Orbital Test Stand

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Team 7

Project Proposal
Document

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1.0 INTRODUCTION

The mechanical engineering department at Northern Arizona University received a problem statement from Orbital Sciences in Phoenix, Ariz., regarding the procedure currently being used to rotate launch vehicles on its horizontal test stand. Currently, Orbital is using an overhead crane to rotate the fairings of the Antares launch vehicle when testing. The procedure, as classified by Orbital engineers, is inefficient and unsafe. This report documents a semester's long worth of work from our team, which was the one tasked with solving Orbital's test stand problem. This report details everything from the initial problem definition all the way to our final design selection. The primary goal of our design is to provide continuous rotation to the test stand via a design that is safe and reliable.

2.0 PROBLEM DEFINITION

The following section identifies the problem associated with Orbital's test stand as it was presented both by our team (customer needs, goals, objectives) and by Orbital itself (constraints). The customer needs, goals, and objectives outlined in this section are the items that we would like to fulfill with our final design selection. The constraints were given to us by Orbital and represent the design parameters we are most interested in fulfilling.

2.1 Customer Needs

There are three primary customer needs that we have identified from the problem statement received from Orbital regarding the test stand. They are in the form of dissatisfactory statements from what we understand about the issue that engineers and test specialists are having with the current procedure.

- The procedure for rotating launch vehicles on the test stand is inefficient and unsafe.
- Rotating launch vehicles on the test stand places Orbital engineers in a dangerous position.
- The setup time for testing is exhausted by the need to manually rotate the launch vehicles.

2.2 Goals

The goals section briefly states the items we hope to include in our design. These criteria factored heavily into final design selection. The goals we kept in mind are:

- The new design should be easy to operate.
- The new design should be easy to implement.
- The new design should be easy to maintain.
- The new design should be easy to inspect.
- The new design should be all customer requirements.

2.3 Objectives

The objectives of the project, as defined by our team, are shown in Table 1. It includes goal-oriented objectives, the basis by which those objectives would be measured, and each of their respective units.

Table 1: Objectives for Orbital Test Stand project

Objective	Measurement Basis	Units
Minimize time it takes to load launch vehicle onto test stand	Time to load launch vehicle with new mechanism in place compared to current procedure	minutes
Minimize costs associated with new design concept	New design cost compared to maintaining current procedure and other designs	dollars
Limit new modifications made to test stand	Cost of material for modifications	dollars
Handle the off-center loads of Antares payload fairings when loaded on stand	Strength	psi
Minimize space requirements	Square footage required by new mechanism	ft^2

4.4 Constraints

The constraints of this project were defined by Orbital and are the design parameters that we will meet with our final design. They are listed below in bullet points and range from the maximum speed by which the test stand should rotate to one particular load consideration that Orbital is interested in counteracting.

- Continuous rotation for +/- 360 degrees
- Rotational speed not exceeding 1 RPM
- Counteract off-centered load of 570 lb at 153 in
- Minimal modifications

3.0 CONCEPT GENERATION

After defining the problem, the next steps were to come up with concepts that would fit within the customers need. With Orbital's requirements and teams goals identified each team member came up with two ideas to modify the test stand. Our team came up with the following 10 ideas: Winches, Exterior Wheels, Worm Gears, Gears, Chain, Bowling Ball Return, Rope Belt, Sandwich Wheels, Interior Wheels and Piston. Each concept had the potential to be a solution. Minimizing the number of concepts came after discussing each in detail and identified pros and cons for each. Individually, team members created a decision matrix, each having their unique criteria, category and weight. This individual method removed any favoritism and score influences and resulted in a variety of top three concept for each of the five decision matrix. To finalize the overall top three an average score from each matrix was found and the following concepts were chosen to move on with analysis: Winch, Interior Wheels and Sandwich Wheels.

The team divided in half where two members worked on the Winch Concept, and three members completed analysis on the Interior and Sandwich Wheels. Analysis concluded with max torque values, proposed components and mounting strategies. These concepts were formally presented for Presentation 3: Engineering Analysis, to Professor Raju and discussed with Orbital Engineers. After discussion and input the final concepts to move forward with were the Winch and Interior Wheels.

