Dual Spare Tire Carrier System

Kyle Hartman
Mike Rickner
Daniel Voors

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              Mike Rickner
              Daniel Voors

Faculty Advisor: Josué Njock Libii, Ph.D.

Date: May 6, 2013
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Navistar Defense is in need of a low cost and highly reliable Dual Spare Tire Carrier System that will meet performance requirements and can be installed on heavy tractor applications. This system needs to stow two spare tires located at the back of the cab. With the use of this system, the operator must be able to load/unload a spare tire on each side of the tractor. The design must be operated by a single individual in a timely manner by utilizing electrical, pneumatic, or mechanical assisted components. It is also required to meet or exceed multiple design constraints due to various customer requirements. The system should be designed for manufacturability, ready for mass production, and adaptable for multiple tractor configurations. Navistar Defense is requesting a detailed design, a physical prototype, as well as test and validation data. Target date for completing the prototype installation is May 2013.
Section 1: Detailed Design

Section 1.1: Last Semesters Design

At the conclusion of Senior Design I the team had finished the design process for the Dual Spare Tire Carrier System. Figure 1 depicts a solid model of the final first semester design. The dual spare tire carrier system was designed to carry two spare tires and unload a spare tire to each side of the truck. Figure 2 shows a solid model of the system unloading a tire to each side. This was accomplished by placing two hollow channels (CR) fore and aft of each other. Inside each of CR channels is a smaller channel (AR). The AR channel slides out the end of the CR channel. A trolley slides inside the AR channel and allows the spare tire to be lowered directly to the ground on either side of the truck. Figure 3 shows a solid model of the AR channels inside the CR channels. The tire is raised and lowered via a chain hoist and the tires are held in place by a JEGS Performance Track Mounting Systems. The results of all the analysis conducted last semester can be seen in Figure 1.
Section 1: Detailed Design

Figure 2: Example of both arms fully extended and independent of each other

Figure 3: Transparent section shows the still nested portion of each extension arm
# Section 1: Detailed Design

## Table 1: Table of Results of Analysis (Original Design)

<table>
<thead>
<tr>
<th>Results Summary</th>
<th>Base Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Yield Strength [psi]</td>
</tr>
<tr>
<td>AISI 1020 steel</td>
<td>50,591.10</td>
</tr>
<tr>
<td>Pin tool-steel</td>
<td>239,000.00</td>
</tr>
</tbody>
</table>

## Analysis of AR due to Static Loading Caused by Tire

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure of AR due to Shear Stress</td>
<td>Does not Fail</td>
<td>100+</td>
</tr>
<tr>
<td>Failure of AR due to Tensile Stress</td>
<td>Does not Fail</td>
<td>100+</td>
</tr>
</tbody>
</table>

## Analysis of CR due to Static Loading Caused by Tire

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure of CR due to Shear Stress</td>
<td>Does not Fail</td>
<td>100+</td>
</tr>
<tr>
<td>Failure of CR due to Tensile Stress</td>
<td>Does not Fail</td>
<td>100+</td>
</tr>
</tbody>
</table>

## Analysis of T Beam due to Static Loading Caused by Tire

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure of T Beam due to Shear Stress</td>
<td>Does not Fail</td>
<td>100+</td>
</tr>
<tr>
<td>Failure of T Beam due to Tensile Stress</td>
<td>Does not Fail</td>
<td>100+</td>
</tr>
</tbody>
</table>

## Analysis of Base Plate due to Static Loading Caused by Tire

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure of Base Plate due to Shear Stress</td>
<td>Does not Fail</td>
<td>100+</td>
</tr>
<tr>
<td>Failure of Base Plate due to Tensile Stress</td>
<td>Does not Fail</td>
<td>100+</td>
</tr>
<tr>
<td>Failure Analysis in SolidWorks</td>
<td>Does not Fail</td>
<td>8</td>
</tr>
</tbody>
</table>

## Analysis of AR Pin due to Static Loading Caused by Tire

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure of AR Pin due to Shear Stress</td>
<td>Does not Fail</td>
<td>4</td>
</tr>
<tr>
<td>Failure of AR Pin due to Tensile Stress</td>
<td>Does not Fail</td>
<td>5</td>
</tr>
</tbody>
</table>

## Analysis of Trolley Pin due to Static Loading Caused by Tire

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure of Trolley Pin due to Shear Stress</td>
<td>Does not Fail</td>
<td>37</td>
</tr>
<tr>
<td>Failure of Trolley Pin due to Tensile Stress</td>
<td>Does not Fail</td>
<td>2</td>
</tr>
</tbody>
</table>

## Analysis of AR due to Dynamic Loading Caused by Tire

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflection at end of AR</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Deflection of AR Flange</td>
<td>0.000013&quot;</td>
<td>N/A</td>
</tr>
<tr>
<td>Deflection of Who人 System at the End of AR</td>
<td>0.233&quot;</td>
<td>N/A</td>
</tr>
</tbody>
</table>

## Analysis of Trolley due to Dynamic Loading Caused by Tire

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure of Trolley</td>
<td>Does not Fail</td>
<td>89</td>
</tr>
</tbody>
</table>

## Analysis of Dynamic Effects Caused by Acceleration/Deceleration on a Straight Road

<table>
<thead>
<tr>
<th>Condition</th>
<th>Result</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sliding on Frame Rails</td>
<td>No sliding anticipated</td>
<td>93</td>
</tr>
<tr>
<td>Deflection of Design Impacting Cab</td>
<td>Deflection will not impact</td>
<td>0.04493% of available space</td>
</tr>
<tr>
<td>Failure of Camping Bolts In Shear</td>
<td>Bolts will not fail</td>
<td>122</td>
</tr>
<tr>
<td>Failure of Clamping Bolts in Tension</td>
<td>Bolts will not fail</td>
<td>2.4</td>
</tr>
</tbody>
</table>

