National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594

HWY22MH006

VEHICLE PERFORMANCE/SIMULATION STUDY

Specialist's Study

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A. CRASH

Location: Andrews, Texas
Date: March 15, 2022
Time: 8:17 PM central daylight time (CDT)
Vehicle 1: 2007 Dodge Ram 4x4 Quad Cab pickup truck
Vehicle 2: 2017 Ford Transit 350 MR 12 -Passenger Wagon Towing a Single Axle Trailer

B. VEHICLE PERFORMANCE/SIMULATION STUDY SPECIALIST

Specialist Shane K. Lack
NTSB
Washington, DC

C. SUMMARY

For a summary of the crash, refer to the *Crash Summary Report* which is available in the docket for this crash.

D. DETAILS OF THE ANALYSIS

1.0 Overview

This crash occurred on a two-lane rural highway with a posted speed limit of 75 mph. Prior to the collision, the Ford was traveling north in the northbound lane towing a single axle trailer. The crash occurred after the southbound Dodge crossed into the northbound lane and collided with the Ford. Based on a pre-impact tiremark from the Dodge, the Dodge was heading back towards the southbound lane when the collision occurred. After the initial collision, the trailer separated from the Ford and overturned onto its left side before coming to rest. Figure 1 shows the pre-impact tiremark from the Dodge and the final rest positions of the vehicles and trailer. The primary objective of this study was to estimate the speeds of the vehicles prior to the collision.

