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Validation of Collision Reconstruction Opinion Utilizing EDSMAC4

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ABSTRACT

This paper describes the use of old and new technologies to validate a collision reconstruction opinion regarding the relation of undocumented tire friction marks to a fatal collision.

The collision occurred on a rural two lane mountainous roadway in which an Acura NSX crossed into the opposing traffic lane, from behind a pickup truck, and struck a Volkswagen Beetle head-on. Responding California Highway Patrol (CHP) officers documented specific items of physical evidence utilizing a station line, but discounted four distinct curvilinear tire friction marks present at the collision scene they believed were not associated with the fatal collision. Photographs of the scene were taken, but were limited in their coverage. Approximately 22 months following the collision, a CHP MAIT (Multi-disciplinary Accident Investigation Team) investigation was initiated to confirm or eliminate the tire friction marks as part of the fatal collision as well as determine vehicle speeds at and prior to impact if possible.

Photogrammetry reconstruction methodologies were used in conjunction with a traditional site survey and a 3-D laser scan of the collision site to re-establish the tire friction marks in question in relation to the roadway. The data from the photogrammetry reconstruction, site survey, and site scan were imported into AutoCAD where a traditional collision reconstruction was completed.

To validate the opinions of the traditional collision reconstruction, a three dimensional environment and the tire marks were imported into HVE and an EDSMAC4 event was created in an attempt to reconstruct the collision event. The EDSMAC4 event provided additional confirmation that the tire marks in question were indeed related to the collision event and deposited by the errant vehicle while in a steering induced yaw. An additional EDSMAC4 event, created per the errant driver's statement, refuted his claim that the yaw marks were created by an emergency brake only application due to a mechanical failure of the vehicle's braking system.

INTRODUCTION

In 2004, a black 1996 Acura NSX, driven by a solo male, was traveling west on a rural two lane California State Route. The Acura approached the rear of a black pickup truck at a velocity of 50 to 60 mph, as estimated by the driver of the truck. The Acura quickly closed the gap between the two vehicles and began tailgating the truck as the driver of the truck maintained a speed of 35 mph. The driver of the truck claimed that the Acura maintained its position close to the rear of the truck and drifted to the left twice as if the Acura's driver was trying to take a peek and see if it was clear to pass. The two vehicles entered a blind right hand turn at which point the Acura accelerated into the eastbound lane to pass the truck.

As the Acura traversed the double yellow centerline and entered the eastbound traffic lane to the left rear of the truck, an orange 1973 Volkswagen Beetle, occupied by a solo male driver, was traveling eastbound at 35 mph per a witness behind the Volkswagen. The witness behind the Volkswagen estimated the velocity of the Acura as twice the Volkswagen's speed (65 to 70 mph).

The front of the Acura struck the front of the Volkswagen within the eastbound traffic lane depositing collision scrub marks and gouges upon the roadway. The Volkswagen was re-directed to the west, approximately 30 feet, to position of rest and the Acura continued to the west, approximately 15 feet, to position of rest.

Responding emergency personnel found the driver of the Volkswagen deceased in the driver's seat of the vehicle and found the driver of the Acura on the dirt shoulder next to his vehicle. CHP officers arrived on scene and began the investigation of the collision. Forty-eight 35 mm photographs of the collision scene and vehicles were taken by the on scene supervisor. Witness and involved party statements were obtained. Numerous items of physical evidence consisting of tire friction marks, collision scrubs, gouges, scrapes, vehicle debris, and the vehicles were located at the collision scene and were clearly visible in the photographs. The investigating officers created a station line to document the items of physical evidence. In their investigation, the officers measured and diagramed only the positions of rest of the vehicles, two areas of vehicle debris, and a single gouge in the roadway. The collision scrubs, scrapes, and pre- and post-collision tire friction marks were not documented because, in the opinion of the investigating officers, the marks extended beyond the area of impact and terminated west of the Acura's position of rest and were, therefore, present on the roadway prior to the collision.

Following the collision, the Acura's driver claimed that there was a mechanical failure of his vehicle's braking system. He claimed that he had to swerve into the eastbound traffic lane and apply his emergency brake in order to avoid the truck and attempt to stop the Acura in the dirt pull out. As he entered the eastbound traffic lane, he observed the Volkswagen approaching from around the curve ahead of him.

