Orbital ATK Test Stand

By
Mary Begay, Brett Booen, Calvin Boothe,
James Ellis, and Nicholas Garcia
Team 7

UGRADS - Final Report

Document

Submitted towards partial fulfillment of the requirements for
Mechanical Engineering Design II – Spring 2015

Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86001

Table of Contents

Chapter 1: Introduction

1.1 Abstract

Orbital ATK has a Launch Vehicle Design and Manufacturing facility, located in Chandler, Arizona, which is responsible for conducting tests on payload fairings to ensure the designs will tolerate the dynamic loads experienced during launch. Loading simulation is conducted on the company's test stand in a horizontal position rather than a vertical one. The installation procedure requires the two halves of the clamshell fairing to be mounted one at a time. Technicians manually rotate the ring to stable positions at varying intervals to secure the launch vehicle. Mounting the two pieces is a time-consuming and delicate process due to the use of an overhead crane, which doubles as a brake to prevent the mounting ring from rotating freely. This process puts technicians and engineers at risk in the event that the crane fails. Orbital ATK has asked our capstone team to design, build, and integrate a system to automate the test stand, reduce set-up time, and increase the safety of its employees. The team came up with a design in the form of two wheels driven by electric motors mounted to the interior of the test stand. These wheels work in tandem to rotate the test ring at no more than 1 RPM in unloaded, partially-loaded, and fully-loaded regimes. The design was installed on April 17, 2015, tested on April 21, and will need to undergo final testing before being put into operation.

1.2 Introduction

Orbital ATK is a US-based company specializing in the fabrication of small- and medium-class space and rocket systems. Its product line includes space launch vehicles, missile defense systems, satellites, national security systems, and advanced flight systems. The senior design project presented in this report deals primarily with a certain inefficiency—as identified by Orbital ATK engineers and technicians—involved in the testing of Orbital launch vehicles. Testing for Orbital's line of Antares launch vehicles occurs on a horizontal test stand located in its manufacturing and testing facility in Chandler, Arizona. The current testing procedure is unsafe and inefficient and Orbital would like a mechanism that makes testing easier, safer, and more efficient. For the test, two payload fairings are individually loaded onto the horizontal test stand with a crane. The first payload fairing is loaded onto the top of the test stand and then Orbital engineers have to manually rotate the test stand so that a second fairing can be loaded in conjunction with the first. These payload fairings are approximately 3.9 meters in diameter and 9.9 meters in height and each half of the clamshell fairing is worth $600,000. Orbital ATK would like to see the task of having engineers manually rotate the test stand be replaced with a motorized mechanism that is capable of providing continuous rotation to the test stand.

1.3 Problem Definition

Defining the problem consists of identifying customer needs, defining project goals, establishing project objectives, and minding the constraints outlined by Orbital ATK in the project description.

1.3.1 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.

1.3.2 Project Goals

The goals section briefly states the items factored into the selection of our final design. design. These criteria factored heavily into final design selection.

- 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.

1.3.3 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 the respective units.

Table 1: Objectives for Orbital Test Stand Project

OBJECTIVE	MEASUREMENT BASIS	UNITS
Minimize time it takes to load launch vehicle on the test stand	Time to load launch vehicle with new mechanism compared to current procedure	minutes
Minimize costs associated with final design	Final design cost compared to maintaining current procedure and other designs	$
Limit new modifications made to test stand	Cost of material and labor for modifications	$
Handle the off-center loads of Antares fairings when loaded on stand	Strength	psi
Minimize space requirements for final design	Square footage required by new mechanism	ft^2

1.3.3 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

Chapter 2: Concept Generation and Selection

2.1 Concept Generation

Having a full understanding of the problem, need, and goal associated with the Orbital Test Stand project, each member generated two feasible design concepts. Figure 1 shows the sketches of each team member's suggested designs.