## Analysis of Dynamic Effects Caused by Acceleration/Deceleration on a Curved Road

<table>
<thead>
<tr>
<th>Condition</th>
<th>Result</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sliding on Frame Rails</td>
<td>No sliding anticipated</td>
<td>4.3</td>
</tr>
<tr>
<td>Deflection of Design Impacting Cab</td>
<td>Deflection will not impact</td>
<td>0.0453% of available space</td>
</tr>
<tr>
<td>Failure of Camping Bolts In Shear</td>
<td>Bolts will not fail</td>
<td>122</td>
</tr>
<tr>
<td>Failure of Clamping Bolts in Tension</td>
<td>Bolts will not fail</td>
<td>2.4</td>
</tr>
</tbody>
</table>

## Analysis of Dynamic Effects Caused by A Sudden Impact

<table>
<thead>
<tr>
<th>Condition</th>
<th>Result</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sliding on Frame Rails</td>
<td>No sliding anticipated</td>
<td>1.3</td>
</tr>
<tr>
<td>Deflection of Design Impacting Cab</td>
<td>Deflection will not impact</td>
<td>0.3388% of available space</td>
</tr>
<tr>
<td>Failure of Camping Bolts In Shear</td>
<td>Bolts will not fail</td>
<td>12.5</td>
</tr>
<tr>
<td>Failure of Clamping Bolts in Tension</td>
<td>Bolts will not fail</td>
<td>1.22, Recommend U-bolt replacement after impact</td>
</tr>
</tbody>
</table>

## Analysis of Dynamic Effects Caused by Vertical Movement of the Tire

<table>
<thead>
<tr>
<th>Condition</th>
<th>Result</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical condition at pins</td>
<td>Use tool-steel</td>
<td>6</td>
</tr>
</tbody>
</table>
Section 1: Detailed Design

Section 1.2: Design Problem

Navistar desires a dual spare tire carrier for the PayStar® (5000-MV) specifically the Heavy Equipment Transport Truck (HETT, Pictured in Figure 4) for the Israeli Ministry of Defense. This is specifically required on the HETT tractor based on the requirements from the customers IMOD (Israeli ministry of defense). There is currently nothing designed for commercial tractors that can be leveraged. This is because it is less expensive to call an emergency repair company than to spend extra fuel and waste payload capacity carrying spare tires in the incident that one is needed. However, this particular Navistar client specifically requested a dual spare tire carrier.

Section 1.3: Requirements and Specifications

The Spare Tire Carrier will be used in on and off road applications and it must be compatible with the existing International PayStar® HETT. This design must ultimately meet the constraints and requirements as given by the final customer.

- Tires and location – This tire carrier must carry exactly two tires and they must be stowed above the frame rails along the back of the cab.
- Size – The spare tire carrier system cannot exceed the height of the cab, and cannot exceed 2.56 meters in width. A circle of 4 meters in diameter centered on the king pin of the fifth wheel and extending like a cylinder to the height of the cab, must remain clear.
- Persons required to operate – One person must be able to operate the spare tire carrier system in both loading and unloading operation.
Section 1: Detailed Design

- Safety Features – The design must implement a grab handle to assist the operator in getting on and off the catwalk safely using the currently provided steps.

Section 1.4: Fixed Parameters

The given or fixed parameters are in place to protect the integrity of the base vehicle. This allows for the design to be a simple aftermarket part and will not require any engineering changes to the base vehicle. This also allows for a quick and smooth transition to add this design to any available International PayStar® HETT. The fixed parameters for the spare tire carrier system are:

- Must be operable by one person
- Must stow two spare tires behind the cab
- Must fit on the International PayStar® HETT
- Must stay beyond 2 meters from the center of the fifth wheel
- Must accommodate all trailer connectors, 1x – 15 pin connector, 2x – 7 pin connector, 2x – air gladhands
- Must use only the given and available sources of power, 12-volt electrical, 24-volt electrical, and pneumatic

Section 1.5: Design Variables

As the design for this tire carrier comes to fruition, so too will the necessary design variables. This is a very open ended task. As long as the design meets the given requirements, specifications and parameters any design, geometry or mode of operation can be considered. This part will be sourced to a supplier of Navistar. This selection process of the supplier will allow the design team to manage the conditions surrounding the manufacturing of this design based around the ability of the given supplier. The operating conditions have limited amounts of variability. Any manually operated mechanism must accommodate safe ergonomic standards based upon Navistar commercial designs.

**Hardware:**
- International PayStar® HETT with 51” sleeper and horizontal exhaust
- The spare tires to be carried are 315/80R/22.5 Goodyear’s mounted on 22.5” Painted steel 10-stud 9.00DC rim

**Operating Conditions:**
- Electrical systems can be either 12 volt or 24 volt
- A pneumatic regulator can be used to provide pressures of 60 – 120 psi
- Manual operations can be changed if still within a safe ergonomic load

Section 1.6: Limitations and Constraints

The limitations and constraints set forth by Navistar are set in a way that the completion of this design will be economically viable for the company as well as meet timing requirements to allow for the completion of the current customer contract.

- Less than $1750 piece price
- A robust off-road design
Section 1: Detailed Design

- The design should allow manufacturing of these carriers to begin before May 31st 2013

Section 1.7: Additional Considerations

Additional considerations account for external factors that may affect the performance of the design. This includes initial quality from the supplier as well as adverse external conditions that may affect the integrity of the carrier.