Multiple mechanical inspections of the Acura's braking system were conducted by CHP and defense personnel. CHP personnel claimed the brake system was functioning appropriately while the defense claimed there was a mechanical failure with the braking system.

In addition to the claimed braking system failure, the defense declared the tire friction marks shown in the photographs were related to the collision, and the Acura driver had applied the emergency brake in an attempt to slow his vehicle prior to the collision. The defense produced a dynamics diagram showing the tire friction marks drawn on the roadway and the Acura's motion as being nearly broadside at the beginning of the tire friction marks. As the Acura continued along the tire friction marks, the vehicle became more inline (decreasing sideslip angle yaw) with its direction of travel as it approached the impact location. The defense provided at-collision velocities of both vehicles and a pre-collision velocity for the Acura based on the inclusion of the tire friction marks.

Approximately 22 months after the collision, the District Attorney's office having jurisdictional authority requested CHP MAIT assistance with the collision because of the information provided by the defense team. MAIT obtained defense documentation from the District Attorney's office and documentation from the CHP area office investigating the collision. A cursory examination of the photographs led MAIT investigators to believe that the curvilinear tire friction marks observed in the photographs, east of the impact location, were related to the collision (Figures 1 and 2). After evaluating all available documentation, it was determined that an investigation into the association of the tire friction marks to the collision was required before a reconstruction of the collision event could be completed.

Figure 1: *Collision scene looking west*

Figure 2: *Collision scene looking east*

MAIT SITE INVESTIGATION

Due to the length of time between the collision and the initiation of the MAIT investigation, the California Department of Transportation (Caltrans) was contacted to confirm that the roadway, in the area of the collision, had not been altered since the collision. An initial survey of the collision site was conducted utilizing a Leica TCRA 1105 Plus Total Station Surveying Instrument (TSSI). The survey encompassed the roadway characteristics of the collision site. Included in the survey was the location of the painted lines, reflective pavement markers, pavement edges, embankments, dirt shoulders, signs, guardrails, utility poles (station line beginning and end points), etc. The survey was assigned to an arbitrary set of reference datum in three dimensions with permanent reference nails deposited in the roadway.

Once the roadway data was collected, the data was converted and imported into AutoCAD where the roadway and surrounding environment were drawn. After a base collision site diagram was completed, the photographs were reviewed and evaluated in an attempt to determine if the three curvilinear tire friction marks, located east of the impact location, could be re-established on the AutoCAD diagram utilizing the roadway data surveyed.

The CHP area office completing the original investigation could not provide information regarding the camera used or its zoom setting, eliminating MAIT's use of photo-modeling software. Using the 35 mm prints, MAIT investigators initially scaled the tire friction mark locations laterally on the roadway based on the known widths of the roadway at reflective marker locations. Upon obtaining the scaled measurements of the tire friction marks from the photographs, the marks were re-established upon the roadway within the base AutoCAD diagram. The marks lead directly to, and ended at, the impact location identified by the gouge mark measured by the investigating officers at the collision scene.

In addition to the above "scaling" method of determining the tire friction mark locations, MAIT investigators utilized Photo Reconstruction as outlined in Northwestern University Traffic Institute's Traffic Accident Investigation Manual. The Photo Reconstruction method utilized transparencies of the collision scene photographs while at the collision site (Figure 3). Individual transparencies were aligned at the collision site in a location so that the environment items in each transparency matched the environment items still visible at the collision site. Once the environment items were aligned, the physical evidence visible in the transparency was located and marked, by a second investigator, at the collision site while the first investigator viewed through the transparency to locations in the roadway.

Figure 3: *Photo Reconstruction Method*

By using this method of photogrammetry, not only were investigators able to re-establish the tire friction marks east of the impact location, they were also able to locate the previously documented gouge mark and re-establish the collision scrub at the impact location. Additionally they were able to re-establish the tire friction mark west of the impact location, along the south shoulder of the road. Once the items of physical evidence were marked on the roadway, the marks were surveyed utilizing the Leica TCRA 1105 Plus TSSI. The second survey was re-sectioned into the original survey utilizing the previously established reference nails.

