TECHNOLOGY DIGEST

Timely Technology Transfer — 98-023

# THE ROLLING RESISTANCE OF SEVERELY HOLLOW-WORN WHEELS

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**Summary**

Tests and model predictions have demonstrated that hollow-worn wheels in freight cars significantly increase rolling resistance and lateral forces. The work has been done by the Association of American Railroads to help meet the goal of defining an economic-based criterion for removing or re-truing hollow-worn wheels. Tests were done at the Federal Railroad Administration's Transportation Technology Center with conical and 3.7 millimeter (0.15 inch) hollow-worn wheels on tangent track and curved track up to 7.5 degrees. Predictions were made using the NUCARS dynamics program, with wheels up to 6.2 mm (0.25 inch) hollow, on tangent and curved track (up to 10 degrees). Key results from this study are:

- For cars with all wheels identical, rolling resistance in tangent and curved track rises rapidly with the depth of hollow wear above 2 mm. For example, 6 mm hollow wheels raise resistance by a factor of five to 10 on tangent track compared to tapered wheels.
- Similarly, hollow wheels increase lateral force, especially in tangent track and low-curvature track, where 6 mm hollow wheels give up to eight-fold increase compared to tapered wheels.
- Hollow wheels reduce the effective conicity. Rolling resistance increases rapidly when the conicity becomes negative.
- Results from track tests confirm that the NUCARS model predicts the effects of hollow wheels with reasonable accuracy.

Hollow wheels have deleterious effects on railroad costs. They raise rolling resistance and thereby increase the amount of fuel needed to haul cars. Hollow wheels increase rail wear, and their false flange damages special track work. By impairing the ability of trucks to steer, hollow wheels raise lateral forces in curved track, increasing track deterioration and influencing derailment risk. A survey of North American wheel profiles (TD 98-003) has shown that 6.2 percent of wheels are more than 3 mm (0.12 inch) hollow, and 2 percent are more than 4 mm (0.16 inch) hollow.

**Suggested Distribution:**

o Equipment/Rolling Stock
o Equipment Maintenance
o Planning and Analysis
o Track Maintenance

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## INTRODUCTION AND CONCLUSIONS

To help meet the goal of defining an economic-based criterion for removing or re-truing hollow-worn wheels, the Association of American Railroads (AAR) has studied the effect of hollow wheels on rolling resistance. Work reported in TD 98-004, examined cars with wheels with up to 3 millimeter (0.12 inch) of hollow wear. Work has now been extended to include cars with identical wheels with up to 6.2 mm (0.24 inch) of wear, and cars with differently hollowed wheels. Further track trials have been done with hollow-worn wheels to confirm predictions made using the NUCARS dynamic modeling program. These studies indicate that hollow-worn wheels significantly increase rolling resistance and lateral forces in freight cars. Key results from this latest study are:

- For cars with all wheels identical, rolling resistance in tangent and curved track rises with the depth of hollow wear above 2 mm (0.08 inch).
- Hollow wheels reduce the effective conicity. Rolling resistance increases rapidly when the conicity becomes negative.
- Results from track tests confirm that the NUCARS model predicts effects of hollow wheels with reasonable accuracy.

Hollow-worn wheels raise rolling resistance, increasing the fuel needed to haul cars. They increase rail wear, and the 'false flange' damages special track work. They also raise lateral forces in curved track, increasing track deterioration and influencing derailment risk. Recent studies of North American wheel profiles have shown that 6.2 percent of wheels are more than 3 mm hollow, and 2 percent are more than 4 mm hollow.

## MODELING OF CARS WITH HOLLOW WHEELS

The NUCARS vehicle dynamics program was used to model the effect of hollow wheels on wheel/rail interaction. The study modeled a typical 263-kip freight car with three-piece trucks. Track ranging from tangent to a 10-degree curve was modeled using typical service-worn tangent and curved-rail profiles. Different axle misalignment cases were examined, since tests have shown that trucks on tangent track have axles misaligned, typically by 2 milliradian. Two levels of wheel/rail friction were studied: 0.45 on both rails to simulate dry track; and 0.4 on the head, and 0.2 on the gage face (both rails) to simulate lubricated track.

The study examined wheel profiles, from conical to severely hollow (up to 6.2 mm hollow). To better represent worn wheels, the hollow profiles had the flange thickness reduced by 2 mm per 1 mm of hollow wear. Most analyses were done for the case where all wheels within the car have identical profiles. Further modeling tested the effect of differently worn wheels. For these cases, all axles were identical, but the wheels on the axle were differently hollowed.

