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# A Wheelset Suspension to Prevent Shells on Freight Car Wheels Part I of II

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**Summary**

In a project to develop a conceptual freight car truck design to address truck performance problems identified through the Association of American Railroads' Strategic Research Initiatives Program, Transportation Technology Center, Inc. (TTCI) has proposed a design approach to reduce tractions on the lead wheel contacting the low rail in a curve, thereby

- Reducing the formation of cracks on the wheel tread
- Reducing the incidence of high impact wheels (HIW)

The design approach proposes the introduction of a reduced longitudinal stiffness between the wheelset in a manner similar to some designs of M-976 trucks. The rationale behind this approach is described.

In addition, a method for determining the value for this longitudinal stiffness is presented and suggested as a first approximation for a more accurate NUCARS®* parametric analysis to optimize the stiffness. The results of this analysis will be presented in future *Technology Digests* (TDs).

As related in recent TDs, the formation of two crack bands on HIWs has been linked to measured lateral forces acting on the wheels, resulting in the conclusion that lateral forces may be a root cause for crack band formation.[1,2]

In these TDs, TTCI presents a hypothesis for the progression of these crack bands to the breakout of material from the wheel tread to form HIWs, suggesting that lateral forces are, in turn, a root cause of HIWs. A way forward to the verification of this hypothesis and a solution to HIWs is proposed.[1]

The overall objective of developing an integrated truck design is to develop a truck to:

- Reduce the incidence of HIW
- Improve empty and loaded hunting stability
- Reduce rolling resistance and, consequently, fuel consumption
- Provide predictable performance across wayside detectors, over its maintenance life, which is directly related to truck component condition

The term "integrated" suggests that the design should address the complete truck including brake system and truck to car body interface.

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## INTRODUCTION

Through the Association of American Railroads' Strategic Research Initiatives Program, TTCI is tasked to develop a conceptual freight car truck design to address truck performance problems identified.

The objective of this TD is to suggest a wheelset suspension design and stiffness characteristic that will assist in preventing the formation of shells and resulting HIWs.

A major problem for North American Railroads is that of HIWs. Approximately 50 percent of HIWs have been attributed to thermal mechanical shelling (TMS).[1] TMS is considered to be due to a combination of overheated wheels subjected to rolling contact fatigue.

Instrumented wheelset data suggests a strong correlation between the location of measured traction forces on the tread of the lead wheel contacting the low rail in tight curves and observed cracks on the wheel tread of HIWs; TTCI has developed a hypothesis to suggest the progression from the formation of these cracks to the breakout of material from the wheel tread.[2]

A further analysis of the measured tractions on the tread of the lead wheel contacting the low rail shows high lateral traction forces are, in particular, associated with crack formation.[3]

A NUCARS® parametric analysis[4] shows the:

- Relationship between lateral traction forces on the wheel contacting the low rail and the angle of attack (AOA) of the wheelset
- Role of the wheel/rail coefficient of friction in determining the magnitude of these traction forces

To avoid or reduce the incidence of shelling and resultant HIWs, the use of an improved truck design is suggested.

## SUSPENSION DESIGN APPROACH

Wheel shells and resulting HIWs have been shown to be associated with high AOA of the lead axle in a curve. These high AOAs are associated, in turn, with the attitude of a nonsteering truck in a curve (Figure 1); i.e.,

- Longitudinal forces on the lead wheelset generate moments in a sense to steer the wheelset through the curve and minimize the AOAs.
- The lead wheelset is, however, constrained by the trailing wheelset and cannot yaw in a sense to minimize this AOA by the trailing wheelset.
- Consequently, the lead wheelset aligns to the track with an AOA, α. For standard North American three-piece freight trucks (without primary suspension shear pads) in a nonwarped condition, α, measured in milliradians (mrad), is roughly equal, numerically, to the curvature, measured in degrees.

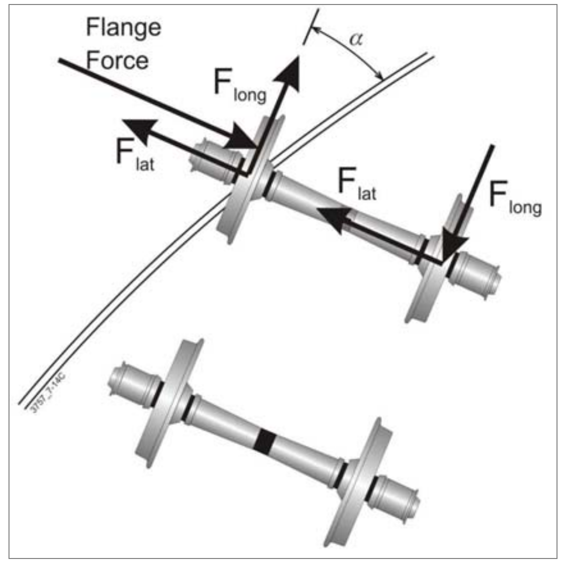


**Figure 1. Orientation of a Nonsteering Truck in a Curve**

A design approach to reduce the magnitude of the lateral traction force could be to introduce a longitudinal spring constraint between the axles (Figure 2); the longitudinal traction forces acting on the lead wheelset are then used to deflect this constraint sufficiently to enable the wheelsets to align to an angle, φ, relative to one another, and consequently attain a more radial position in the curve.

