NATIONAL TRANSPORTATION SAFETY BOARD
VEHICLE PERFORMANCE DIVISION
WASHINGTON, D.C.

VEHICLE PERFORMANCE STUDY/ EVALUATION OF MOTORCOACH ENGINE CONTROL MODULE DATA

A. CRASH INFORMATION

Location: Interstate 70/76 (I-70/76) westbound lanes, Pennsylvania Turnpike at mile-post marker 86.1, Mount Pleasant Township, in Westmoreland County, Pennsylvania

Vehicle #1: 2005 Van Hool C2045, 57-passenger motorcoach

Vehicle #2: 2018 Freightliner Cascadia truck-tractor towing a 2019 Hyundai Translead 53-foot semitrailer

Vehicle #3: 2018 Freightliner Cascadia truck-tractor towing a 2018 Stoughton 53-foot semitrailer

Vehicle #4: 2007 Mercedes Benz C280 4-door sedan

Vehicle #5: 2018 Freightliner Cascadia truck-tractor towing a 2020 Stoughton 28.5-foot semitrailer

Date: January 5, 2020

Time: Approximately 3:30 a.m. Eastern Standard Time (EST)

NTSB #: **HWY20MH002**

B. VEHICLE DYNAMICS GROUP

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C. CRASH SUMMARY

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

D. DETAILS OF STUDY

1.0 Introduction

This accident began when the Van Hool motorcoach departed the right side of the roadway as it was exiting a left-hand curve. After departing the roadway, the motorcoach struck an earthen embankment, traveled back onto the roadway, and overturned before it was struck by vehicle #2, a Fed EX truck. After this collision, the three other vehicles were involved in the accident. When the accident occurred, precipitation was slight and the pavement in the curve was wet. The speed limit in the curve was 70 mph and there was a 55-mph advisory speed posted prior to the curve.

This study examines the electronic speed data downloaded from the motorcoach and focuses primarily on the portion of the data that occurred just prior to the initial crash with the embankment.

1.1 ECM Data

A plot of the speed data obtained from the motorcoach's Engine Control Module (ECM) is shown in Figure 1. This study is primarily concerned with the reductions and variations in speed that occurred between 10 and 3 seconds prior to engine shutoff when the ECM data indicates the motorcoach was slowing but no braking or throttle was being applied by the driver. (During this time period the ECM data indicated: (1) no brake lamp switch activation, which requires minimal depression of the brake pedal by the driver; and (2) 0% throttle, which, implies no throttle pedal/linkage actuation by the driver.) To identify possible causes of the slowing and variations in speed a series of simulations were conducted. These simulations examined several potential causes for the speed readings including the driver steering, the use of the engine compression (Jacobs Vehicle Systems) brake by the driver and the grade of the road. In addition to the ECM data, the study also examines the effects of vehicle speed and wet pavement on the available traction in the curve using measured tire data.

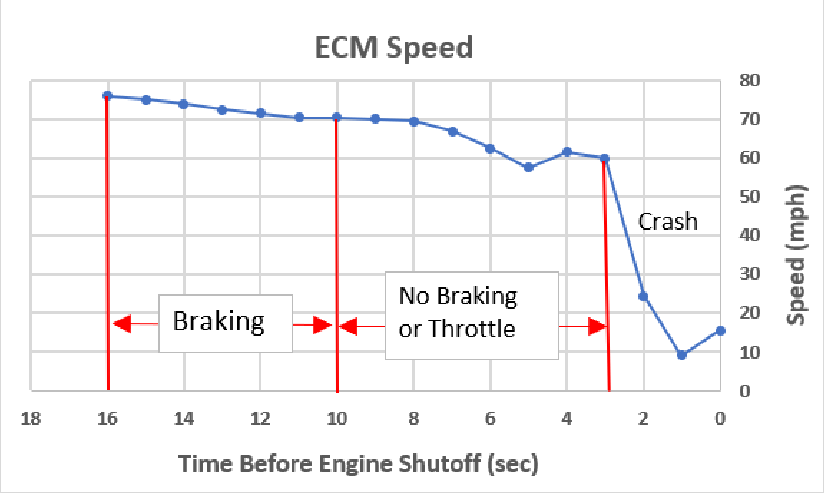

Figure 1 –*Electronic speed data from the Motorcoach's ECM for 16 seconds prior to engine shutoff. The impact with the embankment occurred between 3 and 2 seconds prior to engine shutoff.*

