Developing Hybrid Tipper Trailers

Mitchell Snow

Jeremy Leggoe
School Of Engineering, The University of Western Australia

Peter Lombardi
CEED Client: Roadwest Transport and Equipment Sales

Abstract

This Project was commissioned by Roadwest Transport and Equipment Sales to develop a specialised design of their flagship "Hard-Lite" Side Tipper for the transportation of Fine Particle and granulated payloads. This design provides several improvements to the current iteration of Side Tipper, the most notable being the innovative use of Ultra-High Molecular Weight Polyethylene within the Tipper body without compromising the mechanical and wear properties of the Tipper. This provides a reduction of approximately 600 kilograms over the current model of Tipper, resulting in a total estimated tare weight of 2631 kg for the combined Chassis and Tipper body. The designs, testing and simulation completed over the course of this project will assist Roadwest in the development and fabrication of a working prototype that will undergo field testing to further refine the design before being sold to current and prospective Domestic and International clients.

1. Introduction

1.1 Tipper Design Requirements

Roadwest Transport and Equipment Sales (RWT) is one of the leading manufacturers and suppliers of high-quality specialist tipping trailers, serving Australia's Mining, Earthmoving, Agricultural, and Transport industries. RWT supplies a variety of custom-made trailers, most notably the Side Tipper, End Tipper, and Bowl Tipper. The focus of this project was modifying the design of the "Hard-Lite" Series of Side Tippers to develop a specialised variation of the design that will be used predominately for the transport of fine particle payloads such as mineral sands and ore concentrates. The optimised design was required to be fully compliant with Australian Design Rules (ADR) and National Heavy Vehicle Regulator (NHVR) Guidelines. The key design consideration of the project was to achieve a reduction of the tare weight of the trailer body without significantly compromising on the superior lifetime and wear resistance offered by the current Hard-Lite models.

Achieving a reduction of the tare weight provides significant business value to Roadwest, as prospective clients will be able to carry larger payloads while still complying with NHVR Standards, ensuring that haulage jobs can be completed faster by the client. This increases the operational efficiency of the trailers as well as reducing the lifetime Carbon emissions of the Unloaded tipper as a result of decreased fuel consumption. The current materials used within the body of the trailer are Quenched and Tempered High Strength Swedish Steels.

These steels exhibit high strength and fatigue resistance, which ultimately extends lifetime of the tipper over 10 years (Vos, 2007). The tipper body is designed as a "floating body" that distributes the stress across the entire surface without the need for cross members or additional supports.

The major issue with the current iteration of the Hard-Lite design arises in the repeated transport of fine particle payloads, in particular corrosive ore concentrates such as Nickel and Copper. The current Bar-and-Bush hinge system joining the main body can fail prematurely when transporting these materials, as they create hang up points for the material, causing the deposition of material around the hinged area and premature failure. RWT has additionally experienced discharge issues with the Tippers when operating with fine particle payloads in colder climates or environments, where the moisture present in the payload freezes when exposed to the ambient air, binging the freighted material together. As part of an ongoing optimisation initiative within RWT, the lifetime fuel consumption and Carbon emissions of the Hard-Lite trailers have been under investigation, with the aim of reducing the overall impact of the trailers on the environment.