- Design must withstand desert conditions
  - Desert temperatures vary from 43°F to 115°F
  - Extreme dryness interrupted by sudden downpours including heavy rain and hail
  - Extreme dust conditions
- Finished product must leave the supplier in operable condition
- Design must eliminate opportunities for operator injury
- The max side to side tilt of the truck will be 20°
- Navistar advises keeping a 1 inch clearance from the back of the cab
- Designs will have a usage time of 15 minutes, 7.5 minutes to unload a tire and 7.5 minutes to reload a tire

Section 1.8: Design Revisions

Section 1.8.a: First Design Revision

Upon meeting with Navistar on January 23, 2013 they requested a modal analysis, strength load cases, and durability load cases for our design. They requested we perform these tasks in SolidWorks. The requirements for the modal analysis are that the first natural frequency of the structure should be greater than 15 Hz. The strength load cases are 4g’s applied in the lateral direction, 4g’s applied in the longitudinal direction, and 6g’s applied in the vertical direction. The requirements for the strength load cases are that the stresses should not exceed the yield strength (50,800 psi) of each respective metal. The durability load cases are 2.67g’s applied in the lateral direction, 2.67g’s applied in the longitudinal direction, and 4g’s applied in the vertical direction. The requirements for the durability load cases are that the stresses should not exceed the endurance limit (30,450 psi) of each respective metal. The endurance limit is taken as half of the ultimate tensile strength (60,900 psi). Figure 5 shows that the natural frequency of our structure was 17.259 Hz which is greater than 15 Hz. When the durability load cases were applied the stresses exceeded the 30,450 psi limit which was not acceptable. Figure 6 shows that the 2.67g’s applied in the lateral direction induced stresses of 41,206 psi in the structure. The maximum stresses were in the base plate at the bolt holes. As seen above Figure 7, the issue was corrected by changing the base plate to a box tube material.
Section 1: Detailed Design

### Table 2: Results Summary after Revision 1

<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s Modulus (psi)</th>
<th>Yield Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI 1020 steel</td>
<td>$2.9 \times 10^7$</td>
<td>50,991.10</td>
</tr>
</tbody>
</table>

#### Frequency Analysis of Entire Design

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>First mode (Hertz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Analysis</td>
<td>Does not Fail</td>
<td>17.259</td>
</tr>
</tbody>
</table>

#### Durability Analysis - Stresses due to Xg’s of loading

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.67g’s in Lateral Direction</td>
<td>Does not Fail</td>
<td>3.72</td>
</tr>
<tr>
<td>2.67g’s in Longitudinal Direction</td>
<td>Does not Fail</td>
<td>1.87</td>
</tr>
<tr>
<td>4g’s in Vertical Direction</td>
<td>Does not Fail</td>
<td>9.08</td>
</tr>
</tbody>
</table>

#### Strength Analysis - Stresses due to Xg’s of loading

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>4g’s in Lateral Direction</td>
<td>Does not Fail</td>
<td>2.50</td>
</tr>
<tr>
<td>4g’s in Longitudinal Direction</td>
<td>Does not Fail</td>
<td>1.24</td>
</tr>
<tr>
<td>6g’s in Vertical Direction</td>
<td>Does not Fail</td>
<td>6.08</td>
</tr>
</tbody>
</table>

---

**Figure 5: Modal analysis of spare tire carrier**
To fix the durability load case issue we replaced the ½" steel base plate with a steel tube 14" wide, 90" long, 3" tall, and 5/8" wall thickness. When the durability load cases were applied the stresses were all under the 30,450 psi limit as seen in Figure 7-Figure 9.
Figure 8: 2.67g’s longitudinal direction

Figure 9: 2.67g’s lateral direction

The strength load cases were all under the required 50,800 psi. The strength load cases can be seen below in Figure 10–Figure 12.
Section 1: Detailed Design

Figure 10: 6g’s vertical direction

Figure 11: 4g’s longitudinal direction
Another issue raised by Navistar Engineer was the diameter of the pins connecting the wheels to the AR, CR, and Trolley. The small diameter pins had low safety factors in tension. The pin size was originally determined by the size of the wheels selected. We were only able to find one wheel that was the correct width and diameter suitable for our design. Using higher grade steel was the solution we proposed, but the Navistar Engineers were more comfortable with using larger diameter pins. To solve this issue we found needle roller bearings that were of adequate width (Figure 13). We then designed a wheel that would press over the needle roller bearing (Figure 14). The wheel assembly would then press onto the pins.
Figure 13: Part drawing of wheel

Figure 14: 3d model of the bearing
Section 1: Detailed Design

Section 1.8.b: Second Design Revision

After moving forward several times with Navistar’s approval, we were also then stopped several times and told to change directions. The most recent change they requested was developing an entirely new design based upon a tubular concept that Pat Kelley wanted to see played out. We followed the advice of our project advisor Dr. Libii who stated “As long as they have not scrapped the project, please, do what Navistar says and stay in close contact with them,” and pursued developing the design. After developing this tubular based design (Figure 15) for quote, it was met with a great deal of enthusiasm from Navistar, and they were excited to then get this one built for testing.

This second design revision utilizes the same base, trailer connections, and tire containment. The vertical tower is narrower to accommodate the T tube. The most significant change is in the horizontal top piece. This one utilizes a tube (AR) that slides side to side in a larger tube (CR) that houses it. There is a bearing slotted into the smaller tube to provide smooth gliding action. The AR tube doesn’t roll in the CR tube during operation because at least one of the two lifting tabs extrudes through the slots cut in the CR tube. FEA was performed on this design using SolidWorks the same way it was performed on the first design. Figure 16 shows the naming convention for the tubular design. Figure 17-Figure 24 show the Solidworks results of the stresses and deflection in each component from the weight of the tire.
Figure 16: Naming convention of the tubular design
# Section 1: Detailed Design

## Table 3: Table of Results after Revision 3 to the Design.

<table>
<thead>
<tr>
<th>Material</th>
<th>Young's Modulus (psi)</th>
<th>Yield Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI 1020 steel</td>
<td>$2.9 \times 10^7$</td>
<td>50,991.10</td>
</tr>
</tbody>
</table>