2.0 Software

The dynamics of the motorcoach were modeled using the TruckSim software from Mechanical Simulation [1]. This detailed nonlinear vehicle dynamics model consists of up to 110 differential equations and is fully capable of modeling all aspects of vehicle dynamics that can be modeled with reasonable accuracy including driveline components, tires, and suspension properties.

3.0 Description of Data Sources and Simulated Conditions

3.1 Accident Motorcoach

According to the Vehicle Factors Group Chairman's Factual Report [2], the accident motorcoach was a 2005 Van Hool C2045, 57-passenger motorcoach with a wheelbase of 330 inches (the wheelbase is the distance from the axle number 1 to the midpoint between axles 2 and 3). According to the information in the report, the motorcoach was equipped with an anti-lock braking system (ABS), which would have helped prevent wheel lockup on the wet pavement. In addition to the foundation brakes, the report indicates the motorcoach was equipped with a Jacobs engine brake. (A Jacobs engine brake is a type of engine retarder which uses engine compression to slow the vehicle.) The engine brake and the motorcoach tires are described in more detail later in the report.

3.3 Modeling the Roadway Geometry

Three-dimensional survey data obtained from Google Earth and the Highway Group Chairman's Factual Report [3] were used to model the roadway geometry in the study. The modeling included all key aspects of the roadway geometry that would have significantly impacted the dynamics of the motorcoach including: the road grade, the radius of the curve (1296 ft), the cross-slope of the curve (8%), the cross-slope of the right shoulder (-2%), the length of the two curve transitions (420 ft each), and the total length of the curve (959 ft).

3.2 Tire/Road Friction

According to the Vehicle Group Chairman's Factual report, when the accident occurred, the precipitation was slight, and the pavement was damp. There was no documented evidence of ice or significant water buildup on the roadway. Weather data from the nearest weather station indicates that precipitation in the hour prior to the accident was approximately 0.01 inches and the total accumulation over the previous 3 hours was about 0.04 inches. Given the low level of precipitation in the area and the fact that drainage was adequate, it is likely that the water buildup on the pavement would have been less than 0.02 inches.

The tires on the accident motorcoach were 315/80R22.5. The tread depths of the tires are summarized in Table 1. As indicated by the data, with the exceptions of the left-side tag axle tire (which had a tread depth of 16/32”) the tread depth of the accident tires ranged from between 4/32” to 10/32”.

Table 1- *Tire tread depths of the accident motorcoach [2].*

Tire Position	**Left**		**Right**	
Steer Axle Tires	9/32”		10/32”	
Drive Axle Tires	Outside Tire	Inside Tire	Inside Tire	Outside Tire
	4/32”	6/32”	5/32”	10/32”
Tag Axle Tires	16/32”		10/32”	

The data used to model the tire forces in the study include: 1) Data from testing conducted with similar motorcoach tires at General Dynamics’ Tire Research Facility (TIRF) in support of the Hewitt, Texas accident [4] and 2) friction measurements made using ASTM tires and protocols in the accident curve (a description of the measurements made using the ASTM tires is provided later in the report).

Raw data from the Hewitt tire tests that were used in the study are summarized in Figure 2 and in Table 2. This testing was performed using a tire test machine and evaluated tire forces over a wide range of speeds, water depths and tire tread depths. Additional data can be found in the docket for the Hewitt accident. The data in Figure 2 and Table 2 supports that on wet pavement the tire/road friction (normalized forces) drops off significantly between 40 mph and 70 mph. The data in Table 2 further indicates that the peak frictions at higher speeds for tires with tread depths below 10/32” are approximately twice the slide frictions on wet pavement. (This differs from dry pavement where the differences are typically much smaller.)

