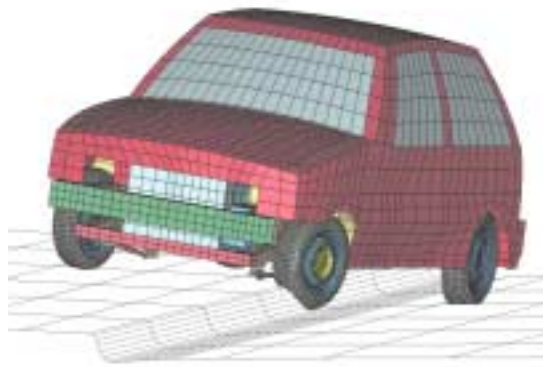


VEHICLE TRAJECTORIES RESULTING FROM TRAVERSING FDOT STREET CURBS

CONTRACT NUMBERS: B-C352 (FDOT) and 6120-561-39 (FSU)

FINAL REPORT



submitted to:

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- B1 Jerry W. Wekezer, Krzysztof Cichocki, *Computer Analysis of Vehicle Trajectories*, Proceedings of XXI SECTAM Conference “Developments in Theoretical and Applied Mechanics”, Orlando, May 19-21, 2002, pp. 121-129
- B2 Jerry W. Wekezer, Krzysztof Cichocki, *Application of LS-DYNA in Numerical Analysis of Vehicle Trajectories*, Proceedings of 7th International LS-DYNA Users’ Conference, Dearborn, May 19-21, 2002
- B3 Jerry W. Wekezer, Krzysztof Cichocki, *Suspension Improvements in FE Models of Two Public Domain Vehicles*, Submitted for presentation at the 82nd Annual Transportation Research Board Meeting, January 2003
- B4 Jerry W. Wekezer, Krzysztof Cichocki, *Numerical Analysis and Experimental Verification of Vehicle Trajectories*, Submitted for presentation at the 82nd Annual Transportation Research Board Meeting, January 2003

APPENDIX C. LS-DYNA INPUT FILES AND RESULTS

CHAPTER 1. INTRODUCTION

1.1 Project Objective

The objective of this project was to determine the trajectories of vehicles after they impact street curbs such as the FDOT Type E and F curbs. In order to obtain reliable predictions regarding real-life situations, various vehicles impacting the curbs at different velocities and approach angles were studied. Also a variety of possible roadway-curb configurations were taken into account. Because of the high costs of full scale experimental tests, the impact scenarios were studied using the computer simulation (finite element method), and select cases are verified experimentally, in order to validate the discrete model.

Since the number of parameters and initial assumptions used for the computer input was very large, it was necessary to limit the number of influences to be studied to those that were most influential and predictable. This included such important influences as the friction between tires and the roadway, the resistance of steering, and the characteristics of the suspension. Eliminated were possible driver reactions. After extensive preliminary analysis the model was further simplified by omitting secondary elements and modeling the elements not directly involved in the collision with simple materials. This reduced the amount of time necessary for the numerical analysis and computer work without compromising the accuracy of the model.

Since the only limitation was the maximum number of assumed finite elements that could be processed by computer, we were able to use a very complex discrete model which was necessary for this project. The model contained a large number of discrete elements, kinematical and contact constraints, dynamic loads and nonlinear material models describing the entire range of material behavior. The computer simulation allowed the displacements, velocities and accelerations, as well as stresses and strains for all the parts of the vehicle for each scenario to be collected. The final results for this project provided a comprehensive set of data concerning the practical application of FDOT street curbs.

1.2 Method of Analysis

The Finite Element Method (FEM) was used as the numerical method for this computer simulation. Although the fundamentals of FEM are the same for a wide variety of commercial codes, specific features of this problem needed additional coding. This coding was added to address the following:

- Solutions performed in a time domain (i.e. in discrete time intervals);
- Solutions algorithm dedicated to nonlinear impact dynamics;
- Structures consisting of shells, beams and solid elements, connected in nodes, or by Multi-Point Constraints (MPC);
- A wide variety of material modeling: linear elastic, elasto-plastic, damage, rate-dependence, rigid materials, etc.;
- Contact algorithm (master – slave);
- Modeling the presence of compressive media (air) in closed volumes;
- Internal control of stability, without the need of user intervention;
- Reliable pre and post processing;

The MSC PATRAN [2] preprocessor was used after initial modifications to the discrete models in LS-INGRID code. Post processing (i.e. analysis of the results) was provided by LS-POST code, delivered with the main LS-DYNA analysis module. Some additional post processing had to be performed by Excel spreadsheets from the data produced by LS-POST. On the basis of previous experiences with numerical analyses of similar problems (nonlinear dynamic analyses of impacts) performed at Crashworthiness and Impact Analysis Laboratory (CIAL) of FAMU – FSU College of Engineering, the latest version of LS-DYNA was chosen as the solution code. Preliminary analyses, data, pre and post-processing were performed on Silicon Graphics Octane workstations (single processor R12000), final set of examples were analyzed on Silicon Graphics Origin 2000 mainframe computer (16 processors R10000), using the queue assignment code Miser. The fundamentals of the assumed method of analysis and the details of its implementation into this specific problem are given in Appendix A.

1.3 Vehicle Models

The choice of vehicle models used in this project was one of its most important factors. The variety of possible vehicle types, weights, dimensions, etc. is very vast, and impossible to implement as a whole into a numerical simulation. Three vehicle types were used:

- a) Ford Festiva: a small (820 kg) utility car was selected since it was the light car used by NCHRP-350 and used for numerical analyses and experimental verification.
- b) Ford Taurus: a middle size (1600 kg) utility car was selected since it was the most advanced model at the time and used as a testbed for model validation and used for selected numerical analyses and also for experimental verification;
- c) Chevrolet C2500: a pickup truck (2000 kg) was selected since it was the heavy vehicle used by NCHRP-350 and used for numerical analyses only.

The discrete models of the first two vehicles were available (public-domain) on National Crash Analysis Center (NCAC) [8] ; but, without any suspensions or steering systems. The Chevrolet C2500 was also available as a public-domain model (NCAC), with its latest version available on Worcester Polytechnic Institute's homepage (www.wpi.edu). This model was equipped with full suspension, steering system, etc. In order to perform the necessary analysis, all three models were downloaded, and adapted to the purposes of this project. Although the Chevrolet C2500 has no need of major modification, both the Ford Festiva and the Ford Taurus had to be completed with reliable suspensions, wheels (rims and tires), and checked in terms of overall weight and inertia characteristics. The following modifications were implemented into the original downloaded discrete model for the Ford Festiva and the Ford Taurus:

- Elements of the front suspensions were digitized using Faro Arm equipment and introduced into the discrete model;
- Characteristics of the springs and dampers for the front and rear suspension were measured experimentally and introduced;
- Tires and rims were modeled using the special shell formulations, allowing very large deformations, and full elastic recovery of the tires;
- Air in tires was modeled using “airbag-simple-pressure” option of the LS-DYNA code;
- Total mass, localization of the center-of-gravity and moments-of-inertia for the entire vehicle were measured experimentally and validated for each discrete model. Additional masses were added to the discrete models, in order to calibrate its inertia characteristics;

Below are the views of all three vehicles, with the essential information regarding their discrete FEM models.

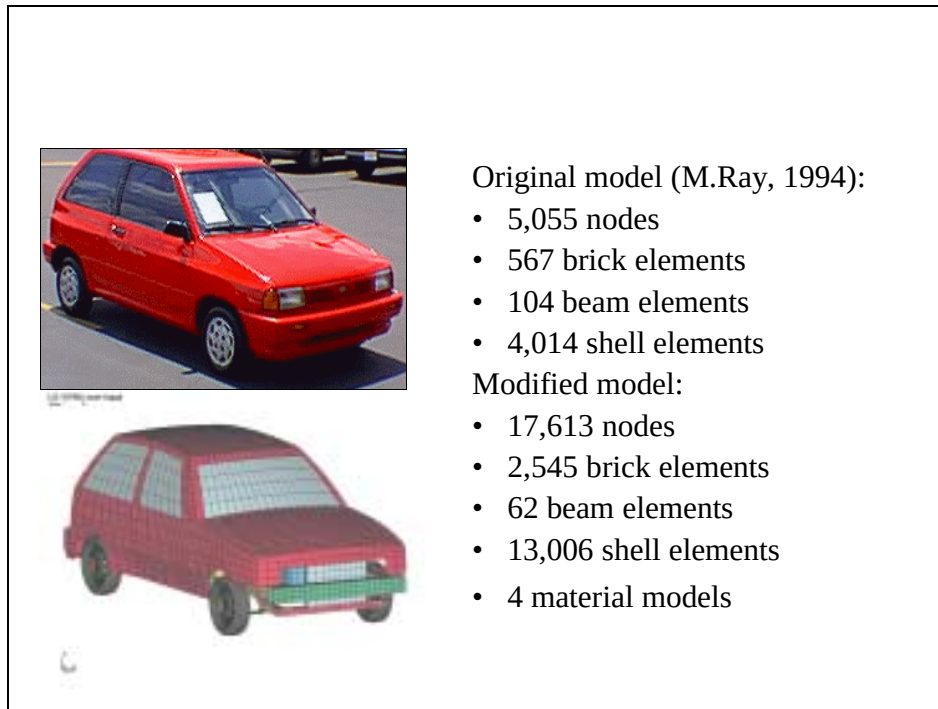


Fig. 1.1 – Ford Festiva: original vehicle and its discrete finite element model

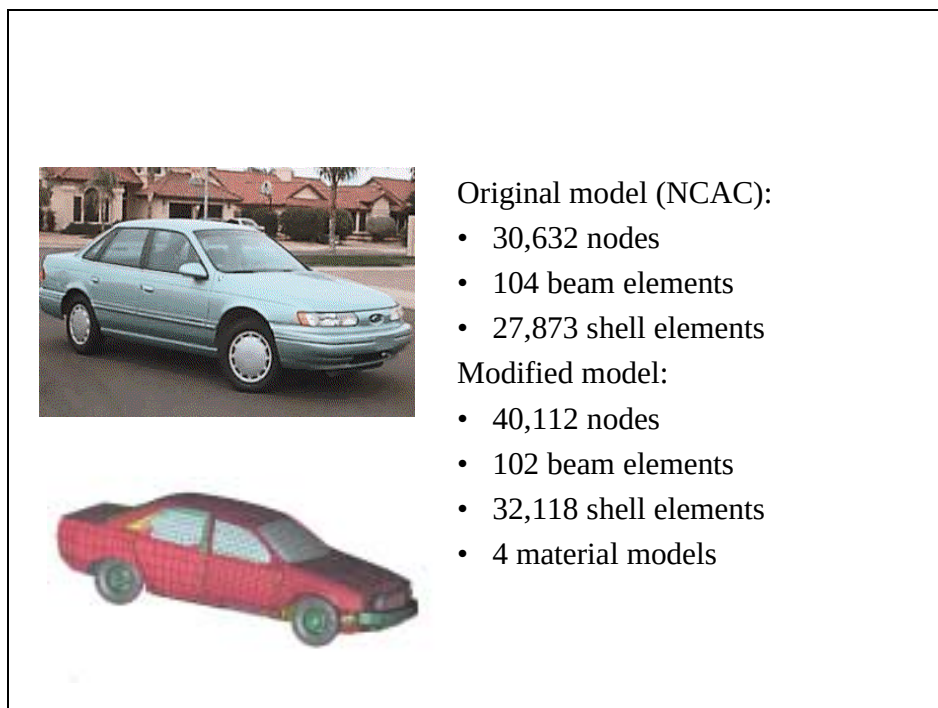


Fig. 1.2 – Ford Taurus: original vehicle and its discrete finite element model

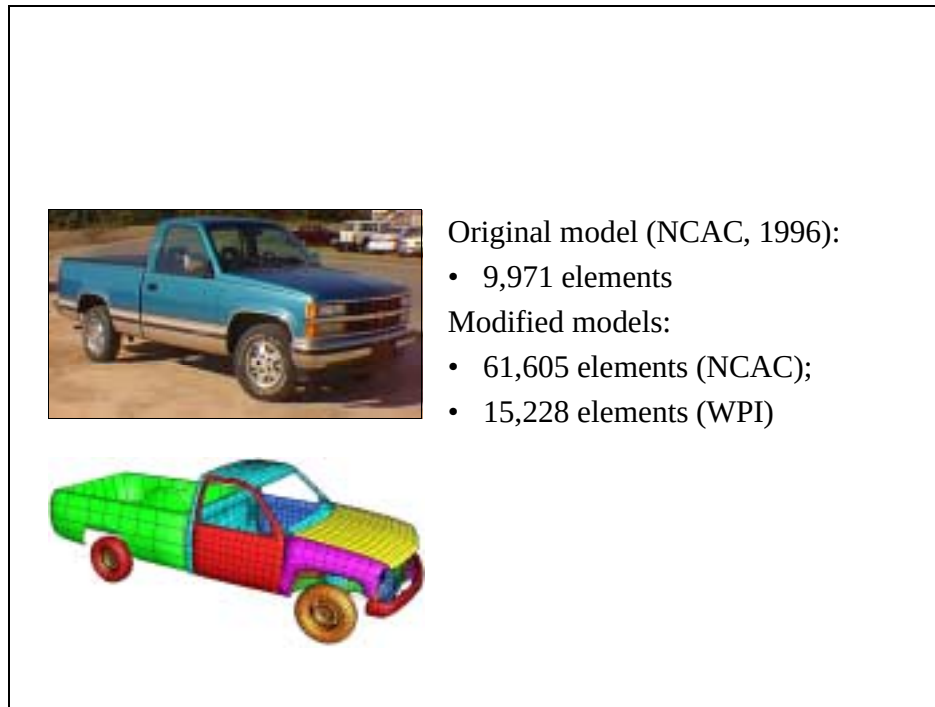


Fig. 1.3 – Chevrolet C2500: original vehicle and its discrete finite element model

1.3.1. Vehicle Models Modifications

In order to adopt the downloaded finite element models of the Ford Festiva and the Ford Taurus to the analysis of trajectories, each model was extensively modified as described below.

Description of Materials

Originally, both models were modeled using the typical elasto-plastic “von Mises” material model for steel, elastic formulation for elements which were expected to work in their elastic limit and special formulations for such elements as tires, elements of the engine, etc, where the complex internal structure of the part were substituted by a homogeneous material of the same shape and overall behavior. This helped to minimize the number of finite elements needed to model the entire structure.

These modifications were implemented into both models, which increased the total number of elements. The Ford Festiva was increased from 5000 to 16000 elements, and the Ford Taurus was increased from 28000 to 32000 elements. This resulted in the computer analysis being extremely time consuming, and vulnerable to computational errors. To eliminate these problems, perfectly rigid materials were assumed for all body elements, except for the suspension and wheels. The elements retained their original density, but were totally non-deformable.

After this operation, the computational time was greatly reduced. The Ford Festiva’s computational time was shortened from 28 to 8 hours. The Ford Taurus’s

computational time was shortened from 36 to 14 hours. Also, there were no problems with “hour-glassing” and other numerical “noise”. The entire numerical analyses for the Ford Festiva and the Ford Taurus were performed using four different material models:

- Rigid materials with density $\rho = 7.86 \cdot 10^{-9} \text{ T/mm}^3$, assumed for non-deformable steel elements;
- Linear elastic material with density $\rho = 7.86 \cdot 10^{-9} \text{ T/mm}^3$, and Young modulus $E = 2 \cdot 10^5 \text{ MPa}$, assumed for steel elements, whose elastic deformations could significantly influence the overall vehicle’s behavior (elements of suspension);
- Elasto-plastic material with density $\rho = 7.86 \cdot 10^{-9} \text{ T/mm}^3$, Young modulus $E = 2 \cdot 10^5 \text{ MPa}$, and yield stress $\sigma_p = 207 \text{ MPa}$, for steel rims.
- Linear elastic material with density $\rho = 1.5 \cdot 10^{-9} \text{ T/mm}^3$, and Young modulus $E = 1 \cdot 10^5 \text{ MPa}$, assumed for tires. These values are not representative for any real tire components (i.e. rubber, fabric, steel) but represent the homogeneous material implemented in order to simplify the discrete model of a tire.

Suspension – Ford Festiva

The Ford Festiva did not have a frame in the classic sense. The actual suspension of the Festiva consisted of:

- **Front.** Swing arms connect the chase of the vehicle to the wheel spindles, which are connected to the wheels; shock absorbers connect the wheel spindles to housings in the wheel wells. A stabilizer bar connects to the middle of the swing arms restricting out of plane movement.
- **Rear.** A bottom swing arm connects to a bracket under the center rear of the car. A swing arm is connected to the wheel spindles, which are connected to the brakes. The shock absorbers connect the wheel spindles to the housings in the wheel wells.

As seen in Figure 1.4, the downloaded discrete models had no realistic suspension system. Wheels were only connected to the body by 2 axles and some bar elements - not very realistic for our application. Also, the housings for mounting the top of the shock absorbers had not been modeled.

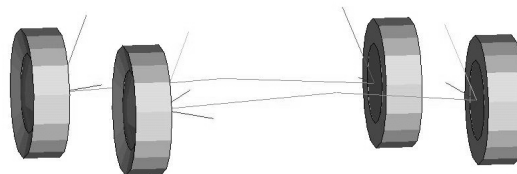


Figure 1.4 - Ford Festiva suspension – downloaded model

Although the actual suspension was very complex, consisting of many elements connected with flexible joints, only basic parts were implemented into the discrete model. Figure 1.5 shows the detailed view of the front suspension. The selected parts were modeled using discrete springs or dampers, beams, shells or solid elements. The geometry of more complicated parts was captured using a digitizing arm (FaroArm device), then imported to the preprocessor and transformed into the finite element mesh.

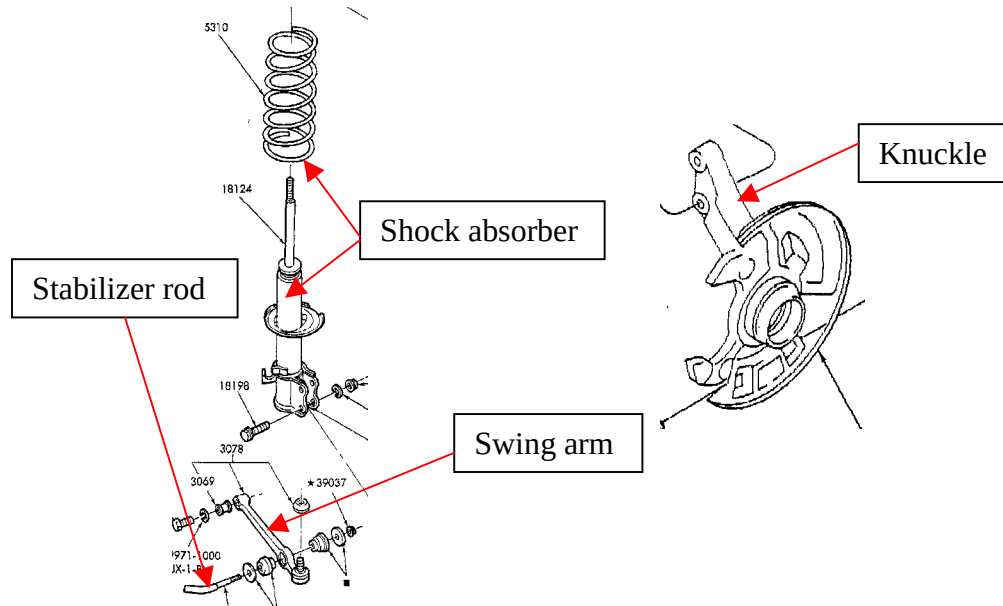


Figure 1.5 Required suspension elements (Ford Festiva). Elements described on this figure were developed and added in the new model.

The characteristics of springs and dampers for the front and rear suspension were determined experimentally at Warsaw University of Technology. The linear dampers used previously for both front and rear absorber models were replaced by dampers with nonlinear curves as shown in Fig. 1.6.

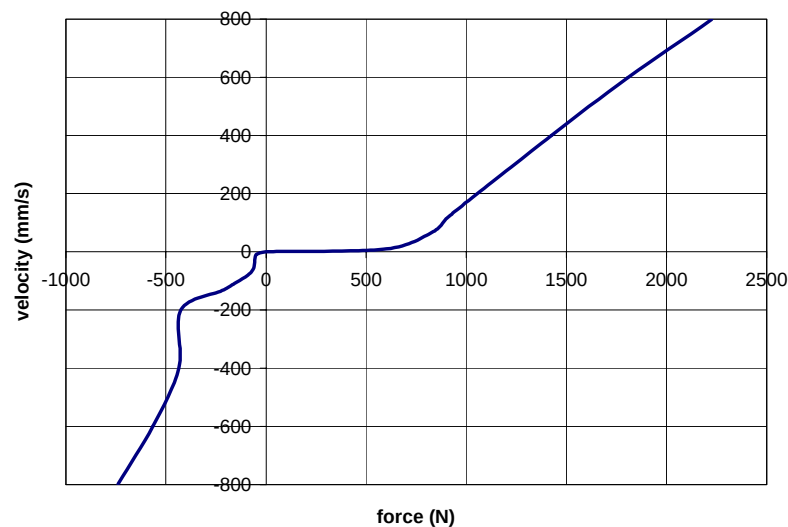


Figure 1.6 Damping curve for Ford Festiva front shock absorber

Ford Festiva Model Modifications.

The existing suspension model was replaced entirely with the exception of the stabilizer bars and drive shafts. Figure 1.7 shows the elements that were added to the suspension model. Wheel knuckles and swing arms were digitized from the actual parts. Shock absorbers could be modeled using discrete springs and dampers. The suspension system had to be connected directly to the vehicle because certain aspects of the vehicles' undercarriage were stiffened to prevent unrealistic buckling. Also, both the front and rear shock absorbers' top mounts had to be modeled. Some minor changes to the bottom of the vehicle were required because of the added geometric the new suspension system.

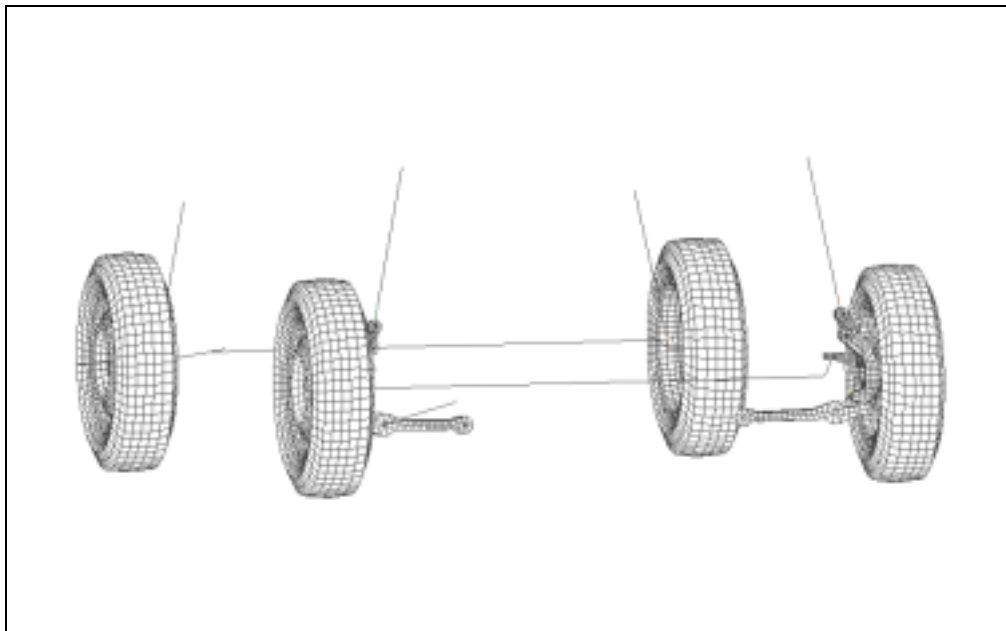


Fig.1 7 Ford Festiva modified suspension

The original (Fig. 1.4), simple wheels were replaced by much more complex parts. To obtain the correct geometry, the rims and tires were digitized using the FaroArm device. To obtain the correct behavior under impact loads, several numerical and experimental drop-tests were performed. The final finite element discrete model contained 2600 shell elements for each wheel. The presence of compressed air in tires was modeled using the “airbag-simple-pressure” option in LS-DYNA code. This uses the linear proportion between internal pressure in the tire and its volume. Due to this, the internal pressure in the tire increased during impact, and recovered the initial shape of the tire after impact.

Suspension – Ford Taurus

The actual suspension of the Taurus consisted of:

- **Front.** Swing arms connect the chase of the vehicle to the wheel spindles, which are connected to the wheels; shock absorbers connect the wheel spindles to housings in the wheel wells. A stabilizer bar connects to the middle of the swing arms restricting out of plane movement
- **Rear.** A bottom swing arm connects to the bracket under the center rear of the car. The swing arm is connected to the wheel spindle, which is connected to the brake. Shock absorber connects wheel spindle to the housing in the wheel well. A stabilizer bar connects the lower ends of the wheel spindle to the frame.

Figure 1.8 shows the schematics of a 1994 Ford Taurus front suspension system of the downloaded discrete model.

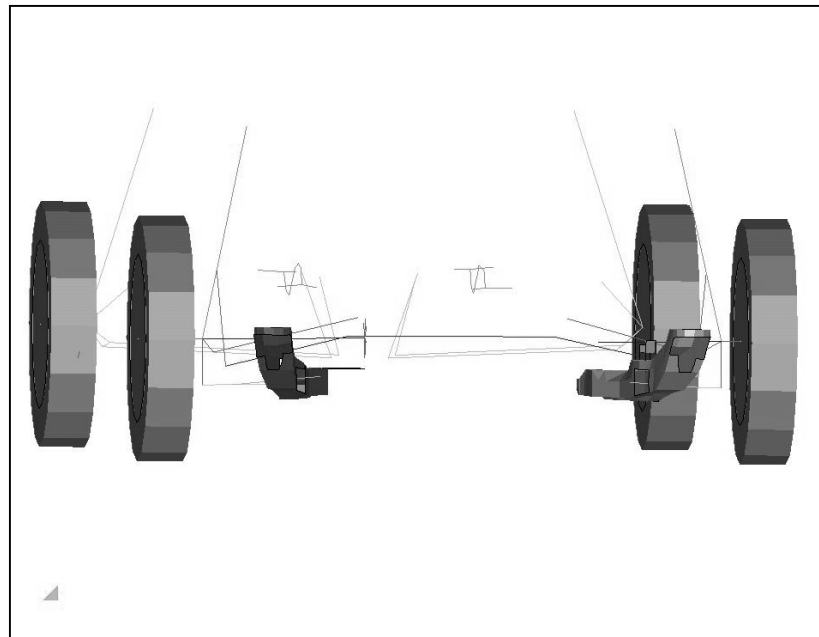


Figure 1.8 Ford Taurus suspension – downloaded model

Although the original suspension is very complex, consisting of many elements connected by flexible joints, only the basic parts were selected to be implemented into the discrete model. Figure 1.9 shows a detailed view of the front suspension. Selected parts (red background) were modeled using discrete spring or dampers, beam, shell or solid elements. The geometry of the more complicated parts was captured using the digitizing arm (FaroArm device), then imported into the preprocessor and then transformed into the finite element mesh.

Ford Taurus model modifications.

The existing suspension model was replaced entirely with the exception of the drive shafts. Figures 1.11 and 1.12 show the elements that were added to the suspension model. The wheel knuckle, stabilizer arm and front swing arm were all digitized from the actual parts. The rear suspension swing arms were acceptable as bar elements because of the slender shape of the actual arms. The shock absorbers were modeled using discrete springs and dampers. The frame and shock absorber housings were acceptable and required only minimal adjustments. The modified suspension is shown in Figure 1.13.

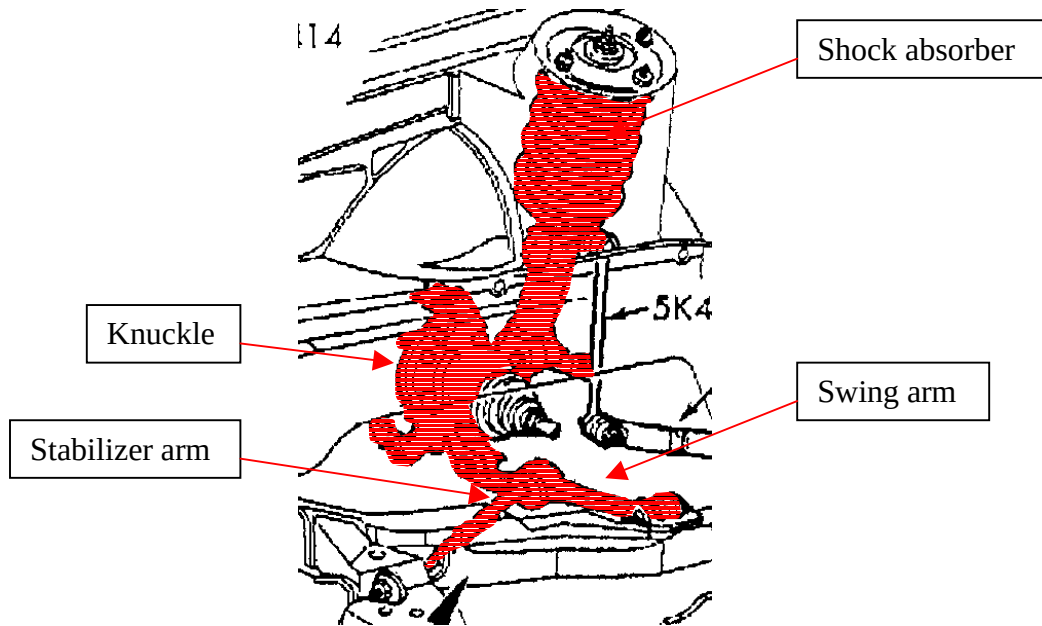


Figure 1.11 Required front suspension elements (Ford Taurus). Note highlighted elements, which were developed and added in the new model.

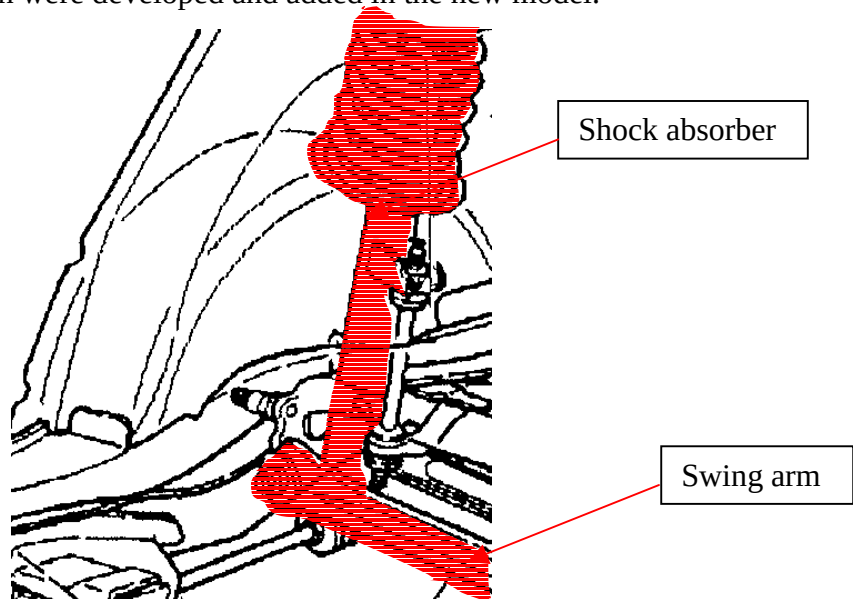


Figure 1.12 Required rear suspension elements (Ford Taurus). Note highlighted elements, which were developed and added in the new model.

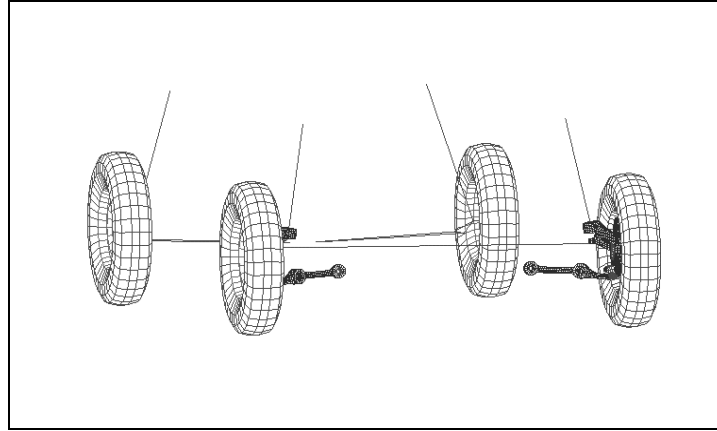


Figure 1.13 Ford Taurus modified suspension

Also in this case wheels were remodeled with much more complex discrete mesh (see Fig. 1.8 and 1.13). The same as for Ford Festiva “airbag-simple-pressure” option was introduced in order to model the presence of compressed air in tires.

Chevrolet C2500 model modifications.

The “reduced” discrete model was downloaded from Worcester Polytechnic Institute home page, consisting of about 16,000 elements. No major modifications were implemented into this model, except certain changes into LS-DYNA input code regarding parameters governing analysis performance, contact with roadway, curb, etc.

Verification of inertial characteristics

In order to check the correctness of assumed discrete models of vehicles, basic inertial characteristics of vehicles were measured experimentally at Vehicle Inertia Measurement facility (VIMF) by S.E.A. Inc (Columbus, Ohio). The results are available in adequate S.E.A report. Real inertia characteristics for Ford Festiva and Ford Taurus were compared with the adequate values for their discrete models, in order to perform initial validation of assumed finite element models of vehicles. The results for Ford Festiva are given in Table 1.1.

Table 1.1 – Inertial characteristics: Ford Festiva. Discrete model without suspension (NCAC) and with suspension (modified NCAC)

Property	SEA measurements	LS-DYNA w/o suspension	% difference	LS-DYNA w/ suspension	% difference
mass [kg]	854.45	814.70	4.85	854.60	0.02
x-coord of CG [cm]	81.92	86.39	5.48	83.00	1.32
dist to wheel [cm]	52.93	54.28	2.54	53.00	0.12
box [kg-m ²]	259.20	220.90	14.78	245.60	5.25
lyy [kg-m ²]	989.99	757.60	23.47	797.70	19.42
lzz [kg-m ²]	1112.00	850.86	23.48	907.50	18.39
lxx [kg-m ²]	47.06	14.88	68.38	19.80	57.93

1.4 Street curbs considered

Two different types of concrete street curbs were assumed in analysis:

- a) FDOT “Type E” curb;
- b) FDOT “Type F” curb;

Their detailed geometric description (from: FDOT Roadway and Traffic Design Standards, January 2000, Topic no. 625-010-003) [11] is given below (dimensions in millimeters).

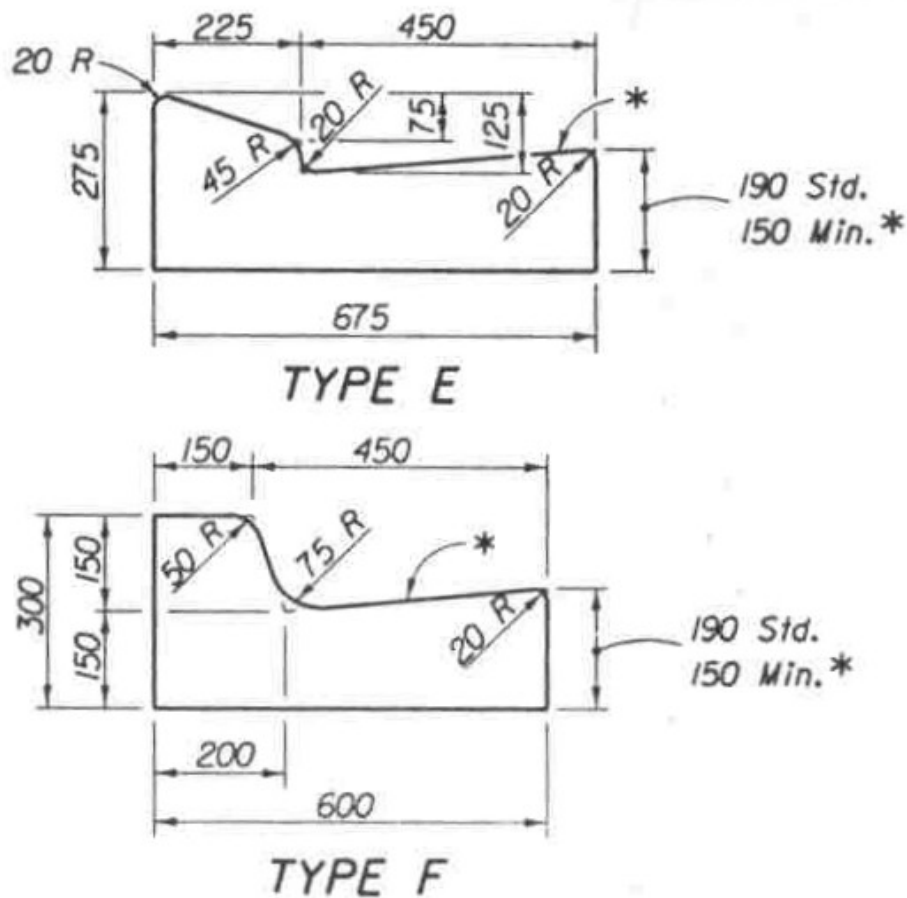


Fig. 1 .4 – FDOT curbs Types E and F.

Type F curb used in the experimental verification at Texas Transportation Institute is shown below.



Fig. 1.14 – FDOT Type F curb (Texas Transportation Institute test site at College Station)



Fig. 1.15 – FDOT Type F curb.

1.5 Matrix of impact parameters

To match the most prevalent condition for Florida's roadways, the following parameters and their values were selected for numerical analyses, in the form of a matrix of impact parameters:

- a) Vehicles: Ford Festiva, Chevrolet C2500;
- b) Curbs: FDOT Type E and F;
- c) Approach Angles: 5, 10, and 15 degrees. (Additionally, the value of the approach angle where the vehicle does not traverse the curb was found by trial-and-error.)
 - For Ford Festiva the additional angle was 12°;
 - For Chevrolet C2500 the additional angle was 3°;
- d) Speeds: 35, 45 and 55 mph. (The intermediate value of 45 mph has to be considered only if the results for 35 and 55 mph are very different, and inconsistent);
- e) Roadway Slopes: Two different values of cross-slope were used 0.02 and 0.06.

In total, 96 different cases were defined for numerical analysis.

A priority of which cases were run was established to optimize the computer analysis so that some of the cases could be interpolated. Consequently, all but a few 45 mph cases were left for interpolation. All other parameters were always taken into account.

For each individual case, the following results were measured:

- a) Vehicle's overall trajectory: i.e. the path of vehicle, with special focus on the ends of the front bumper;
- b) Longitudinal, vertical and lateral (with respect to the curb) displacement of the right corner of the front bumper;
- c) Longitudinal, vertical and lateral (with respect to the curb) velocity of the right corner of the front bumper;
- d) Trajectories of the right corner of the bumper plotted in space together with the curb.

Table 1.2 – Assumed matrix of cases to be considered

[illegible]

1.6 Full-scale crash tests

The purpose of this part of the study was to perform full-scale crash testing to validate the computer model. The testing used a 1992 Ford Festiva and a 1991 Ford Taurus on a segment of FDOT's Type F curb and measured the vehicles' performance using external high-speed film and internal electronic instrumentation. From the instrumentation, time histories of acceleration and angular velocities for the vehicle center of gravity and for the backup accelerometer were recorded for each test. In addition, longitudinal and vertical time histories of displacements for selected points on each vehicle were recorded from the high-speed film.

Test facility

The site selected for installation of the FDOT Type F curb was along a wide out-of-service aircraft landing apron. The apron consisted of an un-reinforced jointed concrete pavement blocks 3.8 by 4.6 meters that was nominally 203-305 mm deep.

Test Article

A length of 22.9 meters of FDOT Type F curb was constructed (Figure 1.5). The curb incorporated a 150 mm high curb with a sloping concrete gutter. The curb was 150 mm wide at the top. The width of the curb at the base of the gutter was 200 mm. The face of the curb sloped back from the gutter on a slope of 1 (horizontal) to 3 (vertical). The overall width of the curb, which included the gutter, was 600 mm. The Type F curb was constructed adjacent to an existing 203 mm thick concrete apron. The curb was rigidly attached to the apron with 13 dowels, which extended into the curb. These dowels were located 610 mm apart and were epoxy anchored into the existing concrete apron. The curb was supported by 150 mm of compacted crush stone. Compacted crush stone was placed in lifts behind the curb to simulate a 1829 mm wide sidewalk. The sidewalk was flush with the top of the curb.

Test Conditions

In order to provide vehicle trajectory data for validation of the computer simulation models, The four crash tests were performed. All procedures and data analysis were in accordance with guidelines presented in National Cooperative Highway Research Program (NCHRP) Report 350 [10]. The four crash tests were:

- Test No. 1 - Ford Festiva, 15 degrees. This test involved a 1992 Ford Festiva impacting the Type F curb at a nominal speed of 45 mph at an impact angle of 15 degrees.
- Test No. 2 - Ford Festiva, 90 degrees. This test involved reusing the Ford Festiva from Test No. 1 and impacting the Type F curb at a nominal speed of 45 mph at an impact angle of 90 degrees (perpendicular to the curb installation).

- Test No. 3 - Ford Taurus, 15 degrees. The test involved a 1991 Ford Taurus impacting the Type F curb at a nominal speed of 45 mph at an impact angle of 15 degrees.
- Test No. 4 - Ford Taurus, 90 degrees. The test involved reusing the Ford Taurus from Test No. 3 and impacting the Type F curb at a nominal speed of 45 mph at an impact angle of 90 degrees (perpendicular to the curb installation).

The detailed description of performed tests, obtained results, etc., are given in report “Full Scale Crash Testing of the Florida DOT Type F Curb” (Contract No. P2002013, Project No. 400091-FSU1-4, February 2002, Texas Transportation Institute) [12]. Also, high-speed films, videos, photos and results from accelerometers are available together with this report.

1.7 Model validation

The following characteristics of vehicle trajectories were studied to validate data from numerical analysis with the corresponding experimental results:

- a) Accelerations of the center of gravity;
- b) Displacements of points located on the vehicle’s body;
- c) Overall dynamic behavior of vehicle’s body registered on a video.

Although, the final report on experimental tests contained more detailed information on vehicle’s behavior during the tests other than those listed above, only the above characteristics were of fundamental importance, and used to validate the discrete models. Accelerations in the discrete model were calculated by interpolation between values of the nodes closest to the position of the vehicle’s center of gravity and were compared to the actual accelerations; and also used to calculate the velocities to compare with the actual velocities. In order to compare the reduction of kinetic energy due to impact effects, modeled velocities had to be compared with the actual velocities; however, the actual velocities were not measured and had to be calculated from the displacement of point on the body or from the accelerations provided. Using the accelerations proved to be more accurate due to inaccuracy of measuring displacements from the film. This technique was used for all four tests. Comparison of the results for all four cases considered showed a good correlation of numerical data with experimental results. It gave a high confidence level for other quantities describing the overall vehicle’s behavior, i.e.: velocities and displacements for points located on vehicle’s body and for center of gravity. A very good correlation between experimental and numerical data was obtained for both: 15° and 90° approach angles for Ford Festiva. However, comparison for Ford Taurus resulted in bigger discrepancies, due to much more complicated kinematics of front suspensions. Table 1.3 shows the comparison between experimental and numerical results of reduction of speed and initial kinetic energy of vehicles before and after traversing the FDOT Type F street curbs.

A detailed description of the models' validation is given in the published papers [13-16], attached to this final report.

Table

1.3.

	EXPERIMENT				NUMERICAL ANALYSIS			
Vehicle (impact angle)	Impact speed (mph)	Exit speed (mph)	Reduct. of speed (%)	Reduct. of kinetic energy (%)	Impact Speed (mph)	Exit Speed (mph)	Reduct of speed (%)	Reduct. of kinetic energy (%)
Festiva (15°)	45.80	44.86	2.04	4.06	45.80	44.74	2.32	4.57
Festiva (90°)	45.05	44.02	2.29	4.52	45.05	43.84	2.67	5.29
Taurus (15°)	45.49	43.81	3.70	7.25	45.49	44.50	2.18	4.31
Taurus (90°)	45.55	42.81	6.00	11.65	45.55	40.26	11.61	21.88

Reduction of initial speed and kinetic energy

CHAPTER 2. RESULTS

This chapter is dedicated to the presentation of the results of the numerical analyses performed for the cases described in Chapter 1.5 (Matrix of impact parameters).

Although the quantity of information available from numerical analysis is very large, on the basis of preliminary analyses and discussions, the right corner of the front bumper (see Fig. 2.2 – 2.3) was selected as the point to observe trajectories of both vehicles. All diagrams reported in this chapter refer to this specific point.

The following variables are plotted for each example:

- longitudinal, vertical and transversal displacement;
- longitudinal, vertical and transversal velocity.

Displacements and velocities are represented as functions of time. Additionally, the trajectories (i.e. the path in space) are plotted for cases when the vehicle traverses the curb.

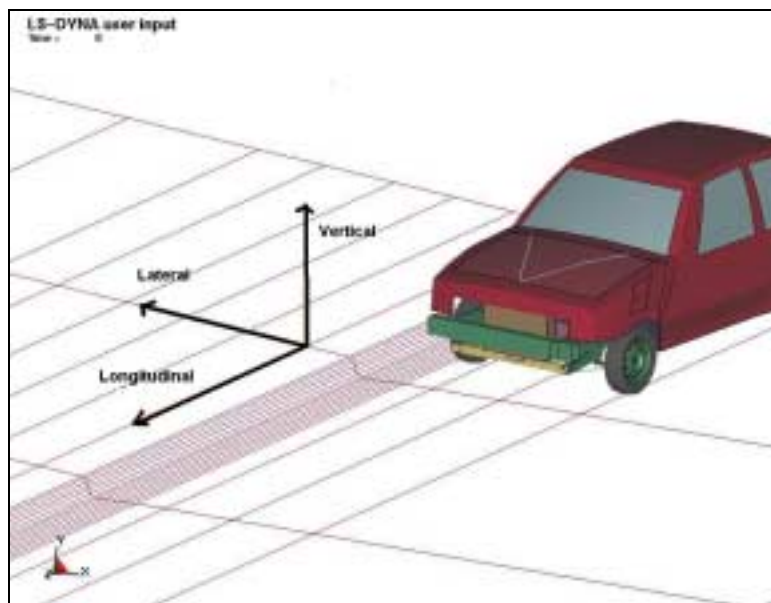


Fig. 2.1 Definition of the local coordinate system

The following symbols are used to reference the events of the first contact between tires and the curb:

- LF** – left front tire contacts the curb
- LR** – left rear tire contacts the curb
- RF** – right front tire contacts the curb
- RR** – right rear tire contacts the curb

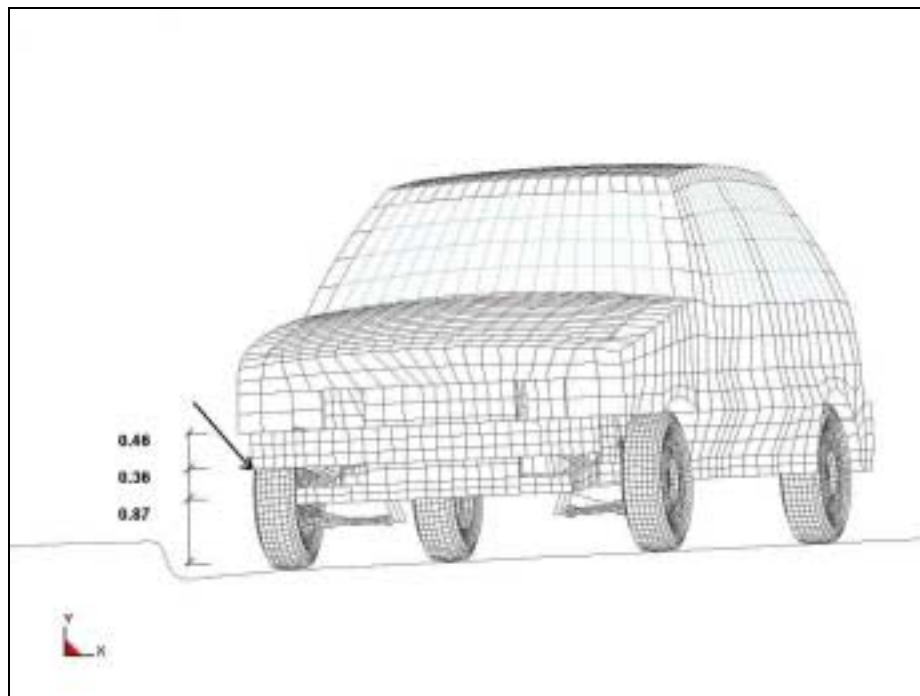


Fig. 2.2 Ford Festiva. Location of the right end of the front bumper

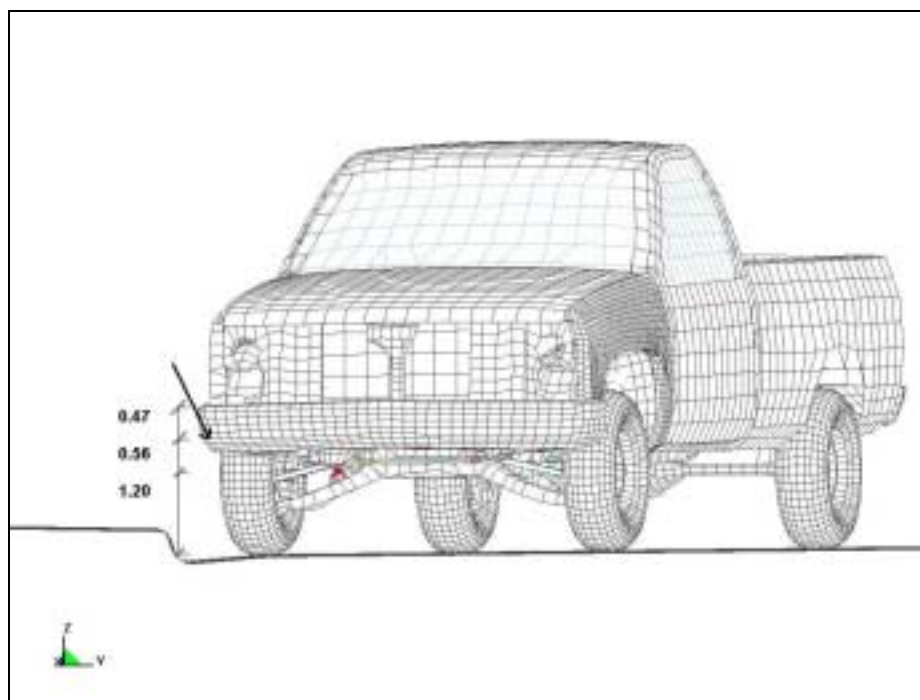


Fig. 2.3 Chevrolet C2500. Location of the right end of the front bumper

2.1 Ford Festiva

2.1.1 Slope 0.06

2.1.1.1 Approach angle 5°

2.1.1.1.1 Velocity 35 mph

2.1.1.1.1.1 “F” curb

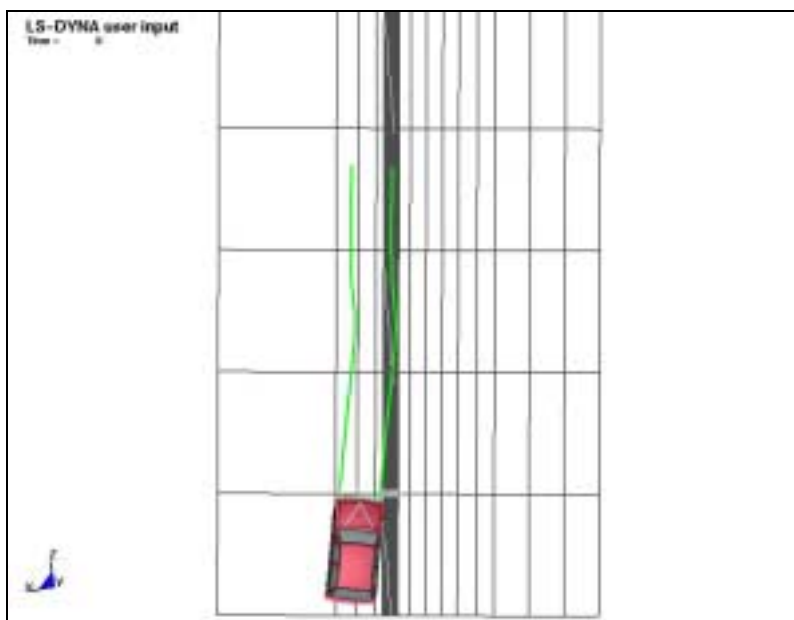


Fig. 2.1.1.1.1.1. (A) Trajectories of bumper corners (upper view)

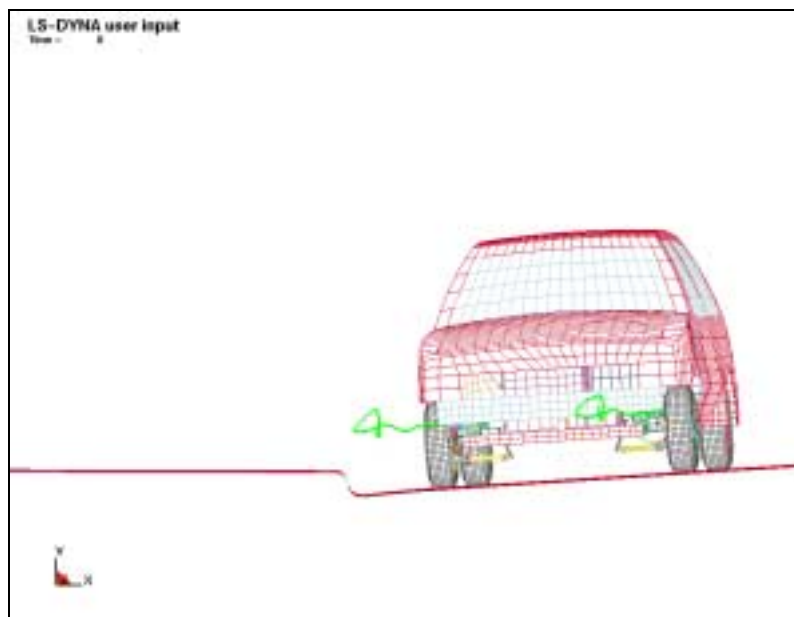


Fig. 2.1.1.1.1.1. (B) Trajectories of bumper corners (front view)

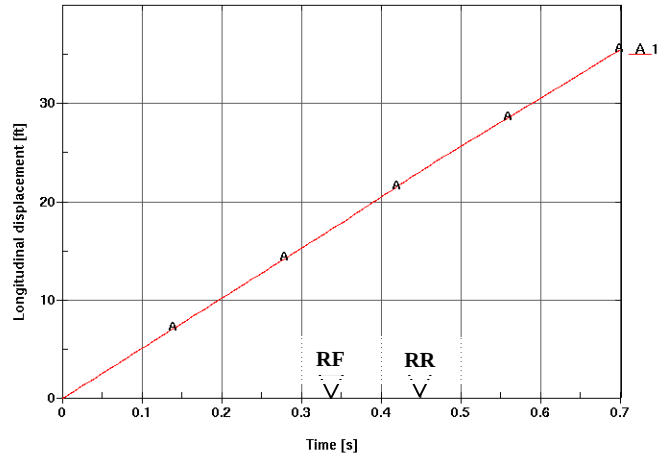


Fig. 2.1.1.1.1. (C): Longitudinal displacement [ft]

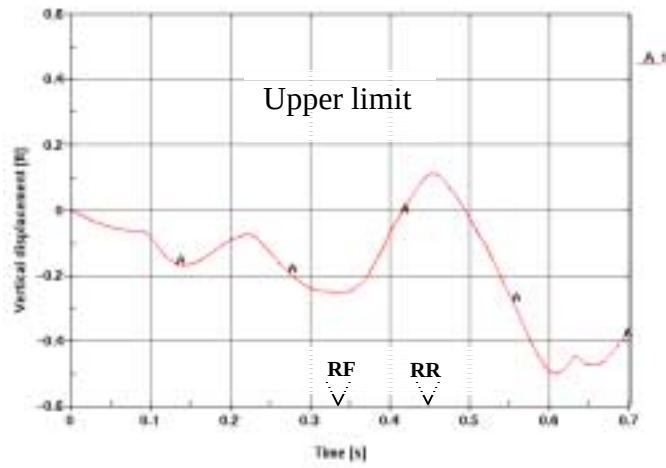


Fig. 2.1.1.1.1. (D): Vertical displacement [ft]

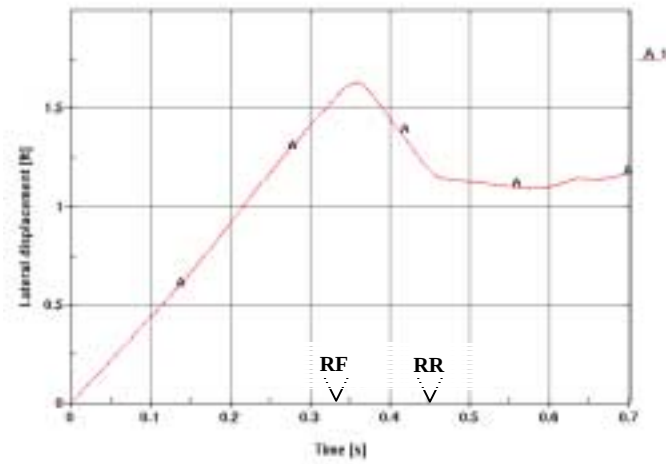


Fig. 2.1.1.1.1. (E): Lateral displacement [ft]

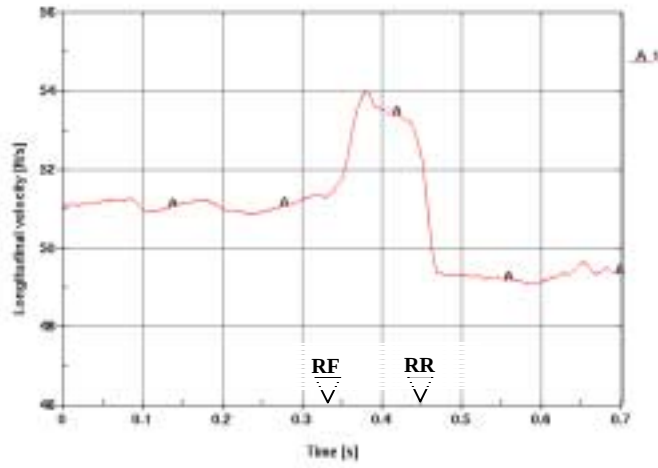


Fig. 2.1.1.1.1.1. (F): Longitudinal velocity [ft/s]

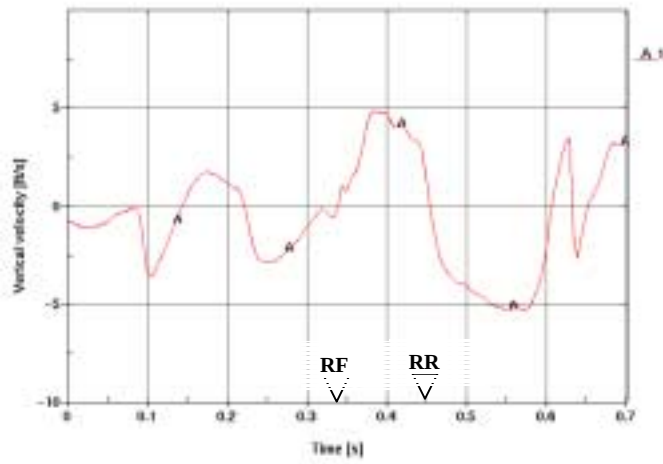


Fig. 2.1.1.1.1.1. (G) Vertical velocity [ft/s]

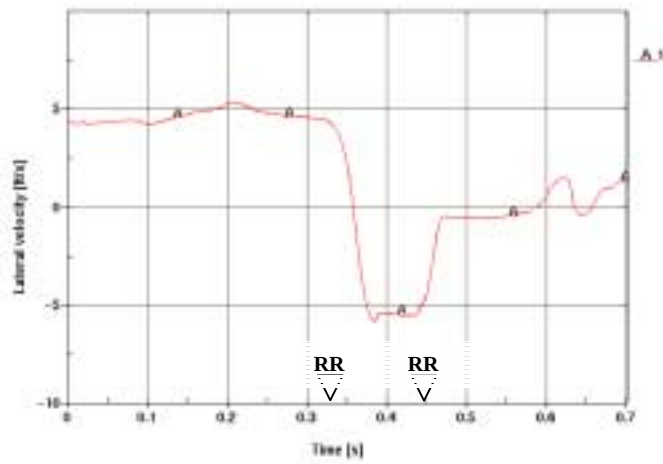


Fig. 2.1.1.1.1.1. (H): Lateral velocity [ft/s]

2.1.1.1.1.2 “E” curb

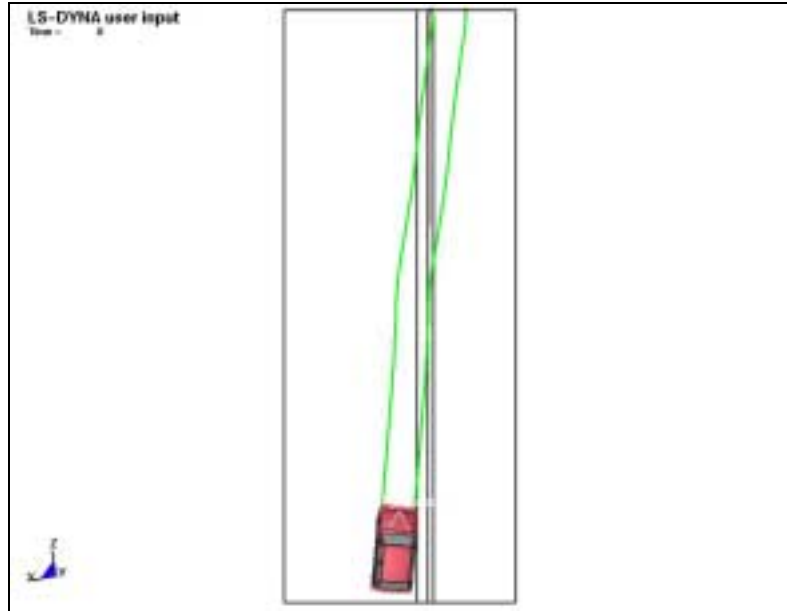


Fig. 2.1.1.1.1.2. (A) Trajectories of bumper corners (upper view)

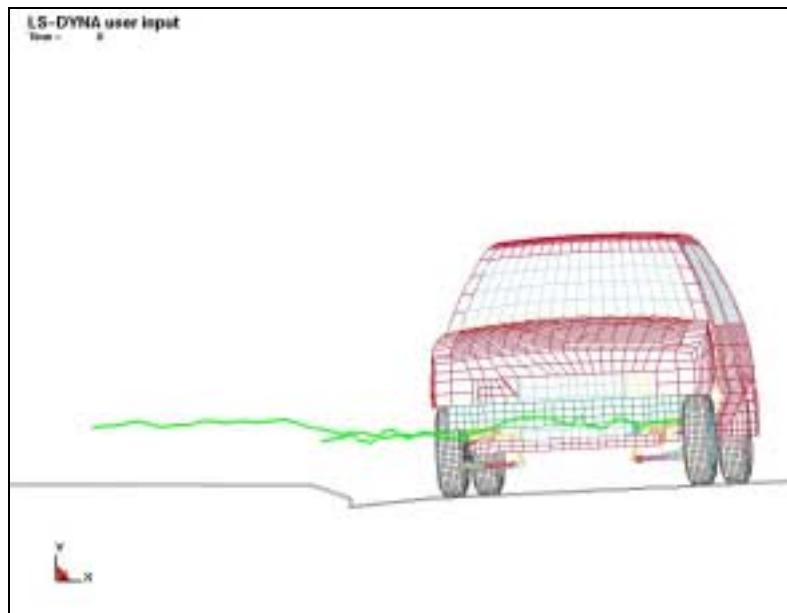


Fig. 2.1.1.1.1.2. (B) Trajectories of bumper corners (lateral view)

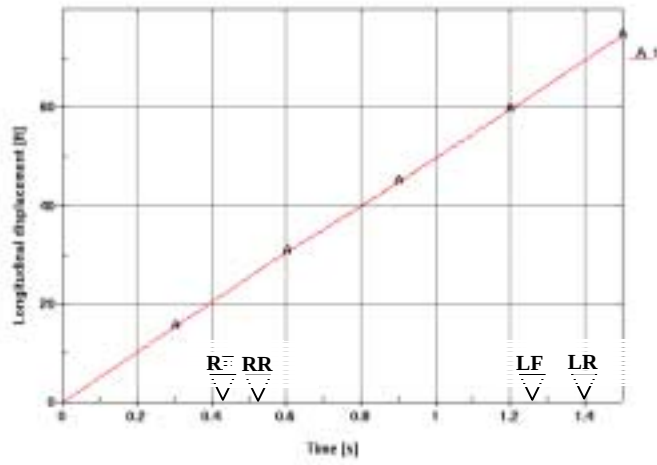


Fig. 2.1.1.1.1.2. (C): Longitudinal displacement [ft]

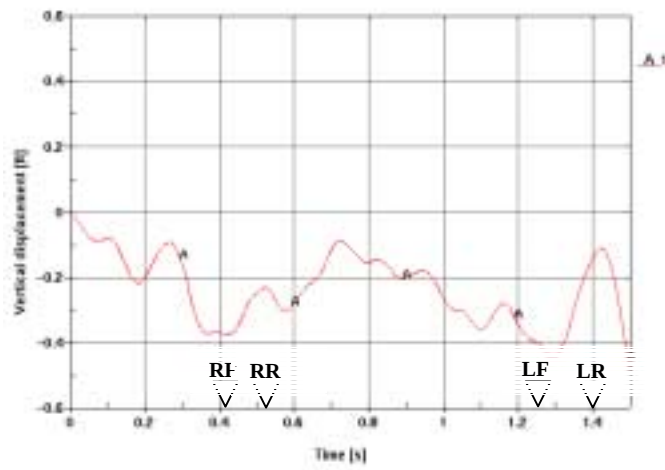


Fig. 2.1.1.1.1.2. (D): Vertical displacement [ft]

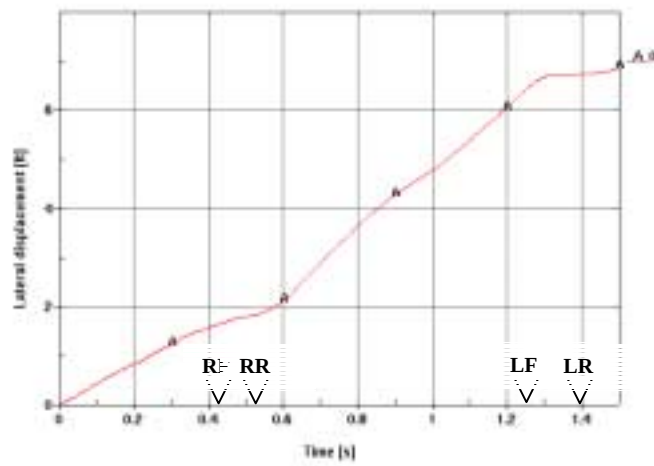


Fig. 2.1.1.1.1.2. (E): Lateral displacement [ft]

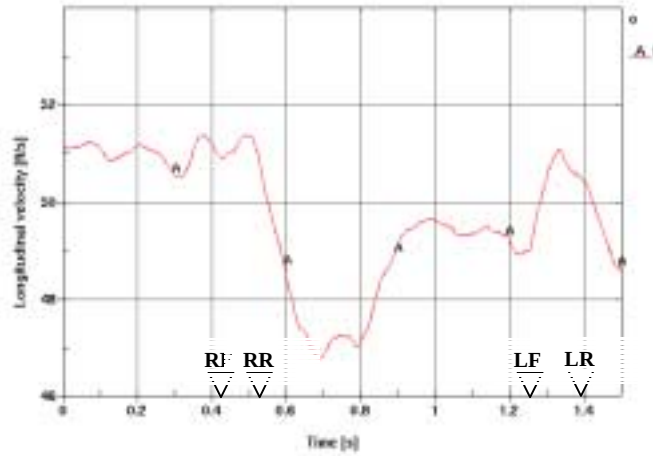


Fig. 2.1.1.1.1.2. (F): Longitudinal velocity [ft/s]

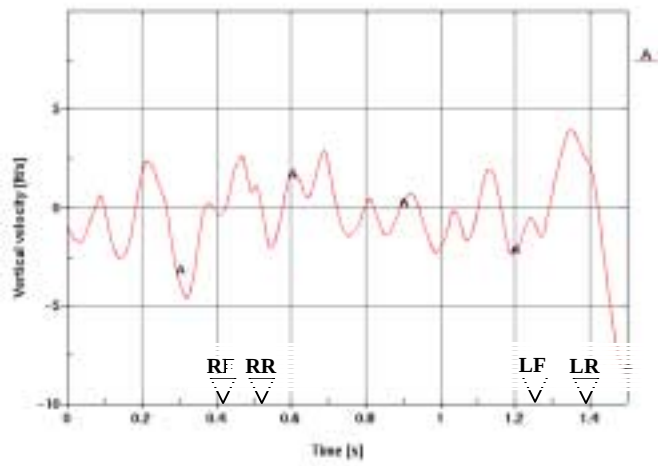


Fig. 2.1.1.1.1.2. (G) Vertical velocity [ft/s]

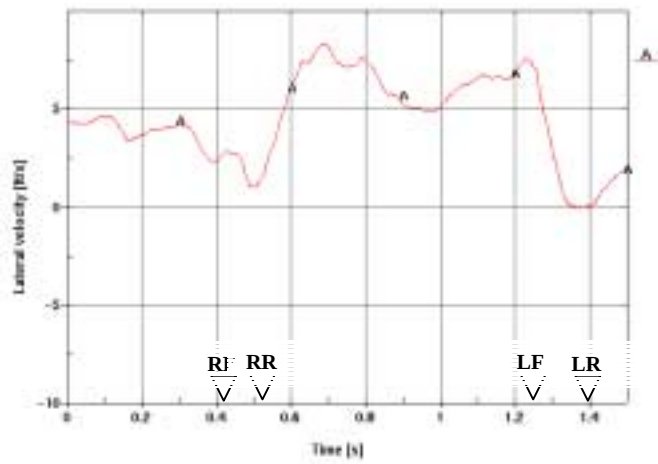


Fig. 2.1.1.1.1.2. (H): Lateral velocity [ft/s]

2.1.1.1.2 Velocity 55 mph

2.1.1.1.2.1 “F” curb

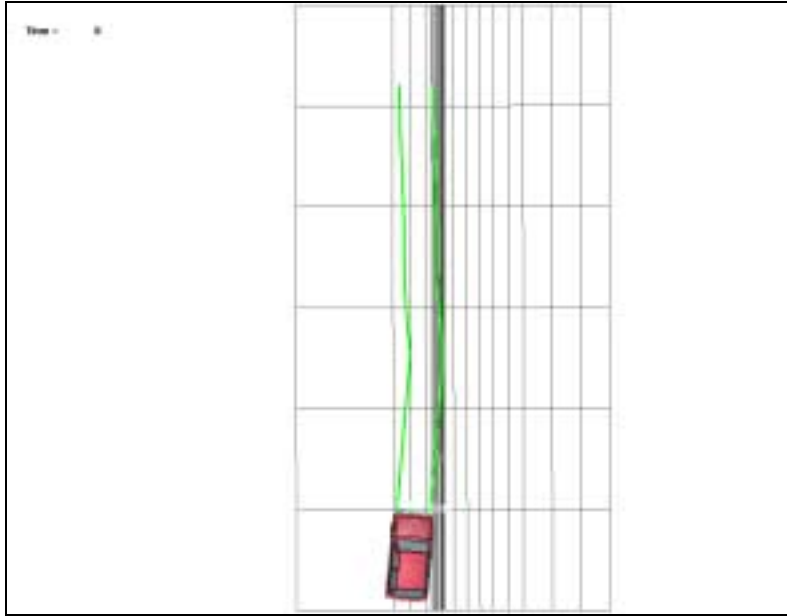


Fig. 2.1.1.1.2.1. (A) Trajectories of bumper corners (upper view)

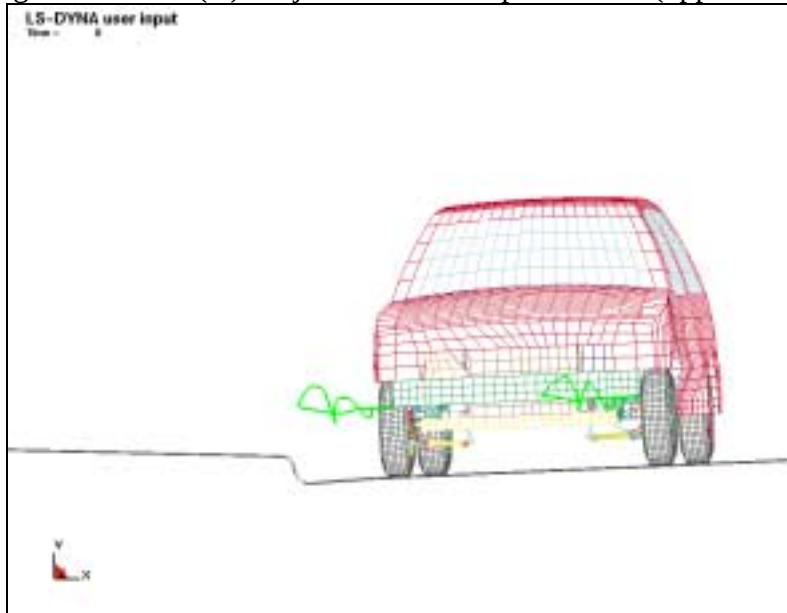


Fig. 2.1.1.1.2.1. (B) Trajectories of bumper corners (lateral view)

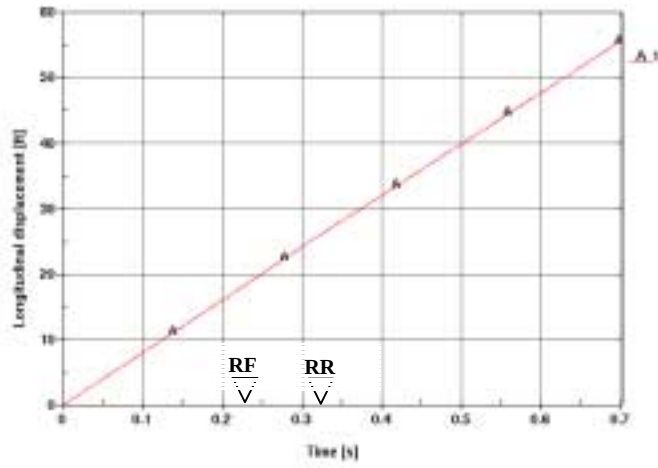


Fig. 2.1.1.1.2.1. (C): Longitudinal displacement [ft]

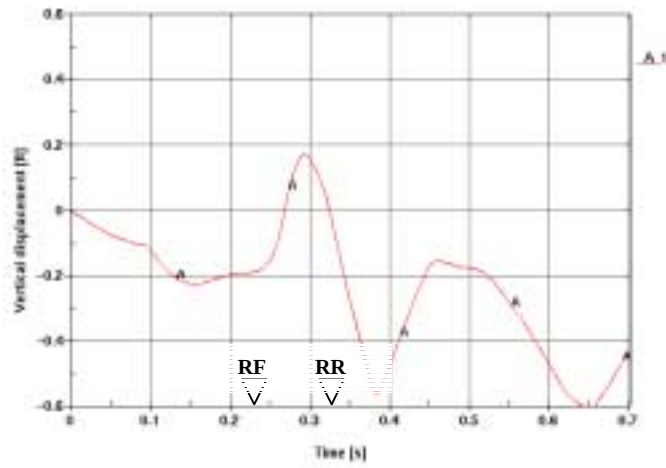


Fig. 2.1.1.1.2.1. (D): Vertical displacement [ft]

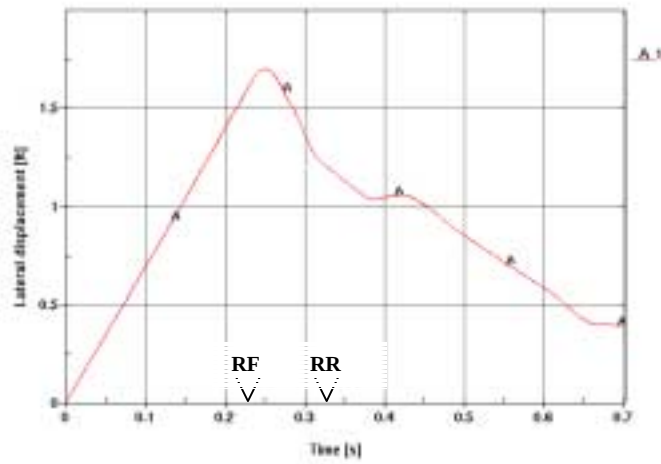


Fig. 2.1.1.1.2.1. (E): Lateral displacement [ft]

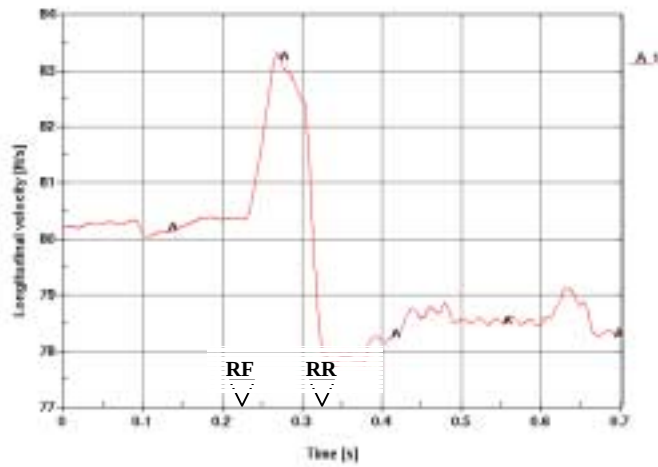


Fig. 2.1.1.1.2.1. (F): Longitudinal velocity [ft/s]

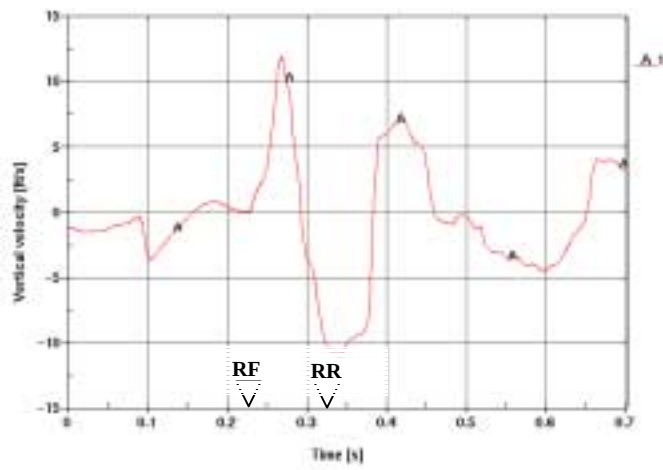


Fig. 2.1.1.1.2.1. (G) Vertical velocity [ft/s]

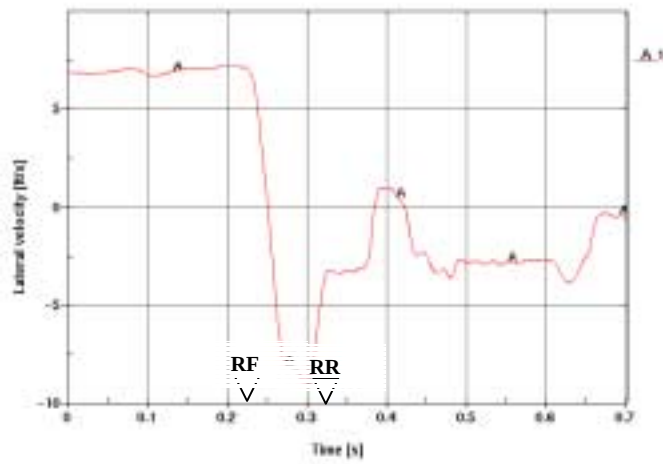


Fig. 2.1.1.1.2.1. (H): Lateral velocity [ft/s]

2.1.1.1.2.2 “E” curb

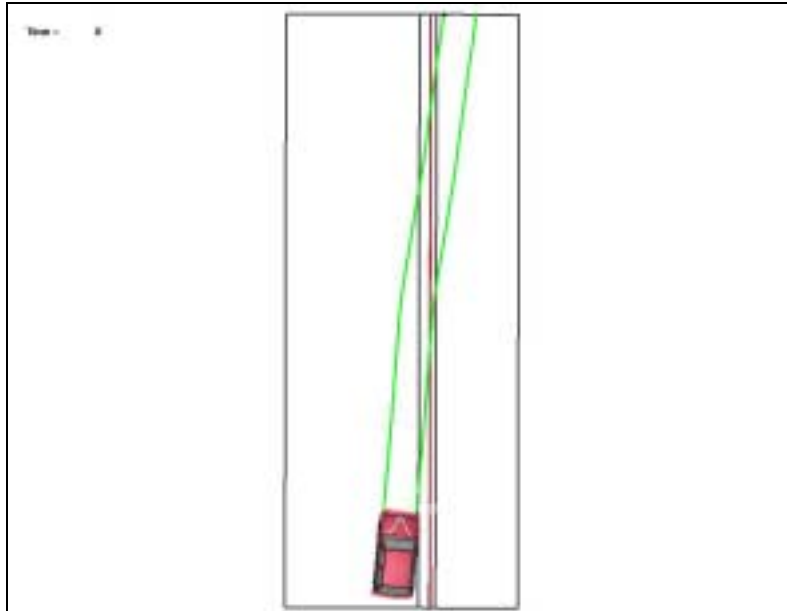


Fig. 2.1.1.1.2.2. (A) Trajectories of bumper corners (upper view)

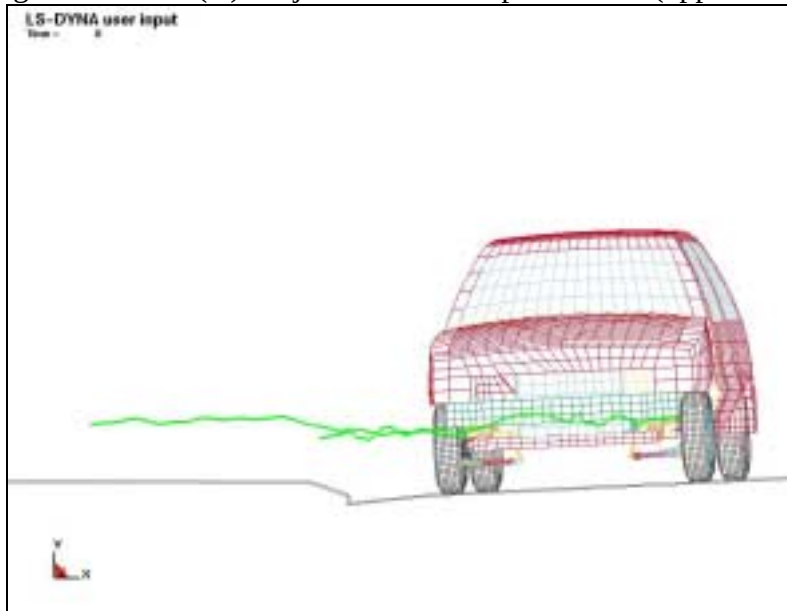


Fig. 2.1.1.1.2.2. (B) Trajectories of bumper corners (lateral view)

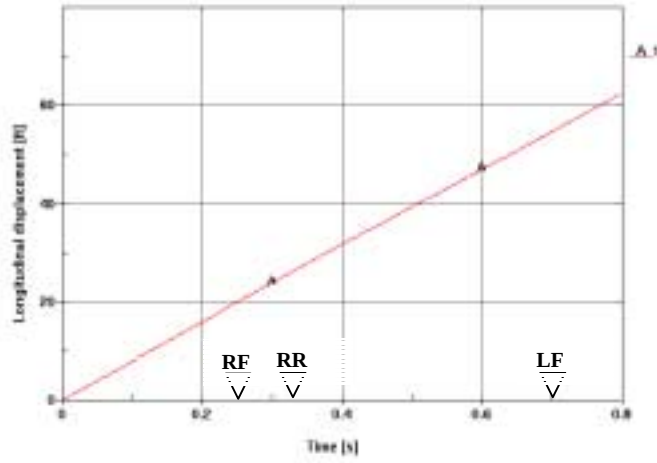


Fig. 2.1.1.1.2.2. (C): Longitudinal displacement [ft]

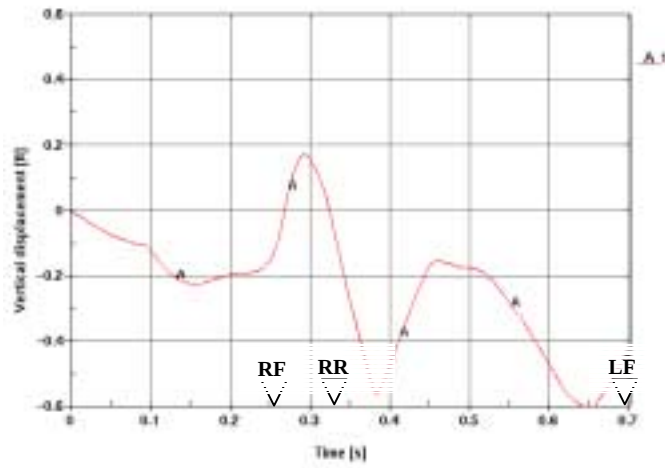


Fig. 2.1.1.1.2.2. (D): Vertical displacement [ft]

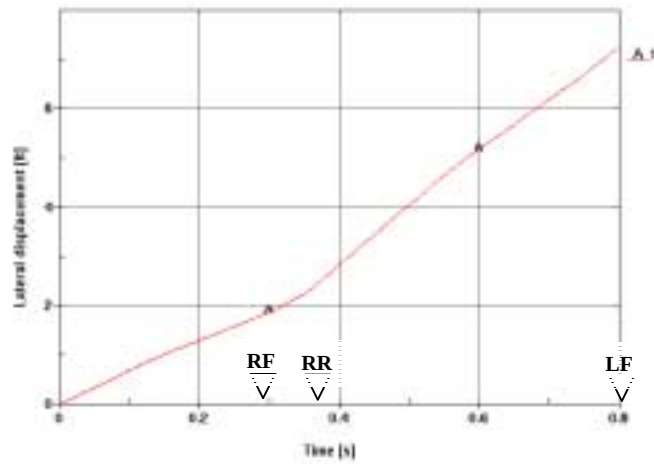


Fig. 2.1.1.1.2.2. (E): Lateral displacement [ft]

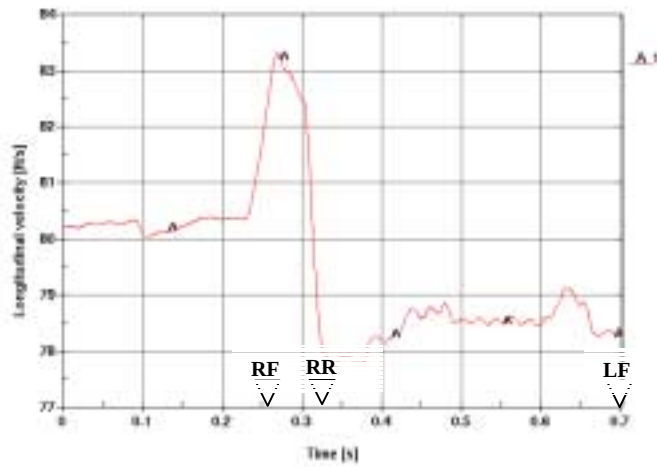


Fig. 2.1.1.1.2.2. (F): Longitudinal velocity [ft/s]

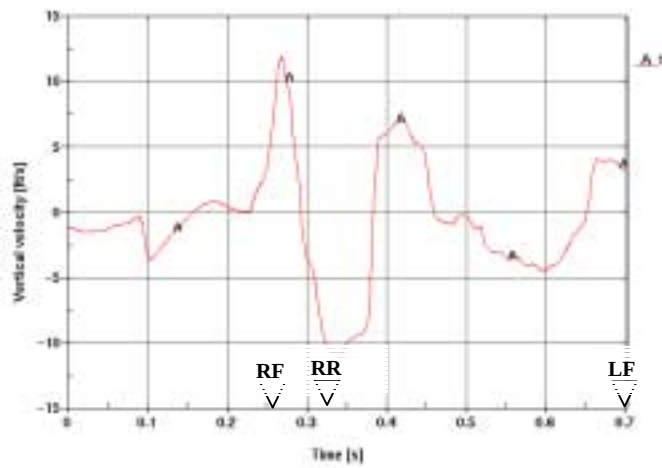


Fig. 2.1.1.1.2.2. (G) Vertical velocity [ft/s]

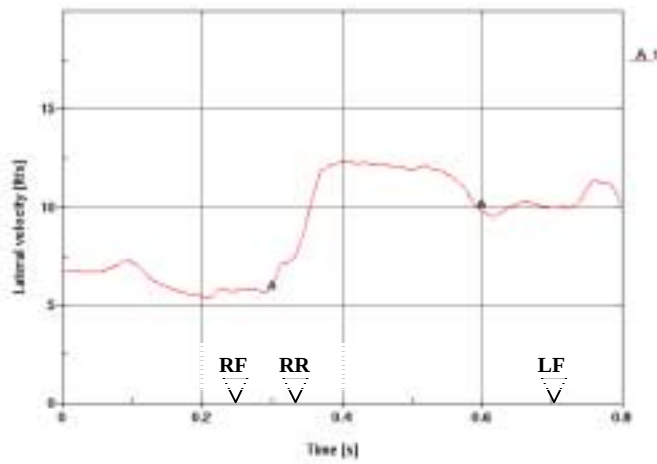


Fig. 2.1.1.1.2.2. (H): Lateral velocity [ft/s]

2.1.1.2 Approach angle 10°

2.1.1.2.1 Velocity 35 mph

2.1.1.2.1.1 “F” curb

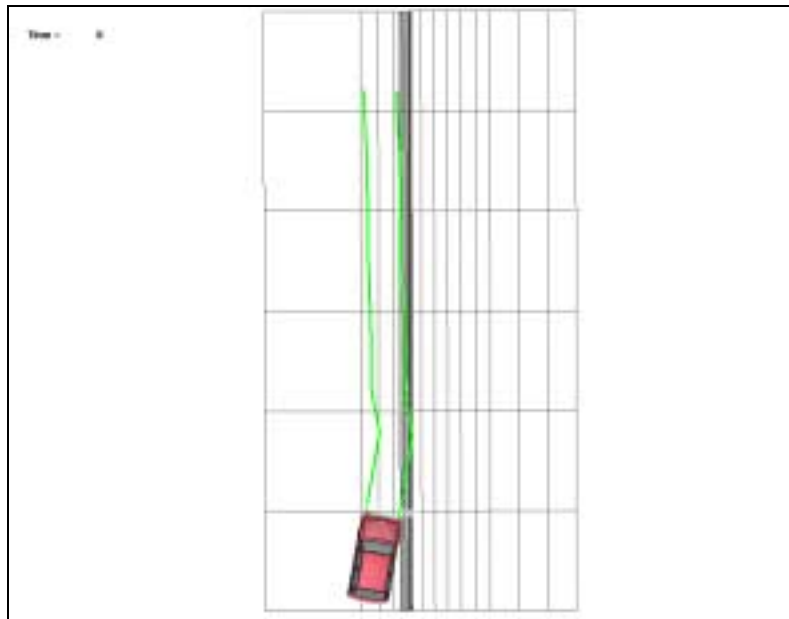


Fig. 2.1.1.2.1.1. (A) Trajectories of bumper corners (upper view)