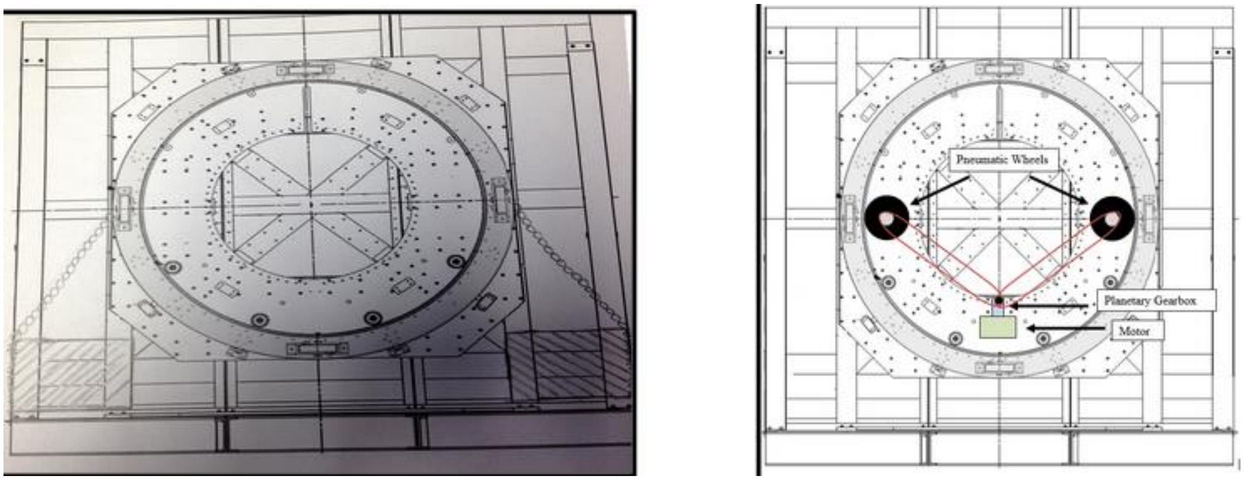

Figure 1: Sketches of Winch Design (left) and Interior Wheel Design (right)

The Winch design incorporated two winches on opposite sides of the test stand. The selected Ramsay Patriot winch was capable to support the static and dynamic loads of 5400 lb. rotating ring when loaded with either of the two 600 lb. Launch vehicle fairings. Mounting strategy consisted of mounting a bracket on the outer rotating ring where the winch cable can be strung through. A braking and locking device was also considered for this concept, where a concrete block with a pneumatic scissor jack on top. The jack would raise and provide friction to stop rotation.

The Interior Wheels design incorporates two pneumatic wheels mounted in the inside of the ring on opposite side along the horizontal center. The wheels are positioned in such a way so that they create contact friction between the wheel surface and the inner surface of the rotating ring. Both wheels would be driven by a single motor and speed reducer. The speed reducer gear box would be attached to a chain link and the other ends to both tires. Having the wheels be placed at horizontal center would allow for consistent surface area for contact friction.

4.0 WINCH VS. WHEELS

The following section compares the aforementioned design concepts that were the two finalists. In it, we compare the two designs through their respective pros and cons, before presenting the problems with the winch design that ultimately led to us choosing the interior wheels design as our final concept.

4.1 Design Comparison

After narrowing our final two design concepts down to the winch design and the interior wheels design, we did a simple pros and cons analysis to figure out which design we thought would more efficiently address the problem previously discussed.

Winch Design

Pros

- Low maintenance
- Easy to operate
- Low installation costs
- Easy to transport
- No mechanism

Cons

- Expensive winches
- Similar to current crane design
- Safety concerns
- Aesthetics

Interior Wheels Design

Pros

- Easy to operate
- Modular
- High fatigue life
- Low-cost components
- Aesthetics

Cons

- High technician costs
- High maintenance
- Safety concerns for belt
- Braking mechanism

Ultimately our group could not come to a consensus on which design we should recommend to Orbital, so when we travelled to their facility to present our two concepts, we presented them as equals and allowed them to decide. Because ultimately it will be them that will be paying for and using this machine, we want them to have the final say as to what they want.

4.2 Winch Implementation Problems

After presenting our ideas to Orbital, we got to go examine the test stand again and realized that our design had missed some crucial elements that were hard to discern since we did not have a 3D rendering of the test stand. One thing that was hard to see was that as the cable wraps around the rotating ring, it will encounter the 4 large bearings shown in Figure 2. This is an issue that was not foreseen in a 2D rendering of the test stand, and this interference with the chain required massive design changes. Ultimately additional guidance brackets would have to be used to guide the chain around the bearings. Another issue that we weren't aware of was actually how limited the space off to the side of the test stand is and that our mounting strategy needed to be redone in order to have the design function like we had initially planned.

