Design of a Stability System to Secure a Mobile Liquid Rocket Test Stand

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The purpose of this paper is to display the methods that were taken into consideration when designing a support system for our Mobile Test Stand. The Mobile Test Stand has not been built yet, so the forces used here are theoretical based on our current engine designs. We are designing this trailer to withstand around 800 lbf of thrust to compensate for future high-power engine designs. Based on this number, we have been tasked to research and develop a way to ensure the trailer, containing the test stand within, is stable. If the trailer has not been secured properly, it could start to move or shake which could cause a multitude of hazardous problems. The primary of these problems includes the trailer rolling over, which would cause damage to personnel, property, and equipment. To test load cases on the trailer we are using SolidWorks FEA as a preliminary estimation. We have calculated the amount of force it needs to withstand is around 600 lbf horizontally and vertically since the engine is at 45°. Knowing this, we will instead design for a larger theoretical thrust force to ensure we can secure a high safety factor of two. The reason we have chosen this factor of safety is that it is achievable with our resources and it lies in the median for the average safety factor for industrial structures under comparable load. To preserve the trailer's ease of mobility we will have to make all our supports expedient in setup and removal. Even though the trailer will be mobile it will still be as secure as a stationary building. This paper will describe the possible methods we have integrated so we can secure the desired safety factor while preserving the trailer's mobility.

I. Introduction

The Tartarus project is a liquid rocketry team that is part of The University of Alabama in Huntsville's Space Hardware Club. The project has the ultimate goal of developing, manufacturing, and testing an 800+ lbf liquid bipropellant rocket engine. Before a flight-ready engine can be designed and manufactured, the team must demonstrate the ability to design, manufacture, and safely operate a static rocket engine which meets targeted performance metrics suitable for given flight profile requirements. In order to gain meaningful insight from data yielded by any static fire test, the project must be able to predict behavior of the rocket engine. It must also support fluid systems throughout firing without drawing on driving design values. In addition, effects on the mobile engine

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test stand and on the trailer that encompasses it must be taken into account. Then, to make sure that the data gathered is accurate, we have to make sure that no outside factors affect the rocket engine. We have also taken measures to protect crew and equipment. One of the measures that we have taken is to design a stability system to secure the mobile rocket engine test stand.

II. Requirements

The main requirements that this system has to have is that it must be able to withstand 600 lbf horizontally and vertically, it also has to be mobile, the setup and takedown has to be quick and simple, and it has to fit within our project's budget. To make sure that the system will withstand the minimum amount of force under any circumstance we have decided to go with a safety factor of two. This means that the system will be able to withstand two times the amount of force that will be applied currently. This allows us to increase the thrust of the engine after we have proved that we can static fire a lower thrust engine. The reason that we decided to go with a safety factor of two is that it fits within our budget and it is just above the median for the average safety factor for industrial structures under comparable load. We wanted to go just above the median due to the nature of the force that is being applied since it is not a conventional force. We also wanted to have a higher safety factor so we could increase the amount of force the engine could produce without having to redesign and remanufacture the support system for later testing. How we got the median average safety factor was from a document written by NASA engineers in 2016 called *The Ultimate Factor of Safety for Aircraft and Spacecraft-Its History, Applications and Misconceptions*. The reason that we chose this document is due to the nature of the force that is being applied. Since the document is dealing with aircraft and spacecraft we decided that since our project is using a liquid propelled rocket engine it relates better to this document. This document states how the factor of safety went from being two to slowly decreasing to around 1.5 which is now the industry average.

Table.1 Minimum Design and Test Factors for Metallic Structures

Verification Approach	Ultimate Design Factor	Yield Design Factor	Qualification Test Factor	Proof Test Factor
Prototype	**1.4**	**1.0***	**1.4**	**N/A or 1.05****
Protoflight	**1.4**	**1.25**	**1.2**	**N/A or 1.05****

*** Structure has to be assessed to prevent detrimental yielding during service life, acceptance, or proof testing.**
**** Propellant tanks and SRM cases only.**

This table applies to our project due to the fact that we have decided to make our main support structure out of 2024 aluminum alloy and stainless steel. This will give us a high safety factor and will allow us to in house manufacture it to our needs.

Another requirement that Tartarus had was that we had to keep the support system mobile. Since the engine was going to be tested within a trailer we had to make sure that the trailer was as sturdy as a building but was still as mobile as a normal trailer. Keeping this balance was a big issue that we encountered since most supports are made to be static in nature. Since we wanted to keep it mobile, we had to look around and find support structures that would be dynamic in nature so that we could set it up and it not be a permanent structure. Another reason that we wanted to have our supports be dynamic was because if it was static it could only be used if the ground was perfectly level. In our case, this would not be applicable since our test fire location was on dirt in an abandoned quarry.