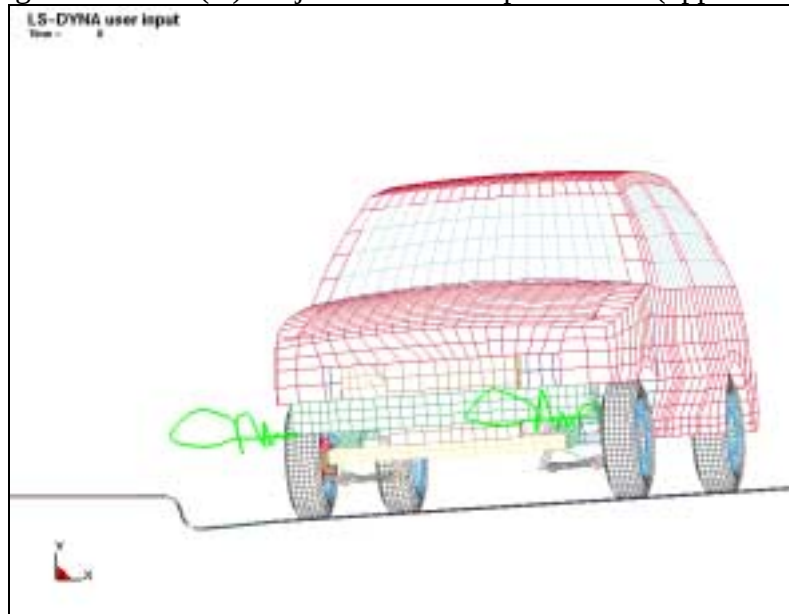


Fig. 2.1.1.2.1.1. (B) Trajectories of bumper corners (lateral view)

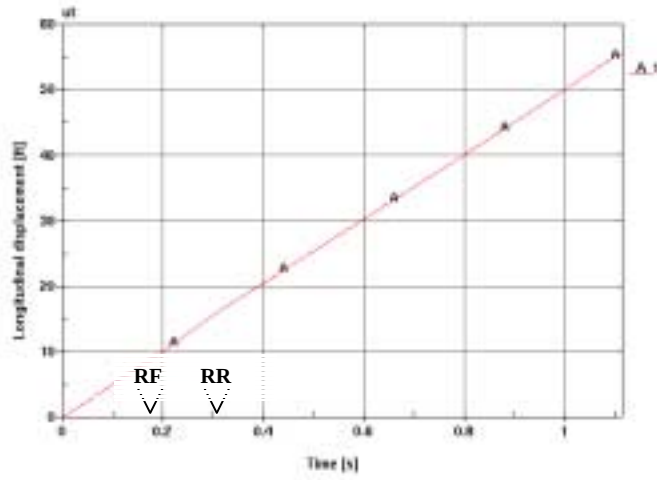


Fig. 2.1.1.2.1.1. (C): Longitudinal displacement [ft]

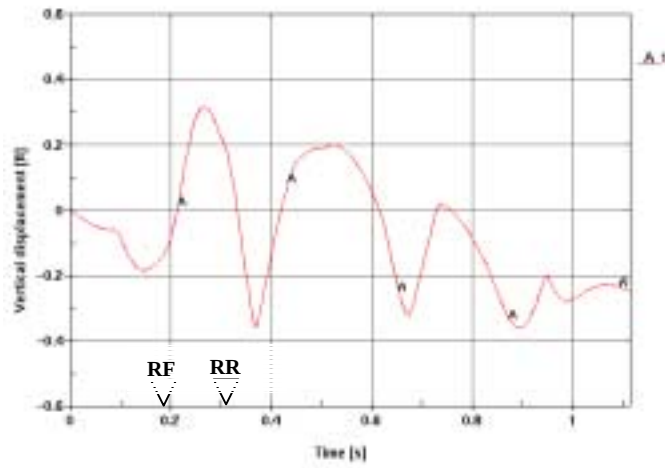


Fig. 2.1.1.2.1.1. (D): Vertical displacement [ft]

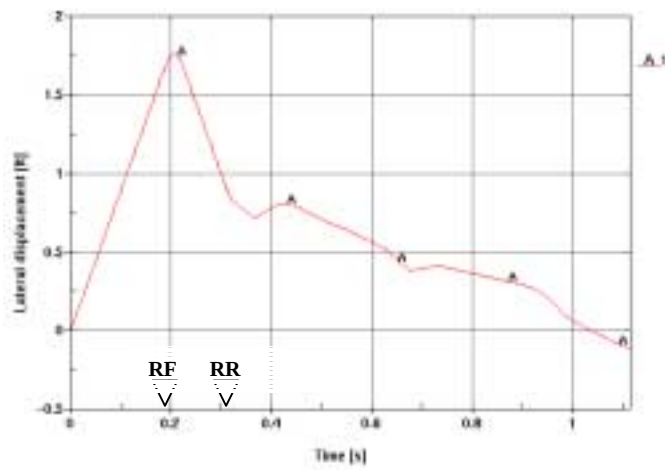


Fig. 2.1.1.2.1.1. (E): Lateral displacement [ft]

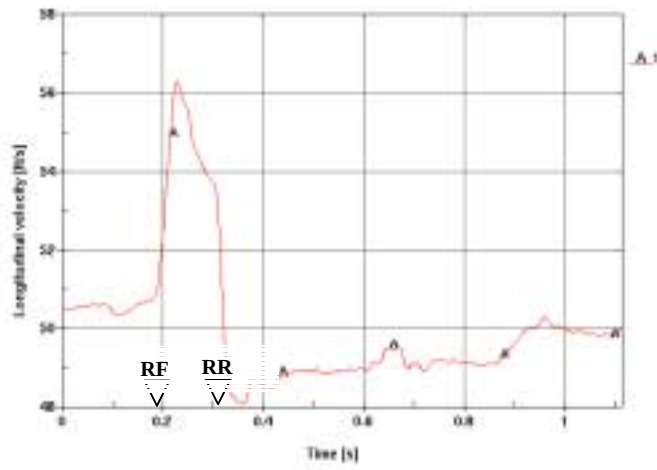


Fig. 2.1.1.2.1.1. (F): Longitudinal velocity [ft/s]

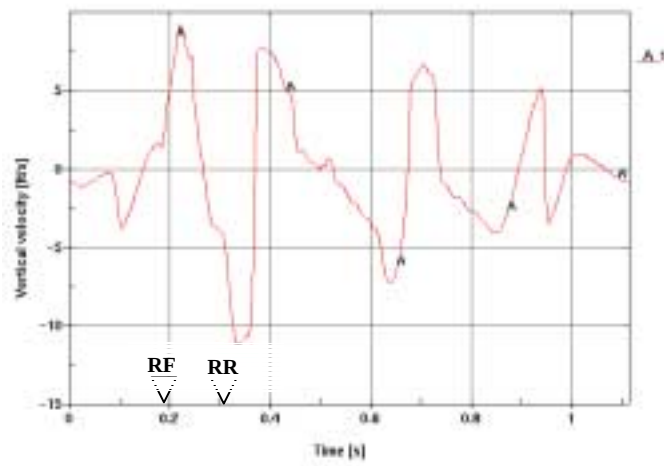


Fig. 2.1.1.2.1.1. (G) Vertical velocity [ft/s]

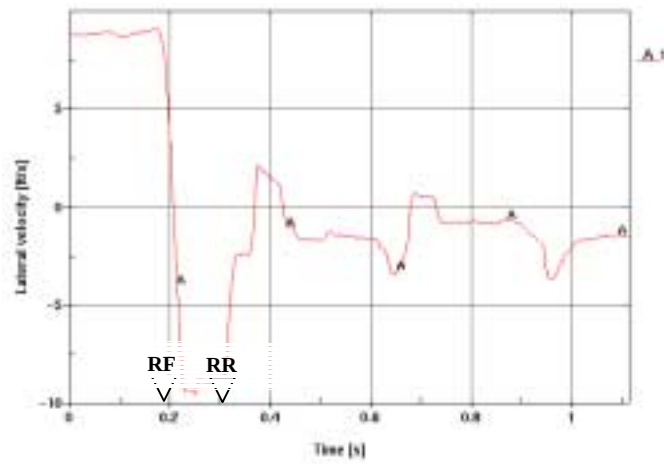


Fig. 2.1.1.2.1.1. (H): Lateral velocity [ft/s]

2.1.1.2.1.2 “E” curb

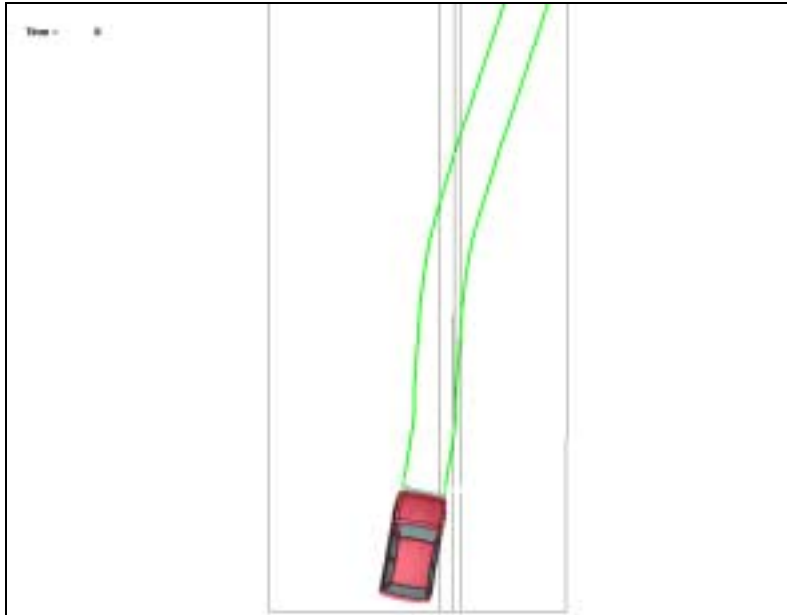


Fig. 2.1.1.2.1.2. (A) Trajectories of bumper corners (upper view)

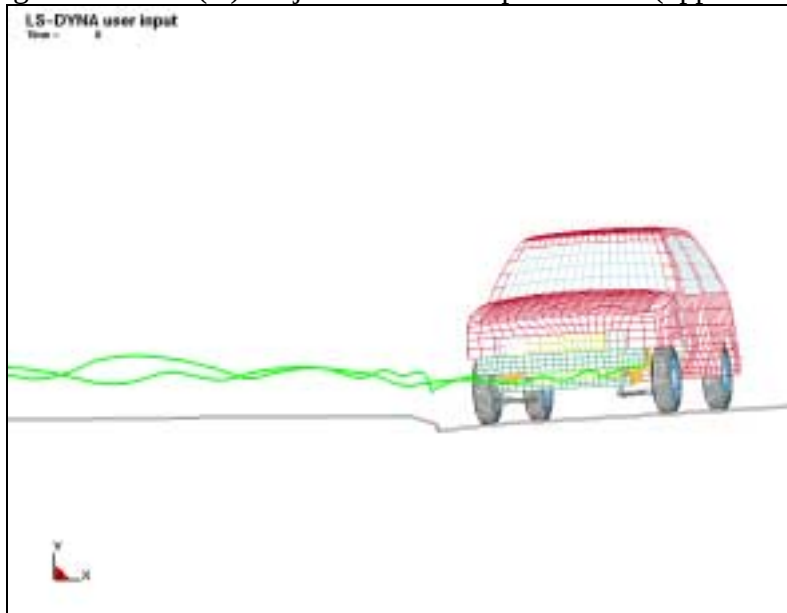


Fig. 2.1.1.2.1.2. (B) Trajectories of bumper corners (lateral view)

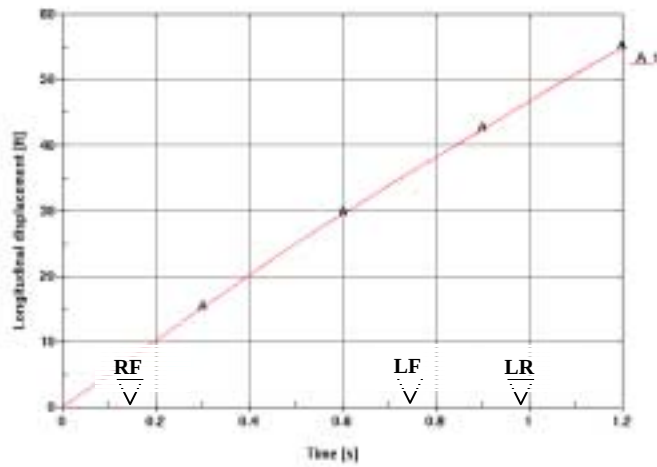


Fig. 2.1.1.2.1.2. (C): Longitudinal displacement [ft]

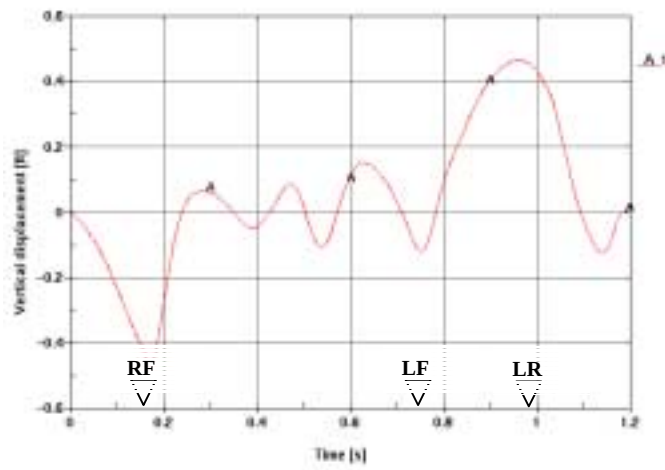


Fig. 2.1.1.2.1.2. (D): Vertical displacement [ft]

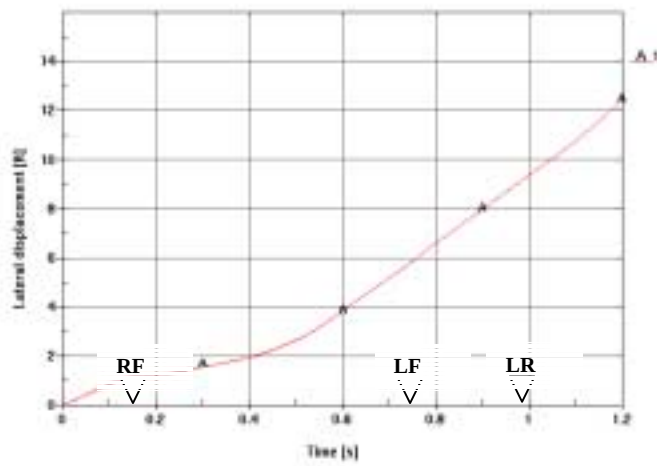


Fig. 2.1.1.2.1.2. (E): Lateral displacement [ft]

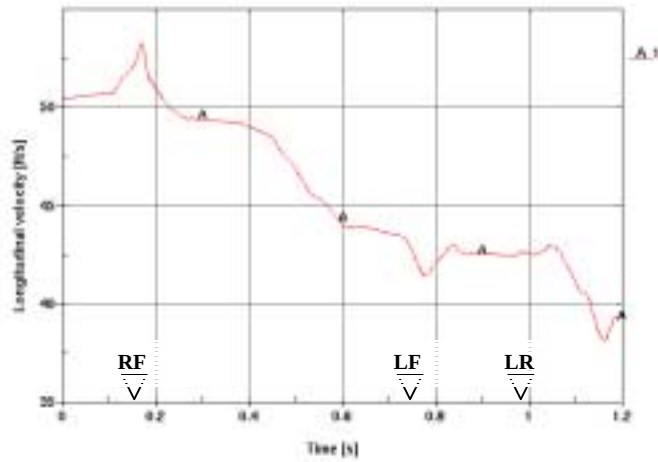


Fig. 2.1.1.2.1.2. (F): Longitudinal velocity [ft/s]

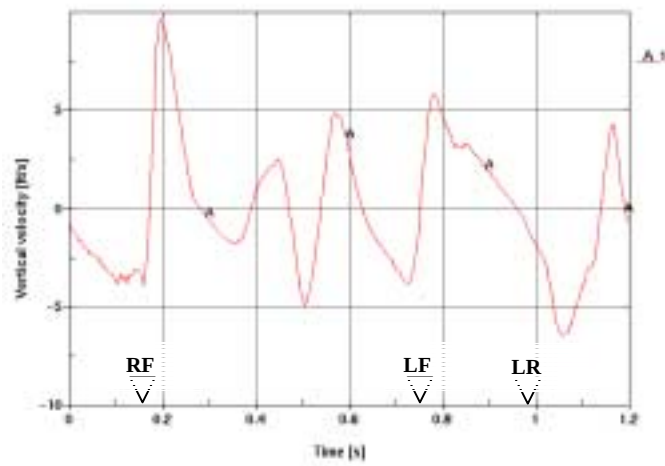


Fig. 2.1.1.2.1.2. (G) Vertical velocity [ft/s]

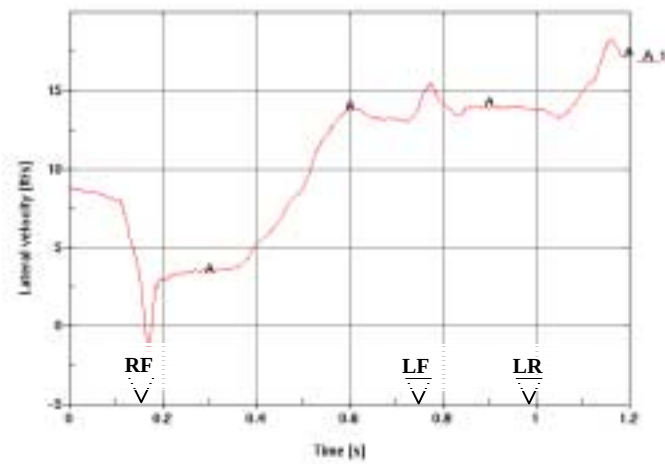


Fig. 2.1.1.2.1.2. (H): Lateral velocity [ft/s]

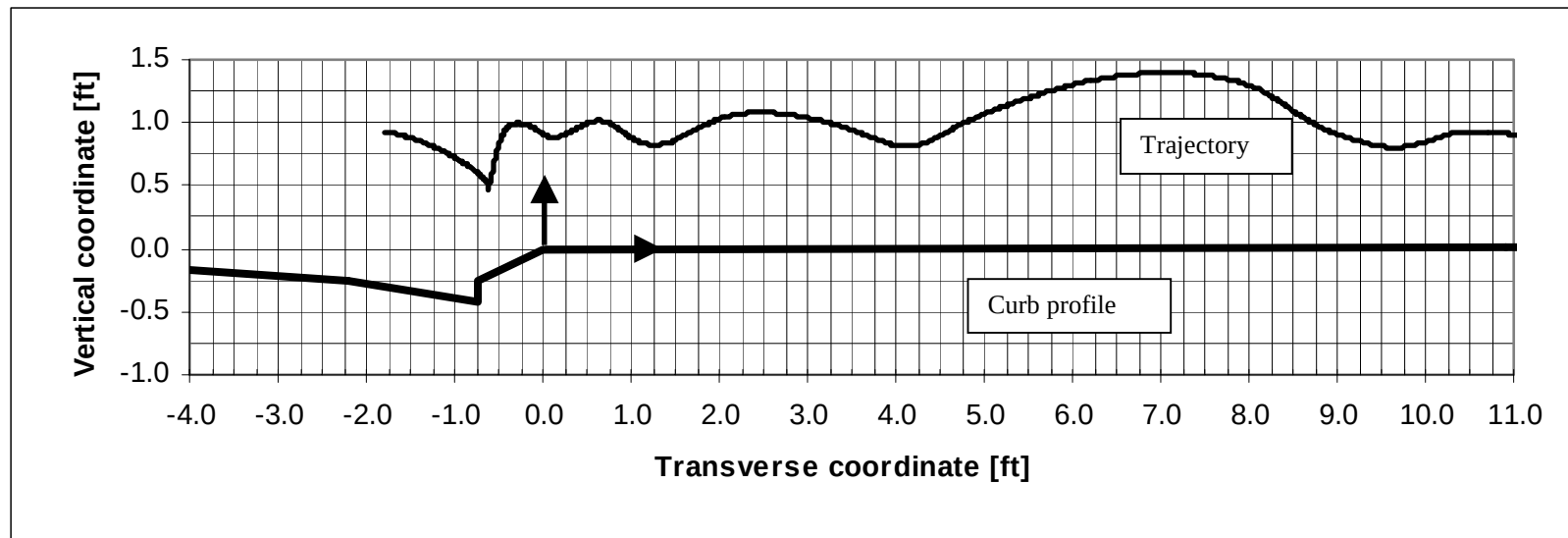


Fig. 2.1.1.2.1.2. (I): Trajectory of the bumper right corner

2.1.1.2 Approach angle 10°
2.1.1.2.2 Velocity 55 mph
2.1.1.2.2.1 “F” curb

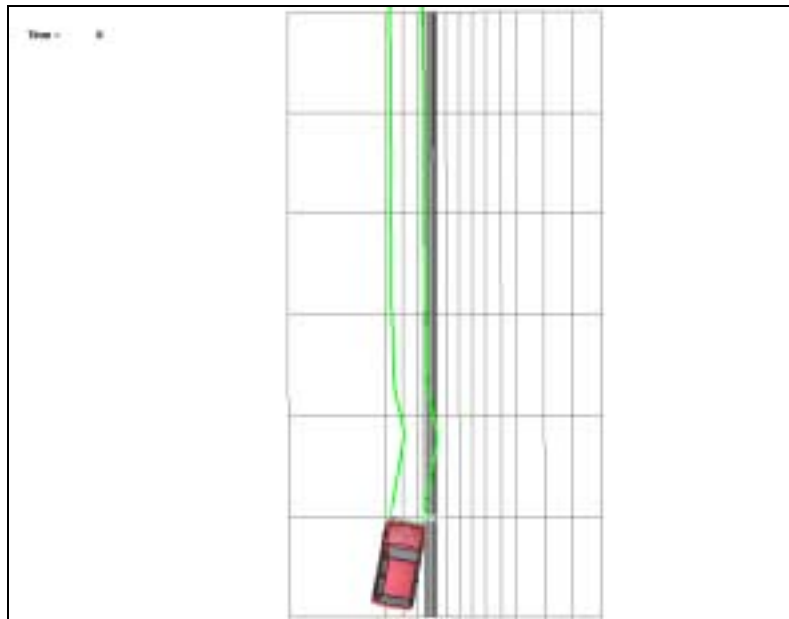


Fig. 2.1.1.2.2.1 (A) Trajectories of bumper corners (upper view)

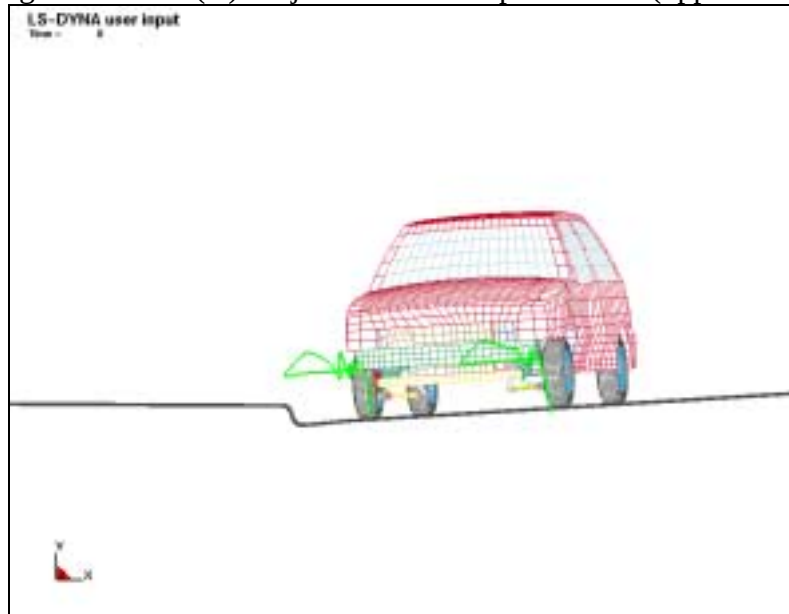


Fig. 2.1.1.2.2.1 (B) Trajectories of bumper corners (lateral view)

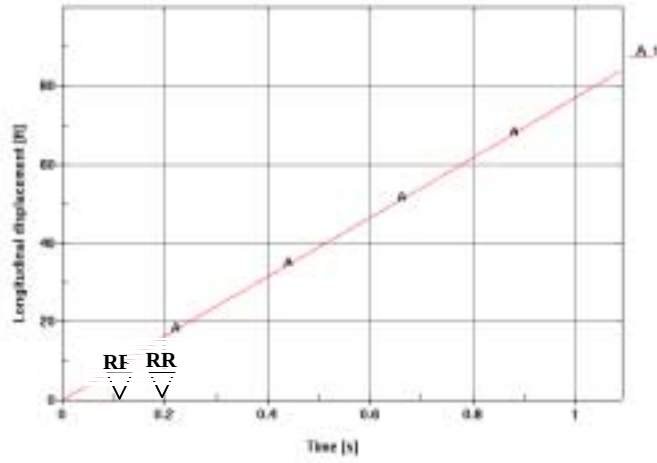


Fig. 2.1.1.2.2.1 (C): Longitudinal displacement [ft]

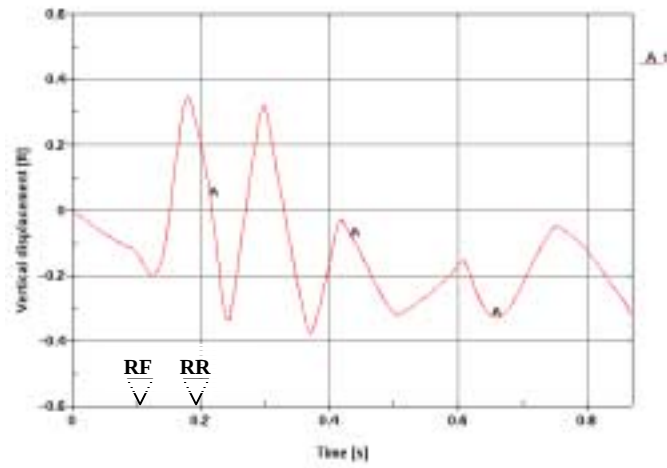


Fig. 2.1.1.2.2.1 (D): Vertical displacement [ft]

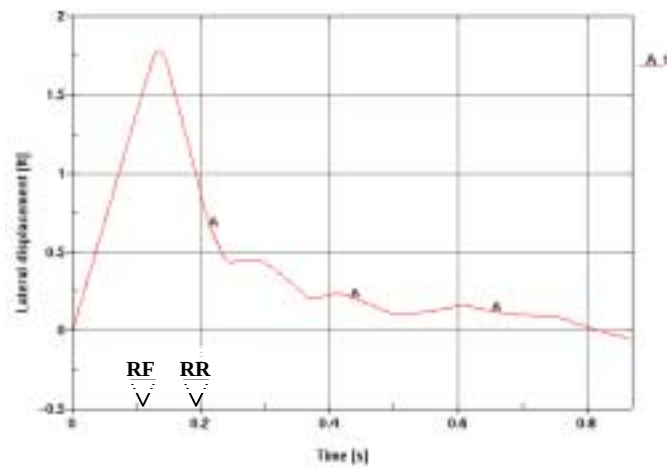


Fig. 2.1.1.2.2.1 (E): Lateral displacement [ft]

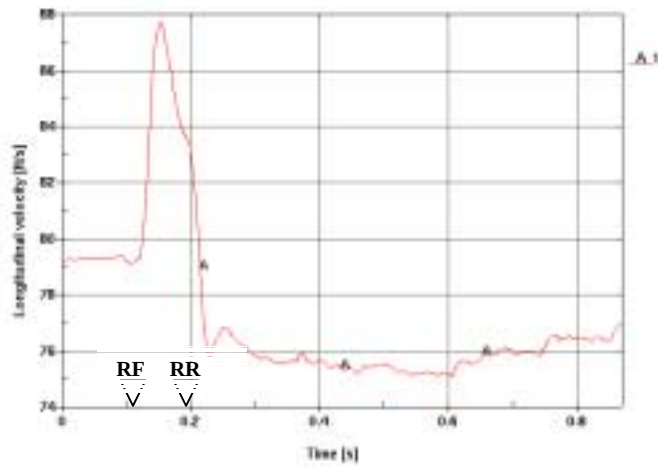


Fig. 2.1.1.2.2.1 (F): Longitudinal velocity [ft/s]

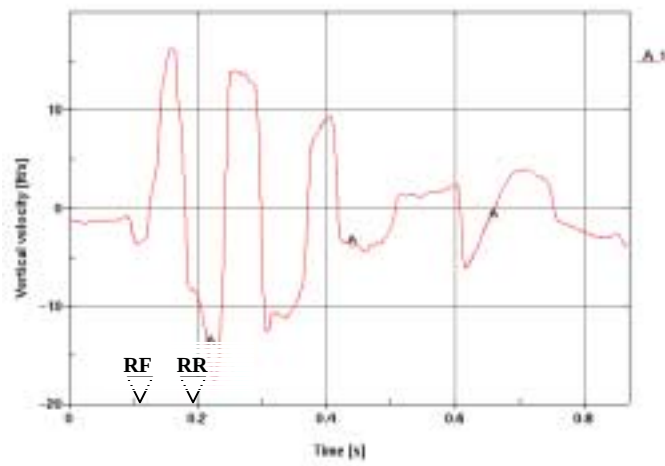


Fig2.1.1.2.2.1 (G) Vertical velocity [ft/s]

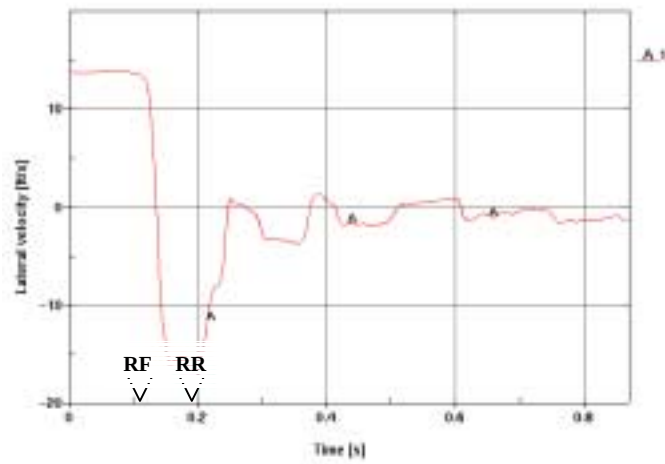


Fig. 2.1.1.2.2.1 (H): Lateral velocity [ft/s]

2.1.1.2.2.2 “E” curb

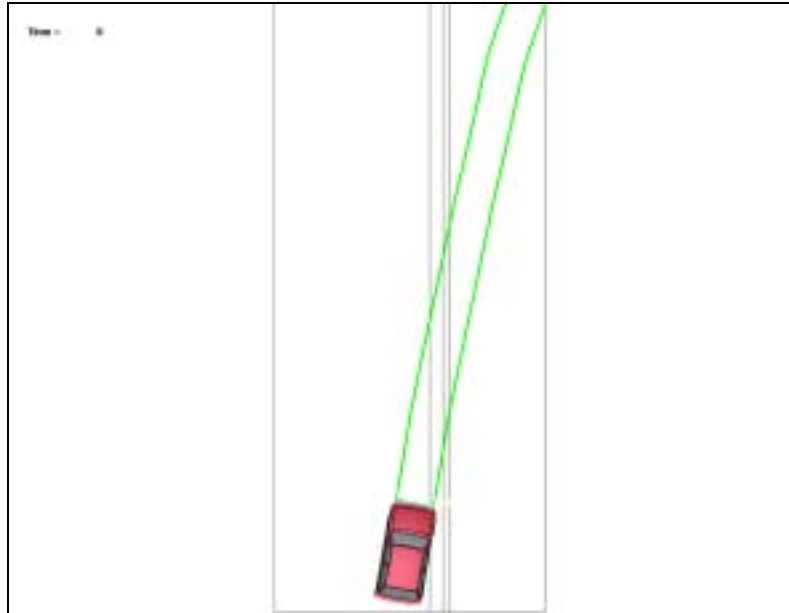


Fig. 2.1.1.2.2.2 (A) Trajectories of bumper corners (upper view)

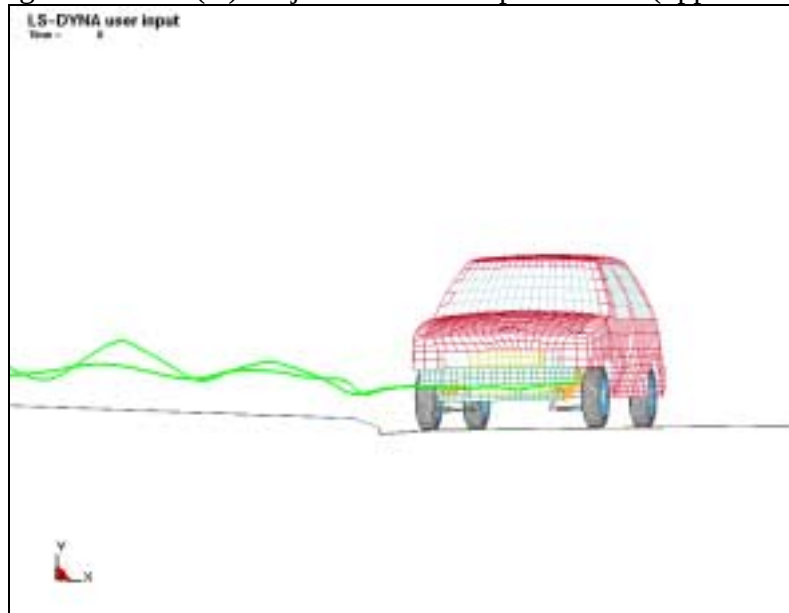


Fig. 2.1.1.2.2.2 (B) Trajectories of bumper corners (lateral view)

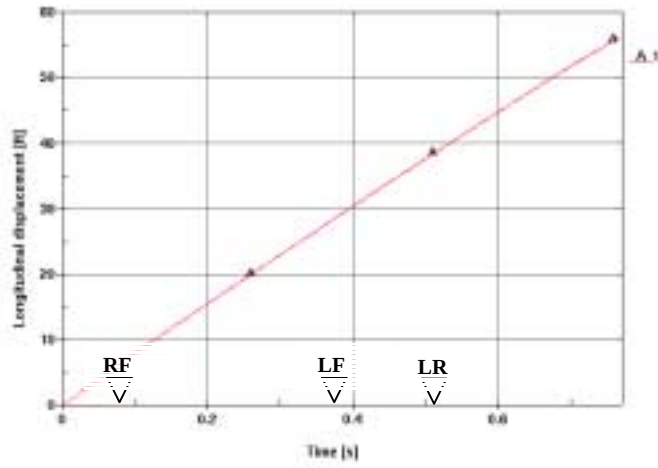


Fig. 2.1.1.2.2.2 (C): Longitudinal displacement [ft]

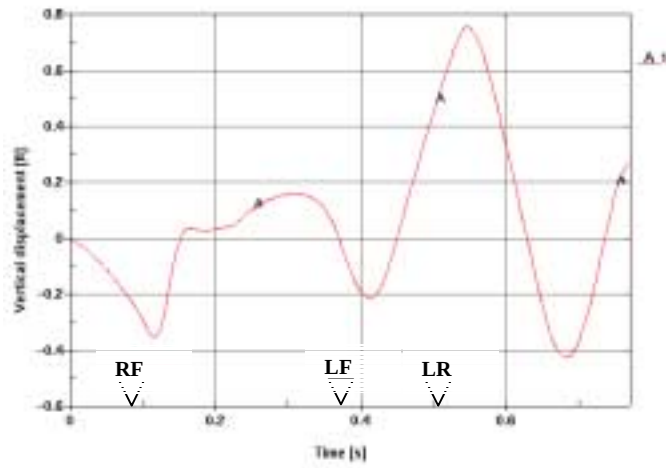


Fig. 2.1.1.2.2.2 (D): Vertical displacement [ft]

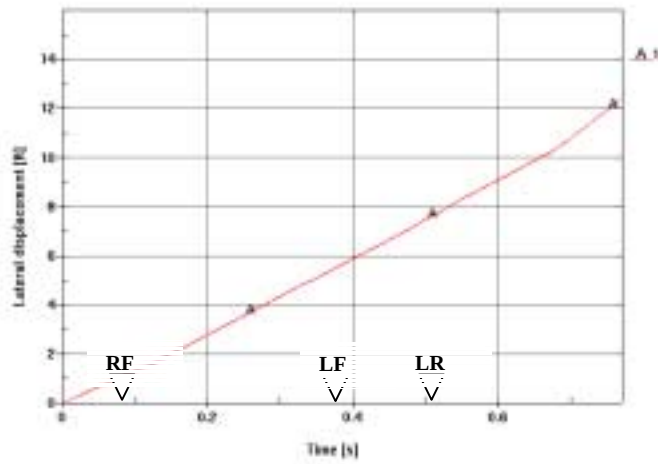


Fig. 2.1.1.2.2.2 (E): Lateral displacement [ft]

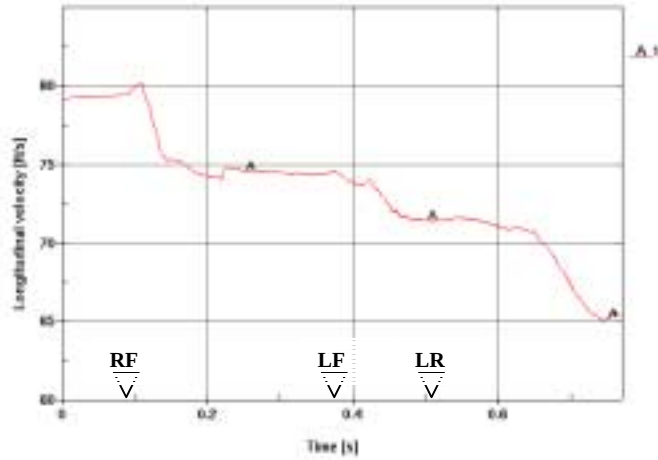


Fig. 2.1.1.2.2.2 (F): Longitudinal velocity [ft/s]

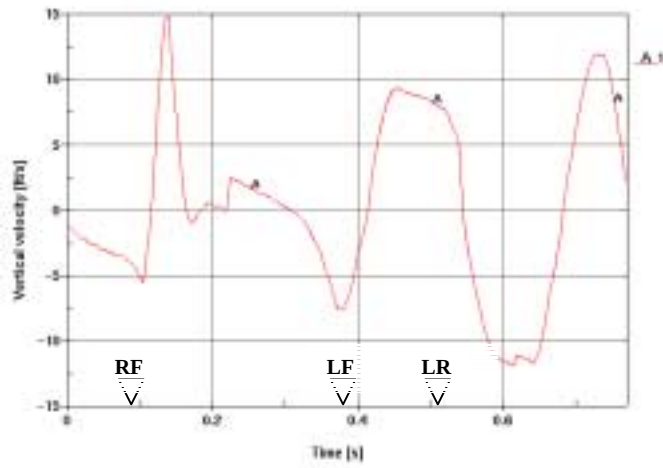


Fig2.1.1.2.2.2 (G) Vertical velocity [ft/s]

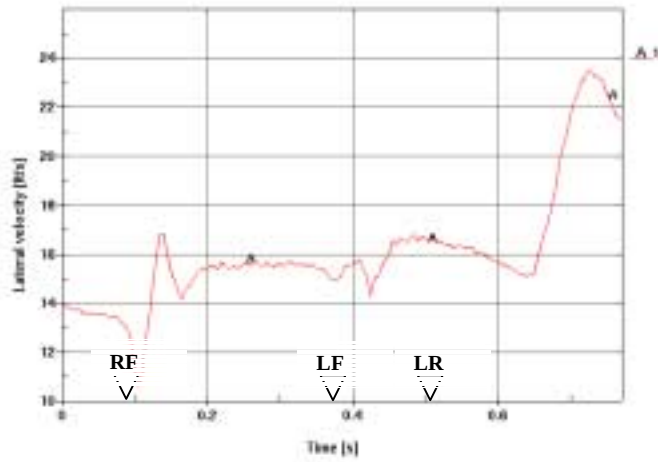


Fig. 2.1.1.2.2.2 (H): Lateral velocity [ft/s]

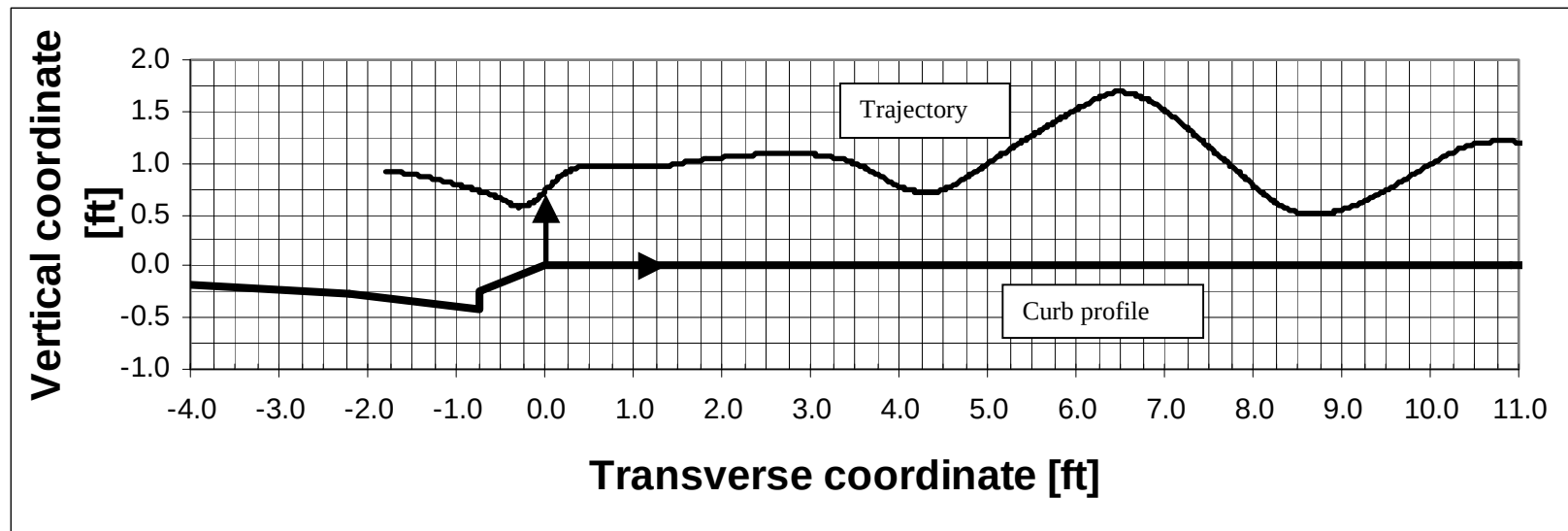


Fig. 2.1.1.2.2.2 (I): Trajectory of the bumper right corner

2.1.1.3 Approach angle 12°

2.1.1.3.1 Velocity 35 mph

2.1.1.3.1.1 “F” curb

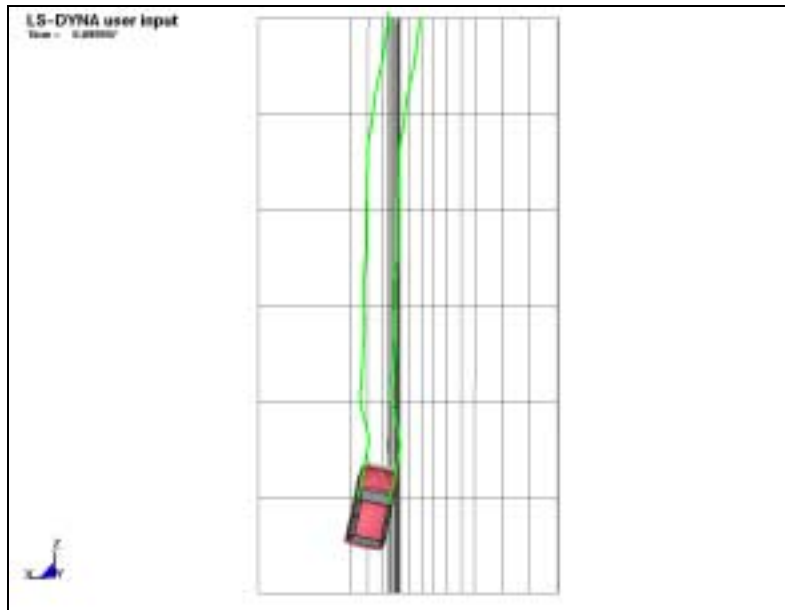


Fig. 2.1.1.3.1.1 (A) Trajectories of bumper corners (upper view)

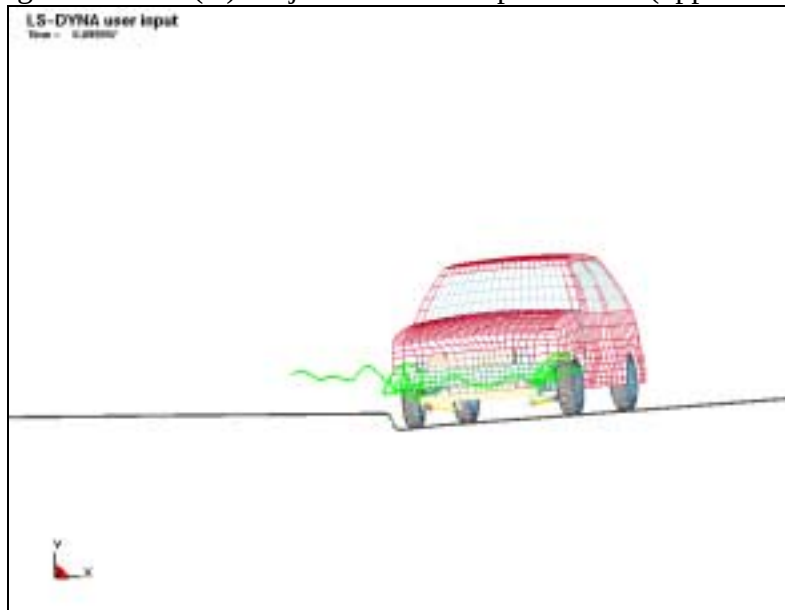


Fig. 2.1.1.3.1.1 (B) Trajectories of bumper corners (lateral view)

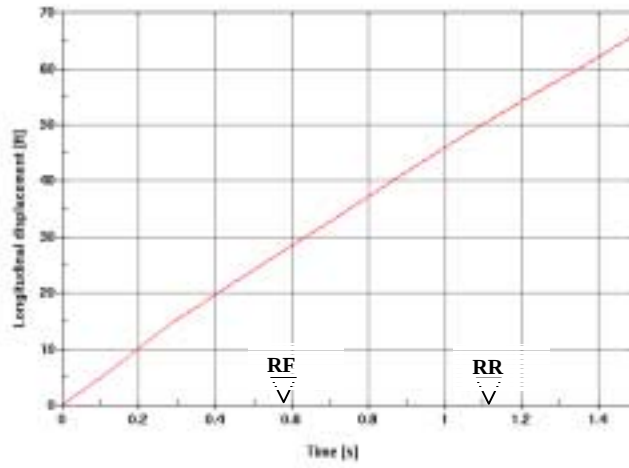


Fig. 2.1.1.3.1.1. (C): Longitudinal displacement [ft]

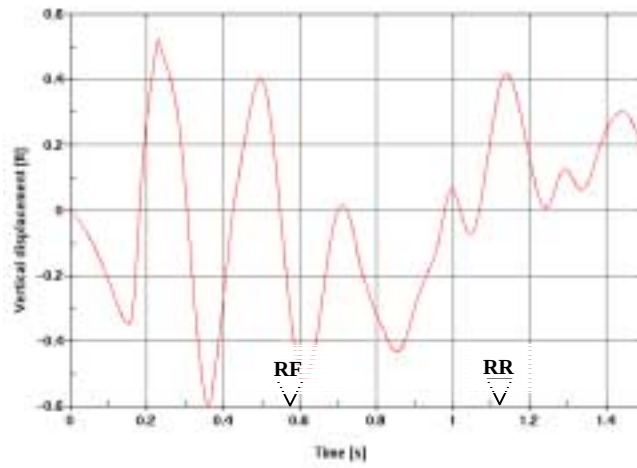


Fig. 2.1.1.3.1.1. (D): Vertical displacement [ft]

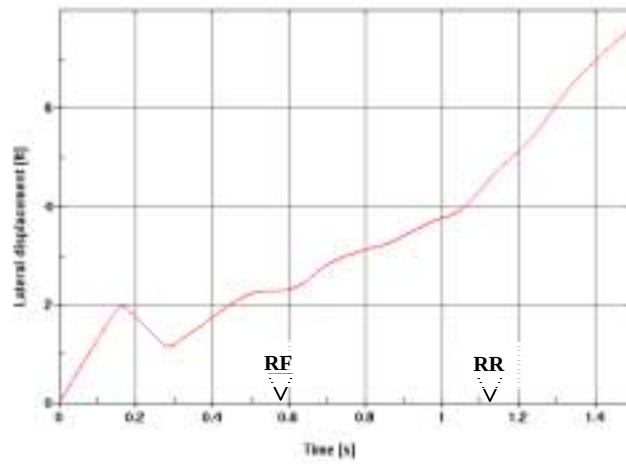


Fig. 2.1.1.3.1.1. (E): Lateral displacement [ft]

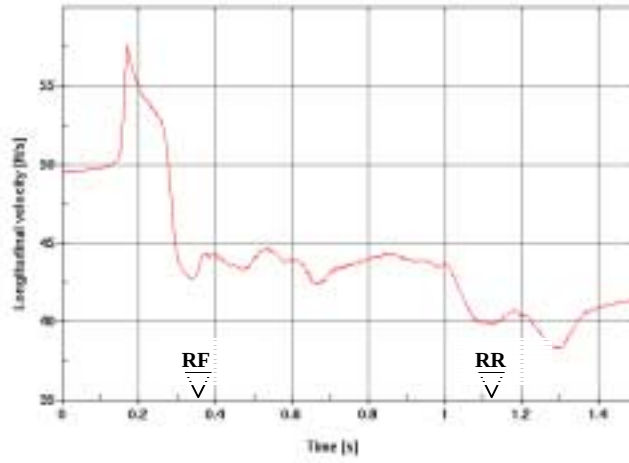


Fig. 2.1.1.3.1.1. (F): Longitudinal velocity [ft/s]

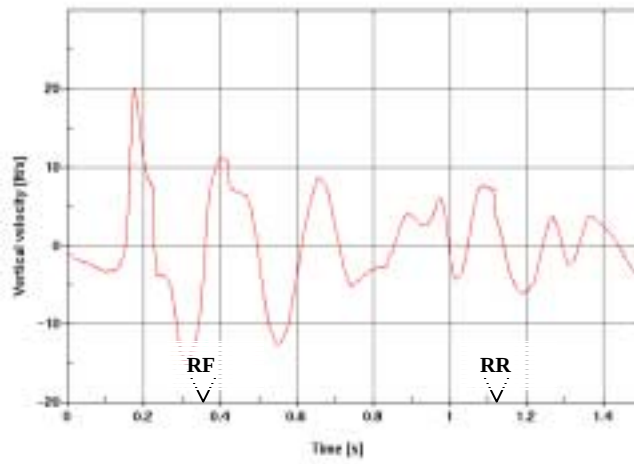


Fig. 2.1.1.3.1.1. (G) Vertical velocity [ft/s]

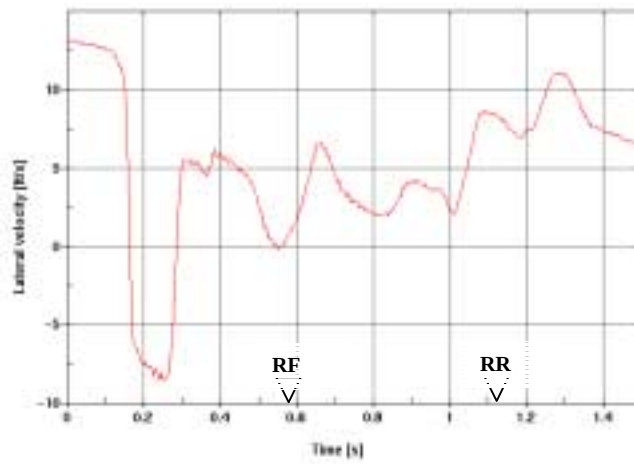


Fig. 2.1.1.3.1.1. (H): Lateral velocity [ft/s]

2.1.1.3.2 Velocity 55 mph

2.1.1.3.2.1 “F” curb

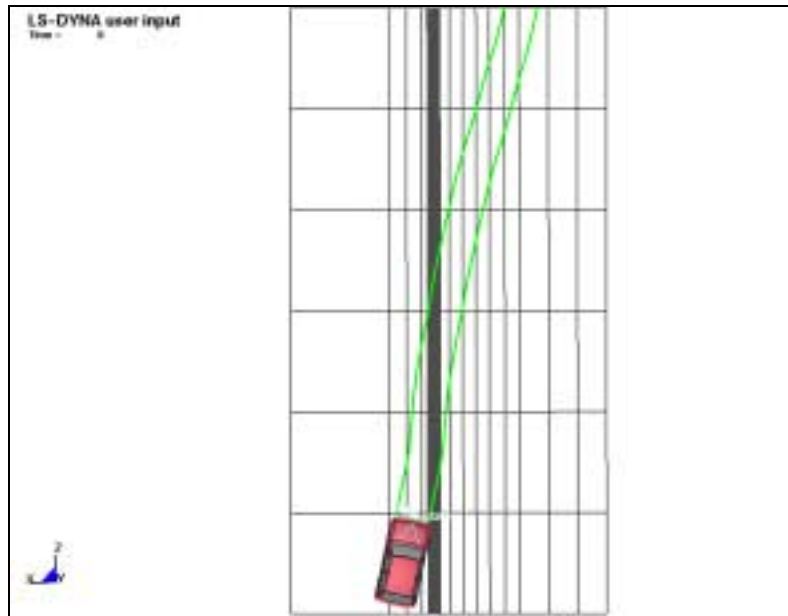


Fig. 2.1.1.3.2.1 (A) Trajectories of bumper corners (upper view)

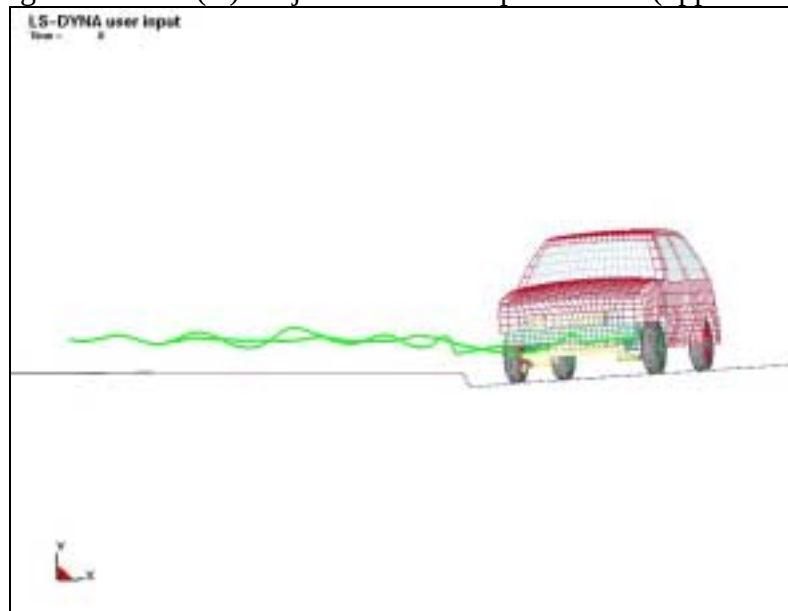


Fig. 2.1.1.3.2.1 (B) Trajectories of bumper corners (lateral view)

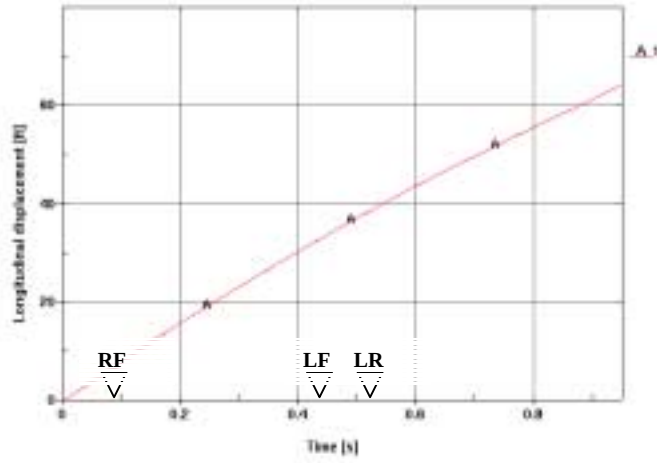


Fig. 2.1.1.3.2.1. (C): Longitudinal displacement [ft]

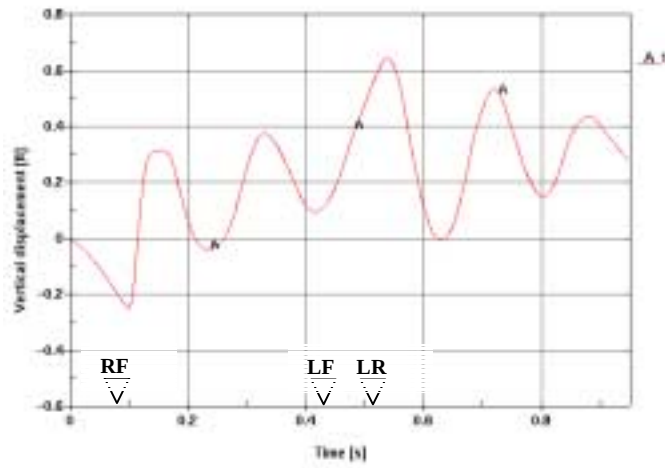


Fig. 2.1.1.3.2.1. (D): Vertical displacement [ft]

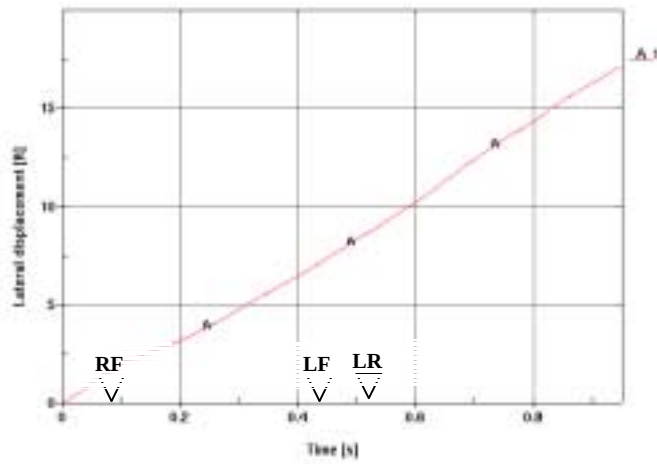


Fig. 2.1.1.3.2.1. (E): Lateral displacement [ft]

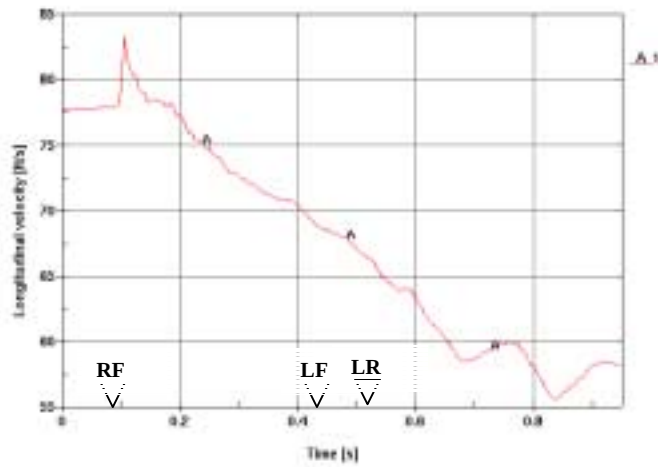


Fig. 2.1.1.3.2.1. (F): Longitudinal velocity [ft/s]

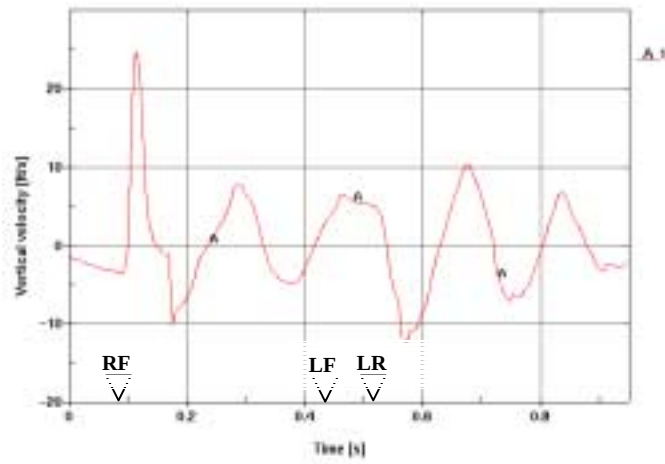


Fig. 2.1.1.3.2.1. (G) Vertical velocity [ft/s]

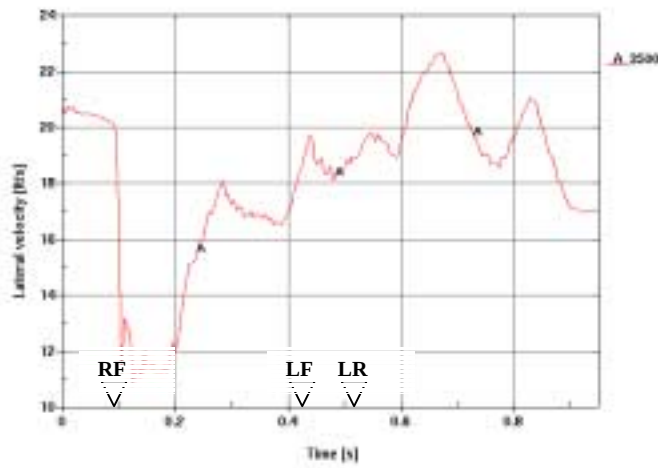


Fig. 2.1.1.3.2.1. (H): Lateral velocity [ft/s]

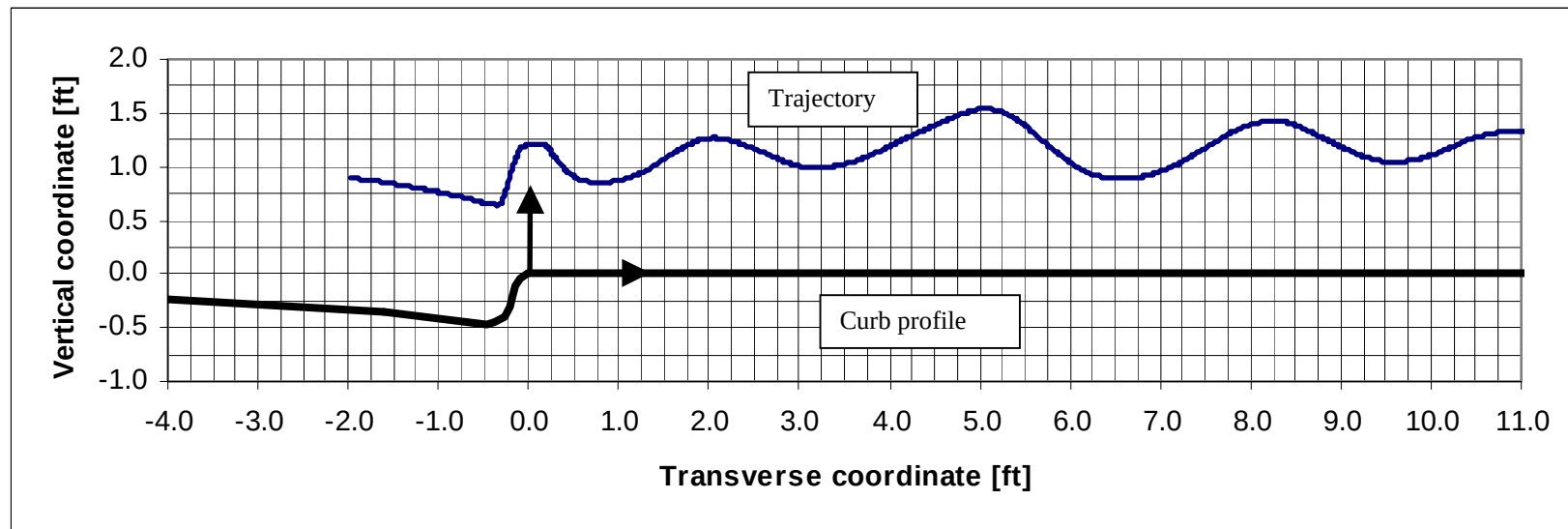


Fig. 2.1.1.3.2.1. (I): Trajectory of the bumper right corner

2.1.1.4 Approach angle 15°

2.1.1.4.1 Velocity 35 mph

2.1.1.4.1.1 “F” curb

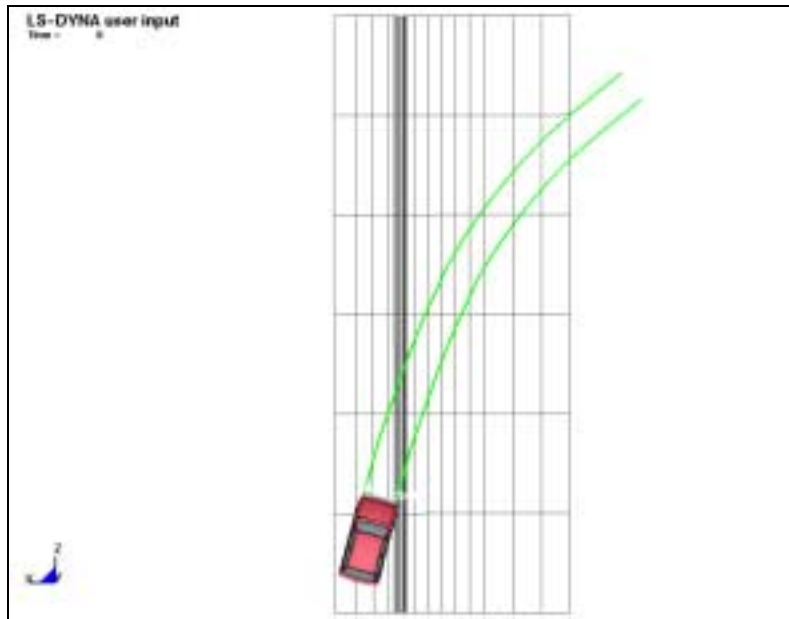


Fig. 2.1.1.4.1.1 (A) Trajectories of bumper corners (upper view)

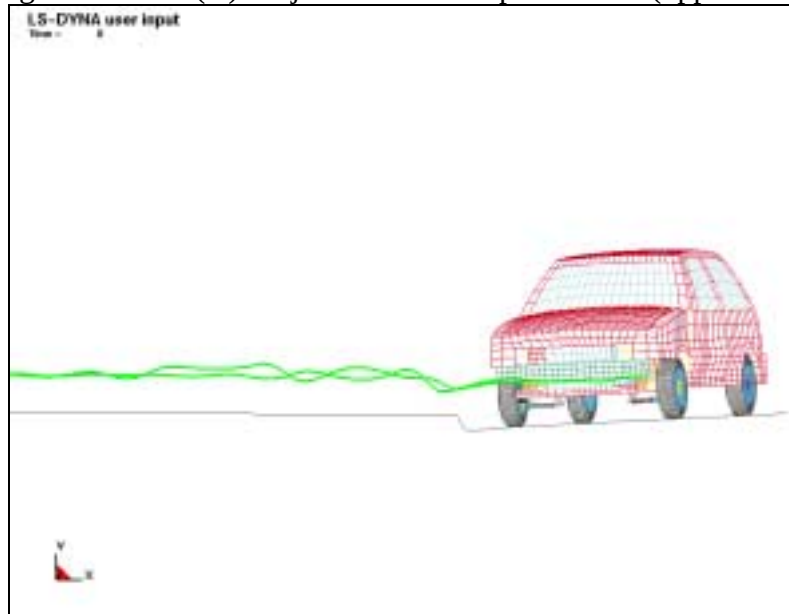


Fig. 2.1.1.4.1.1 (B) Trajectories of bumper corners (lateral view)

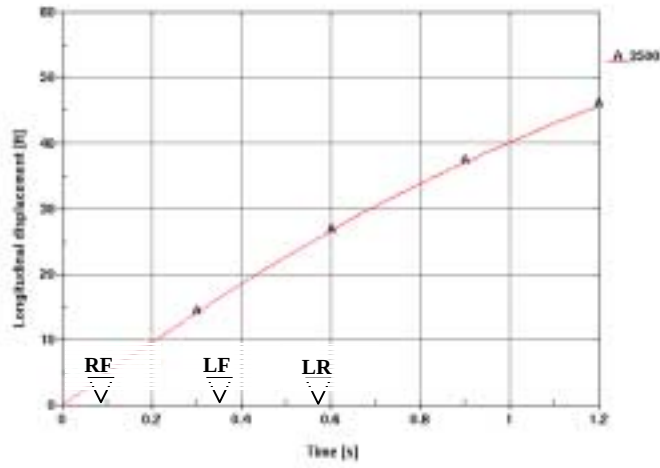


Fig. 2.1.1.4.1.1. (C): Longitudinal displacement [ft]

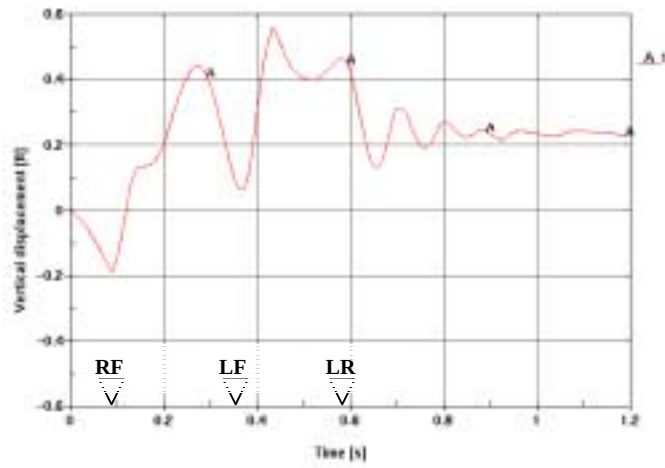


Fig. 2.1.1.4.1.1. (D): Vertical displacement [ft]

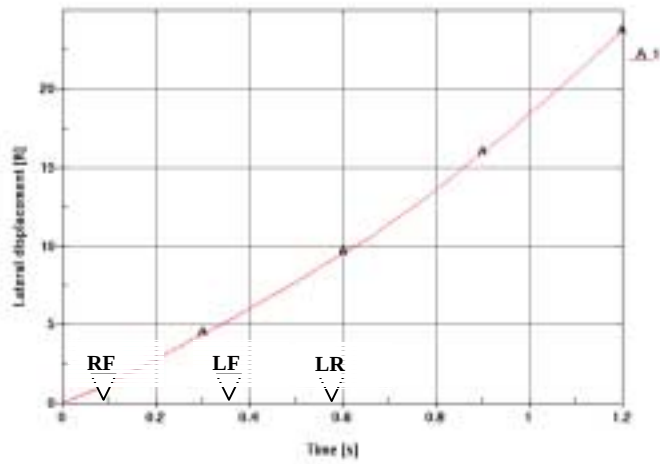


Fig. 2.1.1.4.1.1. (E): Lateral displacement [ft]

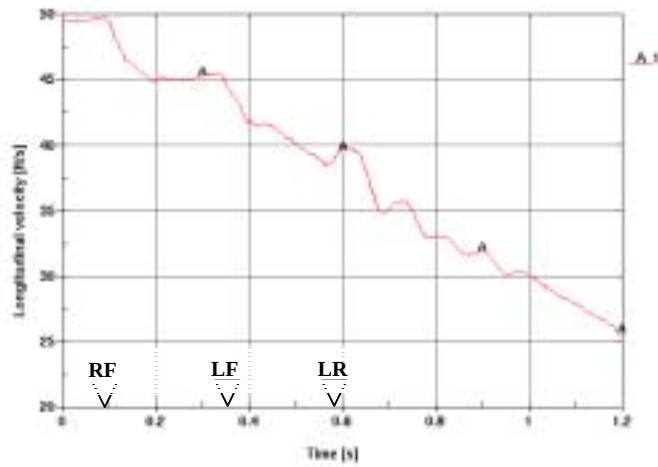


Fig. 2.1.1.4.1.1. (F): Longitudinal velocity [ft/s]

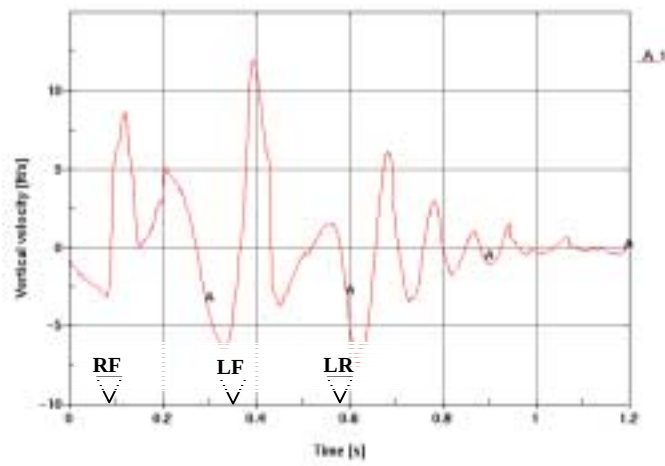


Fig. 2.1.1.4.1.1. (G) Vertical velocity [ft/s]

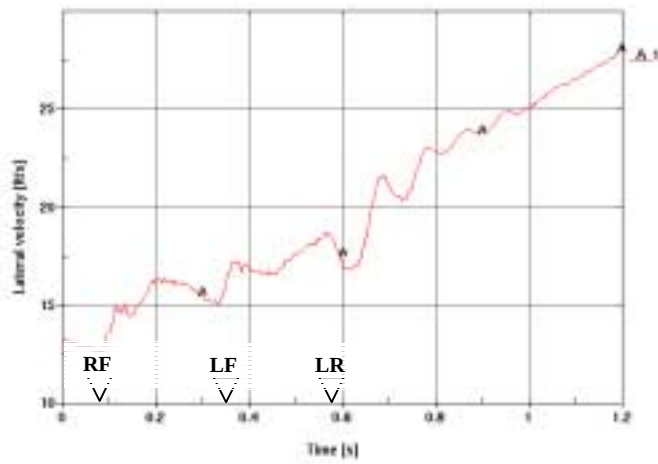


Fig. 2.1.1.4.1.1. (H): Lateral velocity [ft/s]

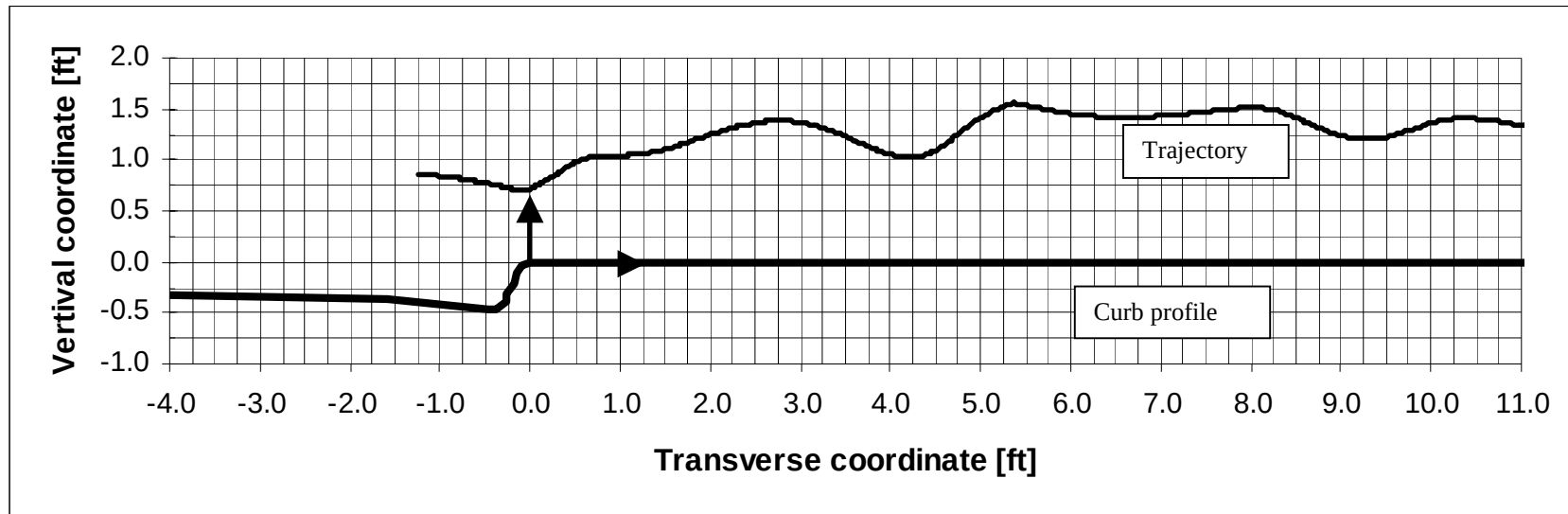


Fig. 2.1.1.4.1.1. (I): Trajectory of the bumper right corner

2.1.1.4.1.2 “E” curb

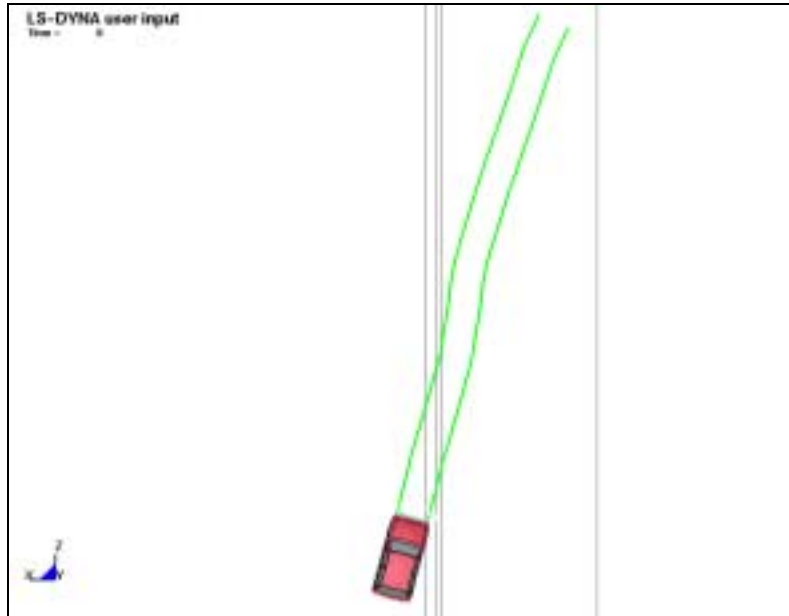


Fig. 2.1.1.4.1.2 (A) Trajectories of bumper corners (upper view)

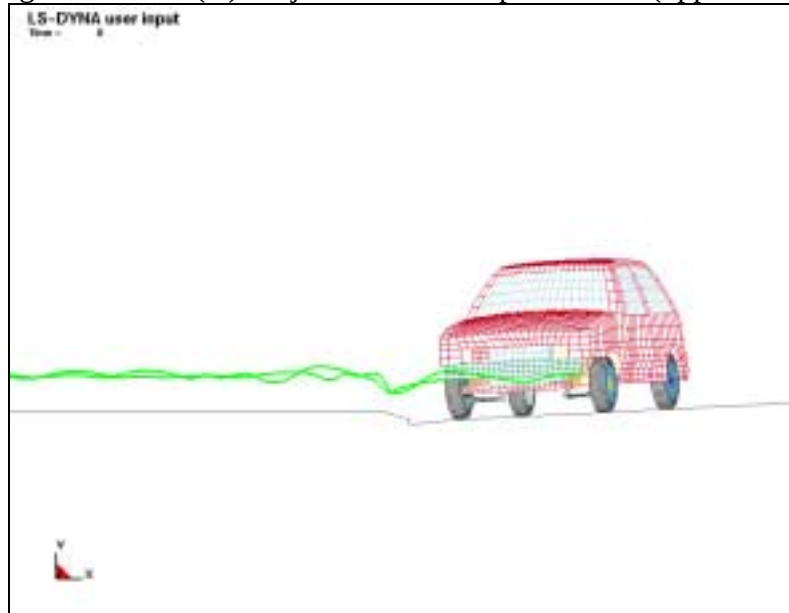


Fig. 2.1.1.4.1.2 (B) Trajectories of bumper corners (lateral view)

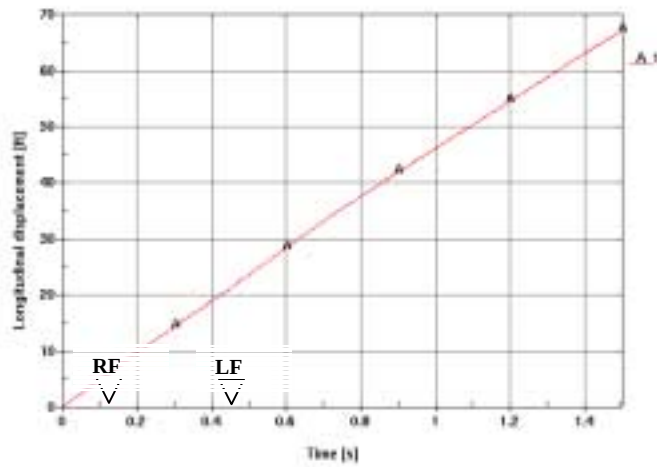


Fig. 2.1.1.4.1.2 (C): Longitudinal displacement [ft]

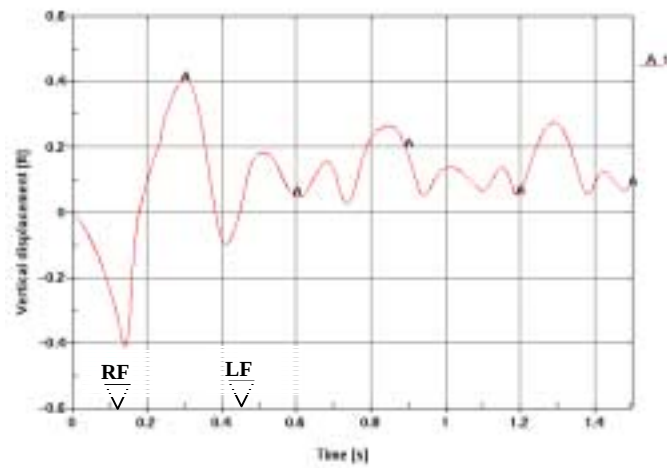


Fig. 2.1.1.4.1.2 (D): Vertical displacement [ft]

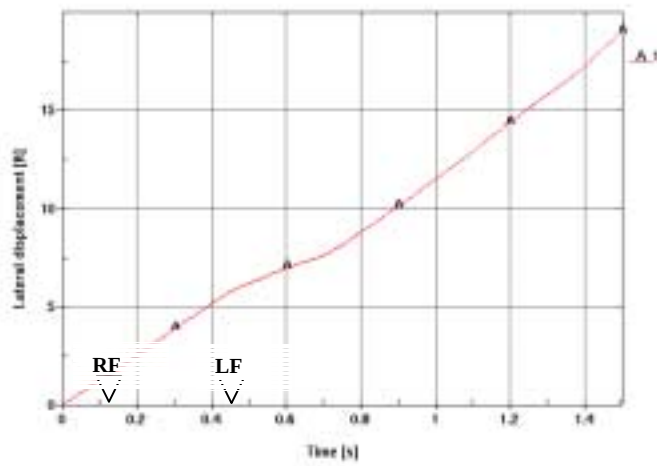


Fig. 2.1.1.4.1.2 (E): Lateral displacement [ft]

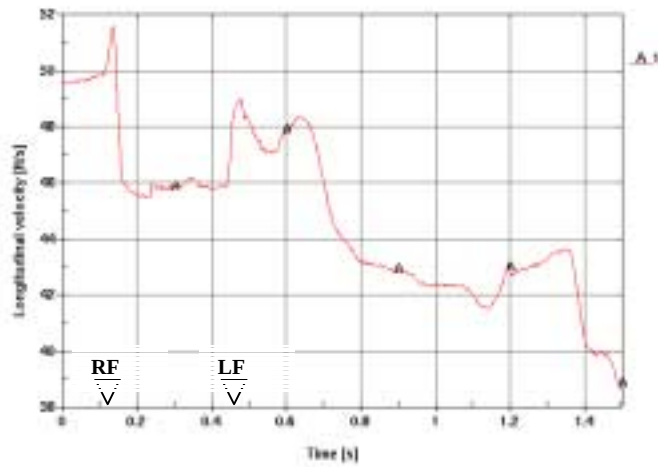


Fig. 2.1.1.4.1.2 (F): Longitudinal velocity [ft/s]

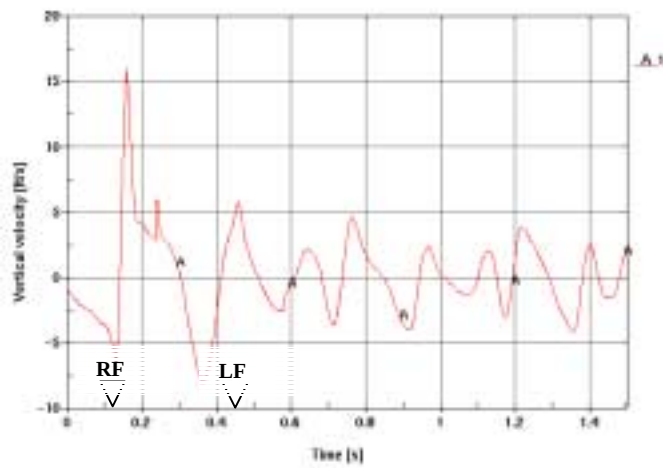


Fig. 2.1.1.4.1.2 (G) Vertical velocity [ft/s]

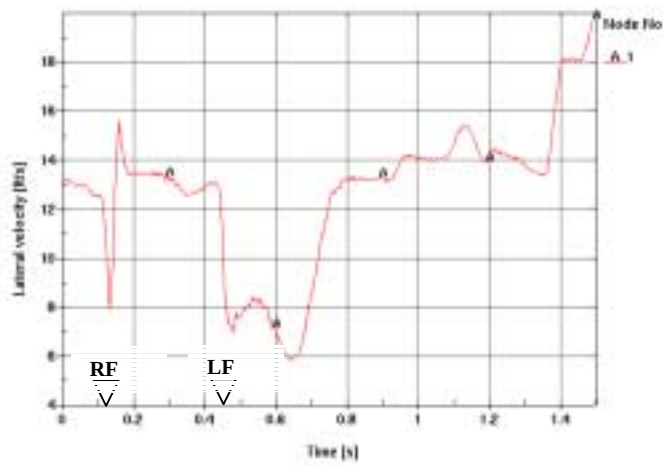


Fig. 2.1.1.4.1.2 (H): Lateral velocity [ft/s]

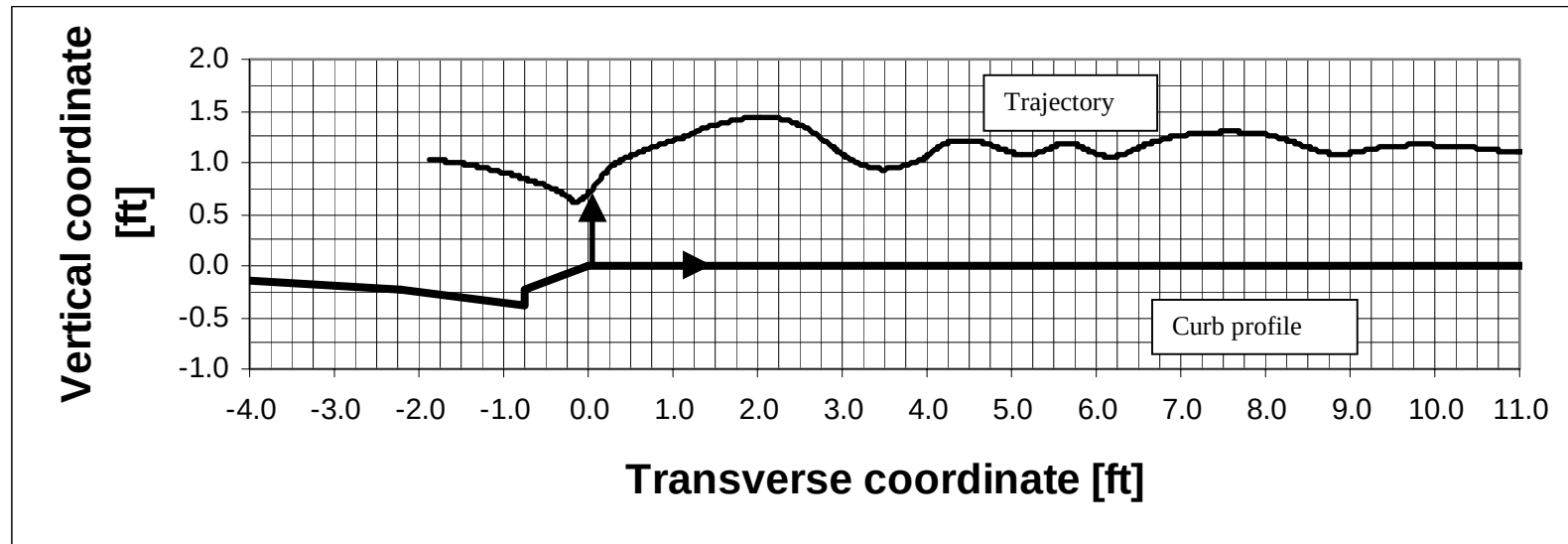


Fig. 2.1.1.4.1.1. (I): Trajectory of the bumper right corner

2.1.1.4.2 Velocity 55 mph

2.1.1.4.2.1 “F” curb

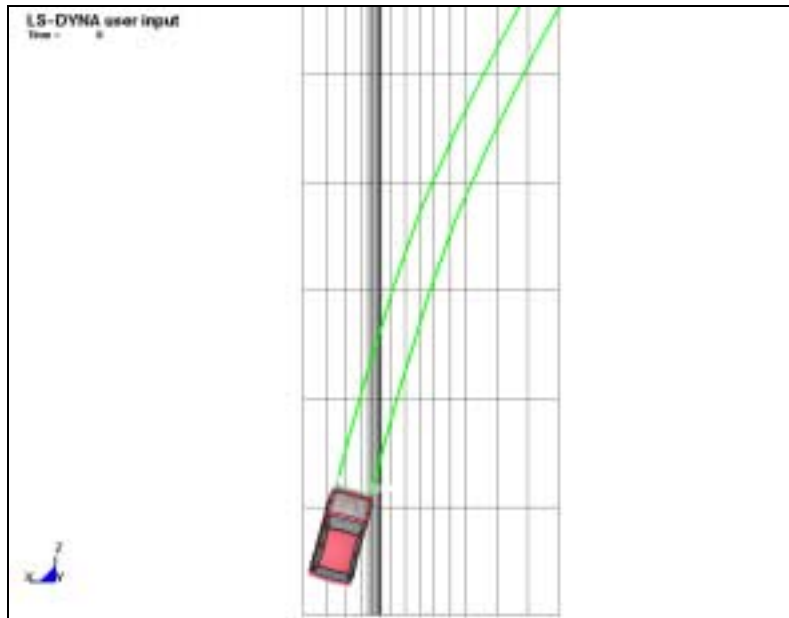


Fig. 2.1.1.4.2.1 (A) Trajectories of bumper corners (upper view)

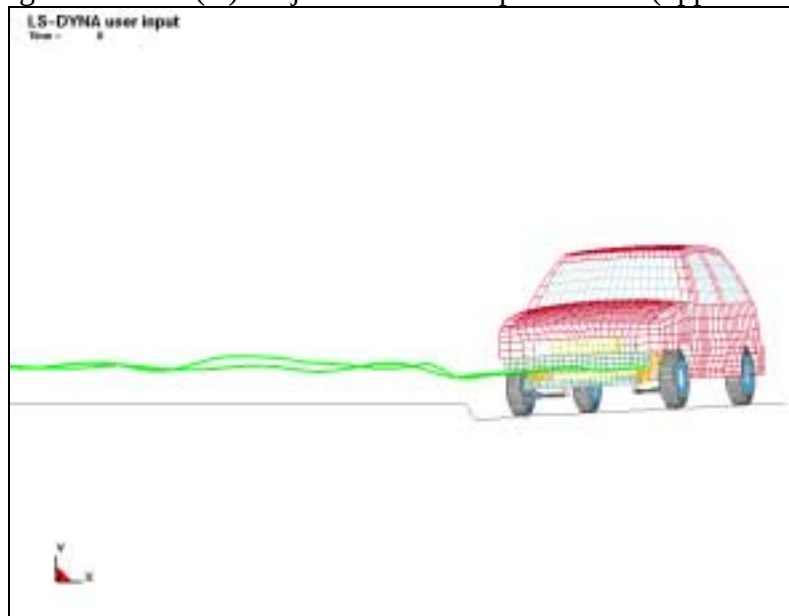


Fig. 2.1.1.4.2.1 (B) Trajectories of bumper corners (lateral view)