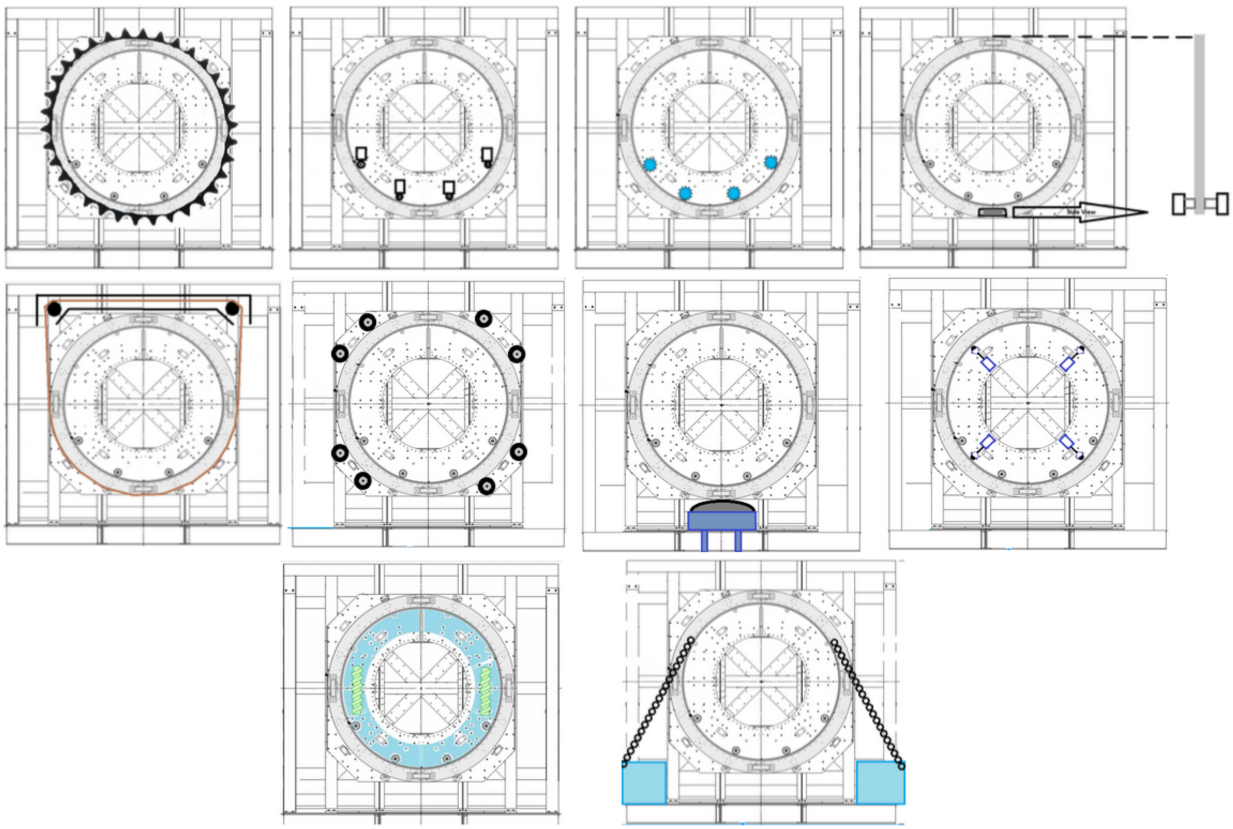

Figure 1: Ten Concept Sketches Completed by the Team

From left to right the sketches are: Chain, Interior Wheels, Gears, Sandwich Wheels, Rope Belt, Exterior Wheels, Bowling Ball Return, Piston, Worm Gears, and Winch. Each concept varied with the number of components being integrated to the amount much modifications that would be required.

Once all concepts were pitched each member was responsible for creating their own decision matrix, assigning weights to the categories they deemed important for this project. The only standardization for this step was concept naming to ensure the proper concepts were graded accurately. Decision matrix categories included: cost, safety, maintenance, modifications/integration, user-friendly, and size although ultimately it was left to each member to decide which categories would be scored. All members worked independently of each other on this task to ensure that each individual's decision matrix was not influenced by other scores.