The model was used to predict wheel/rail rolling resistance (the energy dissipated in the contact patch), at a speed of 30 mph. Wheel-set angles of attack and lateral rail forces were also computed. Increasing axle misalignment caused resistance to rise, especially in tangent track. Reducing wheel/rail friction caused wheel sets to run at higher values of angle of attack, but reduced resistance by about 30 percent. Predictions found using 2 milliradian misalignment and a wheel/rail friction of 0.45 are presented here.

## MODELING RESULTS

For the case of a car with all wheels identical, Exhibit 1 shows the predicted effect of hollow wear and track curvature on rolling resistance. Hollow wear less than 2 mm (0.08 inch) has little effect on resistance except at high track curvature. As hollow wear increases above 2 mm, resistance rises with depth of hollowing. The 5.7 mm (0.22 inch) hollow profile is based on a service-measured profile, and behaves differently from the other profiles at high track curvature. This is probably due to a slightly different profile shape at the end-of-tread area. Small profile changes can have a significant effect on predicted resistance.

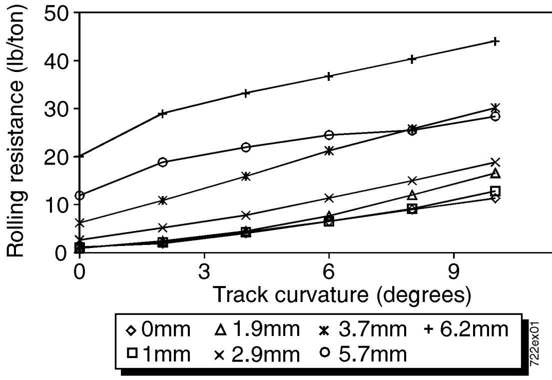


**Exhibit 1. Effect of Hollow Wear and Track Curvature on Rolling Resistance**

Exhibit 2 shows the effect of hollow wear and track curvature on lateral force. The results are similar in form to those shown in Exhibit 1. Above 2 mm wear, force rises with hollow wear, but again the 5.7 mm wheel shows anomalous behavior. The effect of hollow wear is more pronounced in tangent and low-curvature track. This is because at high curvatures the maximum force saturates to levels given approximately by the prevailing friction multiplied by the axle load.

This 2 mm threshold seems related to a change in conicity from positive to negative. Conicity is defined as one half of the slope of the central portion of the plot of wheel-set lateral shift versus wheel rolling-radius difference (right-wheel radius minus left-wheel radius); it provides a measure of the steering ability of the wheel set on the rail.

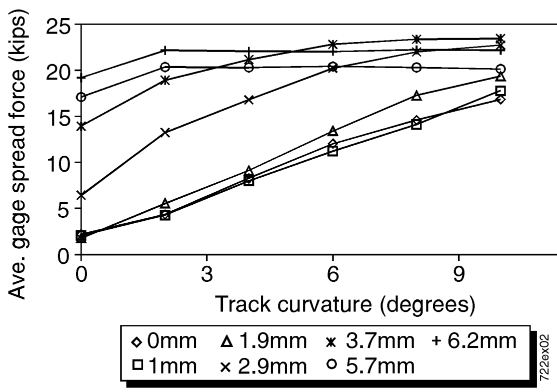


**Exhibit 2. Effect of Hollow Wear and Track Curvature on Lateral Force**

Exhibit 3 shows these rolling-radius difference plots for axles with conical, 1.9 mm (0.08 inch) hollow and 3.7 mm (0.15 inch) hollow wheels. For the conical wheels, as the wheel set shifts to the right, the right-wheel radius rises (relative to the left wheel), and the wheel set tends to steer back to the left. This is normal. In contrast, when the 3.7 mm hollow-wheel wheel set shifts to the right, the left wheel radius increases, and the wheel set tends to steer further to the right. Normal steering has broken down. The 1.9 mm hollow wheel set appears to set the limit for normal steering.