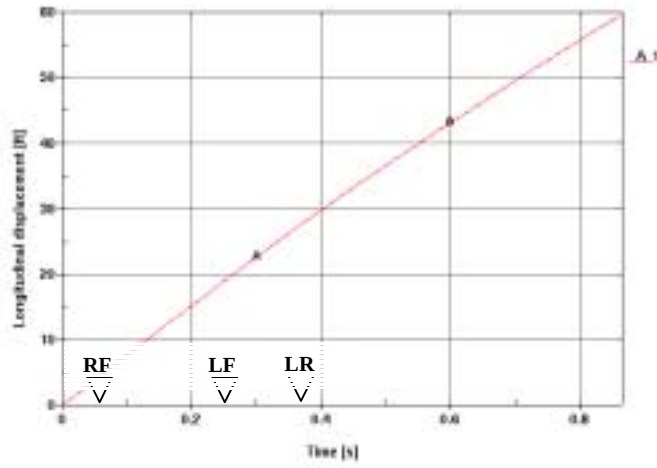


Fig. 2.1.1.4.2.1. (C): Longitudinal displacement [ft]

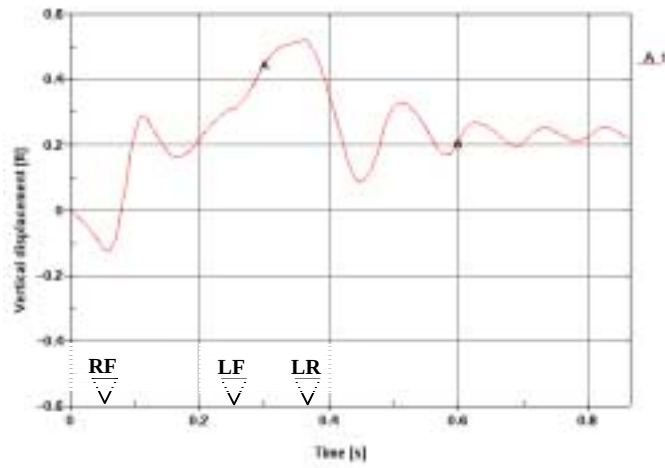


Fig. 2.1.1.4.2.1. (D): Vertical displacement [ft]

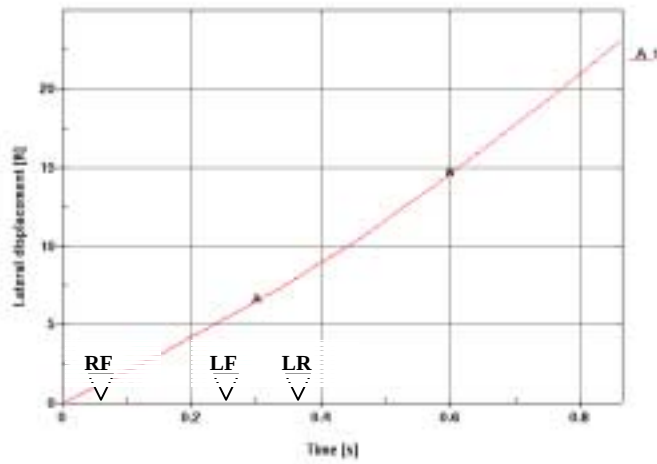


Fig. 2.1.1.4.2.1. (E): Lateral displacement [ft]

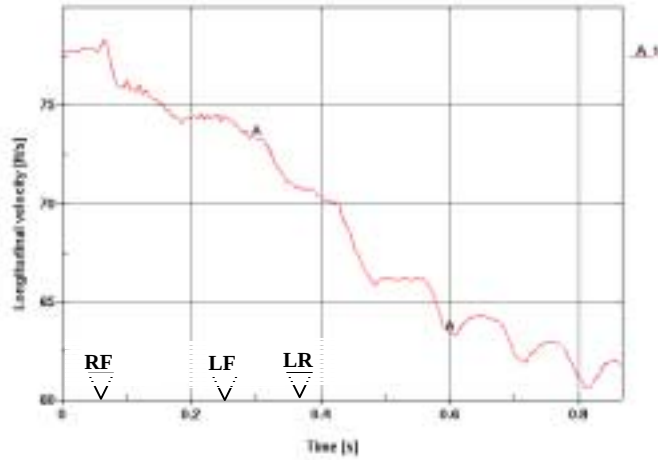


Fig. 2.1.1.4.2.1. (F): Longitudinal velocity [ft/s]

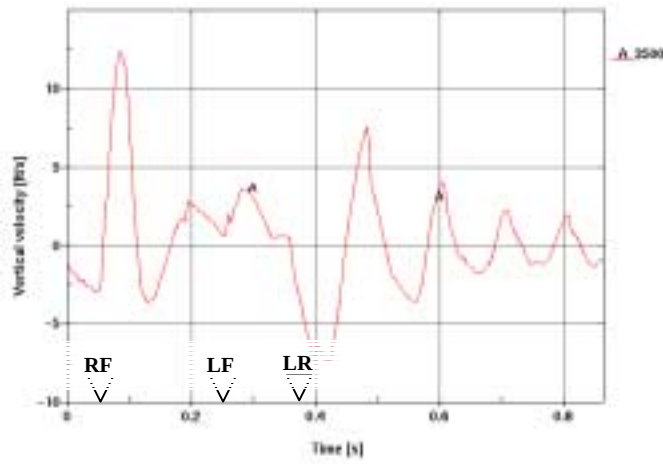


Fig. 2.1.1.4.2.1. (G) Vertical velocity [ft/s]

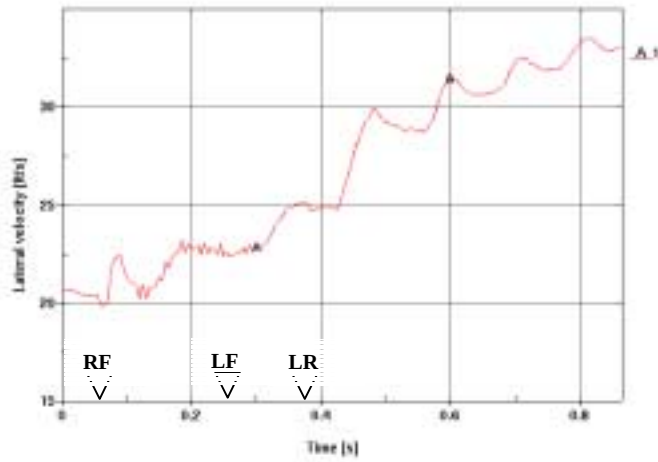


Fig. 2.1.1.4.2.1. (H): Lateral velocity [ft/s]

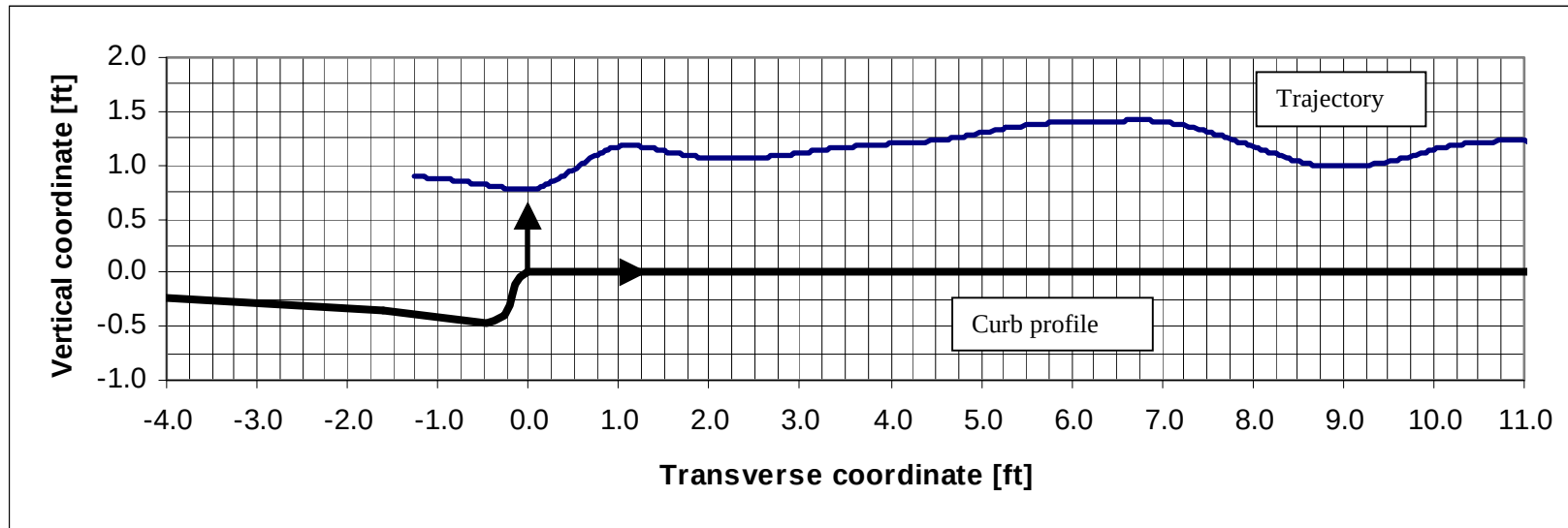


Fig. 2.1.1.4.2.1. (I): Trajectory of the bumper right corner

2.1.1.4.2.2 “E” curb

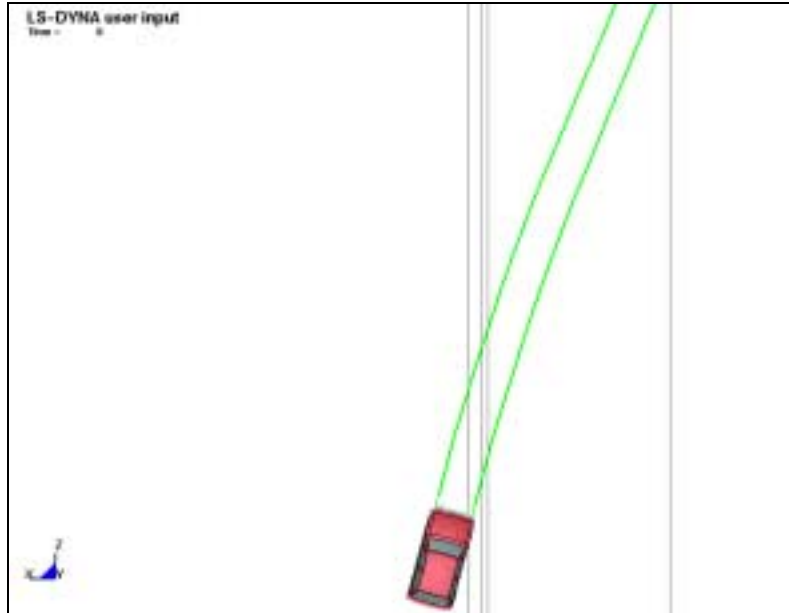


Fig. 2.1.1.4.2.2 (A) Trajectories of bumper corners (upper view)

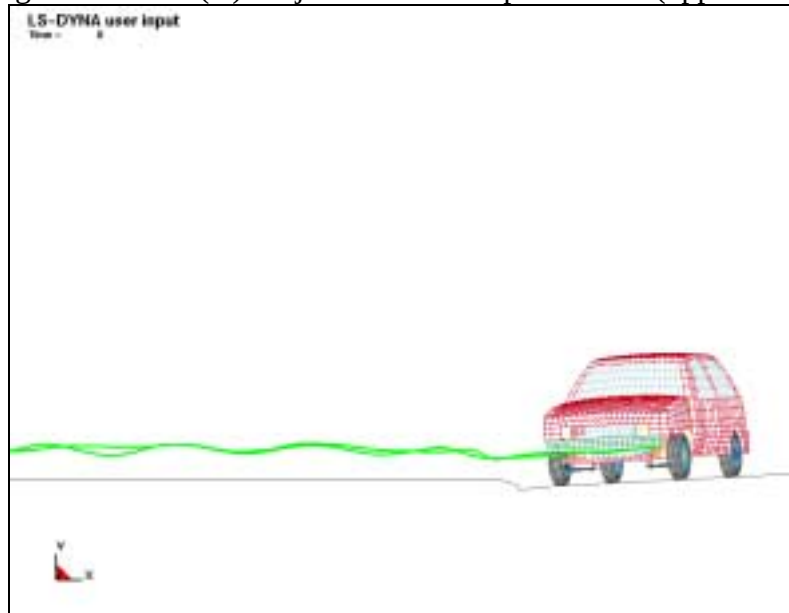


Fig. 2.1.1.4.2.2 (B) Trajectories of bumper corners (lateral view)

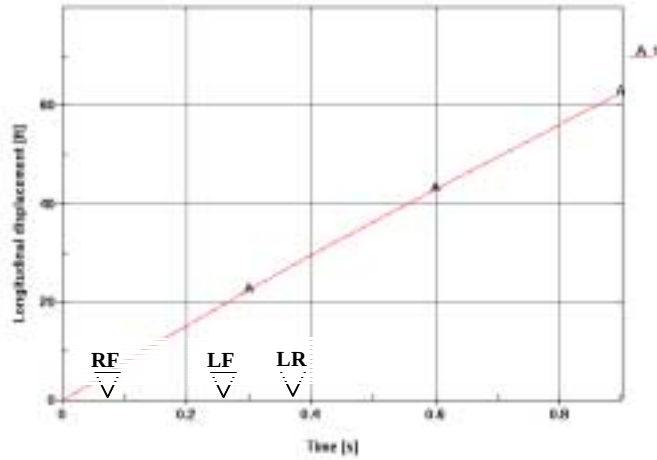


Fig. 2.1.1.4.2.2 (C): Longitudinal displacement [ft]

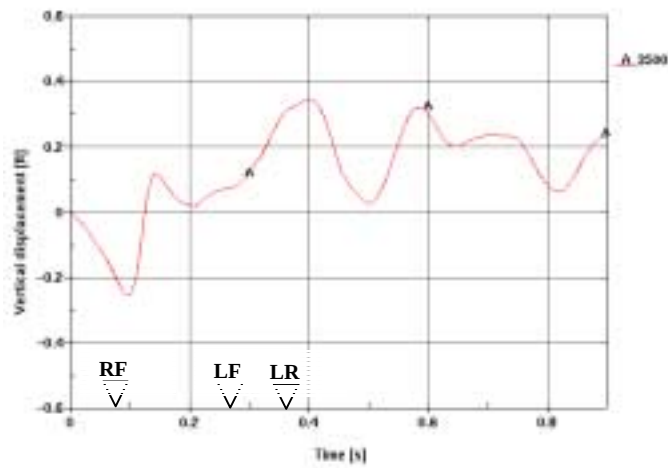


Fig. 2.1.1.4.2.2 (D): Vertical displacement [ft]

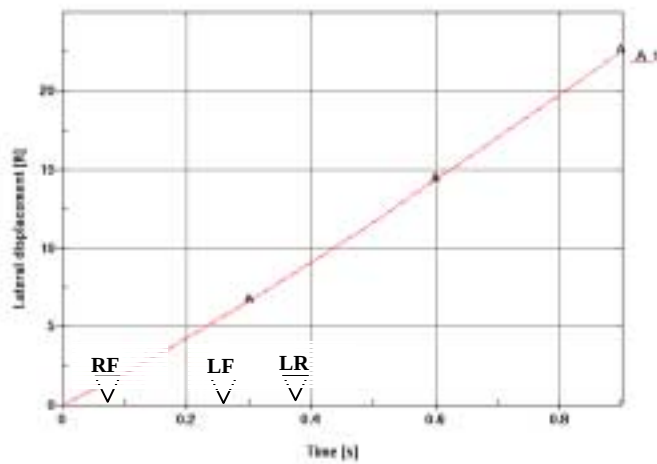


Fig. 2.1.1.4.2.2 (E): Lateral displacement [ft]

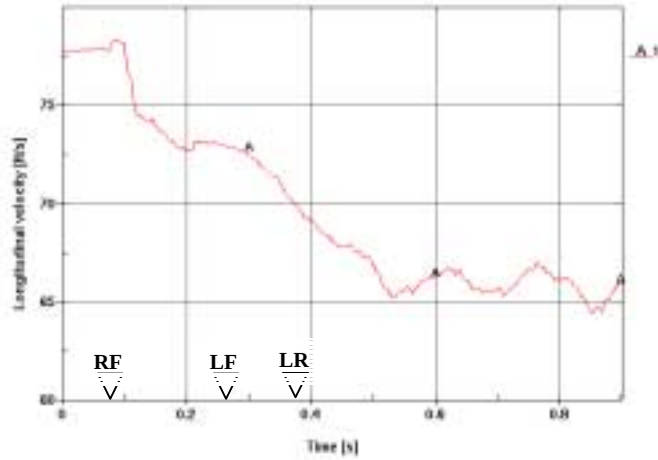


Fig. 2.1.1.4.2.2 (F): Longitudinal velocity [ft/s]

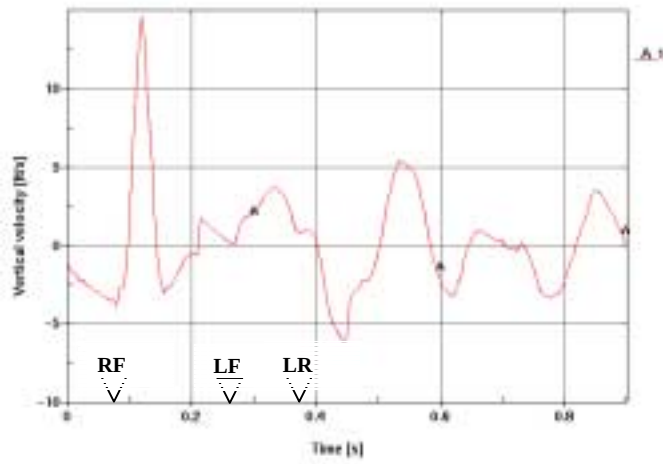


Fig. 2.1.1.4.2.2 (G) Vertical velocity [ft/s]

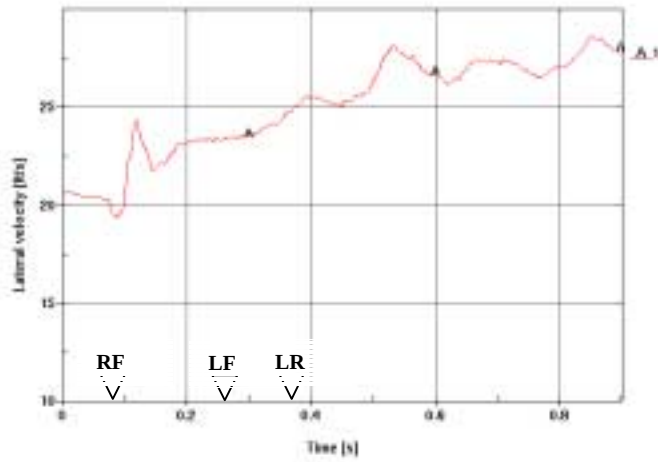


Fig. 2.1.1.4.2.2 (H): Lateral velocity [ft/s]

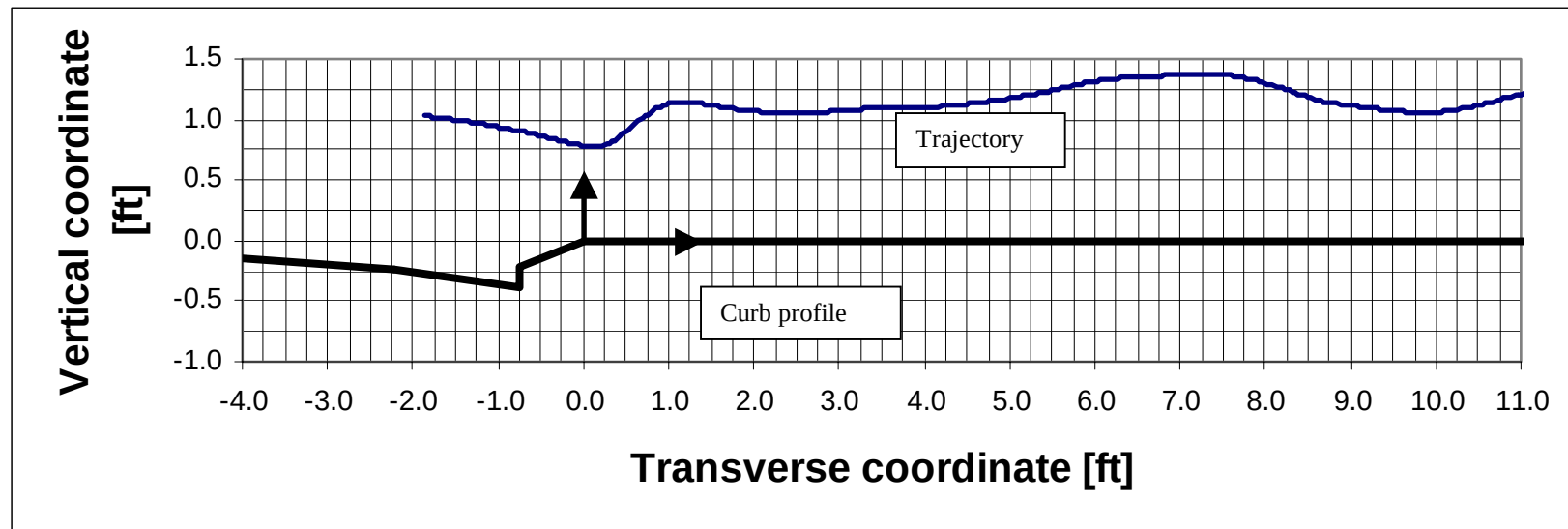


Fig. 2.1.1.4.2.2. (I): Trajectory of the bumper right corner

2.1 Ford Festiva

2.1.2 Slope 0.02

2.1.2.1 Approach angle 5°

2.1.2.1.1 Velocity 35 mph

2.1.2.1.1.1 “F” curb

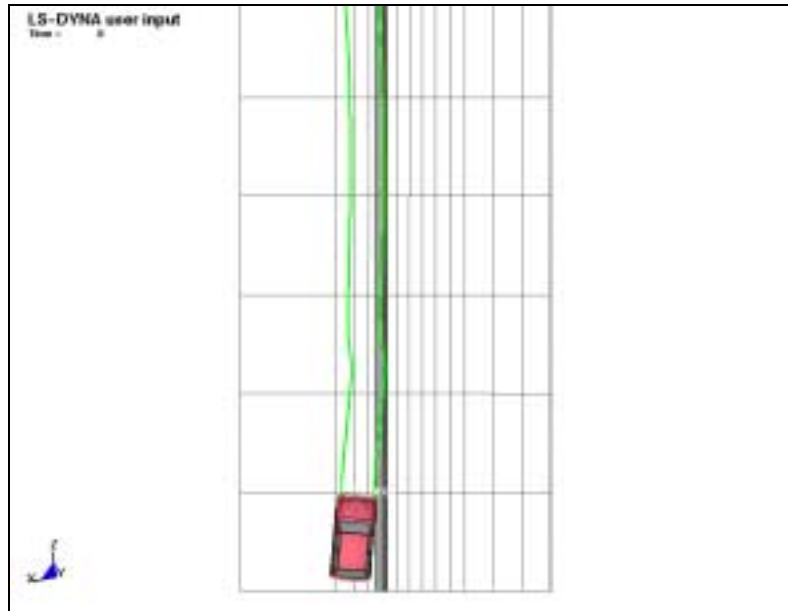


Fig. 2.1.2.1.1.1. (A) Trajectories of bumper corners (upper view)

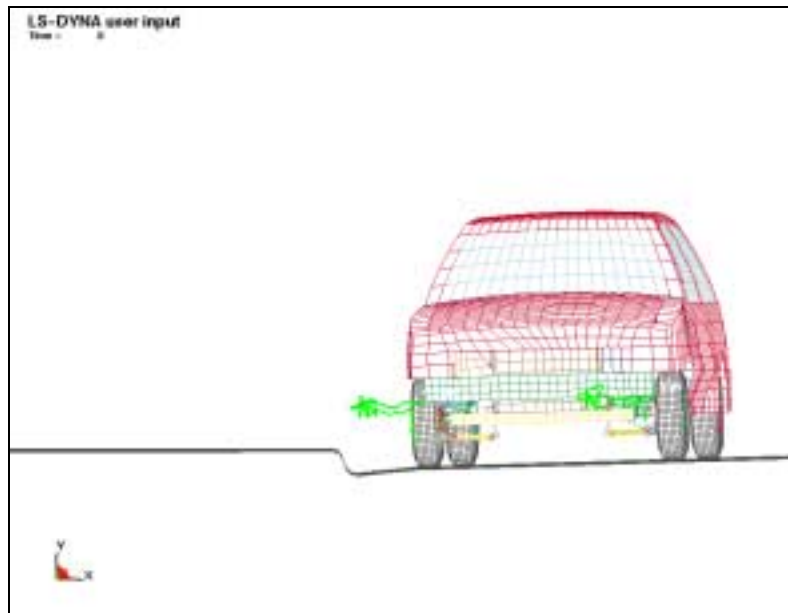


Fig. 2.1.2.1.1.1. (B) Trajectories of bumper corners (front view)

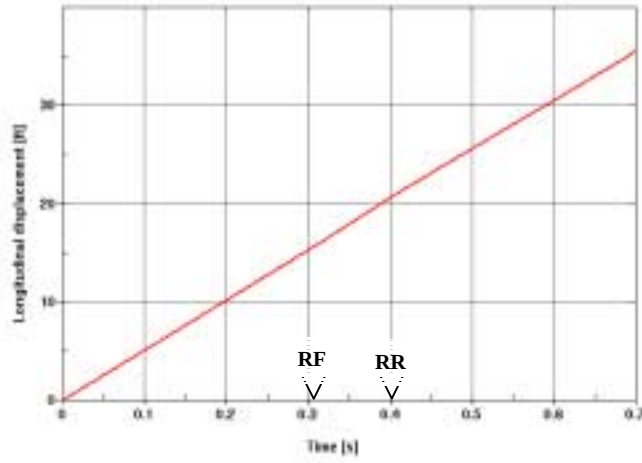


Fig. 2.1.2.1.1.1. (C): Longitudinal displacement [ft]

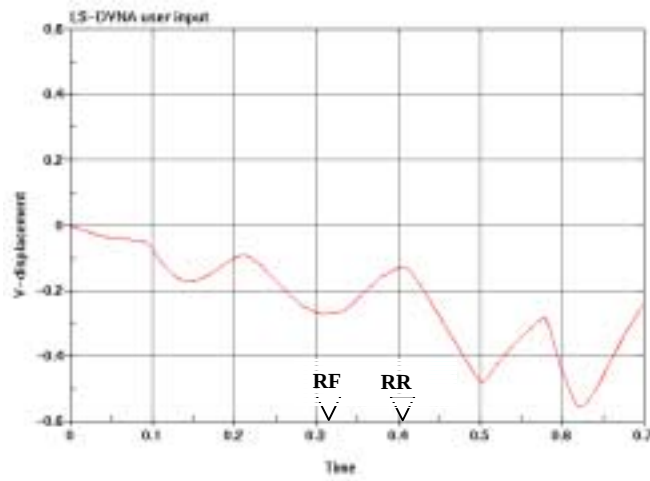


Fig. 2.1.2.1.1.1. (D): Vertical displacement [ft]

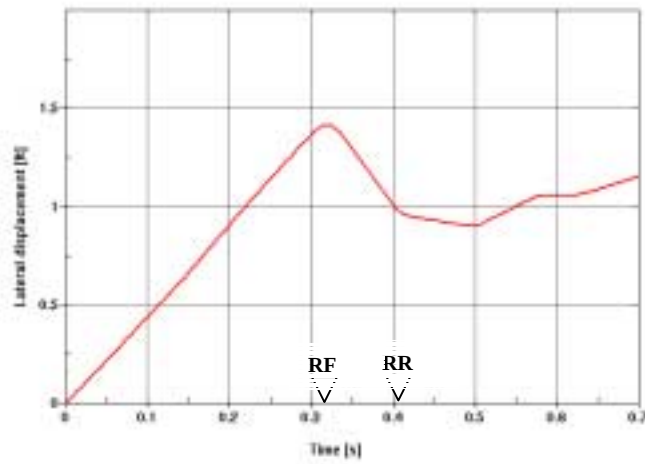


Fig. 2.1.2.1.1.1. (E): Lateral displacement [ft]

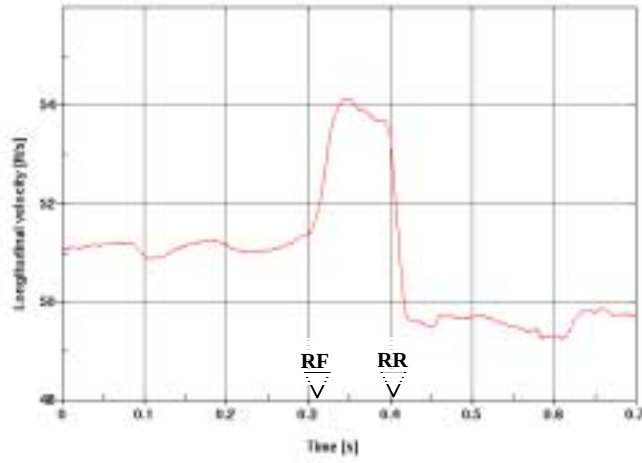


Fig. 2.1.2.1.1.1. (F): Longitudinal velocity [ft/s]

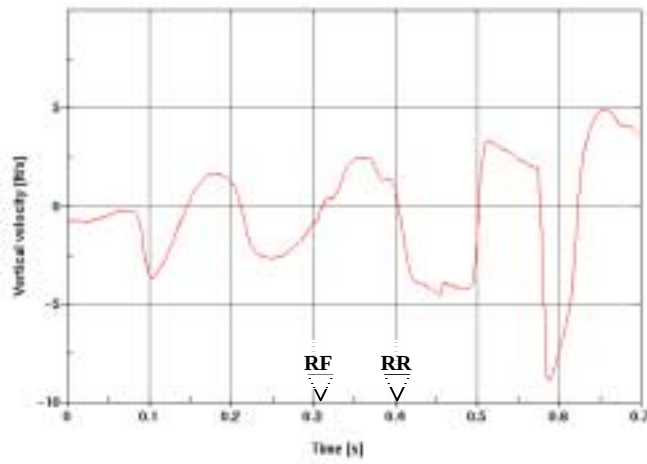


Fig. 2.1.2.1.1.1. (G) Vertical velocity [ft/s]

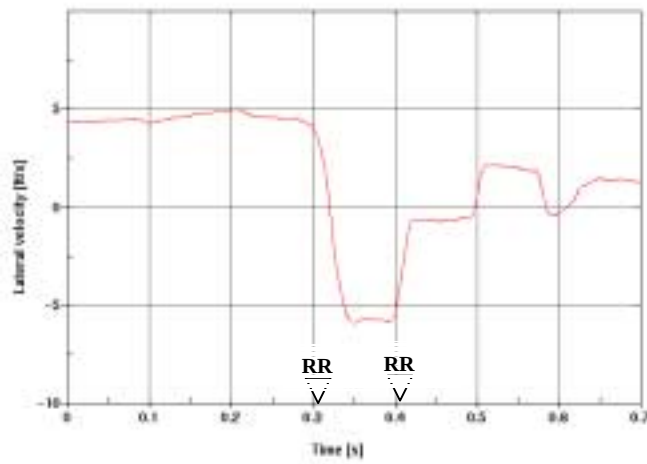


Fig. 2.1.2.1.1.1. (H): Lateral velocity [ft/s]

2.1.2.1.1.2 “E” curb

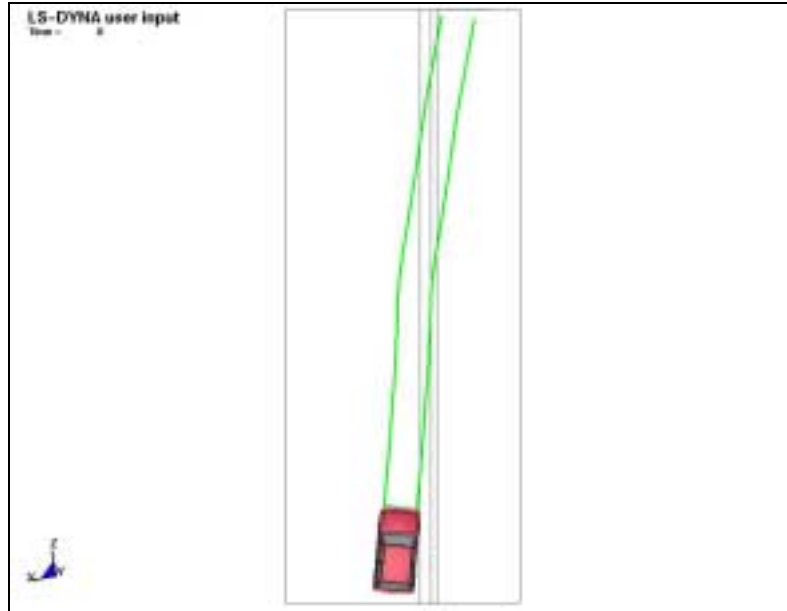


Fig. 2.1.2.1.1.2. (A) Trajectories of bumper corners (upper view)

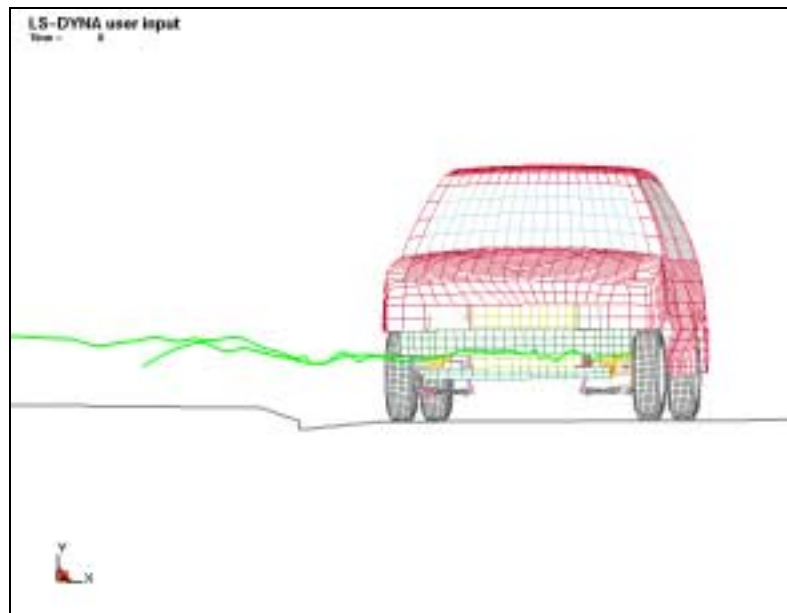


Fig. 2.1.2.1.1.2. (B) Trajectories of bumper corners (lateral view)

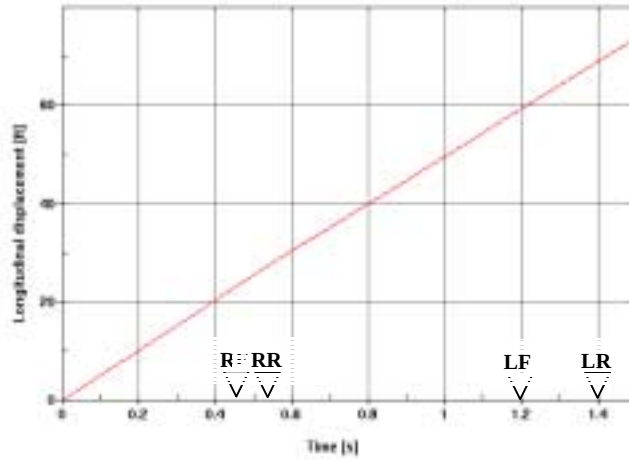


Fig. 2.1.2.1.1.2. (C): Longitudinal displacement [ft]

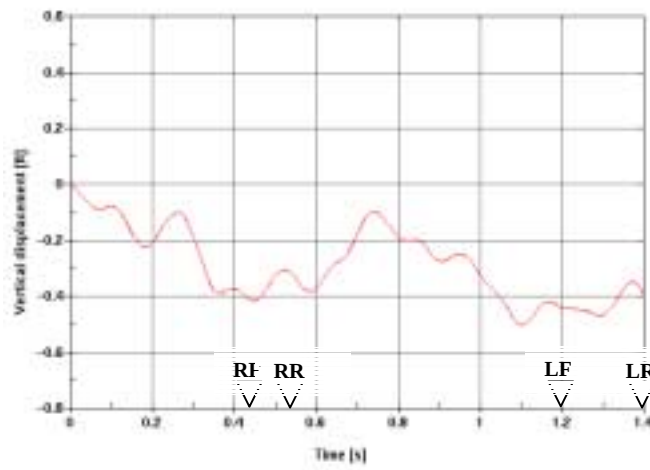


Fig. 2.1.2.1.1.2. (D): Vertical displacement [ft]

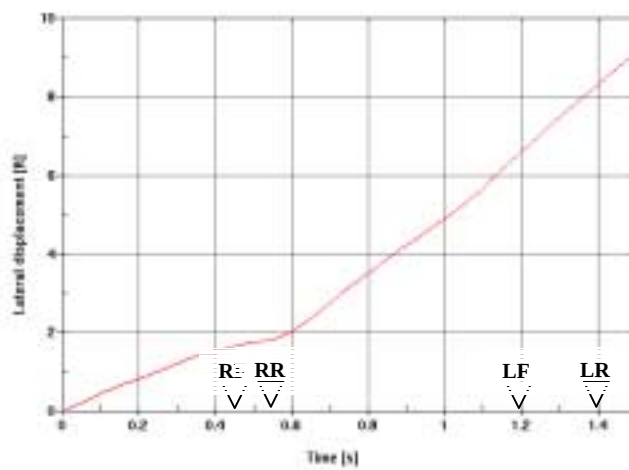


Fig. 2.1.2.1.1.2. (E): Lateral displacement [ft]

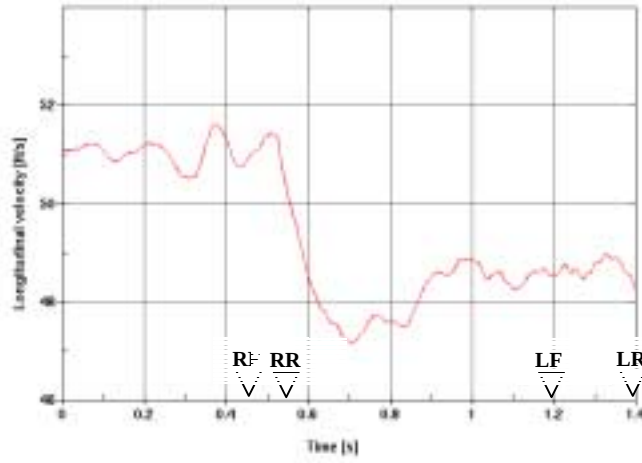


Fig. 2.1.2.1.1.2. (F): Longitudinal velocity [ft/s]

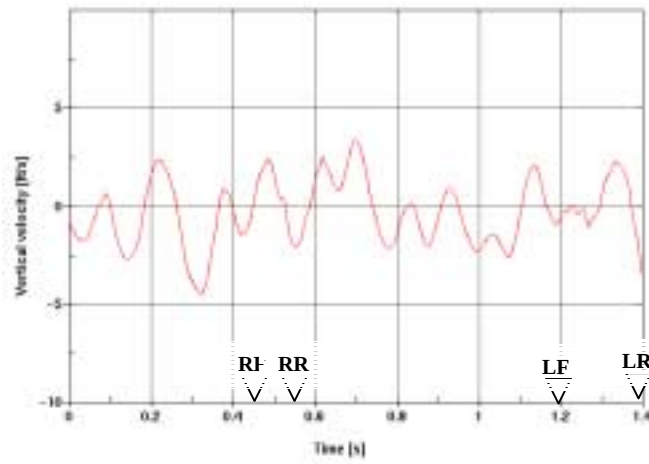


Fig. 2.1.2.1.1.2. (G) Vertical velocity [ft/s]

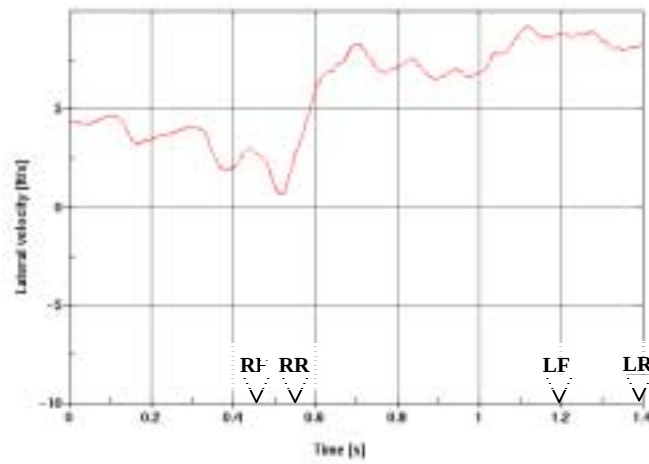


Fig. 2.1.2.1.1.2. (H): Lateral velocity [ft/s]

2.1.2.1.2 Velocity 55 mph

2.1.2.1.2.1 “F” curb

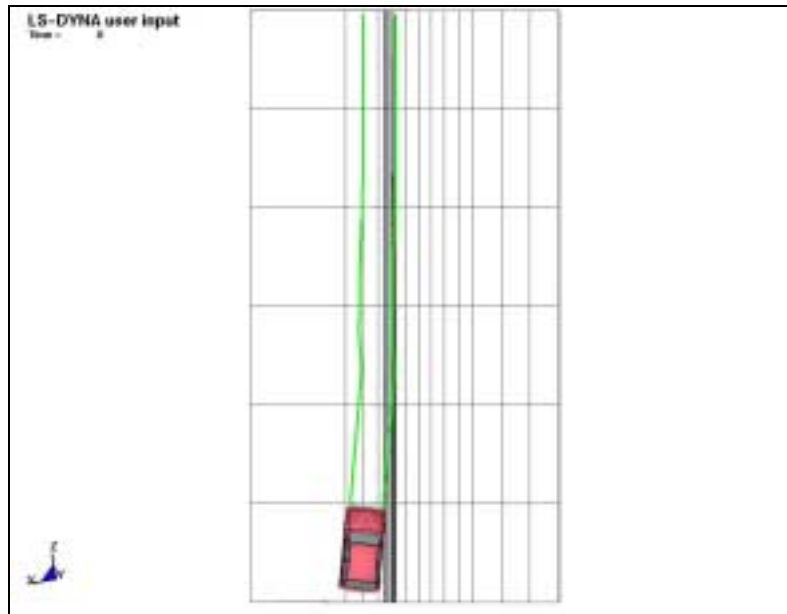


Fig. 2.1.2.1.2.1. (A) Trajectories of bumper corners (upper view)

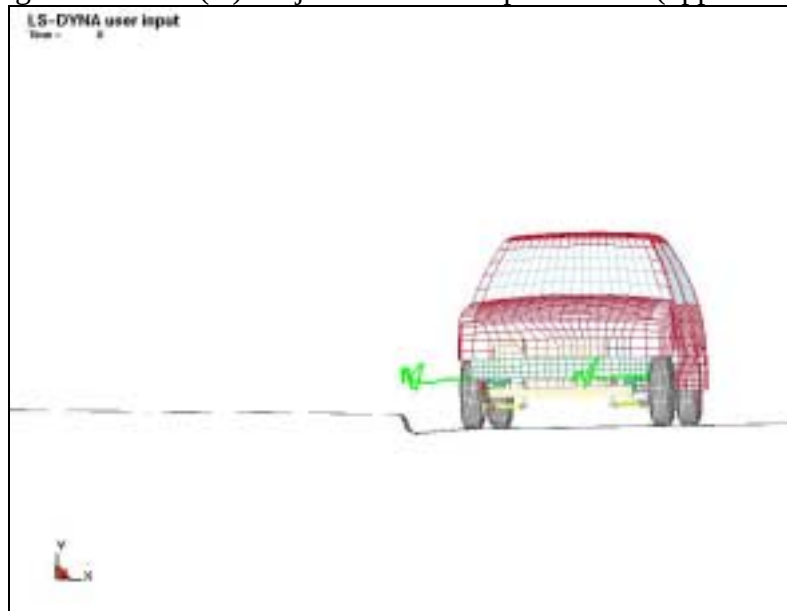


Fig. 2.1.2.1.2.1. (B) Trajectories of bumper corners (lateral view)

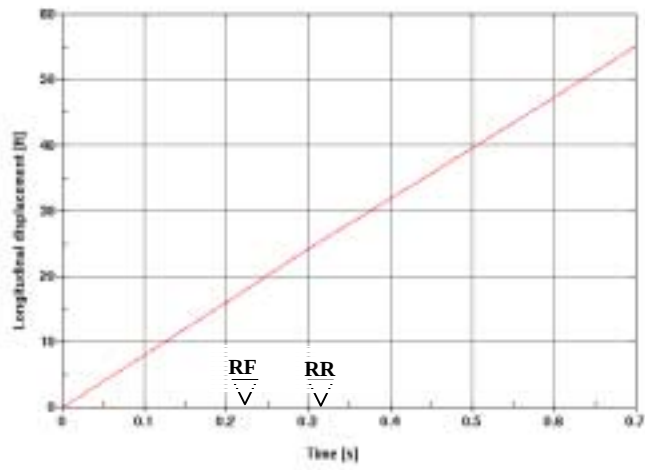


Fig. 2.1.2.1.2.1. (C): Longitudinal displacement [ft]

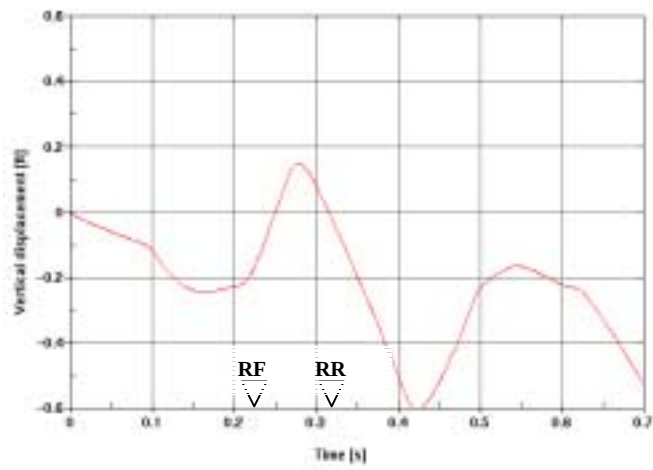


Fig. 2.1.2.1.2.1. (D): Vertical displacement [ft]

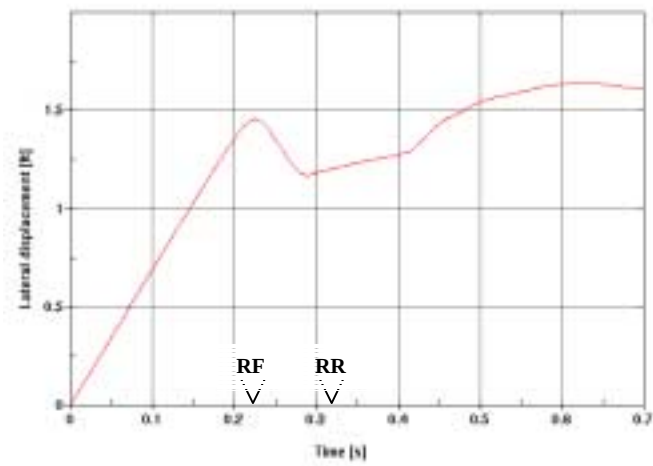


Fig. 2.1.2.1.2.1. (E): Lateral displacement [ft]

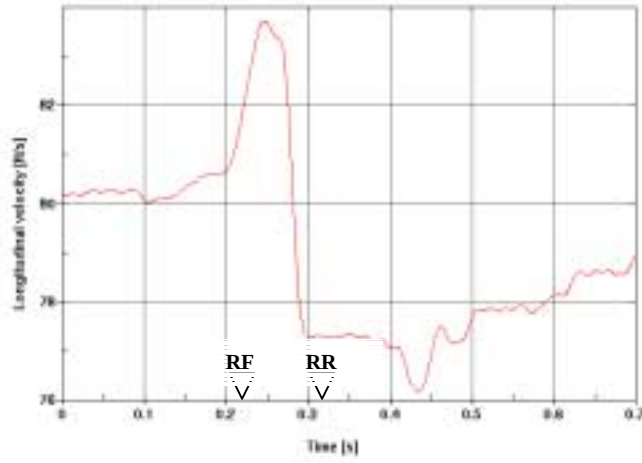


Fig. 2.1.2.1.2.1. (F): Longitudinal velocity [ft/s]

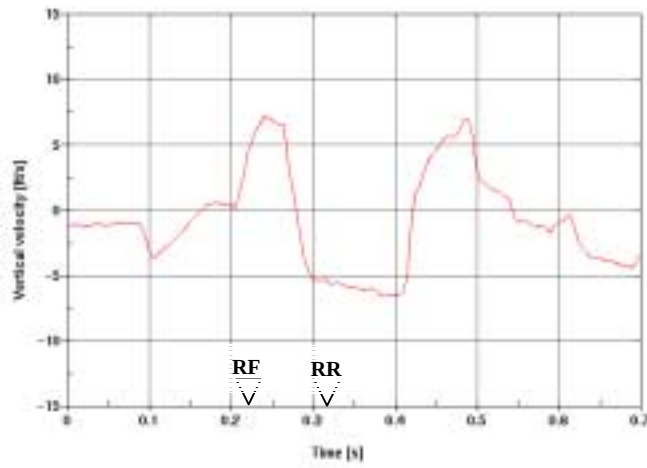


Fig. 2.1.2.1.2.1. (G) Vertical velocity [ft/s]

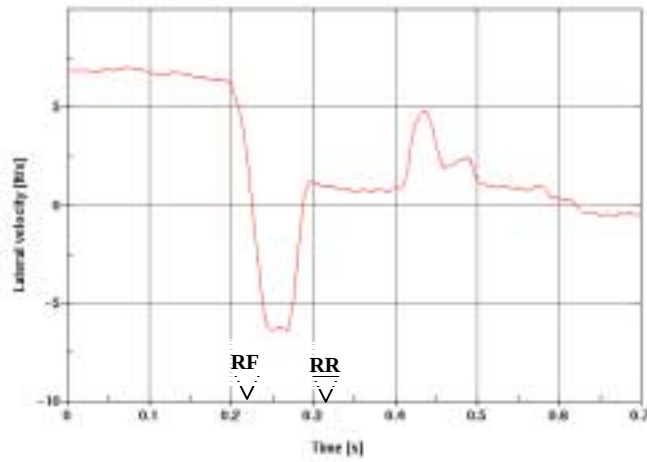


Fig. 2.1.2.1.2.1. (H): Lateral velocity [ft/s]

2.1.2.1.2.2 “E” curb

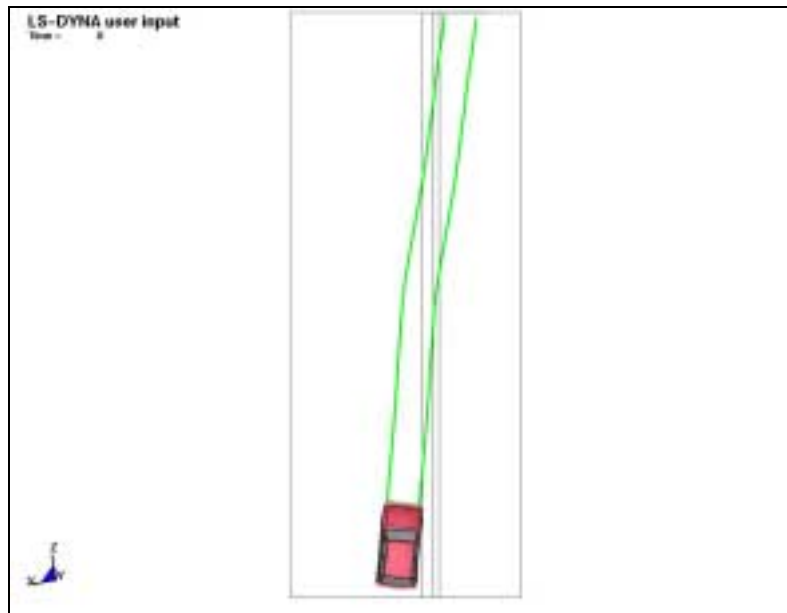


Fig. 2.1.2.1.2.2. (A) Trajectories of bumper corners (upper view)

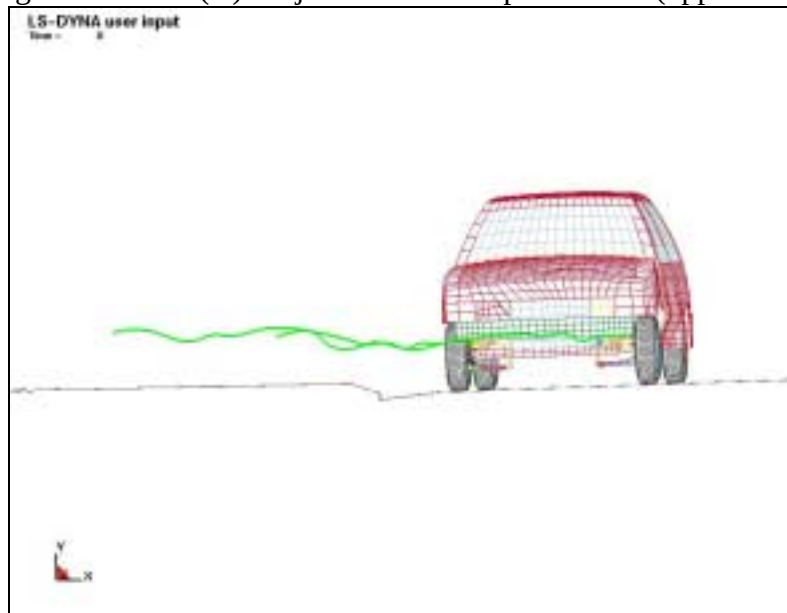


Fig. 2.1.2.1.2.2. (B) Trajectories of bumper corners (lateral view)

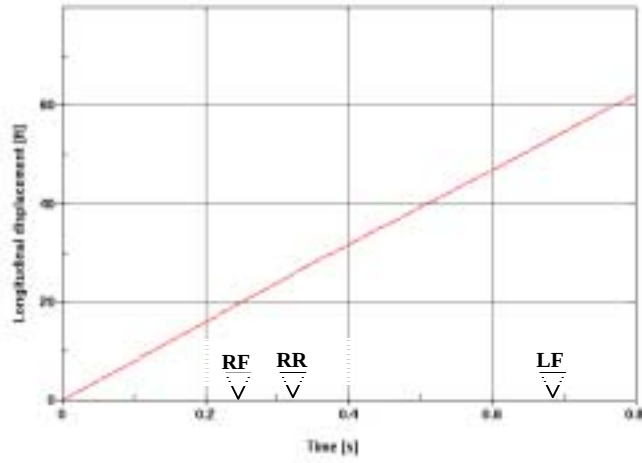


Fig. 2.1.2.1.2.2. (C): Longitudinal displacement [ft]

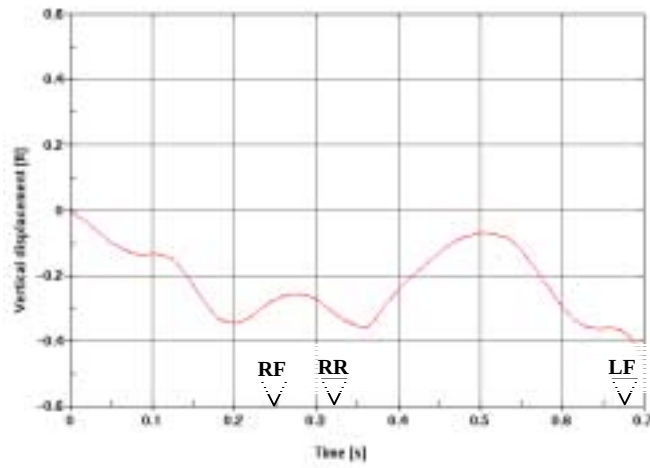


Fig. 2.1.2.1.2.2. (D): Vertical displacement [ft]

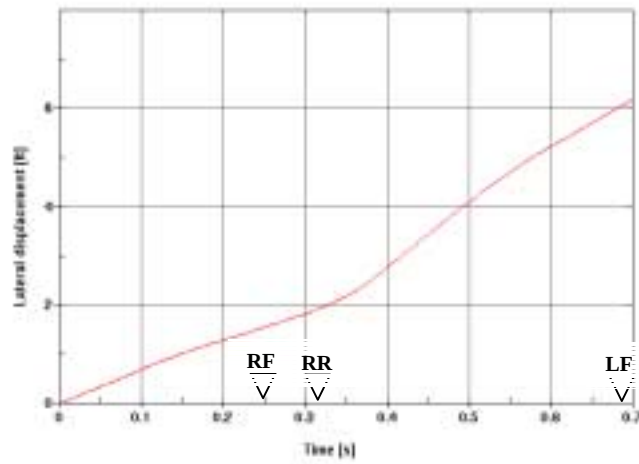


Fig. 2.1.2.1.2.2. (E): Lateral displacement [ft]

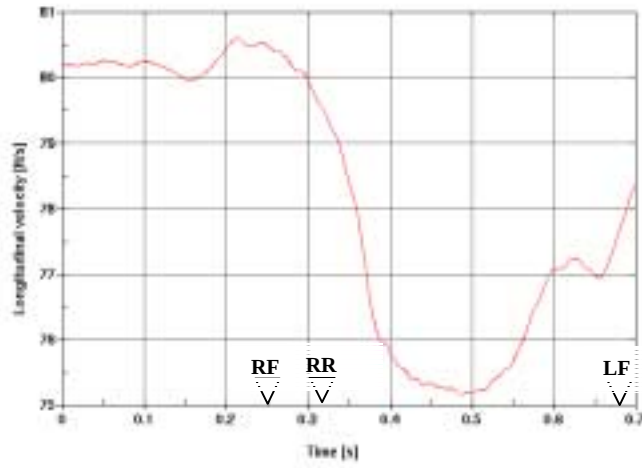


Fig. 2.1.2.1.2.2. (F): Longitudinal velocity [ft/s]

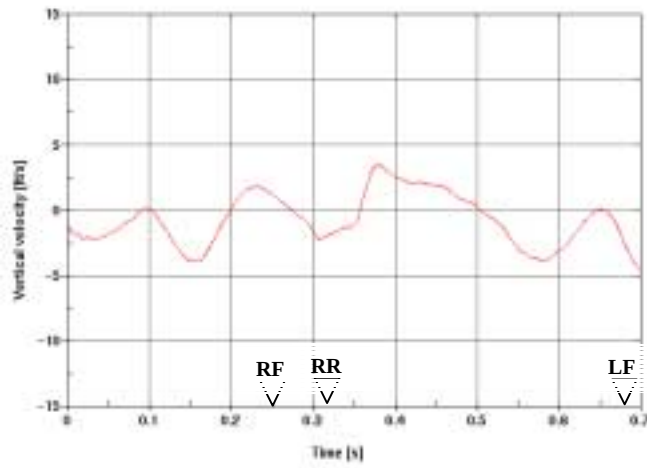


Fig. 2.1.2.1.2.2. (G) Vertical velocity [ft/s]

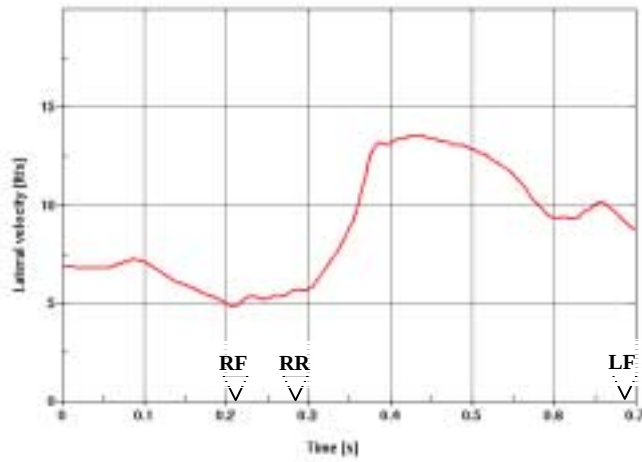


Fig. 2.1.2.1.2.2. (H): Lateral velocity [ft/s]

2.1.2.2 Approach angle 10°

2.1.2.2.1 Velocity 35 mph

2.1.2.2.1.1 “F” curb

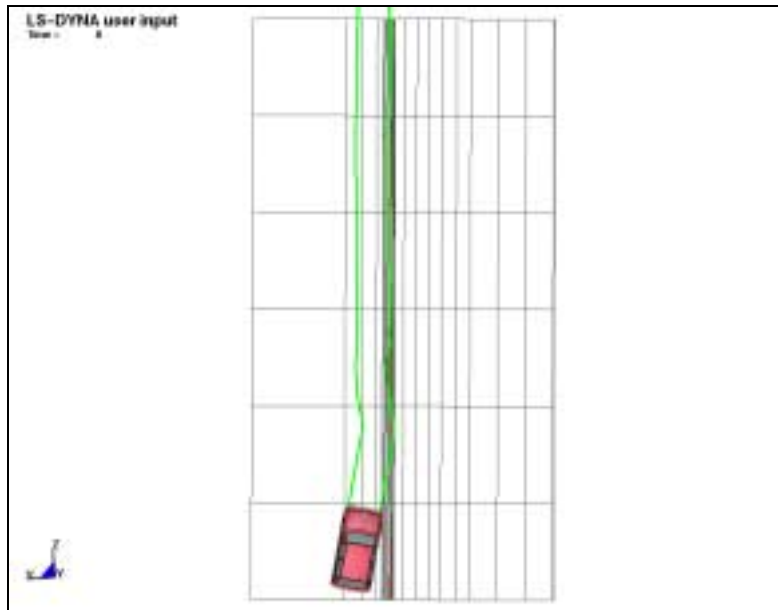


Fig. 2.1.2.2.1.1. (A) Trajectories of bumper corners (upper view)



Fig. 2.1.2.2.1.1. (B) Trajectories of bumper corners (lateral view)

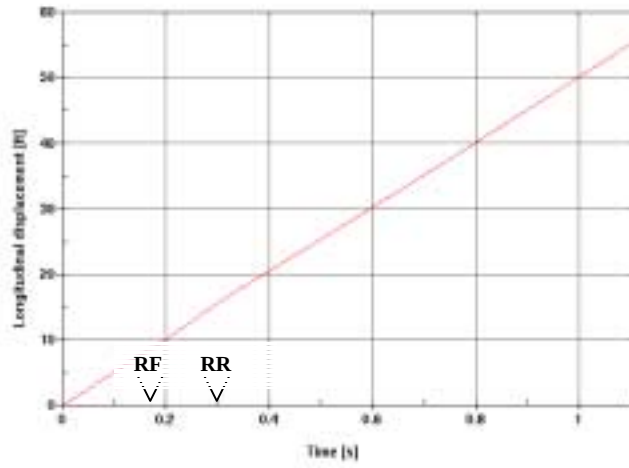


Fig. 2.1.2.2.1.1. (C): Longitudinal displacement [ft]

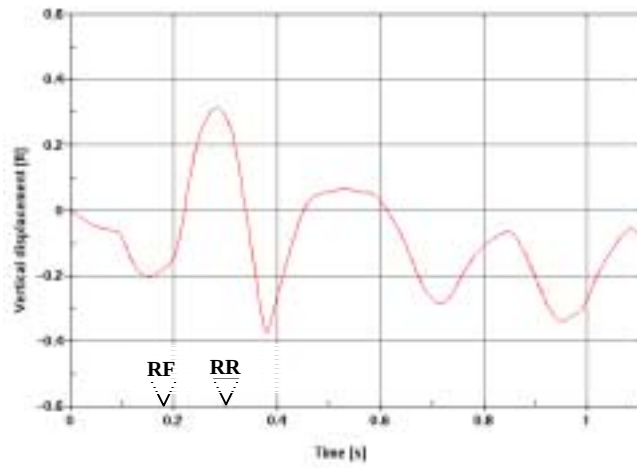


Fig. 2.1.2.2.1.1. (D): Vertical displacement [ft]

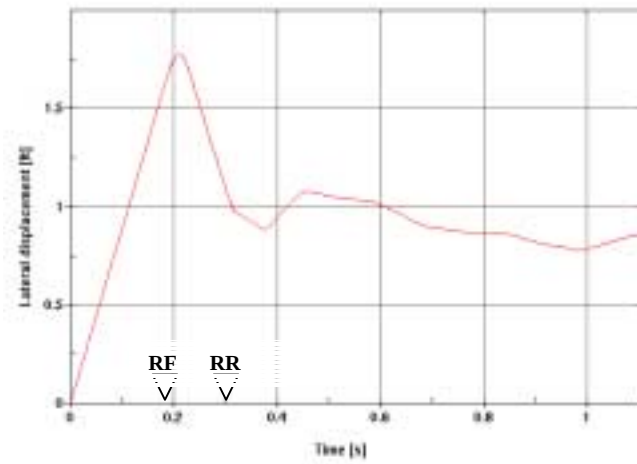


Fig. 2.1.2.2.1.1. (E): Lateral displacement [ft]

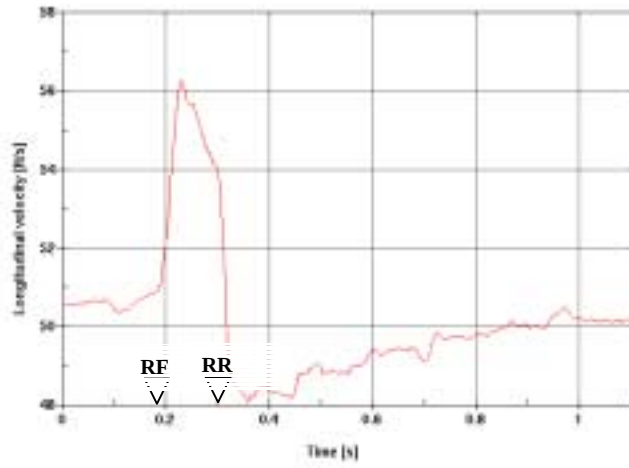


Fig. 2.1.2.2.1.1. (F): Longitudinal velocity [ft/s]

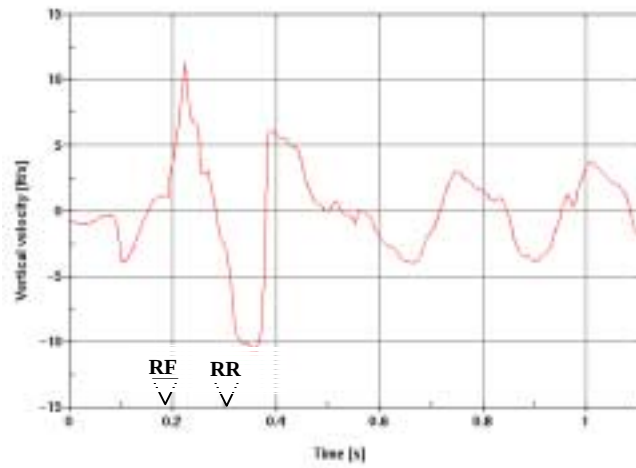


Fig. 2.1.2.2.1.1. (G) Vertical velocity [ft/s]

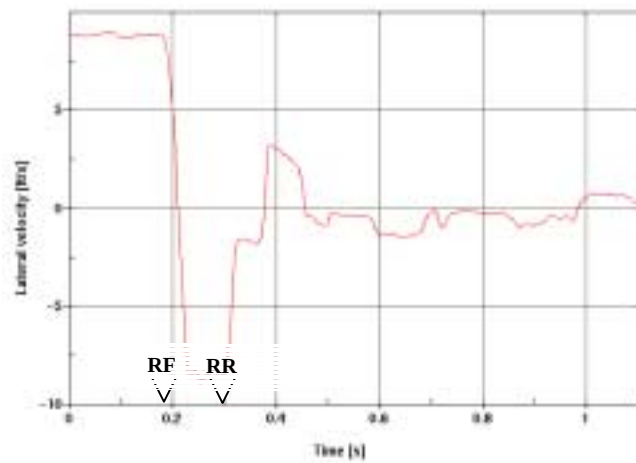


Fig. 2.1.2.2.1.1. (H): Lateral velocity [ft/s]

2.1.2.2.1.2 “E” curb

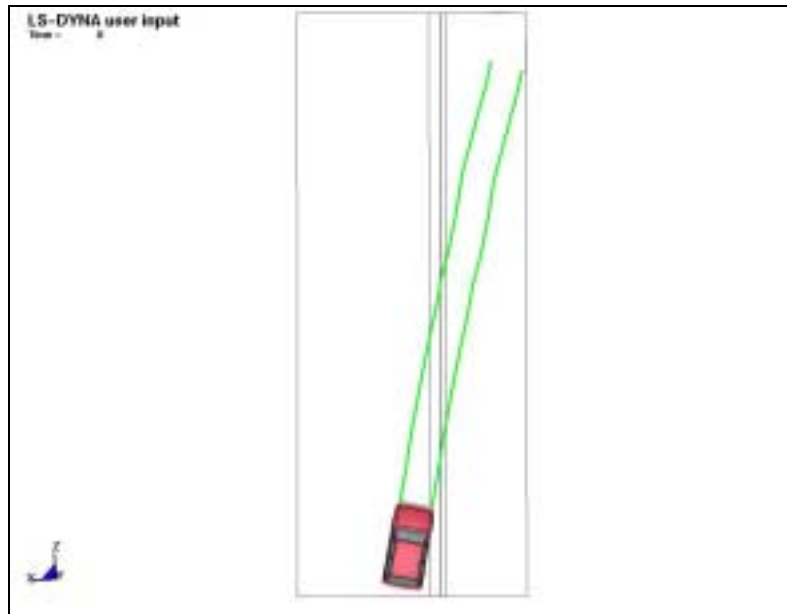


Fig. 2.1.2.2.1.2. (A) Trajectories of bumper corners (upper view)

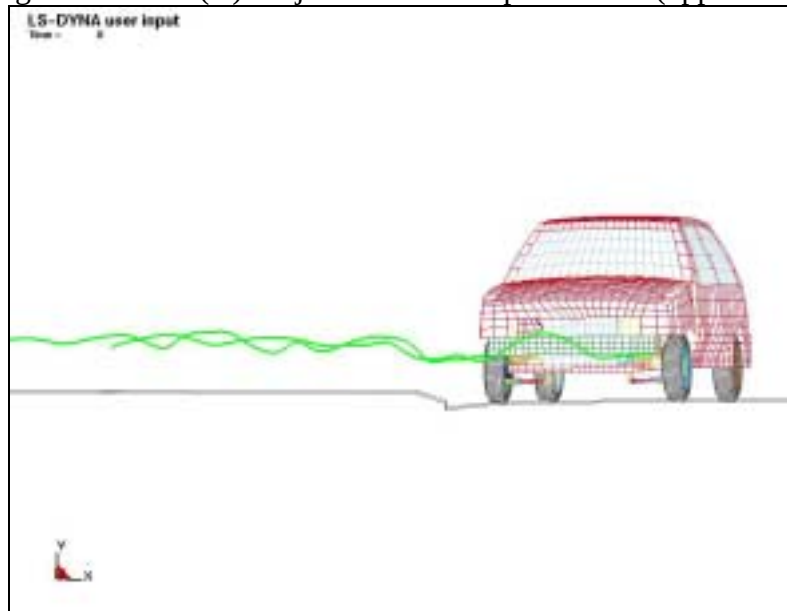


Fig. 2.1.2.2.1.2. (B) Trajectories of bumper corners (lateral view)

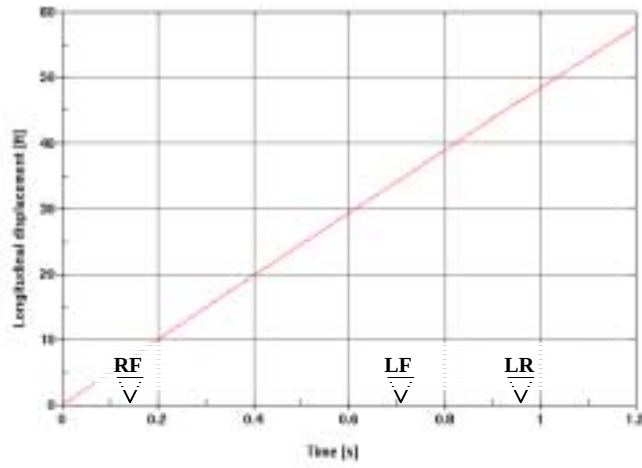


Fig. 2.1.2.2.1.2. (C): Longitudinal displacement [ft]

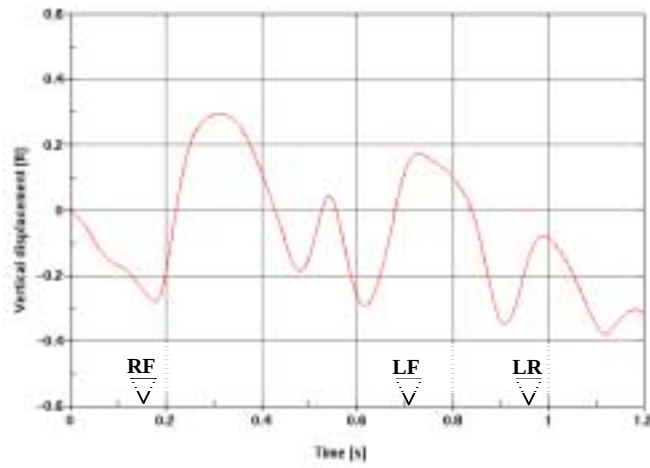


Fig. 2.1.2.2.1.2. (D): Vertical displacement [ft]

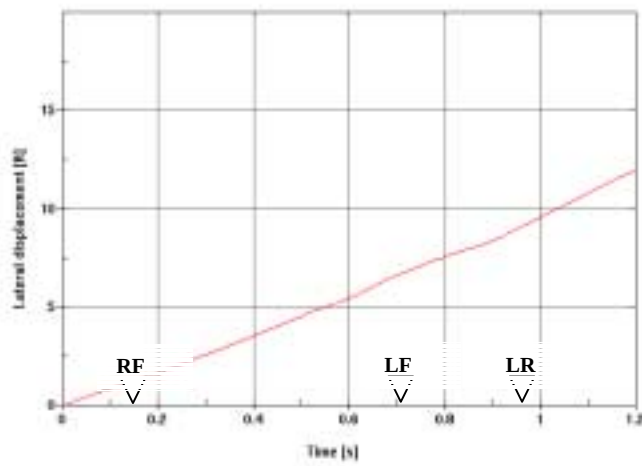


Fig. 2.1.2.2.1.2. (E): Lateral displacement [ft]

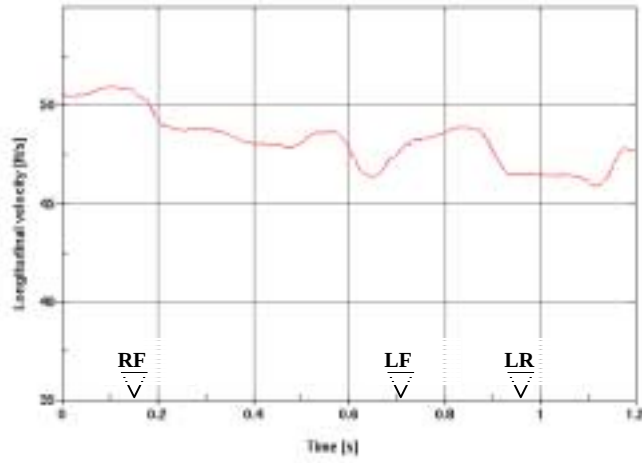


Fig. 2.1.2.2.1.2. (F): Longitudinal velocity [ft/s]

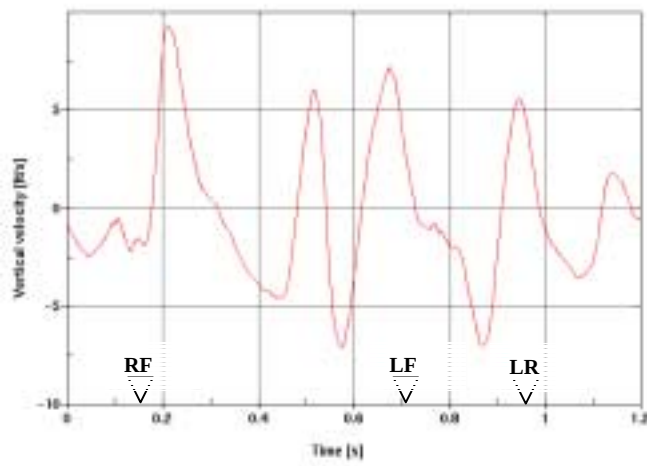


Fig. 2.1.1.2.1.2. (G) Vertical velocity [ft/s]

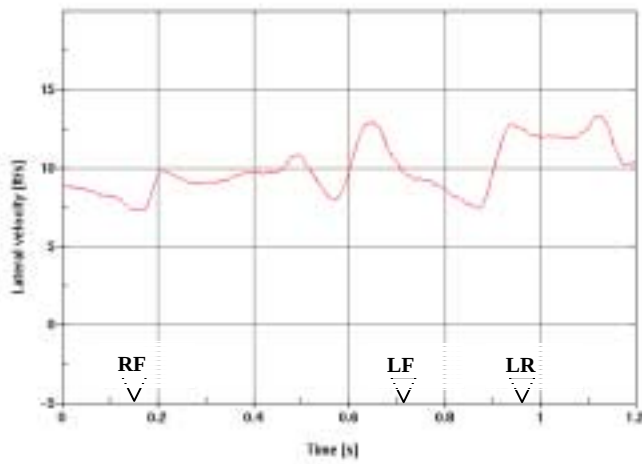


Fig. 2.1.2.2.1.2. (H): Lateral velocity [ft/s]

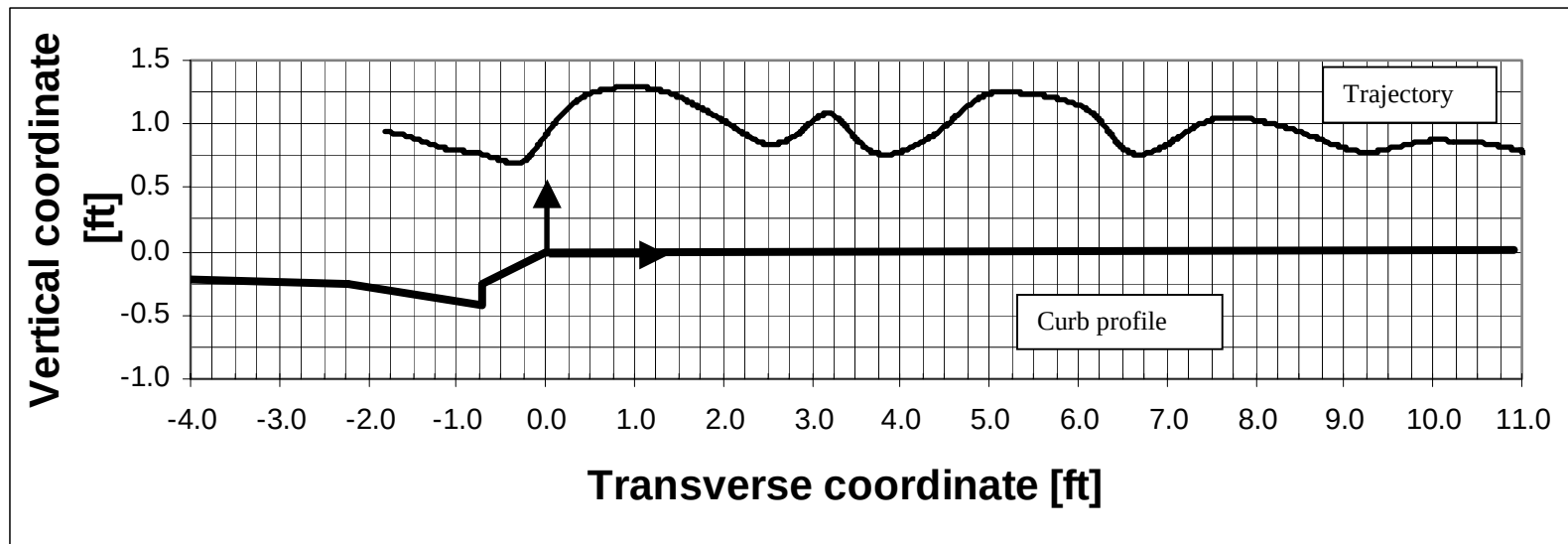


Fig. 2.1.2.2.1.2. (I): Trajectory of the bumper right corner

2.1.2.2 Approach angle 10°

2.1.2.2.2 Velocity 55 mph

2.1.2.2.2.1 “F” curb

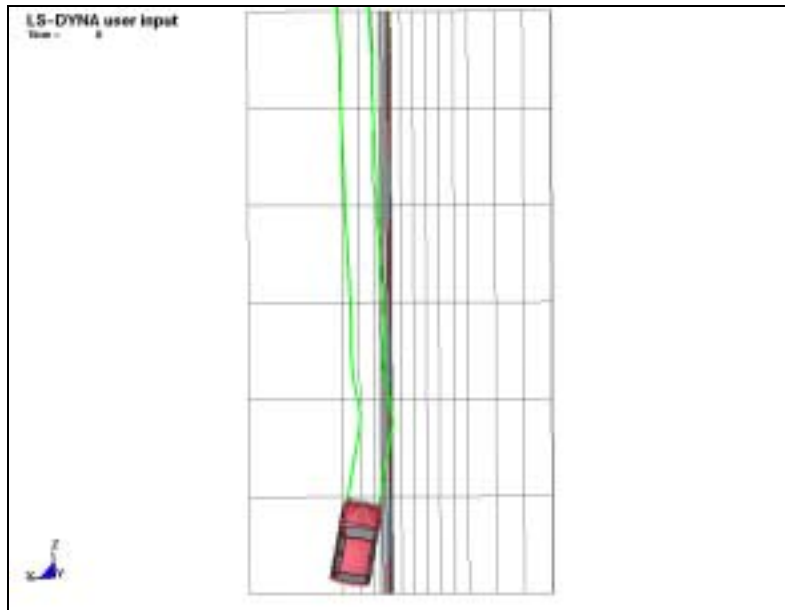


Fig. 2.1.2.2.2.1 (A) Trajectories of bumper corners (upper view)

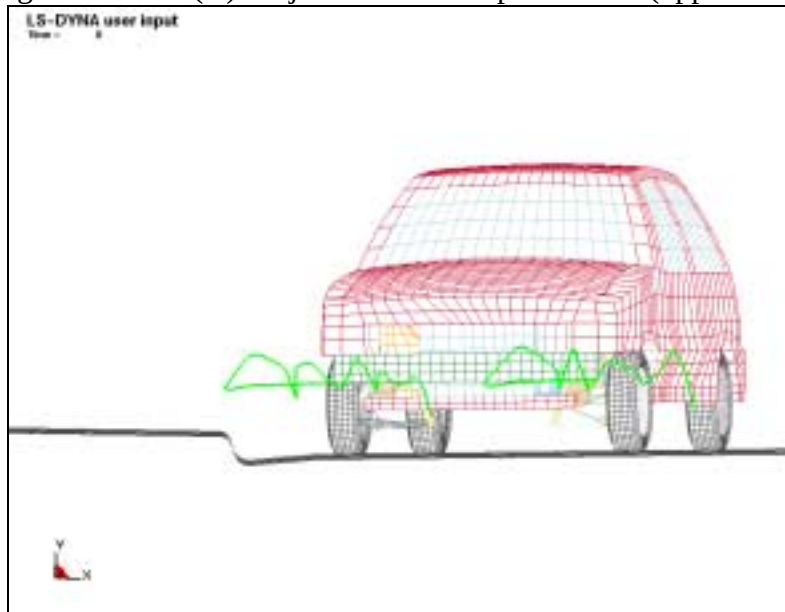


Fig. 2.1.2.2.2.1 (B) Trajectories of bumper corners (lateral view)

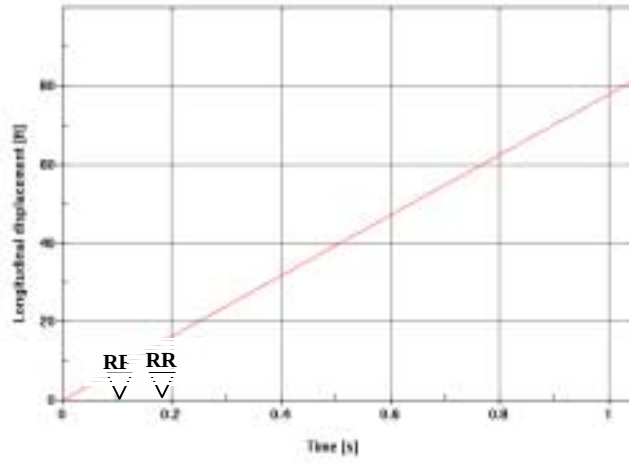


Fig. 2.1.2.2.2.1 (C): Longitudinal displacement [ft]

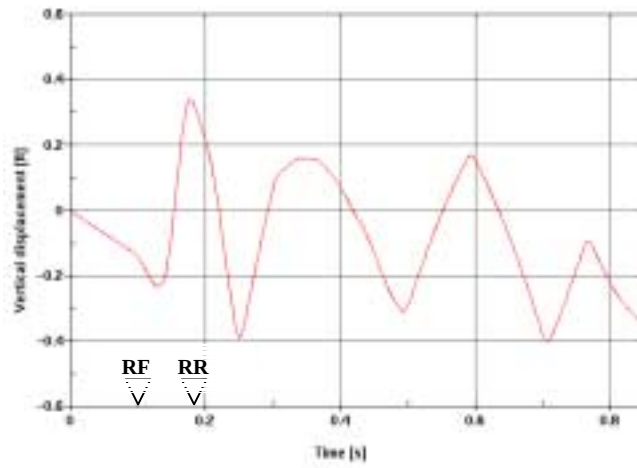


Fig. 2.1.2.2.2.1 (D): Vertical displacement [ft]

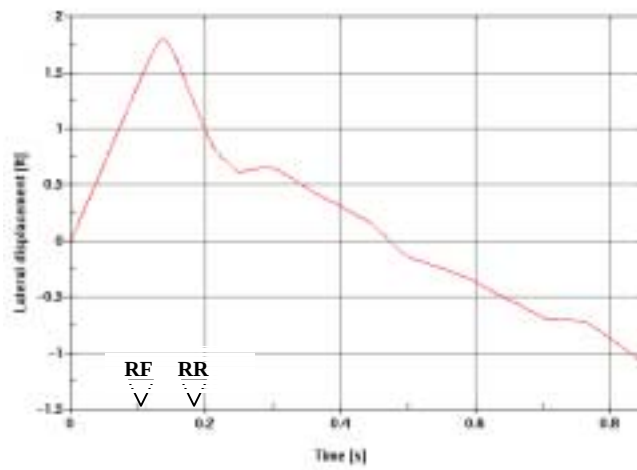


Fig. 2.1.2.2.2.1 (E): Lateral displacement [ft]

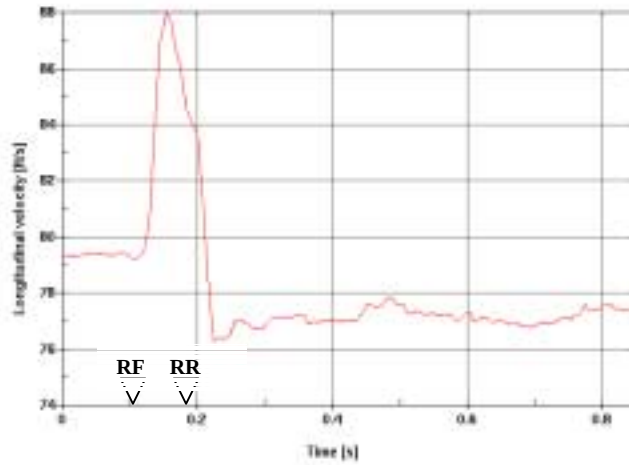


Fig. 2.1.2.2.1 (F): Longitudinal velocity [ft/s]

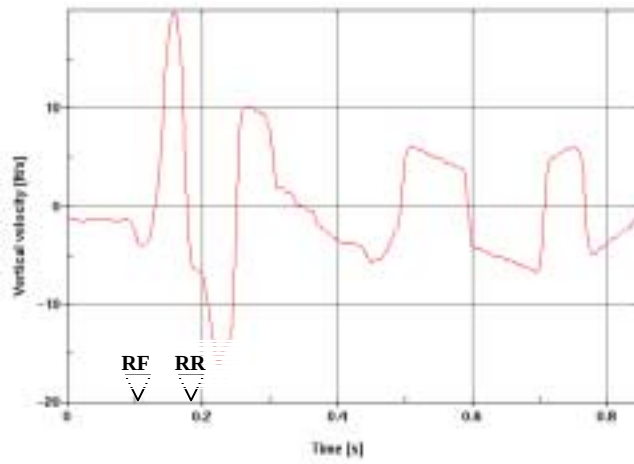


Fig 2.1.2.2.1 (G) Vertical velocity [ft/s]

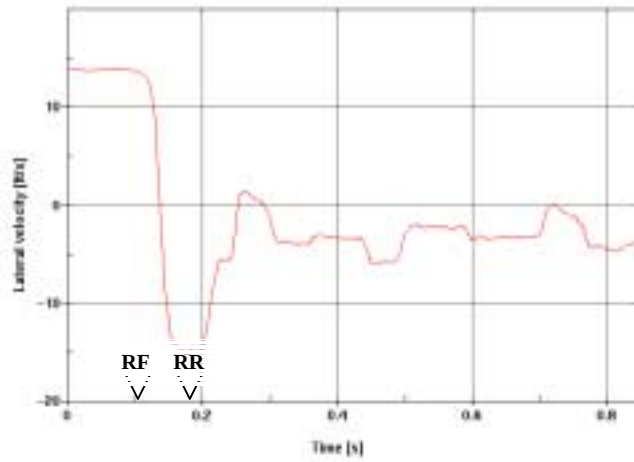


Fig. 2.1.1.2.2.1 (H): Lateral velocity [ft/s]

2.1.2.2.2.2 “E” curb

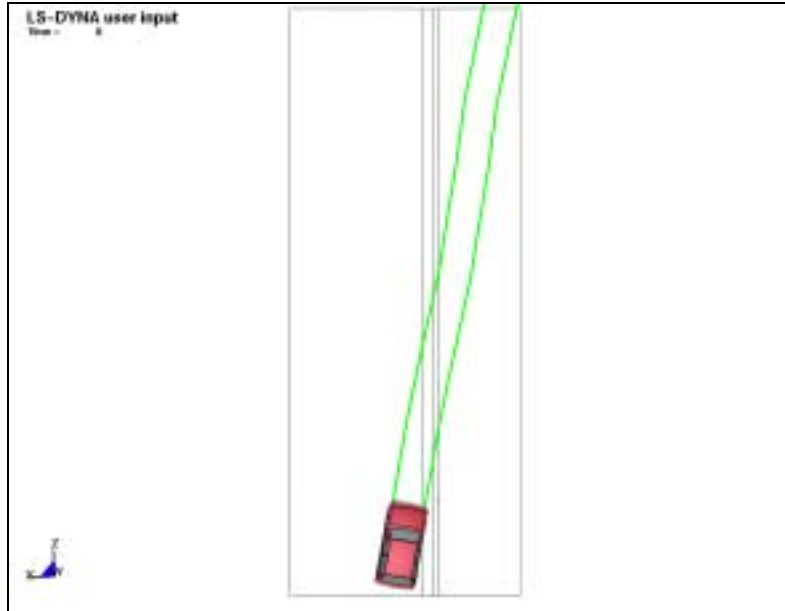


Fig. 2.1.2.2.2.2 (A) Trajectories of bumper corners (upper view)