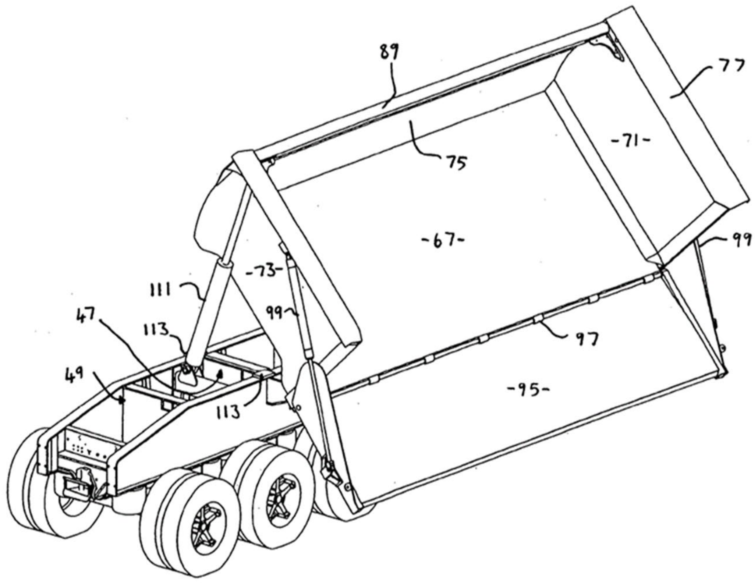

Figure 1 Hard-Lite Side Tipper in the unloading position with the tipping end at full extension (Australia Patent 2008202497, 2008).

1.2 Material Review

Several options have historically been implemented to mitigate the weight and environmental drawbacks of using conventional steels. The use of High-Performance Thermoplastics (HPTPs) (Galos, 2017) was investigated extensively throughout the review process. HPTP's possess high specific strengths, a low coefficient of friction, and have a similar tensile strength to Steel, and are generally more cost effective and easier to manufacture. They are significantly lighter than their Steel counterparts and are immune to the effect of conventional corrosion. This has made them an optimal choice for Bulk Handling solutions, with many manufacturers seeking to use Ultra High Molecular Weight Polyethylene (UHMWPE), Polydicyclopentadiene (PDCPD) and both short and long fibre Carbon Fibre Reinforced Plastics (CFRP) (Chauhan, Karki, & Varis, 2019).

PDCPD was first used within the light automotive industry to significantly reduce the weight of vehicles without compromising strength. The material has excellent shape memory, allowing it to return to its original shape when deformed, as well as possessing strong chemical and wear resistance properties. However, this material was not available on the scale required by Roadwest and could not be considered for this design. CFRP has also been used within the industry, with the short fibre variant being more popular due to its inherent resistance to crack formation and growth. One major disadvantage is that any small cracks that form within the body of the Tipper throughout the loading cycles will be very difficult to detect and repair.

UHMWPE offers superior strength as well as wear and corrosion resistance in comparison to other plastics used within the industry. The plastic also possesses unique Ultraviolet resistance, meaning that the plastic will not degrade when in the presence of sunlight (in contrast to many other HPTPs), making it a popular choice for the manufacture of Tippers, as the material will not degrade when taken out of service for an extended period. RWT has experimented with UHMWPE in the past, manufacturing a prototype End-Tipper that has an 8 mm UHMWPE body reinforced with Steel in 2012. The Tipper is still in operation today and has reported only minor cracking within the body, meaning that this material has been proven to be able to withstand the operational conditions expected for the trailer.

1.3 Review of Hinged Sections

There have been many innovations within the industry aiming to provide a solution for the localised wear and corrosion of the hinge subsection of door-based Side Tippers. One of the most common alternatives to the traditional Bar and bush hinges used within the HardLite range of Tippers is Continuous Surface Hinges. Continuous Hinges span the full length of the two surfaces that they are joining. These hinges are lighter and allow for an unbroken connection between the two surfaces (Zhang & Xu, 2022), which reduces the possibility of material deposition as the size of the possible hang-up points are reduced. However, as these hang-up points are not fully eliminated, they still accumulate material along the hinged area and deteriorate over the lifetime of the tipper at a reduced rate. Flexural hinges are also used within the industry as they allow the floor of the Tipper to be joined to the sidewall without any gaps in the structure. The hinge is designed to elastically deform to provide the range of motion otherwise provided by the door subassembly. As the hinge cannot perfectly elastically deform, the chosen material is selected to be able to withstand a high number of cycles without failing or distorting due to fatigue (Galos, 2017).

2. Design Process

RWT intends to fabricate a working prototype of the Tipper for field testing, thus a full set of Engineering and Manufacturing Drawings as well as CAD models were required to assist RWT staff and workshop personnel in the fabrication of a prototype. As the design will be operating in the field, the design must comply with all necessary regulations and Standards. To ensure compliance without manufacturing a prototype, Finite element analysis must be carried out on the design. Before the development of the design was undertaken, a comprehensive set of design criteria and performance characteristics were determined through rigorous consultation with all major project stakeholders, which included RWT staff and workshop personnel in addition to university supervisors.

