

"EFFECT OF WHEEL AND RAIL PROFILES ON GAGE WIDENING BEHAVIOR,"

by Stephen E. Mace and
Dominic A. DiBrito

TD 94-002

Summary

The Association of American Railroads and Norfolk Southern (NS) recently participated in a joint research project which implicated poor wheel set steering as the cause of a gage widening derailment on the NS in June 1993.

Through track tests at the Transportation Test Center, Pueblo, Colorado, and NS, and with analytical modeling, the research project successfully demonstrated that poor wheel set steering can initiate truck warp and lead to the production of large gage widening forces.

Furthermore, the project demonstrated that poor wheel set steering results from a combination of strong two-point wheel/rail contact caused by excessive gage corner relief grinding of the high rail, hollow worn wheels, and certain rail lubrication conditions.

These results are particularly important because of their relationship to current rail grinding, wheel maintenance and lubrication practices.



Association of American Railroads
Research and Test Department

February 1994



INTRODUCTION AND CONCLUSIONS

Over the past several years, research projects under the Association of American Railroads (AAR) Vehicle/Track System (VTS) Derailment Prevention Program have focused on reducing rail rollover or gage widening derailments.

Studies began in this area following the derailment of the FAST train at the AAR's Transportation Test Center (TTC) in 1986. This work revealed that rail lubrication could be a critical factor in gage widening derailments. Subsequent investigations of double-stack car derailments eventually led to a better understanding of how rail lubrication and two-point wheel/rail contact can reduce wheel set steering moments, sometimes causing serious derailments.

In 1991, investigations of continued gage widening behavior at FAST suggested that, under conditions of strong two-point wheel/rail contact, low conicity wheel profiles and high rail gage face lubrication, wheel set steering moments can actually reverse, causing the truck to warp. Truck warp is the condition in which a system of forces acting on a truck causes it to skew in such a way that both wheel sets develop large angles of attack relative to the rails. By virtue of their large angles of attack, both wheel sets can generate large lateral forces which can potentially spread the rails apart or roll them over.

A recent gage widening derailment on the Norfolk Southern (NS) prompted the AAR to join with NS in a research project aimed at understanding the cause of wheel set steering moment reversal and the role it plays in truck warp.

Through track tests and analytical modeling, the project demonstrated that poor wheel set steering in curves can initiate truck warp and lead to the production of large gage widening forces. Furthermore, the project demonstrated how the following factors, in combination with one another, can reduce or reverse wheel set steering moments:

- Excessive gage corner grinding of the high rail
- Tread hollowing in worn wheels
- High rail gage face lubrication

Finally, the project demonstrated that lubricating the top of the low rail is an effective means of reducing the gage widening forces generated by warped trucks.

RECOMMENDATIONS

This study suggests that further work in the following areas is necessary to achieve optimum solutions to the problem of truck warp initiated by poor wheel set steering:

1. An economic analysis to assess both the benefits and the costs of current rail grinding practices.
2. An economic analysis of the cost of replacing the current wheel maintenance standard with a performance-based maintenance standard. Estimated costs should include the extra fuel required to pull cars with warped trucks.
3. A study to determine if alternative truck designs having greater warp restraint or improved steering systems are feasible.
4. A study to develop an effective means of lubricating the head of the low rail in curves should be developed.

PROCEDURES AND RESULTS

The research project consisted of the following three phases: (1) a revenue service test on the NS, (2) a NUCARS modeling study of wheel set steering moments, and (3) a track test at the TTC.

Revenue Service Test

The revenue service track test was conducted on the NS in a 4-degree curve near the site of an earlier gage widening derailment. A test train was assembled from the coal cars involved in the derailment. The test evaluated the effects of various wheel profiles, rail profiles, and lubrication conditions on truck warp. Measurements of vertical and lateral rail forces, lateral rail deflections, and wheel and rail profiles were used to demonstrate the following principles:

- Multiple trucks in a train can warp and produce gage widening forces exceeding 20,000 pounds per wheel.
- Trucks with worn wheel sets having hollow tread shapes are much more likely to warp than trucks with new AAR1B wheel sets.
- Excessive gage corner relief grinding of the high rail exacerbates truck warp.
- Lubricating the head of the low rail dramatically reduces the gage widening forces.

The data analysis concentrated on truck warp, which is characterized by a large increase in trailing wheel set lateral forces. Because the leading wheel set lateral forces are large in both warped and square trucks, only the trailing wheel set lateral forces were used in this analysis as an indication of truck warp.



