An Integrated Design of Drexel's Formula SAE Chassis

Submitted to: **Dr. Tein-Min Tan**

The Senior Design Project Committee

Mechanical Engineering and Mechanics Department
Drexel University

Team Number: MEM-01

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Abstract:

The handling performance of a racecar is dependent on the torsional rigidity of the chassis. A chassis test rig for Formula SAE racecars will be designed and manufactured. The test rig will be used to statically measure the strains and rigidity of the current Formula SAE racecar chassis. Utilizing Finite element Analysis (FEA) and experimental test data, the chassis design will be evaluated for torsional rigidity and strain. The comparison of data from both FEA and testing will validate the structural integrity and design of the existing and future chassis. Therefore, a general testing procedure, employing a re-useable methodology, will be generated for the use of future teams. A document regarding test procedures and relating the test results to the chassis will be generated for the use of future teams. A validated FEA will be submitted to Formula SAE Drexel Racing for presentation at competition.

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I. Introduction

Project Background:
Drexel University's Formula SAE organization requires FEA be presented at the time of competition in order to provide structural data needed for evaluation of the chassis design. Computer modeling and FEA are used frequently in engineering for design parameter verification for both static and dynamic conditions. While this methodology is often accepted it is somewhat unpredictable since modeling techniques and other modeling parameters can drastically affect the results. Therefore without actual real-world test data, being used for comparison and model refinement, the results can be somewhat inaccurate. A test rig capable of reproducing the computer analysis conditions on the physical chassis can provide a direct link between the computer data and its validity. A correlation factor can be determined by comparison of theoretical rigidity to the actual rigidity, through model refinement this correlation factor could possibly be refined until the model exactly represents real-world conditions.

Ultimately the use of FEA and testing is to determine the torsional rigidity of the chassis and evaluate it with respect to its overall material weight. Increased torsional stiffness of a racecar chassis improves vehicle handling by allowing the tuning of suspension components to control a larger percentage of a vehicle's dynamics. "Predictable handling of a racecar may be achieved by tailoring chassis stiffness so that roll stiffness between sprung and unsprung masses are due almost entirely to the suspension."[1]

Problem Statement:
A racecar frame in motion is subject to loads that cause flex and deformation. These distortions can severely affect performance and handling. Physically measuring the extent of the deformation is difficult and inaccurate when the frame is moving dynamically. Computer modeling theoretical experimentation as well as static real-world frame testing is required to align safety with design as well as accurate prediction of the handling characteristics.

Constraints on the Solution:
There are a variety of constraints to this problem which make it necessary to simplify the problem at hand. Although a racecar chassis can experience a wide range of dynamic loading conditions during use, it is in the best interest of testing to reduce these conditions to those of a static nature. Besides the lack of necessary data to set up a dynamic analysis some general rules can be used to determine static loading conditions that result from dynamic conditions. If there were resources available to fully instrument the chassis to record and define real time data logging from track conditions, much could be gained from measuring g-force and load distribution in the chassis. The equipment required to acquire this information is expensive compared to other

[1] Thompson, Soni, Raju, Law, 1

alternative procedures. Therefore, the majority of the automotive field performs this analysis with static models.

II. Statement of Work

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Overall Objectives:

1. To provide the Formula SAE racecar team with an accurate finite element analysis of the rigidity of the chassis of their current racecar.
2. To create a test rig capable of repeatable rigidity testing for years of use.
3. To produce a repeatable test procedure document, including any necessary calibration techniques to be used for future reference.
4. To deliver a design safety factor report from the correlation between theoretical and actual rigidity of the chassis.
5. To transition from I-DEAS to Pro/Engineer software packages.

Method of Solution:

The method of solution will be divided into two sub sections one being on the proposed finite element (FE) portion of the project and the second being on the Testing portion of the project

Finite Element Analysis:

FEA has become the standard for testing three-dimensional modeled parts and assemblies. When executed properly, computer-based analyses provide insight into the design of structural components and highlight potential design problem areas. This analysis will be performed on computers both belonging to FSAE Drexel Racing, Drexel University Mechanical Engineering, and Mechanics Department. The modeling work will take place in the Formula SAE Drexel Racing Lab at Hess Labs. The computers available for use in Curtis 114 will also be used whenever possible.

Beam Elements:

Beam elements can approximate the chassis structure by assuming the welded tubes of the chassis have stiffness in bending and torsion. Nodes will be placed at the intersection of the welded tubes and at the eight engine-mounting locations. Figure 11 shows the location of the engine as a stressed component in the chassis. The engine will be approximated in the FEA by connecting the nodes located at the engine mounting points with elements of higher stiffness. The yellow anchor nodes in figure 11 will be used at all engine-mounting locations. Approximating the engine this way is a known practice in Formula SAE chassis FEA when the engine is mounted as a stressed component.

Loading and Boundary Conditions:

The loading and boundary conditions of the FEA will aim to simulate the loading and fixturing of the test rig. Two equal and opposite forces will be applied at the front suspension locations on the main chassis frame. The rear suspension components have been included in the model, see figure 9. The free ends of the rear suspension will be the locations of boundary nodes affixing them in place. Using the rear suspension components instead of the frame allows for a more accurate tire to pavement contact approximation.

FEA Overview:

The first phase will be the completion of an analysis using beam elements. The partial wireframe model that already exists will be checked for correctness against the current geometry of the racecar chassis. Adding the rear box, rear suspension components and current engine mounts to the roll hoop configuration will complete the model begun by last year's FEA team. Figures 5,6 and 7 show the existing wireframe from last year as multi-colored lines and new geometry created this year in green. Shown in Figures 8,9, and 10, the wireframe geometry representing the centerlines of the chassis and suspension tubes will be wrapped with mesh of the appropriate cross section to create a finite element mesh (FEM). The primary goal of this first FEA is determine the location of strain gages for testing. A document will be issued detailing the placement of the strain gages and outlining the results of the FEA.

The second phase will be the verification process. By comparing the results of FEA with data gathered from the test rig testing a document will be produced detailing the relationship between the computer model and real-world analysis. The measurements of the existing chassis are approximated due to the chassis already being built. The second phase of the FEA will focus on areas that influence the overall rigidity of the existing design. These areas may produce high stress, lack structural rigidity, or simply lack the realistic state of the existing chassis. Based on the combined results of FEA and testing, the problematic areas regarding the differences between the loading conditions can be identified. These problematic areas will be modeled in greater detail than the first model to provide a higher level of accuracy. From the total results of the FEA and test rig analysis a report outlining the FEA process and results will be produced. This FEA report will include all the information needed for Formula SAE competition in the spring.

Finally a chassis design report will be produced as a support document for future designs of the chassis. This document will include methodology for performing future finite element analyses, and recommendations for design. Future designers of Formula SAE chassis will have the document on file in the Formula SAE Drexel Racing Lab as reference. The design of the 2005 chassis will be modeled using the data collected from the overall analysis of the 2004 chassis and will incorporate all of the knowledge gained in this project.

Evaluation of FEA results:

A proper evaluation of the chassis contains both FEA and real-world test data to support the analysis. Computer-based analyses use a finite number of elements to approximate loading conditions, so there is room for error. Combining this with the craftsmanship of the chassis in terms of proper welds and tubing cuts, etc… this creates a division of results between computer-based testing and real world testing. The comparison of values from testing can help to eliminate error in the analysis for verification purposes at the Formula SAE competition.

Test Rig Concept:
In order for the testing of the chassis to be successful engineering decisions and calculations must be performed in the following four areas of the testing process. First the decision on how the chassis will be mounted and constrained and thusly the design and manufacturing of the required fixturing. Secondly the application of the loads and required rigging to enable this during the test. Thirdly the instrumentation scheme of the test rig must be designed in order to obtain the necessary data to be used for evaluation of the chassis. Lastly the testing procedure and data analysis must be established and followed during testing. Hess labs will be the primary location of work, since they offer the facilities needed to set up the chassis test fixturing and equipment. In the proceeding sections and overview of the perceived path to the solution will be given. .

Chassis Mounting Design:
The rear of the chassis will be fixed in position such that the base of the chassis is suspended off of the test rig base. The rear mounting points of the chassis will be restrained in all x, y and z translations (Ux = Uy = Uz =0) and in two degrees of rotation (Θz = Θx= 0) by a steel fixture designed to attach to the desired rear mounting locations, presumably at the wheel hub. The front center point of the chassis will be rested on a knife-edged steel fixture which creates the pivot point of rotation. Additionally the rear shocks will be removed and replaced with an adjustable solid member to prevent suspension movement during loading. "Note that the numbers quoted (for torsional rigidity) may be for the bare chassis or tub, without the deflection of the suspension links or the various brackets (etc.) required to attach the suspension to the car; measurements on only part of the system can be misleading."[2] With this being the case it is in the best interest to keep the rear mounting points at the wheel hub since it will produce the most realistic results.

Attached in Appendix B are figures which outline the preliminary mounting fixtures and components to be used for the test rig. Figure 1 shows the overall test rig setup including the loading beam discussed in the next section. Figure 2 is a detailed 3-D representation of the rear mounting fixtures used to fix the chassis. This fixture uses both the 3 ¾ inch hub bolt pattern and the 2 ¼ inch diameter hub loading point. Figure 3 is of the knife-edge steel fixture used for a pivot and figure 4 is the preliminary design of the solid shock member used to add rigidity to the suspension linkage. Also Appendix D contains some preliminary Engineering Drawings for the rear mount fixtures and the solid shock member.