The third main requirement that we had was that the supports would have to be easily set up and taken down. This is due to the previous support structures taking up to three hours to set up and another three hours to take down which is not currently viable. We would rather dedicate that time to making sure the engine is in ideal condition for test firing instead of the setup of support structures. The supports also have to be simple to install because we must be able to install it ourselves. If we cannot install the supports, that starts to cut more into our budget which leads us to our last and biggest requirement.

The last requirement is that the whole support system must fit within the project's budget. Since we want to get reliable and strong supports, we have to think of alternatives to normal supports. These include supports intended for RV's and tie downs for the whole trailer. These alternatives are what allowed us to get the safety factor that we desire, making the trailer mobile, the setup quick and simple, and kept us under our current budget.

III. Support Structures

As stated above this project has many requirements for the support system. The best way that we researched and came up with was to use a top rail tie down, wheel chocks, and bottom support to ensure that we have a 360° support system. To deal with the vertical force we decided to install a top rail and then run a stainless steel cable through in and into the ground using penetrators. The reason that we decided to go with the cable and rail system is due to the simplicity and price of the system. The cable, for its price point, also makes it easier for us to keep well within our project's budget and satisfy our safety factor requirement. The best way that we have researched to install this is to run a 80-20 rail with eyelets for the cable to go through. The reason that we don't just run the cable across the top is that we want the weight to be evenly distributed across the whole width of the trailer instead of just the two corners. If it was ran on just the two corners the cable could start to dig into the sides of the trailer. This could jeopardize the structural integrity of the trailer. An example of this would be that it could cause leaks when it rains, ruining equipment permanently installed inside of the trailer. The way that we would secure the cable into the ground would be by using an arrowhead ground anchor which can withstand up to 5000 pounds. How they work is that they go into the ground straight but when they are pulled the anchor portion takes up as much surface area as possible, making it extremely difficult to pull out. As the name states a ground anchor works the same as an anchor meant for water. Even with all of these moving parts the requirements stated previously would still be achieved. An example of how the arrowhead ground anchor would work is shown below in **Fig.1** provided by *Milspec Anchors LLC*

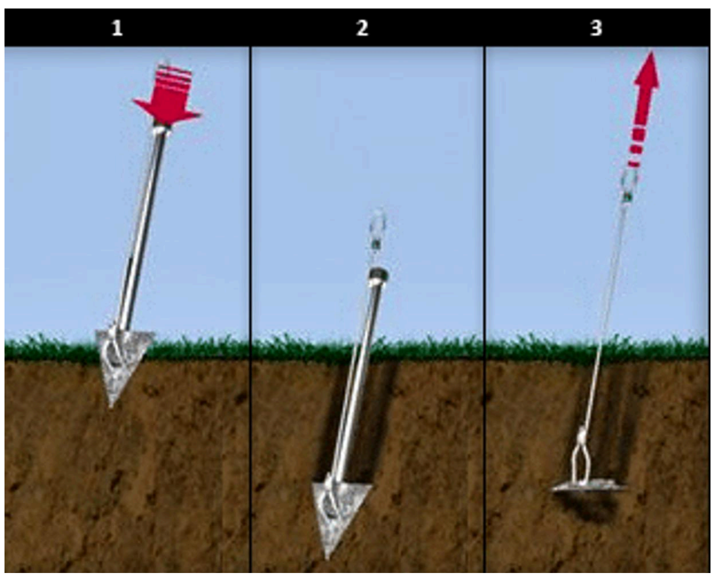

Fig.1 How Arrowhead Earth Anchors Work[5]

To deal with the trailer moving back and forth we have decided to use simple wheel chocks. The reason for this is due to the fact that they have been tried and tested in many scenarios by other users. Since wheel chocks have been around for a long time we already know that they will work for our application since they are used on aircraft which can weigh up to hundreds of thousands of pounds. With this knowledge we know that for our application and the force that would be applied on the chocks we can know for certain that they will withstand the force being applied. How we would install these is we would apply them on both sides of each wheel on the trailer to ensure the maximum amount of support. Since we are using something that is widely available we can know that they will fulfill all of the requirements that we have stated above.

