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16. Abstract

Drivers' last-second braking and last-second steering judgments have been studied extensively by the Crash Avoidance Metrics Partnership (CAMP) Forward Collision Warning (FCW) Requirements project. This previous work was conducted under closed-course conditions using a realistic surrogate target lead vehicle. In the current research, a subset of these tests involving more than 4000 individual test runs has been replicated in the National Advanced Driving Simulator (NADS) facility for comparison purposes.

The major conclusions from this research are as follows:

- Scenarios need to pay careful attention to ensure initial headway conditions prior to the critical approach event correspond to those that are typically experienced in real world driving. More generally, scenarios should have real-world validation.
- Scenarios should emphasize high lead vehicle decelerations. The *0.39-g* deceleration levels gave the best results and have been used in previous CAMP surprise trial research.
- Scenarios should emphasize cases where the relative speed differential is high, particularly when the lead vehicle is stationary.
- Scenarios should emphasize last-second hard braking or hard steering over last-second "normal" maneuvers.
- Crash rates should not be used as a metric, and instead, attention should be focused on the interpretation of last-second maneuver onset behavior.

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TABLE OF CONTENTS

Executive Summary

Drivers' last-second braking and last-second steering judgments have been studied extensively by the Crash Avoidance Metrics Partnership (CAMP) Forward Collision Warning (FCW) Requirements project. This previous work was conducted under closed-course conditions using a realistic surrogate target lead vehicle. In the current research, a subset of these tests involving more than 4000 individual test runs has been replicated in the National Advanced Driving Simulator (NADS) facility for comparison purposes.

The extent to which NADS data can be correlated to research performed in real vehicles is clearly an important question for potential users of the NADS and consumers of data produced by the NADS and other advanced driving simulators. This report provides an in-depth investigation of this question for the rear-end crash scenario.

One key aspect of the previous CAMP research has focused on the driver's perception of *when* they need to initiate a last-second braking or steering maneuver in order to avoid colliding with a vehicle ahead. These timing judgments in the NADS (as measured by required deceleration and the time-to-collision measures) showed generally better agreement with the closed-course values when lead vehicle decelerations were large and when large speed differences existed between the vehicles. Hard last-second braking or steering trials resulted in better agreement than normal last-second braking or steering trials, and agreement was much higher for last-second braking scenarios than for last-second steering scenarios. When there was disagreement, it was usually the case that the NADS drivers reacted more cautiously, initiating braking, or steering earlier than relative to their closed-course counterparts.

Like the corresponding closed-course dataset, results supported an inverse TTC model of braking onset that was developed via logistic regression. The degree to which NADS braking onset results emulate those found under closed-course conditions generally increased as the predicted probability of a hard braking onset increased (when the visual looming cue is most salient). When this looming cue was smaller, NADS drivers made more conservative last-second maneuver judgments relative to the closed-course drivers. These differences observed between the NADS and the closed-course last-second timing judgments appeared to be systemic and are consistent with a visual perceptual deficit in the NADS.

Another key aspect of the previous CAMP research has focused on the peak conflict a driver experiences during the entire approach to the vehicle ahead (e.g., peak longitudinal and lateral decelerations). Peak conflict measures were nearly always lower in the NADS than in the closed course testing for both last second braking and steering maneuvers. Drivers appear to clearly perceive conflict during an approach differently in the NADS than in actual vehicles. Since the most extreme form of peak conflict is a collision, this disagreement suggests that measuring collisions in the NADS will not be a reliable metric for rear-end (and possible other) crash scenarios.

The comparisons contained in this report give a clear prescription for how to achieve the best possible results from the NADS facility in future rear-end crash research:

- Scenarios need to pay careful attention to ensure initial headway conditions prior to the critical approach event correspond to those that are typically experienced in real world driving. More generally, scenarios should have real-world validation.
- Scenarios should emphasize high lead vehicle decelerations. The *0.39-g* deceleration levels gave the best results and have been used in previous CAMP surprise trial research.
- Scenarios should emphasize cases where the relative speed differential is high, particularly when the lead vehicle is stationary.
- Scenarios should emphasize last-second hard braking or hard steering over last-second "normal" maneuvers.
- Crash rates should not be used as a metric, and instead, attention should be focused on the interpretation of last-second maneuver onset behavior.