The team averaged the rank values and the results showed the top three overall concepts to be Interior Wheels, Winch and Rope Belt. These designs had an average ranked score of 1.4, 3.6 and 4.6, respectively.

2.2 Concept Selection

The team divided in half where two members worked on the Winch Concept, and three members completed analysis on the Interior and Rope Belt. 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.

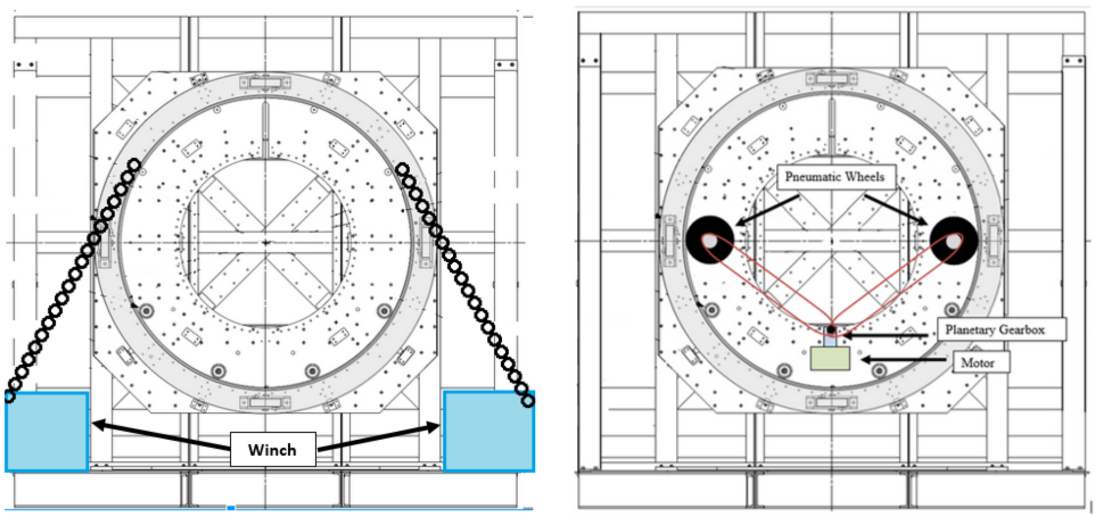

Figure 2: Sketch of Winch Deign (left) and Interior Wheel Design (right).

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 along the horizontal center on the inside of the ring and on opposite sides of each other. 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.

2.3 Design Selection 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, shown below in Table 2**.**

Table 2: Pros and Cons for Winch Design and Interior Wheels Design

Design Concept	Pros	Cons
Winch Design	• Low maintenance • Easy to operate • Low installation costs • Easy to transport • No mechanism	• Expensive winches • Similar to current crane design • Safety concerns • Aesthetics
Wheels Design	• Easy to operate • Modular • High fatigue life • Low-cost components • Aesthetics	• High technician costs • High maintenance • Safety concerns for chain • Braking mechanism

