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DEVELOPMENT OF DESIGN VEHICLES AND CHARACTERISTICS FOR THE HANGUP PROBLEM

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16. Abstract

The overall goal of this project was to develop design vehicles for use in evaluating the operation of low-ground-clearance, long wheelbase / overhang vehicles on extreme hump or sag profile alignments. The literature review indicated that while formal studies had been conducted to develop design vehicles, these vehicles did not include the information needed to assess hang-up susceptibility on a particular vertical alignment. In this study, relevant design vehicle dimensions for 17 hang-up prone vehicle types were developed. Relevant dimensions included wheelbase, ground clearance, and front and rear overhang. Results are presented in a format similar to that used to present design vehicle characteristics in the AASHTO design policy, i.e., both tabular and graphical form. These vehicles can be used in conjunction with the HANGUP software or other tools in designing vertical alignments that reduce the likelihood of hang-up problems. Since they are based on representative samples of both field-collected and manufacturers' data and have been evaluated using the HANGUP software, the researchers conclude that the design vehicles are reasonable and have a rational basis. The proposed vehicles should receive broad review with an eye toward inclusion in appropriate design policies and guidelines.

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EXECUTIVE SUMMARY

The overall goal of this project was to develop design vehicles for use in evaluating the operation of low-ground-clearance, long wheelbase / overhang vehicles on extreme hump or sag profile alignments. The literature review indicated that while formal studies had been conducted to develop design vehicles, these vehicles did not include the information needed to assess hang-up susceptibility on a particular vertical alignment.

No formal studies had ever been undertaken to develop design vehicles for the hang-up problem. From the literature review, it was concluded that there was a common methodology used in developing design vehicles. The steps in this process are:

1. Establish the design vehicles to be developed by anticipating the needs of the users of the end product and observing the variability of the relevant vehicles in prevailing traffic.
2. Determine the dimensions/characteristics to be defined
3. Collect data in the field and from vehicle manufacturers
4. Use the database to define dimensions / characteristics either through the selection of worst case dimensions or some other better-than-worse case measure

In this study, design vehicle dimensions for 17 hang-up prone vehicle types were developed. Results are presented in a format similar to that used to present design vehicle characteristics in the AASHTO design policy, i.e., both tabular and graphical form. The results in presented in tabular form in Table ES-1. These vehicles can be used in conjunction with the HANGUP software or other tools in designing vertical alignments that reduce the likelihood of hang-up problems. Since they are based on representative samples of both field-collected and manufacturers' data and have been evaluated using the HANGUP software, the researchers conclude that the design vehicles are reasonable and have a rational basis. The proposed vehicles should receive broad review with an eye toward inclusion in appropriate design policies and guidelines.

However, there are some limitations that should be noted in applying these design vehicles. The car carrier, double drop, and low-boy trailers hang up on the crest version of the ITE Guideline for a Low Volume Driveway on a Major or Collector Street (6% grade break). The car carrier trailer also hangs-up on the previous AREMA standard rail-highway grade crossing (6-inch drop over a distance of 30 feet).

A design vehicle for extremely long / large loads was not included. Such vehicles require a permit and, in general, are highly susceptible to hang-ups. However, because these rigs are often "customized" to carry a specialized cargo, their dimensions are highly variable and usually represent outliers. In general, it is not feasible to design vertical alignments to accommodate these extreme cases. The problem becomes more one of analysis than design, i.e., knowing the actual dimensions of the vehicle in question, a user finds a suitable route for the vehicle to travel.

While an attempt was made to make this study national in scope, the field data were collected in West Virginia and Pennsylvania. The researchers recognize that there may be a limited number of specialized vehicle types found in specific regions of the United States that have not been included here. For example, the single-unit truck pulling a trailer with a dual-tandem wheel arrangement at the center of the vehicle, was not included in the database since it is relatively rare in the area where this study was conducted.

Table ES-1 Design Vehicle Dimensions

Design Vehicle	Wheelbase (ft)	Front Overhang (ft)	Rear Overhang (ft)	Ground Clearance (in)		
				Wheelbase	Front Overhang	Rear Overhang
Rear-Load Garbage Truck	20	---	10.5	12	---	14
Aerial Fire Truck	20	7	12	9	11	10
Pumper Fire Truck	22	8	10	7	8	10
Single Unit Beverage Truck	24	---	10	6	---	8
Mini-Bus	15	---	16	10	---	8
School Bus	23	---	13	7	---	11
Single Unit Transit Bus	25	18	---	8	6	---
Motorcoach	27	7.6	10	7	10	8
Art. Transit Bus	---	---	10	---	---	9
Articulated Beverage Truck	30	---	---	10	---	---
Low-Boy Trailers <53 feet	38	---	---	5	---	---
Double Drop Trailer	40	---	---	6	---	---
Car Carrier Trailer	40	---	14	4	---	6
Belly Dump Trailer	40	---	---	11	---	---
Passenger Vehicles and Trailers - Private Use	20*	---	13	5	---	5
Passenger Vehicles and Trailers - Commercial Use	24*	---	13	7	---	7
Recreational Vehicles (RV)	27	7.8	16	7	6	8

* distance from rear wheels to hitch

--- hang-up problems not expected on this part of the vehicle

The design vehicles presented should be considered as proposed vehicles since they have not yet received broad-scale review by a recognized highway engineering organization. As such, they have not received any formal endorsement or approval. Therefore, the user assumes any and all risks associated with their use.

It is recommended that the proposed design vehicles be considered by AASHTO, FHWA and related organizations for review, validation, adoption and incorporation into appropriate design policies and guidelines. At the same time, the proposed vehicles should be widely disseminated to Federal Highway Administration offices, state highway agencies, LTAP centers, and geometric design-related technical committees of the Transportation Research Board and the Institute of Transportation Engineers.

As noted above, while the vehicle sample sizes obtained in this study are considered adequate, there may be specialized vehicles found in particular geographic regions that were not included in this study. Thus, as part of the above-noted review process, it is recommended that hang-up prone vehicles that may not have been included in the database for this effort be identified and that the relevant dimensions be determined using the methodology applied here.

As part of the adoption process, it is recommended that the impacts of these design vehicles on existing guidelines and policies be assessed. Relevant guidelines and policies include AASHTO, AREMA and various driveway design guidelines or regulations (at the national, state and local levels). Revision of these policies / guidelines may be necessary based on the design vehicles proposed herein.

Finally, one of the long-term recommendations of the USDOT Grade Crossing Safety Task Force (1996) was to investigate the feasibility of developing a nationwide classification system that would assign compatibility codes of crossings and vehicles for the purpose of helping low-clearance vehicle operators avoid getting hung-up on high-profile grade crossings. Examples of areas of focus for a working group to address this topic were presented; they included:

> "Vehicle characteristics such as: wheelbase, actual ground clearance at points between adjacent axles, and front and rear overhangs and heights above the ground. Based on these, appropriate vehicle classification codes may be determined."

In the researchers' opinions, this study has obtained the data called for by the USDOT Task Force recommendation. Thus, in implementing the results of this research, it seems appropriate to re-visit the idea of developing a compatibility code classification system.

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CHAPTER 1 - INTRODUCTION

1.0 Background

Vehicles with low ground clearance and a long wheelbase and / or overhang can become lodged or "hung-up" on hump or sag profile alignments or those containing sharp grade breaks. These vehicles become hung-up when the undercarriage of the vehicle comes in contact with the roadway surface. Railroad-highway grade crossings and driveway entrances are locations where such "hang-ups" commonly occur. At best, hang-ups result in some vehicular delay and minor damage to the undercarriage of the vehicle and to the pavement surface. In the worst case, major crashes attracting nationwide attention can occur. For example, a vehicle hung-up at a railroad grade crossing can be struck by a train, resulting in the loss of life and millions of dollars in property damage.

The hang-up problem is a significant highway safety issue. A vehicle classification count performed in West Virginia as part of previous research on the hang-up problem found that low-ground-clearance trucks made up about 5.7 percent of all trucks in the traffic stream (Eck and Kang, 1991). Eck and Kang (1991) reported that in Oregon, about one crash per year was the result of a low-ground-clearance vehicle hanging up on a railroad-highway grade crossing and being struck by a train. Furthermore, a regional director of an automobile carrier trucking firm reported 50 to 60 hang-up incidents per month involving auto transporters. Finally, the National Transportation Safety Board has issued a warning that crossing profiles with a high, hump-like alignment are potential impediments in the operation of long-wheelbase or low-ground-clearance vehicles (Eck and Kang, 1991).

Strategies to alleviate the hang-up problem must consider all the elements of the driver-vehicle-highway system. The vehicle design contributes to the problem through low ground clearances and long wheelbases or overhangs. Humped vertical profiles or sharp grade breaks are elements of the roadway that contribute to the problem. Finally, the unsuccessful attempt to cross a vertical profile with a vehicle that cannot negotiate it is the result of a poor decision on the part of the driver. Each of these elements are discussed below.

<u>Vehicle Design</u>

In the United States, the design of the components of commercial vehicles that impact the susceptibility of the vehicle to hang-up problems is essentially unregulated. Consequently, commercial vehicle characteristics vary greatly. In the economically competitive trucking industry, there is continuing pressure to haul larger and higher loads, and to make loading and unloading of the vehicle as easy as possible. Thus, the trend over time has been toward vehicles with longer wheelbases and lower ground clearances.

<u>Roadway Design and Maintenance</u>

A hump or sag profile alignment or one with sharp grade breaks may accommodate automobiles and conventional trucks with no problems. However, when a long wheelbase and / or low-ground-clearance vehicle encounters the alignment, a hang-up may result. Even if the road is designed to accommodate such vehicles, maintenance activities can change the roadway geometry.

For example, railroad-highway grade crossing design standards are available that have some consideration of low-ground-clearance vehicles. However, track maintenance can raise the elevation of the rails over time, creating a more severe geometry that is susceptible to hang-ups.

Communications between the railroad and roadway agency are critical in these instances because the approach to the tracks needs to be adjusted in line with the new track elevation. However, these efforts are not always coordinated because of the differences in ownership. Railroad right-of-way is owned by a private entity (railroad) while the roadway is publicly owned. Another instance in which coordination between public and private owners is needed is when existing driveways are reconnected after roadway construction. For example, a resurfacing project may raise the elevation of the roadway surface by several inches. The owner of a driveway accessed by hang-up susceptible vehicles could have hang-up problems after the resurfacing. Likewise, maintenance activities on a privately owned driveway could create similar problems.

Driver

The human factor is another element related to hang-ups. A driver may know the wheelbase and ground clearance of their vehicle, but that knowledge is typically of little value in knowing for certain whether the vehicle can negotiate a particular hump or sag profile alignment. This uncertainty leads to risk taking behavior, as turning large vehicles around and traveling alternative routes are generally unattractive options and in some cases may not be an option at all.

A complicating matter is the visual "deception" some of these alignments pose to drivers. Due to their curved geometry and gentle gradients, these alignments can appear not be a problem from the driver's perspective. Without additional information relative to the severity of the alignment, it is often not possible for drivers to judge visually whether their vehicle can successfully negotiate a hump profile alignment.

In summary, the preceding discussion has shown that the causes of hang-ups involve all elements of the roadway-vehicle-driver system. In addition, ownership and jurisdictional issues can contribute to the problem. To completely solve the problem, all these elements must be considered. However, solutions that focus on one part of the overall problem can also partially contribute towards the overall goal of solving the problem. Furthermore, the development of tools to analyze the problem will also contribute to its solution because they will provide improved capabilities for those specifically charged with the responsibility to prevent hang-ups. As described in the following section, the goal of this research is to contribute to the overall goal of preventing hang-ups through the development an improved hang-up analysis tool, namely design vehicles that address the hang-up problem.

1.1 Problem Statement

In some aspects of highway design, design vehicles are available so that the designer can dimension the roadway geometry to accommodate prevailing traffic. For example, when designing a turning radius at the intersection of two roadways, the designer can consult the Policy on the Geometric Design of Streets and Highways by the American Association of State Highway and Transportation Officials (AASHTO), also known as the Green Book (AASHTO, 2001), for the turning radii and swept path turning templates for a menu of vehicle types. Designers have a variety of guides addressing various roadway design elements (horizontal and vertical alignment, signing, intersection design, etc.) that either provide design vehicle characteristics, or considered vehicle characteristics in their development. These guidelines come from a variety of sources, including AASHTO, the Institute of Transportation Engineers (ITE), and the American Railway Engineering and Maintenance of Way Association (AREMA, formerly AREA). However, these existing guides are extremely limited in providing input for analyzing hang-up problems. Furthermore, what little guidance is provided may appear in sources with which highway designers are not familiar.

The most prominent and widely used highway design guide is the AASHTO Green Book (2001). This guide contains design vehicles and is generally the first source consulted by highway designers for design vehicle information. The design vehicle information contained in the AASHTO policy includes vehicle turning radii, length, width, and height. However, the vehicles that are presented were not selected with the hang-up problem in mind, thus the design vehicle information in the AASHTO policy does not provide any ground clearance information for the design vehicles that might be considered to have low ground clearance.

A search of the literature revealed that design vehicles for the hang-up problem were not available. Therefore, there is a need to develop design vehicles that specifically apply to the hang-up situation. Required information includes ground clearance, wheelbase, and overhang dimensions for the types of vehicles that are prone to hang-ups. This will allow the hang-up problem to be better addressed in roadway design, maintenance, and operations.

1.2 Project Objectives

The goal of the project is to develop design vehicles to be used in evaluating the operation of low-ground-clearance, long wheelbase / overhang vehicles on high-profile (hump) or sag profile alignments. Several objectives to meet this goal are listed below:

- To review literature pertaining to the establishment of design vehicles
- To identify the types of vehicles that are prone to hang-ups because of low ground clearances or long wheelbases / overhangs

- To gather wheelbase, overhang, and ground clearance measurements for the hang-up prone vehicles, using both manufacturer information and field measurements
- To perform a detailed review of the data for the purpose of establishing design vehicle dimensions
- To present design vehicle information in a form compatible with existing design policies

1.3 Report Organization

Chapter 1 has identified the problem being addressed and outlined the research objectives. Chapter 2, the literature review, reviews research relative to defining design vehicles and identifies a common approach used by researchers. The research methodology is presented in Chapter 3, including the identification of design vehicles, the data collection methods, and data analysis tools. Chapter 4 introduces the established design vehicles, complete with dimensions and sketches. Finally, Chapter 5 presents concluding remarks and suggestions for implementation and usage.

CHAPTER 2 - LITERATURE REVIEW

2.0 Introduction

This literature review deals with the few documented instances of design vehicle development. In particular, it is focused on the methodologies used by others in establishing design vehicles. Although little information could be found in the literature regarding their development, the design vehicles in the AASHTO Green Book are described since they provide a benchmark, both for the dimensions of certain vehicles and as a template for presenting design vehicle information.

2.1 Past Research in Establishing Design Vehicles

This section is focused on three studies in which design vehicle dimensions or characteristics were developed. They are as follows:

- Development of the AASHTO WB-70, WB-100, and WB-105 Design Vehicles
- Development of Two School Bus Design Vehicles (adopted by AASHTO in 2001)
- Development of Wheelbase and Ground Clearance Dimensions for a Generic Hang-Up Prone Vehicle

2.1.1 The AASHTO WB-70, WB-100, and WB-105 Design Vehicles

In the early 1980's, federal highway policy permitted the use of longer tractor-trailer configurations. Initially, there were no design vehicles for these trucks included in the AASHTO design policy. This was a particular concern in intersection design, as it was believed that the larger vehicles would require larger turning radii.

Fambro, Mason, and Neuman (1986) developed the WB-70, WB-100, and WB-105 tractor-trailer design vehicles in response to these changes. At the time, the longest truck-trailer combination in the Green Book (AASHTO, 1984) was the WB-60. Fambro, Mason, and Neuman (1986) established both vehicle dimensions and turning radius characteristics, consistent with the existing design vehicles in AASHTO. In establishing dimensions, the researchers first used field-collected truck classification and dimension information to determine the new truck classes that emerged as a result of the legislation permitting longer configurations. They (Fambro, Mason, and Neuman, 1986) then developed the key design vehicle dimensions using the same field data. To establish the turning template, a turning radius was assigned to each vehicle and modeled on a computer program simulating the vehicle's movement through the curve. This yielded "swept path" information for each turning angle modeled.

Note that while these vehicle classes are certainly long wheelbase configurations, they are not considered low-ground-clearance. Therefore, ground clearance was not an issue in establishing the design vehicles.

2.1.2 School Bus Design Vehicles

Gattis and Howard (1999) addressed the issue of school bus design vehicle characteristics because, while the Green Book in effect at the time (1994) included a "BUS" design vehicle, this vehicle was more similar in characteristics to an intercity bus than to a school bus. In establishing the school bus design vehicles, Gattis and Howard relied on several sources to establish the vehicle dimensions and characteristics, including state transportation agencies, school bus operators, school bus manufacturers, and field collected data. In general, they (1) identified the key characteristics and different variations of school buses, (2) obtained dimension and turning path information for school buses, and (3) used these data to establish design vehicle characteristics for two types of school buses. The methodology is described in greater detail below.

School bus operators provided input on the variations in the types of school buses, and with their guidance, it was determined that two design vehicles should be developed: a 65/66 passenger bus and an 83/84 passenger bus. The researchers (Gattis and Howard, 1999) then contacted school bus manufacturers and requested information on the physical characteristics of those bus types, including maximum height, width, and overall length. In establishing the dimensions of the design vehicle, the worst case dimension for each characteristic was selected. Those worst case results were combined to form one "hybrid" design vehicle for each of the two bus types. While a single vehicle possessing all of the design vehicle characteristics does not exist, these hybrid vehicles (Gattis and Howard, 1999) allow the designs to accommodate all school buses since they should all have less restrictive characteristics.

Note that field data were used in this process only in the establishment of turning radii and swept path characteristics. Since the current research does not involve developing turning templates, no further description on this aspect of the research is presented.

The 2001 edition of the AASHTO Green Book contains two school bus design vehicles. Each of the vehicles presented closely resembles its appropriate counterpart from the Gattis and Howard research, however, there were slight differences in both instances. It is expected that the design vehicles adopted by AASHTO were firmly rooted in this research and modified slightly during the AASHTO design policy review and approval process.

2.1.3 Development of Wheelbase and Ground Clearance Dimensions for a Generic Hang-Up Prone Vehicle

Eck and Kang (1991) presented the only documented information relative to design vehicle characteristics specifically for the hang-up problem. Like Fambro, Mason, and Neuman (1986), Eck and Kang (1991) made a limited survey of traffic to observe the magnitude and types of vehicles of particular concern to their research. To that end, vehicle classification counts were collected on I-79, a regional interstate between Charleston, West Virginia, and Erie, Pennsylvania. On I-79, 13% trucks were observed (Eck and Kang, 1991). Of these 13%, 5.7% (or 0.74% overall) had low ground clearance between the wheels. In addition, Eck and Kang (1991) noted the following categories of hang-up prone vehicles:

- low-bed equipment trailers
- car carriers
- double-drop van semi trailers
- car- and truck- trailer combinations

For identified hang-up prone vehicles, field measurements of wheelbase (the center-to-center distance from the rear axle on the tractor to the front axle on the trailer) and the ground clearance (the vertical distance to the ground at the lowest point along the wheelbase) were collected at a weigh station on I-79 and along I-68. In addition, low-boy trailer manufacturers were contacted (Eck and Kang, 1991) to request ground clearance and wheelbase information. In a few cases, drivers were interviewed to determine if they had ever experienced hang-up problems. (Eck and Kang, 1991)

While conducting the field study, it became apparent that it is not feasible to design roadways to accommodate the lowest ground clearances and longest wheelbases because these were typically outliers in the sample. This could potentially lead to situations where either hang-up considerations are ignored because of the unrealistic measures that would have to be taken to accommodate vehicles of these dimensions, or it could lead to grossly over-designed highways. As a compromise, the wheelbase and ground clearance data were analyzed to determine the 85th percentile for each characteristic. These corresponded to a wheelbase of 30 feet and a ground clearance of 5 inches.

2.1.4 Summary of Previous Design Vehicle Research

Each of the documented efforts establishing vehicles had an overriding common methodology, the steps of which are presented below:

1. Establish the design vehicles to be developed by (a) anticipating the needs of the users of the end product and (b) observing the variability of the relevant vehicles in prevailing traffic
2. Determine the dimensions / characteristics to be defined
3. Collect data both in the field and from manufacturers / operators
4. Use the database to quantitatively define dimensions / characteristics either through the selection of worst case dimensions or some other "better than worst case" measure

2.2 Design Vehicles in the AASHTO Green Book

The design vehicles contained in the AASHTO Green Book (2001) are likely the most widely used design vehicles in the highway engineering field. As such, there is a need to review

(1) the design vehicles presented, (2) the relevant information for each vehicle relative to the hang-up problem, and (3) the format in which the design vehicle information is presented. Table 2-1 provides a summary of the key characteristics of the design vehicles contained in the AASHTO Green Book (2001). The Green Book does not include ground clearance measurements for any of the design vehicles. However, the longest wheelbase and overhang for each vehicle were selected from the presented information and are provided in Table 2-1. Note that the design vehicles presented by AASHTO were primarily selected based on turning path considerations; the hang-up problem was not a consideration. As a consequence, there are many hang-up susceptible vehicle types that are not included in the Green Book (2001). In addition, overhang dimensions were included because of their effect on swept path. The impacts that the overhang and wheelbase dimensions have on hang-ups was likely not considered. As such, it is uncertain whether these dimensions would be suitable in hang-up related analyses. As Eck and Kang (1991) determined, worst case dimensions are sometimes too severe for use in these analyses. The dimensions presented in Table 2-1 are included to provide a limited comparison with the design vehicles established for this research.

Table 2.1 Key Characteristics of the AASHTO (2001) Design Vehicles

Vehicle	Longest Wheelbase (ft)	Longest Overhang (ft)
Passenger Car	11	5 (rear)
Single Unit Truck	20	6 (rear)
40-ft Intercity Bus	24	6.3 (rear)
45-ft Intercity Bus	26.5	8.5 (rear)
City Transit Bus	25	8 (rear)
36-ft School Bus	21.3	12 (rear)
40-ft School Bus	20	13 (rear)
Articulated Bus	22	10 (rear)
40-ft (overall wheelbase) Semitrailer	23.8	3 (front)
50-ft (overall wheelbase) Semitrailer	31.4	3 (front)
62-ft (overall wheelbase) Semitrailer	36.4	4 (front)
65-ft (overall wheelbase) Semitrailer	39.4	4.5 (rear)
67-ft (overall wheelbase) Double Trailer	23	3 (rear)
100-ft (overall wheelbase) Triple Trailer	23	3 (rear)
109-ft (overall wheelbase) Double Trailer	36.4	2.5 (rear)
Motor Home	20	6 (rear)
Passenger Car and Camper Trailer	17.7*	10.9 (rear)
Passenger Car and Boat Trailer	15*	8 (rear)
Motor Home and Boat Trailer	15*	8 (rear)

*from the rear wheels to the hitch

Finally, note that the AASHTO policy (2001) presents the design vehicle information in both tabular and pictorial form. In the tabular presentation, one table is used to present all the design vehicles. In the pictorial presentation, one page of the document is dedicated to each design vehicle, where more detail is provided. A dimensioned side-view drawing and a plan view of the 180 degree turning template is provided for each vehicle. Both items are drawn to scale.

2.3 Concluding Remarks

The process of developing design vehicles was ascertained from three studies which documented similar efforts. The manner in which this general methodology was applied to developing design vehicles for the hang-up problem is described in the next chapter. In addition, the review of the AASHTO design vehicles provided a benchmark to which some of the design vehicles can be compared, as well as a general format for the presentation of the design vehicle information. At the present time, the AASHTO design vehicles do not include the information needed to assess hang-up susceptibility on a particular vertical alignment.

CHAPTER 3 - METHODOLOGY

3.0 Introduction

The literature review indicated that there is a common methodology used in developing design vehicles. This methodology consists of the following steps:

1. Establish the design vehicles to be developed by (a) anticipating the needs of the users of the end product and (b) observing the variability of the relevant vehicles in prevailing traffic
2. Determine the dimensions / characteristics to be defined for each design vehicle
3. Collect vehicle data
4. Use the database to quantitatively define dimensions / characteristics either through the selection of worst case dimensions or some "better-than-worst-case" measure

The chapter is organized so that the manner in which this research addresses these steps is presented in a logical sequence. For the fourth step, where the dimensions are established, there is a longer discussion that includes a description of the HANGUP software package and several key highway design standards / guidelines that relate to hang-up issue. Prior to the establishing of the dimensions from the collected data, four different profiles (three from standards / guidelines) were tested against candidate design vehicle dimensions using the HANGUP software so that the ramifications of the final dimensions would be understood.

3.1 Design Vehicles to be Developed

While there are no quantitative methods or exact rules to apply when establishing how many design vehicles are needed to address the hang-up problem, a few of the considerations are as follows:

- Design vehicle information that is needed but not currently available
- The variability of the vehicle fleet, including sectors that emerge as unique
- The consequences of using common vehicles to represent broader sectors of the vehicle population
- The available resources to collect data
- Local constraints, such as the prevalence of a certain vehicle in the local geographic area

The research investigators, in conjunction with the WVDOT project monitor, developed a preliminary list of the vehicles types for which design vehicle dimensions might be developed. The basis of this list was previous research performed by Eck and Kang (1991) and general knowledge of the commercial vehicles traveling in West Virginia and the mid-Atlantic region. It was generally expected that the preliminary list would be revised if, during the field data collection (1) additional low clearance vehicle types were discovered, (2) some of the identified vehicle types could be combined due to similarity, or (3) vehicle types could be eliminated because their low clearance problem was overestimated. The preliminary list of vehicle types is presented below:

- Rear-Load Garbage Trucks (Packer Trucks)
- Beverage Trucks
- Fire Trucks

- Large School Buses
- Transit (Low Floor) and Intercity Buses
- Liquid Tanker Semi-Trailers
- Dry Bulk Semi-Trailers
- Single Drop Van Semi-Trailers
- Boat Carriers
- Low-Boy Trailers
- Double Drop Van Semi-Trailers (Moving Vans)
- Double Drop Live Stock Carriers
- Car Carriers
- Passenger Vehicle with Trailer
- Specialized Vehicles

The list was revised based on a number of observations made during the data collection and analysis phase. The revisions that were made, along with a brief justification, are described in the following paragraphs.

In discussions with low-boy trailer manufacturers, it was determined that boat trailers were actually standard low-boy trailers with modifications to the deck to accommodate the unusual shape of boat hulls. Since these modifications did not affect the ground clearance or wheelbase of the trailer, "boat trailers" were dropped as a separate design vehicle since they are represented by "low-boy trailers."

During the field data collection, it was observed that "liquid tank semi-trailers", "dry bulk semi-trailers", and "single drop van semi-trailers" did not have ground clearances as low as were expected. It was decided that they were erroneously included in the study as low-clearance or hang-up prone vehicles. Consequently, they were dropped as design vehicles after the first few field data collection efforts.

In discussions with manufacturers of "beverage trucks", it was noted that there are both articulated and single unit varieties of these vehicles, both of which may be hang-up prone. The "articulated beverage truck" has a long wheelbase and low ground clearance to facilitate unloading of the truck. The "single unit beverage truck" has both a long overhang and a relatively long wheelbase with low ground clearance. Therefore, these two vehicle types were established as separate design vehicles.

Review of manufacturer and field data revealed that there are a number of different types of "fire trucks." Of these different varieties, it is likely that only "aerials" and "pumpers" are hang-up prone. The articulated, extremely long fire trucks, called "tillers" were also considered but not developed because they are very scarce, particularly in eastern cities where limited space for streets often causes inadequate turning radii at intersections to accommodate these vehicles. Consequently, two "fire truck" design vehicles were developed, the "pumper" and the "aerial."

When in truck inspection stations, many extremely long (permitted) vehicle configurations were encountered. However, these vehicles were so highly variable that there was virtually no way to aggregate the collected data in any meaningful way. Furthermore, since they are so highly variable, it is likely that each specific vehicle would need to be analyzed on a case-by-case basis if their operator had hang-up concerns. Therefore, long vehicle configurations, which includes any low-boy trailers longer than 53-ft, were dropped from consideration of design vehicle development. However, it should be stressed that the operators of the vehicles should be knowledgeable of the dimensions of their vehicles and a means of testing their vehicle against hang-up prone vertical profiles. Such individuals are referred to Section 3.5, which includes a discussion of the HANGUP software. It is recommended that this software package or a similar analysis tool be used before attempting to cross humps, rail-grade crossings, or other severe vertical profiles.

The “transit bus” design vehicle was separated into four design vehicles: “mini-bus”, “motorcoach”, “single unit transit bus” and “articulated transit bus.” These buses are very different from one another in size and area of potential hang-up. The “mini-bus” and “articulated transit bus” have long rear overhangs, while the “single unit transit bus” and “motorcoach” are more likely to hang-up between the wheels and / or on the front overhang.

Review of manufacturer data on trailers identified the “belly dump trailer” as a potential hang-up prone vehicle. While not common in the Appalachian region of the country, they are common in other parts of the country since they are commonly used to haul dry bulk material such as grain.

Because of their long overhang, long wheelbase, and low ground clearance, “recreational vehicles (RV)” were added as a design vehicle. These are of particular concern in West Virginia because of its robust tourism industry.

During field data collection, two distinct categories of “passenger vehicles and trailers” were noted: those used for private individual / family (commonly recreational) use and those used for commercial purposes. The private use car-trailer combinations, which include boats and campers had been anticipated. However, it was discovered that with today’s more powerful pickup trucks, significant loads can be hauled on a commercial basis. Pickup - trailer combinations were found hauling large loads on flatbed trailers or multiple cars on small car carrier trailers. One advantage of using pickup trucks in lieu of a conventional tractor-trailer truck is that a commercial driver's license is not needed. Consequently, the "passenger vehicle and trailer" design vehicle was separated into "private use" and "commercial" design vehicles.

The final list of design vehicles developed is as follows:

- Rear-Load Garbage Truck
- Aerial Fire Truck
- Pumper Fire Truck
- Single Unit Beverage Truck
- Mini-Bus
- School Bus
- Single Unit Transit Bus
- Motorcoach
- Articulated Transit Bus
- Articulated Beverage Truck
- Low-Boy Trailers <53-ft
- Double Drop Trailer
- Car Carrier Trailer
- Belly Dump Trailer
- Passenger Vehicles and Trailers - Private Use
- Passenger Vehicles and Trailers - Commercial Use
- Recreational Vehicles (RV)

3.2 Dimensional Characteristics to be Defined

There are a large number of vehicle characteristics that could be defined in establishing a design vehicle. Even if the focus is only on those vehicle characteristics which bear on the hang-up problem, the list is relatively long. The following is a list of vehicle dimensions and characteristics pertinent to the hang-up problem.

- ground clearance
- wheelbase
- front and / or rear overhang
- vehicle loading
- tire type and inflation
- age of the equipment / chassis
- angle of approach (vehicle property)
- angle of departure (vehicle property)
- breakover angle (vehicle property)

Each of these characteristics is defined below along with a discussion of the advantages and disadvantages of including them as design vehicle dimensions.

3.2.1 Ground Clearance

Ground clearance is defined as the distance from the bottom of the vehicle body to the ground. It is a key characteristic of the vehicle, along with wheelbase and overhang lengths, that defines the susceptibility of the vehicle to hang-ups. Because of its relative ease of field measurement and importance, ground clearance was defined for each design vehicle.

Ground clearance can be measured in the field or can be obtained from the manufacturer. In Eck and Kang's (1991) prior research efforts to establish dimensions for a generic low clearance vehicle, they found that manufacturer estimates of ground clearance were often optimistic. This is likely because the assumptions of new equipment, properly inflated tires, and reasonable loads (or none at all) are inherent in their estimates. When measuring in the field, ground clearance includes the effects of tire size and inflation, age of the equipment, and vehicle loading. The researchers were cognizant of these variables and sought out vehicles that may have been riding low for these reasons since they represent worst case conditions. In general, field collected ground clearance information was preferred over manufacturer provided data because it more accurately represented the vehicle population. From the perspective of the researchers, manufacturer data has only one general advantage over field data. For vehicles that are not common to the researchers' area, manufacturer data were all that were available. With that exception being noted, field data were favored in all other instances.

3.2.2 Wheelbase and Overhang

As mentioned, long wheelbase and overhang lengths in combination with a low ground clearance make a vehicle susceptible to hang-ups. As such, these attributes are critical dimensions in establishing design vehicles. Inclusion of ground clearance as a design vehicle dimension means that either wheelbase or front or rear overhang, which ever is appropriate based on where on the vehicle will hang-up, needs to be used. For example, rear-loading garbage trucks drag in the rear, therefore, rear overhang is the critical parameter. In contrast, car carrier trailers can drag in the rear or hang-up between the wheels, therefore both wheelbase and rear overhang are needed.

When measuring wheelbase, the longest distance between the centerline of adjacent axles was measured. For semi-trailers, this was usually the distance from the rear drive axle on the tractor to the forward axle on the trailer. For design vehicles with hitches, such as the car carrier trailer, the relative location of the hitch between the axles must also be included. Because a hitch allows for some roll, vehicles with a hitch are not as susceptible to hang-ups as those with the same wheelbase but no hitch. Rear overhang is measured from the centerline of the rear-most wheel to the end of the vehicle. Front overhang is measured from the centerline of the front-most wheel to the front of the vehicle.

3.2.3 Angle of Approach, Angle of Departure, and Breakover Angle

Related data that may be useful in defining hang-up prone vehicles are angle of approach, angle of departure, and the breakover angle. Each is described below.

The angle of approach represents the maximum grade break that a vehicle can traverse when approaching an incline without hanging up on the front overhang. It is defined as the angle between a line connecting the bottom of the front tire and the lowest point on the front overhang.

Similarly, the departure angle is the angle between a line connecting the bottom of the rear tire and the lowest point on the rear overhang. This angle represents the maximum grade break that a vehicle can traverse when departing an incline without hanging up on the rear overhang.

The breakover angle is the angle between a point located on the underside of the vehicle midway between the wheels, and the bottoms of the front and rear tires. It represents the maximum grade break that the vehicle can traverse without hanging up between the wheels.

These three defining angles could potentially be used in two ways. First, because they implicitly encompass the ground clearance - wheelbase / overhang combination into one measure that defines the vehicle's susceptibility to hang-ups, they might be used as the defining dimension for the design vehicles. However, they cannot be directly field measured. They can be estimated from ground clearance and wheelbase / overhang information. However, ground clearance and wheelbase / overhang are a better choice for design vehicle dimensions since they are more readily understood by the highway engineering community. Furthermore, parameters that are estimated indirectly are considered inferior to parameters that can be directly field measured. This second level of computations would blur the research process and results. Therefore, these measures were judged to be inappropriate as defining characteristics of the design vehicles.

The second way they can be useful is that through simple trigonometry, they can be used to calculate the ground clearance when both they and the wheelbase / overhang is known. They were used in this fashion for a few individual vehicles in the data base when manufacturers provided wheelbase / overhang information and the appropriate angle. However, as stated previously, field measured ground clearances were favored over those provided by the manufacturer.

3.2.4 Defining Dimensions for Each Design Vehicle

The dimensions that were used to define each design vehicle are provided in Table 3-1. The dimensions were established based on the discussion in this section regarding the advantages and disadvantages of the various measures, as well as a determination for each vehicle as to where its hang-up susceptibility lies, either between the wheels or on the front or rear overhang.

Note also that additional information was collected for each vehicle in case it was needed for follow-up investigations. The data collected for each vehicle type is shown in Appendix A, which is the vehicle data base used to establish the design vehicles.

Table 3-1 Design Vehicles Developed with their Defining Dimensions

Design Vehicle	Defining Dimensions
Rear-Load Garbage Truck	Rear Overhang and Ground Clearance
Aerial Fire Truck	Wheelbase, Rear and Front Overhang, and all Ground Clearances
Pumper Fire Truck	Wheelbase, Rear and Front Overhang, and all Ground Clearances
Single Unit Beverage Truck	Wheelbase and Ground Clearance, Rear Overhang and Ground Clearance
Mini-Bus	Rear Overhang and Ground Clearance
School Bus	Rear Overhang and Wheelbase
Single Unit Transit Bus	Wheelbase and Ground Clearance, Front Overhang and Ground Clearance
Motorcoach	Wheelbase, Rear and Front Overhang, and all Ground Clearances
Articulated Transit Bus	Rear Overhang and Wheelbase
Articulated Beverage Truck	Wheelbase and Ground Clearance
Low-Boy Trailers <53 feet	Wheelbase and Ground Clearance
Double Drop Trailer	Wheelbase and Ground Clearance
Car Carrier Trailer	Wheelbase and Ground Clearance, Rear Overhang and Ground Clearance
Belly Dump Trailer	Wheelbase and Ground Clearance
Passenger Vehicles and Trailers - Private Use	Trailer Wheels to Hitch and Ground Clearance
Passenger Vehicles and Trailers - Commercial Use	Trailer Wheels to Hitch and Ground Clearance, Rear Overhang and Ground Clearance
Recreational Vehicles (RV)	Wheelbase, Rear and Front Overhang, and all Ground Clearances

3.3 Data Collection Strategy

As mentioned in the previous section, field data were preferred in establishing design vehicle dimensions. Three options were explored in conjunction with field data collection. They were as follows:

- "Simulated" field measurements - Specific vehicles could be loaded in specific ways for field measurement
- Manual field measurements of vehicles as they are encountered
- Automated process using photogrammetric techniques

The "simulated" field measurements might be a good option when the vehicle type in question is not highly variable, or specific conditions are desired. For example, limited variability was found with the bodies of the rear loading garbage trucks studied as part of this research. Most of the variability stemmed from tire inflation, loading, and age of equipment. This approach would have been useful if the research team could have selected an older garbage truck, slightly deflated the tires, and overloaded it. However, the main drawback of this approach is that cooperation is needed from the owner of the vehicle. Since making arrangements to do this is difficult logistically, this option was only used once. A school bus was loaded with children before measurement.

The "simulated" field measurement method is not appropriate when the vehicles within a selected vehicle type are highly variable, such as with low-boy trailers. In this case, it is better to measure a large number of vehicles as they exist in the traffic stream. These measurements provide broader overall coverage of the vehicle type, and offer a better representation of the vehicles as they are actually operated by their owners. One problem with this method is that extreme cases (outliers) can enter the database. Some low-boy trailers had very low ground clearances that would be unrealistic for selection as a design vehicle parameter. Statistical analysis or other methods resulting in the selection of a "better-than-worst-case" dimension counteract this concern. On the other hand, field data does not necessarily ensure that the worst case will be encountered. In cases where this is desired, no guarantees can be made relative to more hang-up susceptible vehicles being encountered.

Field data can be collected in an ad hoc manner at a facility such as a truck inspection station or rest area, or in a more controlled way, such as visiting a fire station to measure fire trucks. For each vehicle type, it was readily apparent which method was best. For fire trucks, garbage trucks, and transit vehicles, sampling at their storage / maintenance location was preferred. Not only was it more efficient for the researchers to sample them when they were all parked in one place, but it was not appropriate to expect these vehicles to stop when they were on the highway system. For the remainder of the vehicles, their owners typically only owned one of the particular vehicle type, therefore there was no centralized facility. However, the truck inspection stations and rest areas attracted a sufficient variety of these vehicles for sampling.

Field data can be collected manually or in an automated way. Student labor was used to collect the information manually. Because they were highly knowledgeable about the subject, concerns regarding their ability to correctly collect the needed measurements were alleviated.

The automated alternative considered for this research involved a photogrammetric process. It was proposed that a pair of 35-mm cameras be mounted at the roadside to capture a stereoscopic profile image of the vehicle undercarriage area. The wheelbase, ground clearance, and overhang information would then be extracted from the stereoscopic image at a later time.

Since only a fraction of the vehicles passing the site would need to be sampled, a trigger would be required that was sensitive only to the small percentage of vehicle types of interest. However, the only trigger with the intelligence to discriminate between the wanted and unwanted vehicles was the human, and humans are too slow to trigger the device in time to capture vehicles moving at 70 mph. In addition, there were concerns with the ability to illuminate the undercarriage of the vehicle at the moment of the picture so that a clear view of the undercarriage would be available for ground clearance measurement. Finally, there were concerns regarding the accuracy of the device, particularly since target points are generally needed on the vehicle, but would rarely be available.

In summary, field data were preferred over manufacturer data, particularly for ground clearance information. The field data were collected manually, at a combination of weigh stations, rest areas, and storage / maintenance facilities for certain vehicle types (e.g., fire stations). Manufacturer data were used to the extent needed. For some vehicle types not common to this area (e.g., belly dump trailers), manufacturers were the only source of data. The photogrammetric automated data collection alternative was dismissed before significant effort was devoted to it.

3.4 Data Collection Sites

As mentioned, both field data and manufacturer data were collected. The rest areas and weigh stations where data were collected are as follows:

- I-79 Southbound weigh station near Fairmont, West Virginia
- I-79 Southbound rest area near Morgantown, West Virginia
- I-79 Northbound weigh station / rest area near Pittsburgh, Pennsylvania

- I-81 Northbound weigh station near the Pennsylvania / Maryland border
- I-64 Westbound near in Charleston, West Virginia

Field measurements were also taken at specific locations where vehicles of interest were headquartered. These locations included:

- Port Authority Transit Garage, Pittsburgh, Pennsylvania (transit buses)
- Mountain Line Transit Authority, Morgantown, West Virginia (transit buses)
- Suburban Sanitation, Fairmont, West Virginia (garbage trucks)
- Waste Management Inc., Charleston, West Virginia (garbage trucks)
- City garage, Pittsburgh, Pennsylvania (garbage trucks)
- Stonewall Jackson Lake, West Virginia (boat trailers)
- Keystone RV Center, Marion, Pennsylvania (RV's)
- University High School, Morgantown, West Virginia (loaded school buses)
- Cameron Coca-Cola Bottling Company, Houston, Pennsylvania (beverage vehicles)
- Various Fire Stations in Pittsburgh, Pennsylvania
- Morgantown Fire Department, Morgantown, West Virginia
- Blacksville Volunteer Fire Department, Blacksville, West Virginia
- Bridgeport Fire Department, Bridgeport, West Virginia
- Black Lick Volunteer Fire Department, Black Lick, Pennsylvania

The manufacturers that contributed dimensional information through personal contact and web sites are included in Table 3-2.

The collected data were assembled in a computerized database for analysis. This database is provided in Appendix A.

Table 3-2 - List of Contacted Manufacturers

Vehicle Type	Manufacturer	Vehicle Type	Manufacturer
Rear-Load Garbage Trucks	Leach	Low-Boys	Challenger
	Heil		Rogers
Fire Trucks	Kaza		Etnyre
	Emergency One		Talbert
Mickey	Beverage trucks		Fontaine
Mini Buses	Girardin		Liddell
	Thor		Trail-Eze
School Buses	Thomas Built		Eager Beaver
Buses	Bluebird		Trail King
	Goshen		Cozad
	Glaval	Livestock Trailers	Barrett Trailers
	Nabo	Car Carriers	Take 3
	Neoplan		Easy Haul
	Chance		Trailer Tech
	Nova	Belly Dumps	Timpte
	Holland		Ranco
	New Flyer		Midland
Motorcoach	MCI		Trail King
	Prevost	Campers	Chalet Camper
		RV's	Featherlite

3.5 Data Analysis and Design Vehicle Dimension Selection

Three options were considered for selecting design vehicle dimensions from the data base:

- Worst Case Dimensions
- Statistical Analysis
- Analysis of Data Relative to Hang-Up Susceptibility on Selected Profiles

The advantages and disadvantages of each are discussed below.

