Installing the thermocouple bricks directly onto the cart would eliminate the need for these wires. Several other thermocouple components run over the boom as well, and these will be addressed in section 2.5.6.

Figure 28 illustrates the layout of the temperature measurement system.

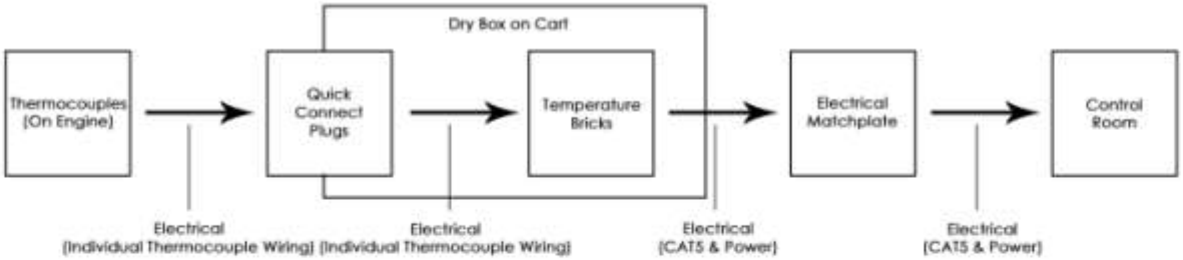


Figure 28. Temperature System Layout

2.5.5. Wire Management

Due to the nature of gas turbine testing, the environments in which the wires for the pressure systems are run are often covered in turbine oil. This oil can eat away at the sheaths and cause significant problems in our data acquisition readings.

Figure 29. Hoffman Straight Wireway [11]

To protect these wires from oil, Hoffman wireways (**Error! Reference source not found.**) should e implemented. The rubber gaskets in the wireway must be made of Viton. Viton is resistant to corrosion caused by gas turbine oil. Since space is limited on the cart, 4 inch square wireways are recommended. These wireways will be fastened around the perimeter of the cart. In the case that oil should spill on them, the wires are sealed inside and protected. This will also protect the wires from the elements such as snow and rain which often get sucked into the cell during test. The wireways will run between the wet box, the dry box, and the electrical matchplate on the cart (see Figure 30 for cart layout).

2.5.6. Electrical Matchplate

The electrical systems were beyond the mechanical scope of the project. There are, however, several electrical systems which tie into the mechanical systems that must be accounted for. These electrical systems include the CAT5 and power cables going to and from each brick. Several thermocouple harnesses and the engine control wiring are also required.

For these surplus electrical systems we have reserved room off the back of the cart which can be allotted to the electrical matchplate, as seen in Figure 30. This space is close to the fuel and oil lines, and they would need to be shielded from the sensitive electrical connections. An option for this is to incorporate the electrical match plate into the front of a sealed electrical box hung in the same section of the cart, with a sealed 4 inch Hoffman wireway coming out of the box and routing the electrical components to their destinations. Overall, the electrical match plate will eliminate the need for the electrical boom.

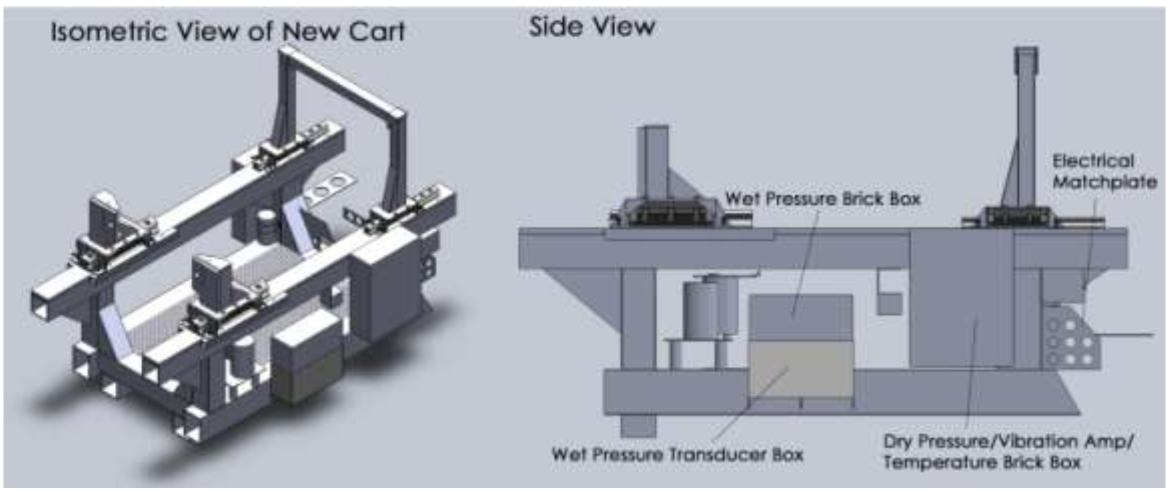


Figure 30. Space Allotment

2.5.7. Summary of Data Acquisition Space Allocation

There has been space allocated for the wet and dry bricks. These will need to be separated, in case there is a leak within the wet brick section.