Chapter 3: Final Design

3.1 Final Design

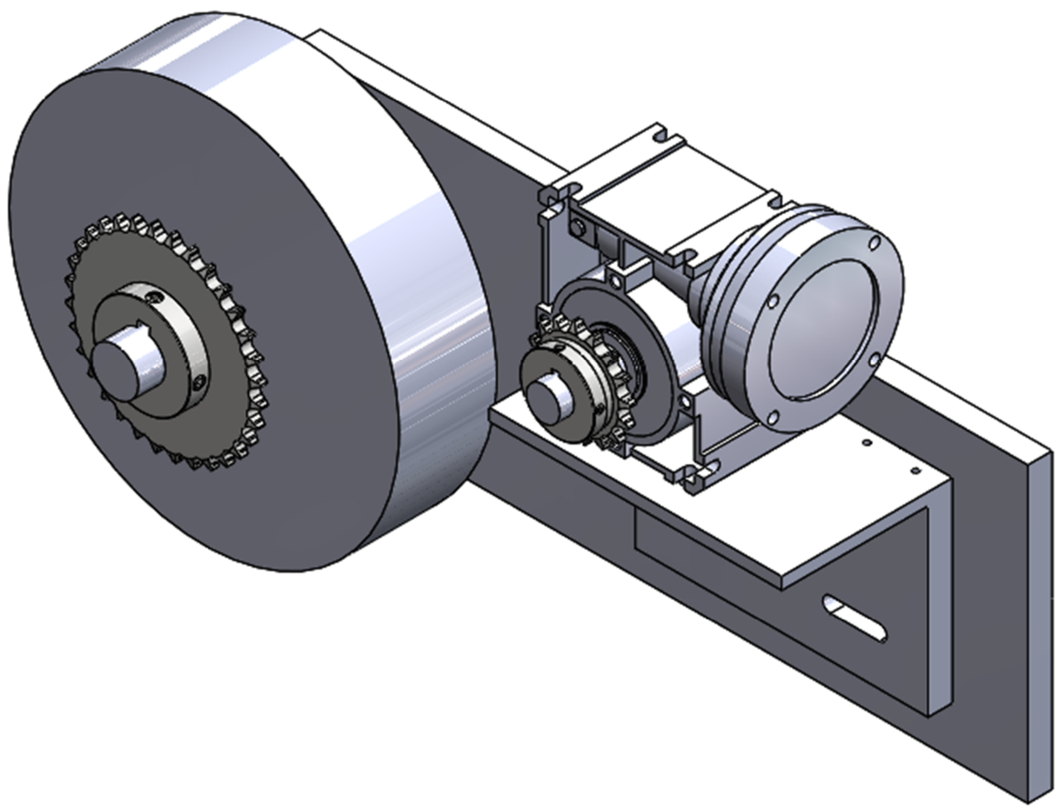

Figure 3: Final Interior Wheels Design CAD Drawing

The final design for the interior wheels design can be seen in Figure 3. The design was broken down into three main components; the adapter plate, the gearbox mounting, and the spindle assembly.

The adapter plate was used to minimize the amount of modifications that Orbital ATK would need to make to the test stand in order to fit our components. A bolt pattern was taken from the CAD model of the test stand and used to line up a bolt pattern for the adapter plate. The adapter plate also has the spindle assembly and the gearbox mount, allowing for easy installation and transportation due to the fact that this was assembled in Flagstaff and were required to go down to Chandler for installation.

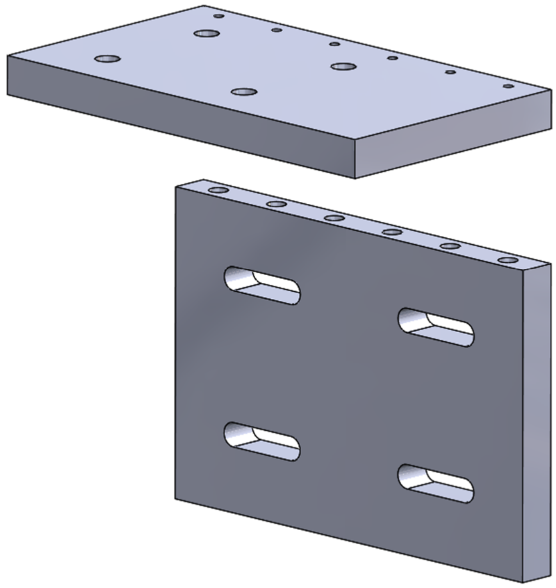

Figure 4: Gearbox Assembly CAD Drawing

The gearbox mount was made using 2 slabs of aluminum that were bolted together using threaded inserts to form an L-bracket. There are 4 slider slots in the vertical plate that allow for the gearbox to be repositioned for optimal chain tension without removing additional links. The 4 holes in the top of the horizontal plate are where the gearbox itself attaches.