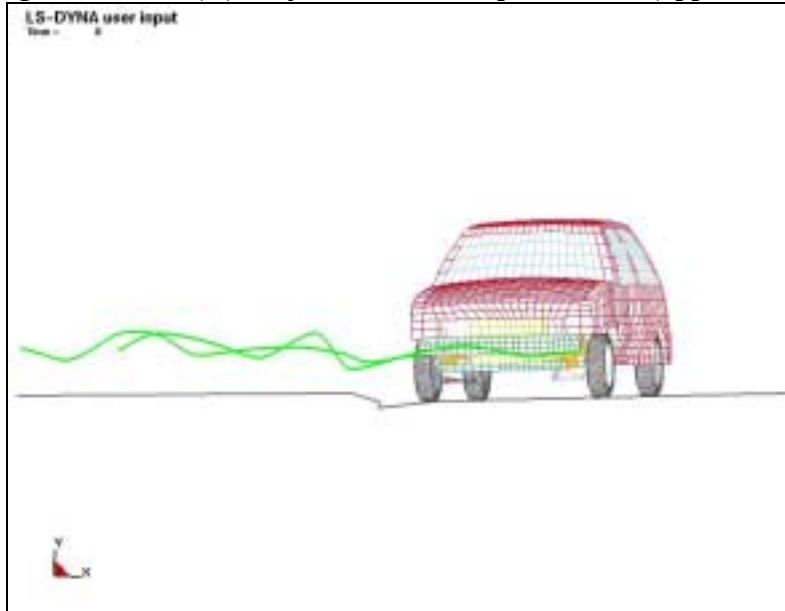


Fig. 2.1.2.2.2.2 (B) Trajectories of bumper corners (lateral view)

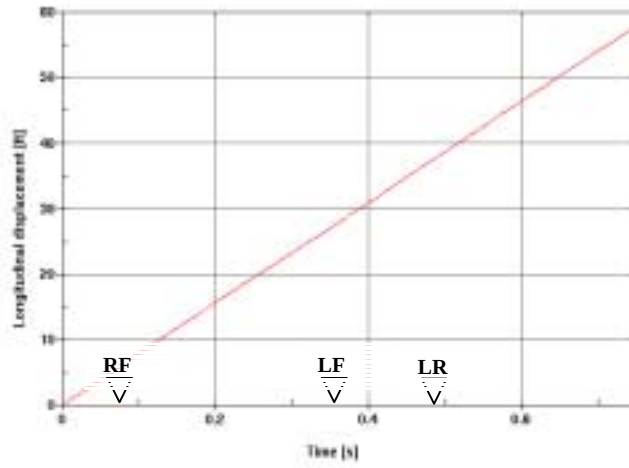


Fig. 2.1.2.2.2 (C): Longitudinal displacement [ft]

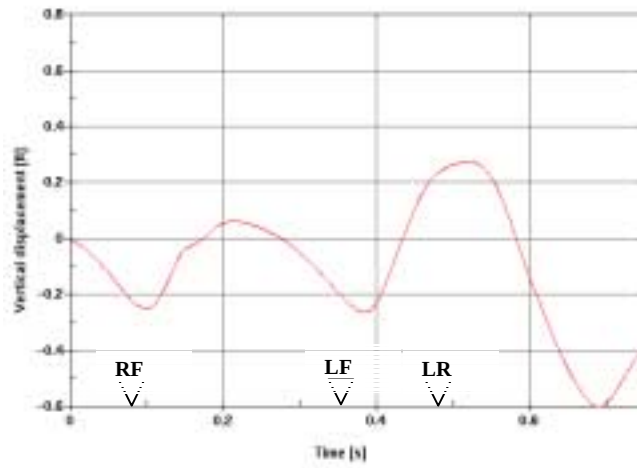


Fig. 2.1.2.2.2 (D): Vertical displacement [ft]

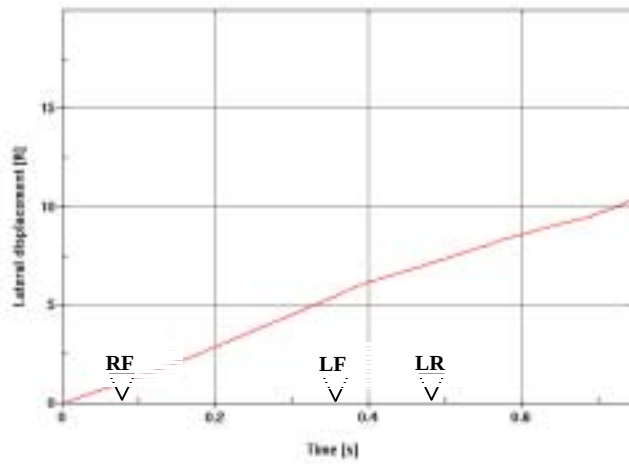


Fig. 2.1.2.2.2 (E): Lateral displacement [ft]

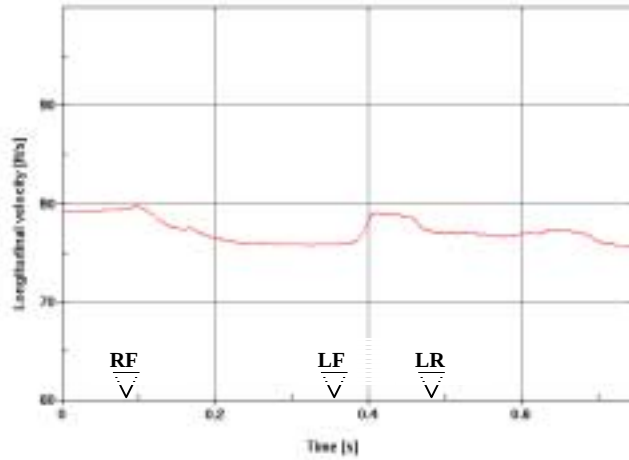


Fig. 2.1.2.2.2 (F): Longitudinal velocity [ft/s]

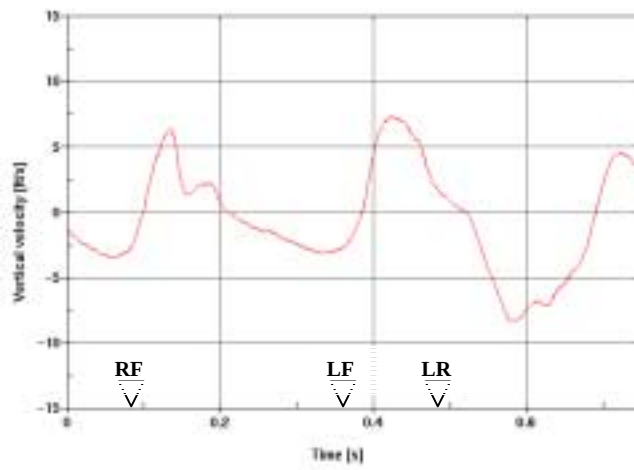


Fig 2.1.2.2.2 (G) Vertical velocity [ft/s]

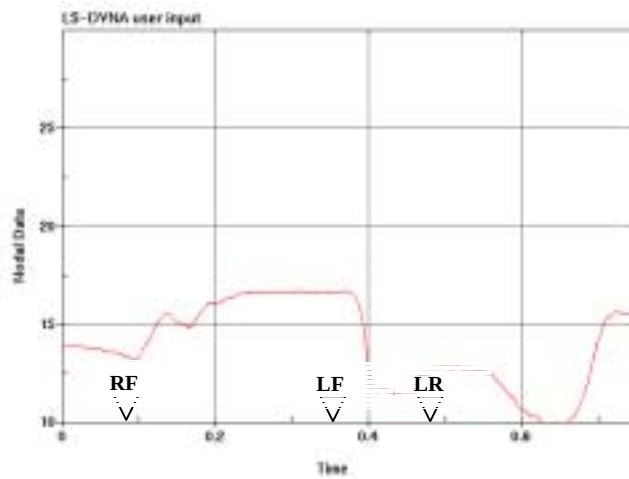


Fig. 2.1.2.2.2 (H): Lateral velocity [ft/s]

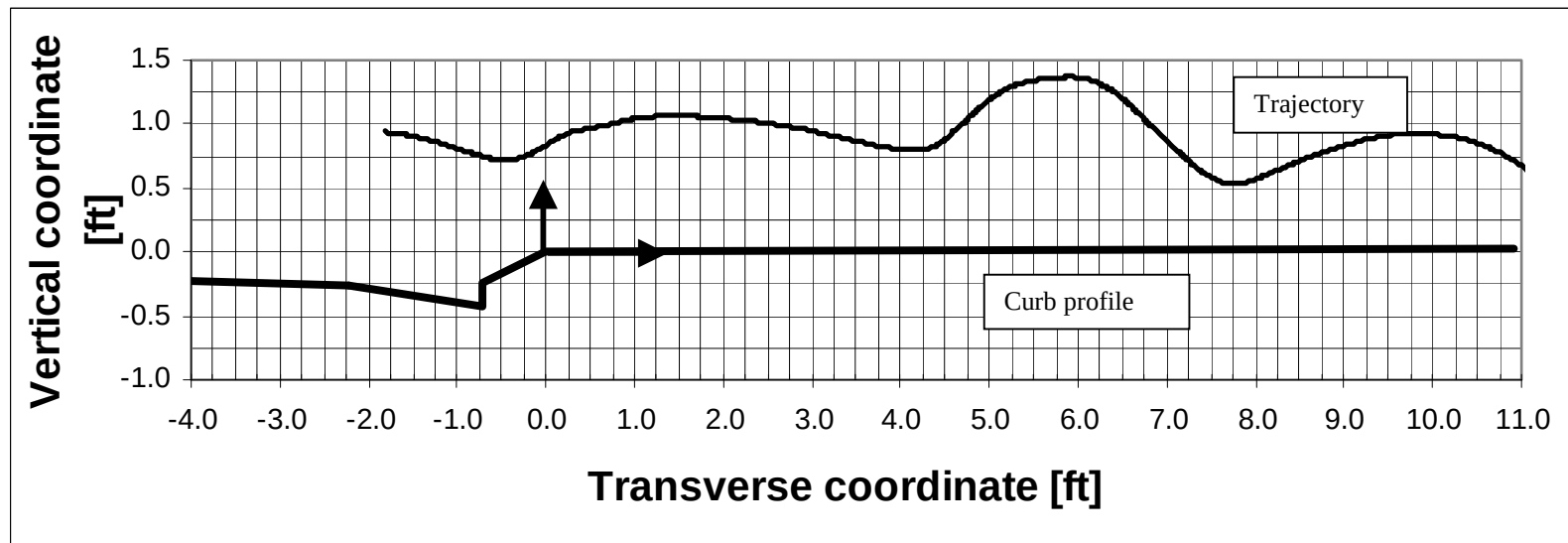


Fig. 2.1.2.2.2 (I): Trajectory of the bumper right corner

2.1.2.3 Approach angle 12°

2.1.2.3.1 Velocity 35 mph

2.1.2.3.1.1 “F” curb

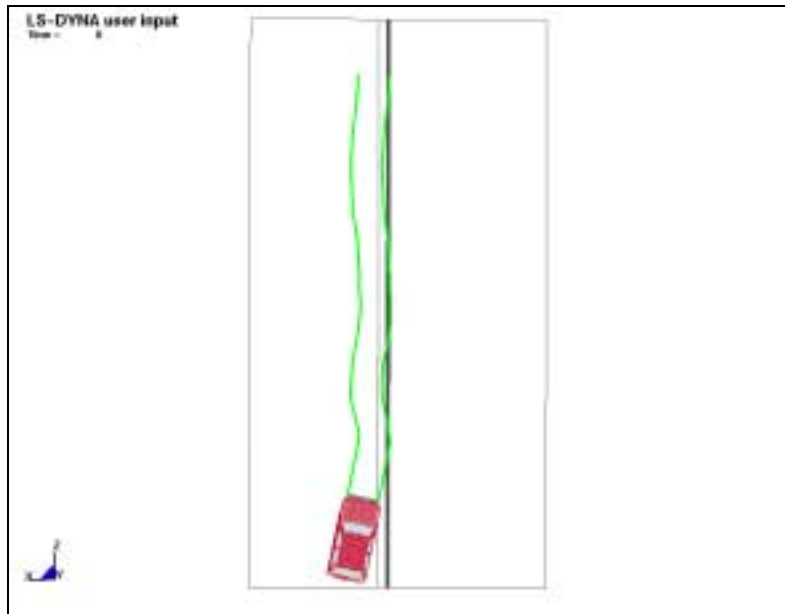


Fig. 2.1.2.3.1.1 (A) Trajectories of bumper corners (upper view)

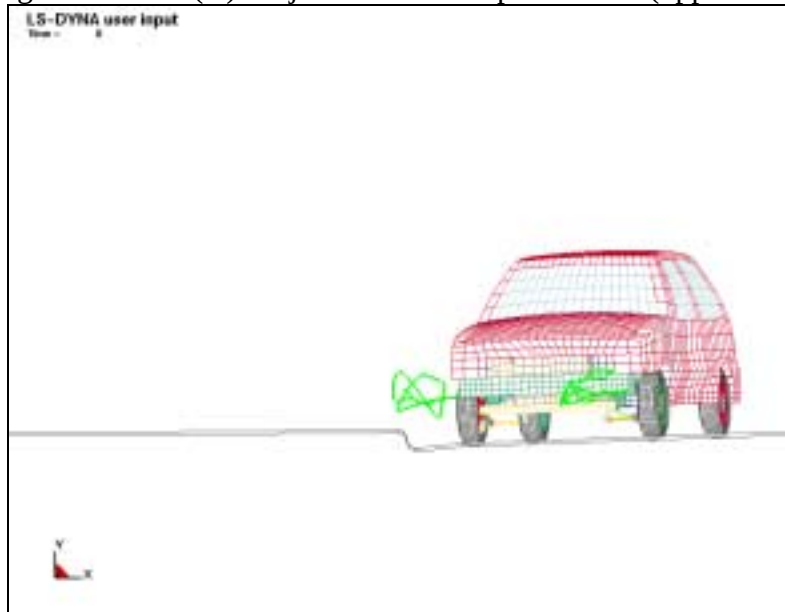


Fig. 2.1.2.3.1.1 (B) Trajectories of bumper corners (lateral view)

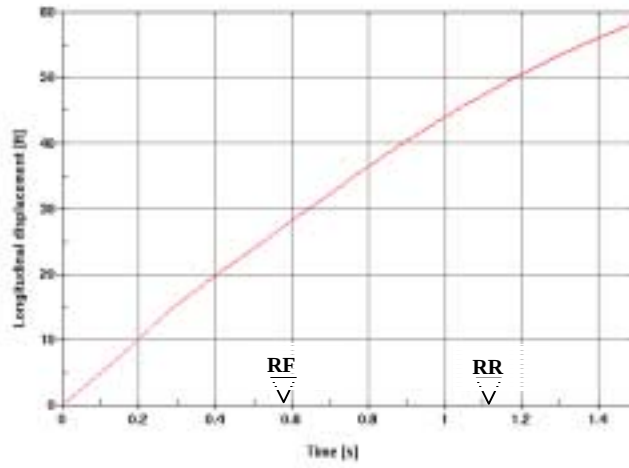


Fig. 2.1.2.3.1.1. (C): Longitudinal displacement [ft]

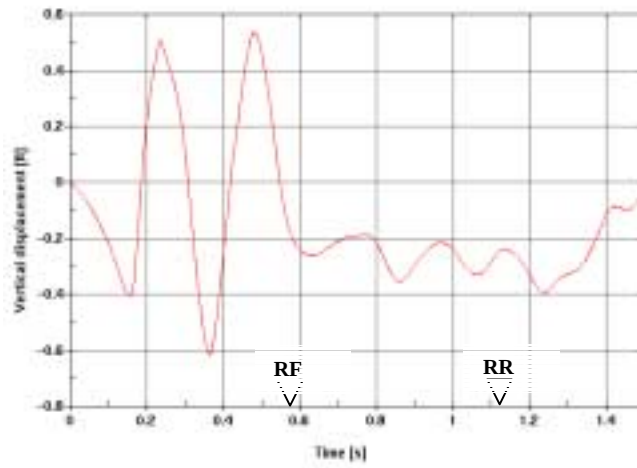


Fig. 2.1.2.3.1.1. (D): Vertical displacement [ft]

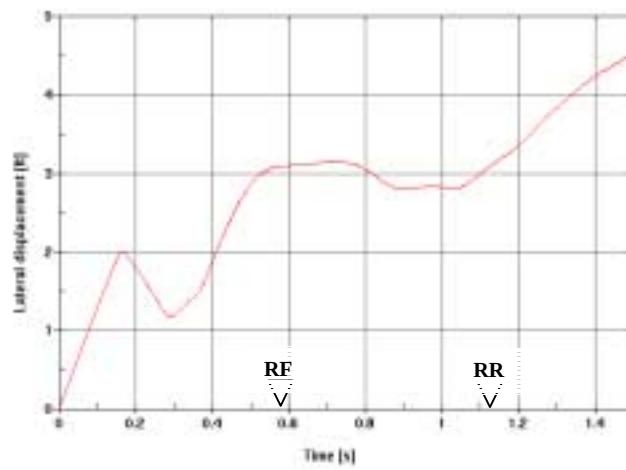


Fig. 2.1.2.3.1.1. (E): Lateral displacement [ft]

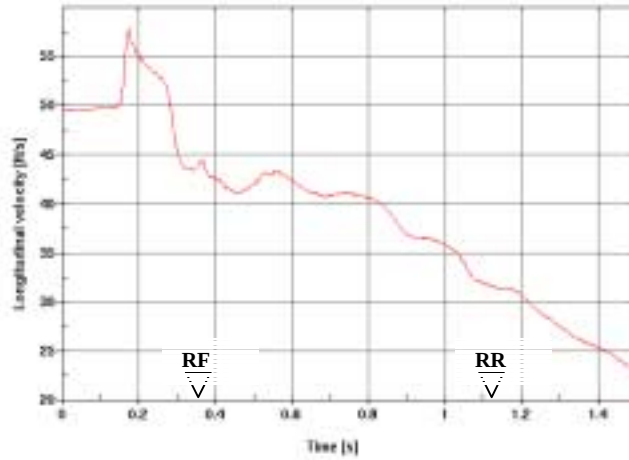


Fig. 2.1.2.3.1.1. (F): Longitudinal velocity [ft/s]

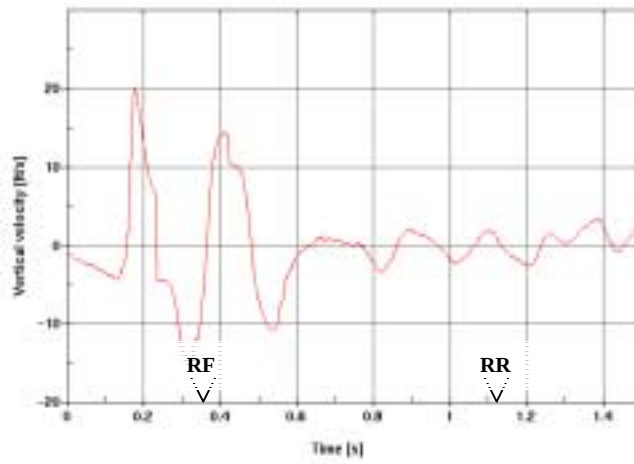


Fig. 2.1.2.3.1.1. (G) Vertical velocity [ft/s]

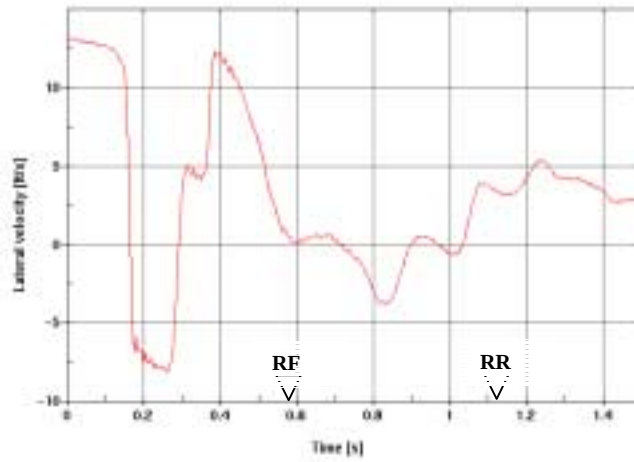


Fig. 2.1.2.3.1.1. (H): Lateral velocity [ft/s]

2.1.2.3.2 Velocity 55 mph

2.1.2.3.2.1 “F” curb

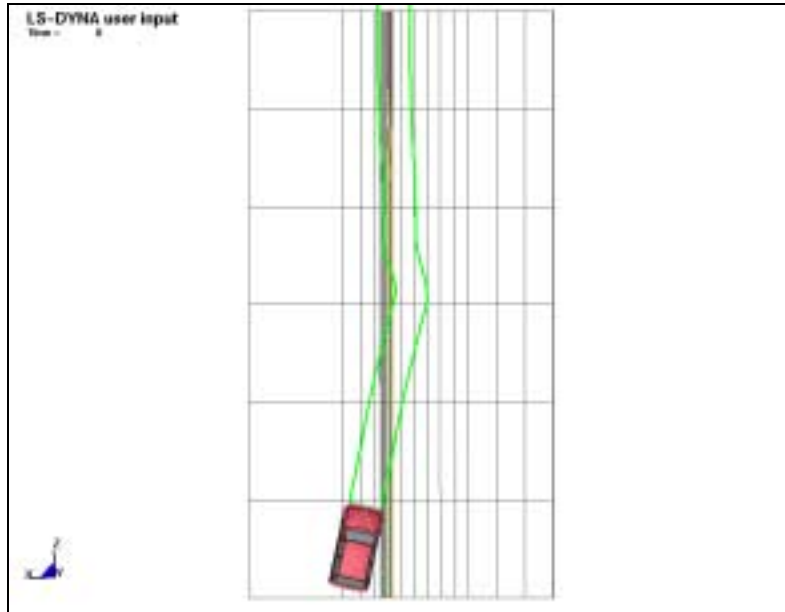


Fig. 2.1.2.3.2.1 (A) Trajectories of bumper corners (upper view)

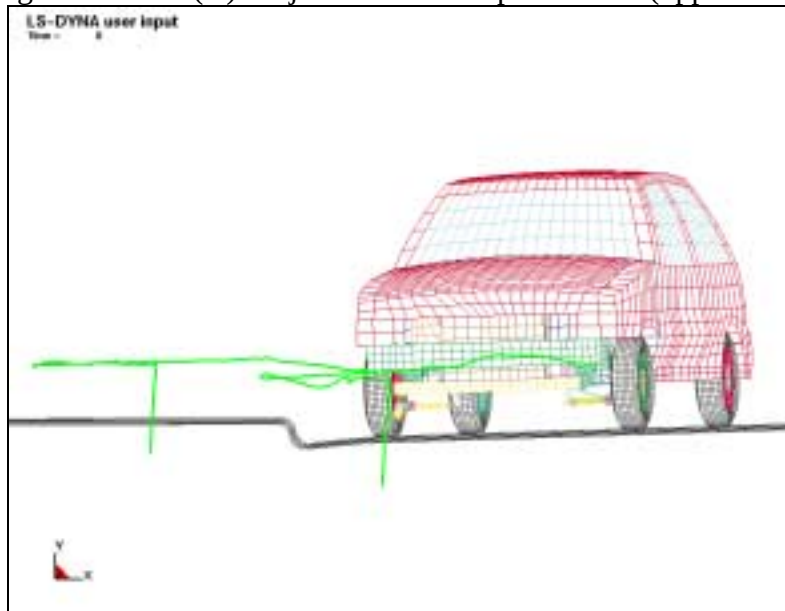


Fig. 2.1.2.3.2.1 (B) Trajectories of bumper corners (lateral view)

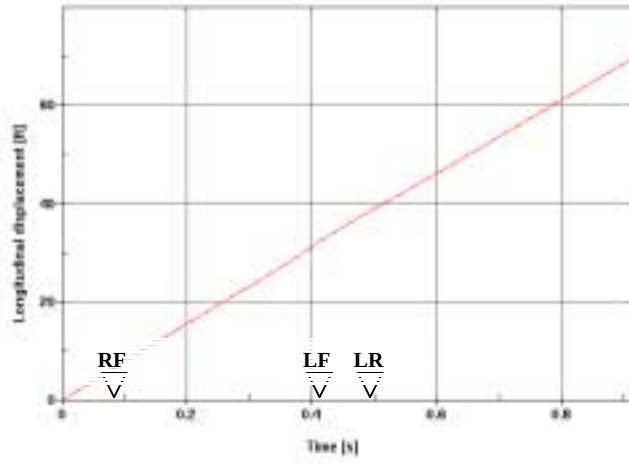


Fig. 2.1.2.3.2.1. (C): Longitudinal displacement [ft]

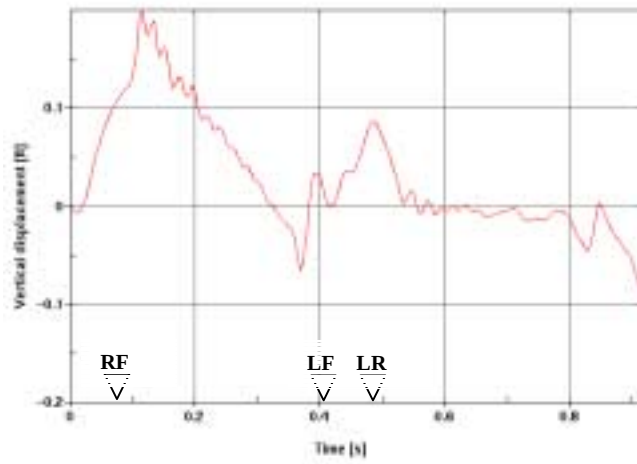


Fig. 2.1.2.3.2.1. (D): Vertical displacement [ft]

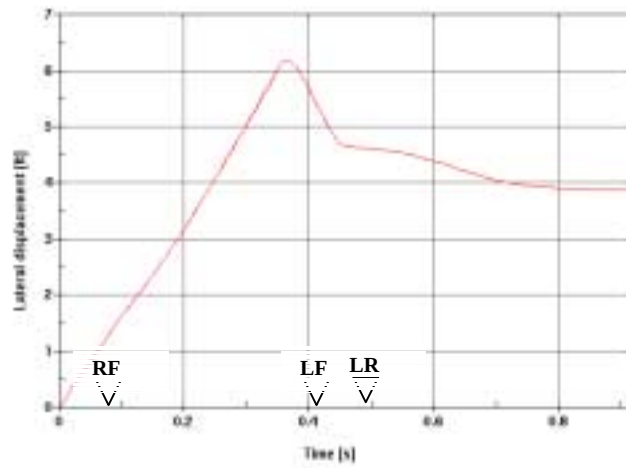


Fig. 2.1.2.3.2.1. (E): Lateral displacement [ft]

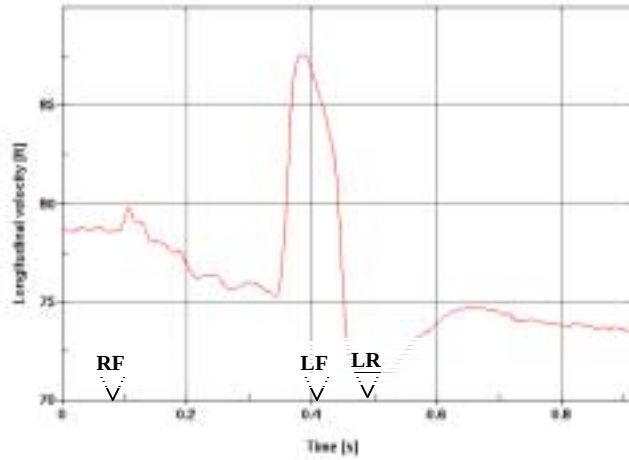


Fig. 2.1.2.3.2.1. (F): Longitudinal velocity [ft/s]

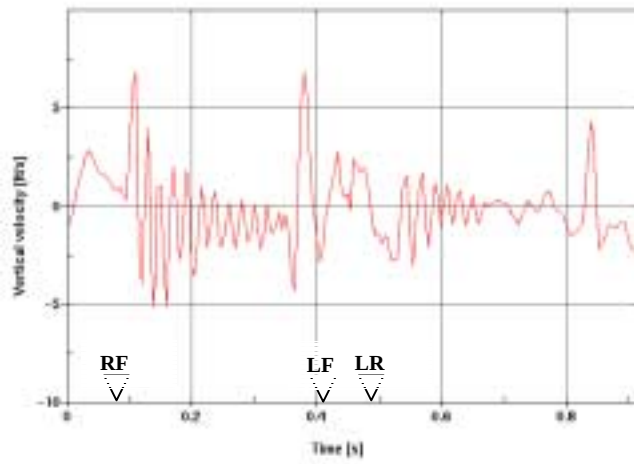


Fig. 2.1.2.3.2.1. (G) Vertical velocity [ft/s]

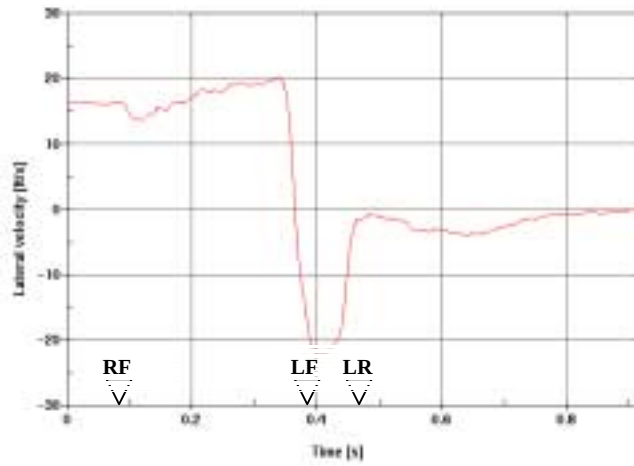


Fig. 2.1.2.3.2.1. (H): Lateral velocity [ft/s]

2.1.2.4 Approach angle 15°

2.1.2.4.1 Velocity 35 mph

2.1.2.4.1.1 “F” curb

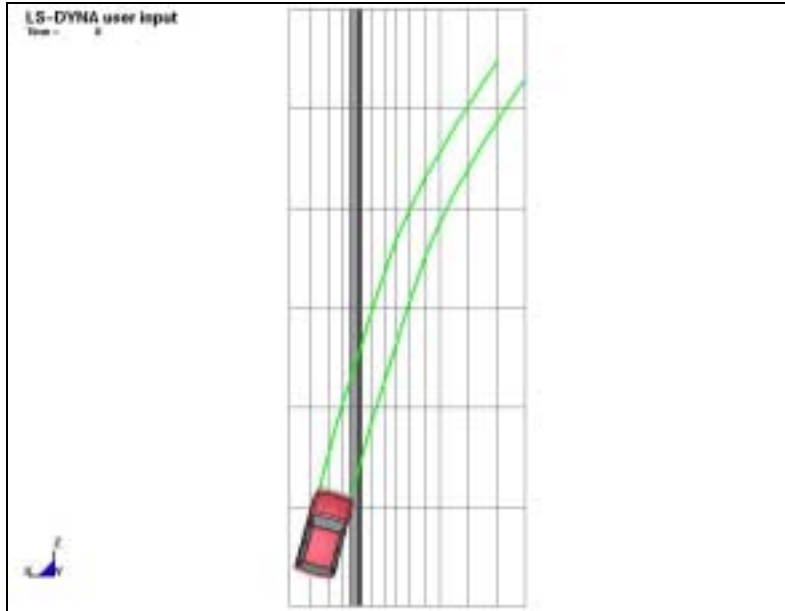


Fig. 2.1.2.4.1.1 (A) Trajectories of bumper corners (upper view)

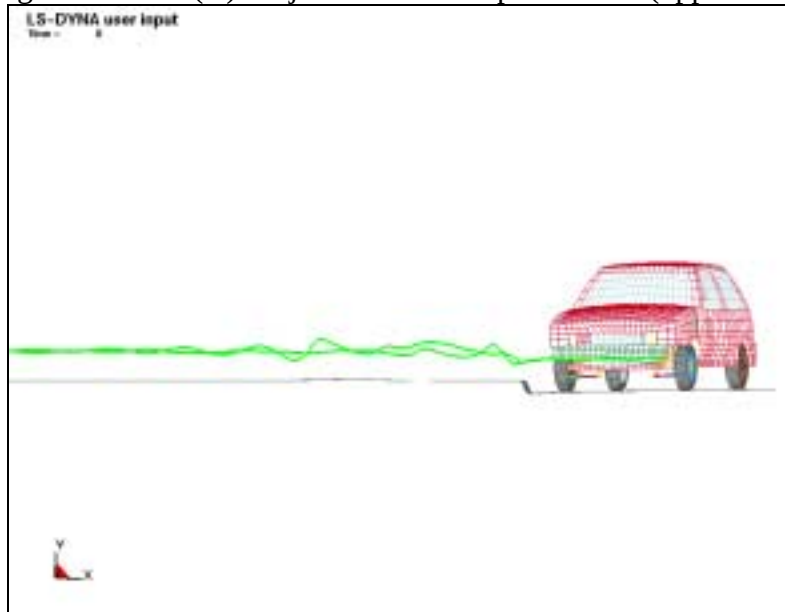


Fig. 2.1.2.4.1.1 (B) Trajectories of bumper corners (lateral view)

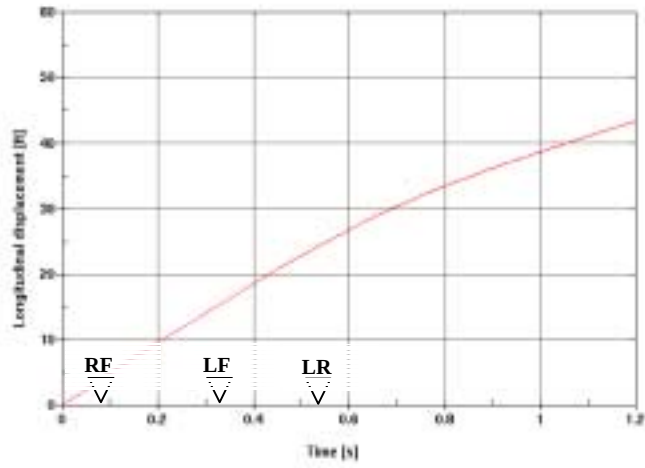


Fig. 2.1.2.4.1.1. (C): Longitudinal displacement [ft]

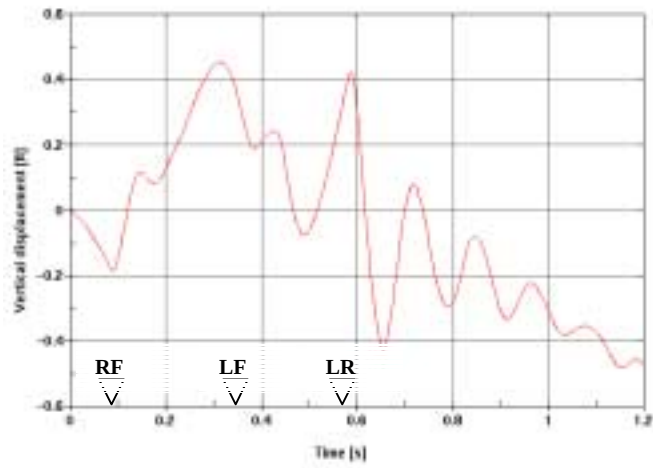


Fig. 2.1.2.4.1.1. (D): Vertical displacement [ft]

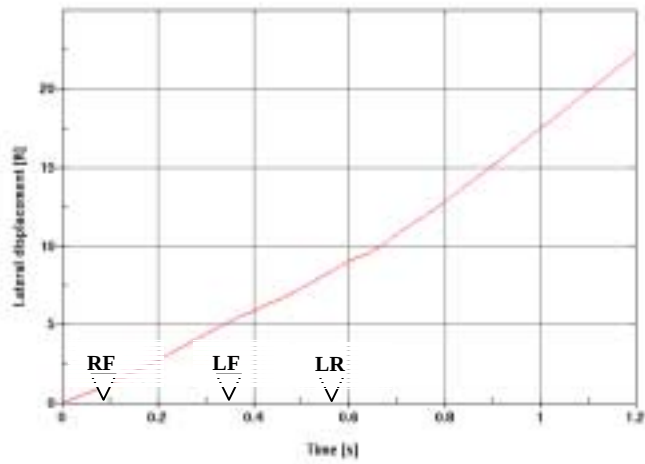


Fig. 2.1.2.4.1.1. (E): Lateral displacement [ft]

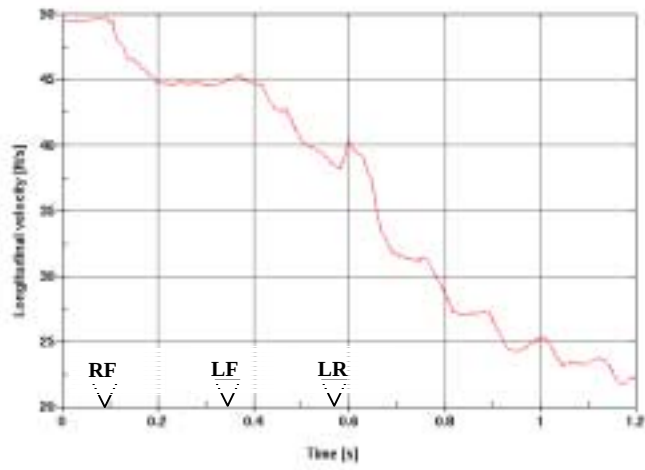


Fig. 2.1.2.4.1.1. (F): Longitudinal velocity [ft/s]

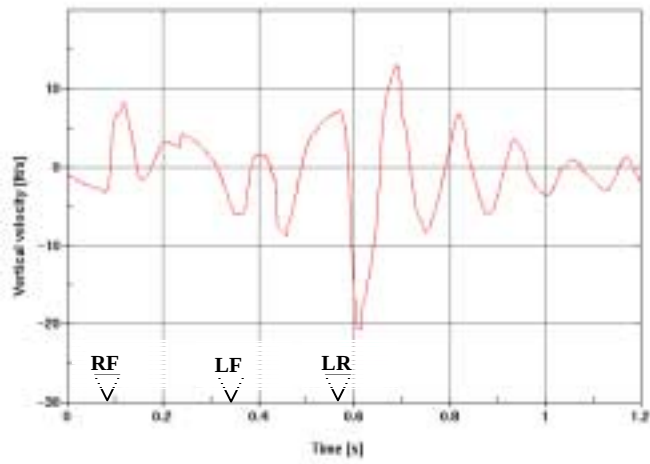


Fig. 2.1.2.4.1.1. (G) Vertical velocity [ft/s]

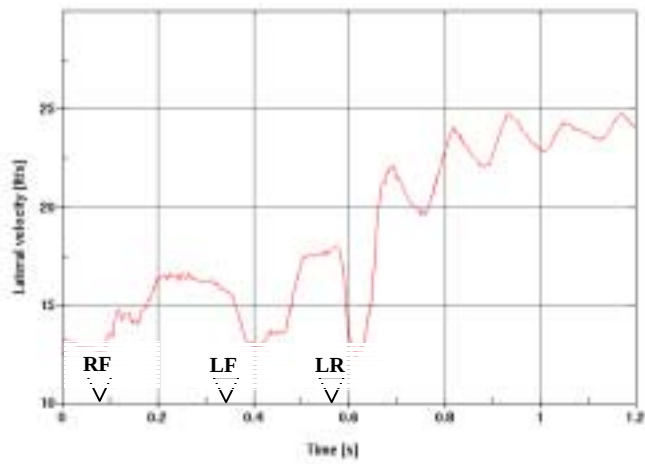


Fig. 2.1.2.4.1.1. (H): Lateral velocity [ft/s]

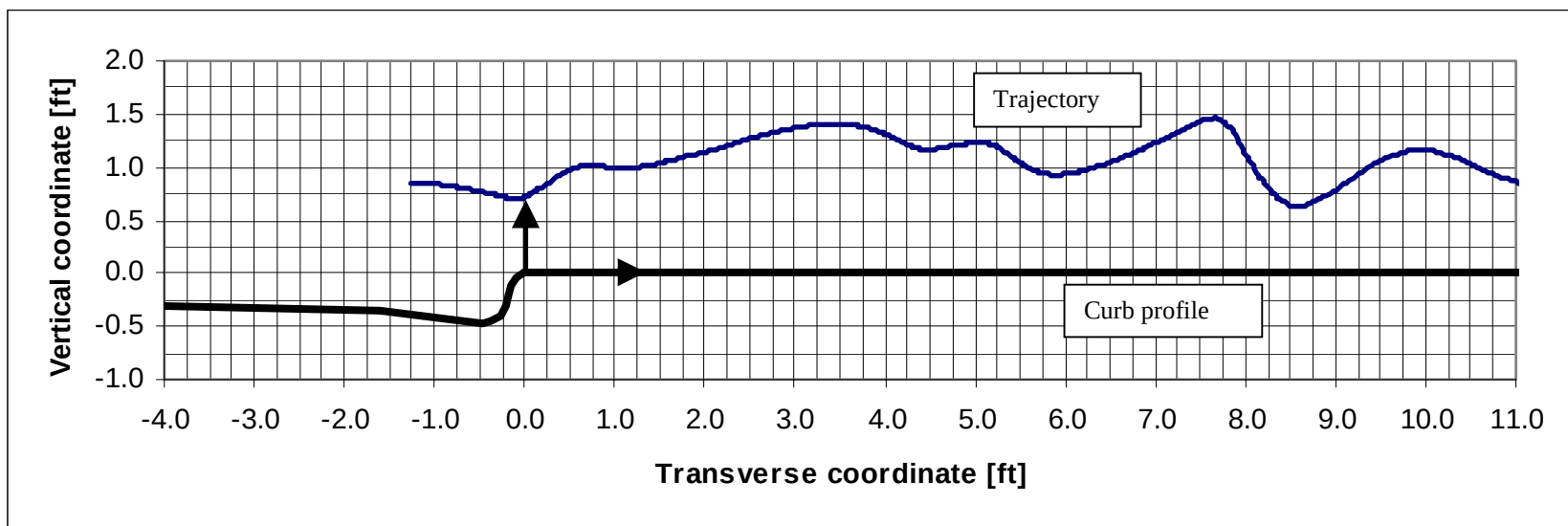


Fig. 2.1.1.4.1.1. (I): Trajectory of the bumper right corner

2.1.2.4.1.2 “E” curb

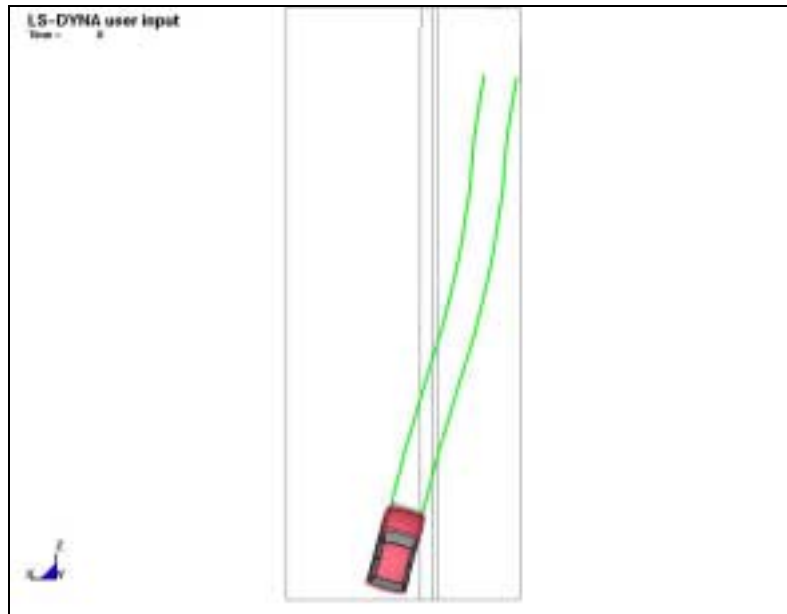


Fig. 2.1.2.4.1.2 (A) Trajectories of bumper corners (upper view)

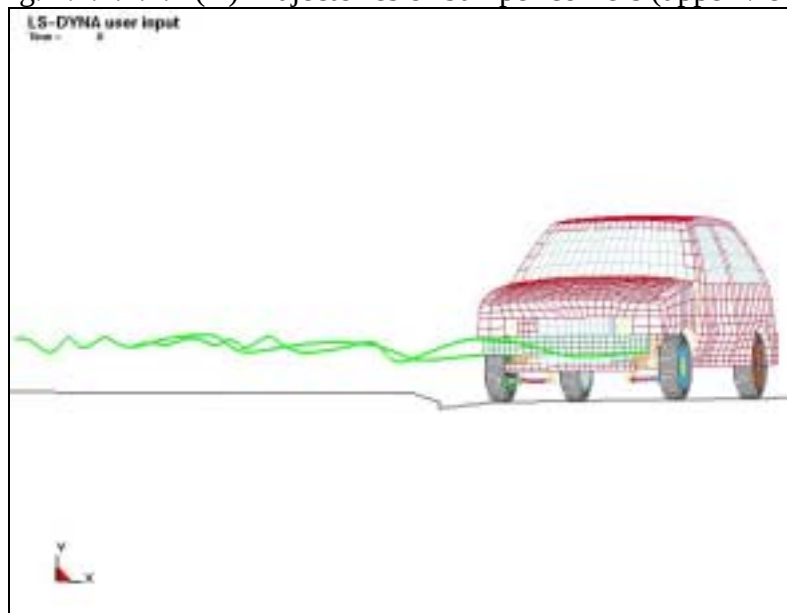


Fig. 2.1.2.4.1.2 (B) Trajectories of bumper corners (lateral view)

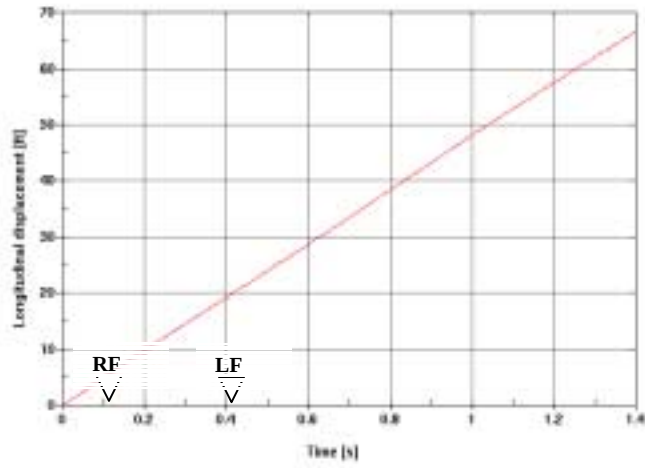


Fig. 2.1.2.4.1.2 (C): Longitudinal displacement [ft]

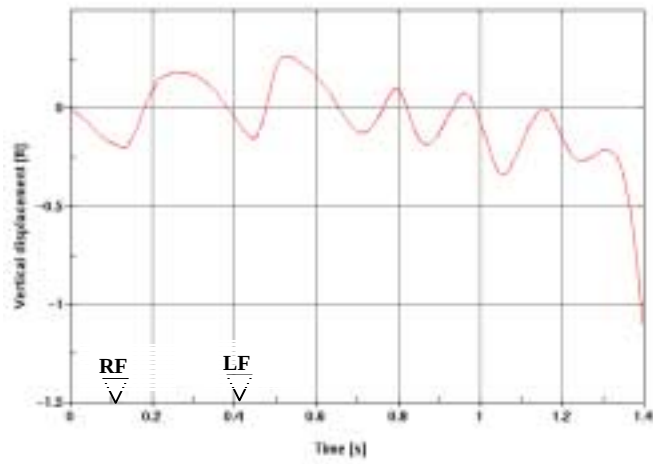


Fig. 2.1.2.4.1.2 (D): Vertical displacement [ft]

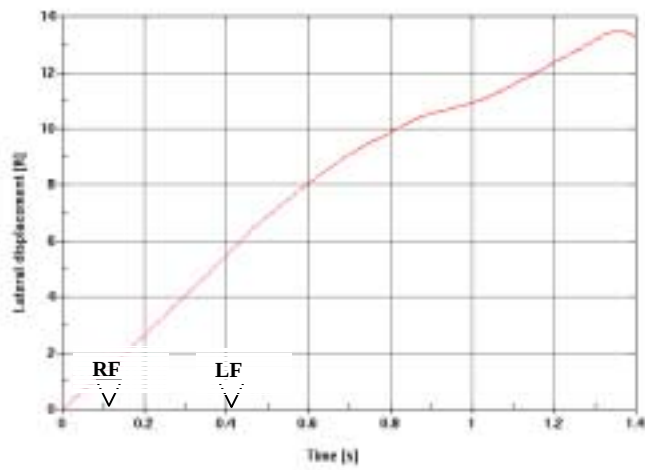


Fig. 2.1.2.4.1.2 (E): Lateral displacement [ft]

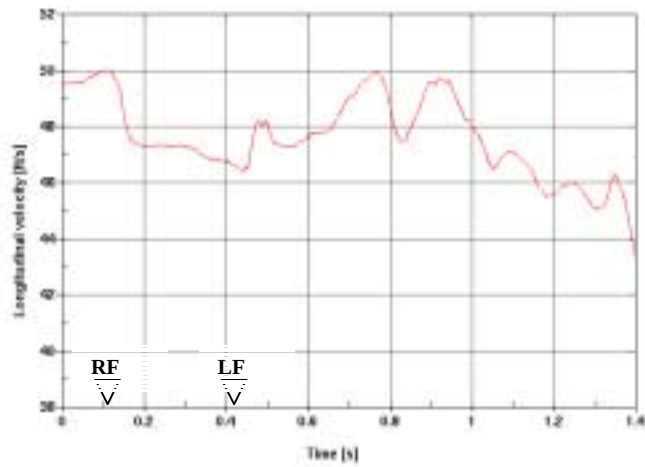


Fig. 2.1.2.4.1.2 (F): Longitudinal velocity [ft/s]

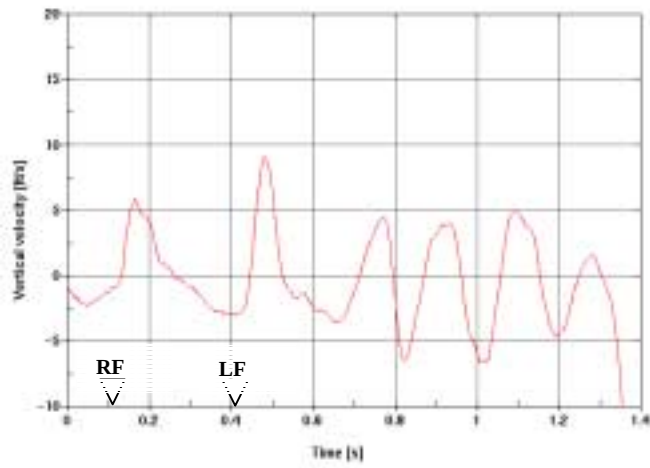


Fig. 2.1.2.4.1.2 (G) Vertical velocity [ft/s]

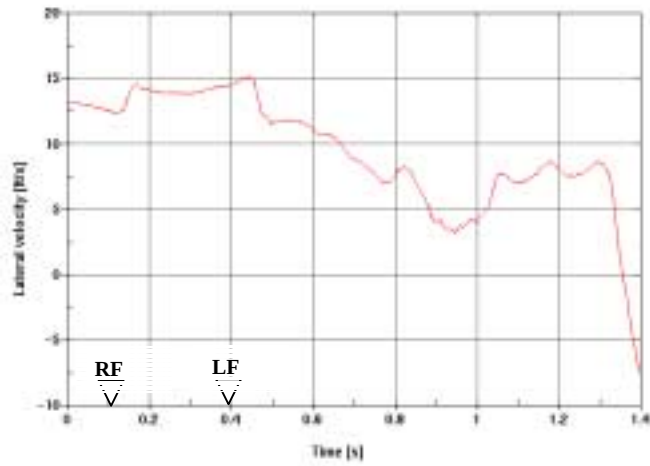


Fig. 2.1.2.4.1.2 (H): Lateral velocity [ft/s]

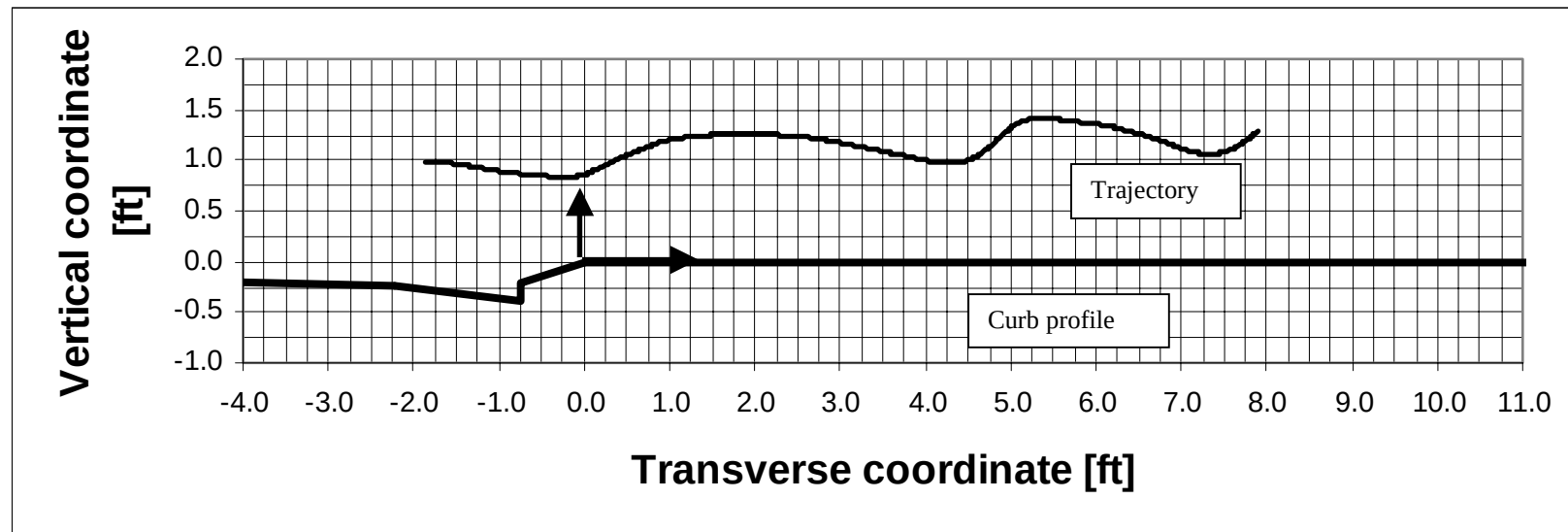


Fig. 2.1.1.4.1.1. (I): Trajectory of the bumper right corner

2.1.2.4.2 Velocity 55 mph

2.1.2.4.2.1 “F” curb

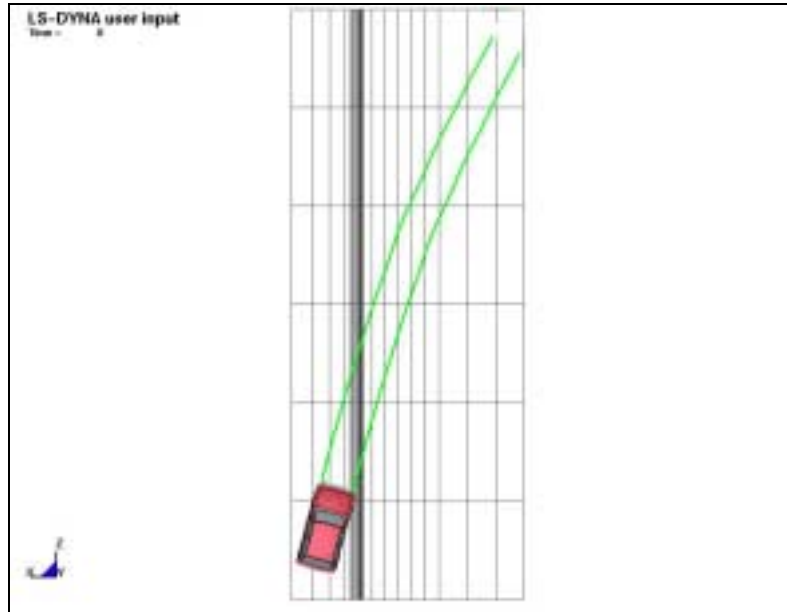


Fig. 2.1.2.4.2.1 (A) Trajectories of bumper corners (upper view)

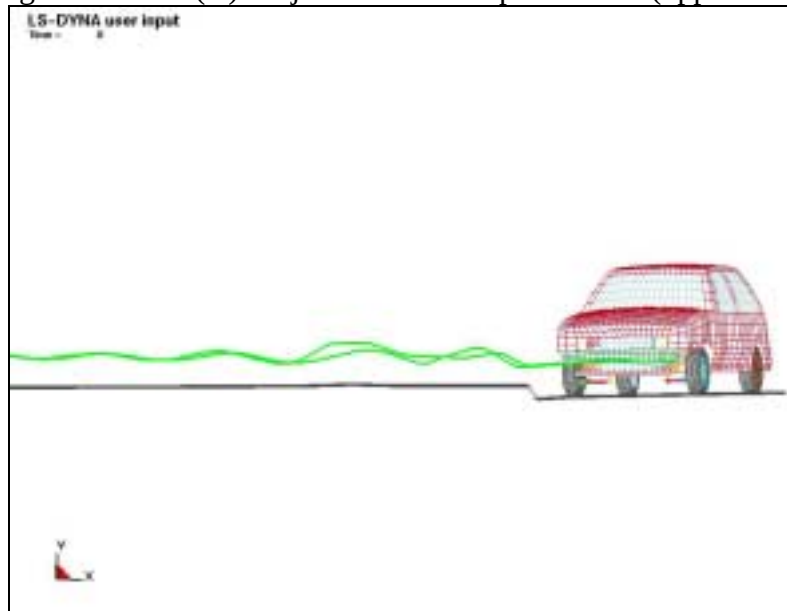


Fig. 2.1.2.4.2.1 (B) Trajectories of bumper corners (lateral view)

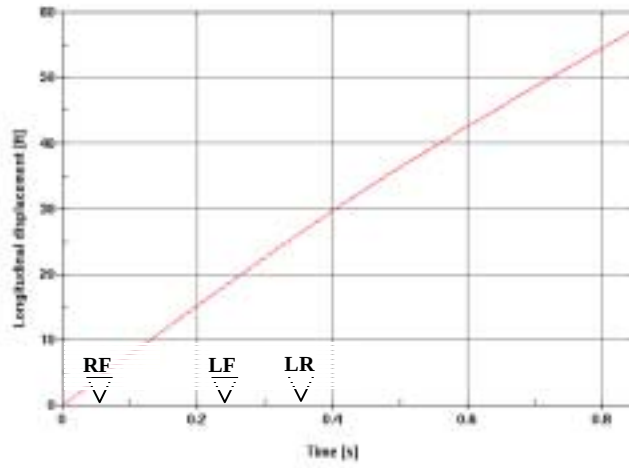


Fig. 2.1.2.4.2.1. (C): Longitudinal displacement [ft]

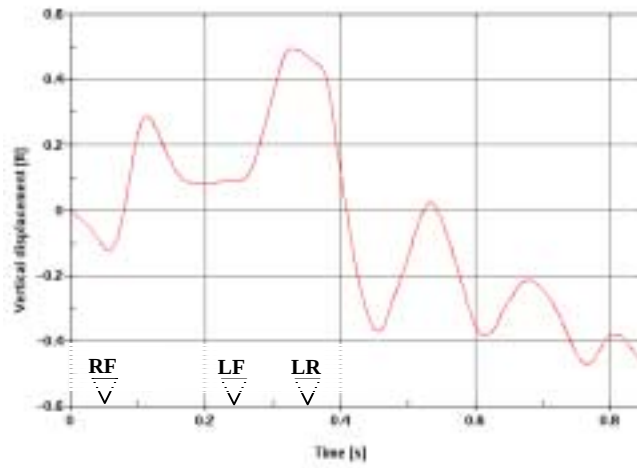


Fig. 2.1.2.4.2.1. (D): Vertical displacement [ft]

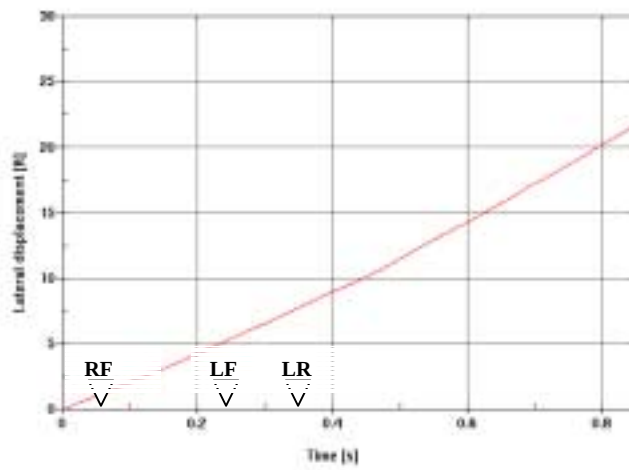


Fig. 2.1.2.4.2.1. (E): Lateral displacement [ft]

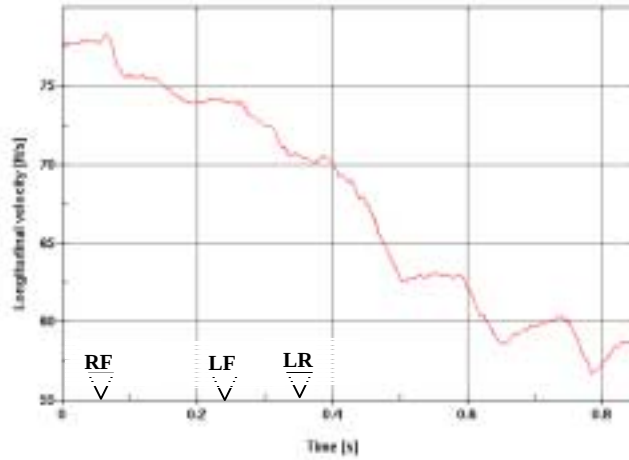


Fig. 2.1.2.4.2.1. (F): Longitudinal velocity [ft/s]

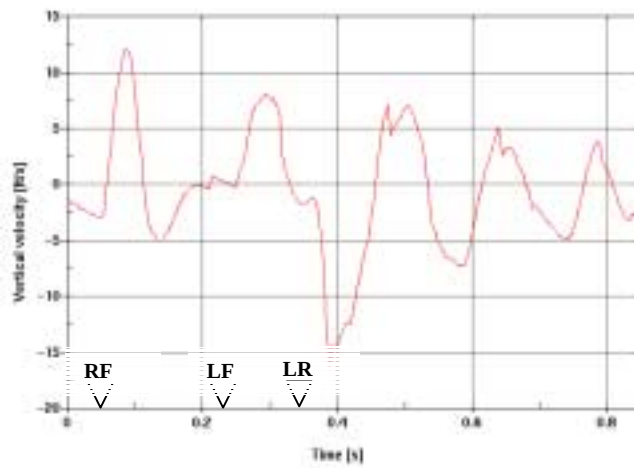


Fig. 2.1.2.4.2.1. (G) Vertical velocity [ft/s]

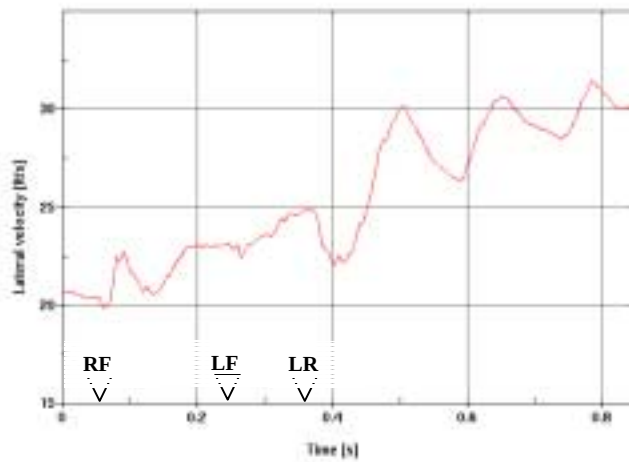


Fig. 2.1.2.4.2.1. (H): Lateral velocity [ft/s]

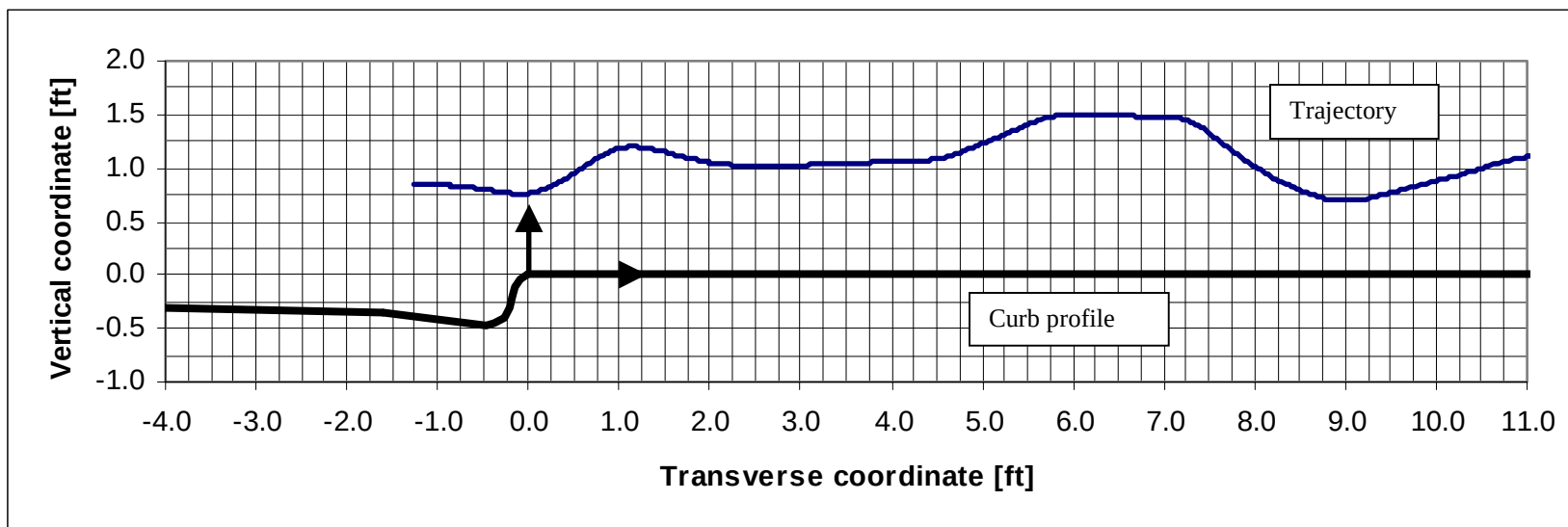


Fig. 2.1.1.4.2.1. (I): Trajectory of the bumper right corner

2.1.2.4.2.2 “E” curb

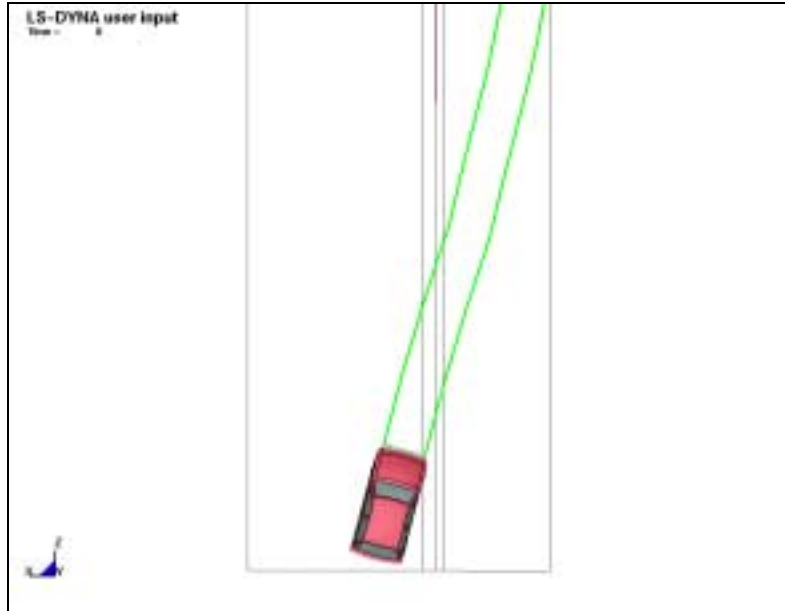


Fig. 2.1.2.4.2.2 (A) Trajectories of bumper corners (upper view)

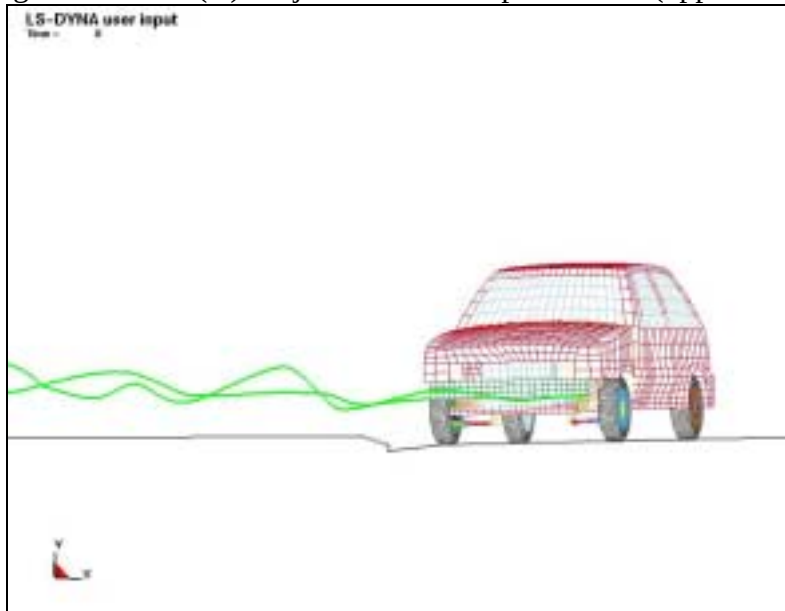


Fig. 2.1.2.4.2.2 (B) Trajectories of bumper corners (lateral view)

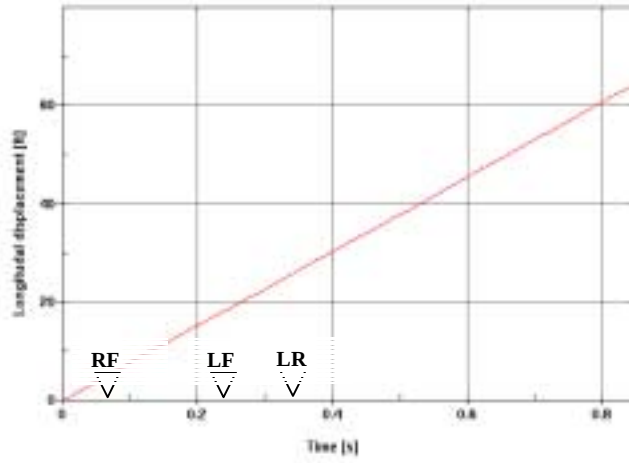


Fig. 2.1.2.4.2.2 (C): Longitudinal displacement [ft]

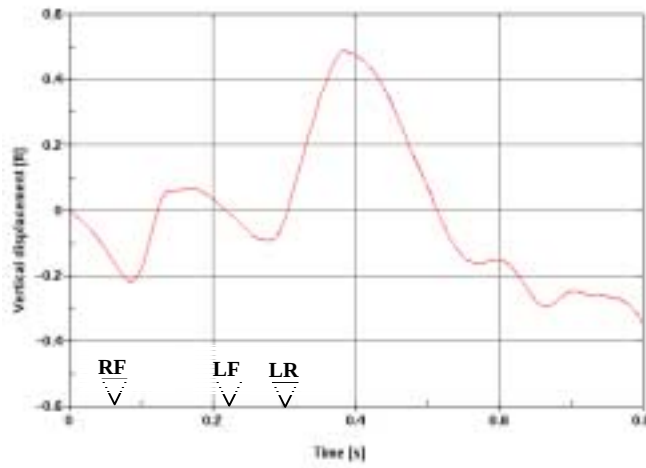


Fig. 2.1.2.4.2.2 (D): Vertical displacement [ft]

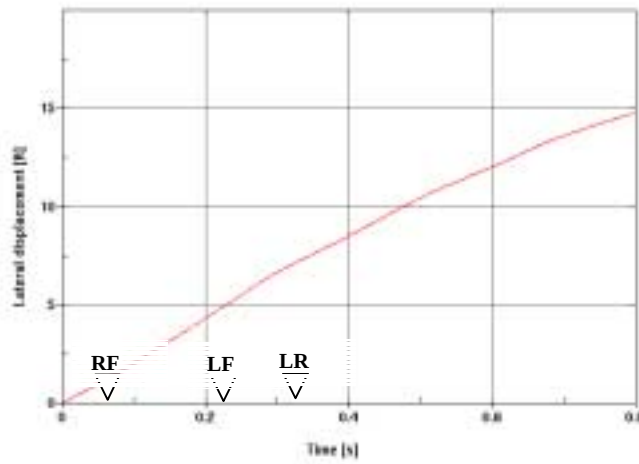


Fig. 2.1.2.4.2.2 (E): Lateral displacement [ft]

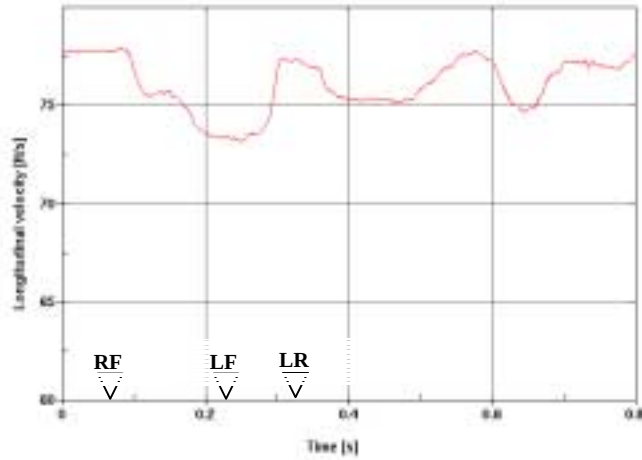


Fig. 2.1.2.4.2.2 (F): Longitudinal velocity [ft/s]

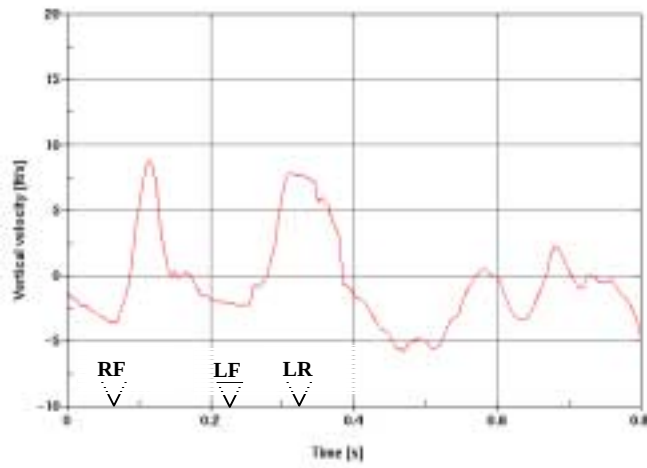


Fig. 2.1.2.4.2.2 (G) Vertical velocity [ft/s]

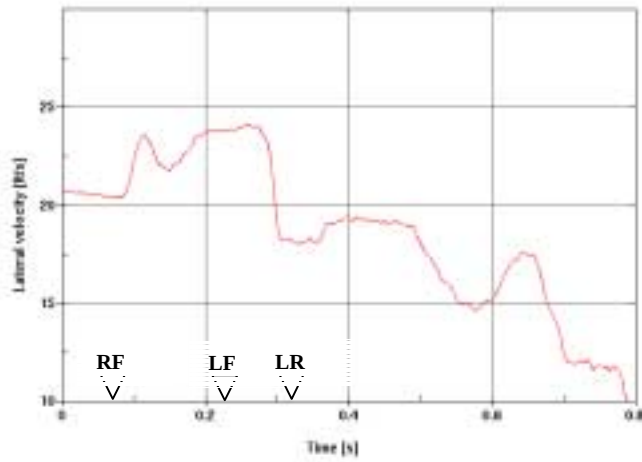


Fig. 2.1.2.4.2.2 (H): Lateral velocity [ft/s]

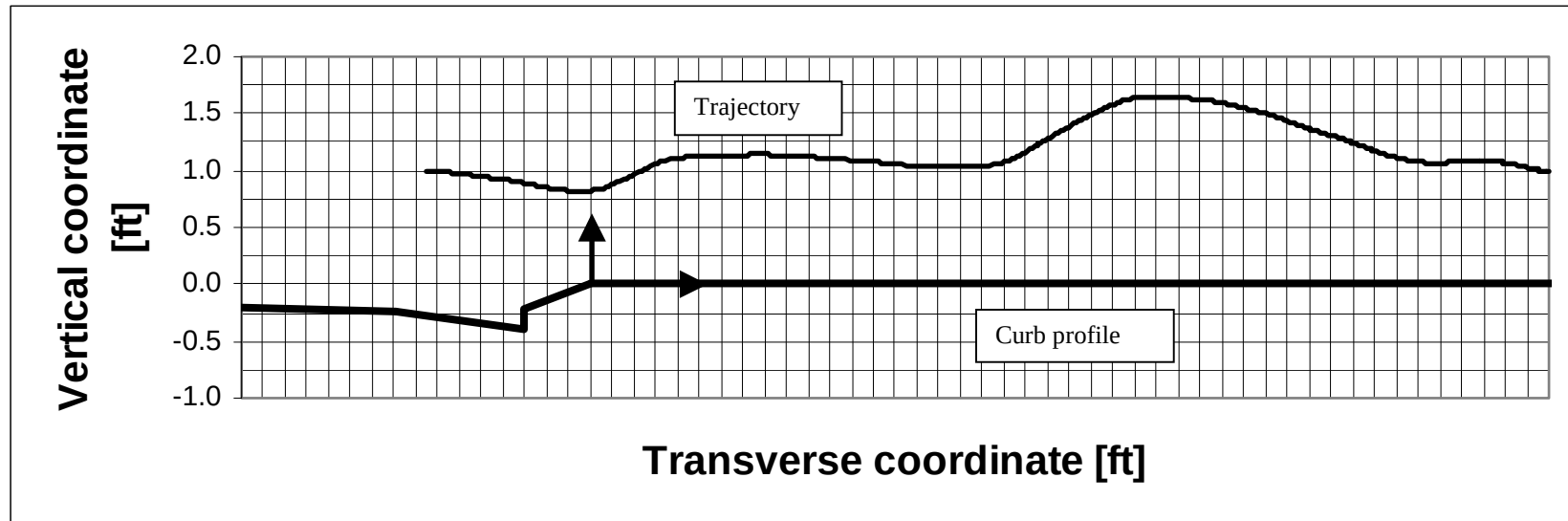


Fig. 2.1.1.4.2.2. (I): Trajectory of the bumper right corner

2.2 Chevrolet C2500

2.2.1 Slope 0.06

2.2.1.1 Approach angle 3°

2.2.1.1.1 Velocity 35 mph

2.2.1.1.1.1 “F” curb

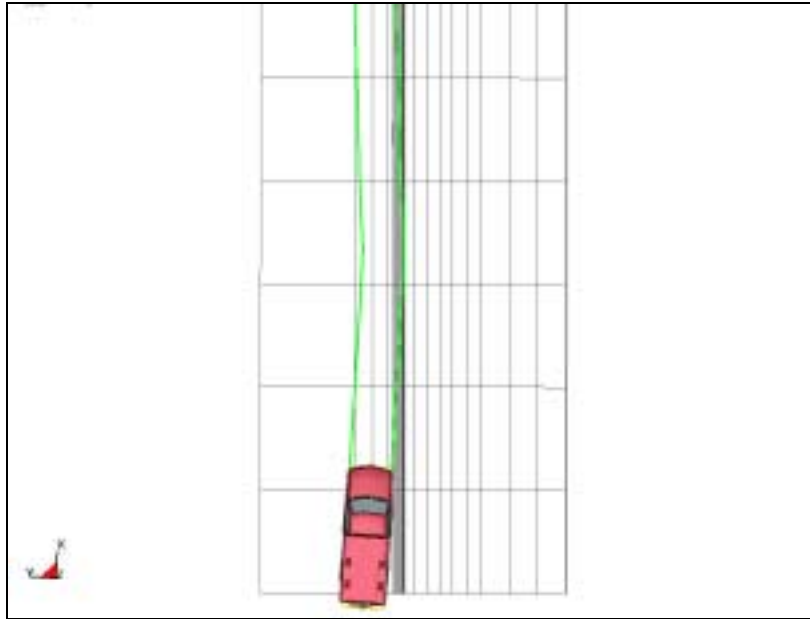


Fig. 2.2.1.1.1.1. (A) Trajectories of bumper corners (upper view)

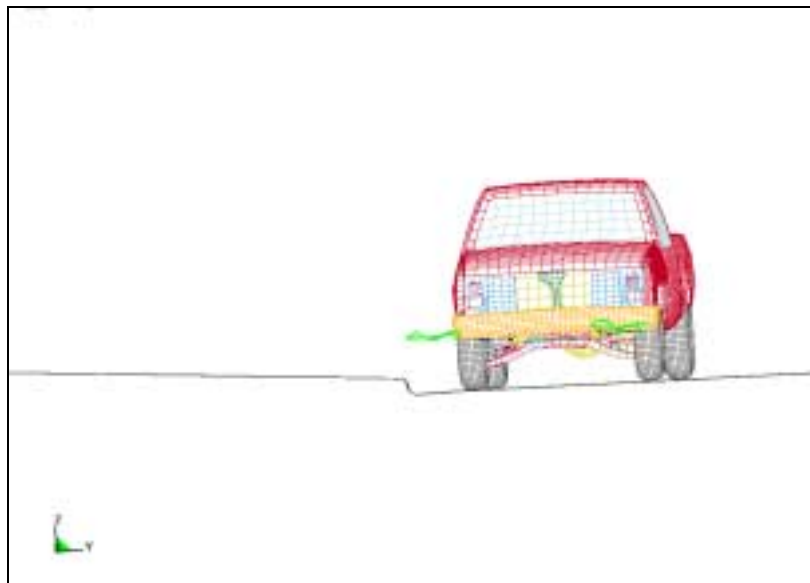


Fig. 2.2.1.1.1.1. (B) Trajectories of bumper corners (front view)

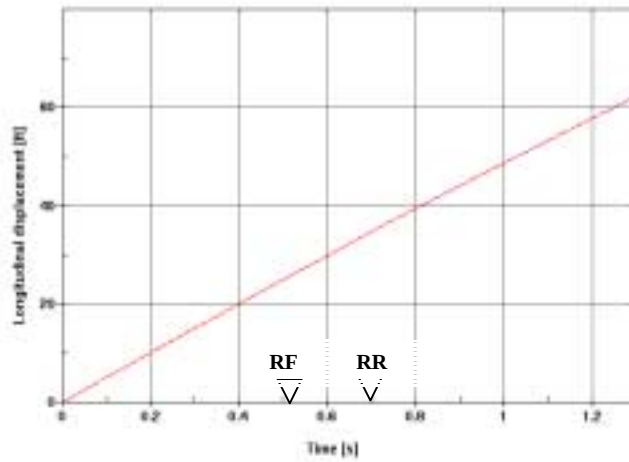


Fig. 2.2.1.1.1.1. (C): Longitudinal displacement [ft]

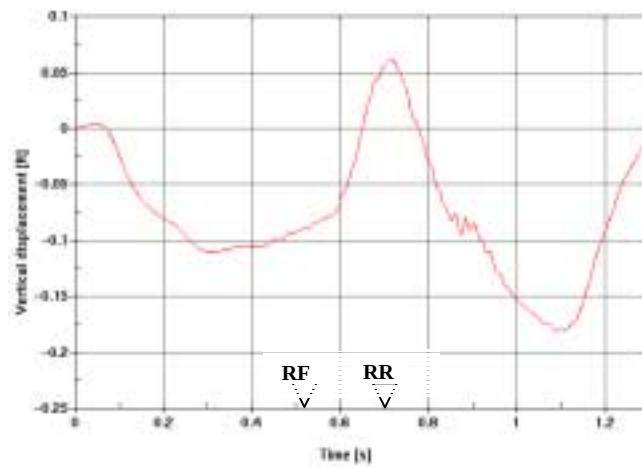


Fig. 2.2.1.1.1.1. (D): Vertical displacement [ft]

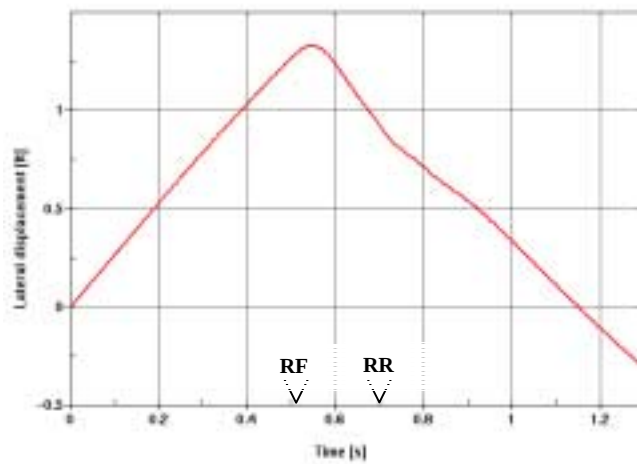


Fig. 2.2.1.1.1.1. (E): Lateral displacement [ft]

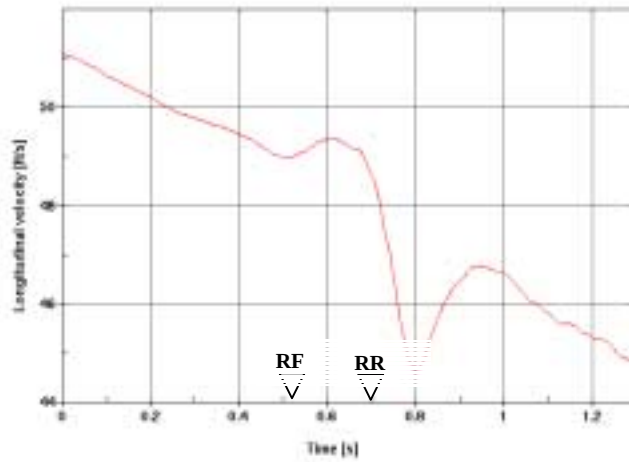


Fig. 2.2.1.1.1.1. (F): Longitudinal velocity [ft/s]

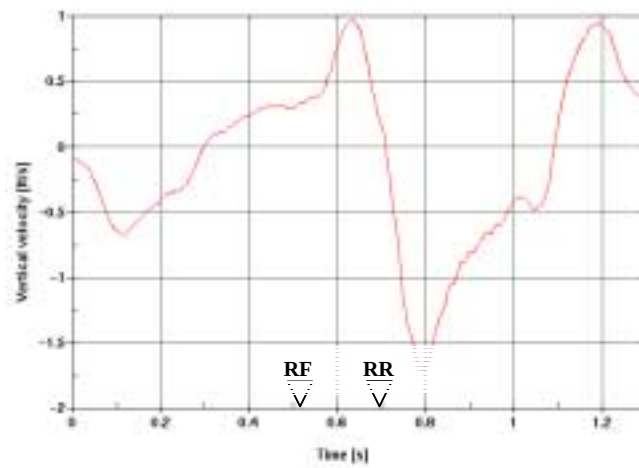


Fig. 2.2.1.1.1.1. (G) Vertical velocity [ft/s]

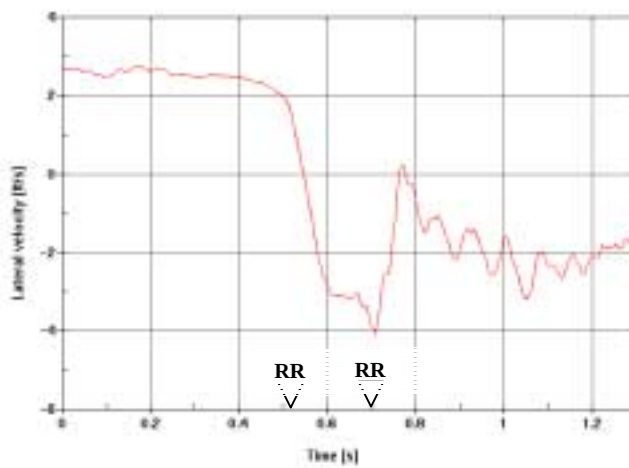


Fig. 2.2.1.1.1.1. (H): Lateral velocity [ft/s]

2.2.1.1.1.2 “E” curb

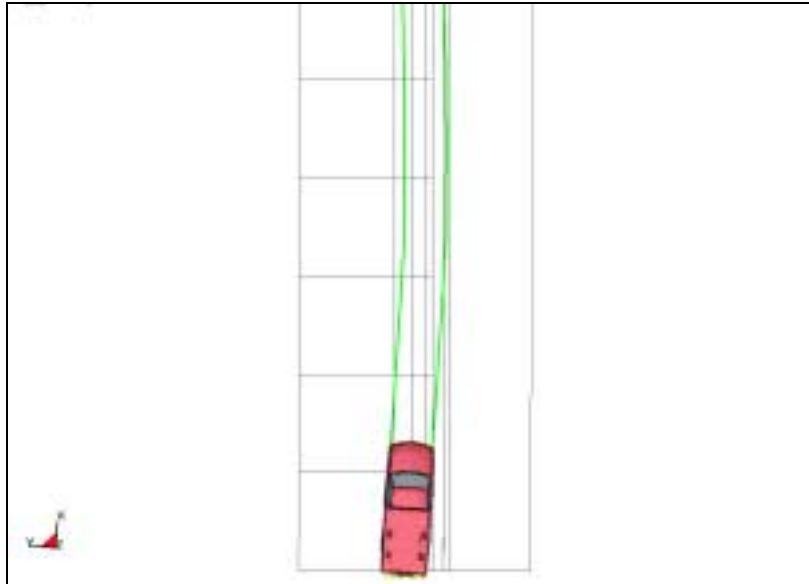


Fig. 2.2.1.1.1.2. (A) Trajectories of bumper corners (upper view)

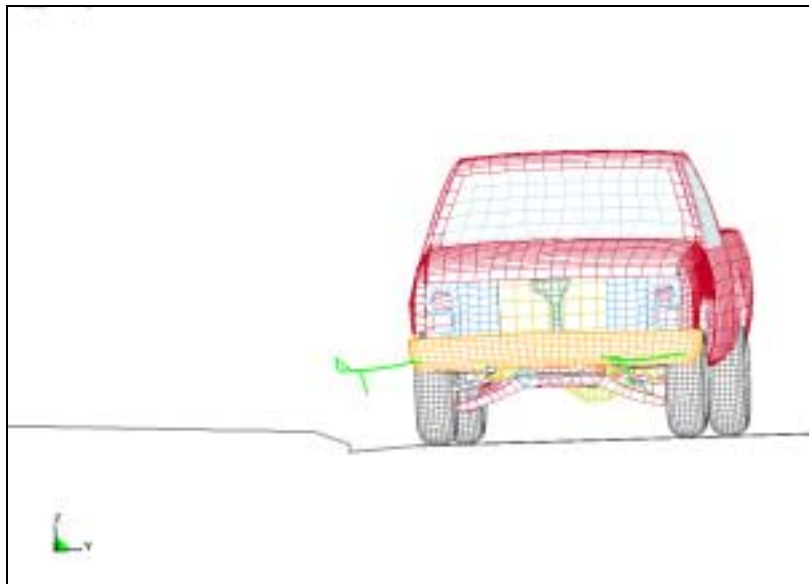


Fig. 2.2.1.1.1.2. (B) Trajectories of bumper corners (lateral view)

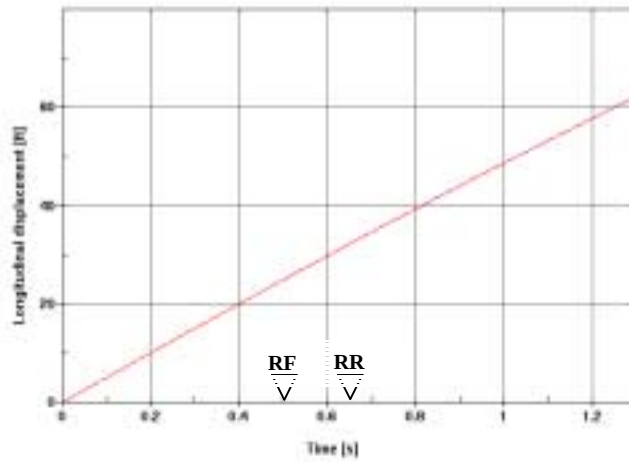


Fig. 2.2.1.1.1.2. (C): Longitudinal displacement [ft]