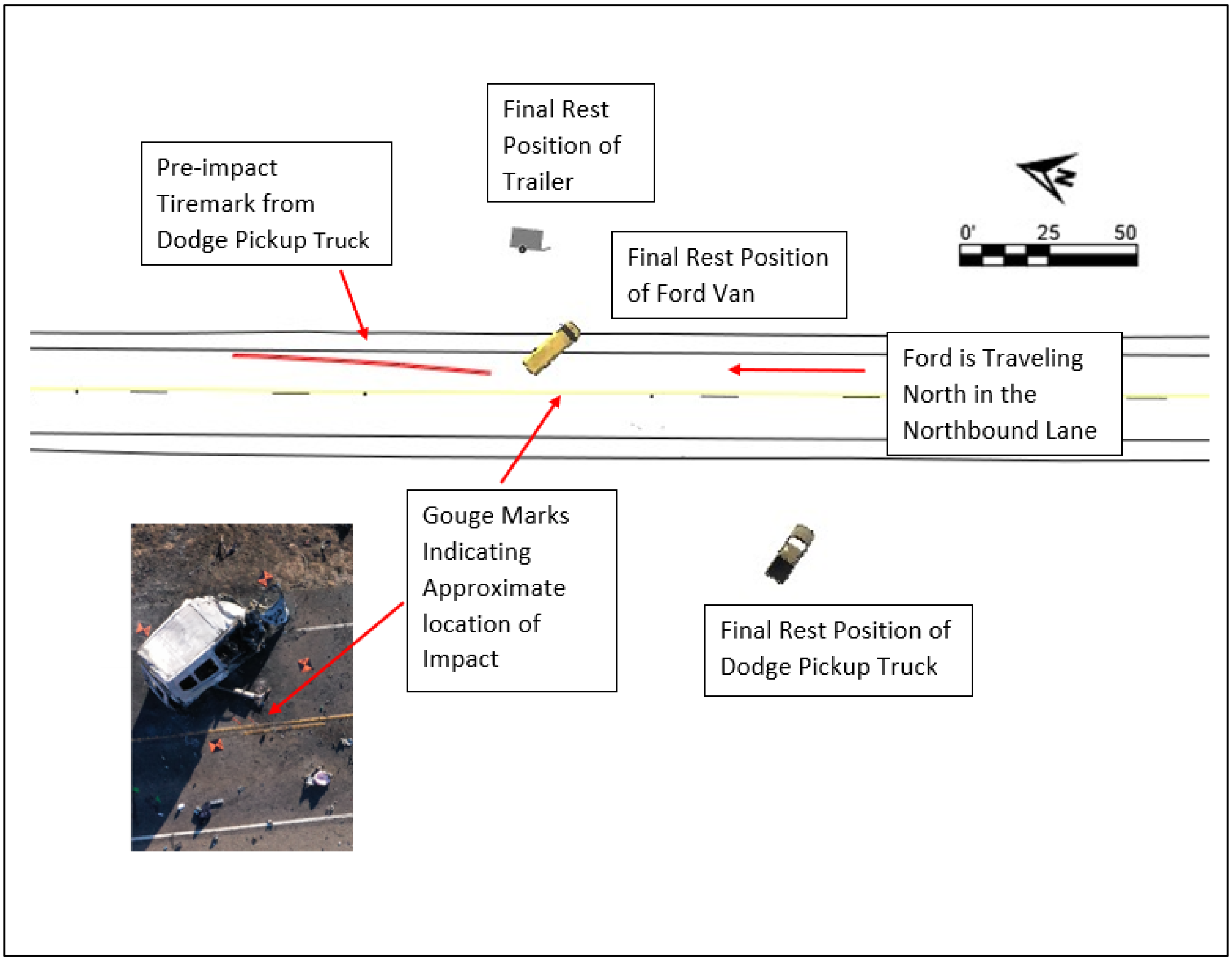

Figure 1

2.0 Software/Methodology

To estimate the collision speeds, a series of simulations were conducted using the PC-Crash software (www.pc-crash.com). The PC-Crash software is widely used in reconstruction to estimate the speeds of vehicles prior to the collision. The software relies on a forward simulation process in which initial conditions (vehicle speeds, surface frictions, roadway geometry, steering and braking etc.) are entered into the simulations. The software then predicts the pre-impact dynamics, collision dynamics and post-impact dynamics based on the initial conditions and the mathematical model. Results of the simulations are compared against the physical evidence to determine consistency, and the initial conditions (speeds, heading, tire friction etc.) can be varied over possible ranges in an iterative process to try and match the evidence. The collision dynamics are modeled using an impulse-momentum collision model. (The PC-Crash manual refers to it as the "Impulse-Restitution Impact Model". The more general term "impulse-momentum collision model" is used in this report to refer to the collision model.) The impulse-momentum model collapses all force information into a single exchange of impulses which occurs within an infinitely small-time step at a single point referred to as an impulse point. The primary advantage of using the impulse-momentum collision model is that it conserves both linear and angular momentum, which allows for the estimation of the post-impact rotational velocities. Tire forces in PC-Crash are determined based on a tire friction/slip curve which estimates both longitudinal and lateral tire forces at each timestep. An example of a normalized longitudinal tire friction vs slip curve is shown in Figure 2. Lateral forces use similar curves. The tire model operates between the peak and slide frictions depending on the amount of longitudinal and lateral slip at each wheel, at each time step. Tire forces due to combined lateral and longitudinal slip are calculated using a generalized tire force curve described in the manual. Integration times steps used for estimating the vehicle dynamics in the simulations were 0.01 milliseconds. (For example, tire forces are calculated at every 0.01 milliseconds.) For a complete description of the mathematical models used by PC-Crash please refer to the PC-Crash software user manual.

The simulations in the study were conducted in 2D. This was considered adequate for the purposes of the study since the momentum was primarily planar.

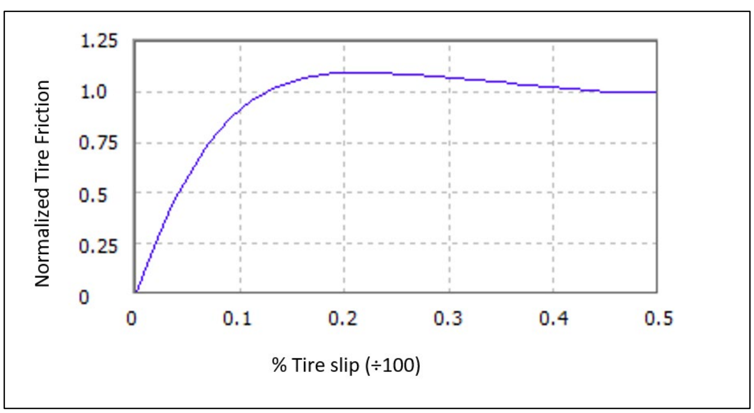

Figure 2.