Chassis Loading Conditions:
A near rigid beam will be securely attached to the front of the chassis at or near the location of the center of the front wheels. The rigid beam will extend beyond the chassis in equal lengths with the mid point of the beam lined up with the centerline of the chassis. Weights will be affixed to one end of the beam to provide the downward

[2] Milliken W., Milliken D., 676

force of the coupling torque. Beneath the other end of the bar will be a screw jack and scale providing the equal and opposite counter force. With both equal and opposite forces applied at exactly the same distance from center of the chassis, the required torque can be applied to the chassis.[3] Additionally another scale will be set under the front pivot point and used to determine if the coupled torque can be applied evenly without producing a downward force on the scale. The force produced by the weight of the chassis will be subtracted from all measurements taken during loading conditions.

It is very important not to overload the chassis during testing. Therefore a method of applying loads incrementally can beneficial to the safety of the chassis as well for checking the linearity and hysteresis of data collected. This is important in verifying the accuracy of the data. It is expected that in low loading conditions the chassis angular deflection will be non linear due to the play in the suspension components and fixturing. This is somewhat of a common event seen in the data presented in many FSAE papers, but has no real negative effect.[4] All data that is contained in the linear region of the graph is considered valid. Figure 1 in Appendix B shows the overall test rig setup and how the loads will be applied to the loading beam in the figure.

Chassis Instrumentation Scheme:
Strain gages will be used in conjunction with dial indicators to verify the FEA model of the chassis. While dial indicators are good for measuring deflection, strain gages are well suited for measuring strain levels and thus stress levels throughout the chassis. The calculation of stress throughout the chassis is an effective way to verify that the FEA model is correct.

There are many important topics on the use of strain gages that must be presented and followed in order to obtain accurate strain readings from the test. First the correct strain gage must be specified for the project. Secondly the proper electronics must be assembled in order to provide proper sensor excitation as well as signal measurement. Also it is very important to follow the proper installation procedure since the accuracy is dependent upon a good bond between the strain gage and the chassis. A proper calibration process must also be followed. Lastly the proper data logging and analysis must be followed to obtain the stress results.

An Analog dial indicator will be used during the experiment in order to measure the angular deflections of the chassis. The Dial indicator used has a range of 1” and can measure increments of .001”. In most cases the deflection measured will be very small since it is not expected for the chassis to flex much. An extension arm will be connected to the chassis its known length used to amplify the linear displacement used to calculate the angular deflection.

Testing and Data Analysis:

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[3] Thompson, Raju, Law, 6 #983053

[4] Reily, George, 144

Data logging and Analysis is the final step in the strain/deflection measurements and will be conducted during the actual testing. There will be multiple strain gages applied to the chassis, as per the Strain Gage Placement Document, which will be produced after the first finite element analysis of the chassis has been performed. Since the electronics for measuring the strain gages can only accommodate one gage at a time, it will be necessary to hook up each gage individually, zero it out, then apply loads and record the voltage levels. While zeroing out the strain gages it will also be necessary to make sure that the dial indicator is in place and reset. A Microsoft Excel spreadsheet will be used for recording the data. A spreadsheet will be used to convert the voltage data into strain levels. After applying the loads, strain and displacement data will be input to the spreadsheet. The last step is the removal of the loads and preparation for the next measurement condition in the test matrix. The overall data-logging process will be very repetitive by moving the dial indicators to different locations where angular displacement is to be measured, as well as hooking up and zeroing the next gage to be measured. Some thought will be given into the linearity and hysteresis of data collected. By incrementing the loads and measuring strain and deflection up to the full loading condition the linearity can be determined. By incrementally removing the loads and recording data linearity once again can be checked, but additionally hysteresis can be evaluated. In multiple FSAE papers there have been problems with obtaining linearity at low load levels due to the play in suspension components.

After the Data is collected it needs to be complied in a fashion that can be easily viewed and used for analysis and comparison with FEA data. More information on this will be available after the testing, when there is data to process and present.

Alternative Solutions:
Methods of solution were evaluated on the basis of cost, resources, time, existing knowledge base, results (accuracy), and results (user-friendliness). Cost refers to the overall amount of money needed to purchase physical testing supplies and software for FEA analysis. Resources refer to what is available to us as students at Drexel University. Time refers to project time, and all lead times associated with the project. Existing knowledge base refers to the information that is available in the field of FEA techniques and testing processes. The accuracy of results takes into account dynamic testing yielding the maximum amount of usable information. The user-friendly component of results is important to non-engineers. The evaluation was conducted with 1 being the best and 4 being the worst for all categories.

1-4 scale	Cost	Resources	Time	Existing knowledge base	Results, Accuracy	Results, User-friendliness	Total
Static FEA, Static Testing	1	1	1	1	4	1	9
Static FEA, Dynamic Testing	3	3	3	3	3	3	18
Dynamic FEA, Static Testing	2	2	2	2	2	2	12
Dynamic FEA, Dynamic Testing	4	4	4	4	1	4	21

A dynamic FEA has a much longer lead-time than a static FEA. Both the results from static FEA or dynamic FEA can be used with a static testing method yielding acceptable test results. Therefore, our first choice as an alternative solution would be to use dynamic FEA with a static testing method.

III. Project Management

Proper project management is crucial to the success of any project and is even more important in the scope of this project. With Formula SAE competition held in May, there is a deadline set by Formula SAE Drexel Racing to have the racecar complete and all engineering data documenting the work done available in advance. A deadline of March 10, 2004, the end of the winter term, is currently the deadline for all the FEA and test rig data.

Two weeks in January, from January 8 to January 22, 2004, have been allotted by Formula SAE Drexel Racing for our team to perform the test rig chassis testing. With these sorts of critical milestones, and a quicker then average pace it is extremely important to keep up to date. Based on weekly project tracking through the correspondence of weekly status reports between team members, Formula SAE management, and our project advisor ; contingency plans will be established as necessary in order to account for events which may delay this project.

Microsoft Word was chosen as the format for weekly reports and other correspondence between parties involved with this project. Microsoft Excel was chosen to manage the progress of the project via Gantt chart, as it is provided to all students and faculty at Drexel University and can be considered a universal format.

Attached in Appendix A are Gantt charts for both the FEA and Test Rig teams designed to track project milestones and clearly organize the order and responsibilities of all the tasks required to complete this project. These Gantt charts will be used to map the progress of the project.

Project Management will be the responsibility of the entire team. The Group Leader will be responsible for communicating the need to revise any project milestone information to the project advisor and Formula SAE management.

IV. Economic Analysis

Budgetary information on components necessary for carrying out this project can be found in Appendix C Table 1.

V. Societal and Environmental Impact

The Societal and Environmental impacts are somewhat limited in this project. Any sort of progress gained in chassis design and testing will benefit those closely related to Formula SAE racing and therefore will have no effect on those outside this group. As for environmental impact, the chassis design has little to no impact upon environment when compared to other systems in racecar design like engine and exhaust, in which there fuel efficiencies and pollutant levels can be important.

The chassis design is critical to making a lighter, faster, and ultimately a winning racecar. Future chassis designs will benefit from this analysis and can be designed stronger and lighter. A lighter chassis requires less fuel to propel it, therefore one of the attributes is fuel economy. Overall, a lighter, better-designed chassis has a better chance of winning the Formula SAE competition. Because of this, this project and the analysis could help the Drexel University Racing Team win the Formula SAE competition.

Additionally with respect to the environment all waste produced from machining of metal components will be recycled. All chemicals used will be handled, stored, and disposed of properly.