Once the photo reconstructed physical evidence was gathered via the survey instrument, the data was again downloaded into AutoCAD where the physical evidence was drawn in relation to the roadway environment. Upon being added to the AutoCAD drawing, the three "photo reconstruction" curvilinear tire friction marks east of the impact location were compared to the "scaled" curvilinear tire friction marks in the same drawing. The two methodologies produced results which closely matched.

In addition to the scene surveys completed on the two previous occasions, MAIT investigators utilized a Leica ScanStation HDS 3600, High Definition Surveying (HDS) instrument to scan the collision site characteristics in three dimensions. The scanner obtained clouds of points that represent the true position of points of contact where the laser pulse struck various environmental objects. The point clouds represent the shape and position of the objects scanned relative to the position of the scanner. Three scans (each with multiple clouds of data) of the collision site were conducted acquiring nearly 14 million additional points. The clouds of points were registered (re-sectioned) to the original survey data via the reference nails (Figure 4).

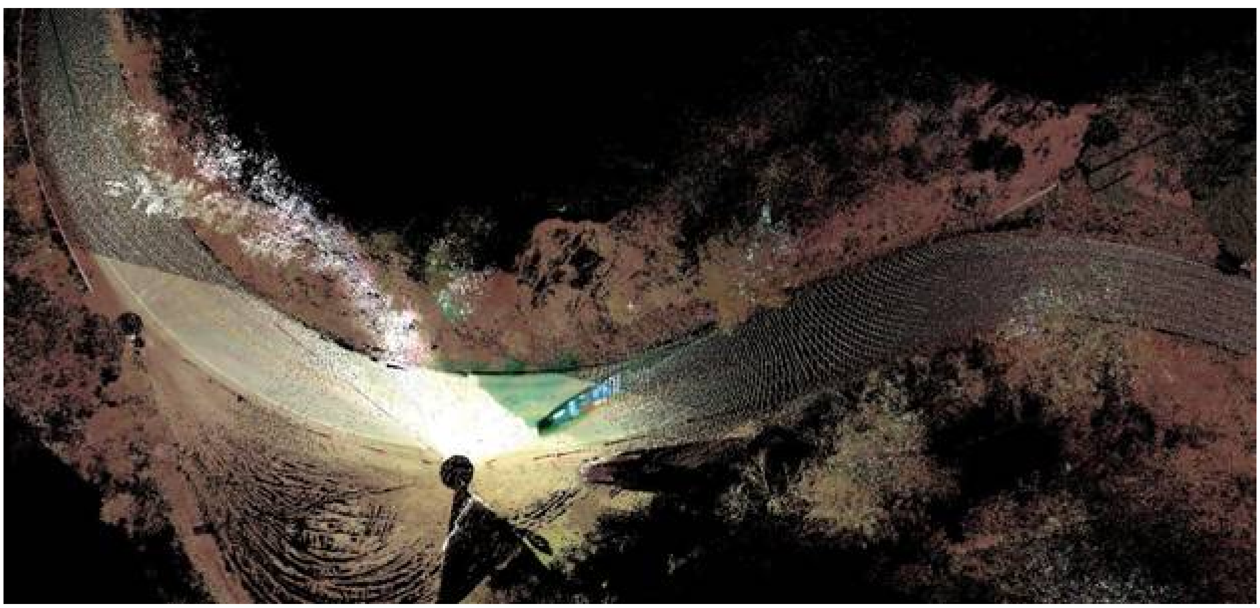

Figure 4: *Leica ScanStation HDS 3600 scan of the collision site*

TIRE FRICTION MARK ANALYSIS

A two-dimensional vehicle dynamics analysis of the collision utilizing the re-established curvilinear tire friction marks was completed (Figure 5). The analysis showed that the three curvilinear tire friction marks, east of the impact location along the Acura's path of travel, led directly to the impact location. In addition, the track width and wheelbase of the Acura matched the re-established tire friction marks. The orientation of the Acura at the impact location, based on the re-established tire friction marks, matched the collision orientation as determined from the damage to the front of the Acura and the Volkswagen.