Three cases where the car had differently hollow-worn wheels were examined. The car had 3.7 mm (0.15 inch) hollow wheels on one side and either 1 mm, 1.9 mm, or 2.9 mm (0.04, 0.08, 0.12 inch) hollow wheels on the other. For all three cases, resistance and lateral force showed the same variation with track curvature as shown in Exhibits 1 and 2 for the condition where all wheels in the car were identical. Further, the mixed wheel resistances and forces could be easily calculated from the identical wheel results. As an example, if RR4 and RR1 are the rolling resistances predicted for a car with all wheels 4 mm hollow and 1 mm nominal hollow wear respectively, the mixed wheel case (RR4,1) is given accurately by:

**(RR4,1) = (RR4 + RR1) ¥ 0.5**

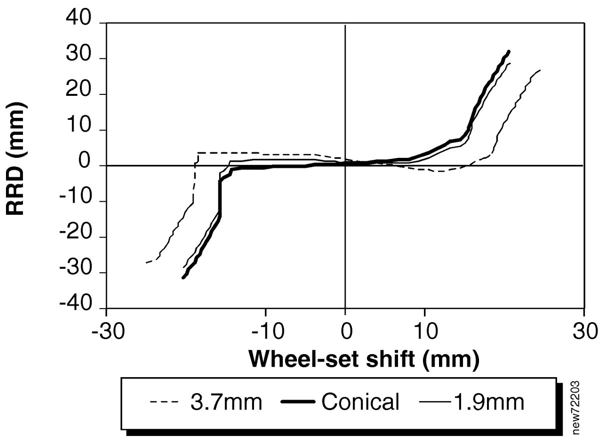


**Exhibit 3. Rolling Radius Difference Plots for Wheel Set with Different Hollow-Wheel Wear**

## MODEL RESULTS COMPARED TO TRACK TESTS

To gain confidence in the ability of NUCARS to model hollow-wheel effects, tests were done on the Wheel Rail Mechanism Loop at the Federal Railroad Administration's Transportation Technology Center near Pueblo, Colorado. Measurements were made at four test locations on dry tangent and curved track (3-, 4-, and 7.5-degree curves). Two five-car consists were tested. The first had all wheels machined to the new AAR-1B profile. The second had wheels machined to the 3.7 mm (0.15 inch) hollow profile. The 263-kip cars had American Steel Foundries Ride Control™ trucks. A force-measuring coupler connected the locomotive and test consist, and instrumented rails and optical laser systems at each location measured vertical and lateral rail forces and wheel-set angle of attack. Rolling resistance was found from average coupler force by allowing for grade variation and subtracting typical values for bearing and aerodynamic resistance. Tests were done at 10, 15, and 20 mph, but there was no consistent effect of speed on coupler force.

For comparison, the tests were simulated by NUCARS using wheel and rail profiles measured from the cars and test sites respectively. Exhibit 4 shows the test values of rolling resistance, compared with the model predictions. Several points can be made. First, the 3.7 mm (0.15 inch) hollow wheels give a significant increase in measured resistance. Second, NUCARS predicts with fair accuracy the effects of conical and hollow-worn wheels, especially since the measured results need to be found from coupler force by subtracting grade and predicted values for aerodynamic and bearing resistance. Third, using real rail profiles measured at each location gives a more uneven variation of rolling resistance with curvature than that shown in Exhibit 1.

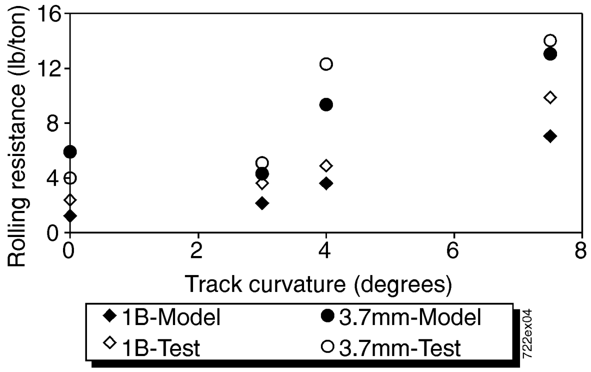


**Exhibit 4. Predicted and Test Rolling Resistance**

NUCARS was less consistent in predicting angle of attack and lateral force, although it verified the main trends seen in the test results. In particular, both tests and predictions confirmed that lateral force saturates at high track curvature (as shown in Exhibit 2). In addition, the tests confirmed predictions that hollow wheels significantly increase lateral force at trailing axles.

## FURTHER WORK

The current work contributes to the goal of defining an economic-based criterion for removing hollow-worn wheels from service. The cost benefits of removing wheels worn 3 mm (0.12 inch) or more were reported in TD 97-048. The rolling resistances recorded in this report will be used in a much-improved economic model to assess the cost benefits of setting the removal criterion at increments above 3 mm.

**Note: Contact Kevin Sawley at (719) 584-0636, with questions or comments about this document.**

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A MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, MAY BE AVAILABLE AT A LATER DATE THROUGH TRANSPORTATION TECHNOLOGY CENTER, INC., PUEBLO, COLORADO.