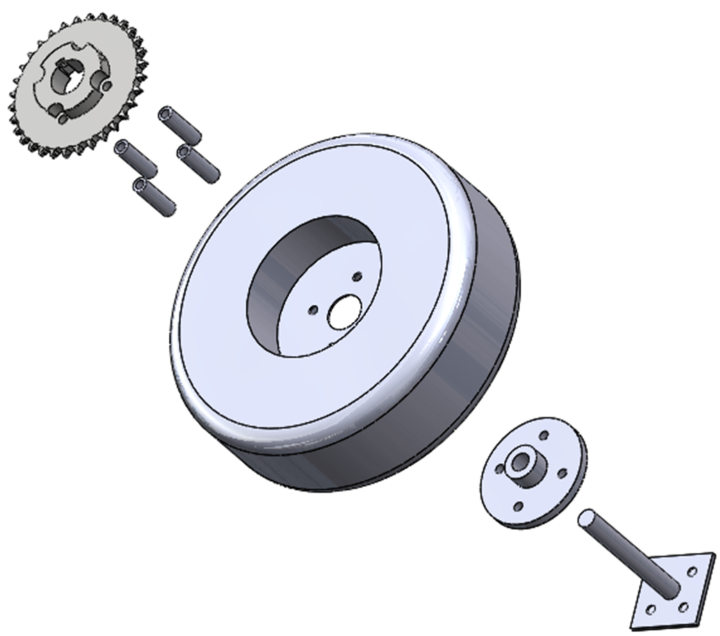

Figure 5: Spindle Exploded View

The spindle assembly was made using a baseplate with 1 inch of the spindle going through the plate and into the adapter plate. The 4 bolts connect the spindle to the adapter plate using threaded inserts. In order to connect the large sprocket to the tire so they would rotate in tandem, the small studs from the hub were removed and replaced with longer bolts. The longer bolts go through the hub, through the tire, and then through the standoffs and into the sprocket. The sprocket had to be custom bored out to support the narrower bolt pattern. The standoffs were required to push the sprocket farther away from the edge of the tire so the tire flange would not interfere with the axis of the chain.

The motor that was used (not pictured) was a 3/4 Hp motor from McMaster-Carr with an output RPM of 1725. This motor was chosen primarily because it connects directly into the speed reducer without any additional modifications.

The gearbox used was a 100:1 speed reducer from Grainger. This would reduce our 1725 RPM from the motor down to about 18 for the small sprocket, giving the high torque required to turn the tires and the test stand ring. The main reason that this gearbox was used was because it is reversible, allowing for the CW and CCW rotation that was deemed a critical design criteria.

Chapter 4: Manufacturing

4.1 Overall Manufacturing Process

The manufacturing process was the longest and most grueling part of this project. The process took over 80 man hours and was made all the more daunting due to only one member of our team being allowed to use a lot of the machines due to not having taken the manufacturing course.