Wheel profiles were found to have a considerable effect on truck warp, as illustrated in Exhibit 1. In this plot, which includes data from tests on two different rail profiles, the shaded areas identify those cars with new AAR1B wheel sets while the unshaded areas identify those cars with worn wheel sets. The lateral force levels indicate that many of the trucks with worn wheel sets warped in the test zone; however, none of the trucks with new wheel sets warped.

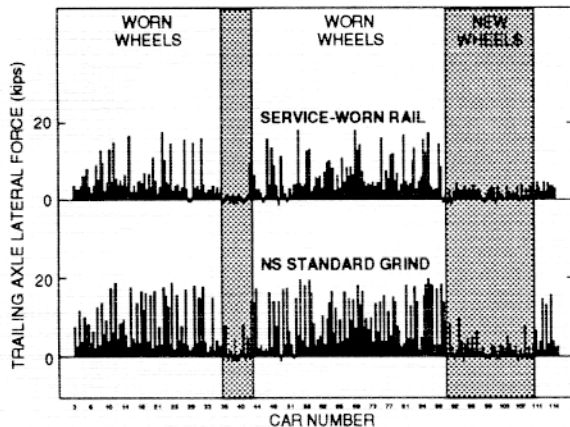


Exhibit 1. Gage Widening Force Comparison

Rail profiles were also found to have a considerable effect on truck warp. Through the use of a Loram grinding train, the following rail profiles were evaluated:

1. Nearly conformal service-worn profile with 3 MGT after grinding.
2. Norfolk Southern standard grinding profile. This profile produced a large contact gap in the flange root area of a flanging worn wheel.
3. New profile with smaller contact gap.

Exhibit 1 compares the trailing wheel set lateral forces measured on the service-worn rail to those measured on the NS standard grind rail. The number of warped trucks increased after the standard grind was applied to the rails.

Finally, low railhead lubrication was shown to have a significant effect on gage widening forces, as shown in Exhibit 2. Comparing these data to Exhibit 1, which contains data from tests on dry railheads, reveals that the lateral forces decreased dramatically after the lubricant was applied.

NUCARS Modeling Study

The revenue service test results were consistent with the idea that trucks can be warped by "anti-steering" moments. To further understand how these moments are produced, a NUCARS modeling study was conducted using a 100-ton hopper car model

developed with actual measured NS wheel and rail profiles. The key findings of the modeling study are summarized below.

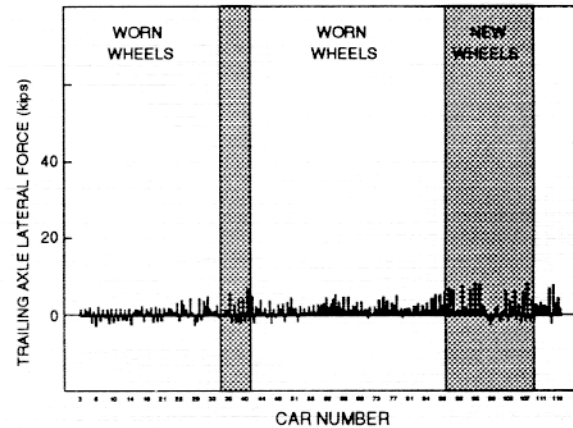


Exhibit 2. Effect of Low Railhead Lubrication

In the entry spiral to curves of 4 degrees or greater, the leading wheel set in a three-piece truck moves laterally into flange contact with the high rail. If the high rail has gage corner relief, then the flanging wheel contacts the rail at areas on both its tread and flange. By virtue of the rolling radius difference between the high rail contact areas and the low rail wheel tread contact area, a system of longitudinal creep forces is generated, as shown in Exhibit 3.

In general, the flange contact area produces a positive longitudinal force and the tread contact area produces a negative longitudinal force. In order to achieve equilibrium, the low rail wheel tread longitudinal force is equal to the difference between the high rail wheel flange and tread longitudinal forces. This system of forces forms a couple called the wheel set steering moment (see Exhibit 3).

Normally, the high rail wheel flange generates a larger positive longitudinal force than the negative force generated by the wheel tread. However, the flange longitudinal force is greatly reduced by high rail gage face lubrication. In this case, the tread longitudinal force can exceed that of the flange and reverse the wheel set steering moment.

The model results indicated that the NS worn wheel set tread would indeed produce a negative longitudinal force of sufficient magnitude to reverse the steering moment on rail with excessive gage corner relief and gage face lubrication, as shown in Exhibit 3. By contrast, the new AAR1B wheel set model produced positive steering moments under the same conditions because of its smaller negative tread longitudinal force.