The review of the photographs, the collision history of the roadway, the re-establishment of the tire friction marks from the photographs and the survey of the collision site, and the dynamics analysis of the collision provided substantial evidence that the tire friction marks were related to the collision. However, the dynamics analysis showed that the Acura was in an increasing sideslip angle yaw rather than the decreasing sideslip angle yaw as shown by the defense expert. The dynamics analysis indicated that the Acura was in a steering induced yaw, not an emergency brake induced yaw.

The additional tire friction mark, shown in photographs west of the impact location, between the two vehicles at their positions of rest, was determined to be a post-collision tire friction mark deposited by the right front tire of the Volkswagen. This mark was also re-established in the AutoCAD diagram and matched the post-collision travel of the Volkswagen in the dynamics analysis.

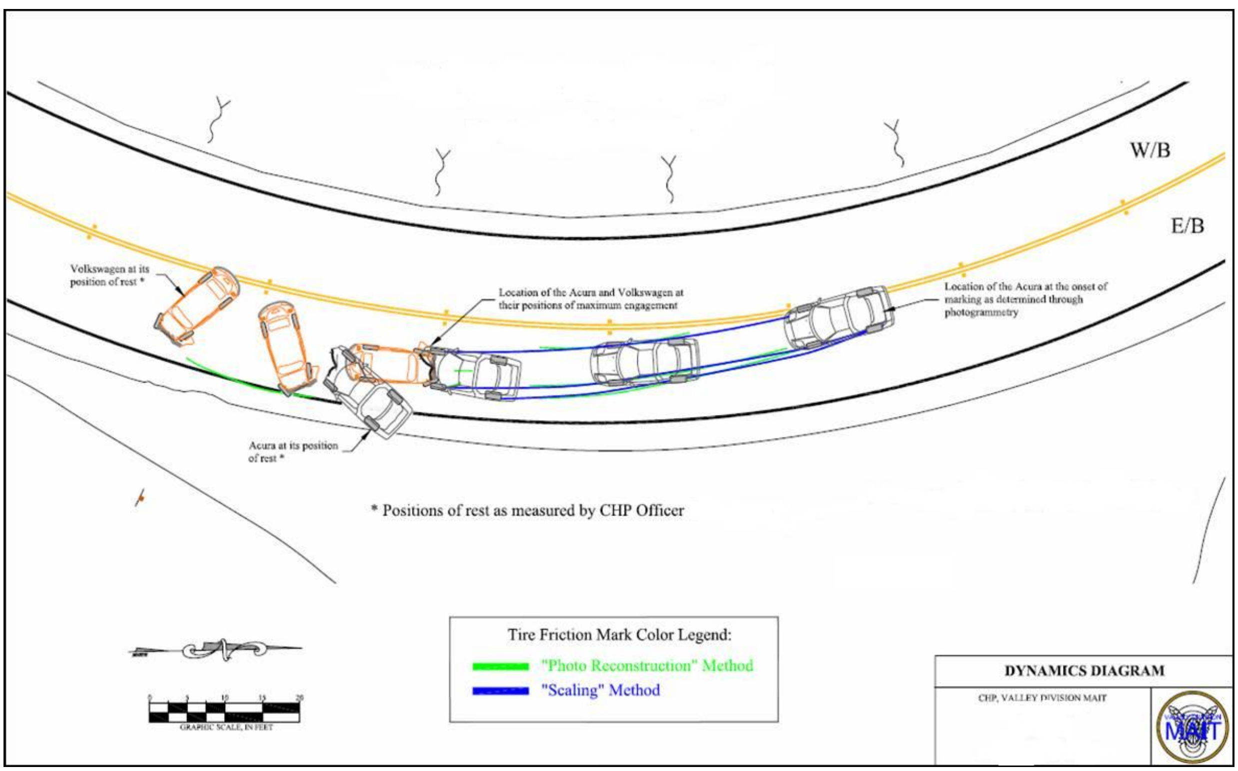

Figure 5: *2-D Dynamics Analysis of Collision*

PRELIMINARY CONCLUSIONS

The preliminary conclusion of the MAIT Investigation was that the tire friction marks in question were part of this collision. As such, the dynamics analysis indicated the Acura was in an increasing sideslip angle yaw as it traveled around the curve within the eastbound traffic lane. The alignment of the damage between the two vehicles indicated that the Volkswagen was traveling near the center of, and in alignment with, the eastbound traffic lane.