1 Project Background

Based on the approved Task 4 Statement of Work (SOW) from the 5 February 2001 *IVI Light Vehicle Enabling Research Program* document, the primary purpose of this study was to better understand the relationship between data acquired using the CAMP surrogate target methodology under closed-course conditions and data acquired using the newly commissioned National Advanced Driving Simulator (NADS). More specifically, this effort simply involved replicating the last-second braking and steering maneuver methodologies previously employed in CAMP/NHTSA Forward Collision Warning (FCW) closed-course testing on the NADS; the objective being the comparison of driver performance and behavior under these two sets of conditions. With respect to the CAMP closed-course portion of this comparison, the last-second braking maneuver results are available from two earlier CAMP FCW system program reports [1, 2], and the last-second steering (or lane-change) maneuver results are available from the Task 1 CAMP FCW Final Report [2]. The experimental methodologies and data from these reports were used extensively in the design of the Task 4 study and provided the closed-course comparison data source.

1.1 History

1.1.1 Human Factors Study

This research on the human factors related to FCW was performed as part of the ongoing CAMP FCW Project [1, 2]. An initial step in this research was to collect and review the major relevant work, both internal to CAMP and from external sources.

One primary goal of the CAMP FCW project is to develop a crash alert timing approach for FCW systems by exploring a number of performance measures. An initial strategy was to develop a fundamental understanding of the timing and nature of drivers' "last-second" braking behavior without a FCW system before conducting subsequent FCW system-driver interface studies. This strategy included identifying and modeling drivers' perceptions of "normal" and "hard" braking kinematic situations that could be used for FCW system crash alert timing purposes.

In addition to these last-second braking studies, last-second steering (or lane-change) trials were conducted in another series of CAMP studies. The collection of steering maneuver data focused on identifying what drivers perceive to be the "last second you normally would" and the "last second you possibly can" change lanes. These braking and steering data were gathered under a variety of approach conditions under closed-course conditions both at the GM Proving Ground in Milford, Michigan and the Transportation Research Center (TRC) in East Liberty, Ohio. The current work gathers corresponding last-second maneuver data using the National Advanced Driving Simulator (NADS) at the University of Iowa.

1.1.2 Closed-Course Testing

FCW closed-course testing was performed as part of the CAMP Forward Collision Warning Requirements Project [1, 2]. CAMP used a "surrogate target" methodology under closed-course conditions to permit experimenters to safely place drivers in realistic rear-end crash scenarios on a test track and observe their behavior. The surrogate target consisted of a molded composite mock-up of the rear half of a passenger car mounted on an impact-absorbing trailer, which is towed via a collapsible beam. The surrogate target is able to absorb impacts of up to *10-mph* velocity differential without sustaining permanent damage.

The closed-course studies examined "last-second" braking and "last-second" steering (lane-change) maneuvers. Drivers performed braking maneuvers using two different braking instructions. The first instruction asked drivers to maintain their speed and brake at the last second possible in order to avoid colliding with the target using "normal" braking intensity or pressure. The second instruction asked drivers to maintain their speed and brake at the last second possible to avoid colliding with the target using "hard" braking intensity or pressure.

Similarly, drivers performed steering maneuvers using two different steering instructions. The first instruction asked drivers to maintain their speed and change lanes at the last second they "normally would to go around the target". The second instruction asked drivers to maintain their speed and change lanes at the last second they "possibly could to avoid colliding with the target."

The strategy of varying instructions during these maneuvers was employed so that drivers' perceptions of "normal" and "non-normal" kinematic situations could be properly identified and modeled for crash alert timing purposes. The scenarios examined lead vehicle stationary, lead vehicle braking, and lead vehicle moving at a slower, but constant speed prior to the last-second maneuver.