[5] **Fig.1 accessed online at**
https://milspecanchors.com/ [retrieved 25 Feb. 2024]

Lastly to support the trailer on the sides we have decided to utilize C-Jacks installed on the bottom of the trailer. The reason that we went with this idea is because for their price they can hold up to around 5000 pounds. This also happens to be the same load capacity as the cable system. Another reason is that they can be easily installed and are quick to set up. We would install this using class 8 bolts which have a sheer strength of 5000 pounds also. We would also use the class 8 bolts to hold the footing to the jack itself. Changing the bolts out would allow us to have an even 5000 pounds around the whole bottom side of the support so we can use 5000 pounds as the basis. An example shown below in **Fig.2** is an example of a C-Jack and the footing that would be installed provided by *BAL, by Norco Industries*.

Fig.2 ADNIK BAL C-Jack with Footing

Shown below is a table that demonstrates the load capacity of each of the C-Jacks and their corresponding height.

Table.2 ADNIK BAL C-JACK Load Capacity Table[6]

FRAME TO GROUND DIMENSION	LEG LENGTH	STATIC LOAD CAPACITY	Boxed Set of 2 w/crank handle
UP TO 15”	19”	5000 LBS	23219
15” TO 18”	22”	4500 LBS	23222
18+” TO 21”	25”	4000 LBS	23225
21+” TO 24”	28”	3500 LBS	23228
24” TO OVER	31”	3000 LBS	23231

IV. Analysis

To validate that the support system we have decided upon will work we have researched ways to analyze the system to make sure that the parts will fit and make sure that they will withstand the force being put on them. The way that we have done this is by doing the following: created a CAD of the whole system,done FEA’s on the whole support system, and test the system by using an alternative support system. To make a CAD of the system we

[6] **Fig.2 & Table.2 accessed online at**
https://balrvproducts.com/ **[retrieved 25 Feb. 2024]**

had to individually create most of the external supports due to them not already being publicly available. The way that we made sure they were accurate is by reading the manual on each supports to ensure that all of the parts will fit as intended. Shown below is the CAD model that we created that displays all of our supports except for the ground anchors.

Fig.3 CAD Model of Support System

By modeling the support system in CAD we were able to fully verify that all of the parts that we chose would fit onto the trailer.

To test force on the trailer we decided first to use FEA's for a virtual simulation into what the stress on each part would be. FEA stands for Finite Element Analysis which is used in structural analysis, heat transfer, and other areas. We mainly want to use structural analysis to ensure that the stress on the support system is going to affect the system in the way that we calculated it to. The heat transfer part of the FEA will be used to ensure that the heat from the engine can not affect the structural support system in any negative way. When using this software we can be able to verify that for almost any case the support system will keep the trailer and everybody safe. As of currently we have not been able to verify using FEA the result of the support system under its force load.

Once we have ensured using FEA that the support system will work we can then transition to real world force testing. This will involve using an alternative external force to ensure that the system can maintain its stability over a determined time. The alternative external force that we have decided on will be a pushing force on the back of trailer, then transition the pushing force to the sides, and then apply a pulling force on the cables themselves to ensure that they will not deform or snap under pressure. If any of these worst-case scenarios were to happen we have fail safes in place to ensure the safety of the project members.

V. Fail Safe

A fail safe has been applied to any scenario that we could think of before any of the equipment will be applied to the trailer. Creating failsafes before applying the equipment allows us to verify where equipment could fail in certain aspects. Doing it this way allowed us to realize that the bolts in the bottom support footing were only able to hold up to 300 pounds before they would shear. Noticing this we were able to replace these with bolts rated for higher sheer force. If any of the components failed during a hot fire then the member in charge of the controls would instantly start the fail safe protocol which turns off the engine and closes all of the propellants bottles. This ensures that there could be no detonation of the bottles which could cause severe injuries to some members. This will mitigate the damage to the engine system as much as possible and allow us to use it for future tests. Due to our damage calculations everyone will be positioned around 150 feet away from the trailer to ensure that if the worst case scenario were to occur all members would be safe. These fail safes were put in place to ensure the safety of everyone included in the project.

VI. Conclusion

This stability system will ensure that any project that wants to utilize a trailer as their mobile test will have a basis and the knowledge to understand the dangers and what to look for in a support. Having the knowledge of what our stability system is capable of ensures that we can have confidence that the engine will perform the same as the calculations. Utilizing tools like CAD and FEA's allowed our project and others to ensure the stability of the system. We choose to use these tools due to the fact that they are readily available to all students that attend a university. We wanted our work on the stability system to readily available to other universitie's projects so they know how to figure out what requirements their individual project needs, what routes they can take to meet the requirements, ways to analyze the solutions to the requirements, and how to create fail safes on if the the solutions fail. All liquid rocket projects have the same goal and that is to launch a rocket into the atmosphere, but before that can happen they need to have a test fire. This is where we want to assist other projects in creating a stability system and help increase the university level liquid rocketry.

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