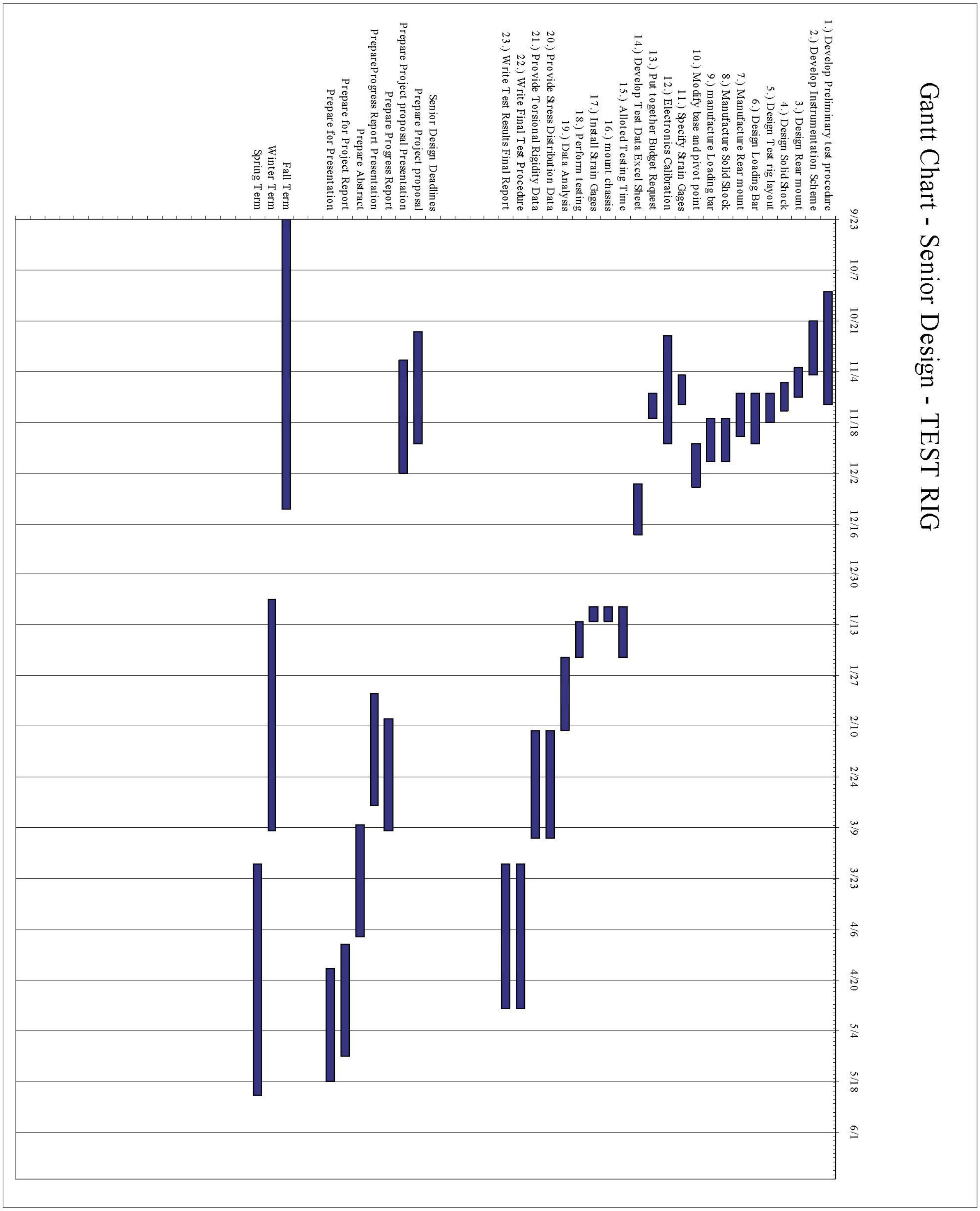
VI. References

1. Thompson, Lonny L., Soni, Pipasu H., Raju, Srikanth and Law, E. Harry, 1998, “The Effects of Chassis Flexibility on Roll Stiffness of a Winston Cup Race Car”, SAE Paper #983053, Clemson University.

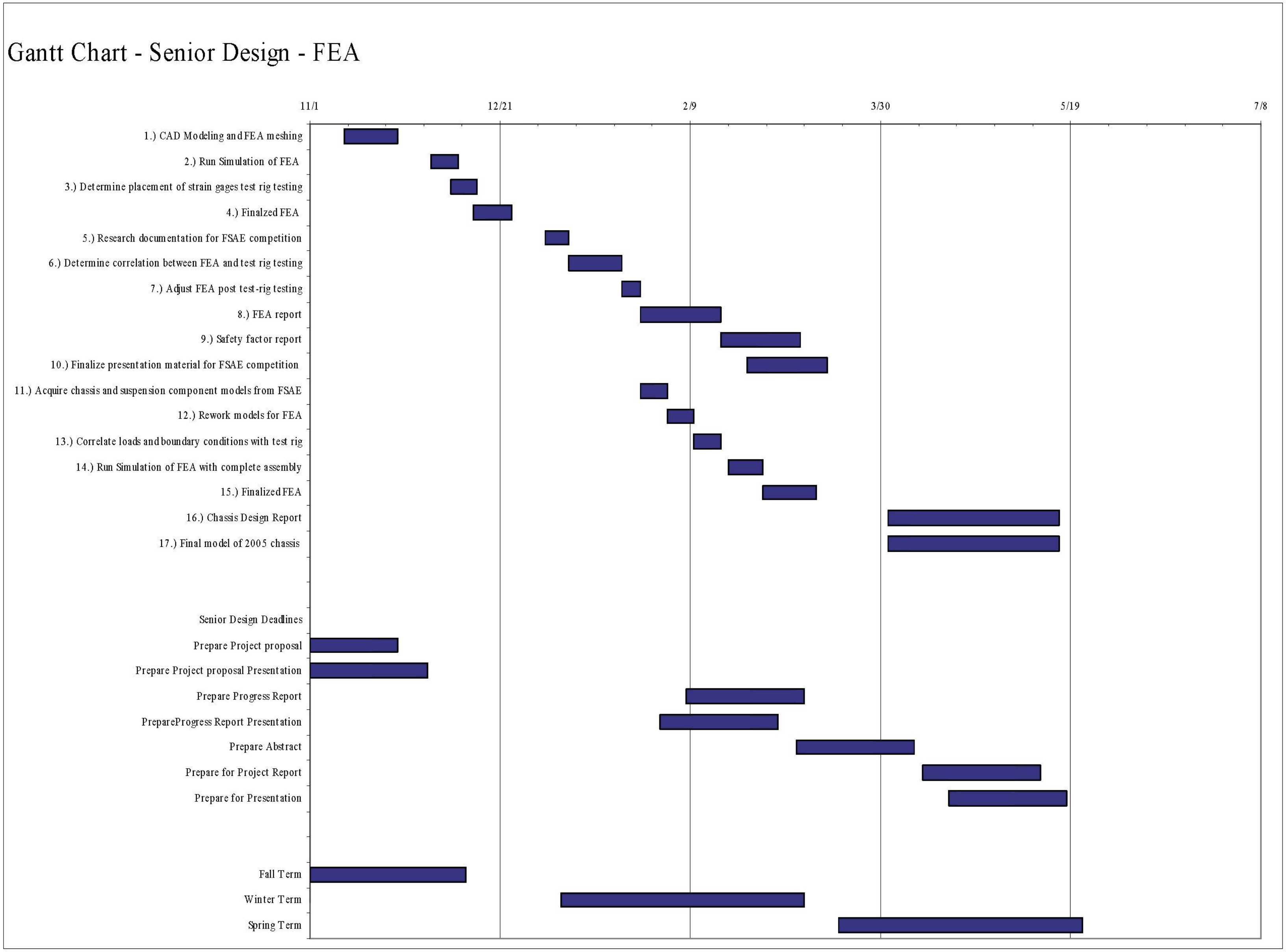
2. Milliken, William F., and Milliken, Douglas L. “Race Car Vehicle Dynamics” pp673-677

3. Thompson, Lonny L., Raju, Srikanth and Law, E. Harry, 1998, “Design of a Winston Cup Chassis for Torsional Stiffness”, SAE Paper #983051 Clemson University

4. Riley, William, B., and George, Albert R. ,2002, “Design, Analysis and Testing of a Formula SAE Car Chassis. Cornell University, pp133-148.


Gantt Chart - Senior Design - TEST RIG
1.) Develop Preliminary test procedure
2.) Develop Instrumentation Scheme
3.) Design Rear mount
4.) Design Solid Shock
5.) Design Test rig layout
6.) Design Loading Bar
7.) Manufacture Rear mount
8.) Manufacture Solid Shock
9.) manufacture Loading bar
10.) Modify base and pivot point
11.) Specify Strain Gages
12.) Electronics Calibration
13.) Put together Budget Request
14.) Develop Test Data Excel Sheet
15.) Alloted Testing Time
16.) mount chassis
17.) Install Strain Gages
18.) Perform testing
19.) Data Analysis
20.) Provide Stress Distribution Data
21.) Provide Torsional Rigidity Data
22.) Write Final Test Procedure
23.) Write Test Results Final Report
Senior Design Deadlines
Prepare Project proposal
Prepare Project proposal Presentation
Prepare Progress Report
PrepareProgress Report Presentation
Prepare Abstract
Prepare for Project Report
Prepare for Presentation
Fall Term
Winter Term
Spring Term
9/23
10/7
10/21
11/4
11/18
12/2
12/16
12/30
1/13
1/27
2/10
2/24
3/9
3/23
4/6
4/20
5/4
5/18
6/1

A-2



Gantt Chart - Senior Design - FEA
11/1
12/21
2/9
3/30
5/19
7/8
1.) CAD Modeling and FEA meshing
2.) Run Simulation of FEA
3.) Determine placement of strain gages test rig testing
4.) Finalzed FEA
5.) Research documentation for FSAE competition
6.) Determine correlation between FEA and test rig testing
7.) Adjust FEA post test-rig testing
8.) FEA report
9.) Safety factor report
10.) Finalize presentation material for FSAE competition
11.) Acquire chassis and suspension component models from FSAE
12.) Rework models for FEA
13.) Correlate loads and boundary conditions with test rig
14.) Run Simulation of FEA with complete assembly
15.) Finalized FEA
16.) Chassis Design Report
17.) Final model of 2005 chassis
Senior Design Deadlines
Prepare Project proposal
Prepare Project proposal Presentation
Prepare Progress Report
PrepareProgress Report Presentation
Prepare Abstract
Prepare for Project Report
Prepare for Presentation
Fall Term
Winter Term
Spring Term

