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# Distance-based Flange Climb L/V Criteria

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## Summary

Supported by predictions from Transportation Technology Center, Inc.'s dynamic simulation model NUCARS™\* and results from full-scale derailment tests with TTCI's Track Loading Vehicle, this digest explains why a distance-based flange climb safety criterion for the ratio of lateral to vertical wheel/rail forces (L/V ratio) is more valid than a time-based criterion.

Early research into flange-climbing derailments resulted in criteria involving the L/V ratio of wheel/rail forces. If the L/V ratio was kept below 1.0, and the maximum contact angle was 75 degrees, a flange-climbing derailment was unlikely. (Just one solution of Nadal's formula for a critical L/V ratio.)

Later researchers observed that flange-climbing was not instantaneous and developed a time-based criterion. The critical L/V ratio now had to be sustained for longer than a specified time for a flange-climbing derailment to be likely. As a result, the Association of American Railroads, *Manual of Standards and Recommended Practices*, Section C, M-1001, Chapter XI acceptance criteria now allow the L/V criteria to be exceeded for less than 50 millisecond.

NUCARS was used to study the effect of a range of axle angles-of-attack (AOA) and L/V ratios on flange-climbing distance. Results show that for large AOA the flange-climbing distance converges to a single value for L/V ratios greater than the Nadal limit.

Although at this time the most appropriate distance criterion for a revised standard has not been established, a comparison has been made between a hypothetical 3-foot distance criterion and the existing 50-millisecond time criterion. For speeds below 40 mph, the distance criterion is less conservative than the existing time-based criterion. It allows critical L/V ratios for longer than the current standard. For speeds above 40 mph, a 3-foot distance criterion is more restrictive than the existing 50-millisecond criterion.

Questions arising from this work include: What happens if the L/V ratio drops below a critical value for a short distance and then exceeds it again? Although the duration of each separate exceedence could be less than 3 feet, can the combined effect lead to a flange-climbing derailment?

Further work is required to establish an appropriate value for the distance-based criterion. A similar study is required to determine reasonable distance criteria for other safety performance criteria such as the truck-side L/V ratio.

\*NUCARS™ is a trademark of Transportation Technology Center, Inc.



**INTRODUCTION**

The development of criteria for flange climbing derailment began with work by Nadal.<sup>1</sup> His formula for the limiting value of lateral to vertical wheel/rail force ratio (L/V) is given below:

$$\frac{L}{V} = \frac{\tan(\delta) - \mu}{1 + \mu \tan(\delta)}$$

where  $\delta$  is the wheel/rail contact angle (relative to the horizontal) and  $\mu$  is the coefficient of friction.

Previous research has shown that for large angles of attack (AOA), L/V ratios greater than Nadal’s value result in flange climb.<sup>2,3,4</sup> L/V ratios less than Nadal’s value will mean the flange of the wheel slips on the rail, and flange climbing does not take place.

The current AAR limit in Chapter XI of the *Manual of Standards and Recommended Practices*<sup>5</sup> for single-wheel L/V ratio is a conservative application of Nadal’s theory for a coefficient of friction of 0.5 and a contact angle of 75 degrees.

Nadal’s theory is conservative for at least three reasons: (1) it assumes a large AOA is present, (2) it does not consider the effect of the non-flanging wheel on the wheel/rail contact conditions for the flanging wheel, and (3) it assumes flange climbing derailment is instantaneous once the L/V limit has been exceeded. Assumption (3) is discussed here.

This work was sponsored by the AAR under Strategic Research Initiative 14A, Car Performance Standards. Also reported are results obtained in a parallel project for the Transit Cooperative Research Program sponsored by the Transportation Research Board of the National Research Council.

**TIME TO CLIMB CRITERIA**

In practice, a flange climbing derailment is not instantaneous. The L/V ratio has to be maintained while the climbing takes place. If, for example, the lateral force returned to zero before the flange had reached the top of the rail, the wheel might be expected to drop down again.

