Technical Report UMTRI-96-29

October, 1996

Automotive Collision Warning Effectiveness: A Simulator Comparison of Text vs. Icons

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HUMAN FACTORS

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-96-29		

4. Title and Subtitle
Automotive Collision Warning Effectiveness:
A Simulator Comparison of Text vs. Icons

5. Report Date

6. Performing Organization Code
account 032922

7. Author(s)
Herbert Yoo, David Hunter, and Paul Green

8. Performing Organization Report No.
UMTRI-96-29

9. Performing Organization Name and Address
The University of Michigan
Transportation Research Institute (UMTRI)
2901 Baxter Rd, Ann Arbor, Michigan 48109-2150
USA

10. Work Unit no. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
Transportation Research Board
2101 Constitution Ave, NW, GR 300
Washington, D.C. 20418 USA

13. Type of Report and Period Covered
2/95 - 8/96

14. Sponsoring Agency Code

15. Supplementary Notes
Funded by Innovations Deserving Exploratory Analysis (IDEA) program

To demonstrate the usefulness of an enhanced driving simulator capable of displaying traffic, 24 drivers participated in an experiment evaluating alternative formats for collision warnings that might appear on a head-up display. During a 15 minute drive (at 35 mi/hr), subjects passed 17 parked cars and 8 oncoming cars, and briefly followed 2 cars (that separately pulled out from the side of the road and then sped off). Subsequently, subjects encountered a car that pulled out from the roadside unexpectedly, requiring subjects to brake and/or swerve to avoid a collision. Each of the 3 warning conditions was responded to by 8 drivers. There were 3 collisions (out of a maximum of 8, 1 per driver) when an icon warning (showing the path to take) was presented, 5 collisions in response to a "swerve left" text warning, and 7 when no warning was presented. Additional data were collected for a second encounter (after another 13 minutes of driving); however, the crash rates were very low (the car pulling out was not a complete surprise), calling into question the value of exposing a subject to multiple scenarios for collision avoidance experiments.

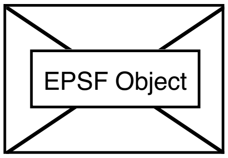
Also explored were alternative measures of collision avoidance: subjective ratings of helpfulness, lateral clearance, impact speed, lane crossing position, throttle release distance, braking onset distance, and peak lateral acceleration. These measures, all ratio scale values, were thought to be more sensitive than collision counts to warning design differences. They were not. There were no significant differences in them due to warning format, suggesting that the number of crashes should be the primary performance measure.

17. Key Words
collision avoidance system, ergonomics, human factors, warnings, simulators, driving, symbols, icons

18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classify. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
none	none	71	

Form DOT F 1700 7 (8-72) Reproduction of completed page authorized



Automotive Collision Warning Effectiveness: A Simulator Comparison of Text vs. Icons

UMTRI Technical Report 96-29
Herbert Yoo, David Hunter, and Paul Green
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1 ISSUES

1. Can a collision avoidance warning system help drivers avoid crashes, and if so, which warning format is more effective: text or icons?
2. Should more than one crash encounter be presented to each subject?
3. What performance measures, other than collision counts, might be sensitive to collision warning design differences?

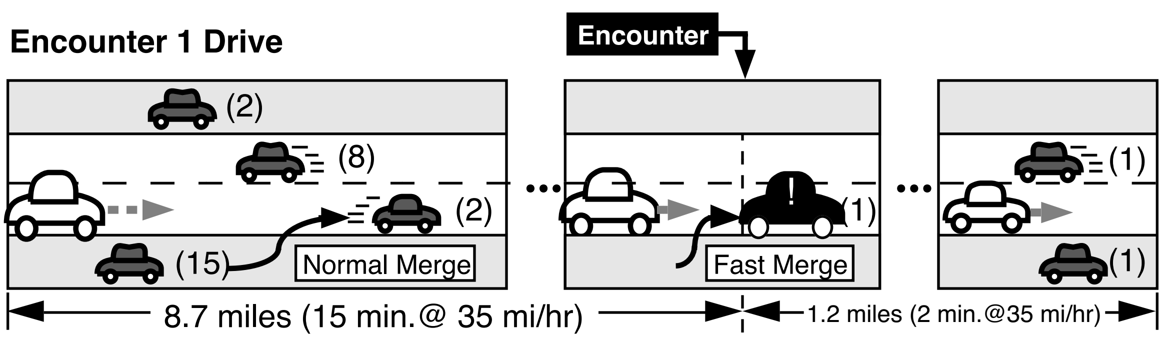
2 METHOD

After passing many (#) vehicles ( ), and following some that merge and drive off, the subject ( ) encounters a vehicle ( ) that merges and drives slowly, leading to a possible crash.

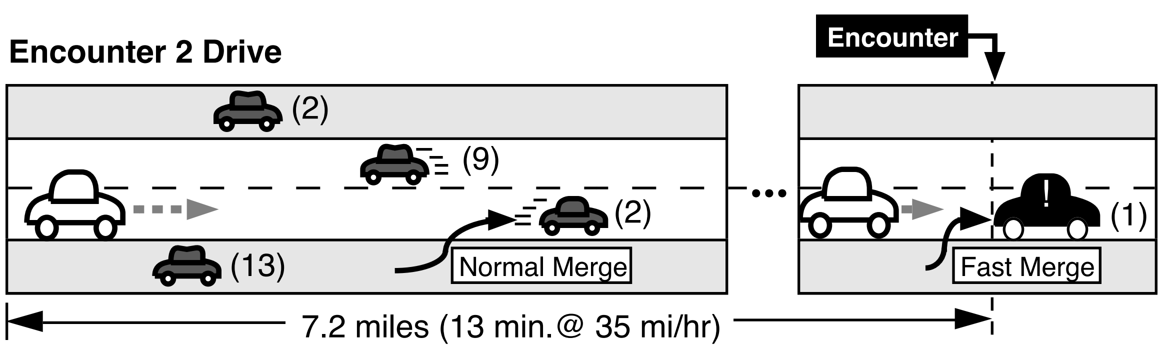
Subjects

Age	Men	Women
18-30	6	6
65-80	6	6

Encounter 1 Drive



Encounter 2 Drive



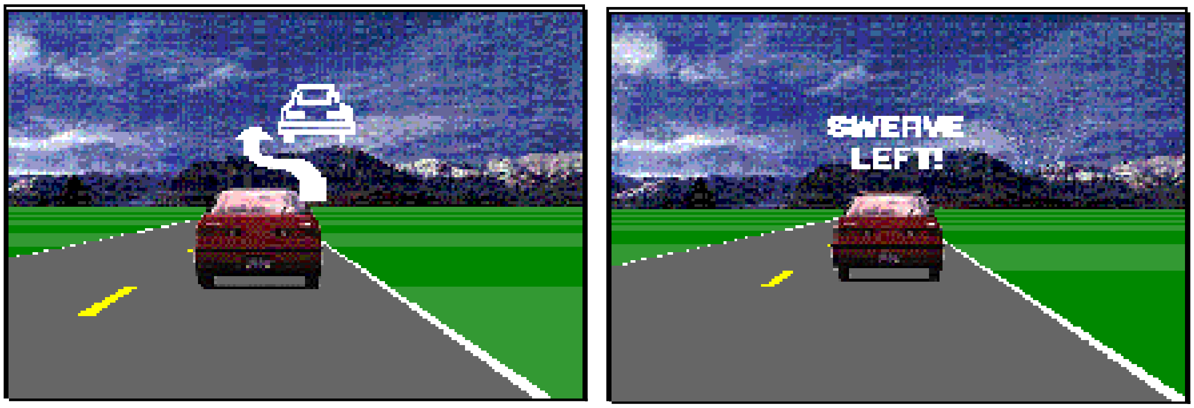
METHOD (continued)

# of Subjects	Warning Shown: Encounter 1	Warning Shown: Encounter 2
4	Icon	Text
4	Icon	None
4	Text	Icon
4	Text	None
4	None	Icon
4	None	Text

Collision Warnings

Icon Text

Subject's View of Encounter Vehicle and Collision Warning in Simulator



3 RESULTS

Subject Responses

	Warning Format	Swerve Left	Swerve Right	Collision	Off Road Left	Off Road Right	Other (drove too slowly)
Encounter 1	Icon	3		3	1		1
	Text	1	1	5	1		
	None	1		7			
Encounter 2	Icon	7					1
	Text	4		1	2		1
	None	5		1			2

4 CONCLUSIONS

- Low cost simulators of this type can be used to effectively simulate collsion scenarios and evaluate warnings.
- The icon warning was most effective, followed by text and no warning. The difference was not statistically significant.
- Use only 1 collsion encounter in collision avoidance experiments
- For a simple experiment, a minimum of 50 subjects is required.
- None of the alternative performance measures (peak lateral acceleration, lane crossing position, lateral clearance, impact speed, brake and throttle activity) showed any significant differences among the three warning types.

PREFACE

This report is the final of three reports describing the application of an enhanced driving simulator. The first two reports (Green, Olson, and Malhotra, 1995a, b) describe the enhancement of the UMTRI Driver Interface Research Simulator, from a two computer configuration to a networked configuration, where traffic information is sent across the network. Traffic can be generated by multiple driving simulators on the network or by computers controlling autonomous vehicles. Effort was expended in the early phases in developing a communication structure for this purpose and making other improvements, in particular, improving the quality of the steering wheel torque feedback to make the simulator suitable for this project. Those efforts will be described in forthcoming articles.

One of the lessons learned from this experiment is that if statistically significant differences among the three warning formats are desired, approximately 50 subjects would have to be tested, with a minimum of 30 minutes of simulator time per subject (to allow for start up, practice, testing, etc.). Such a small scale experiment will require 25 hours of simulator time. On a sophisticated industry simulator, the charge for simulator time (at $1000/hr, a low rate) would be $25,000, a significant amount for a minimal study (and, in fact, only a small portion of the total cost). On simulators such as that at UMTRI, the charge for simulator time for the same experiment would be $5,000 (at $200/hr), assuming the low cost simulator is equally effective in replicating the conditions of interest. Depending on the experiment, the cost of simulator time can range from 5 to 30 percent of the project budget. The point is that the high cost of sophisticated simulator time could make it too expensive to develop new safety technologies. Low-cost simulators, such as the one employed here, can provide the necessary data and, because of their low cost, allow for a broader exploration of design alternatives.

As in any team effort, numerous individuals contributed to the success of this project. Most noteworthy are:

Alan Olson (UMTRI)	for his implementation of the network architecture and development of the scenario control routines
Amitaabh Malhotra (UMTRI)	for his improvements to the steering wheel torque motor control system so subjects would not get sick
Aaron Steinfeld (UMTRI)	for installing the new simulator video recording system
Keith Gates, K.T. Thirumalai (TRB)	for their faith in this novel approach

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INTRODUCTION

This study examines the effectiveness of two visual warnings on collision-avoidance maneuvering. Collision avoidance systems are designed to improve driving safety by alerting drivers to potential collision-producing situations.

Where, when, and why do rear-end collisions occur?

Vehicle collisions result in costs associated with fatalities, injuries, property damage, and traffic delays. Of all types of vehicle collisions, a rear-end collision is one of the most frequent and most costly. The National Highway Traffic Safety Administration (NHTSA) Office of Crash Avoidance Research estimates that there are 3.4 million rear-end collisions each year resulting in over 2,000 fatalities and approximately one million injuries. Rear-end collisions also account for 32 percent of all crash-caused traffic delays (Faciane, 1993).

The relatively high number of rear-end collisions may lead one to believe adverse road conditions or driver characteristics (e.g. sleepy, intoxicated) contribute the most to the total number of rear-end collisions. However, an analysis of rear-end collisions points to the ordinary (sober, nonreckless) driver on a straight, dry road on a dry day as typical. Among rear-end collisions, 34.7 percent occurred between 9:31 AM and 3:30 PM, 78.0 percent in daylight, 80.2 percent with no adverse weather conditions, 72.9 percent on dry roads, 94.2 percent on straight portions of roads, 74.9 percent on level roads, 25.1 percent traveling at 35 mph, 51.0 percent at non-intersections, and 95.7 percent without the influence of alcohol (Najm, Mironer, Koziol, Wang, and Knipling, 1995). These data suggest that human characteristics of ordinary drivers, not environmental factors, are key causal factors in rear-end collisions.

The causal factors of collisions by ordinary drivers were identified in a study of 420 accidents occurring in Monroe County, Indiana between 1972 and 1975. Among these collisions, 90 percent were determined to be due to human error, 35 percent to environmental factors, and 9 percent to vehicle malfunction (with overlapping). For cases involving rear-end collisions, 57 percent were due to recognition error, 27 percent to decision error, and 1 percent due to excessive action (Treat, Tumbas, McDonald, Shinar, Hume, Mayer, Stansifer, and Catellan, 1979).

Collision avoidance systems should offer the largest benefit to ordinary drivers in non-adverse road conditions by alerting them to potential collision-producing situations. A study of target vehicular crashes showed that collisions were attributed to inattention 56.7 percent of the time and to following too closely 26.5 percent of the time (Najm, Mironer, Koziol, Wang, and Knipling, 1995). Inattention was also found to be a leading causal factor in a study of rear-end crashes (Knipling, Mironer, Hendricks, Tijerina, Everson, Allen, and Wilson, 1993). These investigations of the causes of rear-end collisions reveal that they are the most preventable type of collision: when the driver is attentive, a collision will be less likely to occur.

What is involved in responding to a collision warning?

For a collision avoidance system to be reliable and effective, it must (1) accurately identify potential collisions drivers would ordinarily miss and (2) communicate a message that induces the proper response from the driver. The reliability of the system depends on the system's ability to accurately monitor the surroundings, calculate relationships between objects, and display a warning when and only when collision-producing conditions exist.

There are at least four steps in responding to a warning. (1) The driver perceives and comprehends the warning. (2) The driver determines the warning priority. (3) The driver identifies the appropriate response. (4) The driver executes that response (for example, swerving or braking). Each step merits special consideration.

The perception time can be minimized by using a simple signal that conveys a clear, straightforward message. Comprehension of the collision warning signal is just as important as the reliability of a collision avoidance system. Poorly designed warning signals may divert attention to the wrong place at the wrong time, add to information processing load, or startle the driver. Design criteria to be addressed include levels of warning, content of warning (alert versus directives), modality, and coding (Knipling, Mironer, Hendricks, Tijerina, Everson, Allen, Wilson, 1993).

Priorities can be established by message content and by having few false alarms and few misses, so when a warning appears, it is for a genuine event. Imminent collision warnings also must be immediately distinguished from other warnings and messages (Faciane, 1993).

Rapid completion of the third step depends on how well the message indicates what to do, as opposed to what is wrong. In fact, in driver focus group discussions, drivers who have had experience with advanced automotive display systems expressed that warning systems were the greatest concern. They stated that a warning signaling that something was wrong was not enough. The warnings must also assist the driver in determining what course of action is required (Brand, 1990; Green and Brand, 1992).

What type of warning should be used?

Several display and communication options are available for collision warnings: non-speech audio messages, voice synthesized messages, and various types of messages on visual displays. A visual warning, although dependent on visual fixation of the driver, may be preferable to the audio warning when the driver is listening to music. The driver may not be able to distinguish the signal from the music. Even with low sound levels, there may be interference between the audio signal (speech or non-speech) and the lyrics of songs. This interference may affect comprehension of symbols and require increased time for perception of the warning.

There have been several studies that have examined alternative formats for collision avoidance warnings and vehicle following (e.g., Janssen, and Nilsson, 1990; Farber, Farber, Godthelp, and Schumann, 1991; Nilsson, Alm, and Janssen, 1991; Van Winsum, 1991; Godthelp and Schumann, 1993; Janssen, and Nilsson, 1993; Verwey, Alm, Groger, Janssen, Juiken, Schraagen, Schumann, van Winsum, and Wontorra, 1993). (See also Hoffman and Mortimer, 1994; Farber, Freedman, and Tijerina, 1995; Graham, Hirst, and Carter, 1995 for related information.) The gist of those studies is that active gas pedals/intelligent accelerators, throttles whose resistive force is proportional to the likelihood of a frontal collision, are more effective than auditory or visual warnings in preventing rear-end collisions (in a simulator). Less information is available on warning of imminent collisions. Nonetheless, interest in visual warnings persists (McGehee, Dingus, Horowitz, Oberdier, and Parikh, 1993; Schumacher, Olney, Wragg, Landau, and Widman, 1996) and may be what manufacturers will implement.

For that reason, visual collision warnings, displayed using a head-up display (a likely implementation) were explored in this experiment. The two warnings were a command to swerve left, rather than just a notification of a collision situation. One warning was in an icon format, and the other in a text format.

How can warning effectiveness be measured?

To assess the effectiveness of these two messages, the fundamental measure was collision count: the better the message, the fewer collisions occur. However, the problem with counting collisions is that the collision outcome is a binary value; either it occurs or does not. A large number of collisions are required to obtain statistically significant differences, and, because collisions are rare, a large number of subject hours is required. Further, because critical encounters should be a surprise, accepted practice is that there should be just one critical encounter per driver.

There are a number of possible alternative measures that provide ratio scale values, though only one per incident. Lateral clearance measures how close the driver comes to a collision or how far the driver oversteers. Better warnings should lead to larger lateral clearances. Lane crossing position measures indicate how quickly the driver situated his/her vehicle into a safe position. Better warnings should lead to smaller lane crossing values. (The driver changed to another lane sooner.) If the driver collided into the lead vehicle, the collision warning may still have an effect. The warning may decrease the impact speed of the collision, therefore reducing injuries to the drivers and damage to the vehicles. The time or distance from the precipitating event until the throttle is released and brake is actuated indicate which of the two formats is easier to interpret. The sooner these events occurred, the better the warning. Maximum lateral acceleration indicates the severity of the steering effort (greater severity implies more erratic maneuvering).

What important simulator functional requirements for collision-avoidance experiments?

In work related to this study, Adams, Flannagan, and Sivak (1995) describe an experiment conducted in an earlier version of the UMTRI simulator that had been designed for workload, not collision-avoidance, experiments. (See Adams, 1994 for a related literature review.) In that experiment, 12 subjects were given 15 minutes of practice driving the simulator and then a break. After three to four minutes of additional driving, they encountered a large rock just past the crest of a hill. Of interest in this experiment was the maneuver (braking vs. steering) that subjects would choose. After another break, subjects repeatedly drove the half mile segments with similar encounters (a rock just past a hill crest), and were told to wait until the rocks were visible before avoiding them. Nonetheless, subjects drove more slowly in those subsequent trials.

Table 1 shows the maneuvering behavior for the initial unalerted trial and the first 17 (alerted) repetitions. Over time, driver responses shifted from primarily steering, to braking and steering, suggesting that each subject should experience only one collision scenario, a conclusion confirmed here.

Table 1. Maneuver Responses

	Steer			
	unalerted trial		alerted trials	
Brake	yes	no	yes	no
yes	3	1	103	7
no	8	0	94	0

In addition, subjects were asked several questions about the realism of the simulator. All of the subjects rated the simulator as more difficult to drive than a real car, but were generally satisfied with the visual scene and sound. However, no subjects rated the steering inputs as "just right" and only 4 of the 12 rated the braking and accelerator inputs as "just right."

Those comments and other concerns (see Reed and Green, 1995) led to improvements implemented as part of this and related projects. Improvements made include (1) replacing the rope, spring, and bungy cord steering system with a torque motor system, (2) removing instabilities in the lateral control system, (3) adding steering wheel twitch when a lane boundary is crossed and vibration when the vehicle is off the road, (4) replacing the main computer (and optimizing code) to increase scene update rate and, throttle and brake sampling frequency by about 50 percent, (5) removing excess play from the throttle and brake linkages, and (6) replacing the simple digital speed display with a computer-generated instrument cluster (to make speed control more realistic). Evidence from a variety of studies in progress suggests that these changes have made steering much more realistic (reducing lane variance and increasing speed variance closer to real driving) and, just as importantly, have made the simulator feel more realistic. In addition, scriptable traffic was added, a feature necessary for the experiment described here. Other improvements yet to be implemented (necessary for studies with repeated panic braking) include: (1) a gravity vector (causing speed to vary due to hills), (2) tire screech during lockup, (4) high fidelity brake dynamics, (5) more stable low speed dynamics, and (6) scene pitch during braking. To enhance speed perception, road and side scene texture are desired, improvements to occur when the graphics system is replaced.

Purpose of this experiment

Upon reflection of current knowledge, three issues were selected for investigation:

1. Can a collision avoidance warning system help drivers avoid collisions, and, if so, which warning format is more effective: text or icons?

2. Should more than one crash scenario be presented to each subject?

3. What performance measures other than collision counts (crashes) might be sensitive to collision warning design differences?

TEST PLAN

Overview

In this experiment, subjects drove a simulated vehicle at 35 mi/hr. Each subject encountered two accident situations during the drive. The accident encounters were created by a car that had been parked on the right side of the road suddenly merging onto the road in front of the subject's simulated vehicle and maintaining a low speed (5 mi/hr). In these situations, swerving was necessary for the subject to avoid a collision. For each encounter, one of two collision warnings or no warning was displayed on the simulated head-up display. Dependent variables were lateral clearance, impact speed, lane crossing position, throttle release and brake activation distance from the lead vehicle, and maximum lateral acceleration.

Development of accident encounters

Accidents can occur when a driver is faced with an unexpected event in traffic flow. To preserve the element of surprise of accidents, subjects were not informed of the sudden merging of lead vehicles prior to the experiment. Parked cars were placed along the road to serve as decoys and to condition the subjects to expect routine behavior. Before the accident encounters, lead vehicles entered the roadway far ahead of the subject and sped away after maintaining a constant speed. These non-collision-threatening vehicles were placed to familiarize the subject with the ability of parked cars to merge onto the road. To ensure that each subject witnessed the same scenario, the location of the encounter always occurred at the same place on the road rather than the same time into the session.

The length of the drive was relatively long and road activity rather uneventful to remove the driver from heightened awareness. To assure drivers were relaxed as they would be in a nonexperimental situation, music selected by subjects was played while they drove: jazz, classical, or rock. There were no lyrics in the music that the subjects listened to so that there would be no interference in reception of the warning. As reported elsewhere, instrumental music does not interfere with reading comprehension, but comprehension (e.g. of warnings) suffers when lyrics are added (Wickens, 1992).

Test participants

Twenty-four licensed drivers participated in this experiment, 12 younger (18-30, mean of 21) and 12 older (65 and above, mean of 70). Within each age bracket there were 6 men and 6 women. Participants were recruited using lists from previous UMTRI studies and from among friends of the first experimenter. One additional subject was dropped due to motion sickness. All were paid $25 for their participation.

The younger subjects had corrected visual acuity ranging from 20/40 to 20/15. The older subjects had corrected visual acuity ranging from 20/70 to 20/13. Subjects reported driving from 250 to 20,000 miles per year with a mean of approximately 8,200 miles per year. Of the 24 subjects, 19 reported no accidents with the last 5 years, 4 reported one accident, and one subject reported 3.

Test materials and equipment

The ad hoc collision warning symbols were developed by the lead author based on input from the third author. There were no pretests of warning legibility or understandability as problems with either were not anticipated. The classification of the object (icon or text) was the issue at hand and not specific design traits (stroke width, font, etc.). The symbols are shown in Figure 1 and Figure 2. The appearance of these symbols in the simulator is shown in Figure 3 and Figure 4. The location chosen was for ease of implementation.

Figure 1. Icon collision warning

Figure 2. Text collision warning

Figure 3. Icon as seen by subjects

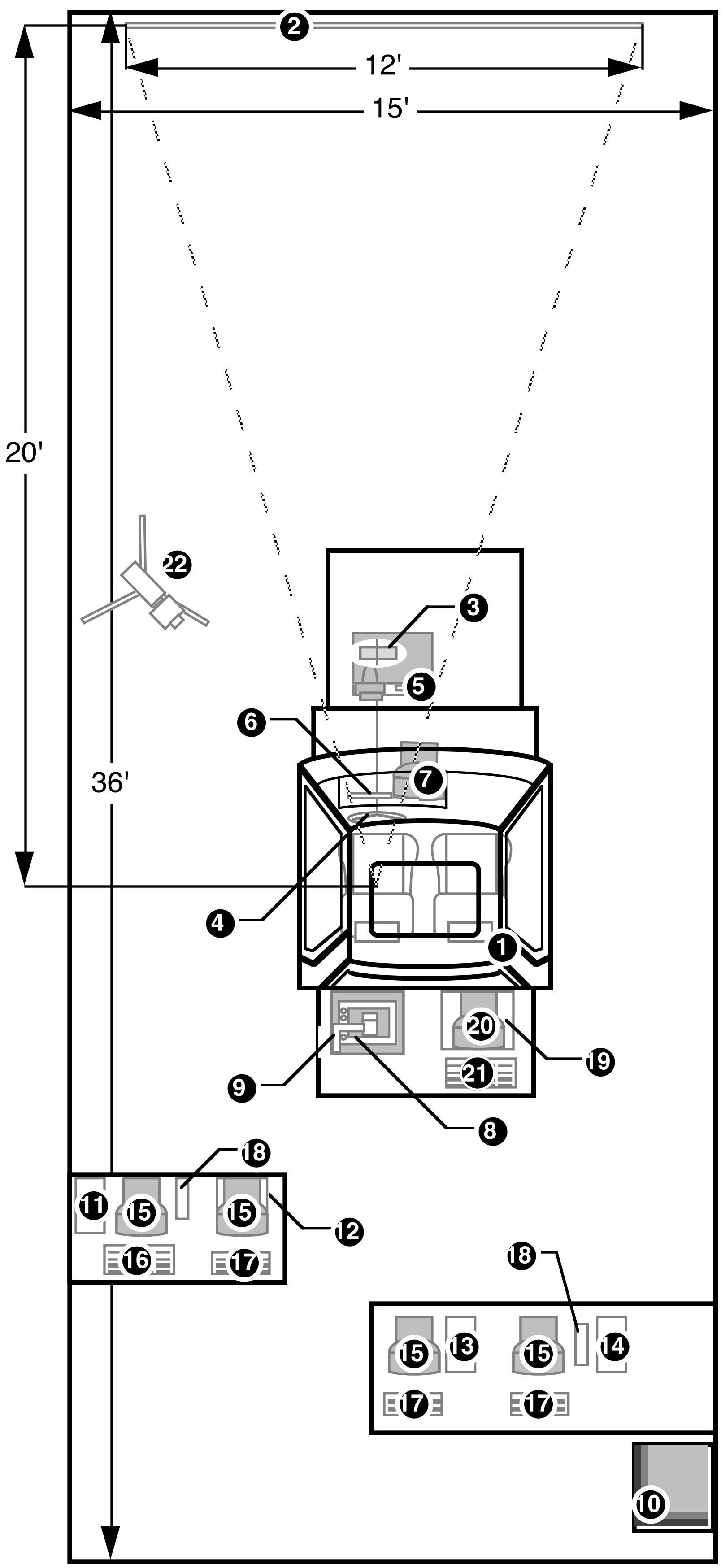
Figure 4. Text as seen by subjects

Note: Both warnings (white in this illustration) were originally red.
The color was changed for clarity in the illustration.

