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# Analysis of AAR-2A Wheel Profile for Locomotives

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**Key Findings:**

- NUCARS® simulations showed improved performance in curves for the AAR-2A profile when considering wheel flange wear and L/V ratios.
- Direct comparison of the simulated wheel flange wear rate of the AAR-2A narrow flange profile compared to the AAR-1B narrow flange profile:
  - Exceeded 75 percent reduction in 2-degree track curves.
  - Was at least 58 percent reduction over the range from 1 to 6 degrees of track curvature.
- NUCARS® simulations showed no significant performance changes on tangent track for the wheel profiles considered.

*NUCARS® is a registered trademark of TTCI

Transportation Technology Center, Inc. (TTCI) conducted a study to investigate the effect of the Association of American Railroads (AAR) wheel profile AAR-2A on locomotive performance. The AAR-2A wheel profile is designed to have a nearly conformal contact condition to a typical worn high rail in a curve. In comparison to the AAR-1B profile, the AAR-2A profile has the potential to provide benefits such as improved steering and reduced rolling resistance, wear, fuel consumption, and surface damage.[1] The AAR-2A profile has recently become the standard for new and turned freight car wheels. The purpose of the study is to determine and quantify the potential benefits of the AAR-2A wheel profile for use in locomotives.

## BACKGROUND

The profile of the rail and wheel determines the contact condition as the train negotiates the track. The contact condition directly affects wheel/rail wear, surface damage, fuel consumption, and maintenance costs. Optimization of the contact condition is a critical aspect in improving the performance of wheel/rail interactions, and the wheel profile can improve the contact condition.

Conformal contact is the condition that describes a wheel flange root in conformal or nearly conformal contact with a rail gage and shoulder area. Compared to two-point contact, conformal contact can improve the performance when negotiating curves by reducing lateral forces and rolling resistance; especially low radius curves where flanging would occur.

TTCI conducted a survey of Class 1 railroads to obtain data on the new and trued wheel profiles that are used on locomotives. The survey showed that new wheels were produced using the AAR-1B wide flange profile. When truing wheels, a larger variety of profiles were used including AAR-1B narrow flange, Unipoint, EE profile (modified Heumann), and C Contour profile. The AAR-1B narrow flange, Unipoint, and EE profile (modified Heumann) profiles do not vary by more than 0.013 inch in the areas of contact with the rail. This is likely within the machining tolerance, so AAR-1B narrow flange was used to represent all three profiles in this study.

Although it was intended to provide nearly conformal contact with rails at the time it was developed in the late 1980s, the AAR-1B profile now creates two-point contact with today's typical worn high rail as seen in Figure 1. The AAR-2A profile was designed to have conformal or near conformal contact with today's worn high rail.

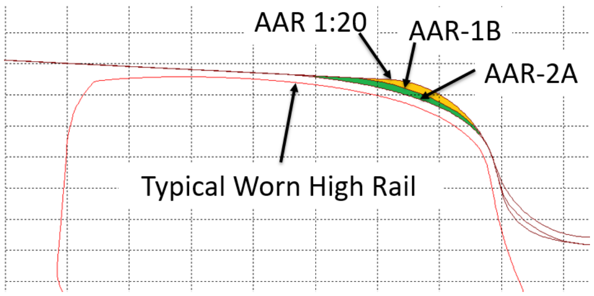


**Figure 1. Overlay of AAR-1B, 1:20, and AAR-2A profiles with typical worn high rail**

This was accomplished by increasing the material in the flange root while maintaining the same 75-degree flange angle of the AAR-1B. The older AAR 1:20 wheel profile is also included in this figure to show the historical progression of freight wheel profiles.

TTCI performed a previous study to determine the effect of changing freight cars from the AAR-1B profile to the AAR-2A profile.[1] Through analytical evaluation, computer simulation, and service testing it was shown that the AAR-2A profiles maintain flange root shape while AAR-1B profiles experience substantial flange root shape change. The testing also showed improvements in flange wear, rolling resistance, and lateral forces in curves. The AAR has changed the standard wheel profile for new and turned freight car wheels from the AAR-1B to the AAR-2A in 2020.