When the flange contacts the rail for a short duration, as may be the case during hunting (kinematic oscillations) of the wheelset, the L/V ratio might exceed Nadal’s limit without flange climbing.

Researchers at the Japanese National Railways (JNR) proposed higher allowable L/V ratios when the time duration of the lateral force on the rail was less than 0.05 seconds (50 msec).<sup>6</sup> Their proposed L/V criterion is shown in Figure 1. For lateral forces with very short time duration, relatively high values of L/V are acceptable.

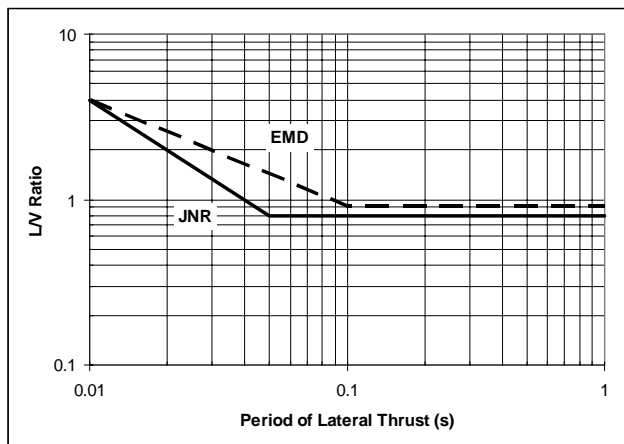


Figure 1. JNR and EMD L/V Criteria

An even less conservative approach was proposed by Electromotive Division of General Motors (EMD).<sup>7</sup> EMD’s L/V criterion is also shown in Figure 1.

Based on the JNR and EMD research, and considerable experience gained from on-track testing of freight vehicles, a 50-millisecond time duration was adopted by the AAR for Chapter XI certification testing of new freight vehicles. Now to be certified, a new freight vehicle must not have an L/V ratio greater than 1.0 for more than 50 milliseconds during testing.

**DISTANCE TO CLIMB CRITERIA**

Imagine a wheel flange in contact with the rail ahead of the wheel’s centerline due to a large AOA. Consider the case where the L/V ratio is such that friction prevents slipping. The wheel will start to rotate about the point of contact with the rail causing the wheelset’s center of gravity to rise. If the AOA is maintained, a new point of contact may develop ahead of the wheel’s centerline. If the L/V ratio is still large enough, the wheel will rotate about this new contact point and continue to rise.

Thus, the distance along the track that the wheel travels while its flange climbs the rail is a function of the geometry of the wheel and rail profiles, the coefficient of friction, and the magnitude of the L/V ratio. It is independent of the speed at which the wheel is traveling (at least over the speed range of normal freight operations).

This observation is supported by predictions from TTCI’s NUCARS dynamic simulation model.<sup>8</sup> Figure 2 shows some typical NUCARS results for flange climb distance against speed for wheels with a flange angle of 63.4 degrees and a corresponding Nadal value of 0.75. Results are shown for two applied lateral forces corresponding to L/V ratios somewhat above this Nadal value.

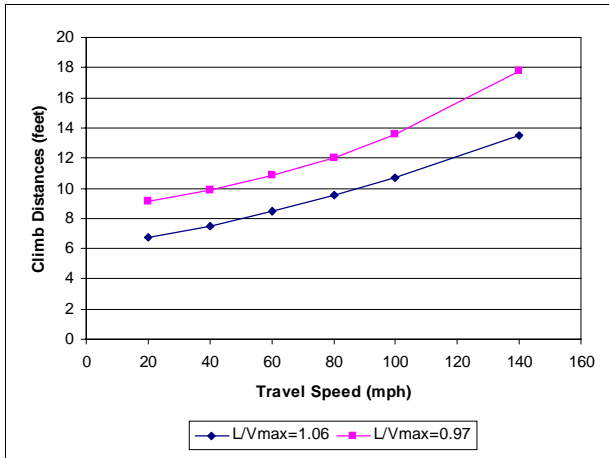


Figure 2. Effect of Speed on Flange Climbing Distance from NUCARS Predictions

For speeds up to 75 mph, the flange climbing distance only varies by a few feet, with larger applied L/V ratios resulting in shorter climb distances. Using a 50-millisecond time limit would give a flange climbing distance of 5.5 feet at 75 mph.