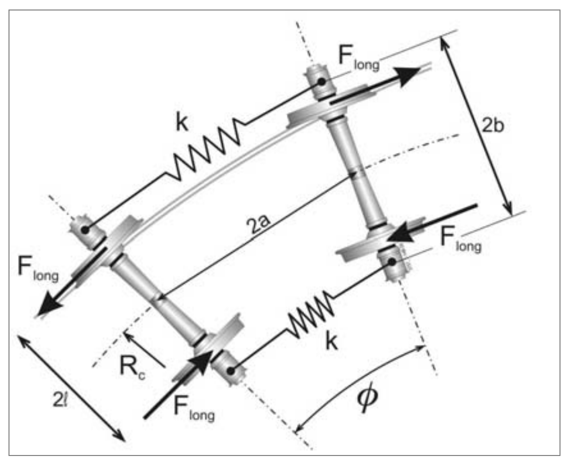


**Figure 2. Orientation of a Steering Truck in a Curve**

A quasi-static radial position of both wheelsets in the curve can be obtained on condition that:

- The moments developed by the longitudinal forces on the lead wheelset are equal but with opposite sense to those developed on the trail wheelset. This requires that the lead wheelset be deflected laterally towards the high rail from the pure rolling position,[5] and that the trailing wheelset be deflected laterally in an opposite sense, towards the low rail, from the pure rolling position. Equal but opposite longitudinal forces are generated on the trail wheelset. This requirement can be met by allowing the truck as a whole to align with a slight AOA to the curve.

- The quasi-static radius differential generated between the wheels on the same axle and the friction coefficient generate a sufficient moment to deflect the springs constraining the wheelsets longitudinally to one another so that radial alignment is possible in the tightest curve; conversely, the longitudinal spring stiffness constraint between the axles is sufficiently soft to allow prevailing longitudinal forces to deflect the springs sufficiently to allow radial alignment of the wheelsets in that curve; radial alignment will occur when the angle between the wheelsets:

$$\varphi = 2a / R_c \quad (1)$$

The requirement for radial wheelset alignment requires the truck designer to determine the relationship between the longitudinal traction force, $F_{long}$ and the longitudinal spring constraint:

The moment to yaw for the leading wheelset is:

$$M = F_{long} \times 2l \quad (2)$$

Where:

2l is the distance between wheel/rail contact patches across the wheelset.

For radial alignment (Equation 1), the reaction moment from the longitudinal spring constraints, k, to the axle is:

$$M = 2k\, b^2\, (2a / R_c) \quad (3)$$

where:

a = ½ truck wheelbase (inches)

b = ½ distance between journal bearing centers across a wheelset (inches)

$R_c$ = radius of curvature (inches)

Equating (2) and (3) gives:

$$k = F_{long}\, (l\, R_c / 2ab^2) \quad (4)$$

Consequently, the suspension designer needs to establish a maximum anticipated longitudinal force generated between the wheel and rail and a minimum curvature for radial alignment to establish the optimal longitudinal suspension stiffness.

In the first approximation, the longitudinal traction force may be considered independent of curvature and gage and dependant only on lateral deflection of the wheelset beyond the lateral, pure rolling position. This force is a maximum on "flange contact" of the lead wheelset with the high rail. Flange contact is not always a clearly defined term, but with a wheel tread that has worn generally to the shape of the high rail, it is that position when contact is made in the flange fillet. A study of measured longitudinal forces as well as those developed as a function of AOA should establish an acceptable design value for $F_{long}$ as the next section indicates.

## Determination of the Maximum Anticipated Longitudinal Traction Force

The quasi-static longitudinal traction forces generated on a single wheelset in a curve are proportional to the lateral deflection of the wheelset from the pure rolling position in the curve.[5] These forces can be equal to and in opposite sense on the two wheels of the wheelset, if the condition mentioned earlier is adhered to.

The proportionality of longitudinal forces with lateral wheelset deflection is illustrated from instrumented wheelset (IWS) results.[3]

The magnitude of these longitudinal forces can be judged from:

- *Measured results on the lead wheel contacting the low rail in a circular curve* (Figure 3); they are equivalent to the lateral forces shown in Figure 7 of Reference 3. Measured longitudinal forces were calculated to average approximately 5,250 pounds for a loaded 286,000-pound car, when a wheelset machined to an AAR-1B profile makes flange contact in an 8-degree circular curve. Rail profiles and friction coefficients were not measured and thus unknown. We assume flange contact is made in the 8-degree curve.

