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Lightweight Car Performance

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Summary

Many of the track-worthiness problems associated with lightweight cars may be related to the interface between the truck and the carbody, the design parameters of the truck, and the relationship between the truck and carbody design parameters.

This digest reports on an ongoing Strategic Research Initiative (SRI) being conducted by the Transportation Technology Center, Inc. on the relationship between the track-worthiness performance requirements and design constraints of lightweight freight rail vehicles. As industry trends push to increase car capacity, this SRI is providing insight into the requirements for safe design and operation of lightweight vehicles.

Parametric studies, with truck turning moment and truck warp stiffness as the variable parameters, examined derailment stability in spiral negotiation with and without the influence of in-train forces, as well as hunting stability. The vehicle modeled had a 27,000-pound 89-foot carbody with a 66-foot truck-center spacing and was equipped with long-travel constant-contact side bearings. This fictitious carbody was chosen as its design is particularly sensitive to the track-worthiness performance issues surrounding lightweight cars. The NUCARS™ dynamic simulation model results showed the conclusions listed below, which are commensurate to industry experience. These results are only a subset of the parametric study. The entire set of results will be published this year in an Association of American Railroads' research report.

- The empty vehicle equipped with standard three-piece trucks is predicted to have derailment and hunting stability under the following conditions:
 - A minimum turning moment of 60,000 in.-lb for sustained hunting stability, obtainable with long-travel constant-contact side bearings of appropriate pre-load.
 - A maximum turning moment of 160,000 in.-lb with good-condition trucks, or 110,000 in.-lb with worn trucks to achieve derailment stability.
 - Long-travel constant-contact side bearings.
- The empty vehicle equipped with warp-stiffened three-piece trucks is predicted to have derailment and hunting stability under the following conditions:
 - A minimum turning moment of 30,000 in.-lb for sustained hunting stability, indicating that constant-contact side bearings may not be necessary to control hunting if the center plate alone generates this level of turning moment.
 - A maximum turning moment for new or worn trucks of 100,000 in.-lb to maintain derailment stability based on a minimum warp stiffness of 50 million in.-lb/radian. The industry has little warp stiffness data for worn warp stiffened truck..
- When loaded to a gross rail load of 286,000-lb, wheel and rail wear rates drop about 15 percent for warp stiffened three-piece trucks as compared to standard three-piece trucks.



Suggested Distribution:

- Mechanical
- Car Department
- Planning & Analysis
- Safety

INTRODUCTION AND CONCLUSIONS

Continuing demand for improved productivity is driving the specifiers and designers of railway equipment to seek innovative means for increased car capacity and performance. These innovations, however, can have conflicting effects on vehicle track-worthiness performance. For example, constant-contact side bearings installed to improve hunting stability, if not properly designed for the operating environment, can create derailment instabilities in other operating regimes.

The objective of this initiative is to provide design and operating guidelines for new lightweight railcars. The industry has a limited base of design guidelines focusing at the systems level. The AAR *Manual of Standards and Recommended Practices* contains comprehensive component level guidelines, but only limited guidelines on the interaction of vehicle components.¹ It is sometimes not until AAR Chapter XI testing or revenue service deployment that track-worthiness performance issues are discovered. This work aims to proactively flag such issues.

The work reported here focuses on hunting and derailment stability as governed by the bolster to carbody connection. These relationships are mapped from the results of parametric NUCARS™ studies of a fictitious 27,000-pound 89-foot torsionally stiff carbody. The results of these studies include:

- When equipped with standard three-piece trucks, the empty vehicle is predicted to have derailment and hunting stability with:
 - A minimum turning moment of 60,000 in-lb to achieve hunting stability
 - A maximum turning moment of 110,000 in-lb for worn trucks or 160,000 in-lb for new trucks to maintain derailment stability
- When equipped with warp-stiffened three-piece trucks, the empty vehicle is predicted to have derailment and hunting stability with:
 - A minimum turning moment of 30,000 in-lb for hunting stability
 - A maximum turning moment of 100,000 in-lb for derailment stability based on a minimum warp stiffness of 50 million in-lb/radian
- When loaded to a gross rail load of 286,000 pounds, the wear index drops about 15 percent for warp stiffened three-piece trucks as compared to standard three-piece trucks

METHODOLOGY

The effort to map the bounds of derailment and hunting stability with respect to the bolster-carbody connection was approached through quasi-static and dynamic analyses of a theoretical lightweight vehicle. This vehicle, by definition, is especially sensitive to the issues limiting lightweight vehicle track-worthiness performance.