### Results Summary Revision 3

#### Base Material

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure of AR due to Shear Stress</td>
<td>Does not Fail</td>
<td>100+</td>
</tr>
<tr>
<td>Failure of AR due to Tensile Stress</td>
<td>Does not Fail</td>
<td>100+</td>
</tr>
</tbody>
</table>

#### Analysis of AR due to Static Loading Caused by Tire

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure of CR due to Shear Stress</td>
<td>Does not Fail</td>
<td>100+</td>
</tr>
<tr>
<td>Failure of CR due to Tensile Stress</td>
<td>Does not Fail</td>
<td>100+</td>
</tr>
</tbody>
</table>

#### Analysis of T Beam due to Static Loading Caused by Tire

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure of T Beam due to Shear Stress</td>
<td>Does not Fail</td>
<td>100+</td>
</tr>
<tr>
<td>Failure of T Beam due to Tensile Stress</td>
<td>Does not Fail</td>
<td>100+</td>
</tr>
</tbody>
</table>

#### Analysis of Base Plate due to Static Loading Caused by Tire

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure of Base Plate</td>
<td>Does not Fail</td>
<td>100+</td>
</tr>
</tbody>
</table>

#### Analysis of AR Pin due to Static Loading Caused by Tire

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure of AR Pin due to Shear Stress</td>
<td>Does not Fail</td>
<td>1.69</td>
</tr>
<tr>
<td>Failure of AR Pin due to Tensile Stress</td>
<td>Does not Fail</td>
<td>3</td>
</tr>
</tbody>
</table>

#### Analysis of AR due to Static Loading Caused by Tire

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflection at end of AR</td>
<td>.0802&quot;</td>
<td>N/A</td>
</tr>
<tr>
<td>Deflection of Whole System at the End of AR</td>
<td>0.471&quot;</td>
<td>N/A</td>
</tr>
</tbody>
</table>

#### Frequency Analysis of Entire Design

<table>
<thead>
<tr>
<th>Condition</th>
<th>Results</th>
<th>First mode (Hertz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Analysis</td>
<td>Does not Fail</td>
<td>15.2</td>
</tr>
</tbody>
</table>

#### Durability Analysis - Stresses due to Xg's of loading

<table>
<thead>
<tr>
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<th>Safety Factor</th>
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<td>1.82</td>
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<tr>
<td>4g's in Vertical Direction</td>
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#### Strength Analysis - Stresses due to Xg's of loading

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<td>2.33</td>
</tr>
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</table>
Section 1: Detailed Design

Figure 17: Stresses induced in AR tube from the weight of the tire

Figure 18: Deflection of AR tube from the weight of the tire
Section 1: Detailed Design

Figure 19: Stresses in whole system from the weight of the tire fully extended

Figure 20: Deflection from weight of tire fully extended
Section 1: Detailed Design

Figure 21: Stresses from the weight of the tire with AR fully extended

Figure 22: Deflection from the weight of the tire with AR fully extended
We again performed the modal analysis, strength load cases, and durability load cases. The first natural frequency was 15.164 Hz which was above the required minimum of 15 Hz (Figure 25). The highest stress for the durability load cases was in the lateral direction (Figure 26-Figure 28). The max stress of 27,837 psi was below the required maximum of 30,450 psi. The highest stress for the strength load cases was again in the lateral direction (Figure 29-Figure 31). The max stress of 41,704 psi was below the required maximum of 50,800 psi.
Section 1: Detailed Design

Figure 25: First Natural Frequency

Figure 26: 2.67g's in lateral direction
Section 1: Detailed Design

Figure 27: 2.67g’s longitudinal direction

Figure 28: 4g’s vertical direction
Figure 29: 4g’s lateral direction

Figure 30: 4g’s longitudinal direction
Figure 31: 6g’s vertical direction
Section 2: Building

Section 2.1: Building Process

After Navistar was unable to provide the funding for this project, we then turned to the IPFW Mechanical Engineering Department for support. They were gracious enough to provide our team with a budget of $600 on April 29, 2013. Once our team had this funding, we then set out to determine how to build the most critical portions of our design. The obvious answer was that the frame and sliding arm must be built to verify that the design can indeed move a tire on and off of the back of the truck.

With this limited budget, our team got very creative in our attempt to build a working prototype and get the job done. The steel pipes for the sliding arm were purchased from the Metal Supermarket in order to make sure the pipes were dimensionally correct to allow proper sliding when completed. The portions of steel necessary to make up the remainder frame were purchased for $0.35 a pound from a local surplus steel yard. Some of the smaller components like D-ring and cutting wheels used in manufacturing were purchased from Tractor Supply Co. Kyle donated some old bearings that came from roller skates that we repurposed to use in our design. Mike lent the team a chain hoist from his garage to further save some money. The design was built in a friend’s garage by the three of us. It is in these ways that our team came together and worked through the challenges before us to get a working prototype built.

![Figure 32: Steel used in the manufacturing process](image)

The first step was to manufacture the large (CR) pipe that would hold the sliding (AR) pipe. We used a ½’ by ½’ piece of angle iron as a straight edge to keep the channel being cut straight and parallel. The channels were cut out using an angle grinder with a 4 ½” cutting wheel. Once the sides of the channel were cut out, we then needed to cut the narrow section at the end that still held the piece of metal in place. The area was too small to insert a cutting wheel, so we used an oxygen-acetylene torch to cut this small section.
The next piece to assemble was the smaller sliding (AR) arm. The first order of business was to establish a starting line parallel to the pipe. This was done by using a torpedo level and determining the top most part on each end of the pipe when it was laid flat. From here, we then used a piece of plastic cord that was the exact circumference of the pipe and marked it into thirds. This was then wrapped around each end and allowed us to mark each end in thirds that were parallel to each other and the pipe. A chalk line was used to connect the marks on each end, giving three straight lines to use as one of the dimensions for locating the bearing locations. On each line a bearing mark was made with an automatic punch at 2 inches in from each end and the exact center of each line as well. Using the punch marks as a guide we then used a pilot drill bit at each location. After each spot was pilot drilled, we then used a step-bit to enlarge to holes to their proper diameter. Just a little bit more clearance was needed for the bearings so we then used a grinder with an abrasive grinding wheel to remove more material where the bearing sits. A 5/16” rod was then cut into 1 ½” sections to act as pins for the bearings. We placed washers on each side of the bearing then welded the pins into place over the clearance holes we had just made. The team then checked that the AR could easily slide through the CR before proceeding. The arm slid nicely so it was on to the finishing touches for this top piece. Holes were drilled at each end of the sliding arm and aligned along the bottom with the channel. These holes were used to mount an eyelet. These eyelets are described in the design, and they have multiple functions. They are the mounting loops for the chain.
Section 2: Building