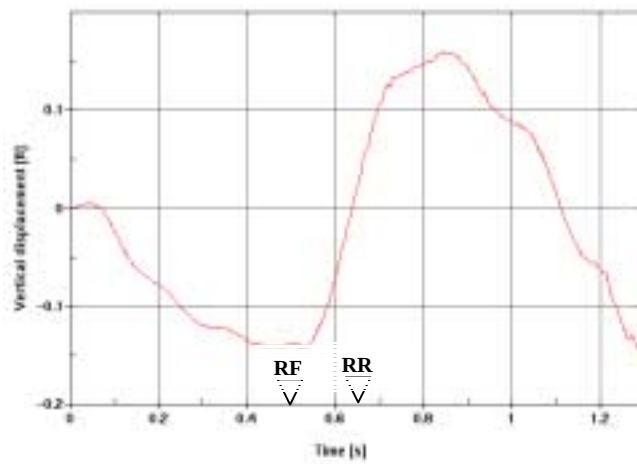


Fig. 2.2.1.1.1.2. (D): Vertical displacement [ft]

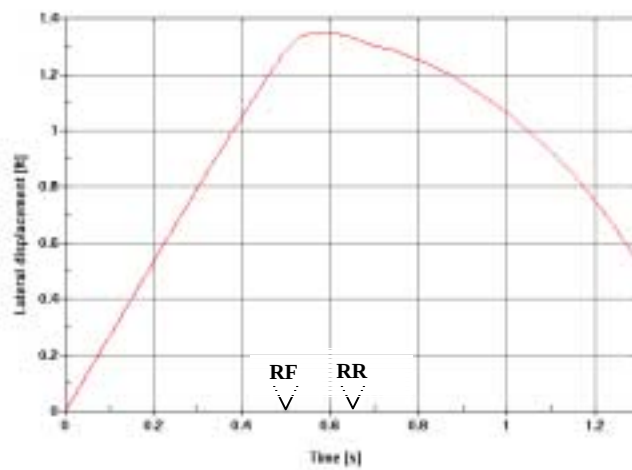


Fig. 2.2.1.1.1.2. (E): Lateral displacement [ft]

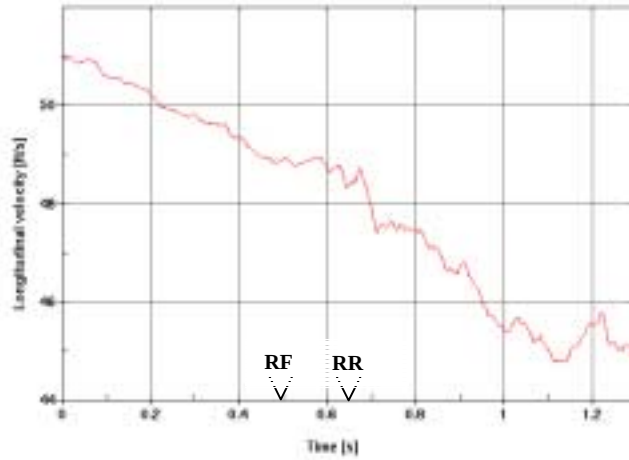


Fig. 2.2.1.1.1.2. (F): Longitudinal velocity [ft/s]

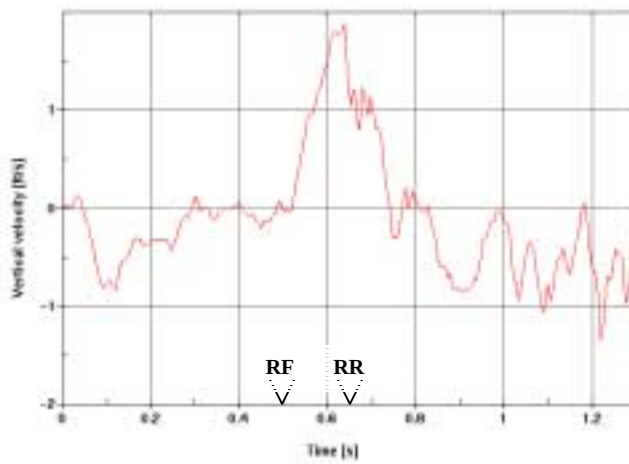


Fig. 2.2.1.1.1.2. (G) Vertical velocity [ft/s]

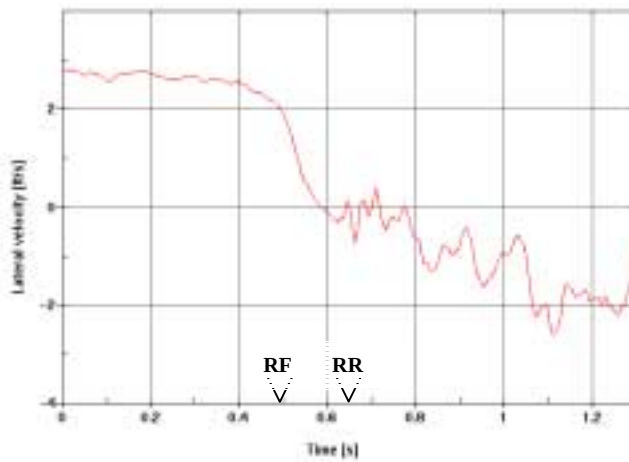


Fig. 2.2.1.1.1.2. (H): Lateral velocity [ft/s]

2.2.1.1.2 Velocity 55 mph

2.2.1.1.2.1 “F” curb

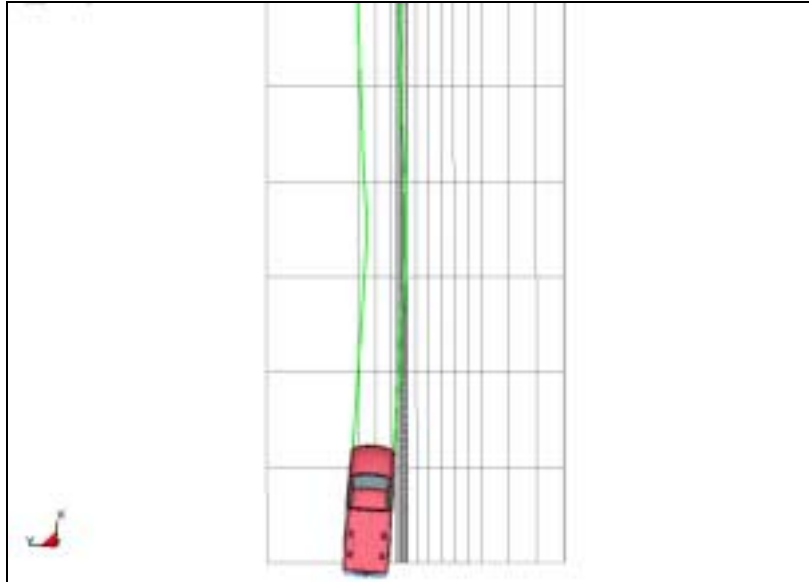


Fig. 2.2.1.1.2.1. (A) Trajectories of bumper corners (upper view)

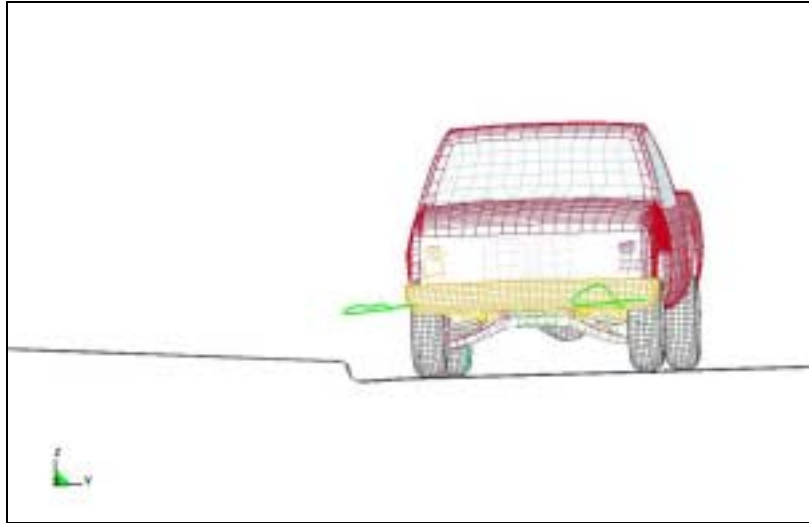


Fig. 2.2.1.1.2.1. (B) Trajectories of bumper corners (lateral view)

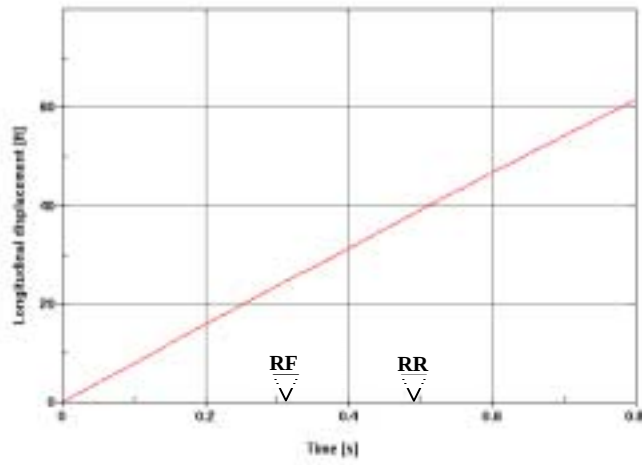


Fig. 2.2.1.1.2.1. (C): Longitudinal displacement [ft]

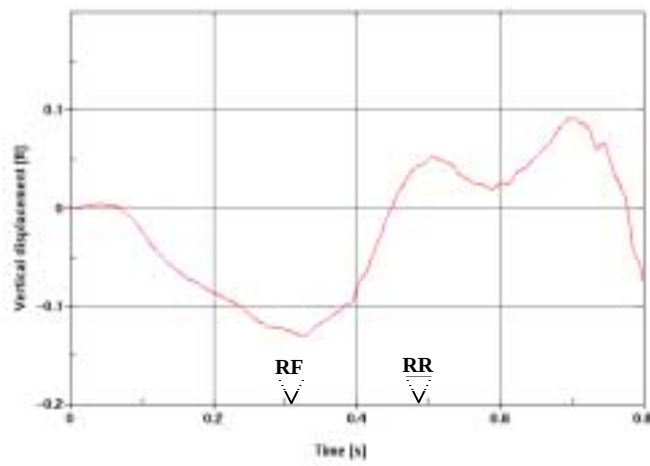


Fig. 2.2.1.1.2.1. (D): Vertical displacement [ft]

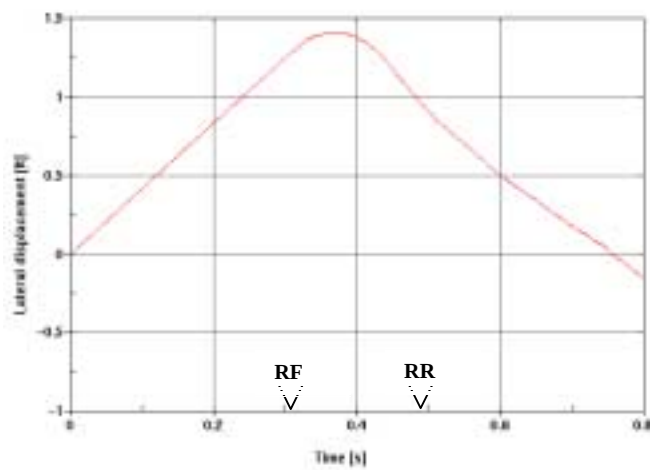


Fig. 2.2.1.1.2.1. (E): Lateral displacement [ft]

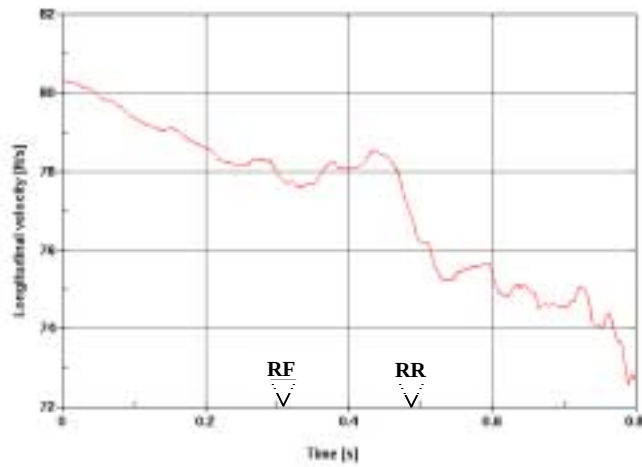


Fig. 2.2.1.1.2.1. (F): Longitudinal velocity [ft/s]

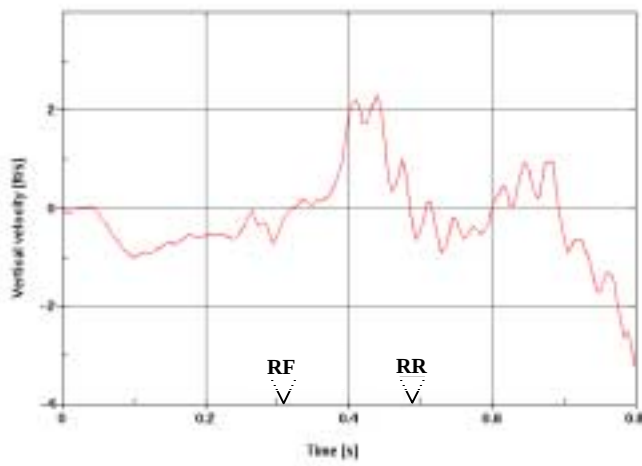


Fig. 2.2.1.1.2.1. (G) Vertical velocity [ft/s]

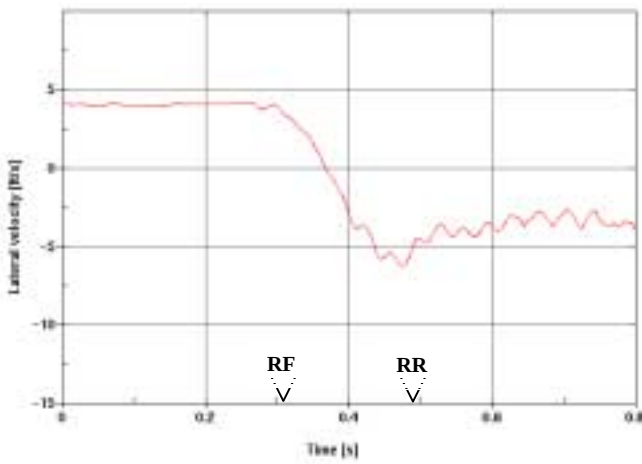


Fig. 2.2.1.1.2.1. (H): Lateral velocity [ft/s]

2.2.1.1.2.2 “E” curb

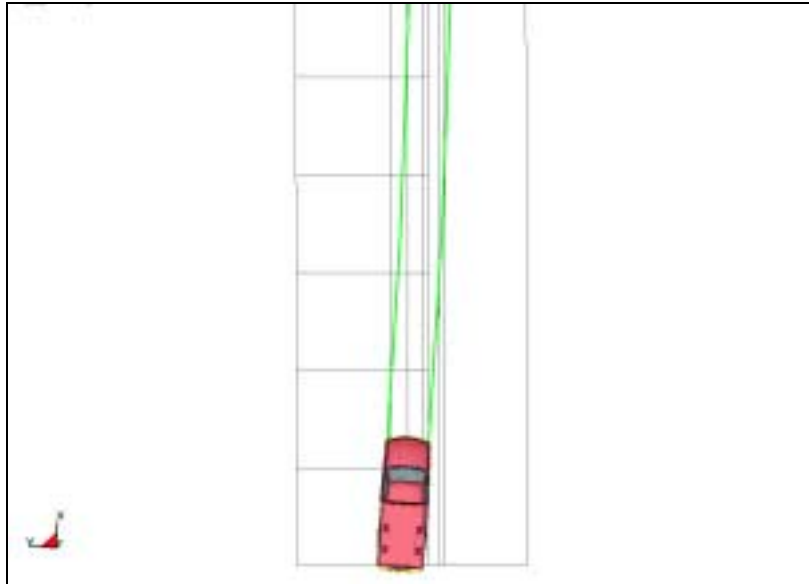


Fig. 2.2.1.1.2.2. (A) Trajectories of bumper corners (upper view)

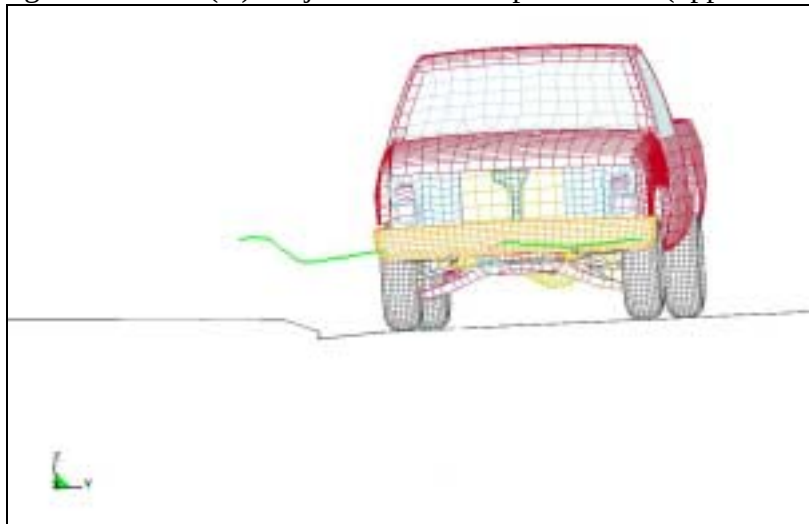


Fig. 2.2.1.1.2.2. (B) Trajectories of bumper corners (lateral view)

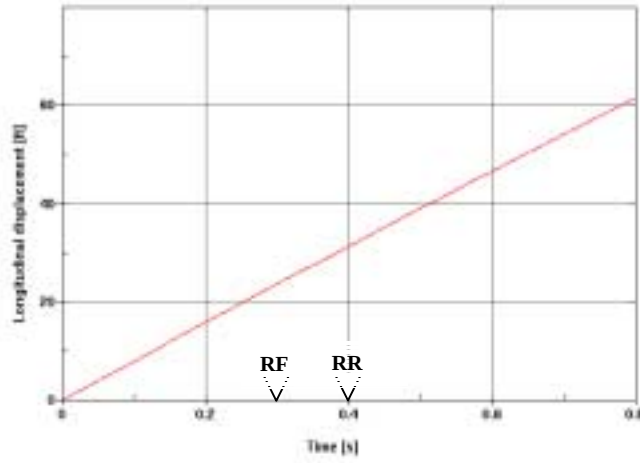


Fig. 2.2.1.1.2.2. (C): Longitudinal displacement [ft]

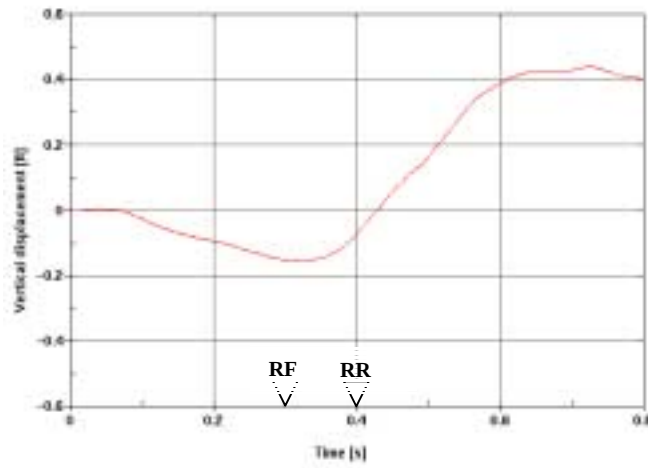


Fig. 2.2.1.1.2.2. (D): Vertical displacement [ft]

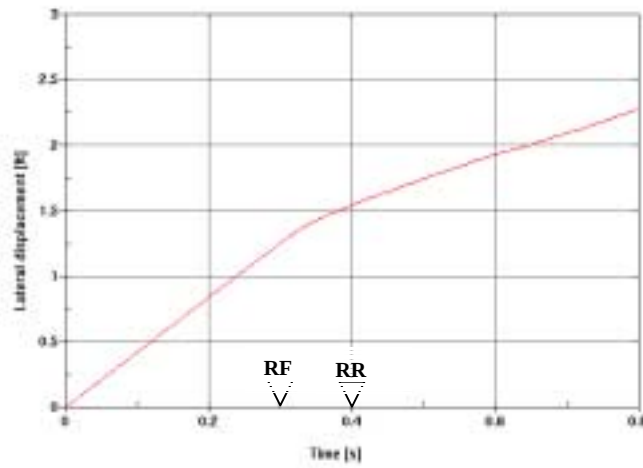


Fig. 2.2.1.1.2.2. (E): Lateral displacement [ft]

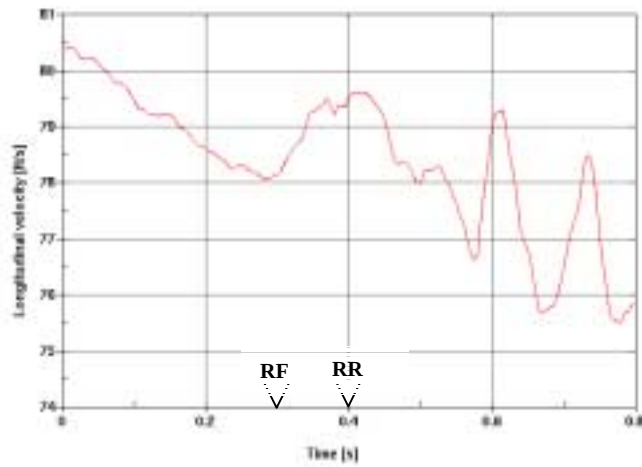


Fig. 2.2.1.1.2.2. (F): Longitudinal velocity [ft/s]

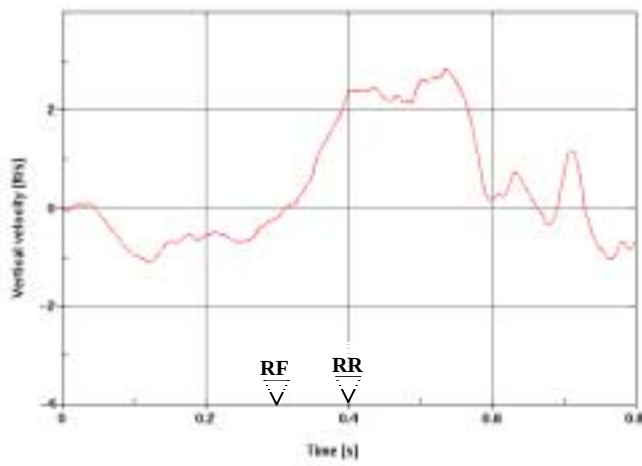


Fig. 2.2.1.1.2.2. (G) Vertical velocity [ft/s]



Fig. 2.2.1.1.2.2. (H): Lateral velocity [ft/s]

2.2.1.2 Approach angle 5°
2.2.1.2.1 Velocity 35 mph
2.2.1.2.1.1 “F” curb

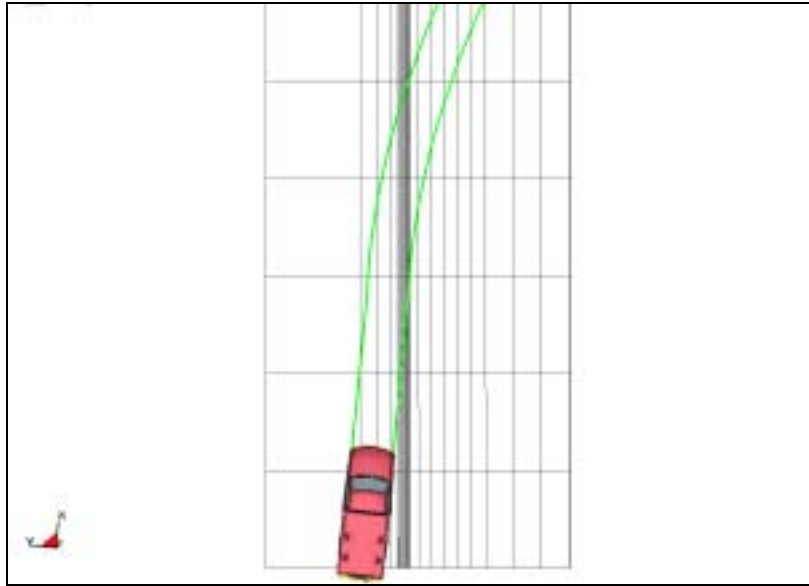


Fig. 2.2.1.2.1.1. (A) Trajectories of bumper corners (upper view)

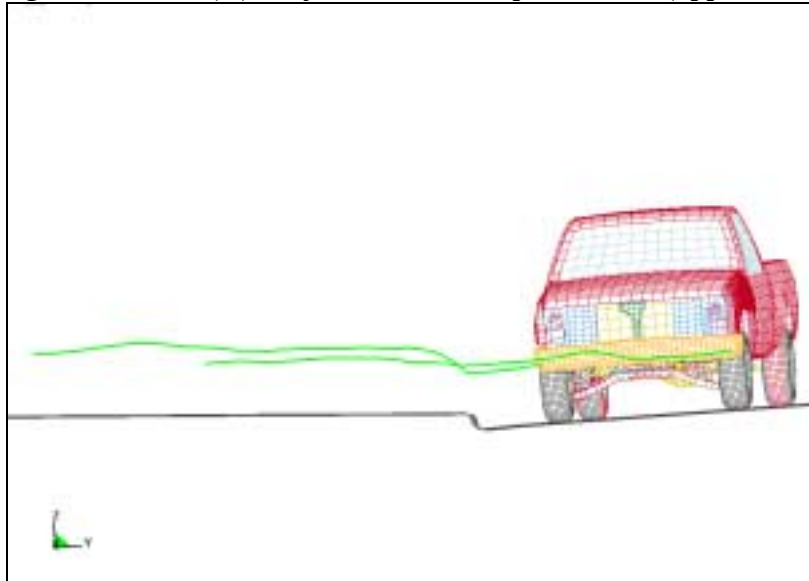


Fig. 2.2.1.2.1.1. (B) Trajectories of bumper corners (lateral view)

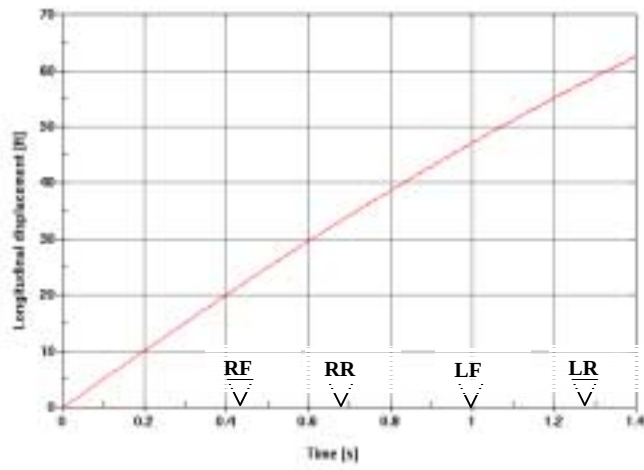


Fig. 2.2.1.2.1.1. (C): Longitudinal displacement [ft]

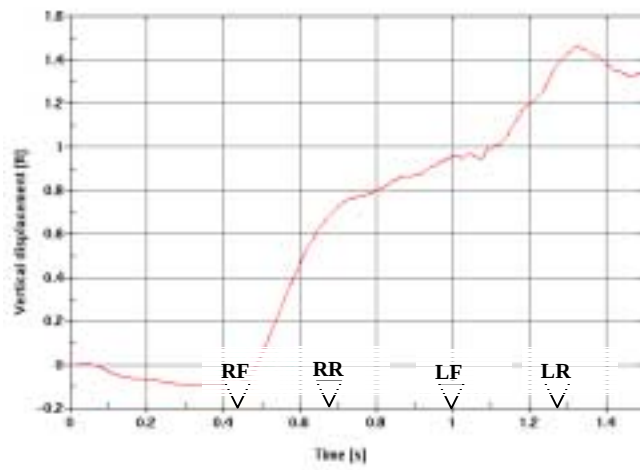


Fig. 2.2.1.2.1.1. (D): Vertical displacement [ft]

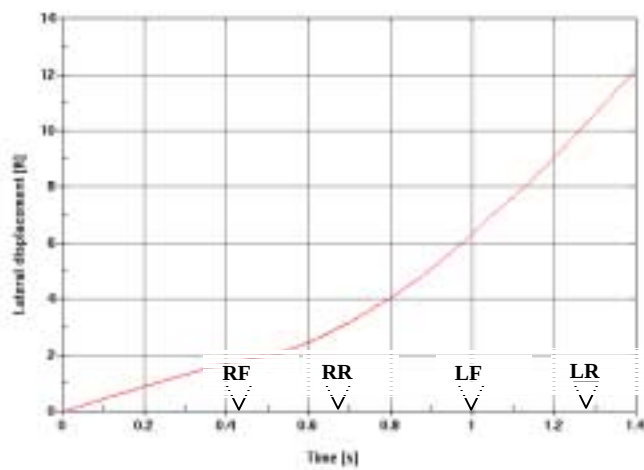


Fig. 2.2.1.2.1.1. (E): Lateral displacement [ft]

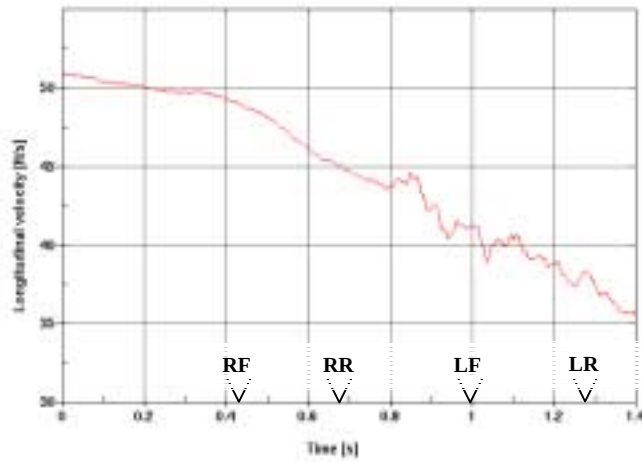


Fig. 2.2.1.2.1.1. (F): Longitudinal velocity [ft/s]

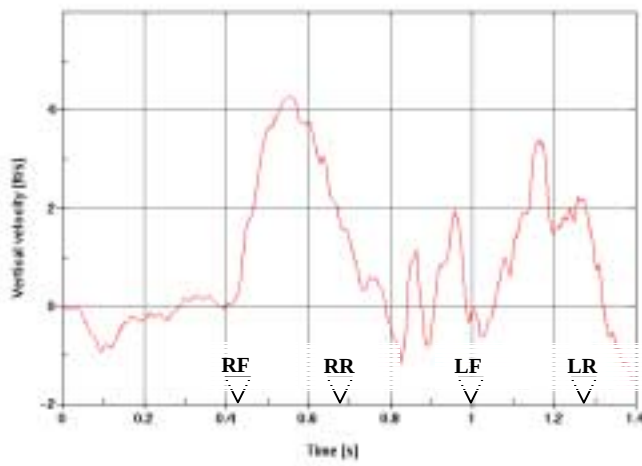


Fig. 2.2.1.2.1.1. (G) Vertical velocity [ft/s]

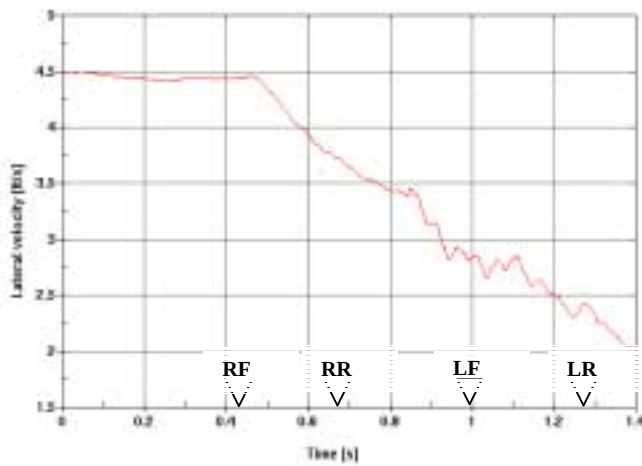


Fig. 2.2.1.2.1.1. (H): Lateral velocity [ft/s]

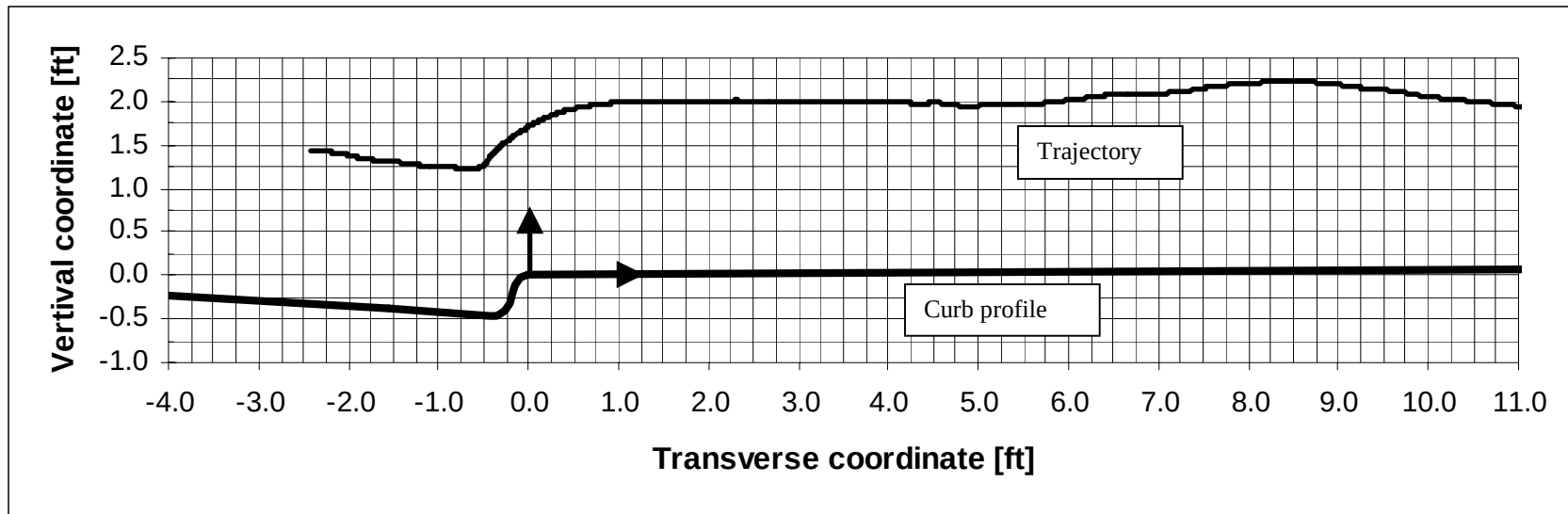


Fig. 2.2.1.4.2.2. (I): Trajectory of the bumper right corner

2.2.1.2.1.2 “E” curb

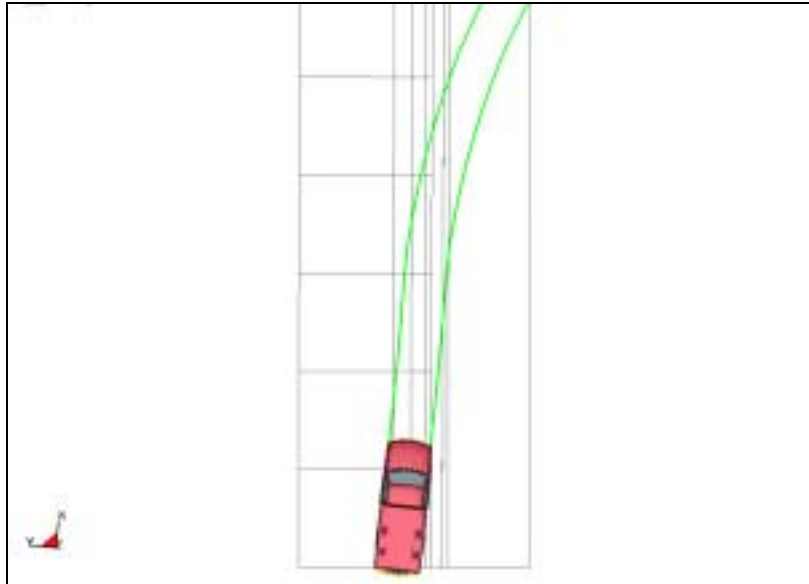


Fig. 2.2.1.2.1.2. (A) Trajectories of bumper corners (upper view)

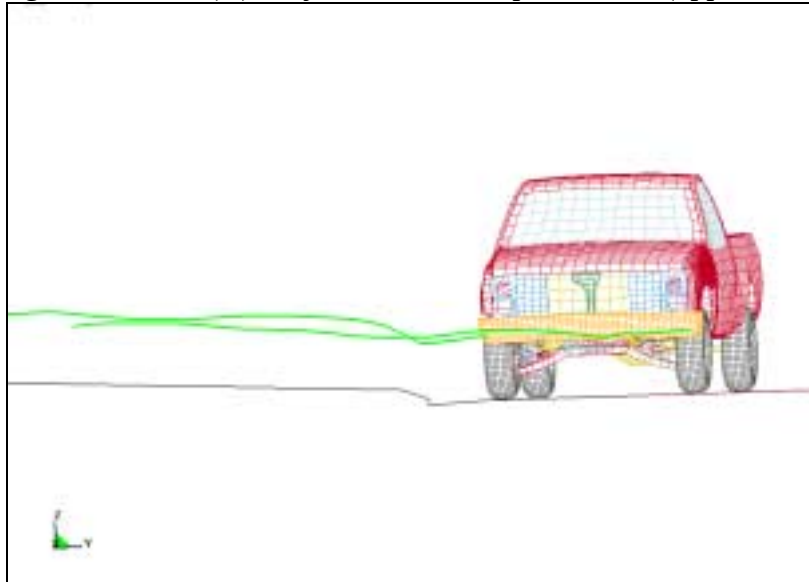


Fig. 2.2.1.2.1.2. (B) Trajectories of bumper corners (lateral view)

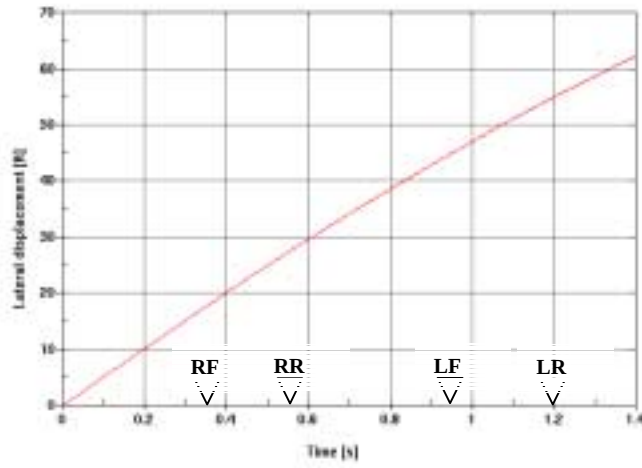


Fig. 2.2.1.2.1.2. (C): Longitudinal displacement [ft]

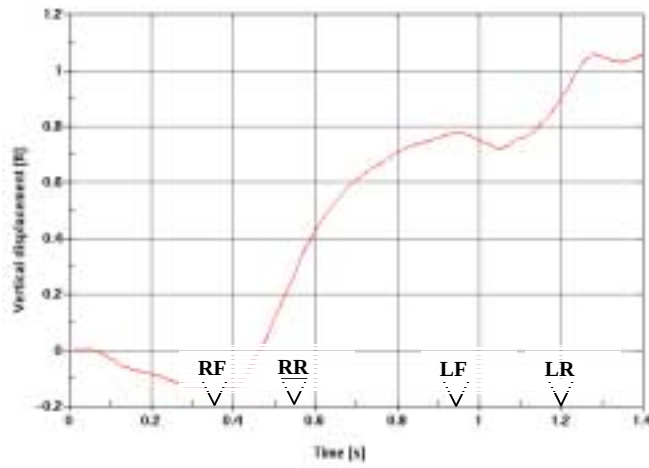


Fig. 2.2.1.2.1.2. (D): Vertical displacement [ft]

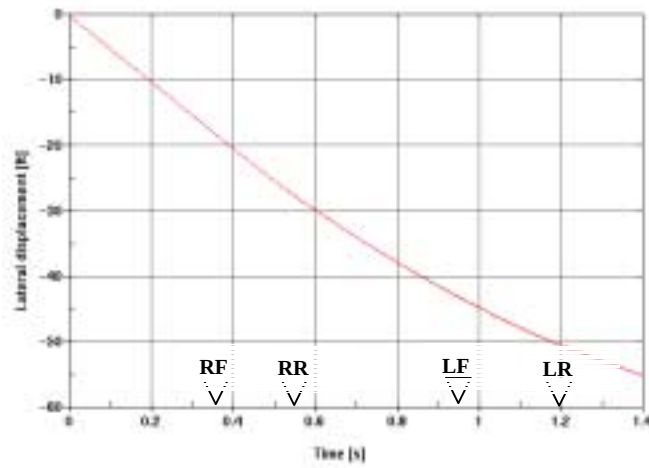


Fig. 2.2.1.2.1.2. (E): Lateral displacement [ft]

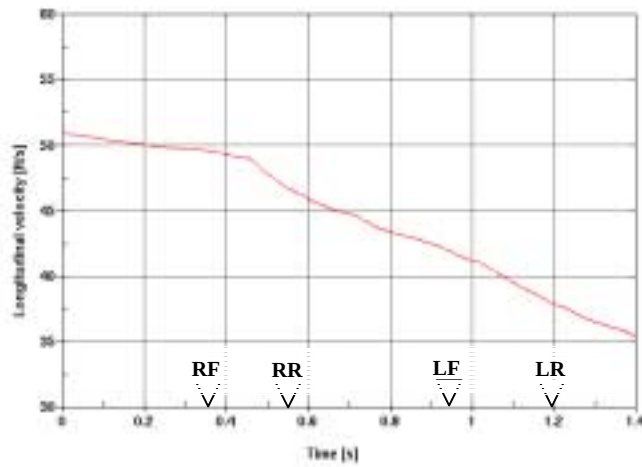


Fig. 2.2.1.2.1.2. (F): Longitudinal velocity [ft/s]

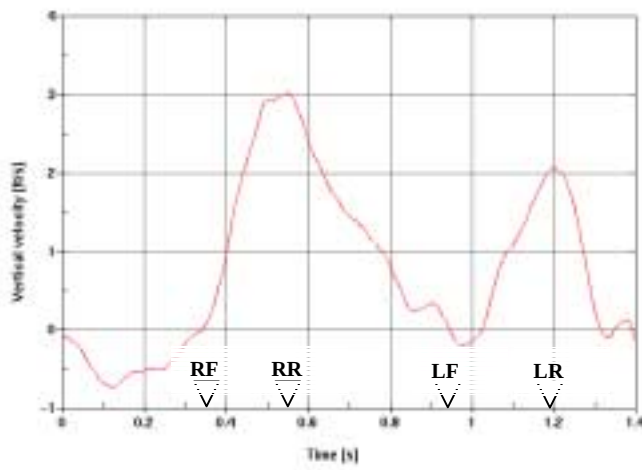


Fig. 2.2.1.2.1.2. (G) Vertical velocity [ft/s]

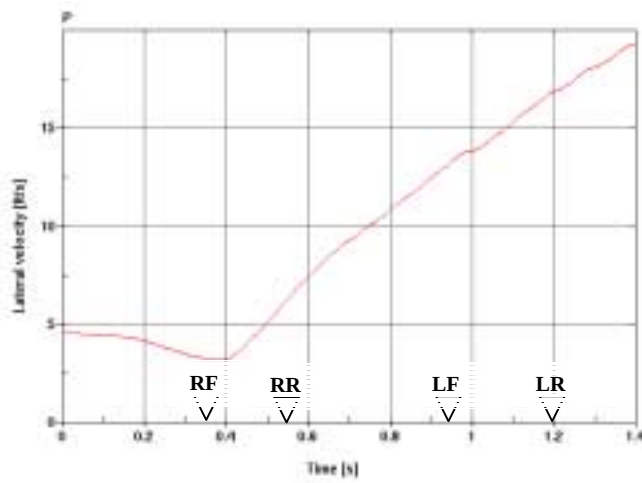


Fig. 2.2.1.2.1.2. (H): Lateral velocity [ft/s]

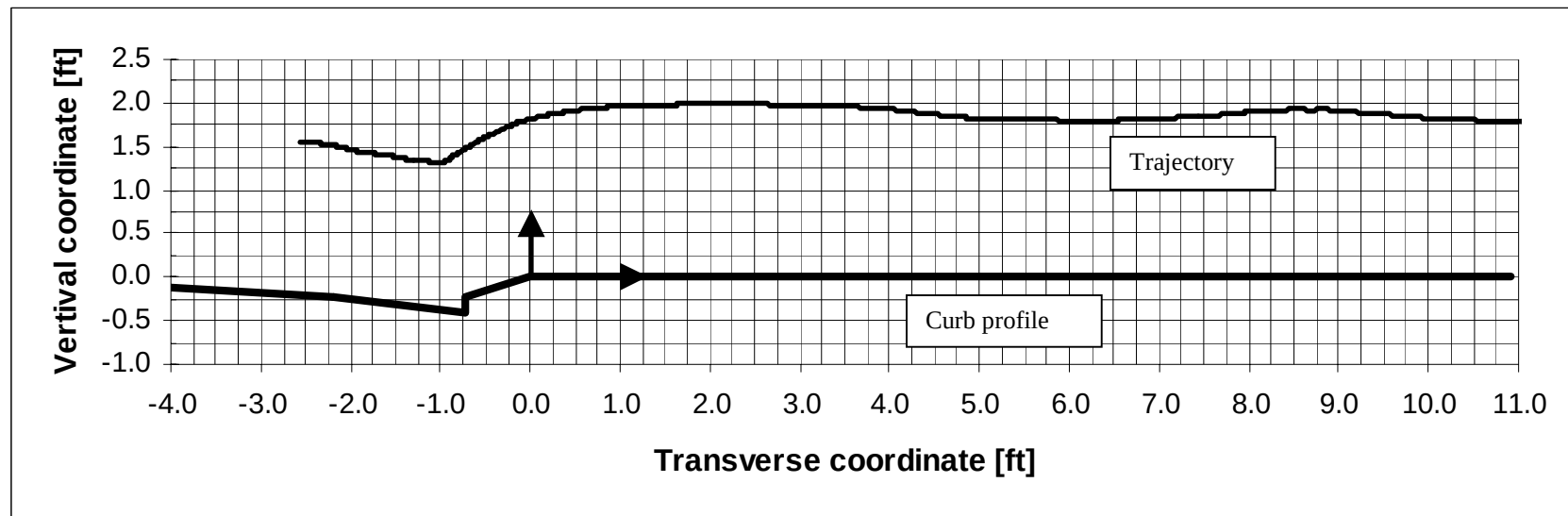


Fig. 2.2.1.2.1.2. (I): Trajectory of the bumper right corner

2.2.1.2 Approach angle 5°
2.2.1.2.2 Velocity 55 mph
2.2.1.2.2.1 “F” curb

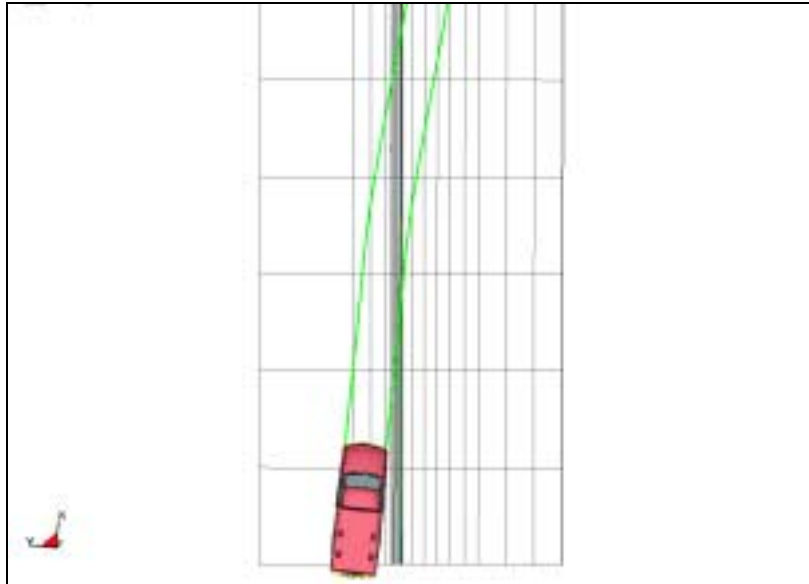


Fig. 2.2.1.2.2.1 (A) Trajectories of bumper corners (upper view)

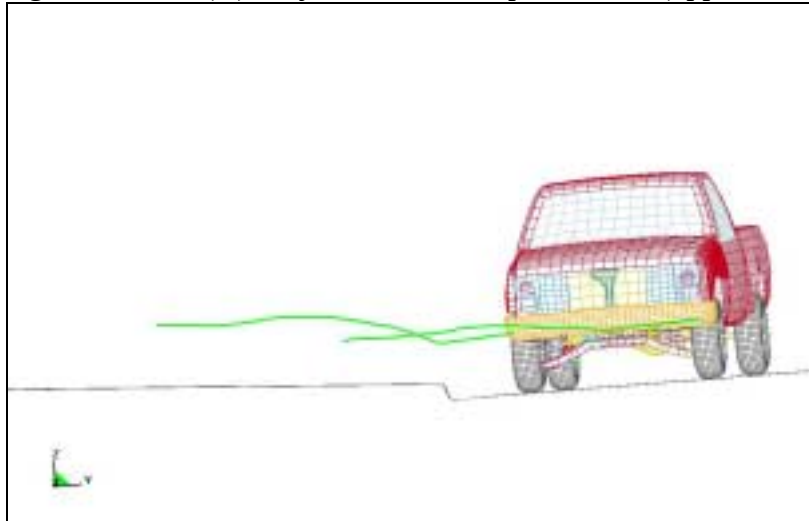


Fig. 2.2.1.2.2.1 (B) Trajectories of bumper corners (lateral view)

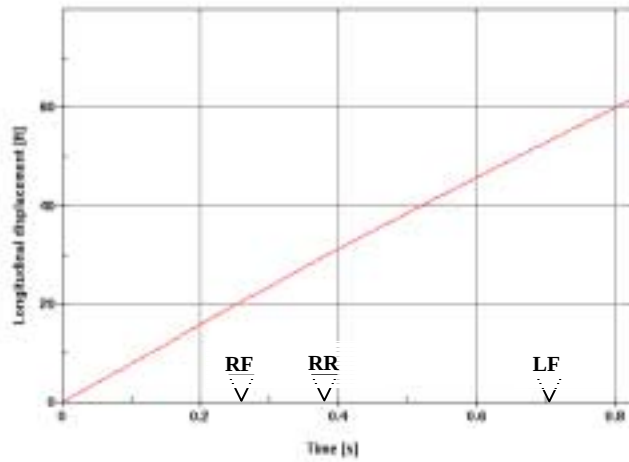


Fig. 2.2.1.2.2.1 (C): Longitudinal displacement [ft]

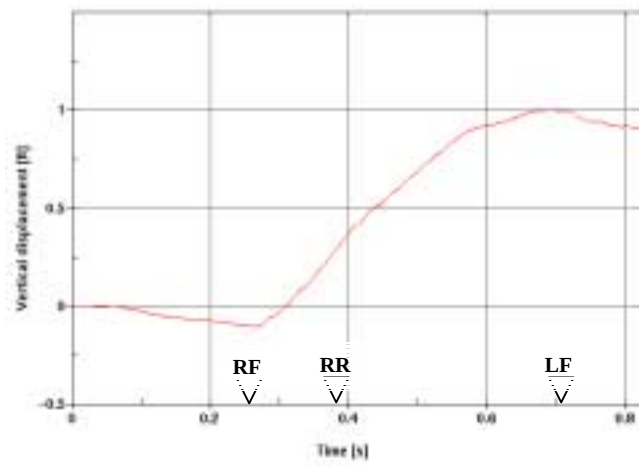


Fig. 2.2.1.2.2.1 (D): Vertical displacement [ft]

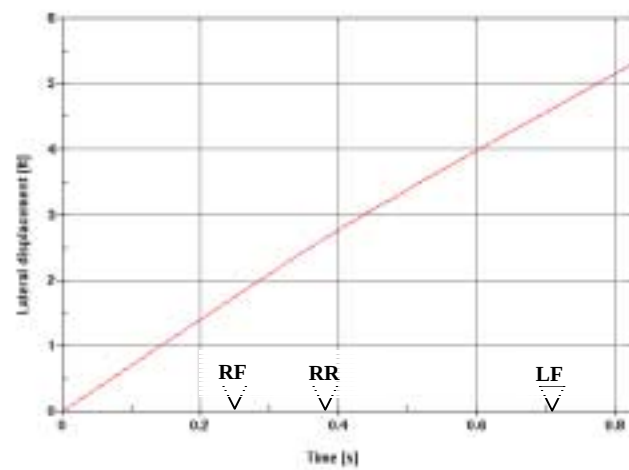


Fig. 2.2.1.2.2.1 (E): Lateral displacement [ft]

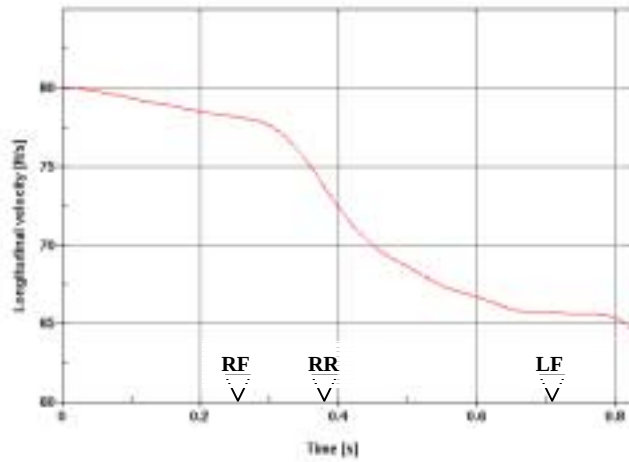


Fig. 2.2.1.2.2.1 (F): Longitudinal velocity [ft/s]

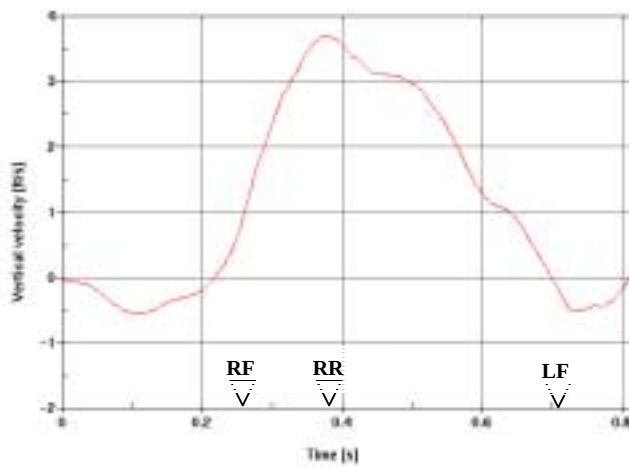


Fig2.1.1.2.2.1 (G) Vertical velocity [ft/s]

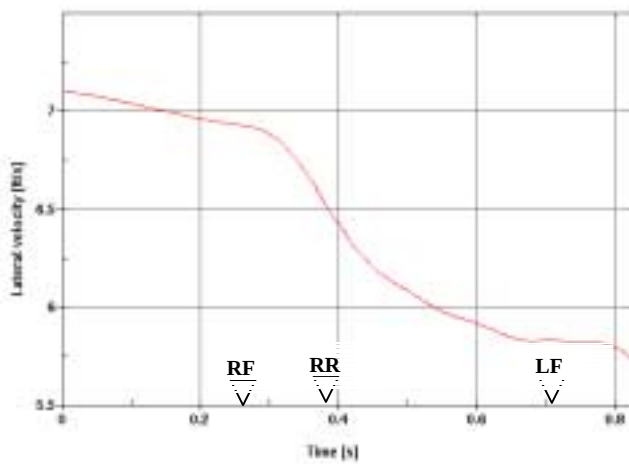


Fig. 2.2.1.2.2.1 (H): Lateral velocity [ft/s]

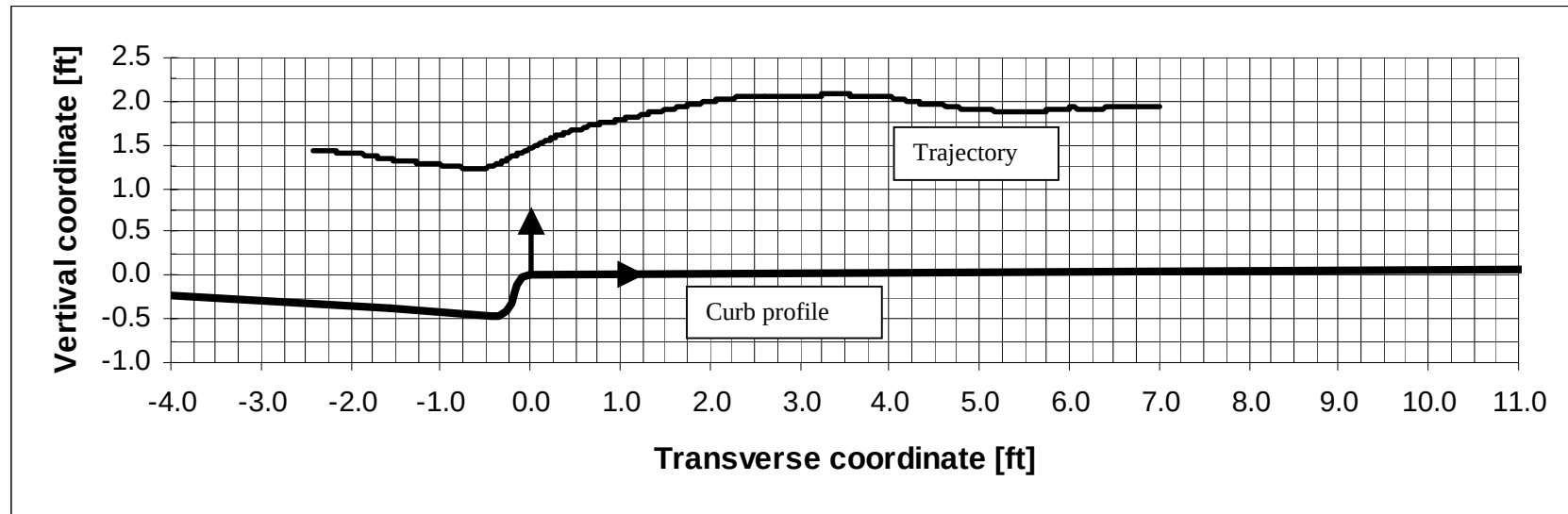


Fig. 2.2.1.4.2.2. (I): Trajectory of the bumper right corner

2.2.1.2.2.2 “E” curb

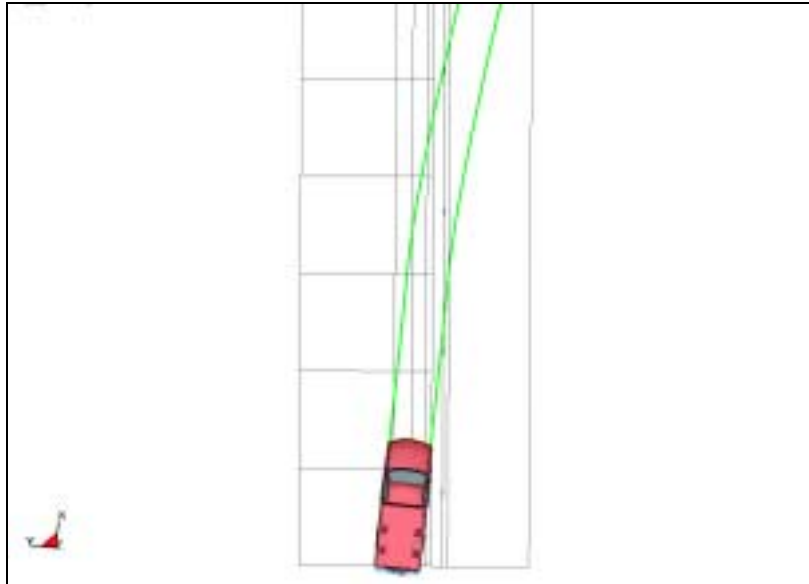


Fig. 2.2.1.2.2.2 (A) Trajectories of bumper corners (upper view)

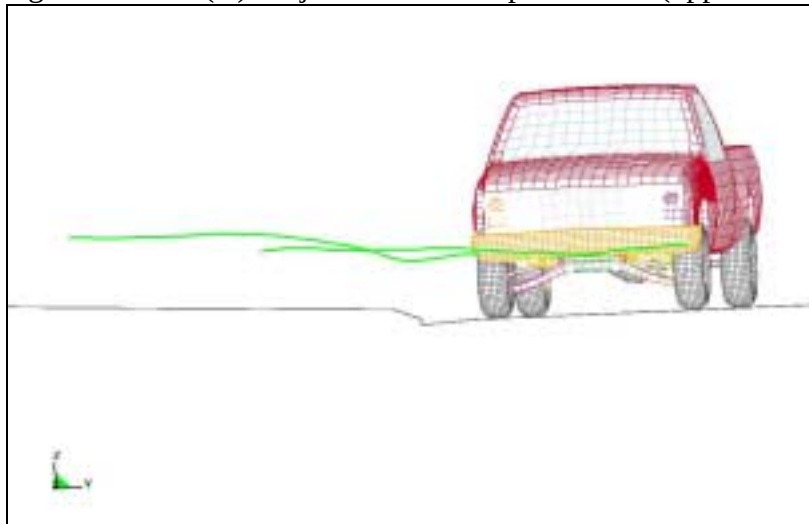


Fig. 2.2.1.2.2.2 (B) Trajectories of bumper corners (lateral view)

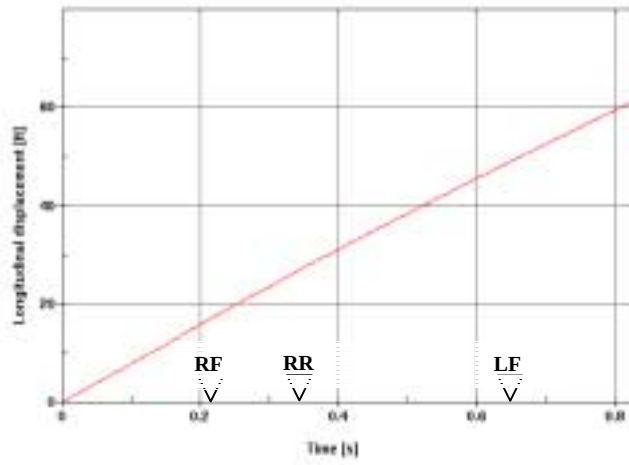


Fig. 2.2.1.2.2.2 (C): Longitudinal displacement [ft]

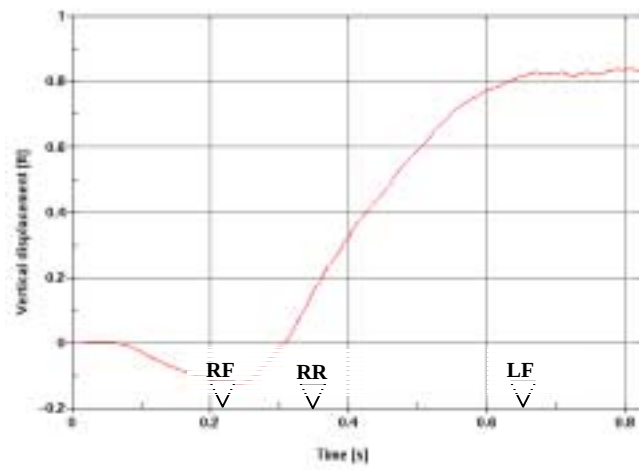


Fig. 2.2.1.2.2.2 (D): Vertical displacement

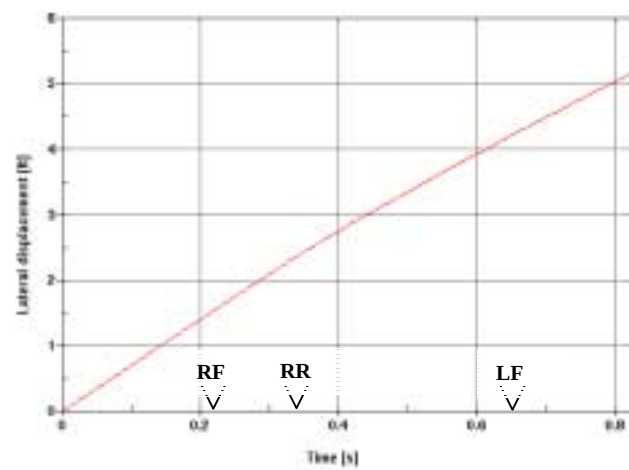


Fig. 2.2.1.2.2.2 (E): Lateral displacement [ft]

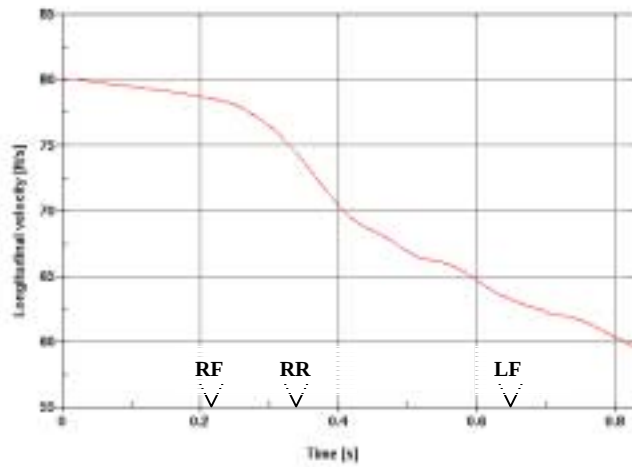


Fig. 2.2.1.2.2.2 (F): Longitudinal velocity [ft/s]

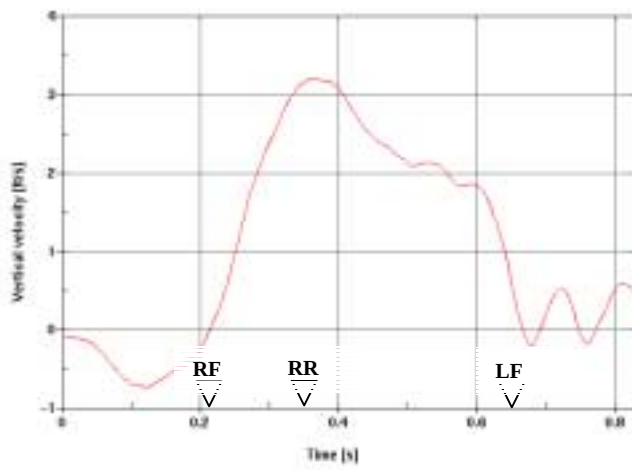


Fig2.1.1.2.2.2 (G) Vertical velocity [ft/s]

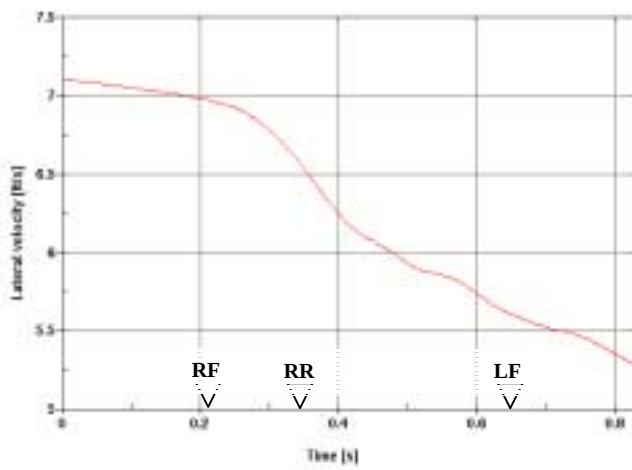


Fig. 2.2.1.2.2.2 (H): Lateral velocity [ft/s]

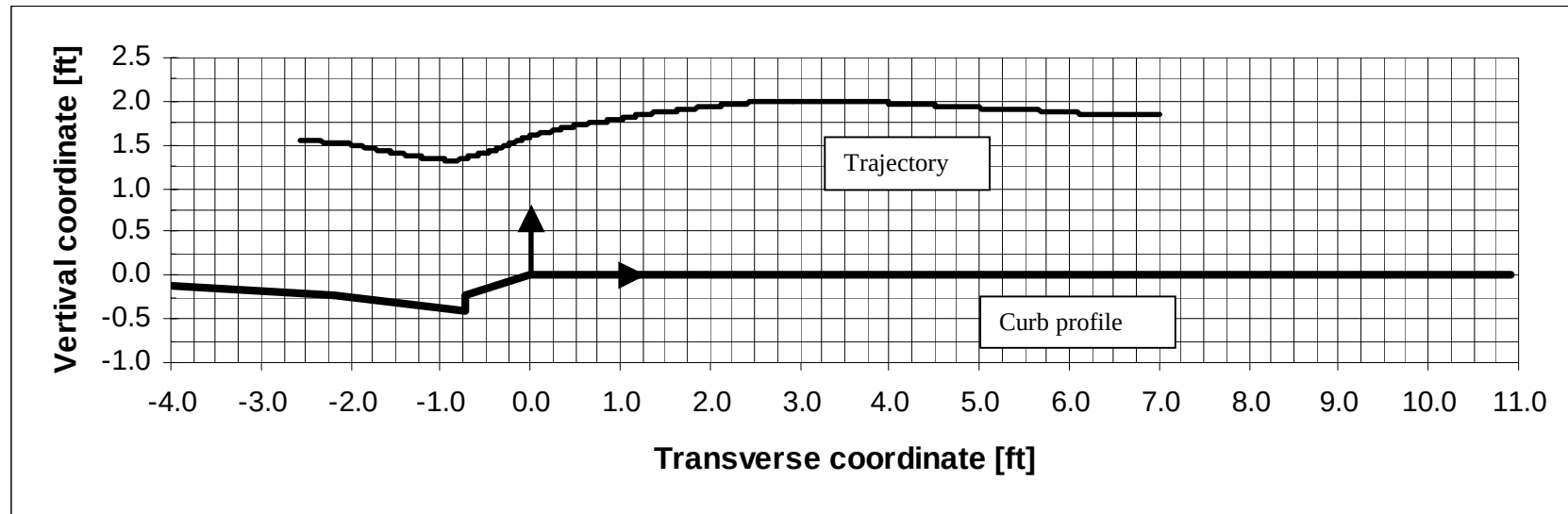


Fig. 2.2.1.2.2.2 (I): Trajectory of the bumper right corner

2.2.1.3 Approach angle 10°
2.2.1.3.1 Velocity 35 mph
2.2.1.3.1.1 “F” curb

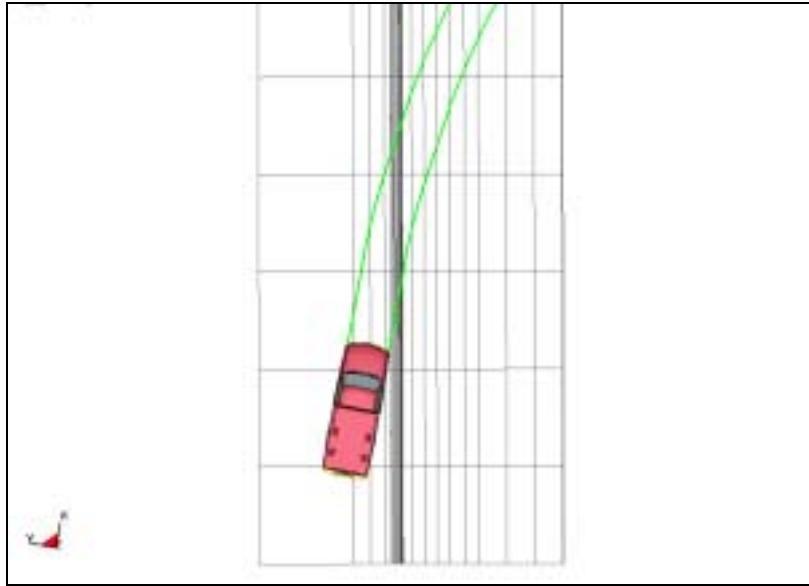


Fig. 2.2.1.3.1.1 (A) Trajectories of bumper corners (upper view)

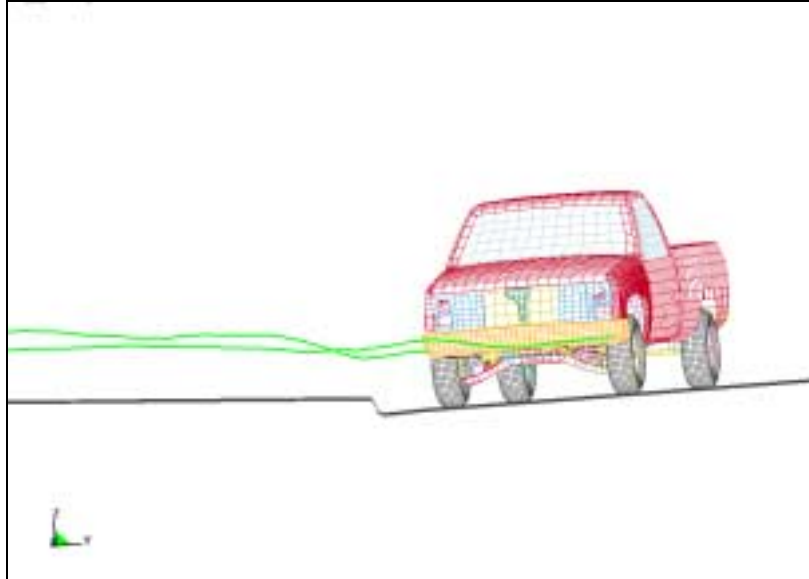


Fig. 2.2.1.3.1.1 (B) Trajectories of bumper corners (lateral view)

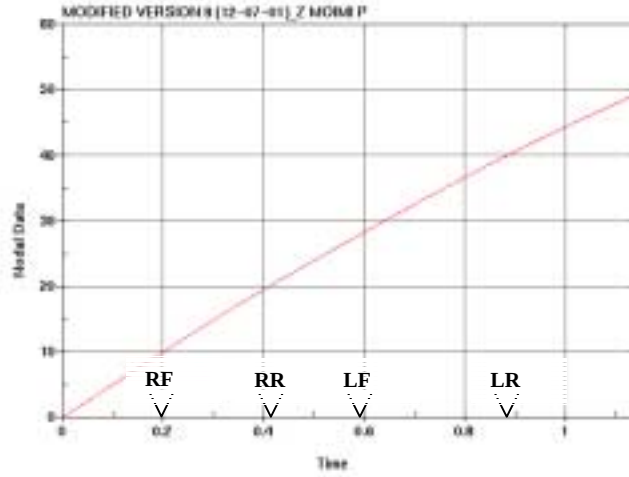


Fig. 2.2.1.3.1.1. (C): Longitudinal displacement [ft]

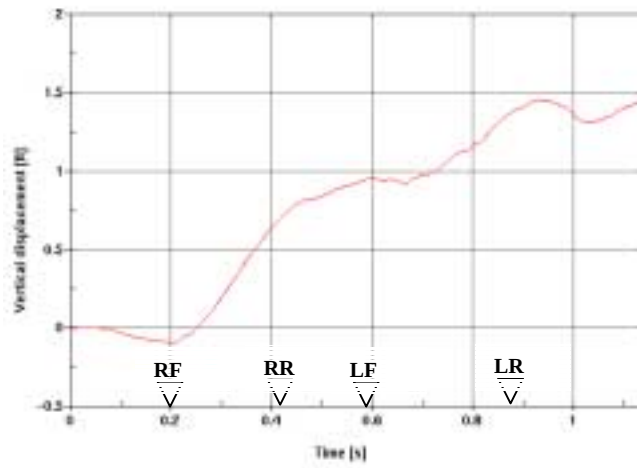


Fig. 2.2.1.3.1.1. (D): Vertical displacement [ft]

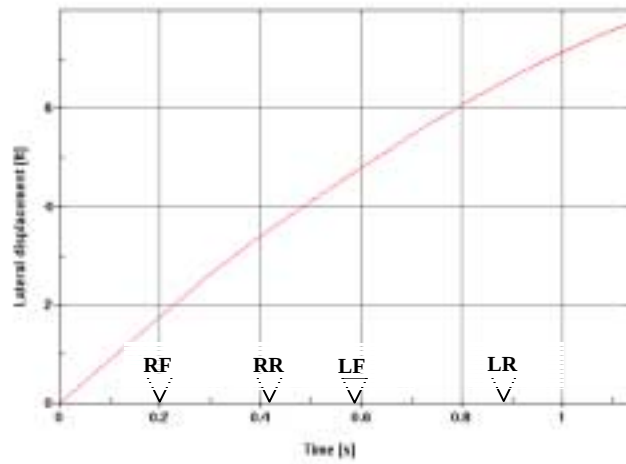


Fig. 2.2.1.3.1.1. (E): Lateral displacement [ft]

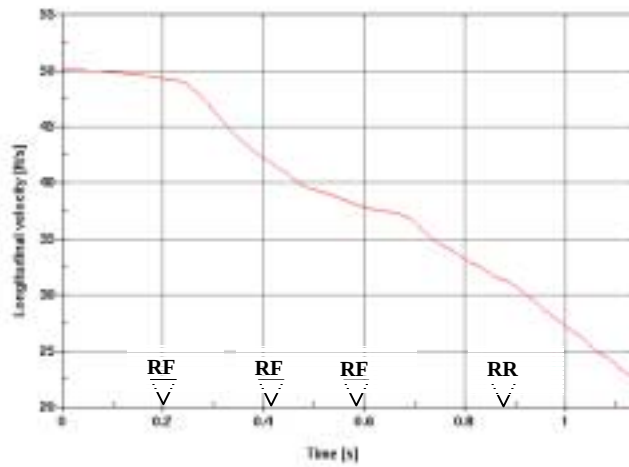


Fig. 2.2.1.3.1.1. (F): Longitudinal velocity [ft/s]

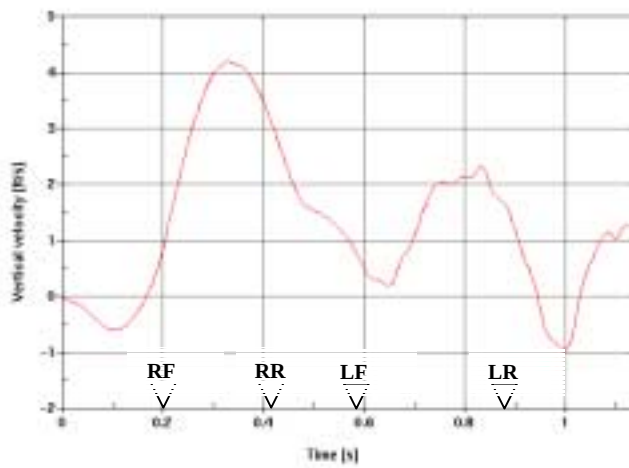


Fig. 2.2.1.3.1.1. (G) Vertical velocity [ft/s]

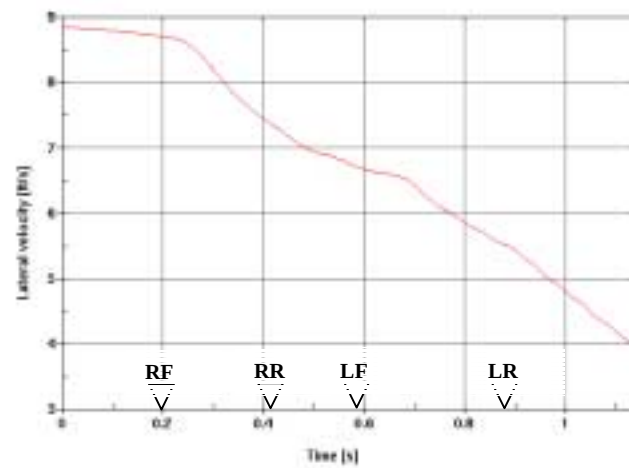


Fig. 2.2.1.3.1.1. (H): Lateral velocity [ft/s]

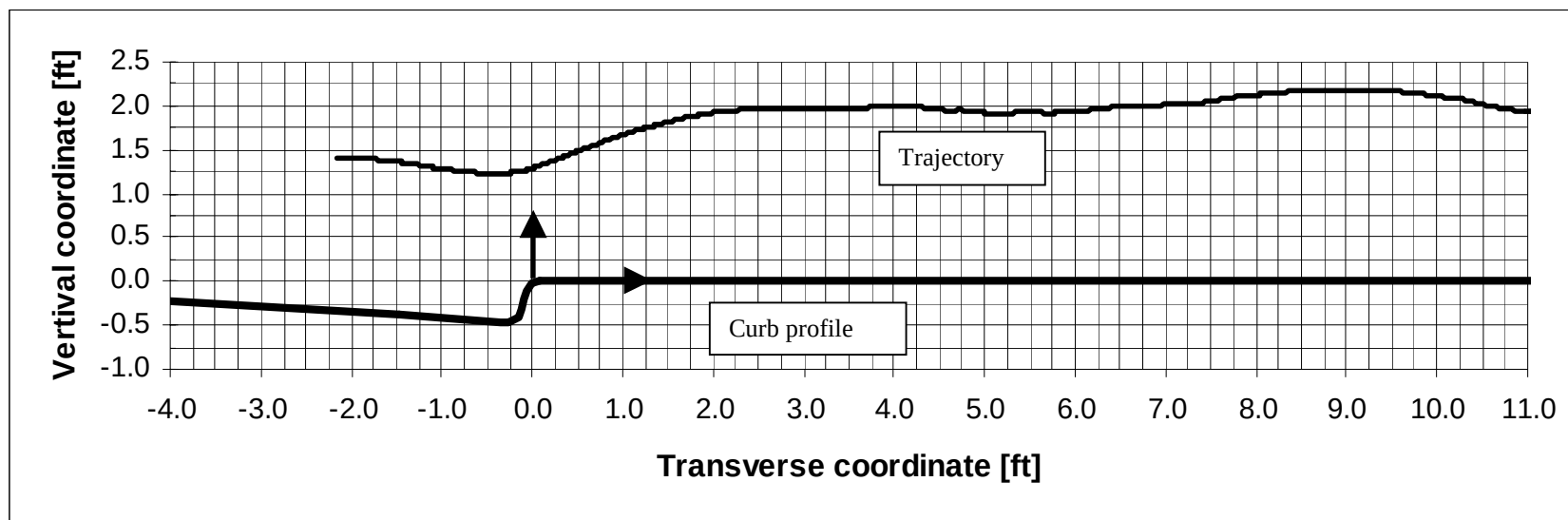


Fig. 2.2.1.4.2.2. (I): Trajectory of the bumper right corner

2.2.1.3.1.2 “E” curb

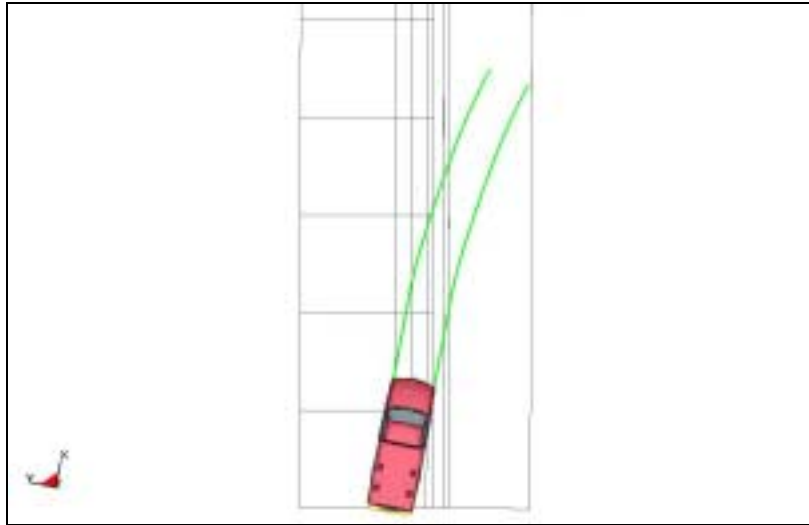


Fig. 2.2.1.3.1.2 (A) Trajectories of bumper corners (upper view)

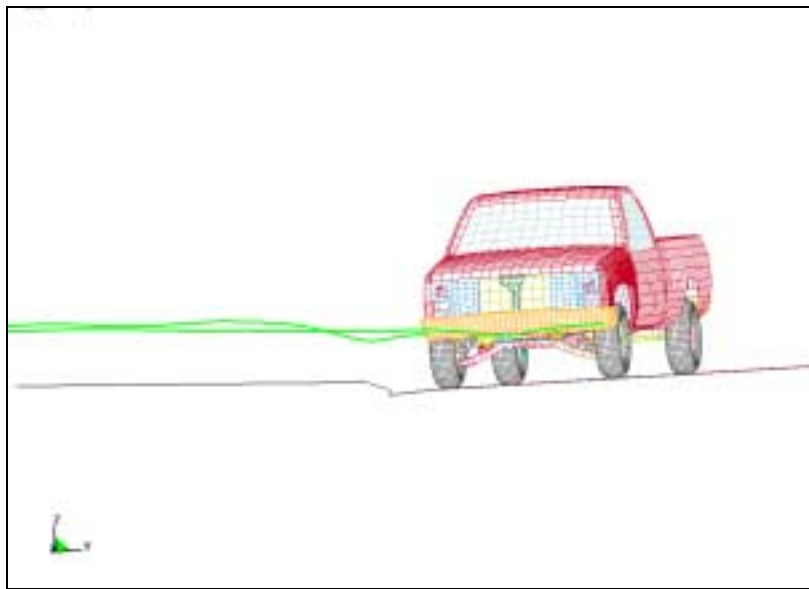


Fig. 2.2.1.3.1.2 (B) Trajectories of bumper corners (lateral view)

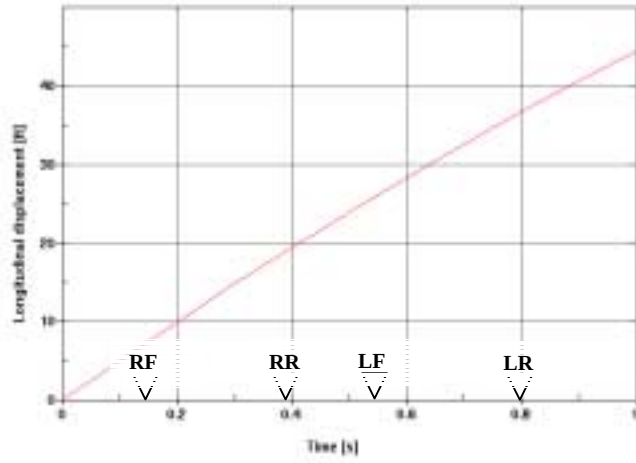


Fig. 2.2.1.3.1.2. (C): Longitudinal displacement [ft]

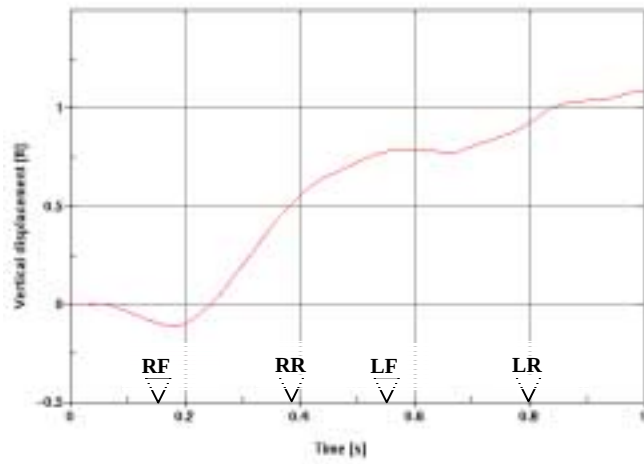


Fig. 2.2.1.3.1.2. (D): Vertical displacement [ft]

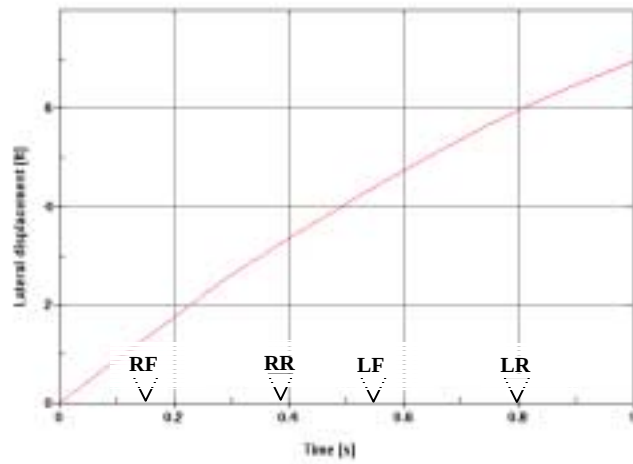


Fig. 2.2.1.3.1.2. (E): Lateral displacement [ft]

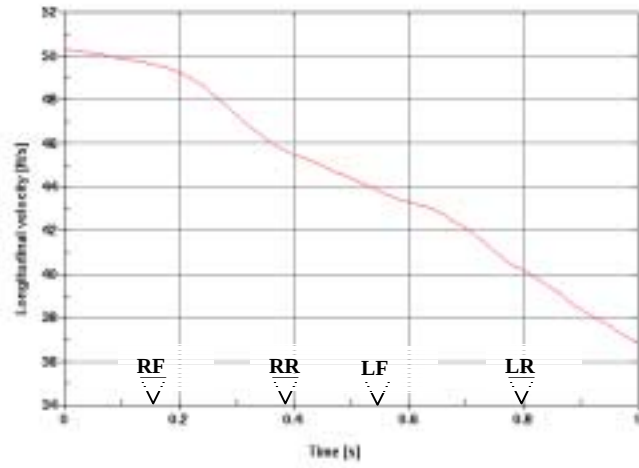


Fig. 2.2.1.3.1.2. (F): Longitudinal velocity [ft/s]

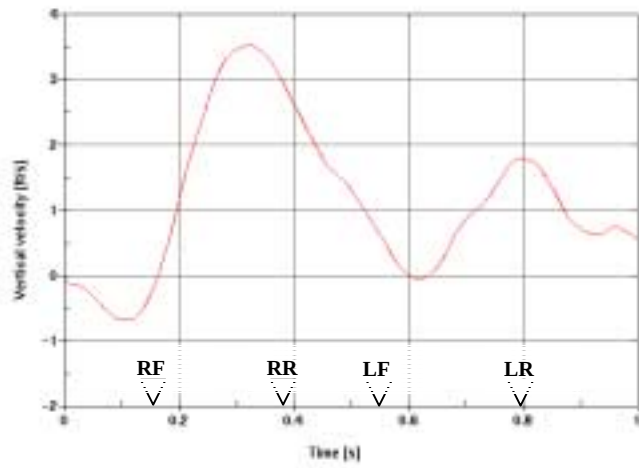


Fig. 2.2.1.3.1.2. (G) Vertical velocity [ft/s]

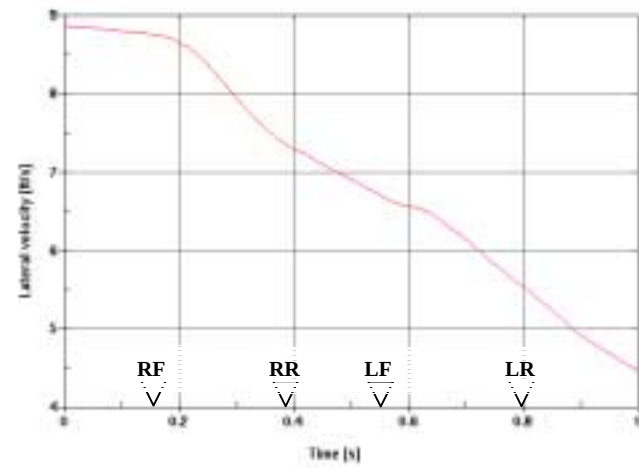


Fig. 2.2.1.3.1.2. (H): Lateral velocity [ft/s]