This experiment was conducted using the UMTRI Driver Interface Research Simulator, a low-cost driving simulator based on a network of Macintosh computers (MacAdam, Green, and Reed, 1993; Green, Olson, and Malhotra, 1996). The simulator consists of an A-to-B pillar mockup of a car, a projection screen, a torque motor connected to the steering wheel, a sound system (to provide engine, drive train, tire, and wind noise), a computer system to project images of an instrument panel, and other hardware. The projection screen, offering a 30 degree field of view, was 20 feet (7.3 m) in front of the driver, effectively at optical infinity.

The driving environment depicted consisted of oncoming cars, parked cars on both sides of the road, cars moving in the same direction, traffic signs, trees, and road edge posts. Subjects drove a 20-feet-wide, two-lane, winding road with hills having a 1 percent grade. The road had solid edge delineations and a dashed centerline. The road for the first encounter was 73 percent straight, 27 percent curved with an average radius of curve of 1200 feet and an average length of curve of 424 feet. The road for the second encounter was 74 percent straight, 26 percent curved with an average radius of curve of 2000 feet and an average length of curve of 387 feet. See Appendix F for a complete description of roads.

The overall arrangement of equipment at the time the experiment was conducted is shown in Figure 5. A Titmus model OV-7M Vision Tester was used to check visual acuity of the subjects. The subjects chose one of the following compact discs to listen to while they drove: Christian McBride, “Gettin’ to it,” PolyGram Records (jazz); Joe Satriani, Relativity Records (Rock); or Ludwig Van Beethoven, Symphony No. 5, Madacy Music Group (Classical).



1. 1985 Chrysler Laser mockup with simulated hood
2. 8'X10' projection screen with 3M hi-white encapsulated reflective sheeting
3. PMI Motion Technologies ServoDisk DC motor (model 00-01602-002 type U16M4) with Copley Controls Corp. controller (model 413) and power supply (model 645)
4. 3-spoke steering wheel
5. Sharp color LCD projection system (model XG-E850U)
6. 4"X13" plexiglas screen
7. ELO Touch Systems Intellitouch monitor (model E284A-1345)
8. Sharp computer projection panel (model QA-1650)
9. 3M overhead projector (model 9550)
10. Kenwood stereo cassette deck (model KX-48C), stereo graphics equalizer (model GE-7030), and AM-FM stereo receiver (model KRA-4080)
11. Power Macintosh 9500/120
12. Power Macintosh 7100/80AV
13. Power Macintosh 8500/120
14. Macintosh Quadra 840AV
15. Macintosh 13" color display (model M1212)
16. Apple Extended Keyboard II
17. Apple Keyboard II
18. Bernoulli Mac Transporter 90-MB drive (model B190TM)
19. IBM personal computer (model 5160)
20. IBM personal computer display (model 5151)
21. Keytronic keyboard (model KB 5151)
22. RCA low level light camera (model TC 1030/H10)

Figure 5. Plan view of laboratory set-up

Test activities and sequence

Subjects began by completing a consent form (Appendix B), completing a biographical form (Appendix C), and having their vision checked. (See Appendix E for complete instructions.) Then the subject was seated in the driving simulator. After the protocol was given, the subject practiced driving twice with a brief break after each. Then the subject encountered two collision situations in approximately 30 minutes of driving. After the second encounter, the drive was terminated. For each encounter, one of two collision warnings (text or icons) or no warning was displayed on the head-up display. (See Table 1.)

Table 1. Type of warning shown for each encounter

	Warning Type Shown	
Subjects	1st Encounter	2nd Encounter
1,7,13,19	Icon	Text
2,8,14,20	Icon	None
3,9,15,21	Text	Icon
4,10,16,22	Text	None
5,11,17,23	None	Icon
6,12,18,24	None	Text

The drive schedule is shown in Table 2. After the drive was completed, the subject filled out a questionnaire and was paid. The questionnaire consisted of an accident history of the subject and a rating of the warning symbols that the subjects saw in the experiment. For complete details, see Appendix G.

Table 2. Drive schedule

Task	Distance (miles)	Time (minutes)	Encounter		
			Parked Cars	Oncoming Cars	Lead Vehicles
Practice Drive 1	1.2	2.0	2	0	0
Break		0.5			
Practice Drive 2	1.2	2.0	2	0	1
Break		0.5			
Test Drive 1	8.7	15.0	17	8	2
Encounter 1					
Test Drive 1	1.2	2.0	1	1	0
Break		0.5			
Test Drive 2	7.4	13.0	15	9	2
Encounter 2					

Note: To estimate the time of each drive, it was assumed subjects drove at the requested speed.

RESULTS

Can a warning system help drivers avoid collisions and, if so, are text or icons more effective?

Table 1 shows the types of maneuvers executed by the 24 drivers for the two encounters. Notice that on the first encounter, the number of collisions associated with each warning was 3 (38 percent) for the icon, 5 (63 percent) for text, and 7 (88 percent) for no warning. While these values are too small for a Chi-squared test of statistical significance, they suggest that a warning has the desired results, and drivers performed better with an icon warning. Furthermore, drivers with icon warnings swerved more often in the desired direction (3, to the left) than those seeing text or no warning (1 each to the left). Interestingly, even on the second encounter, drivers were more likely to swerve in the desired direction when an icon-based warning was provided (7 left for icons; 4 and 5 for text and no warning, respectively).

Out of the six subjects who successfully swerved in the first encounter, four were older subjects. The “other” column in Table 3 refers to subjects who were driving less than 35 mi/hr (contrary to the instructions) and were able to avoid colliding by slowing down.

Table 3. Maneuvers for Both Encounters

	Warning Format	Swerve		Collision	Off Road		Other
		Left	Right		Left	Right	
First Encounter	Icon	3		3	1		1
	Text	1	1	5	1		
	None	1		7			
Second Encounter	Icon	7					1
	Text	4		1	2		1
	None	5		1			2

While the sample size is too small for robust conclusions, the trends are in the direction favoring a warning and, in particular, the use of an icon. One way of analyzing the results is to employ a simple one-way ANOVA using as the dependent variable a binary variable indicating whether or not a collision occurred. For the first collision situation, the effect plot for the type of warning effect is shown in Figure 6. Although the ANOVA does not reveal that the warning effect was significant ($p=0.13$), when only the icon warning and no warning were compared in the model (excluding all cases of the text warning), then these two are significantly different ($p=0.04$).

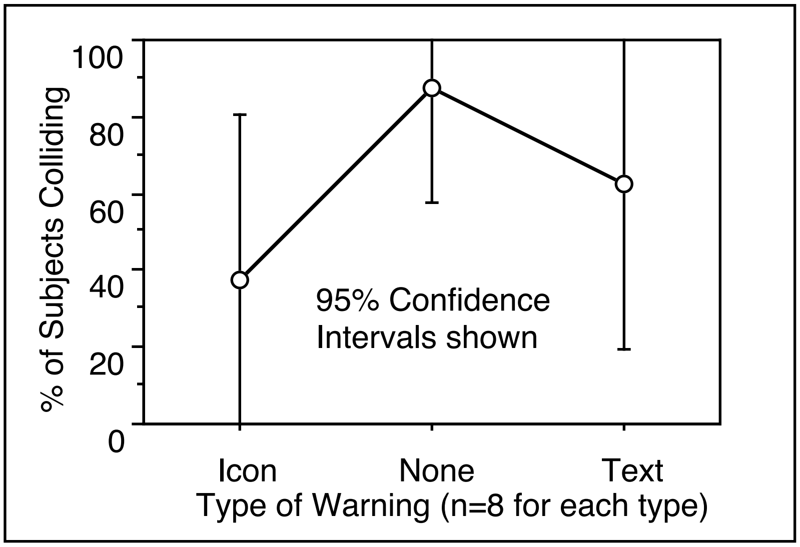


Figure 6. Percentage of subjects who collided with the lead vehicle based on warning format.

Other dependent measures besides the collision indicator were examined in the same type of one-way ANOVA model: point of throttle release, point of brake actuation, maximum lateral acceleration, point of lane crossing, lateral clearance between subject's vehicle and lead vehicle, and speed at impact. None of these measures was influenced significantly by the type of warning given in the first collision scenario. Further discussion of these measures appears later in this section.

Should more than one crash scenario be presented to each subject?

Observations of subjects suggest that they found the simulation to be reasonably realistic and were surprised by the initial encounter. ("Did I die?") Subjects' behavior on the second encounter was markedly different from their behavior on the first. Figure 7 shows that the percentage of subjects who collided with the lead vehicle was drastically lower for the second encounter than for the first.

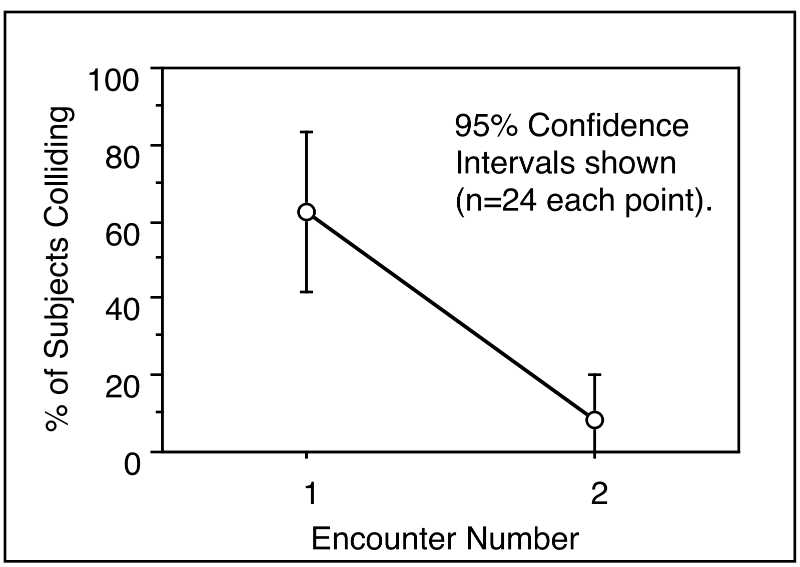


Figure 7. Percentage of subjects who collided with the lead vehicle for each encounter.

Of the 24 drivers, 15 (63 percent) collided in their first encounter, 2 (8 percent) in their second. This difference was statistically significant ($p<0.0001$) as determined by one-way ANOVA in which (as depicted in Figure 7) the dependent variable is the number of crashes and the independent variable is the encounter number. The primary difference between the first encounter and the second encounter was the element of surprise--the subjects' second-encounter data were probably different from their first-encounter data because the subjects had learned to expect another encounter after the first one. Therefore, the validity of the second-encounter data comes into question. For this reason, the following analyses utilize data solely form the **first** encounter.

Despite the fact that only the first encounter is analyzed in what follows, graphical depictions of **all** encounters -- both first and second -- are given in Appendix A.

What performance measures other than crashes might be sensitive to collision warning design differences?

Besides the collision indicator for each subject, other data were collected. These data are presented in Table 4. A brief description of each column follows the table.

Table 4. Performance measures for each subject and encounter

S #	Sex	Age (yr.)	Warning Format	Collision?	Sub-jective Rating	Lateral clearance	Impact speed ft/sec	Impact speed mi/hr	Lane Xing position (feet)	Throttle & Brake Activity: Throttle Released	Throttle & Brake Activity: Brake Engaged	peak lateral acceleration (ft/sec^2)
			Icon	Yes	5	collision	38.6	26.3		46257.9	46345	0.24
1	F	21	Text	No	9	9.4			92164.5	92033.6		3.61
			Icon	No	5	8.4			46357.2	46228.7	46318.3	4.34
2	F	20	None	No		8.2			92170.8	92019.3	92097.4	3.56
			Text	Yes	3	collision	40.2	27.4		46291.7	46333	-0.92
3	F	21	Icon	No	7	8.8			92141.6	92022.7		2.06
			Text	Yes	7	collision	43.8	29.9		46293.2	46357.3	-2.37
4	F	19	None	No		6.6			92162.7	92044.5	92086.7	2.08
			None	Yes		collision	30.5	20.8		46219.9	46332.2	0.24
5	F	23	Icon	No	8	8.9			92145.5	92012.1		2.58
			None	Yes		collision	41.6	28.4		46259.6	46332.9	0.41
6	F	20	Text	Yes	2	collision	35.1	23.9		92063.2	92140.7	0.12
			Icon	No		7.9			46349.3	46318.8		2.55
7	F	70	Text	No	1	9.4			92170.8	92112.9	92128.9	-3.35
			Icon	No	8	**	**	**	**	46227.4	46247	0.35
8	F	72	None	No		5.9			92172.3	92034.4	92114.6	1.36
			Text	No	8	7.1			46361.5	46275.7		3.28
9	F	69	Icon	No	7	8.0			92161.1	92076.6		2.75
			Text	No	2	-7.1			46356.3	46228.8	46277.7	-2.11
10	F	66	None	Yes	5	collision	32.6	22.2		92023.7	92128.6	-3.51
			None	Yes		collision	33.2	22.6		46278.1	46317.7	-0.15
11	F	65	Icon	No	4	**	**	**	**	92016.4	92099.4	0.18
			None	Yes		collision	21.7	14.8		46208.6	46302.6	-0.2
12	F	71	Text	No	8	**	**	**	**	92011.5	92032.8	0.2
			Icon	No	7	9.9			46310.6	46226.7		2.54
13	M	23	Text	No	6	9.3			92122.4	92034.8		2.55
			Icon	Yes	5	collision	28.8	19.6		46258.2	46320.8	0.05
14	M	20	None	No		**	**	**	**	92007	92020.7	0.09
			Text	Yes	3	collision	35.9	24.5		46300.8	46326.6	0.37
15	M	21	Icon	No	7	9.7			92147.4	92011.6	92024.1	3.37
			Text	Yes	4	collision	37.7	25.7		46208.5	46275.2	0.31
16	M	18	None	No		**	**	**	**	92020.7	92034.4	0.23
			None	Yes		collision	36.9	25.2		46225.4	46312.3	0.38
17	M	21	Icon	No	3	12.3			92154.1	92012.7	92140.2	4.42
			None	Yes		collision	34.8	23.7		46280.5	46319.8	0.15
18	M	21	Text	No	5	12.7			92148.4	92025.2	92139	-3.35
			Icon	Yes	6.5	collision	47.4	32.3		46363.4	46373.9	-1.71
19	M	72	Text	No	3.5	6.3			92028.7	92124.8		1.32
			Icon	No	5	**	**	**	**	**	46210.2	-1.14
20	M	74	None	No		8.5			92184.0	92008.1	92017.6	4.14
			Text	Yes	5	collision	38.6	26.3		46316.7	46346.8	0.13
21	M	70	Icon	No	5	7.9			92121.3			2.13
			Text	No	6	10.6			46361.9	46217.1	46299.5	-5.99
22	M	69	None	No		8.8			92151.9	92027.4	92102.3	2.31
			None	Yes		collision	20.7	14.1		46223	46316.9	0.12
23	M	71	Icon	No	7	6.8			92172.2	92011.8	92023.1	2.88
			None	No		9.0			46348.6	46231.7	46259.4	2.23
24	M	67	Text	No		6.1			92174.7	92022.9	92072.9	1.39

Note: Asterisks indicate conditions in which subjects drove too slowly for an encounter to occur.

Notes on selected columns in Table 4:

Measure	Description
Age	2 levels: young (18-30 yrs) and older (65+ yrs)
Warning Format / Collision	The two encounters for each subject are listed in the order presented to each subject. There were three warning formats. The collision column indicates whether the two vehicles collided.
Subjective Rating	For warning trials, this is a post-study rating of the helpfulness of the warning (1=distracting, 5=not helpful or distracting, 9=very helpful).
Lateral Clearance	For those who did not collide, the distance in feet between the two vehicles when the front of the follower passed the back of the leader.
Impact Speed	For those who collided, the speed of the following vehicle.
Lane Crossing Position	For those who swerved, the distance on the road (in feet traveled) where the follower first crosses either lane edge marker.
Throttle Released	The point on the road where the throttle was released (if at all).
Brake Engaged	The point on the road where the brake was engaged (if at all).
Peak Lateral Acceleration	The maximum absolute value of the lateral acceleration of the following vehicle during the time of the encounter. See Appendix H for how this was computed.

In the analysis of whether any of the factors of interest (age group, sex, and, of course, type of warning) had any significant impact on the dependent measures indicated in Table 2, very few significant effects were uncovered. Only two of the models (marked by p-values shown in boldface in Table 5) indicated a significant effect at the 0.05 level. Shown are the p-values for one-way ANOVA models, which considered only a single independent variable. The dependent variables are listed in rows (along with the overall means of these variables), and the single independent variables are listed as the column headers.

Table 5. Mean values of dependent measures and p-values of ANOVA tests.

		Independent Main Effects		
Dependent Measure	Overall Mean	Age	Gender	Warning Type
All Subjects:				
Collision Indicator	62.5 %	**0.036**	0.69	0.13
Subjects who swerved without colliding:				
Peak Lateral Acceleration	0.13 ft/sec^2	0.19	0.33	0.38
Horizontal Clearance	9.1 ft	1	**0.019**	0.67
Point of Lane Crossing	46349.3 ft	0.16	0.29	0.43
Subjects who collided:				
Impact Speed	35.4 ft/sec or 24.1 mi/hr	0.28	0.89	0.15

Note: The point of lane crossing, where the left front tire touched the centerline, was measured from the start of the drive for computational convenience.

Age and gender effects

Overall, fewer subjects in the older age category had collisions than in the young category: 42 percent vs. 83 percent (n=12 for each category); see Figure 8. This is a statistically significant difference (p=0.036), as determined by an ANOVA analysis. However, ANOVA did not reveal any other measures to be significantly different at the 0.05 level for young and older subjects. Measures tested were peak lateral acceleration, horizontal clearance between the subject and lead vehicles at the time the lead vehicle was overtaken, and point of lane crossing for those subjects who swerved around the lead vehicle to avoid a collision; and impact speed for those who were not able to avoid a collision. (See Table 5 for the resultant p-values.)

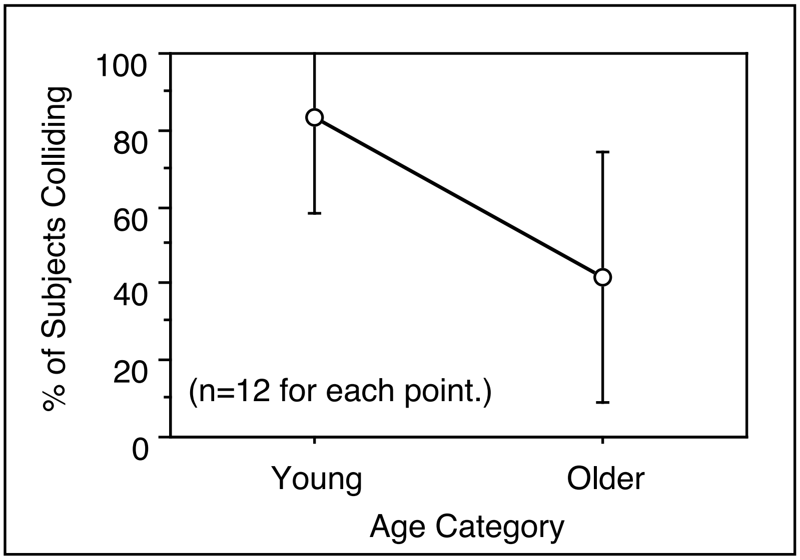


Figure 8. Percentage of subjects who collided with the lead vehicle by age.

Only one of the measures considered here was significantly different for men and women, according to a series of simple ANOVA analyses. (See Table 5 for a summary of the results of these tests.) While 58 percent of the women and 67 percent of the men collided with the lead vehicle, this difference is not statistically significant. However, there is a significant difference (p=0.02) between men's and woman's lateral clearance--that is, the horizontal gap between the two vehicles at the time the subject overtakes the lead vehicle (assuming that this event occurred within the 12-second time window considered). Lateral clearance for men was an average of 5.7 feet while women averaged 2.6 feet. See Figure 9 below.

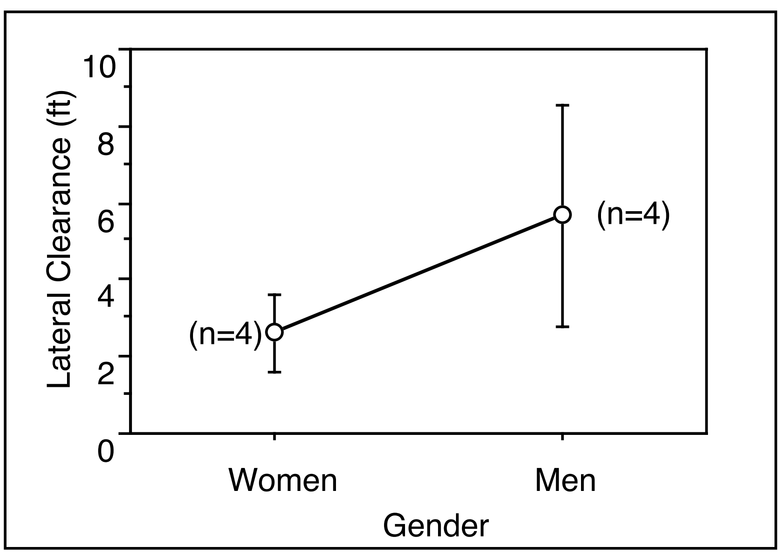


Figure 9. Gender comparison of lateral clearance.

Subjects' ratings of warnings

Subjects were asked whether they noticed a warning and, if so, to rate the warning on a scale from 1 to 9, with 1 being very distracting, 5 being no effect, and 9 being very helpful. The overall mean response was 5.4, which indicates that on average, the subjects did not feel that the warnings were exceedingly helpful or distracting. In a series of one-way ANOVAs, none of the categorical variables (age category, sex, type of warning, encounter number (first or second), and whether a collision occurred) led to significant differences (at the .05 level) in drivers' ratings. This pooling approach was chosen to improve the error estimate, necessary given the small sample size.

CONCLUSIONS

Can a warning system help drivers avoid collisions and, if so, are text or icons more effective?

Maybe. Of the subjects who were not given a collision warning, 88 percent (7 of 8) had a collision. For text warnings and icon warnings, the numbers were 63 percent (5 of 8) and 38 percent (3 of 8), respectively. These numbers may suggest a difference in the effectiveness of the various types of warnings, but, due to the small sample size, the differences observed were not all statistically significant; however, the difference between no warning and the icon warning is significant.

Because the lack of significance might be attributable to small sample size in this case (24 subjects) rather than the lack of a real effect, a larger study is indicated. For example, if the observed percentages had remained the same in a study with twice the number of subjects as in this study, the main effect of the warning type would have been identified by ANOVA as significant ($p=0.012$).

Subjects were asked whether they noticed a warning and, if so, to rate the warning on a scale from 1 to 9 (1 being very distracting, 5 being no effect, and 9 being very helpful). The overall mean response was 5.4, which indicates that, on average, the subjects did not feel that the warnings were exceedingly helpful (but they weren't distracting either). None of the categorical variables available was a significant predictor of subjects' opinions on this matter; these variables were age category, sex, type of warning, encounter number (first or second), and whether a collision occurred (yes or no).

Should more than one crash scenario be presented to each subject?

No. After the first encounter, almost all of the subjects were expecting another encounter. They tended to take their foot off the accelerator or even press the brake as they passed parked cars. Therefore, to study the most realistic collision situations in a simulator, there must be only one collision encounter for each subject to preserve the element of surprise. When the subjects were indeed faced with the second encounter, they avoided a rear-end collision far more successfully (8 percent crashes) compared with the first (63 percent crashes).

What performance measures other than crashes might be sensitive to collision warning design differences?

None. The alternative performance measures that were analyzed were peak lateral acceleration, lane crossing position, lateral clearance, impact speed, brake activity, and throttle activity. None of the other measures showed any significant differences among the three types of warnings. The significant levels of those other measures had consistently higher p values than collision counts. The lack of significance was perhaps due to the small sample size of this study.