The dry pressure bricks will reside, along with the vibration amplifiers and the thermocouple bricks, in the electrical box shown in Figure 30. For the pressure interface at the box, there will be Twintec quick disconnects incorporated into the side of the box. For the output, a wireway is needed to protect the output electrical from the surrounding oil and fuels. This wireway will join both the wet and dry electrical boxes and run to the electrical match plate.

As discussed earlier, there will need to be pressure transducers along with the wet bricks. These will be routed to the brick side of the Staubli plates via flexible hose. The other end of the Staubli plate will be routed towards the engine via flexible hose. The Staubli plates will be moved from the back of the cart and incorporated into the side of the wet pressure electrical box.

2.6. Oil Drip Pan

After a brief discussion with the operators, it was found that there were issues with the existing oil drip pan. When the cart is moved into the test cell, sudden movements would cause the oil to splash over the top and out of the drip pan.

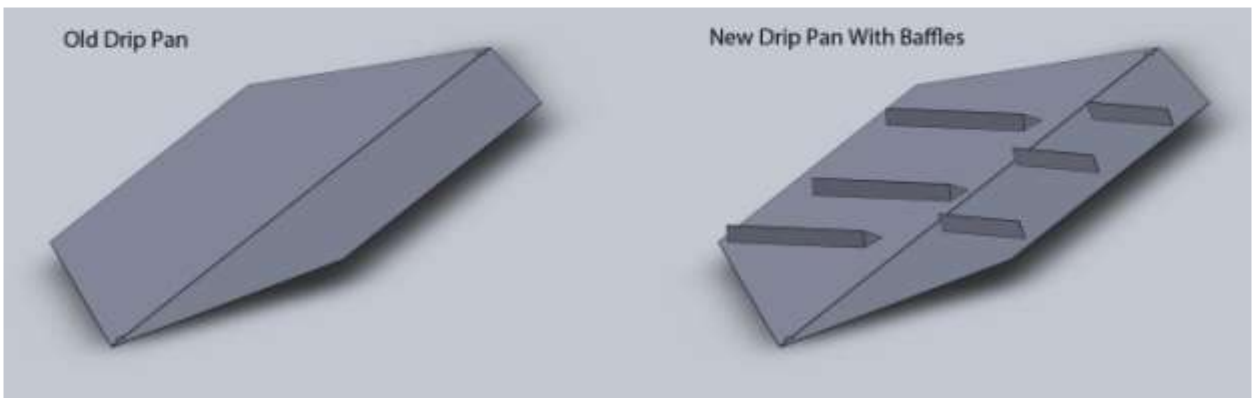


Figure 31. Drip Pan Comparison

Our simple fix was the addition of baffles to the existing oil drip pan. These can be made of gage 16 sheet metal and are welded onto the drip pans already installed on the carts. These baffles will prevent the oil from splashing around while still allowing it to drain out. A CAD example of this modification can be seen in Figure 31.

2.7.Steel Grate Modifications

On the existing carts there is a steel grate which lines the bottom of the cart. This is intended to catch any hardware or tools which are dropped during rigging, while still allowing oil to drain and filter through to the oil drip pan. There has been a section removed from the existing grating to allow for an additional engine accessory (which is only present on a specific version of Engine A). Currently the hole has been left unchanged, but this can cause difficulties when something is dropped into the hole. We were asked to investigate the problem further, and came up with a simple removable door solution. Shown in Figure 32, this cover plate can be either completely removable or a simple hinged door. When other engines are being tested it will remain on, catching anything that is dropped. When the engine with that specific accessory is tested it can be removed or left open, allowing for sufficient clearance of the engines accessory.