Two key findings emerged from the braking and steering maneuver onset behavior in the closed-course studies. First, very few significant differences were observed in last-second braking behavior as a function of test site (e.g., Milford or TRC proving grounds), age, or gender. Second, significant differences were observed between last-second braking onsets and last-second steering onsets. These differences indicated that the relative timing of last-second braking onsets versus last-second steering onsets (i.e., earlier or later during the approach) is highly dependent on the kinematic conditions.

1.1.3 Simulator Research

The current driving simulator research (FCW Task 4) used the NADS to compare data collected in the simulator with data collected on the test track by CAMP in support of FCW system alert timing development. NADS results were compared with previous CAMP studies to determine how performing these types of maneuvers in the simulator compare to performing the same maneuvers on a test track. The work was done to provide an understanding of how braking and steering performance in the NADS compared to test track data.

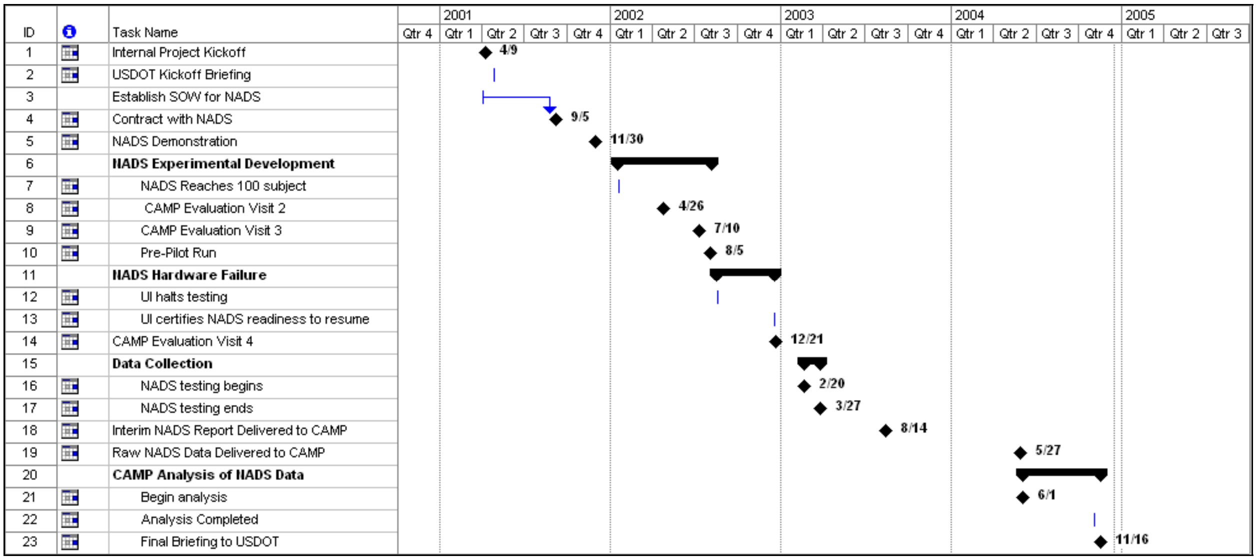
For braking maneuvers, data collection focused on identifying what drivers perceive to be the "last second possible" to brake under two different braking intensity instructions: "normal" braking intensity and "hard" braking intensity. For steering maneuvers, data collection focused on identifying what drivers perceive to be the "last second you normally would" and the "last second you possibly can" change lanes without braking. All four of these instructions were tested under a variety of kinematic (or vehicle-to-vehicle approach) conditions.

Drivers performed last-second maneuvers under these instructions under conditions in which the driver and the lead vehicle were traveling at about the same speed and the lead vehicle brakes (referred to as a POV DECELERATION condition), conditions in which the lead vehicle was traveling at a constant speed less than the drivers' vehicle (referred to as a CONSTANT ΔV condition), and conditions in which the lead vehicle was stopped (referred to as a POV STATIONARY condition).

