Disclaimer

This document is an Abbreviated Design Report Document Developed by four undergraduate Mechanical Engineering Students at California State Polytechnic University (San Luis Obispo) for Solar Turbines. This abbreviated document only includes information related to the overall layout and processes of the project. Sensitive and Confidential Information has been removed from the report and any information included is in no way a public disclosure on the part of Solar Turbines for any related Intellectual Property.

CALIFORNIA POLYTECHNIC STATE UNIVERSITY

Solar Turbines

A Caterpillar Company

Quick Mobile Power Unit Trailer Connections

Final Design Review Report

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Abstract

This Final Design Review document encompasses the entirety of a sponsored senior project which was conducted by a group of four undergraduate mechanical engineers at California Polytechnic University San Luis Obispo. The primary sponsor of this project was Solar Turbines, a subsidiary of Caterpillar Incorporated. Solar Turbines is in the business of development and application of modern-day energy solutions with a large focus on gas powered turbines. Cal Poly acted as a supplemental support of this project and provide the students with mentorship as well as access to its state-of-the-art facilities for the development of an innovative solution to the design challenge submitted by Solar Turbines. The submittal states a desire to improve the deployment timeline of Solar Turbines' Titan 130 Gas Turbine Mobile Power Unit. This unit hosts a split drive train with a turbine mounted on one semi-trailer (driving trailer) and a generator mounted on another semi-trailer (driven trailer). These two trailers must be accurately aligned and securely fastened, currently taking roughly 12 hours. Seven of these hours account for aligning and leveling the two trailers and five hours account for securing the trailers using tension bolt fasteners. The process is desired to be reduced to 4 hours without compromising the strength of the connection points. The specified alignment tolerance of the trailers was given as ± ¼ inch. The primary stresses in the connection are due to the torsional load resulting from the rotation of the turbine. There are two load conditions that were factored into the design: the normal operating load and the short circuit load. The normal operation load of #### ft-lb_f is the torque to be experienced by the bolts as a result of the normal operation of the turbine. The short circuit load (#### ft-lb_f) is the resulting torque the system undergoes should the generator seize. This document initially presents the background research and function identification processes followed by the ideation process used to develop various solutions to the problem. The final selection processes are also laid out in detail with the final solution chosen being a hydraulically actuated form of alignment using hydraulic arms and wedge connections between the trailers. Critical component dimensions were then confirmed using hand calculations and ANSYS to conduct FEA. Manufacturing and assembly plans including a bill of materials for a full prototype are provided. In addition, testing plans which can be applied to any scale of prototype are also provided. Due to the emergence of Covid-19 during the third phase of the project, prototype development was unable to be completed. Instead further ANSYS analysis (Rigid Body Dynamic) was done in order to further support the solution provided. The goal of this final document is to provide Solar Turbines with all material listed in the Scope of Work agreement and easily lay out prototype development and testing plans that can be used by Solar Turbines if they decide to build a prototype themselves.

1.0 Introduction

This document is a Final Design Review done by a group of four Cal Poly undergraduate Mechanical Engineers for Solar Turbines regarding their Mobile Power Unit Trailer Connection Project. Solar Turbines is a subsidiary of Caterpillar Incorporated focusing on the development and application of modern-day energy solutions to various industries worldwide. One product Solar Turbines is known for is their industrial gas turbine. From mid-sized to large-scale applications there are over 15,000 units operating in over 100 countries worldwide [1]. The focus of this project is specifically on the Titan 130 Gas Turbine Mobile Power Unit model which allows for the delivery of high-quality power generation to temporary sites as well as sites located in harsher environments. The current design utilizes a split drivetrain configuration with a driver (turbine) semi-trailer and driven (generator) semi-trailer. These two trailers are transported to site for deployment. On site, the generator trailer is placed in the desired position to be used as a reference point for alignment. The turbine trailer is then aligned with the generator trailer. The current method of alignment is multiple attempts at reversing the driving trailer into position with a spotter guiding the truck driver. Once aligned to the desired tolerances of ± ¼ inch the two trailers are then jacked up level into place and secured using eight tension bolts. The tension bolts are tensioned using standard hand tools. The total process takes roughly 12 hours. Through the sponsorship of this project Solar Turbines hopes to reduce the process time to 4 hours, and thus reduce the total time of the deployment process.

This document will present the final design solution to the design challenge. The entire process of concept generation is laid out. All the research conducted by the team to better understand the nature of the design challenge is also laid out in the document. The final design is presented in detail in order to show that it can reduce the time to align and attach the two trailers. Specific components of the proposed system are also analyzed, and final dimensions are given. Due to the emergence of Covid-19 during the third quarter of the project the manufacturing and testing of a scaled down prototype was unable to take place and so the scope of the project was changed to accommodate for that fact. Everything previously created in preparation of prototype development will still be provided in the document along with an additional chapter which includes additional Ansys Analysis (Rigid Body Dynamic) as well as notes on any modifications made to the design since the Critical Design Review. The new goal of this document is to provide Solar Turbines with the information they need to make an informed decision on whether to follow through on prototype development and testing of this system.