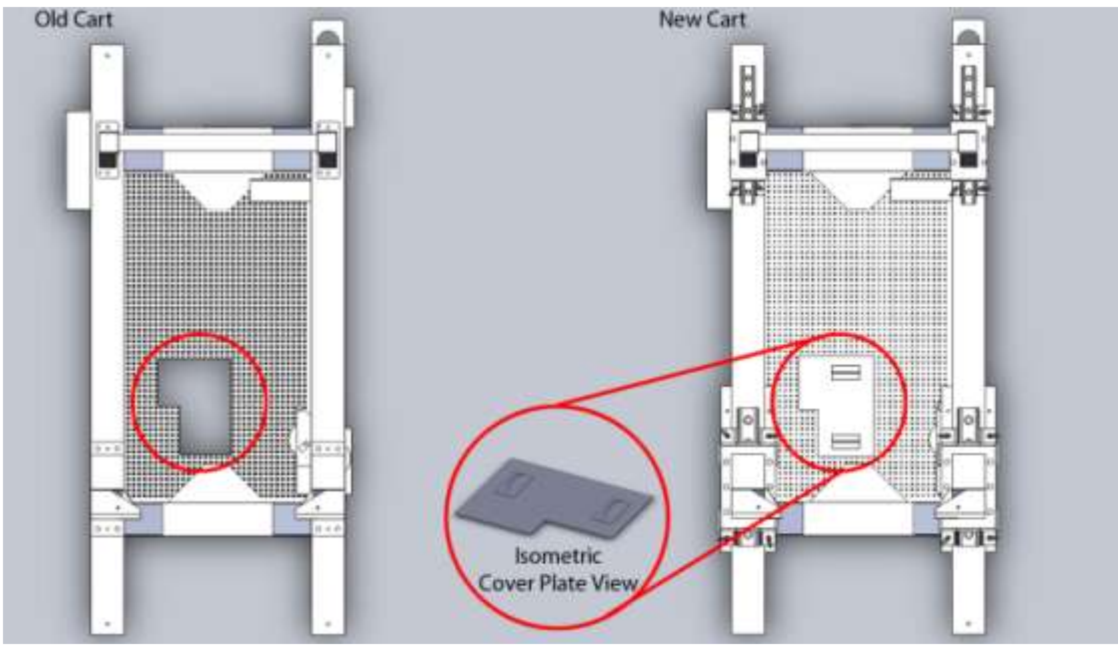


Figure 32. Steel Grate Modifications

2.8. Bill of Materials

The following is a bill of materials for all the components required for the redesigned test cart.

TABLE VII: BILL OF MATERIALS

Item	Quantity	Description	Cost (Total)
1	2	Linear recirculating roller bearing assembly, RUE65-E	$5,906.02
2	2	Linear recirculating roller bearing assembly, RUE100-E-L	$10,195.34
3	16	Locating Pin	$319.84
4	3	Esterline 9116 Dry Pressure Brick (16 Channels)	$20, 910
5	250 feet	Nylon Tubing	$35
6	Misc.	Swagelok Fittings	$1500
7	3	Twintec BH Series 16-Port Quick Connects	$60
8	12	Barbed Fittings	$120
9	2	Esterline 9022 Wet Pressure Brick (12 Channels)	$10, 220
10	20	Esterline Transducer	$2, 000
11	2	Transducer Cable (Pack)	$728
13	2	Esterline 9046 Temperature Brick (16 Channels)	$10, 990
		TOTAL	**$62,984.20**

3. Conclusion

The primary objective of this project was to reduce the overall test time required for each engine in the West Test Cell. This was accomplished by designing a universal cart, compatible with both Engine A and Engine B. Using a universal cart provides more room in the cell to work and helps to standardize the mounting procedure. Both of which contribute to a reduction in turnaround time.

Replacing the numerous pressure and temperature lines running between the cart and the control room with more compact pressure bricks significantly reduces the number of connections which must be made during set up, reducing test time.

The addition of the Staubli quick connect plates makes the connection between cart and cell equipment much faster. Instead of making individual connections, multiple lines are connected at once using one quick connect lever as opposed to a dozen wrench connections.

In order to accommodate both Engine A and Engine B, several changes had to be made to the cart. The dimensions of both engines' hardpoints were accommodated by the addition of the adjustable mounting system. The INA carriage and rail system provides more than adequate strength to support the engine, and allows for quick and easy adjustment of the mount dimensions. The addition of the quick release pins will ensure the mounts can be aligned precisely and securely in their proper locations.

The electrical boom concept has been replaced with an electrical match plate, along with on-cart bricks and amplifiers. This will not only simplify the electrical components, but also improve readings by allowing less interference with long wire runs.

The electrical matchplate room was reserved for everything running to and from the cart to the control room. This includes CAT5 and power cables for each brick, engine controls and the existing thermocouple harnesses. The main purpose of the electrical matchplate is to eliminate the boom. The matchplate must be sealed from the surrounding fluids and should be incorporated into an electrical box, with sealed Hoffman wireways incorporated into it.

The vibration charge amps should be moved from the electrical cabinet on the wall to the dry box on the cart. The inputs for the charge amps can be run through the electrical match plate. The existing cabling from the vibration transducers can remain the same, just shortened since there is less of a run.

Alongside the vibration charge amps, 3 dry pressure bricks will be placed in the dry box on the cart. These will measure all the dry pressure readings off the engine, and the user interface will be simplified with Twintec quick connects. The tubing from the engine to the bricks will be nylochem 0.125 inch tubing. For the engine connections, compression fittings must be used and 12 inches of steel tubing is necessary at the hot sections to dissipate the heat before it enters the nylochem portion of the tubing. The output signal from the dry pressure bricks which runs to the control room will go through the electrical matchplate as well.

Also in the dry box on the cart will be the 2 temperature bricks. Only the individual thermocouples will be included in this, and the other temperature harnesses will run though the electrical match plate to bricks off the cart. This is to save on room and simplify our systems on the cart. The temperature bricks will also use quick connects mounted into the side of the dry box on the cart. This is to improve the user interface and simplify the rigging of the engine.

In the wet box on the cart will be the 20 wet pressure transducers and 2 wet pressure bricks. The existing Staubli plates will be used as the quick connect interface on the box. Flexible hosing can be reused between the Staubli plates and the engine as well as the Staubli plates and the pressure transducers. The output signal from the wet bricks which runs to the control room will be run through the electrical matchplate.

StandardAero already had a design for an improve dolly, one that wouldn't suffer from unwanted shifting during steering. Since this redesign already satisfied the objectives of this project, it was deemed unnecessary to further alter the design.

In addition to the primary objective of reducing turnaround time, the redesigned cart also satisfies the conditions set by the customer and constraints inherent in making the new cart compatible with the current cell.