1.2 Timeline

Key dates for the current FCW Task 4 project are summarized in Table 1-1:

Table 1-1



ID	ℹ	Task Name	
1	▦	Internal Project Kickoff	4/9
2	▦	USDOT Kickoff Briefing	
3		Establish SOW for NADS	
4	▦	Contract with NADS	9/5
5	▦	NADS Demonstration	11/30
6		**NADS Experimental Development**	
7	▦	NADS Reaches 100 subject	
8	▦	CAMP Evaluation Visit 2	4/26
9	▦	CAMP Evaluation Visit 3	7/10
10	▦	Pre-Pilot Run	8/5
11		**NADS Hardware Failure**	
12	▦	UI halts testing	
13	▦	UI certifies NADS readiness to resume	
14	▦	CAMP Evaluation Visit 4	12/21
15		**Data Collection**	
16	▦	NADS testing begins	2/20
17	▦	NADS testing ends	3/27
18	▦	Interim NADS Report Delivered to CAMP	8/14
19	▦	Raw NADS Data Delivered to CAMP	5/27
20		**CAMP Analysis of NADS Data**	
21	▦	Begin analysis	6/1
22	▦	Analysis Completed	
23	▦	Final Briefing to USDOT	11/16

2 Experimental Design

2.1 Overview

The project used the NADS to gather driver's last-second braking and steering maneuver behavior. The simulation was conducted at the NADS facility located at the University of Iowa. The results were compared to data collected by CAMP in several studies on a test track. This work was intended to provide an understanding of how last-second braking and steering behavior in the NADS compares to that obtained under closed-course conditions. This comparison is thought to be particularly informative for deciding on the merit and nature of future rear-end crash studies which may be conducted on the NADS.

This section describes the experimental apparatus, participant demographics, experimental procedures, dependent measures, and data analysis methods associated with this simulator study.

2.2 Apparatus

The NADS consists of a *24-foot* diameter dome mounted on a motion platform that is capable of moving laterally, longitudinally, or both in the horizontal plane (Figure 2-1). The dome is able to hold an entire car, tractor, or truck cab. In this study a Chevy Malibu was used as the cab in the dome.

Three systems—motion, visual, and auditory—are integral parts of the simulator.

1. The motion system consists of a six-degree of freedom motion hexapod atop of a *64-foot* x *64-foot* X-Y planar track. Within the dome, the vehicle buck had four high-frequency vibration actuators (located at the tire locations). Altogether, this system provides the driver with a feeling of realistic motion including actual acceleration, braking, and steering cues.
2. A 15-projector LCD (liquid crystal display) that produces high-resolution imagery is an integral part of the visual system. The field of view is *360°* horizontal and *39°* vertical. This system provides a realistic field of view, including rear-view mirror and

side mirror images. The NADS produces realistic animation of busy traffic situations, three-dimensional objects that vehicles may encounter (animals, potholes, concrete joints, pillars, etc.), high-density, multiple-lane traffic, common intersection types (including railroad crossings, tunnels, etc.), and time of day and atmospheric effects.

3. The auditory system is motion-correlated, with three-dimensional, realistic sounds produced by other vehicles (including sirens), highway surfaces, contact with objects (potholes, pillars, etc.), and environmental sources (including wind).

Figure 2-1 NADS Facility

2.3 Participant Demographics

Eighty drivers were selected and 72 drivers completed the two-day study. Participants completed two sessions lasting approximately *1½* (for steering) to *2½* (for braking) hours each, usually on consecutive days. A list and description of participants who did not complete the two-day study or whose data were dropped because of motion problems can be found in *Appendix A*.

The participants completing the study were equally divided into three age groups: young (20 to 30), middle (40 to 50), and older (60 to 70). These were the same groupings used in the closed course testing. The mean age for each age group was 26, 46, and 64, respectively. In addition, each age group was equally divided between male and female drivers.

2.4 Experimental Procedures

This study included both last-second braking and last-second steering trials, and utilized a fixed-effects factorial design. Age, gender, and order of drives (braking or steering first) were the between-subjects factors. Instructions for braking (either "normal" or "hard" intensity) and for steering (either last-second normal or last-second possible) were within-subject factors.