2.0 Background

This chapter introduces the design challenge and as well as the extensive research conducted by the team to better understand the challenge. The research was broken down as follows:

1. Existing products: exploring current products that are used in other industries
2. Patents: exploring current solutions/designs for aligning and rigidly attaching heavy loads.
3. Other related research: exploring possible products/design that could be integrated into future possible solutions.

Each of the research aspects above will be explained extensively in the following sections.

2.1 Overview of the Design Challenge

Solar Turbines is a leading provider of energy storage solutions for both the power generation and oil & gas markets. One of their products is the Titan 130 Gas Turbine Mobile Power Unit (T130GMPU). The T130GMPU consist of a turbine and a generator. Both components are built into custom semi-trailers as shown in Figure 1.

Figure 1. Titan 130 Gas Turbine Mobile Power Unit [1]

As of now, it takes approximately 12 days to commission the T130GTMPU. One of the crucial steps in the commissioning process is aligning the two trailers to a high degree of accuracy and then rigidly connecting them. This step can take up to 12 hours. Table 1 show a rough estimate of the time it takes for each step of the total process.

Table 1. A rough time study of the alignment and bolting process

Alignment Steps	Time (hour)
1. Backing the Turbine trailer into the generator trailer within the required tolerance.	#
2. Bolting the two trailers together. This step involves 8 Tension Bolts.	#

The first step in the alignment process is to set up the driven trailer (generator) on jacks. After securing the driven trailer at the desired location and height, the driver trailer (turbine) is backed into the stationary driven trailer. The two trailers must be within the tolerance required for the studs to clear and for the nuts to be installed without seizing. The holes on the flanges in question must be parallel otherwise the current hardware in use will not clear properly. Solar Turbines disclosed this tolerance as a less than #-inch horizontal offset. After being aligned, hydraulic jacks are used to level the two trailers together, though this step in the process will not need to be addressed by the proposed design. Finally, the two trailers are bolted together using 8 tension bolts (4 on each side). Each tension bolts contains 12 bolts as shown in Figure 2 below. The purpose of the tension bolts is to meet the strength requirements while still allowing them to be fastened using standard hand tools.

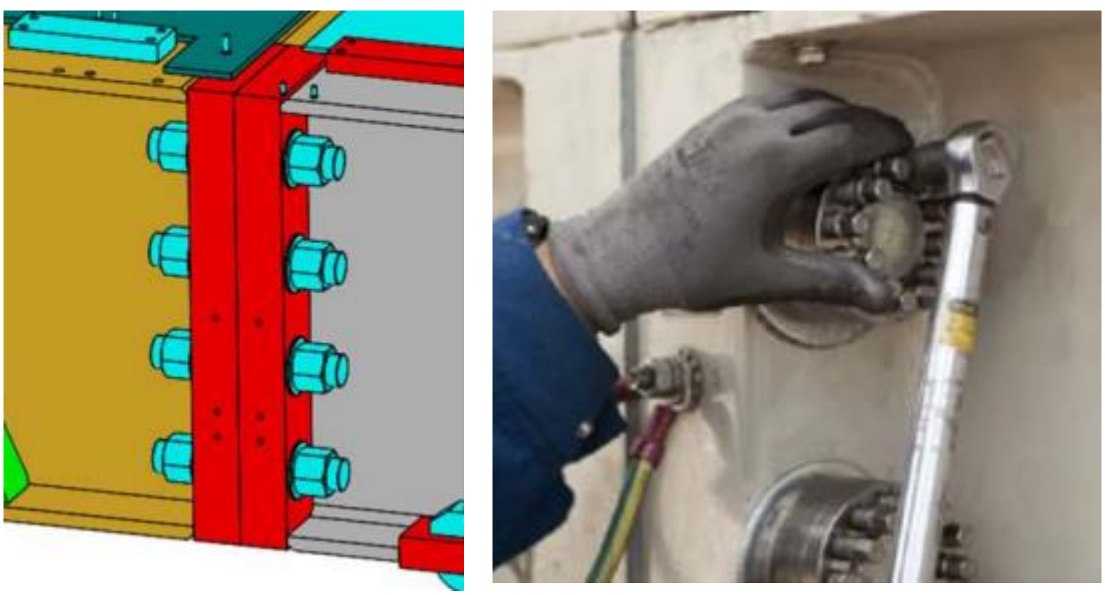
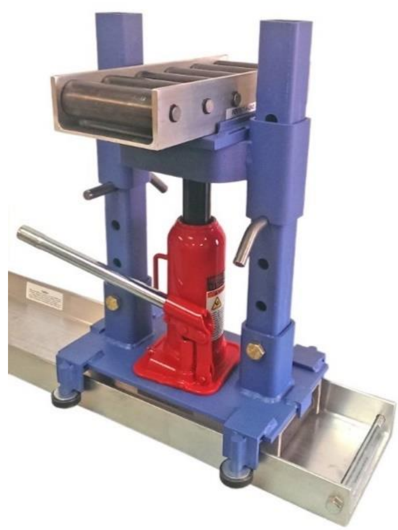