Predictions using NUCARS compare well with results from tests with TTCI's Track Loading Vehicle (TLV).<sup>2,3,4</sup> Figure 3 compares TLV results with NUCARS predictions for a wheelset with an AOA of 5 milliradians, and a wheel/rail contact angle of 75 degrees (Nadal value of 1.13). The scatter in the TLV results is thought to be due to track geometry irregularities and local variations in rail cross-section and friction coefficient.

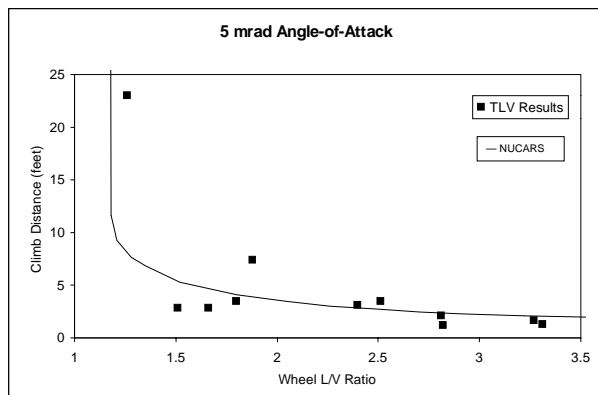


Figure 3. Comparison of TLV Results and NUCARS Predictions

NUCARS has also been used to study the effect of AOA on flange climbing distance.<sup>4,8,9</sup> Some results are shown in Figure 4, for a wheelset with a flange angle of 63.4 degrees (Nadal value of 0.75), for a range of applied L/V ratios. To achieve the range of L/V ratios shown, the vertical force was held constant and the applied lateral force was increased.

These results show that as the AOA increases, the applied L/V ratio, provided it is greater than 0.75, has less and less effect on the flange climbing distance. For large AOA the flange climbing distance becomes asymptotic to a value less than 3 feet.

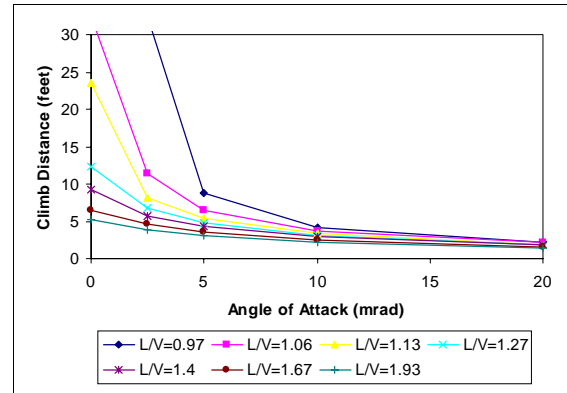


Figure 4. Effect of Angle-of-Attack on Flange Climbing Distance

Conventional three-piece freight trucks commonly develop AOA values greater than 10 mrad during normal daily operations. Therefore, it seems reasonable to set a distance criterion at or closer to this asymptotic value. For any given L/V ratio, the wheel may travel further before derailment, if the angle-of-attack is small, but such a small value cannot be guaranteed.

### COMPARISON OF CRITERIA

The most appropriate value for a distance criterion has not been established. However, to demonstrate how a distance-based criterion would compare with the existing time-based criterion (50 msec), a value of 3 feet will be used.