The NS worn wheel set tread generated larger negative longitudinal forces than the AAR1B wheel set because of the smaller rolling radius difference between its high and low rail wheel treads. As shown in Exhibit 4, this small difference, -1 millimeter compared to 2 millimeters, reversed the steering moments produced by the two profiles.

TTC Track Tests

Track tests were conducted in the 7.5-degree curve of the TTC Balloon Track using a pair of instrumented wheel sets having NS hollow tread profiles

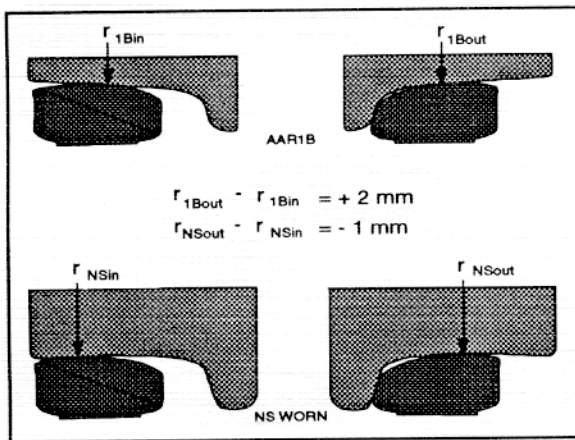


Exhibit 4. New and Worn Wheel Comparison

and a pair with worn Heumann profiles. Exhibit 5 compares the truck steering moments produced by the different wheel sets on rail with excessive high rail gage corner grinding and gage face lubrication. The change in wheel profile from worn Heumann to NS hollow tread reduced the truck steering moment from approximately -40 kip-inches to -340 kip-inches and caused the test truck to warp severely in the curve. Also, in both tests, the steering moments increased dramatically in the conformal rail profile test zone compared to the gage corner relief grind zone. These results were consistent with the predictions of the modeling analysis.

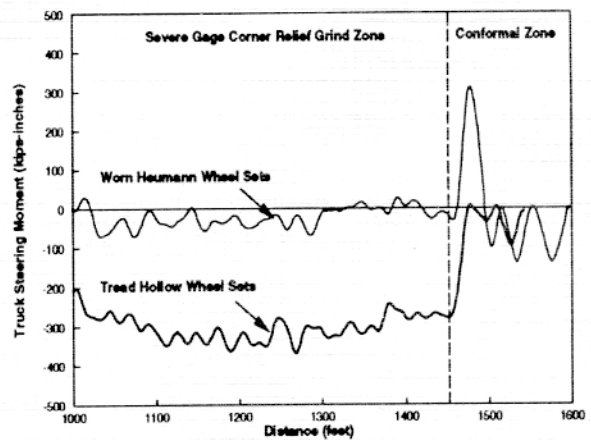


Exhibit 5. Steering Moment Comparison

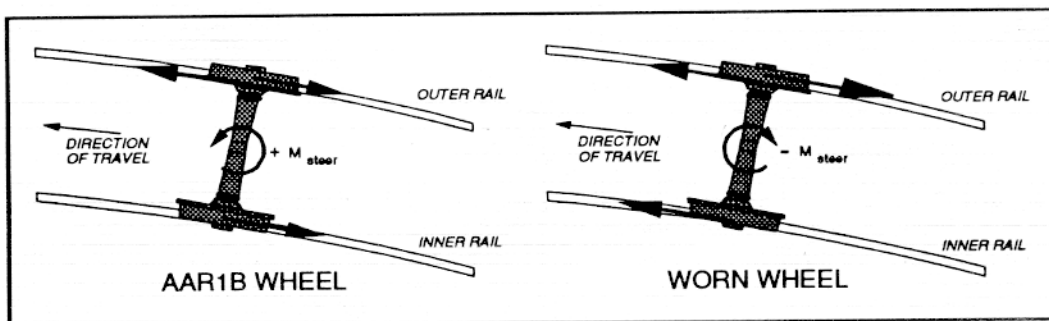


Exhibit 3. New and Worn Wheel Steering Moment Comparison

Note: Contact Stephen E. Mace at (719) 584-0563 with questions or comments about this document.

DISCLAIMER

Preliminary results in this document are disseminated by the Association of American Railroads (AAR) for informational purposes only and are given to, and are accepted by, the recipient at the recipient's sole risk. The AAR makes no representation or warranties, either expressed or implied, with respect to this document or its contents. The AAR assumes no liability to anyone for special, collateral, exemplary, indirect, incidental, consequential, or any other kind of damages resulting from the use or application of this document or its contents. Any attempt to apply the information contained in this document is made at the recipient's own risk.