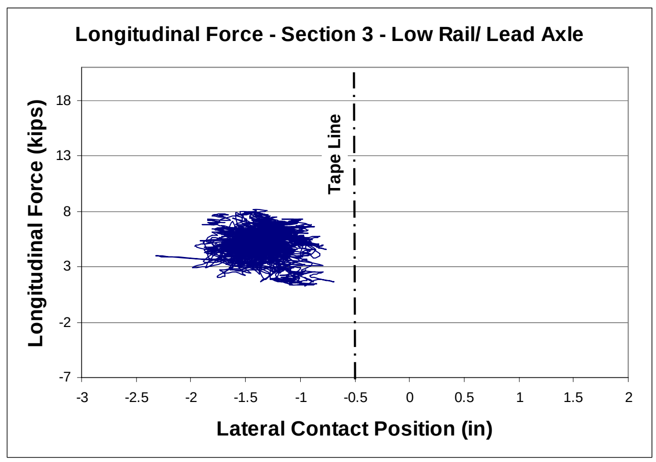


**Figure 3. Longitudinal Traction Forces Measured on the Wheel Contacting the Low Rail in the Curve described in Reference 3**

- *The results from the parametric study of a single wheelset in a curve.*[4] Figure 4 shows the longitudinal forces generated from this analysis for a wheelset machined to a wheel profile making conformal (single point) flange contact with the high rail. The analysis shows:
  - Negative longitudinal forces due to the sign convention used in the analysis.
  - Longitudinal forces on the wheel contacting the low rail in the curve increasing as flange contact is made and as AOA and resulting creepage increases; these forces then decrease as limiting friction is reached with further increases in AOA.

- The longitudinal force generated for a wheel/rail friction coefficient of 0.3 is a minimum of 6,000 pounds for AOAs greater than 1 mrad; there is flange contact between the wheelset and the high rail; this figure is, practicably, similar to the IWS measurements above.

286,000-pound car: Longitudinal force on the wheel contacting the low rail as a function of AOA and friction coefficient

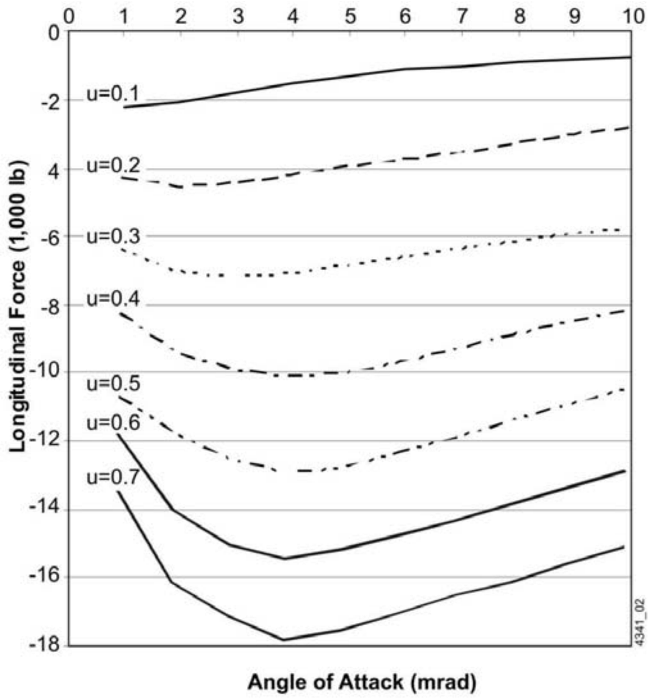


**Figure 4. Longitudinal Forces as a Function of Wheelset AOA and Wheel/Rail Friction Coefficient**

Using the relationship from Equation 4 together with the following values:

| | |
|---|---|
| a = 5 ft 10 inches / 2 | = 35 inches |
| b = 79 inches / 2 | = 39.5 inches |
| l = (4 ft 8 ½ + 3) / 2 inches | = 29.75 inches |
| $R_c$ = 574 ft (10-degree curve) | = 6,888 inches |

a typical value for the longitudinal stiffness, k between the axles, k might be 22,630 pounds per inch.

This stiffness is for a direct coupling between axles. Adapter pads used in some M-976 trucks are comprised of two stiffnesses arranged in series (one on either adapter); consequently, if adapter pads are used to provide this constraint, their individual stiffness must be double this value.

## CONCLUSIONS

The suspension design approach to reduce the traction forces on the lead wheel contacting the low rail in a curve and prevent the formation of wheel shells uses a longitudinal stiffness between the wheelsets which could be typical of that incorporated in some M-976 truck designs.

The methodology presented for the determination of the stiffness of the longitudinal constraint utilizes:

- IWS measurements made in an 8-degree curve
- Results from a NUCARS model of a single wheelset in a curve

The stiffness so derived can be used as a first approximation for a more sophisticated parametric design approach considering:

- A NUCARS model of a complete car including the effects of the truck suspension and interface with the car body
- The subsequent consideration of stiffness requirements for truck hunting stability

The overall objective of developing an integrated truck design is to develop a truck to:

- Reduce the incidence of HIW
- Improve empty and loaded hunting stability
- Reduce rolling resistance and, consequently, fuel consumption
- Provide predictable performance across wayside detectors, over its maintenance life, which is directly related to truck component condition.

The term "integrated" implies that the design should integrate the truck suspension with the brake system and truck to car body interface.

Future TDs will present the results of a NUCARS parametric study of a complete car including the hunting stability.

## REFERENCES

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