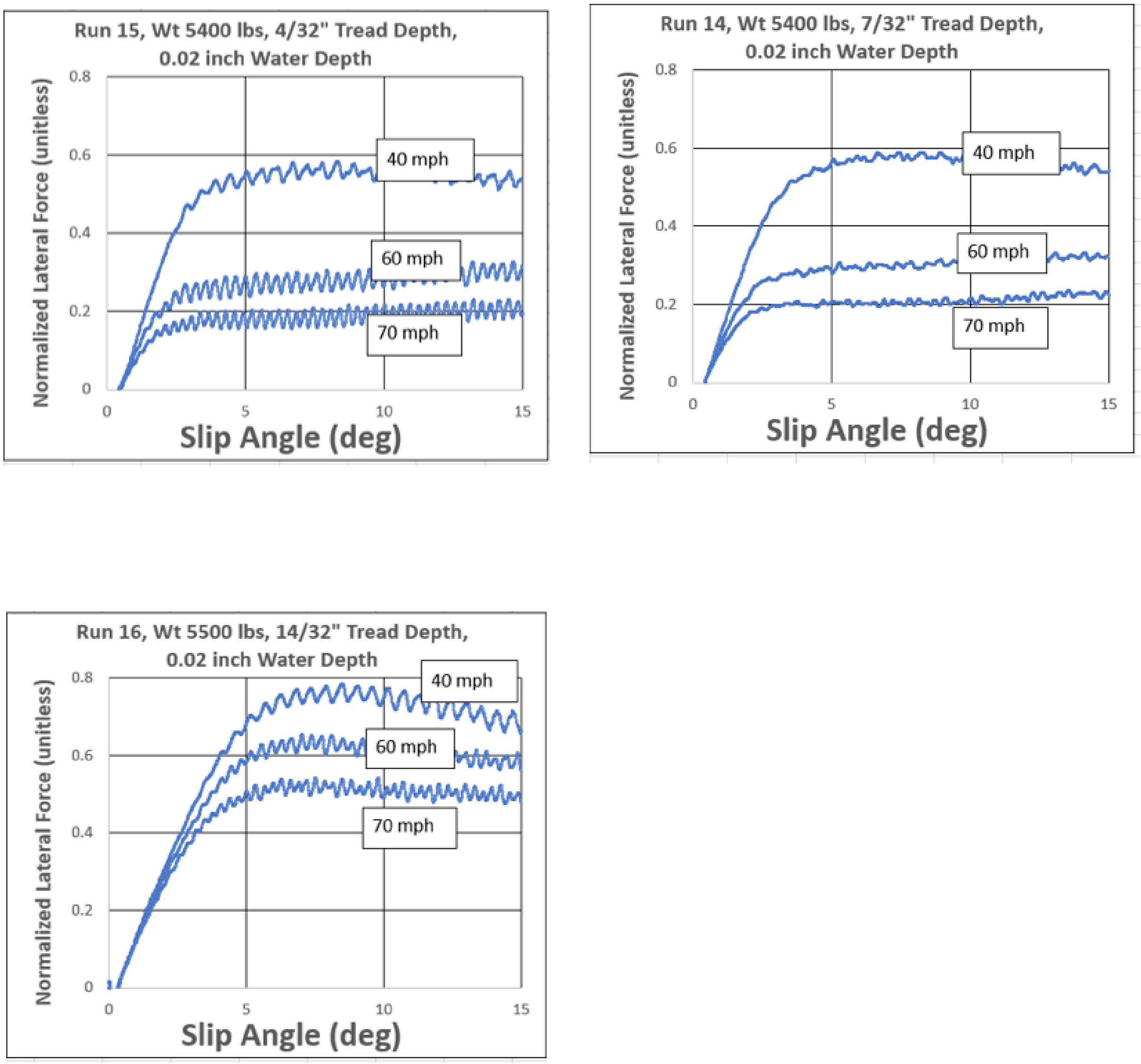

Figure 2- *Normalized lateral tire force measurements from the TIRF testing conducted in support of the Hewitt, TX accident [4] using tires similar to the accident tires.*