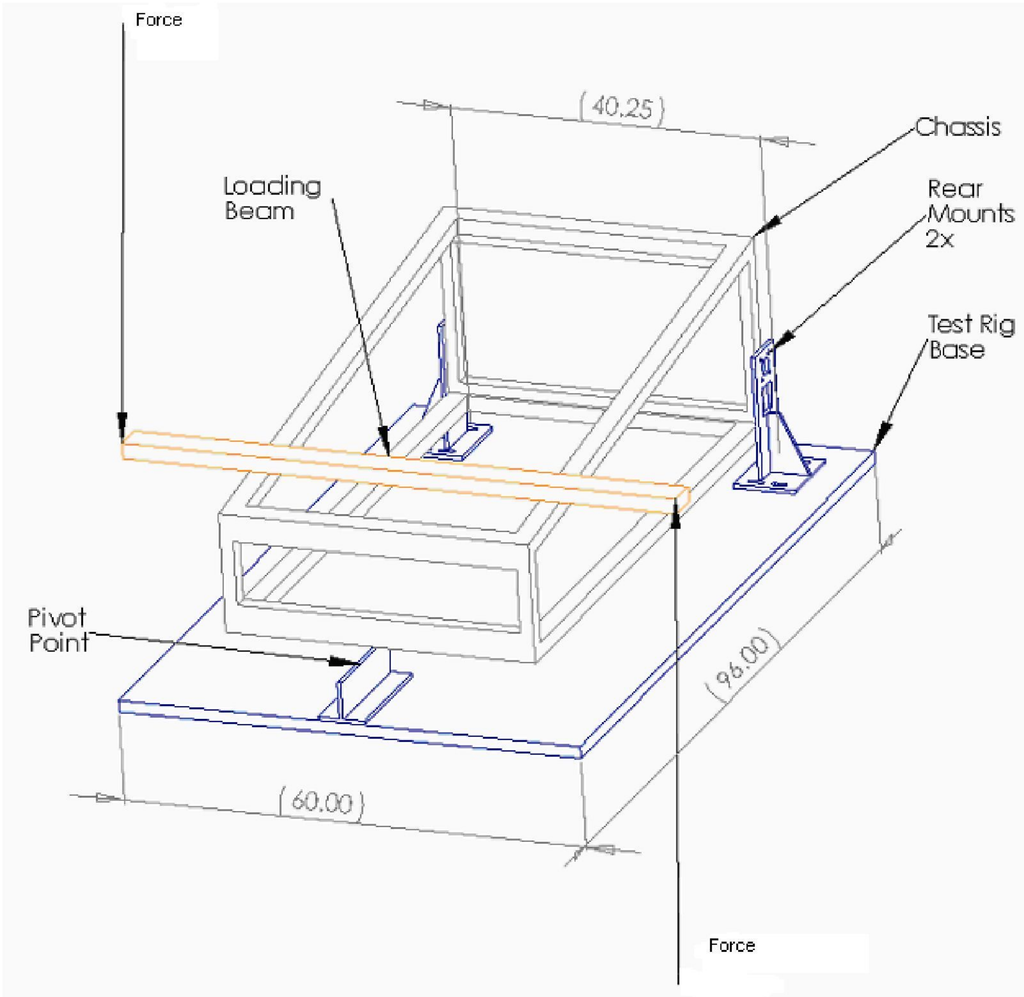


Figure 1. Test Rig Layout

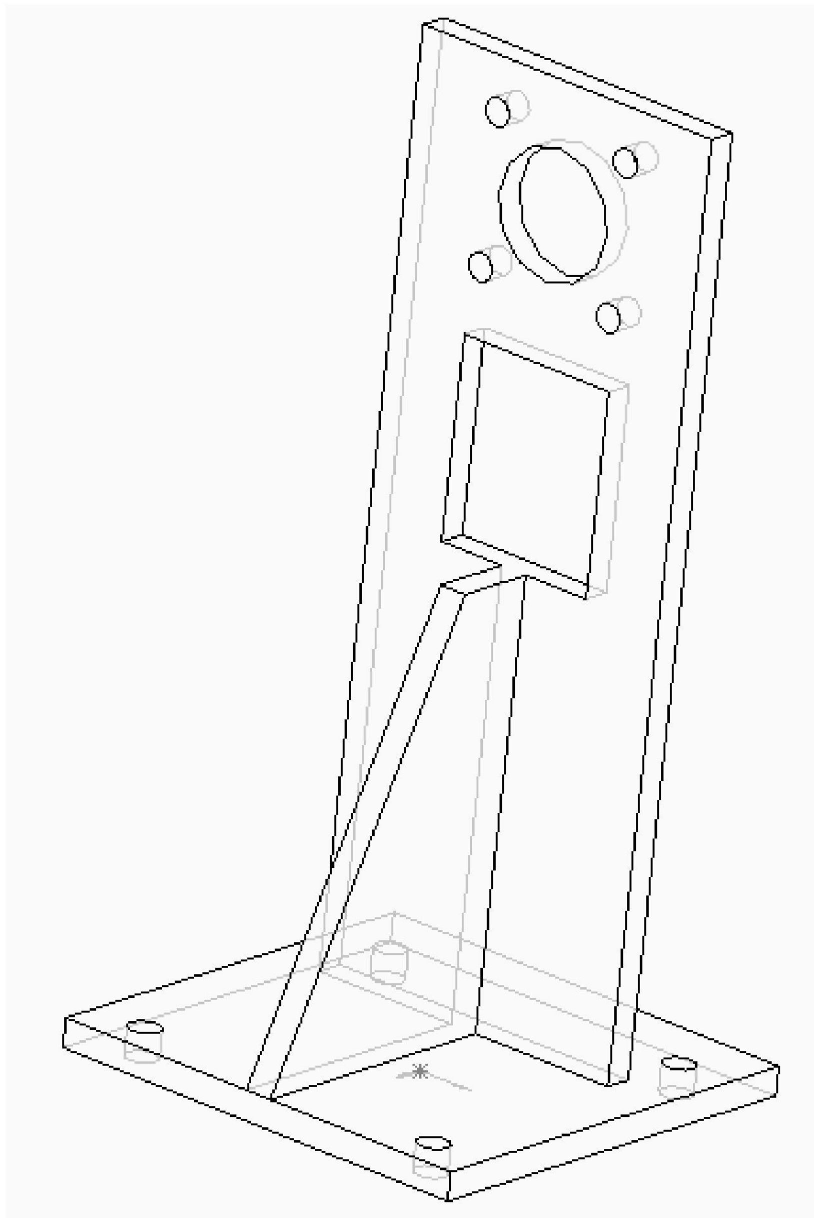


Figure 2. Rear mount Fixture

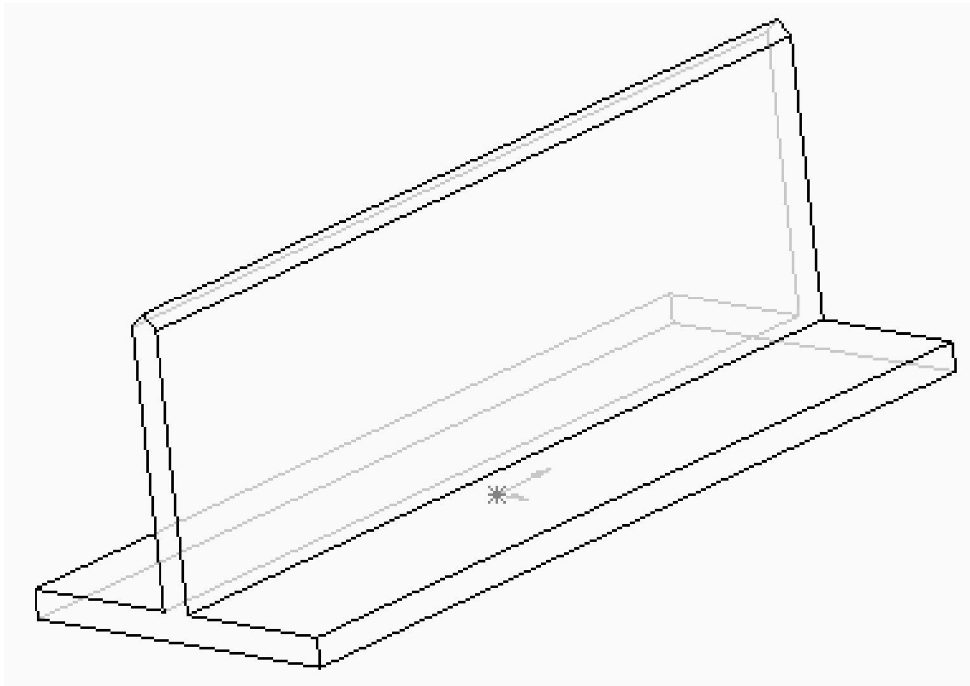


Figure 3. Knife-edge Pivot Point