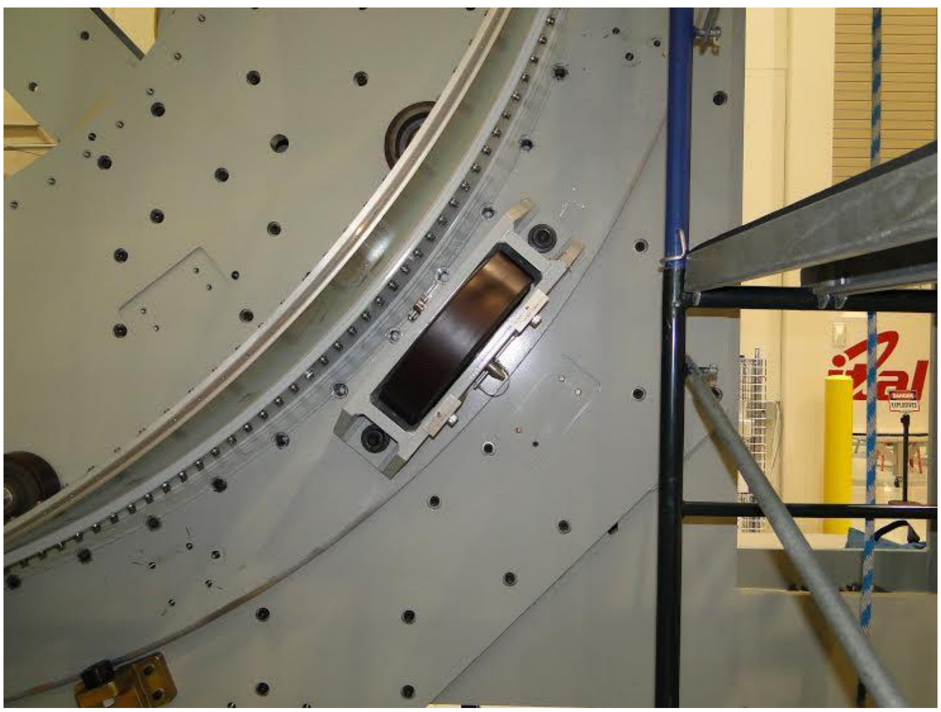

Figure 2: Test stand rotation bearing

After discovering these shortcomings with the winch design and hearing Orbital's decision, it was finalized that we would move forwards with the interior wheels design.

5.0 INTERIOR WHEELS DESIGN

After presenting and discussing our final two design solutions to Orbital, the interior wheels concept was chosen. The interior wheels was chosen over the dual winch design due to ease of operator use, aesthetics, and space constraints. See Figure 1 on Page 4 for the sketch of this design. This concept takes the form of two wheels mounted to the interior of the test ring, each of which is chain driven via motor and gearbox assembly. Adapter plates will be manufactured at Northern Arizona University on which the wheels, motors, and gearboxes will be mounted. These will then be mounted to the test frame in keeping with our constraint of minimal modifications to the existing structure.

5.1 Wheels Selection

Two tire treads were investigated for the final design: smooth tread and J-tread. The smooth tread was investigated for its greater contact area which in turn would yield a higher traction between the wheels and the test stand. However, the smooth tread tires only have a load rating of about 230 lbf while the J-tread tires have a load rating of 590 lbf at 60 psi. Despite the lower contact area of the J-tread tires the higher load and pressure ratings achieve the necessary contact and friction forces. The tires are 16.1 inches in diameter and 4.7 inches wide. To attain the minimum normal force to prevent the test stand from rotating when only one half of the fairing is loaded the tire center must be mounted no more than 7.95 inches from the test ring. A tire pressure of 60 psi will create a contact area of 9.5 in^2 and a normal force of 570 lbf per wheel.

Pneumatic tires are the best choice for this design because they allow the easy integration and removal of the wheel while also achieving the necessary normal forces. Since the wheels must be mounted with the centers less than one radii from the interior of the ring it is best to mount the wheels in their deflated state and then inflated to 60 psi. In the event the wheels need to be replaced they are deflated and removed. Another benefit is the option to vary the tire pressure to adjust the normal force in case there is too much or too little traction. After all calculations were performed our team selected Product # 2181T31 from McMaster-Carr.

5.2 Motor and Gearbox Selection

We selected a 1 horsepower AC motor to drive our wheels. The motor's high starting torque is needed to get the 6740 lbf ring and fairing rotating. These motors also come with electrical leads for connecting control devices. However, its output of 1725 RPM is too high for our constraint of rotating the test ring no more than 1 RPM.