Table 2 – *Longitudinal Peak and Slide frictions from the Hewitt, TX tires tests for 0.02-inch water depth.*

	40 mph		60 mph		70 mph	
Tread depth (in)	Peak	Slide	Peak	Slide	Peak	Slide
4/32	----	---	0.37	0.15	0.26	0.12
7/32	0.66	0.29	0.34	0.16	0.24	0.12
8/32	0.59	0.27	---	---	---	---
15/32	0.68	0.53	0.65	0.30	0.57	0.24

The tire test data from the Hewitt motorcoach tire tests were calibrated to the accident road surface traction using ASTM E-274 [5] test measurements from the accident curve and comparing them to similar ASTM measurements made on the TIRF test surface. (ASTM E-274 is a standard used to measure skid resistance on paved surfaces. Tires used in the testing are the ASTM E-524 smooth tire [5] and the ASTM E-501 ribbed tire [5]. Testing is typically performed at a constant speed of 40 mph as the tires are dragged over a wet pavement surface at a specified water depth.) To aid in the calibration, additional measurements of the peak and slide frictions were made using ASTM smooth (ASTM E-524) and ribbed tires (ASTM E-501) in the accident curves at speeds of 40, 50, 55, 60 and 70 mph [3]. The water depth used in these measurements was 0.02 inches (the depth typically used in ASTM E-274 testing and close to the estimated water depth at the time of the accident). Based on the evaluation of the Hewitt tire tests data and the ASTM tire data, it was determined that it was sufficient for the purposes of this study to use the peak and slide frictions from the ASTM smooth tires to estimate the tire frictions for the accident tires with tread depths between 4/32" and 10/32" (7 of the 8 tires) and to use the ribbed ASTM tire to model tires with tread depth greater than 10/32" (1 of 8 tires). It is likely that these frictions underestimate the actual tire/surface frictions since the testing conducted in the Hewitt accident indicates that partially treaded motorcoach tires will develop slightly greater friction values than the smooth ASTM tire at similar speeds. As indicated by the data in Figure 3, the peak tire frictions generated by the smooth ASTM tires in the testing conducted at various speeds in the curve exceed the friction demand. These results support that there was likely adequate traction for the motorcoach to safely negotiate the curve. (Friction demand is the minimum tire friction needed for a point mass to negotiate the curve radius). The data further indicates that there were significant reductions in peak frictions in tests conducted at the 70-mph speed versus tests conducted at the 55- mph advisory speed with the smooth tire.