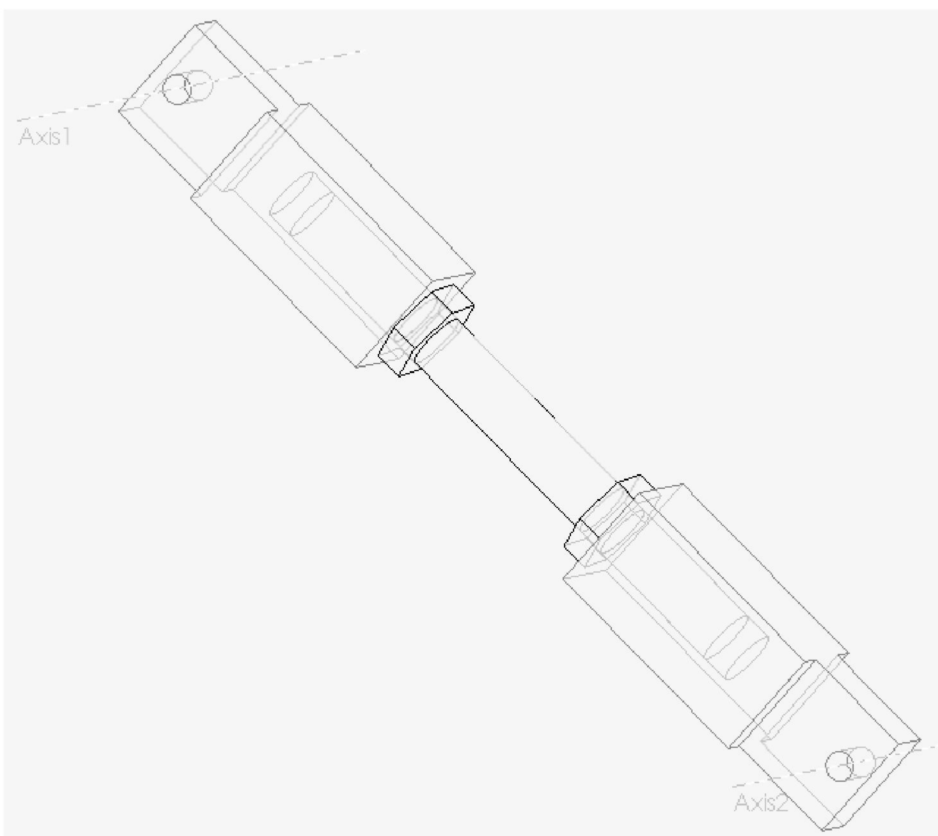


Figure 4. Solid Shock

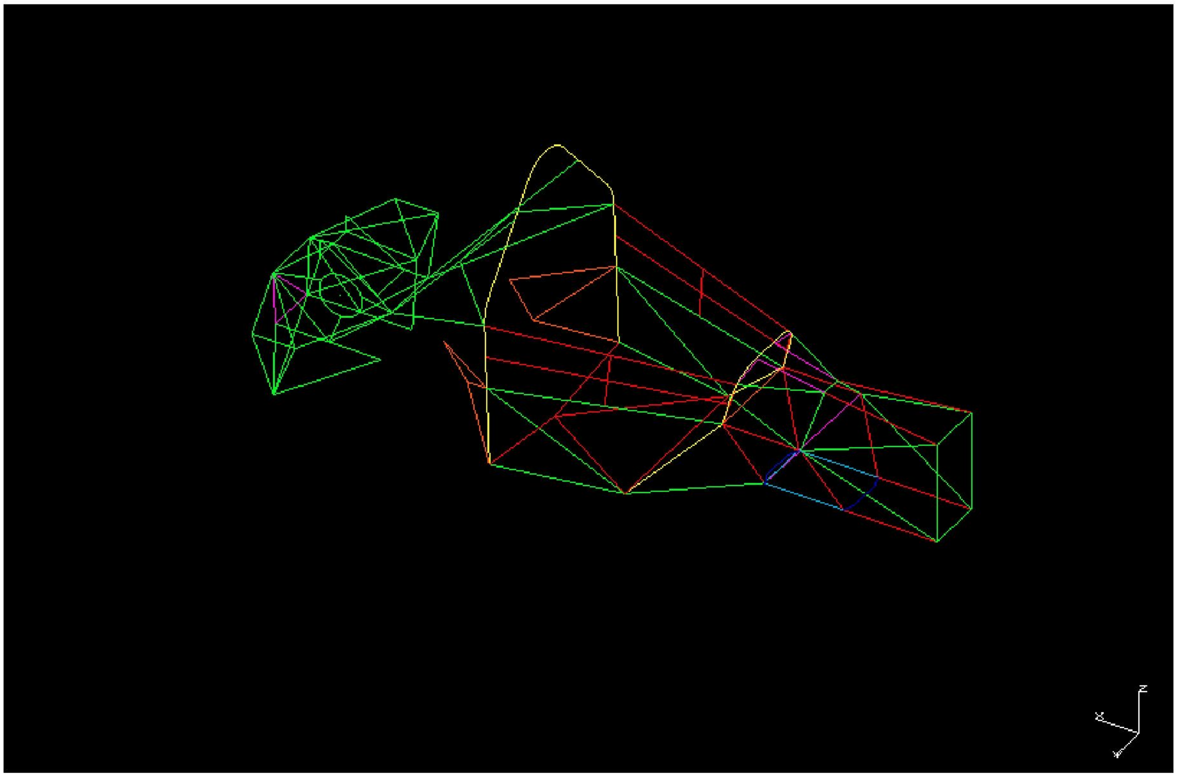


Figure 5. Isometric view wireframe model

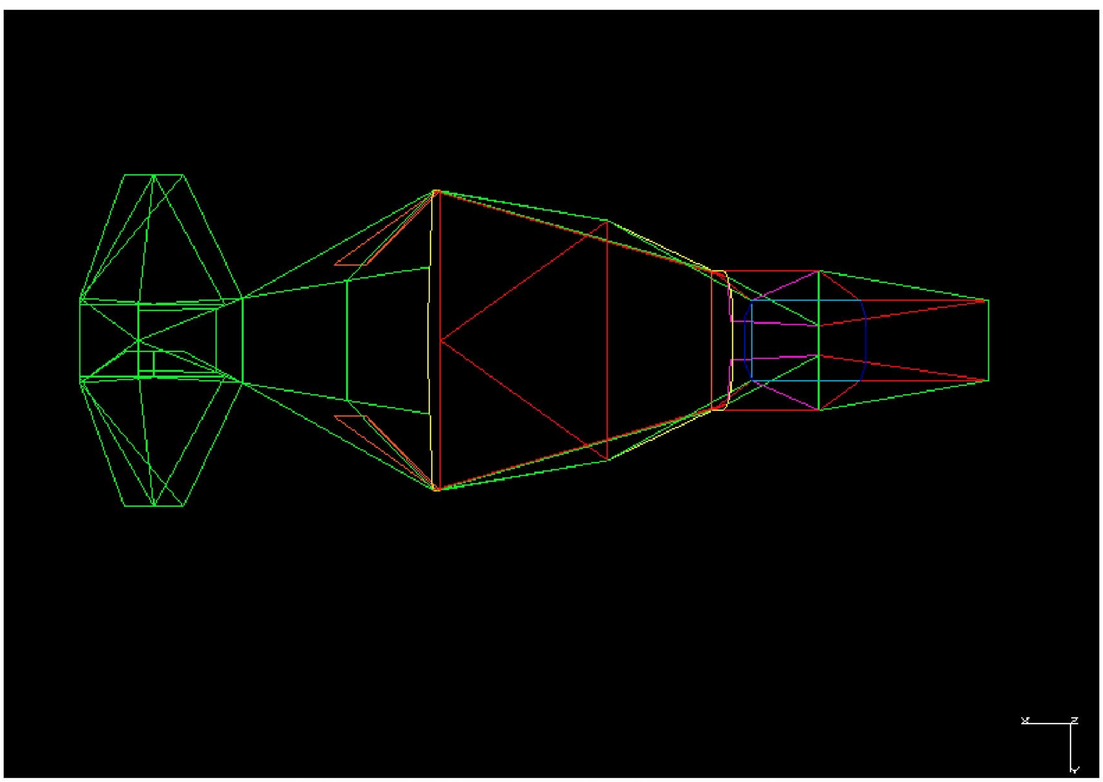


Figure 6. Top view wireframe model