Figure 2. Side view of the connection and the tension bolts [1]

2.2 Existing Products/Designs

With extensive research the team was unable to find any existing products and designs that were specific to the proposed project. Due to the driver and driven trailers both being massive the team agreed to search for similar products relating to aligning and securing heavy objects. Various methods and procedures were researched. The team found 5 ideas that were determined to be most relatable to the design objective. One similar product discovered was the 5 Point Six-directional system. This tool helps align mobile homes with their foundation. In addition, the Never Miss Hitch tool was found to be a simple yet effective way for reversing and guiding a hitch to its connection. Another method that was investigated was how pipe flanges are aligned using a tool designed purposely for adjustment during alignment. There were 3 tools that were found to be very useful during the alignment process. The FA4TM, Broad-Head Bull, and Gearench TITAN Flange aligning tools provide a similar function. They are used to align flanges together when the hole is partially aligned. The full list of these researched products including images can be found in Table 2 below.

Table 2. Existing Designs

Description of Design	Design
<u>5 Point Six-Directional System:</u> This tool is used to help move and align mobile homes. This make it easy to move objects in the x, y, and z plane [2].	

<u>Never Miss Hitch:</u> This tool is used to assist the driver that is trying to reverse and connect an object to a hitch [3].	

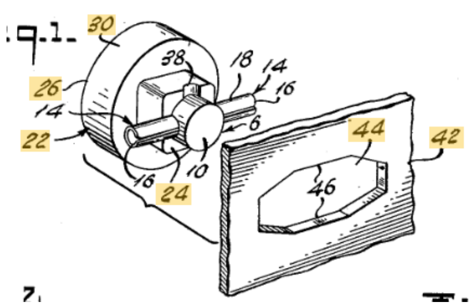
Table 2. Existing Designs (Continued)

<u>FA4TM:</u> This tool is used during the final adjustment process of alignment of large flanged pipes. As shown in the figure this tool hooks into a hole on one of the flanges to help you mechanically adjust the alignment of the hole [5].	
<u>1-1/4" (32 MM) BROAD-HEAD BULL:</u> This specialized tool helps in the alignment process for any object that will need bolt holes aligned. These tools help you align flanges so that the holes meet together [6].	
<u>Gearench TITAN 2 in. Flange Aligning Tool:</u> This specialized tool helps in the alignment process for holes. This tool can be used with plates, flanges, or with any two surfaces being bolted together. The tool is inserted into the partially aligned hole and with adjustment it can be pushed through to help align [4].	

2.3 Patent Search Results

As part of the mission to better understand the design challenge, the team decided to perform a patent search. This research was intended to further explore current solutions to the problem. While these patents are not directly applicable to the project, they provide ideas for current methods of alignment and attachment which could possibly be scaled up to suit the project. An example is patent US5371926A, which is for a shoe clasp. While not feasible for this project, a similar method of attaching and tensioning the trailers could be applied. Hydraulic attachment options were also examined to explore how hydraulic components could possibly be integrated into the design. Shown below in Table 3 are some relatable patents found with a brief explanation.

Table 3. Similar Patents

Name	Explanation	Figures /drawings
US3136017A Releasable Fastening Device Actuated by Rotation [7]	This spring-loaded device is inserted through an oblong hole and turned ninety degrees to provide tension.	
US5371926A Tension Lock Buckle\ [8]	Designed for shoe straps, this device uses a cam to tension two bodies to each other.	