The selection of worst-case dimensions was the method used by Gattis and Howard (1999) in establishing school bus design vehicles. The main advantage of this approach is that all vehicles of that type should be accommodated by a design based on that particular design vehicle. In that sense it is the most conservative approach available. One disadvantage is that this approach yields unreasonable results when outliers enter the data set. For example, the ground clearance for one low-boy trailer measured in a parking area was less than 1 inch. This is an unacceptable value for the design vehicle dimension because most designs can not be realistically expected to accommodate a vehicle with a 1-inch ground clearance. Furthermore, most of the other ground clearances for this vehicle type were around 5 inches and up. Therefore, the worst case dimension is not acceptable for all vehicle types, particularly highly variable types like low-boy trailers or passenger cars towing trailers. However, in this research, the worst case dimensions were used when applicable.

Several statistical measures could be used, including the mean, median, 85th percentile or 15th percentile. Using one of these measures is better than using worst case dimensions in situations where outliers are present. However, the usage of statistical measures dictates the need for a larger sample, which was not always possible. Statistical measures were used in one case, that being the wheebase for low-boy trailers.

The preferred approach to selecting vehicle dimensions when worst case dimensions were not appropriate was through testing of the candidate vehicle dimensions on sample profiles with the HANGUP software. Before describing how this software package was used in the research, it is appropriate to provide more detail about the package.

HANGUP Software

The HANGUP software program was developed to analyze vertical alignments with grade breaks to determine whether a specified vehicle would hang-up and to identify the hang-up points. The program simulates the movement of low-ground-clearance vehicles over humps or through sag curves, identifying for the user locations where hang-ups occurred. The program is a tool that can be used to evaluate existing alignments, to analyze alternative designs, and to assist in the geometric design of vertical hump and sag alignments. The information is presented (Eck and Kang, 1991) through a plot of the vertical alignment, with arrows indicating areas where potential hang-ups will occur, and a chart utilizing "0's" (no hang-ups occurring) and "1's" (hang-ups occurring) for varying ground clearances and vehicle dimensions. (Eck and Kang, 1991)

To perform an analysis of a specific vehicle on a particular profile, two general inputs are required:

- Vertical Profile Information - The geometry information is supplied by the user for a specific alignment either from the field or from a design. The locations of breakpoints and lengths and severity of grades are input so that a profile of the alignment can be established.

- Vehicle Information - Wheelbase or overhang and ground clearance information are needed.

Note that the program can also analyze a specific vertical profile using all combinations of ground clearance and wheelbase / overhang within a certain range. This yields results that show which combinations of ground clearance and wheelbase / overhang will cause hang-ups on a particular alignment.

<u>Application of HANGUP to this Research</u>

Four profiles were entered into the HANGUP program for use in this research. The profiles are contained in tabular form in Appendix B; a description of each is as follows:

- <u>AREMA Manual for Railway Engineering</u> (AREMA, 1993) - The AREMA standards specify the following:

  "The surface of the highway shall be in the same plane as the top of rails for a distance of 2 feet outside of the rails for either multiple or single-track crossings. The top of rail plane shall be connected with the grade line of the highway each way by vertical curves of such length as is required to provide riding conditions and sight distances normally applied to the highway under consideration. It is desirable that the surface of the highway be not more than 3 inches higher nor 6 inches lower than the top of the nearest rail at a point 30 feet from the rail, measured at a right angle thereto, unless track superelevation dictates otherwise."

The high-profile (hump) version was used in this research. Note that the updated editions of AASHTO and AREMA now indicate a 3-inch drop instead of 6 inches at 30 feet. The 6-inch drop was used in this research, as it is more conservative.

- ITE Guidelines for Driveway Location & Design (ITE, 1987) - "Low Volume Driveway on Major or Collector Streets" - This guideline specifies a maximum grade break of 6%. The high-profile (hump) variety of this crossing was used in this research. It consisted of a +3% grade intersecting with a -3% grade with no connecting vertical curve.
- A typical double track railroad crossing developed from actual survey data was used. This profile had a + 4 to 5% approach grade, a track bed approximately 25 feet in width, and a departure grade of approximately -6%.
- A severe sag curve having a 15% (-2% to +13%) grade break was used to test rear overhangs. This is equivalent to ITE's (1987) "Low Volume Driveway on a Local Street." There was no vertical curve connecting these grades. This profile was representative of a typical rural driveway in rough terrain such as West Virginia. The -2% grade corresponds to the cross slope of the roadway, and the +13% is the grade of the driveway.

Each profile was analyzed using the HANGUP software option where all combinations of wheelbase / overhang and ground clearance were analyzed. The boundary between the problem combinations and the other combinations for each profile were then drawn on a common graph. The database for each vehicle type was then plotted on this graph, a sample of which is presented in Figure 3.1. The plots revealed the vehicles that would hang-up on particular profiles. By analyzing these graphs in conjunction with engineering judgement, the design vehicle dimensions were selected. A complete set of these plots are provided in the Appendix C. The results are provided and discussed in Chapter 4.

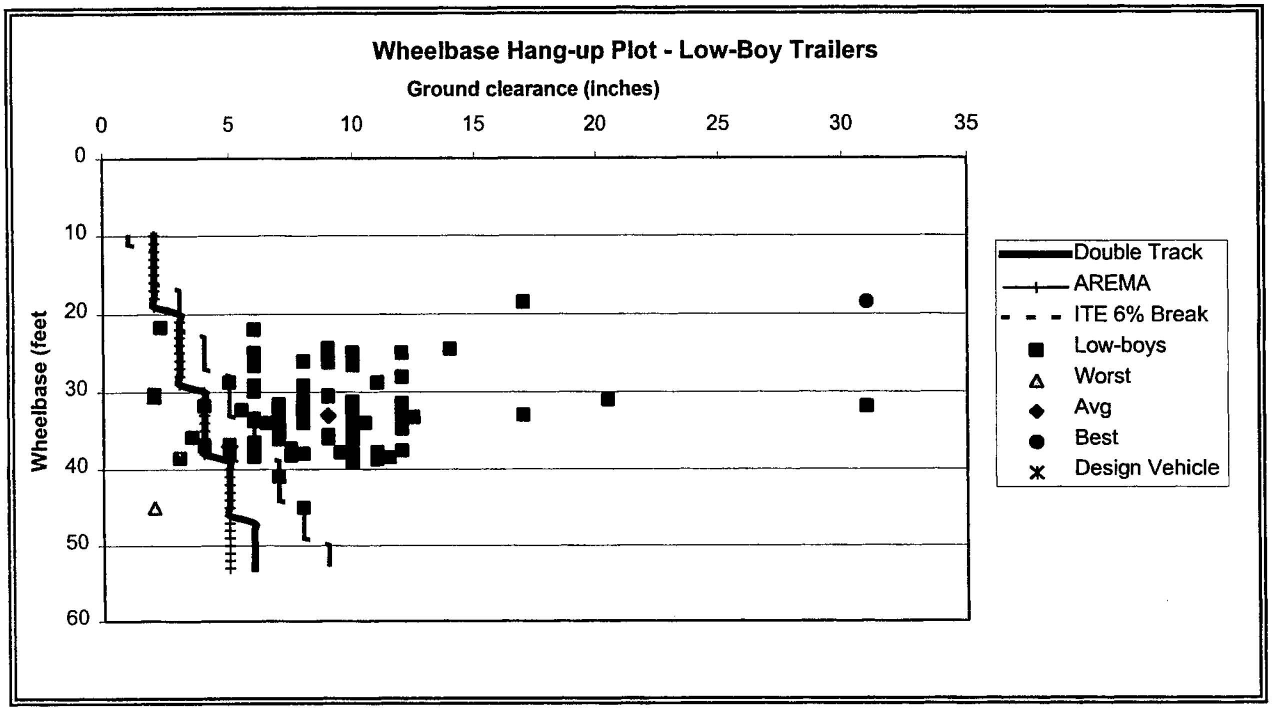

Figure 3-1 - Example Data Plot

Note that for the following vehicle types, the worst case (or near worst case) dimensions were used:

- Rear-Load Garbage Truck
- Pumper Fire Truck
- Single Unit Beverage Truck
- Mini-Bus
- School Bus
- Articulated Transit Bus

- Articulated Beverage Truck
- Belly Dump Trailer

Dimensions that were less severe than the worst case scenario were used for the following vehicle types:

- Aerial Fire Truck
- Motorcoach
- Low-Boy Trailer
- Double Drop Trailer
- Car Carrier
- Passenger Vehicle and Trailer - Private
- Passenger Vehicle and Trailer - Commercial
- Recreational Vehicle
- Single Unit Transit Bus

In most instances, a single outlier or two was discarded before selecting worst-case dimensions from the remaining data points. Three design vehicle dimensions were determined with greater effort.

For the Motorcoach, the rear overhang dimensions were selected by eliminating the worst case dimensions for both overhang and ground clearance, and rounding the next longest overhang from 10.5 feet to 10 feet, and accepting the next lowest ground clearance of 8 inches.

For the Low-Boy Trailer, the wheelbase was selected using the 85th percentile dimension, which was 38 feet.

Finally, the worst case dimensions for the rear overhang of the Passenger Vehicle and Trailer - Commercial design vehicle were eliminated. This corresponded to a vehicle that was carrying a utility pole that extended well beyond the rear of the trailer. The two worst case vehicles of the remaining data set were vehicles towing a race car transporter and a car carrier, both of which were common trailer types. The 7-inch ground clearance from the race car transporter was used in conjunction with the 13-foot rear overhang of the car carrier to set the design vehicle dimensions.

CHAPTER 4 - RESULTS

4.0 Introduction

In this chapter, the results of the methodology described in the preceding chapter are presented. Results focus on three main areas: sample sizes, design vehicle dimensions, and results of the HANGUP software runs for the design vehicles. Each is discussed in a separate section.

4.1 Sample Sizes

A sampling unit was considered to be a single vehicle, regardless of whether only a single dimension was available or if all dimensions were available. The data could be field measured or from the manufacturer. Vehicles that were field measured usually had a full set of all desired measurements. Manufacturer data may or may not have had all of the desired dimensions, as ground clearance was an attribute that was frequently not provided.

In general, if it was anticipated that the dimensions of a particular vehicle type were not highly variable, then a large sample size was not necessary because worst case dimensions would be selected. On the other hand, if a particular vehicle type was highly variable, such as low-boy trailers, then a larger sample size was desired. Although no statistical testing was performed relative to sample size, the researchers were pleased with the sample size gathered for each vehicle type. The sample sizes are provided in Table 4-1.

Table 4-1 - Sample Sizes

Design Vehicle	Sample Size
Rear Load Garbage Truck	44
Aerial Fire Truck	9
Pumper Fire Truck	14
Single Unit Beverage Truck	11
Mini-Bus	6
School Bus	30
Single Unit Transit Bus	47
Motorcoach	18
Articulated Transit Bus	7
Articulated Beverage Truck	9
Low-Boy Trailers <53 feet	93
Double Drop Trailer	28
Car Carrier Trailer	29
Belly Dump Trailer	20
Passenger Vehicles and Trailers - Private Use	59
Passenger Vehicles and Trailers - Commercial Use	45
Recreational Vehicles (RV)	42

4.2 Design Vehicle Dimensions

Design vehicle dimensions are provided in Table 4.2. Drawings of each are provided in Figures 4.1 to 4.17 at the end of this chapter. Where numbers are omitted in Table 4.2, this is an indication that hang-up problems are not expected on this part of the vehicle.

Table 4-2 - Design Vehicle Dimensions

Design Vehicle	Wheelbase (ft)	Front Overhang (ft)	Rear Overhang (ft)	Ground Clearance (in)		
				Wheelbase	Front Overhang	Rear Overhang
Rear-Load Garbage Truck	20	---	10.5	12	---	14
Aerial Fire Truck	20	7	12	9	11	10
Pumper Fire Truck	22	8	10	7	8	10
Single Unit Beverage Truck	24	---	10	6	---	8
Mini-Bus	15	---	16	10	---	8
School Bus	23	---	13	7	---	11
Single Unit Transit Bus	25	18	---	8	6	---
Motorcoach	27	7.6	10	7	10	8
Art. Transit Bus	---	---	10	---	---	9
Articulated Beverage Truck	30	---	---	10	---	---
Low-Boy Trailers <53 feet	38	---	---	5	---	---
Double Drop Trailer	40	---	---	6	---	---
Car Carrier Trailer	40	---	14	4	---	6
Belly Dump Trailer	40	---	---	11	---	---
Passenger Vehicles and Trailers - Private Use	20*	---	13	5	---	5
Passenger Vehicles and Trailers - Commercial Use	24*	---	13	7	---	7
Recreational Vehicles (RV)	27	7.8	16	7	6	8

* distance from rear wheels to hitch

--- hang-up problems not expected on this part of the vehicle

A few comparisons can be made to the AASHTO Green Book design vehicles. A complete list of the longest wheelbase and longest overhang (front or rear) for each AASHTO design vehicle was presented in Table 2-1. Key parameters for comparison with the hang-up design vehicles are summarized in Table 4-3 and discussed below.

Table 4-3 Key Comparisons of AASHTO Design Vehicles with Hang-Up Design Vehicles

AASHTO Design Vehicle	Compared Parameter	AASHTO Dimension (ft)	Hang-Up Design Vehicle	Dimension (ft)
Single Unit	Wheelbase	20	Mini-Bus	15
			Rear Load Garbage Truck	20
			Aerial Fire Truck	20
			Pumper Fire Truck	22
			Single Unit Beverage Truck	24
City Transit Bus	Wheelbase	25	Single Unit Transit Bus	25
	Front Overhang	---		18
	Rear Overhang	8		---
Intercity Bus	Wheelbase	26.5	Motorcoach	27
	Rear Overhang	8.5		10
Motor Home	Wheelbase	20	Recreational Vehicle	27
	Rear Overhang	6		16
36-ft School Bus	Rear Overhang	12	School Bus	13
40-ft School Bus		13		
Passenger Car and Camper Trailer	Rear Overhang	10.9	Passenger Vehicle and Trailer - Commercial	13
			Passenger Vehicle and Trailer - Private	13
	Wheelbase	17.7	Passenger Vehicle and Trailer - Commercial	27
			Passenger Vehicle and Trailer - Private	20

The AASHTO Single Unit design vehicle has a wheelbase of 20 feet and a rear overhang of 6 feet. The Mini-Bus, at 15 feet, is the only comparable vehicle in this study with a shorter wheelbase. The Garbage Truck and Aerial Fire Truck both have wheelbases of 20 feet, and the Pumper Fire Truck and Single Unit Beverage have wheelbases longer than 20 feet. All five of these vehicles have rear overhangs well in excess of 6 feet, ranging from 10 feet to 16 feet.

This demonstrates the value to design vehicles for the hang-up problem. For example, consider a highway engineer designing an access drive (with sharp grade breaks) to a convenience store served by single unit trucks. Using existing AASHTO design vehicles, the designer could conclude that single-unit trucks have wheelbases up to 20 feet and therefore design for that vehicle. However, the results of this work have shown that single unit beverage trucks can have wheelbases up to 20 percent longer than the current AASHTO design vehicles. This could be significant if the design provided only a small margin of safety, relative to hangups, for the 20-foot wheelbase vehicle.

At 25 feet, the Single Unit Transit Bus from this research has exactly the same wheelbase as the AASHTO (2001) City Transit Bus. However, whereas AASHTO's rear overhang was longer than the front, this research found the opposite, proposing an 18-foot overhang for the front. The rear overhang from AASHTO's Articulated Bus was the same as that found in this research, i.e., 10 feet. The Motorcoach is comparable to the 45-foot Intercity Bus from AASHTO, but the Motorcoach has a 0.5-foot longer wheelbase and 1.5-foot longer rear overhang.

AASHTO's Motor Home is much smaller than the Recreational Vehicle from this research. At 27 feet, the Recreational Vehicle as a 7-foot longer wheelbase, and its 16-foot rear overhang is 10 feet longer than the Motor Home.. The RV design vehicle established in this research is closer in size to a Motorcoach. In fact, it appears to use a motorcoach chassis. As such, the data suggest that there are two general classes of RVs. In the adoption process, consideration should be given to establishing a second, smaller RV design vehicle to represent more typical versions of this vehicle, which are also susceptible to hang-ups.

Likewise, the School Bus from this research has longer dimensions than both of AASHTO's school buses. The rear overhang matches AASHTO's longer 40-foot School Bus, while the wheelbase is 1.7 feet longer than either of AASHTO's school buses.

With respect to the passenger cars and trailers, AASHTO again uses smaller wheelbases and overhangs. Their longest wheelbases and overhangs for the AASHTO vehicles occur with the camper trailer as the towed vehicle. The distance to the hitch is 17.7 feet and the rear overhang is 10.9 feet. The design vehicles from this research use a distance to hitch of 27 feet and 20 feet and a rear overhang of 13 feet for both.

Relative to trailers, the longest wheelbase is 40 feet, belonging to the Belly Dump, Car Carrier, and Double Drop Trailers. These are closely followed by the Low-Boy Trailer at 38 feet, and finally the Articulated Beverage Truck at 30 feet. The longest wheelbase in AASHTO belongs to the WB-65 semitrailer at 39.4 feet. The shortest is the 23-foot trailer used in double and triple trailer configurations.

4.3 HANGUP Software Runs

Finally, to shed light on both the performance of the design vehicles and typical hang-up prone alignments, the results of the HANGUP analyses run using the design vehicles on the four test profiles are provided in Table 4-4. As can be seen, the car carrier hangs-up on all of the alignments, and the double drop trailer and low-boy trailer hang up on the "ITE Guidelines for Low Volume Driveway on a Major or Collector Street" humped driveway connection.

Table 4-4 - Results of HANGUP Analyses - Design Vehicles on Test Profiles

Design Vehicle	Hang-up on...(Y/N)			
	ITE Driveway (6% grade break)	AREMA Rail Crossing	2 Track Crossing	ITE Sag Driveway (15% grade break)
Rear-Load Garbage Truck	N	N	N	**Y**
Aerial Fire Truck	N	N	N	**Y**
Pumper Fire Truck	N	N	N	**Y**
Single Unit Beverage Truck	N	N	N	**Y**
Mini-Bus	N	N	**Y**	**Y**
School Bus	N	N	N	**Y**
Single Unit Transit Bus	N	N	N	N
Motorcoach	N	N	N	**Y**
Articulated Transit Bus	N	N	N	**Y**
Articulated Beverage Truck	N	N	N	N
Low-Boy Trailers <53 feet	**Y**	N	N	**Y**
Double Drop Trailer	**Y**	N	N	N
Car Carrier Trailer	**Y**	**Y**	**Y**	**Y**
Belly Dump Trailer	N	N	N	N
Passenger Cars and Trailers - Private Use	N	N	**Y**	**Y**
Passenger Cars and Trailers - Commercial Use	N	N	**Y**	**Y**
Recreational Vehicles (RV)	N	N	**Y**	**Y**