3.0 Survey Data

Survey data of the crash scene was obtained from the Texas Department of Public Safety (TXDPS) and the NTSB Office of Highway Safety and entered into the simulations.

The survey data included the roadway geometry, the locations of a tiremark and several gouge marks, and the final rest positions of the vehicles and trailer (see Figure 1). Based on this information and aerial photos taken in the drone survey it was possible to reconstruct the post-collision trajectories and final rest positions of both vehicles and the trailer.

The survey data contained a single tire friction mark from the Dodge that was located in the northbound lane (see Figure 1). This tiremark terminated in the area of impact. Inspection of the tiremark found that the outside and inside edges of the tire imprinted on the roadway surface. The friction mark extended southwestward in the northbound travel lane for approximately 73 feet and terminated just prior to impact. The distance between the two edges of the friction mark measured approximately 7.5 inches apart consistently throughout the length of the mark.

4.0 Vehicle Data

The vehicle weights, dimensions and vehicle damage measurements used in the study were obtained from the NTSB Office of Highway Safety. According to this data the weight of the Dodge was approximately 7410 lbs and the weight of the Ford van was about 8830 lbs. The weight of the one axle trailer that the Ford was towing was about 1350 lbs. The moments of inertia used in the simulations were calculated using the default formula in the software. Damage to the vehicles and trailer are shown in Figure 3. The photograph in the upper left of Figure 3 shows the front of the Dodge. The photograph in the upper right of Figure 3 shows the front of the Ford. The photographs at the bottom of Figure 3 show side views of the Ford and the trailer.

Figure 3

5.0 Tire/Road and Surface Friction data

The tire/roadway friction used in the simulations, 0.87, is based on measurements made by the TXDPS using an ABS-equipped vehicle. Tire slide frictions were adjusted to 80 to 90 percent of the ABS measured friction based on tire data in the software documentation and reference [1]. The range used to model friction on the rock/desert surface in the areas surrounding the roadway was 0.40 to

0.70. This range is based on data for gravel surfaces listed in reference [1] and is consistent with ranges listed in the PC-Crash reference manual and data from other sources in the literature.

6.0 Driver Actions/Braking

The simulations begin at impact. No braking or steering by either driver was modeled in the simulations. The fronts of both vehicles were heavily damaged and there are indications that the front wheels may have been locked by damage. There were also indications that the fronts of the vehicles may have been sliding on the ground. To model this in the simulations the front wheels of the vehicles were locked post collision. Simulations were also conducted with the right front wheel of the Dodge not locked.

7.0 Trailer Dynamics

The examination of the vehicles and physical evidence indicates that after the initial collision with the Dodge, the Ford began to rotate counterclockwise, and the left rear corner of the Ford collided with the front left of the trailer which was rotating clockwise (see Figure 3). After separating from the Ford, the trailer was rapidly rotating and overturned onto its left side. Due to uncertainty in assigning a deceleration rate to the complicated motion of the trailer, priority was given to the dynamics of the Ford and Dodge when evaluating the simulation results. Both the initial collision between the Ford and the Dodge and the secondary collision between the Ford and the trailer were modeled in the simulations. The overturning of the trailer onto the left side was not modeled in the simulations.