Figure 5 plots the two criteria on a graph of speed against distance. To be safe from derailment, a critical L/V ratio should be present for less than 3 feet; i.e., below the horizontal line.

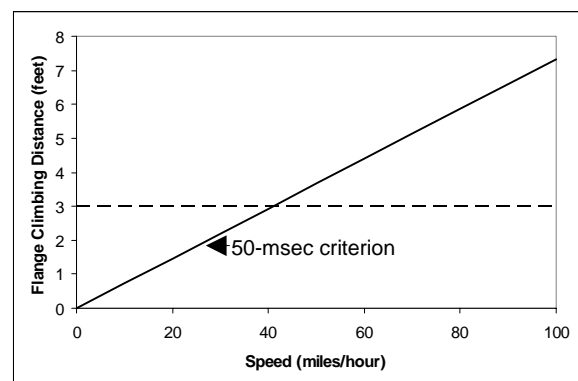


Figure 5. Comparison of Distance and Time-Based Criteria

Figure 5 shows that the 50-millisecond time-based criterion is more conservative than the 3-foot distance-based criterion for speeds below 40 mph. This means that critical L/V values would be permitted for longer distances under a distance-based rule at low speeds.

For speeds above 40 mph, the 3-foot distance-based criterion would be more restrictive than the existing time-based criterion.

A comparison of the two criteria for a real example is shown in Figure 6. The L/V measurements are from an instrumented wheelset on a car undergoing Chapter XI tests at the Transportation Technology Center. The car was traveling 10 mph.

The L/V ratio rises to a value of 1.0 at 9.47 seconds. After a further 50 millisecond, it is still above 1.0, so this car did not meet the existing Chapter XI criteria. The car did not derail.

Using a distance-based criterion of 3 feet, at 10 mph, the time limit on L/V becomes 0.2 seconds. Within this time, the L/V drops below 1.0, so the performance would be considered acceptable.

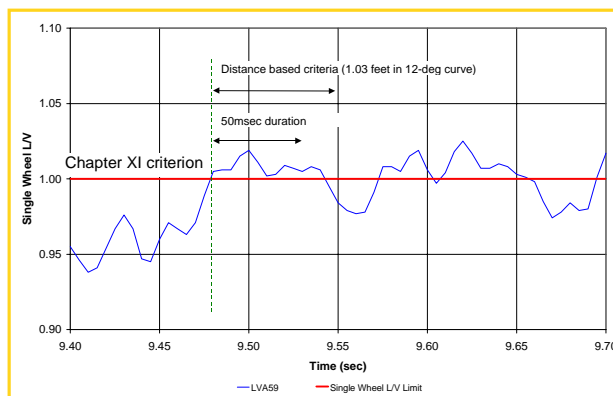


Figure 6. Comparison of Criteria using Test Data

## FUTURE WORK

Further work is required to establish an appropriate value for the distance-based criterion. This will involve more modeling and will be an extension of the work completed on transit vehicles for TCRP.<sup>9</sup>

Although, in the example given in Figure 6, performance would be acceptable under a 3 foot distance criteria, it can be seen that after dropping below 1.0, the L/V ratio soon increases above 1.0. Assuming that AOA and friction coefficients are held constant, this drop in L/V may be due to one of two effects. It may be that the wheel has fallen back to a normal rolling position. In this case, the second exceedence of Nadal's limit is a separate event.

Alternatively, a drop in L/V might occur when the flange tip makes contact with the head of the rail with

corresponding reductions in contact angle, and Nadal's limit. In this case, both exceedences in Figure 6 would be part of the same flange-climbing event and a derailment is likely. Further work is required to determine how drops below Nadal's limit for short distances should be handled. This will require investigation of the effects angle-of-attack and the forces acting on the non-flanging wheel.

A similar study is required to determine a reasonable criterion for truck-side L/V. In the case of the truck-side L/V, the issue is rail rollover and not derailment, but the same principles apply — a certain distance is required to roll the rail over.

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