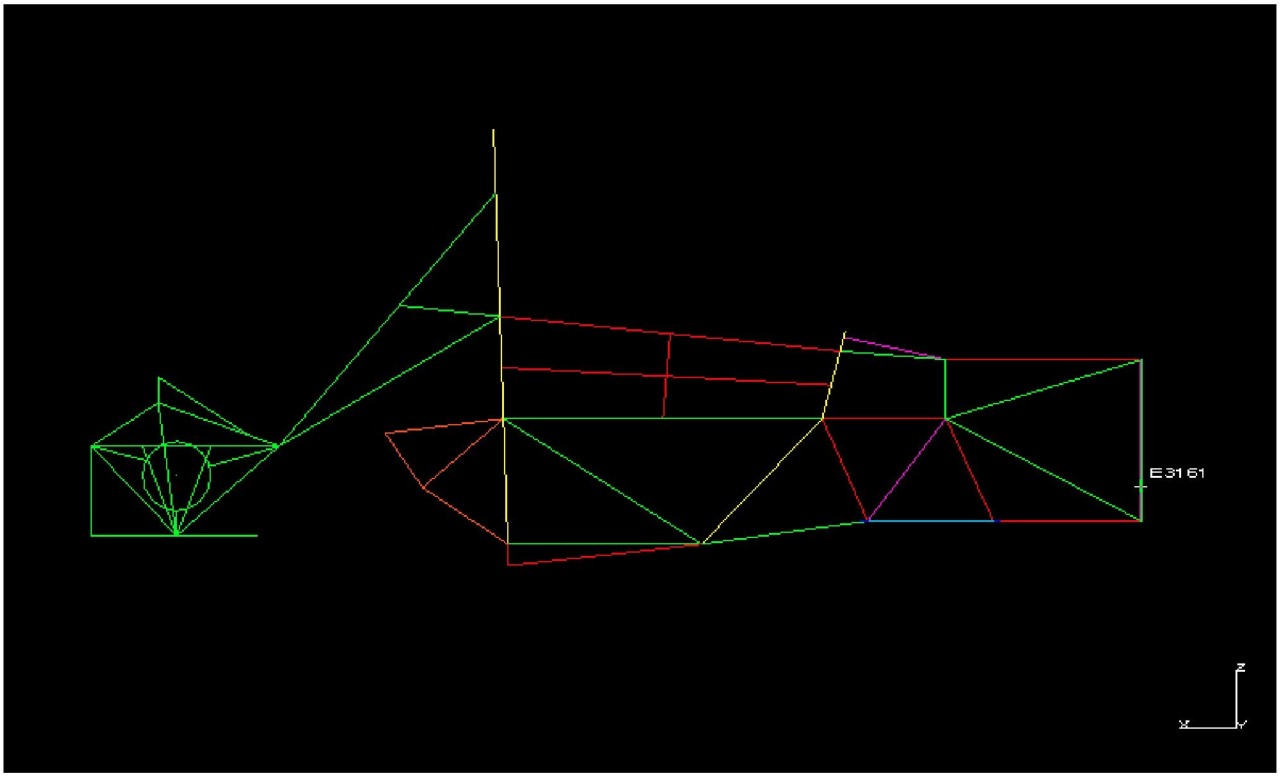


Figure 7. Front view wireframe model

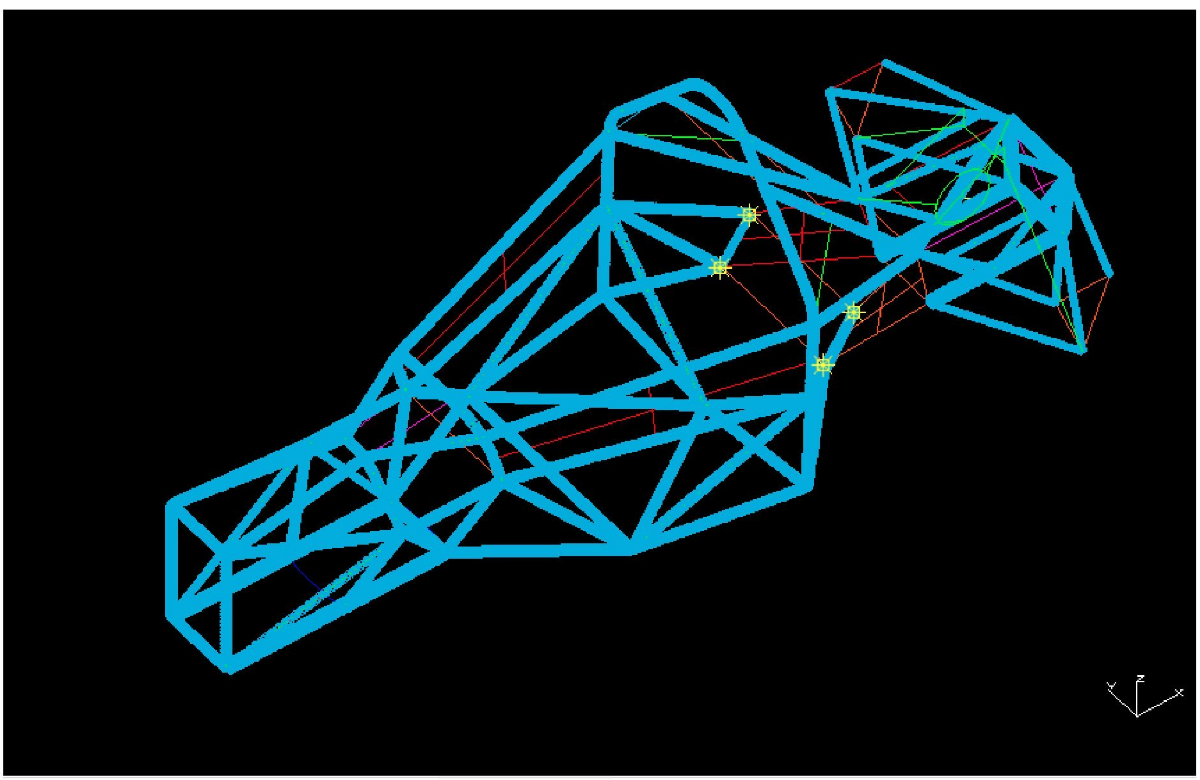


Figure 8. Isometric view FEM

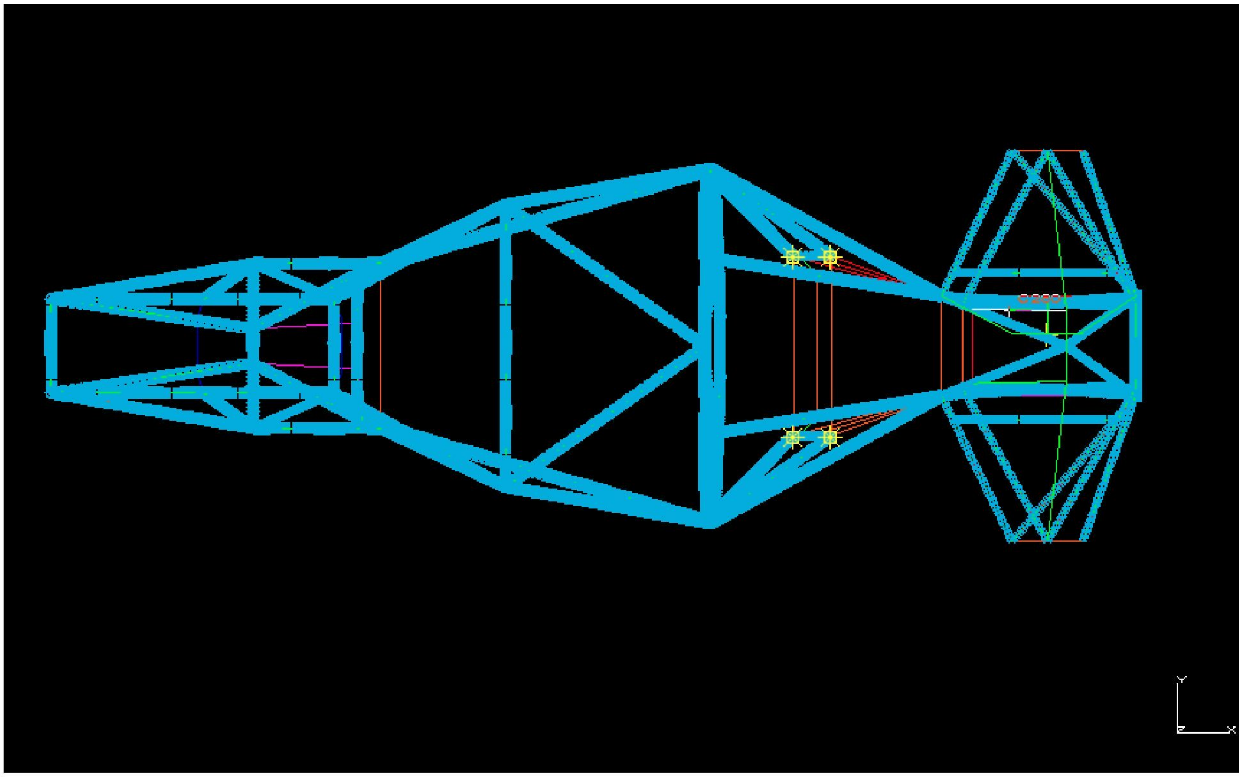


Figure 9. Top view FEM

