NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF RESEARCH AND ENGINEERING
WASHINGTON, D.C. 20594

Vehicle Dynamics and Visualization Study

Date : March 12, 2011

Location: Interstate 95 (I-95) New England Thruway, at mile marker 3.2, in New York, Bronx County New York

Vehicle: 1999 Prevost H3-45 56- Passenger Motorcoach

Motor Carrier: World Wide Travel of Greater New York Ltd.

NTSB # : HWY-11-MH-005

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1.0 Introduction/ Overview of Results

In this accident a three-axle motorcoach departed the traveled portion of the roadway, crossed a 10-foot-wide paved shoulder and struck a blocked-out W-beam guardrail located along the right side of the roadway. After striking the guardrail, the bus traveled several hundred feet along the guardrail, leaning on the guardrail for most of the way before overturning on its right side, sliding for several feet and striking a support for an overhead sign. This report summarizes the calculation of the motion of the bus shown in the visualization for this accident. The primary objective of the visualization was to introduce the accident sequence to the public, not to precisely reconstruct the physics at every point in the accident sequence. To achieve this goal, survey measurements of the roadway, guardrail and other physical evidence were used to accurately reconstruct the path of the bus from just prior to the impact with the guardrail until final rest. The time history motion of the bus along the path was then calculated using a series of simulations and Electronic Data Recorder (EDR)[1] data. Because of the complex motion of the bus after striking the guardrail and the limited information on speed throughout the accident sequence, not all of the physics of the bus' motion after striking the barrier could be uniquely determined using the simulations. The simulations do show that the theory that the bus was initially traveling in the right hand lane prior to departing the traveled portion of the roadway is consistent with the physical evidence. The simulations and their limitations are described in the report.

2.0 Description of The Roadway

[1] Refer to "Electronic Control Module Specialist's Factual Report", available at http://www.ntsb.gov/investigations/dms.html

The geometry of the section of roadway where the accident occurred is shown in figure 1 below. According to information contained in the Highway Group Chairman's Factual Report the horizontal curvature on the southbound lanes of I-95 just prior to the accident consisted of a 1,600 foot radius curve that turned to the right in the direction of travel. The 1,600 foot radius horizontal curve ended approximately 770 feet prior to the accident location. The horizontal curvature transitioned to a 4,500 foot radius curve that turned to the left in the direction of travel. The accident location was within the 4,500 foot radius curve

The speed limit for buses on the section roadway where the accident occurred was 50 mph.

Figure 1 – Aerial view of roadway looking southbound.

2.0 Accident Sequence

Physical Evidence used in Reconstructing the Path of the Bus Shown in the Visualization

The physical evidence used to reconstruct the path of the bus in the visualization is shown in figures 2 thru 7 below. According to this evidence, shortly after negotiating the 1600 foot curve right hand curve (figure 1) the bus departed the right side of the road, crossed a 10-foot-wide shoulder and struck a blocked-out W beam guardrail in the location depicted in figure 1 above. The tiremark evidence indicating the path of the bus as it departed the roadway is shown in figure 2 below. There was no physical evidence indicating the path of the bus prior to these tiremarks. After impacting the guardrail, the bus veered to the left and lost contact with the guardrail for a short distance as indicated by the tiremarks and lack of damage to the guardrail shown in figure 3. The bus then veered back toward the guardrail along the path indicated by the tiremarks in figure 4 and struck the guardrail a second time. After impacting the guardrail the second time the bus continued forward while leaning on the guardrail for several hundred feet (figure 5). As the bus continued to travel forward while leaning on the guardrail it struck two signs located alongside the guardrail (figures 5 and 6). The location of the damage found on the signs indicated that the bus was leaning substantially to the right when it made contact with these signs. After striking the signs, the bus continued forward for several feet before overturning onto its right side (as indicated by the damage to guardrail in figure 6). After overturning onto its right side, the bus slid for several feet before striking the support for the overhead sign (figure 7) and coming to rest.

Figure 2 – Guardrail damage caused by the initial impact of the bus with the guadrail. Arrows point to tiremarks and scrapemarks indicating the path of the accident vehicle as it traveled across the 10 foot shoulder and impacted the guardrail. It could not be determined if the bus made contact with the red sign in the foreground. (Unless indicated by an arrow, tiremarks and scrapemarks shown in the photograph are not associated with this accident.)

Figure 3 – After initially striking the guardrail the bus veered away from the guardrail and lost contact the guard rail for short distance. The arrows shown in the photograph indicate evidence of the path of the bus during the time it lost contact with the guardrail. Note that there is no evidence of contact damage from the bus visible on the guardrail. (Unless indicated by an arrow, tiremarks and scrapemarks shown in the photograph are not associated with this accident.)

Figure 4 – Arrows highlight the physical evidence indicating the path of the bus as it veered back towards the guardrail and impacted the guardrail for a second time. (Unless indicated by an arrow, tiremarks and scrapemarks shown in the photograph are not associated with this accident.)