## SIMULATION MATRIX

To evaluate the effect of the AAR-2A wheel profile on the performance of locomotives, TTCI performed a robust sequence of NUCARS® simulations replicating various speeds, track curvature, rail wear conditions, track frictions, traction forces, locomotive truck types, and wheel profiles.

The track overall layout was split into two categories, curved and tangent track. Tangent track consisted of 2,000 feet of straight track simulated at 40, 50, 60, and 70 mph. Curve track consisted of at least 500 feet of tangent track, a spiral into 600 feet of constant curve with 4-inch superelevation, and a spiral back to tangent track. Curved runs were simulated at balance speed for 1-, 2-, 4-, 6-, 8-, 10-, and 12-degree curves with 4 inches of superelevation.

The rail profiles simulated were new 136 RE and typical worn profiles measured in curved and tangent track. The friction coefficient of the rail was varied in three ways: 1) dry rail (0.5 coefficient on all surfaces), 2) gage face lube (0.2 coefficient on gage face and 0.5 coefficient on top of rail), and 3) top-of-rail lubrication plus gage face lube (0.35 top-of-rail coefficient, 0.2 coefficient on gage face).

Simulations were run with and without longitudinal tractive and braking forces transferred from the wheel to the rail. Two types of locomotives were modeled, one with radial trucks and one with non-radial trucks. The five wheel profiles that were simulated were AAR-1B wide flange, AAR-1B narrow flange, AAR-2A wide flange, AAR-2A narrow flange, and C Contour profile (denoted in figures as: 1B WF, 1B NF, 2A WF, 2A NF, and C Con, respectively).

A wide variety of simulation outputs were evaluated including body displacement, body rotation, wheel and rail wear indexes at several locations, and vertical, lateral, and longitudinal forces between the wheels and the rail. The primary outputs used for analysis were wear to the top and gage side of the rail, wear to the tread and flange of the wheel, single wheel and net axle lateral-to-vertical (L/V) force ratios for curved runs, and lateral acceleration for tangent runs.

## SIMULATION RESULTS

The completed simulation results were compared for each wheel profile across the range of degrees of curvature for curved runs and across the range of speeds for tangent runs. The tangent track simulations had negligible differences between the five wheel profiles evaluated, and none of these simulations showed incipient hunting behavior. The remainder of the analysis focused on the curving performance.

Figure 2 shows the maximum single wheel L/V results over a variety of curvatures for the five wheel profiles modeled. The AAR-2A profile has lower L/V ratios in general than the AAR-1B and the C Contour profile. This effect is more pronounced at lower track curvatures before hard flanging occurs.

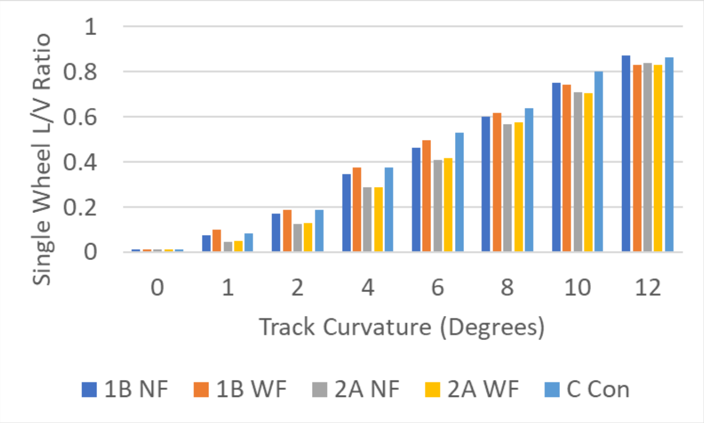


Figure 2. Maximum single wheel L/V ratio values

Because locomotive wheels are typically trued multiple times during their lives and most railroads true their wheels to the AAR-1B narrow flange profile (or a closely related profile), it makes sense to consider the AAR-1B narrow flange profile as the base case to compare against the performance of the other profiles. Figure 3 shows the single wheel L/V ratio results reorganized as the percent change in the results attributed to each profile compared to the AAR-1B narrow flange results. Because the results from the AAR-1B narrow flange represent the base case, these values have a 0 percent change for each track curvature considered.