The throttle control systems of both engines had to be combatable with the new cart. It was found that there was sufficient space on a single cart for both a FADEC control system for Engine A and the mechanical actuator for the throttle on Engine B. Both systems were therefore left in their current configuration. The FADEC control boxes are currently removable, and will have to be removed for testing and rigging of Engine B.

The hooks currently used by the crane to lift the cart from the dolly to the cell did not conflict with any of the redesigned components of the cart and were therefore left in their original configuration.

To reduce the overall cost of modifying the carts, it was important to reuse as much of the existing components as possible. Any components that did not conflict with the mounting of either engine, or any of the redesigned features were left in their original place. This included the throttle controls, the rear mount crossbar, the FADEC mounting points, air start lines and fuel lines.

Implementing the redesigned cart will reduce the total time taken to test an engine and free up more space on the preparation floor. It will significantly reduce the number of connections and, as a result, troubleshooting and setup time will be minimized. In addition to fulfilling the primary goal of this report, the redesign will add increased accuracy to the testing measurements, reduce oil spillage, and improve engine stability.

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Appendix A: Concept Evaluation

The concepts considered for this project are detailed in this Appendix.

Sliding Rail Concepts

Engines A and B both have hardpoints for attaching to mounts when in operation, transport, and during testing. The two engines have different locations for the hardpoints. Our design must accommodate both engines hardpoints. This will require a movement both longitudinally, along the length of the cart, and vertically to different heights.

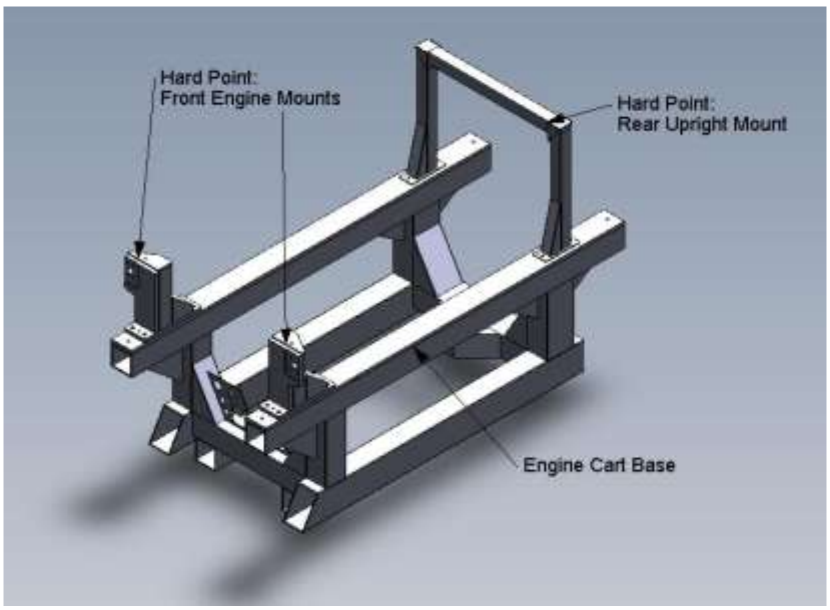


Figure 33. Major Components of Cart

The primary focus of the mounting system redesign is to reduce the time it takes to load the engines onto the cart. The system for adjusting the hardpoints must, above all else, require minimal setup time. Early concepts involved simply drilling multiple sets of holes for the bolts fixing the mounts in place. The operators could simply unbolt the mounts, move them to the required location, and replace the bolts. This would be a rather simple and cheap redesign, but has significant draw backs in terms of setup time and operator labor. The mounts supporting the hardpoints are heavy and moving them by hand would be difficult. Alternatively, using a crane or another lifting mechanism would only add to the turnaround time between tests. The tightening of the bolts would need to be done by hand, an arduous and time consuming process.

The focus of the redesign process of the mounts has been to develop a system in which the mounts could be slid from one location to the other. This will eliminate most of the heavy lifting. Two types of sliding systems have been considered for use on the cart.

The first system considered was a round monorail. This would feature a shuttle fixed to each of the mounts which would slide along a bar fixed to the top of the cart base. The shuttle would be lined with bearings to permit smooth and easy motion of the mounts. Figure 34 below shows a sketch of the round rail design. Note that the sketches in this section are not to scale, and are only a rough conceptual outline of the design.

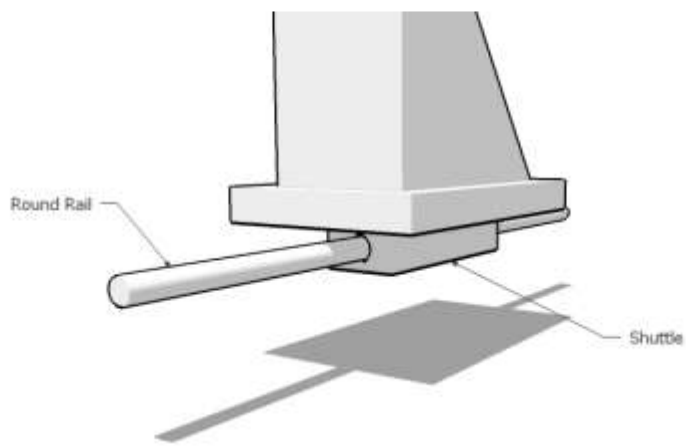


Figure 34. Mount on Round Rail

The second system considered was similar to the first in that it consisted of a shuttle and monorail. Instead of using a round rail (which would have poor lateral load capabilities) a ‘C’ shaped shuttle, sliding along a matching, grooved rectangular rail would be used. The primary advantage of this design is its ability to withstand strong lateral moments. Similar to the first design, bearings in the shuttle would allow for smooth motion of the mounts. Figure 35 below shows a sketch of the shuttle and rail design.

