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Research Summary – Structural Performance Of TC-117 Tank Cars Under Derailment Conditions

Transportation of Dangerous Goods | Scientific Research Division

SUMMARY

This research evaluated the structural performance of TC-117 tank car designs in derailment scenarios, using a combination of derailment simulations, puncture performance evaluations, and considerations for cold weather material performance. TC-117 tank cars were predicted to have better performance than legacy TC-111 cars under derailment conditions; TC-117J tank cars (compliant with the new specifications) were found to have fewer punctures than several variants of TC-117R tank cars (retrofitted older cars) in all modelled scenarios. Model results suggest that tank car punctures could increase between 5 to 10% at -40°C compared to performance at an ambient temperature of 20°C.

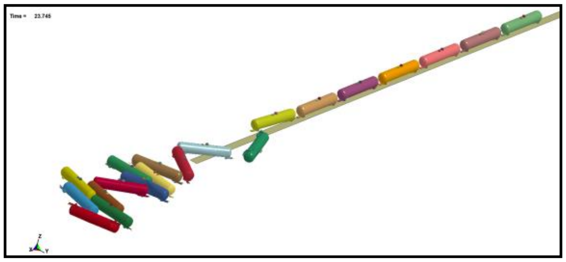

Figure 1 – A sample final pileup result from one of the derailment simulations

BACKGROUND

The current standard for rail tank cars carrying flammable liquids, TC-117, requires new cars (TC-117J) to have 9/16-inch-thick tank shells made from normalized TC-128B steel, 11-gauge jackets, ½-inch-thick full-height head shields, and top fittings protection meeting Section 8.2.3.4.1 of Transport Canada Standard TP14877, Containers for Transport of Dangerous Goods by Rail. Older, existing tank cars can be retrofitted to the TC-117R design. While the modifications required by TC-117R are expected to improve crashworthiness performance, the level of improvement will depend on the specifications of the original tank car.

OBJECTIVES

The overall objective is to predict the crashworthiness performance of TC-117J tank cars and TC-117R variants and assess their safety benefits through their relative performance in:

- a 100-car unit train of the same tank car design; and
- a non-realistic 100-car mixed consist train of alternating tank cars and box cars.

The performance metrics are the number of cars punctured and the number of failed top fittings in a range of different accident scenarios.

METHODS

The methodology for estimating the number of punctures started from prior work done for the United States (U.S.) Department of Transportation (DOT) Federal Railroad Administration (FRA), with updates made to the model to consider:

- Failures of top fittings protection;
- Inter-car connections that model how torque is transmitted between cars in derailments;
- The effect of cold temperatures on tank car puncture resistance.

A model of a box car was also created for the mixed consist cases.

The overall methodology for estimating puncture performance is as follows:

- Characterize the load environment associated with tank car derailments through multiple derailment simulations of unit trains of tank cars and mixed consist trains to derive a histogram of expected impact forces;
- Quantify the puncture resistance of given tank car designs for a nominal range of impactor sizes and impact forces, based on prior research;
- Combine the load environment histograms, the puncture resistance curves, and nominal impactor size distributions, to evaluate the probability of puncture for a set of designs and operating speeds.

A similar methodology was also adopted for the estimation of fittings failure:

- Quantify the distribution of velocities with which fitting protective structures hit the ground through derailment simulations;
- Characterize the strength of the protective structures through detailed finite element (FE) analysis of individual cars' protective structures hitting the ground at specified speeds;
- Estimate the likelihood of fittings failure by combining the above two elements.

The updated model was used in simulations of 100-car trains at a range of speeds from 5 to 60 mph (8-97 km/h). The consist was either a unit train of one TC-117 design, or a non-realistic mixed train consisting of alternating tank cars and box cars. This mixed consist train was designed to create a more severe impact environment where each tank car can interact with the edges and vertices of the rigid box cars surrounding it. For the unit train scenarios, one (1) TC-117J and eight (8) TC-117R designs based on different source tank cars were simulated. For the mixed consist scenarios, one (1) TC-117J and the two (2) worst-performing TC-117R designs from the unit train scenarios were simulated.

Eighteen simulations were performed at each speed to account for variations in force to initiate derailment, track conditions, and ground conditions. This resulted in a histogram of predicted impact forces, and resulting number of tank car punctures, at each speed. Outputs from the simulations also gave predicted impact velocities for top fittings in the derailments.

The challenge of the cold weather modelling effort was to develop a material model and methodology that reflected the change in material properties like the yield stress, ultimate stress, and elongation, while also reflecting the drastic reduction in Charpy energies under cold weather conditions. This was addressed by the following:

- Model the Charpy test using detailed, high-fidelity FE models of Charpy specimens;
- Tune the material model so that Charpy results at low temperatures are reasonably simulated;
- Transfer the corresponding material properties to a puncture model;
- Use those results to estimate cold weather performance.

RESULTS

The puncture and top fittings performance of several TC-117 variants were estimated using the approach described, in unit and mixed consist trains, for a variety of operating speeds and temperatures. An overview of the puncture performance and top fittings results in unit trains is presented in Figures 2 and 3.