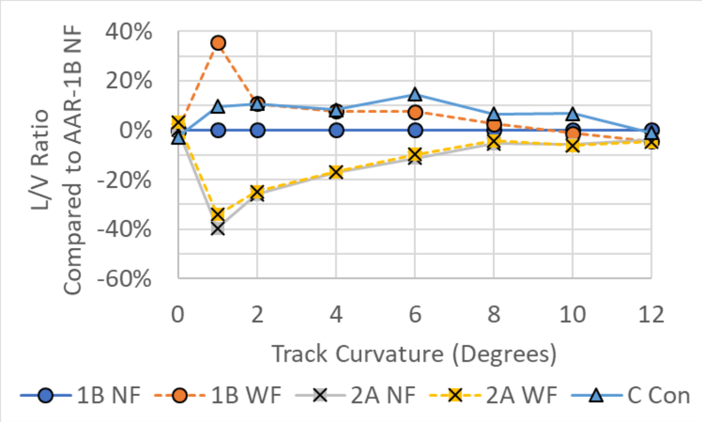


Figure 3. Maximum single wheel L/V ratio values compared to the AAR-1B narrow flange profile

Although the L/V results are generally indicative of curving performance, it is the wheel (and corresponding rail) wear performance that may be of most interest to anyone considering a wheel profile change for locomotives. Figure 4 shows the performance of each wheel profile in terms of the percentage change in total wear from wheel/rail contact as a function of track curvature.

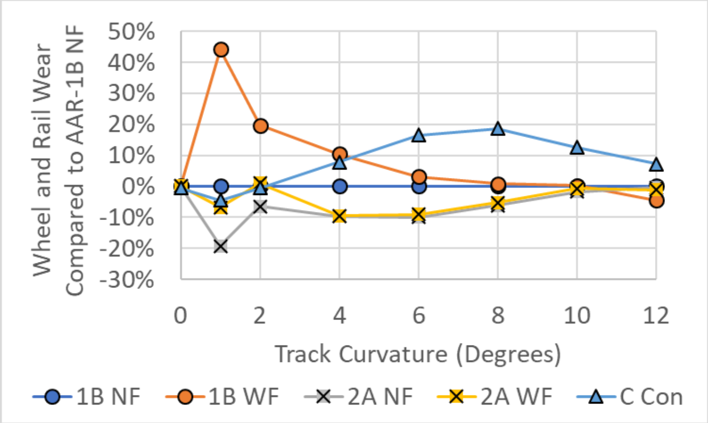


Figure 4. Wheel and rail wear compared to AAR-1B narrow flange profile

Notably, the AAR-2A narrow flange wheel is estimated to produce a 9.7 and 10.0 percent reduction in wheel and rail wear in 4- and 6-degree curves, respectively, as a composite average of the other variables in the simulation matrix.

Wear on the flanges of locomotive wheels can be particularly problematic with regard to limiting wheel life. Restoring a design profile on a wheel with a thin flange requires a deep cut and much material removal by the truing lathe. Therefore, the wear specifically on the flange of the wheel (and gage face of the rail) is useful to evaluate. Figure 5 shows the wheel flange and rail gage face wear performance of each wheel profile compared to the AAR-1B narrow flange. The AAR-2A narrow flange wheel is estimated to produce between 58.2 percent and 75.9 percent reduction in wheel flange wear for curves between 1 and 6 degrees.

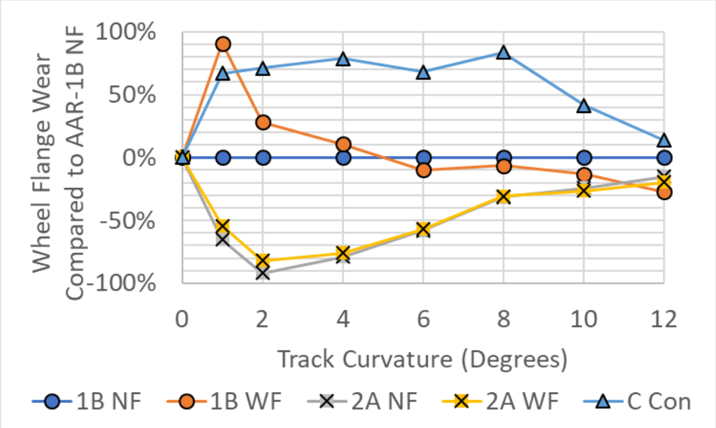


Figure 5. Wheel flange wear and rail gage face wear compared to the AAR-1B narrow flange profile