hoist, guides that keep the arm located correctly in the channel while the other loop is fully extended as it moves the tire, and finally these eyelets also serve as the stops to prevent the arm from sliding all the way out in either direction. A hole was also drilled through the top of each pipe when they were in the stowed position. This hole is for a safety pin that prevents the arm from sliding while the truck is in motion.

Figure 35: Bearings welded on the AR tube.

Figure 36: AR tube assembly inside CR tube.

The upright piece (T-beam) was made out of 4 x 4” square tubing. The top was cut to the radius of the CR with the oxygen-acetylene torch. This was done so that the CR nested nicely onto the vertical piece and provided a good area to put a nice strong weld. The bottom of the T-beam was welded in the center of a section of 6 x 2” rectangular tubing. This rectangular tubing represented the base of our design. Two additional pieces were added to the base piece to give the design a larger foot print. This was done so the design would stay upright in the back of a pickup truck since Navistar could not provide a vehicle for
which to test the design on. To complete the design we added a D-ring to the upright T-beam and the base piece. These served as anchor points for our testing tire. Navistar could not provide a tire, but we were able to borrow a semi-truck rim from a friend to act as our flat tire for testing purposes.

Section 2.2: Completed Build

The design is now complete to the absolute best of our ability and within the budget we were given. Our team spent approximately $500 of our budget to create a representative prototype capable of fulfilling the critical tests that were needed. This was a great learning opportunity for our team to actually use tools and equipment we did not have a lot of experience with previously. It was also quite fun to get out in the shop and build something you designed.
Section 3: Testing

Section 3.1: Testing Parameters

Based upon an initial conference call with Navistar, it was found that the tests were to be mainly functional in nature. That is they were to meet the operational requirements and specifications set forth at the beginning of this project. Durability testing using the shaker lab or test track is extremely expensive. These can easily cost tens of thousands of dollars for simple tests even when performed with Navistar’s own equipment. It was for this reason that Navistar agreed to the following test parameters. The prototype design must meet or exceed the following criteria.

- Two tires are stowed behind the cab
- Final design does not contact cab or reach within 2 meters of the fifth wheel
- Can be safely operated
- Can be operated by one person
- Fit on an International PayStar HET
- Safely hold all (5) trailer connections
- Unloading/loading of tire is possible in under 7.5 minutes each

Unfortunately, Navistar was not able to provide our team with a truck to test this design. Because they did not receive the contract, they did not make any more HETT’s, therefore, the only HETT currently in existence is still in Israel. Getting our team and our design there was outside of our budget, so instead, we tested our functional prototype in a way that would give us confidence that the actual design would pass testing as well. It is unfortunate that we could not conduct testing identical to the way we planned to earlier in the semester, but that is the way business needs change. Our team has learned this semester how to adapt and be flexible to get a job done in the face of changing conditions. In the following descriptions of the tests performed, we will provide correlation as to what we were able to accomplish with our limited budget to the type of test that was originally planned earlier in the semester.

Section 3.2: Testing Procedures:

A detailed and clear procedure (step by step) of the testing processes is to follow.

Section 3.2.a: Testing Procedure (Visual):

Test Parameter: Complete visual inspection to insure tire carrier design does not contact cab in any manner.

Conclusion: This inspection was performed by taking very careful dimensions of our finished prototype. The prototypes dimensional footprint fit within the prescribed footprint we had to work with that was given to us by Navistar.

Test Parameter: Complete visual inspection to verify two tires are stored behind the cab.
Section 3: Testing

**Conclusion:** This inspection was also done by taking careful dimensions of the design which showed that it could be safely located behind the cab. It was proven both dimensionally and with the aid of our flat tire, that the system could store two tires.

**Test Parameter:** Complete visual inspection of the vehicle to verify it is the International PayStar HET and that the tire carrier correctly fits on the tractor.

**Conclusion:** The actual truck was in Israel, but we were able to verify that the prints we were using were indeed from the International PayStar HET. We were also able to verify our prototype did fit into the specified area.

**Test Parameter:** Complete visual inspection of the trailer connections. Verify they are clear and tucked away and do not impose harm on any operator or equipment.

**Conclusion:** Navistar could not provide the trailer connections for testing. Our group viewed these as a “non-critical” component, because as long as the connections fit there is nothing to break. The bracket to hold the trailer connections is nothing more than a piece of sheet metal with several mounting holes drilled in it. Our prototype left adequate room for this bracket and our team has full confidence the design will indeed work.

**Section 3.2.b: Testing Procedure (Distance):**

**Test Parameter:** Measure distance from center of the fifth wheel to the tire carrier design. Verify the distance is over 2 meters.

**Conclusion:** The process to test that the design stays out of the clearance area is very simple. The part of the design nearest to this circle is at the center and where the tires are slightly wider than the design. By taking the width of the design and tires at these locations, we can then transpose those measurements to the master model provided by Navistar to ensure that the design will not contact the trailer. The design passed this test.