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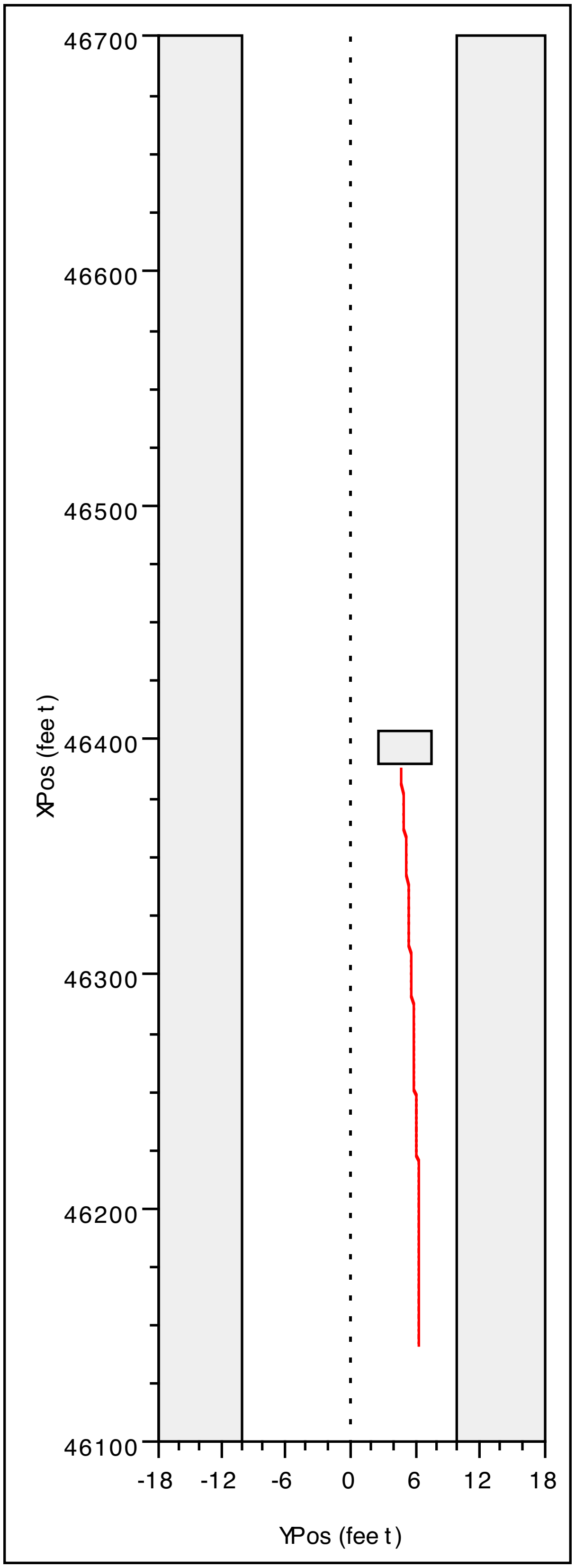
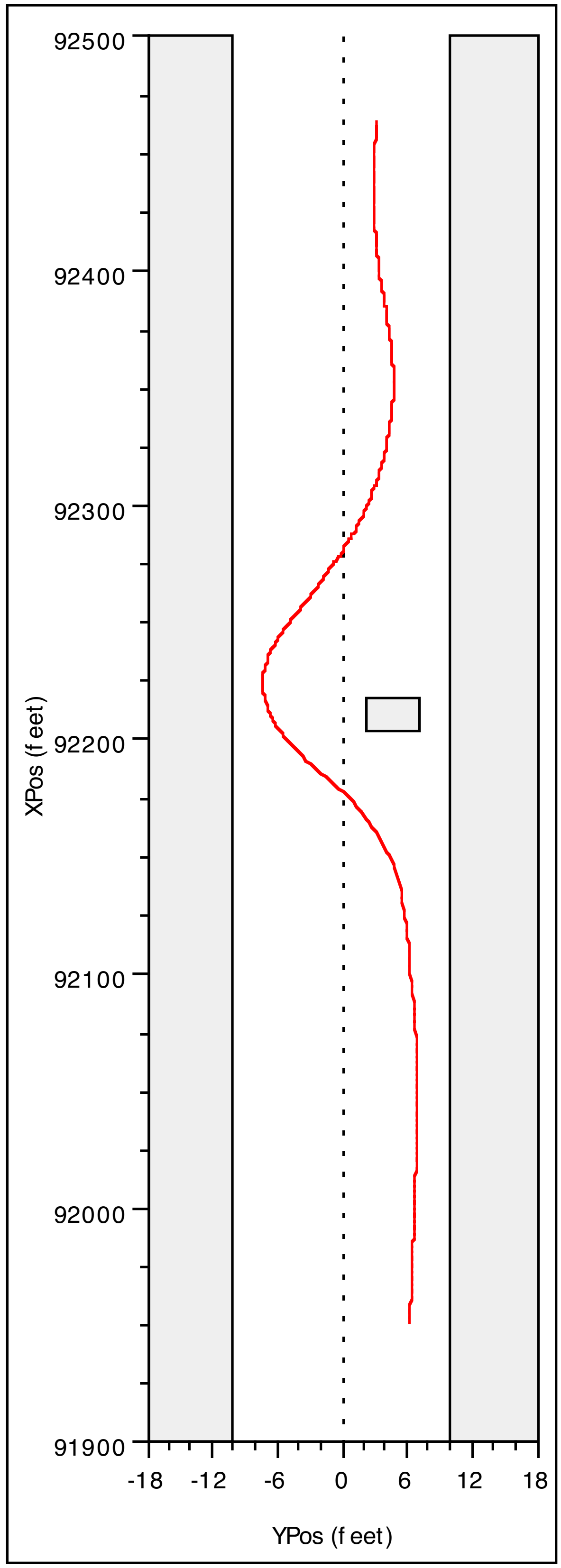
APPENDIX A - SUBJECT PATHS

The following pages depict the two encounters for each of the 24 subjects graphically. As suggested by the graphs, the simulated road is 20 feet wide and extends from Ypos=-10 to Ypos=+10. On the vertical axis, the Xpos is the distance, in feet, from the start of the simulation. Naturally, it is impossible to show the interplay over time of two moving vehicles perfectly in only two dimensions, since the time dimension is lost. Therefore, these graphs do not attempt to show both vehicles' paths. Instead, the line on each graph is the path (over time) of the center of the subject's vehicle, while the box represents the lead vehicle, frozen in time at the instant when the subject overtook it. Each graph depicts only the first 12 seconds after the subject passed a certain point on the road; therefore, the path ends either at the point of impact or at the point the subject's vehicle had reached after 12 seconds. The average speed of the subject may thus be gauged roughly by how long the path appears in the graph. For example, Subject 2 apparently traveled faster in the first encounter than the second since the path is longer in the first encounter graph.

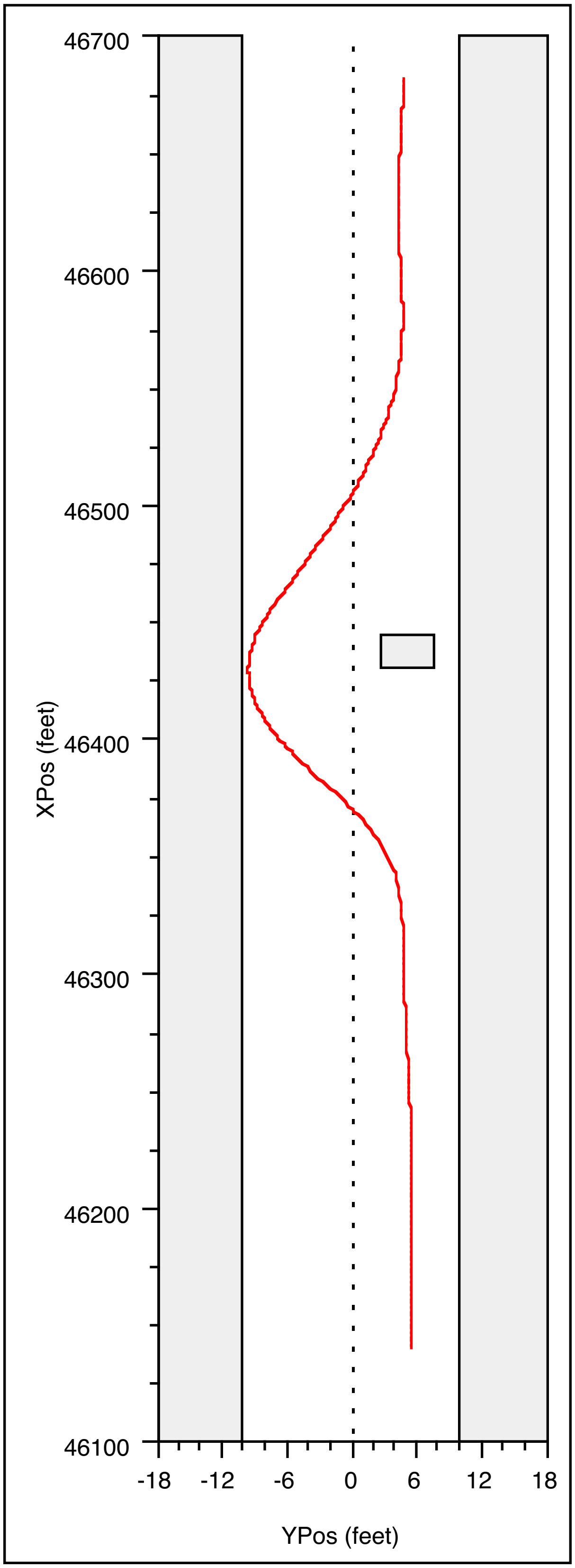
The lead vehicle is absent from some of the graphs. This occurs whenever the subject slowed down enough so that the follower never overtook the leader during the first 12 seconds. For example, in the case of Subject 8, first encounter, no box is shown on the graph. The subject had in this case slowed down so much that the lead vehicle stayed in front until long after it had initially created the collision hazard; the subject was therefore able to pass the lead vehicle safely at some time much later than the 12-second period of interest.



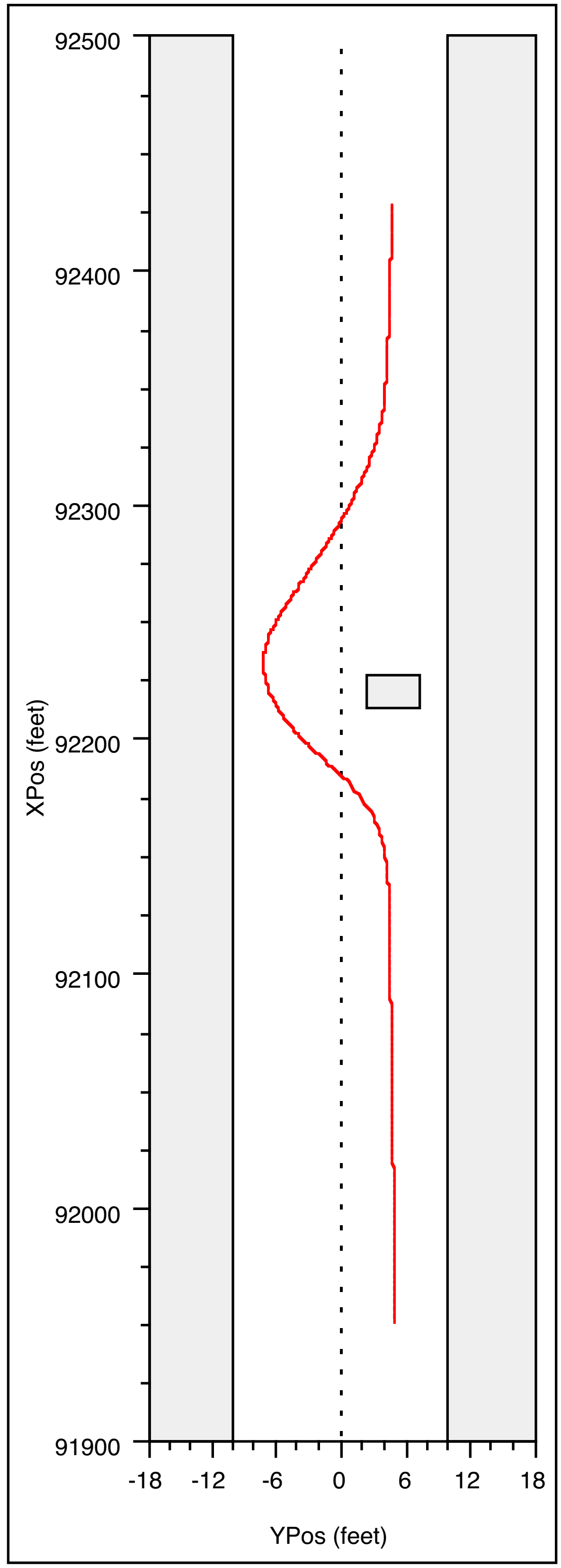
Subject 1, First Encounter, Icon Warning



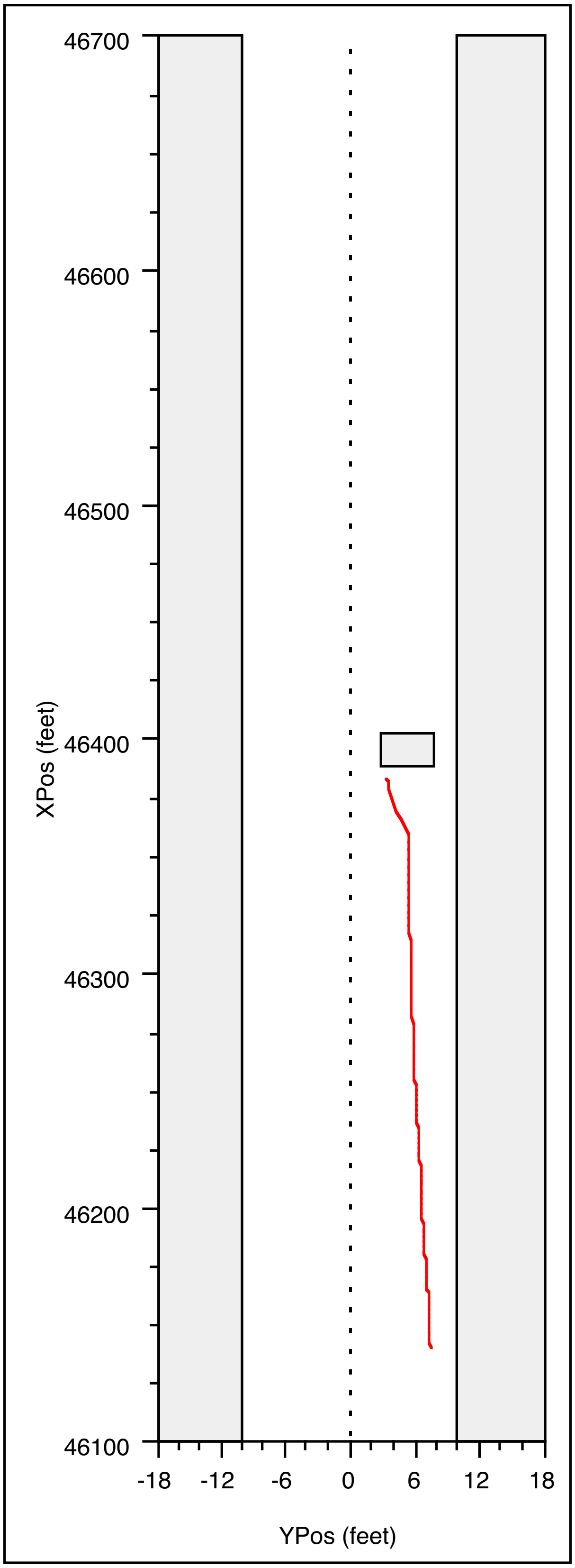
Subject 1, Second Encounter, Text Warning



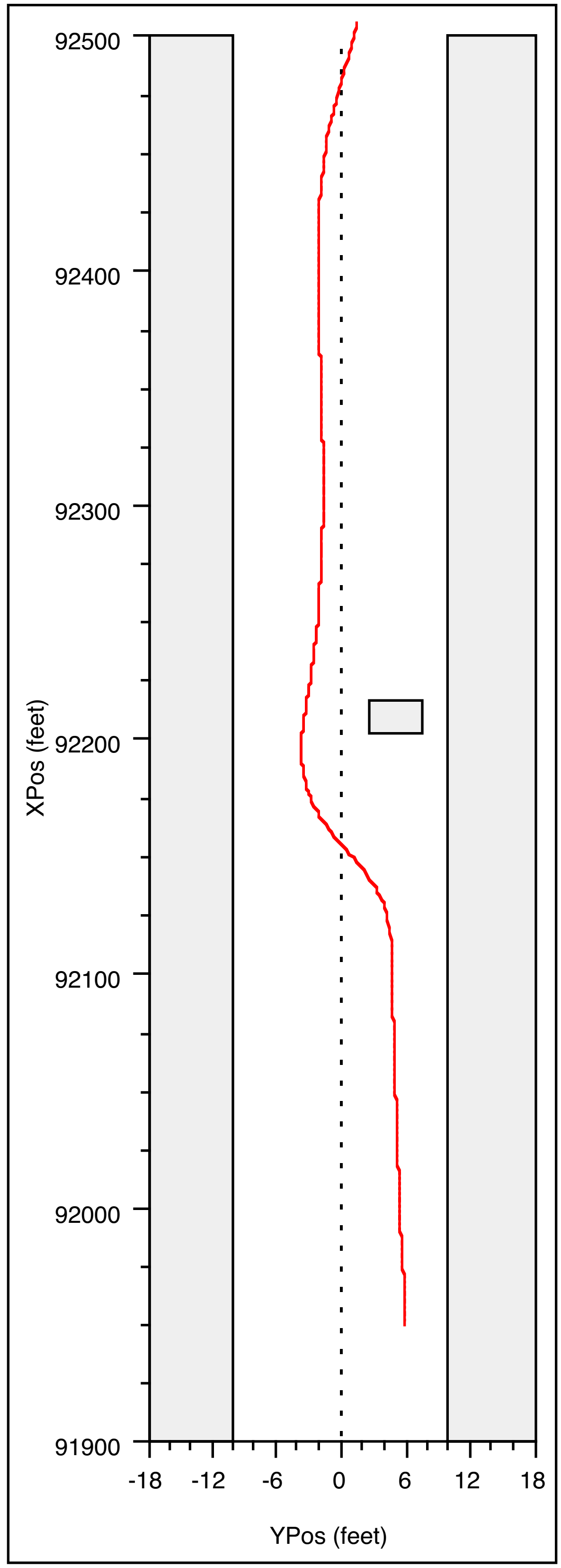
Subject 2, First Encounter, Icon Warning



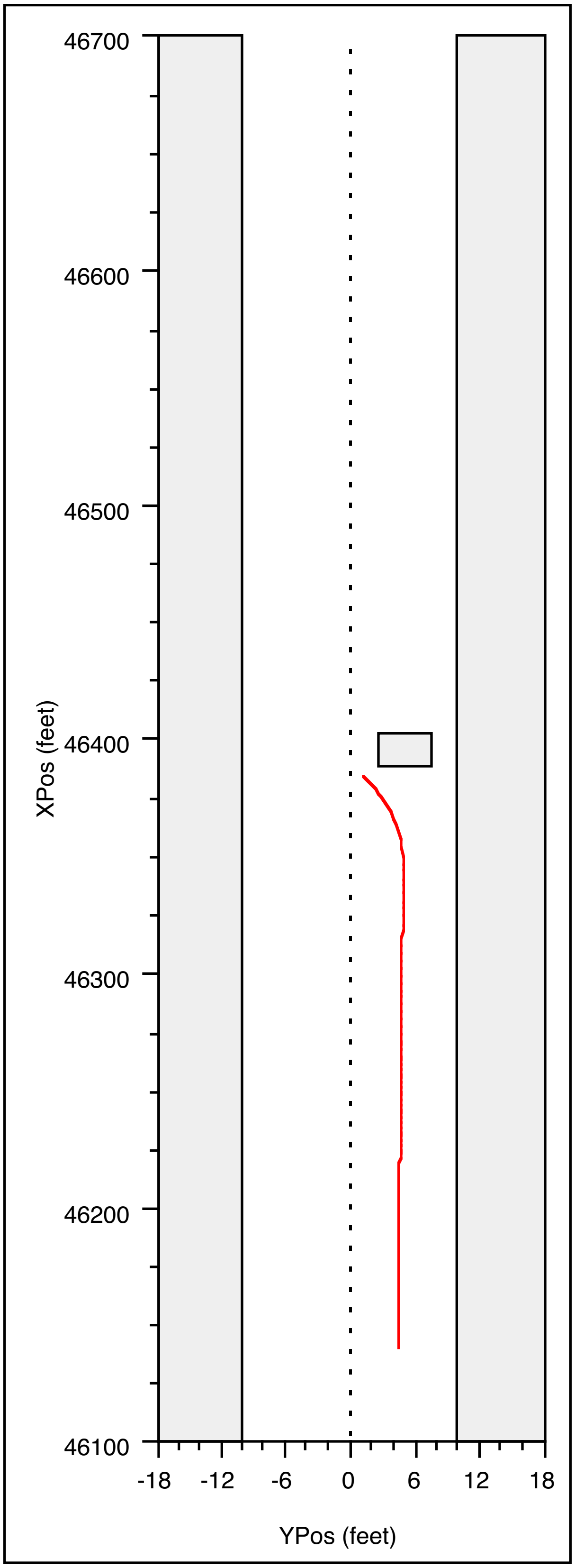
Subject 2, Second Encounter, No Warning



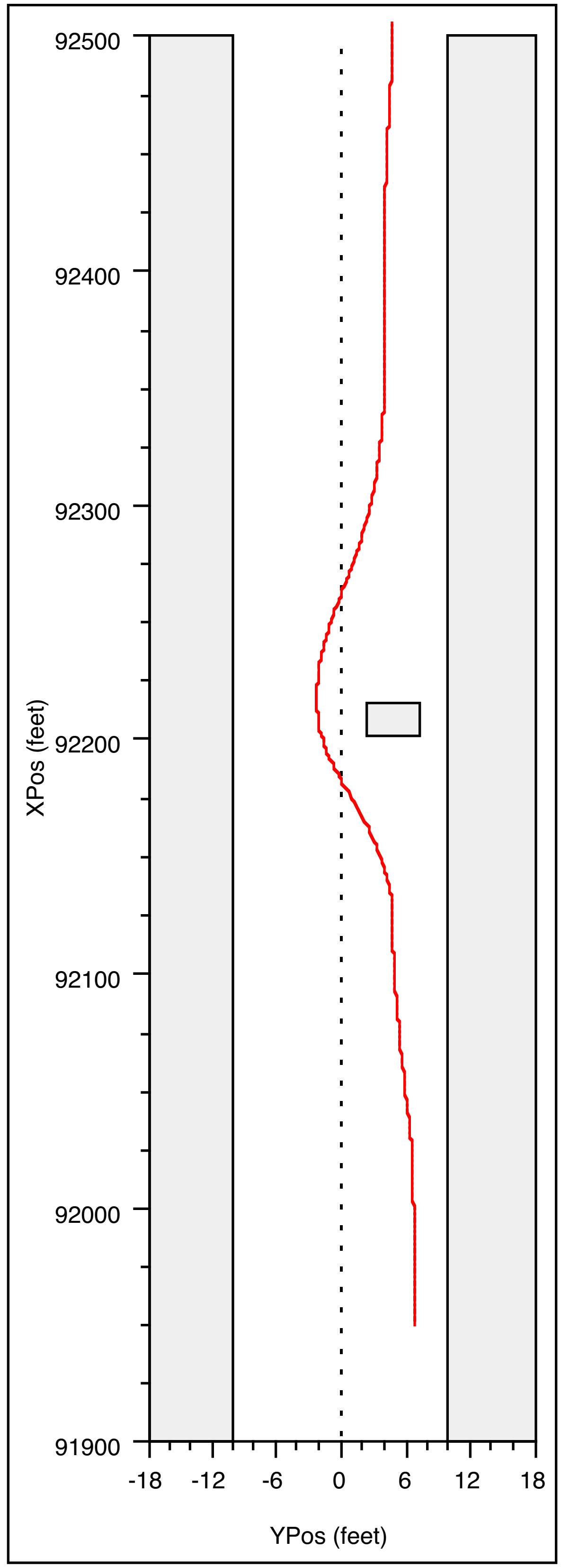
Subject 3, First Encounter, Text Warning



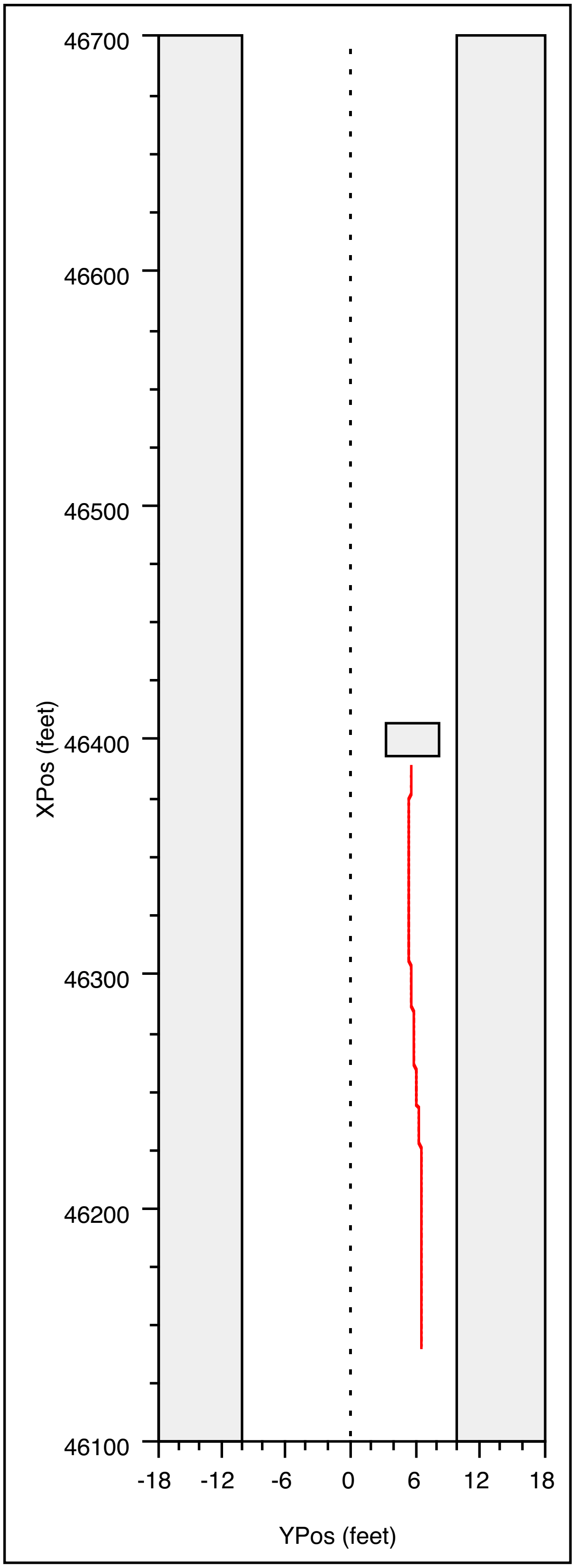
Subject 3, Second Encounter, Icon Warning