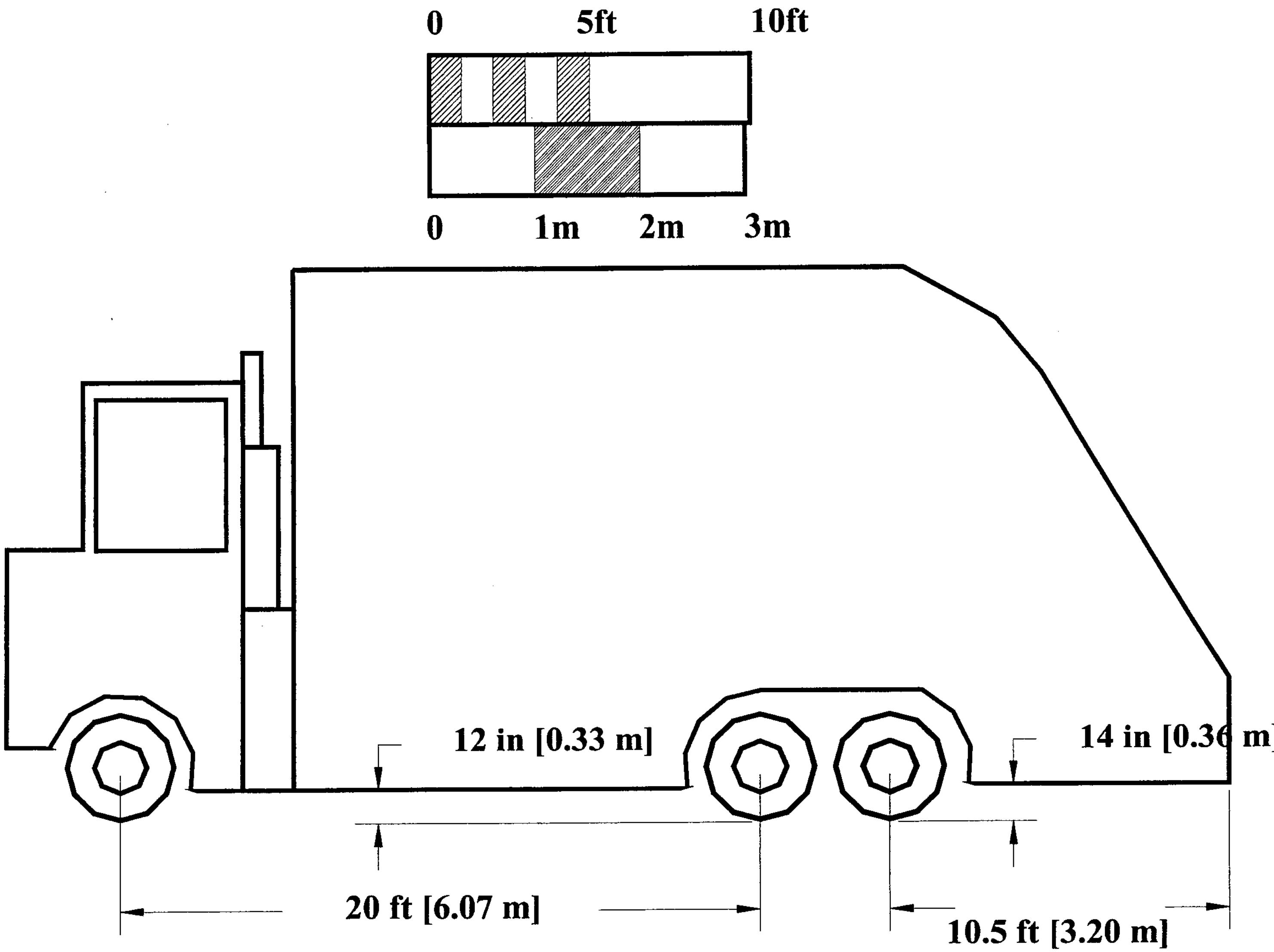

Figure 4.1 – Rear Load Garbage Truck

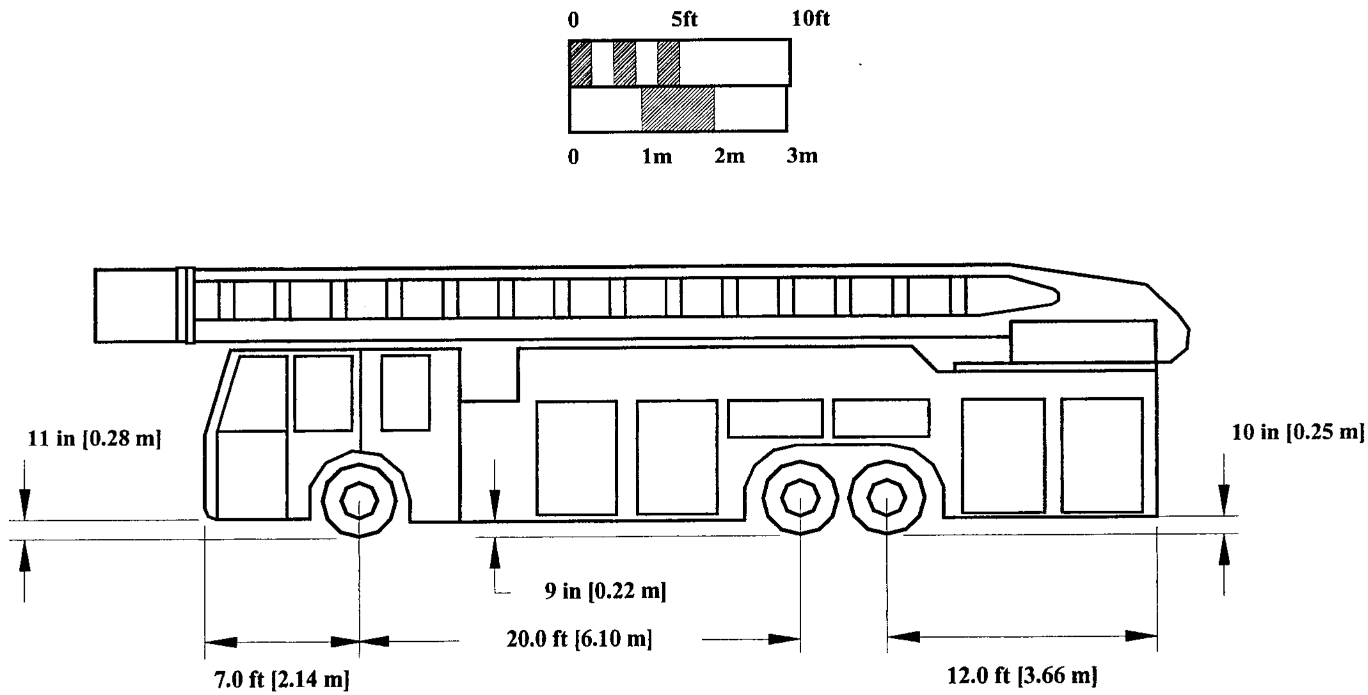

Figure 4.2 – Aerial Fire Truck

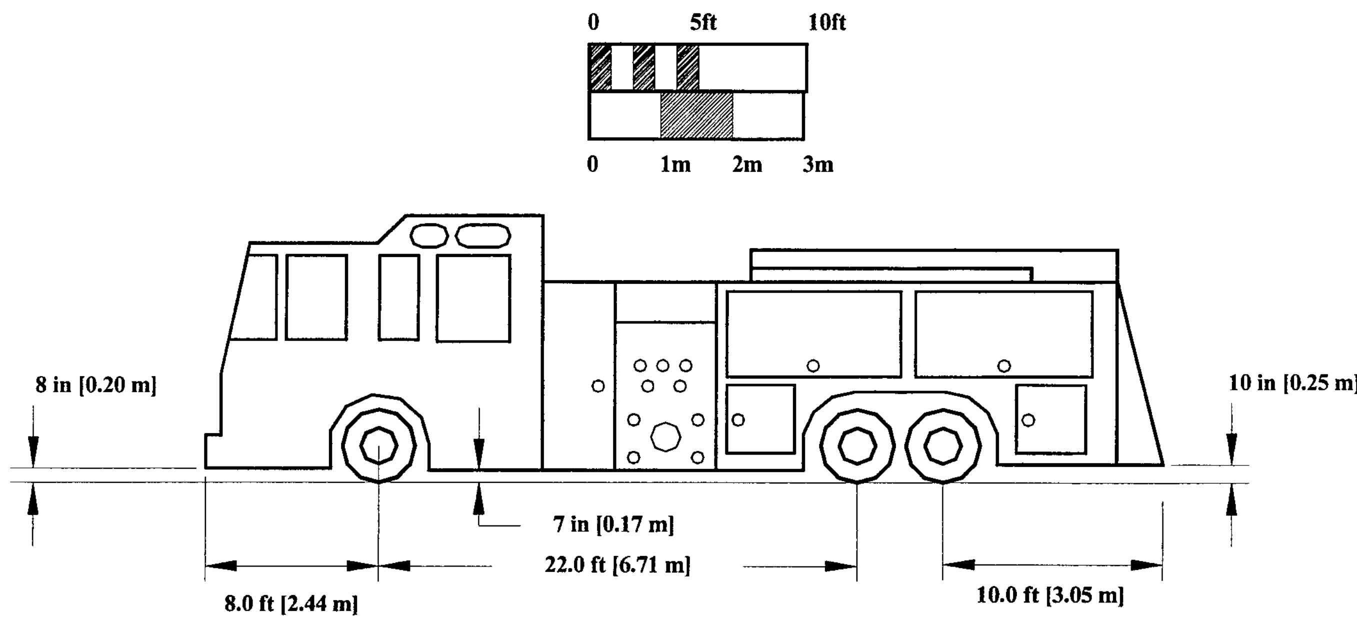

Figure 4.3 – Pumper Fire Truck

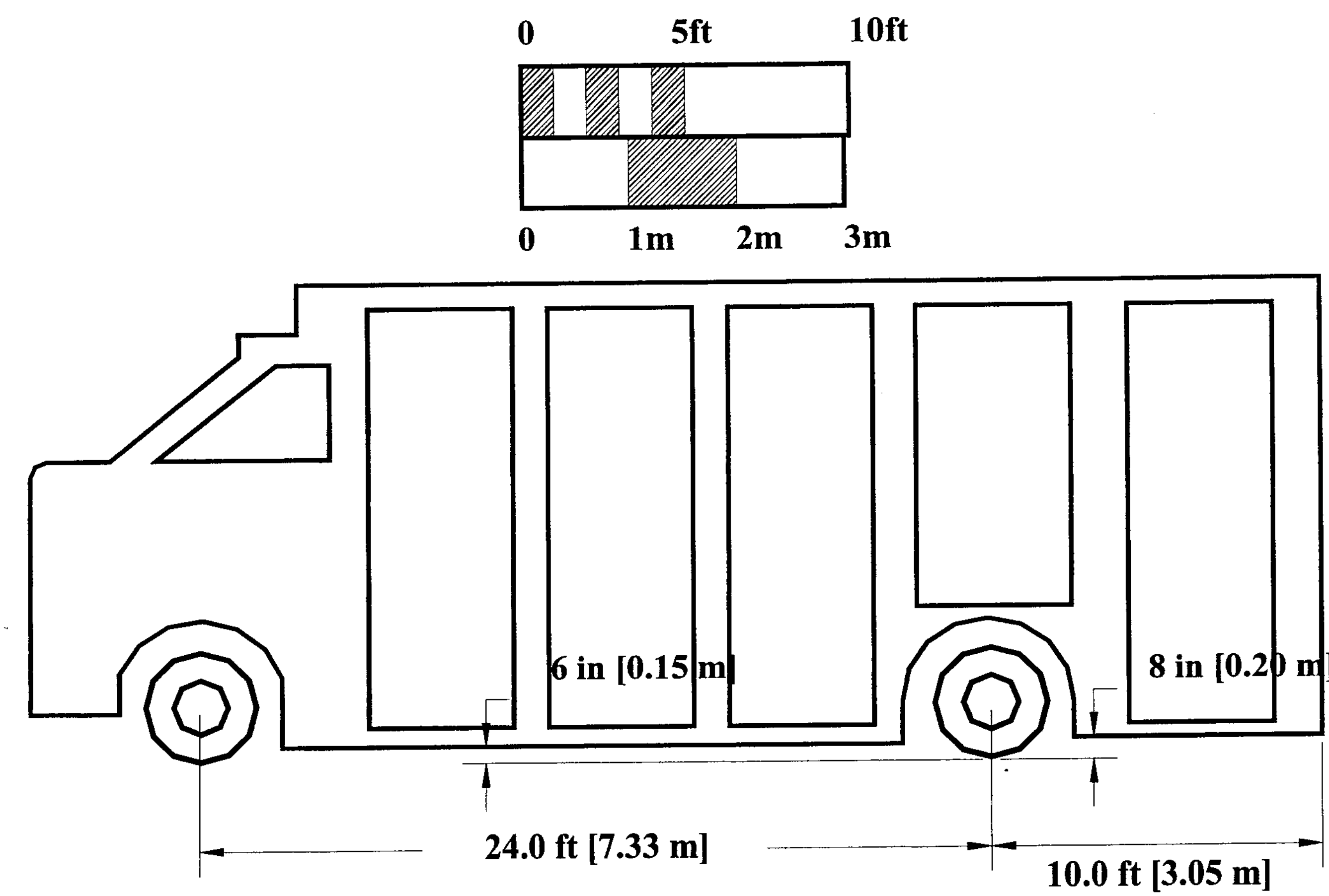

Figure 4.4 – Single Unit Beverage Truck

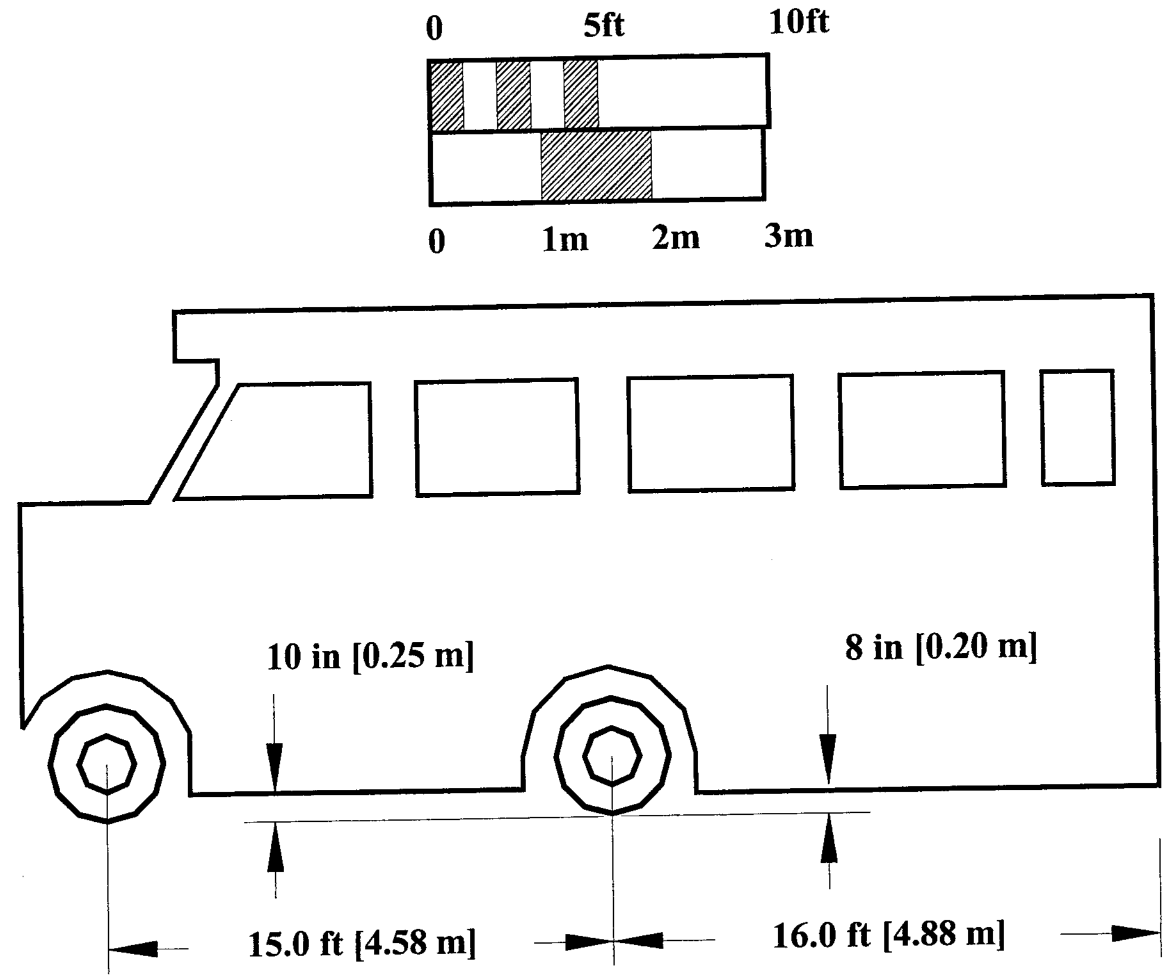

Figure 4.5 – Mini Bus

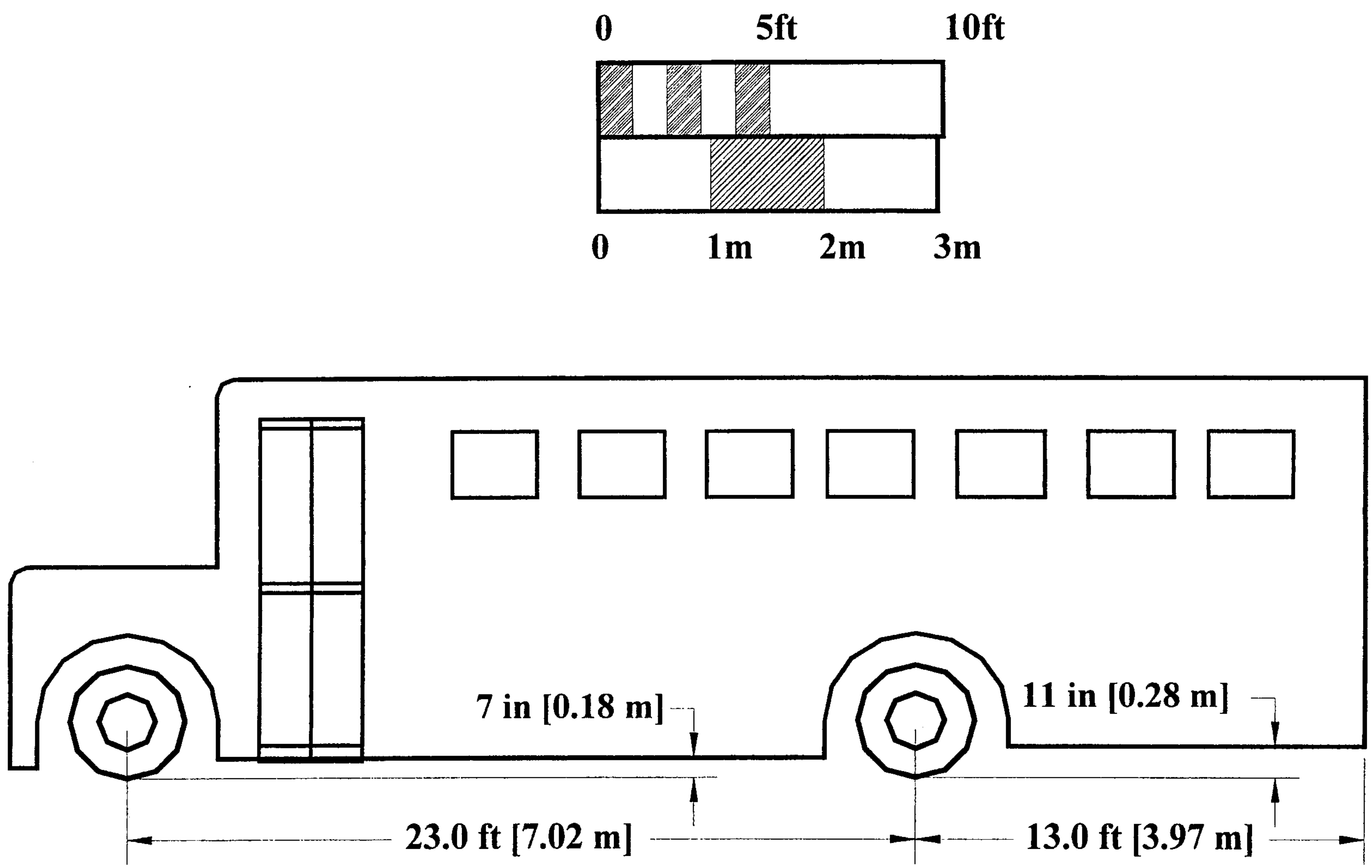

Figure 4.6 – School Bus

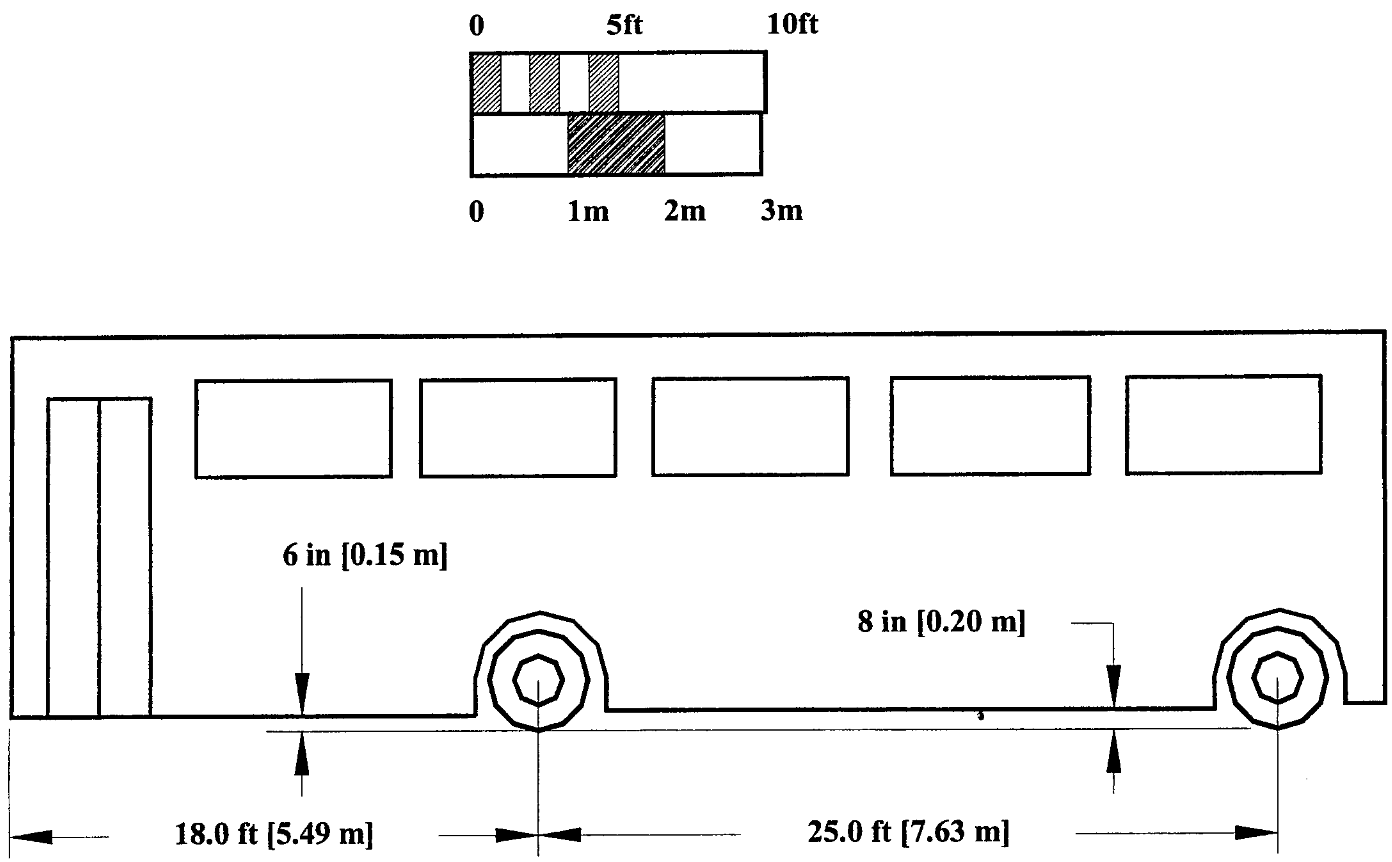

Figure 4.7– Single Unit Transit Bus

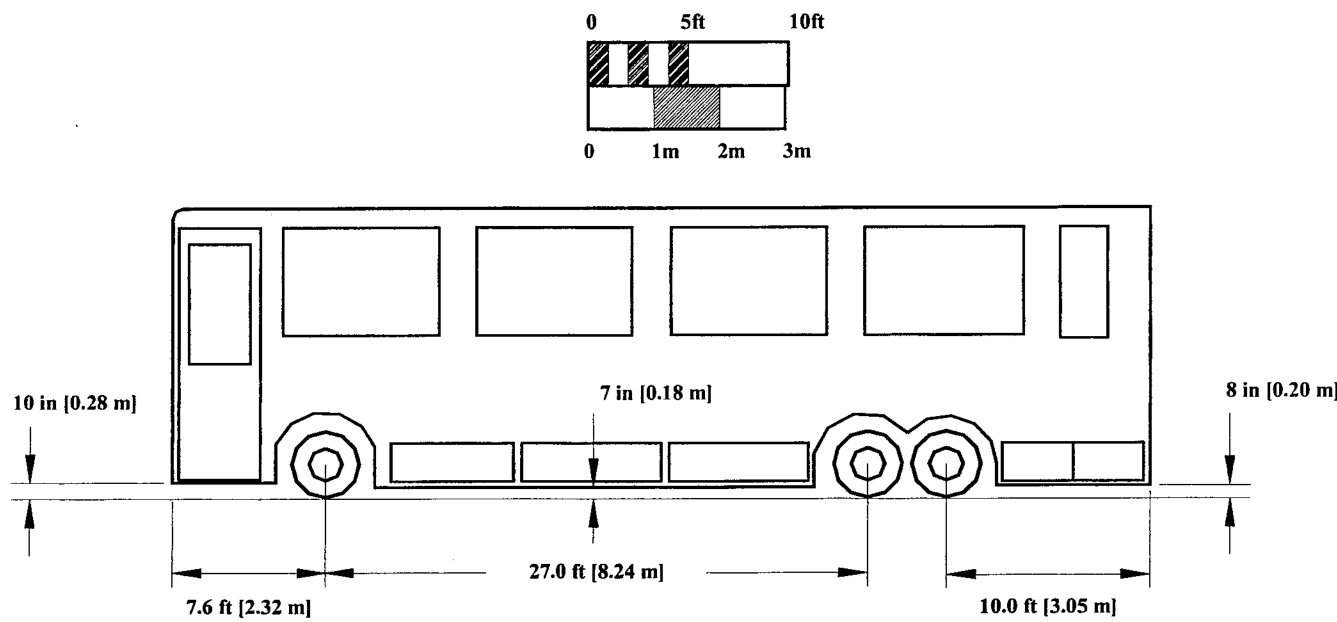

Figure 4.8 – Motorcoach

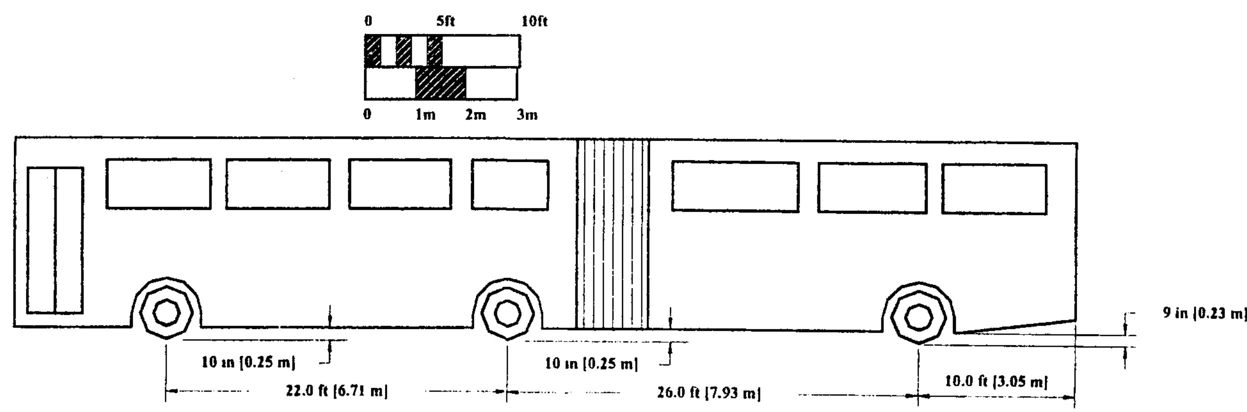

Figure 4.9 – Articulated Transit Bus

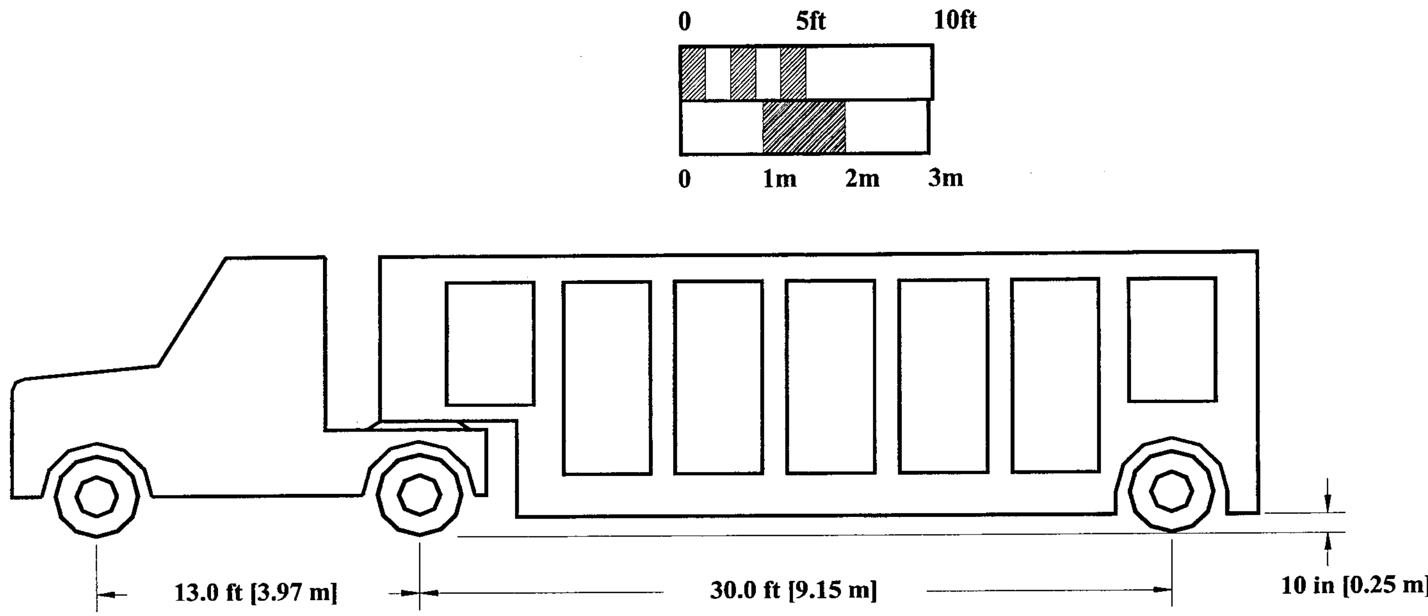

Figure 4.10 – Articulated Beverage Truck

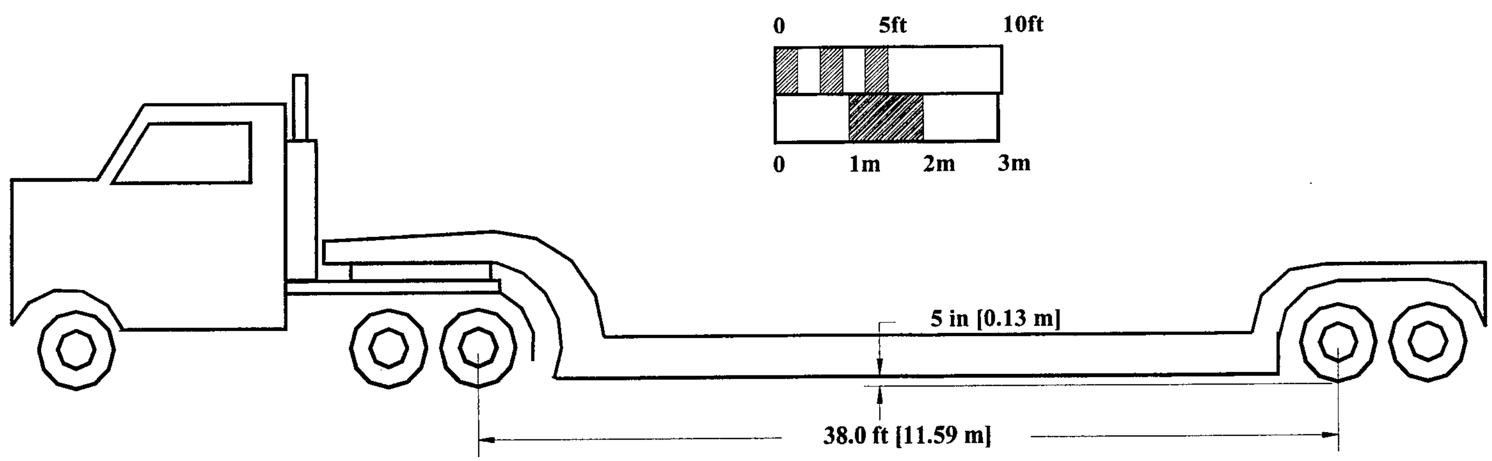

Figure 4.11– Low-boy Trailers < 53 ft

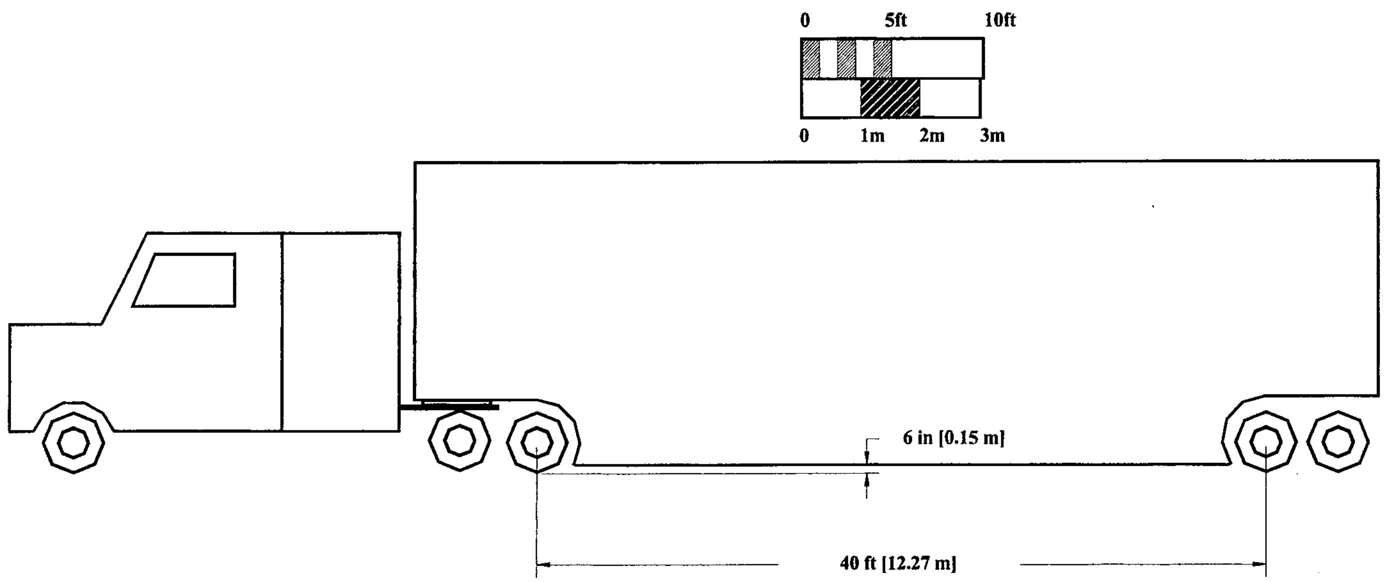

Figure 4.12 – Double Drop Trailer

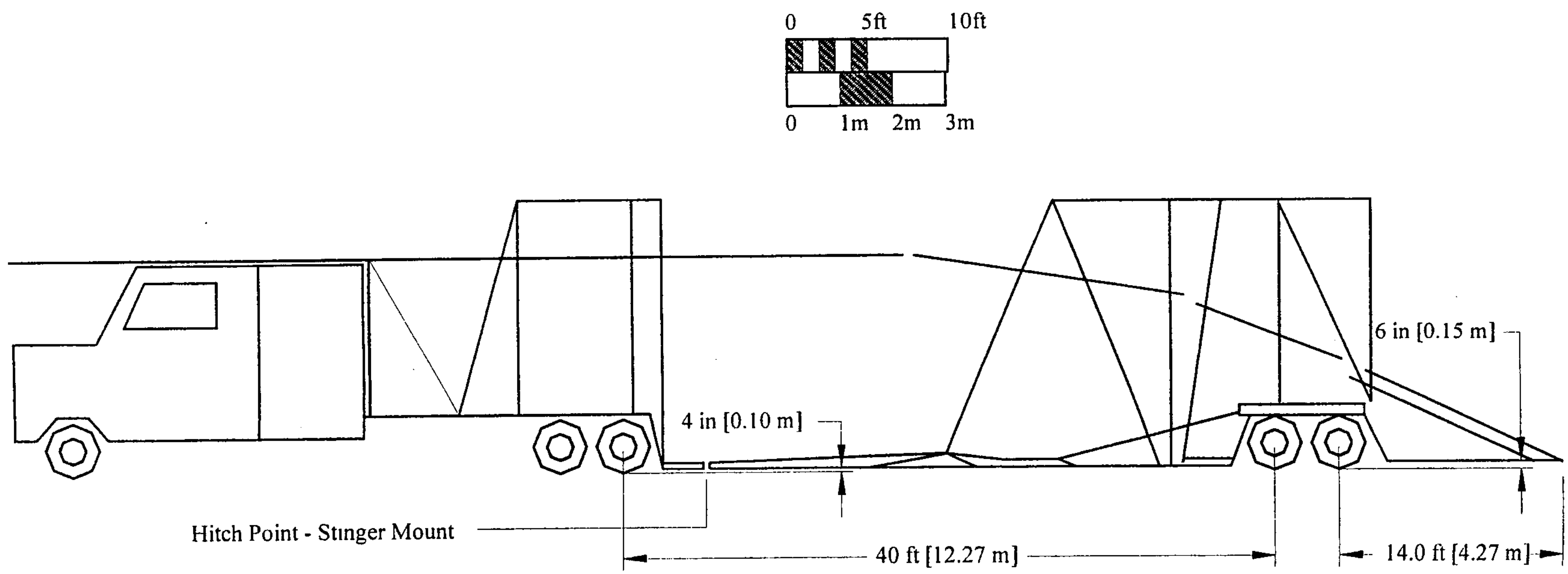

Figure 4.13 – Car Carrier

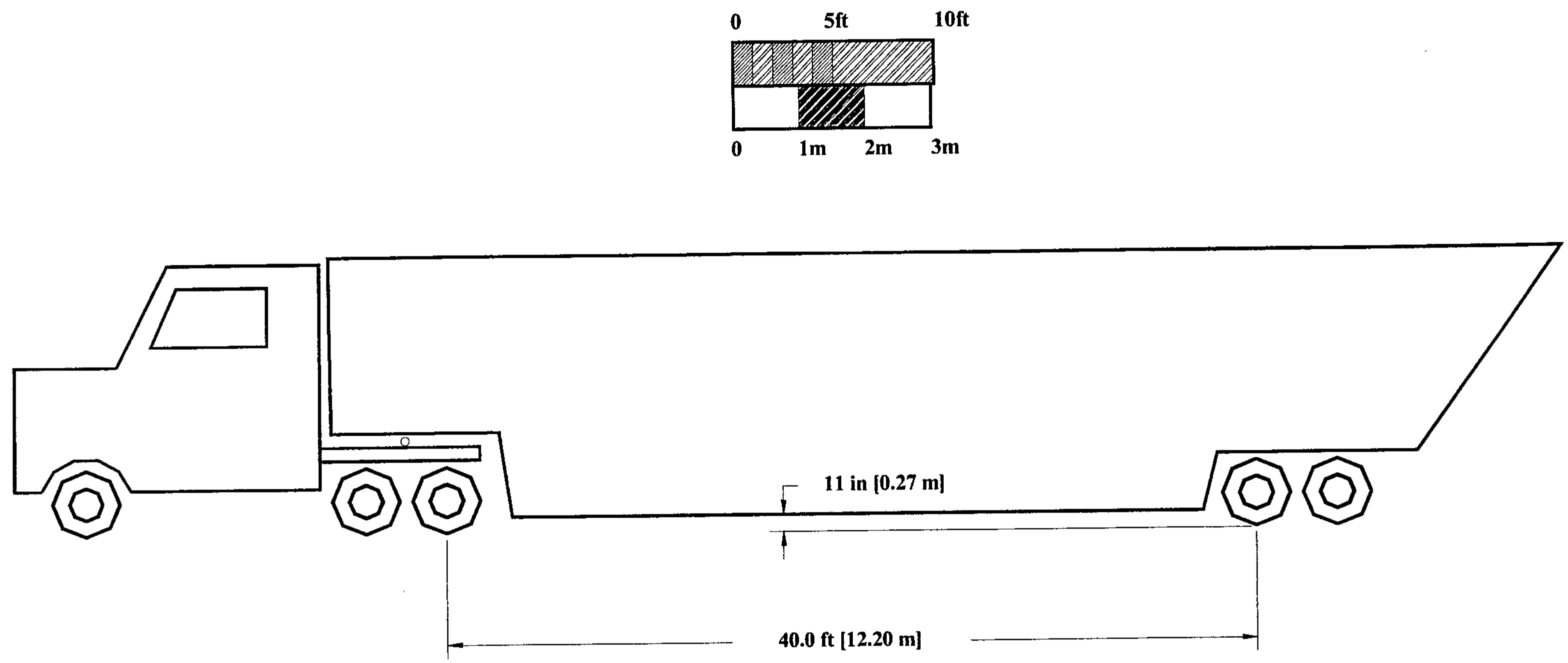

Figure 4.14 – Belly Dump Trailer

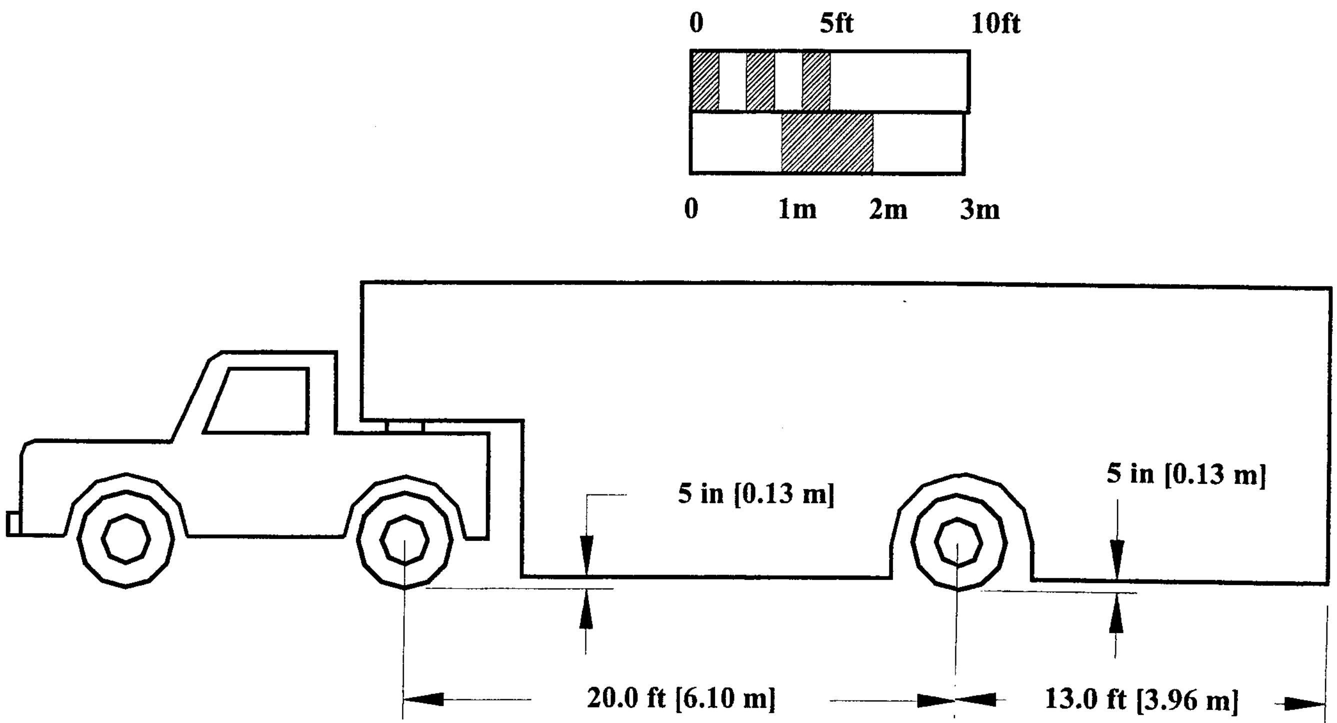

Figure 4.15 – Passenger Vehicles and Trailers – Private Use

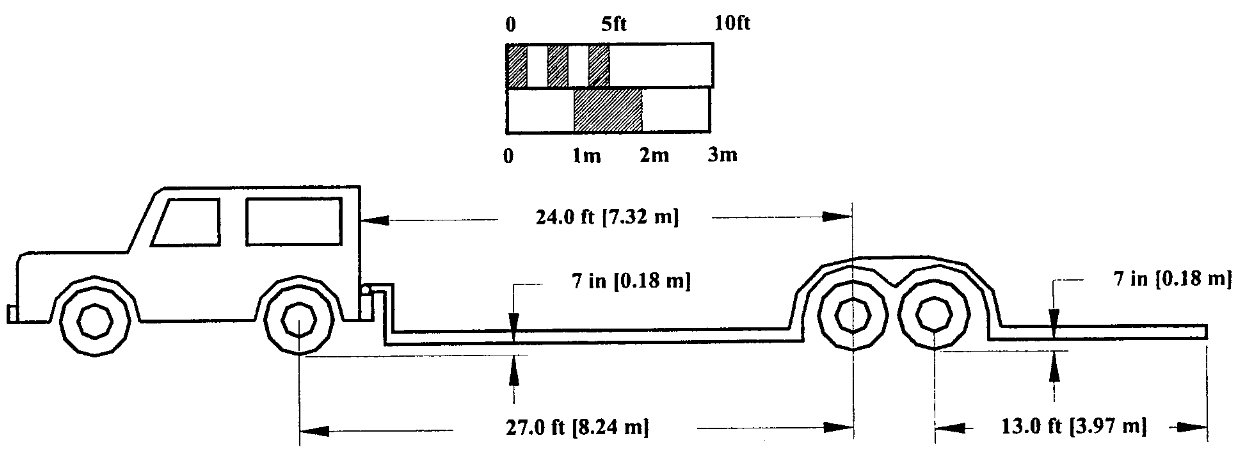

Figure 4.16 – Passenger Cars and Trailers – Commercial use

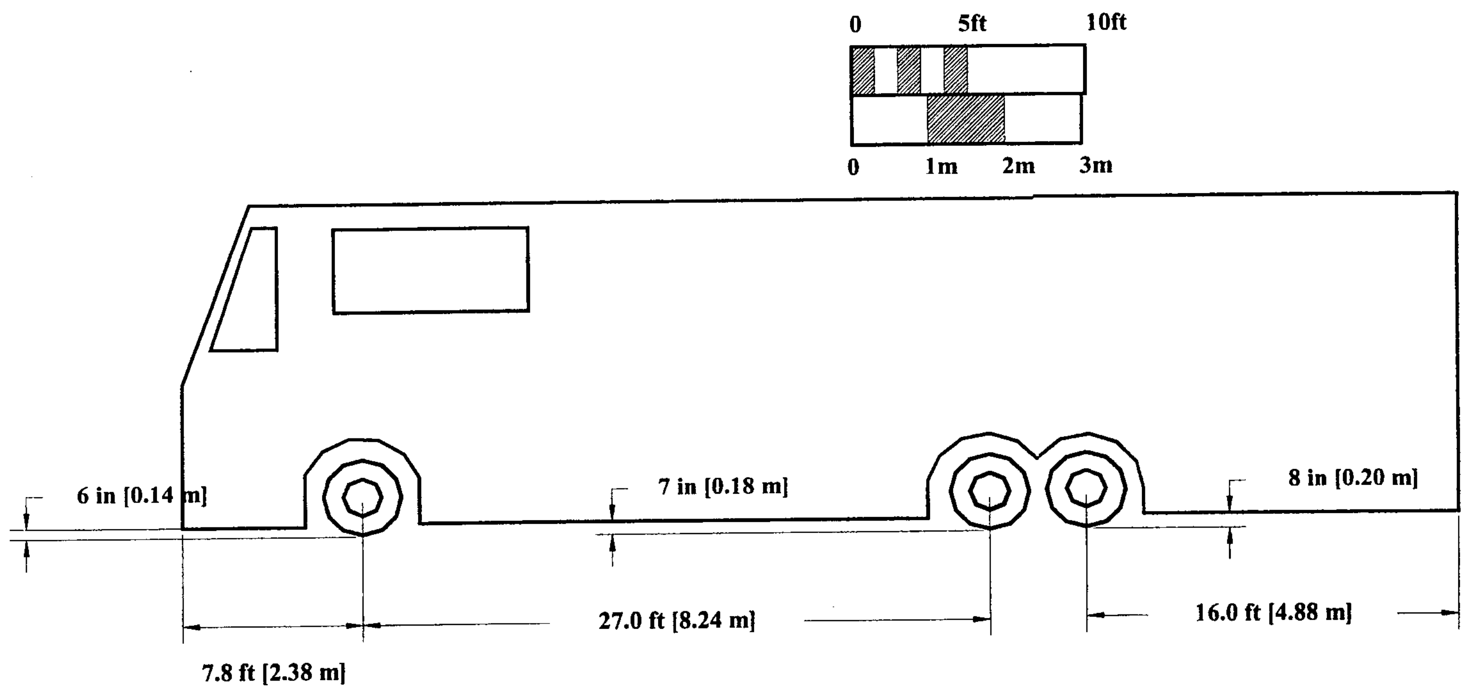

Figure 4.17 – Recreational Vehicles

CHAPTER 5 - CONCLUSIONS, RECOMMENDATIONS AND IMPLEMENTATION

Conclusions

The overall goal of this project was to develop design vehicles for use in evaluating the operation of low-ground-clearance, long wheelbase / overhang vehicles on extreme hump or sag profile alignments. The literature review indicated that while formal studies had been conducted to develop design vehicles, these vehicles did not include the information needed to assess hang-up susceptibility on a particular vertical alignment.

No formal studies had ever been undertaken to develop design vehicles for the hang-up problem. From the literature review, it was concluded that there was a common methodology used in developing design vehicles. The steps in this process are:

1. Establish the design vehicles to be developed by anticipating the needs of the users of the end product and observing the variability of the relevant vehicles in prevailing traffic.
2. Determine the dimensions/characteristics to be defined
3. Collect data in the field and from vehicle manufacturers
4. Use the database to define dimensions / characteristics either through the selection of worst case dimensions or some other better-than-worst-case measure

In this study, design vehicle dimensions for 17 hang-up prone vehicle types were developed. Results are presented in a format similar to that used to present design vehicle characteristics in the AASHTO design policy, i.e., both tabular and graphical form. These vehicles can be used in conjunction with the HANGUP software or other tools in designing vertical alignments that reduce the likelihood of hang-up problems. Since they are based on representative samples of both field-collected and manufacturers' data and have been evaluated using the HANGUP software, the researchers conclude that the design vehicles are reasonable and have a rational basis. The proposed vehicles should receive broad review with an eye toward inclusion in appropriate design policies and guidelines.

However, there are some limitations that should be noted in applying these design vehicles. The car carrier, double drop, and low-boy trailers hang up on the crest version of the ITE Guideline for a Low Volume Driveway on a Major or Collector Street (6% grade break). The car carrier trailer also hangs-up on the AREMA standard rail-highway grade crossing (6-inch drop over a distance of 30 feet).

A design vehicle for extremely long / large loads was not included. Such vehicles require a permit and, in general, are highly susceptible to hang-ups. However, because these rigs are often "customized" to carry a specialized cargo, their dimensions are highly variable and usually represent the outliers discussed earlier in this report. In general, it is not feasible to design vertical alignments to accommodate these extreme cases. The problem becomes more one of analysis than design, i.e., knowing the actual dimensions of the vehicle in question, a user finds a suitable route for the vehicle to travel.

While an attempt was made to make this study national in scope, the field data were collected in West Virginia and Pennsylvania. The researchers recognize that there may be a limited number of specialized vehicle types found in specific regions of the United States that have not been included here. For example, the single-unit truck pulling a trailer with a dual-tandem wheel arrangement at the center of the vehicle, was not included in the database since it is relatively rare in the area where this study was conducted.

The design vehicles presented should be considered as proposed vehicles since they have not yet received broad-scale review by a recognized highway engineering organization. As such, they have not received any formal endorsement or approval. Therefore, the user assumes any and all risks associated with their use.

Recommendations

It is recommended that the proposed design vehicles be considered by AASHTO, FHWA and related organizations for review, validation, adoption and incorporation into appropriate design policies and guidelines. At the same time, the proposed vehicles should be widely disseminated to Federal Highway Administration offices, state highway agencies, LTAP centers, and geometric design-related technical committees of the Transportation Research Board and the Institute of Transportation Engineers.

As noted above, while the vehicle sample sizes obtained in this study are considered adequate, there may be specialized vehicles found in particular geographic regions that were not included in this study. Thus, as part of the above-noted review process, it is recommended that hang-up prone vehicles that may not have been included in the database for this effort be identified and that the relevant dimensions be determined using the methodology applied here.

As part of the adoption process, it is recommended that the impacts of these design vehicles on existing guidelines and policies be assessed. Relevant guidelines and policies have been identified in this report, namely AASHTO, AREMA and various driveway design guidelines or regulations (at the national, state and local levels). Revision of these policies / guidelines may be necessary based on the design vehicles proposed herein.

Implementation

The results of this research, i.e., the design vehicles and their dimensions, are immediately implementable. Although at this time they cannot yet be considered to be part of a formal guideline or policy, the design vehicles and their dimensions certainly should be of immediate assistance to designers concerned about the hang-up problem at grade crossings, bridge approaches, driveway entrances and other locations with extreme vertical geometry.

To maximize the payoff from this research, and as part of the implementation process, the proposed design vehicles should be disseminated widely to AASHTO, FHWA, AREMA, and technical committees of TRB and ITE for further review and ultimately adoption into design policies.

One of the long-term recommendations of the USDOT Grade Crossing Safety Task Force (1996) was to investigate the feasibility of developing a nationwide classification system that would assign compatibility codes of crossings and vehicles for the purpose of helping low-clearance vehicle operators avoid getting hung-up on high-profile grade crossings. Examples of areas of focus for a working group to address this topic were presented; they included:

> "Vehicle characteristics such as: wheelbase, actual ground clearance at points between adjacent axles, and front and rear overhangs and heights above the ground. Based on these, appropriate vehicle classification codes may be determined."

In the researchers' opinions, this study has obtained the data called for by the USDOT Task Force recommendation. Thus, in implementing the results of this research, it seems appropriate to re-visit the idea of developing a compatibility code classification system.

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APPENDIX A
Vehicle Dimension Database

REAR LOAD GARBAGE TRUCKS

No.	Overhang (in) Rear	[see notes below] Wheel Base (in) f to r1	r1 - r2	r2 - r3	Ground Clearance (in) Between Tires	Rear Overhang	Make/ Model/ Year	Hopper Manufacturer and Size	Picture?	Anything Unusual? [Small Tires, Flat Tires Overloaded]	Source (I, P, or F)	(Internet, Phone, Field) Other	
1	80	159	52		19.5	20.5	Mack	Heil 25	No	small load	F (3/12/01)	WV B67 548	315 8R 225 tires
2	96	179	54		14	15	Ford 8000	Heil 20	No	small load	F (3/12/01)	WV B67 515	315 8R 225 tires
3	84	160	49			13.5		Heil 25	No	empty	F (3/12/01)	WV B67 514	315 8R 225 tires
4	96	194	55		11	14.25	Ford L8000	McNeilus 25	No		F (3/12/01)	WV B67 516	315 8R 225 tires
5	94	202	55		14	16.75	Int 4900 DT466E	McNeilus 25	No		F (3/12/01)	WV B67 574	315 8R 225 tires
6	99	197	54		14.75	16.25	Ford L9000	Goliath 25	No	empty	F (3/12/01)	WV B90 205	315 8R 225 tires
7	85	207	53		12.5	18	Ford L9000	Heil 25	No	wheel turned	F (3/12/01)	WV B67 519	315 8R 225 tires
8	86	201	52		14	17	Ford L8000	McNeilus 25	No	small load	F (3/12/01)	WV B79 452	315 8R 225 tires
9	106	244	56		14	14	Mack	EZ Pack 31		empty	F (3/22/01)	WV B59 188	315 80R 225 7 years old
10	89	122	51		18	15.75	ack (Low Cab	EZ Pack 20		loaded	F (3/22/01)	WV B92 169	14 80R 20PR & 11R225 (standard tire) Appolo
11	105	185	55		14	16	White GMC	Leach 20	Y load cushions	empty	F (3/22/01)	WV B59 996	315 80R 225
12	101	196	54		13	17.5	Volvo	Leach 25		empty	F (3/22/01)	WV B83 778	315 80R 225
13	97	184	54		15	16.5	Volvo	Leach 25		empty	F (3/22/01)	WV B60 201	315 80R 225
14	101	193	---		14.5	16.5	Volvo	Leach 18		few bags	F (3/22/01)	WV B92 163	12R 225
15	89	212	54		17	17	Western Star	Dempster	No	empty	F (5/8/01)	I-81 N Marion	
16	61	183	54	53	17	21	Mack	Leach 31	No	empty	F (5/10/01)	I79 N Pitt	
17	70	184	54	53	18	26	Mack	Leach 31	No	empty	F(5/10/01)	I-79 N Pitt	
18	88	207	53		18	25	Mack	McNeilus 32	No	empty	F(5/10/01)	I-79 N Pitt	
19	69	145	53		16	16	Mack	Leach 25	No	empty	F(5/10/01)	I-79 N Pitt	
20	113	185	51		23	20	Mack	Leach 31	No	empty, back wheel up	F(5/10/01)	I-79 N Pitt	
21	114	182	54		18	18	Mack	Leach 31	No	empty	F(5/10/01)	I-79 N Pitt	
22	60	185	53	53	19	20	Mack	Leach 31	No	empty	F(5/10/01)	I-79 N Pitt	
23	99	196	54		22	14	Mack	Leach 31	No	empty	F(5/10/01)	I-79 N Pitt	
24	100	215	68		13	22	Mack	25	No	no truck bed tags	F(5/15/01)	Suburban Sta.-rebuilt frames	
25	117	159	60		13	14	Mack	25	No	no truck bed tags	F(5/15/01)	Suburban Sta. - rebuilt frames	
26	107	216	65		16	20	Mack	25	No	no truck bed tags	F(5/15/01)	Suburban Sta. - rebuilt frames	
27	103	165	66		13	17	Mack	25	No	no truck bed tags	F(5/15/01)	Suburban Sta. - rebuilt frames	
28	106	136	55		13	21		Leach 25	No	empty	F(5/21/01)	City Garage @ Pittsburgh	
29	103	148	54		18	18		Crane Carrier 6	No	recycle truck	F(5/21/01)	City Garage @ Pittsburgh	
30	99	147	54		17	20		Crane Carrier 6	No	recycle truck	F(5/21/01)	City Garage @ Pittsburgh	
31	106	142	54		19	16.5		Loadmaster	No	out of business	F(5/21/01)	City Garage @ Pittsburgh	
32	106	142	56		18	14		Leach 25	No	front OH -84, GC -16	F(5/21/01)	City Garage @ Pittsburgh	
33	104	142	55		18	18		Leach	No	front OH -86, GC - 15	F(5/21/01)	City Garage @ Pittsburgh	
34	104	144	57		18	19		Leach 25	No	front OH - 203, GC - 15	F(5/21/01)	City Garage @ Pittsburgh	
35	105	139	58		16	19	Peterbuilt	Leach	No		F(5/21/01)	City Garage @ Pittsburgh	
36	93	112				16		Leach 16	load cushio	manufacturer	Fax (5/23/01)	Aplha hip	
37	93	125				16		Leach 18		manufacturer	Fax (5/23/01)	Aplha hip	
38	93	138				16		Leach 20		manufacturer	Fax (5/23/01)	Aplha hip	
39	82	186	?			16		Leach 25		manufacturer	Fax (5/23/01)	Aplha hip	
40	98	150	?			16		Leach 20		manufacturer	Fax (5/23/01)	2RII hip	
41	98	171	?			16		Leach 25		manufacturer	Fax (5/23/01)	2RII hip	
42	98	217	?			16		Leach 31		manufacturer	Fax (5/23/01)	2RII hip	
43	123	215			30	20		Heil 32	no	manufacturer	Fax (6/22/01)	CDE model	H -56", GC-24"
44	123	254			30	20		Heil 32	No	manufacturer	Fax (6/22/01)	Conventional	OH-46, GC-30

Based on the sample we have, the design vehicle dimensions would be as follows:

Overhang (in Rear	Wheel Base (in) f to r1	r1 - r2	r2 - r3	Between Tires	Rear Overhang	
123	254	68	53	11	13.5	worst case
96	176	55	53	17	18	average
60	112	49	53	30	26	best case

sample size = 44

AERIAL FIRE TRUCKS

No.	Overhang (in) Front	Overhang (in) Rear	Wheel Base (in) f to r1	Wheel Base (in) r1 to r2	Ground Clearance (in) Between Tires	Ground Clearance (in) Overhang Front	Ground Clearance (in) Overhang Rear	Make/ Model/ Year	Body Type (see below) and Manufacturer	Picture?	Anything Unusual? [Small Tires, Flat Tires Overloaded]	Source (I, P, or F)	(Internet, Phone, Field) Other
1	61	90	230	0	9		14		aerial	no		F (5/21/01)	Pittsburgh
2	51	126	198	54	16	11	19		aerial - Ferrara Fire Apparatus	no	HME 1871 Series	F (5/21/01)	Pittsburgh
3	82	120	171	57	12	14	16		aerial - Pierce	no		F (5/21/01)	Pittsburgh
4	80	84	166	56	12	19	9		aerial - American LaFrance	no	Heil Fire Pump	F (5/21/01)	Pittsburgh
5	72	103	226	0	10	19	12		aerial - Thibault	no		F (5/21/01)	Pittsburgh
6	77	124	204	54	12	12	13		aerial - 98 Pierce	no	custom chasis	F(5/22/01)	Morgantown Station 1
7	91.25	147	259	0	22			Kaza	Aerial	no		P(6/19/01)	manufacturer - Laurie Sperberg
8	70	146	226	0	17.5	21	10.5	American Lefrance	Aerial	no		F(7/6/01)	Bridgeport
9	82	155	245	0		20		Emergency One	aerial	no		Fax (7/10/01)	manufacturer

Based on the sample we have, the design vehicle dimensions would be as follows:

Overhang (in) Front	Overhang (in) Rear	Wheel Base (in) f to r1	Wheel Base (in) r1 to r2	Between Tires	Overhang Front	Overhang Rear	
91.25	155	259	57	9	11	9	worst case
74	122	214	25	14	17	13	average
70	122	213.89	55	14	17	13	average without zeros
51	84	166	0	23	21	19	best case

sample size= 9

PUMPER FIRE TRUCKS

No.	Overhang (in) Front	Overhang (in) Rear	[see notes below] Wheel Base (in) f to r1	Wheel Base (in) r1 to r2	Ground Clearance (in) Between Tires	Ground Clearance (in) Overhang Front	Ground Clearance (in) Overhang Rear	Make/ Model/ Year	Body Type (see below) and Manufacturer	Picture?	Anything Unusual? [Small Tires, Flat Tires Overloaded]	Source (I, P, or F)	(Internet, Phone, Field) Other
1	0	120	254	56	20		20	American Lefrance	worst case design	no		P-Chief engineer (Randy) 5/16/01	
2	87	81	184	0	13	14	11		pumper -3D Manufacturer	no		F (5/21/01)	Pittsburgh
3	0	101	200	0	14		13	Chevy 70 diesel	MAC - Kodiak	no		F (5/21/01)	Pittsburgh
4	72	87	157	0	10		16		pumper - Pierce	no		F (5/21/01)	Pittsburgh
5	82	78	180	0	7	8	10		pumper - American LaFrance	no		F (5/21/01)	Pittsburgh
6	88	86	171	0	11	18	14		pumper - Pierce	no		F (5/21/01)	Pittsburgh
7	0	87	235	0	11		10		pumper - Pierce	no	2 wheel drive	F(5/22/01)	Morgantown Station 1
8	87	86	229	0	10.5	17.5	17		pumper - Pierce	no		F(5/27/01)	Black Lick, PA
9	0	30	220	0	16			Emergency One	two worst case	no		P(6/19/01)	manufacturer
10	87	92	175	0	22			Kaza	Pumper	no		P(6/19/01)	manufacturer - Laurie Sperberg
11	95	84	191	0	12	9.5	23	Pierce	pumper	no		F(7/6/01)	Bridgeport
12	75	87	192	0	12	19	10.5	Pierce	pumper	no		F(7/6/01)	Bridgeport
13	56	98	258	54	19		18	Freightliner	pumper	no		F(7/10/01)	Blacksville
14	56	84	194	0	14	21	10	Ford 8000 Gruman	pumper	no		F(7/10/01)	Blacksville

Based on the sample we have, the design vehicle dimensions would be as follows:

Overhang (in) Front	Overhang (in) Rear	Wheel Base (in) f to r1	Wheel Base (in) r1 to r2	Between Tires	Overhang Front	Overhang Rear	
95	120	258	56	7	8	10	worst case
56	86	203	8	14	15	14	average
65	86	215	55	14	15	14	average without zeros
0	30	157	0	22	21	23	best case

sample size = 16

SINGLE UNIT BEVERAGE TRUCK

No.	Rear Overhang (in)	Wheel Base (in) f to r1	Wheel Base (in) r1 to r2	Ground Clearance (in) Between Tires	Ground Clearance (in) Rear Overhang	Drop Length (in)	Make/Model/ Year Body Manu.	No. of Bays	Picture?	Anything Unusual? [Small Tires, Flat Tires Overloaded]	Source (I, P, or F)	(Internet, Phone, Field Other
1	90	252		6	19		International	6	No		F(5/7/01)	
2	98	272		6	18		Mickey	5	No	Load Bear Series-Grizzly	F(5/10/01)	
3	84	254		11	15		International	6	No	fully loaded	F(5/10/01)	I-79N Pitt
4	82	196		14	12	99	International	4	No	hauling 60 45lb bottles	F(5/10/01)	I-79N Pitt
5	82	253		16	18	156	International	6	No	empty	F(5/10/01)	I-79N Pitt
6	90	276		10	10	180	Chevy Diesel	6	No		F(5/10/01)	I-79N Pitt
7	81	258		10	17	160	International	6	No		F(5/10/01)	Coke plant @ Houston
8	85	254		10	21	157	International	6	No		F(5/10/01)	Coke plant @ Houston
9	85	257		10	20	156	International	6	No		F(5/10/01)	Coke plant @ Houston
10		295		20			Mickey	7	No	Manufacturer - worst case	P (6/14/01)	
11	100	281		16	21		Hackney	5	No	Columbia Propane - 12klbs	F(7/10/01)	Star City

Based on the sample we have, the design vehicle dimensions would be as follows:

Rear Overhang (in)	Wheel Base (in) f to r1	Wheel Base (in) r1 to r2	Ground Clearance (in) Between Tires	Ground Clearance (in) Rear Overhang	Drop Length (in)	Max. # of bays per side	
100	295	0	6	10	180	7	worst case
88	259	0	12	17	151	6	average
81	196	0	20	21	99	4	best case

sample size = 12

MINI BUS

No.	Overhang (in) Front	Overhang (in) Rear	Wheel Base (in) f to r1	Ground Clearance (in) Between Tires	Ground Clearance (in) Overhang Front	Ground Clearance (in) Rear	Make/ Model/ Year	*Low Floor?*	City	Picture?	Anything Unusual? [Small Tires, Flat Tires Overloaded]	(Internet, Phone, Field) Source (I, P, or F)	Other
1	0	117	204	10		18	International 3400 T444E	No	Pittsburgh	No	Airport Shuttle (3rd kind)	F(5/21/01)	
2	0	60	176	8			Girardin	No	Manufacturer	No	Airport Shuttle (3rd kind)	P (6/19/01)	
3	30	70	187	12			Thor (El Dorado Nat.)	No	Manufacturer	No	Airport Shuttle (3rd kind)	P (6/19/01)	
4	0	85	158	11.5			Glaval	No	Manufacturer	Yes	Airport Shuttle (3rd kind)	P (6/21/01)	Universal Model
5	0	95	176	11.5			Glaval	No	Manufacturer		Airport Shuttle (3rd kind)	P (6/21/01)	Universal Model
6	0	85	186	11.5			Glaval	No	Manufacturer		Airport Shuttle (3rd kind)	P (6/21/01)	Universal Model