4.2 Adapter Plates

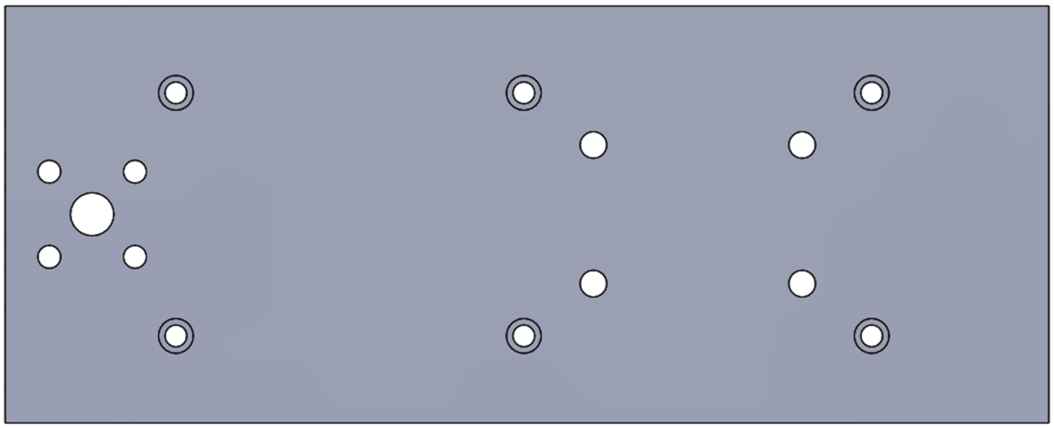

Figure 6: Adapter Plate

Figure XX shows the adapter plate. The plate dimensions are 30x12x1 in., and were made from 6061 Aluminum. The 6 bolt pattern is for the adapter plate to connect directly to the test stand. The larger 4 bolt pattern is where the bolts that go through the sliders connect. The smaller 4 bolt pattern with the large hole in the center is where the spindle connects. The plate was manufactured using a manual mill and threaded inserts to prevent cross threading with the steel bolts and the weaker aluminum plate.

4.3 Motor and Gearbox

The gearbox assembly L-bracket shape was made by connecting two 1 inch thick plates of 6061 aluminum using threaded inserts. Six threaded inserts complete the L-shape and provide the structure for the cantilevered motor and gearbox assembly. The holes for the threaded inserts were made using a manual mill. The slider holes were made using a manual mill and took about 1 hour per each slot, making up a large part of the manufacturing time.

4.4 Wheel Assembly

To manufacture the wheel spindle assembly, the process began with welding the spindle to the back plate so that it could be bolted onto the adapter plate. The main manufacturing came from having to bore out the thick part of the sprockets to allow the bolts from the hub to pass through. This process was done using the Haas CNC machine after expensive drill bits were broken when this was attempted using the manual mill.

Chapter 5: Implementation

5.1 Integration

The design was installed at Orbital ATK on April 17, 2015. Initial installation took approximately two hours, but the team feels that the high-skilled technicians can complete the entire installation process in 15 minutes or less. The adapter plate was bolted on to the test stand and the remaining components were installed directly on the adapter plate in a modular fashion. This setup allows for easy installation. Figure 7 shows the two identical components of the team's final design mounted on to the test stand. Both the left and right assemblies are mounted along the test stand's horizontal centerline. Figure 8 shows a close up view of the two finished assemblies. The contact area (i.e. friction) between the tire and the ring is easily noticeable.