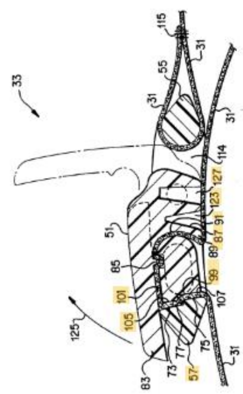
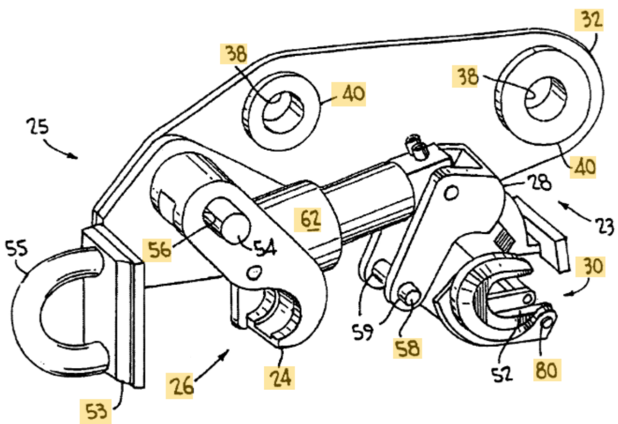
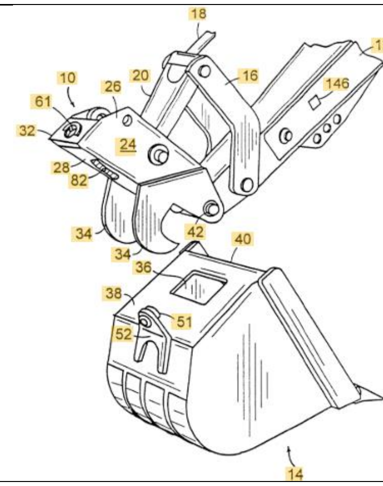
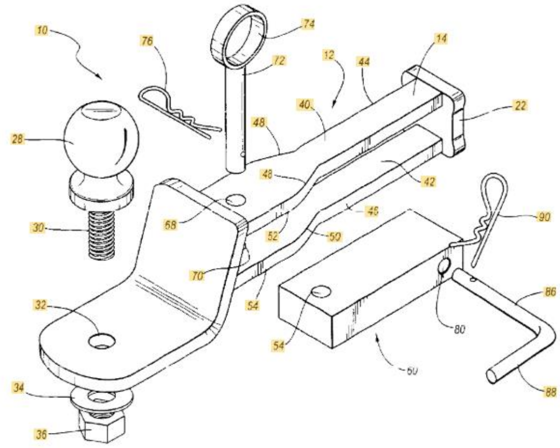
		
US6902346B2 Hydraulic Coupler [9]	This device is used to attach implements to heavy equipment. A hydraulic cylinder latches two hooks around mating pins on the implement.	

Table 3. Similar Patents (Continued)

USRE37320E1 Hydraulic Latch Pin Assembly [10]	This uses a hook system to attach a tool to a piece of heavy equipment. The hooks are used to take a majority of the load while a pin is used to keep them in place.	
US6863294B1 Easy Alignment Trailer Hitch [11]	This is used to help align a truck and trailer. The truck is backed up close to the trailer and the top pin is pulled. This allows the hitch to be pulled out and rotated to align with the hitch. Once it is attached, the truck is backed up and the pin is reinserted.	

2.4 Technical Literature

To examine possible future designs and better understand the challenge, additional technical research was performed. Alignment done quickly with a high degree of tolerance was the main aspect of the design Solar Turbines emphasized. There were multiple articles on the use of electronic equipment paired with GPU based algorithms to accurate align various objects. Two such articles included one article on “precise robotic assembly” [12] as well as an article on a “fast and high-performance algorithm based on multi-vector quaternions” [13]. From these articles it was decided that electrical components paired with low to high level processing units could potentially mitigate many of the alignment issues. A more mechanical approach to alignment was found in an article from the Mechanical Engineering Center at the High Energy Accelerator Research Organization based in Japan. This article described “the use of inclinometers along with a pair of offset bars to align objects with a certain degree of accuracy” [14]. In order to understand the effect of bolting misalignment, an article by Wenguang Liu was read. He used an “numerical method to investigate the effects of bolt misalignment on the stress distribution around the plate hole” [15]. He found that the stress concentration increases around the edge of the hole when the bolt and the hole are misaligned [15]. Also, he found that the peak stress values occur at "α = 0°, 90°, 180°, 270°" which is similar to the stress concentration zone during perfect alignment [15].