The trailer model in PC-Crash assumes an almost instantaneous exchange of impulses between the trailer and the tow vehicle at the hitch during a collision and a common velocity at the hitch point. This was considered adequate for this project since the physical evidence on the roadway and the damages to the vehicles indicate that most of the forward momentum of the Ford and the trailer were dissipated in the initial collision with the Dodge (as indicated by the fact that the Ford came to a stop abruptly after the collision with the Dodge and the trailer was redirected off the right side of the road, see figures 1 and 4). In the simulations which closely matched the physical evidence (see Figure 4) the trailer separation occurs about 50 milliseconds after the collision between the Ford and the Dodge, and the Ford is rotating between 275 and 300 degrees/sec counterclockwise when the trailer separates. The trailer is rotating at between 420 and 500 degrees/sec clockwise when it separates from the Ford. The separation occurs after the Ford and the trailer's forward speeds have been reduced from 59 to 66 mph to about 10 mph as the result of the initial collision with the Dodge. The secondary collision between the Ford and the trailer occurs about the same time as the trailer separation. The delta-v of the trailer in this secondary collision was about 12 to 15 mph and the delta-v of the Ford about 1.8 to 2.3 mph. These low changes in momentum are consistent with the relatively light damages to the left front corner of the trailer and the left rear of the Ford (see Figure 3).

8.0 Estimating the Collision Speeds

Once the vehicle and survey data were entered into the simulations the pre-impact speeds of the vehicles were estimated using the Collision Optimizer feature in the software.

PC-Crash has a built-in Collision Optimizer which automatically estimates the pre-impact speeds of the vehicles. The Optimizer works by varying the impact speeds and collision parameters to identify the collision speeds that minimize the overall error between the simulation results and the trajectories and final rest positions of the vehicles. The data used in the simulations is described earlier in this report. The location of the initial collision between the Dodge and the Ford was identified by the gouge marks shown in Figure 1.

The range of speeds evaluated in the Optimizer study were from 70 to 120 mph for the Dodge, and 50 to 80 mph for the Ford. To check for local minima the collision speeds were increased in 5 mph increments and the results compared with the physical evidence. Surface frictions of the rock/desert surfaces surrounding the roadway were varied over the ranges described earlier in 0.10 increments. The objective of this portion of the study was to identify ranges of collision speeds that were consistent with the physical evidence. Simulation results were evaluated based on the trajectories and final rest positions of the Ford and the Dodge and the trajectory of the trailer. Because there was higher confidence in the deceleration rates and trajectories of the Ford and the Dodge, the results for the Ford and Dodge were given priority over the trailer results when evaluating simulations. A simulation result that closely matched the physical evidence is shown in Figure 4.

The results of the Collision Optimizer study showed good correlation with the physical evidence when the Dodge was traveling between about 90 and 105 mph prior to the collision and the Ford was traveling between about 60 and 65 mph prior to the collision. Results of the simulations for the limits of these ranges are shown in Tables 1 and 2. Optimizer results outside of these speed ranges showed poorer correlations with either the final rest positions of the vehicles and/or the post-collision trajectories of the vehicles. To account for uncertainties in defining precise cutoff points for the speed ranges when evaluating simulation results, the lower ranges of the speed estimates were adjusted by -5 mph and the upper range of the speed estimates increased by 5 mph. This adjustment increased the range of preimpact speeds for the Dodge to 85 to 110 mph and the range of estimated preimpact speeds of the Ford to 55 to 70 mph.