Gearbox configurations we looked at included worm drives and planetary drives. Spur gears were out of the question due to the prohibitive size to achieve the gear reduction we needed of nearly 200:1. Worm drives were the next option researched, however, worm drives are non-reversible and fail our constraint of clockwise and counterclockwise rotation. We found that planetary gearboxes give us the large reductions needed while maintaining the ability to reverse rotation. One prohibitive factor is the cost and further research is being done on companies with the best-priced planetary gearboxes. A good candidate motor sold through Grainger reduces the motor output to 18 RPM with a torque of 1655 in-lbf.

5.3 Sprockets and Chain Selection

To transmit the output rotation of the gearbox to the wheels a sprocket and chain system will be used. On the output shaft of the gearbox will be mounted a 16 tooth gear and on the wheel a 32 tooth gear. This additional stage steps the output 18 RPM to the required 9 RPM for the wheels to rotate the test stand at 1 RPM. The chain chosen is a single-strand steel chain with a working load of 803 lbf. Chain length will be calculated when the relative positions of the components are known in the near future. McMaster-Carr is the distributor for the chain and sprockets. The chain's Product # is 6261K176, the 16-tooth sprocket has a Product # of 6280K479, and the 32-tooth gear has a Product # of 6236K472.

5.4 Spindle Assembly

We chose a spindle assembly made by Gempler (Figure 3). This assembly is a four hole straight spindle stub axle. This will allow the spindle to be bolted right on to the mounting plate. The spindle comes with all necessary parts. It has a total load capacity of 1250 pounds.

Figure 3: Spindle Assembly

5.5 Mounting Plate

The mounting plate (Figure 4) will be custom built to fit the test stand. The gearbox, motor, and spindle assembly can be all attached to the mounting plate using pre-existing holes on the test stand. From there, the mounting plate will be attached to the test stand. This combines all the separate parts into one cohesive part that can be attached and detached when needed.

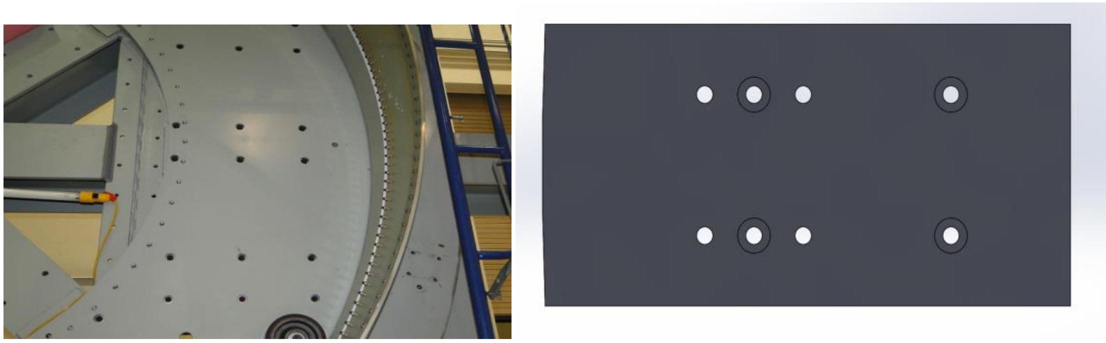

Figure 4: Pre-existing holes (left) and mounting plate (right)

6.0 COST ANALYSIS

The cost analysis for this design is shown in Table 2. Each parts' cost was taken from the manufacturer. As for labor costs, we assumed a rough estimate. The total cost of the design is $4014.96.

Table 2: Cost Analysis and Bill of Materials for Interior Wheels Design

Description	Quantity	Cost (each)	Line Total
Motor	2	$241.79	$483.58
Speed Reducer	2	$983.00	$1966.00
Roller Chain	2	$38.90	$77.80
16 T Sprocket	2	$37.03	$74.06
32 T Sprocket	2	$80.13	$160.26
Pneumatic Tire	2	$35.78	$71.56
Mounts	2	$15.00	$30.00
Spindle Assy.	2	$75.85	$151.70
Labor	n/a	$1000.00	$1000.00
		Total	$4014.96

7.0 CONCLUSION

In conclusion, this report serves as the project plan that we will reference during the Spring 2014 semester at NAU. We have selected our final design, which we are calling the Interior Wheels Design. The bill of materials will be our guide as we begin ordering parts in the coming weeks after receiving approval from Orbital to go ahead with this design.