The car model has a body weight of 27,000 pounds. This is slightly heavier than the lightest car bodies listed in the 2002 UMLER registry.² The length of the car, 89 feet, coupled with an infinite torsional body-stiffness, makes the car particularly sensitive to wheel unloading in track twist conditions. The model also includes long-travel constant-contact side bearings. Standard travel designs would induce unacceptable wheel unloading behavior. The vertical constraints of the side bearings were held constant, but the turning moment contributed by the side bearings was varied within the limits defined by the truck and carbody interface.

The truck and carbody interface primarily functions as a pivot and an attachment point. The center plate provides both of these functions. Vertical, lateral, longitudinal, and rotational loads are transmitted from the carbody to the truck through the center plate. Constant-contact side bearings are an additional design option at the truck and carbody interface, designed to increase the turning moment through the transmission of vertical and rotational forces.

AAR Standard M-948 contains two specifications in the design of the truck and carbody interface. These specifications can be summarized as:

- A minimum of 15 percent of the carbody weight must be carried in the center plate.
- The maximum rotational torque (turning moment), including contributions from the side bearings and the center plate, must not exceed a single wheel L/V ratio of 0.82. The equation used to compute this L/V value is described in the specification.

Figure 1 contains a graphical representation of the AAR specifications. The figure also shows the allowable range of rotational turning moments (torques) for the lightweight car modeled in this study. Figure 1 shows that the designer and specifier of a vehicle with a 27,000-pound carbody can design for a turning moment between 40,000 and 160,000 in-lb.

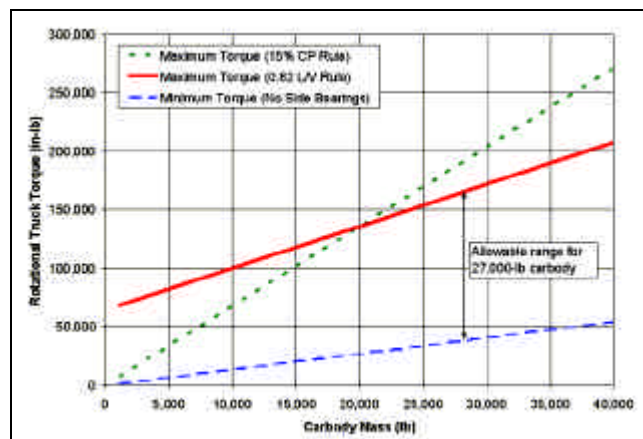


Figure 1. AAR M-948 Guidelines

Truck warp stiffness is another key design option that plays an important role in hunting and derailment stability.

TECHNOLOGY DIGEST

Standard three-piece trucks in good condition provide up to 50 million in-lb/radian of warp stiffness per spring nest. In a worn condition, warp stiffness can be as low as 1 million in-lb/radian. Warp stiffened trucks offer a range of stiffness between 50 million in-lb/radian with an effective maximum of 100 million in-lb/radian. There is little data on the warp stiffness of worn warp stiffened trucks. The parametric

A map of derailment and hunting stability based on turning moment and truck warp stiffness was generated from results of a parametric NUCARS™ study. Derailment stability was evaluated by simulating traversing a reverse curve complete with entry and exit spirals at balance speed. Hunting stability simulations were conducted on tangent track at a speed of 70 mph.

NUCARS studies investigated performance for the entire range of possible truck warp stiffness.