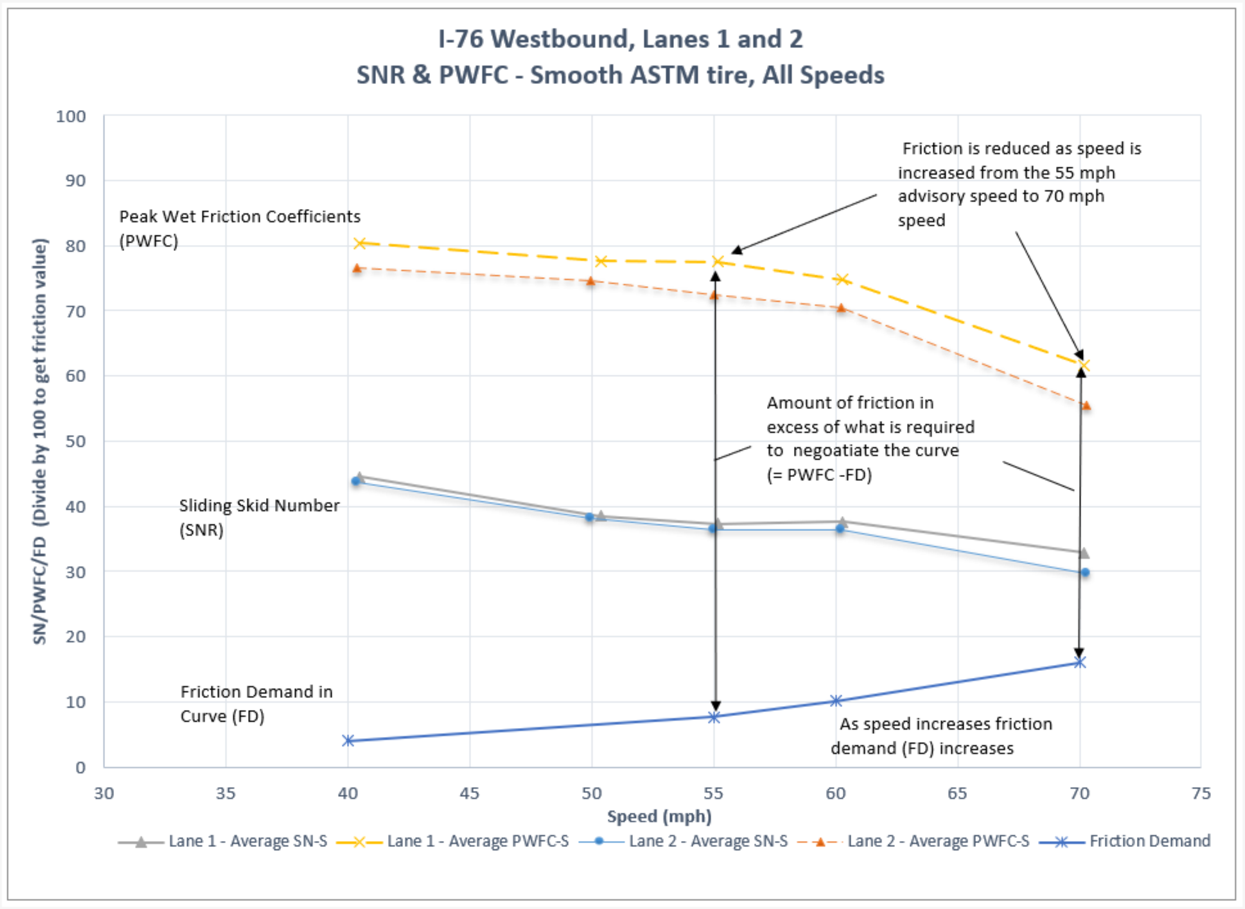

Figure 3 –*Comparison of ASTM smooth tire measurements at various speeds in the curve with the friction demand in the curve. Lane 1 is the left lane and Lane 2 is the right lane for motorists traveling in the westbound direction. The friction measurements shown are the average frictions.*

3.3 Modeling the Jacobs Engine Compression Brake

According to the Vehicle Group Chairman's Factual Report [2] the accident motorcoach was equipped with a Jacobs Engine Brake (commonly known as a "Jake Brake"). This type of brake uses engine compression to slow the vehicle and is often referred to as a compression brake or engine retarder. Because of the vehicle damage it could not be determined if the compression brake was in operation when the accident occurred.

To determine if the compression brake was operational (turned "on") at the time of the accident a series of simulations were conducted in which engine braking was modeled.

Data for the compression brake obtained from the manufacturer's website is summarized in Table 3. To model the jake brake in the simulations this data was converted to negative torque and entered into the engine model table in the simulations.

Table 3 – *Manufacturer data for the Motorcoach's compression brake.*

Engine RPM*	Braking HP**
1100	116
1300	233
1500	285
1700	324
1900	404
2100	443

*Revolutions Per Minute (RPM)
** Horsepower (HP)

The logic used to control the compression brake in the simulations was as follows: when the compression brake switch was in the "on" position, the compression brake was engaged unless the brake pedal or throttle was being applied by the driver. This logic is based on information in the Vehicle Group Chairman's Factual Report [2].