**Section 3.2.c: Testing Procedure (Loading and Unloading):**

Items required to complete test:
- Stop Watch
- Tire Carrier mounted back of cab on host vehicle with step tool box
- Spare Tire
- Manual Chain Hoist
- Lifting Sling

1. Make sure host vehicle is parked and emergency brake is on.
2. Start you stop watch timer.
Section 3: Testing

(4.) Remove safety pin from top of bar, so the arm can slide left and right.

(5.) Locate tire strap on tire [3] Remove one of the tire straps from the tire you want to unload.

(6.) Move the top sliding bar over center of the tire for unloading.
Section 3: Testing

(7.) Wrap lifting sling around tire and through bottom hook on manual chain hoist [5].

(8.) Latch top hook of chain hoist through the eye hole of the sliding arm [6].

(9.) After the tire is secure, lift the tire by using chain hoist.

(10.) Safely exit the catwalk and return to the ground

(11.) Pull tire and arm out by pulling on the chain hoists operational chain. This chain will always hang at the same length and will not raise or lower the hoist as long as both sides of the chain are gripped. Continue sliding arm out this time by pulling the tire until arm is fully extended. [7]
Section 3: Testing

(12.) After arm is fully extended begin to lower tire to the ground using chain hoist. [8]

(13.) When tire is resting on the ground. Remove tire strap, and chain hoist.
(14.) Stop the stop watch. Ensure the lowering process has taken less than 7.5 minutes.

(15.) Start stop watch again, this time for the loading process.

(16.) Reverse steps 6 – 15 (with exception of the original stop watch instructions) to load tire back up to stored position.

(17.) Stop the stopwatch. Ensure the loading process has taken less than 7.5 minutes.

(18.) As a safety double check, ensure all pieces are safely stowed and tightened. There should be no movement of any part of this when the tractor begins travel again.

Section 3.3: Completion of Testing

After the functional operation of the tire carrier it can be determined whether or not the design met all other requirements and specifications set forth in the test parameters. During the exercise of loading and unloading the tire, was this operation done by only one person, and is that person confident it can be performed again safely in the future? If both of these questions are met with an answer of “yes” and all other parameters are met, then it can be determined that this design has successfully met all test parameters.

Section 3.4: Testing Results

The prototype we were able to build did indeed fit into the allowable space on the back of the HETT tractor. Figure 39 shows the width of the prototype is less than the allowable 14”. This means the prototype would not contact the back of the trailer and would stay at least two meters from the king pin. We only had one rim but it was clear that the prototype was capable of carrying two tires. The trailer connections were not available but the area in which the trailer connections would reside was never entered. The trailer connections posed no danger to the operator and were never in any danger of being damaged. During testing Dan Voors was able to unload the tire in 2 minutes and 46 seconds. He was able to load the tire in 3 minutes and 54 seconds. The loading time takes longer because it takes more time to strap the tire in place than it does to unstrap it. Figure 40-Figure 46 shows Dan unloading the tire. Figure 47 clearly shows that even if we had used the actual tire for an HETT tractor we would still be able to lower it to the ground without contacting the tractor. We even showed in Figure 48 that if they decided to use an even larger tire it could still be lowered by turning the tire parallel to the truck. Dan was able to successfully load and unload the tire by himself well under the required time, and was able to do so without injuring himself or damaging the tractor.
Section 3: Testing

Figure 39: Side view of Prototype showing width

Figure 40: Prototype set up in the back of Dan's truck and Dan removing chain hoist from toolbox
Section 3: Testing

Figure 41: Dan bringing chain hoist into position and hooking it on the eyelet

Figure 42: Dan wrapping chain hoist around the rim, and beginning to remove tire strap
Section 3: Testing

Figure 43: Dan raising the rim with the chain hoist and sliding the rim out beyond the edge of the tractor

Figure 44: Dan lowering the rim to the ground and then descending the ladder to the ground
Section 3: Testing

Figure 45: Dan removing chain hoist from rim and rolling it away from the tractor

Figure 46: Dan with the rim free and clear of the tractor
Section 3: Testing

Figure 47: Center of rim 24" from side of tractor leaving ample room to lower an actual HETT tire

Figure 48: Side of rim still 16" from side of tractor showing larger tires can be turned sideways and safely lowered
Section 4: Evaluation and Recommendations

Section 4.1: Evaluation

Based upon discussion and investigation of the final design, it was determined by our Senior Design team and our Navistar contact Brandon Bultemeier, as well as his Director Pat Kelley, that the final concept did indeed meet or exceed all design requirements and specifications set forth by Navistar at the beginning of this project. However, they were not awarded the anticipated contract to supply the HETT trucks to the Israel Ministry of Defense. This happens in the business world from time to time as the demand and market for certain products changes. Due to the loss of this contract Navistar could no longer afford to fund this project due to the freeze in budgetary spending.

In December, our team estimated the initial cost of the prototype to be approximately $3,880. This was in excess of the arbitrary cost of $1,750 Navistar had given us. The $1,750 came to light because it was the cost of an initial design Navistar pulled together by cutting and welding an engine hoist and some cheaply made sheet metal holders together. This design had to be worked on during the first use, because it was not even robust enough for this trial. This creation that only cost $1,750 could not be operated by one person, Brandon Bultemeier had said late in the fall semester that the $1,750 “may have been a little unrealistic” after we initially mentioned the growing cost of this project. On our first conference call with Navistar in January, there was no real issue with the cost. Pat Kelley acknowledged the higher cost, but then followed it up with “it sounds like we have a better mouse trap here.” Once given the “go ahead” to receive formal quotes, Milton manufacturing priced this design at $4,554.77 for the prototype and a price of $2,904.35 if a quantity of 50 were ordered. This means that our original estimate was quite good, only off by 17%. Navistar had no initial problem with this cost until the purchasing department got involved. They then requested additional quotes, these additional quotes took more time, but eventually supported that Milton was the most cost effective option. We were then told by Director Pat Kelley that funding would be provided for this. Navistar then came back again some time later and stated that they would like to see an entirely new design to try and get some cost reduction in the design. We then made a new design and sent that out for quote. Milton quoted the first prototype at $3,238.82 and a price $2,060.07 if 50 were ordered. This took the production cost down nearly $900 dollars. We were then told by Pat Kelley that we had successfully met the budget requirement and he would talk to the appropriate people at Navistar to secure the funding. This never transpired. Due to Navistar’s loss of that particular contract, they could not release any money towards our senior design project.