Based on the sample we have, the design vehicle dimensions would be as follows:

Overhang (in) Front	Overhang (in) Rear	Wheel Base (in) f to r1	Ground Clearance (in) Between Tires	Ground Clearance (in) Overhang Front	Ground Clearance (in) Rear	
30	117	204	8		18	worst case
5	85	181	10.75		18	average
30	85	181	10.75		18	average without zeros
0	60	158	12		18	best case

sample size = 6

SCHOOL BUS

No.	Overhang (in) Rear	Front	Wheel Base (in)	Ground Clearance (in) Between Tires	Rear Overhang	Make/ Model/ Year	Type C or D?	Picture?	Anything Unusual? [Small Tires, Flat Tires Overloaded]	Source (I, P, or F)	(Internet, Phone, Field) Other
1	156		276	12	25	International	C	No	Note: 1-15 parked in	F(5/7/01)	
2	120		250	14.5	22	International	C	No	dirt lot.	F(5/7/01)	
3	136		276	10	22	Ford	C	No		F(5/7/01)	
4	129		206	17 (front)	24	Carpenter	D	No	Flat Nose	F(5/7/01)	
5	129		205	16 (front)	24	Carpenter	D	No	Flat Nose	F(5/7/01)	
6	158		276	13	21	GMC	C	No		F(5/7/01)	
7	126		256	13	25	Ford	C	No		F(5/7/01)	
8	156		270	7	20	Thomas Built	C	No		F(5/7/01)	
9	120		253	12	20	Chevy	C	No		F(5/7/01)	
10	158		228	24	30	International	D	No	Flat Nose	F(5/7/01)	
11	158		275	8.5	22	GMC	C	No		F(5/7/01)	
12	157		276	12	20	Thomas Built	C	No		F(5/7/01)	
13	106		192	9	24	International	C	No	short	F(5/7/01)	
14	112		193	12	24	International	C	No	short	F(5/7/01)	
15	153		274	16	24	Ford-Ward	C	No		F(5/7/01)	
16	156		279	20	12	International	C	No		F(5/9/01)	Coopers Rock
17	118		239	14	14	Thomas Built	D	No	flat nose	F(5/10/01)	Motor Pool
18	121		271	11.5	15	Bluebird	D	No	flat nose	F(5/10/01)	Motor Pool
19	134		258	12	18	International	C	No		F(5/10/01)	I-79 N Pitt
20				18	22	Bluebird	C	No	10" at door	F(5/23/01)	UHS
21				19	26	International	C	No	10" at door	F(5/23/01)	UHS
22				19	26	International	C	No	9" at door	F(5/23/01)	UHS
23				16	21	Bluebird	C	No	10" at door	F(5/23/01)	UHS
24				18	24	Bluebird	C	No	12" at door	F(5/23/01)	UHS
25				20	25	International	C	No	12" at door	F(5/23/01)	UHS
26				18	23	Bluebird	C	No	9" at door	F(5/23/01)	UHS
27				18	23	Bluebird	C	No	12" at door	F(5/23/01)	UHS
28	155	40.4	275.6			Thomas Built		No		I (5/23/01)	Allan Haggai
29	136.5	40.4	275.6			Thomas Built		No		I (5/23/01)	Allan Haggai
30	131.5	40.4	252			Thomas Built		No		I (5/23/01)	Allan Haggai

Based on the sample we have, the design vehicle dimensions would be as follows:

Overhang (in) Rear	Front	Wheel Base (in)	Ground Clearance (in) Between Tires	Rear Overhang	
158	40.4	279	7	12	worst case
138	40	253	15	22	average
106	40.4	192	24	30	best case

sample size= 30

SINGLE UNIT TRANSIT BUS

No.	Overhang (in) Front	Overhang (in) Rear	Wheel Base (in) f to r1	Wheel Base (in) r1 to r2	Ground Clearance (in) Between Tires	Ground Clearance (in) Overhang Front	Ground Clearance (in) Overhang Rear	Make/ Model/ Year	*Low Floor?*	City	Picture?	Anything Unusual? [Small Tires, Flat Tires Overloaded]	Source (I, P, or F) (Internet, Phone, Field)	Other
1	0	84	156		11		12	Ford-E	No	Mo'town	No	(small bus)	F(5/7/01)	
2	0	84	158		11		12	Ford-E	No	Mo'town	No	(small bus)	F(5/7/01)	
3	214	100	180		4	9	12	Flxible	No	Mo'town	No		F(5/7/01)	
4	98	102	180		9	15	8	Flxible	No	Mo'town	No		F(5/7/01)	
5	0	100	189			16	12	Wheeled Coach	No	Mo'town	No		F(5/7/01)	
6	0	102	192		16		12	Wheeled Coach	No	Mo'town	No		F(5/7/01)	
7	53	112	178		10	17	12	Goshen Coach	No	Mo'town	No		F(5/7/01)	
8	52	72	180		8.5	12	12	Goshen Coach	No	Mo'town	No		F(5/7/01)	
9	54	99	210		6	10	14	Holland Bus	No	Mo'town	No		F(5/7/01)	
10	60	96	211		6	11	19	Holland Bus	No	Mo'town	No		F(5/7/01)	
11	88	114	285		10	11	11	Nova Classic	No	Pittsburgh	No	Classic model	F(5/21/01)	
12	100	118	276		11	10	10	99 Neoplan lowfloor	Yes	Pittsburgh	No		F(5/21/01)	
13	84	102	300		12	6	10	Flxible	No	Pittsburgh	No		F(5/21/01)	
14	90	116	282		9	7	7	91 Orion	No	Pittsburgh	No		F(5/21/01)	
15	90	120	270		8.5	8	6	87 Neoplan	No	Pittsburgh	No		F(5/21/01)	
16	84	126	270	52	11	13	9	01 Neoplan Metroliner	No	Pittsburgh	No		F(5/21/01)	
17	86	118	264		23	13	18	Nabi	No	Manufacturer	Yes	Model 416	I (5/22/01)	
18	86	118	276		24	13	18	Nabi	Yes	Manufacturer	Yes	Model 40LFLW	I (5/22/01)	
19	91	123	275		20	14	19	Nabi	No	Manufacturer	Yes	Model 40C-LFW Compobus	I (5/22/01)	
20	26	101	245		21	15	16	Nabi	No	Manufacturer	Yes	Model 30-LFN	I (5/22/01)	
21	93.5	103.5	231.5	52	20	13	18	Neoplan	No	Manufacturer	Yes	AN340/3 40'	I (5/22/01)	
22	93.5	118	274.5	54	24	13	20	Neoplan	No	Manufacturer	Yes	AN340/3 45'	I (5/22/01)	
23	95.5	102	231.5	52.5	18	16	17	Neoplan	No	Manufacturer	Yes	AN 116/3 40'	I (5/22/01)	
24	95.5	116	274.5	54	21	16	20	Neoplan	No	Manufacturer	Yes	AN 116/3 45'	I (5/22/01)	
25	93.25	120.75	205.75		18	13	19	Neoplan	No	Manufacturer	Yes	AN435	I (5/22/01)	
26	93.25	120.75	266		23	13	19	Neoplan	No	Manufacturer	Yes	AN440	I (5/22/01)	
27	93	113	214		18	13	17	Neoplan	Yes	Manufacturer	Yes	AN435LF	I (5/22/01)	
28	93	113	274		24	13	17	Neoplan	Yes	Manufacturer	Yes	AN440LF	I (5/22/01)	
29	93	113	274		24	13	17	Neoplan	Yes	Manufacturer	No	AN440TLF	I (5/22/01)	
30	93	113	334		29	13	17	Neoplan	Yes	Manufacturer	No	AN445TLF	I (5/22/01)	
31	60	107	168					Holland Bus	No	Manufacturer	Yes	Classic American Series 26'	Fax (5/16/01)	
32	60	112	208					Holland Bus	No	Manufacturer	Yes	Classic American Series 31'	Fax (5/16/01)	
33	95	128	267					Holland Bus	No	Manufacturer	Yes	Classic American Series 40'	Fax (5/16/01)	
34	104	126	190		29	18	22	Holland Bus	No	Manufacturer	Yes	Rear engine trolley	Fax (5/16/01)	
35	101	124	268					Nova RTS Express	No	Manufacturer	No		I (6/14/01)	
36	91	90	298.7		26	12	15	Nova RTS	No	Manufacturer	No		I (6/14/01)	
37	112.3	123.5	244		20	17	19	Nova LFS	Yes	Manufacturer	No		I (6/14/01)	
38	51	118	176		15	10	20	Chance Coach, Inc	No	Manufacturer	Yes	american heritage streetcar	I(6/15/01)	
39	90	106	163.5		12	13	19	Chance Coach, Inc	Yes	Manufacturer	Yes	Opus low floor bus	I(6/15/01)	
40	81.5	118.5	151		22	11	16	Bluebird	No	Manufacturer	Yes	29' Q-bus	I (6/15/01)	
41	81.5	118.5	221		19	12	15	Bluebird	No	Manufacturer	Yes	35' Q-bus	I (6/15/01)	
42	51	118	176		21	10	20	Chance Coach, Inc	No	Manufacturer	No	american heritage streetcar	P (6/19/01)	
43	90	106	163		14	13	16	Chance Coach, Inc	No	Manufacturer	No	opus	P (6/19/01)	
44	42.75	107.25	178					Goshen Coach	No	Manufacturer	No		P (6/19/01)	
45	0	128	208		11.5			Glaval	No	Manufacturer	Yes	Apollo - longest	P (6/21/01)	
46	0	128	218		11.5			Glaval	No	Manufacturer			P (6/21/01)	
.47	0	128	234		11.5			Glaval	No	Manufacturer			P (6/21/01)	

Based on the sample we have, the design vehicle dimensions would be as follows:

Overhang (in) Front	Overhang (in) Rear	Wheel Base (in) f to r1	Wheel Base (in) r1 to r2	Ground Clearance (in) Between Tires	Ground Clearance (in) Overhang Front	Ground Clearance (in) Overhang Rear	
214	128	334	54	4	6	6	worst case
72	111	227	53	16	13	15	average
85	111	227	53	16	13	15	average without zeros
0	72	151	52	4	6	6	best case

sample size = 47

MOTORCOACH

No.	Overhang (in) Front	Overhang (in) Rear	Wheel Base (in) f to r1	Wheel Base (in) r1 to r2	Ground Clearance (in) Between Tires	Ground Clearance (in) Overhang Front	Ground Clearance (in) Overhang Rear	Make/ Model/ Year	Carrier	Picture?	Anything Unusual? [Small Tires, Flat Tires Overloaded]	Source (I, P, or F)	Other (Internet, Phone, Field)
1	-	54/81	280	49	13.5	-	15	MCI		No	no passengers	F(4/30/01)	
2	65	92	260		8	15	8	MCI		No	no passengers	F (5/10/01)	
3	71	77	283	46	10	15	11	MCI		No	no passengers	F(5/10/01)	
4	82	84	288	60	12	13	8	Prevost		No	no passengers	F(5/14/01)	
5	82	84	288	60	12	13		Prevost		No	no passengers	F(5/14/01)	
6	78.25	150.25	315					MCI E4500		No	Manufacturer	I (6/12/01)	
7	78.25	150.25	315					MCI J4500		No	Manufacturer	I (6/12/01)	
8	75.9	131.5	318					MCI D4000		No	Manufacturer	I (6/12/01)	
9	75.9	153.1	318					MCI D4500		No	Manufacturer	I (6/12/01)	
10	92.2	118.9	214					MCI F3500		No	Manufacturer	I (6/12/01)	
11	84.1	83.5	315					MCI G4500		No	Manufacturer	I (6/12/01)	
12	70.7	107	317		11			Prevost		No	Manufacturer	P (6/19/01)	XLII-45 model
13	69.25	103.5	316		11			Prevost		No	Manufacturer	P (6/19/01)	H3-45 model
14	71.5	103.5	268		11			Prevost	Jerry	No	Manufacturer	Fax(6/20/01)	H3-41 model
15	70.75	82.5	279		11			Prevost	Jerry	No	Manufacturer	Fax(6/20/01)	XLII-40 model
16	80	126	282	60	10	10	9	Van Hool		No	all airbags deflated	F(6/27/01)	
17	70	107	315	48	7	12	10	Prevost		No	hell bus - private coac	F(7/2/01)	
18	73	100	312	48	11	11	11.5	Prevost		No	hell bus - private coac	F(7/2/01)	H3-45 model

Based on the sample we have, the design vehicle dimensions would be as follows:

Overhang (in) Front	Overhang (in) Rear	Wheel Base (in) f to r1	Wheel Base (in) r1 to r2	Ground Clearance (in) Between Tires	Ground Clearance (in) Overhang Front	Ground Clearance (in) Overhang Rear	
92.2	153.1	318	60	7	10	8	worst case
76	109	294	53	11	13	10	average
65	77	214	46	13.5	15	15	best case

sample size= 18

ARTICULATED TRANSIT BUS

No.	Overhang (in) Front	Overhang (in) Rear	Wheel Base (in) f to r1	Wheel Base (in) r2 to r3	Ground Clearance (in) Between Tires	Ground Clearance (in) Overhang Front	Ground Clearance (in) Overhang Rear	Make/ Model/ Year	*Low Floor?*	City	Picture?	Anything Unusual? [Small Tires, Flat Tires Overloaded]	Source (I, P, or F)	(Internet, Phone, Field) Other
1	99	117	264	236	10	9	9	92 IKARUS	No	Pittsburgh	No	aka Naby	F(5/21/01)	to hinge - 159", GC - 12"
2	96	120	207	300	14	9	9	99 Neoplan	No	Pittsburgh	No		F(5/21/01)	to hinge - 220", GC - 11"
3	100	116	264	232	20	15	19	Nabi	No	Manufacturer	Yes	Model 436	I (5/22/01)	
4	93.25	120.75	209.19	297 19	18	13	19	Neoplan	No	Manufacturer	Yes	AN 460	I (5/22/01)	
5	47.5	49	170	212				Chance Coach Inc	No	Manufacturer	Yes	AMTV	I (6/15/01)	ROH1=93.5, FOH2=50
6	0	0	228.2	306.4	21	9D	9d	New Flyer	yes	Manufacturer	Yes	D 60 LF	I (6/25/01)	need info
7	0	0	208	309				New Flyer	No	Manufacturer	Yes	D 60 HF	I (6/25/01)	need info

Based on the sample we have, the design vehicle dimensions would be as follows:

Overhang (in) Front	Overhang (in) Rear	Wheel Base (in) f to r1	Wheel Base (in) r2 to r3	Ground Clearance (in) Between Tires	Ground Clearance (in) Overhang Front	Ground Clearance (in) Overhang Rear	
100	120.75	264	309	10	9	9	worst case
62	75	221	270	17	12	14	average
87	105	221	270	16	12	14	average without zeros
0	0	170	212	21	15	19	best case

sample size= 7

ARTICULATED BEVERAGE TRUCK

No.	Wheel Base (in) f to r1	r1 to r2	r2 to r3	r3 to r4	Ground Clearanc Between Tires (in)	Length of Drops (in)	Make/ Model Year Body Manu.	No. of Bays	Tractor Type/ characteristics	Picture?	Anything Unusual? [Small Tires, Flat Tires Overloaded]	Source (I, P, or F)	(Internet, Phone, Field) Other
1	144	292	32		12		Mickey	7	Freightliner	No		F(5/7/01)	
2	149	342			10	271	Mickey load bear 2000	8	International	No		F(5/10/01)	I-79 N Pitt
3		372			13	291	Mickey load bear 2000	9	Sterling	No	1/3 load	F(5/10/01)	I-79 N Pitt
4		326			12.5	290	Mickey load bear 2000	9	Mack	No	3/4 load	F(5/10/01)	I-79 N Pitt
5		327	46		11	246	Mickey load bear 2000	10	Mack	No	full load	F(5/10/01)	I-79 N Pitt
6	156	327			11.5	245	Mickey load bear 2000	8	Mack	No		F(5/10/01)	Coke plant @ Houston
7		340			14	343	Mickey load bear 2000	8	International	No		F(5/10/01)	Coke plant @ Houston
8		358			14		Mickey	13		No	worst case	P (6/14/01)	manufacturer
9		310			14	231	Mickey	8	International	No •	3/4 Full	F (7/9/01)	I-64

Based on the sample we have, the design vehicle dimensions would be as follows:

Wheel Base (in) f to r1	r1 to r2	r2 to r3	r3 to r4	Ground Clearanc Between Tires (in)	Length of Drops (in)	Max. # of bays per side	
156	372	46	0	10	343	13	worst case
150	333	39	0	12	274	8	average
144	292	32	0	14	231	7	best case

sample size= 9

LOWBOY TRAILERS

Trailer less than or equal to 53 feet in length

	Rear Overhang (in)	Wheel Base (in) r1t to r2t	r2t to r1	r1 to r2	r2 to r3	r3 to r4	r4 to r5	Overall Trailer Length	Length of Drop (in)	Ground Clearance (in) Under trailer	Rear Overhang	Make/ Model/ Year	Hauling	Tractor Type	Picture?	Location (if field measured)	Anything Unusual? [Small Tires, Flat Tires Overloaded]	Source (I, P, or F)	(Internet, Phone, Field) Other
1	0		412					412			4.5	Fontaine	casting	Western Star	No	I-79 S		F(4/30/01)	See sketch
2	56		222	34	32			524		17	13	Equipment trailer	empty	Ford 900 (dump)	No	Sabraton Fast Lube		F(5/7/01)	
3	67	52	399	52				570		12.5	22	Fontaine	4 trusses	Freigthliner	No	I-81N		F(5/8/01)	
4	0	54	372	123				549		8	15	Trail King	JLG lift	Kenworth	No	I-81N		F(5/8/01)	
5	0		360	39	159			558			1	Take 3			Yes	I-81N		F(5/8/01)	
6	117	52	421	52				642			1	Pace	2 boats	International	Yes	I-81N		F(5/8/01)	
7	119	54	372	50				595		20.5	18	Trail - Eze	empty	Kenworth	No	I-81N		F(5/8/01)	
8	0	52	364	122				538		2	10	Transcraft	2 mini backhoes	Peterbuilt	No	I-81N		F(5/8/01)	
9	0	52	368	123				543		2	15		4 bobcats	Kenworth	No	I-81N		F(5/8/01)	
10	82	53	383	49				567		31	21	Landoll	2 railroads houses	White GMC	No	I-81N	on hydraulics - can lift up	F(5/8/01)	
11	109	54	346	122				631		11	15	Alabama	empty	Kenworth	No	I-81N		F(5/8/01)	
12	0		294					294		14	14		2 cars		No	I-81N	16 feet to trailer	F(5/8/01)	
13	0		448	56	56	56		616	408	7.5	-	Daily	drill	Freigthliner	No	I-81N		F(5/8/01)	
14	0		451	50				501		12	16	McCord	empty		Yes	I-81N	1575R1745	F(5/8/01)	
15	0	52	462	48				562		11.5	-	Trail King	empty	Peterbuilt	No	I-81N		F(5/8/01)	
16	0	55	386	51	52			544	296	10	12	Trail king	empty	International	No	I-81N		F(5/8/01)	
17	0	52	432	55	54			593	330	9	-	Blackhawk	Etnyr	Mack	No	I-81N		F(5/8/01)	
18	0	53	456	56				565	383	8	-	Trail King	pickup	Peterbuilt	No	I-81N		F(5/8/01)	
19	14	53	456	51				574	372		-	Fontaine	empty	Mack	No	I-81N		F(5/8/01)	
20	0		492	45	92			629	393	7	11		yatch	Kenworth	No	I-81N		F(5/8/01)	
21	79		319	38	38	38		512	215	10	22	APTIA	log cabin		No	I-81N	mobile home trailer*	F(5/8/01)	
22	0	84	386	52				522	288	12	-	Cozad	tranformers	Volvo	No	I-81N		F(5/8/01)	
23	0		418	52	52			522	327	7	-	Talbert	empty	Freigthliner	No	I-81N		F(5/8/01)	
24	0		425	48				473		10	-	Fruehauf	bulldozer	Peterbuilt	No	Glenmark Center		F(5/9/01)	
25	52		463	55				570	440	3	-	Daily	bulldozer	Freigthliner	No	I-79 S reststop		F(5/9/01)	
26	0	52	457	50				559	439		-	Canadian	bucket loader	Western Star	No	I-79 N truck stop		F(5/9/01)	
27	0		430	50	50	50		580		3.5	-	Talbert	CAT 777	Peterbuilt	No	I-79 N truck stop	uneven ground	F(5/9/01)	
28	0	50	454	50				554	352	11	-	Hunt	New Holland Combine	Freigthliner	No	I-79 S reststop		F(5/9/01)	
29	0	54	315	56	54			479	332	9	-	Loadking	empty	Freigthliner	No	I-79 N - Pitt		F(5/10/01)	
30	0	52	408	51	51			562	317	6.5	-	Trail King	bucket loader	Freigthliner	No	I-79 N - Pitt		F(5/10/01)	
31	0	52	387	52				491	309	12	-	Rogers	empty	International	No	I-79 N - Pitt		F(5/10/01)	
32	0	52	450	52	52			606	326	6	-	Keen	bucket loader	Freigthliner	No	I-79 N - Pitt		F(5/10/01)	
33	0	52	387	51	52			542	310	12	-	Rogers	backhoe	Autocar	No	I-79 N - Pitt		F(5/10/01)	
34	0	52	379	52				483	302	7	14	Eager Beaver	empty	International	No	I-79 N - Pitt		F(5/10/01)	
35	0	56	403	50				509	317	7	-	Trail King	metal detector	International	No	I-79 N - Pitt		F(5/10/01)	
36	89	53	396	48				586	326	17	16	Scottys	3 axle dump	Volvo	No	I-79 N - Pitt		F(5/10/01)	
37	0	55	401	52	52			560	315	6	-	Talbert	Trencher	Kenworth	No	I-79 N - Pitt		F(5/10/01)	
38	0	53	461	50				564	375	11	-	Trail King		Peterbuilt	No	I-79 N - Pitt		F(5/10/01)	
39	117		396	51	51			615	293	12	12	Trail King	boat	Mack	No	I-79 N - Pitt		F(5/10/01)	
40	0	52	405	54	54			565	307	6	-	Talbert	bucket loader	Kenworth	No	I-79 N - Pitt		F(5/10/01)	
41	0	52	459	56	56			623	378	6	-		front loader	Kenworth	No	I-79 N - Pitt		F(5/10/01)	
42	0	52	416	55	55			578	325	7	-	Talbert	front loader	Kenworth	No	I-79 N - Pitt		F(5/10/01)	
43	0	52	454	54	54			614	372	9.5	-	Trail King	empty	Peterbuilt	No	I-79 N - Pitt		F(5/10/01)	
44	0	54	392	50				496	268	7	-	Rogers	ditch box	Kenworth	No	I-79 N - Pitt		F(5/10/01)	
45	116	56	366	50				588	334	9	20	Trail King	JLG lift	Western Star	No	I-79 N - Pitt		F(5/10/01)	
46	0	54	453	54	54			615	295	5	-	Talbert	Crane	Peterbuilt	No	I-79 N - Pitt		F(5/10/01)	
47	0	52	406	50	52			560		10	-	Trail King	Sheeps foot	Peterbuilt	No	I-79 N - Pitt		F(5/10/01)	
48	53	52	442	54				601		5	-	Aldora	boat	Peterbuilt	No	I-79 N - Pitt		F(5/10/01)	
49	0	54	427	48				529	330	9	-	Dynaweld	empty	Kenworth	No	Mo'Town Excavator	unloaded	F(5/16/01)	
50	0		367	50	50			467	309	9	-	Challenger	empty	Mack	No	City Garage	unloaded	F(5/15/01)	
51	0		375					375	291	10	-	Hyster	empty	White GMC	No	Pittsburgh		F(5/21/01)	
52	0		299	49				348	264	9	-	Challenger	empty	-	Yes	Manufacturer	RG 35 model	I (5/23/01)	
53	0		293	49	49			391	264	9	-	Challenger	empty	-	Yes	Manufacturer	RG 50 Model	I (5/23/01)	
54	0		395	50				445	264	7	-	Rogers	empty	-	Yes	Manufacturer	Classic Series Model CR35-Air	I (5/23/01)	
55	0		421	50	50			521	288	7	-	Rogers	empty	-	Yes	Manufacturer	Classic Series Model CR50-Air	I (5/23/01)	
56	0		389	49				438	264	7	-	Rogers	empty	-	Yes	Manufacturer	Ultima Series Model CP35-SP	I (5/23/01)	
57	0		415	49	49.75			513.75	288	7	-	Rogers	empty	-	Yes	Manufacturer	Ultima Series Model CP50-SP	I (5/23/01)	
58	0		433	50	50			533	288	7	-	Rogers	empty	-	Yes	Manufacturer	Ultima Series Model CP50-SP	I (5/23/01)	
59	0		313	54	54			421	288	8	-	Etnyre	empty	-	Yes	Manufacturer	5000P-RTN50TD3-T1	I (5/23/01)	
60	0		378	50				428	360	8	-	Talbert	empty	-	Yes	Manufacturer	TWD-30-SRG-T1	I (5/23/01)	

61	0		385	54				439	264	8	-	Talbert	empty	-	Yes	Manufacturer	TWD-35SA-HRG-1-T1	I (5/23/01)	
62	27		408	54	54			543	276	8	-	Talbert	empty	-	Yes	Manufacturer	T3DW-50SA-HRG-I-T1	I (5/23/01)	
63	0		320	54	54			428	300	6	-	Talbert	empty	-	Yes	Manufacturer	T3(4)DW-55-HRG-1-T1(EC3/1)	I (5/23/01)	
64	0		350					350	350	8	-	Fontaine	empty	-	No	Manufacturer	"Double Drop" I-Beam	I (5/23/01)	
65	0		350					350	350	6	-	Fontaine	empty	-	No	Manufacturer	"Double Drop" Box Beam	I (5/23/01)	
66	0		438	54.5	54.5			547	300	6	-	Fontaine	empty	-	Yes	Manufacturer	TL50 Series	I (5/23/01)	
67	0		264					264	264	6	-	Fontaine	empty	-	Yes	Manufacturer	Ram50	I (5/23/01)	
68	0		465	50	50			565	465	11	-	Fontaine	empty	-	Yes	Manufacturer	352SS	I (5/23/01)	
69	0		300					300	288	6	-	Liddell	empty	-	Yes	Manufacturer	Model C-50-S	I (5/23/01)	
70	0		300					300	204	10	-	Trail - Eze	empty	-	No	Manufacturer	TE70RG - rigid gooseneck	I (5/23/01)	
71	0		300					300	204	10	-	Trail - Eze	empty	-	No	Manufacturer	TE80RG - rigid gooseneck	I (5/23/01)	
72	0		456					456	252	10	-	Trail - Eze	empty	-	No	Manufacturer	TE100RG - rigid goosenec	I (5/23/01)	
73	0		456					456	252	10	-	Trail - Eze	empty	-	No	Manufacturer	TE120RG - rigid goosenec	I (5/23/01)	
74	0		416	50	50			516	264	10	-	Trail - Eze	empty	-	No	Manufacturer	E100DGNT - detach. Goos	I (5/23/01)	
75	0		470	60	60			590	318	10	-	Trail - Eze	empty	-	No	Manufacturer	E100DGNT - detach. Goos	I (5/23/01)	
76	0		392					392	264	8	-	Eager Beaver	empty	-	Yes	Manufacturer	Model 35GSL-BR	(5/16/01)	
77	0		345	54	54			453	345	5	-	Trail King	empty	Butch Odegaard	Yes	Manufacturer	Model TK70MED #6298	P(6/14/01	closed
78	0		359	49	56			464	359	6	-	Trail King	empty	Butch Odegaard	Yes	Manufacturer	Model TK90MED #4314	P(6/14/01	closed
79	0		540	60				600		8	-	Cozad	empty		Yes	Manufacturer		P(6/14/01)	
80	0		408	59	59			526	343	8	-	Fontaine	Loadking fifth wheel	Kenworth	No	I-79 S reststop	can expand to 80'.	F(6/25/01)	
81	0		406	55	55	55		571	340	7	-	Fontaine	extrusion press	International	No	I-79 S reststop		F(6/26/01)	
82	0		459	53				512	376	7.5	-	Daily	chute (20K lb)	Eagle	No	I-79 S reststop		F(6/28/01)	
83	0		460	52				512	372	6	-	Talbert	water tank/pumping syste	Western Star	No	I-79 S reststop	28K lb	F(6/28/01)	
84	0		444	48				492	375	4	-	Trail King	electric voltage boxe	Freightliner	No	Morgantown	15K lb	F(7/2/01)	
85	49		456					505	380	2.25	-	Trism	auling crane (84k lb	Freightliner	No	I-79 S reststop	has blown rear tire	F (7/3/01)	
86	0		408	48	48			504	324	10.5	-	Eager Beaver	dozer	White GMC	No	I-64		F (7/9/10)	
87	101		300	52				453	206	12	-		carnival ride	White GMC	No	I-65		F (7/9/10)	
88	0		381	55	55			491	308	4	-	Trism(fontaine)	volvo dump truck 59	Freightliner	No	I-66		F (7/9/10)	
89	0		434	51				485	278	10	-	chiederNation	something big	Freightliner	No	I-67		F (7/9/10)	
90	0		417	51	51			519	318	12	-	Trail King	empty	International	No	I-68		F (7/9/10)	
91	0		337	51	51			439	235	12	-		truck cab	Mack	No	I-69		F (7/9/10)	
92	0		377	56	56			489	269	12	-		empty	Western Star	No	I-70		F (7/9/10)	
93	0		388	58				446	301	5.5		Hyster	drill	Peterbuilt	No	-68 Coopers rock		F(8/7/01)	

Based on the sample we have, the design vehicle dimensions would be as follows:

Rear Overhang (in	Wheel Base (in) r1t to r2t	r2t to r1	r1 to r2	r2 to r3	r3 to r4	r4 to r5	Overall Trailer Length	Length of Drop (in)	Ground Clearance (in) Under trailer	Rear Overhang	
119	84	540	123	159	56	0	642	465	2	1	worst case
13	54	397	55	56	50	0	508	315	9	14	average
0	50	222	34	32	38	0	264	204	31	22	best case

average without zeros = 77"

sample size = 93

DOUBLE DROP TRAILERS

No.	Wheel Base (in) r1 to r2	r2 to r3	r3 to r4	r4 to r5	Rear Overhan	Ground Clearance Between Tires (in)	Over hang (in)	Length of Drop (in)	Make/ Model/ Year	Special Type (livestock, moving, etc)	No. of Drops	Belly Box Add-on?	Anything Unusual? [Small Tires, Flat Tires Overloaded]	Source (I, P, or F)	(Internet, Phone, Field) Other	Picture?
1		408	50		108	11	16		Kaylan	Mack tractor	1	No	9' overhang/rear hangs up often	F(4/30/01)	I-79 S	Yes
2	52	450	50			14		365	Bullnde EBY	Livestock carrier	1	No		F(5/8/01)	I-81 N Marion	No
3	52	377	51		106	14	15	288	Kentucky		1	No		F(5/8/01)	I-81 N Marion	No
4	52	368	130				18		Trail king	Kenworth tractor	1	No		F(5/8/01)	I-81 Marion	No
5	54	374	123			13.5	21		Transcraft	Kenworth tractor	*	No		F(5/8/01)	I-81 Marion	No
6	52	340	159		138	15	20	138	North American	Peterbuilt tractor	1	No		F(5/8/01)	I-81 Marion	Yes
7	53	398	50		129	11	22		Walbash	Fneghtliner tractor	*1	No		F(5/8/01)	I-81 Marion	No
8		401	122			14.5				Fneghtliner tractor	1	No		F(5/8/01)	I-81 Marion	No
9	54	382	122			14.5			TMI	Kenworth tractor	1	No	hauling 13 trailers	F(5/8/01)	I-81 Marion	No
10	52	382	122			6	21.5		Talbert	Fneghtliner tractor	1	No	hauling backhoe	F(5/8/01)	I-81 Marion	No
11	55	377	125			13			Fontaine	Kenworth tractor	1	No	hauling drill bits	F(5/8/01)	I-81 Marion	No
12	52	408	51		84	9	26	329	Kentucky	Freightliner tractor	1	No		F(5/8/01)	I-81 Marion	No
13	52	346	51	51		11	18.5	209	Kentucky	Volvo tractor	1	No	moving trailer	F(5/8/01)	I-81 Marion	No
14		357	50		110	10.5	16	203	Kentucky	Moving trailer	1	No		F(5/10/01)	I-79 N Pitt	No
15	52	408	49			12		117	Kentucky	Moving trailer	1	No		F(5/10/01)	I-79 N Pitt	No
16	52	381	50					222	Freightliner		1	No		F(5/10/01)	I-79 N Pitt	No
17	52	403	49		99	13	18	212	Kentucky	Moving trailer	1	No		F(5/10/01)	I-79 N Pitt	No
18	52	396	48		121	10	20		Great Dane		1	No		F(5/10/01)	I-79 N Pitt	No
19	52	377	49		110	11	22	270	Kentucky		1	No		F(5/10/01)	I-79 N Pitt	No
20		660	48			12			Kentucky	manufacturer	1	No		P(6/21/01)	Mark Shutt	No
21		660	122						Kentucky	manufacturer	1	No	widespread model	P(6/21/01)	Mark Shutt	No
22		372			262	10.5				Peterbuilt tractor	1	No	hauling cat dozer	F(6/27/01)	I-79S Rest	no
23		348	48			12.5		200	Kentucky	Freightliner tractor	1	No	moving trailer	F(7/2/01)	9 S rest area	
24		408	52		97	10.5	12	277	Kentucky	Freightliner tractor	1	No		F(7/9/01)	I-64	No
25		268				20.5	12.5	167			1	No		F(7/9/01)	I-64	No
26		373	57			22	22	295	livestock		1	No		F(7/9/01)	I-64	No
27		473				10		374	carnival equip	Freightliner tractor	1	No		F(7/9/01)	I-64	No
28		432	51			6	20.5	247	carnival equip	Mack tractor	1	No		F(7/9/01)	I-64	No

Based on the sample we have, the design vehicle dimensions would be as follows:

Wheel Base (in) r1 to r2	r2 to r3	r3 to r4	r4 to r5	Rear Overhan	Ground Clearance Between Tires (in)	Over hang (in)	Length of Drop (in)	
55	660	159	51	262	6	12	117	worst case
53	405	75	51	124	12	19	245	average
52	268	48	51	84	22	26	117	best case

sample size = 31

CAR CARRIER TRAILERS

No.	Rear Overhang (in)	Wheel Base (in) f to r1	r1 to r	r2 to hitch	hitch to r3	r3 to r4	r4 to r5	Ground Clearance (in) Betwee Tires	Rear Overhan	At Hitch	Length o Drop (in)	Make/ Model/ Year	Stinger or High Mount?	Car Carrying Capacity?	Tractor Type	Picture?	Anything Unu [Small Tires, Overloaded]	Source (I, P, or F)	(Internet, Phone, Field) Other
1	126		·	108	324	48		4.75	9			Orange Blossom	Stinger			No	Loaded	F(5/8/01)	I-81 N Marion
2	126			48	444	48		6	8.5			Cottrell	Stinger	7		No		F(5/8/01)	I-81 N Marion
3	150		52	50	408			7.5	10.5	4.5	328	Cottrell	Stinger	empty	Internationa	No	empty	F(5/8/01)	I-81 N Marion
4	130			51	413			4	9		314	Cottrell	Stinger	10		No	Loaded	F(5/8/01)	I-81 N Marion
5	132		52	77	334	52		7	8	6	334	Cottrell	Stinger	1	Freightliner	No		F(5/10/01)	I-79 N Bridgeville
6	160		52	76	327	52		6	8	5	327	Cottrell	Stinger	7	Peterbuilt	No		F(5/10/01)	I-79 N Bridgeville
7	127		52	104	316	51		5.5	7	5	316	Carterbuilt	Stinger	8	Freightliner	No		F(5/10/01)	I-79 N Bridgeville
8	153		52	103	308	51		9.5	9	5	308		Stinger	9	Volvo	No		F(5/10/01)	I-79 N Bridgeville
9	136		52	112	306	52		6.5	8.5	5.5	306	Cottrell	Stinger	6	White GMC	No		F(5/10/01)	I-79 N Bridgeville
10	140		52	122	316	51		5	9	5	316	Cottrell	Stinger	9	Peterbuilt	No		F(5/10/01)	I-79 N Bridgeville
11	133		52	98	317	50		3	7	2	317	Cottrell	Stinger	5		No		F(5/10/01)	I-79 N Bridgeville
12	156		51	104	306	52		5	11	5	306	Cottrell	Stinger	8	Freightliner	No		F(5/10/01)	I-79 N Bridgeville
13	141		52	102	301	50		6	9	6	301	Bankhead	Stinger	empty		No		F(5/10/01)	I-79 N Bridgeville
14	117	226	452	51				6.5	10.5		358	Pleasant Valle	High Mount	empty	Freightliner	No		F(5/10/01)	I-79 N Bridgeville
15	150			120	285	52		7	8.5	7.5	285	Cottrell	Stinger	1	White GMC	No		F(5/10/01)	I-79 N Bridgeville
16	166		52	101	307	51		5.5	8.5	5.5	307	Cottrell	Stinger	1	Volvo	No		F(5/10/01)	I-79 N Bridgeville
17	151		54	43	334	52		8	7	2.5	334	Cottrell	Stinger	10	Internationa	No		F(5/10/01)	I-79 N Bridgeville
18	149		52	75	330	52		5	8	5	330	Cottrell	Stinger	3	Volvo	No		F(5/10/01)	I-79 N Bridgeville
19	114		52	52	408	135		7	10	4.75	307	Cottrell	Stinger	11	White GMC	No		F(5/10/01)	I-79 N Bridgeville
20	114			35	408	35		12	12		342	Kaufman Easy loader	Stinger	6	Kenworth	No		F(5/10/01)	I-79 N Bridgeville
21	135		52	53	413			6.5		6	309	Cottrell	High Mount	5	Volvo	No		F(5/10/01)	I-79 N Bridgeville
22	147		52	56	282	52	175	9.5	6			Cottrell	Stinger	8	Freightliner	No		F(5/10/01)	I-79 N Bridgeville
23	105		52	109	317	52	127	7	10	4		Carterbuilt		10	Peterbuilt	No		F(5/10/01)	I-79 N Bridgeville
24					456			6				Take 3, Model 50 Six Pac high m.		6		Yes - online	Manufacturer	P(6/14/01)	Michael Callahan
25					408			20				Take 3, LoPro	high	4		Yes - online	Manufacturer	P(6/14/01)	Michael Callahan
26	168			38	384			13				Easy Haul	high	4			Manufacturer	P(6/14/01)	
27	139		52	43	346			7	7	3		Cottrell	Stinger	2		No	-79 S rest sto	F(6/26/01)	
28	128	193	52	51	408	51		9	6	4		Commercial 3	stinger	3	Freightliner	No	-79 S rest sto	F(6/27/01)	
29	120			64	418			5	11	6	370		stinger	6		No	I-64	F(7/9/010	

Based on the sample we have, the design vehicle dimensions would be as follows:

Rear Overhang (in)	Wheel Base (in) f to r1	r1 to r	r2 to hitch	hitch to r3	r3 to r4	r4 to r5	Ground Clearance (in) Betwee Tires	Rear Overhan	At Hitch	Length of Drop (in)	
168	226	54	122	456	135	175	3	6	2	370	worst case
138	210	72	76	354	54	151	7	9	5	321	average
105	193	51	35	282	35	127	20	12	7.5	285	best case

sample size = 29

BELLY DUMP TRAILERS

No.	Overhang (in) Front	Rear	Wheel Base (in) f to r1	r1 to r2	r2 to r3	r3 to r4	Ground Clearance Betwe Tires	Overhang Front	Rear	Make/ Model/ Year	Hauling	Tractor Type	Picture?	Anything Unusual? [Small Tires, Flat Tires Overloaded]	Source (I, P, or F)	(Internet, Phone, Field) Other
1		0	52	375	50	0	11	at hopper		Timpte		Mack	yes		F(5/8/01)	I-81 Marion
2		0		401	49	0	16	at hopper		Sparta		-	yes	manufacturer	I (5/23/01)	
3		24.5		471	49	0	19	at hopper		Timpte		-	yes	manufacturer	I (5/23/01)	45' Super Hopper
4		24.5		363.5	49	0	19	at hopper		Timpte		-	yes	manufacturer	I (5/23/01)	40' Super Hopper
5		0		268.5	48	51	14	at hopper		R-Way's			yes	manufacturer	I (6/22/01)	40'
6		50		342	50	0	17	at hopper		Ranco	LW 21-37		yes	manufacturer	I (6/22/01)	see assump
7		50		386	50	0	17	at hopper		Ranco	LW21-40		yes	manufacturer	I (6/22/01)	see assump
8		50		409	50	0	17	at hopper		Ranco	LW21-42		yes	manufacturer	I (6/22/01)	see assump
9		50		325	50	0	17	at hopper		Ranco	LW21-35-3		yes	manufacturer	I (6/22/01)	see assump
10		50		386	50	0	17	at hopper		Ranco	LW21-40-3		yes	manufacturer	I (6/22/01)	see assump
11		50		409	50	0	17	at hopper		Ranco	LW21-42-3		yes	manufacturer	I (6/22/01)	see assump
12		50		292	50	0	17	at hopper		Ranco	21-38		yes	manufacturer	I (6/22/01)	see assump
13		50		358	50	0	17	at hopper		Ranco	21-34		yes	manufacturer	I (6/22/01)	see assump
14		50		431	50	0	17	at hopper		Ranco	21-40		yes	manufacturer	I (6/22/01)	see assump
15		50		454	50	0	17	at hopper		Ranco	21-42		yes	manufacturer	I (6/22/01)	see assump
16		50		431	50	0	17	at hopper		Ranco	21-40-3		yes	manufacturer	I (6/22/01)	see assump
17		50		454	50	0	17	at hopper		Ranco	21-42-3			manufacturer	I (6/22/01)	
18		0		384	60	60	14	at hopper		Midland	p close under load 42' triple axle			manufacturer	I (6/22/01)	
19		0		444	60	0	14	at hopper		Midland	Cross dump close under load 42' double axle			manufacturer	I (6/22/01)	
20		0		491	49	49	14	at hopper		Trail King			yes	manufacturer	E (7/25/01)	

Based on the sample we have, the design vehicle dimensions would be as follows:

Overhang (in) Front	Rear	Wheel Base (in) f to r1	r1 to r2	r2 to r3	r3 to r4	Ground Clearance	
0	50	52	491	60	60	11	worst case
0	32	52	394	51	8	16	average
0	46	52	394	51	53	16	average without zeros
0	0	52	268.5	48	0	19	best case

sample size =20

PASSENGER VEHICLE & TRAILER - PRIVATE USE

No	Rear Overhang (in	rt=rear trailer wheel Wheel Base (in) r to rt1	rt1 to rt2	Length to hitch (in)	Ground Clearance(in Betwee Tires	Rear Overhang	Make/ Model/ Year	Car Type	Hauling	Picture?	Location (if field measured)	Anything Unusual? [Small Tires, Flat Tires Overloaded]	Source (I, P, or F)	(Internet, Phone, Field) Other
1	161	300	35	246	17	15	Hornet by Keystone	Ford	camper	No	I-81 Manon		F(5/8/01)	
2	114	261	36	207	12	12	Roulottes -camper	Ford	camper	No	I-81 Manon		F(5/8/01)	
3	52	160		104	12	13	U-Haul	Ford F-150		No	I-79 Rest Area	man. By Paramount Mfg. Co.	F(5/9/01)	
4	128	276	34	-	16	14	Terry by Fleetwood	Dodge Ram 2500	camper	No	I-79 Rest Area	fifth wheel	F(5/9/01)	
5	122	216	30	-	18	13	Alum-lite	Ford F-250XLT	camper	No	I-79 N Pitt	fifth wheel	F(5/10/01)	
6	56	176	35	52	9	9.5	U-Haul	U-Haul	car	No	I-79 N Pitt		F(5/10/01)	
7	96	33		24	11	9	Magic Tilt	Ford	boat	No	I-79 N Pitt		F(5/10/01)	
8	123	247	34	-	10	18	Carri-lite		camper	No	I-79 N Pitt	5th wheel, by Carriage	F(5/10/01)	
9	53	173	34	128	10	12	U-Haul	Ford Bronco XLT		No	I-79 N Pitt		F(5/10/01)	
10	38	150		106	9	4.5	Featherlite	Chrysler Grand voyager	shopvac, wheelbarrow	No	I-79 N Pitt		F(5/10/01)	
11	0	178		-	11		Penske	Moving van	empty	No	I-79 N Pitt		F(5/10/01)	
12	59	234	34	168	8	14	Foster	Ford	bobcat	No	I-79 N Pitt		F(5/10/01)	
13	139	179	42	99	4.5	5.5	U-Haul	U-Haul	car	No	I-79 N Pitt		F(5/10/01)	
14	52	48		199	5	8		Ford F150	boat	No	I-79 N Pitt		F(5/10/01)	
15				90	8	4.5	Ryder car trailer	Ryder truck	towing car	No	I-79 N Pitt		F(5/10/01)	
16	45	142		91	6.5	13.5	U-Haul	Uhaul	Pontiac Bonneville	No	I-79 S Rest area		F(6/26/01)	
17	91	196	31	140	12	13	open car trailer	Chevy 2500	Buick Century	No	I-79 S Rest area		F(6/26/01)	
18	90	201		138	9	16	Sun Ridge by Fleetwood	GMC Suburban	camper	No	I-79 S Rest area		F(6/26/01)	
19	40	227		177	10	12	Wesco boat trailer	Ford F150	fishing boat	No	I-79 S Rest area		F(6/26/01)	
20	66	220		140	13	11.5	United Transporters	Uhaul - Ford		No	I-79 S Rest area		F(6/26/01)	
21	108	238	35	189	10	11.5	87 Hi Lo Camper	Ford F150	camper	No	I-79 S Rest area		F(6/26/01)	*man. Calls owners for suggestio
22	84	187		141	14	12	small trailer	Chevy 1500	camping supplies	No	I-79 S Rest area		F(6/26/01)	
23	44	180	35		6	12.5	U-Haul	Ram 1500		No	I-79 S Rest area		F(6/28/01)	
24	128	264	36		18	17	Cameo LXI	Ford F350	5thwheel camper	No	I-79 S Rest area		F(6/28/01)	
25	70	178		125	13	12	Rockwood Freedom	GMC 1500 Sub	camper	No	I-79 S Rest area		F(6/28/01)	
26	48	152		107	6.5	13	U-Haul	Ford Caravan		No	I-79 S Rest area	tirepcold=50	F(6/28/01)	
27	54	221		179	11	15	Tracker trailstar	Chevy 1500	boat	No	I-79 S Rest area		F(7/2/01)	
28	41	199		160	8.5	12	boat trailer	Ford Explorer	fishing boat	No	I-79 S Rest area		F (7/2/01)	
29	42	144		103	12	10.5	Cedar by Fleetwood	Dodge Caravan	camper	No	I-79 S Rest area		F (7/2/01)	
30	75	205	34	159	10	12	car trailer	Chevy 1500	car/sofa	No	I-79 S Rest area		F (7/2/01)	
31	60	197	26	148	11.5	9.5	Cub	GMC Safari	camper	No	I-79 S Rest area		F (7/2/01)	
32	124	146	31	194	17	13	Sunline Solaris	Ford F150	camper	No	I-79 S Rest area		F(7/3/01)	
33	84	196	26	144	8.5	6	Funlite camper	Chevy Astro		No	I-79 S Rest area		F (7/3/01)	
34	104	265	33	149	12.5	21	Hornet by Keystone	Ram 250 Van	camper	No	I-79 S Rest area		F (7/3/01)	
35	84	215	33	155	12	13	Sunline	Chevy Silverado	camper	No	I-79 S Rest area		F (7/3/01)	
36	96	231	35	184	11	9.5	Catalina lite	Dodge van	Coachman trailer	No	I-79 S Rest area		F (7/3/01)	
37	48	221		174	10	13	Stratos trail	F 150 Econoline	empty	No	Stonewall Jackson Lake	boat trailers	F(7/5/01)	
38	53	222		174	16.5	11.5	Ranger trail	Chevy Truck	empty	No	Stonewall Jackson Lake	boat trailers	F(7/5/01)	
39	42	223		175	17	18.5	Trail Star	Chevy Truck	empty	No	Stonewall Jackson Lake	boat trailers	F(7/5/01)	
40	46	223		178	16.5	17	Trail Star	Buick car	empty	No	Stonewall Jackson Lake	boat trailers	F(7/5/01)	
41	46	223		175	13.5	20	Trail Star	Dodge Caravan	empty	No	Stonewall Jackson Lake	boat trailers	F(7/5/01)	
42	51	230		179	16	16.5	Stratus Trail	Chevy Truck	empty	No	Stonewall Jackson Lake	boat trailers	F(7/5/01)	
43	49	227		168	15	12.5	Trail Star	Chevy Silverado	empty	No	Stonewall Jackson Lake	boat trailers	F(7/5/01)	
44	50	239		186	12	12	Custom Frame	Ford Truck	empty	No	Stonewall Jackson Lake	boat trailers	F(7/5/01)	
45	49	238		186	12	13.5	Trail Star	Chevy Caprice	empty	No	Stonewall Jackson Lake	boat trailers	F(7/5/01)	
46	48	233		167	11	11	Javelin	Ford Truck	empty	No	Stonewall Jackson Lake	boat trailers	F(7/5/01)	
47	39	237	33	182	7	10	Custom Haul	Chevy Silverado	empty	No	Stonewall Jackson Lake	boat trailers	F(7/5/01)	
48	58	240		191	11	12	Stratus Trail	Chevy Silverado	empty	No	Stonewall Jackson Lake	boat trailers	F(7/5/01)	
49	91	248		197	16	16		Ford F250	Bayliner	No	Stonewall Jackson Lake	boat trailers	F(7/5/01)	
50	45	216		164	15	15	Tee Nee	Ford F350	empty	No	Stonewall Jackson Lake	boat trailers	F(7/5/01)	
51	55	252		207	12	10.5	Triton Boats	Yukon	empty	No	Stonewall Jackson Lake	boat trailers	F(7/5/01)	
52	54	222	34	178	10	12	Road runner	Yukon	Celebrity boat	No	I-79 S Rest area	boat trailers	F(7/6/01)	
53	49	243		193	14	12	Maxum	Ram 1500	Maxum boat	No	I-79 S Rest area	boat trailers	F(7/6/01)	
54	39	184		128	13	12	Shoreland	Ford F250	wave runners	No	I-79 S Rest area	boat trailers	F(7/6/01)	
55	58	188		128	12	15	Enterpnse Inc	Ford F150	3 4-wheelers	No	I-79 S Rest area	utility trailer	F(7/6/01)	
56	54	223	39	91	5	12	Ryder car trailer	Ford E350	towing car	No	I-79 S Rest area		F(7/6/01)	
57	124	246	36		21	24	Montana by Keystone	GMC 3500		No	I-79 S Rest area	fifth wheel	F(7/6/01)	
58	88	182	39	182	18	20	Wildwood	Ford F250		No	I-79 S Rest area	camper - fifth wheel	F (7/6/01)	
59	67			146	16.5	16.5	Chalet camper			No	manufacturer		E (7/4/01)	

Based on the sample we have, the design vehicle dimensions would be as follows:

Rear Overhang (in	r to rt1	rt1 to rt2	Length to hitch (in)	Ground Clearance(in) Betwee Tires	Rear Overhang	
161	300	42	246	4.5	4.5	worst case
70	207	34	154	12	13	average
0	33	26	24	21	24	best case
156					5	

sample size 59

PASSENGER VEHICLE & TRAILER - COMMERCIAL USE

rt=rear trailer wheels

No.	Rear Overhang (in)	Wheel Base (in) f to r	Wheel Base (in) r to rt1	Wheel Base (in) rt1 to rt2	Wheel Base (in) rt2 to rt3	Length to hitch (in)	Ground Clearance(in) Between Tires	Ground Clearance(in) Rear Overhang	Make/ Model/ Year	Car Type	Hauling	Picture?	Location (if field measured)	Anything Unusual? [Small Tires, Flat Tires Overloaded]	Source (I, P, or F)	(Internet, Phone, Field) Other
1	118		390	34	34	291	19	13.5	Appalachian	Dodge truck	empty	No	I-79	auto carrier	F(4/30/01)	
2	142		384	34	34	-	10	13.5	Cargo Mate	Ford F-350	empty	No	Rick Austin's	car carrier	F(5/7/01)	
3	64		204	70		-	12	13.5	Betterbuilt	Ford F-550	empty	Yes	I-81 Manon	livestock trailer	F(5/8/01)	
4	49		226	36		142	13	15	Alum-line	Chevy	empty	No	I-81 Manon		F(5/8/01)	
5	118		296	34		185	7	-	Carmate	GMC 3500		No	I-81 Manon		F(5/8/01)	
6	58		197			91	11	11	Pace	Ford 250D		No	I-81 Manon		F(5/8/01)	
7	72		252	34	25	132	18	14	Crosscountry	Chevy 3500D		No	I-81 Manon		F(5/8/01)	
8	48		136			52	11	14		Ford		No	I-81 Manon		F(5/8/01)	
9	65		212	33	33	-	24	12		International	empty	No	I-81 Manon		F(5/8/01)	
10	82		236	59		168	13	12	Interstate	Ford club XLT		No	I-79 Rest Area		F(5/9/01)	
11	38		168	35		107	15	14	Utility	Chevy 1500	arcade trailer	No	I-79 Rest Area		F(5/9/01)	
12	63		228	41		-	19	18	Cornelius	Ford F-350	stainless steel	No	I-79 Rest Area	fifth wheel / light load	F(5/9/01)	
13	110		392	36	36	-	12	20	Trailers Inc.	Dodge Ram 3500	pool	No	I-79 Truck stop	fifth wheel	F(5/9/01)	
14	0		46			173	10	15	Trailex	Dodge Ram 2500		No	I-79 Truck stop		F(5/9/01)	
15	128		308			252	18.5	22		Ford super duty	mobile office	No	I-79 N Pitt		F(5/10/01)	
16	126		328	33		-	12	22		Dodge Ram 3500	mobile office	No	I-79 N Pitt		F(5/10/01)	
17	56		198			-	10	11	Hercules	Chevy	plywood	No	I-79 N Pitt	byHomesteaders	F(5/10/01)	
18	40		145			103	7	12.5		Toyota Highlander		No	I-79 N Pitt		F(5/10/01)	
19	50		178			108	13.5	17	Good buddy	Ford F350	wire	No	I-79 N Pitt		F(5/10/01)	
20	73		166			124	9.5	8		Ford F350 dump		No	I-79 N Pitt		F(5/10/01)	
21	98		310			45	14.5	15.5	Diamond	Ford F350	empty	No	I-79 N Pitt	fifth wheel	F(5/10/01)	
22	62		197	34		139	16	13	Diamond	GMC 3500	empty	No	I-79 N Pitt		F(5/10/01)	
23	158		377	37	37	277	14	13	Trailer division of Lowes	Ford F350	3 cars	No	I-79 N Pitt	fifth wheel	F(5/10/01)	
24	0		355	48		264	12	20	McElrath Inc.	Ford F450	lumber	No	I-79 N Pitt	fifth wheel	F(5/10/01)	
25	67		171	34		132	10	13		Chevy	empty	No	I-79 N Pitt		F(5/10/01)	
26	60		242	36		144	9	8		International	water tank	yes	I-79 N Pitt		F(5/10/01)	
27	68		213	25		144	9	16	Cross Country	Ford F350	bobcat	No	I-79 N Pitt		F(5/10/01)	
28	192		341			192	13	34		Ford F 800	4 telephone poles	No	I-79 N Pitt		F(5/10/01)	
29	68		228			220	12	12	Featherlite	EMC 3500	livestock trailer	No	WVU farms	fifth wheel	F(5/14/01)	
30	44		172	33		120	12	15	Reese	Chevy Custom Deluxe	lawn movers	No	Mo'town		F(5/17/01)	
31	51		169			112	16	12	Carry-On	Chevy S 10	fertilizer	No	Mo'town		F(5/17/01)	
32	120		480			-	10		Trailer Tech		hauls cars	No	Manufacturer	fifth wheel	P(6/18/01)	
33	101		468			-	11		Barrett Trailers		livestock trailer	No	Manufacturer	comb. Of horse and other	P(6/19/01)	Larry
34	125		214	34		-	14	12	Coachman Imperial	Chevy 2500		No	I-79 S Rest area		F(6/25/01)	
35	84		216	32		162	5	7	race car trailer	Chevy Astro	hauling car	No	I-79 S Rest area		F(6/26/01)	
36	57		122	36		-	6	12	Ryder car trailer	Ryder truck	hauling car	No	I-79 S Rest area		F(6/26/01)	
37	107		194	51		138	9	14	Kiefer built	Ram 2500	feed products	No	I-79 S Rest area		F(6/26/01)	
38	45		165	38		108	15	17	Kodiak	Chevy 2500	glassware	No	I-79 S Rest area		F(6/27/01)	
39	60		170			123	10.5	13	Carmate	Chrysler Voyager	antiques	No	I-79 S Rest area		F(6/27/01)	
40	57		226	35		171	11.5	14	livestock	Ram 1500		No	I-79 S Rest area		F(6/28/01)	
41	58		263	36		137	7	10	Fulton car trailer	GMC 6500		No	I-79 S Rest area	max.tirep=50	F(6/28/01)	
42	149		371	34	34		11.5	13.5	Cargo Mate	Ford F250	19K lbs	No	I-79 S Rest area		F (7/2/01)	
43			187	31		60	9	12	Cotner	GMC Suburban		No	I-79 S Rest area	livestock trailer	F(7/6/01)	
44	49		177			120	10	10	Pace	Ford F250		No	I-79 S Rest area		F (7/6/01)	
45	92		251	50		212	15.5	12.5	Trailking	Mack Dump	empty	No	I-64 weigh station		F (7/9/01)	

Based on the sample we have, the design vehicle dimensions would be as follows:

rt=rear trailer wheels

Rear Overhang (in)	Wheel Base (in) f to r	Wheel Base (in) r to rt1	Wheel Base (in) rt1 to rt2	Wheel Base (in) rt2 to rt3	Length to hitch (in)	Ground Clearance(in) Between Tires	Ground Clearance(in) Rear Overhang	
192	0	480	70	37	291	5	7	worst case
79	0	244	38	33	150	12	14	average
0	0	46	25	25	45	24	34	best case

sample size= 45

RECREATIONAL VEHICLES (RV)

No.	Overhang (i Front	Rear	Wheel Base (in) f to r1	r1 to r2	r2 to r3	Ground Clearance (in Betwee Tires	Overhang Front	Rear	Make/ Model/ Year	Picture?	Anything Unusual? [Small Tires, Flat Tires Overloaded]	Source (I, P, or F)	(Internet, Phone, Field) Other
1	60.0	142	206			10	8	14	Gulf Stream	No		F(5/7/01)	Rick Austin's Trailer Sales
2	52.0	149	177			12	15	14	Classic	No		F(5/7/01)	Rick Austin's Trailer Sales
3	0	126	222			14	15		Crown Royal	No	towing car	F(5/8/01)	I-81N
4	0.0	118	231			13	17	16	Dolphin	No		F(5/8/01)	Keystone RV Center
5	0.0	141	231			12		16	Dolphin	No		F(5/8/01)	Keystone RV Center
6	0.0	137	192			11		17	Hurricane-Thor	No		F(5/8/01)	Keystone RV Center
7	0.0	119	226			14		17	Sea Breeze	No		F(5/8/01)	Keystone RV Center
8	0.0	130	227			12		13	National RV Tradewinds	No		F(5/8/01)	Keystone RV Center
9	70.0	130	207			13	14	12	National RV Tradewinds	No		F(5/8/01)	Keystone RV Center
10	0.0	235	189			9.5		17	Euroroller	No		F(5/8/01)	Keystone RV Center
11	0.0	148	218			11		17	National RV Dolphin	No		F(5/8/01)	Keystone RV Center
12	0.0	130	192			13		18	Hurricane -Thor	No		F(5/8/01)	Keystone RV Center
13	0.0	132	190			9		16	Fourwinds-Thor	No		F(5/8/01)	Keystone RV Center
14	0.0	142	264	33	33				Tenton Homes	Yes		F(5/8/01)	Keystone RV Center
15	0.0	170	258	34					Fourwinds-Thor	No		F(5/8/01)	Keystone RV Center
16	0.0	153	260	33					Prowler	Yes		F(5/8/01)	Keystone RV Center
17	0.0	108	180			9		8	Gulf Stream Conquest	No		F(5/9/01)	I-79 S rest area
18	0.0	117	187			12		13	Gulfstream conquest	No		F(5/9/01)	I-79 S rest area
19	0.0	148	226			14	6	16	Southwind by Fleetwood	No		F(5/10/01)	I-79 N Pitt
20	94.0	127	252			14	6	16	Endevor by Holiday Rambler	No		F(5/10/01)	I-79 N Pitt
21	48.0	233	209			11		12	Southwind by Fleetwood	No	82" to wheel-hitch towing car	F(5/10/01)	I-79 N Pitt
22	69.0	226	226			11	16.5	11	Renegade	No	226" wheel towheel towing car	F(5/10/01)	I-79 N Pitt
23	0.0	107	180			10		16	Argosy	No	84" to hitch towing car	F(5/10/01)	I-79 N Pitt
24	55.0	161	211			12	13	16	Cruise Air III	No		F(5/12/01)	Bridgeport
25	69.0	107	316			11	11	11	Featherlite	Yes	Model H3 - 45'	P(6/14/01)	Man.Tom Breznik
26	83	121	274			17		11	Newman London Cruise	No	66" to hitch towing car	F(6/25/01)	I-79 S rest area
27	45	144	228.			7.5		6	Southwind by Fleetwood	No	198.5" to hitch towing trailer**	F(6/25/01)	I-79 S rest area
****note: trailer is 33" f-r1, ROH of 97.5, GC of 8". It is a Haulmark trailer, and is loaded with a car. Gets hung up on driveway entrances**													
28		95	274			12		10	Coachman	No	83" to hitch towing car	F(6/25/01)	I-79S rest area
29		189				11		10	Thor Hurricane	No	towing car	F(6/26/01)	I-79S rest area
30	72.0	127	227			13	15	14	Tradewinds	No	towing car	F(6/26/01)	I-79 S rest area
31		132	197			10	8.5		Conquest by Gulfstream	No		F(6/27/01)	I-79 S rest area
32	48	88	141			10		10	Georgetown by Forest River	No		F(6/27/01)	I-79 S rest area
33		151	176			10		11	Tioga by Fleetwood	No		F(6/27/01)	I-79 S rest area
34	73.0	133	240			15.5	15	16.5	Discovery by Fleetwoo	No	towing car	F(6/28/01)	I-79 S rest area
35		144	175			10		10	Tioga by Fleetwood	No		F(6/28/01)	I-79 S rest area
36	81	120	252			13	16.5	12	Dutch Star by Newma	No		F(6/28/01)	I-79 S rest area
37	49	146	205	43		14	13	14	Bounder by Fleetwood	No		F(7/6/01)	I-79 S rest area
38	38	131	230			11.5		12	Pace Arrow by Fleetwood	No	towing car	F (7/2/01)	I-79 S rest area
39	78	126	204			13	11	9	Ambassador	No	Holiday Rambler	F (7/3/01)	I-79 S rest area
40	45	140	172	50				10	Imperial	No	Holiday Rambler-towing car	F (7/3/01)	I-79 S rest area
41	39	154	228			11.5		11	Endeavor	No	Holiday Rambler-towing car	F (7/3/01)	I-79 S rest area
42	44	137	227			14		12	Hurricane by Thor	No	drags in rear	F (7/3/01)	I-79 S rest area

Based on the sample we have, the design vehicle dimensions would be as follows:

Overhang (i Front	Rear	Wheel Base (in) f to r1	r1 to r2	r2 to r3	Ground Clearance (in) Betwee Tires	Overhang Front	Rear	
94.0	235.0	316.0	50.0	33.0	7.5	6	6	worst case
32.8	140.8	217.7	38.6	33.0	11.9	12.5	13.1	average
60.6	140.8	217.7	38.6	33.0	11.9	12.5	13.1	average without zeros
0.0	88.0	141.0	33.0	33.0	17	17	18	best case

sample size= 42

APPENDIX B
Profiles Used in HANGUP Testing

AREMA Manual for Railway Engineering (AREMA, 1993)
Hump Railroad Crossing

Distance (feet)	Elevation (inches)
-35	-6.0
-22	-4.5
-15	-3.0
-8-	-1.5
-5	0.0
0	0.0
5	0.0
8	-1.5
15	-3.0
22	-4.5
35	-6.0

Note: Point 0,0 is the center of the rails

ITE Guidelines for Driveway Location and Design (ITE, 1987)
"Low Volume Driveway on Major Streets or Collector Streets"

Distance (feet)	Elevation (inches)
100	-36.00
-90	-32.40
-80	-28.80
-75	-27.00
-70	-25.20
-60	-21.60
-50	-18.00
-40	-14.40
-30	-10.80
-25	-9.00
-20	-7.20
-10	-3.60
0	0
10	-3.60
20	-7.20
25	-9.00
30	-10.80
40	-14.40
50	-18.00
60	-21.60
70	-25.20
75	-27.00
80	-28.80
90	-32.40
100	-36.00

Note: Point 0,0 is the center of the grade break.

Typical Double Track Railroad Crossing

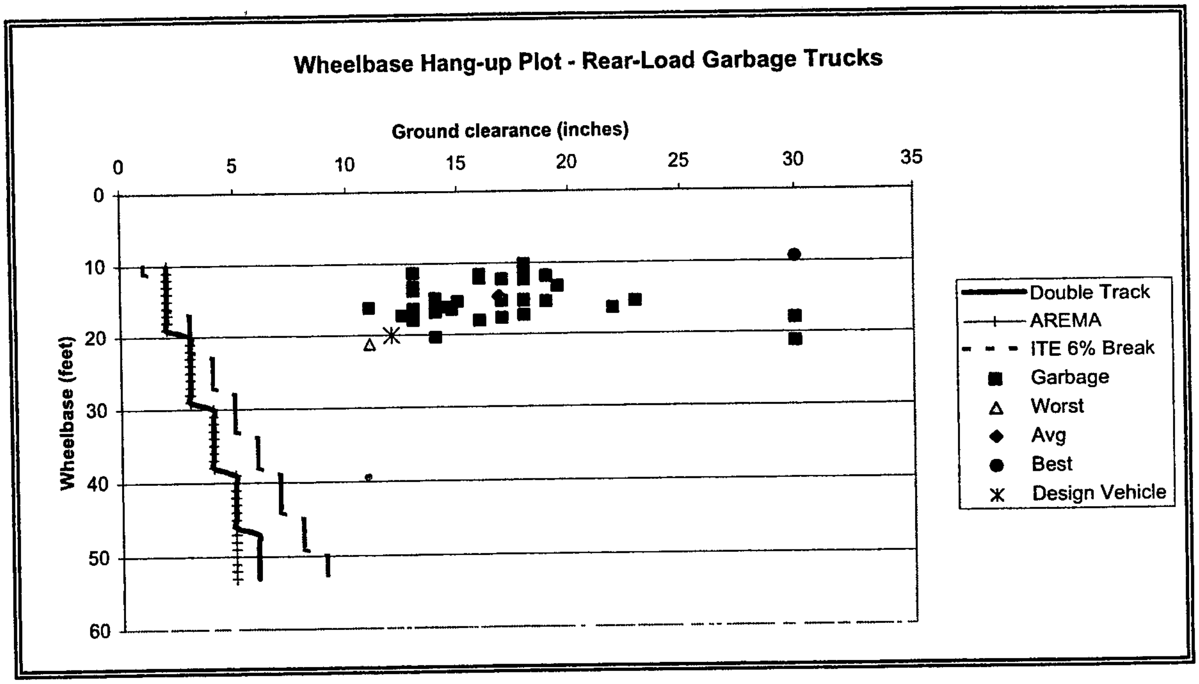
Distance (feet)	Elevation (inches)
-80	-31.32
-55	-17.16
-45	-10.92
-35	-5.88
-25	-1.68
-15	0.36
-5	0.0
0	0.0
10	-0.48
20	-3.84
30	-8.76
40	-15.0
50	-22.32
75	-43.44

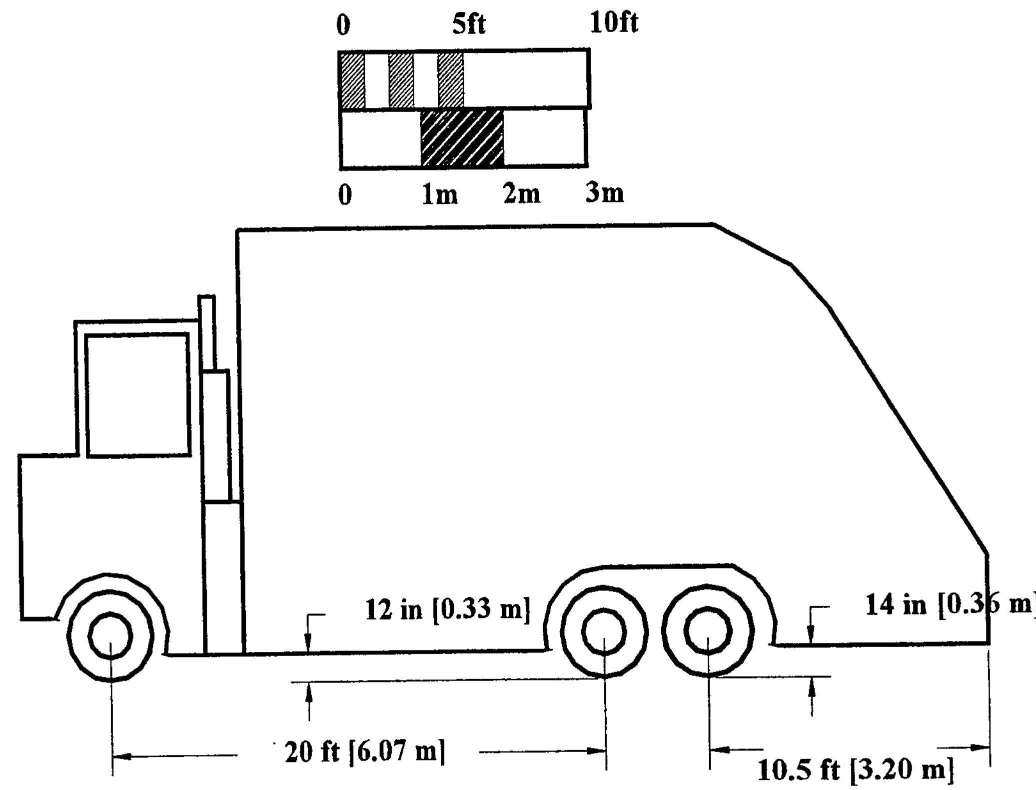
ITE Guidelines for Driveway Location and Design (ITE, 1987)
"Low Volume Driveway on a Local Street"

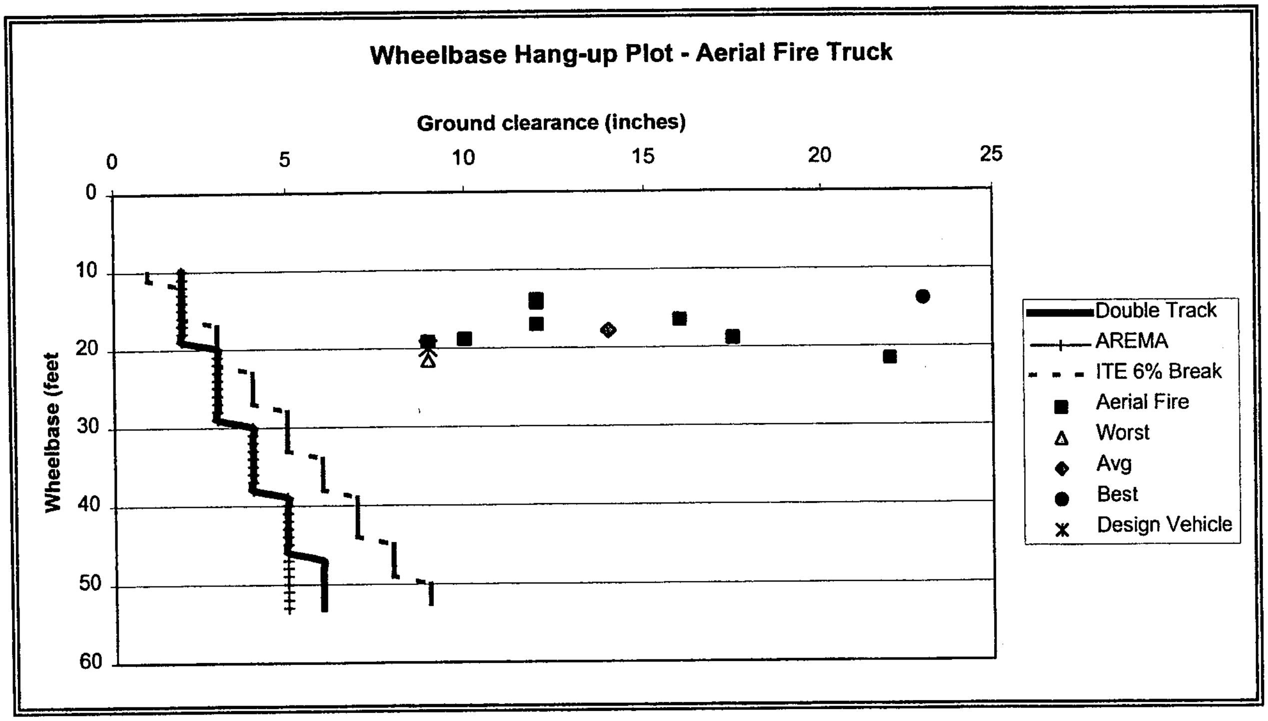
Distance (feet)	Elevation (inches)
-100	24.0
-90	21.6
-80	19.2
-70	16.8
-60	14.4
-50	12.0
-40	9.6
-30	7.2
-20	4.8
-10	2.4
-5	1.2
0	0
5	7.8
10	15.6
20	31.2
30	46.8
40	62.4
50	78.9
60	93.6
70	109.2
80	124.8
90	140.4
100	156.0

Note: Point 0,0 is the center of the grade break.

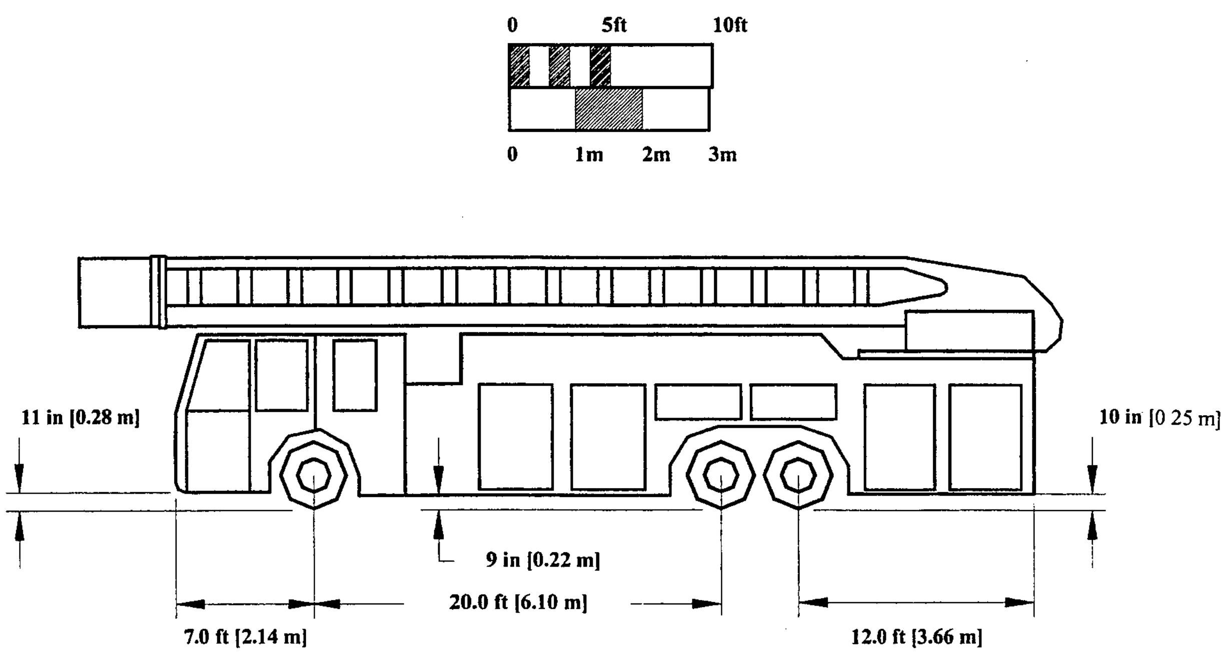
APPENDIX C
HANGUP Plots


Wheelbase Hang-up Plot - Rear-Load Garbage Trucks
Ground clearance (inches)
0
5
10
15
20
25
30
35
Wheelbase (feet)
0
10
20
30
40
50
60
Double Track
AREMA
ITE 6% Break
Garbage
Worst
Avg
Best
Design Vehicle

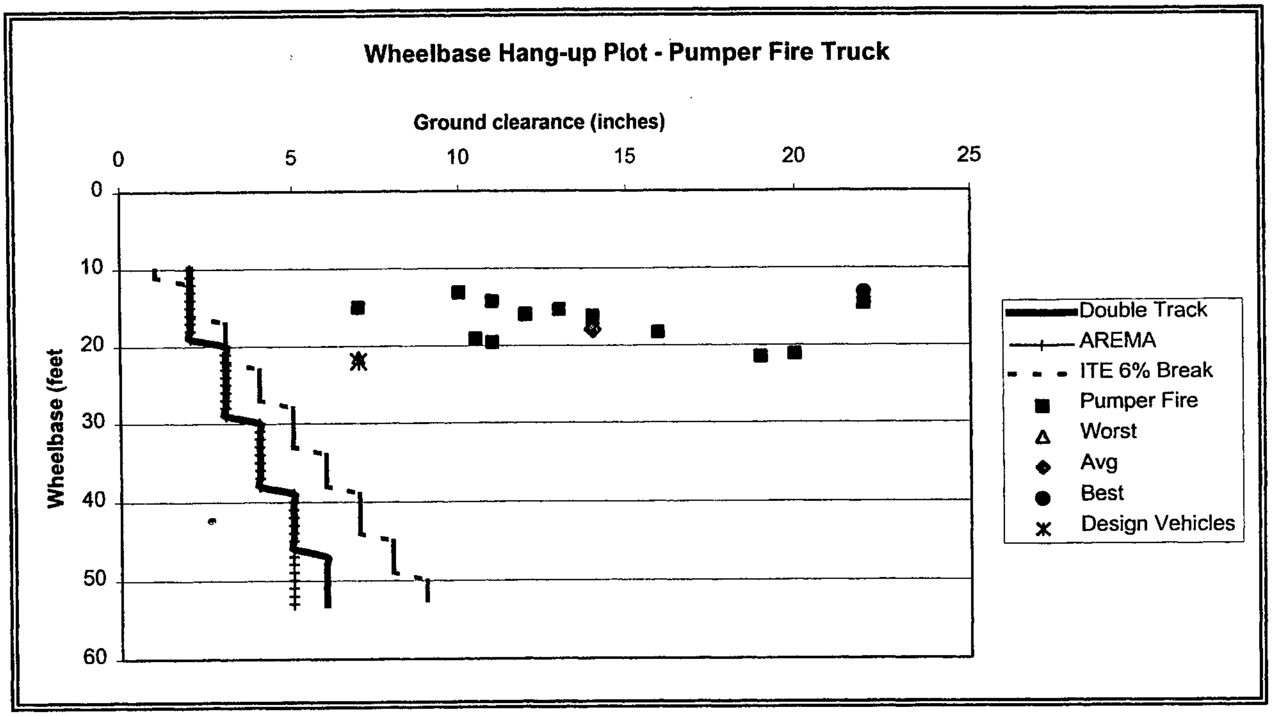

0
5ft
10ft
0
1m
2m
3m
12 in [0.33 m]
14 in [0.36 m]
20 ft [6.07 m]
10.5 ft [3.20 m]



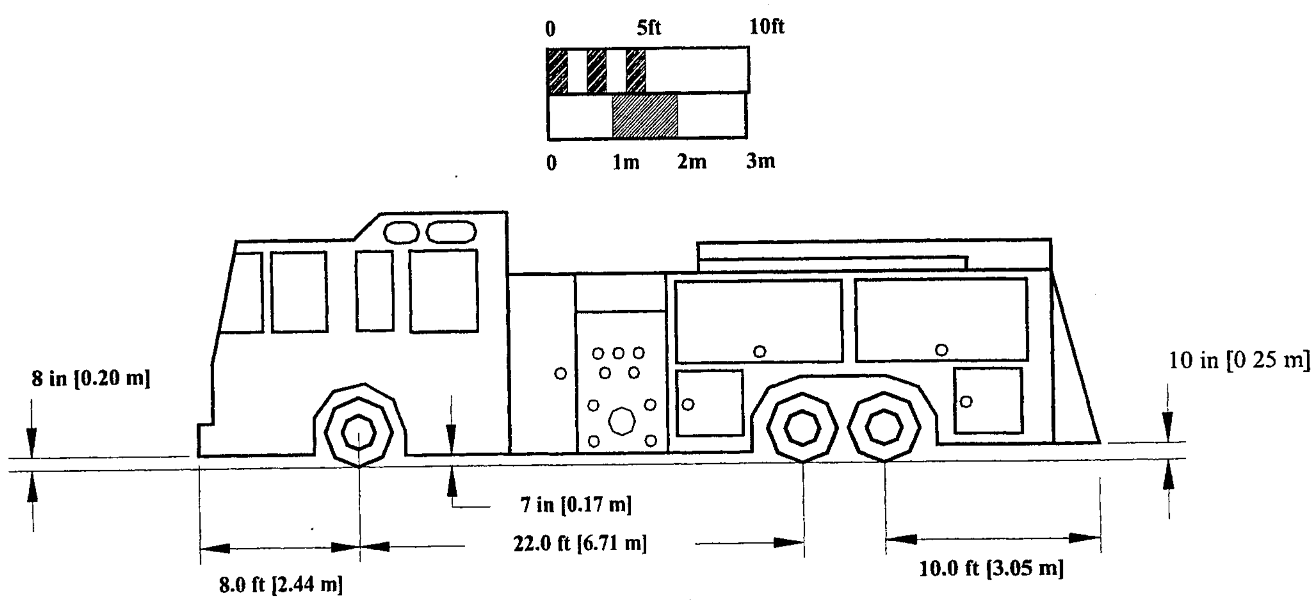
Wheelbase Hang-up Plot - Aerial Fire Truck
Ground clearance (inches)
0
5
10
15
20
25
0
10
20
30
40
50
60
Wheelbase (feet
Double Track
AREMA
ITE 6% Break
Aerial Fire
Worst
Avg
Best
Design Vehicle



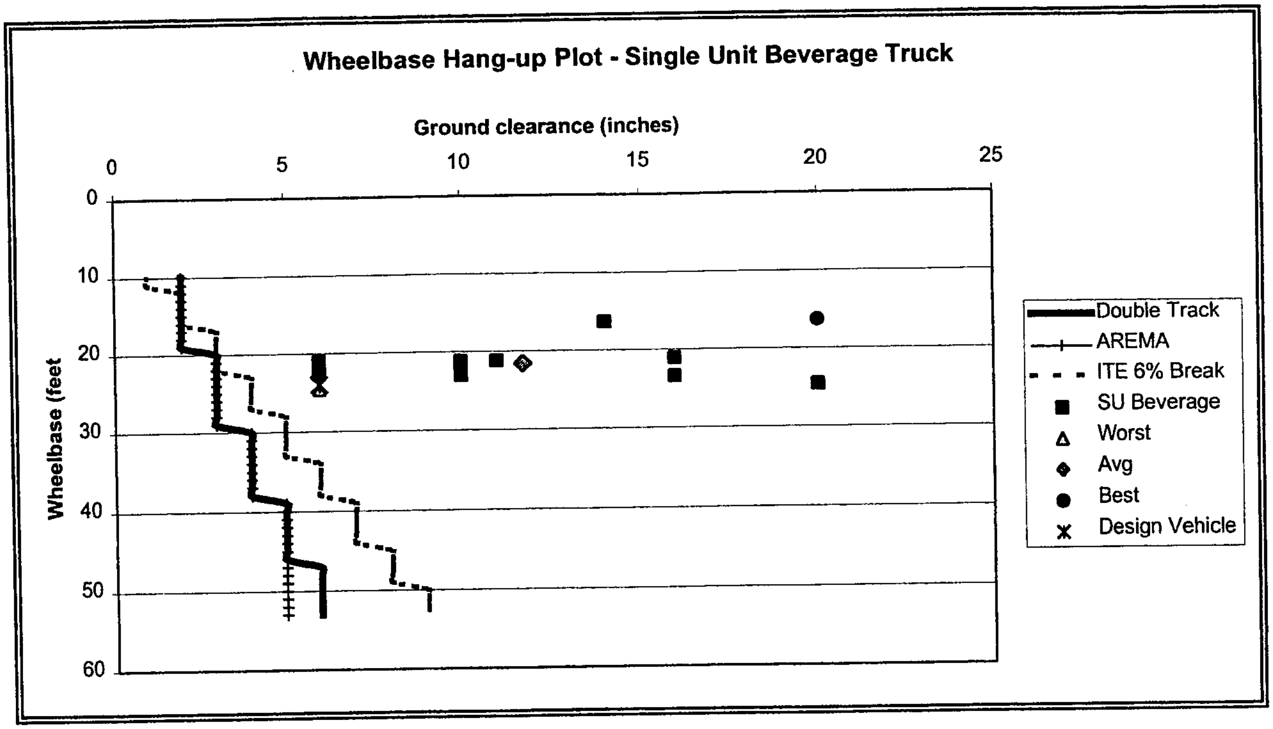
0
5ft
10ft
0
1m
2m
3m
11 in [0.28 m]
10 in [0 25 m]
9 in [0.22 m]
20.0 ft [6.10 m]
7.0 ft [2.14 m]
12.0 ft [3.66 m]