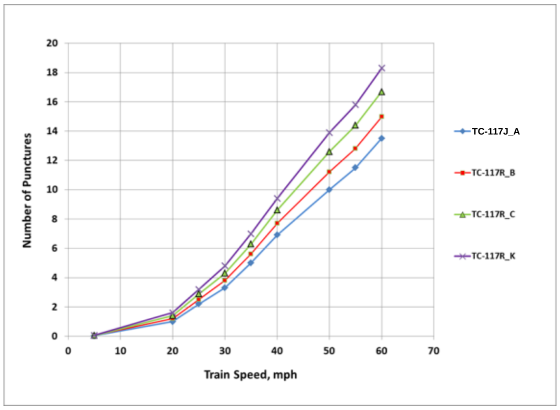

Figure 2 – Number of punctures vs. different speeds for 4 types of tank cars in unit trains at 20°C

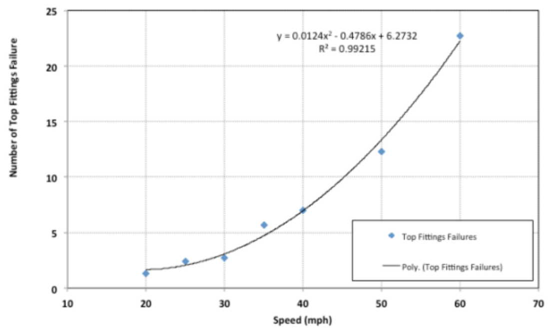

Figure 3 – Top fittings failure as a function of speed in unit trains

Sample results of the cold weather performance evaluation are shown in Figure 4.

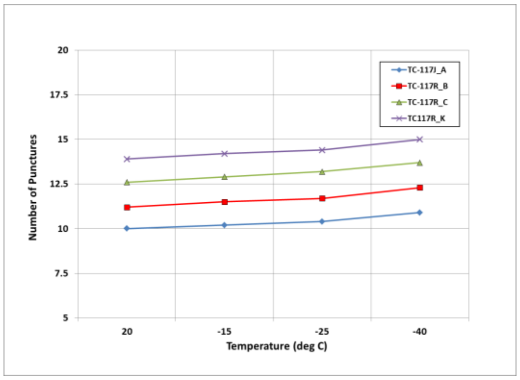

Figure 4 – Number of punctures vs. temperature for 4 types of cars at 50mph in unit trains

Mixed consist trains experienced the same average number of cars derailed at the speeds simulated, but a greater number of punctures in the tank cars compared to the unit trains, confirming that a more severe derailment environment was created.

CONCLUSIONS

Results showed that structural damage in derailments increases significantly with speed. The TC-117J tank car had fewer punctures than any of the TC-117R variants in all scenarios modelled. Comparisons to prior work suggest that any of the TC-117 variants has better performance than the legacy TC-111 cars, with the TC-117J design offering the best performance. As expected, the two (2) variants with non-normalized steel shells have slightly more punctures than similar variants with normalized steel shells, and thinner shells experience more punctures when compared to thicker shells of the same material. An example comparison of the difference in performance between a TC-117J and one (1) TC-117R variant at different speeds in a unit train is shown in Table 1.

Table 1 – Selected Unit Train Results at 20°C

		Most Likely Number of Punctures at 20° C		% Improvement due to Speed	% Improvement Compared to TC-117R_K	
Tank Car Type	Tank Shell Type	30 mph	50 mph	50 to 30 mph	30 mph	50 mph
TC-117J	9/16" TC128B, normalized	3.3	10.0	67%	31%	28%
TC-117R_K	1/2" A516-70 normalized	4.8	13.9	65%	-	-

Table 2 shows that when placed in an unrealistic mixed consist train which creates a more severe derailment environment, the benefit of a TC-117J compared to a lesser-performing tank car decreases by several percentage points, but the new-built TC-117J continues to provide the best reduction in punctures of all the simulated TC-117 variants.

Table 2 – Selected Mixed Consist Train Results at 20°C

		Most Likely Number of Punctures at 20° C		% Improvement Compared to TC-117R_K	
Tank Car Type	Tank Shell Type	30 mph	50 mph	30 mph	50 mph
TC-117R_K	1/2" A516-70, normalized	4.2	6.5	-	-
TC-117J	9/16" TC128B, normalized	3.1	5.0	26%	20%
TC-117R_F	7/16" TC128B, non-normalized	4.1	6.4	2%	1%

Top fittings failures were found to increase significantly with speed in a similar way to tank punctures.

A material model was developed to account for the change in steel properties and failure mode with temperature. The model was calibrated by comparing simulations of Charpy impact tests with laboratory test results, and further extended to cover both normalized and non-normalized tank car steels. It was found that temperature has a slight effect on the number of punctures. In general, there is a 5-10% increase in the predicted number of punctures when temperature drops from 20 to -40 °C.

Comparisons to a limited set of available accident data suggest that the model predictions for tank punctures are consistent with field observations from derailments, while slightly overpredicting top fittings failures.

FUTURE ACTION

This work does not provide evidence to support using train configuration as a consideration for reducing punctures. Further studies would have to be performed to understand the complex interplay of factors such as train length, volume of cars, in-train forces, and train consist that may affect both the likelihood and severity of derailments.

The methodology used to estimate change in performance of tank cars in cold temperatures used in this project was novel work based on a theoretical construct. Puncture testing of tanks in cold temperature conditions may help validate this approach.

The model overpredicted the failure of top fittings when compared to representative derailment incidents and may benefit from further refinement and validation if greater analysis of the results is desired.

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Report: Structural Performance of TC-117J Tank Cars and TC-117R Variants under Derailment Conditions (2022)

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KEYWORDS

Puncture, modelling, unit train, mixed train, mixed consist, HAZMAT, dangerous goods, TC128B, A516-70, TC-117J, TC-117R, TC-111, tank car, flammable liquids, top fittings