Current and historical options for materials and door mechanisms were investigated in the context of both Roadwest and their competitors to determine a material and mechanism that was suitable for the specialised application. It was ultimately decided that a hybrid design involving both Steel and a continuous UHMWPE sheet that forms the door mechanism would yield the most optimal results. The initial modifications to the existing Tipper were made in CAD program Solidworks. The in-house material libraries and parameters were leveraged over the course of the site work and helped to expediate the development of an design prototype. A total of 9 major revisions were made over the course of the project to arrive at the final design.

The design verification was completed using non-linear mechanical simulation program Ansys Mechanical and involved testing a number of different critical load cases to ensure the compliance with NHVR regulations and AS3990:1993 – Mechanical Equipment: Steelwork. Each of the load cases were initially completed with a coarse mesh to ensure that the model would converge and were then recompiled on a finer meshing size to ensure that any localised stress concentrations were highlighted. A nominal mesh size of approximately 4 million elements was chosen for the fine mesh as it adequately captured the contours of the different model cases. 4 test cases were analysed with the loading and support conditions for the test cases being based on the parameters taken from a historical FEA report for the analysis of a Hard-Lite completed for RWT, which assumed a combined design loading of 40 tonnes distributed uniformly over the surface of the Tipper.

The Finite element analysis was only used to calculate the static loading on the design; the cyclic fatigue associated with the repeated bending of the continuous UHMWPE sheet during door opening needed to be investigated. Conventional fatigue testing rigs are unable to capture the full range of motion required for the Tipper. Thus, a specialised fatigue rig was designed to take a small section of the UHMWPE sheet and articulate it through the 85° bending cycle under the power of an air operated cylinder. This testing rig was fabricated by RWT and simulates the realistic operating conditions expected for the Tipper, allowing for an accurate representation of the fatigue properties of the material. The material is to be placed in the testing rig and iterated through the maximum expected lifetime of the tipper of 31200 cycles. The material is to be monitored frequently over this testing period for any signs of crack initiation or fretting.

3. Results And Discussion

3.1 Design Formulation

From very early on in the project, the decision was made to incorporate the use of 8mm UHMWPE sheets into the design at the request of RWT by implementing a flexural hinge from the the centre portion of the tipper body. This decision was spurred on by the historical success of the UHMWPE End Tipper within the field, with the low coefficient of friction making it ideal for discharging granulated payloads. It was suggested by RWT that the development of a hybrid design would yield more beneficial results for the company as well as be easier to incorporate into the current manufacturing processes used by Roadwest. This design was intended to serve as a transitional model to verify key design criteria before moving the development of future trailers with a full plastic design. The current iteration has LxWxH dimensions of $(8890, 2498.87, 1780.63)\ mm$, an estimated weight of 2631 kg (which is a saving of approximately 600 kg over the current Tipper body). An isometric view of the tipper assembly in the open configuration is shown in Figure 2.

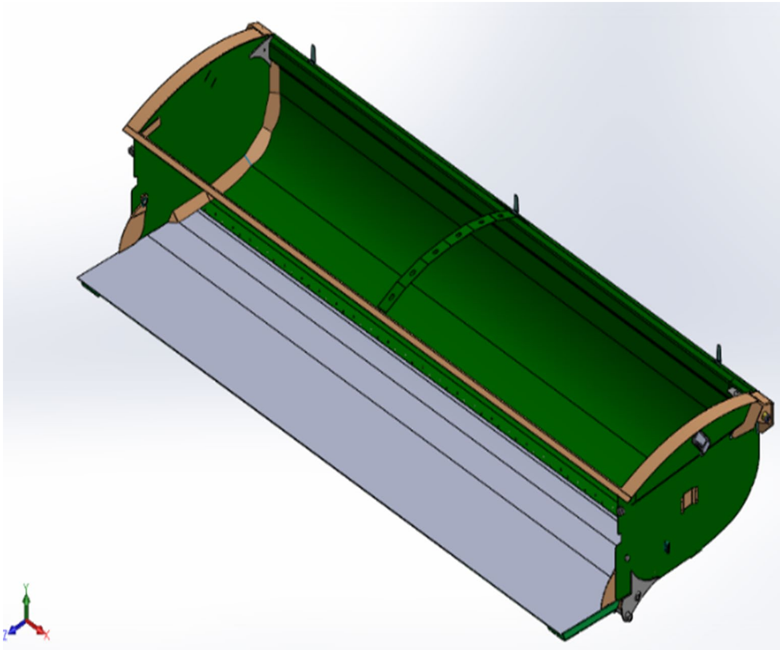

Figure 2 Isometric view of the Tipper in the open configuration.