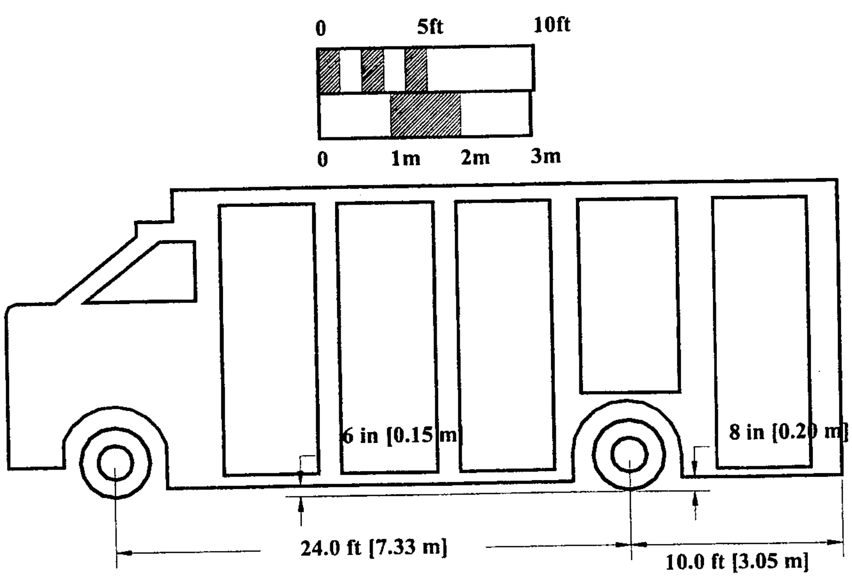


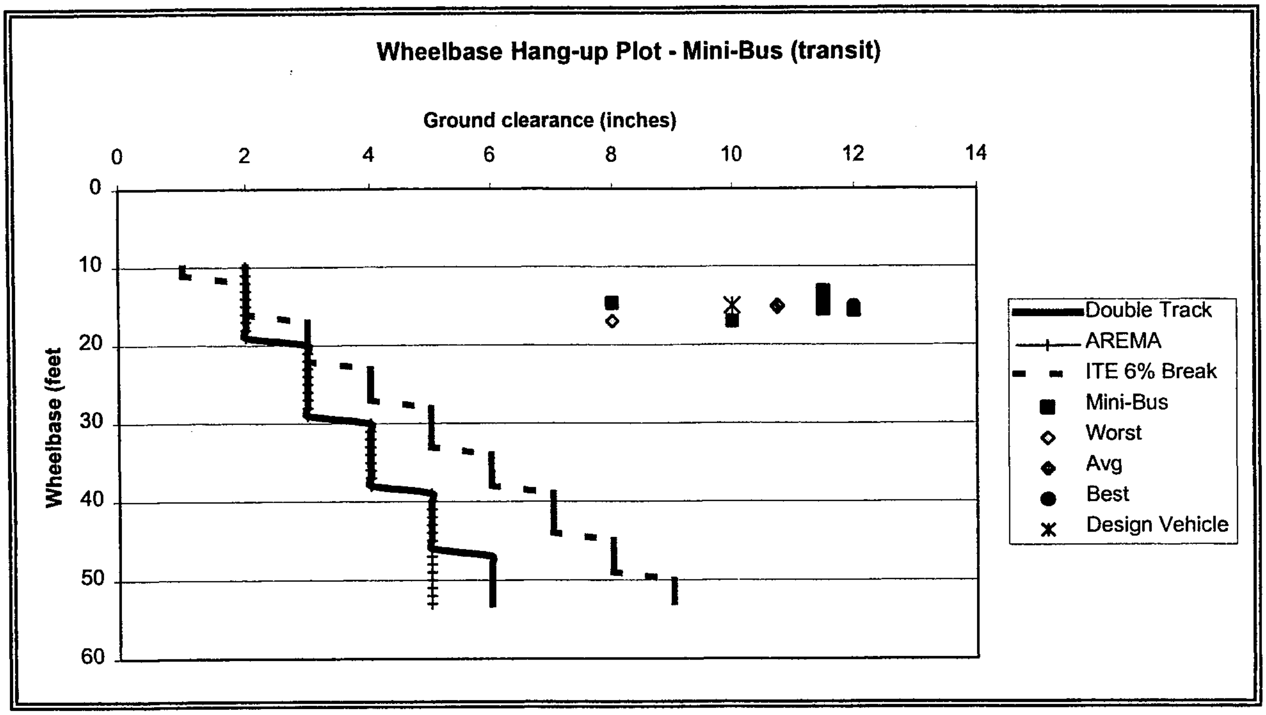
Wheelbase Hang-up Plot - Pumper Fire Truck
Ground clearance (inches)
0
5
10
15
20
25
Wheelbase (feet
0
10
20
30
40
50
60
Double Track
AREMA
ITE 6% Break
Pumper Fire
Worst
Avg
Best
Design Vehicles

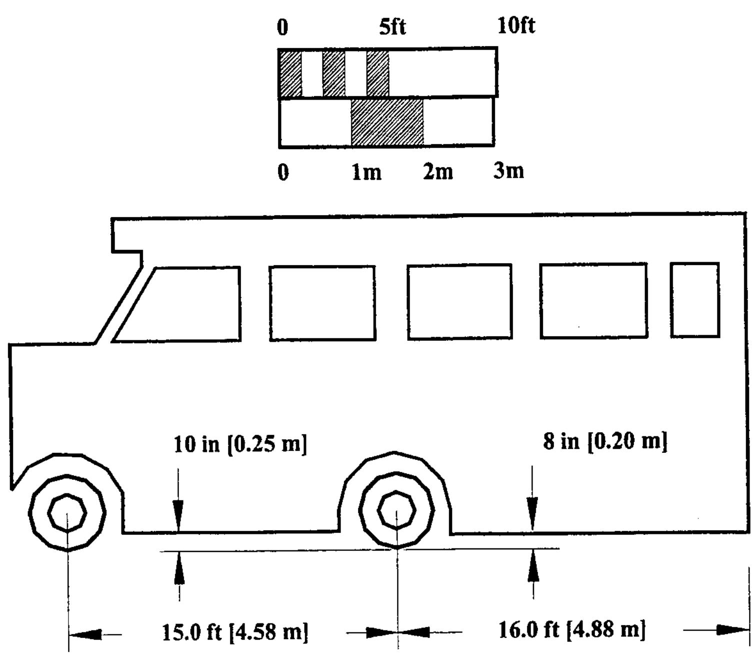


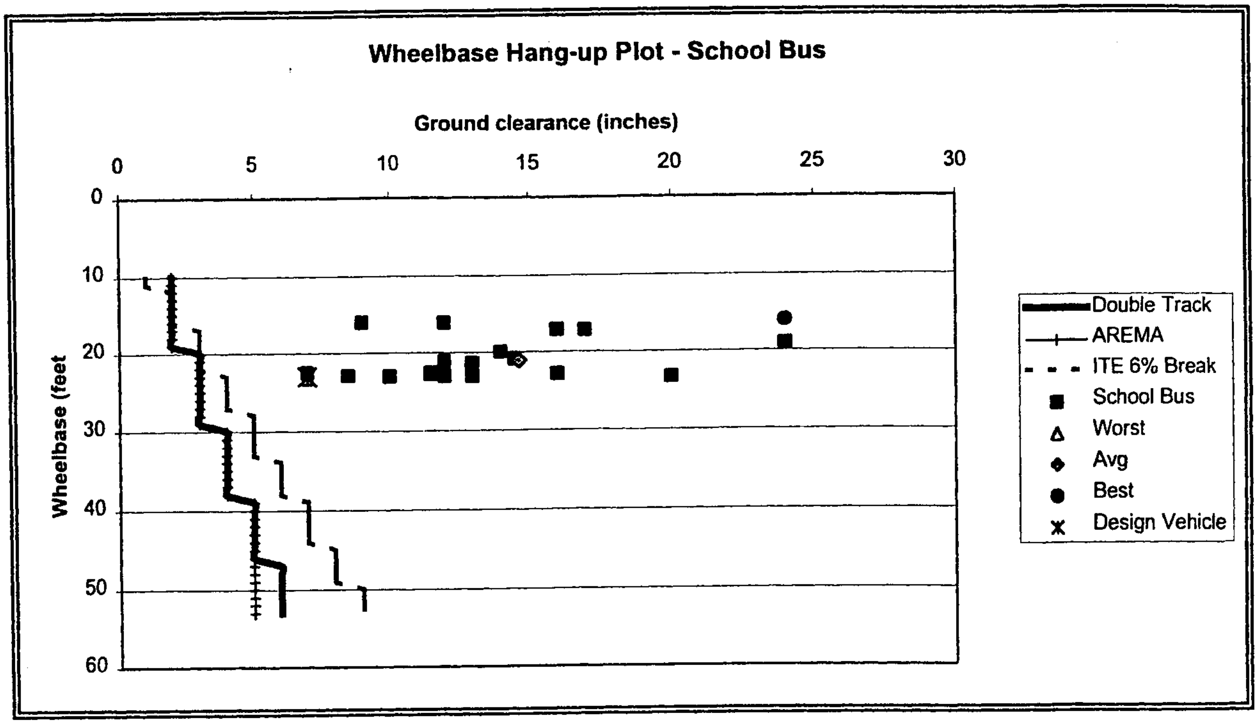
0
5ft
10ft
0
1m
2m
3m
8 in [0.20 m]
10 in [0 25 m]
7 in [0.17 m]
22.0 ft [6.71 m]
8.0 ft [2.44 m]
10.0 ft [3.05 m]


Wheelbase Hang-up Plot - Single Unit Beverage Truck
Ground clearance (inches)
0
5
10
15
20
25
0
10
20
30
40
50
60
Wheelbase (feet
Double Track
AREMA
ITE 6% Break
SU Beverage
Worst
Avg
Best
Design Vehicle

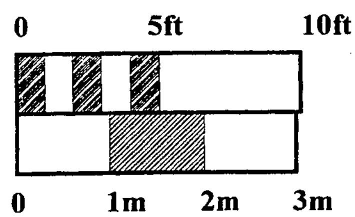

0
5ft
10ft
0
1m
2m
3m
6 in [0.15 m]
8 in [0.20 m]
24.0 ft [7.33 m]
10.0 ft [3.05 m]


Wheelbase Hang-up Plot - Mini-Bus (transit)
Ground clearance (inches)
0
2
4
6
8
10
12
14
Wheelbase (feet
0
10
20
30
40
50
60
Double Track
AREMA
ITE 6% Break
Mini-Bus
Worst
Avg
Best
Design Vehicle

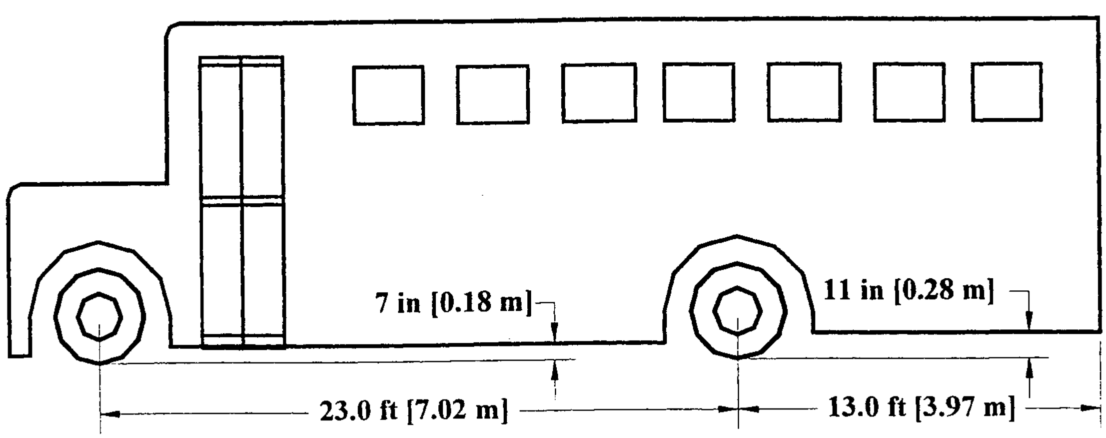

0
5ft
10ft
0
1m
2m
3m
10 in [0.25 m]
8 in [0.20 m]
15.0 ft [4.58 m]
16.0 ft [4.88 m]



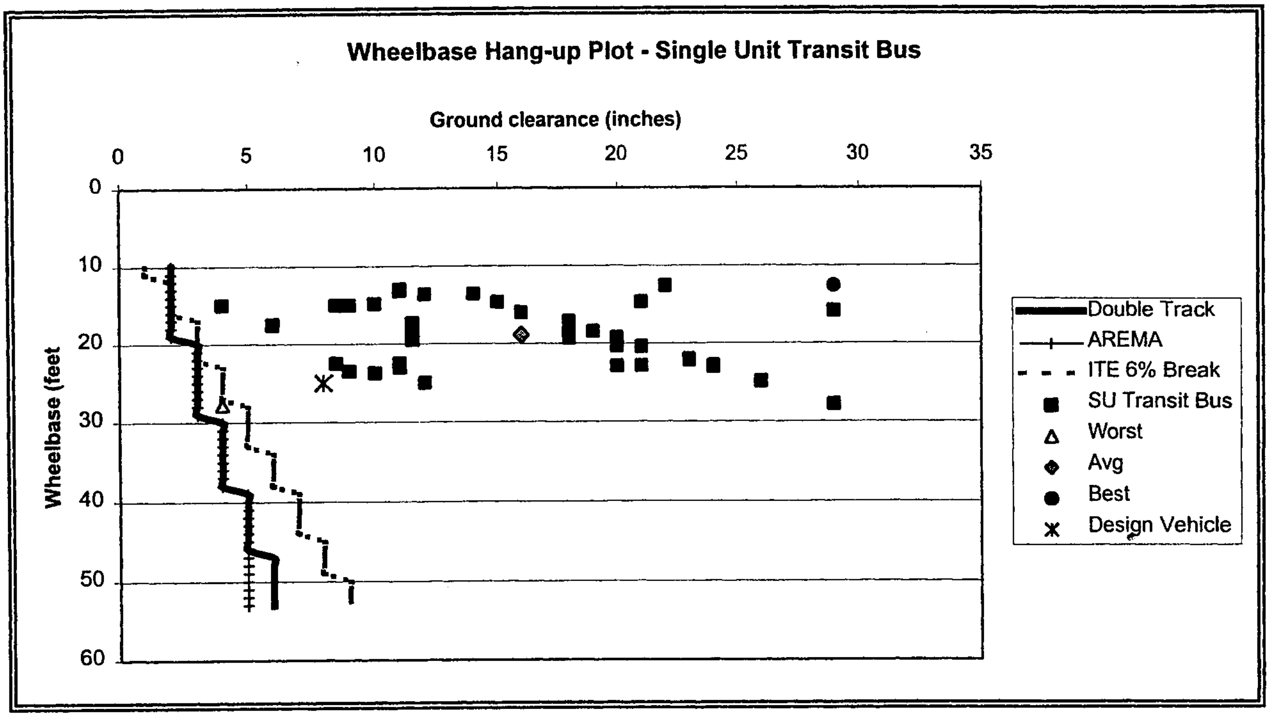
Wheelbase Hang-up Plot - School Bus
Ground clearance (inches)
0
5
10
15
20
25
30
Wheelbase (feet
0
10
20
30
40
50
60
Double Track
AREMA
ITE 6% Break
School Bus
Worst
Avg
Best
Design Vehicle



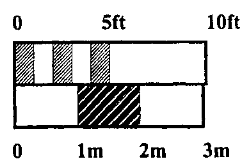
0
5ft
10ft
0
1m
2m
3m



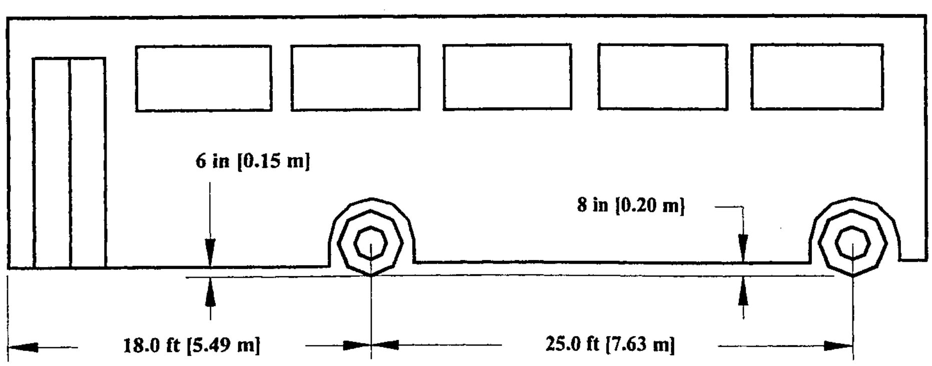
7 in [0.18 m]
11 in [0.28 m]
23.0 ft [7.02 m]
13.0 ft [3.97 m]



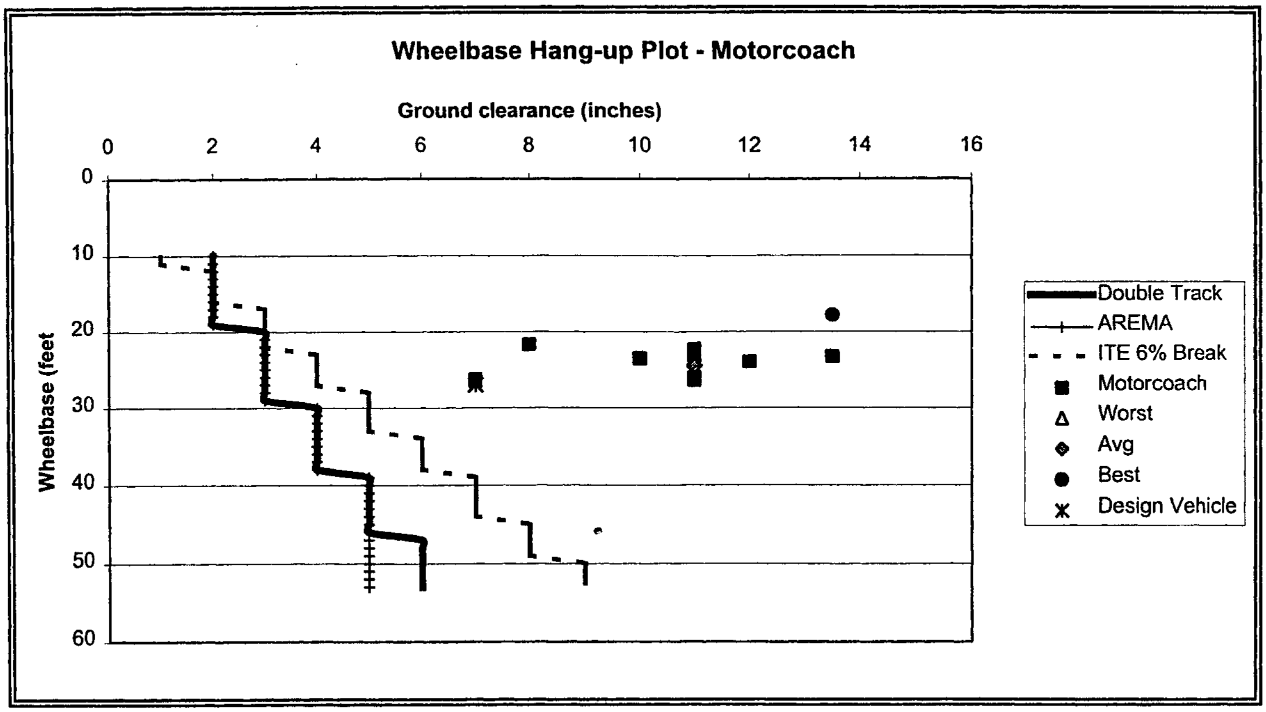
Wheelbase Hang-up Plot - Single Unit Transit Bus
Ground clearance (inches)
0
5
10
15
20
25
30
35
Wheelbase (feet
0
10
20
30
40
50
60
Double Track
AREMA
ITE 6% Break
SU Transit Bus
Worst
Avg
Best
Design Vehicle

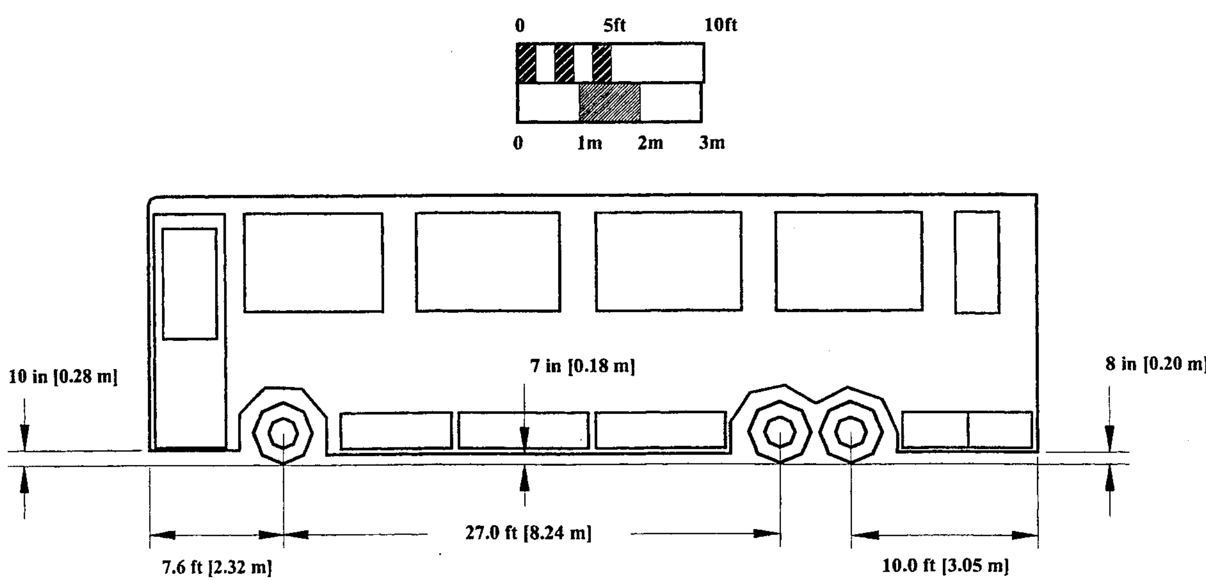


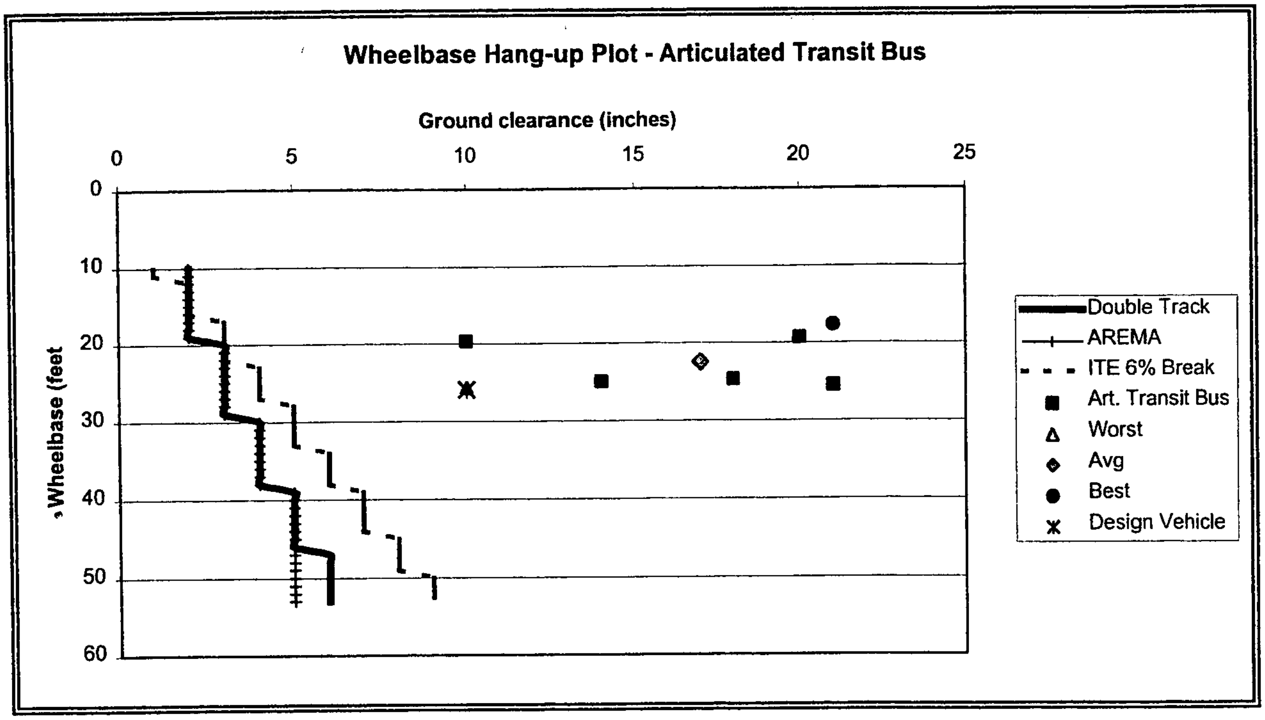
0
5ft
10ft
0
1m
2m
3m

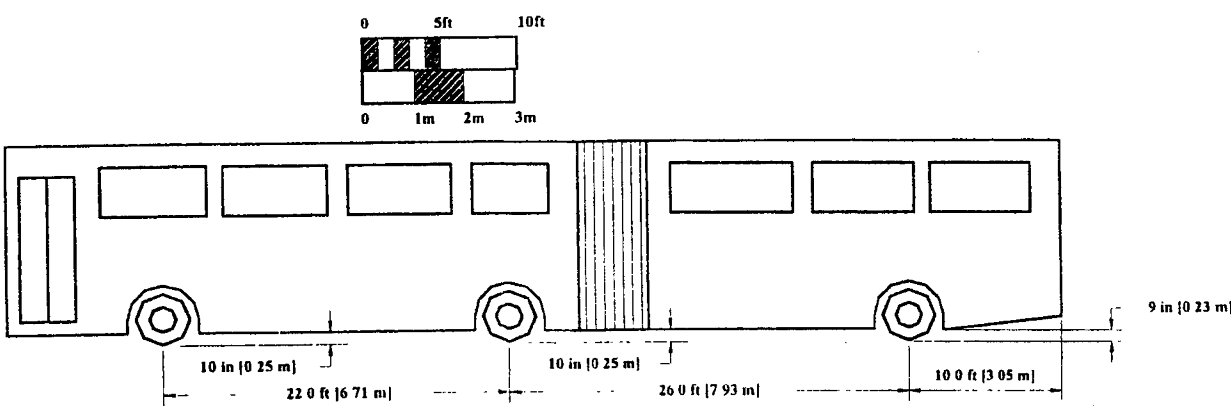


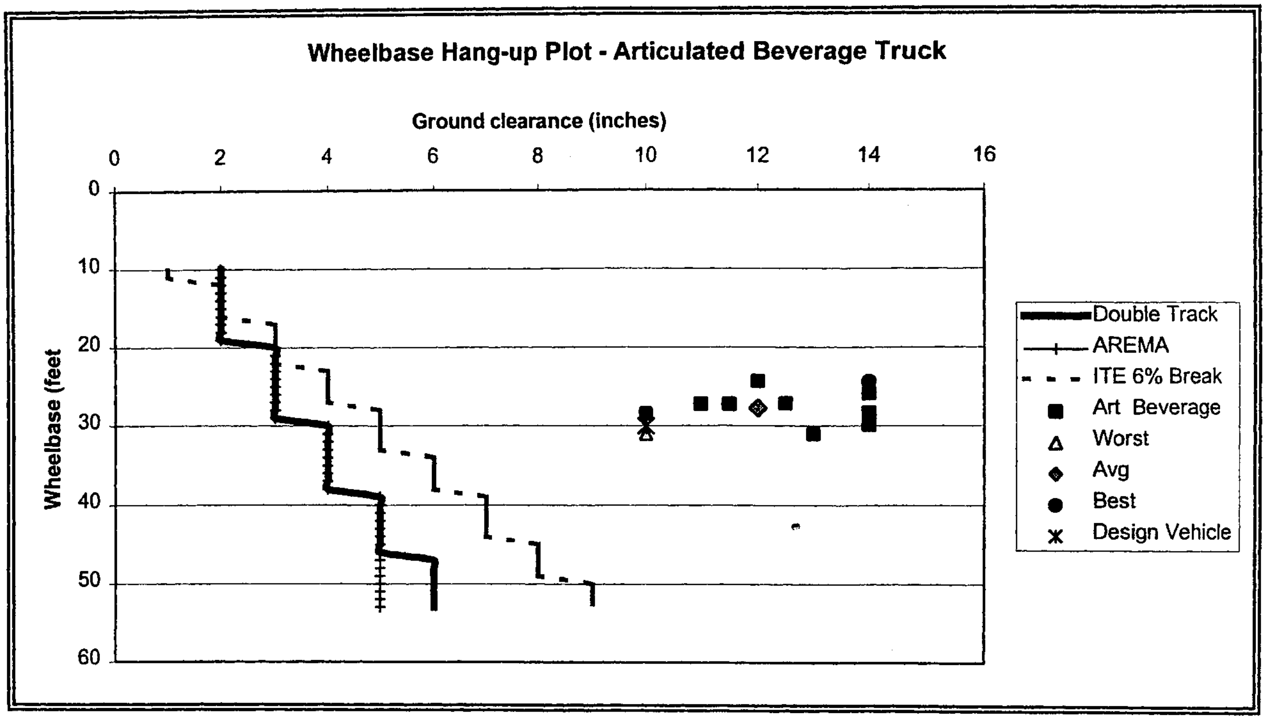
6 in [0.15 m]
8 in [0.20 m]
18.0 ft [5.49 m]
25.0 ft [7.63 m]

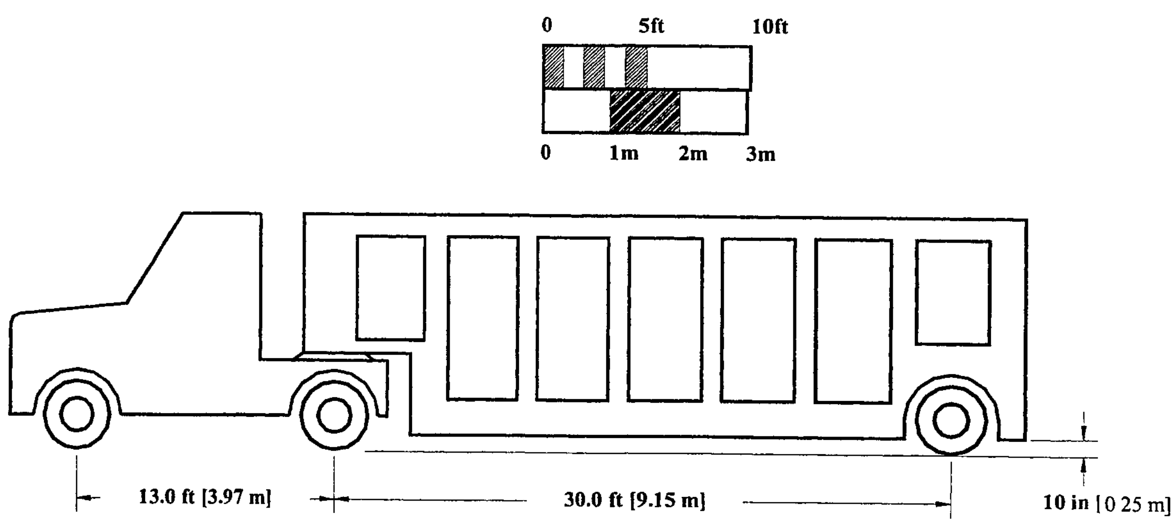

Wheelbase Hang-up Plot - Motorcoach
Ground clearance (inches)
0 2 4 6 8 10 12 14 16
Wheelbase (feet
0 10 20 30 40 50 60
Double Track
AREMA
ITE 6% Break
Motorcoach
Worst
Avg
Best
Design Vehicle

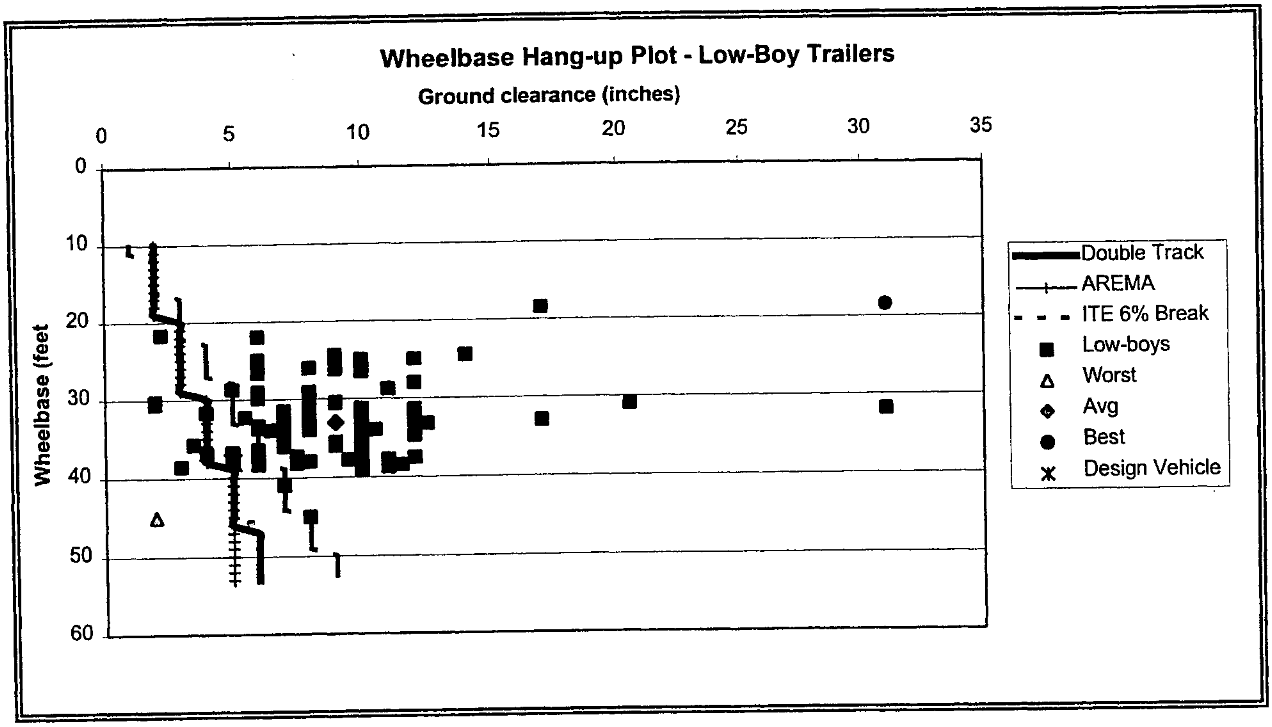

0 5ft 10ft
0 1m 2m 3m
10 in [0.28 m]
7 in [0.18 m]
8 in [0.20 m]
7.6 ft [2.32 m]
27.0 ft [8.24 m]
10.0 ft [3.05 m]


Wheelbase Hang-up Plot - Articulated Transit Bus
Ground clearance (inches)
0
5
10
15
20
25
0
10
20
30
40
50
60
Wheelbase (feet
Double Track
AREMA
ITE 6% Break
Art. Transit Bus
Worst
Avg
Best
Design Vehicle

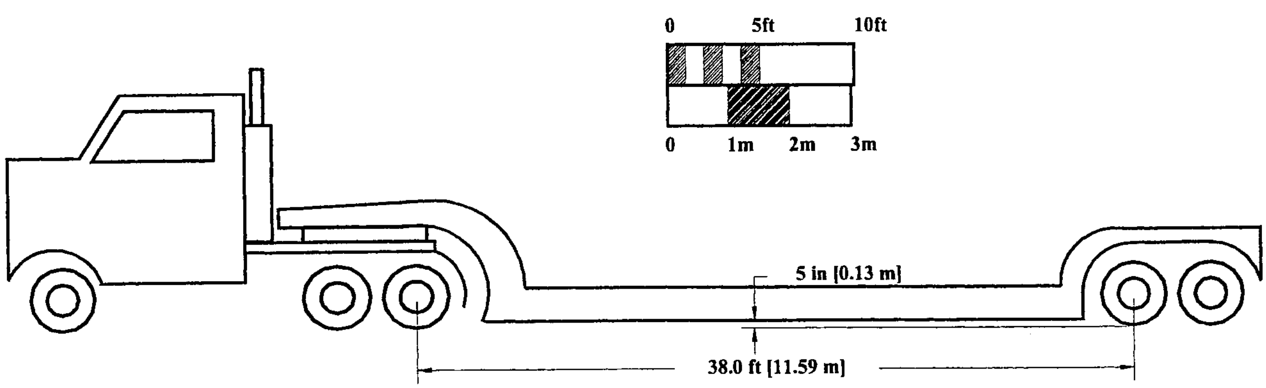

0
5ft
10ft
0
1m
2m
3m
9 in [0 23 m]
10 in [0 25 m]
10 in [0 25 m]
22 0 ft [6 71 m]
26 0 ft [7 93 m]
10 0 ft [3 05 m]


Wheelbase Hang-up Plot - Articulated Beverage Truck
Ground clearance (inches)
0
2
4
6
8
10
12
14
16
Wheelbase (feet
0
10
20
30
40
50
60
Double Track
AREMA
ITE 6% Break
Art Beverage
Worst
Avg
Best
Design Vehicle

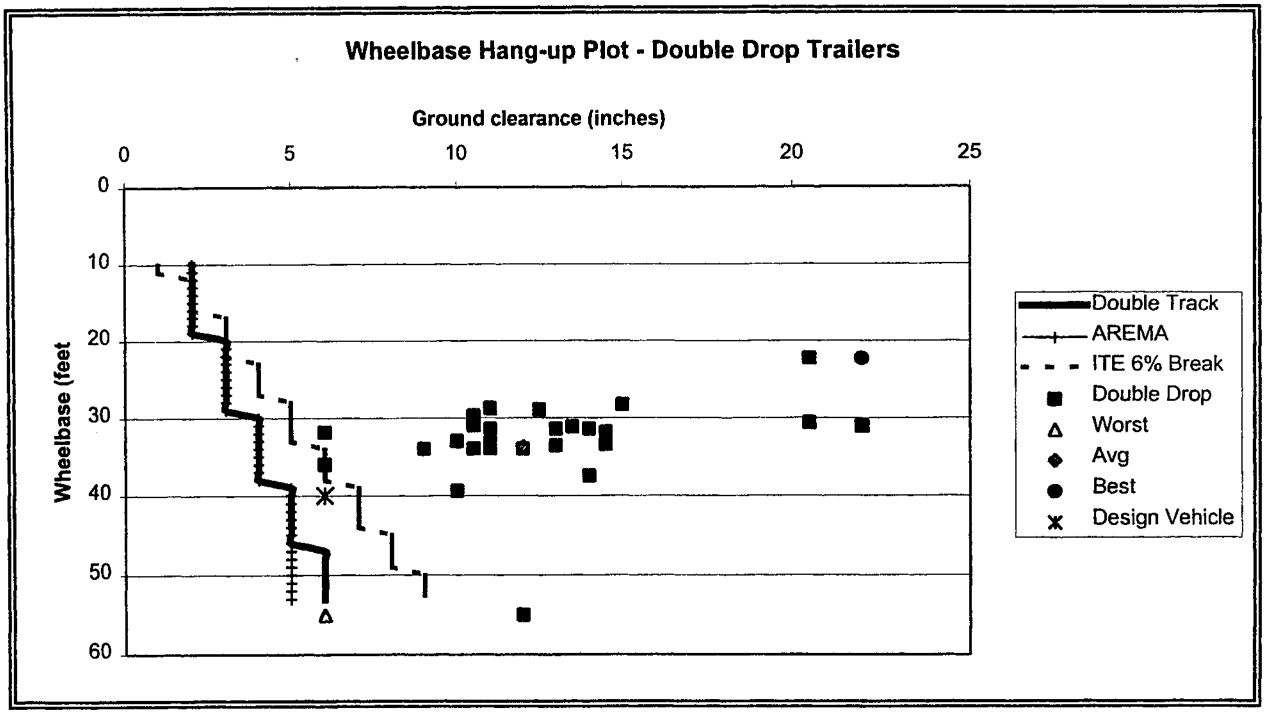

0
5ft
10ft
0
1m
2m
3m
13.0 ft [3.97 m]
30.0 ft [9.15 m]
10 in [0 25 m]



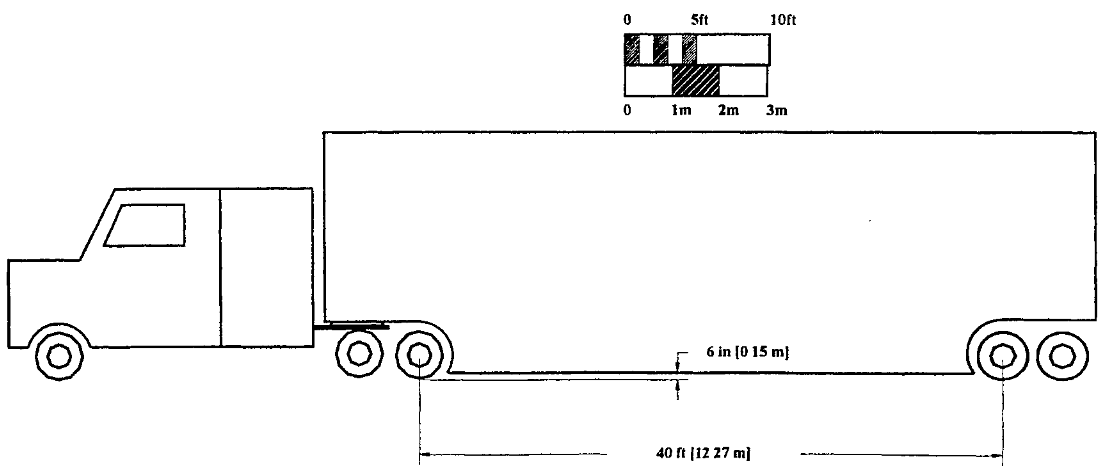
Wheelbase Hang-up Plot - Low-Boy Trailers
Ground clearance (inches)
0
5
10
15
20
25
30
35
Wheelbase (feet
0
10
20
30
40
50
60
Double Track
AREMA
ITE 6% Break
Low-boys
Worst
Avg
Best
Design Vehicle



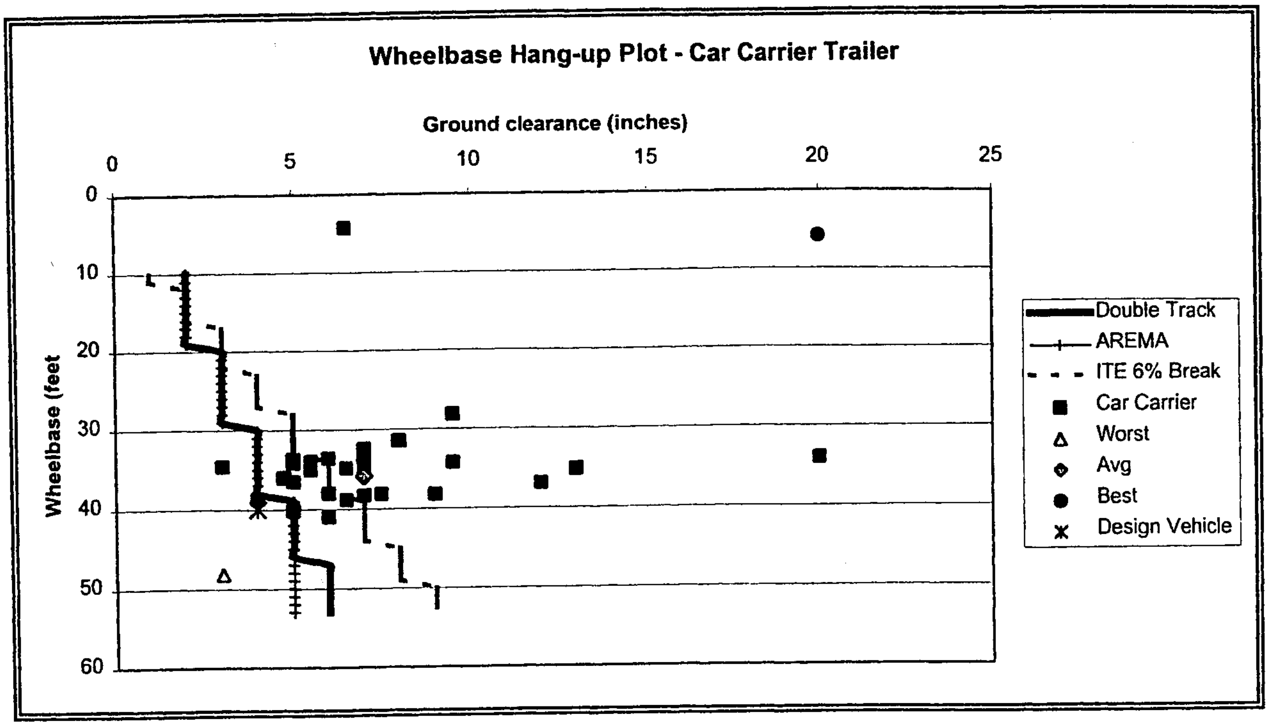
0
5ft
10ft
0
1m
2m
3m
5 in [0.13 m]
38.0 ft [11.59 m]