A velocity analysis was also completed utilizing a collinear momentum analysis and equations of motion. The velocity analysis concluded that the Volkswagen was traveling at approximately 30 to 35 mph at impact and the Acura was traveling at approximately 49 to 52 mph at impact. The analysis also indicated that the Acura was traveling between 51 and 54 mph when it began to mark the roadway based on the re-established tire friction marks.

MAIT investigators, desiring further validation of their preliminary conclusions, opted to attempt a computer collision simulation utilizing the recently acquired Engineering Dynamics Corporation (EDC) Human Vehicle Environment (HVE) software.

HVE PREPARATION

MAIT investigators determined a need to obtain or create a three-dimensional environment of the collision site. The environment would need to include the tire friction marks and positions of rest of the involved vehicles in addition to the standard roadway surface, striping, shoulders, embankments, and guardrails.

Utilizing the points collected from the first and second surveys, a base three-dimensional diagram was created in AutoCAD which included the re-established tire friction marks and the positions of rest of the involved vehicles. The base diagram encompassed the roadway, striping, shoulder, and guardrail in the vicinity of the collision. It was determined that additional roadway and environment would be necessary to provide a more realistic environment.

The 14 million data points obtained with the Leica ScanStation HDS 3600 became very useful at that time. The multiple scan clouds were processed using Leica's Virtual Surveyor function within their Cyclone software to extract additional point data for the roadway, lane lines, shoulders, and embankments at and beyond the collision location. The additional point data was imported into AutoCAD where it was incorporated into the original three-dimensional base drawing.

Line work, outlining the various environment items, was created in the base diagram. Once the line work was created, the environment items were surfaced utilizing a combination of the AutoCAD *RULESURF* and *3DFACE* commands. The striping and tire friction marks were created initially as two dimensional surfaces. They were moved to the surface of the roadway utilizing the *FACEMOVE.LSP* routine provided by Collision Engineering Associates. Once completed, the base diagram, which included the roadway, striping, tire friction marks, vehicle positions of rest, shoulders, guardrail, and embankments, was exported from AutoCAD as a Version 12 drawing interchange format (.dxf) file.

The .dxf file was imported into HVE via the Environment Editor. During the import process, the .dxf file was scaled by a factor of 12 (converting from feet to inches) and flipped about the x-axis (z-axis down). Using the 3-D Editor, the surface colors and textures, types, and overlay names were changed to reflect the surface being edited.

As described earlier, the collision occurred in a rural area which was heavily wooded. In an attempt to simulate a wooded environment, vertical surfaces, extending approximately 200 feet above the roadway surface, were created around the original AutoCAD environment. The vertical surfaces were then exported from AutoCAD as a Version 12 .dxf file and imported into HVE via the Environment Editor as noted above. A wooded texture was applied to the vertical surfaces and the surfaces were saved as a library object. The vertical surface library object was imported into the original HVE environment and provided the necessary background of a wooded area.

Once the Environment was created, it was necessary to obtain or create the vehicles required for the simulation. The Volkswagen was in the database of vehicles provided in HVE but the Acura NSX was not. A generic "box" vehicle was an option for use but a more realistic appearance would be required if the simulation were to be utilized in court.

EDC Customer Service provided MAIT investigators with a solution. EDC suggested the option of purchasing a three-dimensional CAD based vehicle from any number of web based sites. EDC would assist in converting the CAD vehicle body to a HVE geometry file that could be associated with a generic HVE vehicle.

A Honda (Acura) NSX was located at the 3D CAD BROWSER web site. The .dxf file format was purchased and forwarded via e-mail to EDC for conversion. The Acura geometry file was returned to MAIT investigators in the .h3d file format which was placed in the HVE "vehicles" computer file folder.