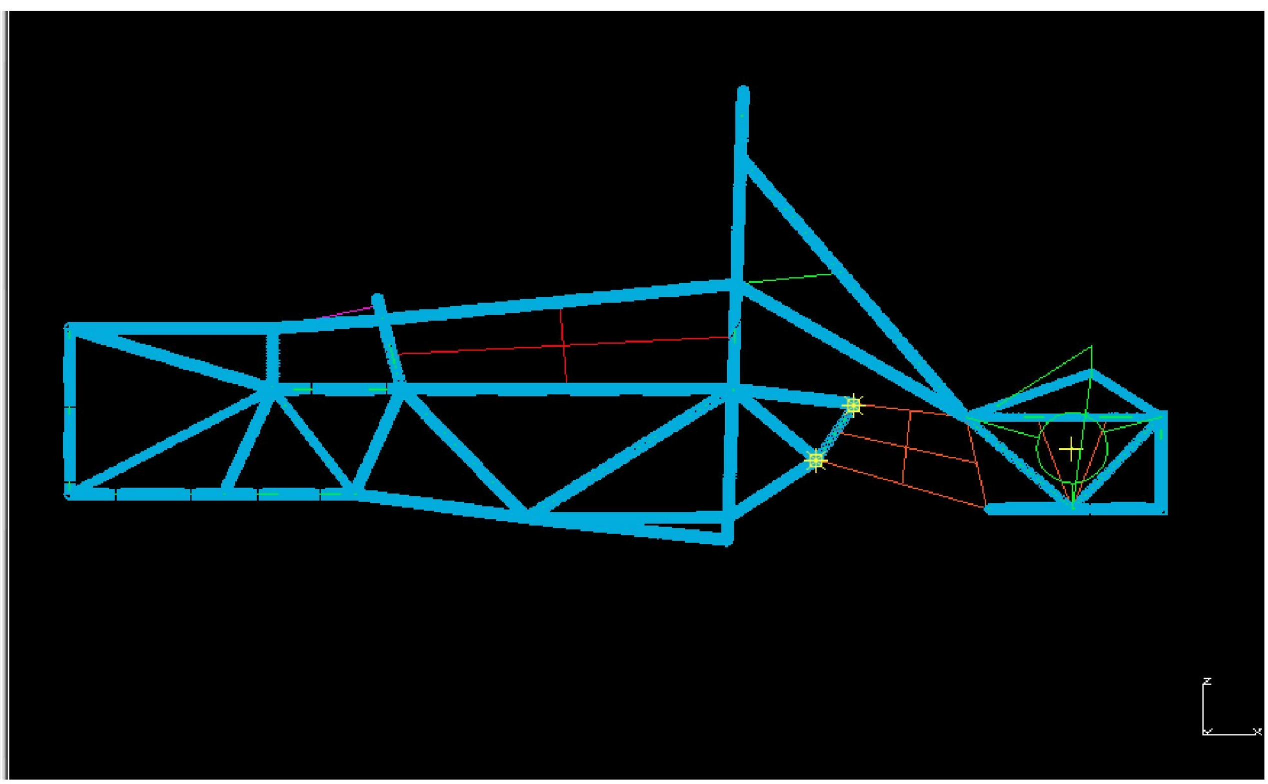


Figure 10. Front view FEM

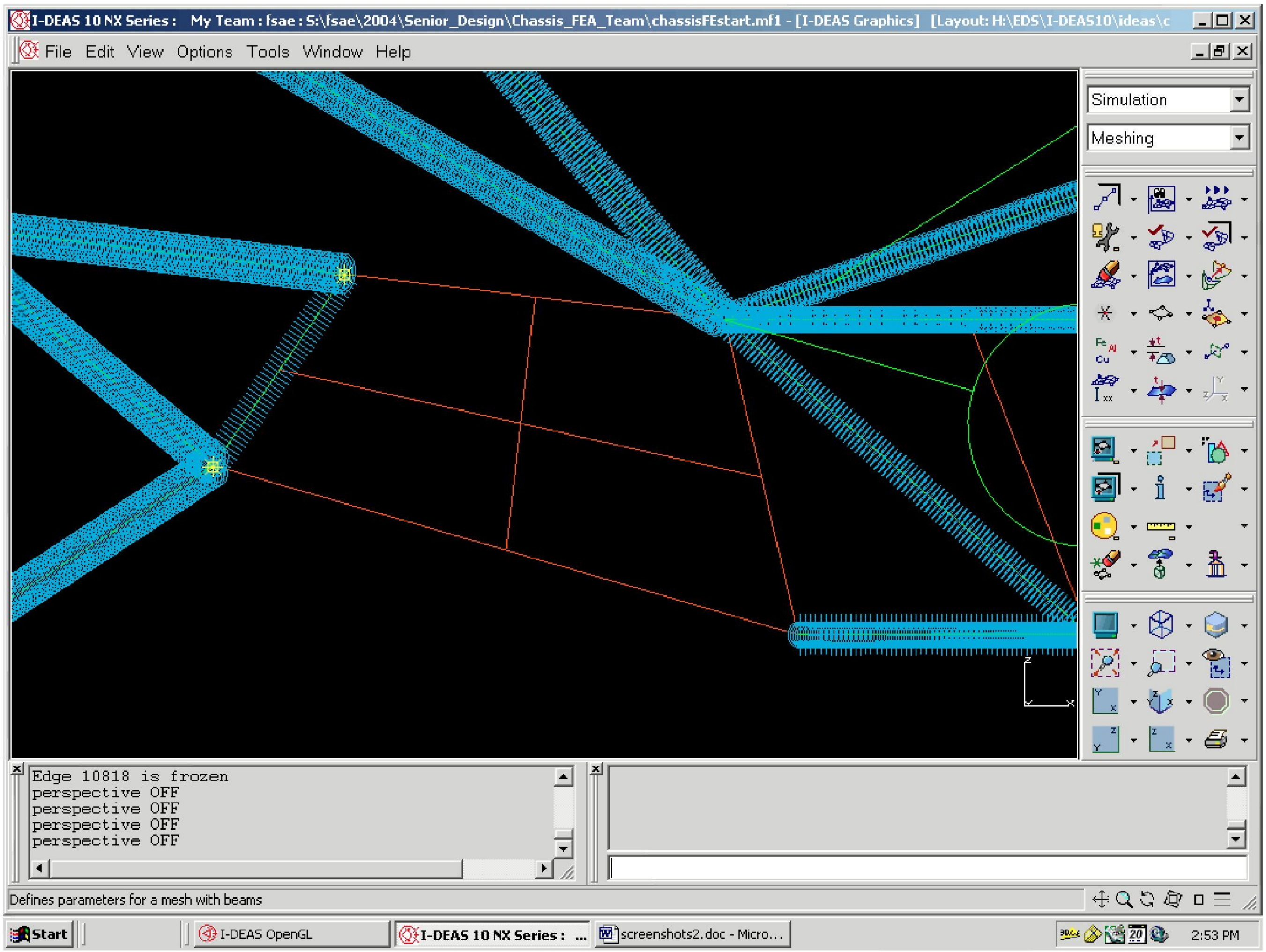


Figure 11. Close up of engine mounting location

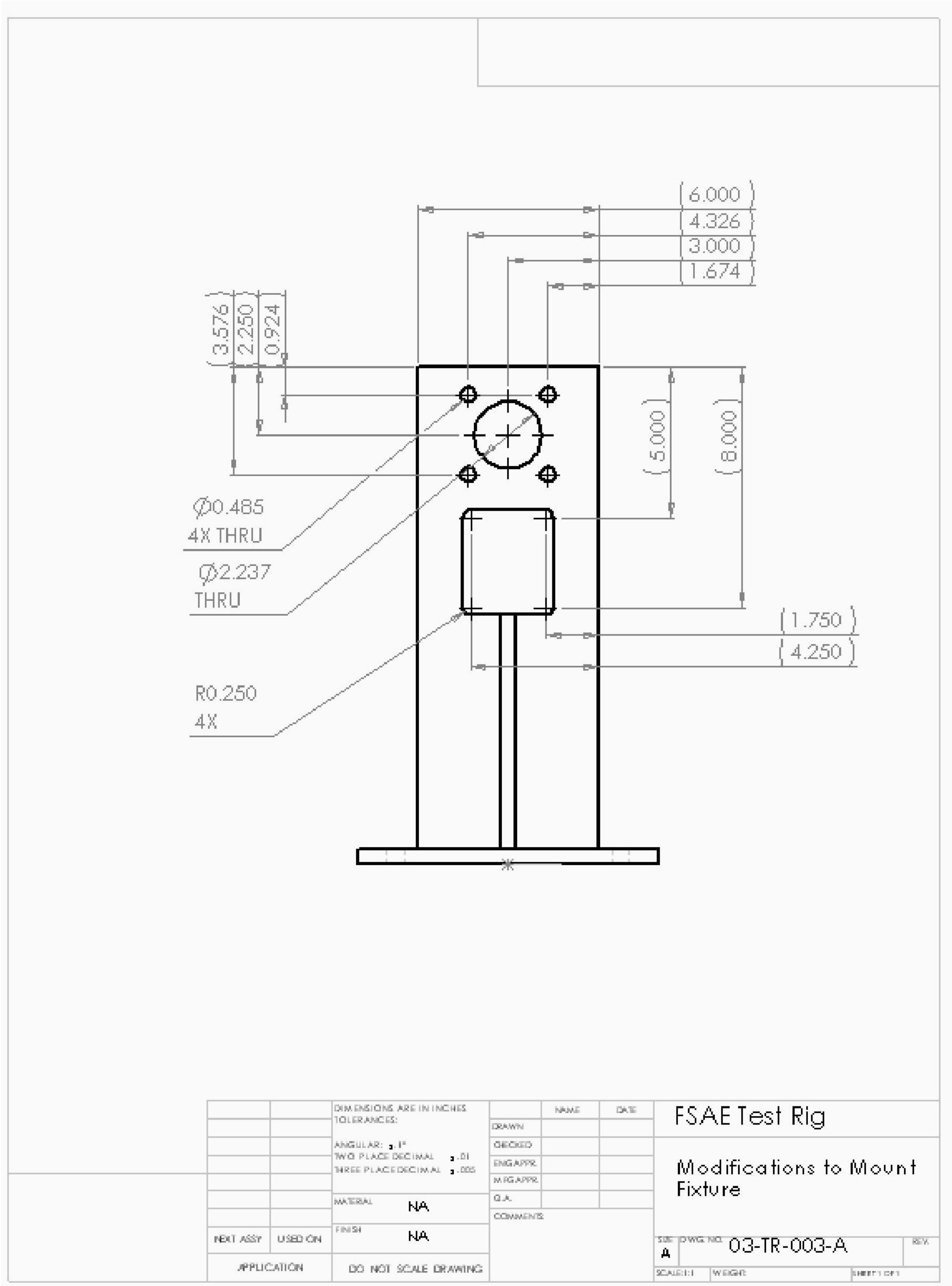
Table 1.