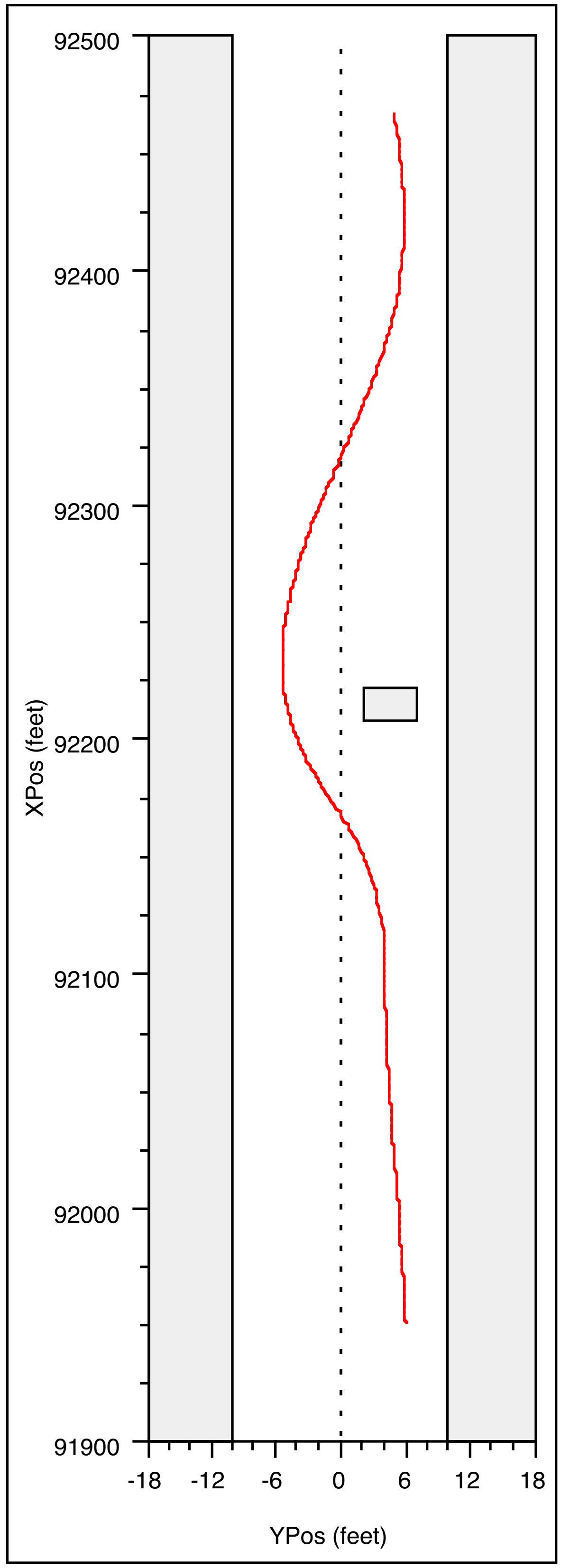
Subject 4, First Encounter, Text Warning



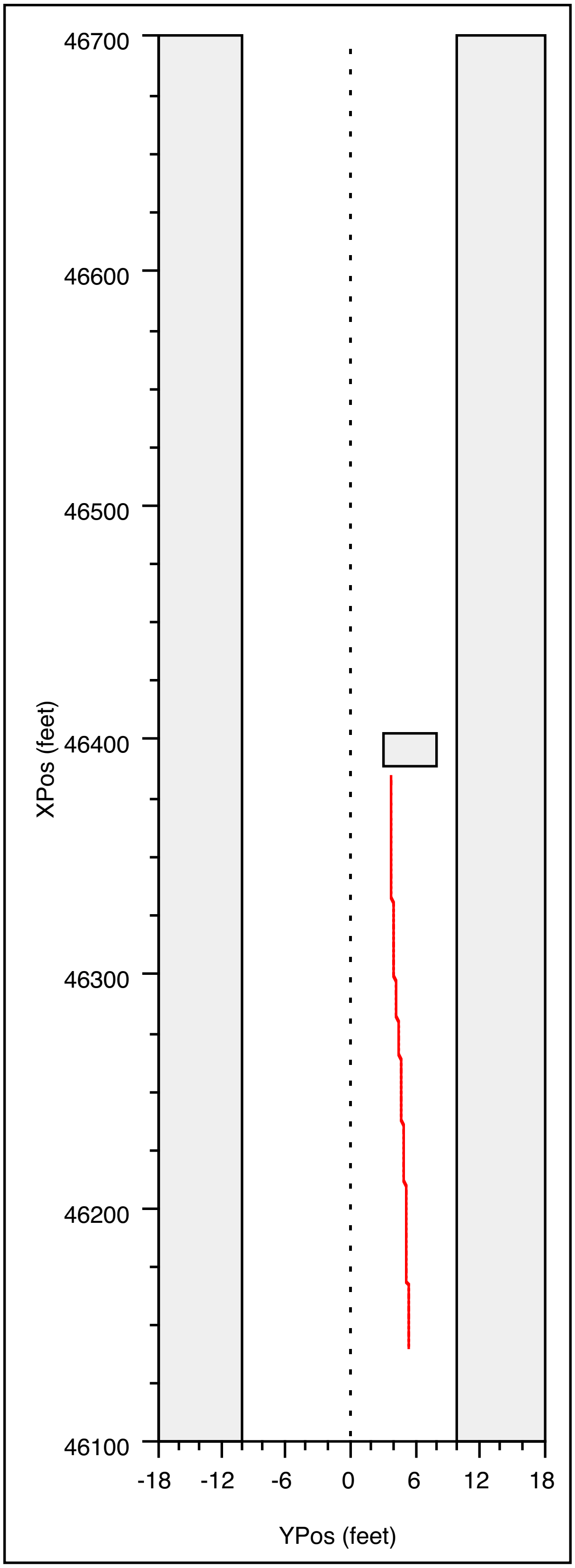
Subject 4, Second Encounter, No Warning



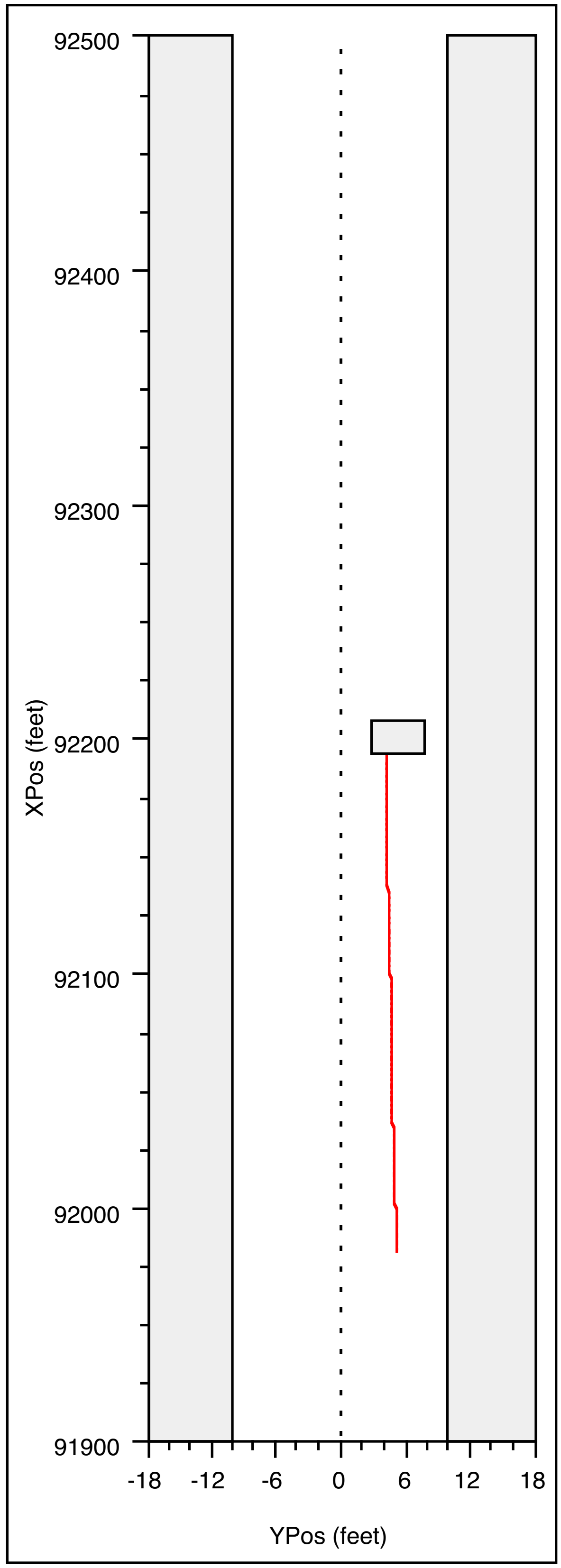
Subject 5, First Encounter, No Warning



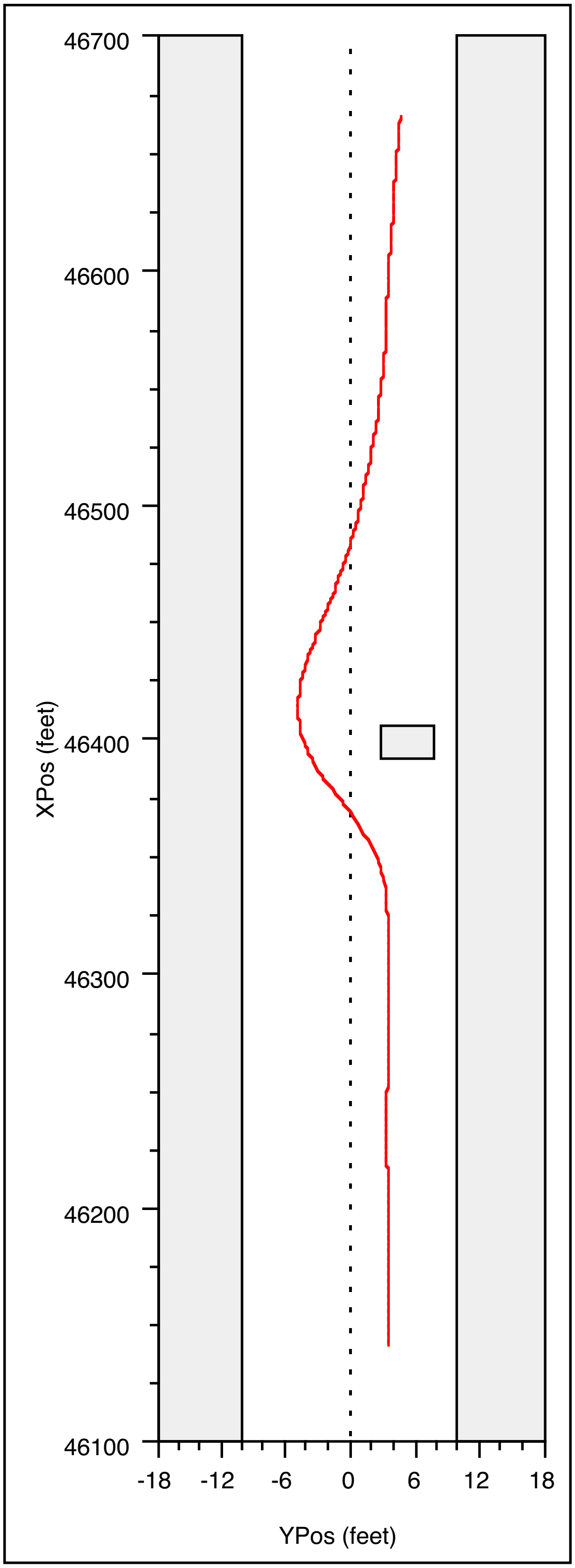
Subject 5, Second Encounter, Icon Warning



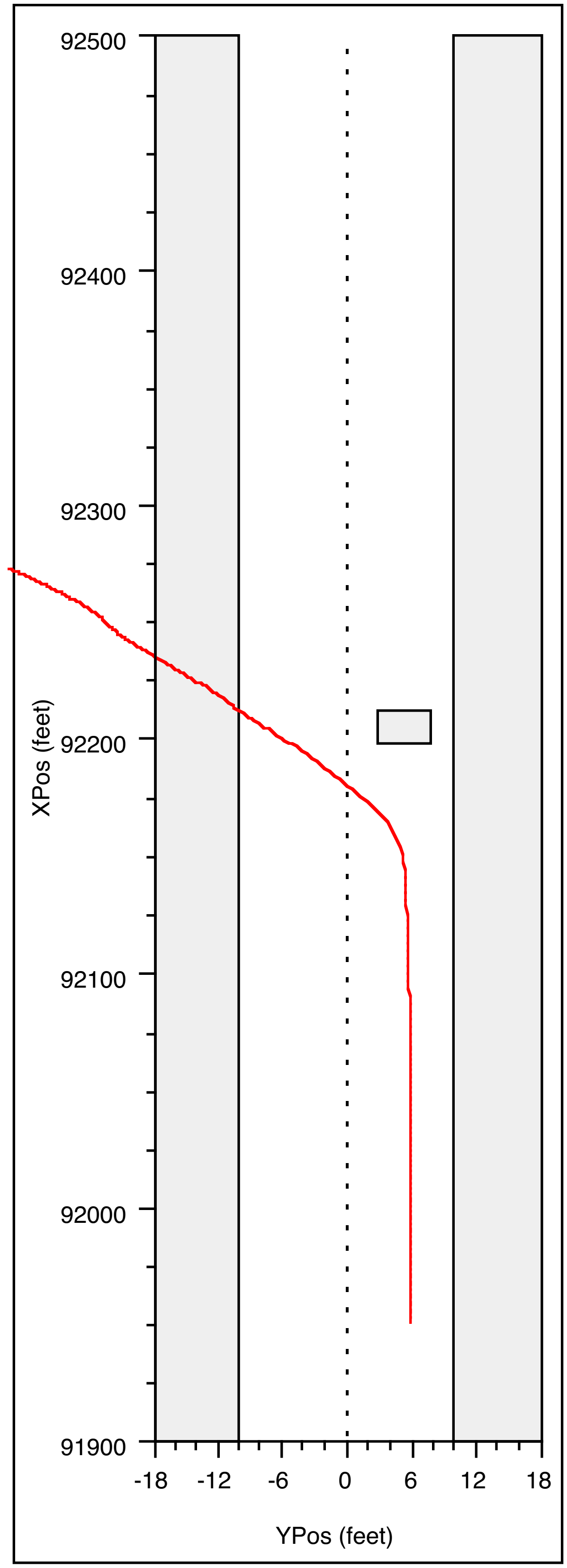
Subject 6, First Encounter, No Warning



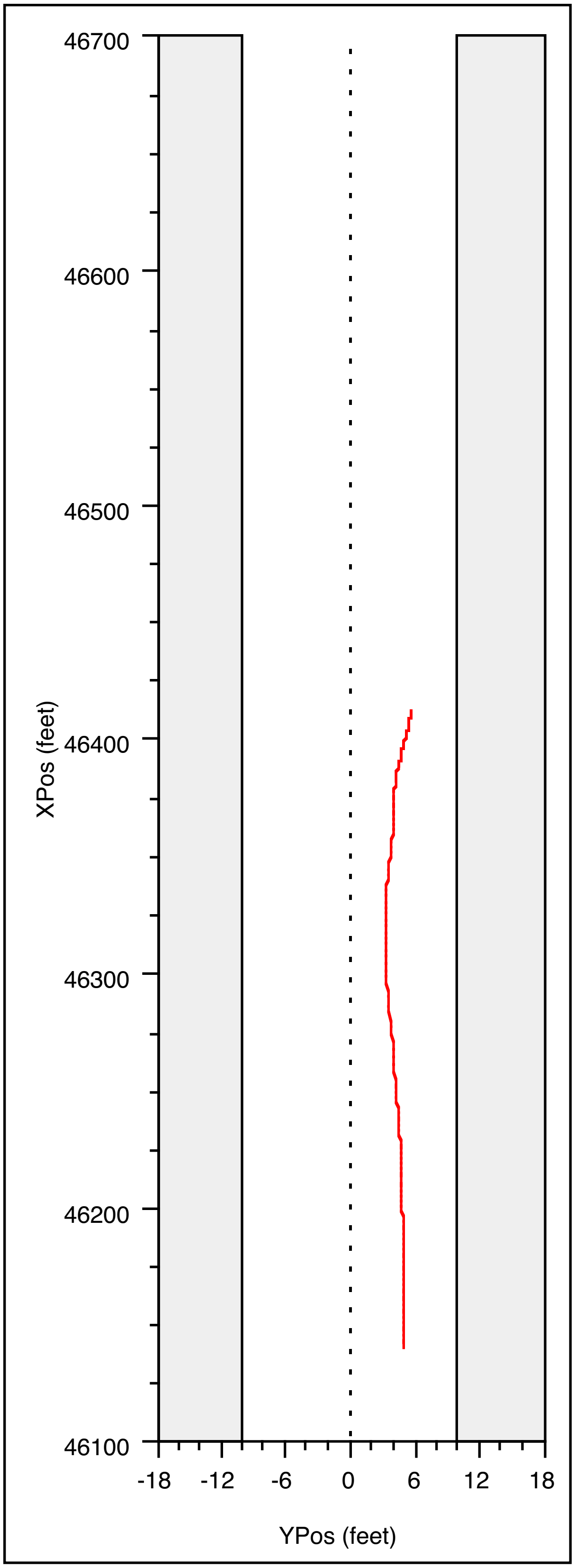
Subject 6, Second Encounter, Text Warning



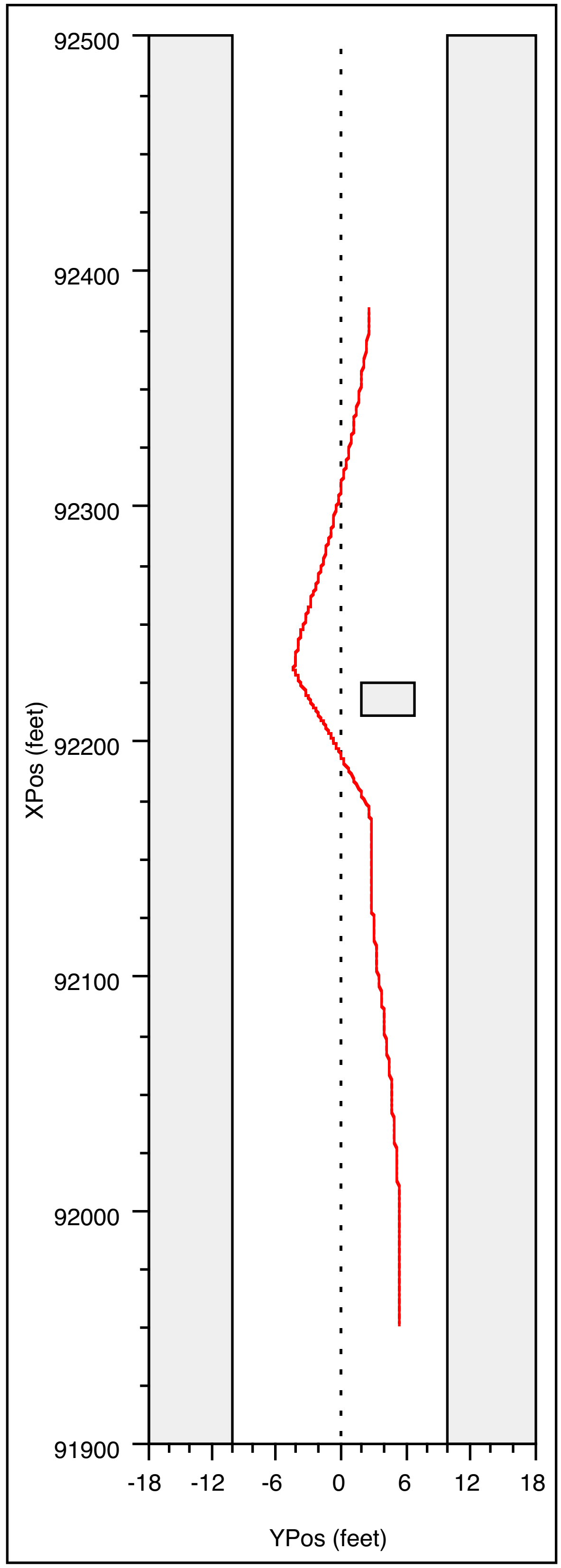
Subject 7, First Encounter, Icon Warning



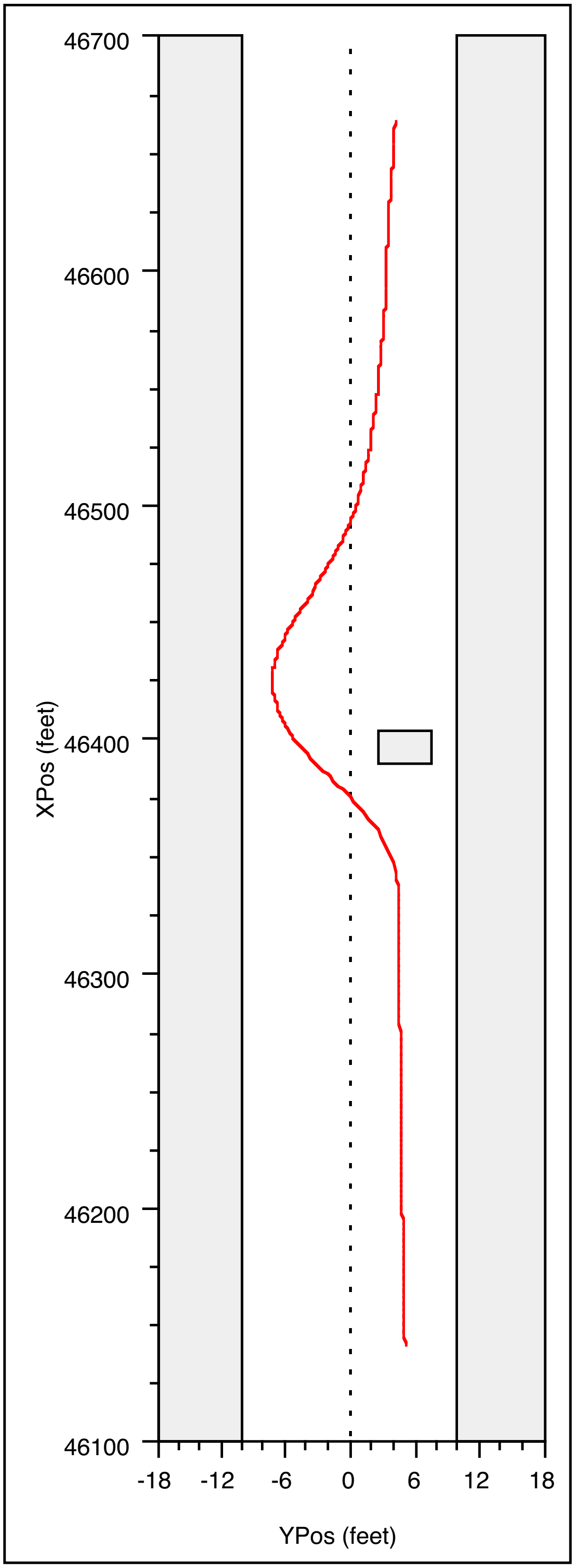
Subject 7, Second Encounter, Text Warning



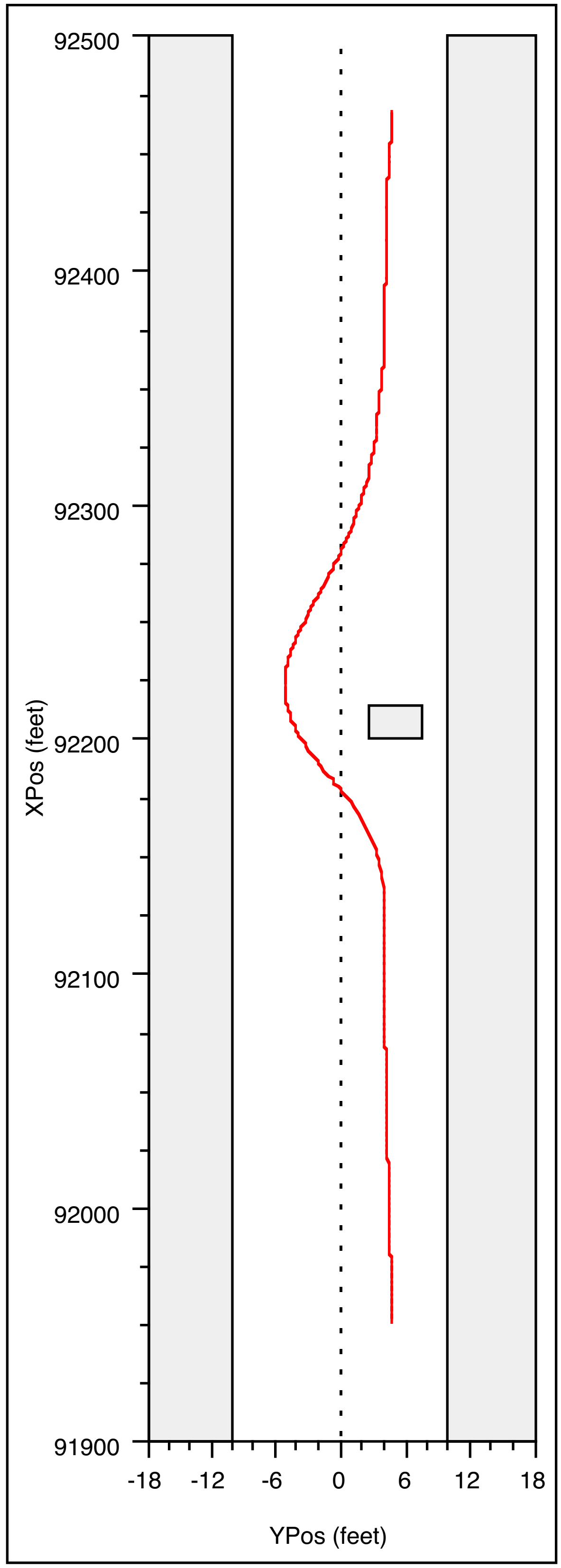
Subject 8, First Encounter, Icon Warning