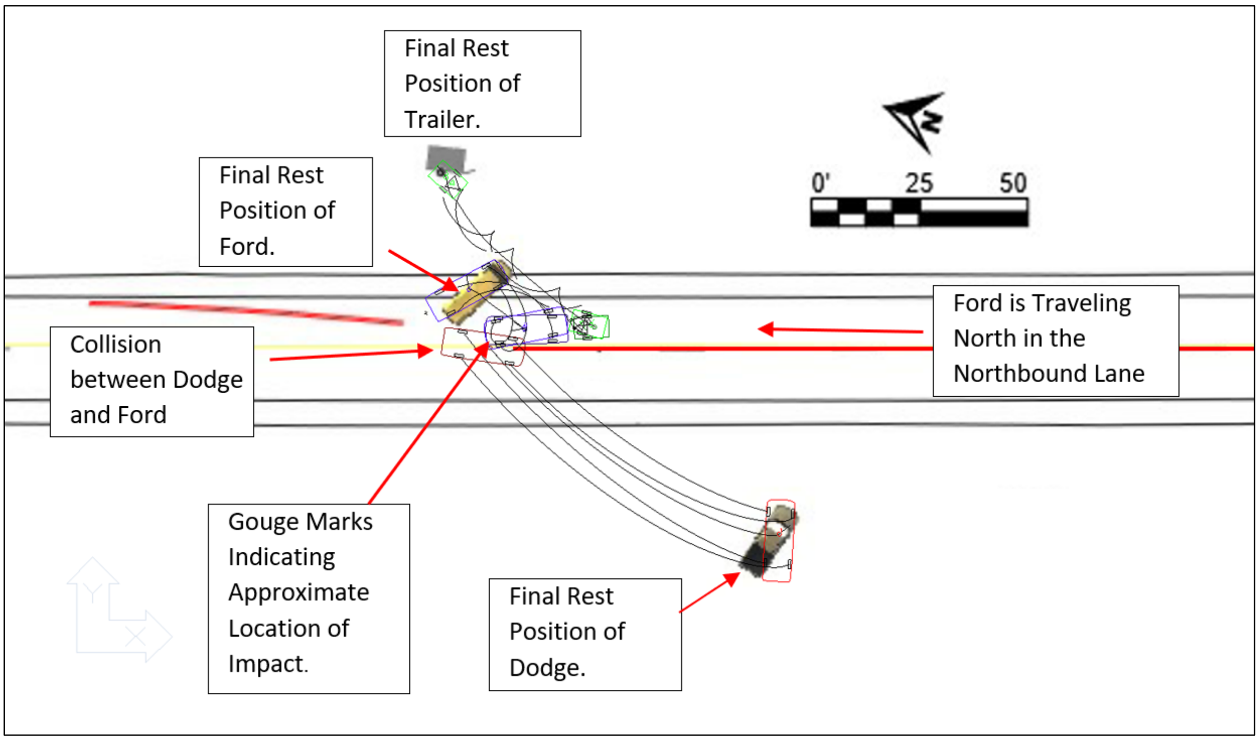

Figure 4 – Simulation result which closely matched the physical data overlaid on the physical evidence shown in Figure 1. Simulation results are shown as vehicle outlines. Solid vehicles indicate the final rest positions of the crash-involved vehicles.

Table 1†

	Dodge	Ford	Trailer	Ford (2nd collision)	Trailer (2nd Collision)
Pre-impact					
Vel [mph]	90	58.5	58.5	9.7	29.2
Dir [deg]	-8.28	-178.18	-178.18	144.81	155.39
Omega [deg/sec]	0	0	0	246.93	-499.99
Post-Impact					
Vel [mph]	33.82	12.04	15.28	11.33	18.14
Dir [deg]	-47.31	149.16	135.21	148.72	145.69
Omega [deg/sec]	45.31	274.85	-586.12	257.93	-422.94
ΔV [mph]	67.16	48.8		1.83	11.97

† Zero degrees is along the centerline of the road in the southbound direction of travel. Direction angles are for the velocities shown. Counterclockwise rotations are positive.

Table 2†

	Dodge	Ford	Trailer	Ford (2nd collision)	Trailer (2nd Collision)
Pre-impact					
Vel [mph]	105	65.5	65.5	9.8	34.0
Dir [deg]	-8.28	-178.18	-178.18	138.73	-154.50
Omega [deg/sec]	0	0	0	280.30	-554.29
Post-Impact					
Vel [mph]	40.23	12.53	16.54	11.67	20.25
Dir [deg]	-45.55	145.39	131.48	144.61	142.55
Omega [deg/sec]	51.92	314.91	-671.38	294.49	-473.86
ΔV [mph]	76.95	55.91		2.31	15.11

† Zero degrees is along the centerline of the road in the southbound direction of travel. Direction angles are for the velocities shown. Counterclockwise rotations are positive.

E. RESULTS AND DISCUSSION

The results of the simulations indicate that the Dodge was traveling between 85 and 110 mph prior to the collision, and the Ford was traveling between 55 and 70 mph prior to the collision. The posted speed limit in the area where the crash occurred is 75 mph.

Submitted by:

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References

[1] Brach, Raymond M. and Brach, R. Matthew, "Vehicle Accident Analysis and Reconstruction Methods," SAE International, Warrendale, PA, 2011.