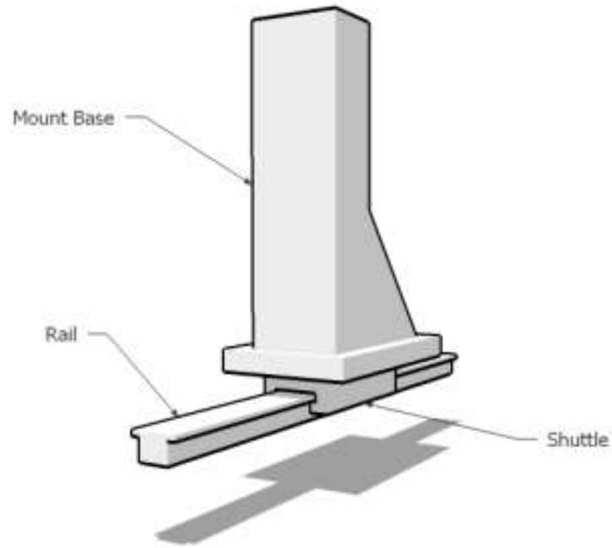


Figure 35. Shuttle and Rail Design

The rail designs mentioned above will be capable of quickly sliding the mounts into their proper position, but a method must be developed for fixing the mounts in the appropriate location for each engine.

Every new cart must first be loaded with an engine, moved into the cell, and lined up with the dyno before the mounts can be fixed in place. This ensures a proper alignment with the dyno for each type of engine. It only needs to be performed the first time, as all engines of a particular type have the same dimensions.

Our design for fixing the mounts in place must be strong enough to withstand any longitudinal loads and also permit the operators to align the mounts on its initial use. Several designs have been considered for fixing the mounts

Mount Securing Concepts

The following concepts were considered to secure the front and rear mounts to the test cart once in the desired location.

Bolts/Pins

One option would be to have a set of bolts fixing the mounts to the top of the cart. These bolts could be removed, allowing the mounts to slide along their rails. Once the mounts are in their proper locations for a specific engine the bolts would be replaced, securing the mounts in place. This system has the advantage of being strong and would also permit the operators to easily align the mounts on their initial use; once the driveshaft is aligned with the dyno, the bolts could be placed in the precise location required for that type of engine.

Similar to the method described above, locating pins could be used to fix the mounts in place. Locating pins consist of a bolt, or pin, with a button on the top and a ball bearing near the bottom. The ball bearing is held in place by a release mechanism connected to the button. Once the button is pressed, the ball bearing can be depressed into the bolt allowing the pin to be easily removed. This would allow a faster realignment of the mounts, compared to the use of bolts.

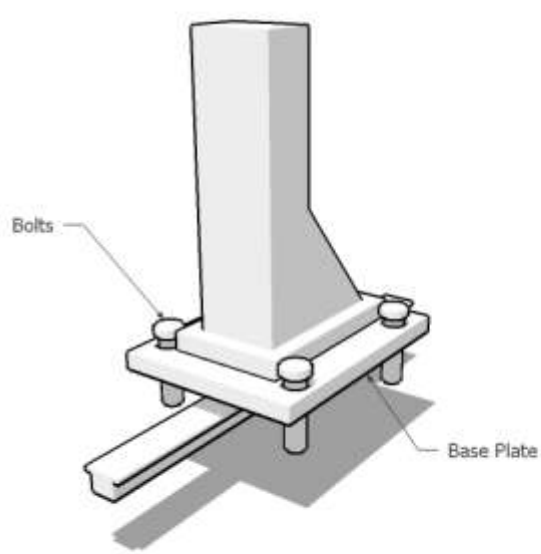


Figure 36. Mount with Bolts/Pins

Latch

A latch could be used to fix the mount to the cart base. This latch would need to be either fixed to the mount or the base and physically restrain the mount in its proper location.

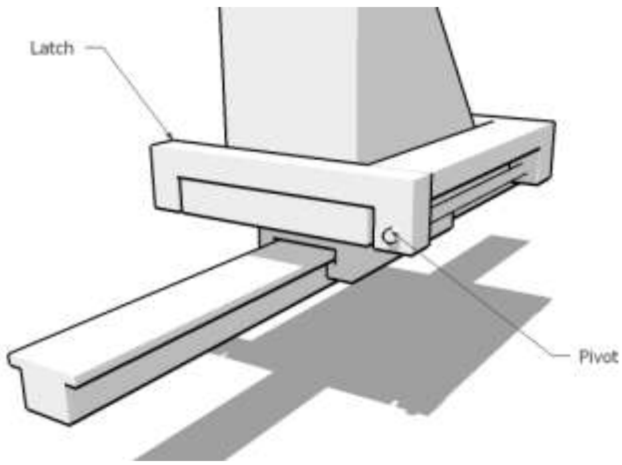


Figure 37. Mount with Latch

Lead Screw

A lead screw could be used to slide the mount along the rail, and also hold it firmly in place. A lead screw system would consist of two long circular screws running the length of the rail fixed to either side of the mount. The circular screws would be connected to a gear system which could be turned using a crank. Turning the crank would move the mount longitudinally along the length of the cart base, allowing for quick alignment of the hardpoints. The gears would require a locking system to prevent the mount from moving freely along the rail. A locating pin or latch locking the crank in place could be used to prevent the mount from moving.