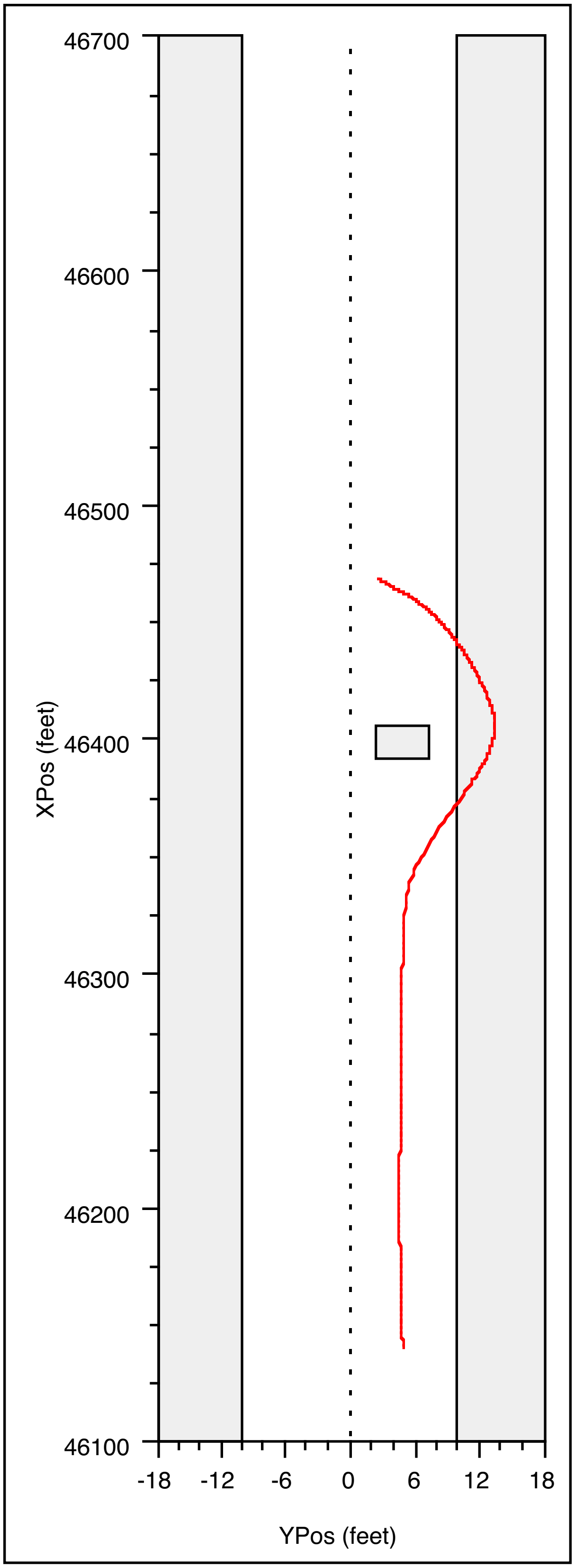
Subject 8, Second Encounter, No Warning



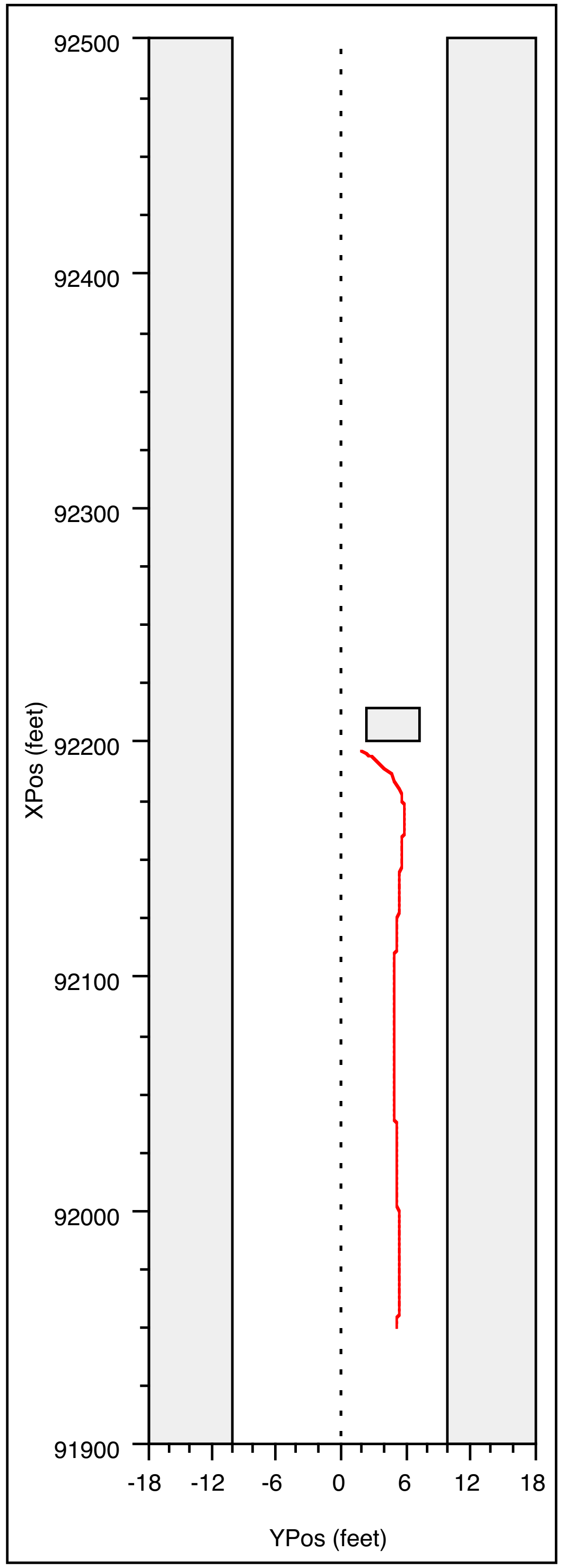
Subject 9, First Encounter, Text Warning



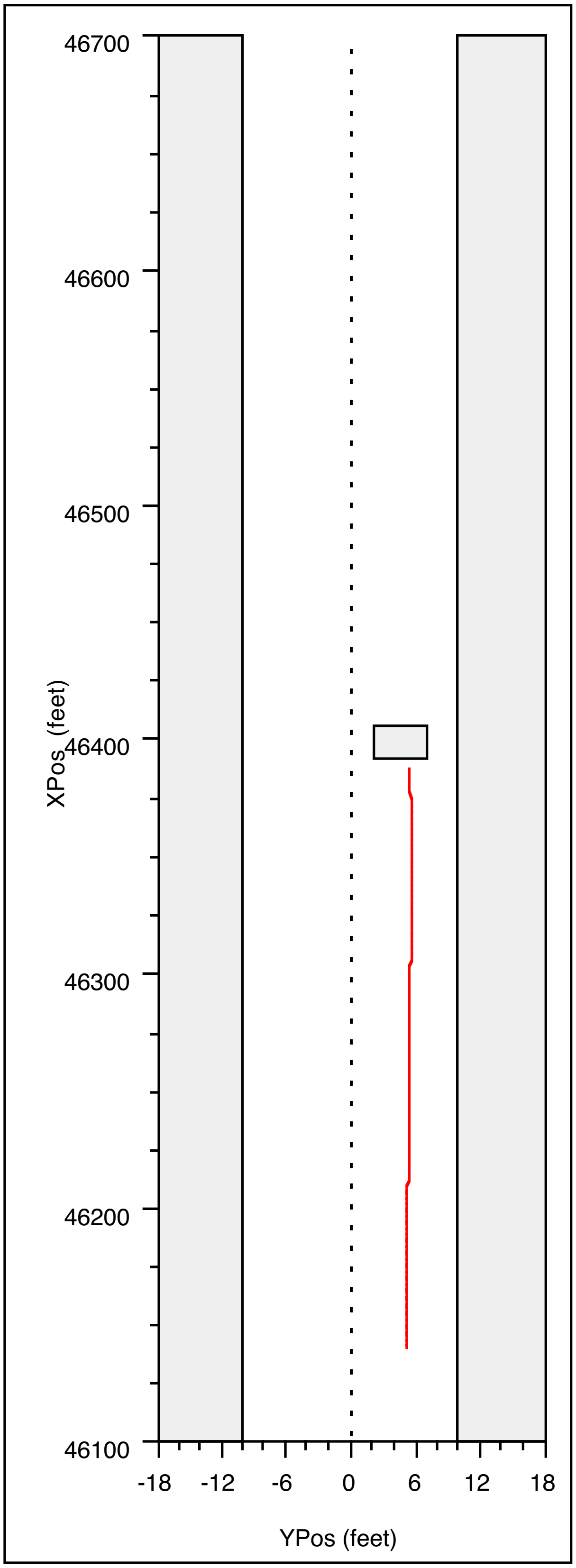
Subject 9, Second Encounter, Icon Warning



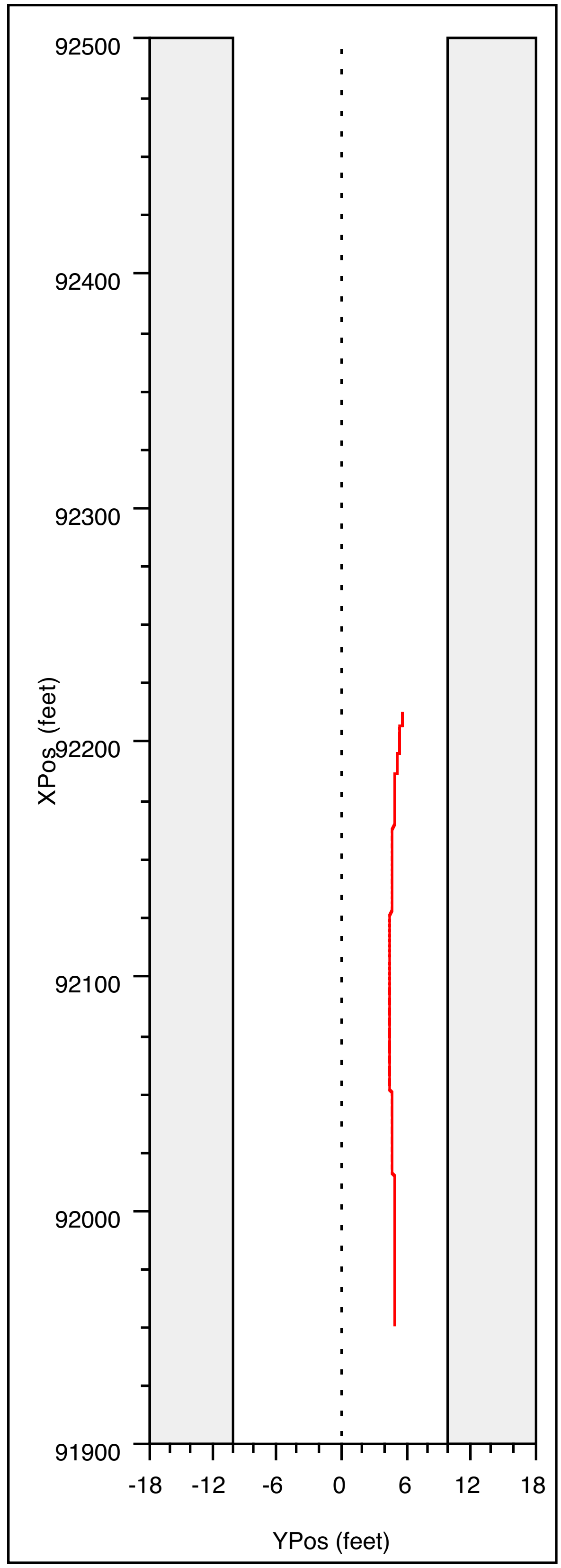
Subject 10, First Encounter, Text Warning



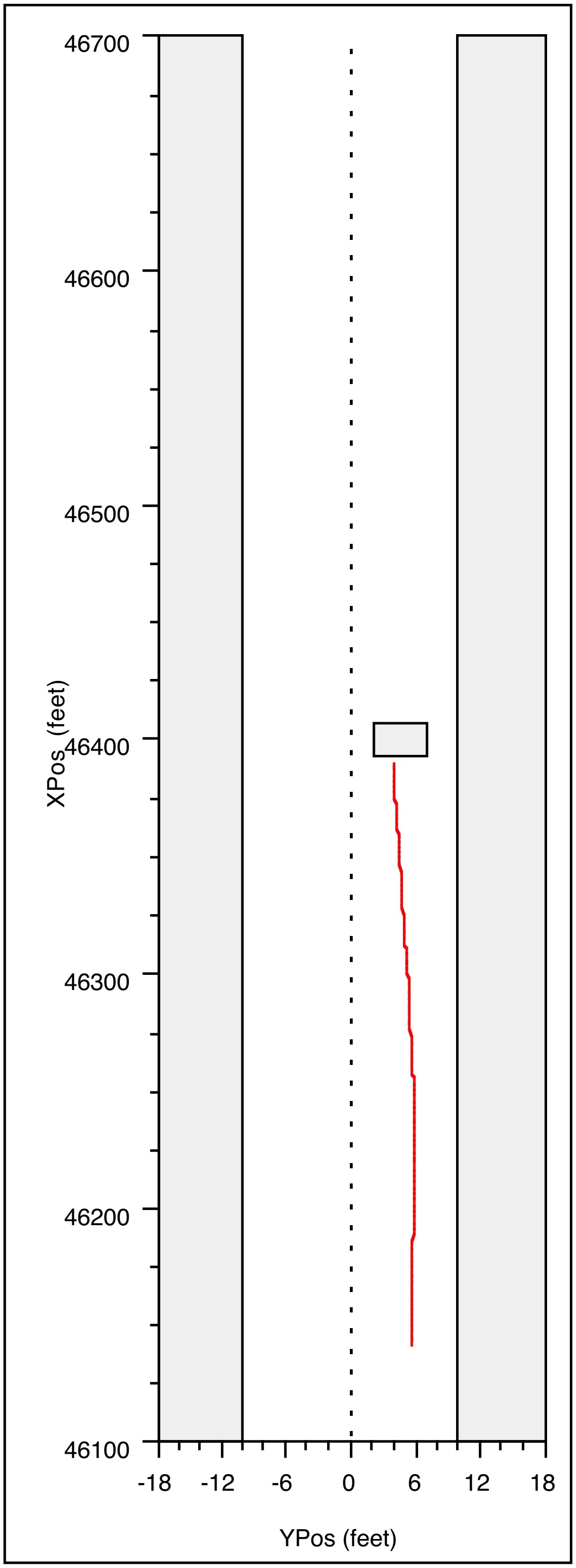
Subject 10, Second Encounter, No Warning



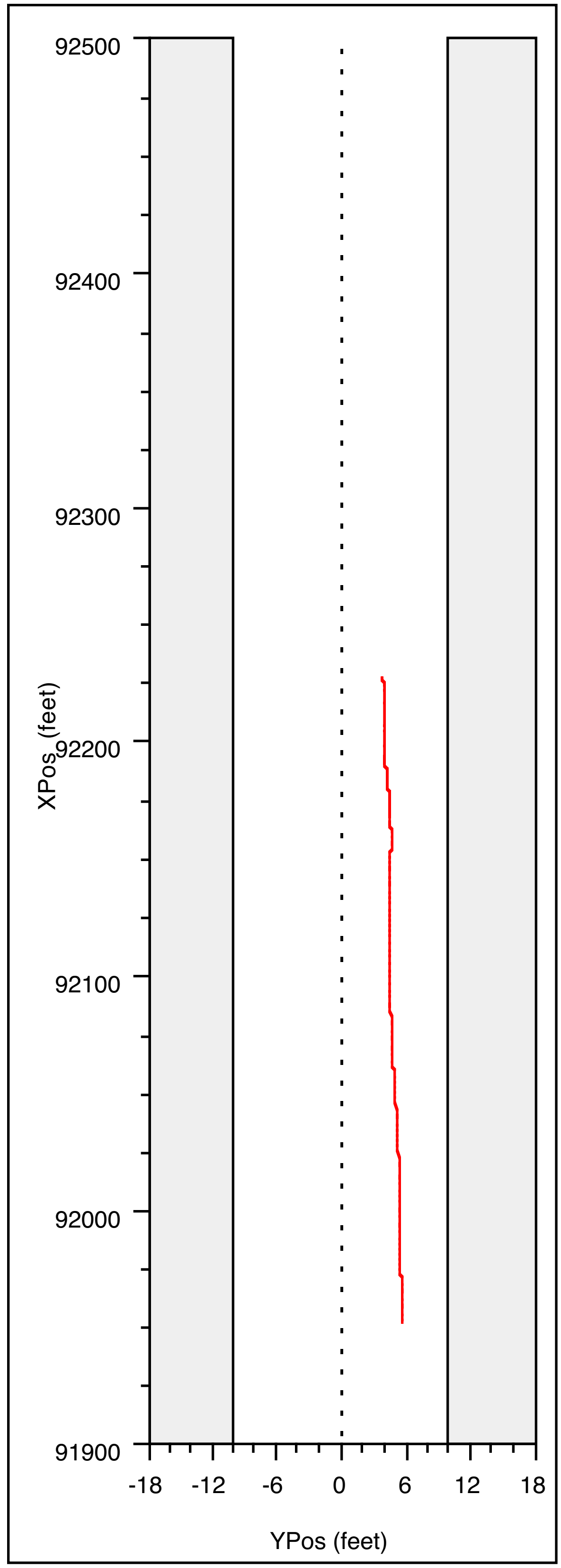
Subject 11, First Encounter, No Warning



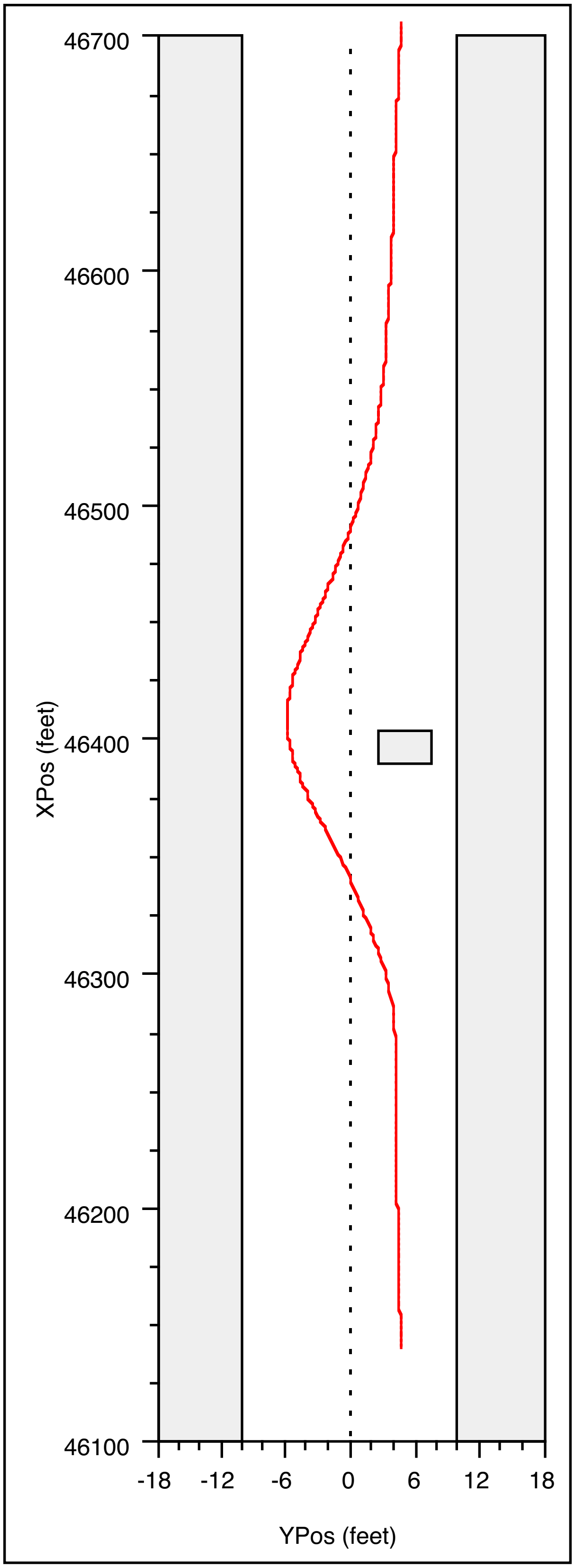
Subject 11, Second Encounter, Icon Warning



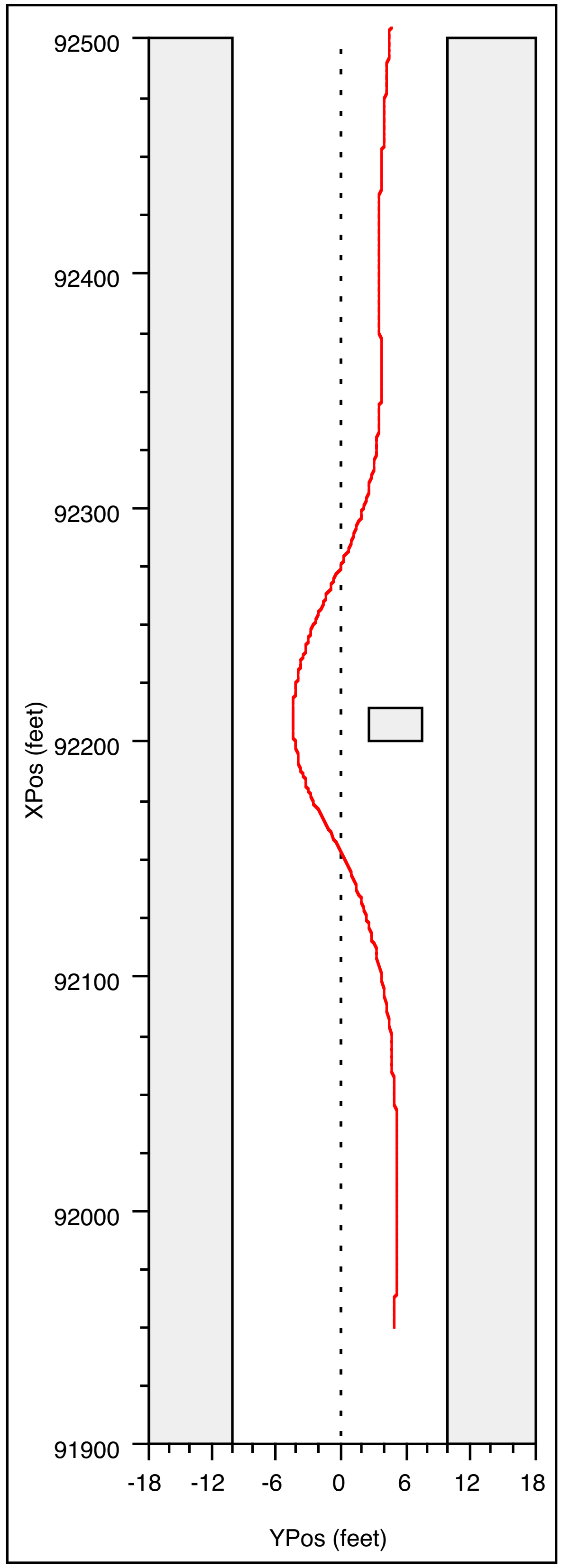
Subject 12, First Encounter, No Warning



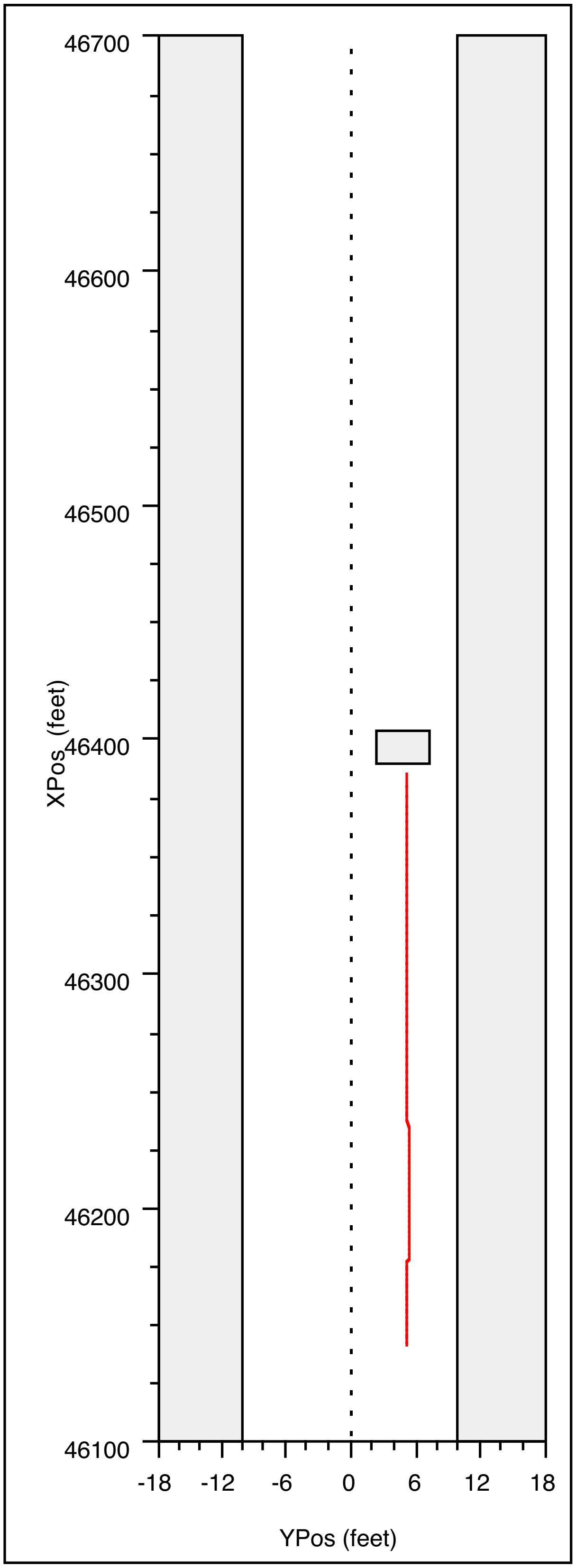
Subject 12, Second Encounter, Text Warning