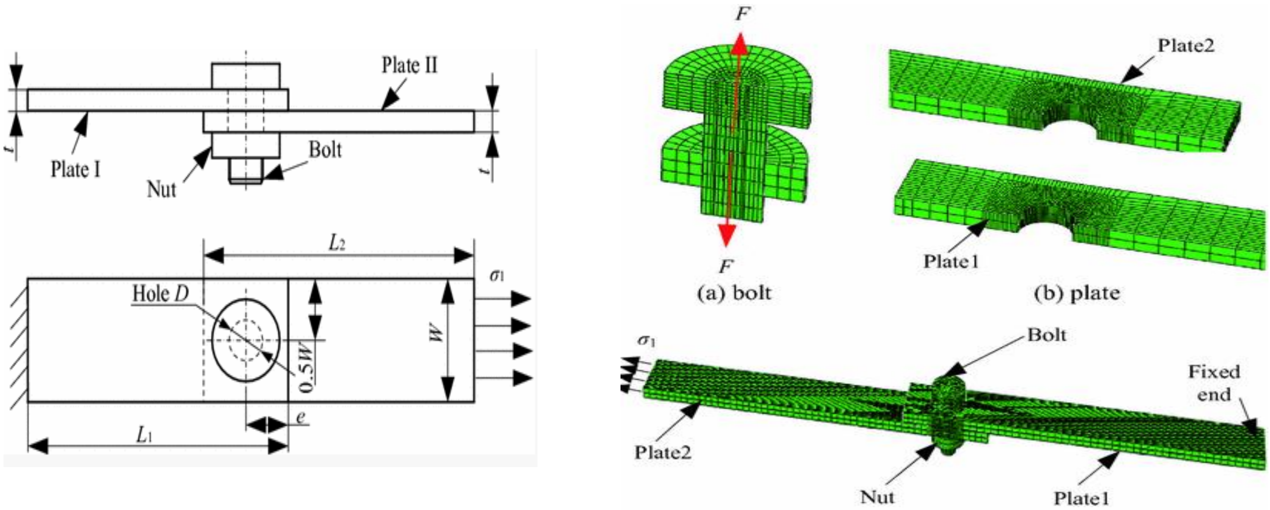


Figure 3. Finite Element Analysis model [15]

In exploration of methods of decreasing the time to fasten the trailers, alternative methods of attachment were explored. An article was found describing different types of hand fasteners, which could possibly be scaled up to fasten larger objects. These fasteners could also be fitted with hydraulic actuators to adapt them to the large scale of this project. Some examples of alternative fasteners include lever actuated, slide actuated, and turn operated fasteners [16].

In order to expand the team's knowledge of steel joints/connections, a document by Dr. Seshu Adluri, who is a professor at Memorial University, is being referenced. In this document, Dr. Adluri shows typical steel connections that are used in many industries [17]. These existing designs will help in the derivations/development of a better steel connection which would reduce the time of bolting.

Various industry standards were researched in addition to the research already completed. This was an important step to be done prior to the design process as Solar Turbines puts priority on the safety of their workers and potential users. The industry standards referenced were those set by two major entities OSHA (Occupational Safety and Health Administration) and ASME (The American Society of Mechanical Engineers). Because worker safety is of heavy importance the OSHA standards played a key role in ensuring the team's design meets the general safety requirements of both operation and construction. Within the OSHA standards, two listed publications were referenced. OSHA2236 Industry Standards for Materials Handling was referenced due to the heavy weights involved in the alignment process [18]. While much of this document referenced training and other aspects that Solar Turbines themselves would handle, reading through this standard reminded the team to not extend prefabricated components beyond their intended ratings. OSHA3080 provides general standards for the use of hand and power tools [19]. This standard was used to ensure that the equipment workers will be expected to use in the setup and operation of our design would not be used in an improper fashion. This was done by examining what the typical approach to such equipment is in industry.

Hydraulics came up as a potential mechanical system to provide mobility in the alignment solution. ASME's *Hydraulic Fluids: A Guide To Test Selections and Use* [20] was used as a reference to further expand the team's knowledge on potential issues that selecting a hydraulic system might pose, especially in varying weather conditions. The biggest issue that stood out within this document was the fact that no hydraulic cylinder perfectly contains the fluid thus a very small amount of internal leakage of the fluid over time is expected. This led the team to the conclusion that though good for mobility, the hydraulic system could not replace bolts as the sole fasteners.

2.5 Other Related Research

To expand the knowledge about alignment, the team began researching some other methods of alignment. One method found during research was the use of timber joints as shown in Figure 4. Timber joints are a common example of mechanically aligning and attaching two objects rigidly and permanently.