The testing parameters and test plan developed for this project are very functional in nature. They both revolve around whether or not the design fits on the tractor and whether or not it can successfully load and unload a tire with only one person operating the design.

On April 29, 2013 we received $600 dollars from the IPFW Department of Engineering to try and build a working prototype. A task we were able to successfully accomplish. The prototype was able to stow two tires behind the cab without contacting the cab or interfering with the trailer swing. The prototype was operated successfully with a single operator and was operated multiple times without a single injury. By
Section 4: Evaluation and Recommendations

measuring the prototype we were able to verify that it would indeed fit on the International Paystar HETT. The prototype was able to load/unload a tire in under the required maximum of 7.5 minutes each. The prototype was also able to hold all 5 trailer connections safely. We determined this by carefully watching the area where the trailer connections would be.

Because the functional prototype passed all critical testing, our team has deemed this design a success and has full confidence in it in the future. A complete timeline of the events transpiring with Navistar can be found in the Appendix.

Section 4.2: Recommendations

Our first recommendation is to weld the CR tube to the top of the T beam in increments or to stitch weld the two together. The excessive heat from welding the whole thing continuously caused the CR tube to become deformed (Figure 49). The heat caused the ends of the T beam to bend downward slightly. In mass production, this bending during the welding process could also be remedied by utilizing a welding jig or fixture to hold the design in place while welding. Another recommendation is to put horseshoe type collars around the ends of the CR tube. The slot cut into the CR tube allowed the ends to flare open. A horseshoe type collar would make the ends more rigid and prevent the tube from flaring open while still allowing the arm and chain hoist to freely slide. Our last recommendation is to angle the slot openings (Figure 50). This will allow the eyelets to re-enter the tube easier during loading and unloading of the spare tire.

Figure 49: Ends of CR tube can be seen to be bent downwards slightly
Figure 50: Angled slot opening
Conclusion

“Navistar Defense is proud to advise your team that the design now satisfies our expectations. This memo is to acknowledge and congratulate you on an excellent job!” This is a direct quote from a letter written by Pat Kelley and Brandon Bultemeier at Navistar. This letter, which can be found in the appendix, states how pleased Navistar was with this design and how unfortunately they can longer provide funding for this project.

This semester’s project has been a great learning experience all unto itself. Through the previous work experience our group members have had, we all agree that this has been the most “real-world” project we have had in a school setting. This may be in part due to the fact that this project did not follow the perfectly designed curriculum for the class. We experienced real world setbacks. These setbacks included everything from management changing decisions to working with a hesitant purchasing department. In hindsight, all of these problems have made us stronger engineers more capable of facing challenges in the workplace. We have taken away some excellent lifelong lessons. We have learned the value of organizing and documenting forms of communication, be they conference calls or email. This can be difficult when using calls. Calling people is a much more effective way to get things done, but it can be harder to trace. We have also learned more about the purchasing process large companies use to order parts and release funding. Often times purchasing will not have the urgency for a project that engineering has. It is here we learned as engineers to step up and stay on top of purchasing as well as to contact suppliers on our own to constantly follow up and keep the urgency on them as well. We have also learned the constant driving force in business and engineering, money. Without money, projects don’t happen, no matter how great they may be or how much someone else would like to see them done.

The biggest lesson we have learned though, is to keep after things and try until the very end. Although Navistar was constantly changing decisions and eventually pulled all funding, we kept working hard to provide the best results we possibly could. We worked to provide them with all the information they would need to “hit the ground running” when this project is reopened. This was in an effort to create as much sustainability as possible into this project. Without making certain that the information and work done on this project is crystal clear for another engineer, it would prove to be useless in the future. As engineers working for companies of all sizes, we may be pulled on or off projects all the time. This means that we must be comfortable with and learn how to present our work in such a way that another engineer can pick up our work and continue where we left off.

In conclusion we deem this Senior Design II project a success! Though we faced certain challenges and setbacks our team was able to persevere, build a working prototype, and perform functional testing meeting the requirements of Senior Design II.
References


A - 1/23 – Conference call with Navistar to go over current design and get funding approved. The team was given “take-aways” to complete before they would give approval. These take-aways included some additional FEA on critical portions and modal analysis. Navistar was very aware our estimated cost is $3,880. Pat Kelly, the director, recognized this cost and admits our team’s concept is a much better design. Brandon Bultemeier in a previous conversation mentioned the target cost $1,750 may have been unrealistic. $1750 was given because an initial attempt at piecing together a prototype with an engine hoist and some mismatched sheet metal $1,750. This early attempt by the Navistar mechanics resulted in a failure. It didn’t meet the necessary criteria, it could not be operated by one person, and even with two people it did not work well at all. Our design was held to an even stricter set of criteria.

B - 2/4 – Follow up meeting with Navistar. All design criteria from Joe Calash (Lead vehicle Engineer) were answered. To meet the criteria, some changes were made. This led to changing the wheels and bearings and the bottom plate. A Gant Chart was presented that laid out timing for the remainder of the semester. This included timing for getting quotes, issuing a PO, build time, and test time. There were no additional issues with the design. Approval to begin quoting was given from Brandon Bultemeier (Program Manager) and Patrick Kelley (Director Product Development). Navistar advised to create data package and to quote with Milton Manufacturing.

C - 2/13 – Data package was created and sent to Milton for quote.