Drexel Racing Senior Design 2003 Project Proposal
Project Cost

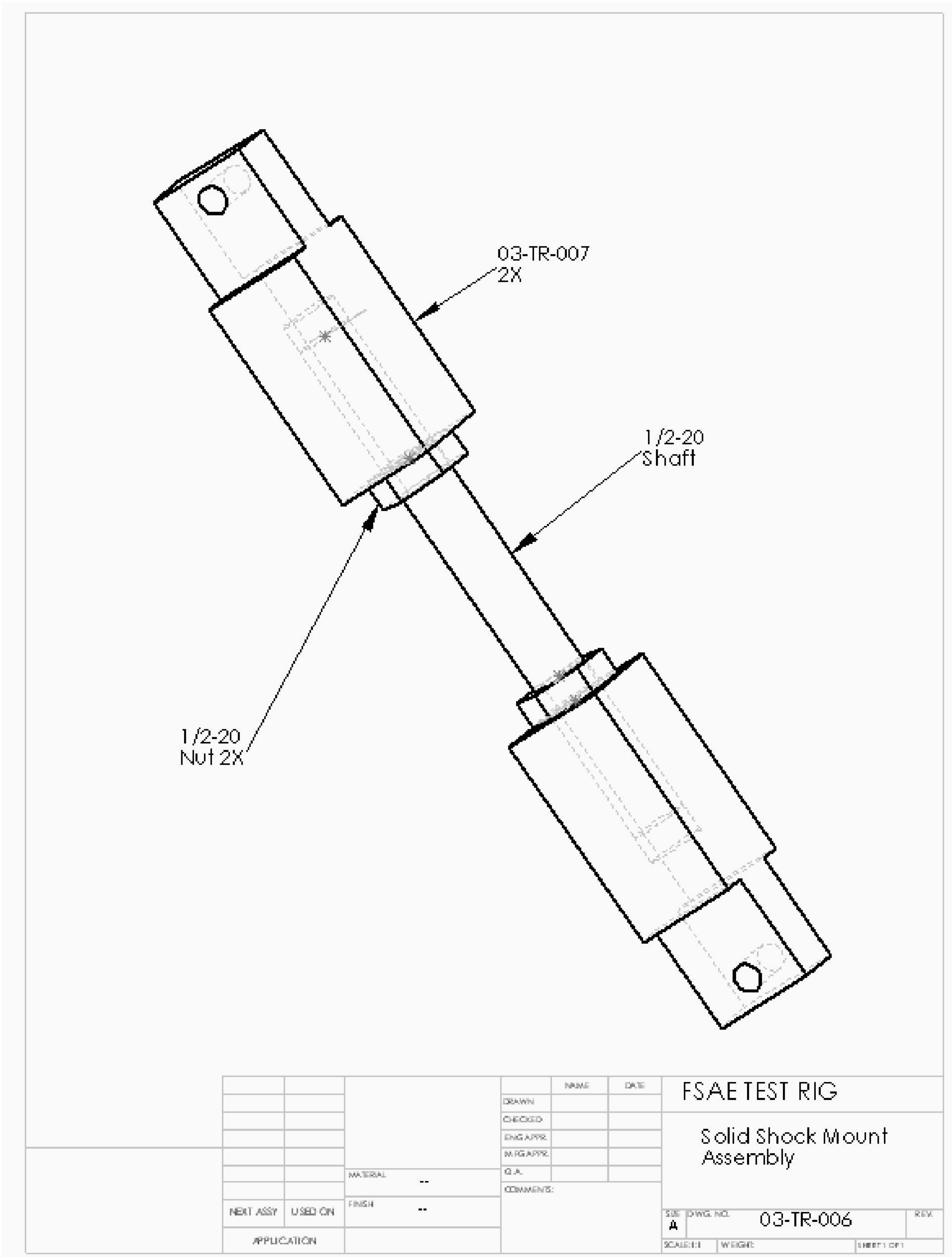
Programs:	
SDRC I-DEAS including FEA module	provided by Drexel
Pro/Engineer	provided by Drexel
Pro/Mechanica	provided by Drexel
Test Rig Components:	
Steel	provided by Drexel
Hardware	provided by Drexel
Dial Indicators/stands	provided by Drexel
(30) Strain gages	$165.00 @ $5.50 ea
(30) Terminal Pads	$30.00 @ $1.00 ea
Bonding Agent	$22.20/ounce
(1) Wheatstone bridge module	$69.00
4-lead Insulated sensor cable	$28.50/100ft.
Acetone	$3.50
Acid Primer	$4.00
400 grit wet and dry	$3.00
Neutralizer	$4.00
Rosin Solvent	$4.00
Varnish	$5.00
Digital variable Power Supply	provided by Drexel
Digital Multi-meter	provided by Drexel
Oscilloscope	provided by Drexel

Total: $338.20[1]
Approx.: $340

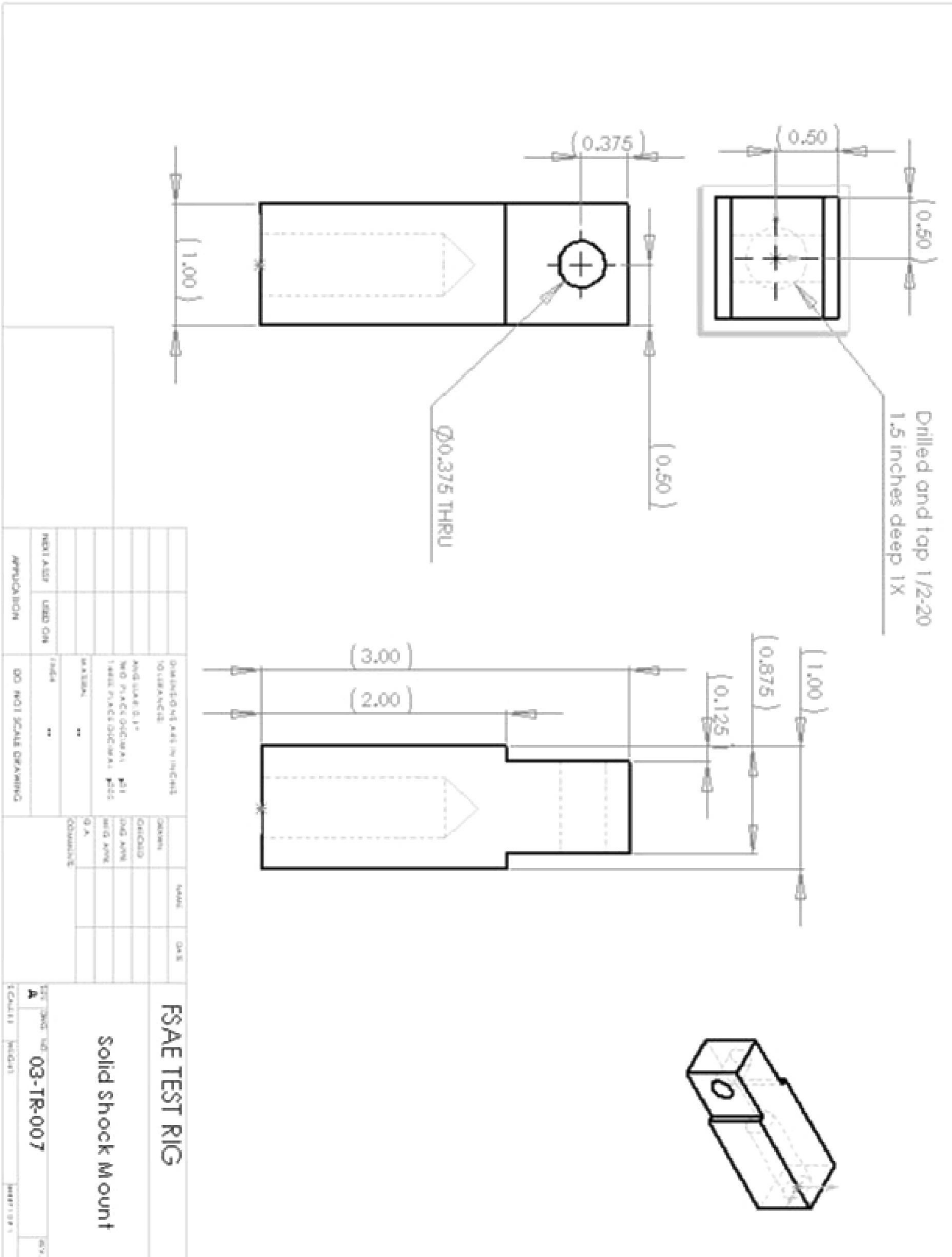
[1] Drexel may supply some components in order to reduce costs further.



Dwg 1. Rear Mount Fixture



Dwg 2. Solid Shock Mount Assembly



Dwg 3. Solid Shock Mount

APPENDIX E.

Appendix E – Resumes

Missing from submitted document.