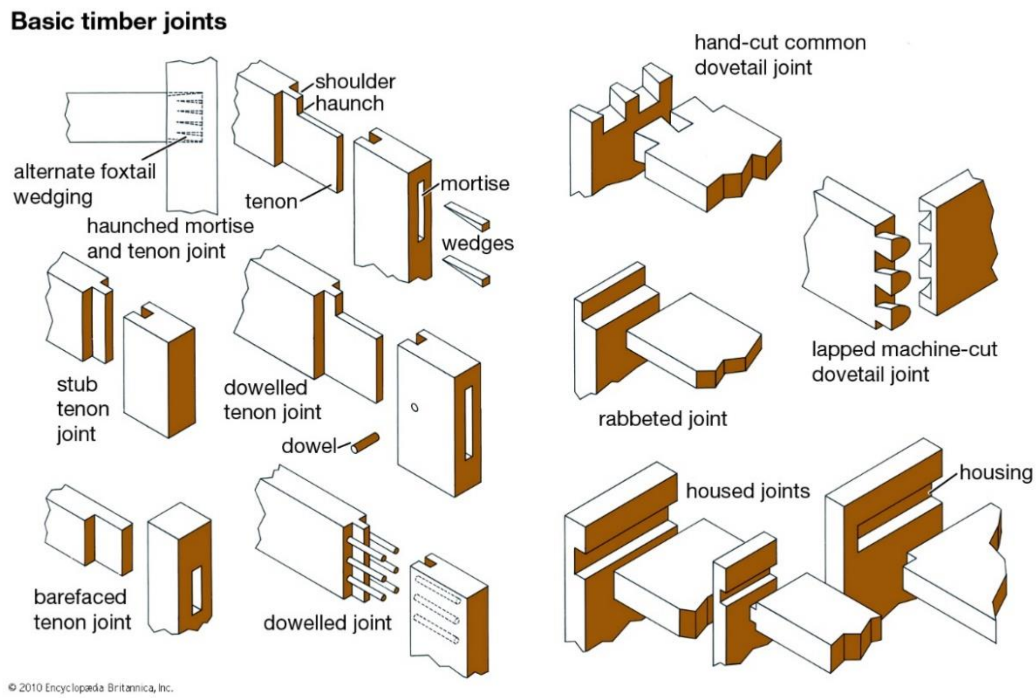


Figure 4. Timber Joints [21]

After looking thoroughly at each timber joint, the team realized that having sloped surfaces could help align objects. For example, combining dowelled and dovetail joints could help the team generate future designs to overcome the design challenge. Furthermore, the team investigated different sloped/tapered surfaces (three-shapes) as shown in the Figure 5 below. These different shapes could be used to generate tapered connection joints which could apply to the alignment of the two trailers.

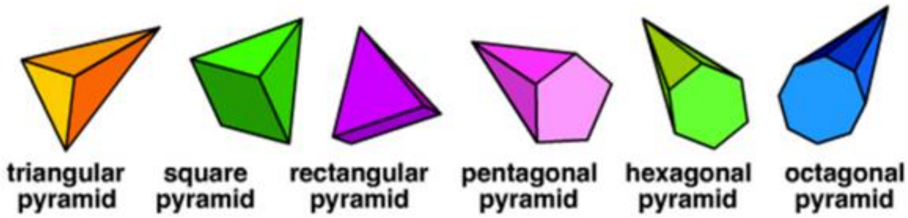


Figure 5. 3-D tapered shapes [22]

Some of the most common devices to rigidly attach two objects together are latches. There are many different types of latch mechanisms as shown in Figure 6; however, they all achieve the same goal of locking two objects together. Unfortunately, these latches do not apply any tension between the two objects unless a spring is integrated into the latching mechanism.

Figure 6. Different types of latches [23]

All the products covered in this section helped us generate ideas that could possibly be integrated into the solution to the design challenge.

3.0 Objective

This section includes the problem statement of the design challenge proposed by Solar Turbines. In addition, the boundary diagram and a description of the scope of design challenge is presented. This chapter will end by covering the quality function development (QFD) chart which includes the engineering specifications based on the customer needs and wants.

3.1 Problem Statement

Currently Solar Turbines' Titan 130 Gas Turbine Mobile Power Units need to be aligned and bolted together manually, taking about 12 hours total. Technicians and operators need a system or tool developed to quickly, accurately, and securely align and attach the driving trailer to the driven trailer. The goal is to reduce installation time to 4 hours without compromising the integrity of the connections.

3.2 Boundary Diagram

For this project, the initial conditions proposed by Solar Turbines will be such that the driven trailer is fixed in a stationary position. As seen in Figure 7 the driving trailer will then be reversed to meet and align with the driven trailer. Once an alignment tolerance of ± ¼ inch is met, the two trailers will be rigidly attached. The area in which the tension bolts are currently used to secure both trailers will be the primary area of focus in the initial design phases. This boundary area will also be where any modifications might occur which would change the structure of the trailers.