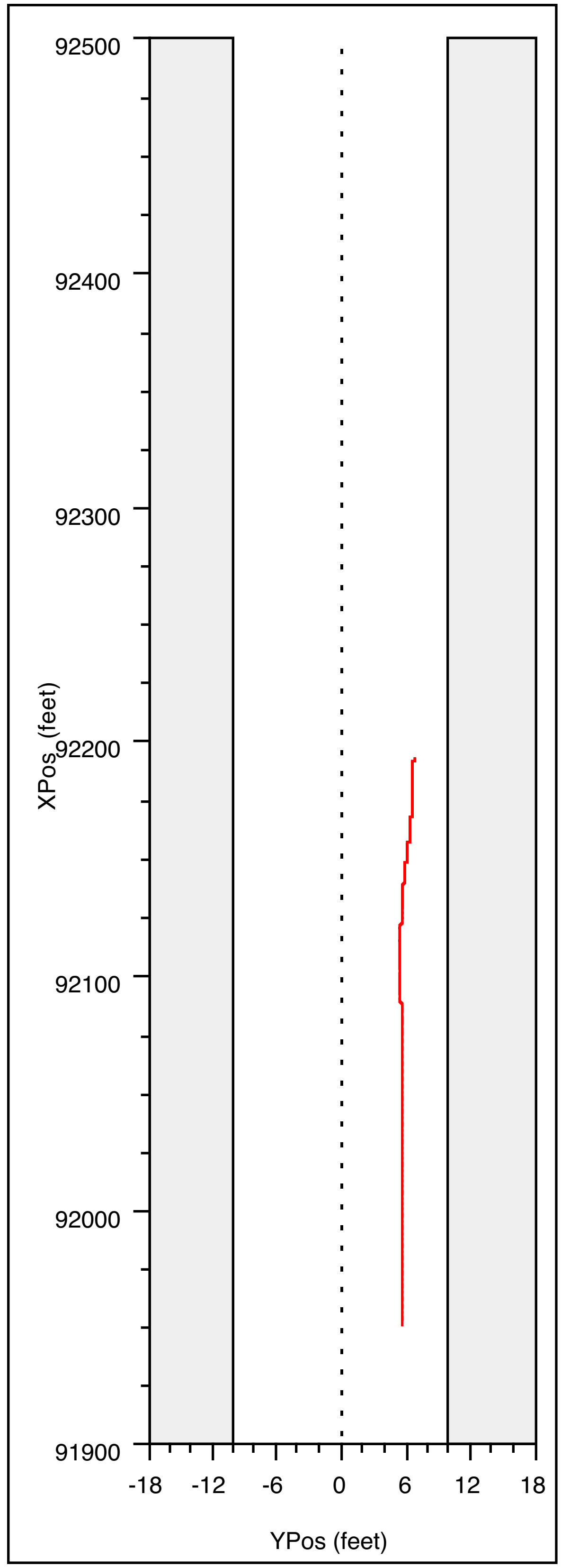
Subject 13, First Encounter, Icon Warning



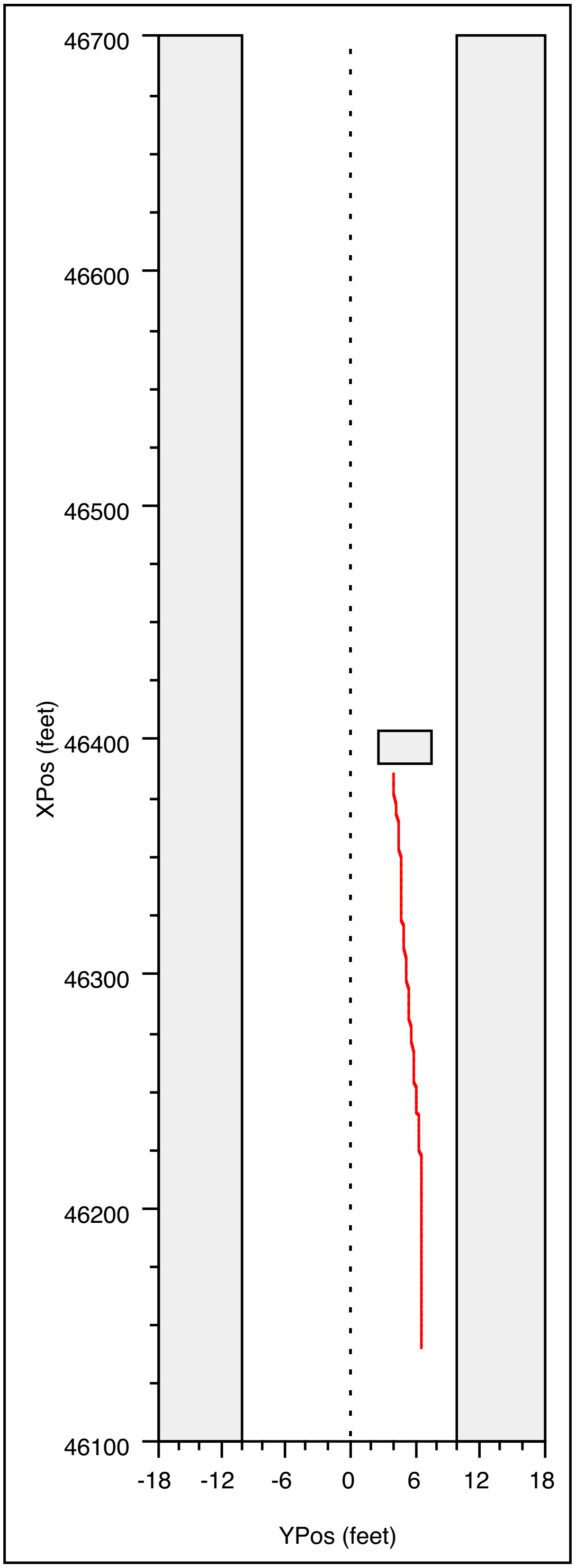
Subject 13, Second Encounter, Text Warning



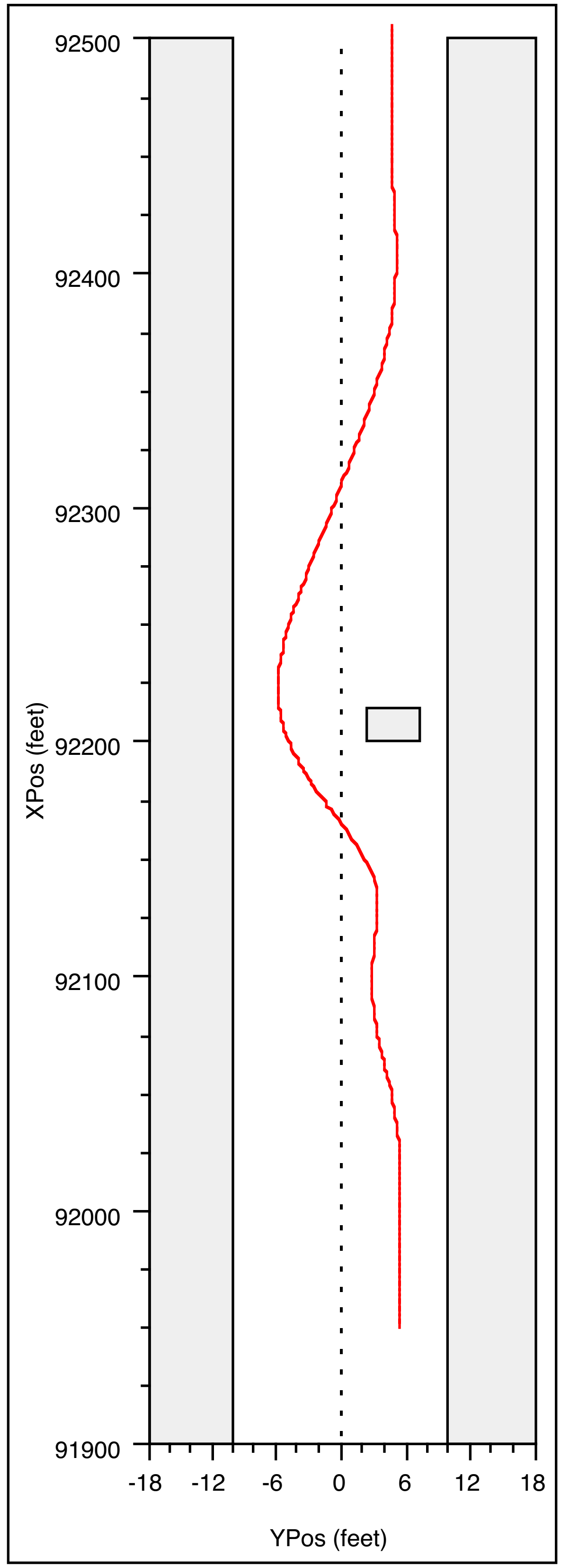
Subject 14, First Encounter, Icon Warning



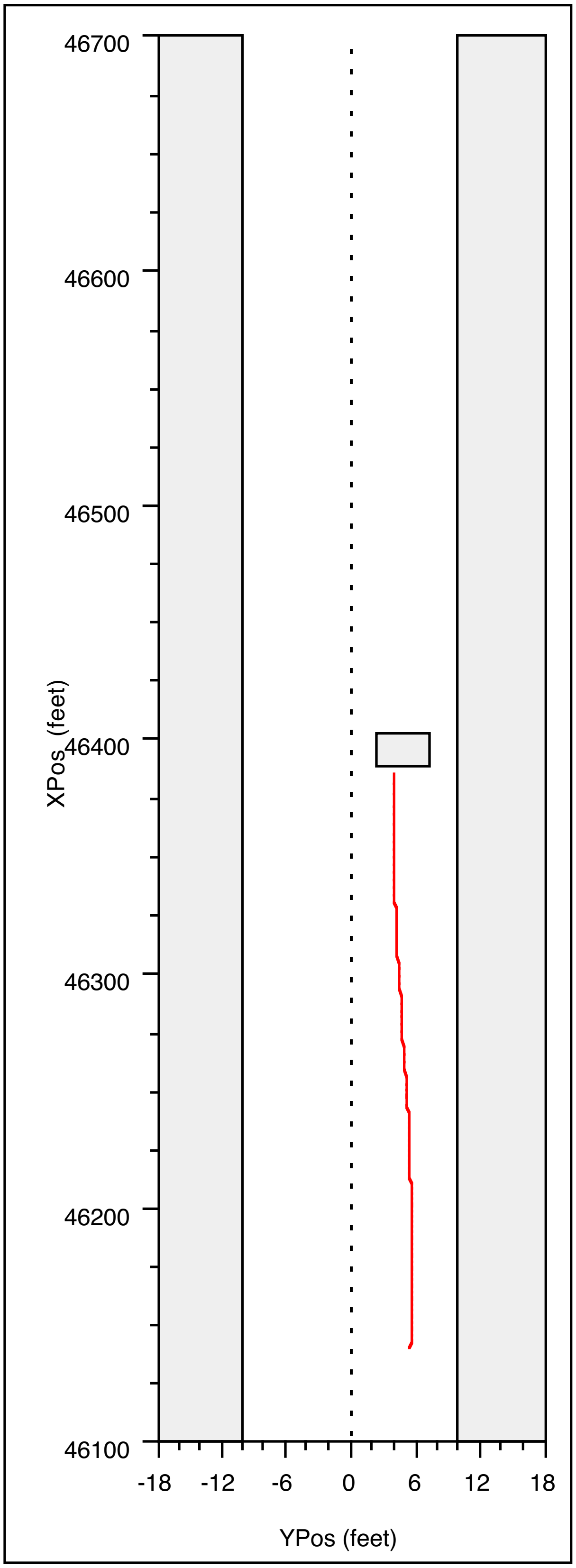
Subject 14, Second Encounter, No Warning



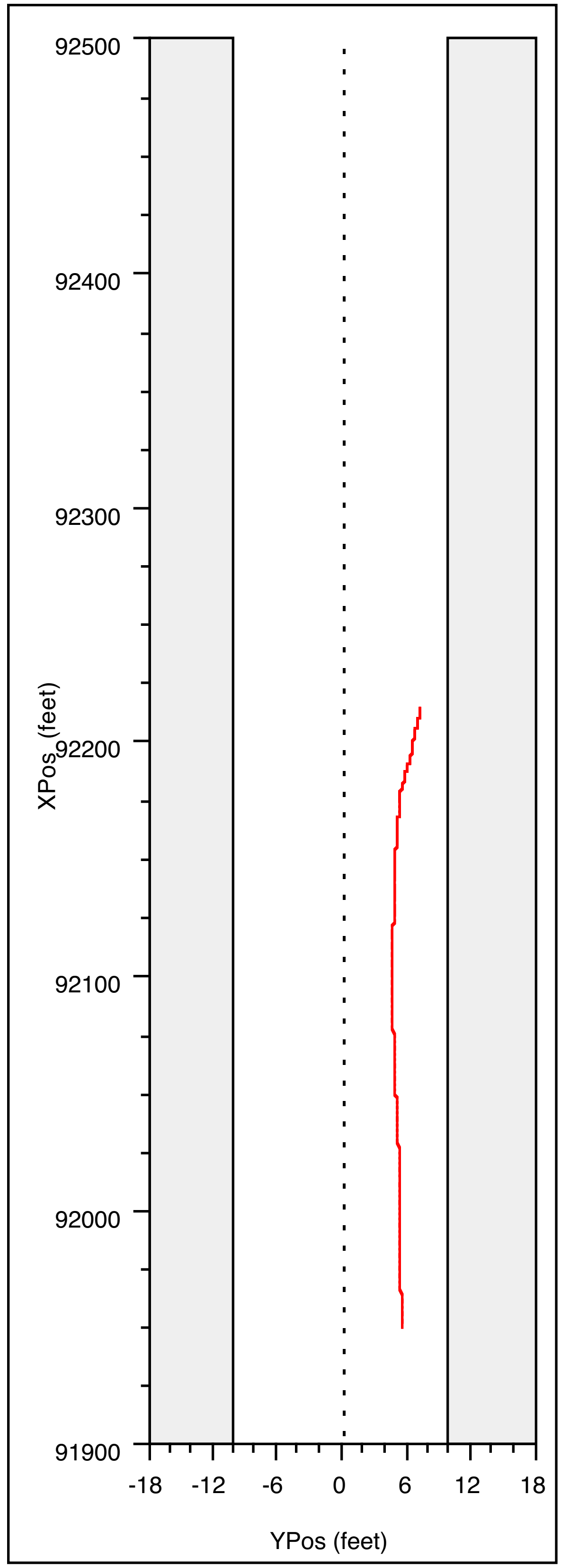
Subject 15, First Encounter, Text Warning



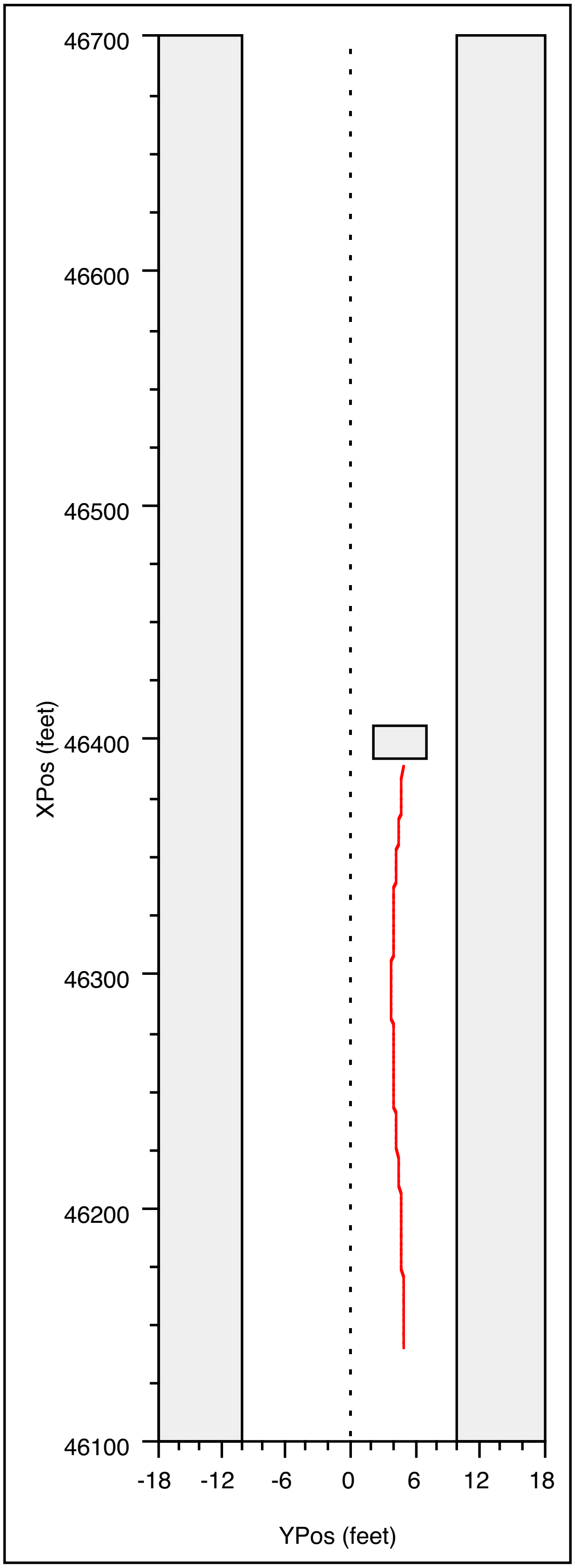
Subject 15, Second Encounter, Icon Warning



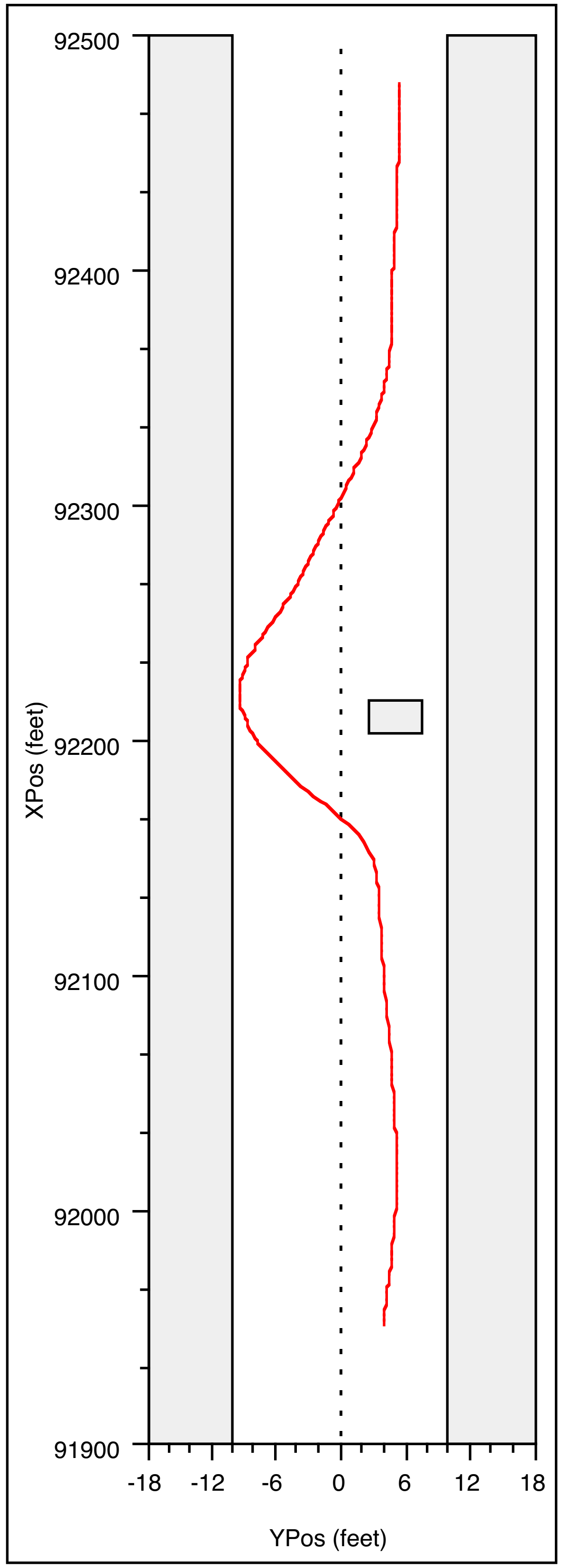
Subject 16, First Encounter, Text Warning



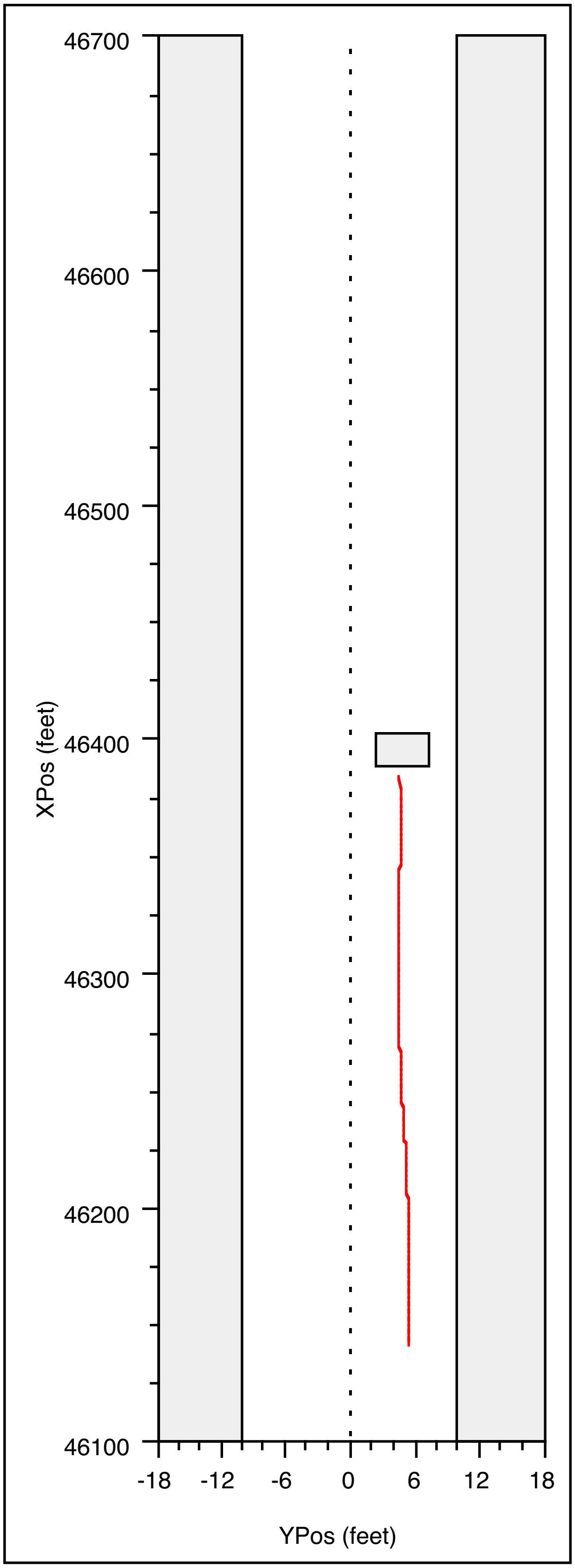
Subject 16, Second Encounter, No Warning