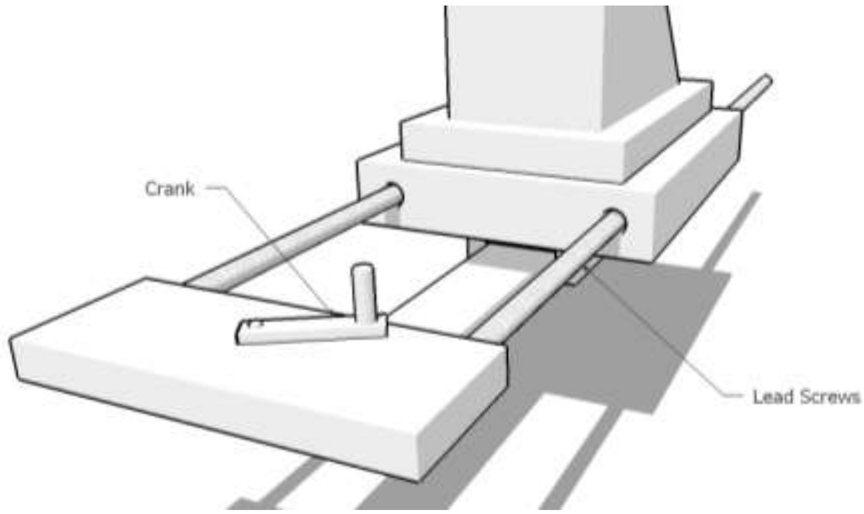


Figure 38. Mount with Lead Screws

Criteria Selection

A screening matrix was developed to narrow down the design concepts. Based on variables within each concept a second screening matrix was developed to analyze secondary options.

The basis for the screening table is that each criterion will be assigned a positive, negative, or a zero (neutral) for each concept. The selection of the sign is based on the performance of the concept when compared to the original. An improvement is marked as positive, a decrement is marked as negative, and a non-improvement is marked as zero. The sign was determined by unanimous decision. From TABLE VIII and TABLE IX, concepts displaying a positive or zero net value were selected to be further analyzed in the scoring matrix. The highest ranked concepts rated by the scoring matrix are shown in TABLE X.

TABLE VIII: CONCEPT SCREENING MATRIX (RAIL SYSTEMS)

	CONCEPT VARIANTS	
SELECTION CRITERIA	**Circular Monorail**	**‘C’ Shaped Monorail**
Ease of mobility	+	+
Capability to withstand heavy loads	+	+
Capability to withstand lateral loads	-	+
Affected by misalignment of shaft/rail	-	0
Requires minimal maintenance	0	0
Is simple to use	+	+
Is quick to install and remove	-	-
Base plate stability	+	+
PLUS	4	5
NEUTRAL	1	2
MINUS	3	1
NET	1	4
RANK	2nd	1st
CONTINUE?	No	Yes

For the Rail system, the “C” shaped design has passed the screening matrix. The selected system has more pluses than minuses, which were considered in making the decision. It had more positive criteria that satisfied our customer's requirements.

TABLE IX: CONCEPT SCREENING MATRIX (MOUNT FIXING OPTIONS)

CONCEPT VARIANTS

SELECTION CRITERIA	**Pins**	**Bolts**	**Latch**	**Lead Screws**
Ease of handling	+	-	0	+
Ease of use	+	0	0	+
Load handling	-	+	-	+
Vibration handling	-	+	-	0
Manufacturing ease	0	0	+	-
Manufacturing cost	+	+	+	0
Installation time	0	-	0	+
Ensure rigidity	-	+	-	0
Requires minimal maintenance	+	0	0	0
PLUS	4	4	2	4
NEUTRAL	2	3	4	4
MINUS	3	2	3	1
NET	1	2	-1	3
RANK	3rd	2nd	4th	1st
CONTINUE?	Yes	Yes	No	Yes

In regards to the various mount fixing options, bolts, pins, and lead screws have passed the selection criteria. We selected all the concepts that received a positive score and carried them forward to scoring matrix.

Concept Scoring

In order to reduce the remaining concepts to a select few, a scoring matrix was employed. The basis for scoring is that important criteria for each concept are rated from 1-5, with the highest total scores selected for further development. The criteria selected were largely based on the customer needs with some additional criteria such as strong rigidity, cost, and overall safety. The criteria were arranged in order of importance and a weighting factor was added to each criterion, with the total of all weighting factors adding up to 100. The scores for each concept and criterion were multiplied by the individual weighting factors and total scores were summed, determining the overall rank of each concept. The top two concepts have been selected for further development according to the scoring matrix shown in TABLE X.