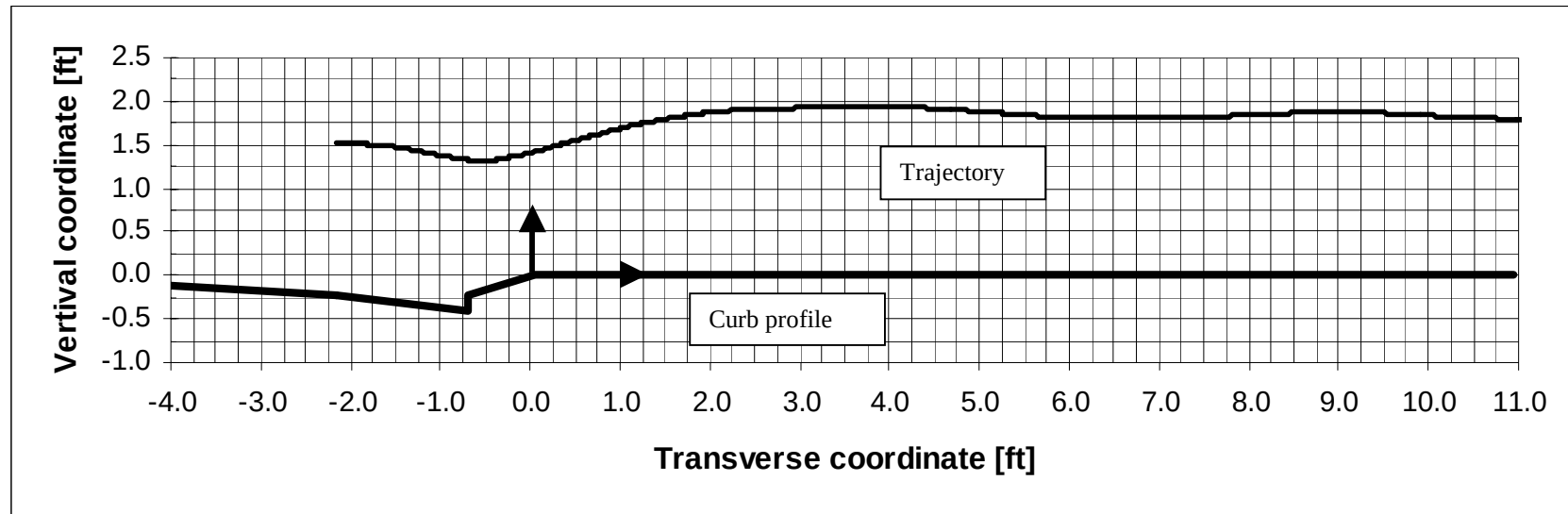


Fig. 2.2.1.4.2.2. (I): Trajectory of the bumper right corner

2.2.1.3.2 Velocity 55 mph

2.2.1.3.2.1 “F” curb

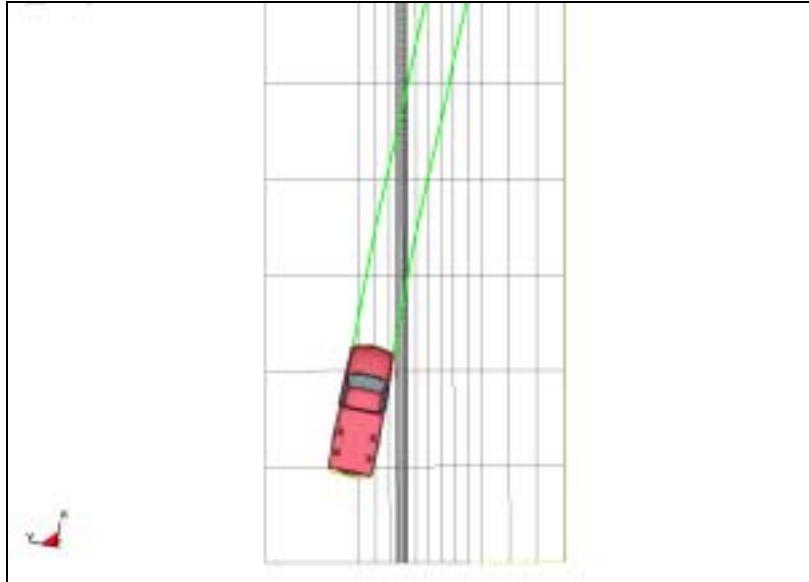


Fig. 2.2.1.3.2.1 (A) Trajectories of bumper corners (upper view)

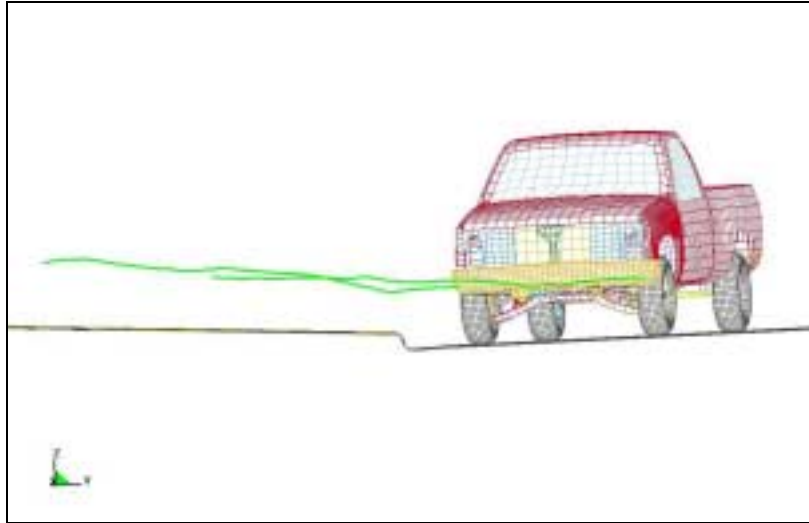


Fig. 2.2.1.3.2.1 (B) Trajectories of bumper corners (lateral view)

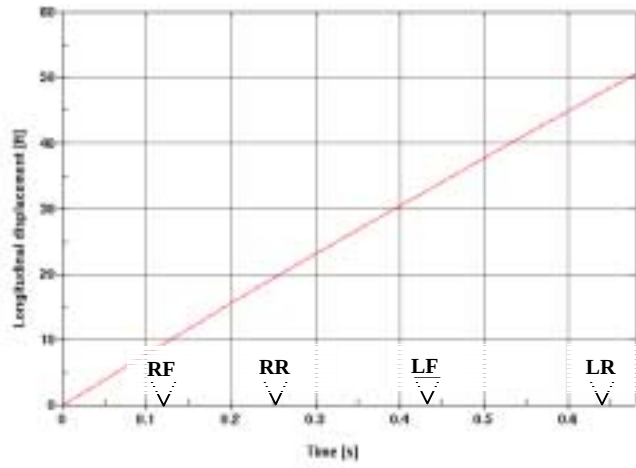


Fig. 2.2.1.3.2.1. (C): Longitudinal displacement [ft]

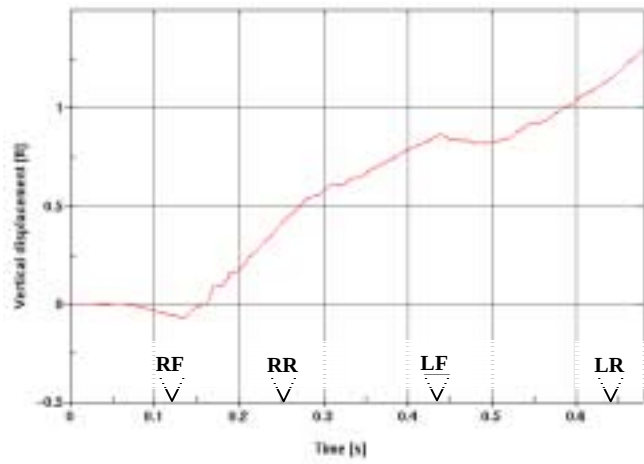


Fig. 2.2.1.3.2.1. (D): Vertical displacement [ft]

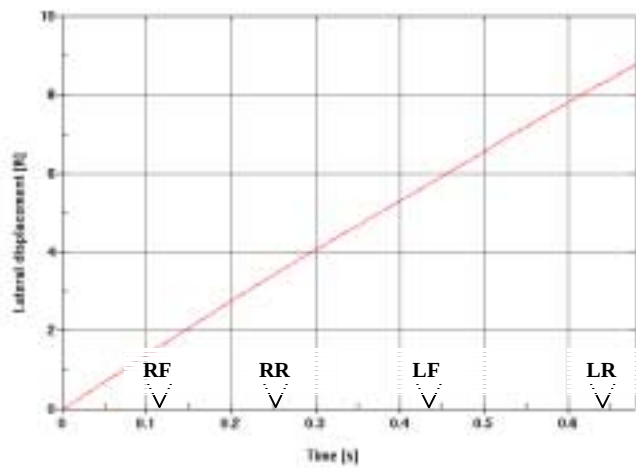


Fig. 2.2.1.3.2.1. (E): Lateral displacement [ft]



Fig. 2.2.1.3.2.1. (F): Longitudinal velocity [ft/s]

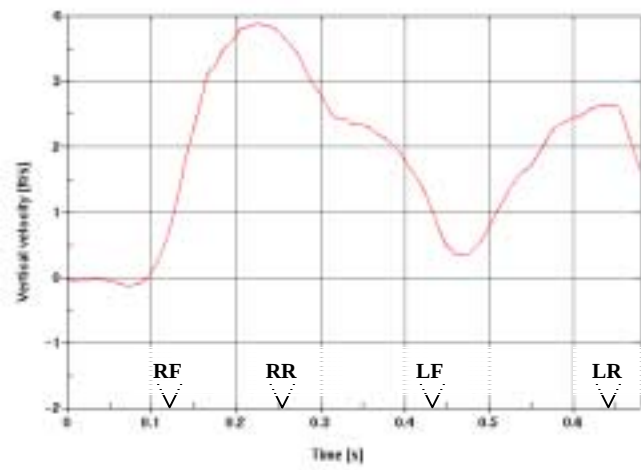


Fig. 2.2.1.3.2.1. (G) Vertical velocity [ft/s]

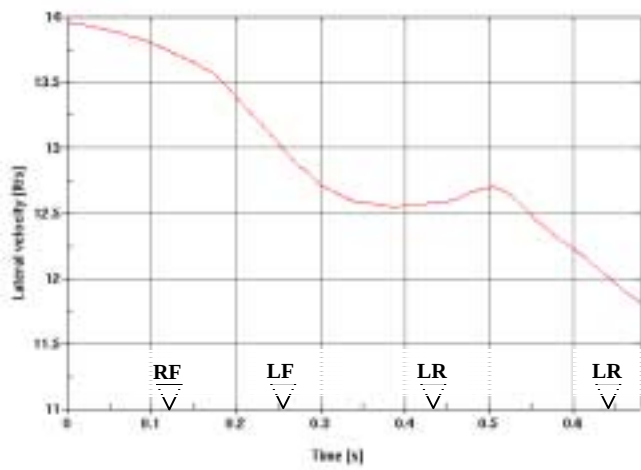


Fig. 2.2.1.3.2.1. (H): Lateral velocity [ft/s]

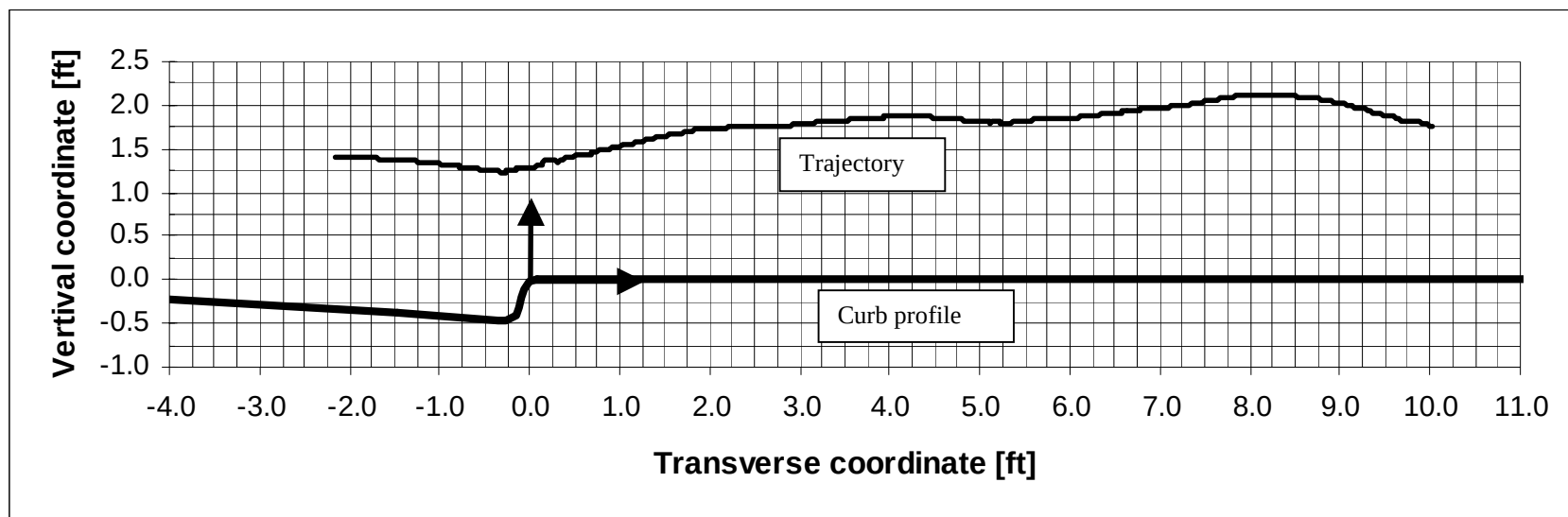


Fig. 2.2.1.3.2.1. (I): Trajectory of the bumper right corner

2.2.1.3.2.2 “E” curb

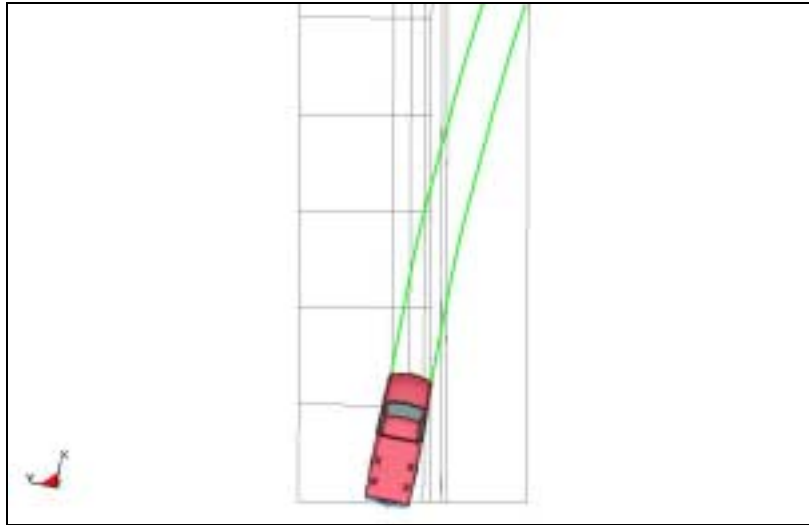


Fig. 2.2.1.3.2.2 (A) Trajectories of bumper corners (upper view)

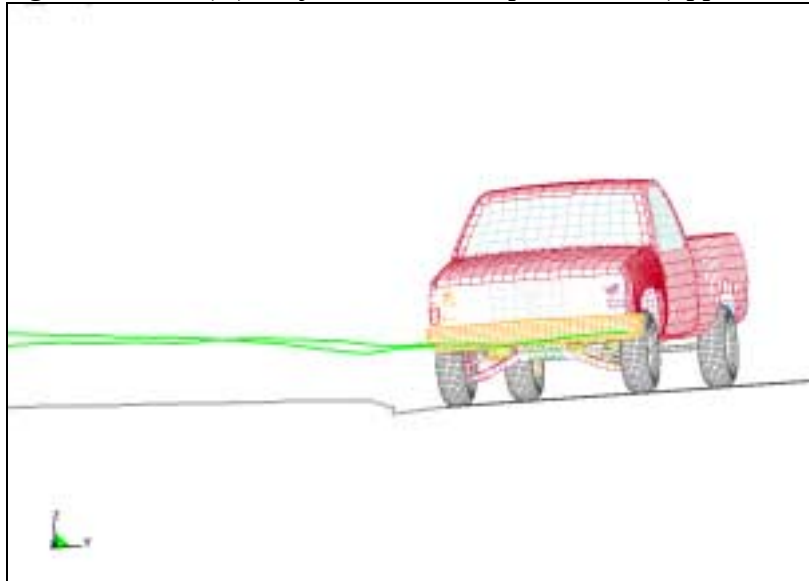


Fig. 2.2.1.3.2.2 (B) Trajectories of bumper corners (lateral view)

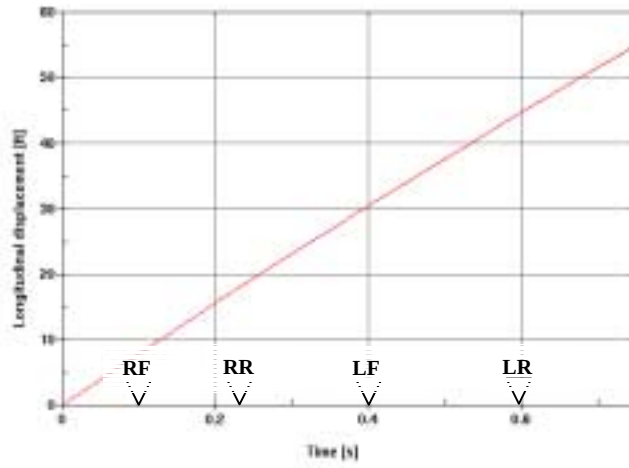


Fig. 2.2.1.3.2.2. (C): Longitudinal displacement [ft]

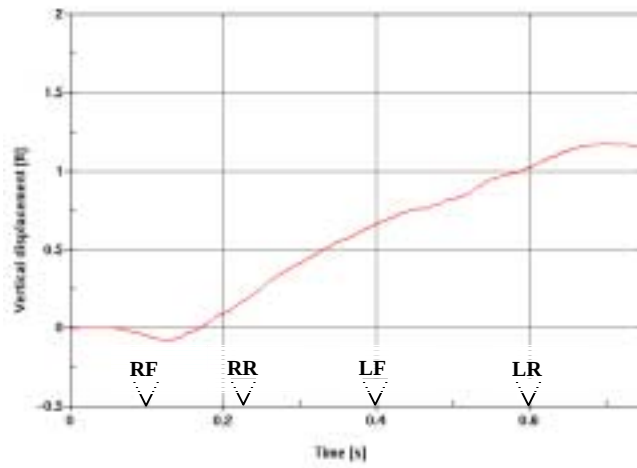


Fig. 2.2.1.3.2.2. (D): Vertical displacement [ft]

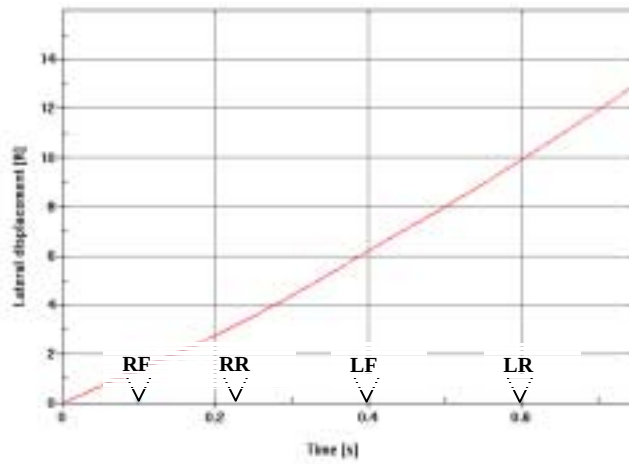


Fig. 2.2.1.3.2.2. (E): Lateral displacement [ft]

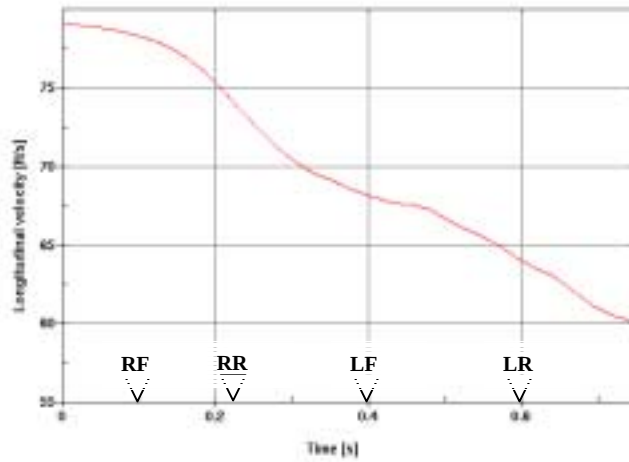


Fig. 2.2.1.3.2.2. (F): Longitudinal velocity [ft/s]

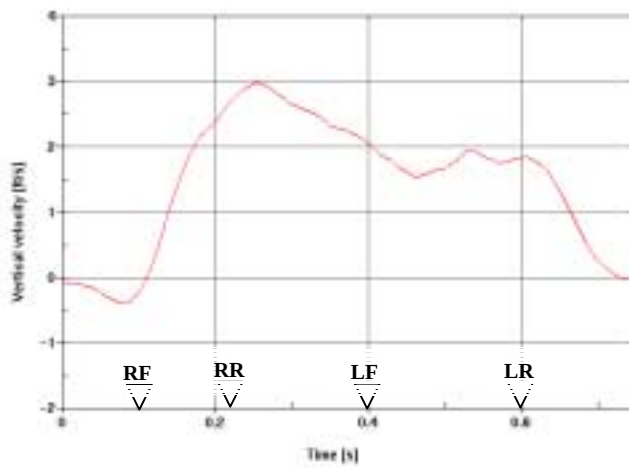


Fig. 2.2.1.3.2.2. (G) Vertical velocity [ft/s]

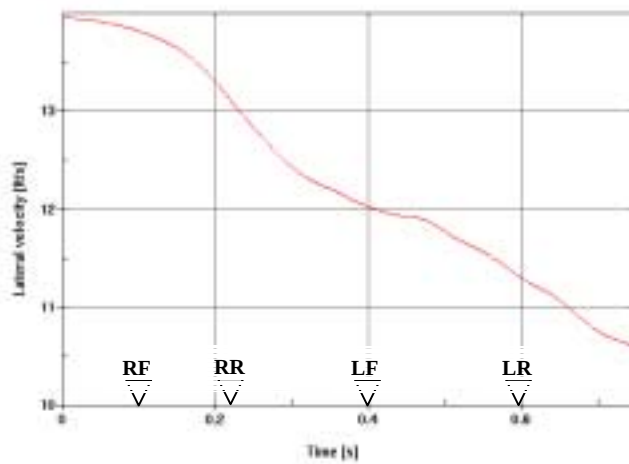


Fig. 2.2.1.3.2.2. (H): Lateral velocity [ft/s]

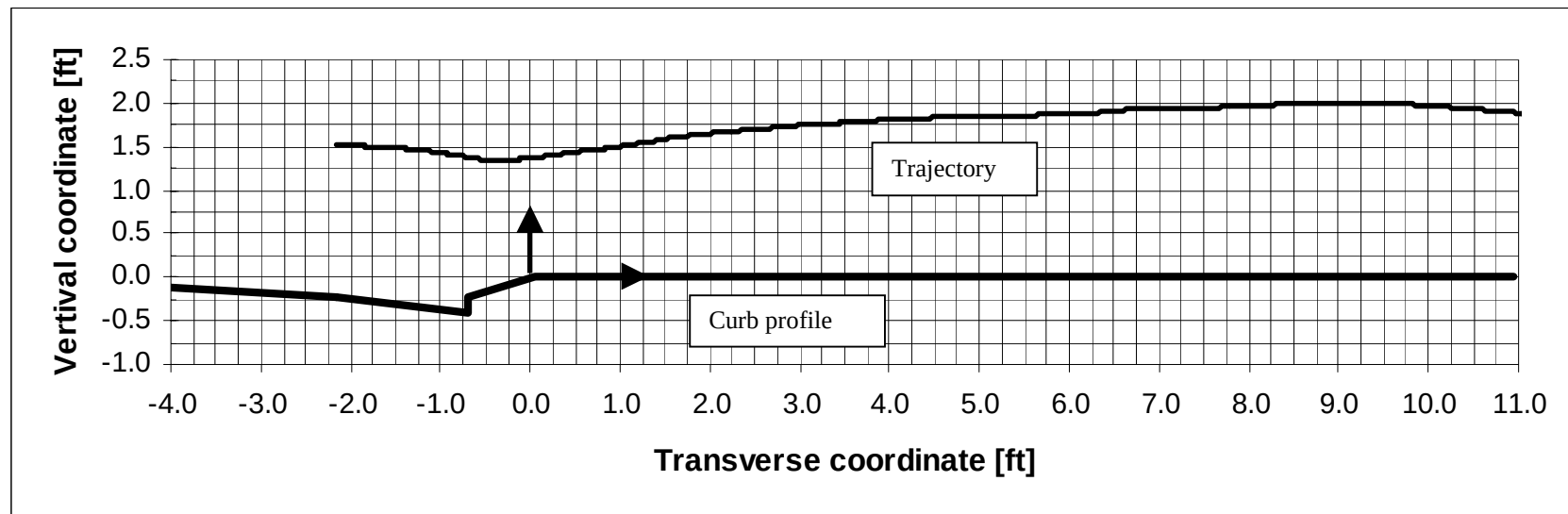


Fig. 2.2.1.4.2.2. (I): Trajectory of the bumper right corner

2.2.1.4 Approach angle 15°

2.2.1.4.1 Velocity 35 mph

2.2.1.4.1.1 “F” curb

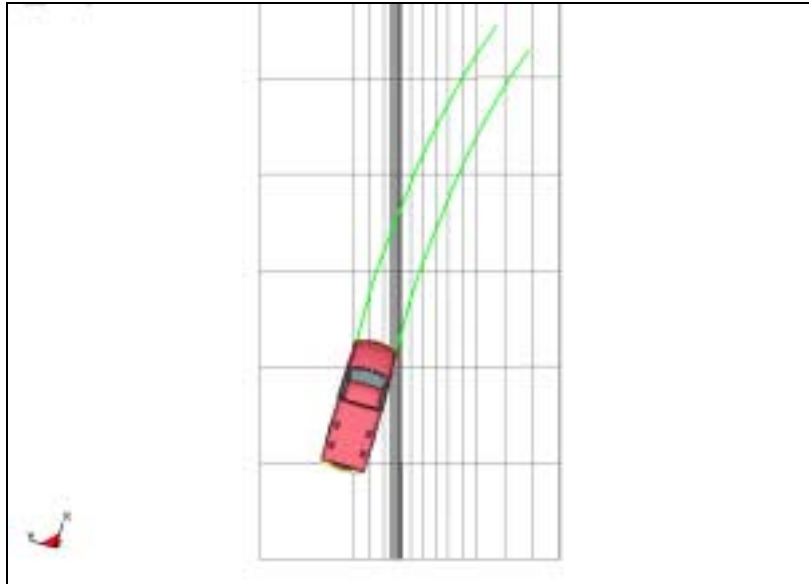


Fig. 2.2.1.4.1.1 (A) Trajectories of bumper corners (upper view)

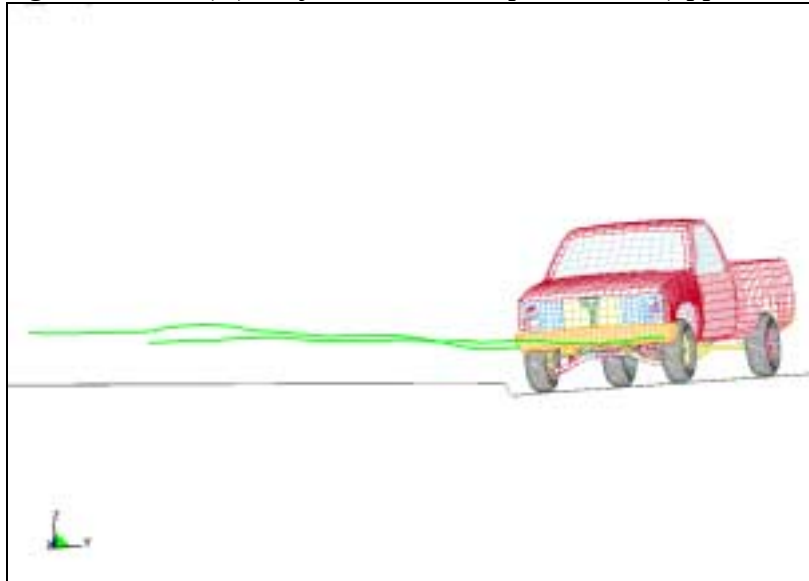


Fig. 2.2.1.4.1.1 (B) Trajectories of bumper corners (lateral view)

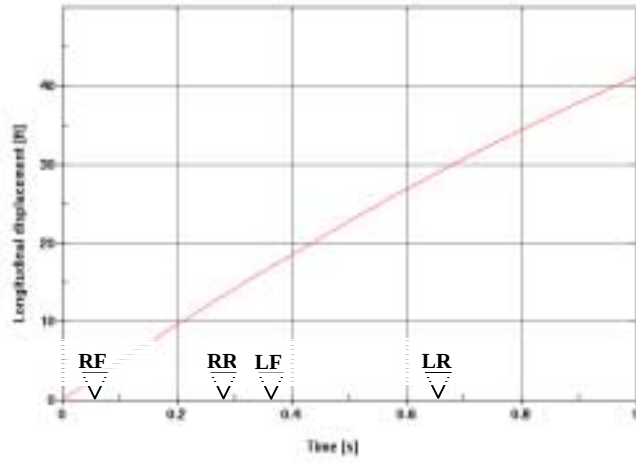


Fig. 2.2.1.4.1.1. (C): Longitudinal displacement [ft]

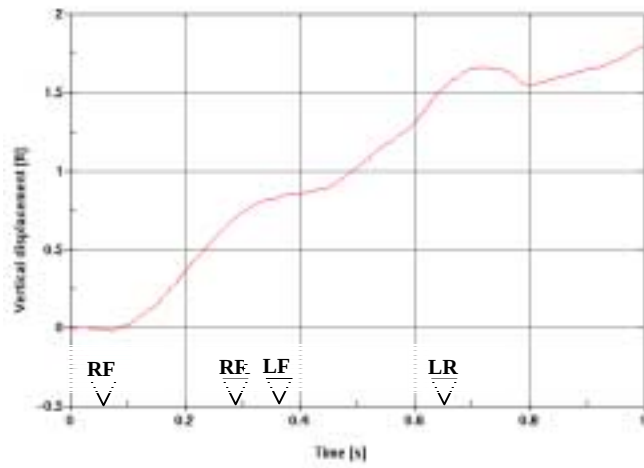


Fig. 2.2.1.4.1.1. (D): Vertical displacement [ft]

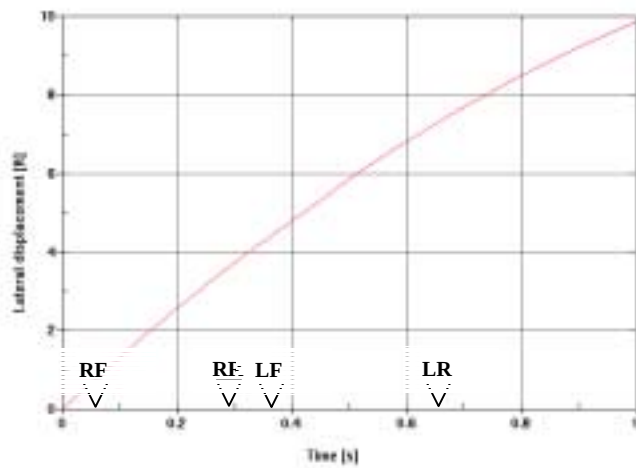


Fig. 2.2.1.4.1.1. (E): Lateral displacement [ft]

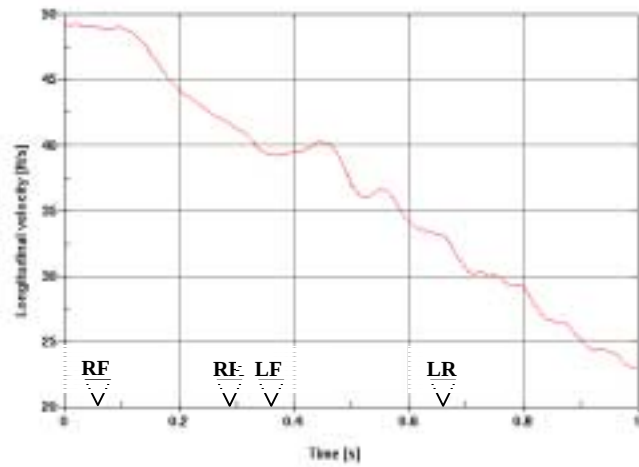


Fig. 2.2.1.4.1.1. (F): Longitudinal velocity [ft/s]

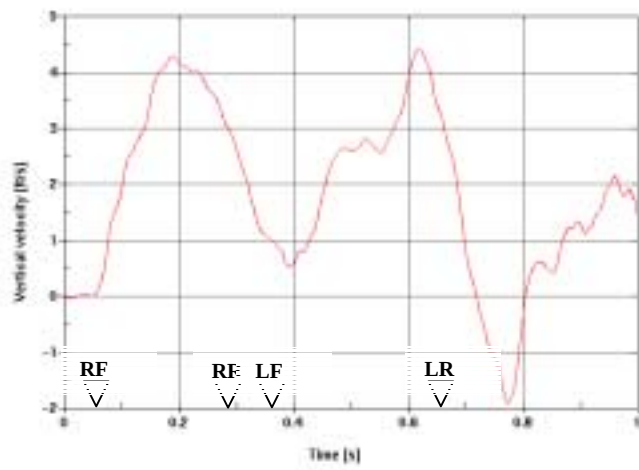


Fig. 2.2.1.4.1.1. (G) Vertical velocity [ft/s]

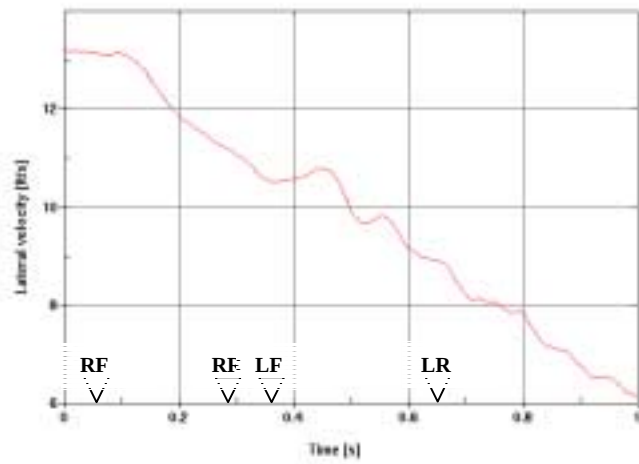


Fig. 2.2.1.4.1.1. (H): Lateral velocity [ft/s]

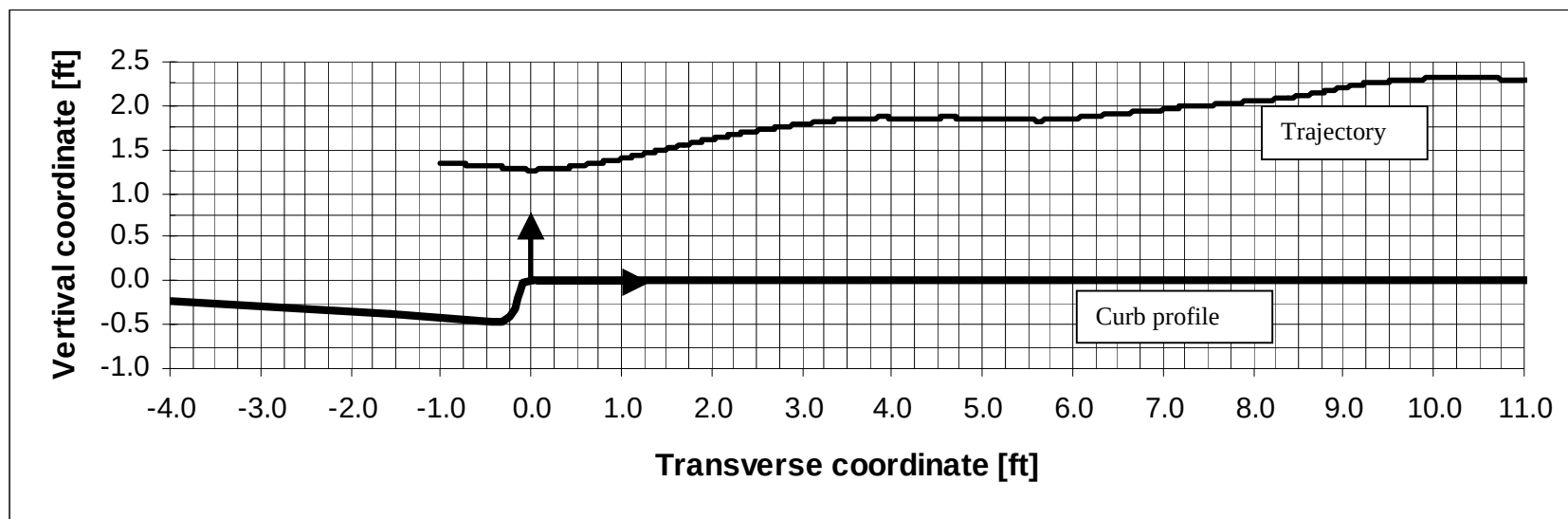


Fig. 2.2.1.4.1.1. (I): Trajectory of the bumper right corner

2.2.1.4.1.2 “E” curb

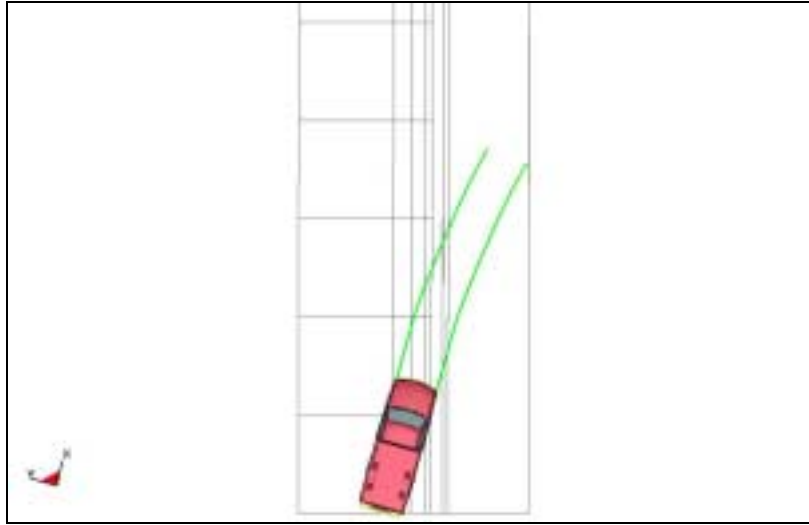


Fig. 2.2.1.4.1.2 (A) Trajectories of bumper corners (upper view)

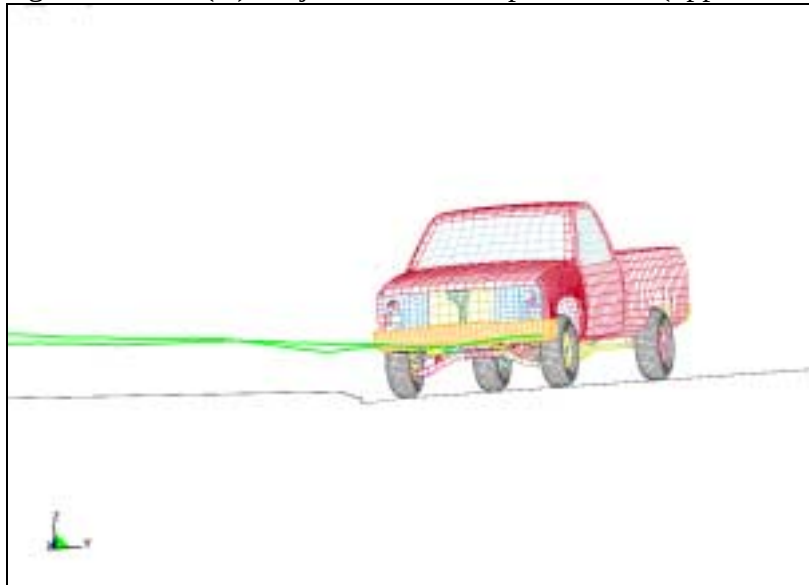


Fig. 2.2.1.4.1.2 (B) Trajectories of bumper corners (lateral view)

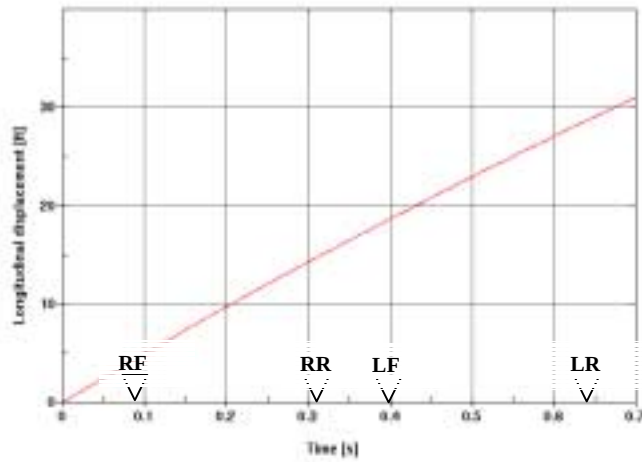


Fig. 2.2.1.4.1.2 (C): Longitudinal displacement [ft]

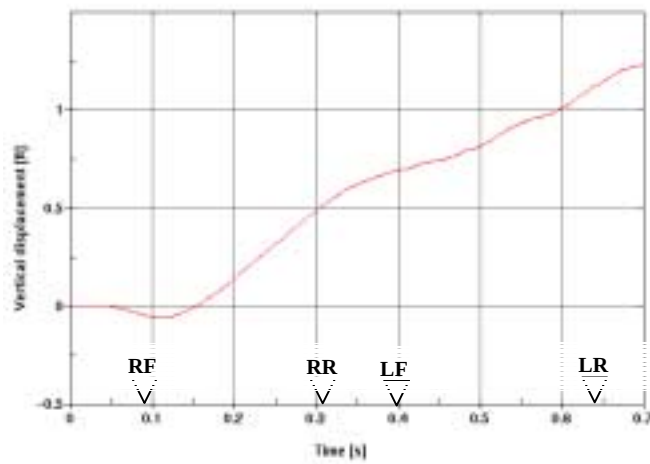


Fig. 2.2.1.4.1.2 (D): Vertical displacement [ft]

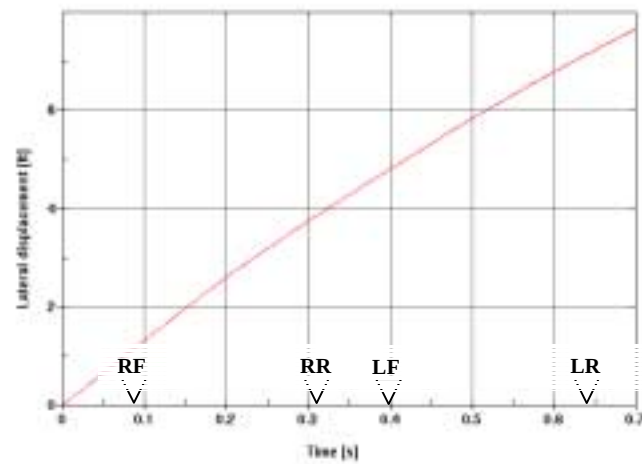


Fig. 2.2.1.4.1.2 (E): Lateral displacement [ft]

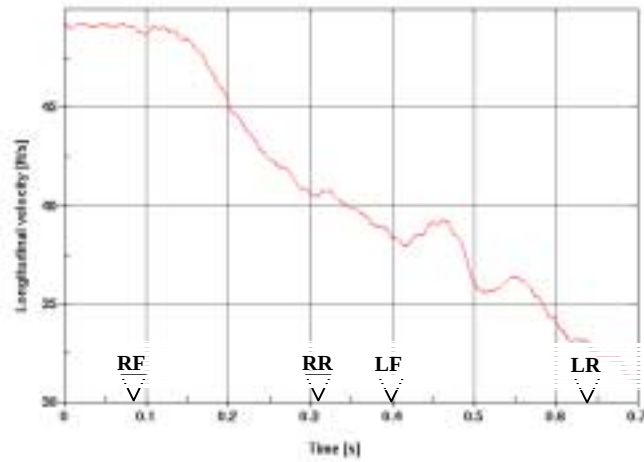


Fig. 2.2.1.4.1.2 (F): Longitudinal velocity [ft/s]

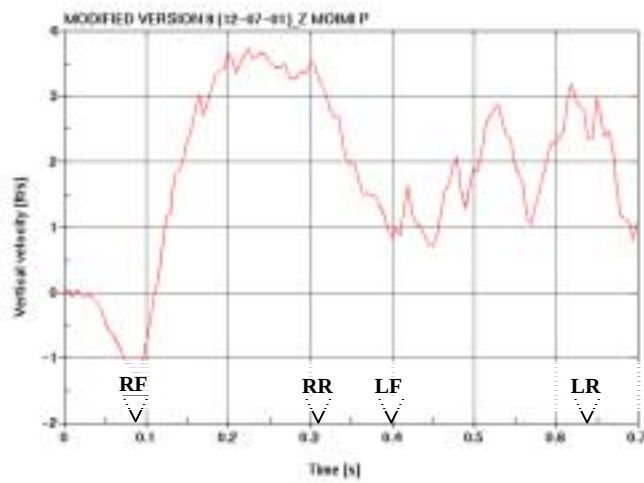


Fig. 2.2.1.4.1.2 (G) Vertical velocity [ft/s]

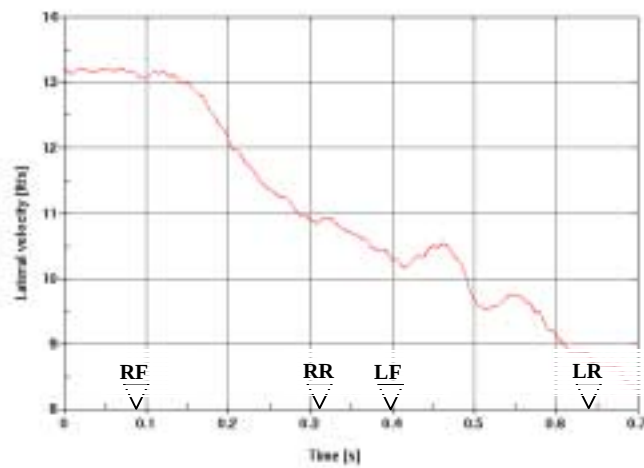


Fig. 2.2.1.4.1.2 (H): Lateral velocity [ft/s]

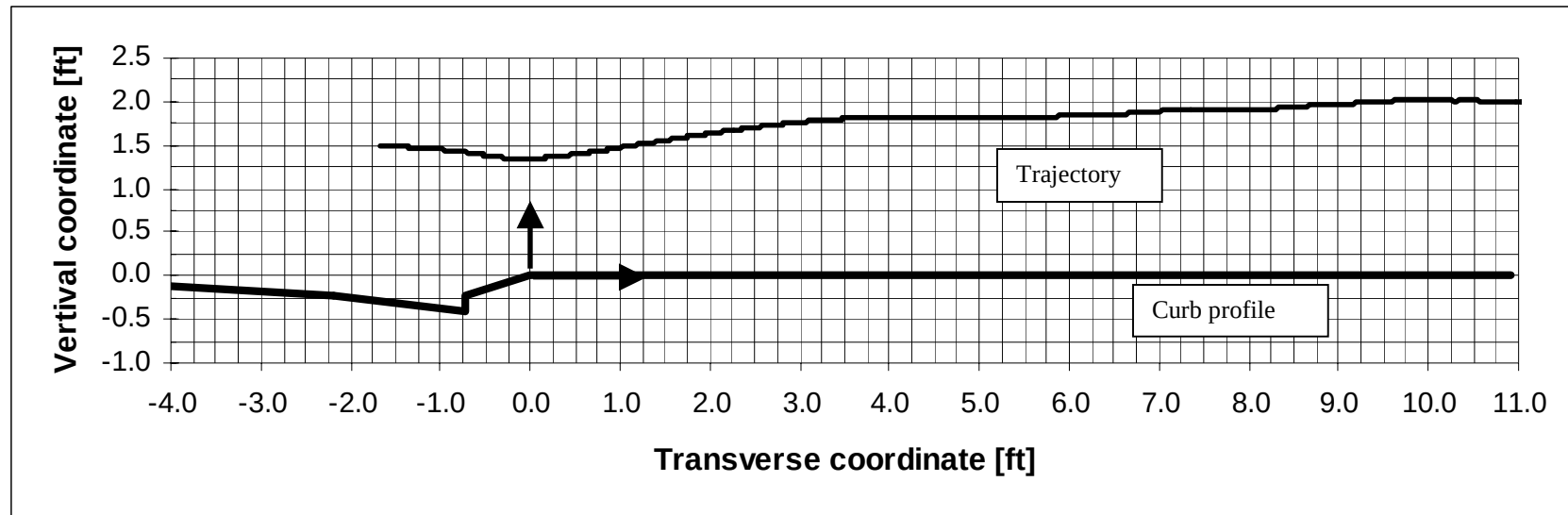


Fig. 2.2.1.4.1.1. (I): Trajectory of the bumper right corner

2.2.1.4.2 Velocity 55 mph

2.2.1.4.2.1 “F” curb

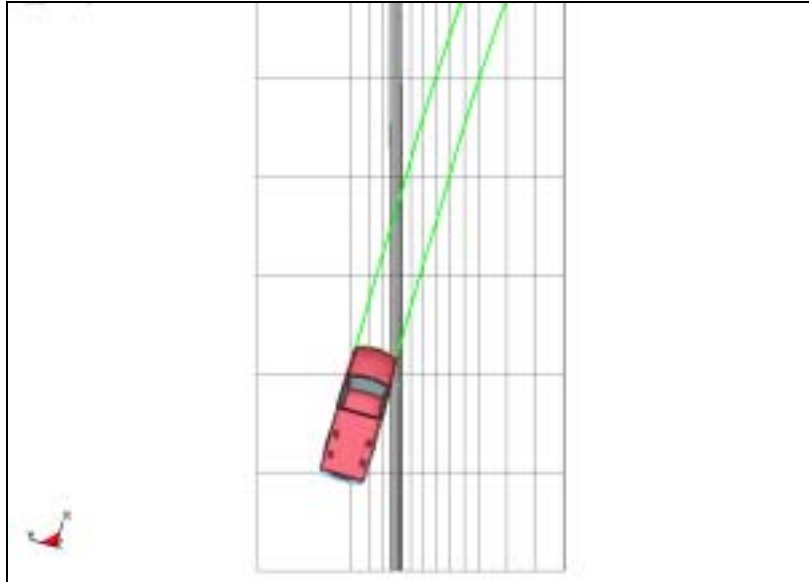


Fig. 2.2.1.4.2.1 (A) Trajectories of bumper corners (upper view)

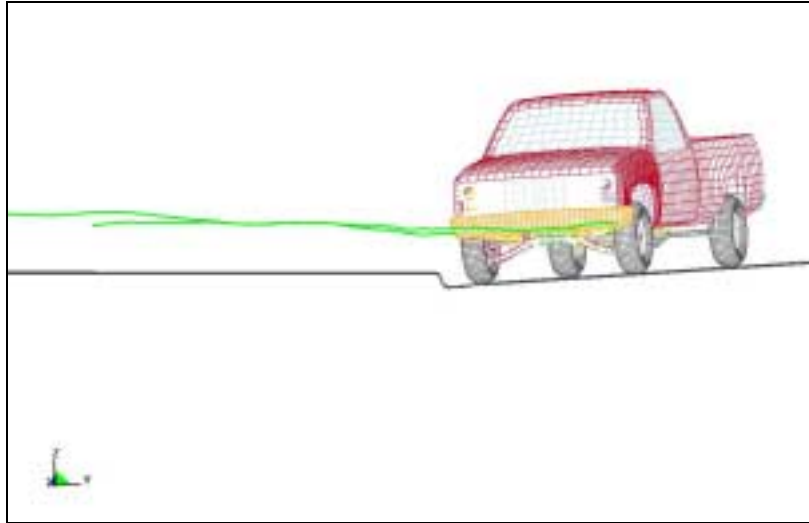


Fig. 2.2.1.4.2.1 (B) Trajectories of bumper corners (lateral view)

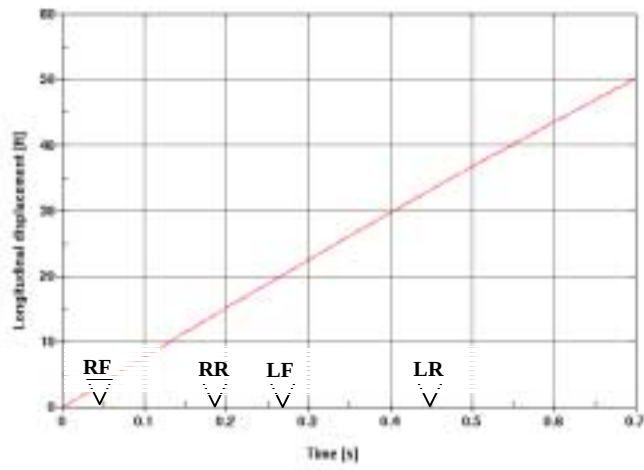


Fig. 2.2.1.4.2.1. (C): Longitudinal displacement [ft]

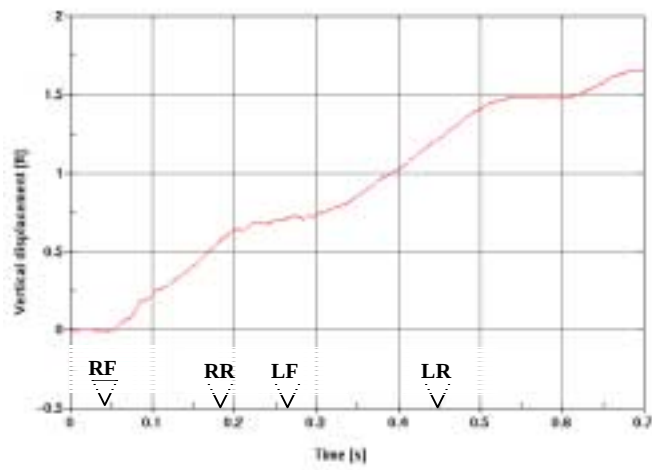


Fig. 2.2.1.4.2.1. (D): Vertical displacement [ft]

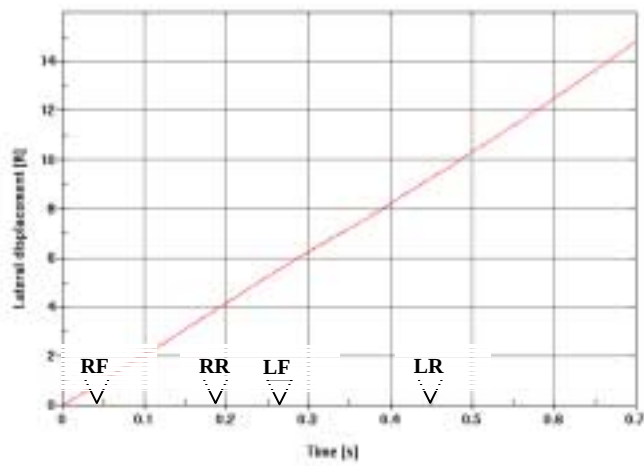


Fig. 2.2.1.4.2.1. (E): Lateral displacement [ft]

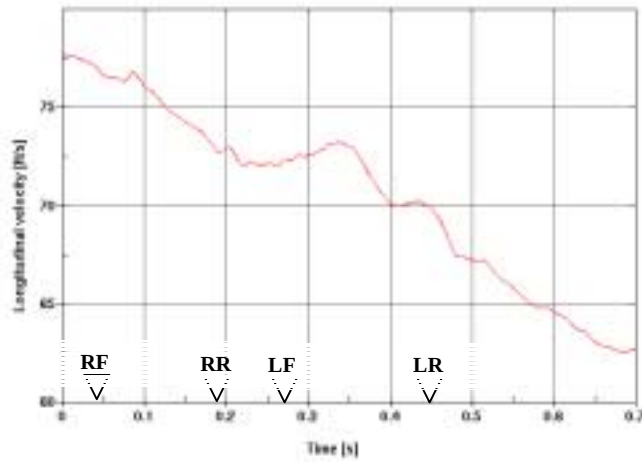


Fig. 2.2.1.4.2.1. (F): Longitudinal velocity [ft/s]

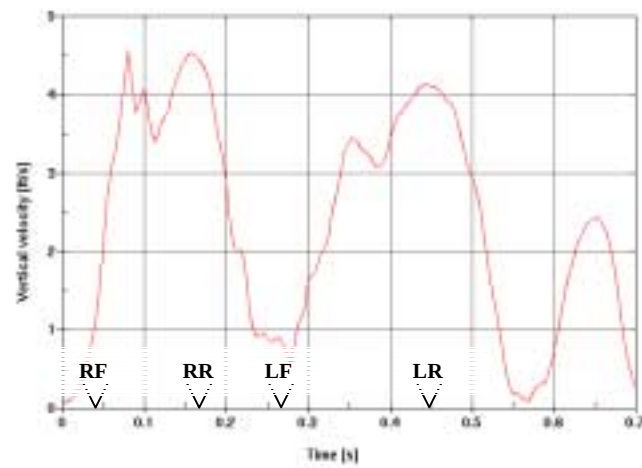


Fig. 2.2.1.4.2.1. (G) Vertical velocity [ft/s]

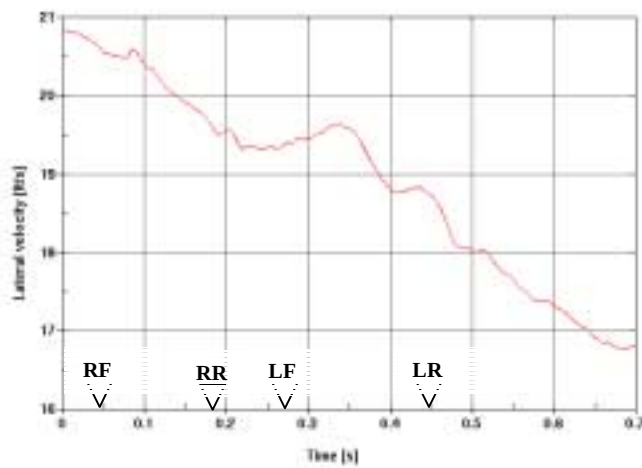


Fig. 2.2.1.4.2.1. (H): Lateral velocity [ft/s]

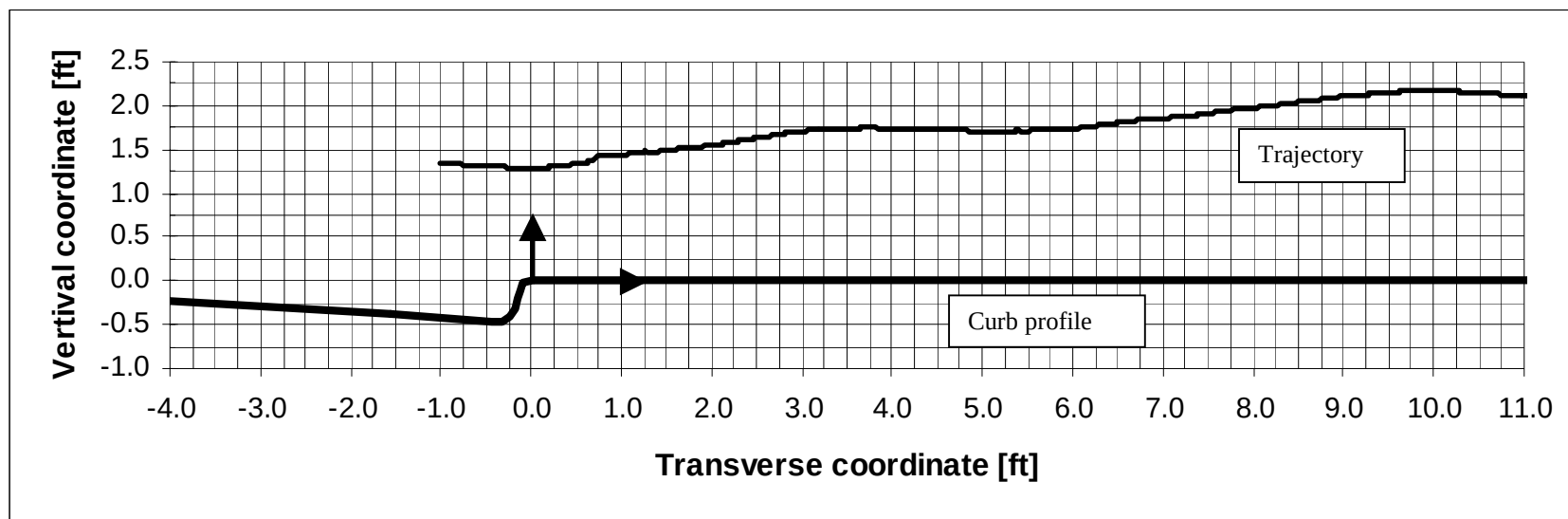


Fig. 2.2.1.4.2.1. (I): Trajectory of the bumper right corner

2.2.1.4.2.2 “E” curb

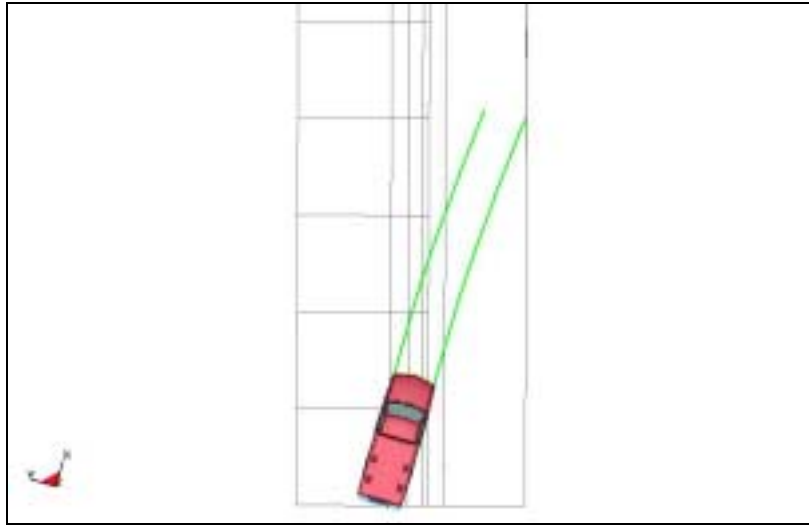


Fig. 2.2.1.4.2.2 (A) Trajectories of bumper corners (upper view)

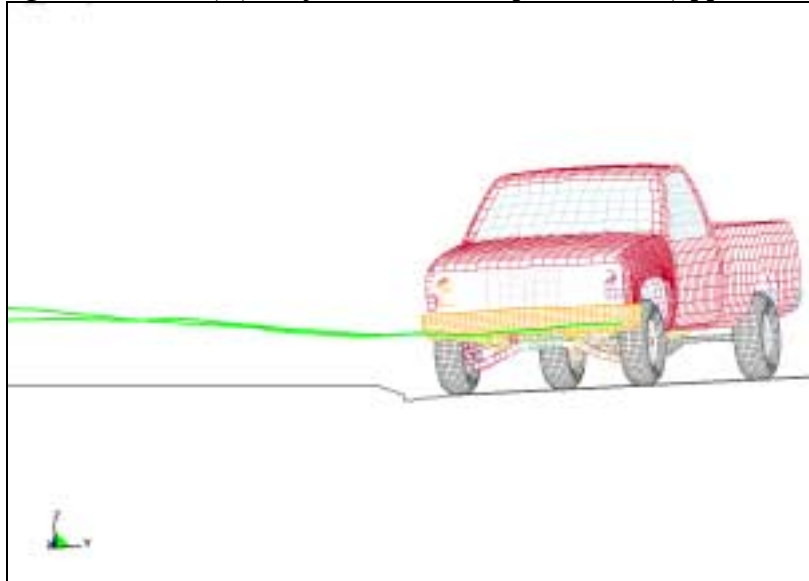


Fig. 2.2.1.4.2.2 (B) Trajectories of bumper corners (lateral view)

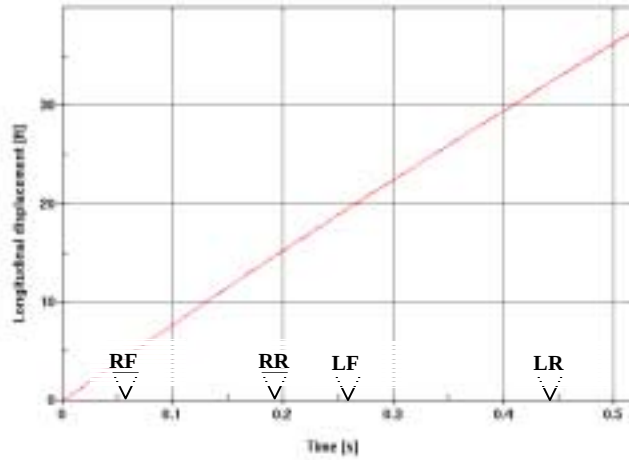


Fig. 2.2.1.4.2.2 (C): Longitudinal displacement [ft]

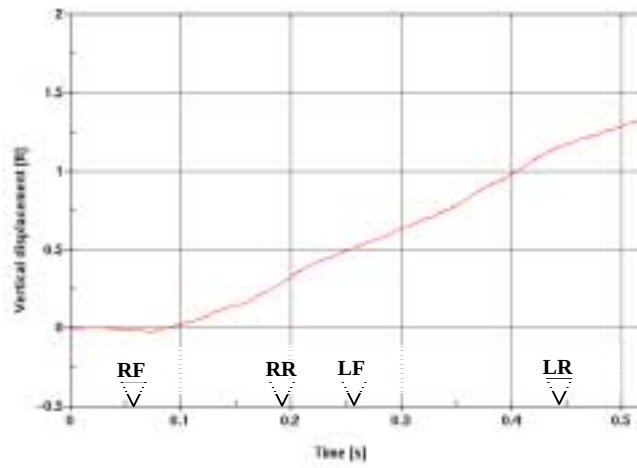


Fig. 2.2.1.4.2.2 (D): Vertical displacement [ft]

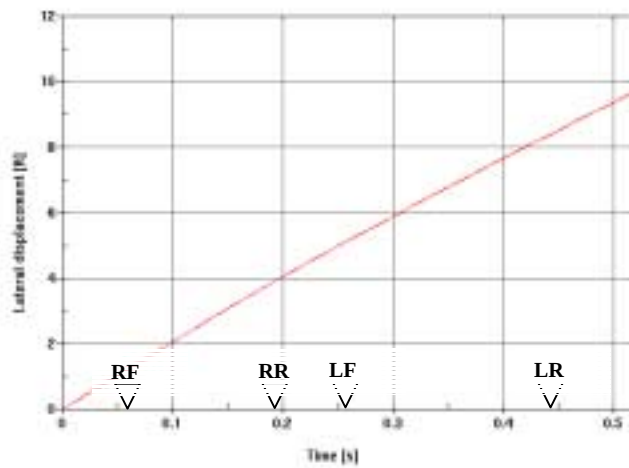


Fig. 2.2.1.4.2.2 (E): Lateral displacement [ft]

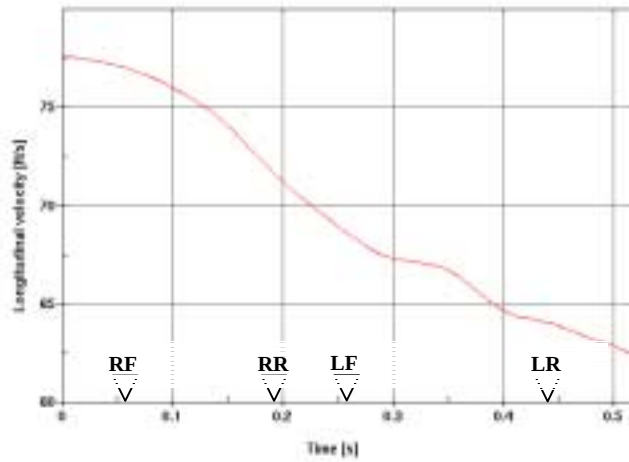


Fig. 2.2.1.4.2.2 (F): Longitudinal velocity [ft/s]

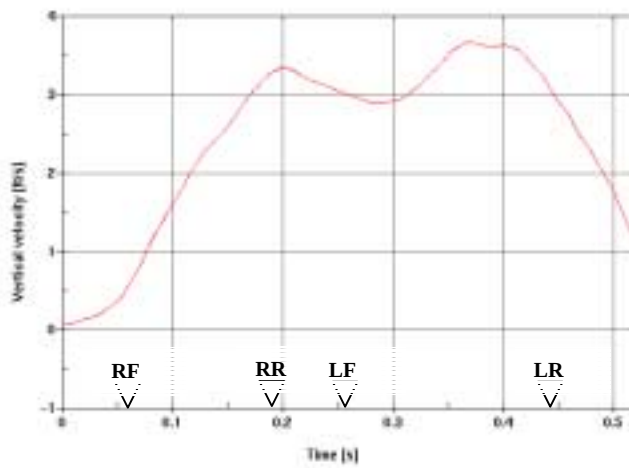


Fig. 2.2.1.4.2.2 (G) Vertical velocity [ft/s]

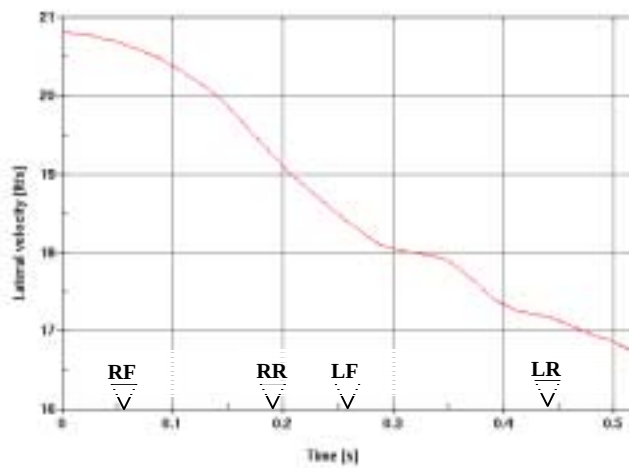


Fig. 2.2.1.4.2.2 (H): Lateral velocity [ft/s]

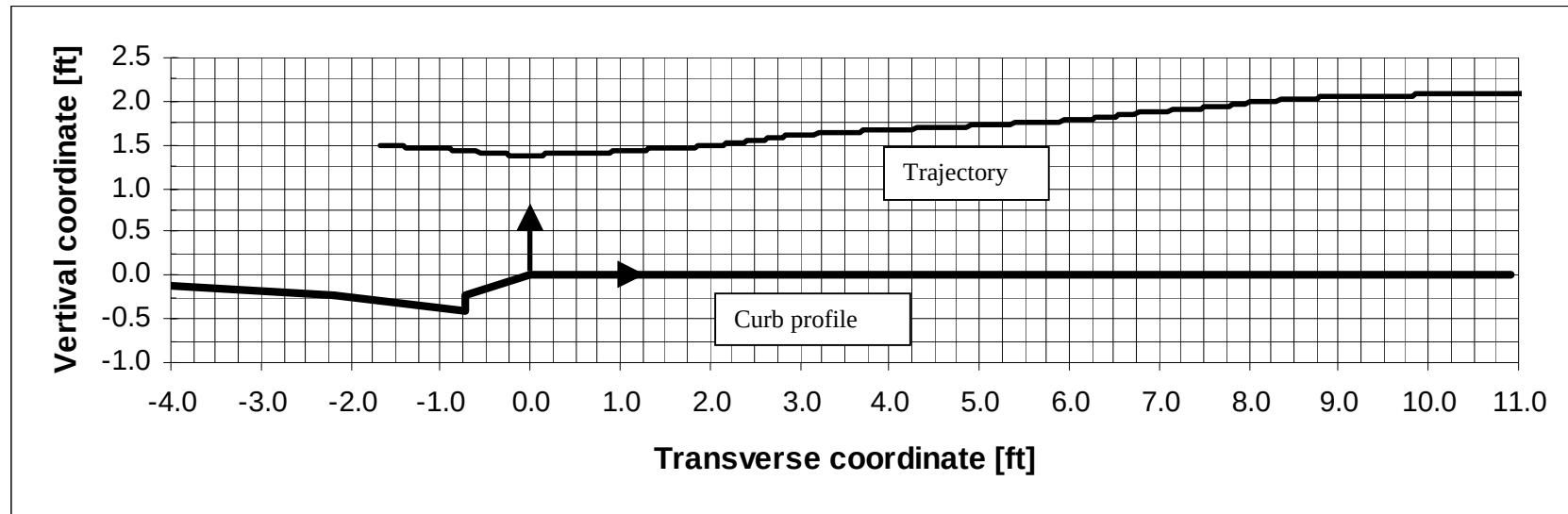


Fig. 2.2.1.4.2.2. (I): Trajectory of the bumper right corner

C2500/E_curb/15_degrees/55_mph/6_slope

2.2 Chevrolet C2500

2.2.2 Slope 0.02

2.2.2.1 Approach angle 3°

2.2.2.1.1 Velocity 35 mph

2.2.2.1.1.1 "F" curb

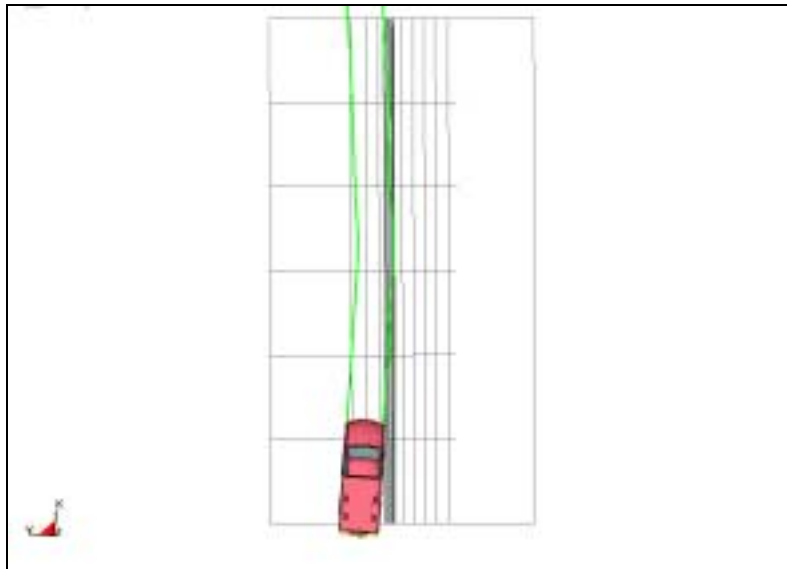


Fig. 2.2.2.1.1.1. (A) Trajectories of bumper corners (upper view)

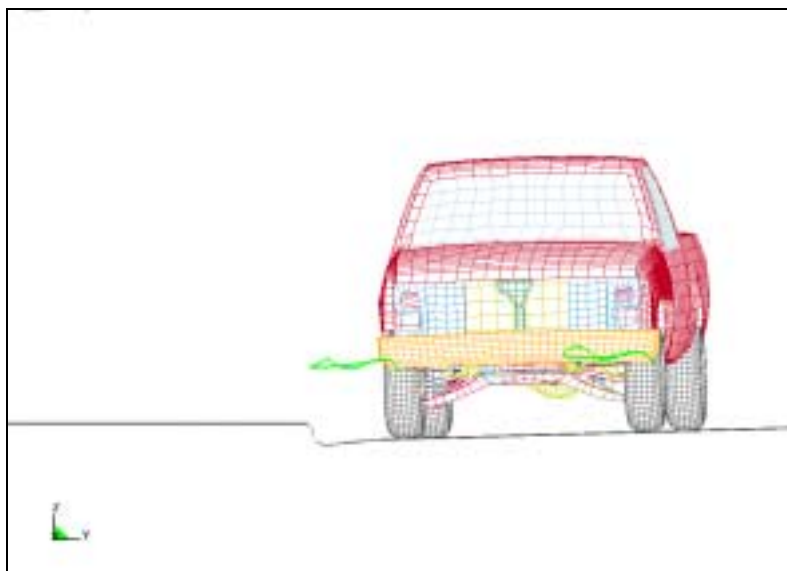


Fig. 2.2.2.1.1.1. (B) Trajectories of bumper corners (front view)

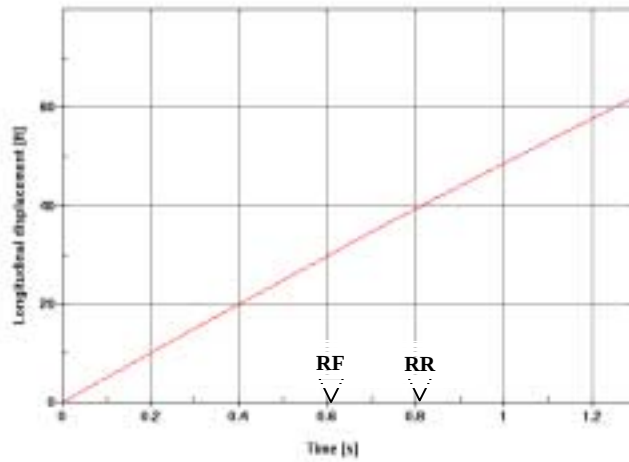


Fig. 2.2.2.1.1.1. (C): Longitudinal displacement [ft]

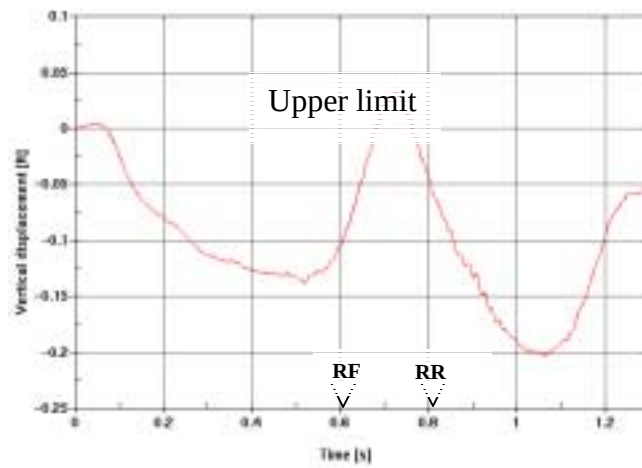


Fig. 2.2.2.1.1.1. (D): Vertical displacement [ft]

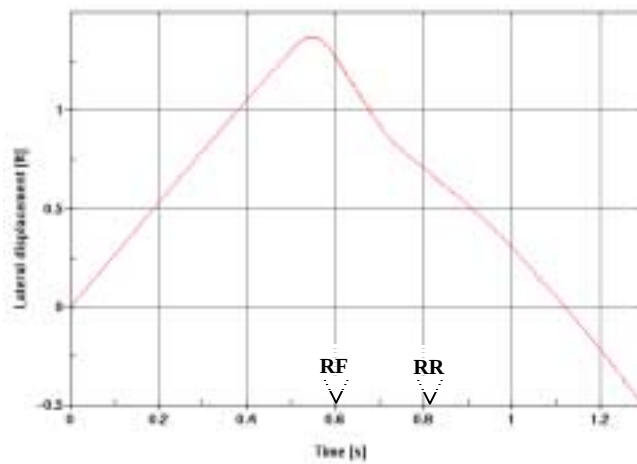


Fig. 2.2.2.1.1.1. (E): Lateral displacement [ft]

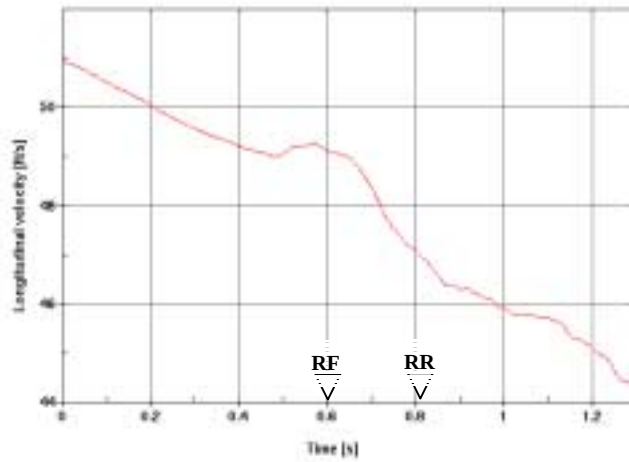


Fig. 2.2.2.1.1.1. (F): Longitudinal velocity [ft/s]

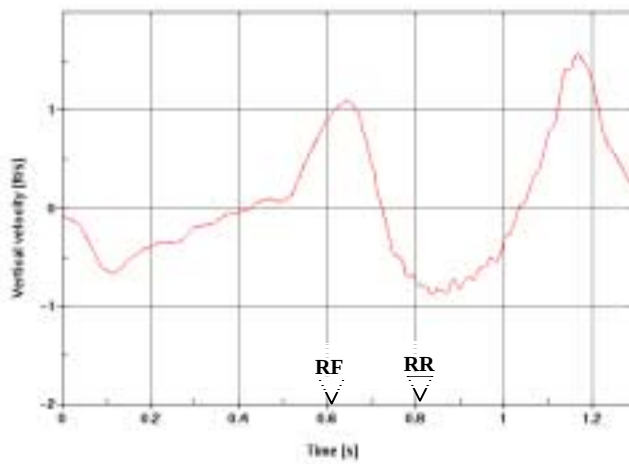


Fig. 2.2.2.1.1.1. (G) Vertical velocity [ft/s]

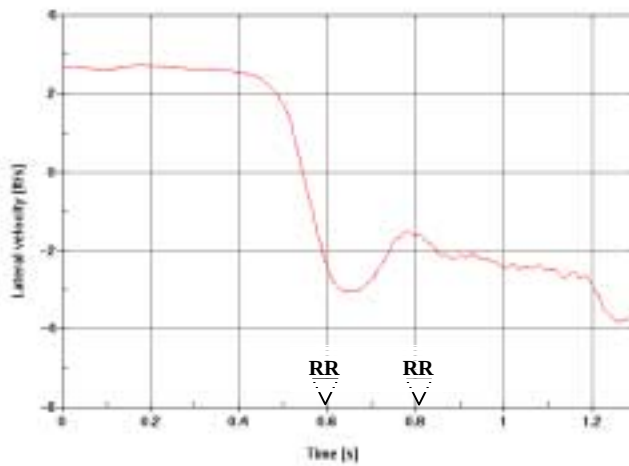


Fig. 2.2.2.1.1.1. (H): Lateral velocity [ft/s]

2.2.2.1.1.2 “E” curb

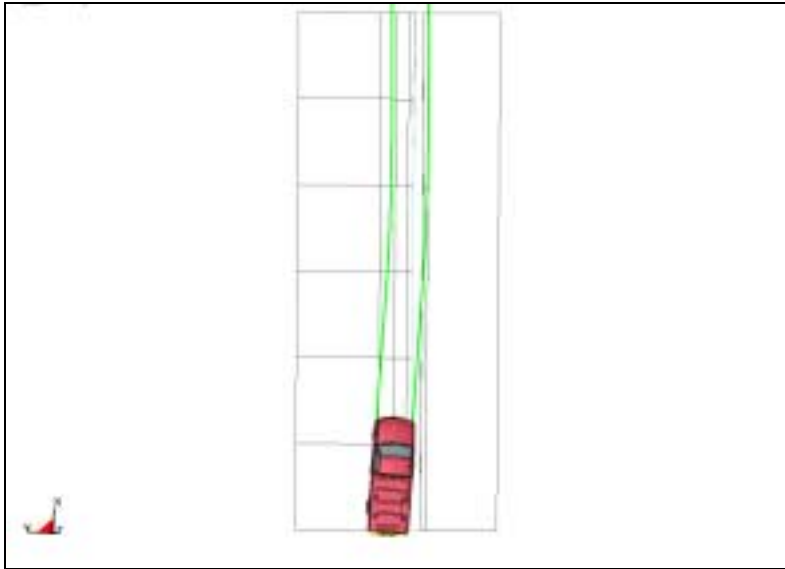


Fig. 2.2.2.1.1.2. (A) Trajectories of bumper corners (upper view)

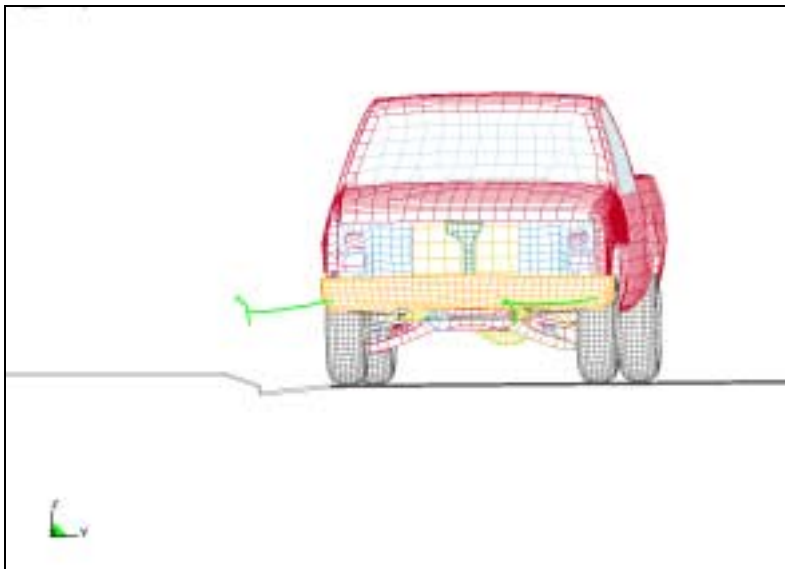


Fig. 2.2.2.1.1.2. (B) Trajectories of bumper corners (lateral view)

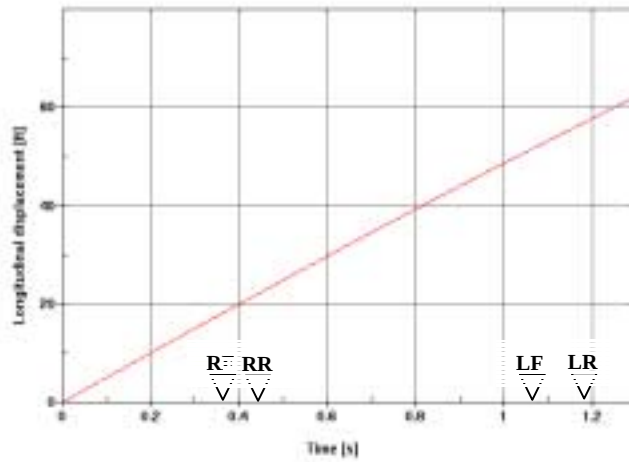


Fig. 2.2.2.1.1.2. (C): Longitudinal displacement [ft]

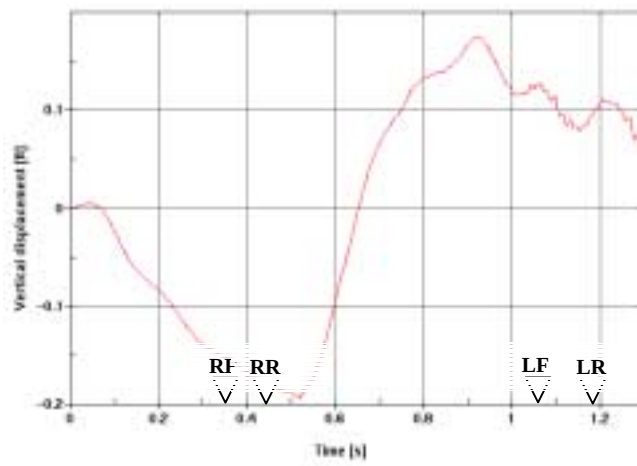


Fig. 2.2.2.1.1.2. (D): Vertical displacement [ft]

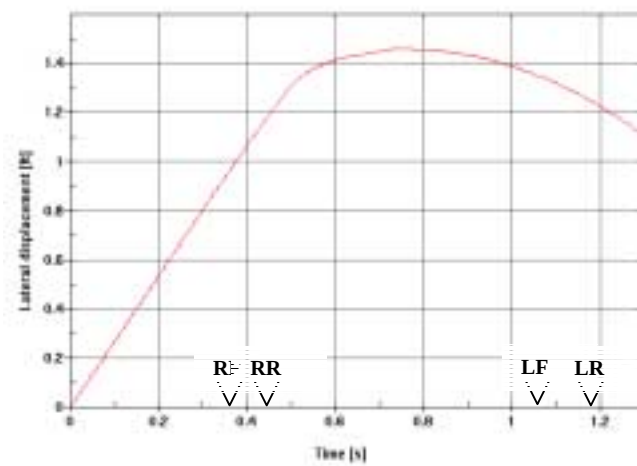


Fig. 2.2.2.1.1.2. (E): Lateral displacement [ft]

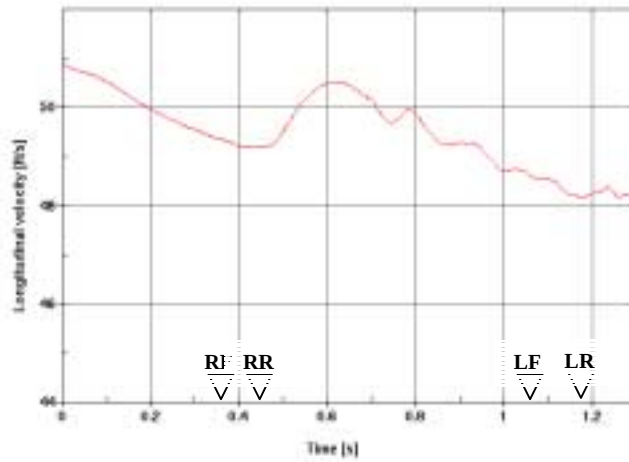


Fig. 2.2.2.1.1.2. (F): Longitudinal velocity [ft/s]

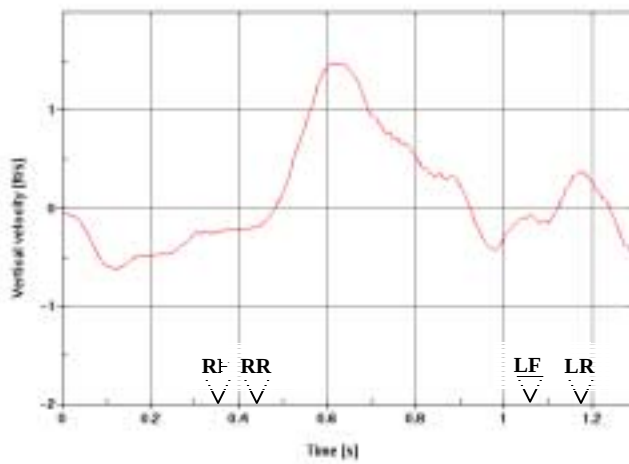


Fig. 2.2.2.1.1.2. (G) Vertical velocity [ft/s]

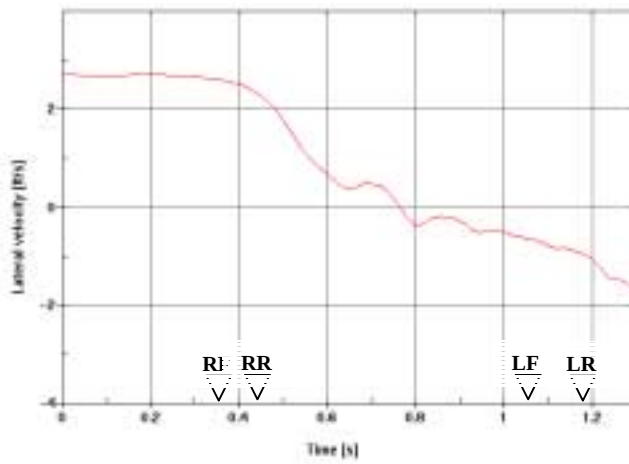


Fig. 2.2.2.1.1.2. (H): Lateral velocity [ft/s]

2.2.2.1.2 Velocity 55 mph

2.2.2.1.2.1 “F” curb

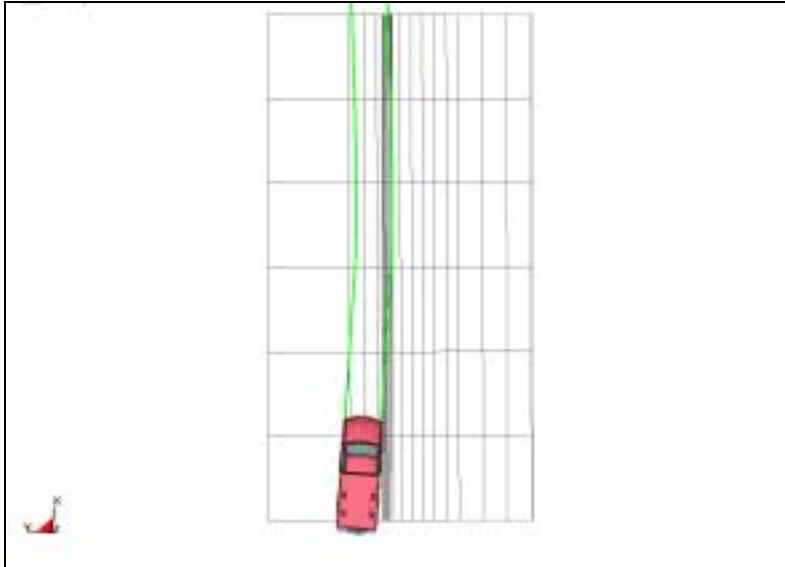


Fig. 2.2.2.1.2.1. (A) Trajectories of bumper corners (upper view)