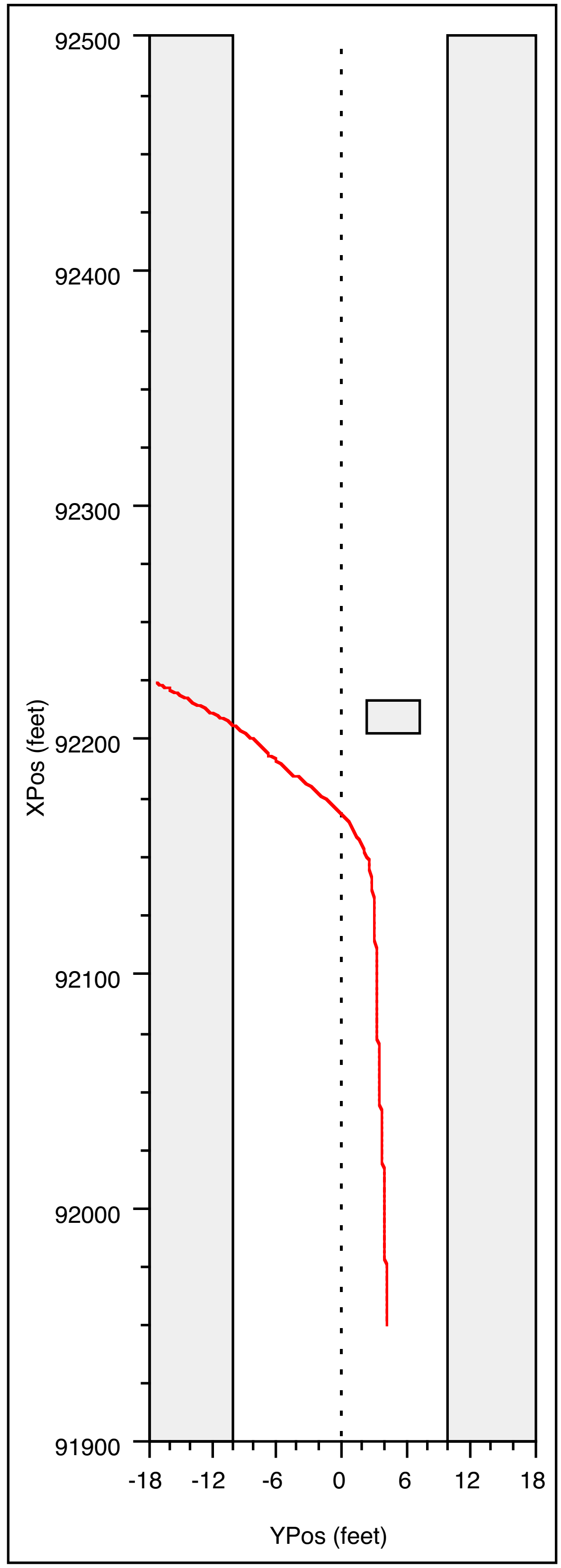
Subject 17, First Encounter, No Warning



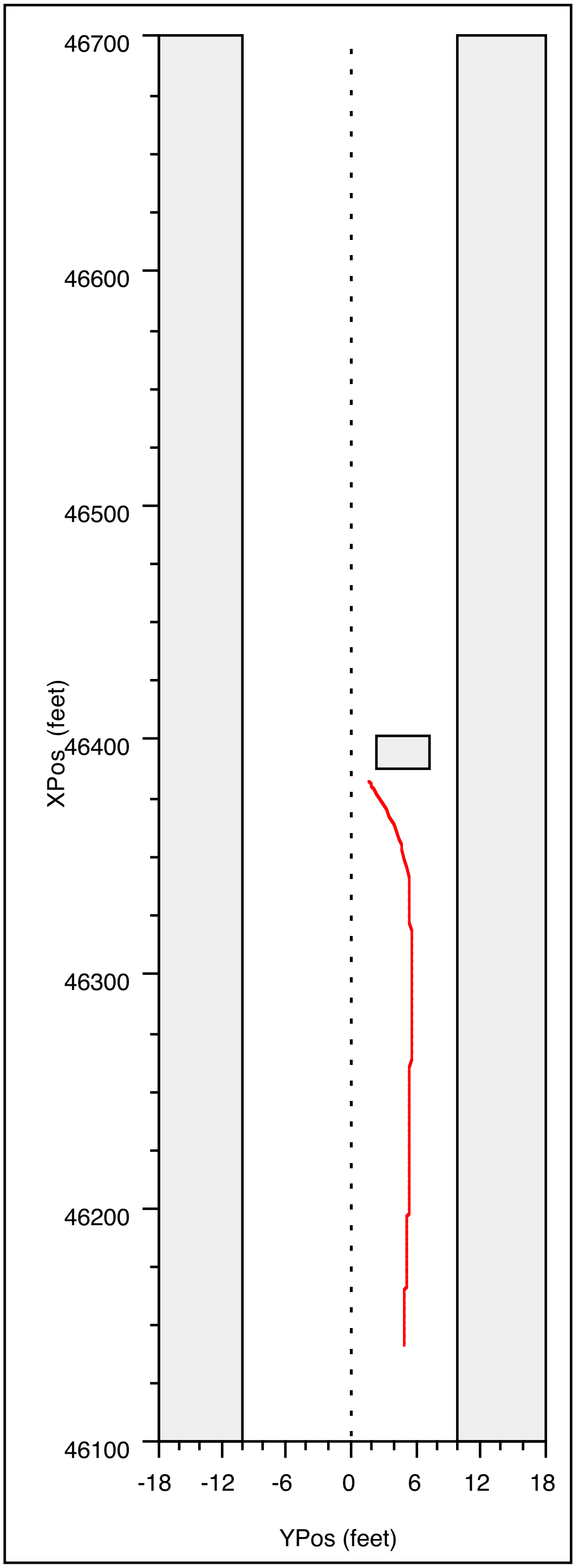
Subject 17, Second Encounter, Icon Warning



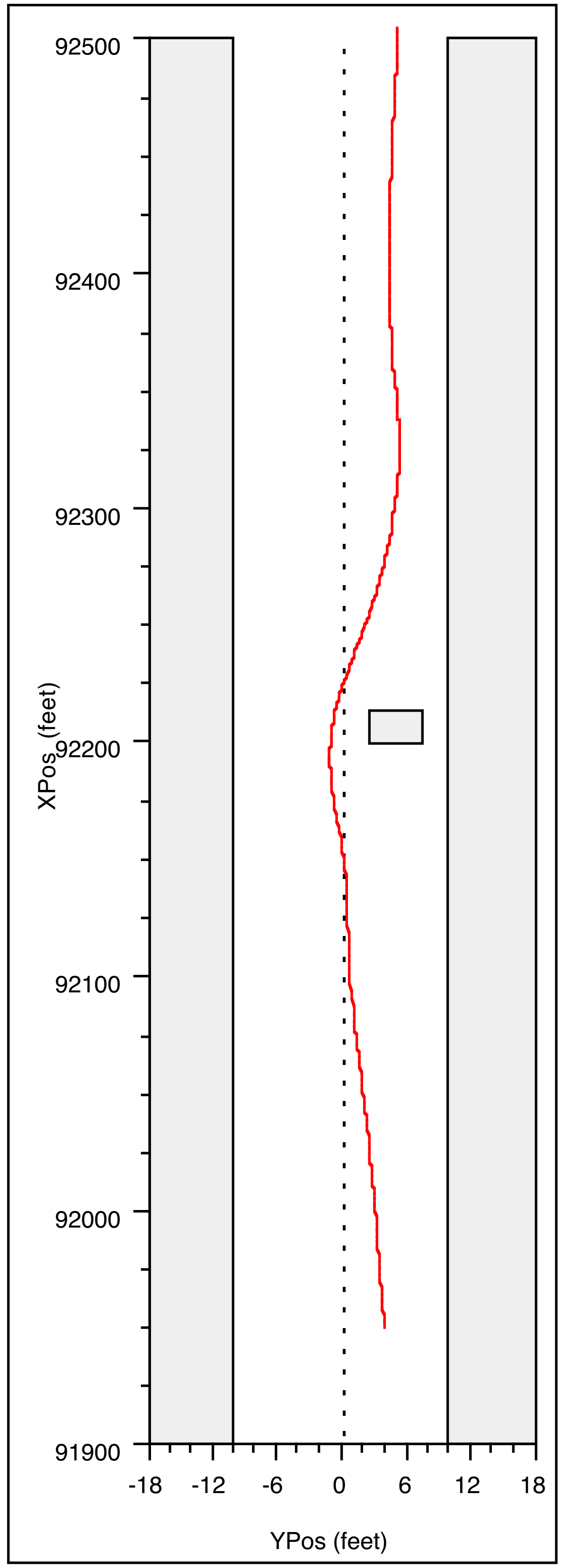
Subject 18, First Encounter, No Warning



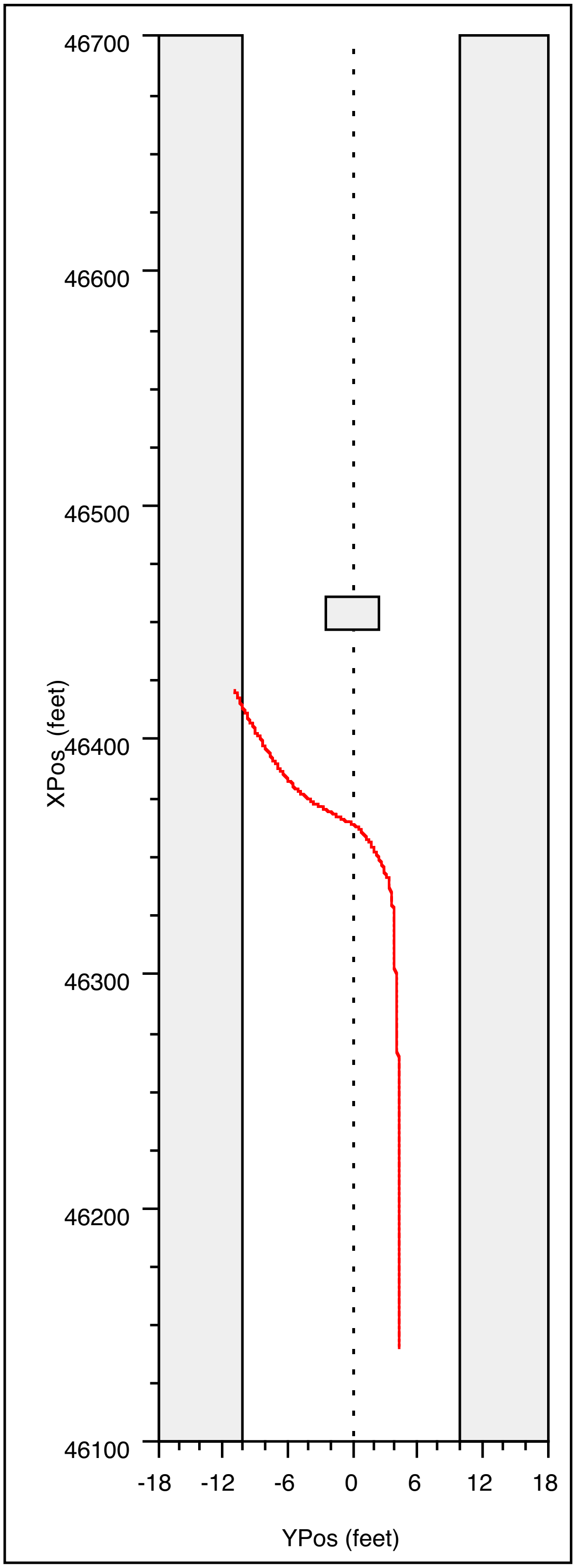
Subject 18, Second Encounter, Text Warning



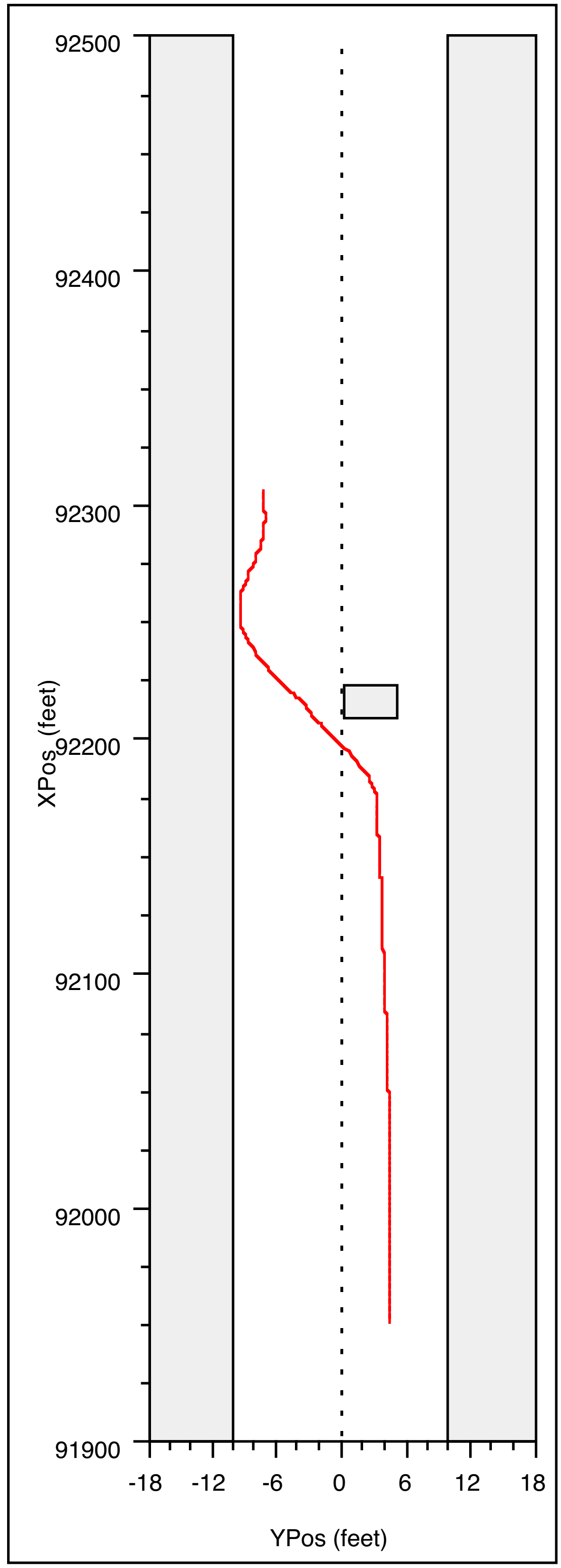
Subject 19, First Encounter, Icon Warning



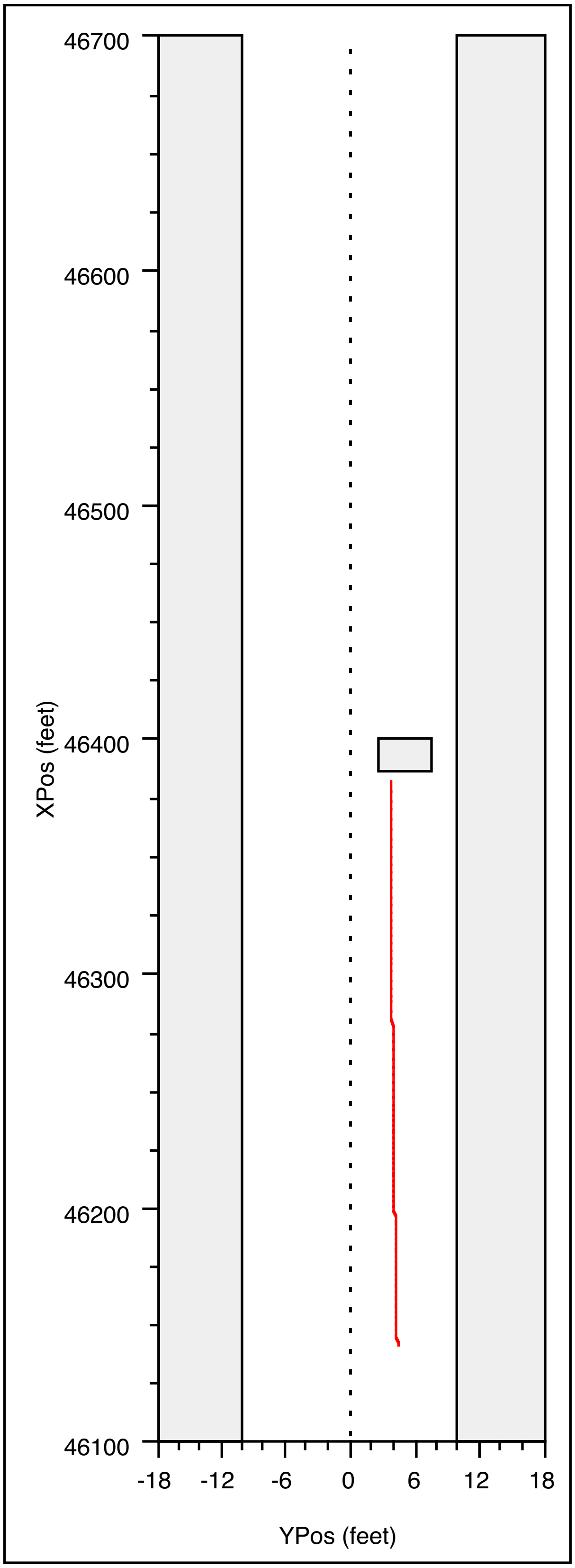
Subject 19, Second Encounter, Text Warning



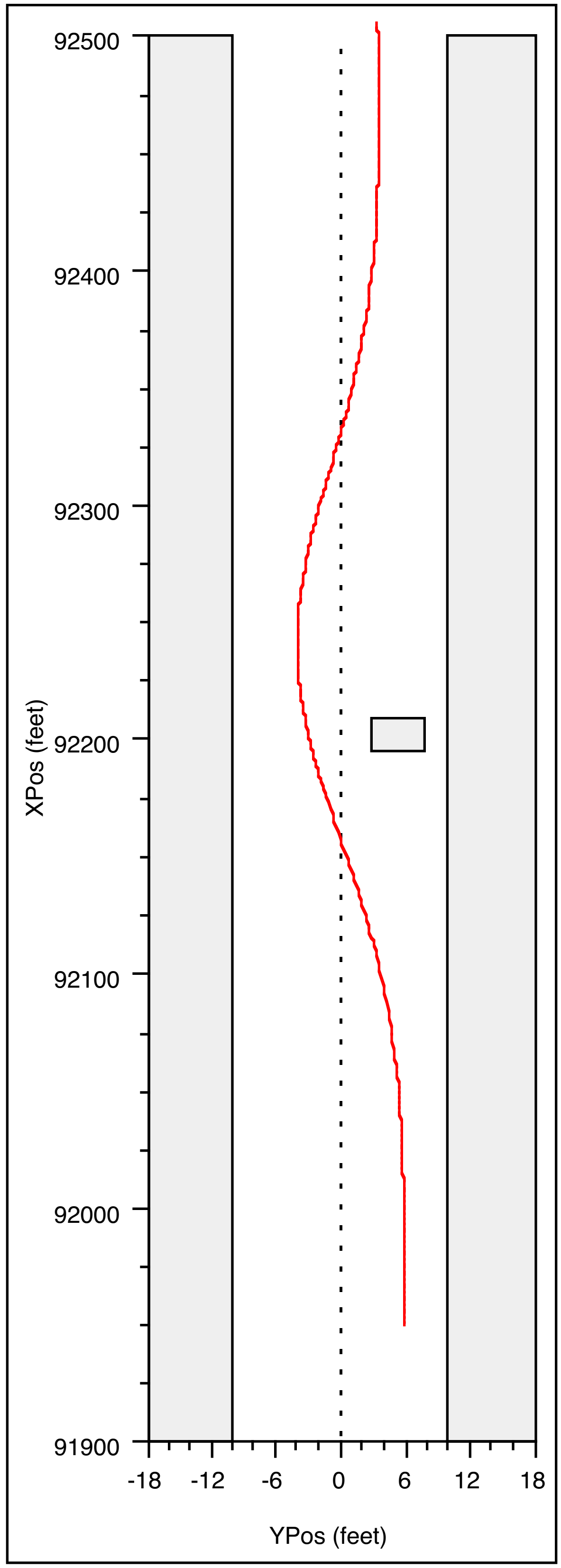
Subject 20, First Encounter, Icon Warning



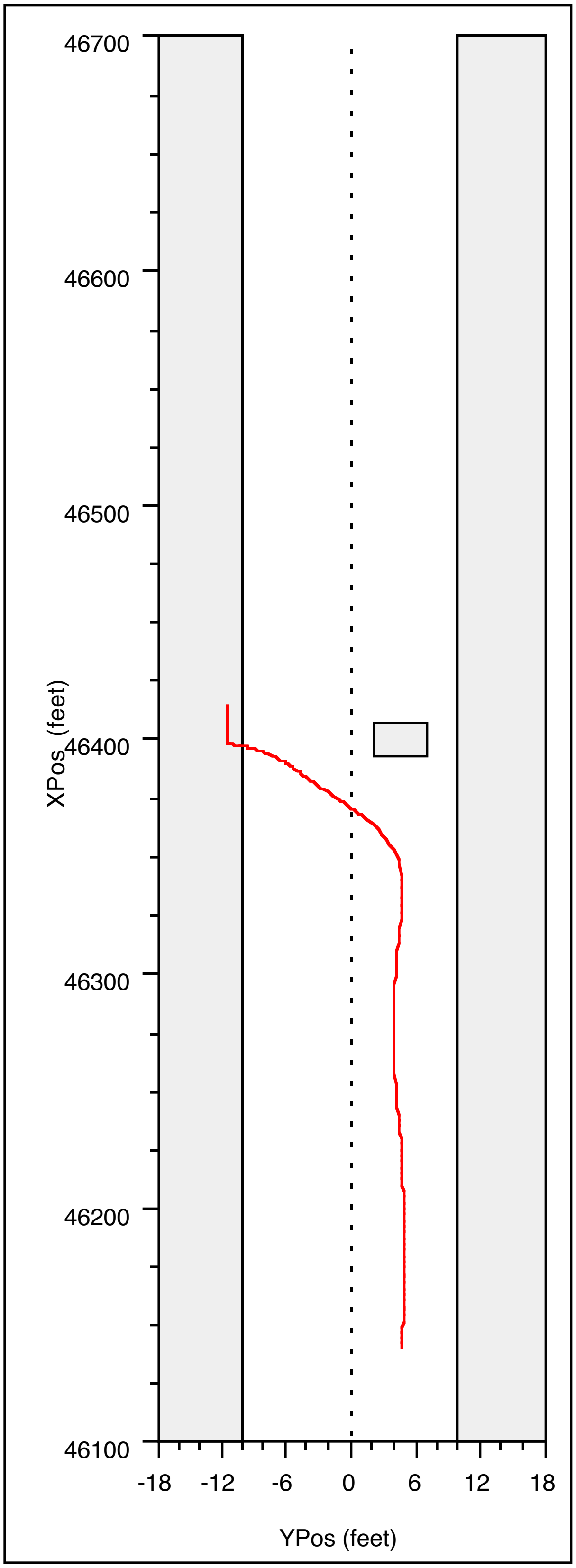
Subject 20, Second Encounter, No Warning



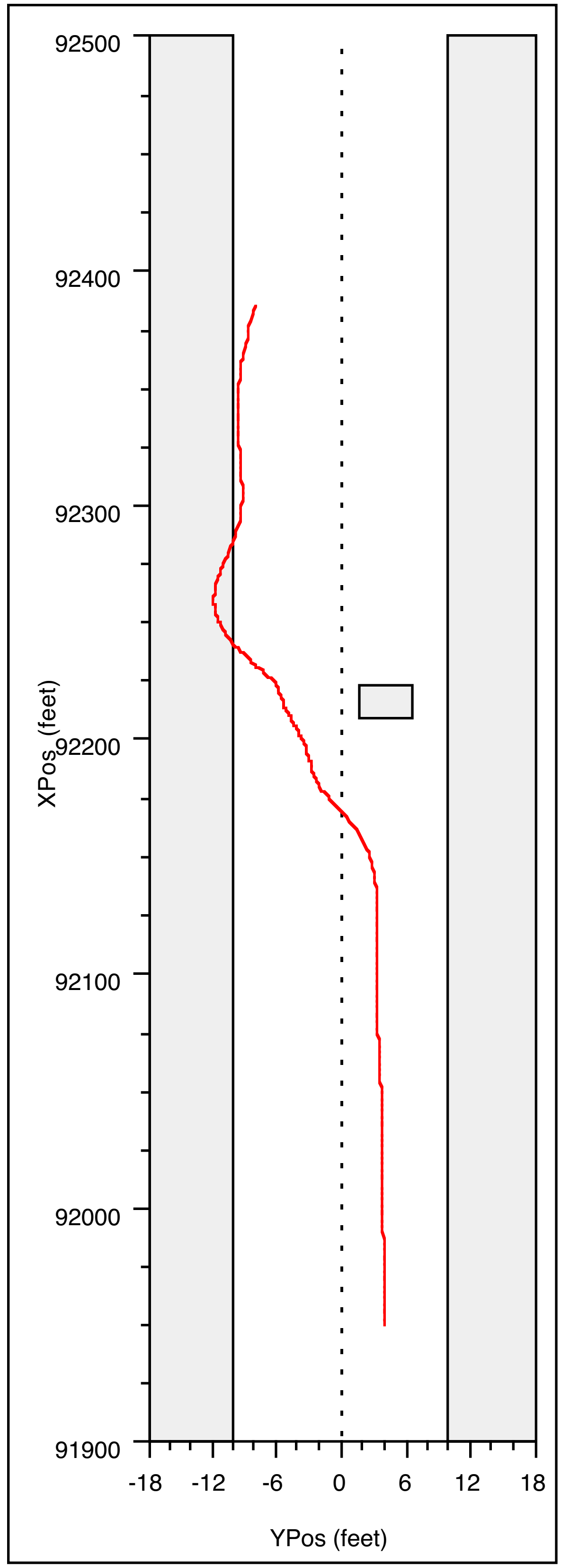
Subject 21, First Encounter, Text Warning