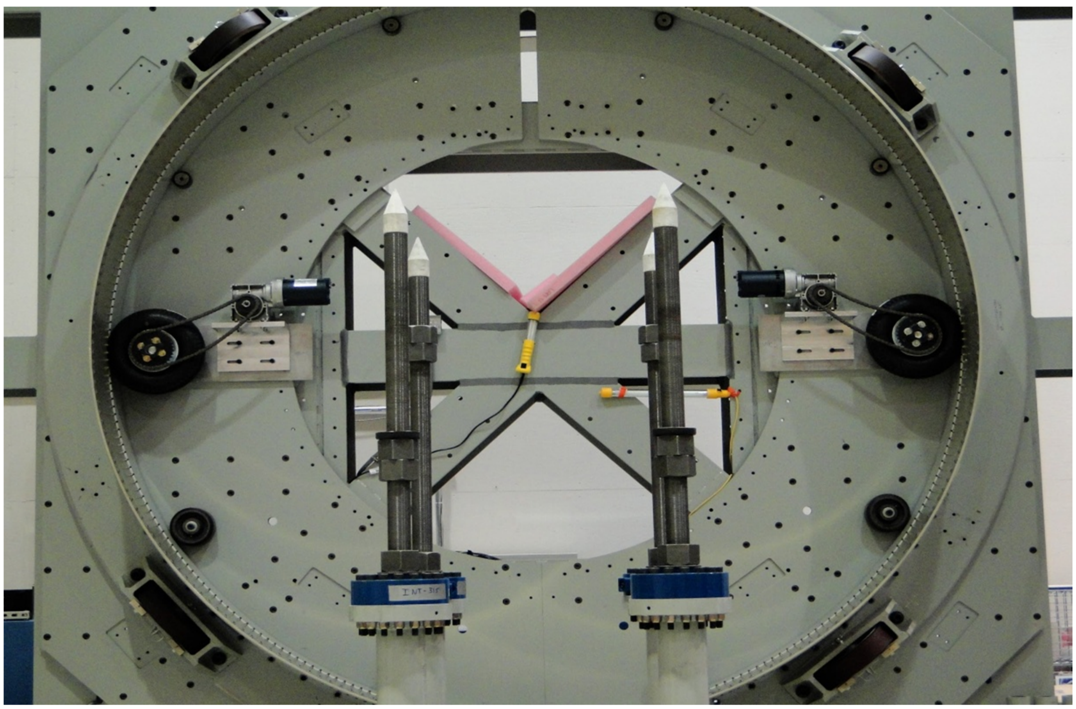

Figure 7: Front View of Team's Final Interior Wheels Design

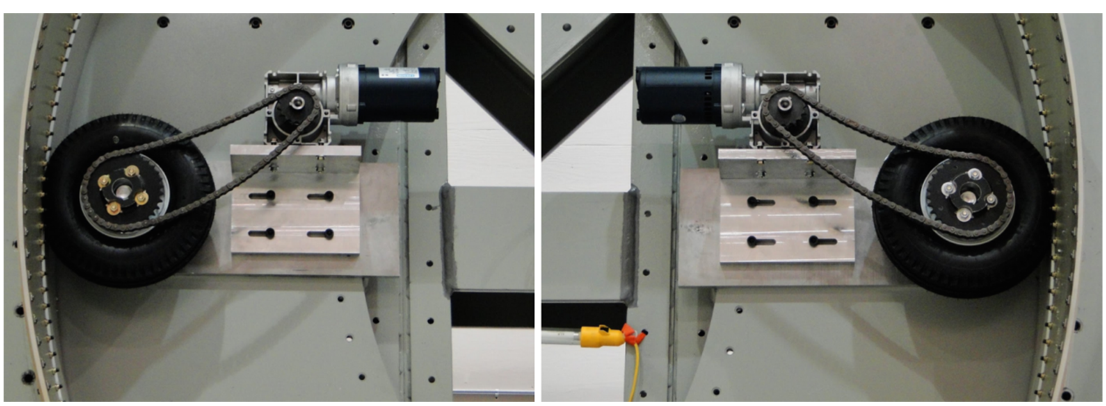

Figure 8: Close Up of Design's Left and Right Installations

5.2 Testing

Preliminary testing of the design took place April 21-22, 2015 at Orbital ATK. The first attempt at installation proved unsuccessful because the tires on each assembly did not come into contact with the outer ring of the test stand. The team initially thought about taking the plates off of the test stand and slotting them so that the tire could be pressed against the test stand in a similar manner that the roller chain gets tensioned with the slotted gear mount plates. After deliberation, however, the team instead decided to replace the 16-inch tire on each design with an 18-inch tire to get the necessary contact area between the two tires and the ring. With the new tires in place, Orbital ATK could perform the first tests as the team intended.

A second problem presented itself on the first day of testing (April 21) when the motors stalled out the first time technicians tried to operate the design. Initially, the belief by both technicians and the team was that the larger tires provided too much contact friction for the 1725 RPM motors to handle. The next day, however, electrical engineers at Orbital ATK responsible for the wiring of the motors decided to double check the connections. It turns out that the motors were wired wrong. After this minor electrical issue was resolved, technicians performed a second set of tests on April 22 that proved successful. The team was not present at the testing, but Orbital ATK sent videos of the design rotating the ring both clockwise and counter clockwise. In the end, the successful test on April 22 was the moment when the team could say it successfully completed the task it set out to complete when taking on the Orbital ATK project.