TABLE X: CONCEPT SCORING MATRIX (MOUNT FIXING OPTIONS)

CONCEPTS

		Pins		Bolts		Lead Screws	
SELECTION CRITERIA	**Weight**	**Rating**	**Weighted score**	**Rating**	**Weighted score**	**Rating**	**Weighted score**
Ease of handling	10	3	30	2	20	4	40
Ease of use	10	4	40	2	20	3	30
Load handling	15	1	15	5	75	4	60
Vibration handling	10	2	20	4	40	3	30
Manufacturing	5	4	20	3	15	2	10
Turnaround time	15	5	75	2	30	5	75
Maintenance	5	5	25	3	15	2	10
Overall Safety	10	5	50	2	20	3	30
Durability	5	3	15	4	20	5	25
Cost	10	5	50	4	40	3	30
Total score	100	-	340	-	295	-	340
Rank	-	1st		2nd		1st	
Develop Concept?	**-**	**yes**		**No**		**yes**	

From here on, only two concepts were selected to be considered, developed further and integrated to the final design.

Concept Selection and Analysis

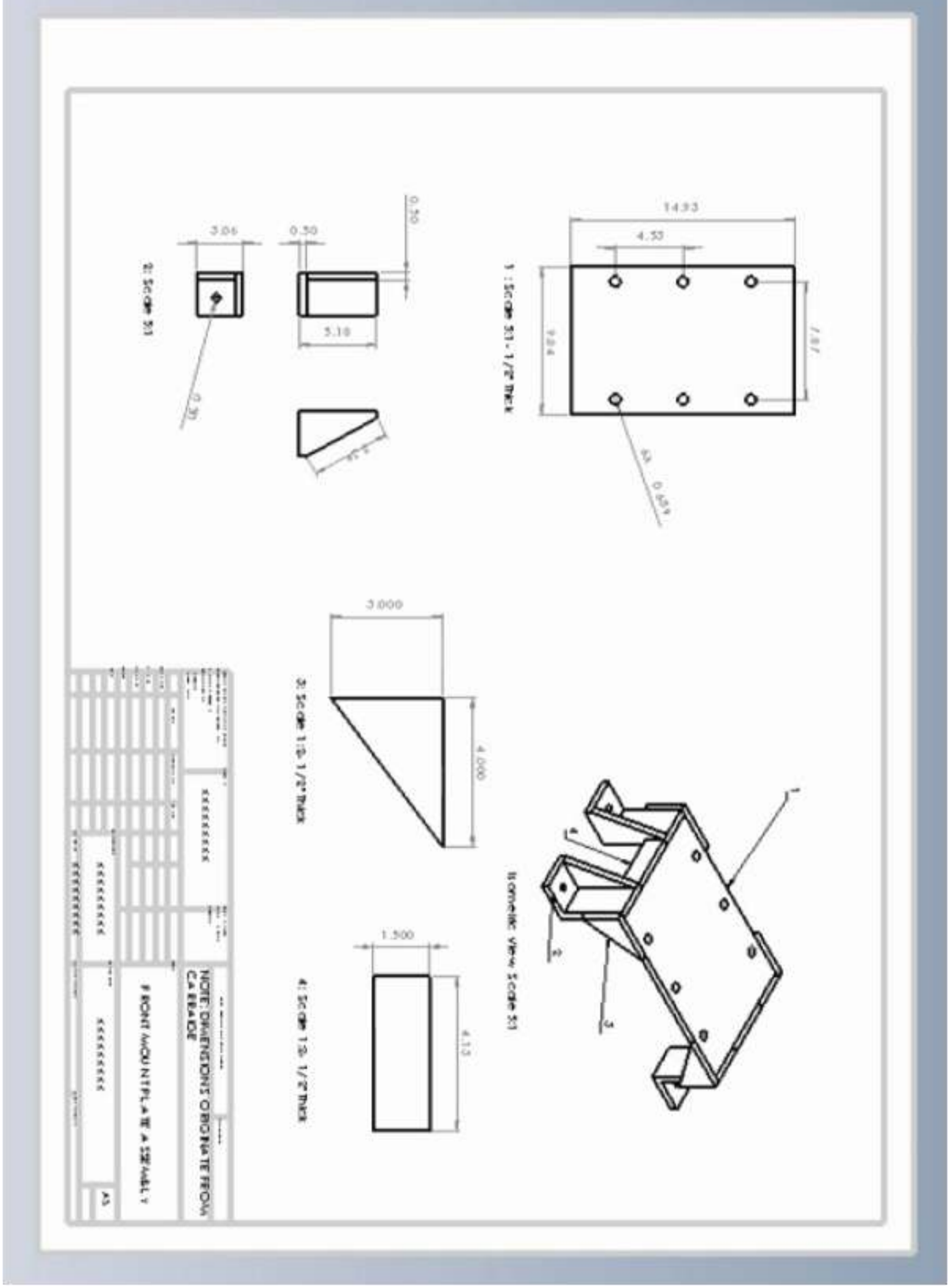
Based on the criteria used for this project's analysis, the pros and the cons as well as decision matrices were evaluated. This led to an effective group decision on the ideal designs, with the customer’s requirements in mind.