Figure 5 – After striking the guardrail again a second time the bus made contact with the two signs the right of the road shown in this photograph. The arrows on the right highlight damage to the signs caused by impact with bus. Note that the location of the damage indicates that the bus was leaning heavily to the right when it contacted these signs. Arrows on the left point to evidence found on the shoulder indicating the path of the bus after striking the guardrail a second time. Note also the damage visible on the guardrail indicating that the bus was in contact with the guardrail. (Unless indicated by an arrow, tiremarks and scrapemarks shown in the photograph are not associated with this accident.)

Figure 6 - Close up of contact damage from the bus found on the first sign shown in figure 5. The main damage to the second sign was to the left side support post which was destroyed by the impact with the bus. Arrow in the background highlights the overhead sign stanchion which the bus struck before coming to final rest. Note damage to guardrail just before the overhead sign stanchion. This damage suggests the bus was rolled approximately 90 degrees to the right at this point.

Figure 7 - Final rest position of the bus

3.0 Methodology

The motion of the bus shown in the visualization was calculated using a series of simulations performed with the Human Vehicle Environment (HVE) system[2]. HVE is commercially available software that is used to reconstruct accidents and model three-dimensional vehicle dynamics. Vehicle parameters and three-dimensional survey data gathered during the investigation were entered into the simulations and used to calculate the bus' motion and verify results. The three-dimensional survey data used in the simulations was sufficient to allow for an accurate reconstruction of the vehicle path (see section 2.0) including the roll orientation of the bus around its horizontal axis as it traveled down the guardrail. The results of the HVE

[2] http://www.edccorp.com/products.html

simulations detailed in this study are consistent with the results of earlier simulations of the accident conducted with TruckSim[3] in support of the biomechanics study.

4.0 Overview of Visualization/Bus Motion

This section provides a general overview of the visualization. (Details of the simulations are provided in the next section of the report.)

Roadway and Scene Depicted in the Visualization

The roadway and the shoulder of the roadway in the area of the accident shown in the visualization are scale models built from the three-dimensional survey data. The location of guardrail and signs shown in the video are also accurately depicted. The model bus shown in the visualization is a scale model based on the manufacturer's data and NTSB measurements.

Lighting Conditions

The lighting conditions shown in the visualization do not depict the actual lighting conditions at the time of the accident.

Motion Depicted in the Visualization

This section provides a general overview of the motion of the bus shown in the video. The next section describes relevant details regarding the simulations.

[3] TruckSim is a commercially available software that is widely used by industry and academia to model the dynamics of large vehicles such as trucks and buses. For more information go to : http://www.carsim.com/products/trucksim/index.php

In the video the bus is initially traveling in the right hand lane at 64 mph. This is consistent with the theory that the bus was traveling the in the right lane prior to the accident. As the bus exits the 1600 foot right hand curve just prior to the accident the steering is held constant in the simulations causing the bus to leave the road and strike the guardrail along the same path as the accident vehicle as indicated by the black marks on the shoulder in the video. This accident scenario is consistent with the theory that the accident was the result of the driver holding his steering constant as he exited the right hand curve. The speed of the bus from the beginning of the visualization until the bus strikes the guardrail is 64 mph. This speed is consistent with data from an EDR onboard the bus which indicated that it was traveling about 64 mph for approximately 10 seconds prior to the bus striking the guardrail.

After initially striking the guardrail in the video, the bus veers away from the guardrail along the marks shown in figure 3. (These marks are depicted as black lines in the video.) The maximum roll angle orientation of the bus along its longitudinal axis during the initial impact with the guardrail in the video was estimated from the location of the tiremarks on the roadway and the damages to the guardrail[4]. After veering away from the guardrail in the visualization, the bus veers back towards the guardrail along the marks shown in figure 4. (Again, the marks on the shoulder are depicted as black lines in the video.) After striking the guardrail the second time the simulated bus continues to travel forward while leaning on the guardrail for several hundred feet before overturning onto its right side. The roll angle orientation of the bus around its longitudinal axis during this portion of the video was calculated from the marks on the road, the damage to the guardrail, and the damage from the bus found on the two signs shown in figure 6. (Again, the marks on the shoulder are depicted by black lines.) After overturning onto its right

[4] It could not be determined from the physical evidence if the bus contacted the red sign next to the guardrail during the first collision with the guardrail (see figure 2). In the video it is not depicted as touching the sign.

side, the simulated bus slides for several feet before striking the support pole for the overhead sign and coming to rest. The location of the rollover shown in the video was determined by damage to the guardrail indicating that the bus was on its side (figure 6). The location of the overhead sign stanchion was included in the survey information. The speed of the bus after striking the guardrail until final rest in the video is not uniquely determined by the information available; different choices for parameters used in the model could result in a different solution that also matches the physical evidence.

5.0 Details of Supporting Simulations

The motion of the bus shown in the visualization consists of three separate simulations which were combined together into a single motion for the visualization. To describe the relevant details of the simulations, the video is broken down into three separate segments each of which was simulated separately:

Part 1: The motion of the bus prior to striking the barrier.