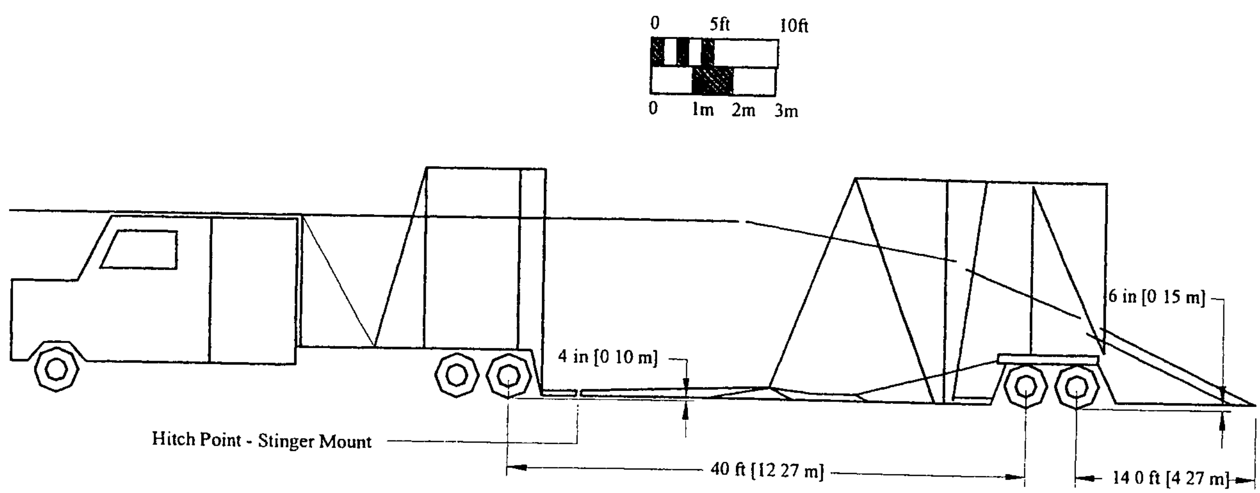


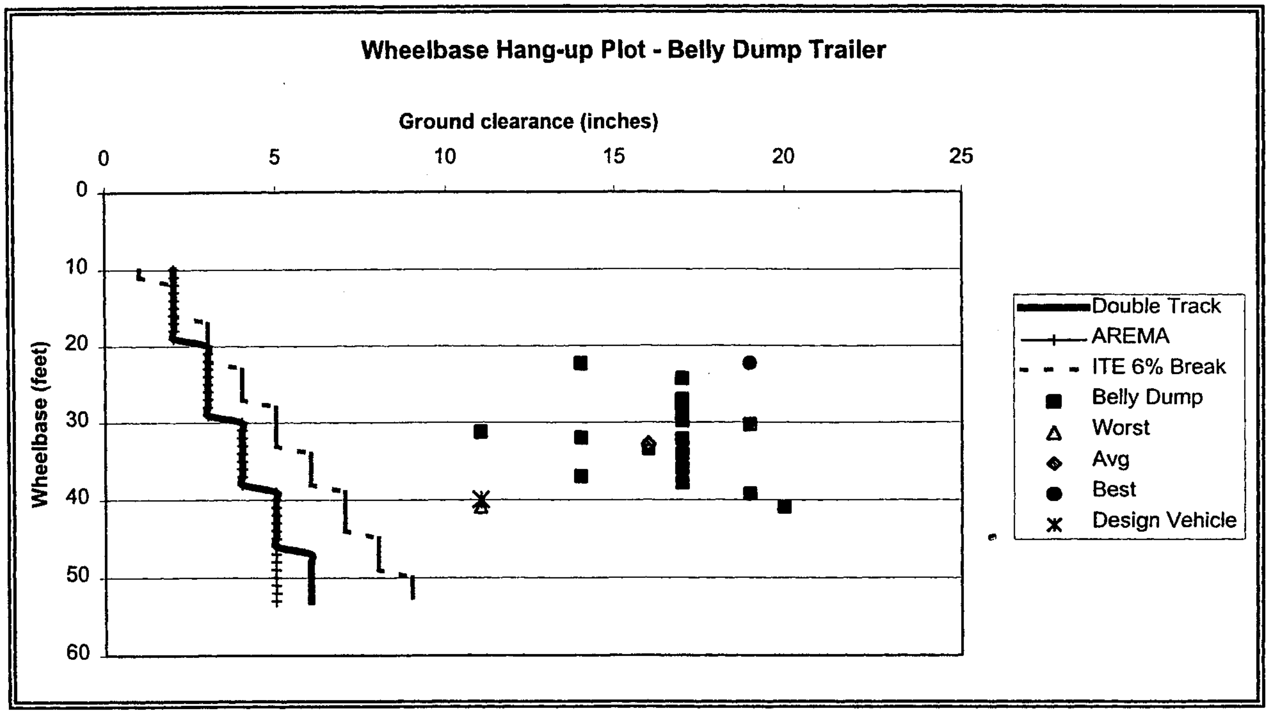
Wheelbase Hang-up Plot - Double Drop Trailers
Ground clearance (inches)
0
5
10
15
20
25
Wheelbase (feet
0
10
20
30
40
50
60
Double Track
AREMA
ITE 6% Break
Double Drop
Worst
Avg
Best
Design Vehicle



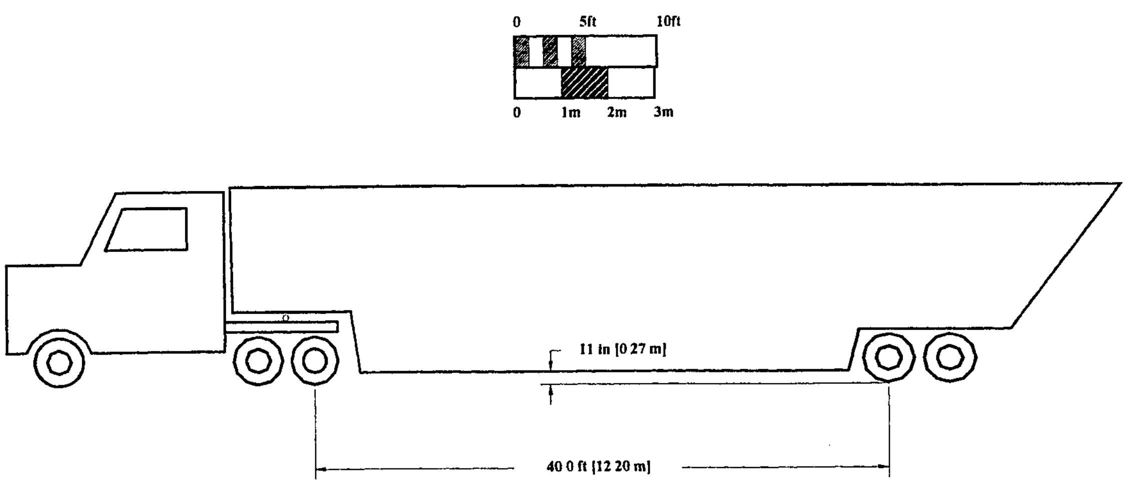
0
5ft
10ft
0
1m
2m
3m
6 in [0 15 m]
40 ft [12 27 m]


Wheelbase Hang-up Plot - Car Carrier Trailer
Ground clearance (inches)
0
5
10
15
20
25
Wheelbase (feet
0
10
20
30
40
50
60
Double Track
AREMA
ITE 6% Break
Car Carrier
Worst
Avg
Best
Design Vehicle

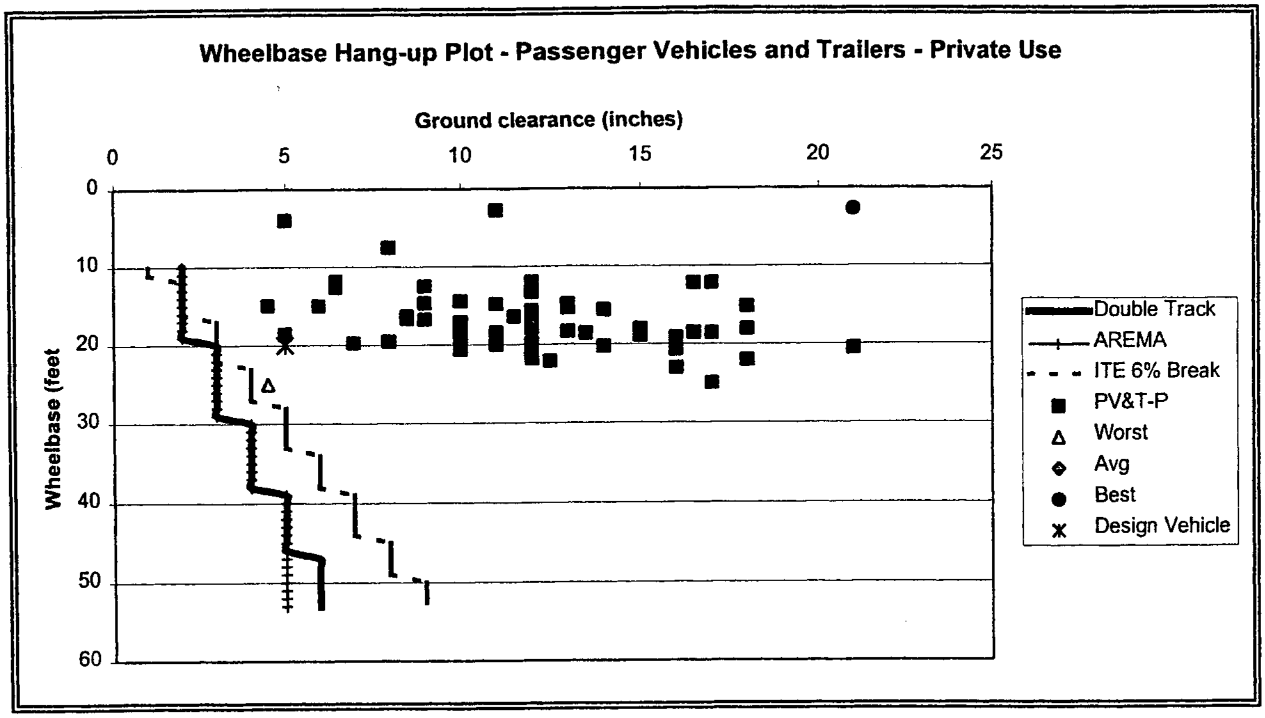

0
5ft
10ft
0
1m
2m
3m
4 in [0 10 m]
6 in [0 15 m]
Hitch Point - Stinger Mount
40 ft [12 27 m]
14 0 ft [4 27 m]

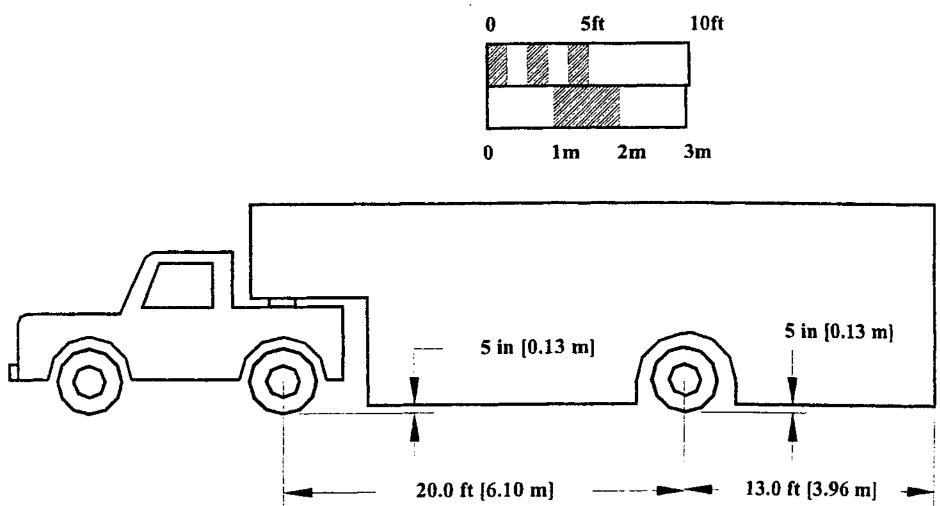


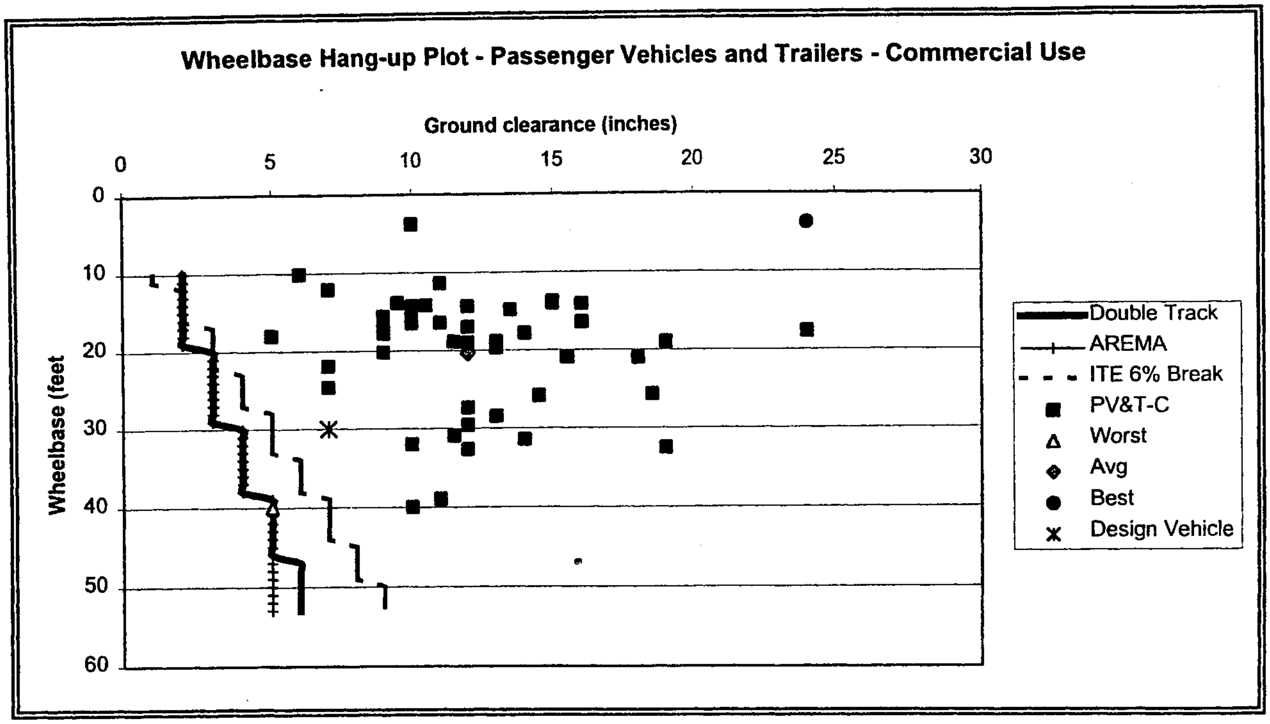
Wheelbase Hang-up Plot - Belly Dump Trailer
Ground clearance (inches)
0
5
10
15
20
25
Wheelbase (feet)
0
10
20
30
40
50
60
Double Track
AREMA
ITE 6% Break
Belly Dump
Worst
Avg
Best
Design Vehicle

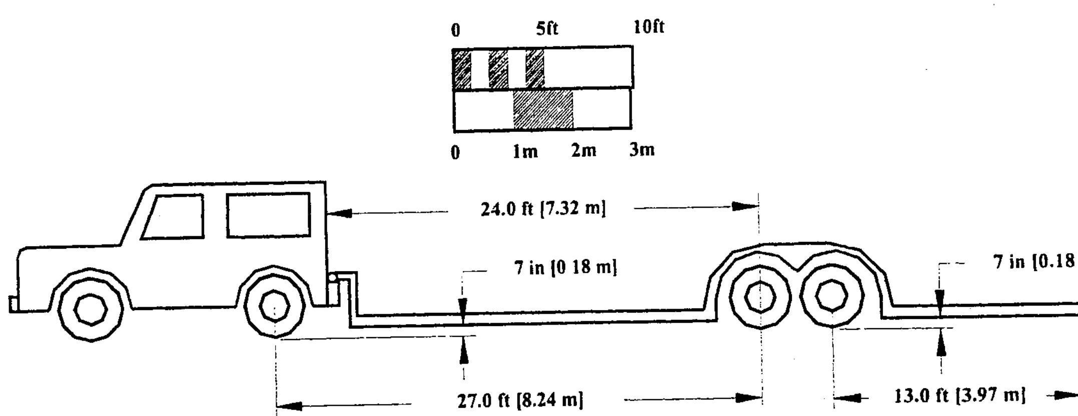


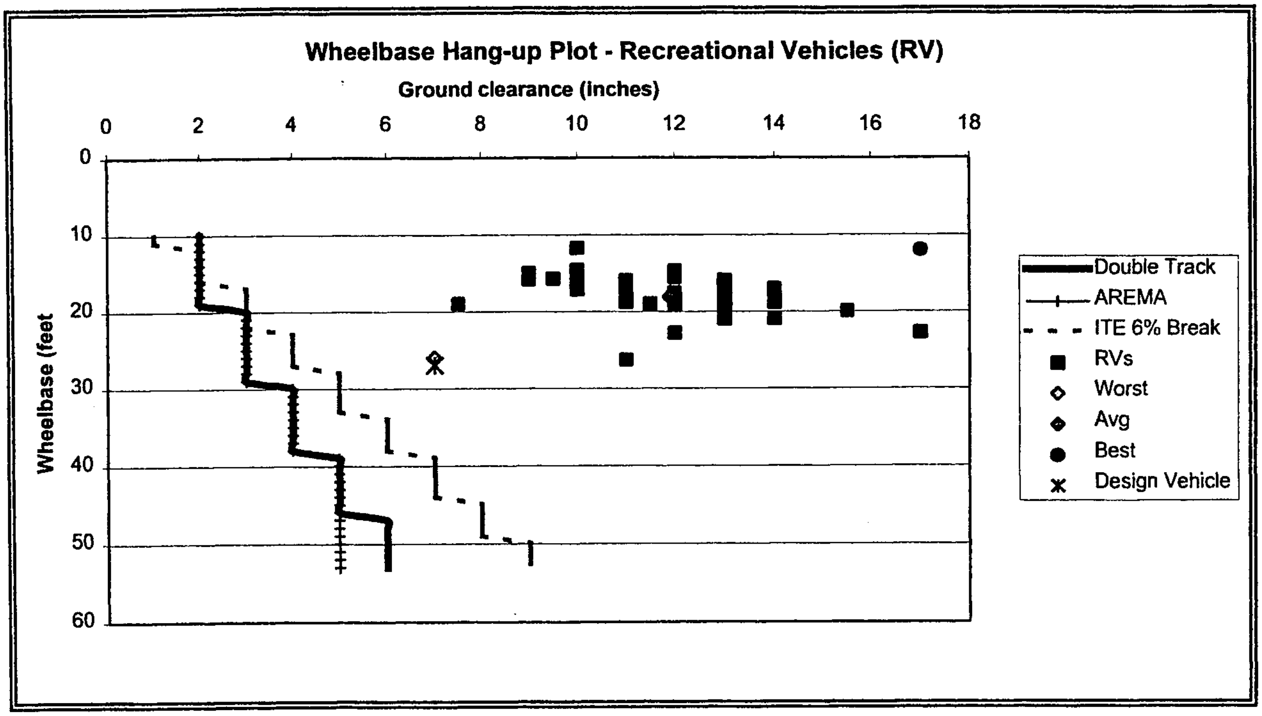
0
5ft
10ft
0
1m
2m
3m
11 in [0 27 m]
40 0 ft [12 20 m]

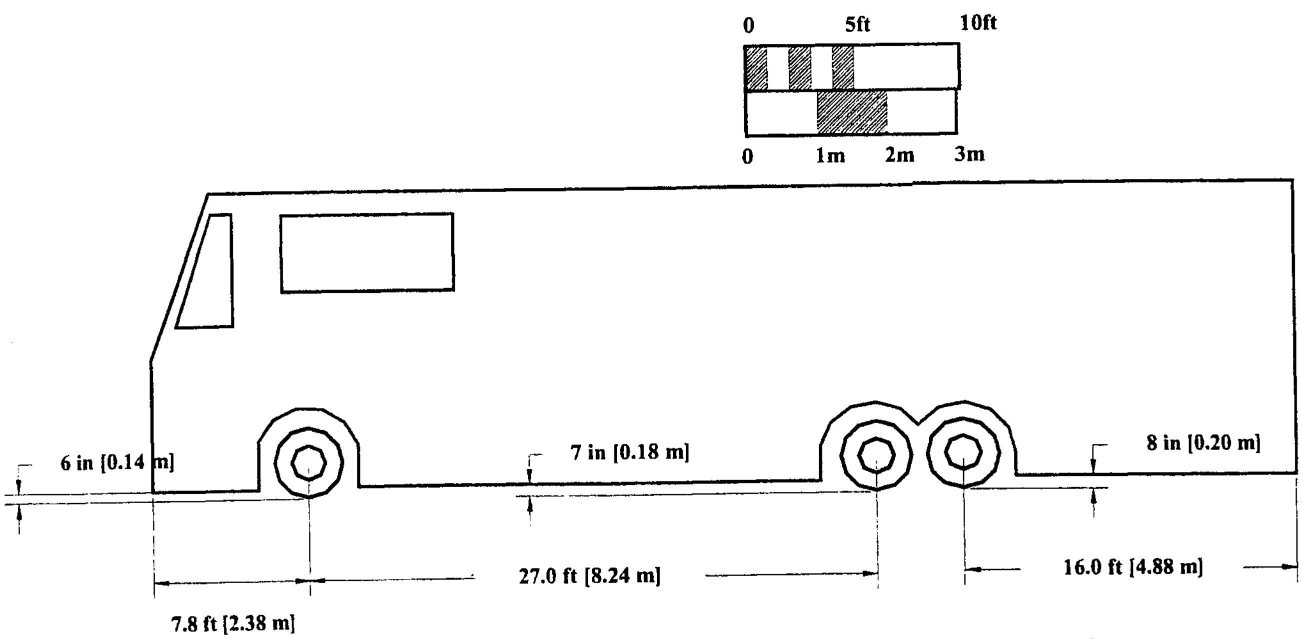

Wheelbase Hang-up Plot - Passenger Vehicles and Trailers - Private Use
Ground clearance (inches)
0
5
10
15
20
25
Wheelbase (feet
0
10
20
30
40
50
60
Double Track
AREMA
ITE 6% Break
PV&T-P
Worst
Avg
Best
Design Vehicle

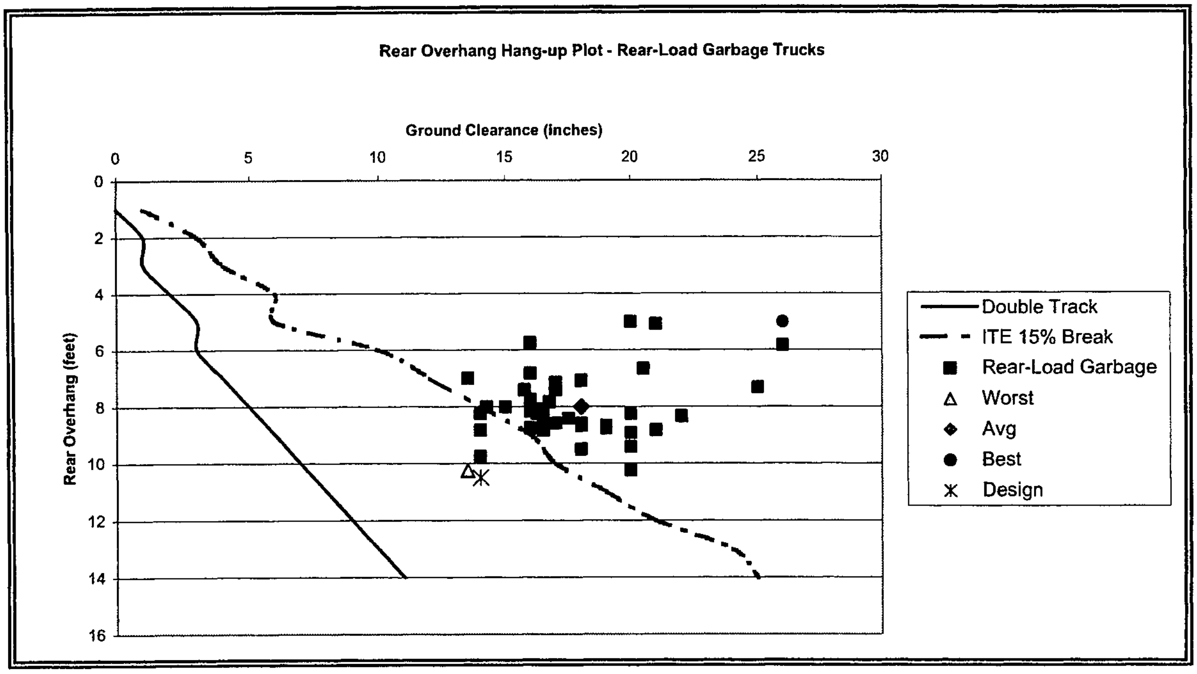

0
5ft
10ft
0
1m
2m
3m
5 in [0.13 m]
5 in [0.13 m]
20.0 ft [6.10 m]
13.0 ft [3.96 m]

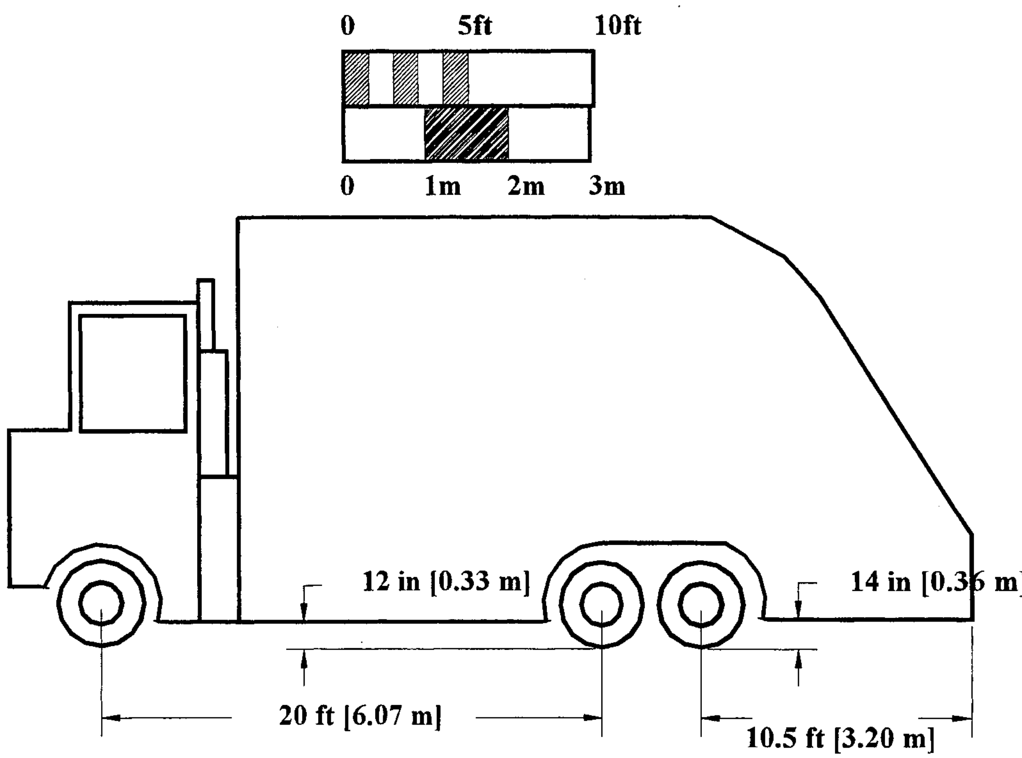

Wheelbase Hang-up Plot - Passenger Vehicles and Trailers - Commercial Use
Ground clearance (inches)
0
5
10
15
20
25
30
Wheelbase (feet
0
10
20
30
40
50
60
Double Track
AREMA
ITE 6% Break
PV&T-C
Worst
Avg
Best
Design Vehicle

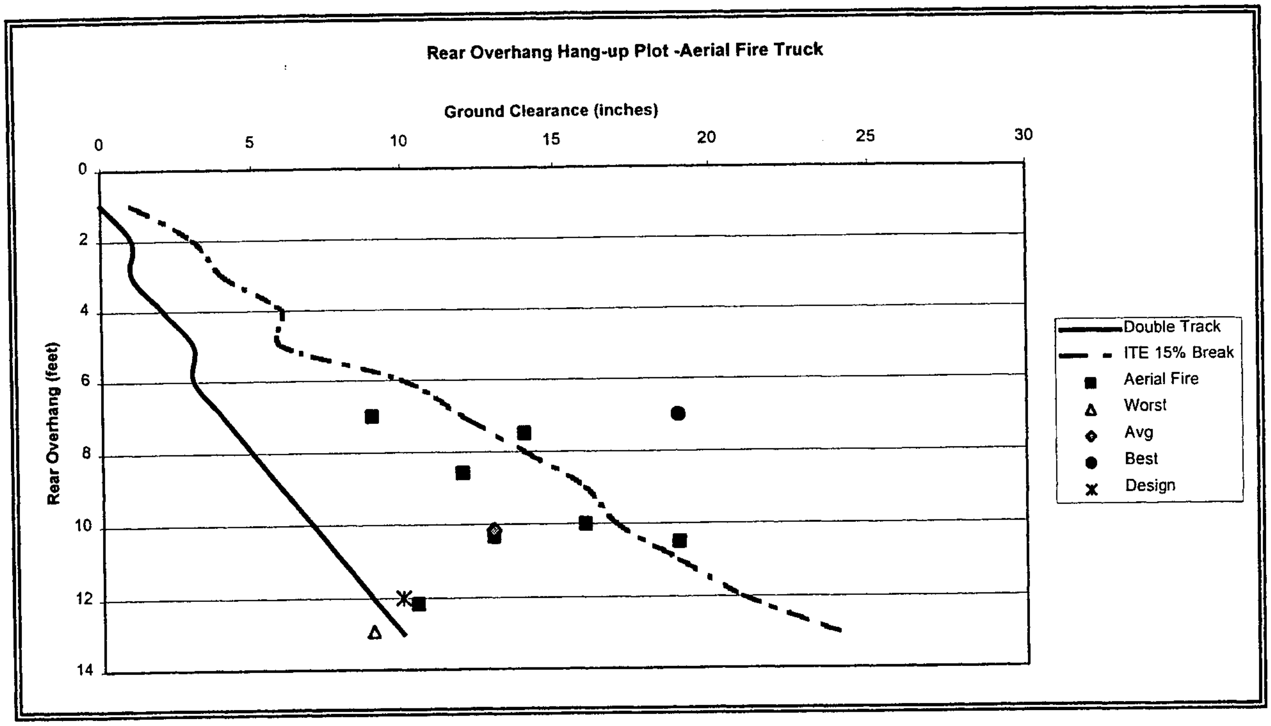

0
5ft
10ft
0
1m
2m
3m
24.0 ft [7.32 m]
7 in [0 18 m]
7 in [0.18 m]
27.0 ft [8.24 m]
13.0 ft [3.97 m]

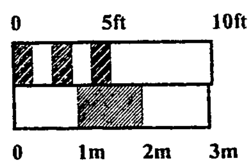

Wheelbase Hang-up Plot - Recreational Vehicles (RV)
Ground clearance (inches)
0 2 4 6 8 10 12 14 16 18
Wheelbase (feet
0 10 20 30 40 50 60
Double Track
AREMA
ITE 6% Break
RVs
Worst
Avg
Best
Design Vehicle

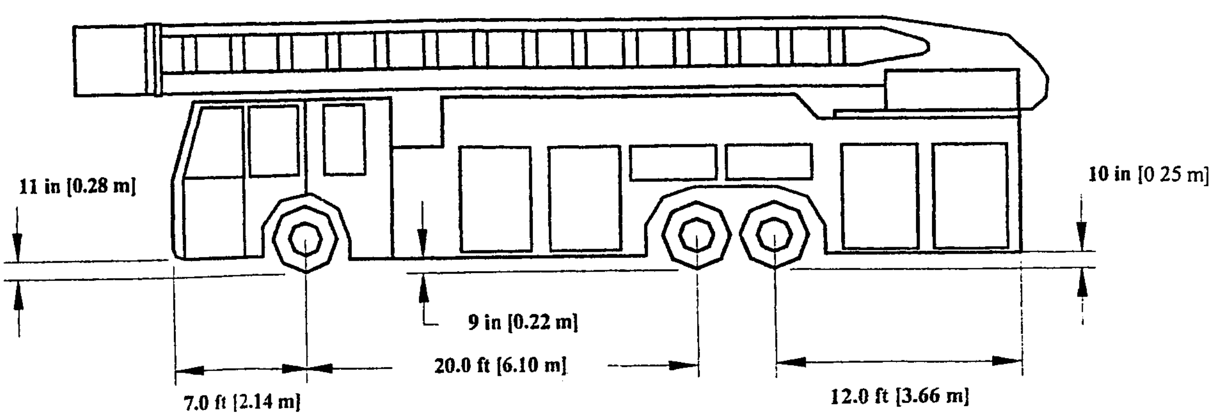

0 5ft 10ft
0 1m 2m 3m
6 in [0.14 m]
7 in [0.18 m]
8 in [0.20 m]
7.8 ft [2.38 m]
27.0 ft [8.24 m]
16.0 ft [4.88 m]

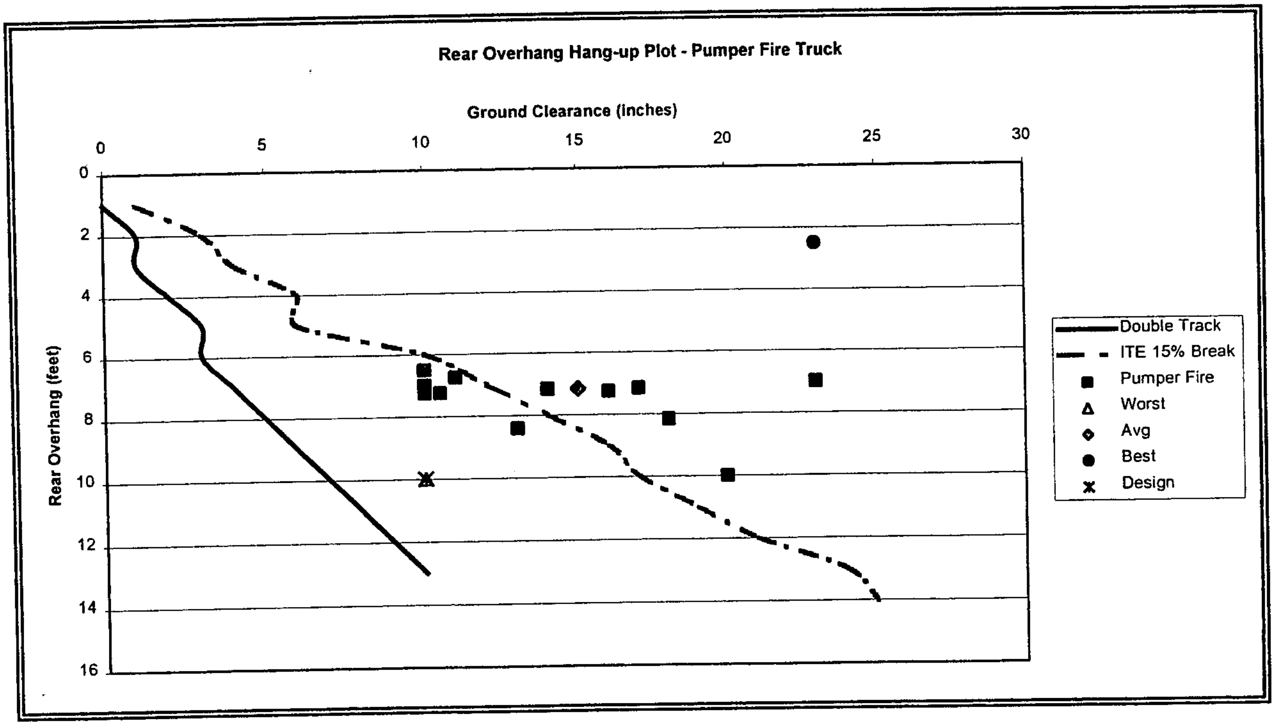

Rear Overhang Hang-up Plot - Rear-Load Garbage Trucks
Ground Clearance (inches)
0
5
10
15
20
25
30
Rear Overhang (feet)
0
2
4
6
8
10
12
14
16
Double Track
ITE 15% Break
Rear-Load Garbage
Worst
Avg
Best
Design


0
5ft
10ft
0
1m
2m
3m
12 in [0.33 m]
14 in [0.36 m]
20 ft [6.07 m]
10.5 ft [3.20 m]

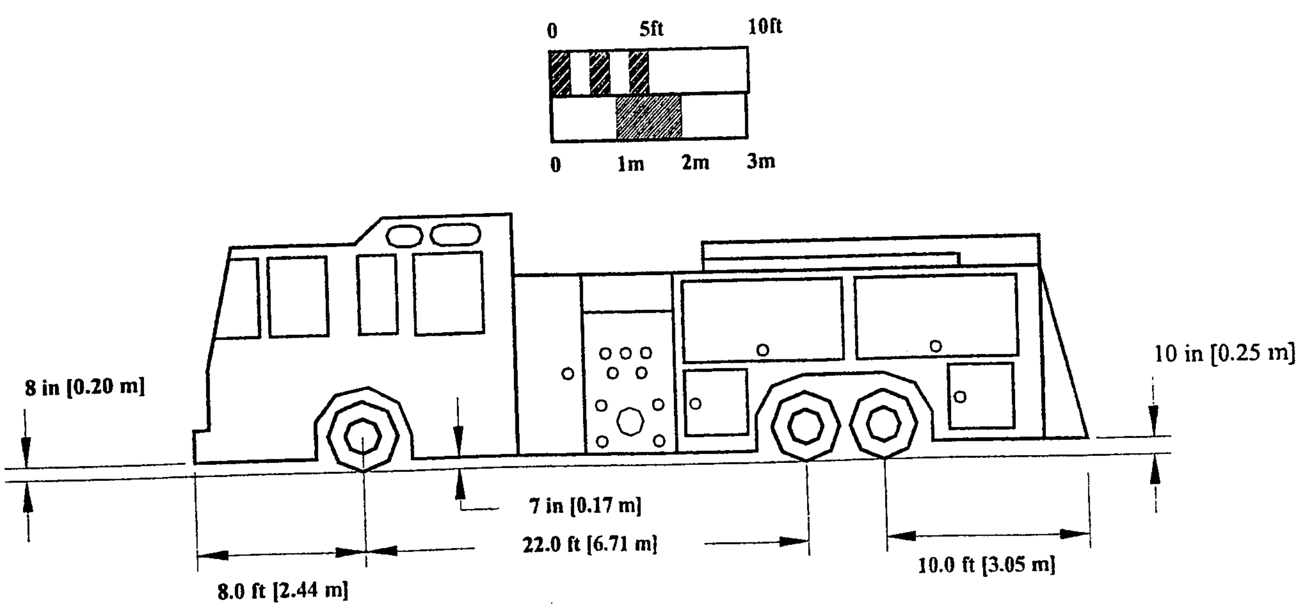

Rear Overhang Hang-up Plot -Aerial Fire Truck
Ground Clearance (inches)
0
5
10
15
20
25
30
Rear Overhang (feet)
0
2
4
6
8
10
12
14
Double Track
ITE 15% Break
Aerial Fire
Worst
Avg
Best
Design


0
5ft
10ft
0
1m
2m
3m

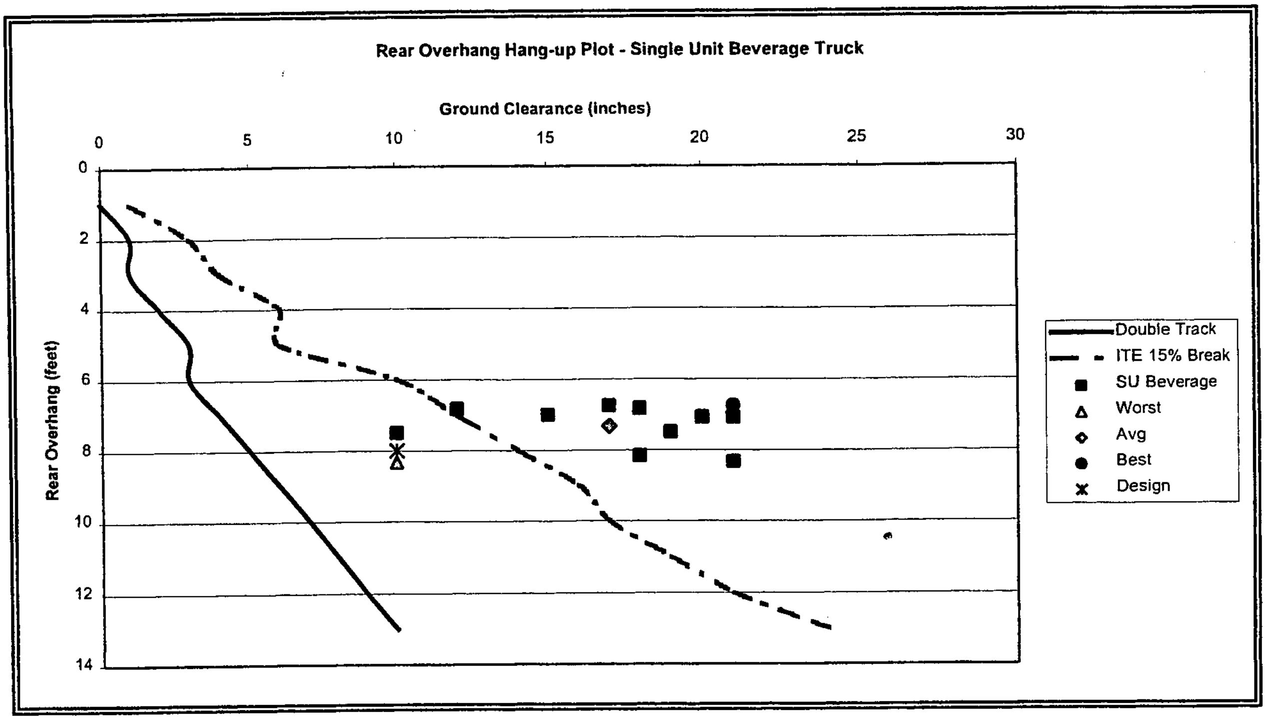

11 in [0.28 m]
10 in [0 25 m]
9 in [0.22 m]
20.0 ft [6.10 m]
7.0 ft [2.14 m]
12.0 ft [3.66 m]