The Acura was then created by using a HVE "Generic Class 2" vehicle and substituting the Acura .h3d geometry file for the generic geometry file. Vehicle specifications were obtained from Expert Autostats as well as web based sources. The generic weight, center of mass location, track width, wheel base, and tires were changed to reflect the specifications of the Acura. Once the generic specifications had been replaced by the Acura specifications, the newly created Acura was saved as a permanent vehicle in a user defined HVE database (Figure 6).

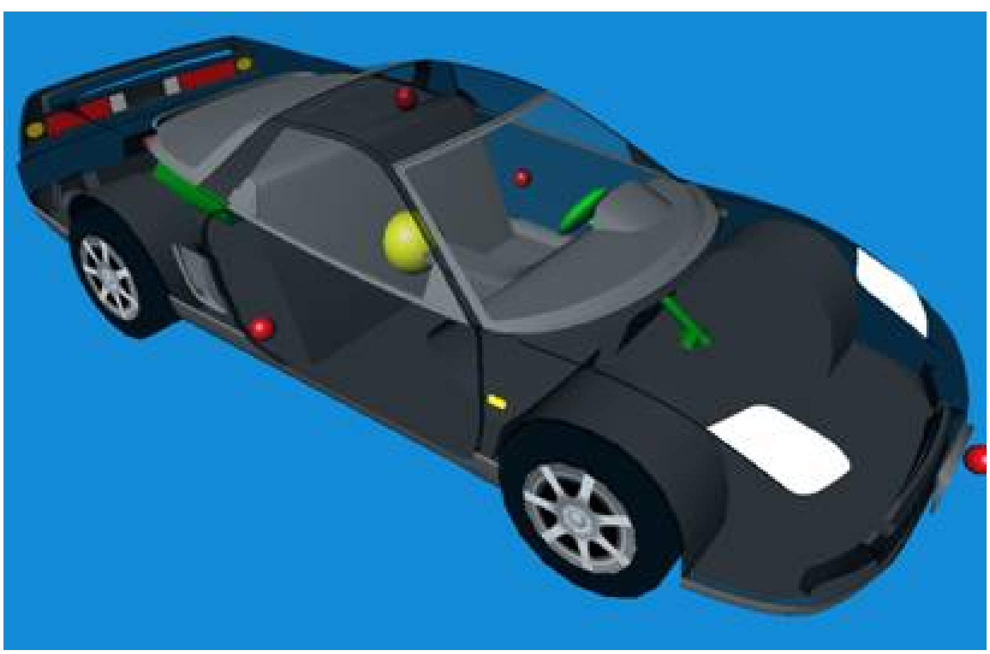

Figure 6: *Acura NSX created for HVE*

HVE SIMULATION

The EDSMAC4 calculation method was utilized to simulate the Collision Event in the Event Editor of HVE. The impact velocities of 30 mph (Volkswagen) and 49 mph (Acura) calculated by hand were the initial target impact velocities for the EDSMAC4 event. The vehicles were moved to locations approximately 0.25 seconds prior to impact based on their impact velocities to begin the simulation of the Collision Event. The initial velocities were adjusted for both vehicles to attain the target impact velocities. In addition, the Acura's sideslip angle and yaw rate were adjusted to maintain tracking on the re-established tire friction marks to impact with the Volkswagen. No pre-collision steering, braking, or acceleration inputs were initially added for either vehicle.

Vehicle positions of rest, post-collision steer angles, and approximate impact locations were known. The actual impact velocities, vehicle orientations at impact, and post-collision braking were not precisely known. Numerous iterations of the EDSMAC4 Collision Event were run varying the initial conditions and post-collision braking values until a Collision Event run resulted in the vehicles attaining the appropriate positions of rest.

Once the EDSMAC4 Collision Event was created, it was necessary to determine if the Acura could attain the parameters set forth as the initial conditions at the beginning of the EDSMAC4 Collision Event while traversing the curve and following the re-established tire friction marks. Utilizing the initial conditions of the Collision Event as the target for an EDSMAC4 Pre-Collision Event run, numerous iterations were attempted with the Acura at various speeds and steering inputs until the Acura closely followed the re-established tire friction marks and attained the initial conditions of the Collision Event. No braking conditions were created for either vehicle pre-collision.