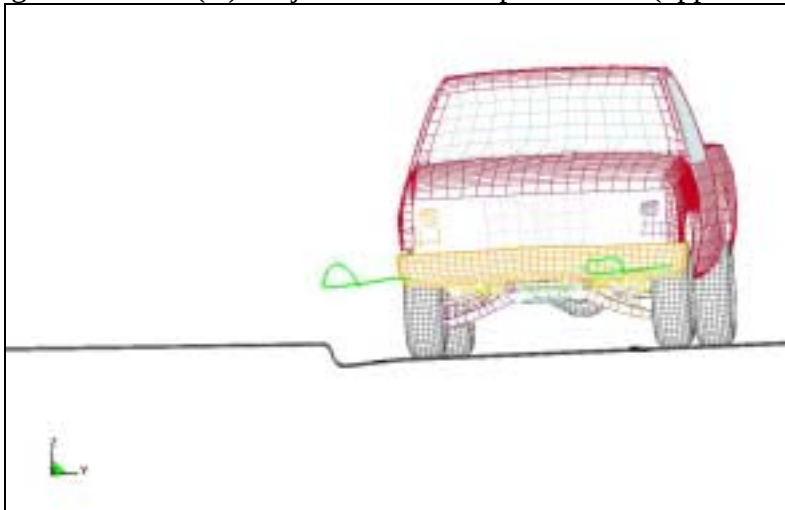


Fig. 2.2.2.1.2.1. (B) Trajectories of bumper corners (lateral view)

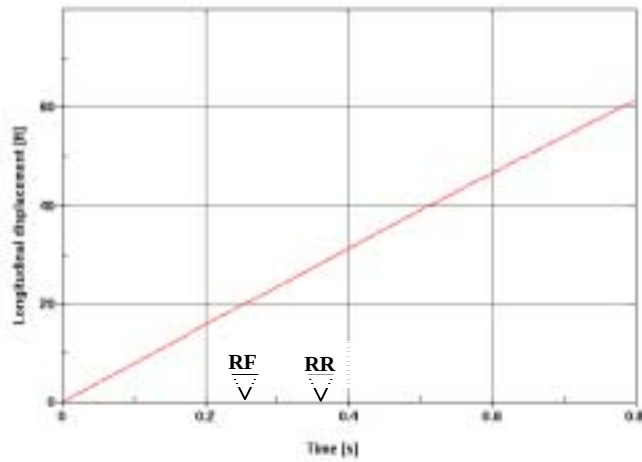


Fig. 2.2.2.1.2.1. (C): Longitudinal displacement [ft]

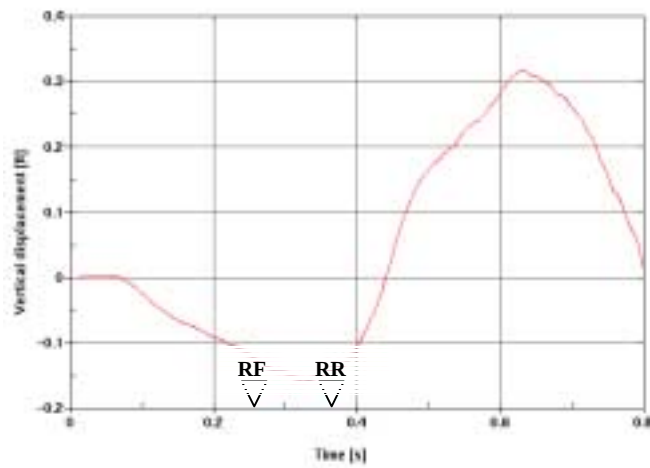


Fig. 2.2.2.1.2.1. (D): Vertical displacement [ft]

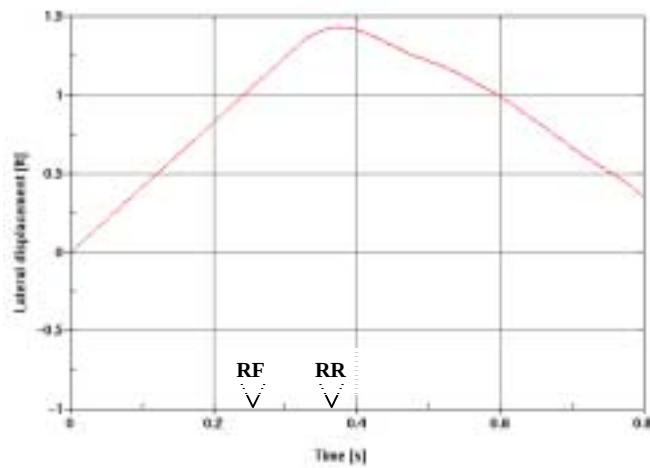


Fig. 2.2.2.1.2.1. (E): Lateral displacement [ft]

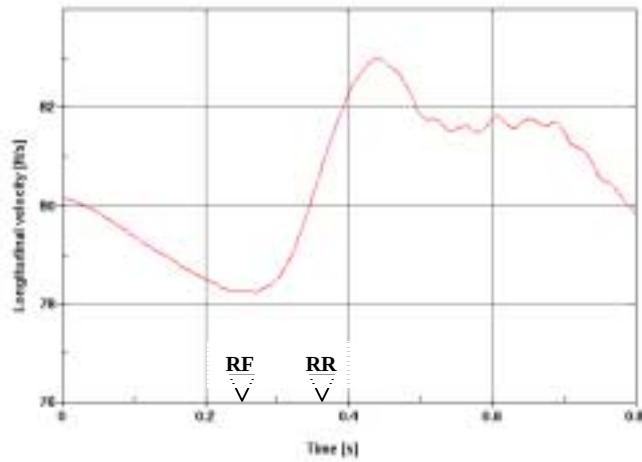


Fig. 2.2.2.1.2.1. (F): Longitudinal velocity [ft/s]

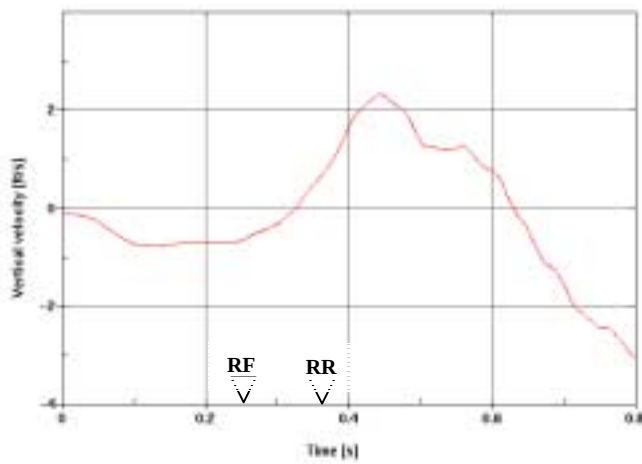


Fig. 2.2.2.1.2.1. (G) Vertical velocity [ft/s]

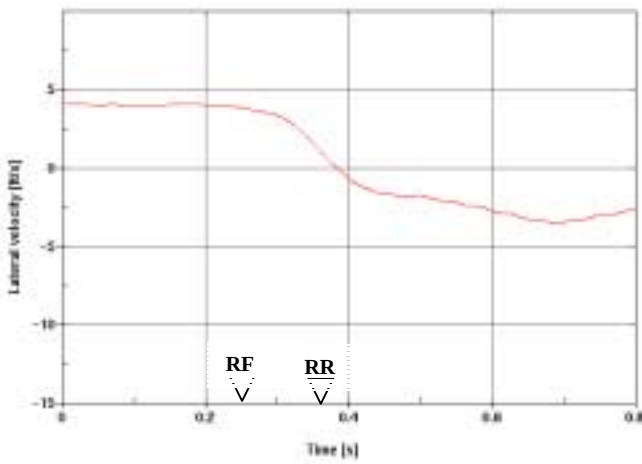


Fig. 2.2.2.1.2.1. (H): Lateral velocity [ft/s]

2.2.2.1.2.2 “E” curb

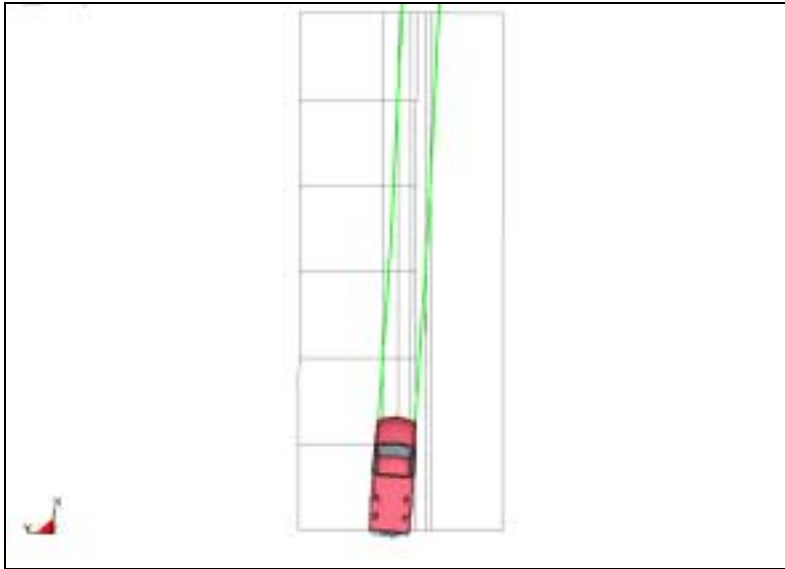


Fig. 2.2.2.1.2.2. (A) Trajectories of bumper corners (upper view)

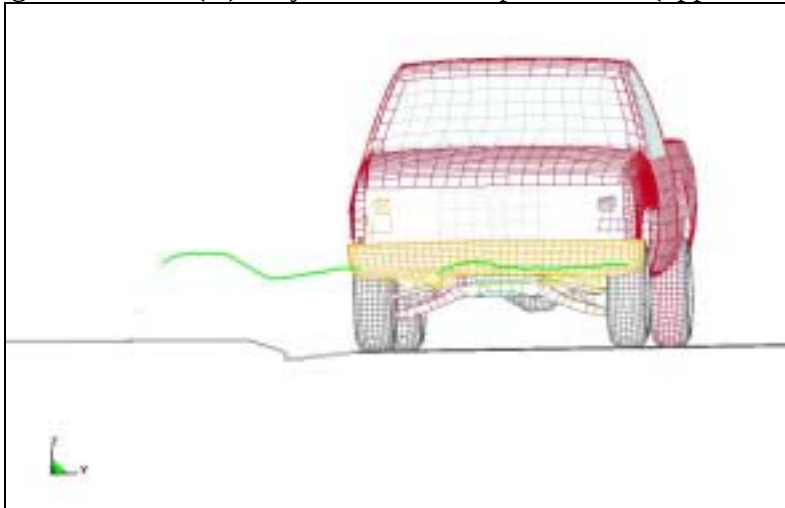


Fig. 2.2.2.1.2.2. (B) Trajectories of bumper corners (lateral view)

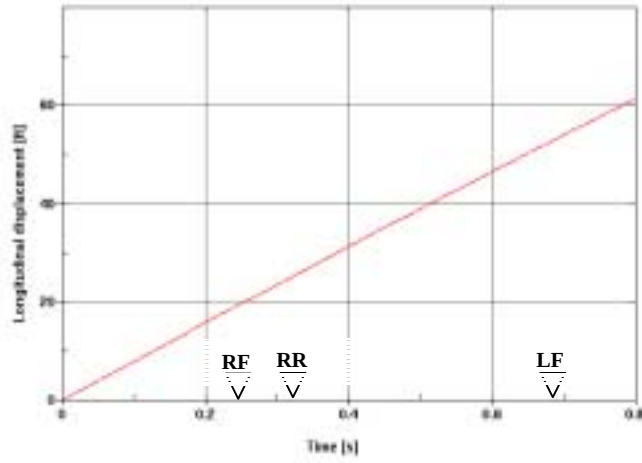


Fig. 2.2.2.1.2.2. (C): Longitudinal displacement [ft]

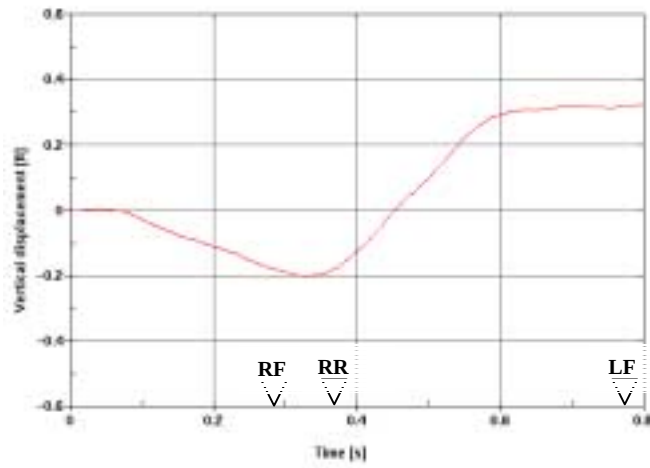


Fig. 2.2.2.1.2.2. (D): Vertical displacement [ft]

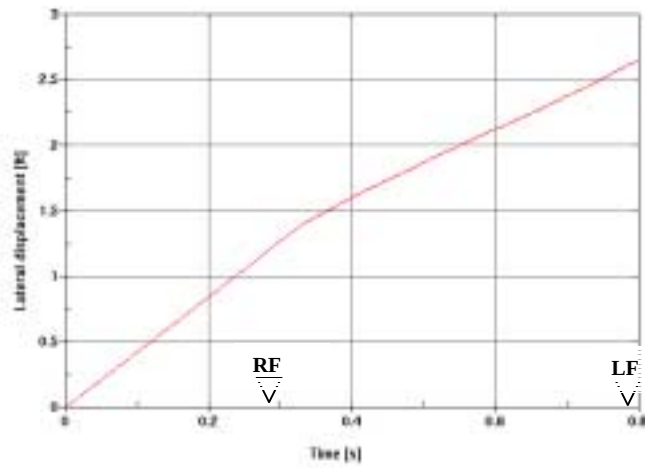


Fig. 2.2.2.1.2.2. (E): Lateral displacement [ft]

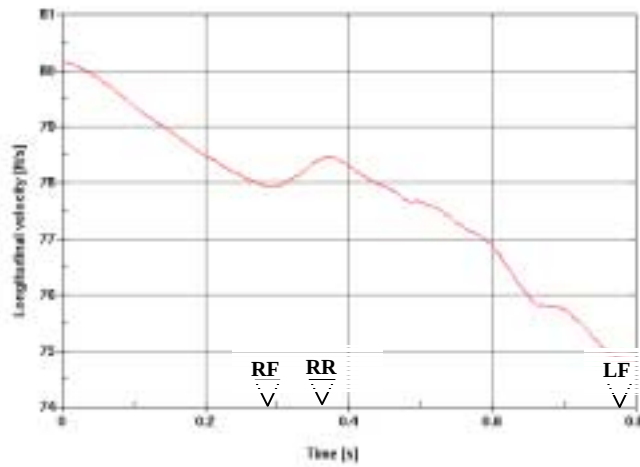


Fig. 2.2.2.1.2.2. (F): Longitudinal velocity [ft/s]

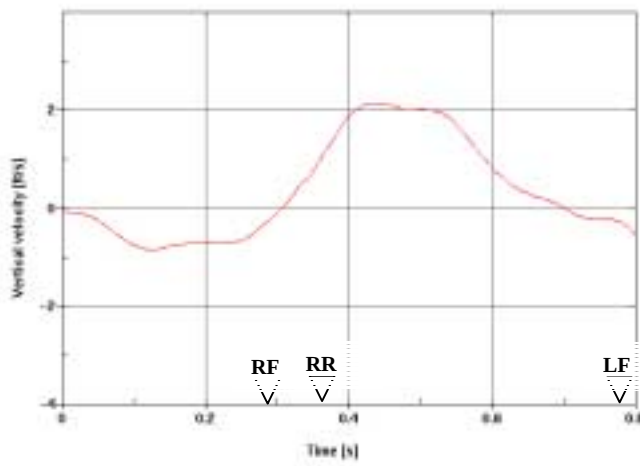


Fig. 2.2.2.1.2.2. (G) Vertical velocity [ft/s]

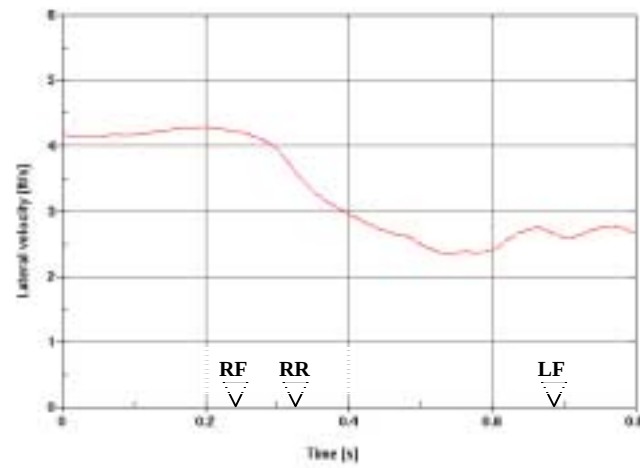


Fig. 2.2.2.1.2.2. (H): Lateral velocity [ft/s]

2.2.2.2 Approach angle 5°

2.2.2.2.1 Velocity 35 mph

2.2.2.2.1.1 “F” curb

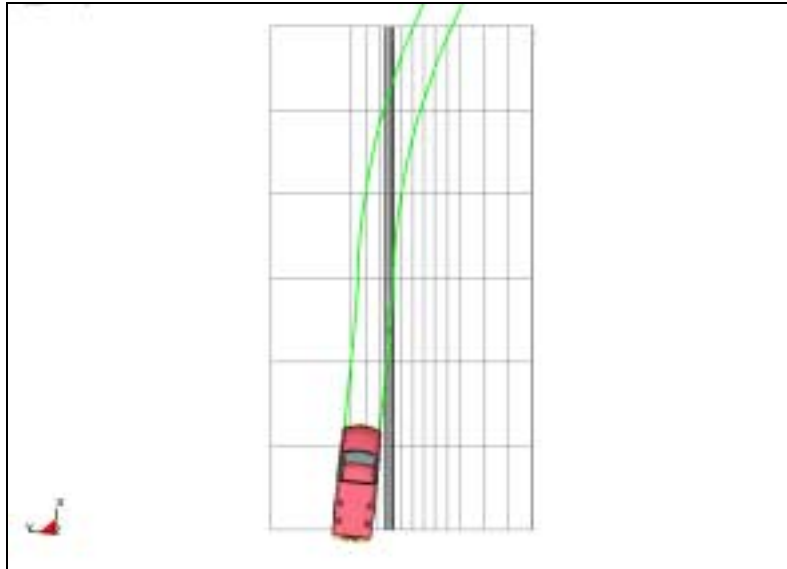


Fig. 2.2.2.2.1.1. (A) Trajectories of bumper corners (upper view)

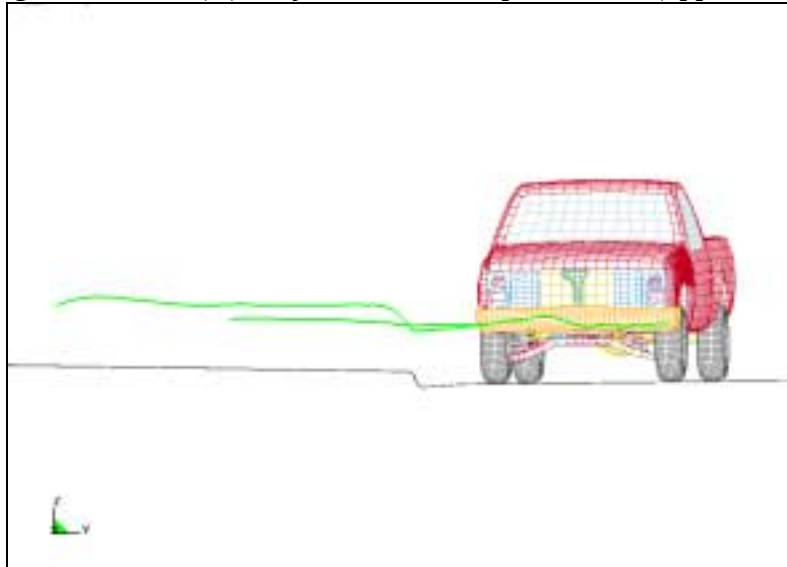


Fig. 2.2.2.2.1.1. (B) Trajectories of bumper corners (lateral view)

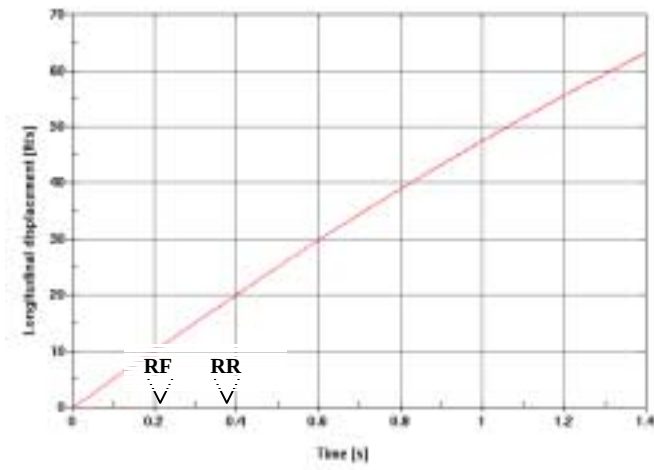


Fig. 2.2.2.2.1.1. (C): Longitudinal displacement [ft]

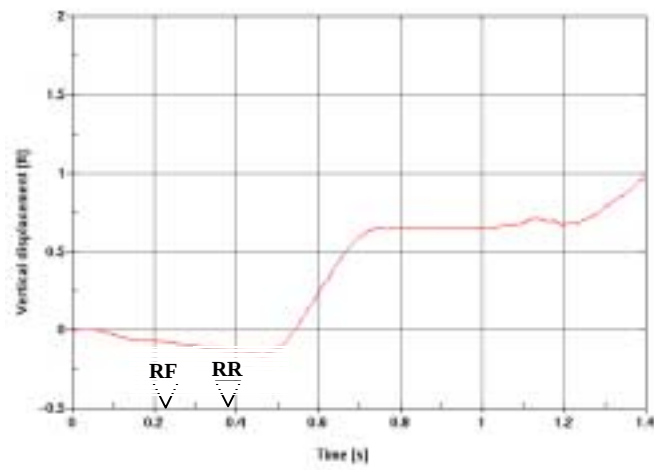


Fig. 2.2.2.2.1.1. (D): Vertical displacement [ft]

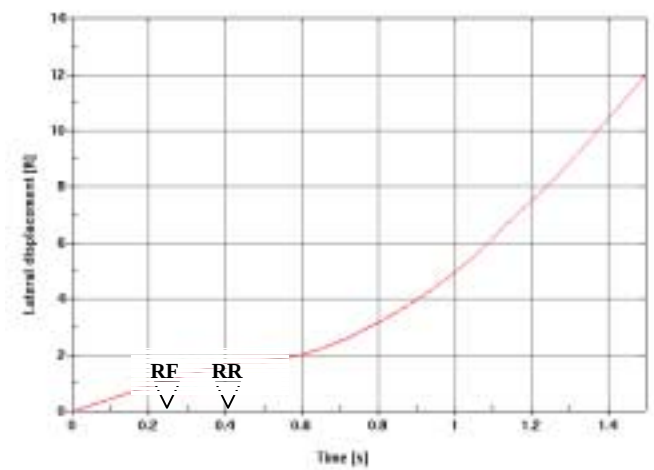


Fig. 2.2.2.2.1.1. (E): Lateral displacement [ft]

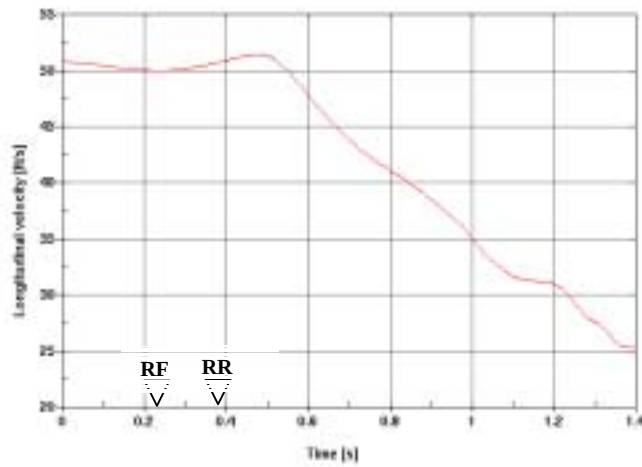


Fig. 2.2.2.2.1.1. (F): Longitudinal velocity [ft/s]

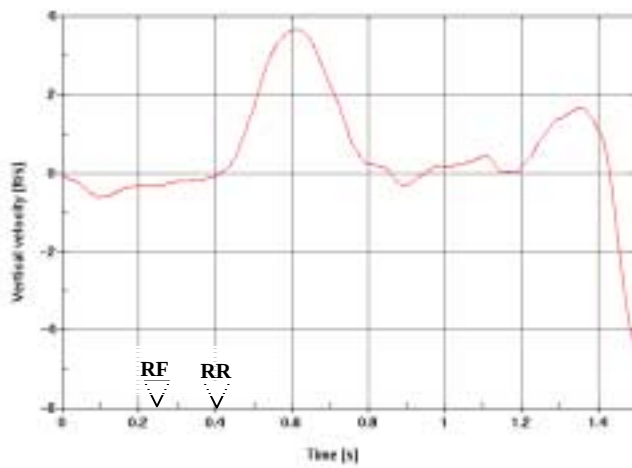


Fig. 2.2.2.2.1.1. (G) Vertical velocity [ft/s]

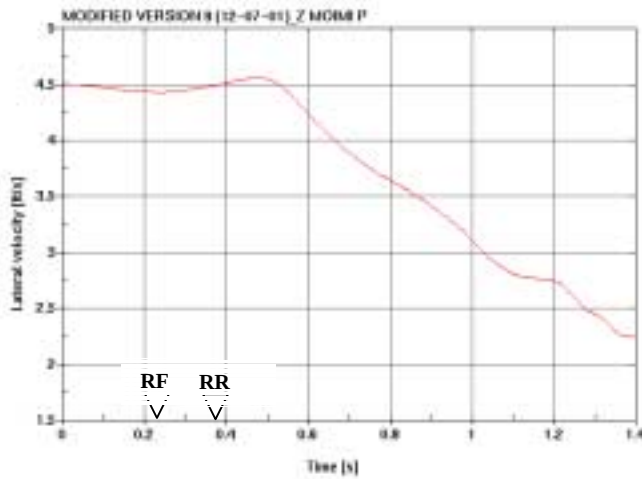


Fig. 2.2.2.2.1.1. (H): Lateral velocity [ft/s]

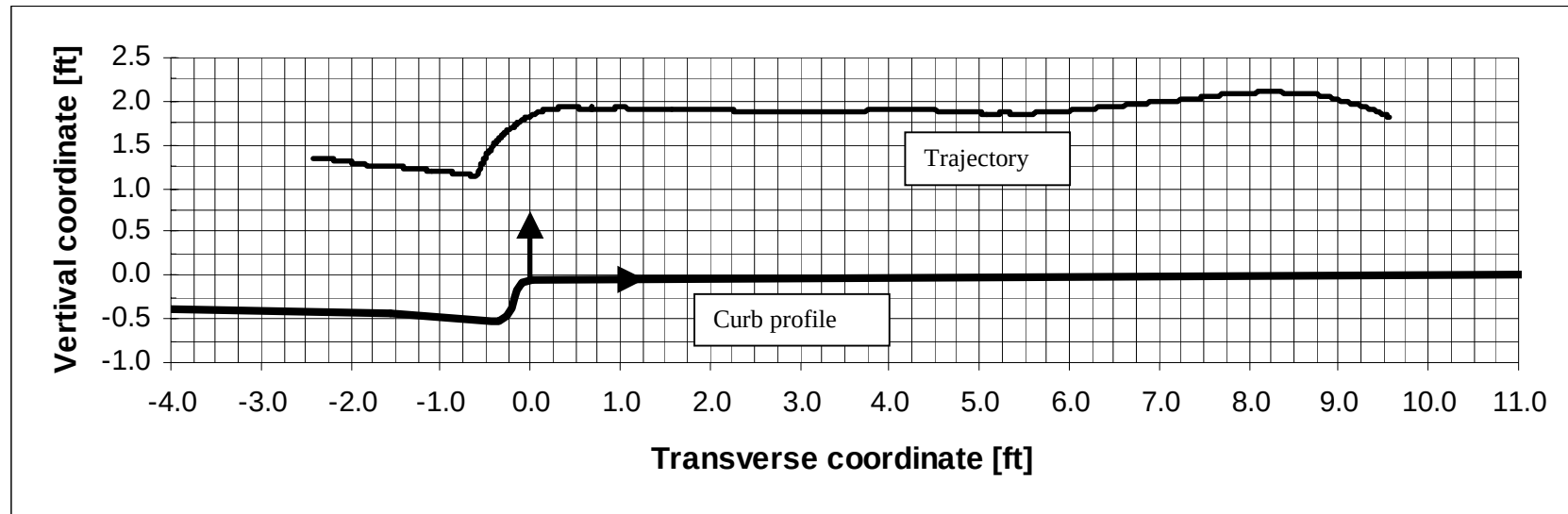


Fig. 2.2.2.2.1.1. (I): Trajectory of the bumper right corner

2.2.2.2.1.2 “E” curb

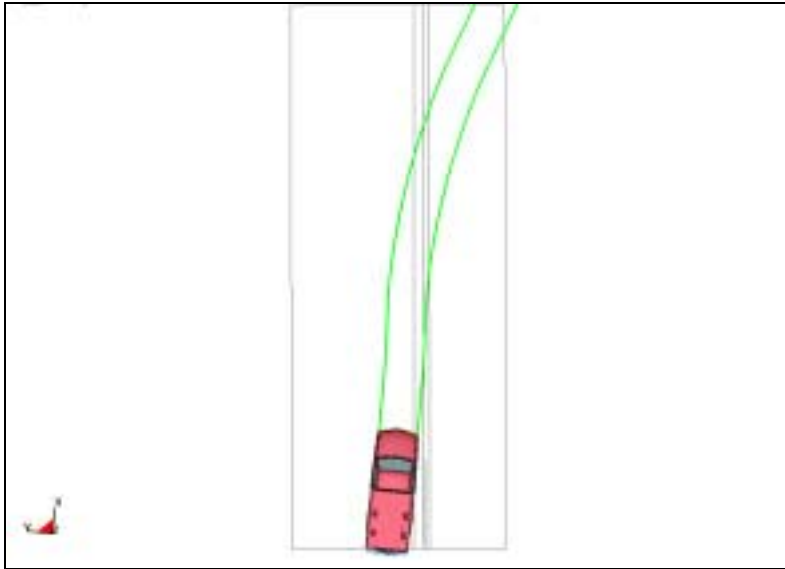


Fig. 2.2.2.2.1.2. (A) Trajectories of bumper corners (upper view)

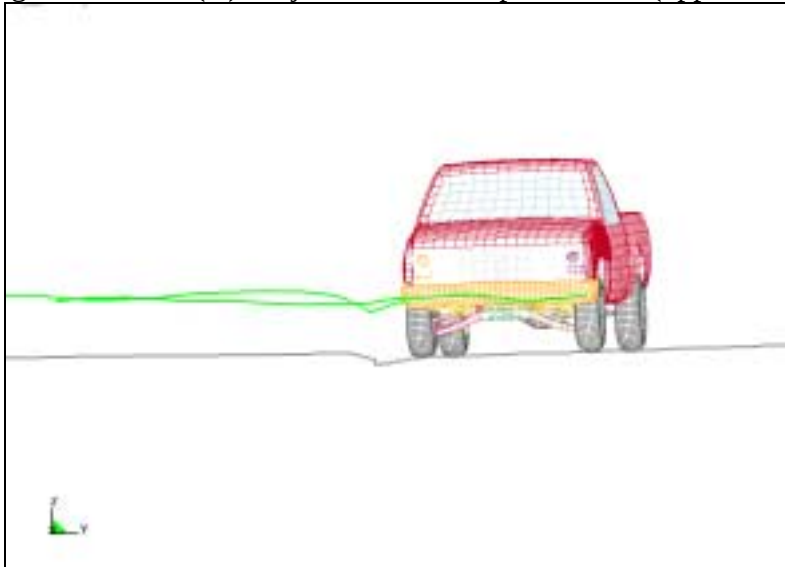


Fig. 2.2.2.2.1.2. (B) Trajectories of bumper corners (lateral view)

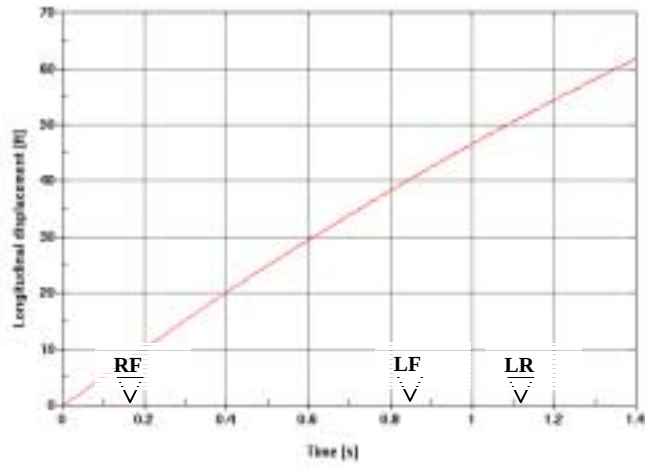


Fig. 2.2.2.2.1.2. (C): Longitudinal displacement [ft]

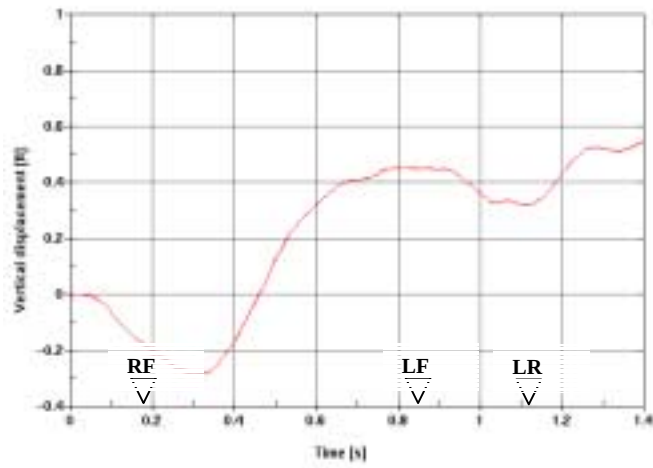


Fig. 2.2.2.2.1.2. (D): Vertical displacement [ft]

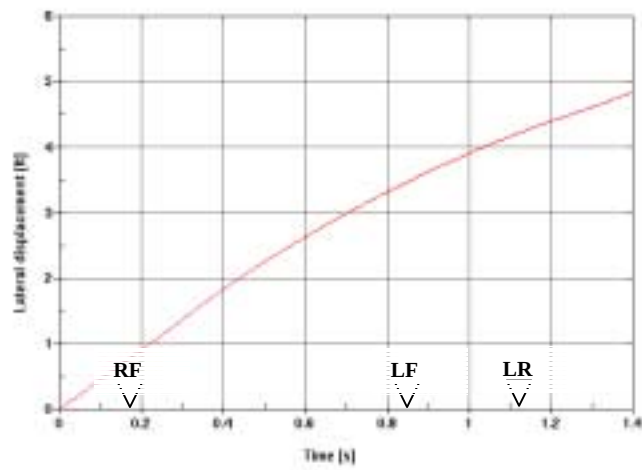


Fig. 2.2.2.2.1.2. (E): Lateral displacement [ft]

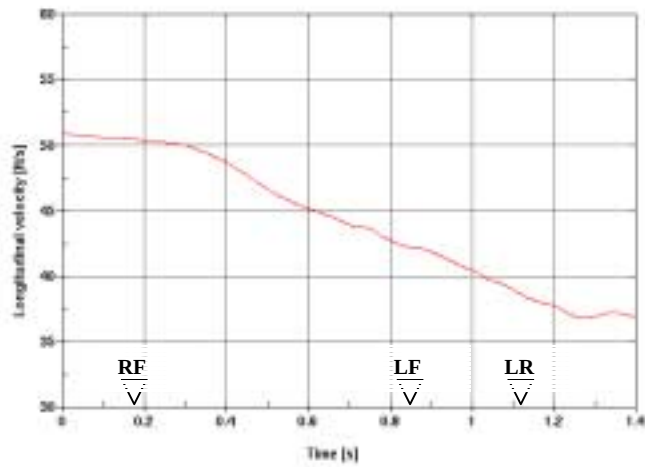


Fig. 2.2.2.2.1.2. (F): Longitudinal velocity [ft/s]

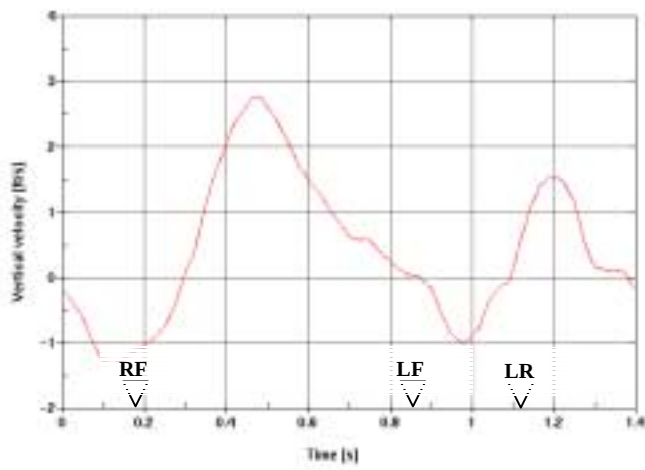


Fig. 2.2.2.2.1.2. (G) Vertical velocity [ft/s]

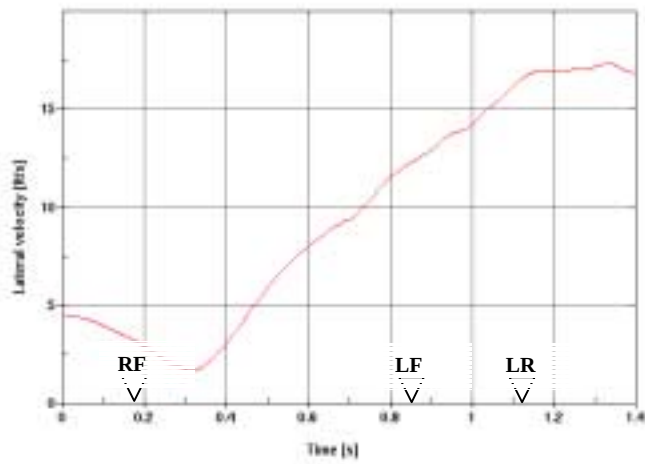


Fig. 2.2.2.2.1.2. (H): Lateral velocity [ft/s]

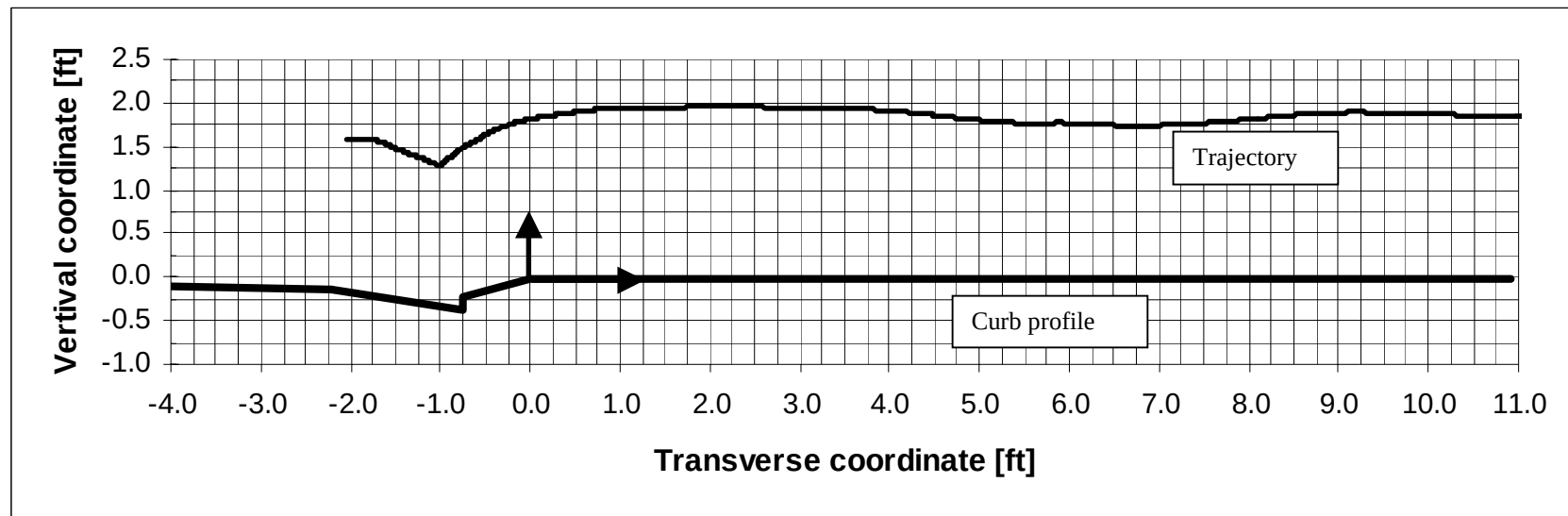


Fig. 2.2.2.2.1.2. (I): Trajectory of the bumper right corner

2.2.2.2 Approach angle 5°
2.2.2.2.2 Velocity 55 mph
2.2.2.2.2.1 “F” curb

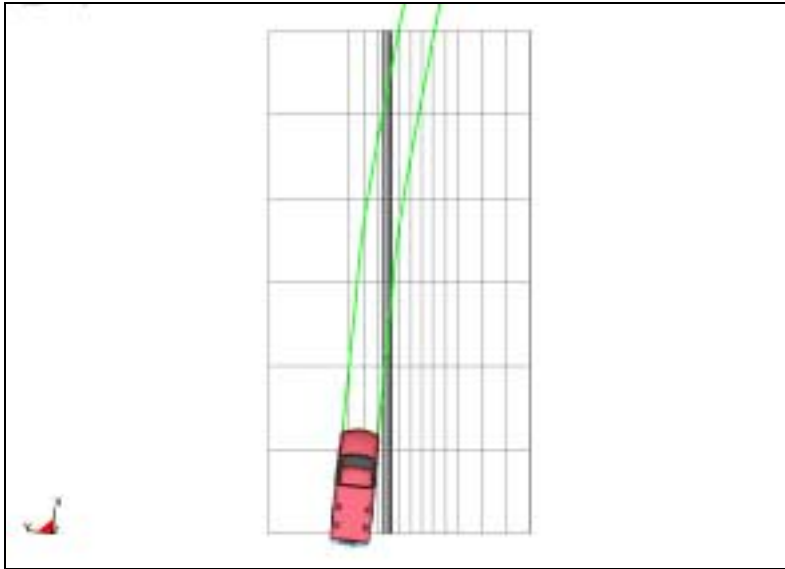


Fig. 2.2.2.2.2.1 (A) Trajectories of bumper corners (upper view)

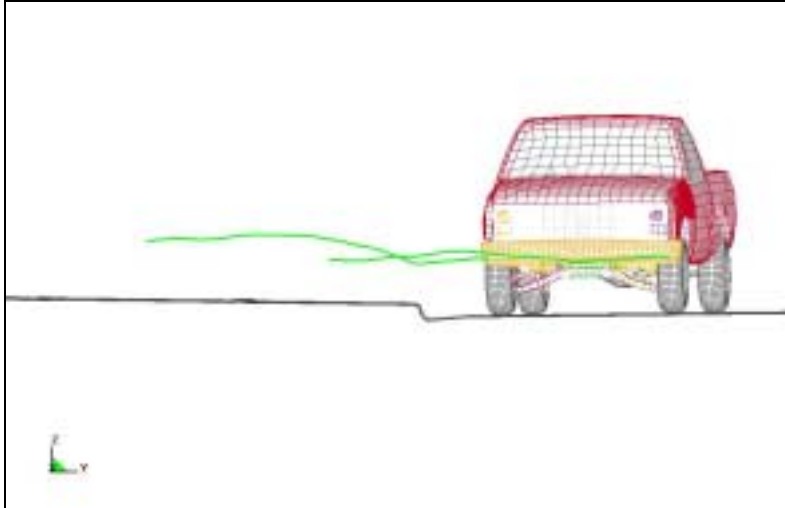


Fig. 2.2.2.2.2.1 (B) Trajectories of bumper corners (lateral view)

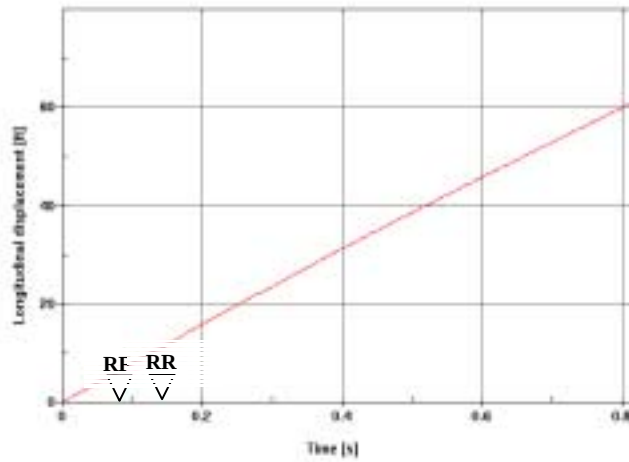


Fig. 2.2.2.2.1 (C): Longitudinal displacement [ft]

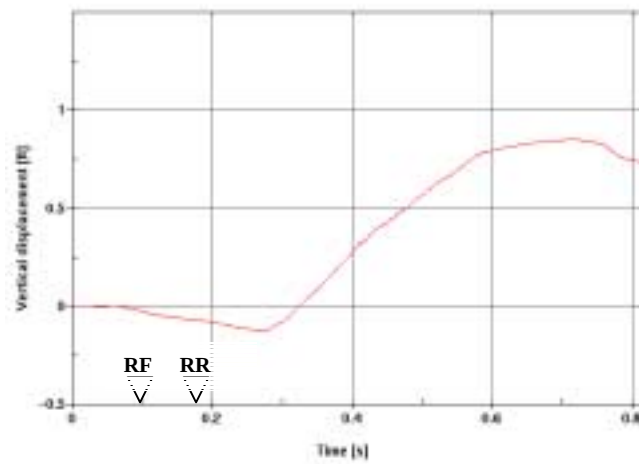


Fig. 2.2.2.2.1 (D): Vertical displacement [ft]

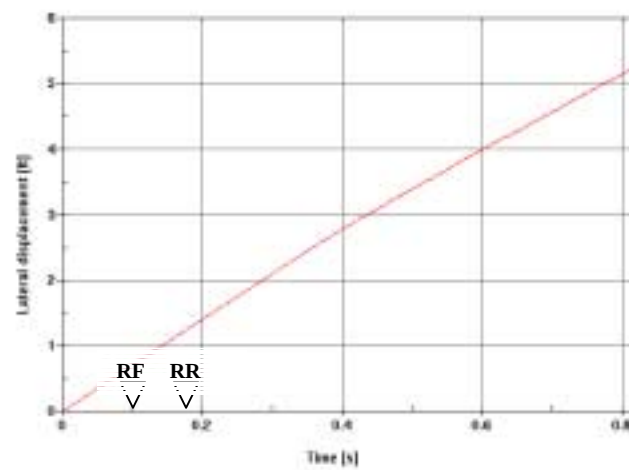


Fig. 2.2.2.2.1 (E): Lateral displacement [ft]

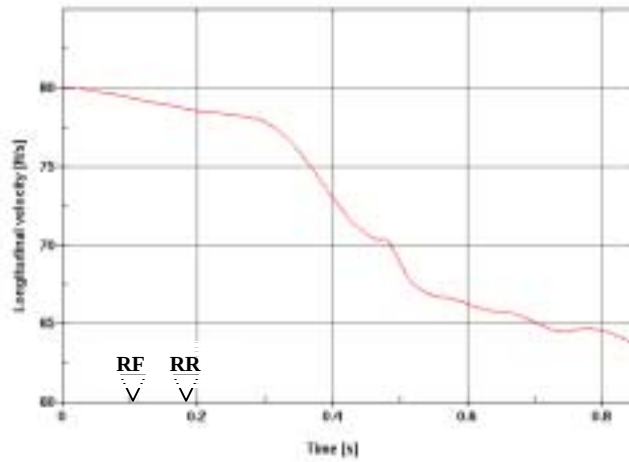


Fig. 2.2.2.2.1 (F): Longitudinal velocity [ft/s]

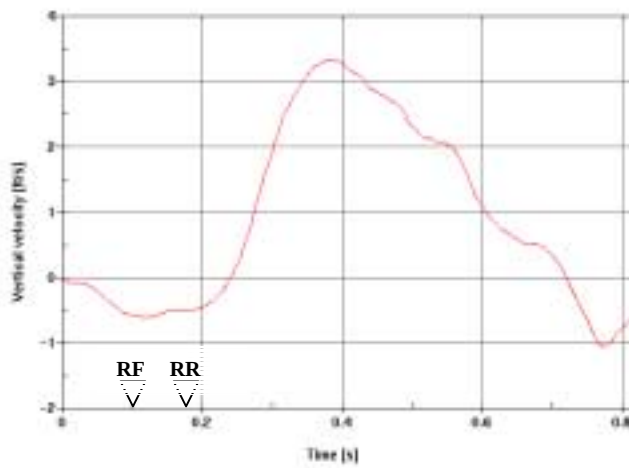


Fig2.2.2.2.1 (G) Vertical velocity [ft/s]

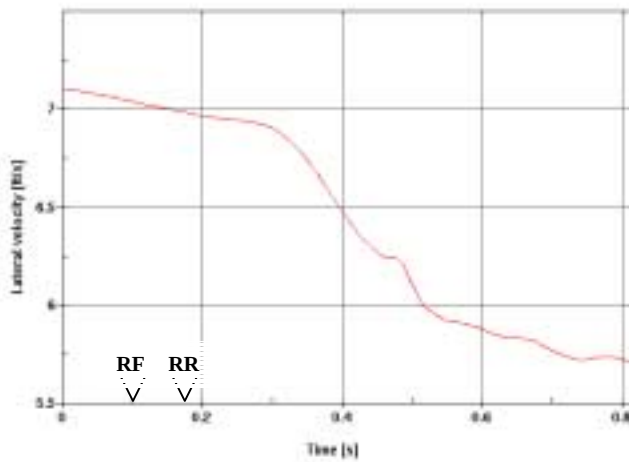


Fig. 2.2.2.2.1 (H): Lateral velocity [ft/s]

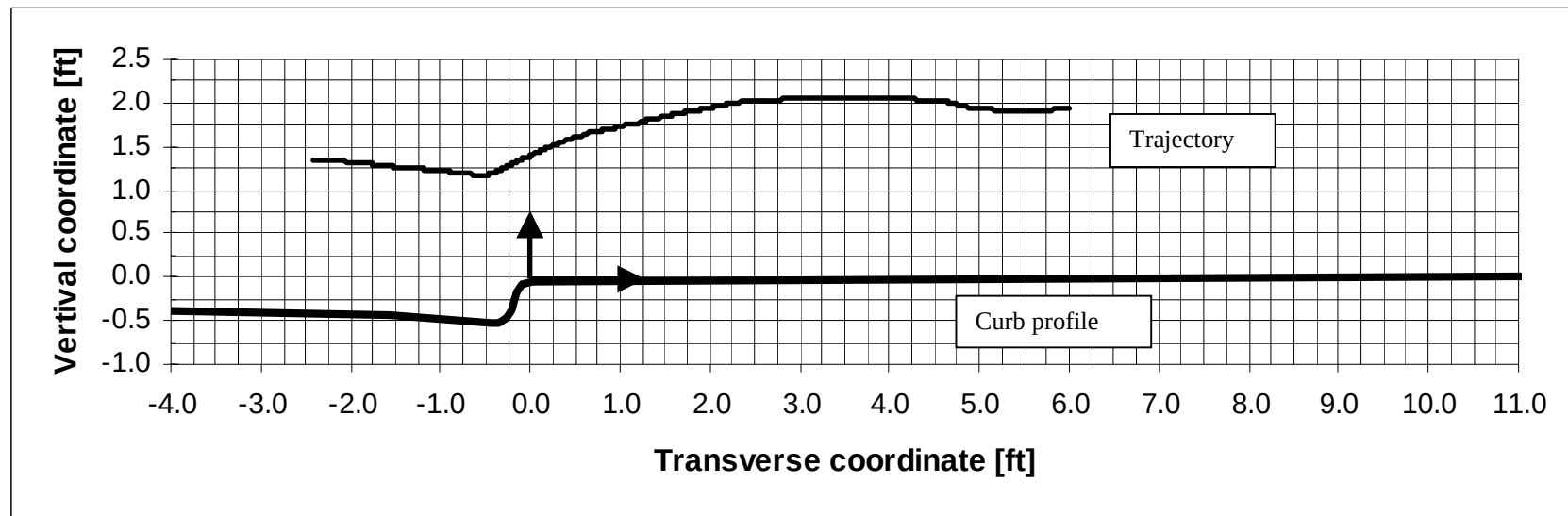


Fig. 2.2.2.2.1. (I): Trajectory of the bumper right corner

2.2.2.2.2.2 “E” curb

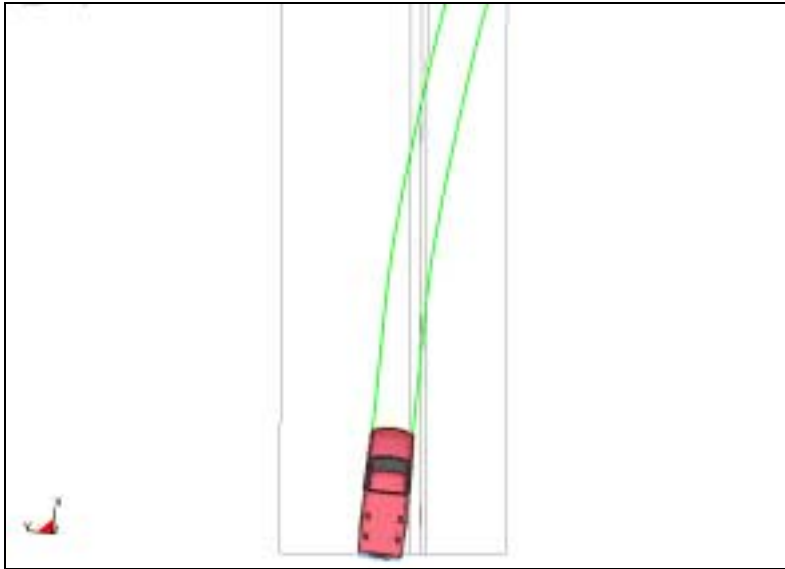


Fig. 2.2.2.2.2.2 (A) Trajectories of bumper corners (upper view)

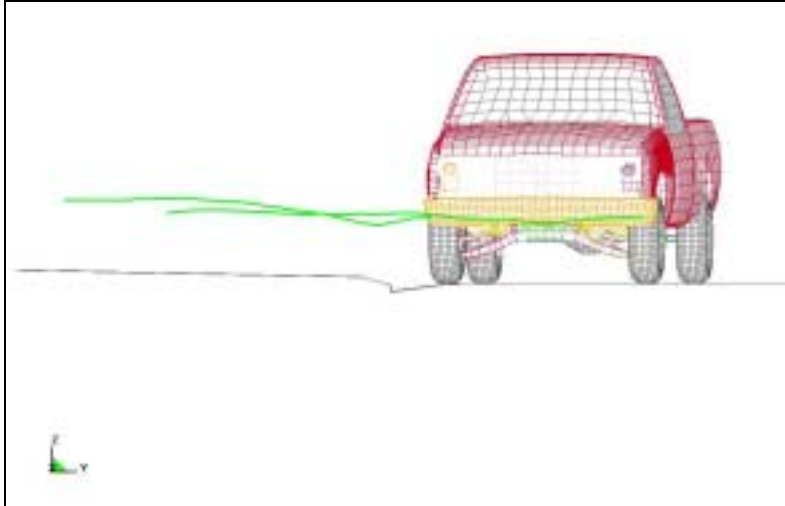


Fig. 2.2.2.2.2.2 (B) Trajectories of bumper corners (lateral view)

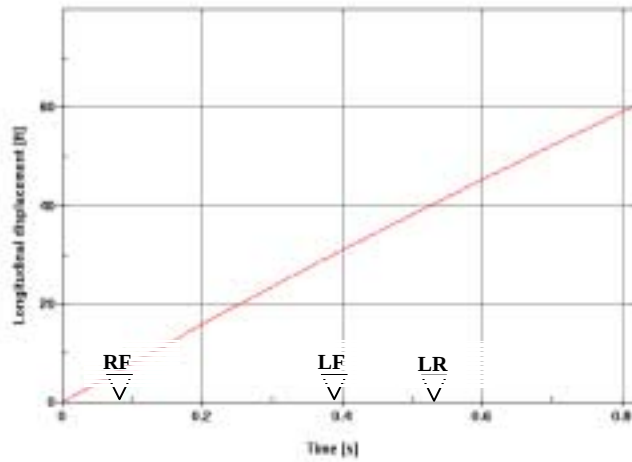


Fig. 2.2.2.2.2 (C): Longitudinal displacement [ft]

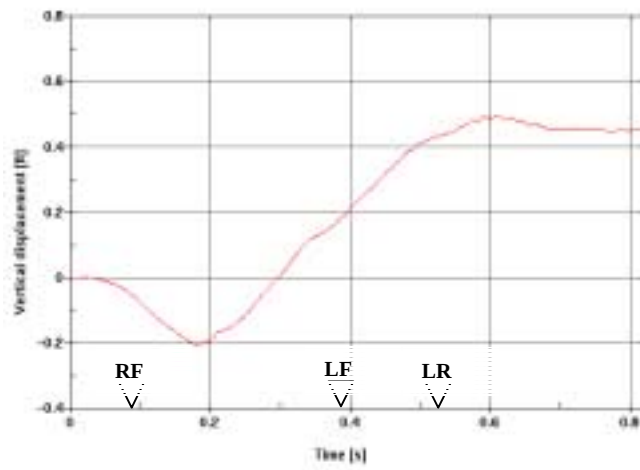


Fig. 2.2.2.2.2 (D): Vertical displacement [ft]

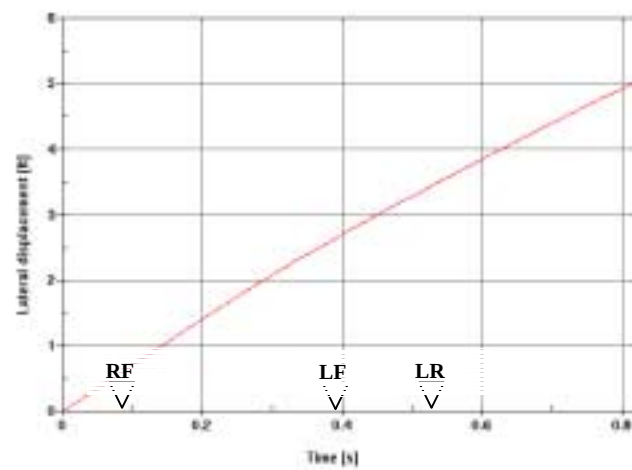


Fig. 2.2.2.2.2 (E): Lateral displacement [ft]

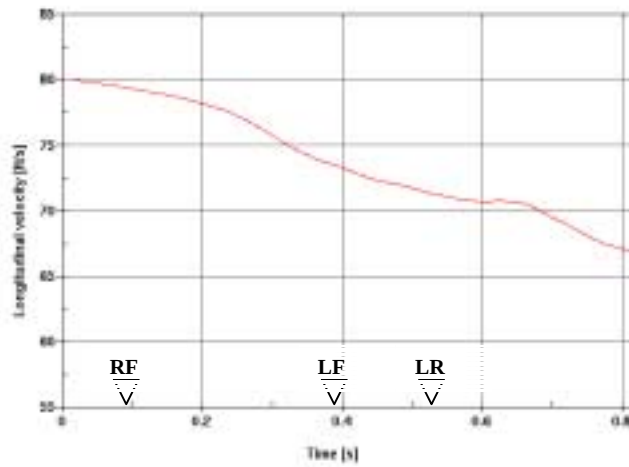


Fig. 2.2.2.2.2 (F): Longitudinal velocity [ft/s]

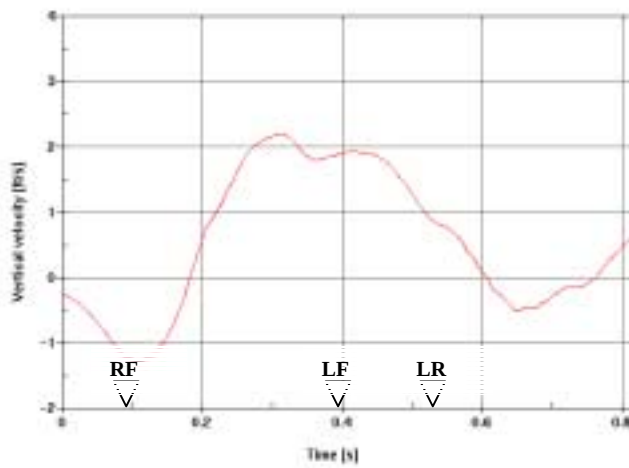


Fig2.1.1.2.2.2 (G) Vertical velocity [ft/s]

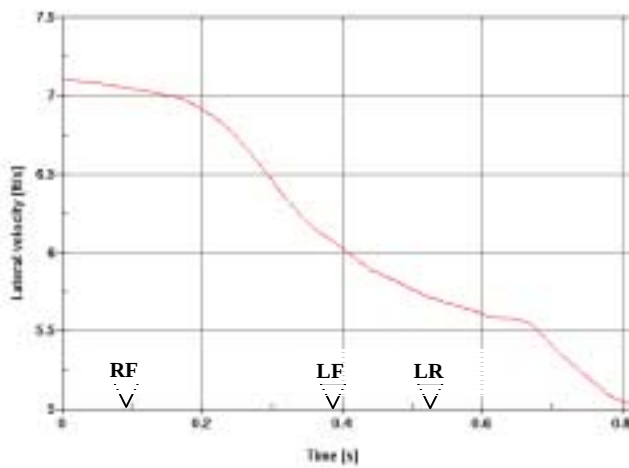


Fig. 2.2.2.2.2 (H): Lateral velocity [ft/s]

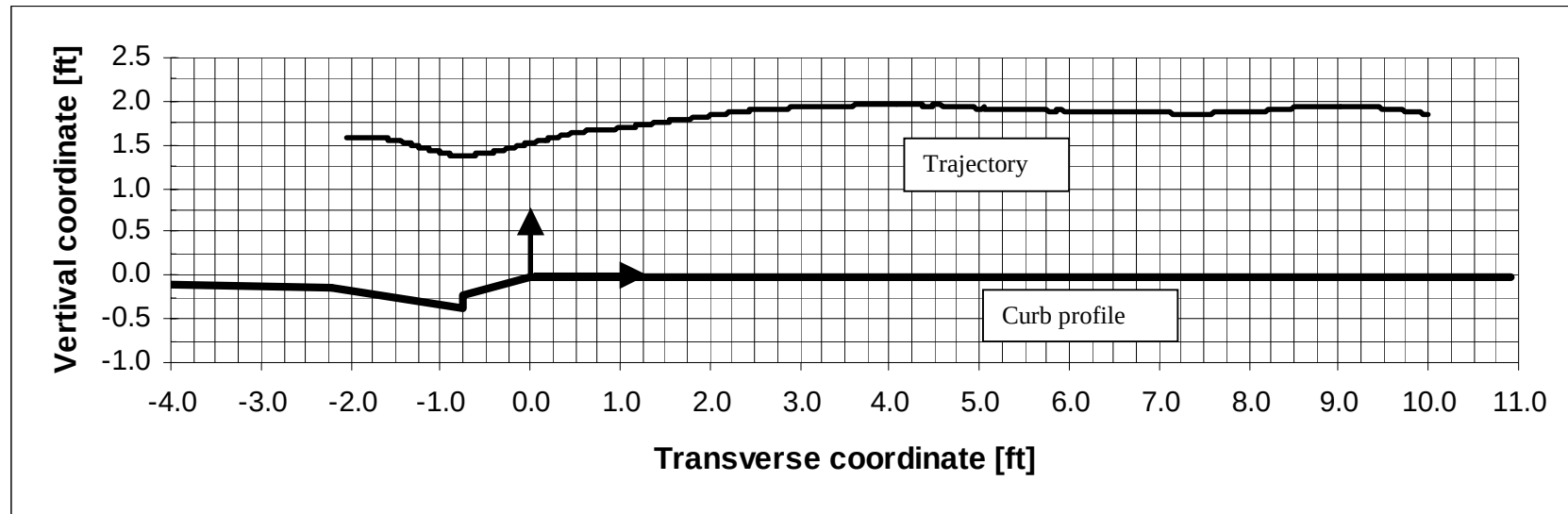


Fig. 2.2.2.2.2 (I): Trajectory of the bumper right corner

2.2.2.3 Approach angle 10°

2.2.2.3.1 Velocity 35 mph

2.2.2.3.1.1 “F” curb

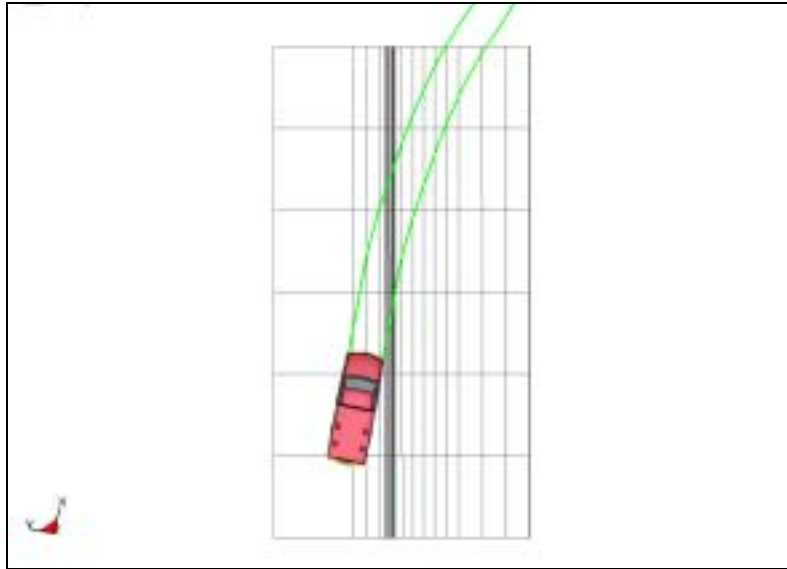


Fig. 2.2.2.3.1.1 (A) Trajectories of bumper corners (upper view)

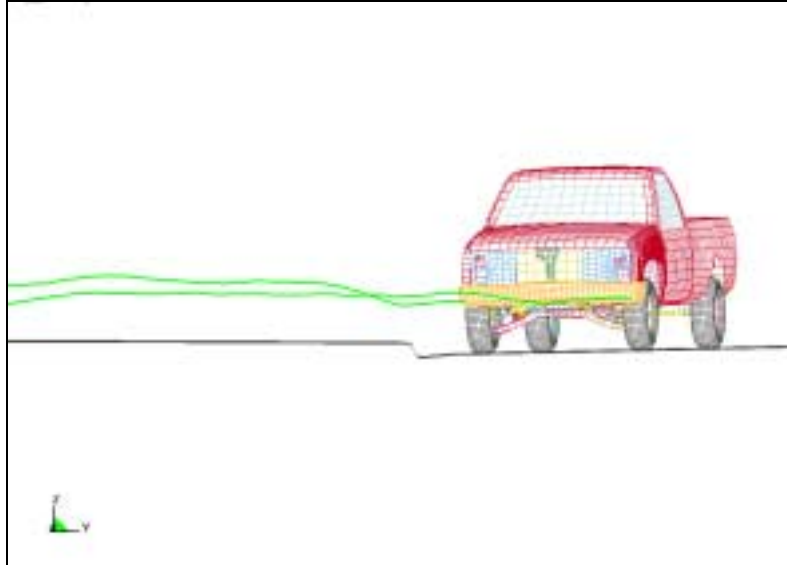


Fig. 2.2.2.3.1.1 (B) Trajectories of bumper corners (lateral view)

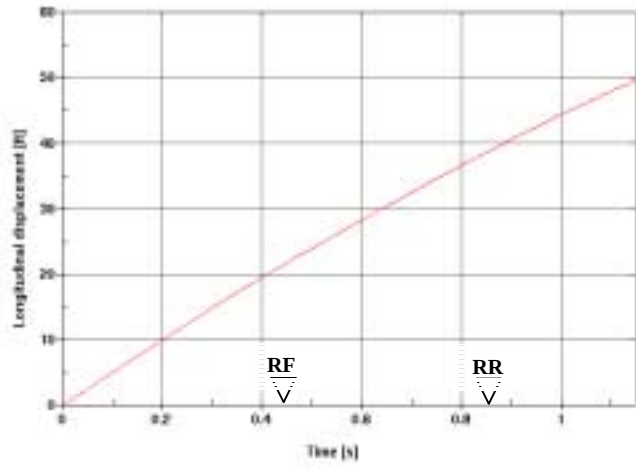


Fig. 2.2.2.3.1.1. (C): Longitudinal displacement [ft]

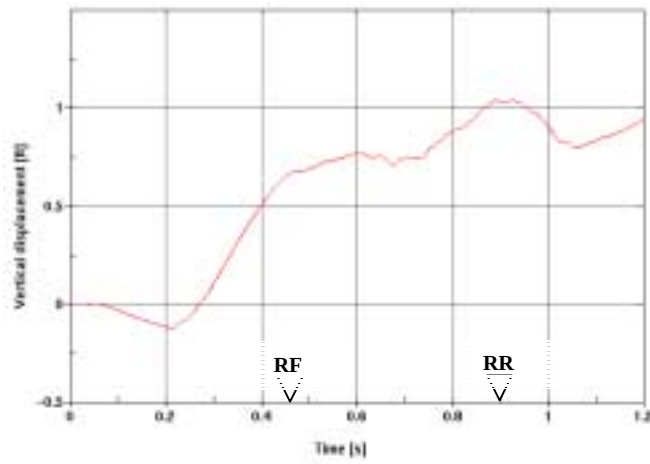


Fig. 2.2.2.3.1.1. (D): Vertical displacement [ft]

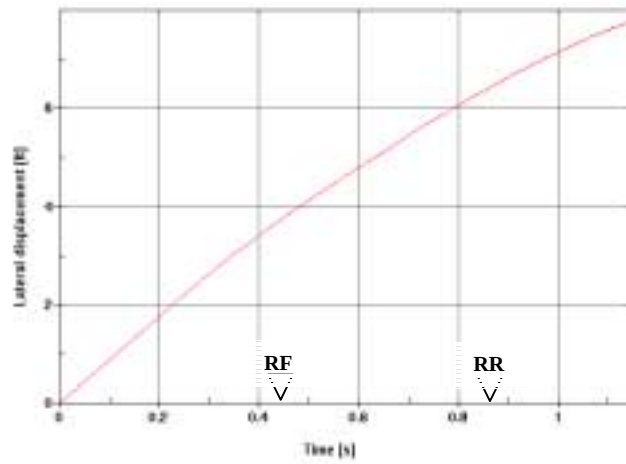


Fig. 2.2.2.3.1.1. (E): Lateral displacement [ft]

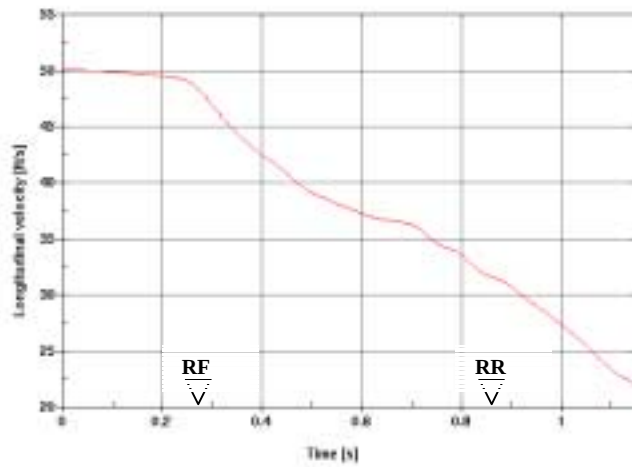


Fig. 2.2.2.3.1.1. (F): Longitudinal velocity [ft/s]

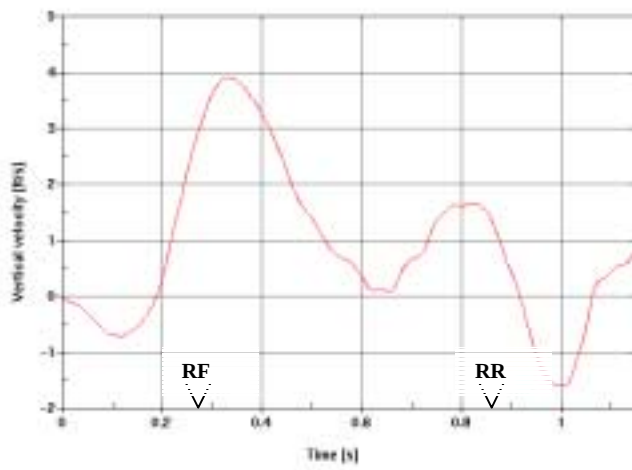


Fig. 2.2.2.3.1.1. (G) Vertical velocity [ft/s]

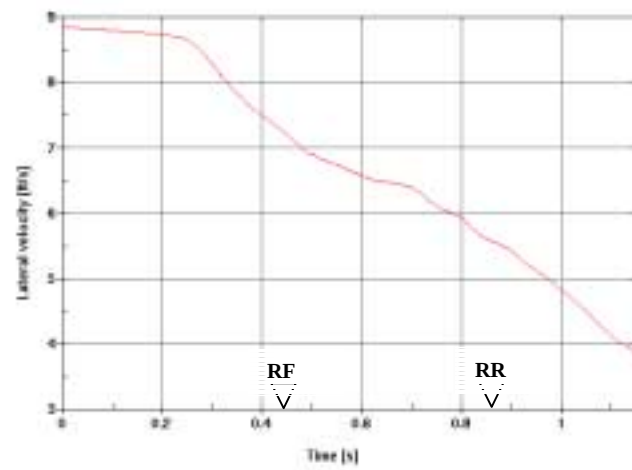


Fig. 2.2.2.3.1.1. (H): Lateral velocity [ft/s]

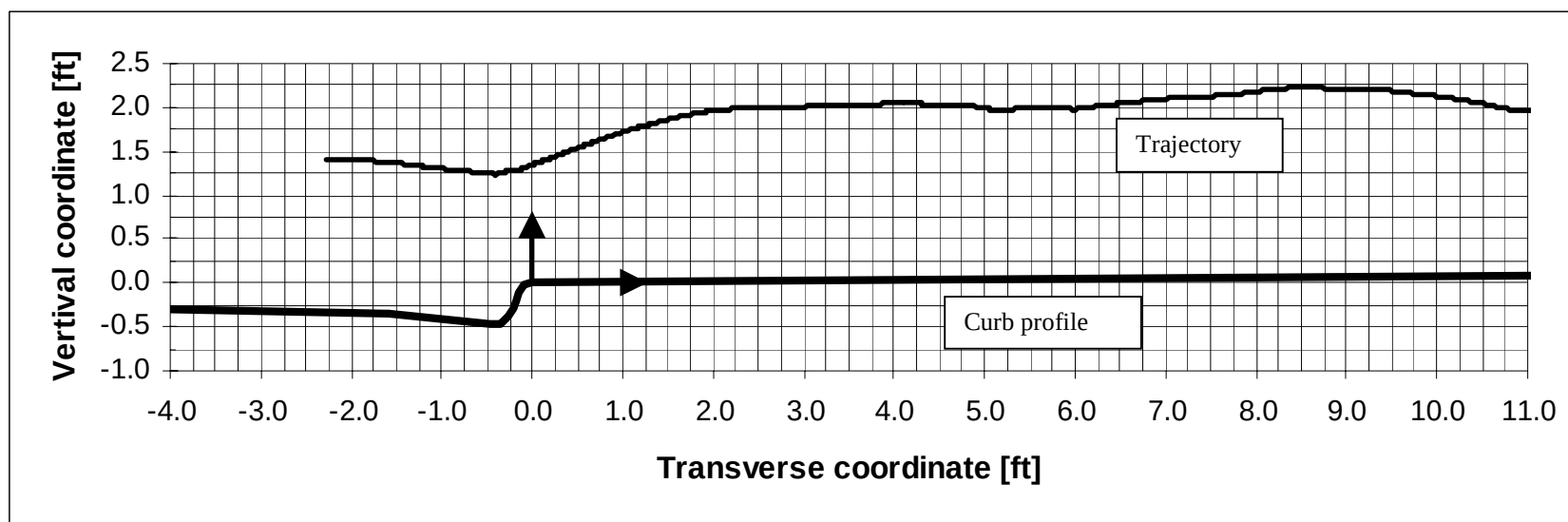


Fig. 2.2.2.3.1.1. (I): Trajectory of the bumper right corner

2.2.2.3.1.2 “E” curb

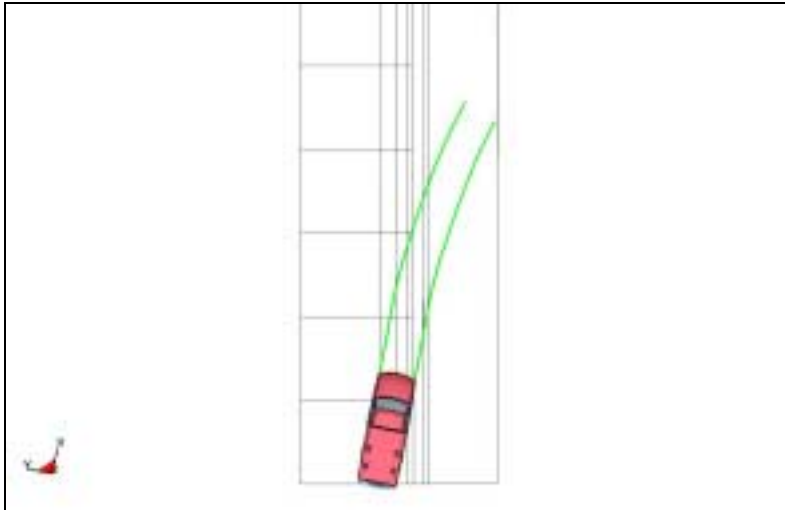


Fig. 2.2.2.3.1.2 (A) Trajectories of bumper corners (upper view)

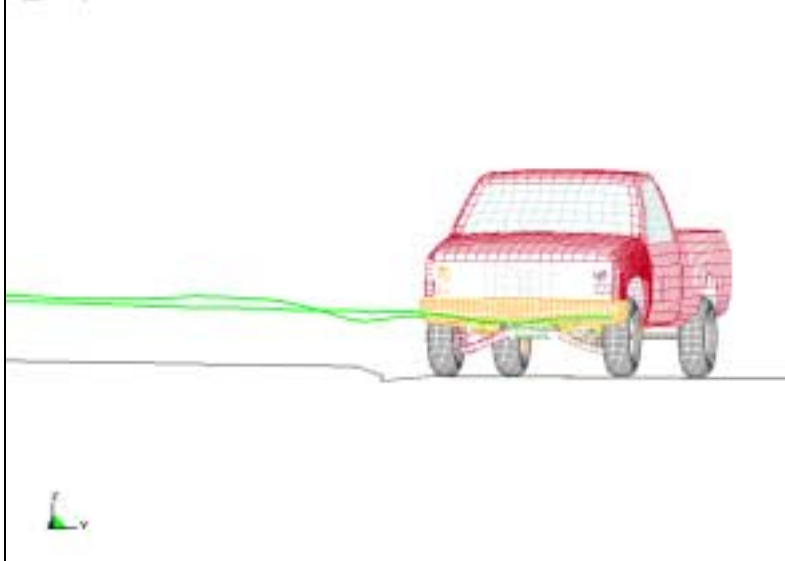


Fig. 2.2.2.3.1.2 (B) Trajectories of bumper corners (lateral view)

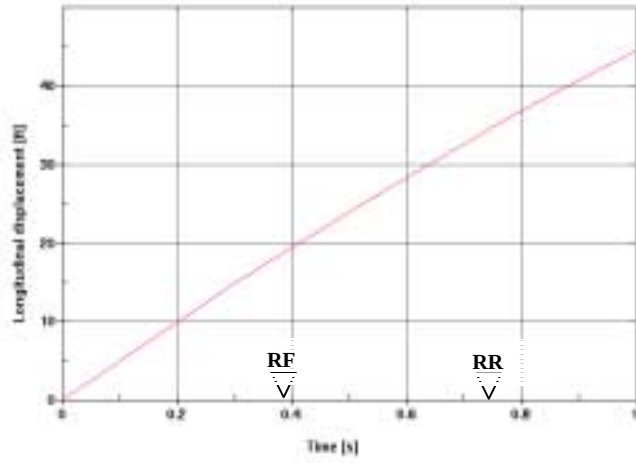


Fig. 2.2.2.3.1.2. (C): Longitudinal displacement [ft]

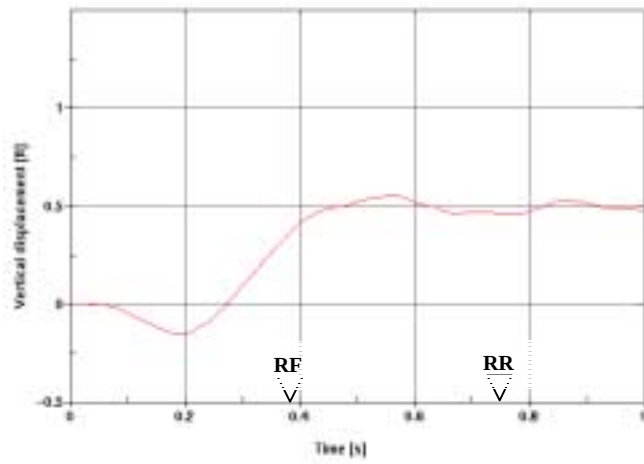


Fig. 2.2.2.3.1.2. (D): Vertical displacement [ft]

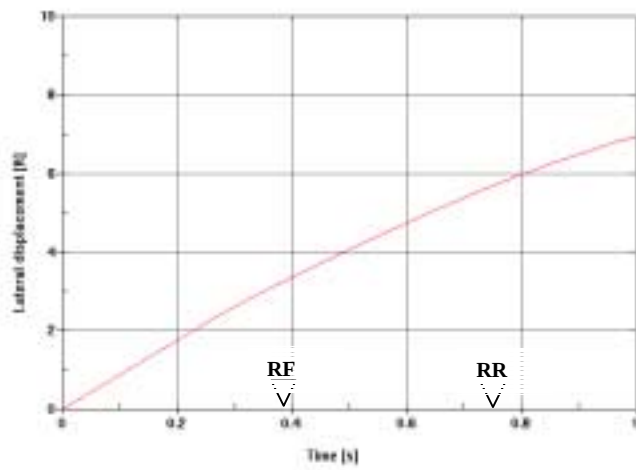


Fig. 2.2.2.3.1.2. (E): Lateral displacement [ft]

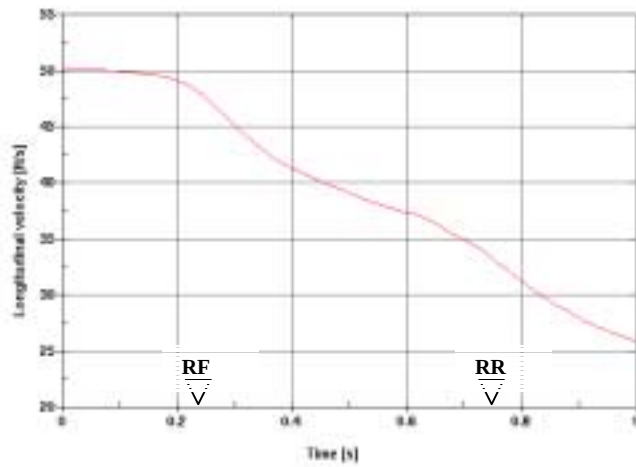


Fig. 2.2.2.3.1.2. (F): Longitudinal velocity [ft/s]

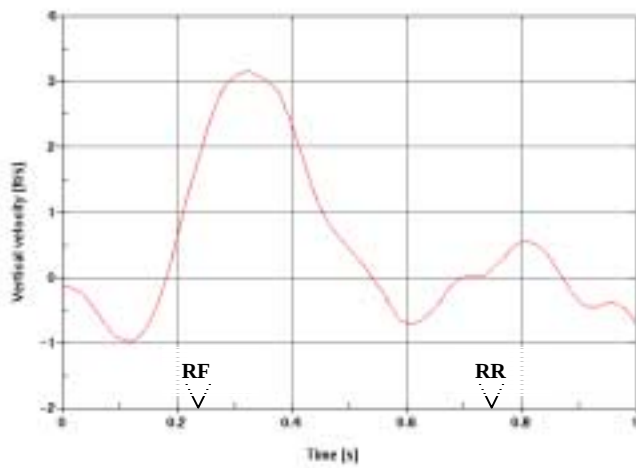


Fig. 2.2.2.3.1.2. (G) Vertical velocity [ft/s]

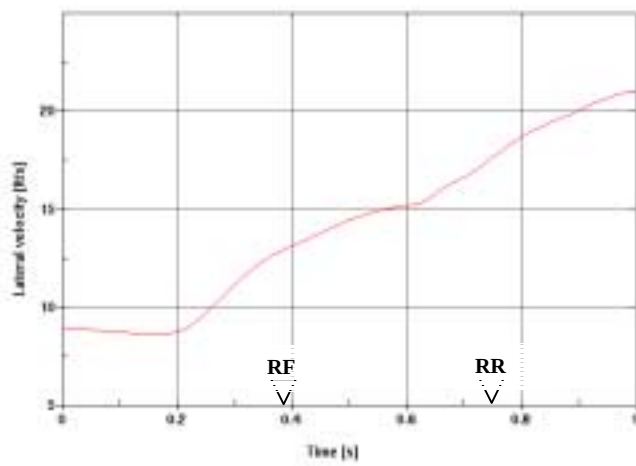


Fig. 2.2.2.3.1.2. (H): Lateral velocity [ft/s]

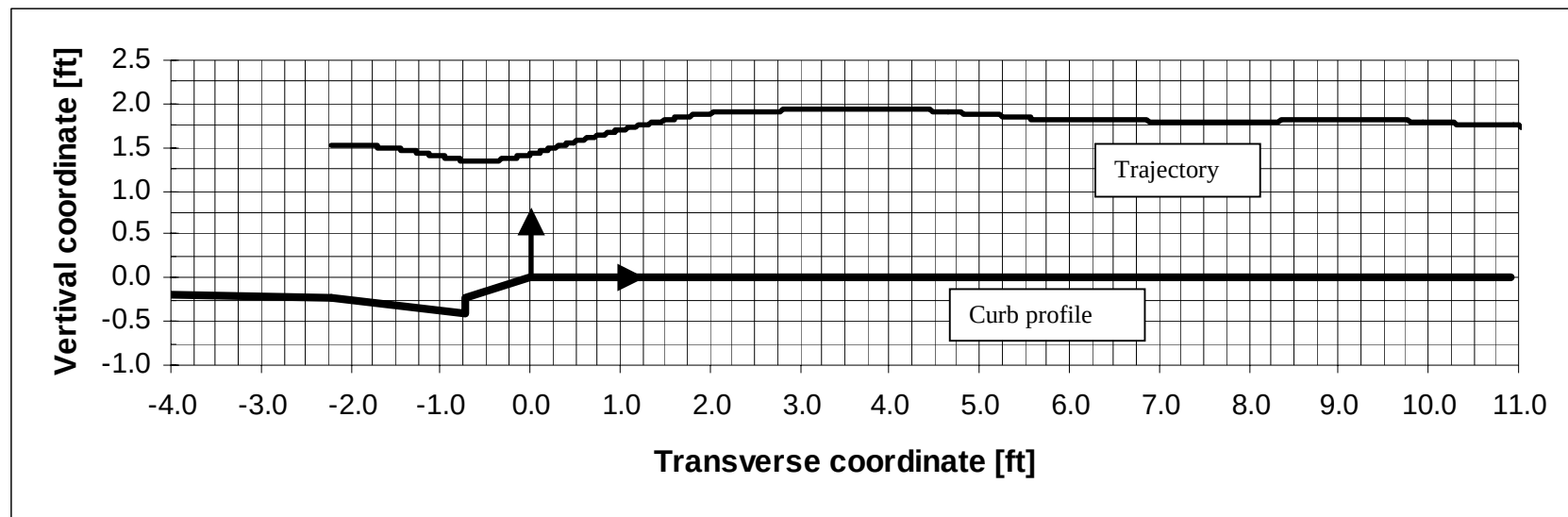


Fig. 2.2.2.3.1.2. (I): Trajectory of the bumper right corner

2.2.2.3.2 Velocity 55 mph

2.2.2.3.2.1 “F” curb

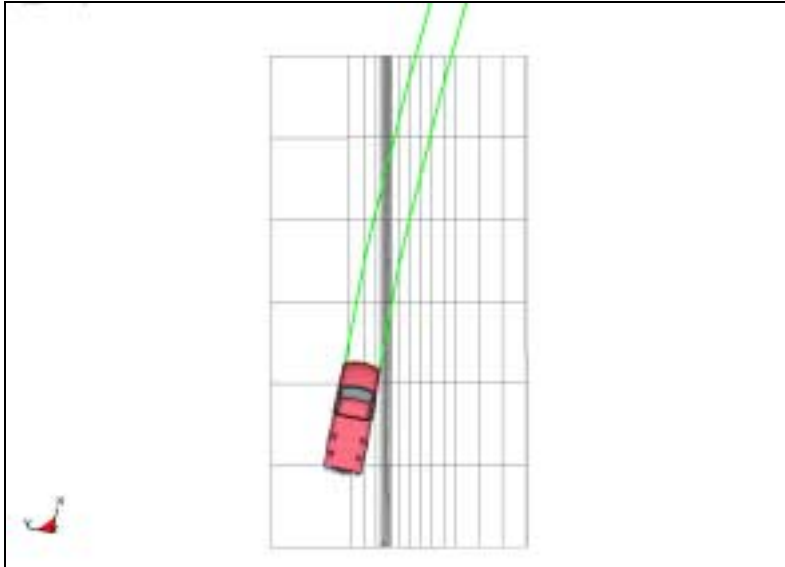


Fig. 2.2.2.3.2.1 (A) Trajectories of bumper corners (upper view)

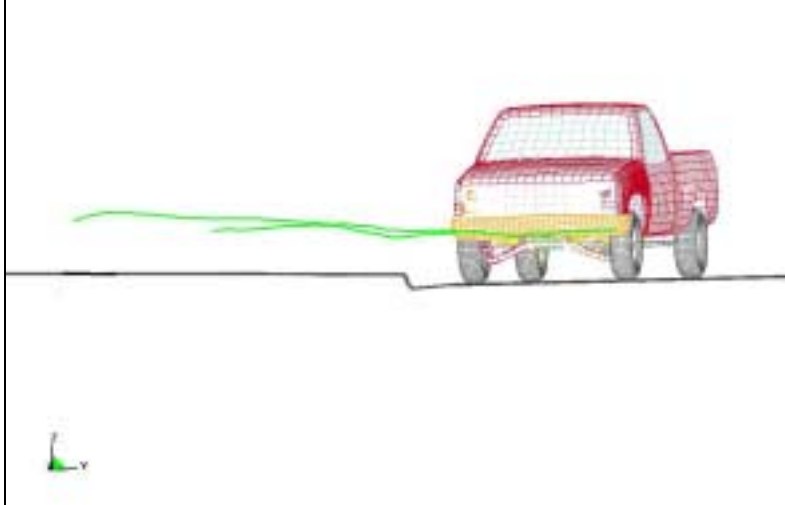


Fig. 2.2.2.3.2.1 (B) Trajectories of bumper corners (lateral view)