A pseudo-randomization was used to balance the order of presentation of the trials so that learning effects could be controlled and minimized. The randomization procedure is included in Appendix C.

Participants were processed in the following sequence for the study:

1. Driver Recruitment and Screening
2. Pre-Drive Simulator Screening
3. In-Vehicle Testing Sessions
4. Post-Drive Briefing

A description of what each process step involved will now be described.

2.4.1 Driver Recruitment and Screening

Participants were recruited via local newspaper advertisements and word of mouth. They were asked to contact the NADS office via phone or the NADS website to volunteer to participate in studies at the NADS facility. A subset of potential participants who fit the age criteria for participation in this study was contacted by phone using NADS screening procedures. Participants were informed that the purpose of the study was to perform last-second braking and steering maneuvers in a variety of conditions. Candidates were also told of the time commitment, study compensation, and potential study dates.

Individuals expressing interest in participating were screened to ensure that they met the study requirements. Participants were required to hold a valid driver’s license, be a licensed driver for at least two years, drive more than 3,000 miles per year and more than 5 days a week, and have the ability to operate an automatic transmission vehicle without special equipment. Participants were excluded if they had participated in a simulator study within the past 12 months. Individuals meeting all of the inclusion criteria were required to pass a health screening in which they were asked several general health questions.

Individuals who met all of the above criteria were scheduled for a study session. They were asked to refrain from drinking alcohol and taking non-prescription drugs for the 24 hours preceding the session. They were also able to wear glasses or contacts, if applicable, during the driving session. They were told that mobile phones, beepers, or pagers are not allowed during the study, that hats and gum chewing were not allowed, and that a seat belt must be worn at all times while driving. The importance of attending the scheduled sessions was stressed and the participants were told to contact study personnel if they were unable to attend their scheduled sessions.

2.4.2 Pre-Drive Simulator Screening

When participants arrived at the NADS, they were again told about the study requirements and asked to read and sign an informed consent document thereby agreeing to participate in the study. They also filled out a questionnaire that was used to verify inclusion criteria. The experimenter verified that the participant met all inclusion criteria and that no alcohol or unapproved non-prescription drugs were consumed in the 24 hours prior to the study.

2.4.3 In-Vehicle Testing Sessions

Drivers came to the NADS on two occasions—one day to complete the braking trials and one day to complete the steering trials. Whenever possible, the trials were completed on two consecutive days. The order of the trials (braking then steering, or steering then braking) was randomized and counterbalanced across participants.

When the drivers entered the simulator, they were given instructions for adjusting the seat and the mirrors and were advised of the location of the emergency stop button. Additionally, they were advised about the audio and video recording. Directions for the drive were explained using the in-vehicle experimental protocol (see Appendix B). The exact order of the reading of the experimental protocol depended on the order of their drives.

2.4.4 Braking & Steering Instruction Descriptions

Braking and steering instructions were both categorized and blocked as a "normal" or a "hard" maneuver. The complete set of maneuver instructions given to the drivers prior to each trial block can be found in Appendix B. The key part of the maneuver instructions to the participants are phrased below:

“Normal” Brake Instruction:
…"For these drives you should quickly accelerate to the target speed. Then maintain your speed and brake at the last second possible to avoid colliding with the lead vehicle using NORMAL braking intensity or pressure."

“Normal” Steer Instruction:
…"For these drives you should quickly accelerate to the target speed. Then maintain your speed and change lanes at the last second you NORMALLY would to avoid the lead vehicle (without braking)."

“Hard” Brake Instruction:
…"For these drives you should quickly accelerate to the target speed. Then maintain your speed and brake at the last second possible to avoid colliding with the lead vehicle using HARD braking intensity or pressure."

“Hard” Steer Instruction:
…"For these drives you should quickly accelerate to the target speed. Then maintain your speed and change lanes at the LAST SECOND possible to avoid colliding with the lead vehicle (without braking)."