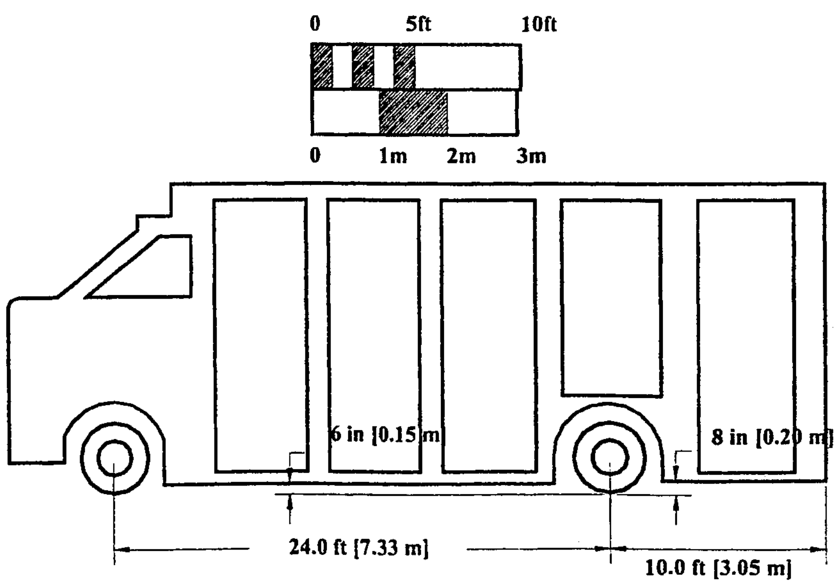
Rear Overhang Hang-up Plot - Pumper Fire Truck
Ground Clearance (inches)
0
5
10
15
20
25
30
Rear Overhang (feet)
0
2
4
6
8
10
12
14
16
Double Track
ITE 15% Break
Pumper Fire
Worst
Avg
Best
Design



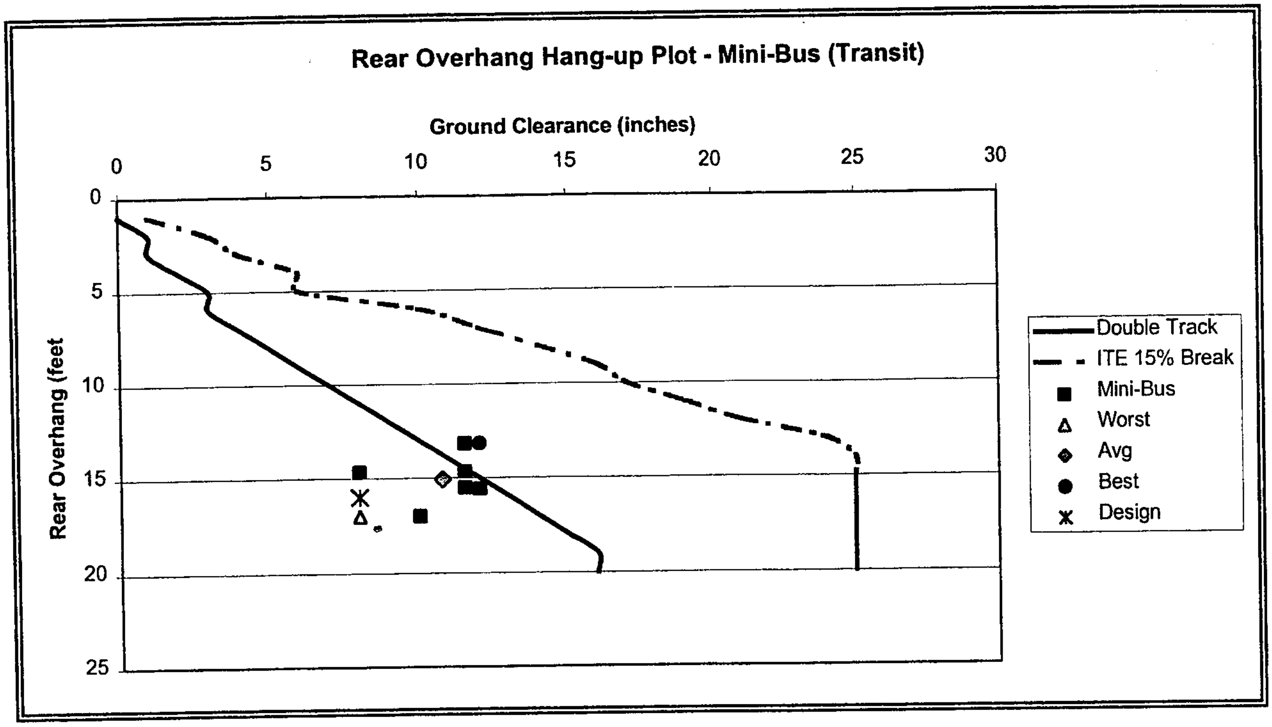
0
5ft
10ft
0
1m
2m
3m
8 in [0.20 m]
10 in [0.25 m]
7 in [0.17 m]
22.0 ft [6.71 m]
8.0 ft [2.44 m]
10.0 ft [3.05 m]

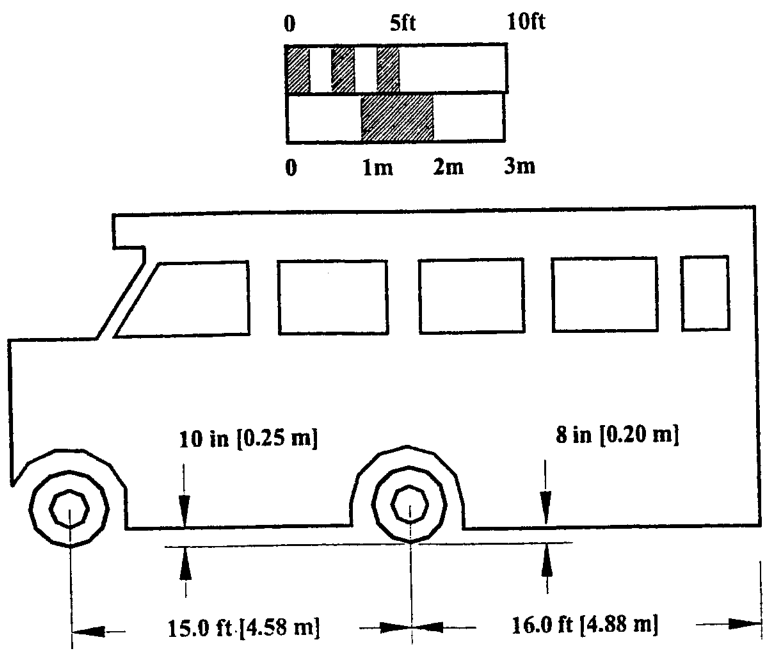


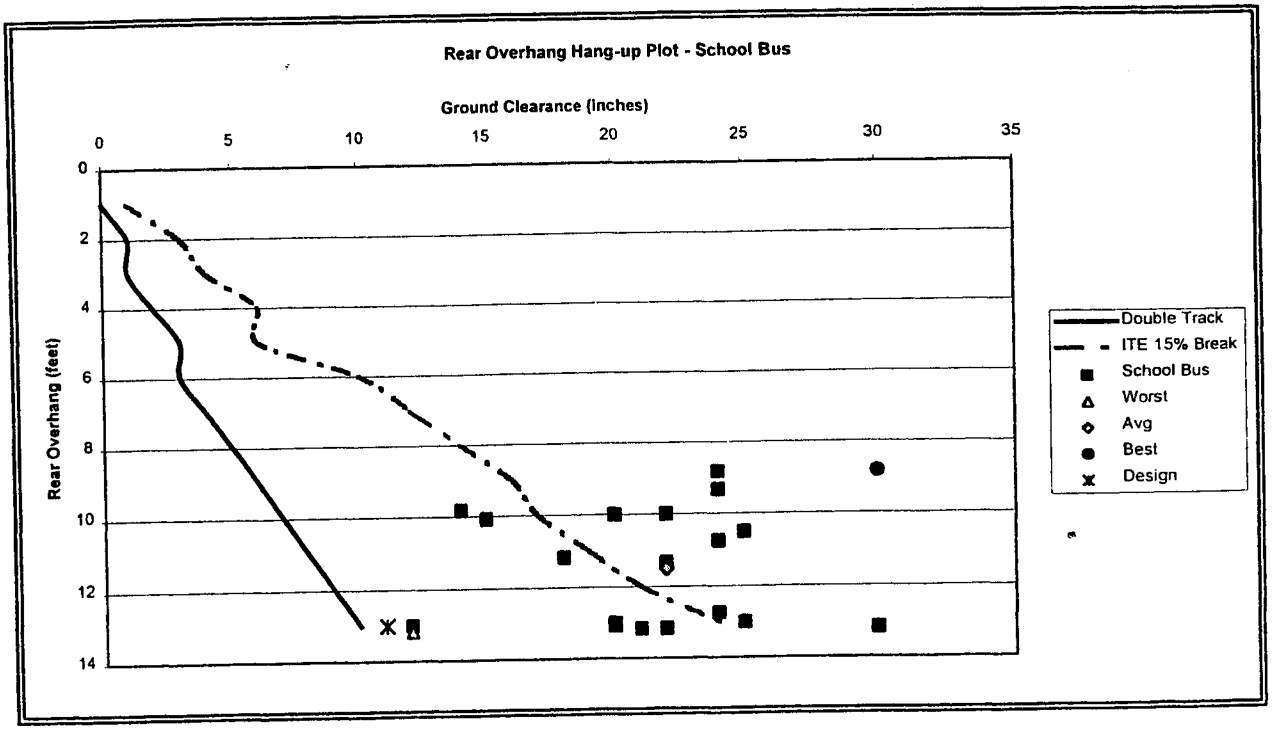
Rear Overhang Hang-up Plot - Single Unit Beverage Truck
Ground Clearance (inches)
0
5
10
15
20
25
30
Rear Overhang (feet)
0
2
4
6
8
10
12
14
Double Track
ITE 15% Break
SU Beverage
Worst
Avg
Best
Design

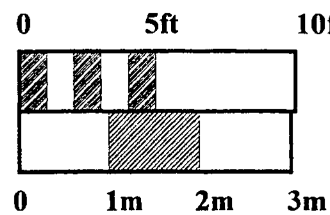


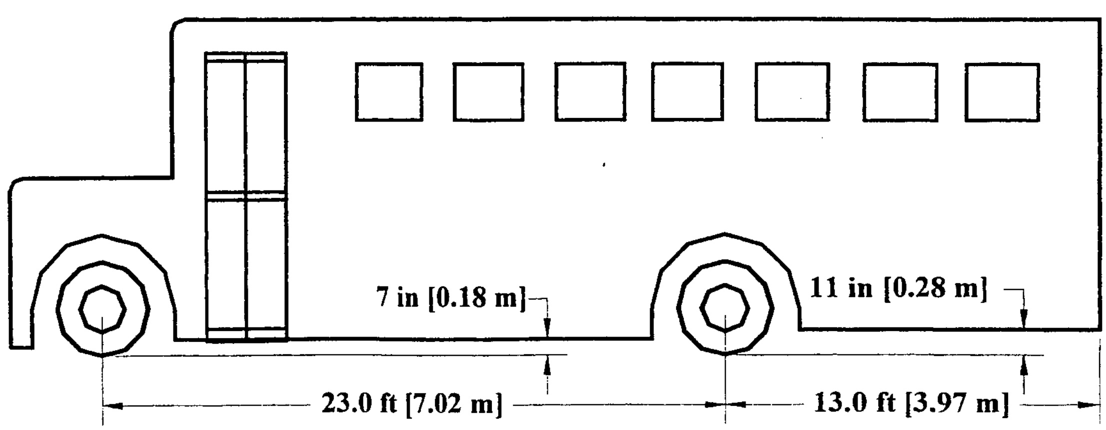
0
5ft
10ft
0
1m
2m
3m
6 in [0.15 m]
8 in [0.20 m]
24.0 ft [7.33 m]
10.0 ft [3.05 m]

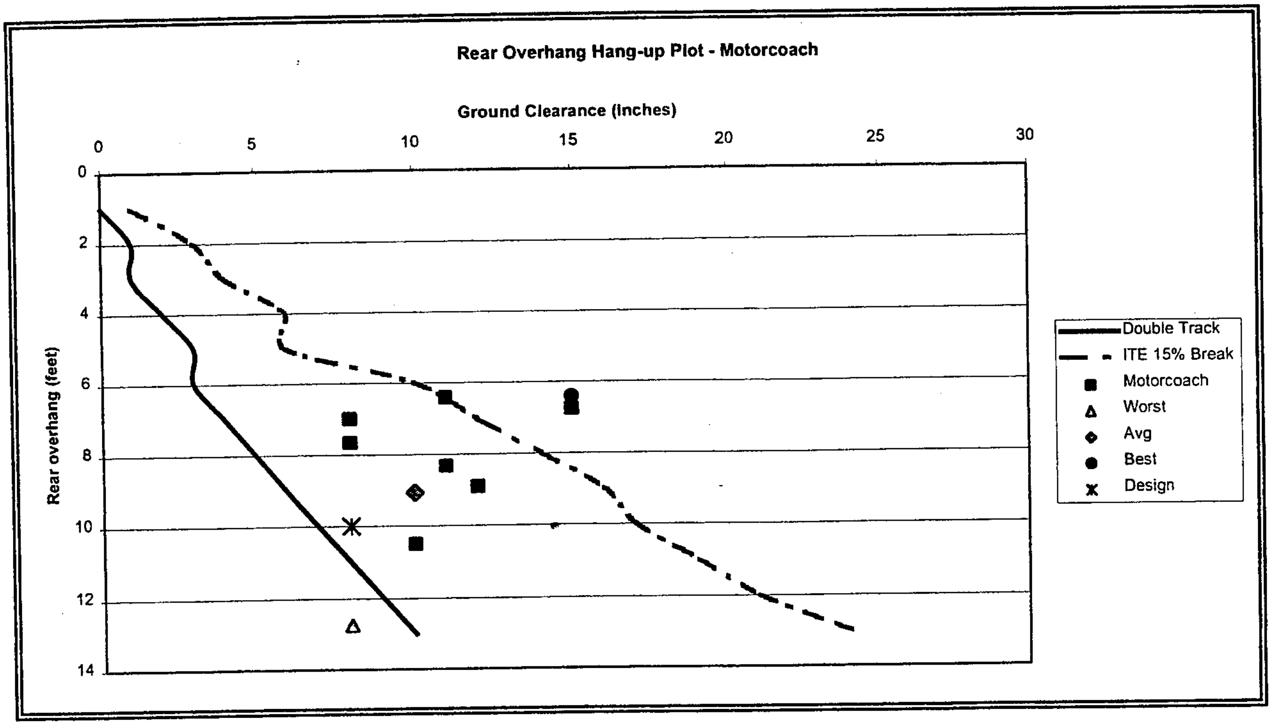

Rear Overhang Hang-up Plot - Mini-Bus (Transit)
Ground Clearance (inches)
0
5
10
15
20
25
30
Rear Overhang (feet
0
5
10
15
20
25
Double Track
ITE 15% Break
Mini-Bus
Worst
Avg
Best
Design


0
5ft
10ft
0
1m
2m
3m
10 in [0.25 m]
8 in [0.20 m]
15.0 ft [4.58 m]
16.0 ft [4.88 m]

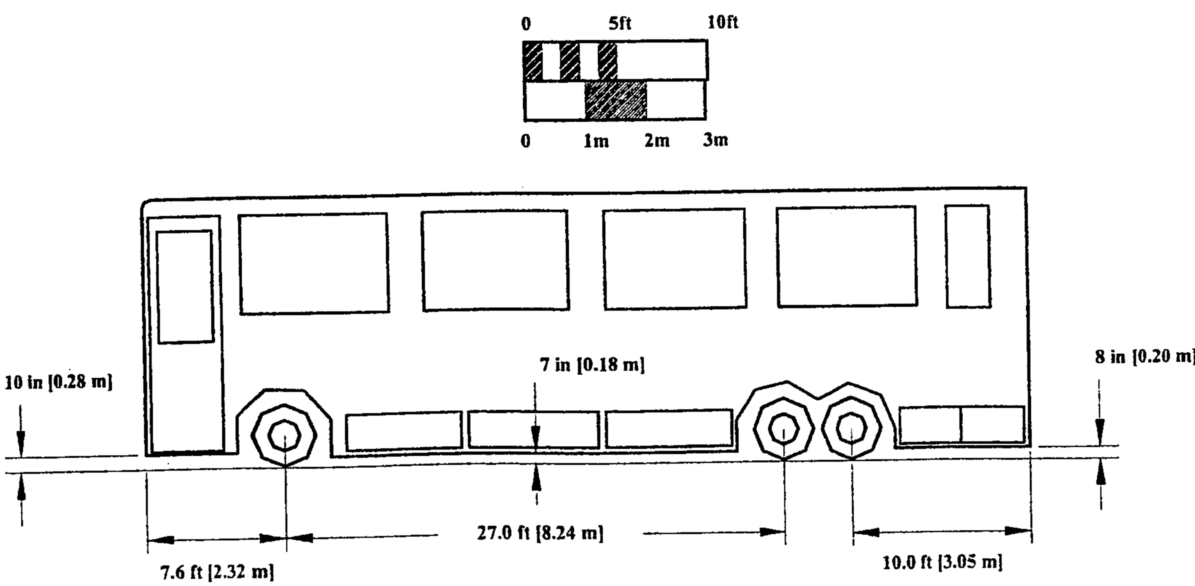

Rear Overhang Hang-up Plot - School Bus
Ground Clearance (inches)
0
5
10
15
20
25
30
35
0
2
4
6
8
10
12
14
Rear Overhang (feet)
Double Track
ITE 15% Break
School Bus
Worst
Avg
Best
Design


0
5ft
10ft
0
1m
2m
3m

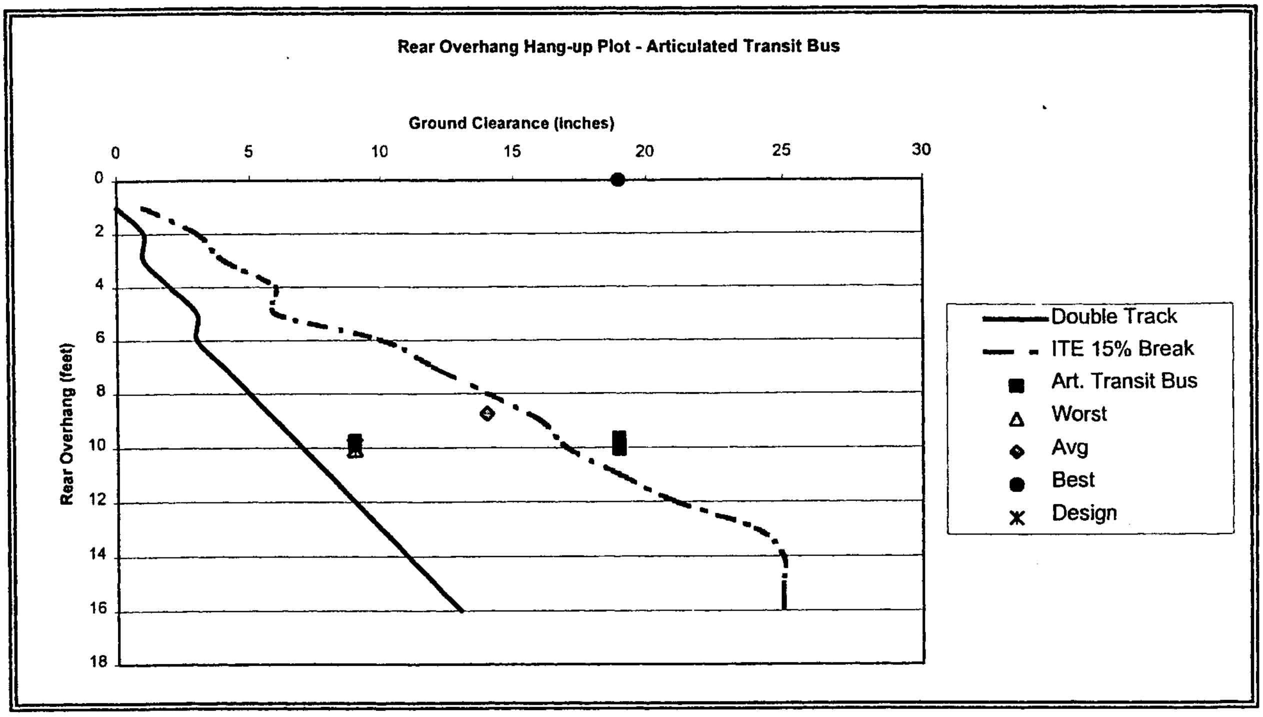

7 in [0.18 m]
11 in [0.28 m]
23.0 ft [7.02 m]
13.0 ft [3.97 m]

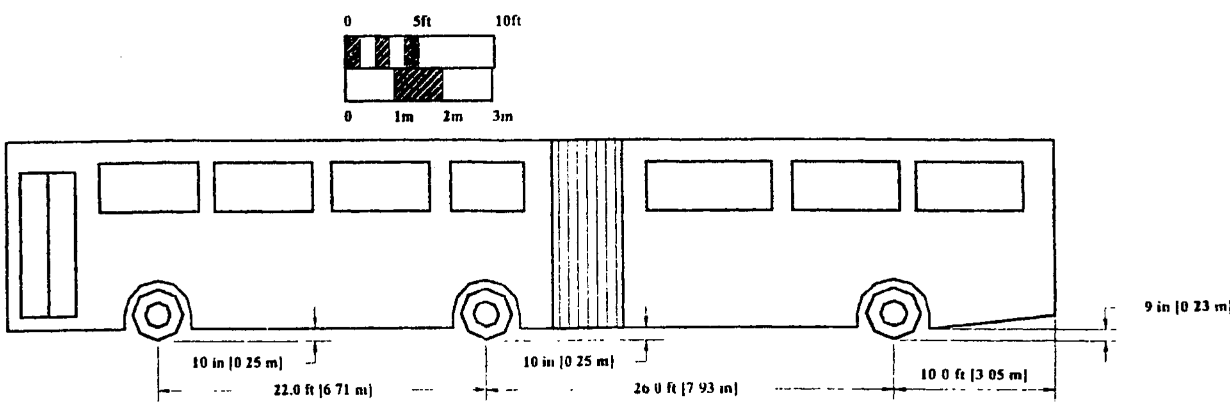


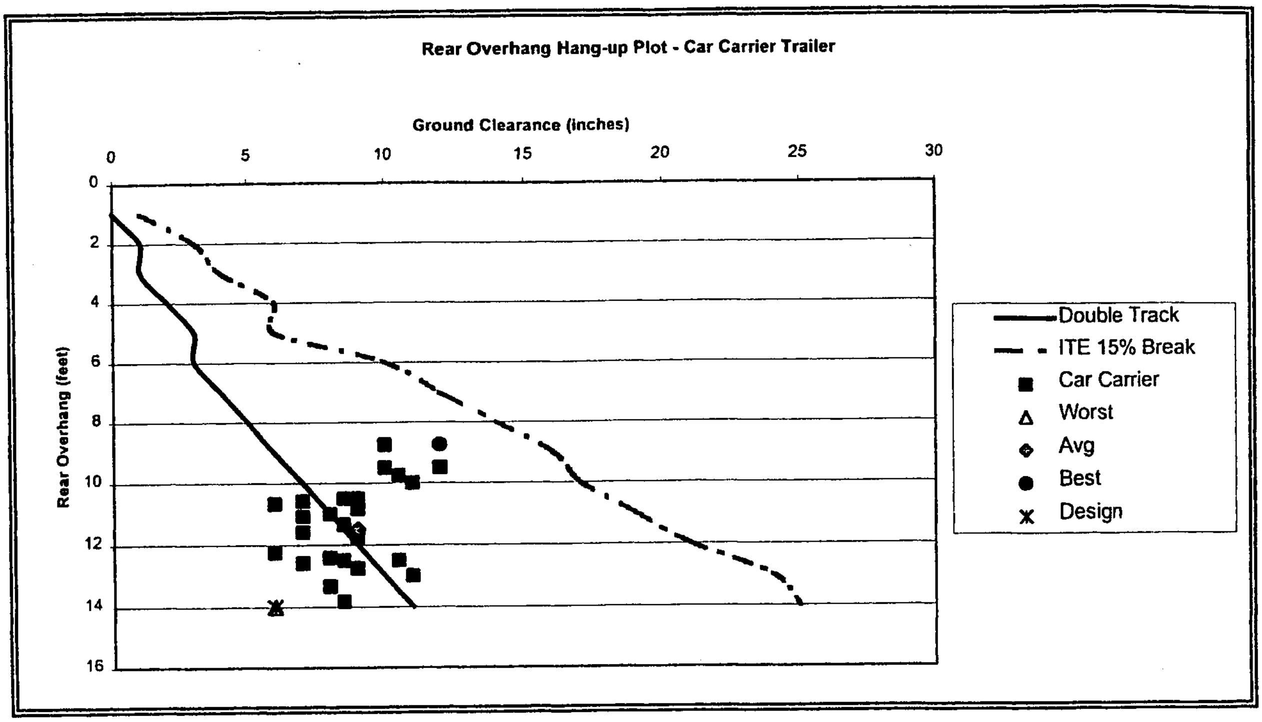
Rear Overhang Hang-up Plot - Motorcoach
Ground Clearance (inches)
0
5
10
15
20
25
30
Rear overhang (feet)
0
2
4
6
8
10
12
14
Double Track
ITE 15% Break
Motorcoach
Worst
Avg
Best
Design



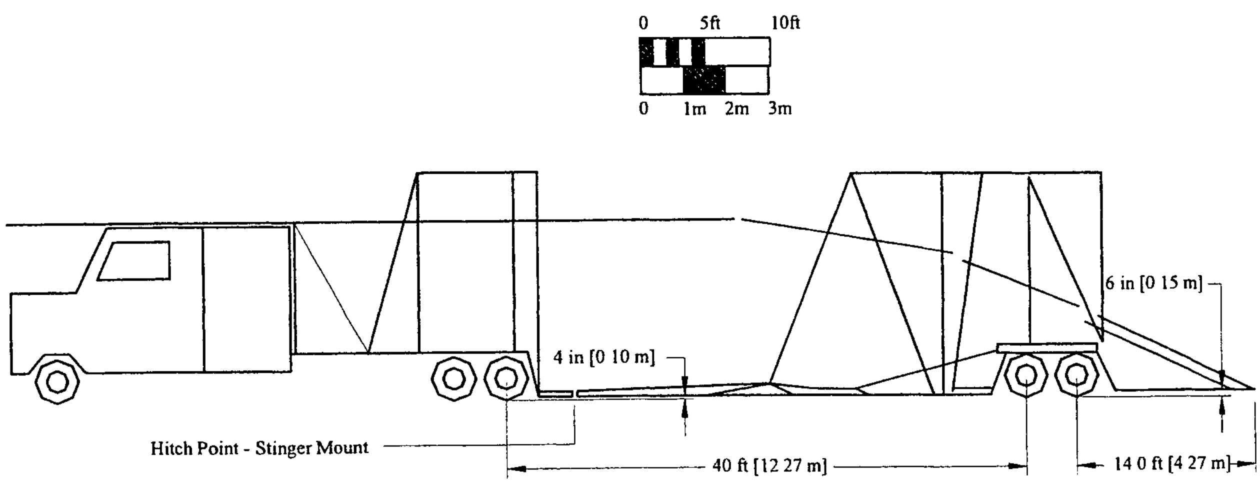
0
5ft
10ft
0
1m
2m
3m
10 in [0.28 m]
7 in [0.18 m]
8 in [0.20 m]
27.0 ft [8.24 m]
7.6 ft [2.32 m]
10.0 ft [3.05 m]


Rear Overhang Hang-up Plot - Articulated Transit Bus
Ground Clearance (inches)
0 5 10 15 20 25 30
Rear Overhang (feet)
0 2 4 6 8 10 12 14 16 18
Double Track
ITE 15% Break
Art. Transit Bus
Worst
Avg
Best
Design

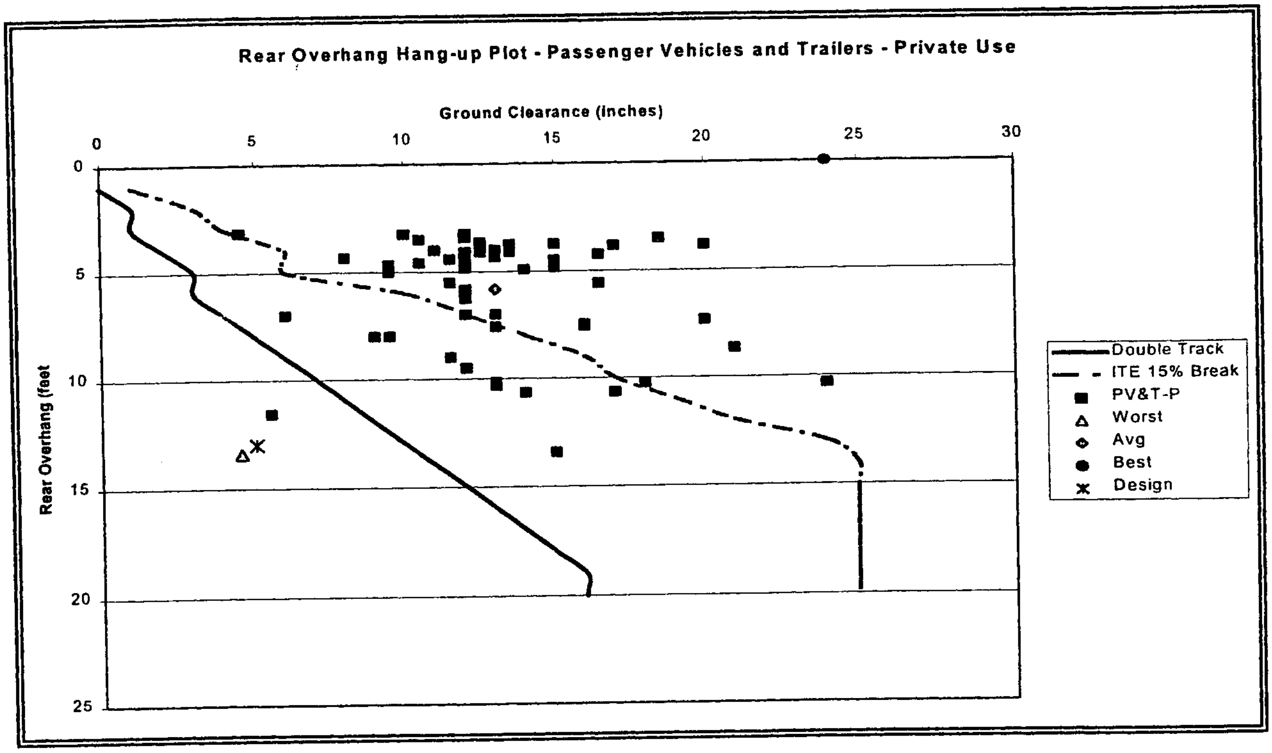

0 5ft 10ft
0 1m 2m 3m
9 in [0 23 m]
10 in [0 25 m]
10 in [0 25 m]
22.0 ft [6 71 m]
26 0 ft [7 93 m]
10 0 ft [3 05 m]

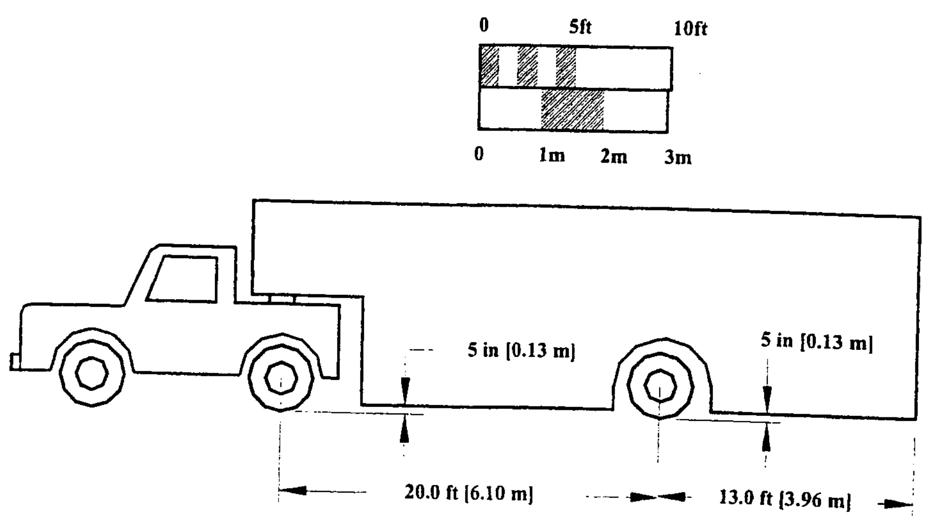


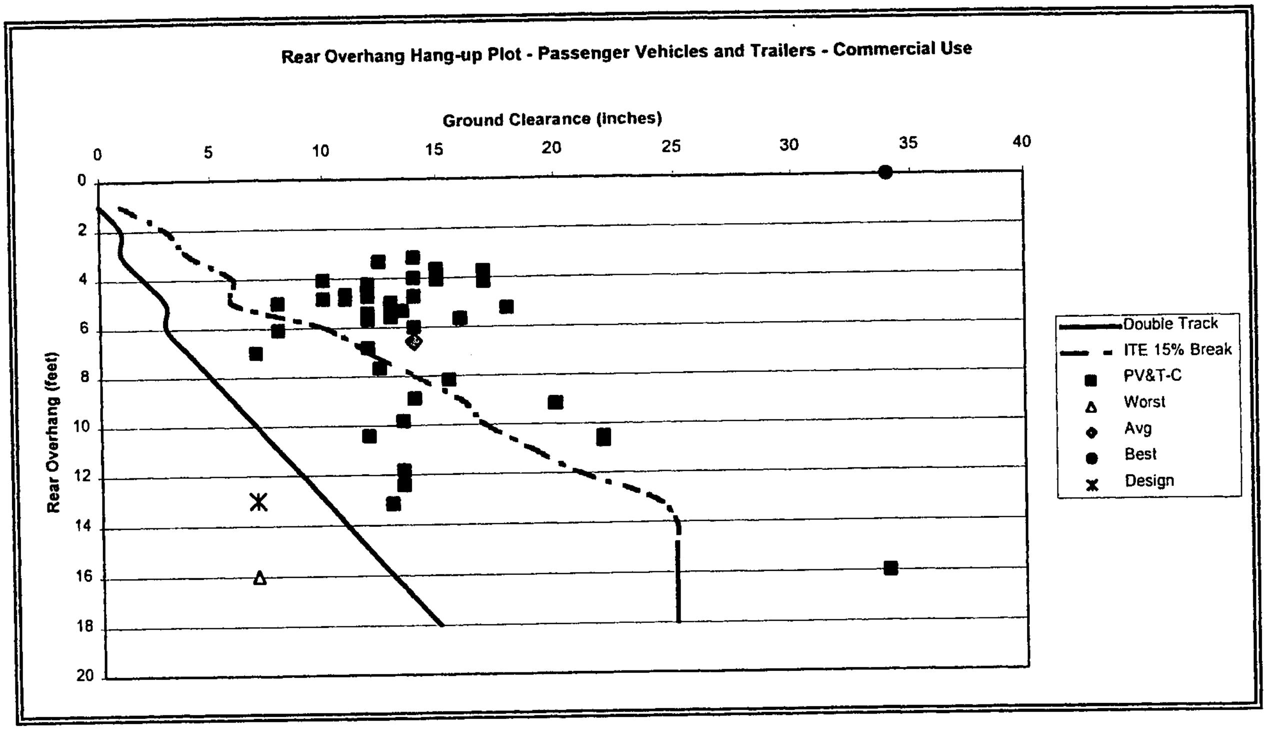
Rear Overhang Hang-up Plot - Car Carrier Trailer
Ground Clearance (inches)
0
5
10
15
20
25
30
Rear Overhang (feet)
0
2
4
6
8
10
12
14
16
Double Track
ITE 15% Break
Car Carrier
Worst
Avg
Best
Design

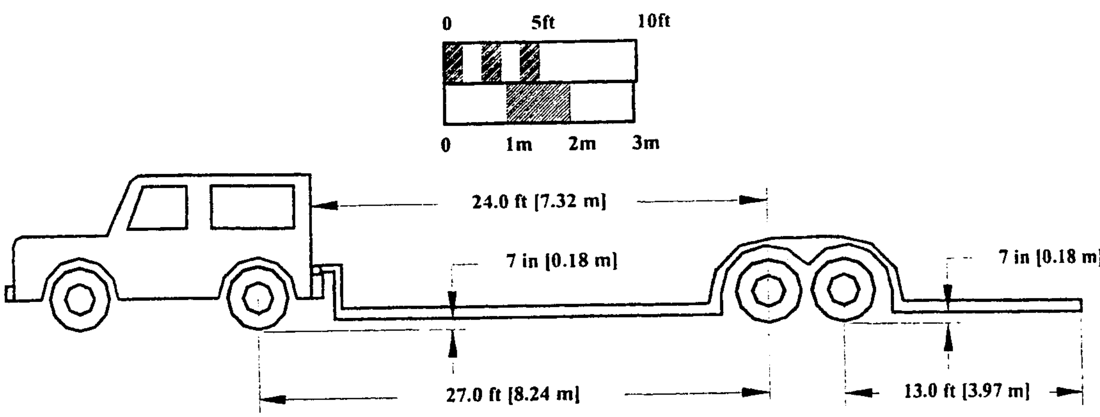


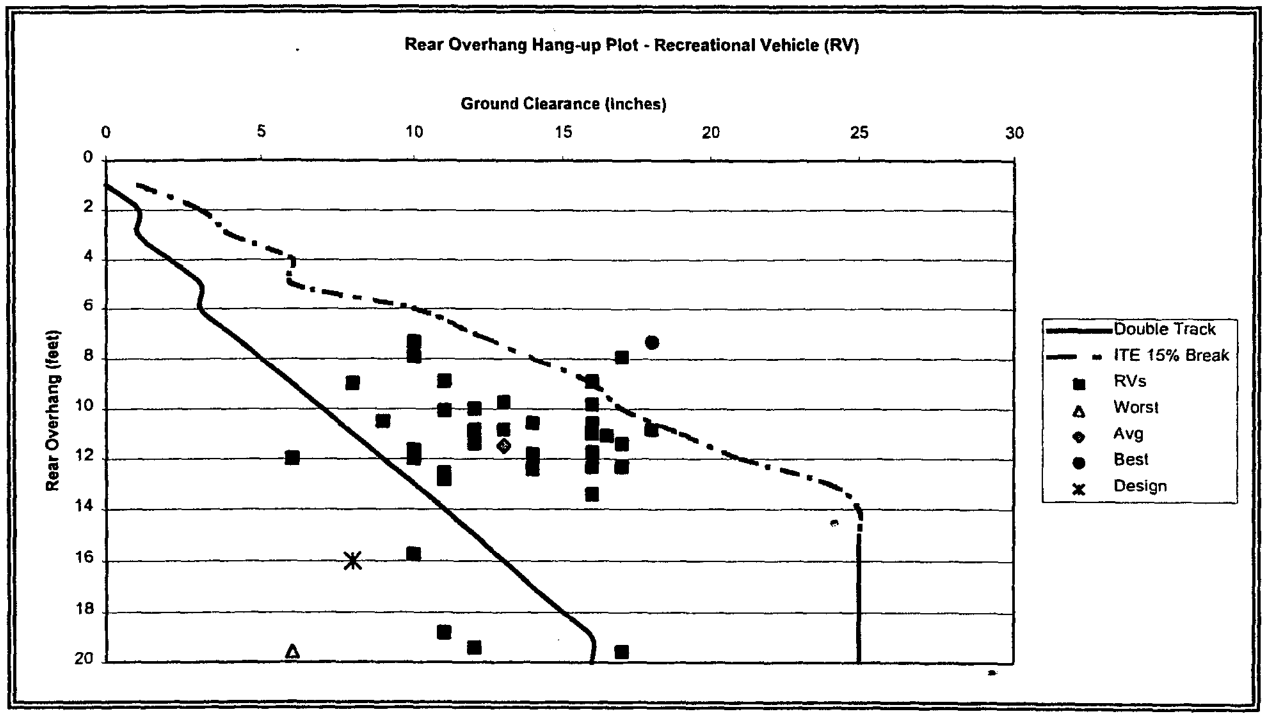
0
5ft
10ft
0
1m
2m
3m
6 in [0 15 m]
4 in [0 10 m]
Hitch Point - Stinger Mount
40 ft [12 27 m]
14 0 ft [4 27 m]

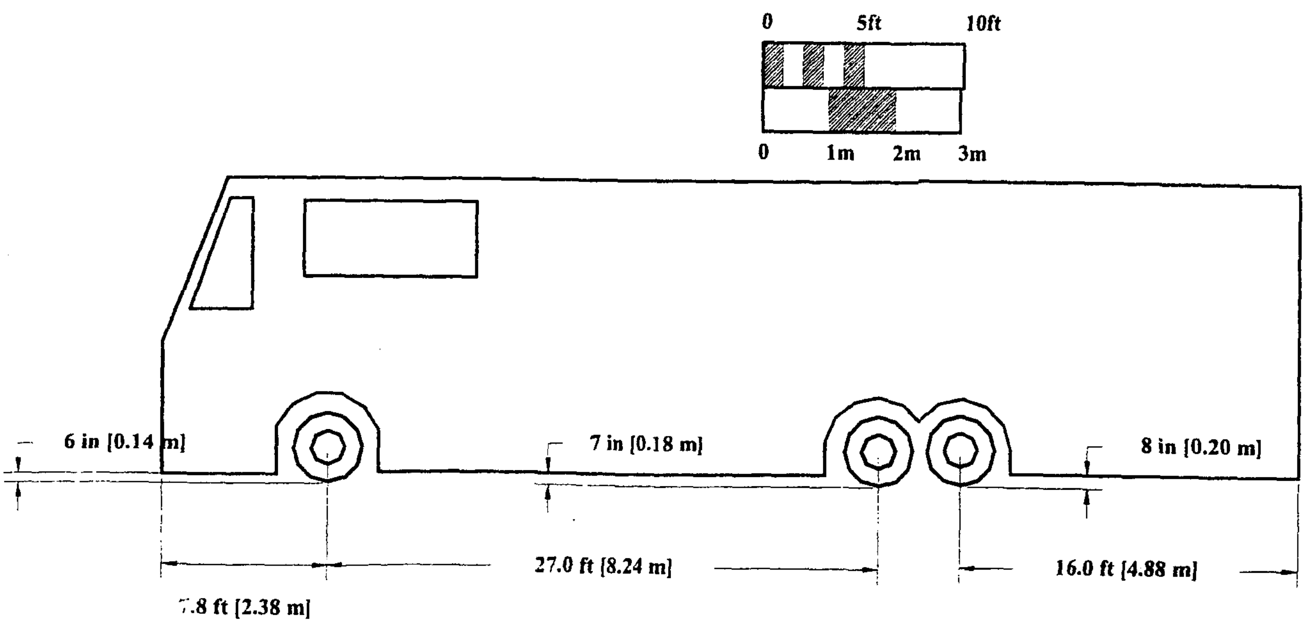

Rear Overhang Hang-up Plot - Passenger Vehicles and Trailers - Private Use
Ground Clearance (inches)
0
5
10
15
20
25
30
Rear Overhang (feet
Double Track
ITE 15% Break
PV&T-P
Worst
Avg
Best
Design


0
5ft
10ft
0
1m
2m
3m
5 in [0.13 m]
5 in [0.13 m]
20.0 ft [6.10 m]
13.0 ft [3.96 m]


Rear Overhang Hang-up Plot - Passenger Vehicles and Trailers - Commercial Use
Ground Clearance (inches)
0 5 10 15 20 25 30 35 40
Rear Overhang (feet)
0 2 4 6 8 10 12 14 16 18 20
Double Track
ITE 15% Break
PV&T-C
Worst
Avg
Best
Design


0
5ft
10ft
0
1m
2m
3m
24.0 ft [7.32 m]
7 in [0.18 m]
7 in [0.18 m]
27.0 ft [8.24 m]
13.0 ft [3.97 m]


Rear Overhang Hang-up Plot - Recreational Vehicle (RV)
Ground Clearance (inches)
Rear Overhang (feet)
0
5
10
15
20
25
30
0
2
4
6
8
10
12
14
16
18
20
Double Track
ITE 15% Break
RVs
Worst
Avg
Best
Design


0
5ft
10ft
0
1m
2m
3m
6 in [0.14 m]
7 in [0.18 m]
8 in [0.20 m]
27.0 ft [8.24 m]
16.0 ft [4.88 m]
.8 ft [2.38 m]