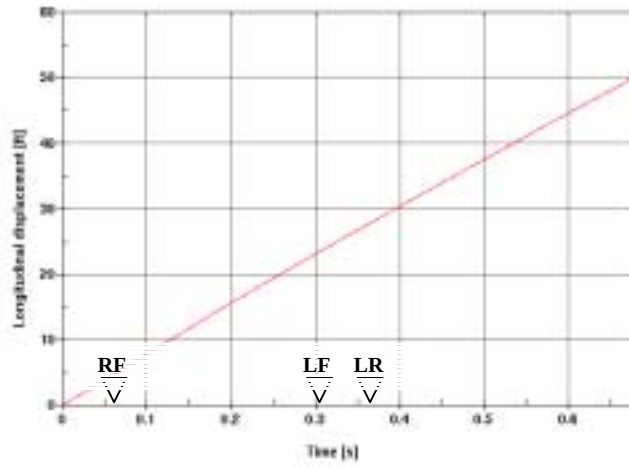


Fig. 2.2.2.3.2.1. (C): Longitudinal displacement [ft]

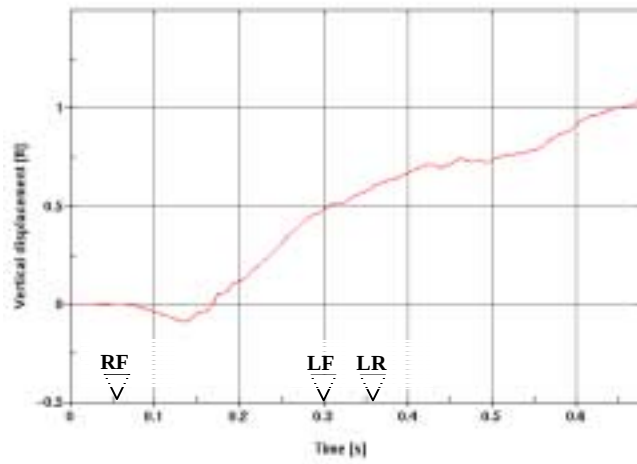


Fig. 2.2.2.3.2.1. (D): Vertical displacement [ft]

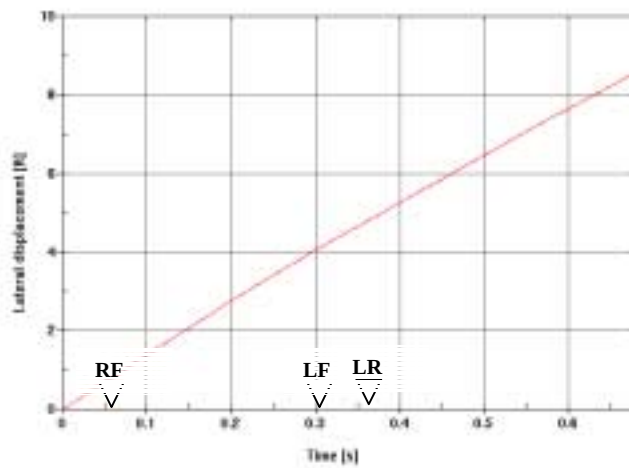


Fig. 2.2.2.3.2.1. (E): Lateral displacement [ft]

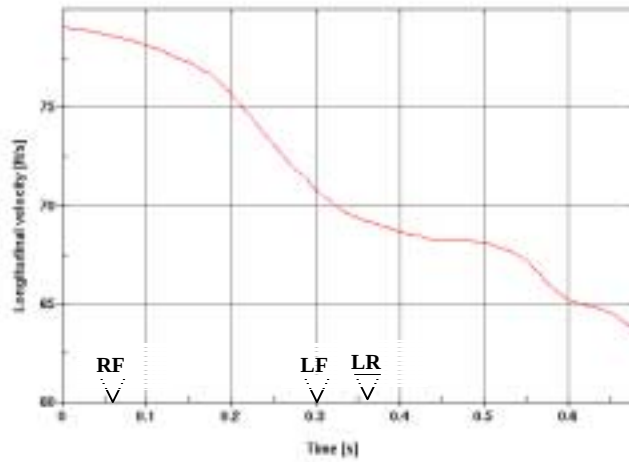


Fig. 2.2.2.3.2.1. (F): Longitudinal velocity [ft/s]

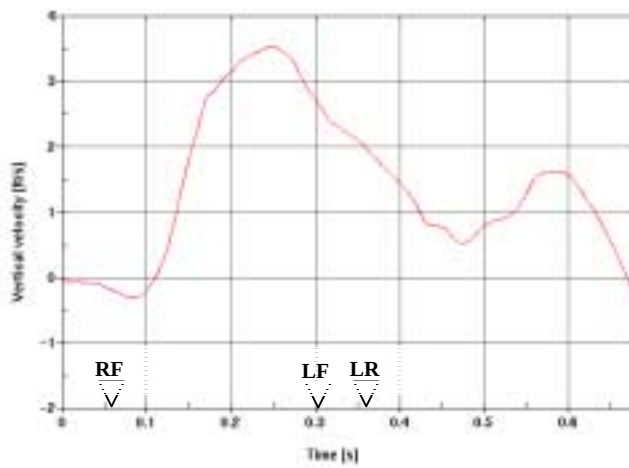


Fig. 2.2.2.3.2.1. (G) Vertical velocity [ft/s]

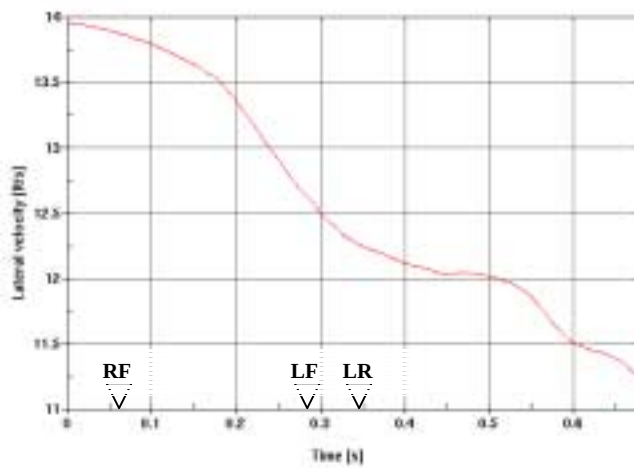


Fig. 2.2.2.3.2.1. (H): Lateral velocity [ft/s]

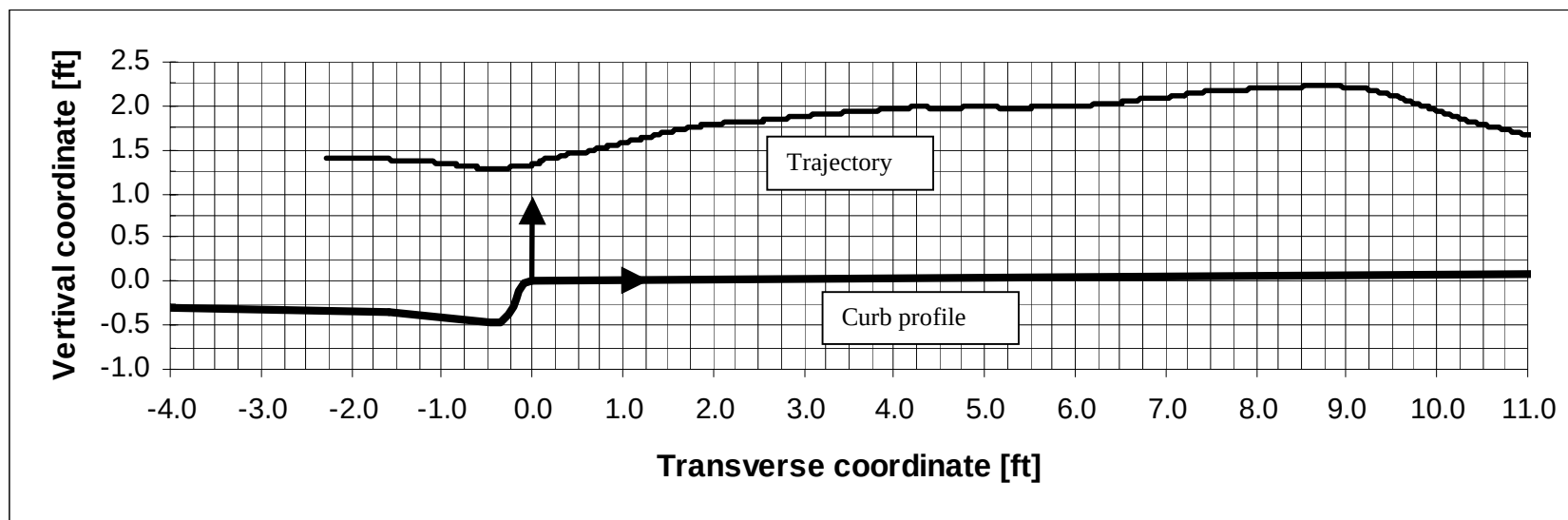


Fig. 2.2.2.3.2.1. (I): Trajectory of the bumper right corner

2.2.2.3.2.2 “E” curb

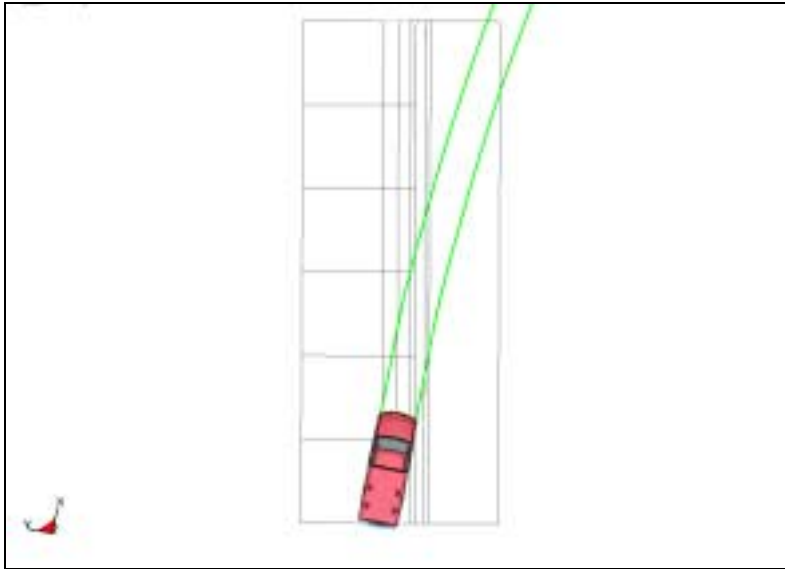


Fig. 2.2.2.3.2.2 (A) Trajectories of bumper corners (upper view)

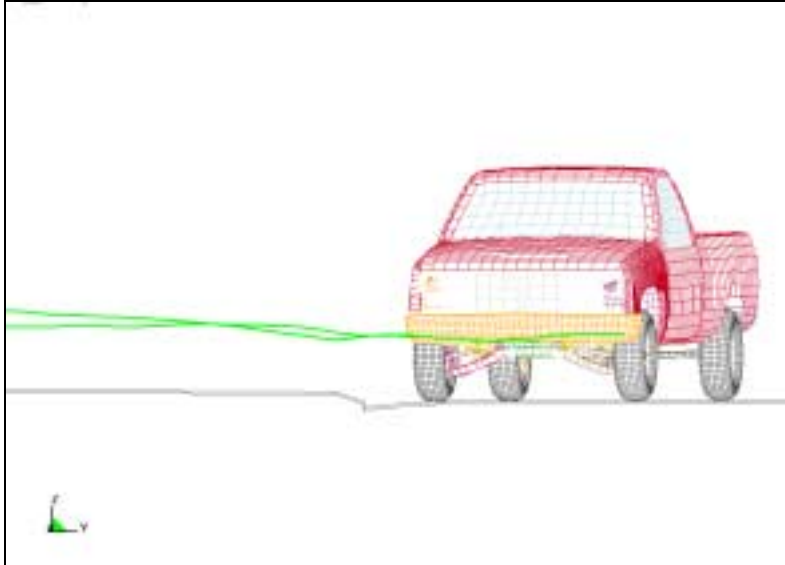


Fig. 2.2.2.3.2.2 (B) Trajectories of bumper corners (lateral view)

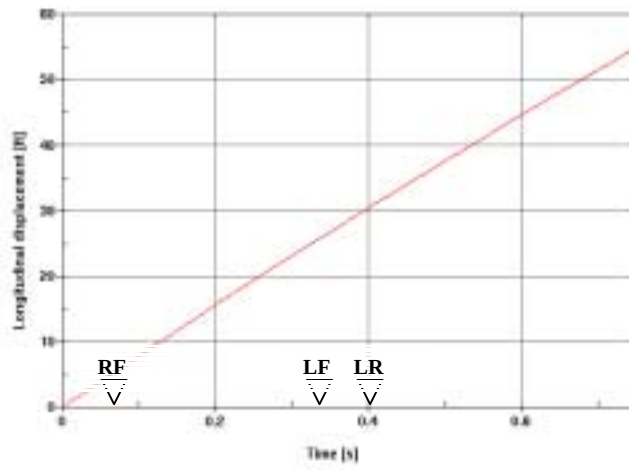


Fig. 2.2.2.3.2.2. (C): Longitudinal displacement [ft]

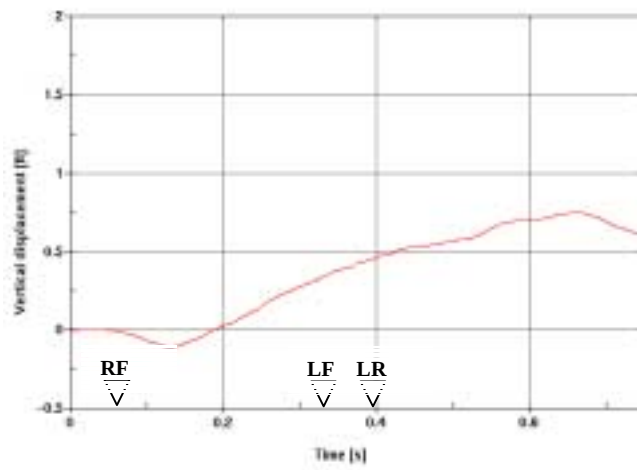


Fig. 2.2.2.3.2.2. (D): Vertical displacement [ft]

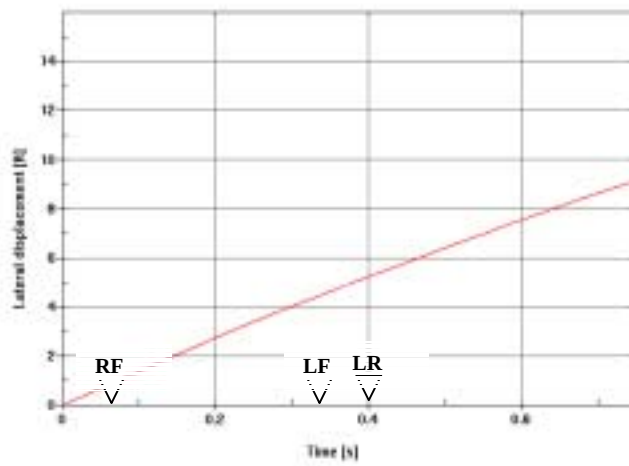


Fig. 2.2.2.3.2.2. (E): Lateral displacement [ft]

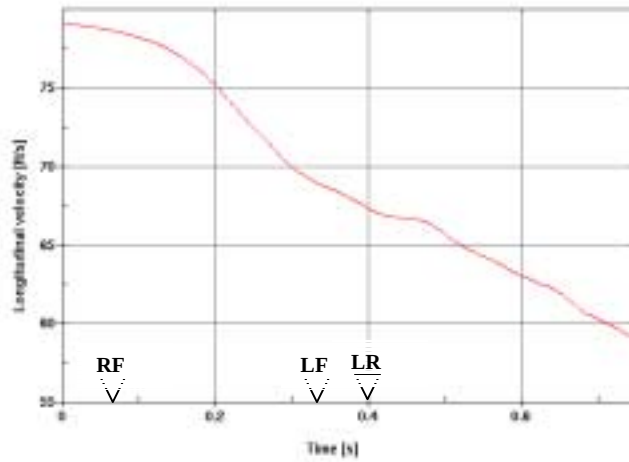


Fig. 2.2.2.3.2.2. (F): Longitudinal velocity [ft/s]

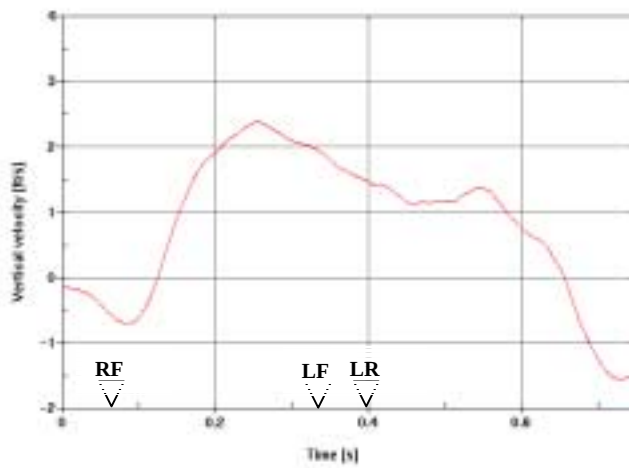


Fig. 2.2.2.3.2.2. (G) Vertical velocity [ft/s]

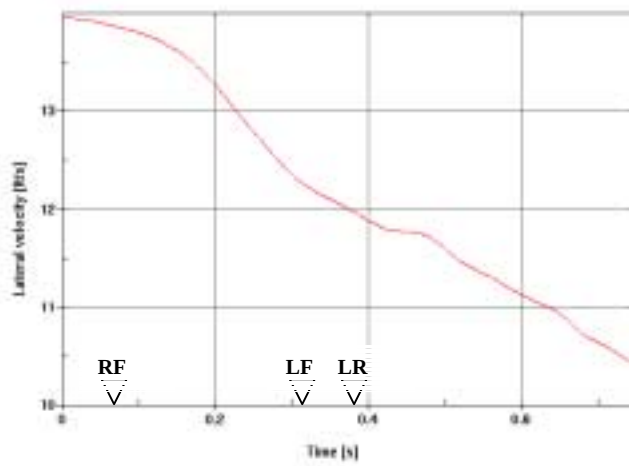


Fig. 2.2.2.3.2.2. (H): Lateral velocity [ft/s]

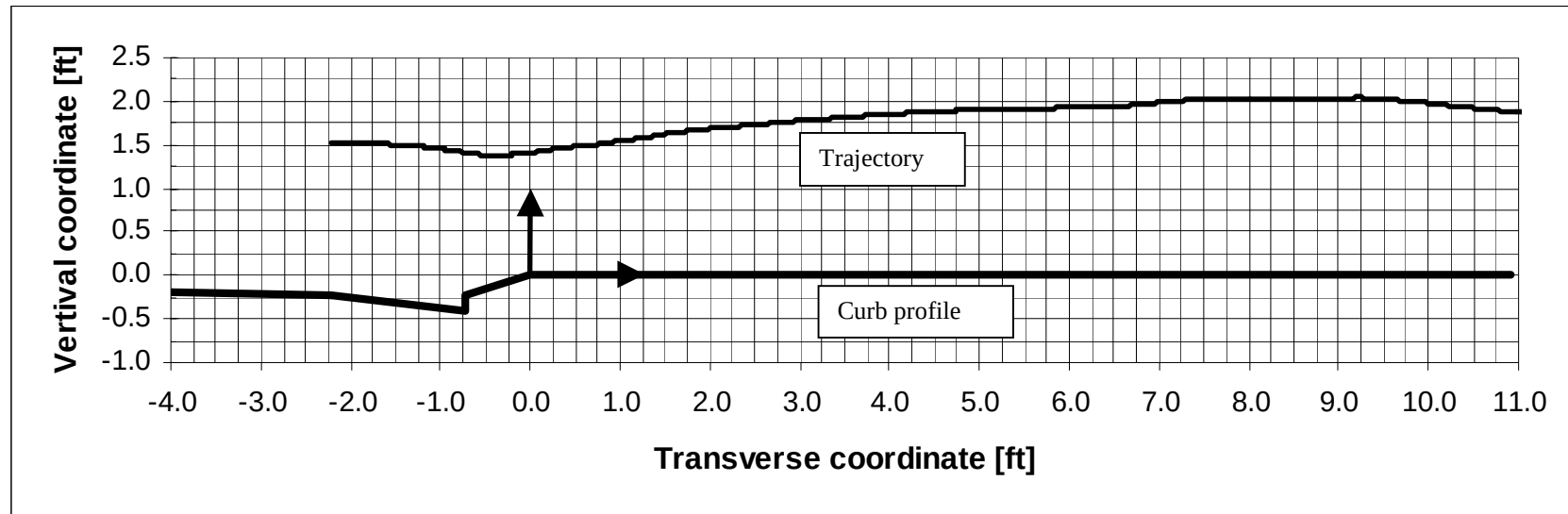


Fig. 2.2.2.3.2.2. (I): Trajectory of the bumper right corner

2.2.2.4 Approach angle 15°

2.2.2.4.1 Velocity 35 mph

2.2.2.4.1.1 “F” curb

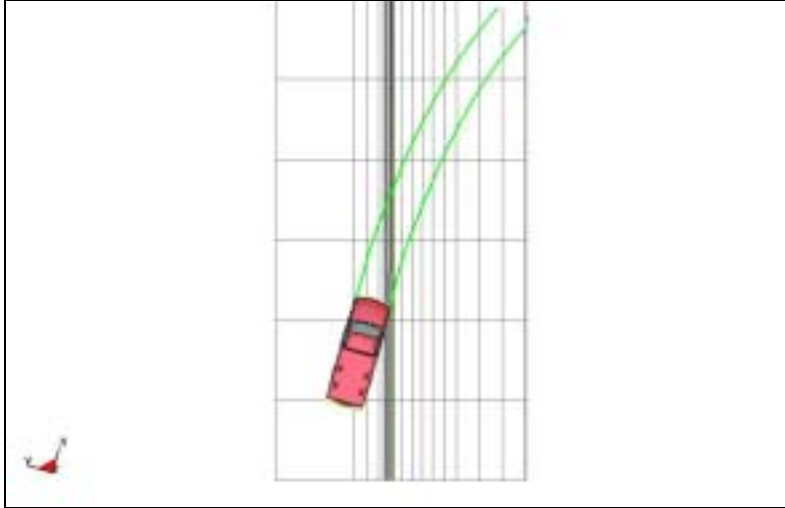


Fig. 2.2.2.4.1.1 (A) Trajectories of bumper corners (upper view)

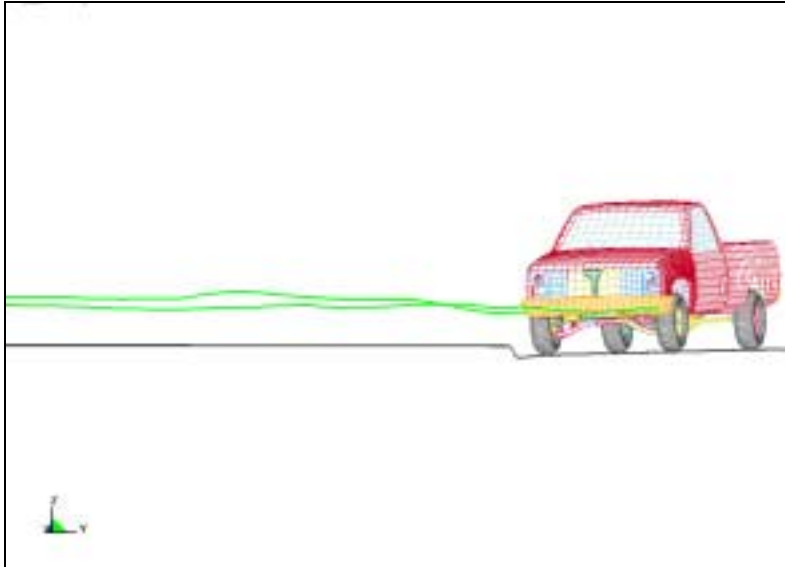


Fig. 2.2.2.4.1.1 (B) Trajectories of bumper corners (lateral view)

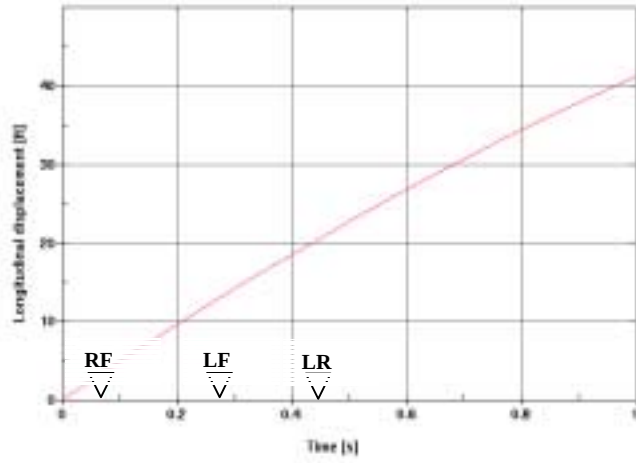


Fig. 2.2.2.4.1.1. (C): Longitudinal displacement [ft]

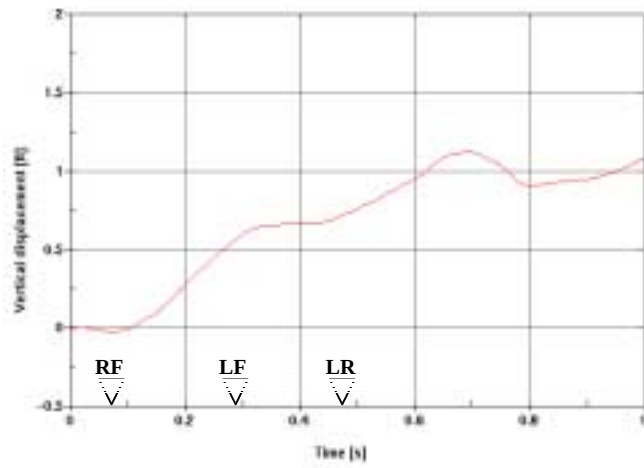


Fig. 2.2.2.4.1.1. (D): Vertical displacement [ft]

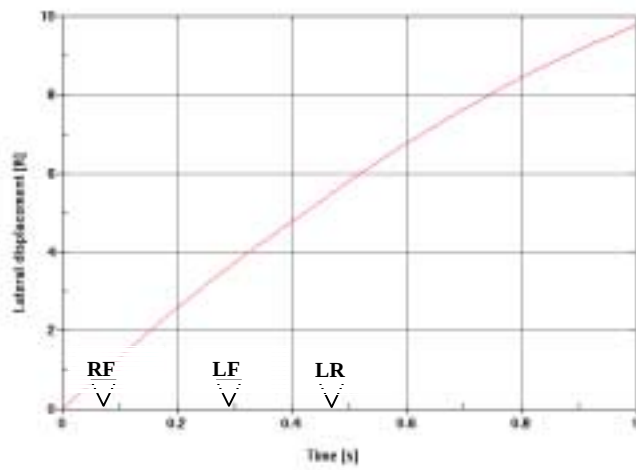


Fig. 2.2.2.4.1.1. (E): Lateral displacement [ft]

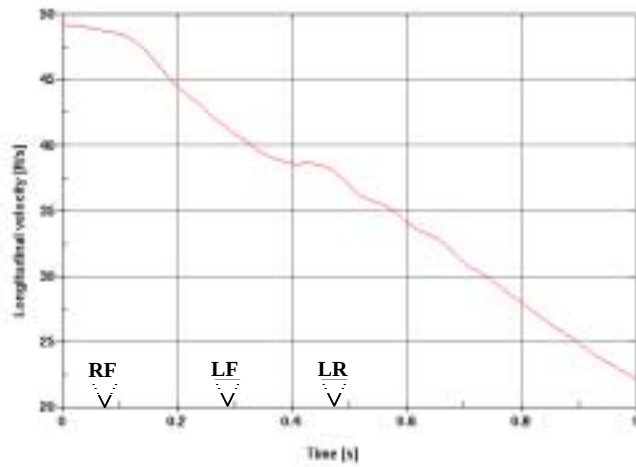


Fig. 2.2.2.4.1.1. (F): Longitudinal velocity [ft/s]

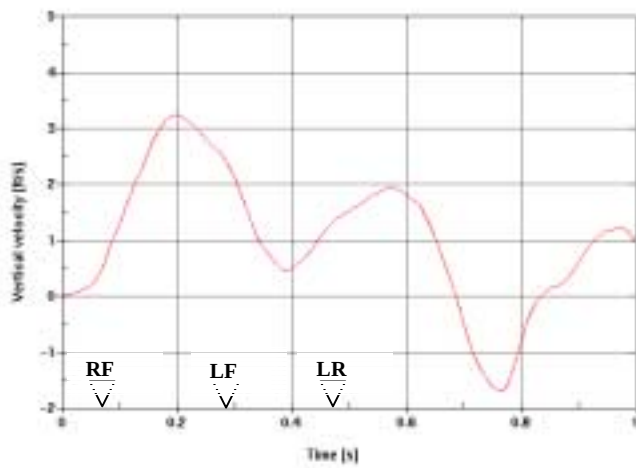


Fig. 2.2.2.4.1.1. (G) Vertical velocity [ft/s]

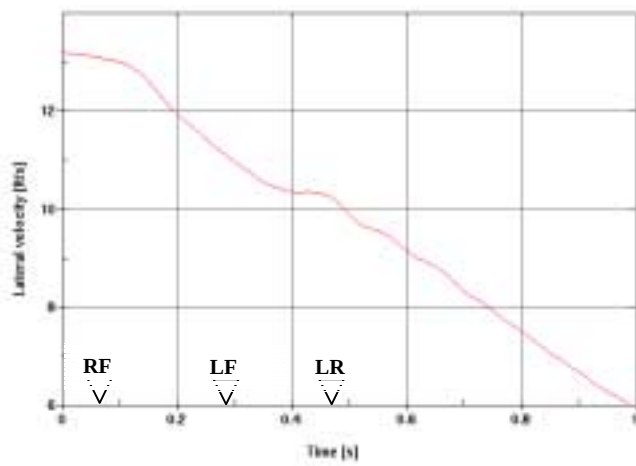


Fig. 2.2.2.4.1.1. (H): Lateral velocity [ft/s]

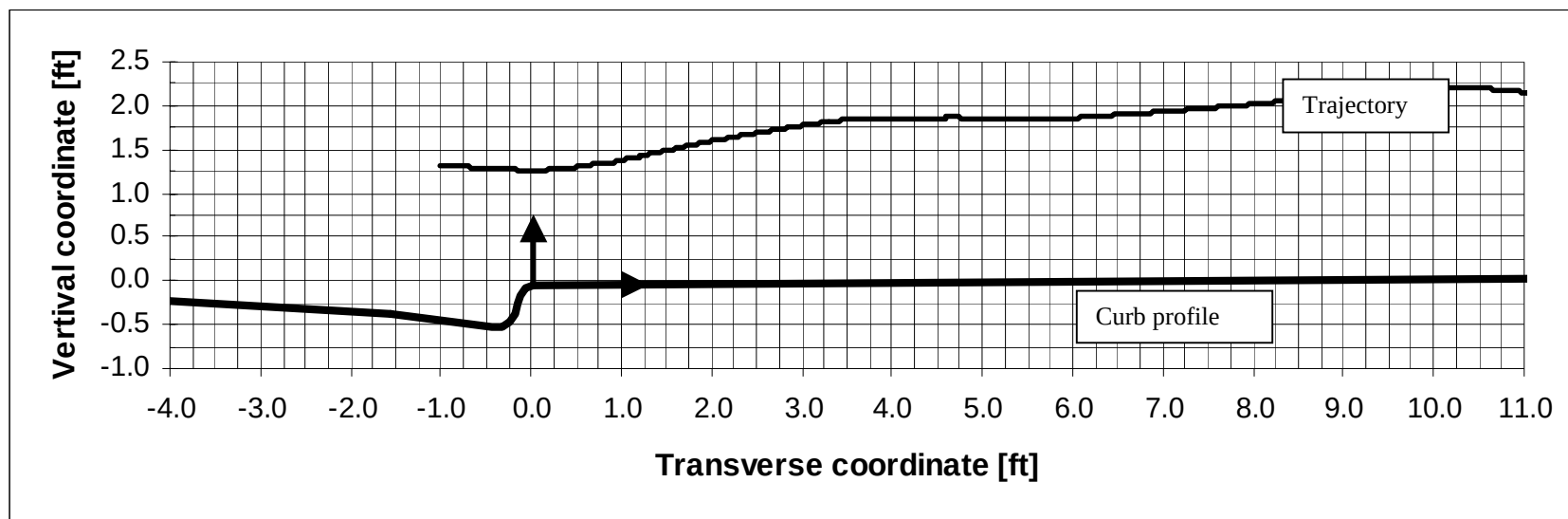


Fig. 2.2.2.4.1.1. (I): Trajectory of the bumper right corner

2.2.2.4.1.2 “E” curb

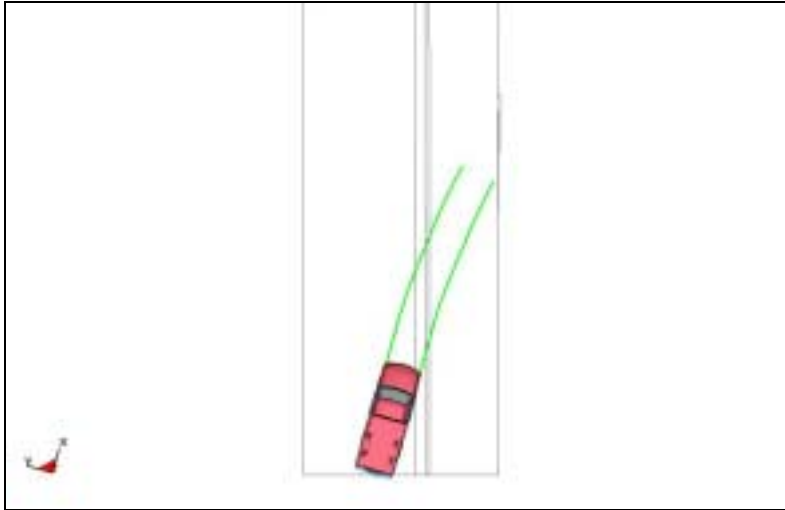


Fig. 2.2.2.4.1.2 (A) Trajectories of bumper corners (upper view)

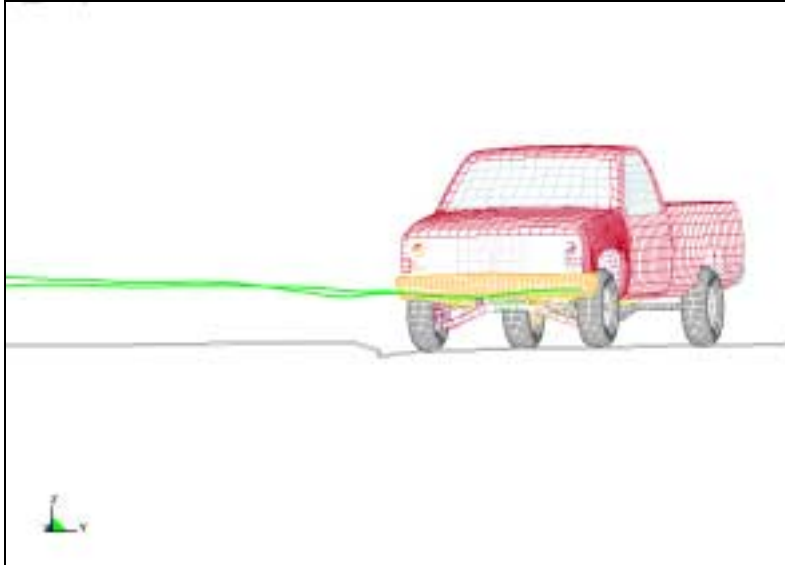


Fig. 2.2.2.4.1.2 (B) Trajectories of bumper corners (lateral view)

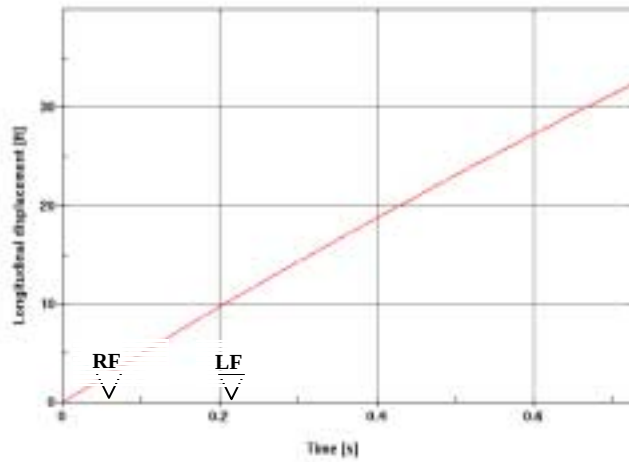


Fig. 2.2.2.4.1.2 (C): Longitudinal displacement [ft]

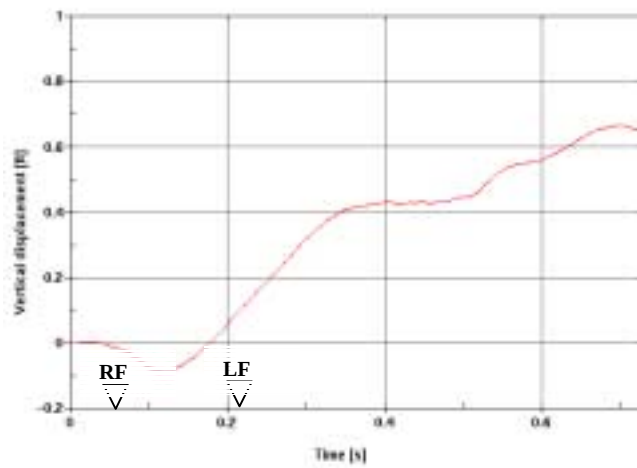


Fig. 2.2.2.4.1.2 (D): Vertical displacement [ft]

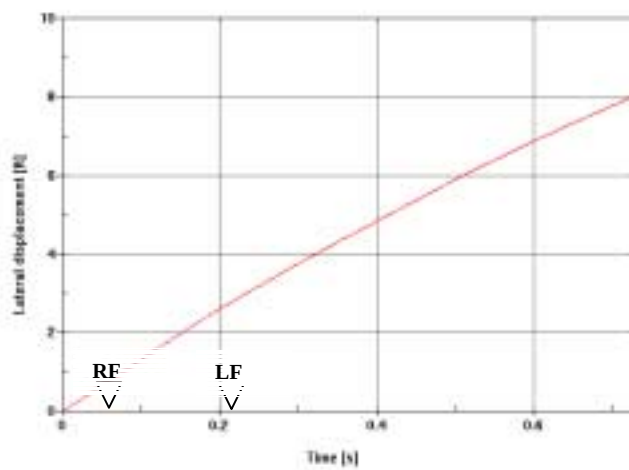


Fig. 2.2.2.4.1.2 (E): Lateral displacement [ft]

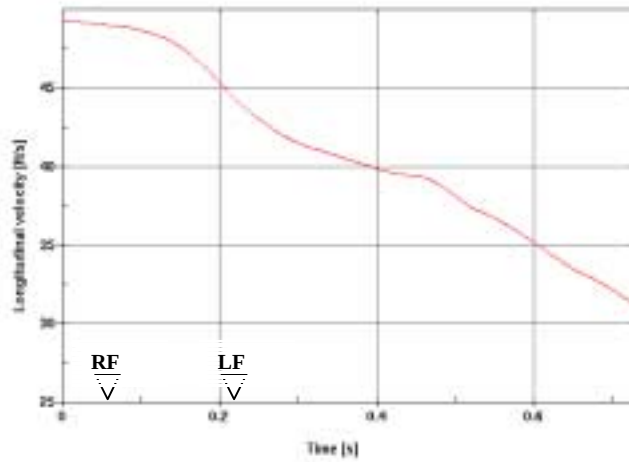


Fig. 2.2.2.4.1.2 (F): Longitudinal velocity [ft/s]

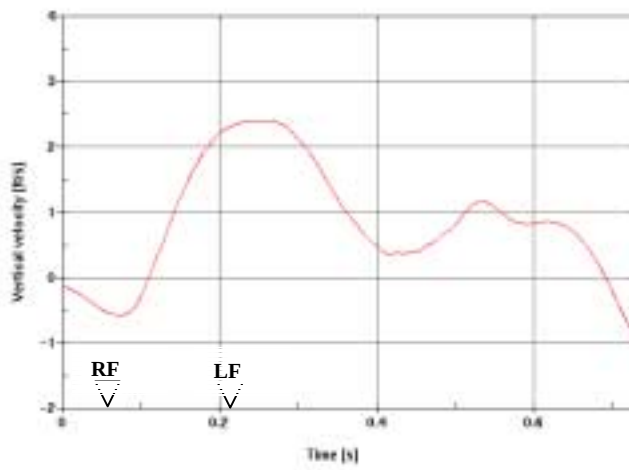


Fig. 2.2.2.4.1.2 (G) Vertical velocity [ft/s]

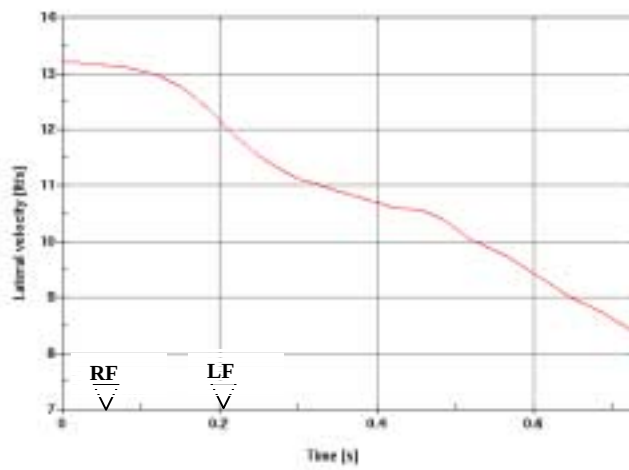


Fig. 2.2.2.4.1.2 (H): Lateral velocity [ft/s]

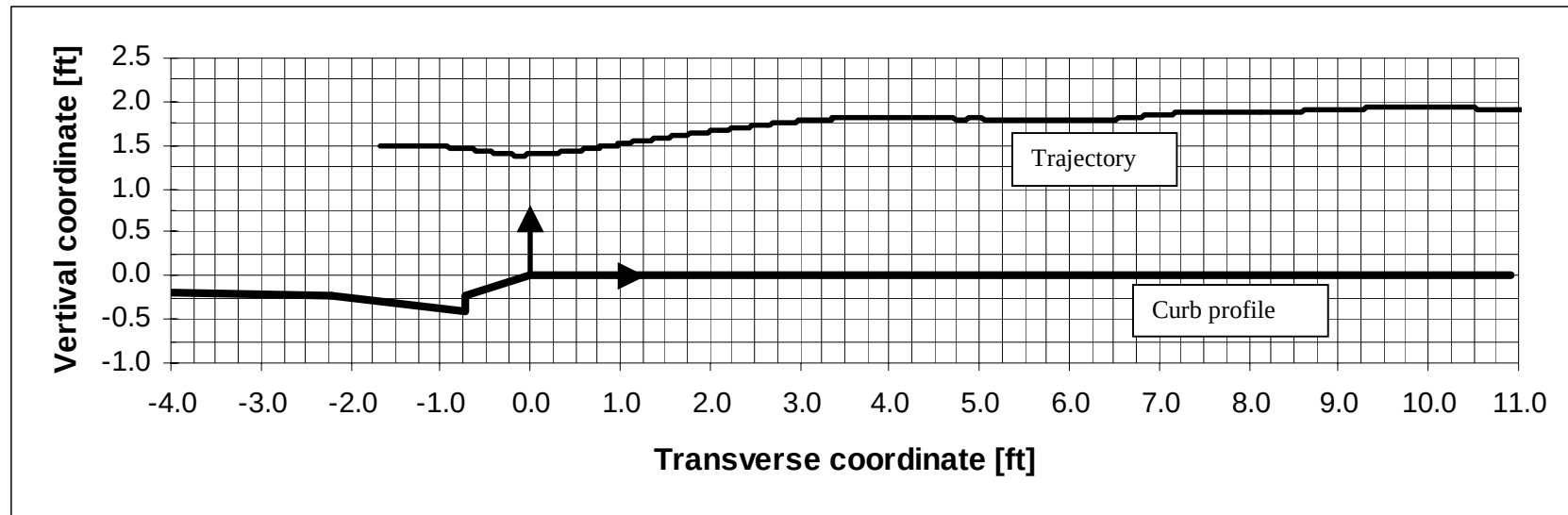


Fig. 2.2.2.4.1.2. (I): Trajectory of the bumper right corner

2.2.2.4.2 Velocity 55 mph

2.2.2.4.2.1 “F” curb

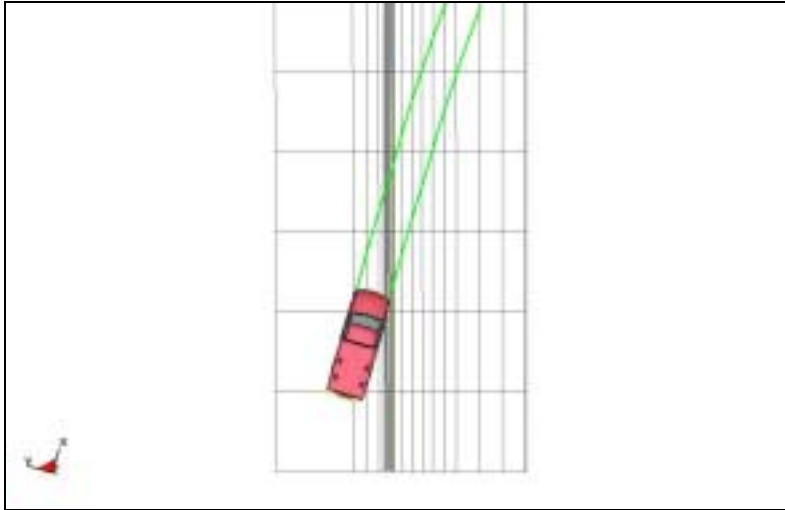


Fig. 2.2.2.4.2.1 (A) Trajectories of bumper corners (upper view)

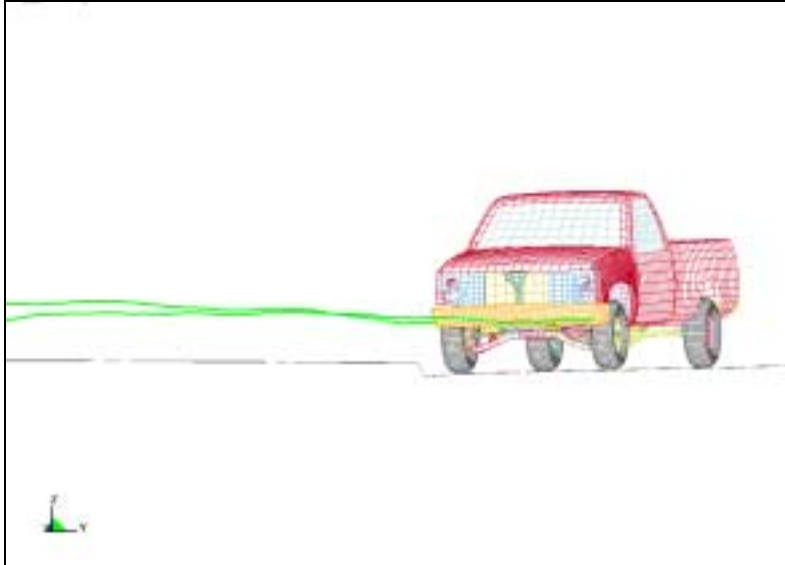


Fig. 2.2.2.4.2.1 (B) Trajectories of bumper corners (lateral view)

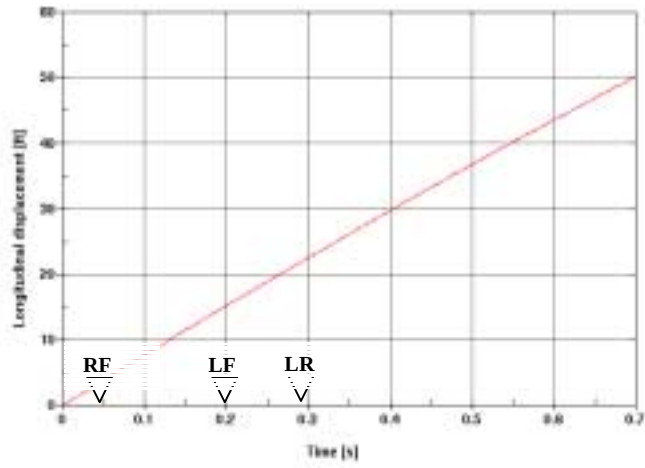


Fig. 2.2.2.4.2.1. (C): Longitudinal displacement [ft]

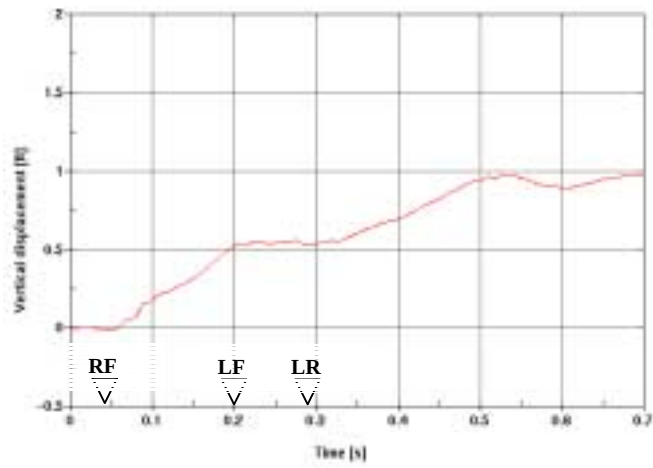


Fig. 2.2.2.4.2.1. (D): Vertical displacement [ft]

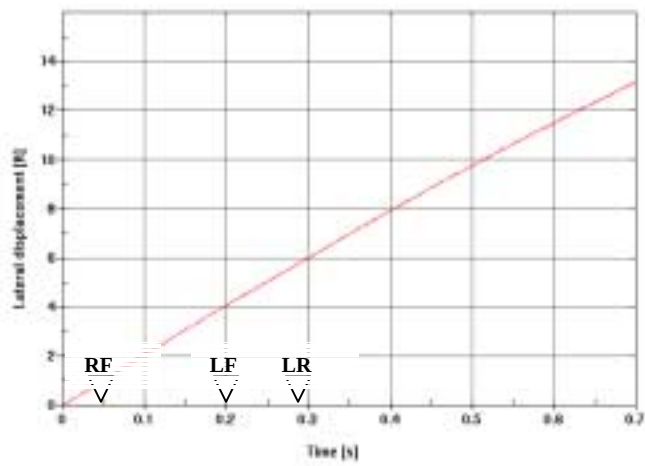


Fig. 2.2.2.4.2.1. (E): Lateral displacement [ft]

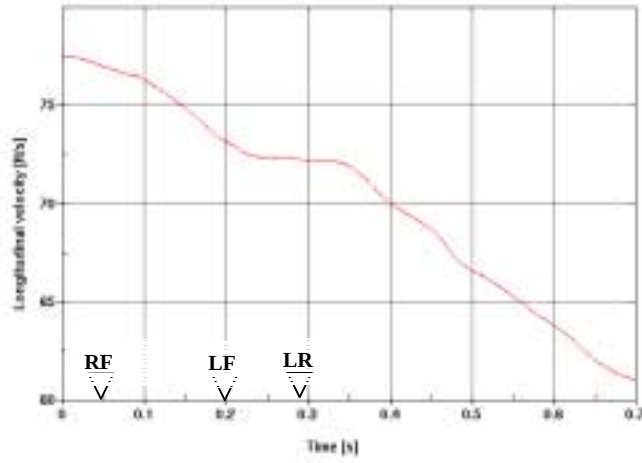


Fig. 2.2.2.4.2.1. (F): Longitudinal velocity [ft/s]

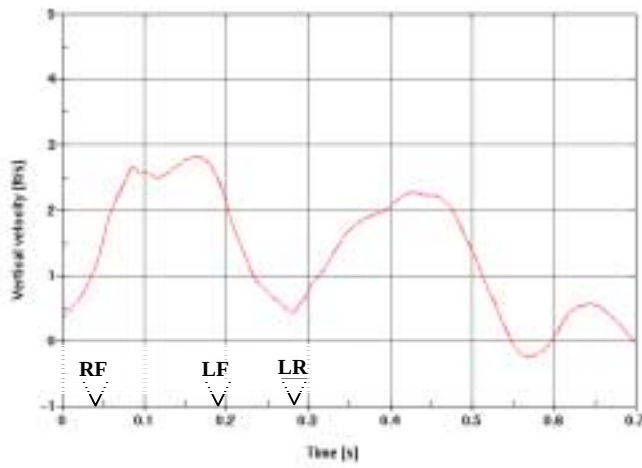


Fig. 2.2.2.4.2.1. (G) Vertical velocity [ft/s]

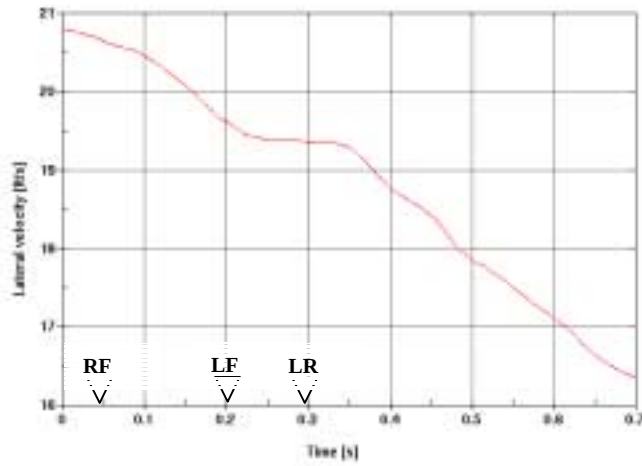


Fig. 2.2.2.4.2.1. (H): Lateral velocity [ft/s]

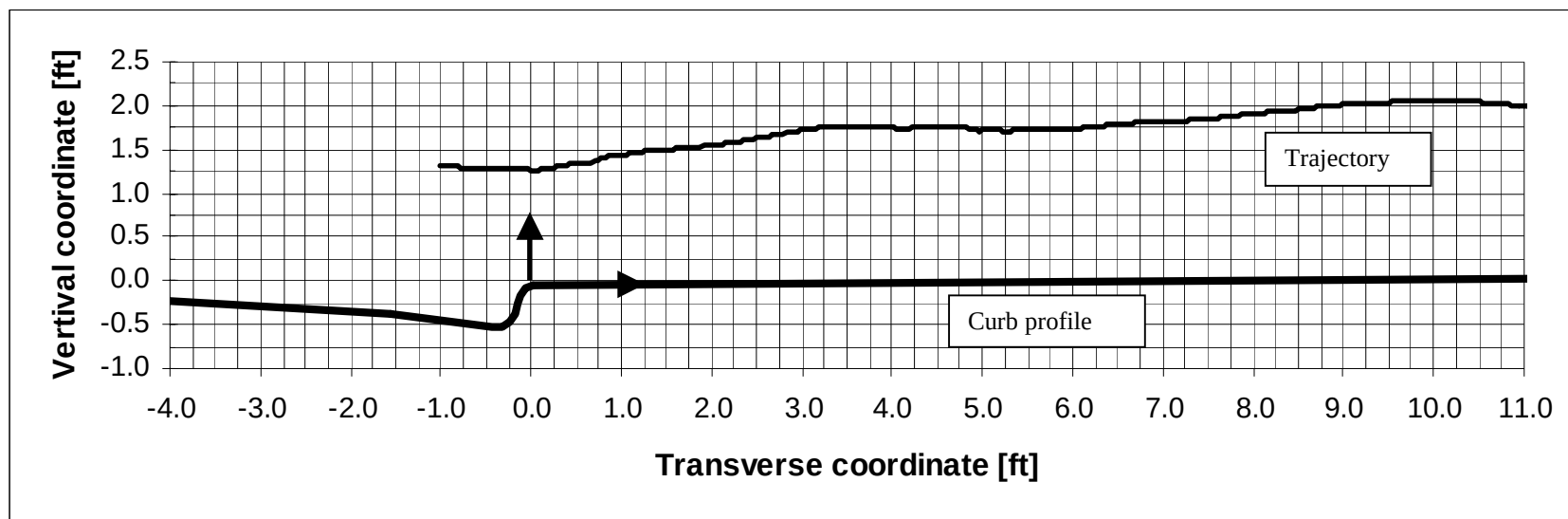


Fig. 2.2.2.4.2.1. (I): Trajectory of the bumper right corner

2.2.2.4.2.2 “E” curb

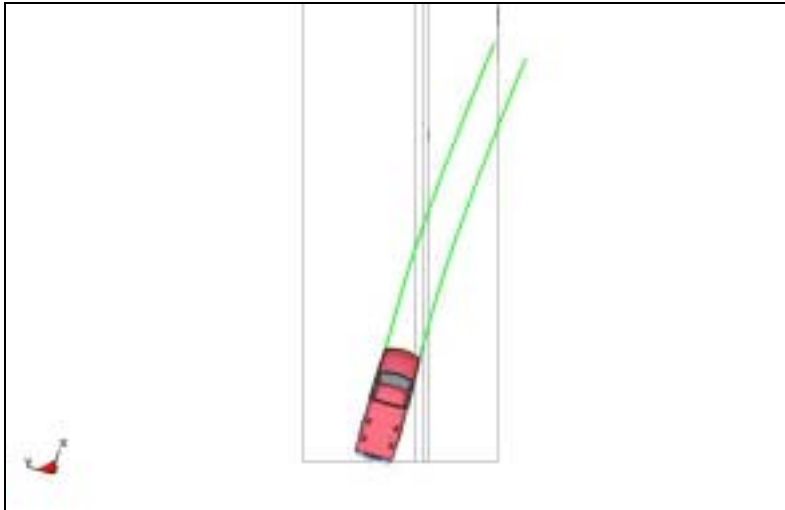


Fig. 2.2.2.4.2.2 (A) Trajectories of bumper corners (upper view)

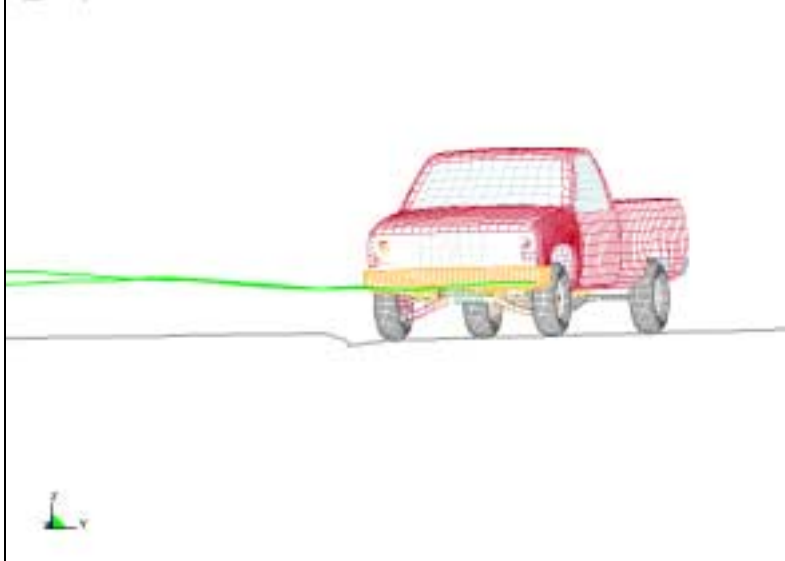


Fig. 2.2.2.4.2.2 (B) Trajectories of bumper corners (lateral view)

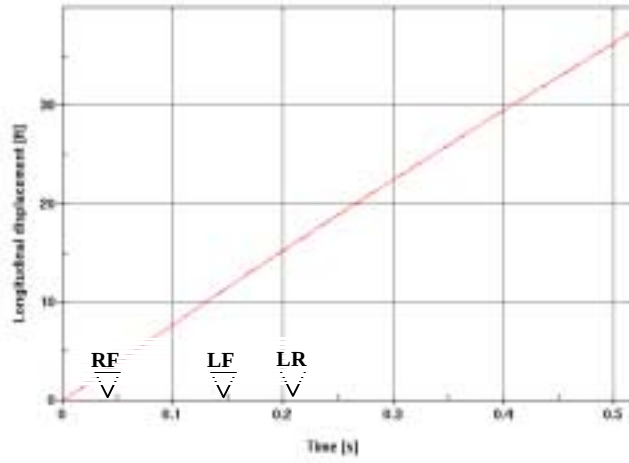


Fig. 2.2.2.4.2.2 (C): Longitudinal displacement [ft]

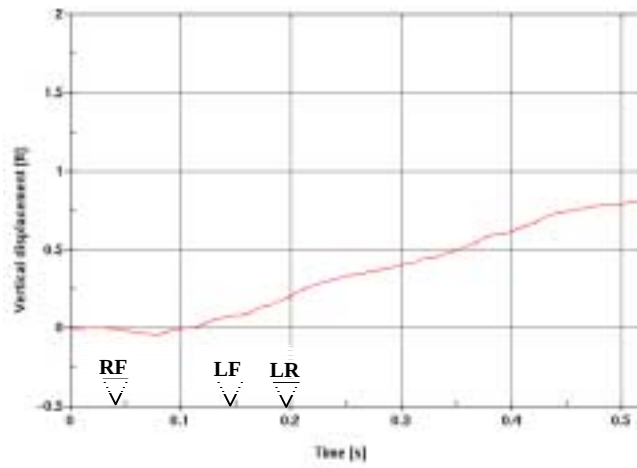


Fig. 2.2.2.4.2.2 (D): Vertical displacement [ft]

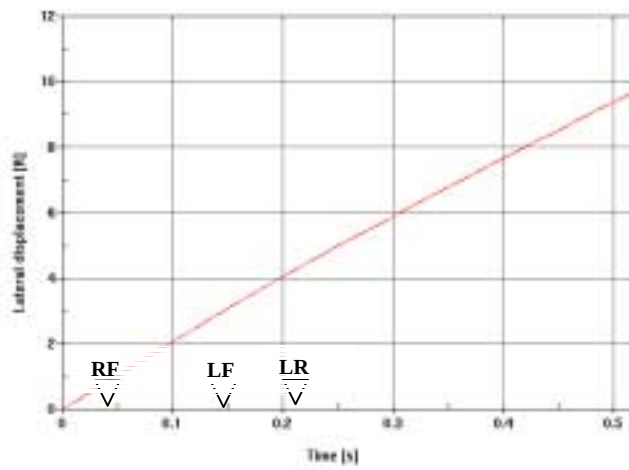


Fig. 2.2.2.4.2.2 (E): Lateral displacement [ft]

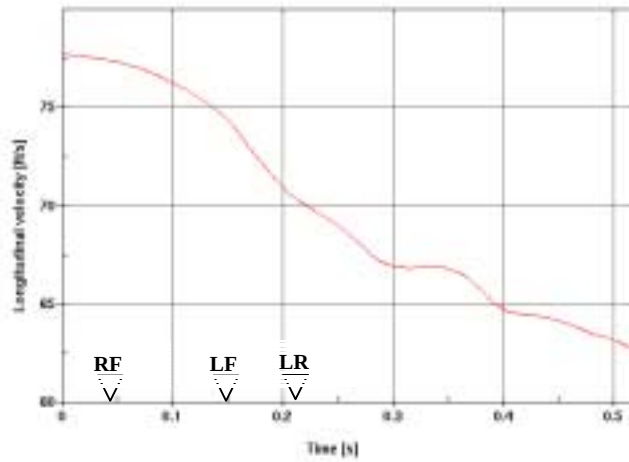


Fig. 2.2.2.4.2.2 (F): Longitudinal velocity [ft/s]

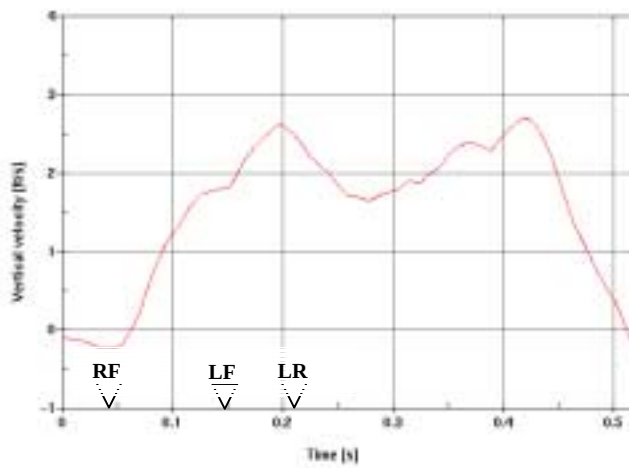


Fig. 2.2.2.4.2.2 (G) Vertical velocity [ft/s]

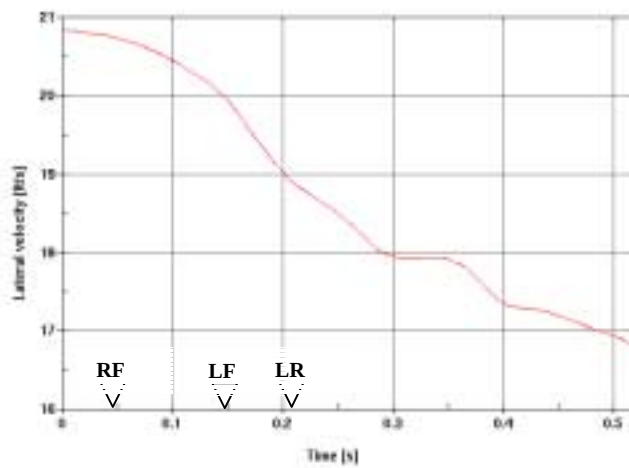


Fig. 2.2.2.4.2.2 (H): Lateral velocity [ft/s]

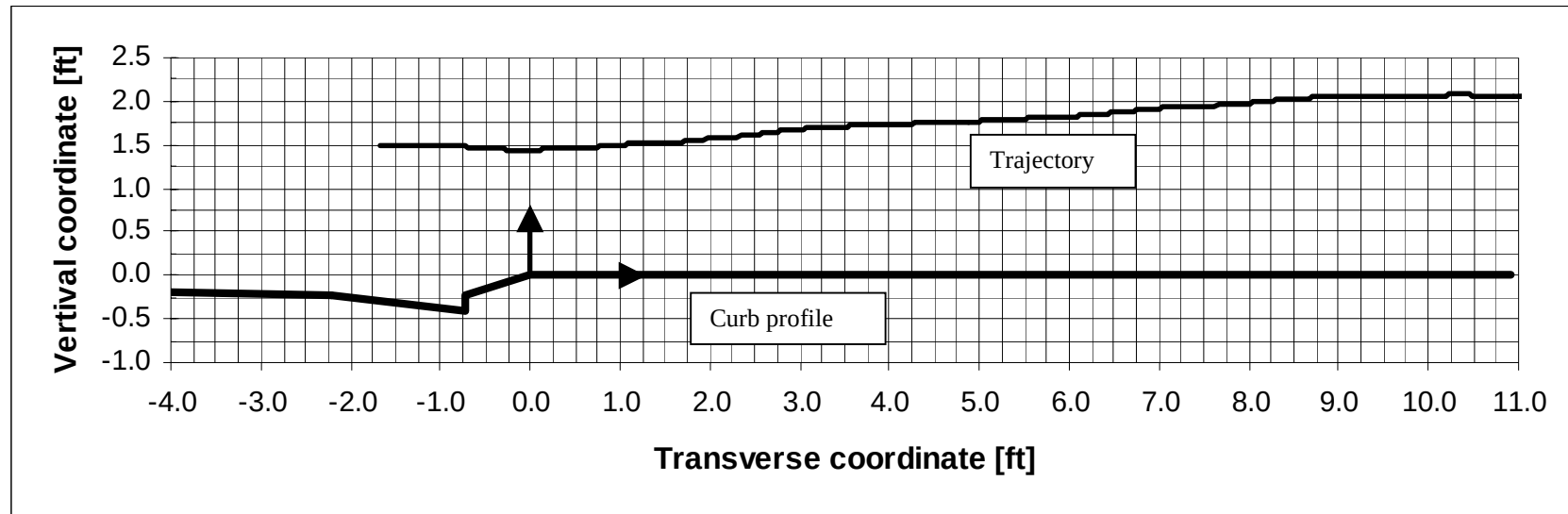


Fig. 2.2.2.4.2.2. (I): Trajectory of the bumper right corner

C2500/E_curb/15_degrees/55_mph/2_slope

CHAPTER 3. CONCLUSIONS

3.1 General Comments

The analysis of the numerical results leads to the following general comments:

- For a given set of parameters describing individual impact scenarios it is possible to determine the maximum angle for which the vehicle does not traverse the curb. For Type F curb the limiting values of the approach angle for vehicles considered in this project are:
 - Ford Festiva: 12° ; for 35 to 55 mph
 - Chevrolet C2500: 3° . for 35 to 55 mphThese limits provide an estimate that smaller vehicles (Ford Festiva) impacting Type F curbs at angles shallower than 12° are likely to rebound from the curb. If the approach angle is bigger than 12° – the vehicle is likely to traverse the Type F curbs. The same conclusion applies to the limit value of 3° for Chevrolet C2500 but the angle is much shallower due to larger dimension of the wheels, the different characteristics of the suspensions and it's inertial characteristics.
- For Type E curbs there is no deviation of trajectories: for all cases the vehicles traverse this curb. No limiting value of approach angle was established.
- Analysis of trajectories shows that there are no excessive variations of vertical displacement for both vehicles, i.e. jumps, rollovers, sliding, etc. For values of approach angle greater than the limit value, vehicles traverse the curb, and enter on the sidewalk without any significant change from their initial trajectory.
- No human reaction has been taken into consideration in this analysis. This is due it's unpredictable character, and difficulty of implementing it directly into a numerical code.
- Severe damage of vehicles' components due to the impact did not occur in the numerical analyses. Few local indentations of the rims and damage of the tires was observed during the extreme approach angle tests at 90° .
- For approach angles not exceeding 15° , no damage was observed.

3.2 Analysis of results

Trajectories of the right corner of the front bumper for Ford Festiva and Chevrolet C2500 were studied in order to formulate the useful graphs for evaluating the behavior of vehicle traversing Type E and F curbs. The following dot diagrams show maximum vertical displacements behind the curbs measured from the top of the curb. The static distance between the front corner of the bumper and the grade for each vehicle were:

1. Ford Festiva: 1.23 ft;
2. Chevrolet C2500: 1.76 ft.

The ordinate values on diagrams start from: 1.25 and 1.75 ft, respectively. This graph gives the user an idea about dynamic behavior of the vehicle, and the influence of the assumed parameters (curb type, approach angle, velocity, and slope).

The Ford Festiva has only a limited number of trajectories, when the vehicle traverses the curb, because of relatively high limit value of approach angle for Type F curb (12 degrees). Because of this, all values are placed together in Figure 3.1.

Chevrolet C2500 traverses the Type F Curb for all values of approach angle exceeding 3 degrees. The adequate diagrams are then divided in two parts:

1. Figure 3.2 – diagram for F curb;
2. Figure 3.3 – diagram for E curb.

Below each diagram is a legend table identifying each case on the diagram.

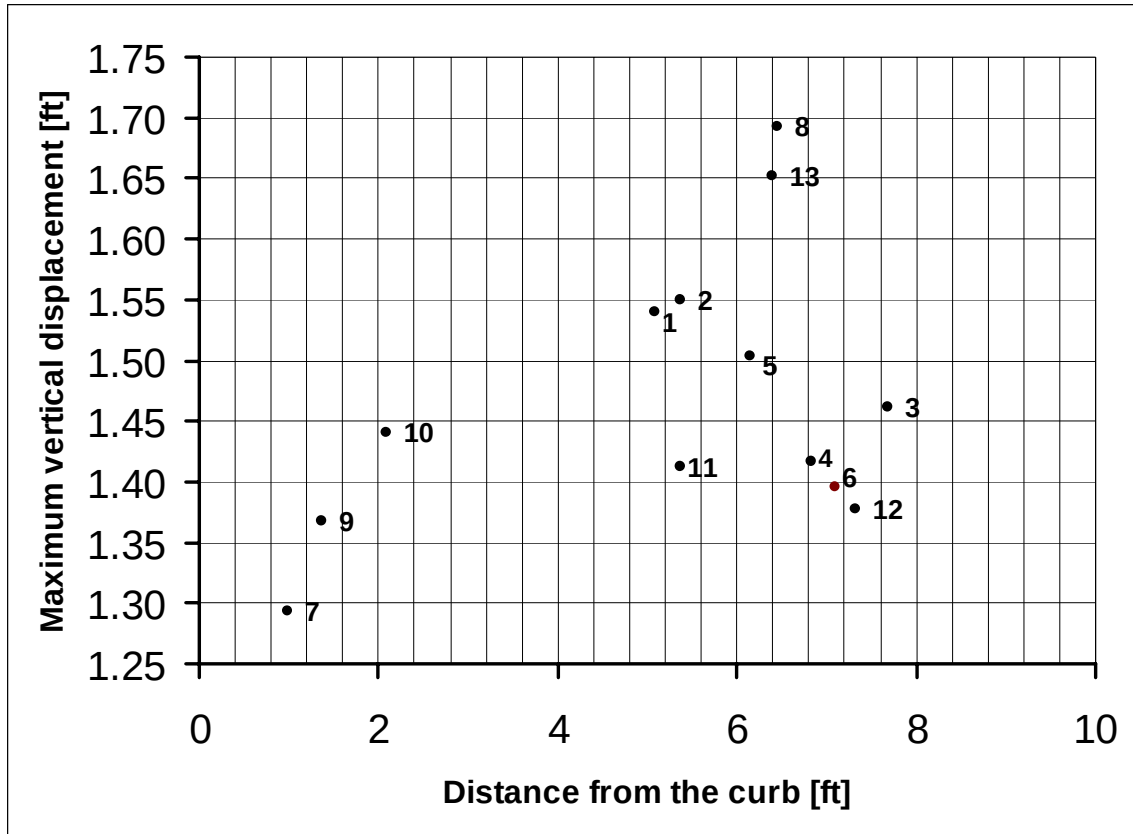


Figure 3.1. Ford Festiva. Maximum vertical displacement of the right corner of the bumper for various combinations of impact parameters. Each combination is distinguished by its number (see legend below).

Case No.	Curb type	Approach angle	Velocity (mph)	Slope
1	F	12	55	0.06
2	F	15	35	0.06
3	F	15	35	0.02
4	F	15	55	0.06
5	F	15	55	0.02
6	E	10	35	0.06
7	E	10	35	0.02
8	E	10	55	0.06
9	E	10	55	0.02
10	E	15	35	0.06
11	E	15	35	0.02
12	E	15	55	0.06
13	E	15	55	0.02

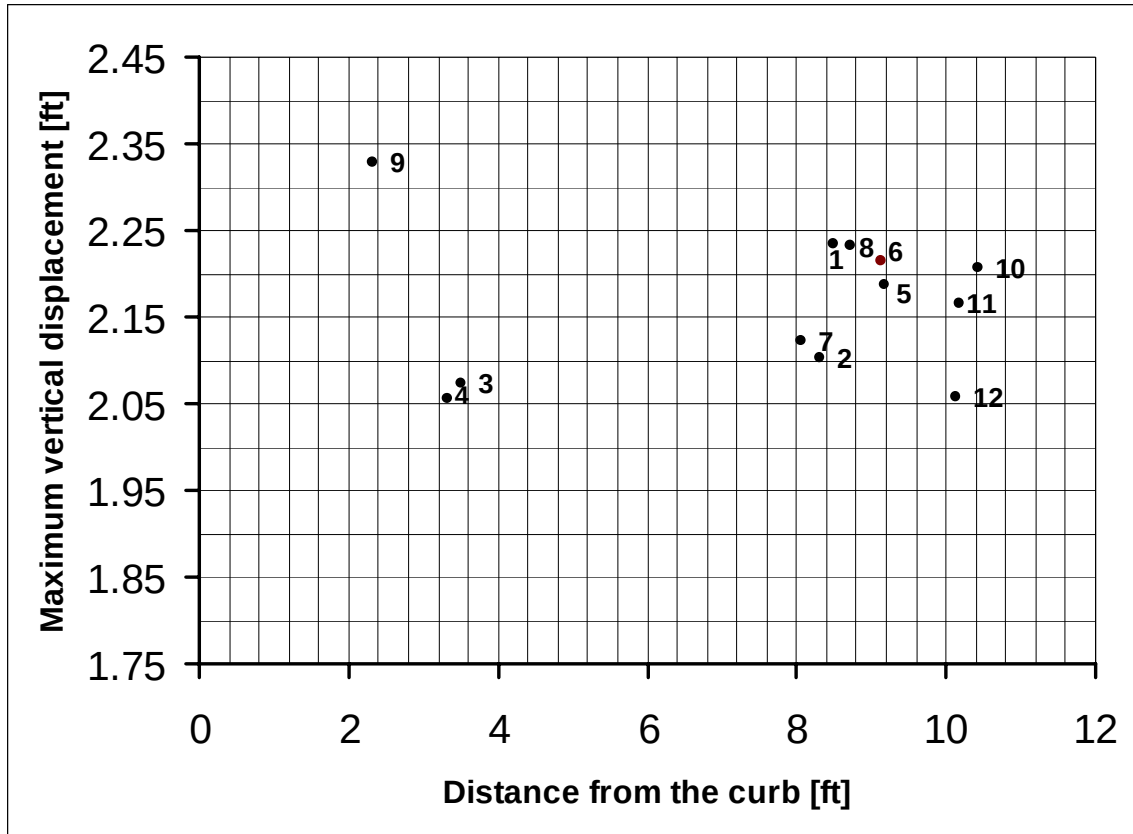


Figure 3.2. C2500. Maximum vertical displacement of the right corner of the bumper for various combinations of impact parameters (F curb). Each combination is distinguished by its number (see legend below).

Case No.	Curb type	Approach angle	Velocity (mph)	Slope
1	F	5	35	0.06
2	F	5	35	0.02
3	F	5	55	0.06
4	F	5	55	0.02
5	F	10	35	0.06
6	F	10	35	0.02
7	F	10	55	0.06
8	F	10	55	0.02
9	F	15	35	0.06
10	F	15	35	0.02
11	F	15	55	0.06
12	F	15	55	0.02

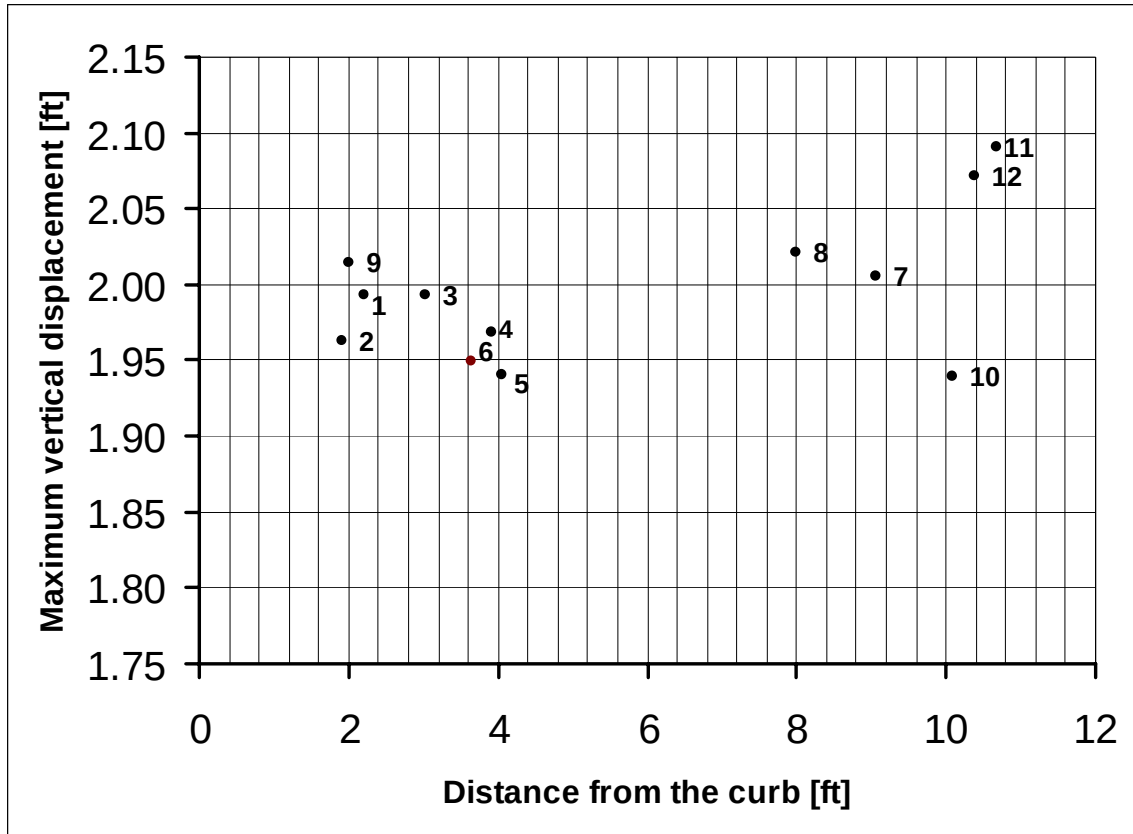


Figure 3.3. C2500. Maximum vertical displacement of the right corner of the bumper for various combinations of impact parameters (E curb). Each combination is distinguished by its number (see legend below).

Case No.	Curb type	Approach angle	Velocity (mph)	Slope
1	E	5	35	0.06
2	E	5	35	0.02
3	E	5	55	0.06
4	E	5	55	0.02
5	E	10	35	0.06
6	E	10	35	0.02
7	E	10	55	0.06
8	E	10	55	0.02
9	E	15	35	0.06
10	E	15	35	0.02
11	E	15	55	0.06
12	E	15	55	0.02

Figures 3.4 through 3.7 show all possible trajectories for a given vehicle and street curb. They clearly depict all possible ranges of vertical displacements for bumper corner.

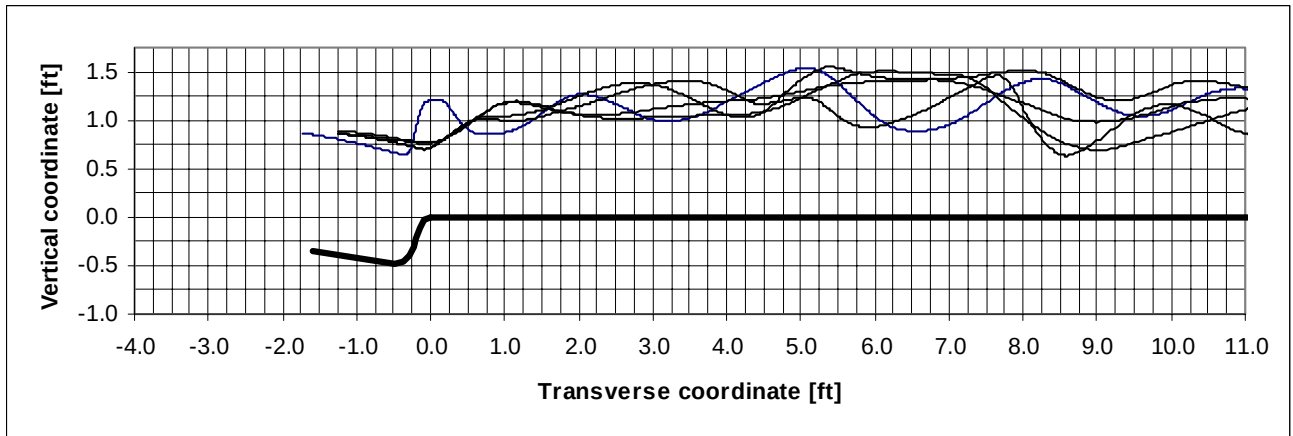


Figure 3.4. Ford Festiva: all trajectories (F curb).

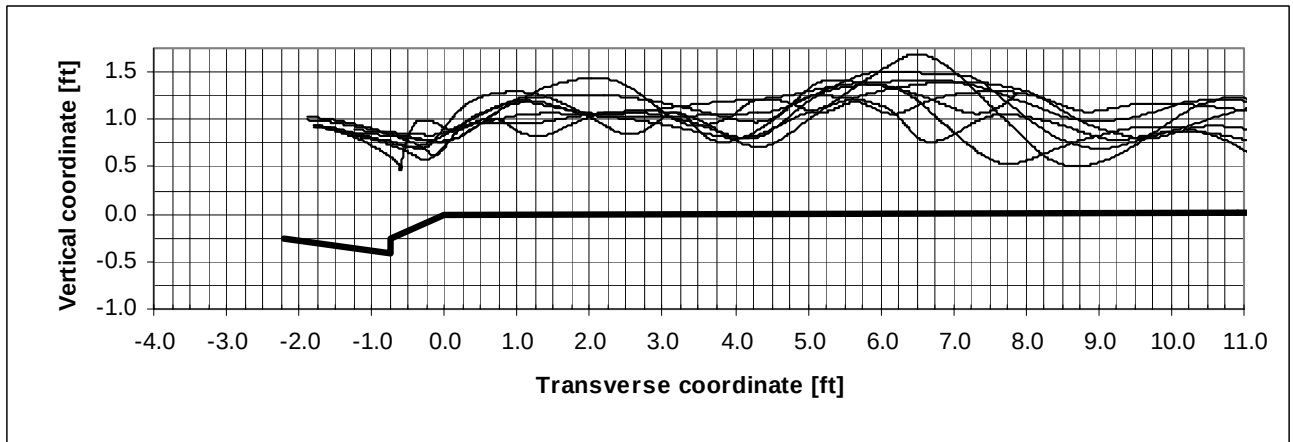


Figure 3.5. Ford Festiva: all trajectories (E curb).

The analysis of Ford Festiva trajectories leads to the following conclusions:

- For Type F curb, the maximum vertical displacement did not exceed 1.55 ft. This means that the dynamic relative displacement is 0.28 ft above the static one. Maximum displacements are localized 5.0 – 8.0 ft from the curb.
- For Type E curb, the maximum vertical displacement did not exceed 1.68 ft. The dynamic relative displacement is 0.41 ft above the static one. Maximum displacements are localized 2.0 – 7.0 ft from the curb, and hard to predict due.

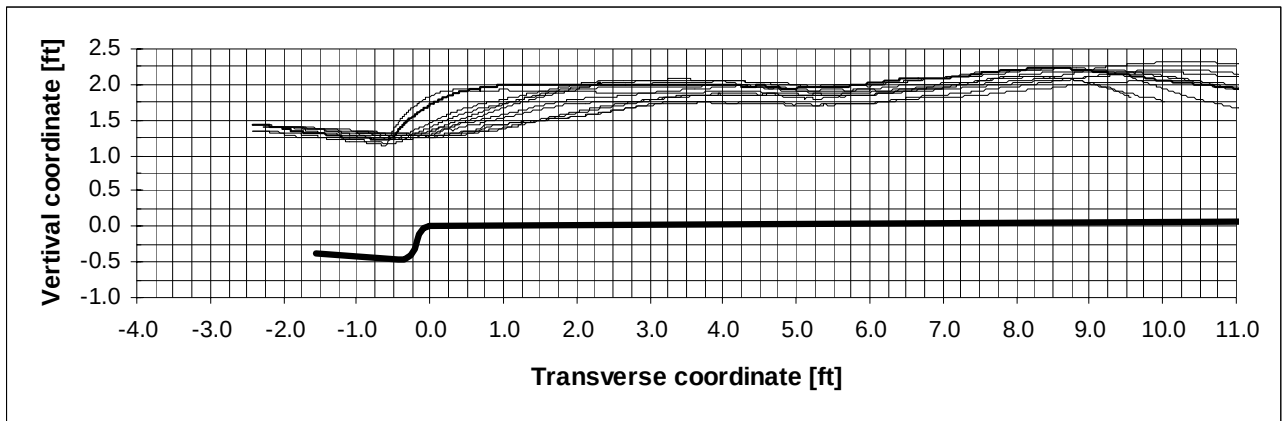


Figure 3.6. C2500: all trajectories (F curb).

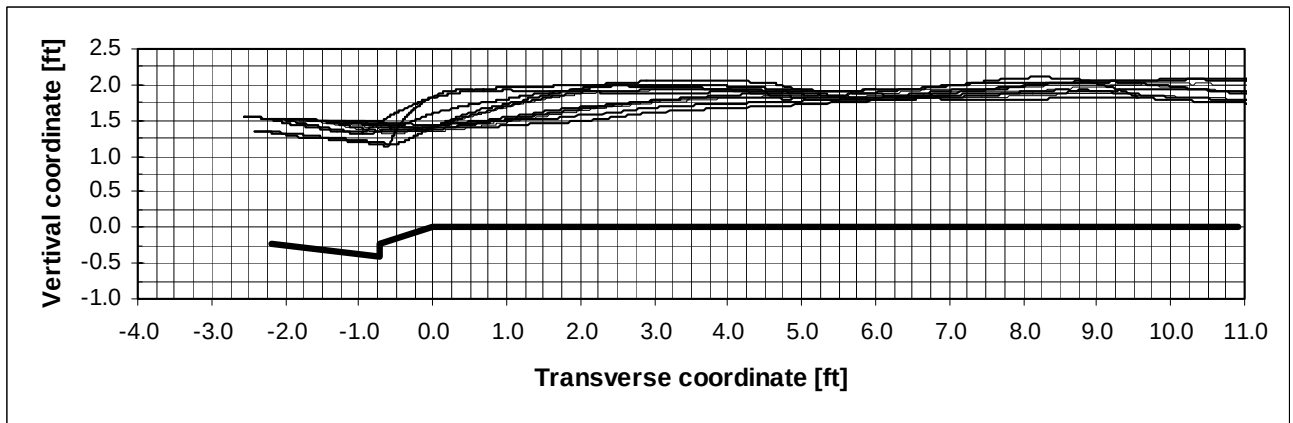


Figure 3.7. C2500: all trajectories (E curb).

The analysis of Chevrolet C2500 trajectories leads to the following conclusions:

- For Type F curb, the maximum vertical displacement never exceeded 2.33 ft. This means that the dynamic relative displacement is 0.57 ft above the static one. Maximum displacements are localized 8.0 – 11.0 ft from the curb.
- For Type E curb, the maximum vertical displacement never exceeded 2.10 ft. The dynamic relative displacement is 0.34 ft above the static one. Maximum displacements are distributed more evenly along the curb.

3.3 Final conclusions

The numerical analyses resulted in a large amount of data regarding vehicle behavior during and after its impact with Type E and F curbs. Although the assumed matrix of considered cases cannot be complete because of the wide variety of possible parameters governing the phenomenon, some essential observations can be formulated.

- FDOT F curb may serve as a roadside safety device only for small vehicles (Ford Festiva size), and only for relatively low values of impact angles. For bigger vehicles this curb does not influence their trajectory significantly, and consequently does not prevent traversing the curb.
- FDOT E curb can not be considered as a roadside safety device for any vehicle. Its inclined shape causes relatively easy traversing the curb, and low reduction of initial velocity.
- To stop errant vehicles after their entrance on the sidewalk, the adequate additional roadside safety devices (barriers) can be applied. Their placement, height, and distance from the top of the curb can be calculated from the trajectories provided in this report. No reduction in initial velocities should be taken into consideration while designing these barriers.
- There are many additional factors that should be considered in order to accurately predict the behavior of errant vehicles such as:
 - The influence of driver's reaction on the resulting trajectory;
 - The variation of roadside terrain such as ditches, vegetation, etc.
 - The variation of the curb shape, in terms of its height and profile.

Numerical simulation is a powerful mean of analysis for complex, real-life situations, where it is impossible to test experimentally or calculate analytically the needed entities. For the problem considered in this project, the results obtained by computer simulation (Finite Element Method) and verified partially by experimental full-scale tests provide valuable information, regarding vehicles' behavior in time and space.

Any further modification of input parameters can be easily implemented and analyzed, in order to gain a better knowledge about the characteristics of the phenomenon.

ACKNOWLEDGEMENTS

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