Part 2: The motion of bus from the initial impact with guardrail until shortly after the second impact with the guardrail.

Part 3: The motion of the bus from shortly after the second impact with the guardrail until final rest.

Part 1: The Motion of the Bus Prior to Striking the Barrier

This portion of the video includes the motion of the bus from the beginning of the video until just before the first impact with the guardrail. The speed of the bus during this portion of the bus is about 64 mph. This speed is consistent with EDR data from the bus which indicated it was traveling about 64 mph prior to impact the guardrail.

The motion for the bus for this portion of the visualization was calculated using the program SIMON (SImulation MOdel Non-linear)[5] which is part of the HVE system. SIMON is commercially available software that is fully capable of modeling the three-dimensional dynamics of large vehicles such as trucks and buses. The simulated motorcoach dimensions, wheel base, cg height and inertias used in the simulations were accurately estimated based on manufacturer's data, NTSB measurements and the number of passengers. Reasonable ranges of friction were used for the roadway.

In the simulation shown in the video the bus is initially traveling in the right hand lane at a constant speed of 64 mph (the approximate speed based on the EDR data). As the simulated bus exits the 1600 foot curve prior to the accident the steering is held constant causing the bus to leave the right hand side of the road along the same path as the accident vehicle (as indicated by the tiremarks shown on the roadway in the video). The simulation ends just prior to the impact with the guardrail. When the simulation ends the bus is traveling about 64 mph.

The results of the simulations indicate that the theory that the bus was initially traveling in the right hand lane and that the accident was the result of the driver holding the steering constant as he exited the right hand curve just prior to the accident location is consistent with the physical evidence.

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[5] http://www.edccorp.com/products/simon.html

Part 2: Motion of the Bus from Impact with the Guardrail until Shortly after the Second Impact with the Guardrail

This portion of the video includes the motion of bus from just before the first impact with the guardrail until shortly after the second impact with the guardrail. The path of the bus depicted in this portion of the video is consistent with the path of the bus indicated by the survey measurement and physical evidence described earlier section 2.0 of this report. The speed of the bus after impact with guardrail could not be uniquely determined by the information available; different choices for parameters used in the model could result in a different solution that also matches the physical evidence.

The time history motion of the bus in this portion of video was modeled using the SIMON software. The same inputs were used as for first part of this study. A bus into guardrail model was not available and building a precise barrier model was beyond the scope of this investigation. The dynamics of the impact with the barrier in the simulation were modeled using impulsive forces and moments. The forces and moments were adjusted by trial and error to drive the simulated bus along the path of the accident vehicle as indicated by the evidence found on the guardrail and roadway. (In the simulations the steering is released at impact with the guardrail and there is no driver input after the collision with the guardrail.) This approach is sometimes referred to as the kinematic approach since the forces being generated are determined by the path and speed of the vehicle instead of vice versa. While this method has its limitations it was considered adequate for the purposes of this visualization because the emphasis was primarily on showing the path of the bus of the bus after striking the guardrail.

Part 3: Motion of the Bus from Shortly after the Second Impact with the Guardrail until Final Rest

This portion of the bus' motion begins where the previous simulation ended and continues until the bus reaches its final rest position. The path of the bus depicted in this portion of the video is consistent with the survey measurements and physical evidence described earlier in section 2.0 of this report. The speed of the bus after impact with guardrail could not be uniquely determined by the information available; different choices for parameters used in the model could result in a different solution that also matches the physical evidence.

The time history motion for this portion of the animation was modeled using Engineering Dynamics Corporation GENeral Analysis Tool (EDGEN)[6]. EDGEN is a "kinematics spreadsheet" developed by Engineering Dynamics Corporation (EDC). EDGEN is part of HVE system. EDGEN uses positions and velocities supplied at up to eight user-specified locations to determine the time required to travel between each location. In this simulation, the targets were key pieces of evidence along the path of the bus including: the points where the bus impacted the signs, the point where the bus rolled onto its right side, the point where the bus impacted the support for the overhead sign and the final rest position of the bus.

6.0 Summary/Discussion/Limitations

This report summarizes the calculation of the motion of the bus shown in the visualization for this accident. The path of the bus shown in the video is consistent with the available physical evidence. The speed of the bus prior to striking the guardrail is consistent with EDR data taken from the bus. Because of limitations discussed in this report, the motion shown in the video

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[6] http://www.edccorp.com/products/edgen3.html

should not be considered a unique reconstruction of the accident. Different choices for parameters used in the model could result in a different solution that also matches the physical evidence.

The results of the simulations detailed in this report support that the theory that the bus was initially traveling in the right hand lane and that the accident was the result of the driver holding the steering constant as he exited the right hand curve just prior to the accident location is consistent with the physical evidence. The fact that this scenario is consistent with the physical evidence does not eliminate the possibility that there could be other accident scenarios that could also be consistent with the physical evidence.