Chapter 6: Cost Analysis

The team was allocated $1000 from Orbital ATK to complete this project. Table 3 shows a breakdown of the team's budget. The motors and speed reducers were purchased for the team by Orbital ATK. As such, these items do not factor into the team’s final budget.

Table 3: Total Budget and Parts List for the Final Design

Description	Distributor	Part No.	Cost	Quantity	Line Total
Motor	McMaster-Carr	6135K77	267.18	2	534.36
Speed Reducer	Grainger	29TL65	1013.00	2	2026.00
Roller Chain	McMaster-Carr	6261K176	38.90	2	77.80
16 T Sprocket	McMaster-Carr	6280K479	37.03	2	74.06
32 T Sprocket	McMaster-Carr	6236K472	80.13	2	160.26
Trailer Wheel	McMaster-Carr	2181T31	35.78	2	71.56
Spindle-Backing-Wheel Hub	P&M Trailers	-	50.42	2	100.84
Threaded Insert, 3/8"-16 x 1"	McMaster-Carr	90248A032	12.60	8	100.80
Threaded Insert, 5/8"-18 x 11/16"	McMaster-Carr	90248A087	9.88	2	19.76
Threaded Insert, 1/2"-20 x 21/32"	McMaster-Carr	90248A086	7.88	2	15.76
Cap Screw, 1/2"-20 x 1-1/4"	McMaster-Carr	90128A842	7.26	2	14.52
Cap Screw, 5/8"-18 x 2"	McMaster-Carr	91251A402	10.54	2	21.08
Cap Screw, 1/2"-20 x 5"	Copper State	03CSFY-0500500	1.44	8	11.52
Standoff 2-3/4"	NAU Shop Stock	-	0.81	8	6.48
Bearing Grease	P&M Trailers	-	11.71	1	11.71

Total Project Cost:	$ 3,246.51
Total NAU Cost:	$ 936.15

Chapter 7: Conclusions

7.1 Conclusion

Orbital ATK came to NAU with a problem that needed a solution. Through interviews with employees and an initial fact-finding trip to Orbital ATK in Chandler, Ariz., the team determined that Orbital ATK needed a safe, reliable, and motorized system to provide automated rotation to its horizontal test stand. Throughout the course of the Fall 2014 semester, the team came up with multiple ideas and then in November 2014 presented two final designs to Orbital ATK for them to decide. The two final designs were a winch concept and an interior wheels concept. Orbital ATK chose the interior wheels design because it was aesthetically pleasing, fit better with the existing design of the test stand, and would be less disruptive to the surrounding mechanisms. The team's interior wheels concept consisted of two interior wheels, powered by electric motors, that when driven provide rotation to the ring. The Spring 2015 semester was dedicated entirely to manufacturing the design. The team oversaw the successful installation of the design on April 17, 2015 and goal of rotating the ring was realized on April 22, 2015 when the system performed its first successful test. The team met the objectives that were readily available to meet at the time of installation, but further testing needs to occur before the system is used when launch vehicles are mounted on the test stand.

7.2 Acknowledgements

The team received help from a wide range of people over the course of the nine months spanning the project, but would like to acknowledge a few who stood out. The successful completion of our project would not have been possible without these people and entities. A huge thanks goes out to those of you listed below and the many others who helped us along the way!

Steve Hengl, Orbital ATK

Ross Gentle, Orbital ATK

Joseph Regulski, Orbital ATK

Garrett Haupt, Orbital ATK

Randy Bone, Orbital ATK

Roger Cundick, IMS Steel

Jason Jacob, Grainger

Srinivas Kosaraju, NAU

NAU Machine Shop

McMaster Carr