The next step was to create one EDSMAC4 Final Event which essentially dropped the Collision Event and allowed the Pre-Collision Event vehicles to continue through the collision sequence to their positions of rest. Some minor revisions to the vehicle control tables and timing were necessary to achieve the appropriate positions of rest for the Acura and Volkswagen following the collision. Again, no pre-collision braking conditions were created for either vehicle.

The EDSMAC4 Final Event revealed that the Acura could follow the path dictated by the re-established tire friction marks to the impact location while in a steering only induced yaw and an initial velocity of 55 mph prior to entering the curve (Figures 7a to 7e). As the Acura passed the beginning of the re-established tire friction marks, it was traveling approximately 52 mph. The impact velocity of the Acura was 49 mph and the impact velocity of the Volkswagen was 29.8 mph.

A truck was added to the EDSMAC4 Final Event simulation based on the statement obtained from the witness driving a black truck ahead of the Acura. The truck maintained its position within the westbound traffic lane as the Acura began passing it in the blind curve. The truck added additional realism to the simulation as well as a viewing platform for the simulation (Figure 8).

Figure 7a: *Acura entering eastbound lane*

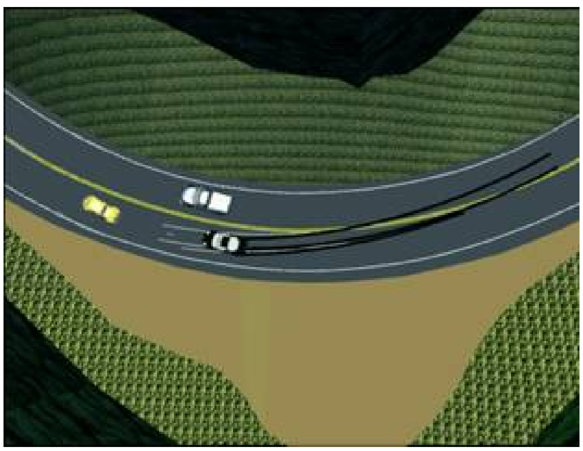

Figure 7b: *Acura within eastbound lane*

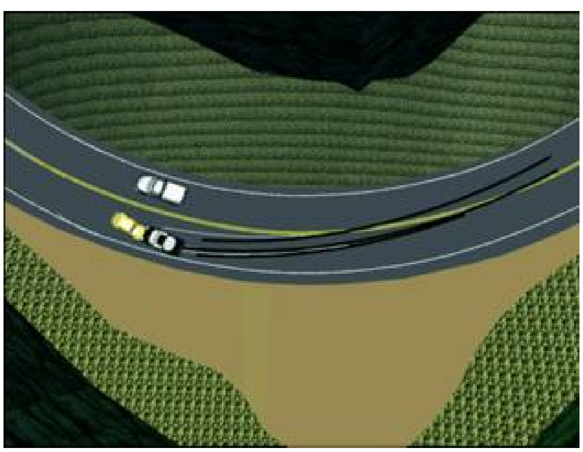

Figure 7c: *Acura and VW at-impact*

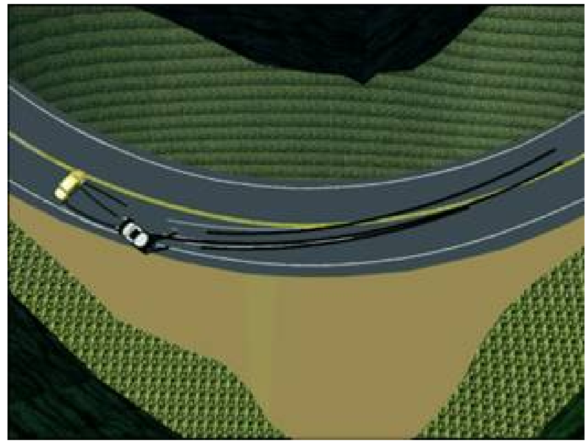

Figure 7d: *Acura and VW at position of rest*

Figure 7e: *View from within the VW*

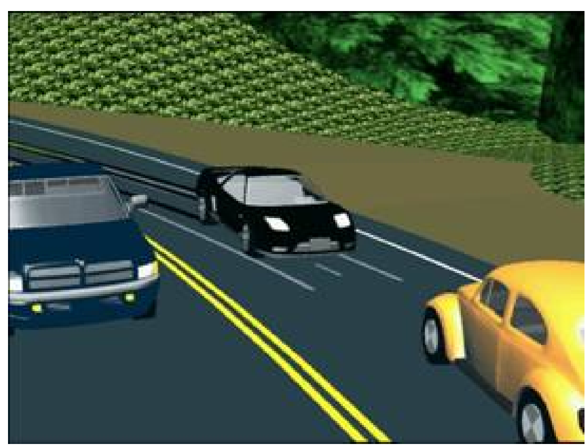

Figure 8: *View from in front of the truck*