## DISCUSSION

Although these simulation results show substantial wear benefits for the AAR-2A wheel profile, note that these results are applicable only as long as the design profiles exist on the wheels of the locomotive and have not worn to a different profile. In the case of freight car wheels, profiles that create nonconformal contact with typical worn high rail profiles have been shown to wear into more conformal shapes within the first 50,000 miles of service.[1] There is no evidence to suggest this same effect would not also occur in locomotives. The top part of Figure 6 shows that AAR-1B and C Contour wheels produce nonconformal two-point contact when matched with a typical worn high rail. The bottom part of Figure 6 shows that a small random sample of as-worn locomotive wheel profiles produce conformal contact when matched with the same typical worn rail. In fact, this is the motivation for the AAR-2A profile — to produce new and turned wheels that do not require an extended wear-in process. Wheels with nonconformal profiles such as the AAR-1B and C Contour profile start their service lives with a high wear rate when negotiating track curves that gradually slows as their shape naturally begins to resemble that of an AAR-2A profile.

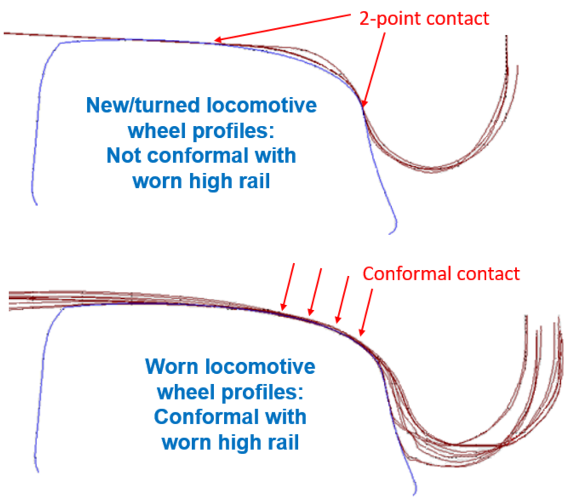


Figure 6. New and worn locomotive wheel profiles overlaid on a typical worn rail profile

Although this analysis did not specifically address the actual or predicted wear lives of the various wheel profiles for locomotives, related testing of freight car wheels with AAR-1B wide flange and AAR-2A wide flange profiles shows that the reduced flange wear rate of the AAR-2A profile compensates for the slightly narrower initial flange thickness.[1] The initial flange thicknesses are identical for the AAR-1B narrow flange and AAR-2A narrow flange wheels.

## IMPLEMENTATION CONSIDERATIONS

Because the wheel truing process is substantially different for locomotive wheels compared to freight car wheels, consideration must be given to replacing locomotive wheel cutter heads as opposed to making a software change on a freight car wheel lathe. Railroads would also need to consider the fact that the benefits of the AAR-2A profile are greatest when the wheel has been recently trued. As the AAR-1B profile wears to a conformal shape with a typical worn high rail, the relative benefits are reduced.

## CONCLUSION

Results show that the AAR-2A profile improves performance through reduced L/V ratios, wheel wear, and rail wear over the AAR-1B profile. Performance improvements were greatest with worn rail profiles in curves, with different truck types and rail friction conditions affecting which track curvatures showed the most improvement. The wheel flange wear rate for the AAR-2A narrow flange profile compared to the AAR-1B narrow flange profile exceeded 75 percent reduction in 2-degree track curves and was at least 58 percent reduction over the range from 1 to 6 degrees of track curvature. No significant performance changes were noted for wear or lateral acceleration on tangent track for the AAR-2A profile.

The C Contour wheel profile showed no benefit generally in L/V ratio and a higher wear rate than the AAR-1B narrow flange profile.

## References

1. Wu, H., Cummings, S. December 2017, Development of AAR-2A Wheel Profile for North American Freight Railroads," Research Report R-1026, Association of American Railroads, Pueblo, CO.

**For comments or questions about this publication, contact Jack_Schultz@aar.com**