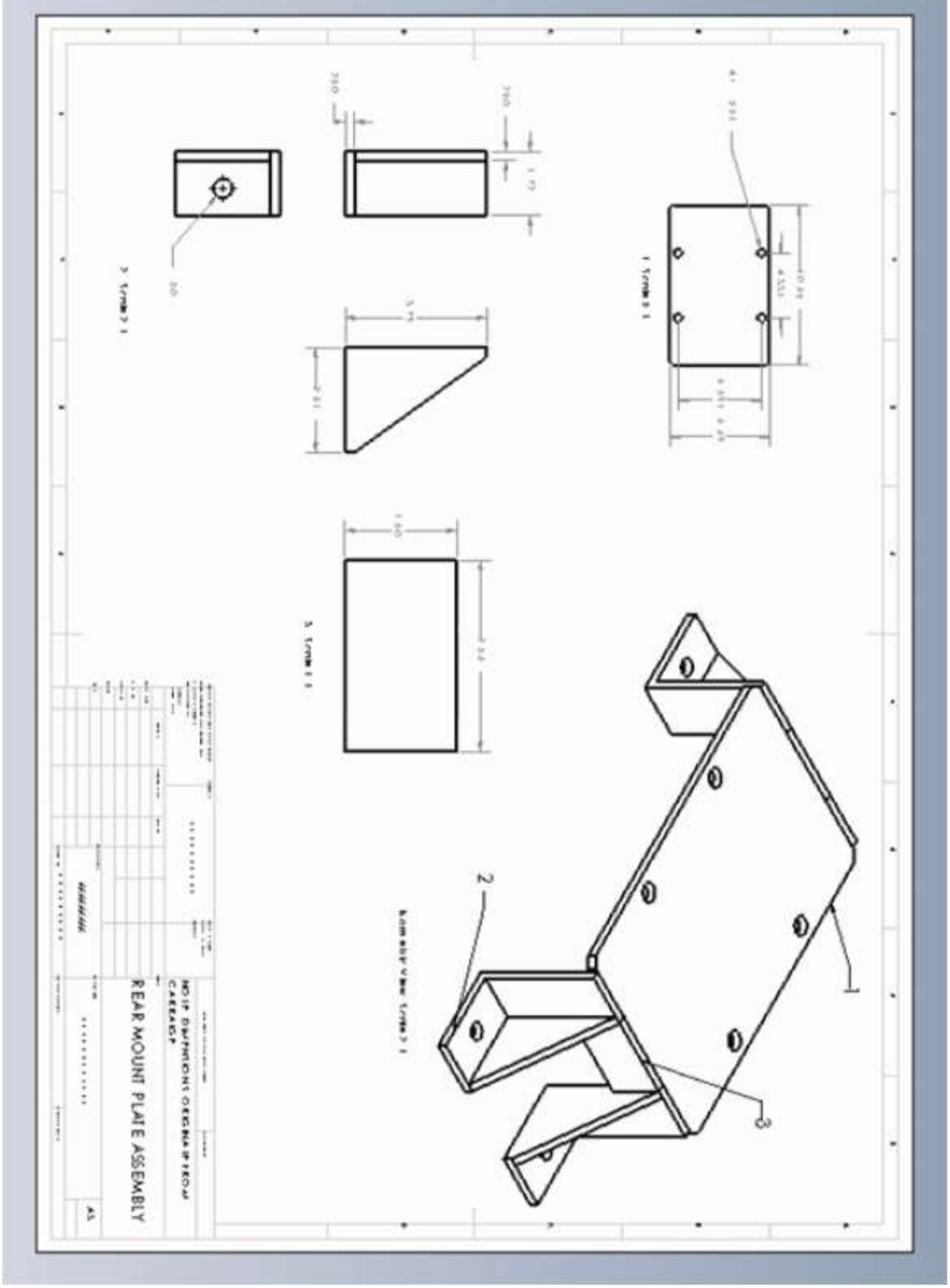
The concept screening process led to the conclusion that both the pins and the lead screw designs showed potential as a final design. Both concepts were carried forward for further development. The team considered combining the two designs into the final test cart design, but after further analysis we came to the conclusion that winding the lead screw to set up the mounts in their respective locations would be more time consuming than sliding the carriages into place manually. Securing them down using locating pins would be much faster and easier to use. Therefore, locating pins were selected as our final concept for 'mount fixing' options.

The team came to the conclusion that the dominant railing system is the 'C' shaped monorail system and shall be integrated in our final design. Additionally, our final design will be fused with the West Test Cell's original test carts and will henceforth fulfill our customer's needs.

Appendix B: Design Drawings

The following pages contain the design drawings for all altered or modified components of the redesigned cart.


1: Scale 3:1 - 1/2" Thick
2: Scale 3:1
3: Scale 1:9 - 1/2" Thick
4: Scale 1:9 - 1/2" Thick
Isometric View Scale 3:1
14.53
4.53
3.000
4.000
1.500
NOTE: DIMENSIONS ORIGINATE FROM CARRIAGE
FRONT MOUNT PLATE ASSEMBLY
A5


REAR MOUNT PLATE ASSEMBLY