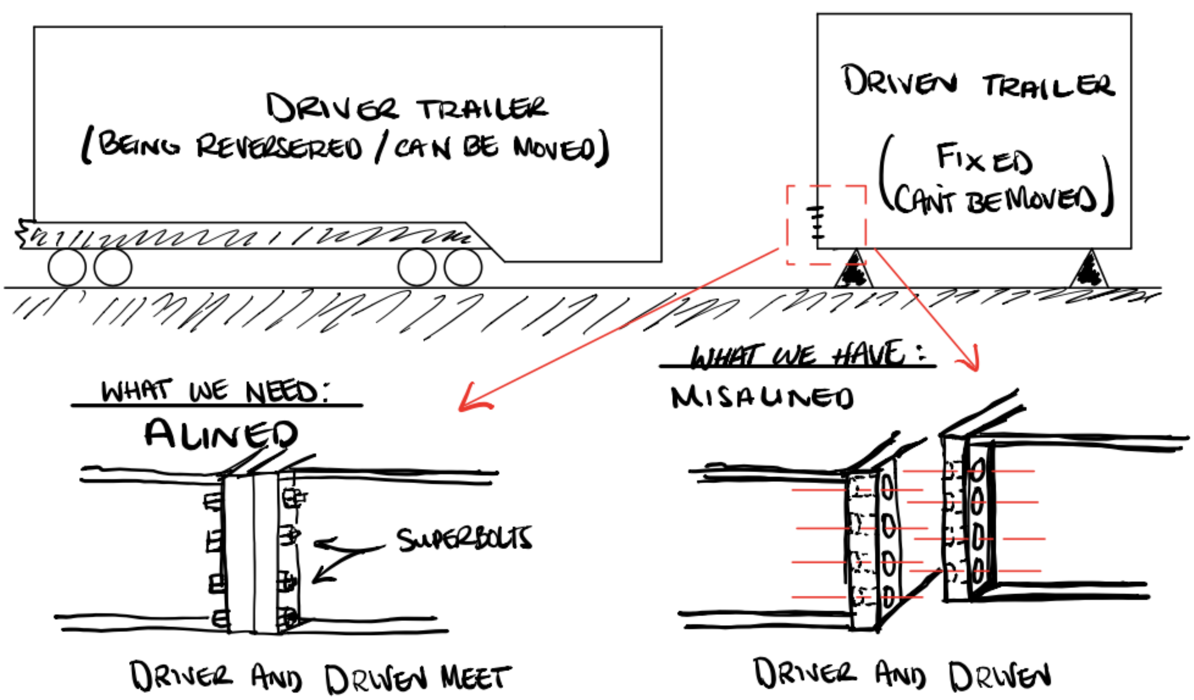


Figure 7. Boundary Diagrams.

3.3 Quality Function Development

Table 4 lists some necessary engineering specifications. This table includes target "goal" values of the final design proposed. The risk column indicates the expected difficulty in attaining the target value within tolerance (High [H], Medium [M], Low [L]). These customer specifications will also be tested using the methods specified in the compliance column, based on the type of measurement. Methods of compliance include Analysis (A), Testing (T), Similarity to Existing Designs (S), and Inspection (I).

Meeting the proposed time targets as well as the alignment tolerances were aspects of the design that were given a high risk because they are the most critical specifications. The manufacturing and process cost, number of operators, as well as manufacturing time were given low risk because they are trying to be minimized, but they are not critical quantities. The weather resistance was also given a low risk because potential design solutions do not include weather-sensitive components. The size and stress resistance requirements were given a medium risk because they must be considered but are attainable specifications.

Table 4. Engineering Specifications

Spec. #	Specification Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Time to Align	#	Max	H	A,T,S
2	Time to Attach	#	Max	H	A,T,S
3	Manufacturing Cost	Minimize	-	L	A,S
4	Number of Operators	# (operators)	+0/- 1	L	S
5	Manufacturing Time	# (weeks)	Max	L	A,S
6	Process Cost	Minimize	-	L	A,S
7	Stress Resistance	Target Loads	Min	M	A
8	Weather Resistance	-50 to 100°C Resistant to Sand 10-year life	+/- 10°C	L	A
9	Size	Minimize if Beyond Trailer Footprint	-	M	I
10	Alignment Tolerance	+/- 0.25	-	H	A,T,S

This table is a method of determining what the actual problem to be solved is, as well as how the different requirements correlate with one another. The QFD table also lists the customers this product would involve, including the operators, manufacturers, financial officers, engineers, and the end MPU users. The table then lists the needs and wants of the customers and ranks how much each customer values these needs/wants. The current system's performance is used as a benchmark to rate potential solutions. The interactions and correlations between these lists are useful in determining what the important areas of focus are.

4.0 Project Management

The development of an innovative solution for Solar Turbines' proposed project will be following a strict timetable. As shown on the Gantt chart attached in Appendix (B) there are dates by which certain milestones of the project need to be completed. As this project will take place over the course of three consecutive quarters, each quarter will have its own major milestones. The cumulative milestone of each quarter and a brief description of what that each quarter will entail is listed below as well as visually shown in Appendix (C).