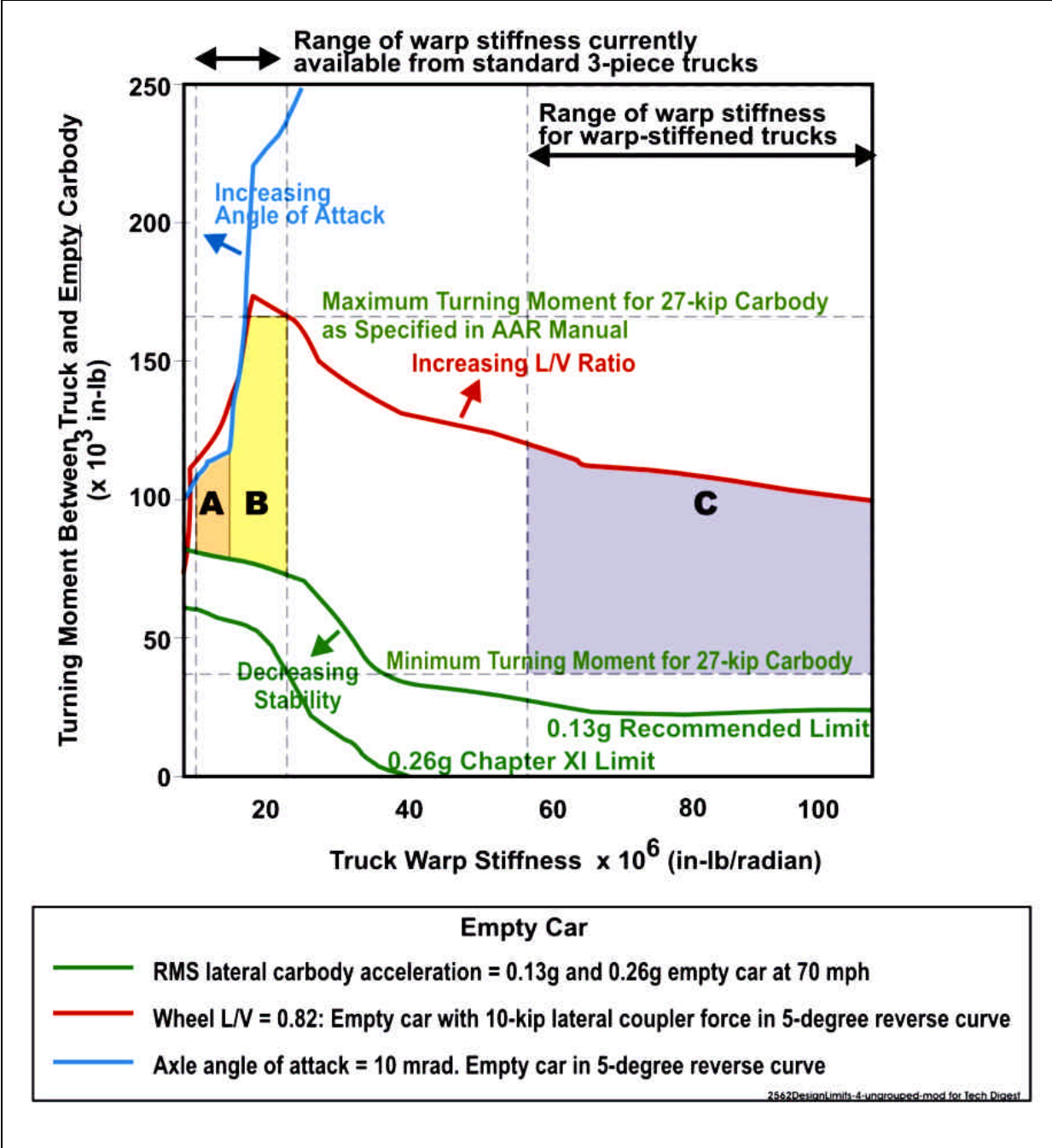


Figure 2. Map of Stability for a Theoretical Lightweight Car

RESULTS

Figure 2 depicts a summary of the results. The orange shaded area (A) indicates the operating range with stable hunting and derailment performance for the vehicle equipped with standard three-piece trucks in worn condition. The yellow shaded area (B) shows the same for standard three-piece trucks in good condition. The purple shaded area (C) indicates an operating range with stable hunting and derailment performance for the vehicle when equipped with warp-stiffened trucks. The boundaries of these areas are discussed as follows.