D - 3/1 – Milton quotes the cost at $4,554.77 for the prototype and $2,904.35 each if 50 are purchased. This quote was only differed by 17% from our original estimate. Conference call with Navistar ends with Pat Kelley telling us he will talk to the appropriate person and secure our PO.

E - 3/5 – Navistar now says that additional quotes are needed before a PO is issued. This was the first we heard of this, the Navistar Purchasing group gets involved.

F – 3/6 - Purchasing sends out additional quotes to interested suppliers.

F - 3/15 – Purchasing agrees Milton is providing the most competitive price. Brandon agrees to work with the proper manager to get a PO issued and funding released.
Appendix

G - 3/20 – Navistar now raises concerns for the first time that our team has not been made aware of prior. The cost has now become an issue and they require additional information before releasing a PO.

I – 3/22 – The timing is now starting to slip and our team becomes concerned that Navistar may not provide funding for our design. We reach out to our advisor showing the timeline of events, explaining the situation, and sharing our concern that Navistar may no longer be willing to fund this project. We ask for help and guidance in how to handle this situation and what we need to do moving forward. Dr. Libii advises “These things happen. As long as they have not scrapped the project, please, do what Navistar says and stay in close contact with them.” We followed this advice exactly and as the letter from Navistar states, we kept an open line of communication with Navistar throughout the entire project.

H–3/27 - Team creates tube design for cost reduction, all components were re-evaluated using Solid Works per the criteria set forth from Navistar. The technical data package was created and sent to Milton for re-quote.

J – 4/9 – Quote received from Milton, and immediately shared with Navistar.

K – 4/11 – Conference call with Navistar to discuss the new quote. Director said he is going straight from this meeting to go and get our PO released, he tells us it will be done by the next day, Friday, at the latest.

L – 4/15 - Navistar informs team that the program is officially canceled, as the contract for the HETT truck was not awarded to Navistar. Our team immediately notifies Dr. Libii and Dr. Raez, we personally talk to Dr. Raez.

M – 4/22 - Official letter is received from Navistar. As advised by Dr. Libii, we continue to work with the course coordinator Dr. Raez and Department Chair Dr. Younis to determine the next course of action.

N - 4/29 – IPFW agrees to provide $600 in funding for this project.

O-4/25 – Dr. Libii approached hallway at IPFW, has not read letter from Navistar, “Someone must bit the bullet”.


Q- 5/1 – Meeting with Dr. Raez Dr. Younis display prototype, Email sent to Dr. Libii asking him to view our prototype. His response was 5 reasons why he cannot.

R-5/2 – Meeting with Dr. Yen
Figure 51: Quote from Milton for original design
Dear Bob:

Thank you for this opportunity.

We are pleased to submit the following:

<table>
<thead>
<tr>
<th>Line</th>
<th>Part No.</th>
<th>Part Description</th>
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<tr>
<td>1</td>
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<td>Tire Carrier Assembly</td>
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|      | Rev -    | For use Base Tube, Item #HVR007, unable to locate 14”x3” tubing. Quoted using 14”x4”.
|      |          | No finish is shown on the drawing. Quoted without paint. |

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Salesperson: House Account

Prices valid thru 4/20/2013

Please call with any questions. F.O.B. Elk Grove Village; Freight Charges NOT included in Quoted price.

Sincerely,

David Flack

Figure 52: Quote form HiGrade for original design
Appendix

Figure 53: Quote from Knapheide for original design
**Figure 54: Quote form Milton for tube design**

<table>
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*Prices quoted are based on quality received and shipped at one time and not on the total quantity ordered. Prices subject to acceptance within 60 days.*

**REMARKS:**

Thanks for the opportunity!

Milton Manufacturing, Inc.
By Balder Salinas
Figure 55: Quote from Milton for tube design
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Letter from Navistar

April 22, 2013

Re: Spare Tire System Design – Israeli HETT (Heavy Equipment Tank Transport)

Dear IPFW Senior Design Team,

Your team has continued to develop a great line of communication with the Navistar Defense team during the entire design process – ranging from concept, design reviews, and final proposals. Most importantly, the latest and most critical stage of measuring design costs vs. business objectives - afforded you a window into the reality Military contractors face every day; Great designs solve practical solutions but ultimately win business on their ability to be cost competitive. Your final proposals went thru dramatic refinements that ultimately resulted in meeting our cost target by simplifying design complexity without sacrificing performance – in fact, we could easily argue that in addition to meeting business targets, your final/current design has significantly higher confidence in durability and less maintenance – traits that build end-customer confidence long after the initial sale. Navistar Defense is proud to advise your team that the design now satisfies our expectations. This memo is to acknowledge and congratulate you on an excellent job!

Unfortunately, the IDF (Israel Defense Forces) announced a few weeks ago the vehicle contract will be awarded to a European competitor (likely Mercedes) as our tractor did not meet speed-on-grade requirements (terminal velocity). As a result, Navistar Defense Business has elected to discontinue any investment in the project at least thru 2013, and we are not in a position to procure the Spare Tire system upgrade (until we address the Powertrain issues); we apologize for any inconvenience this causes. Although Navistar Defense cannot support hardware upgrades, we remain interested in confirming how implementing the design changes affect DFM (Design for Manufacturability) and how decreased system complexity results in a more effective and improved proposal. Therefore, the following items below are requested to be presented at the close of this project to satisfy our needs:

1. Project Report
2. Drawing Package (Assembly and Component)
3. FEA Analysis Summary
4. Supplier Quotes
5. Cost Improvement Matrix (Comparing each design revision)
6. Design for Manufacturability Matrix (Comparing each design revision)

Navistar Defense Product Team has begun mobilizing a solution plan to solve the Startability/Grade-ability challenge and I suspect that when we enact these changes (Target November 13) we will likely be in a position to overhaul the vehicle in several areas, including the Spare Tire System. Again, we want to thank your team for the great work you’ve completed thru the course of this project, and congratulate you, and wish you continued success.

Thank you and Best regards,

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