4.0 Description of Simulations

Precise data from which to reconstruct the motorcoach's movements and the driver's steering prior to the motorcoach leaving the roadway was not available. In order to try to reproduce the ECM readings a series of simulations were conducted modeling a wide range of potential scenarios. Some of the accident scenarios modeled in the simulations include:

- The motorcoach driving through the curve.
- A rapid lane change/collision avoidance maneuver in the curve.
- The motorcoach drifting off the right side of the curve in the area of the crash.
- Reductions in tire/road friction to the point where the motorcoach lacked sufficient traction to negotiate the curve.

The simulations were conducted both with and without the engine brake turned "on". The vehicle data, road geometry and tire properties used in the simulations are described earlier in this report. Speeds and braking used in the simulations are based on the data from the motorcoach's ECM (see Figure 1). The simulations modeled the motion of the motorcoach from prior to entering the curve transition up until the general location where the crash occurred.

The results of the simulations were evaluated by comparing the simulation results with the speed and braking data from the ECM of the motorcoach, and the location of the crash in the curve.

E. RESULTS/DISCUSSION

As indicated in the introduction, this study was primarily concerned with identifying the type of motorcoach dynamics that would result in the slowing and variations in speed that occurred between 10 and 3 seconds prior to the engine shutoff in the motorcoach's ECM speed data (Figure 1).

In the simulations, speed readings similar to the ECM readings between 10 and 3 seconds could be modeled by applying aggressive back and forth steering in the curve when the jake brake was on. This steering resulted in "fishtailing" which caused variations in the speed readings just prior to the location where the crash occurred. (Fishtailing occurs when the rear tires begin to lose traction and the driver counter-steers in an attempt to stabilize the vehicle.) Other attempts to match the data were unsuccessful.

These results support that shortly before the collision the motorcoach was swerving in a manner that caused the drive axle tires to lose traction and the vehicle to begin to "fishtail". Because the motorcoach was traveling at a high speed on wet pavement it could not be determined from the simulations if the steering indicated in the simulations occurred in response to tires beginning to slide on the wet pavement or if it was the result of the driver's attempt to rapidly maneuver the motorcoach in the curve. Both explanations are consistent with the available range of data.

Attempts to model the ECM data without the jake brake engaged were unsuccessful and did not reproduce the overall slowing or variations in speed indicated in the ECM data just before the crash. While it cannot be verified if the jake brake was turned on at the time of the accident, the results of the simulations indicate that if the jake brake was engaged it would have increased the risk of the drive axle tires beginning to slide and the motorcoach "fishtailing".

The tire data described in this report supports that reducing the speed of the motorcoach to the 55-mph advisory speed prior to entering the transition and the curve would have increased the available tire friction. Reducing the speed to 55 mph would have also reduced the overall friction demand. The increase in traction along with the reductions in the friction demand would have better enabled the driver to maintain control.

There was not sufficient information (for example tiremarks, roadway evidence or electronic data) to determine the path of the vehicle in the curve prior to the crash or to determine its lane position in the curve prior to the crash.

The tire data and estimates described in this report indicate that the driver would have had sufficient friction to safely negotiate the curve on the wet pavement. However, motorcoach characteristics such as a high center-of-gravity (cg) and the fact that the driver sits several feet forward of the center-of-gravity could reduce the ability of a driver to control a motorcoach on wet pavement at high speeds in comparison to other vehicles such as automobiles.

References

[1] https://www.carsim.com/products/trucksim/

[2] "Vehicle Group Chairman's Factual Report", available in the NTSB docket for this accident; https://data.ntsb.gov/Docket/Forms/searchdocket

[3] "Highway Factors Group Chairman's Factual Report", available in the public docket for this accident; https://data.ntsb.gov/Docket/Forms/searchdocket

[4] For details on the tire testing from the Hewitt accident please refer to the "Vehicle Dynamics Simulations Study" and Attachments contained in the NTSB public docket for the Hewitt, Texas accident; NTSB accident #HWY-03-MH-022; https://data.ntsb.gov/Docket/Forms/searchdocket

[5] ASTM International - Standards Worldwide