Once the EDSMAC4 Final Event was complete, an additional event was created based on the Acura driver's claim that he utilized the emergency brake of the Acura to put the vehicle into a side skid toward the dirt area, in an attempt to scrub-off speed and stop. The EDSMAC4 Final Event was copied and the driver table for the Acura was changed to apply the emergency brake in the area where the re-established tire friction marks began. As would be expected from a rear brake only application in a curve, the EDSMAC4 E-Brake Final Event (Figures 9a to 9d) caused the rear of the vehicle to wash out to the left creating a greater yaw rate than had been experienced in the steering only EDSMAC4 Final Event. The E-Brake Final Event also demonstrated that a vehicle with an emergency brake application in a curve would have an increasing sideslip angle versus the decreasing sideslip angle as suggested by the defense.


Figure 9a: *Acura beginning emergency brake application*

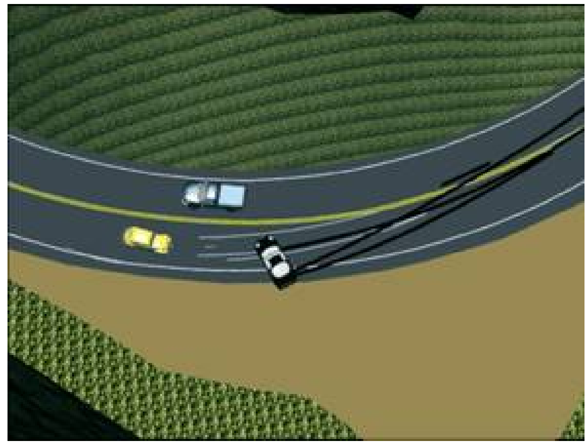
Figure 9b: *Acura broadside in eastbound lane*


Figure 9c: *Acura at impact with VW*

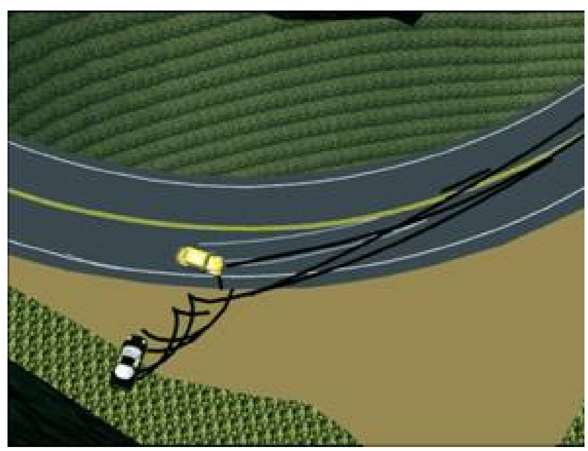
Figure 9d: *Acura and VW at position of rest*

CONCLUSIONS

A typical MAIT investigation, as with any investigation, consists of many segments which, when evaluated together, allow MAIT investigators to form opinions as to the causation of a collision. A review of the photographs was the catalyst that initiated a full reconstruction of the collision outlined previously. Prior investigations would have likely concluded with MAIT rendering an opinion based on the information discussed through the Preliminary Conclusions section of this paper. The EDSMAC4 simulation provided additional confirmation that MAIT's initial conclusions regarding the tire friction marks and the collision were accurate. More important, the physics based simulation provided a significant visible illustration of MAIT's opinion for court purposes. In addition, by changing a single pre-collision condition (emergency brake application) the same physics based simulation program demonstrated that the emergency brake application theory was not plausible.

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