Hunting stability forms a lower bound for standard three-piece trucks. Standard trucks, on this vehicle, must have at least 60,000 in-lb of turning moment to maintain lateral carbody accelerations at or below the AAR Chapter XI limit of 0.26 g (RMS). A more conservative, but recommended limit of 0.13 g (RMS) can be achieved with 80,000 in-lb of turning moment. Warp stiffened trucks are predicted to have hunting stability at 30,000 in-lb of turning moment. However, the minimum achievable turning moment for the 27,000-lb carbody is 40,000 in-lb. This implies that the warp stiffened trucks do not require side bearings for hunting stability for this scenario.

The maximum wheelset angle of attack generated in the reverse curve forms a bound in the upper-left corner of the operating area for standard three-piece trucks. This implies that worn three-piece trucks have decreased derailment stability, lowering the allowable turning moment to 110,000 in-lb. Standard three-piece trucks in good condition face less of a danger of high angles of attack, and warp stiffened trucks show no indications of induced high angles of attack.

The L/V ratio trend-line shown in Figure 2 is extremely sensitive to track condition and in-train force environment. The line represents an L/V value of 0.82 and was generated with 10,000 pounds of lateral coupler force in a standard 300-foot spiral. This force could be experienced towards the middle of a mixed-freight train operating on descending grades of 1 percent or greater, in curves of 5-degrees or greater. Assuming a critical L/V ratio of 0.82, the maximum turning moment to maintain derailment stability for the car equipped with warp-stiffened trucks is between 100-110 million in-lb/radian.

Simulations of the test vehicle in a loaded condition (286,000 lbs) predict decreased rail and wheel wear rates on the order of 15 percent for warp-stiffened trucks as compared to standard three-piece designs.

CONCLUSIONS

The parametric studies showed that supplemental turning moment is required for derailment stability of lightweight cars equipped with standard trucks. Long travel side bearing design is essential, particularly for worn three-piece trucks. The improved load distribution offered by long-travel designs is a key factor in the design of lightweight cars. Warp stiffened trucks showed adequate hunting stability without supplemental turning moment through side bearing application. Long-travel constant-contact side bearings may be required in performance regimes such as twist and roll, yaw and sway or in operating conditions such as very low center-plate friction.

Both L/V wheel-climb and axle angle-of-attack are issues that put an upper bound on turning moments for lightweight cars equipped with standard three-piece trucks. Worn standard three-piece trucks have a limit near 110,000 in-lb, while newer standard trucks are limited to 160,000 in-lb. These limits are further lowered under the influence of large in-train forces and/or track irregularities.

Axle angle-of-attack is not a limiting factor for lightweight cars equipped with warp stiffened trucks. L/V wheel-climb provides the upper bound on turning moment for such cars. This limit (100-110 million in-lb/radian), is constant through a large range of warp stiffness values, although it remains sensitive to in-train force and track perturbation effects.

FUTURE WORK

TTCI is conducting warp stiffness testing of several common truck designs to better quantify the range of warp stiffness options currently available to car designers and specifiers.

This SRI includes plans to review the L/V criterion in AAR Chapter XI specifications and provide recommendations for distance-based criteria instead of a time-based (50 msec) limit. The SRI will also continue research in the performance of lightweight car designs.

REFERENCES

1. *AAR Manual of Standards and Recommended Practices*, Section C — Part II, Vol 1, 1997.
2. *The Official Railway Equipment Register*, 2002. R.E.R. Publishing Corporation.

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