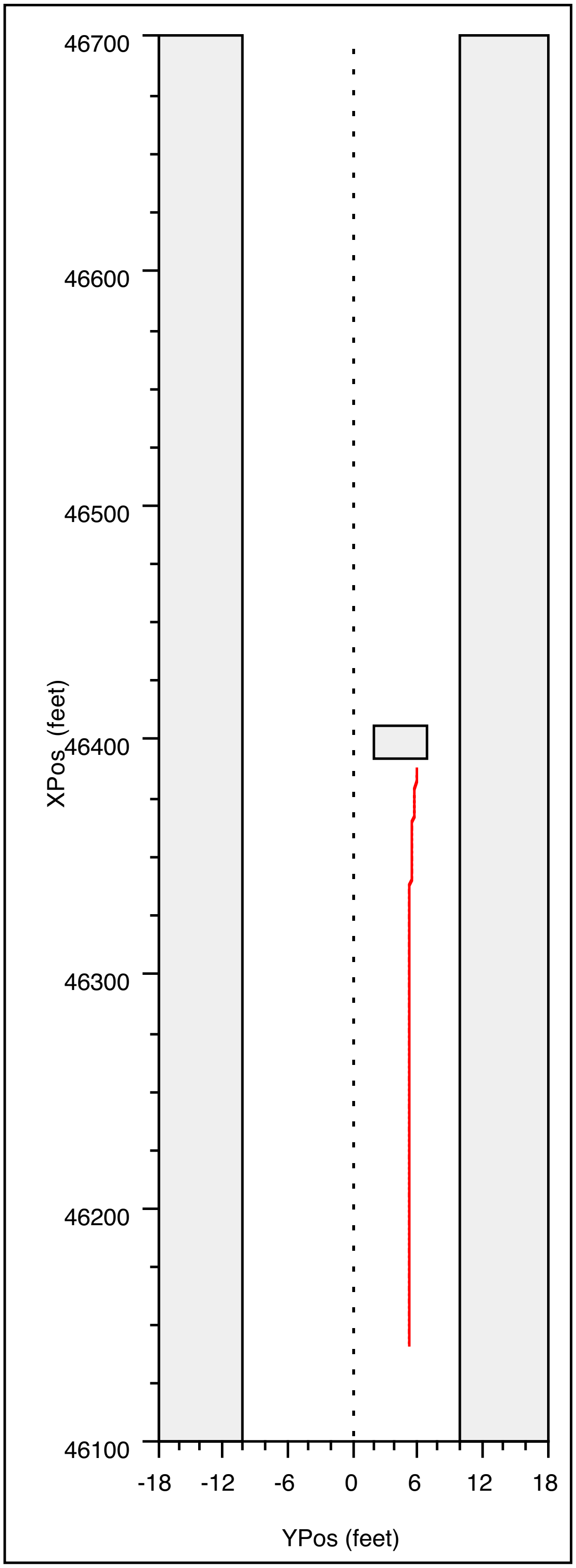
Subject 21, Second Encounter, Icon Warning



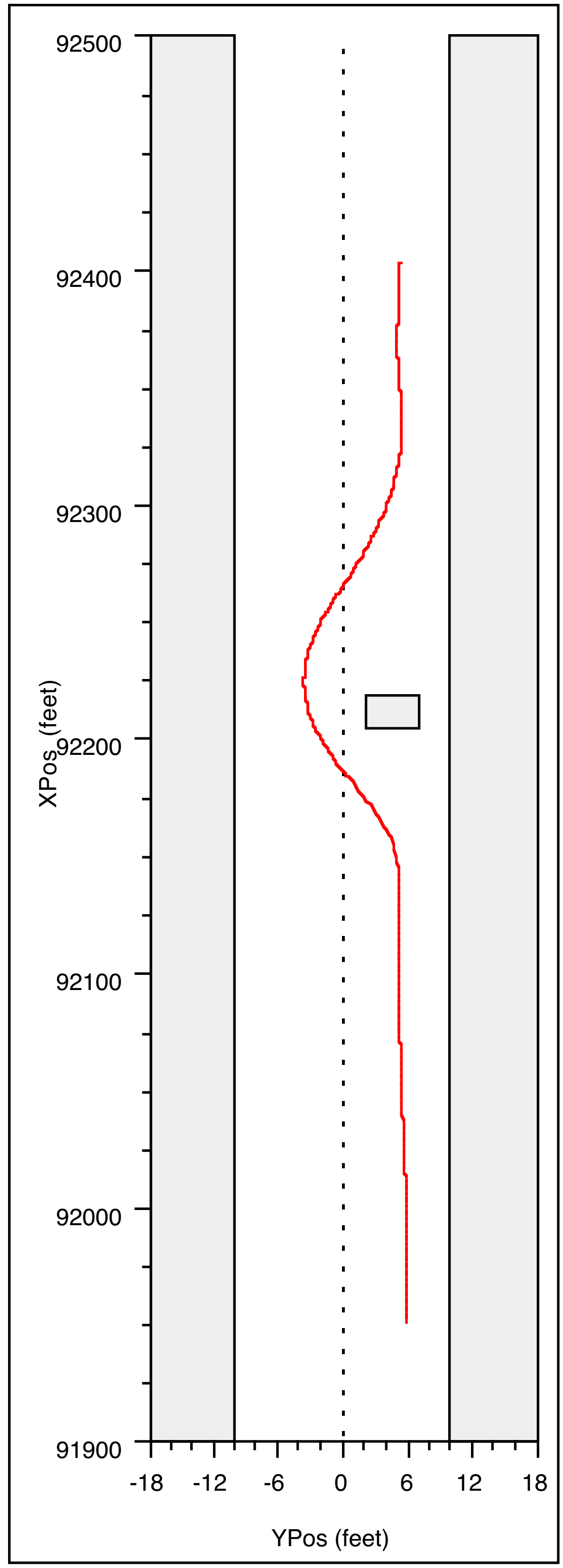
Subject 22, First Encounter, Text Warning



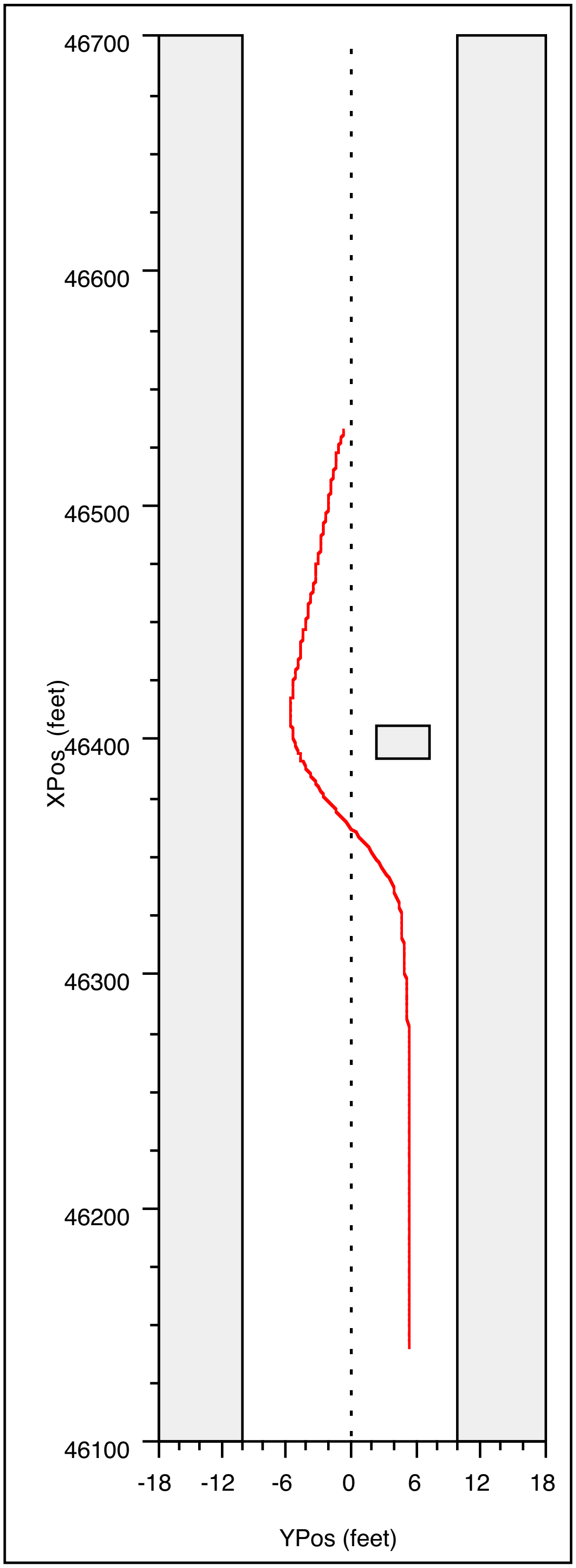
Subject 22, Second Encounter, No Warning



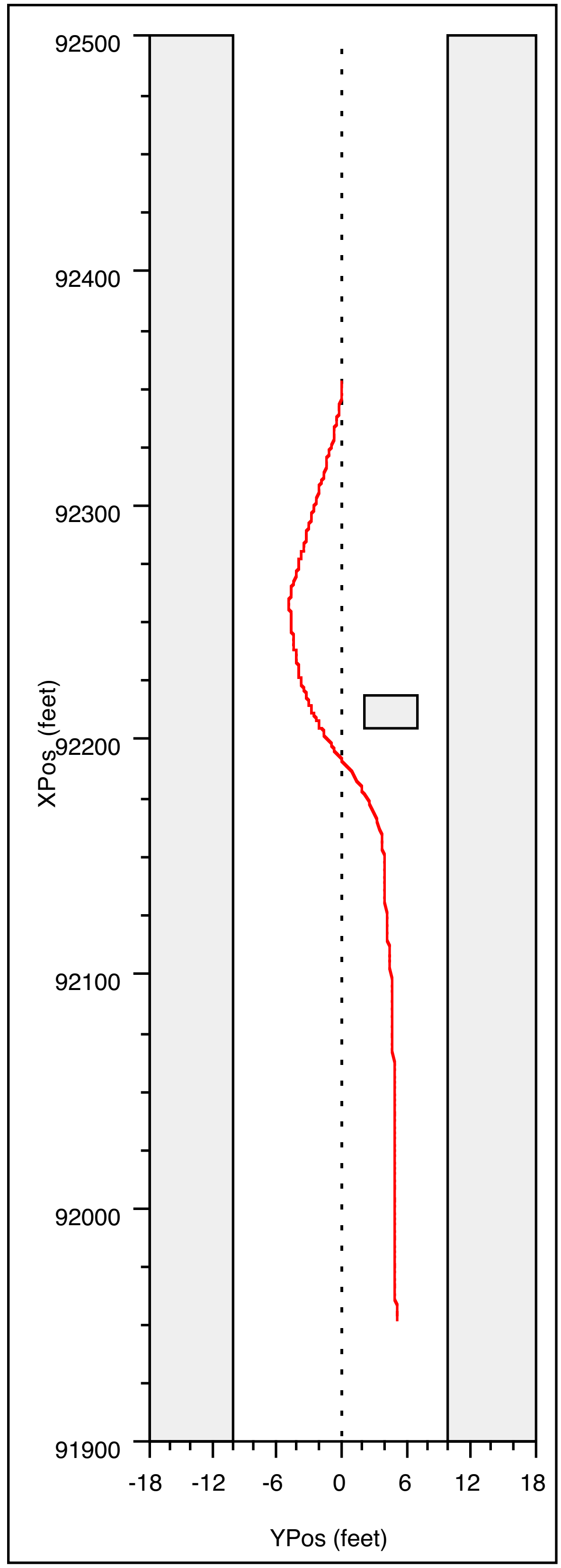
Subject 23, First Encounter, No Warning



Subject 23, Second Encounter, Icon Warning



Subject 24, First Encounter, No Warning



Subject 24, Second Encounter, Text Warning

APPENDIX B - CONSENT FORM

Subject: ____________ Date: _____________

Driver Behavior Study

Participant Consent Form

University of Michigan Transportation Research Institute
Human Factors Division

The purpose of this experiment is to study driver behavior. You will be asked to drive a simulated car in the laboratory and respond to a written questionnaire afterwards. You will be asked to drive the simulator as if you were driving a real vehicle.

Some people experience motion discomfort in the simulator. If this occurs, tell the experimenter immediately, and he/she will stop the simulator.

The experiment will take approximately 1-1/2 hours, and you will be paid $25 for your participation. If you have any problems or discomfort while participating in this experiment, you can withdraw at any time. You will be paid regardless.

A few if the sessions will be videotaped. Do you object to being videotaped?

Yes No

I have read and do understand the information above.

______________________________ _________________________
Print your name Date

______________________________ _________________________
Sign your name Witness (experimenter)

APPENDIX C - BIOGRAPHICAL FORM

Subject: ____________ Date: _____________

University of Michigan Transportation Research Institute

Human Factors Division

Driver Behavior (IDEA) Biographical Form

Name: ____

Sex (circle one): Male Female Age: _________

Occupation: ____

(If retired, please note your former occupation. If student, note your major)

Education (circle highest level completed):

some high school	high school degree
some trade/tech school	trade/tech school degree
some college	college degree
some graduate school	graduate school degree

Other:__________________________________

What kind of car do you drive the most?

Year: __________ Make: _____________ Model: ________________

Approximate annual mileage: _________________

How many years have you been driving? ____________________

Do you usually listen to music while driving? Yes _____ No _____

If Yes, what type of music? _________________________________

How often do you use a computer?

never	less than once once a month	few times a month	few times a week	daily

TITMUS VISION: (Landolt Rings)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	Corrective lenses worn?
T	R	R	L	T	B	L	R	L	B	R	B	T	R	
20/200	20/100	20/70	20/50	20/40	20/35	20/30	20/25	20/22	20/20	20/18	20/17	20/15	20/13	Yes / No

APPENDIX D - QUESTIONNAIRE

Subject: ____________ Date: _____________

University of Michigan Transportation Research Institute

Human Factors Division

Collision Avoidance System Questionnaire

Did you notice a collision warning on the head-up-display in the first near-collision?

Yes No

If Yes, please rate from 1 to 9 how the warning influenced your maneuvering decision in the first near-collision:

1 2 3 4 5 6 7 8 9

Very Distracting No Effect Very Helpful

Did you notice a collision warning on the head-up-display in the second near-collision?

Yes No

If Yes, please rate from 1 to 9 how the warning influenced your maneuvering decision in the second near-collision:

1 2 3 4 5 6 7 8 9

Very Distracting No Effect Very Helpful

Have you ever taken a driver's education course? Yes No

Have you even taken a safety driving course? Yes No

How many accidents have you been involved in within the past five years? _____

If so, what type of accidents ?

rear-end crossing paths at an intersection head-on

other (please describe) _______________________________________

____

(This information as well as all other information will be kept confidential.)

APPENDIX E - EXPERIMENT INSTRUCTIONS

IDEA EXPERIMENT INSTRUCTIONS

Before subject arrives:

- **Check schedule to determine subject name and number.**
- **Have all forms ready: consent, biographical, and payment forms (cash if not U-M employee)**
- **Set up vision tester and video equipment if applicable.**
- **Set up simulator. Set simulator volume at 7. Turn off all collision warnings. Set headway and minimum collision distance to 99. Set appropriate collision warning graphic. Have disk ready to save data.**

When subject arrives:

“Hi, are you ________ ?” (use subject’s name)
“I’m _________ (experimenter’s name).”
“Thank you for coming, let’s go down to the conference room so we can begin.”

- **Take subject to conference room and be seated.**

“The purpose of this experiment is to study driver behavior. You will be asked to drive our simulator and fill out a questionnaire afterwards. The experiment will take approximately one to one and a half hours to complete which you will be paid $25 for your participation. Some people experience motion discomfort. If you experience motion discomfort, you can stop anytime. You will be paid regardless.”

Forms:

“Before we start, there is some paperwork to complete. This consent form basically repeats in writing what I just said.”

- **Have subject read and sign the consent form**

“Also, we need to know a little more about you.”

- **Go though biographical form with subject.**

“You will be listening to music as you drive the simulator. Which type of music would you like to listen to? Classical, rock, or jazz?”

- **Show subject the CDs and bring the CD that was chosen to the laboratory.**

To the Laboratory

“Let’s now go to the laboratory so we can check you vision. Please put on contacts or glasses if you use them when you drive.”

- **Turn on both eye switches on the vision tester. Adjust the height of the vision tester for the subject. Make sure subject wears any vision**

correction that is worn while driving. Note on the biographical form if corrective lenses were worn.

“Can you see in the first diamond that the top circle is complete but the other three are incomplete? In each diamond, tell me the location of the complete circle - top, left, right, or bottom.”

- **Prompt the subject until s/he has missed two in a row. Record the last number answered correctly on the bottom of the biographical form.**

- **Stop test when 2 consecutive incorrect answers are given. Take the last correct answer to be the subject’s visual acuity.**

<u>* The Simulator*</u>

“Please have a seat in the simulator. The seat and steering wheel tilt may be adjusted for your comfort.”

- **Make sure the subject is wearing the seat belt. Show the subject the seat controls and the steering wheel adjustment lever. After subject is comfortable, show her/him around the simulator (gas, brake, instrument panel, etc.)**

“You don’t need to turn on the engine or shift gears. I will be turning on and off the simulator. The road scene will be projected onto the screen straight ahead. The road has curves and hills, but no intersections. There are parked cars, oncoming traffic, and other cars traveling in the same direction as you.”
The steering system will feel very much like a real car’s, so simply drive as you would a regular car. The speedometer is displayed on the instrument panel so you can monitor your speed at all times. Try to maintain a constant speed of 35 miles per hour.”
“Drive in the right lane and drive naturally and safely - just as you would drive in the real world. Do not pass any cars and avoid colliding into stationary objects and other cars.”

- **If subject is being videotaped, start recording.**

<u>The Drive</u>

“First, you will be given two warm-up drives to get used to the simulator.”

- **Do not collect data. Do not activate lead car.**

- **During the first practice run, direct them off the road, over the lane markers, and into the other lane so that they will be familiar with the vehicle behavior and audio feedback.**

- **End practice drives when the UMTRI sign appears on the right side of the road of the program.**

- **For the second practice run, activate lead car.**

"If there are no more questions, we will now start the experiment. There will be a brief break during the drive."

- **Activate collision warning. Think to check if headway and collision warning distances and warning graphic were properly set. If not, cover up projector before setting them.**

- **Start music. - Set rock music (Satriani) at 4**
  Set classical music (Beethoven) at 5
  Set jazz (McBride) at 5

- **Start data collection.**

- **Two minutes after the first encounter, (when you see an UMTRI road sign) stop stimulator. Cover up a portion of projector so that the subject does not see the menu options.**
- **WRITE OUT DATA FILE. If this is not done, the computer will crash later when trying to save data. Set appropriate collision warning graphic for second encounter. Start second data file.**

- **Remove obstruction from projector and continue with the drive.**

- **Stop simulator after subject has faced the second encounter. Write data out to a file. Stop music.**

"This concludes the simulator portion of the experiment. You may get out of the car now. We will head back to the conference room to fill out a questionnaire."

- **Stop videotape**

<u>Questionnaire & Payment of Subject</u>

- **Present subject the appropriate questionnaire. Make sure the questionnaire is properly filled out and pay the subject (if not UM employee) or fill out a payment form (if a UM employee). If the subject is an UM employee, inform him/her that the amount will be on their next paycheck. Thank subject and walk him/her to the elevator.**

APPENDIX F - DESCRIPTION OF ROADS

First Encounter Road Description

Length (ft)	Type	Road Curvature (ft)
	Begin	
1350	Straight	0
270	Curve Right	1500
960	Straight	0
270	Curve Left	1500
1230	Straight	0
870	Curve Right	750
330	Curve Left	1500
540	Curve Left	750
2790	Straight	0
300	Curve Right	1500
600	Curve Right	750
690	Straight	0
1050	Straight Hill	0
1380	Straight	0
630	Curve Left	750
270	Curve Left	1500
1710	Straight	0
300	Curve Right	1500
600	Curve Right	750
3150	Straight	0
630	Curve Left	750
270	Curve Left	1500
480	Straight	0
270	Curve Right	1500
600	Straight	0
270	Curve Left	1500
1740	Straight	0
300	Curve Right	1500
570	Curve Right	750
150	Straight	0
300	Curve Left	1500
570	Curve Left	750
2610	Straight	0
300	Curve Right	1500
600	Curve Right	750
690	Straight	0
1050	Straight Hill	(1% Grade)
1380	Straight	0
630	Curve Left	750
270	Curve Left	1500
1440	Straight	0
300	Curve Right	1500
600	Curve Right	750
1950	Straight	0
630	Curve Left	750
270	Curve Left	1500
3300	Straight	0
1050	Straight Hill	(1% Grade)
780	Straight	0
270	Curve Right	1500
1380	Straight	0
270	Curve Left	1500
1560	Straight	0
	End	

Second Encounter Road Description

Length (ft)	Type	Road Curvature
	Begin	
630	Straight	0
270	Curve Left	1500
960	Straight	0
270	Curve Right	1500
1230	Straight	0
300	Curve Right	1500
510	Curve Right	750
120	Curve Left	1500
570	Curve Left	750
2790	Straight	0
300	Curve Left	1500
600	Curve Left	750
660	Straight	0
1020	Straight Hill	(1% Grade)
1380	Straight	0
630	Curve Right	750
270	Curve Right	1500
1710	Straight	0
300	Curve Right	1500
600	Curve Right	750
3150	Straight	0
630	Curve Left	750
270	Curve Left	1500
480	Straight	0
270	Curve Right	1500
600	Straight	0
270	Curve Left	1500
1740	Straight	0
300	Curve Right	1500
300	Curve Right	750
870	Straight	0
420	Curve Left	750
2610	Straight	0
300	Curve Right	1500
600	Curve Right	750
660	Straight	0
1020	Straight Hill	(1% Grade)
1380	Straight	0
630	Curve Left	750
270	Curve Left	1500
1440	Straight	0
300	Curve Right	1500
600	Curve Right	750
1950	Straight	0
630	Curve Left	750
270	Curve Left	1500
3270	Straight	0
1020	Straight Hill	(1% Grade)
780	Straight	0
270	Curve Right	1500
1380	Straight	0
270	Curve Left	1500
1560	Straight	0
330	Curve Left	15000
330	Curve Right	15000
1050	Straight	0
	End	

APPENDIX G - DESCRIPTION OF TRAFFIC

First Encounter Traffic Description

Distance into Drive	Traffic
2400	Parked Car on Right Side of Road
6870	Oncoming Car
7920	Parked Car on Right Side of Road
10860	Parked Car on Left Side of Road
11160	Car Merges into the Lane from the Right
13980	Parked Car on Right Side of Road
14610	Oncoming Car
14730	Oncoming Car
16050	Parked Car on Right Side of Road
16530	Parked Car on Right Side of Road
17220	Oncoming Car
17760	Lead Car Speeds up to 50 mi/hr
20130	Parked Car on Right Side of Road
22200	Parked Car on Right Side of Road
22980	Parked Car on Right Side of Road
25980	Parked Car on Right Side of Road
27420	Oncoming Car
29430	Car Merges into the Lane from the Right
30210	Parked Car on Right Side of Road
31470	Parked Car on Right Side of Road
33420	Parked Car on Left Side of Road
35730	Lead Car Speeds up to 50 mi/hr
35940	Parked Car on Right Side of Road
36690	Oncoming Car
39330	Parked Car on Right Side of Road
39900	Oncoming Car
41100	Oncoming Car
41880	Parked Car on Right Side of Road
44910	Parked Car on Right Side of Road
46170	Car Merges into the Lane from the Right
46410	Lead Car Maintains a Speed of 5 mi/hr

Second Encounter Traffic Description

Distance into Drive	Traffic
1680	Parked Car on Right Side of Road
5580	Oncoming Car
6600	Parked Car on Right Side of Road
6960	Parked Car on Right Side of Road
9180	Parked Car on Right Side of Road
9900	Parked Car on Left Side of Road
10200	Car Merges into the Lane from the Right
13650	Oncoming Car
13770	Oncoming Car
15090	Parked Car on Right Side of Road
15480	Parked Car on Right Side of Road
16260	Oncoming Car
16800	Lead Car Speeds upto 50 mi/hr
18030	Parked Car on Right Side of Road
21240	Parked Car on Right Side of Road
23280	Parked Car on Right Side of Road
25080	Parked Car on Right Side of Road
26460	Oncoming Car
28470	Car Merges into the Lane from the Right
29250	Parked Car on Right Side of Road
32640	Parked Car on Left Side of Road
34680	Parked Car on Right Side of Road
34770	Lead Car Speeds upto 50 mi/hr
35730	Oncoming Car
39270	Oncoming Car
39330	Oncoming Car
40140	Oncoming Car
42930	Parked Car on Right Side of Road
43950	Parked Car on Right Side of Road
45210	Car Merges into the Lane from the Right
45450	Lead Car Maintains a Speed of 5 mi/hr

APPENDIX H - CALCULATION OF THE SECOND DERIVATIVE

To compute an approximation to the second derivative of a continuous function of time whose values are known only at discrete intervals, the following approximation was used:

$$f''(t) \approx \frac{1}{h^2}\left[\frac{f(t+2h)+f(t-2h)}{12}+\frac{2\big(f(t+h)+f(t-h)\big)}{3}-\frac{3f(t)}{2}\right]$$

The value of *h* should be small. Clearly, to use this approximation the value of the function *f* should be known for evenly spaced times. This presents a minor problem, since the simulator does not record measurements at regular time intervals. Therefore, an Excel spreadsheet was used to interpolate the values of the function at even time increments based upon the values which were available. The estimate of the second derivative was then based on these interpolated values using the equation above.

The second derivative obtained using this approach is wildly oscillatory, so it was smoothed using an *ad hoc* kernel smoother: The smoothed value at a given point was simply taken to be the weighted average of the ten values preceding it and the ten following it. Here is the weighting scheme of the smoother:

	Weight
f(t-10h), f(t+10h)	1/350
f(t-9h), f(t+9h)	7/350
f(t-8h), f(t+8h)	12/350
f(t-7h), f(t+7h)	16/350
f(t-6h), f(t+6h)	19/350
f(t-5h), f(t+5h)	21/350
f(t-4h) through f(t+4h)	22/350

The smoothed values are the ones which are presented in the report as the values of the second derivative.