3.2 Finite Element Analysis

The analysis focused on the Total Deformation and both the Equivalent Von-Mises and Principal Stresses of each of the test cases, hence only these results were requested in the solution module. The initial simulations of the model helped to shape the decision to reinforce the UHMWPE with steel sheets to increase rigidity as well as place additional cross members along these sections to achieve a reduction in stress concentrations. The simulations additionally assisted in the development of the door hook, as it was shown that the door assembly needed additional support when in the open configuration to prevent the hinged area from undergoing hyperextension.

Design Case	**Maximum Deformation (mm)**	**Maximum Von-Mises Stress (MPa)**	***Maximum Principal Stress (MPa)***
Open Body	67.88	**786.3**	**846.20**
Closed Body	**39.04**	**439.01**	**682.52**
Door Hook	**0.51**	**585.93**	**614.47**
Bolt Pretension	**16.82**	**478.93**	**573.98**

Table 1 Total Deformation and Equivalent Von-Mises Stress obtained from the design cases on the fine mesh controls

For the Open Body case, the maximum deformation and VM Stresses are found to be distributed along the center of the body, which corresponds to the maximum load incident on the body and is comparable to the current operating conditions experienced by the Hard-Lite Tipper. Additionally, the principal stresses are predominately concentrated along the UHMWPE door and hinged sections and are above the permissible stress range for the material. This was counteracted by supporting the plastic door with additional Steel supports that ensure no plastic deformation can occur within the UHMWPE. The Closed Body Case additionally has both the Deformation and VM Stress concentrated along the central section, with the maximum values once again falling within the allowable values for the materials chosen. The maximum principal stresses are focused on the hinged section, in particular the point of discontinuity between the Steel supports and the door itself. This point was reinforced by placing a cross member below the hinge to support the deformation of this section and prevent significant plastic deformation. The Door Hook case had all stresses concentrated around the points of contact with the main body and were initially of significant concern. These areas were reinforced by using doubling plates, adding additional thickness to the sections to allow for more rigidity and strength allowing it to comply with the required parameters. Finally, the Bolt Pretension case predicted negligible deformation, with stresses concentrated around each individual bolt, gradually building in intensity towards the center of the tipper. The stress values were within the allowable ranges, concluding that the bolt type and pattern chosen will be effective in operational conditions.

4. Conclusion and Future Work

The goal of this design project has been to develop a design that is able to mitigate the design flaws of the previous design for the specialised granulated payload application. The design and simulation of analytical components do not comprehensively reflect the realistic conditions of the trailer and capture complex loading conditions such as variations in payload distribution. Most importantly, the analysis does not sufficiently capture the unloading and discharge behaviour of the trailer. Thus, it is necessary to undertake the development and fabrication of a working prototype to confirm that the design will work effectively under real conditions before rolling out the design to current and prospective clients. This design is expected to begin construction in Q4 of 2023 with the prototype being completed by the end of 2023. This lead time is to ensure that all materials and necessary equipment for the manufacture of the trailer arrives, in addition to allocating a timeslot for the trailer to be fabricated within RWT's internal assembly line schedule. Once the prototype has been developed, RWT has met with several prospective clients that are willing to allow the Tipper to trial under mine site conditions. These trial periods are expected to last 1-2 weeks at a time, with the tipper being regularly monitored to ensure that they hold up to the required standards. Following the field testing of the prototype, any design revisions that need to be made based on the testing feedback will be incorporated before rolling the design into the Hard-Lite manufacturing line for RWT to market and sell to their clients.

5. References

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