Quarter 1: Preliminary Design Review

Major Milestones:
(10/17/19) Completion of Scope of Work Document
(11/21/19) Preliminary Design Review

During the first quarter, the project was selected, and the team was formed. The need of the customer was then defined which led to the creation of the mentioned problem statement. This problem statement was then used to create the QFD chart (Appendix A). The background research had been ongoing, but more specific research was completed once the engineering specifications were defined. Various design ideas were developed during the ideation phase of the design process. It is important to note these ideas were at first created with maximum quantity being the end-goal. The mass quantity of ideas was then broken down into how each desired function was being met the by the proposed concept. These function concepts were then used to develop Pugh and Morphological Matrices which in turn were used to develop a final Weighted Decision Matrix. This Weighted Decision Matrix was used to select a final concept. Some basic calculations were done to ensure the selected concept would be able to meet required loads. The normal operating and short circuit torsion loads were considered. Once it was determined that the concept was feasible a rough CAD model was developed. This CAD model was then used to develop a final concept prototype. It is important to note this prototype was merely a proof of concept and will not be the prototype undergoing extensive testing.

Quarter 2: Critical Design Review

Major Milestones:
(1/16/20) Interim Design Review
(2/17/20) Critical Design Review
(3/13/20) Manufacturing & Test Review

During this quarter majority of the design analysis was conducted. A final CAD model was developed based on various analysis. FEA analysis was conducted on various models of proper design dimensions in order to justify the design dimensions and part sizing. Though the whole process could not be modeled at this time in FEA each area of concern received an FEA approach to verify the initial hand calculations. The bolts ended up being designed to take both the normal operating condition as well as the short circuit condition with the Wedges being designed as a redundant safety feature with respect to the short circuit loads. A manufacturing plan was created including a bill of materials from which parts will be ordered.

Note: In order to include an easy comparison in how the project changed at the beginning of the third quarter the expected milestones and activities are listed below follow by the actual layout the quarter was given.

Expected Quarter 3: Final Design Review

Major Milestones:
(4/28/20) Verification Prototype Sign Off
(5/19/20) Design Verification Plan Sign Off
(5/29/20) Senior Design Expo

During this quarter majority of the manufacturing of the final prototype will be executed. The manufacturing is expected to adhere to the following schedule:

1. Manufacture scale model of end of trailers
2. Manufacture scale model of wedges
3. Cut holes for wedges and fasten the wedges to the turbine trailer.
4. Create roller members for lateral mobility of the generator trailer
5. Weld contact areas for latching mechanism onto trailer
6. Create any additional member arms needed for the hydraulic system and support of the structure.

To test the final prototype the team plans to scale the trailer models to a size which would allow for alignment to be demonstrated. This idea would give one of the best representations how the final product may operate. A pulley system is under currently under consideration as described in the design verification plan section.

After finalizing the testing method, thorough testing of this prototype will be conducted to ensure it meets the requirements laid out in the early design phases. Once testing is complete the project itself will be presented at the Senior Design Expo, though technical specifications will be limited in order to protect Solar Turbines' intellectual property.

Actual Quarter 3: Final Design Review

Major Milestones:
(5/8/2020) Review of Manufacturing and Test Plans with Solar Turbines
(5/22/2020) Review of User Manual with Solar Turbines
(5/30/2020) Completion of Additional Ansys Analysis
(6/5/2020) Submittal of Final Design Report
(6/12/2020) Final Presentation of Project to Solar Turbines

As mentioned previously in chapter 6 of this document there were some major changes in the scope of work for this project due to the emergence of Covid-19. The quarantine had a major effect on the end goal of the project due to the team's inability to access machine shops for the manufacturing and testing of the prototype. With many local shops having to close the outsourcing of manufacturing as well also was deemed unfeasible. Instead more importance was placed upon the manufacturing and test plans as well as the user manual to be provided in the appendices of the final report. In addition, further Ansys analysis was conducted in attempt to model the whole system and get similar observations that could be achieved through the testing of a prototype. In order to ensure that each document was up to the standards of Solar Turbines review sessions were held with the Solar sponsor's in order to receive feedback immediately on those documents.

5.0 Conclusion

As explained in this Final Design Report, the primary goal of this project is the creation of a system to reduction of time in the alignment and attachment of the two trailers used in the Titan 130 Gas Turbine Mobile Power Unit. The system developed utilizes a combination of sliding Teflon on Teflon sheets, wedges and a hydraulic system to align the trailers. After the alignment tolerance of ¼ of an inch is met, bolts will be used to rigidly secure the two trailers. The force to engage and disengage the wedges will be provided by the hydraulic system. Due to the degradation of hydraulic strength primarily due to fluid loss, bolts were deemed necessary to provide the consistent tension force after the wedges are engaged. Given the provided assumption that the truck driver will be capable of getting the trailer within +/- 3.5 inches of the desired tolerance, the wedges themselves will suffice to achieve the final alignment. The total deployment process will be reduced to a timeframe of less than four hours. Analysis of critical components as well as rigid body dynamics analysis of the whole system were provided in this document. As mentioned Covid-19 prevented the team's ability to manufacture and test a prototype; however, Manufacturing, Assembly, and Testing documents are provided in the report/appendices to allow Solar Turbines to develop and test their own prototype if they choose to do so.

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