The above instructions were the same ones used in the previous CAMP studies [1, 2].

2.4.5 Post-Drive Briefing

Following completion of the trials each day, the participant completed a questionnaire before exiting the simulator. This simulator sickness questionnaire (SSQ) was designed to obtain participants’ self reports of discomfort immediately after their driving session [3]. The results can be found in *Appendix G*. Upon exiting the simulator each day, participants were asked to complete another questionnaire, which was designed to assess participants’ views on the realism of several aspects of the simulator. On day two, participants were also asked to complete a payment voucher form to receive compensation for participation. All documentation used for processing the participants can be found in *Appendix D*.

2.5 Variables Examined

2.5.1 Independent Measures

The between-subjects measures were *Age*, *Gender*, and *Order* of the maneuvers (see the six master orders used in Appendix B). Instructions for braking (either normal or hard intensity) and for steering (either last-second normal or last-second possible) were within-subjects factors.

2.5.2 Dependent Measures

Several dependent variable measures were collected and calculated at various points throughout the braking and steering trials. These measures will be described in detail in the sections that follow.

2.6 Key Measurement Categories

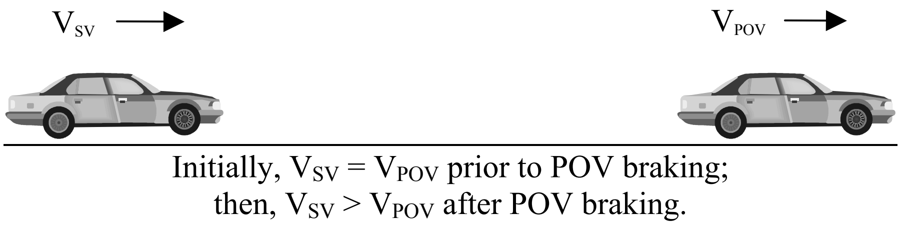
The key dependent measures compared between the CAMP closed-course and NADS facilities can be categorized as maneuver onset and peak conflict variables. **Maneuver onset** measures are used to characterize the state of the kinematic conditions at the start of the maneuver, whereas **peak conflict** measures give an indication of the degree of the approach conflict that was attained throughout the entire approach maneuver. Details of the rationale behind these onset measures can be found in [1, 2].

2.7 Kinematic Groupings and Conditions

In order to replicate the CAMP closed-course study for last-second braking and steering maneuvers, there were three general choreographed groupings for the kinematic conditions. In all situations, the SV approached the Principal Other Vehicle (POV) at a targeted speed before either braking or steering to avoid a collision (depending on the maneuver instruction condition). The groupings are defined in the left-to-right order they will be displayed on various figures in the results section of the report.

2.7.1 POV Deceleration Cases

This is one of two scenarios where the POV is moving. For this particular scenario, both the SV and the POV start out stopped in the same lane and separated by a few car lengths. The SV and the POV begin to accelerate from the stopped position to the <u>same</u> target speed (either *30*, *45*, or *60 mph*). At some point, the POV begins to decelerate at a constant deceleration rate (either *0.15*, *0.28*, or *0.39 g's*). The SV driver reacts to this rate of slowing by either braking in the same lane or steering left to avoid colliding into the POV. This scenario is diagramed in Figure 2-2 below.



Initially, $V_{SV} = V_{POV}$ prior to POV braking;
then, $V_{SV} > V_{POV}$ after POV braking.

Figure 2-2 POV Deceleration Scenario

2.7.2 Constant ΔV Cases

Also classified as a POV moving scenario, the constant ΔV cases were choreographed as follows. For this case, the target speed of the POV is less than the target speed of the SV ($V_{POV} < V_{SV}$). Both the SV and the POV start out stopped in the same lane. The SV and the POV begin to accelerate to their prescribed target speeds. As the SV driver closes in on the POV, the SV avoids colliding into this vehicle by either braking in the same lane or steering to the left. This scenario is diagramed in Figure 2-3 below.

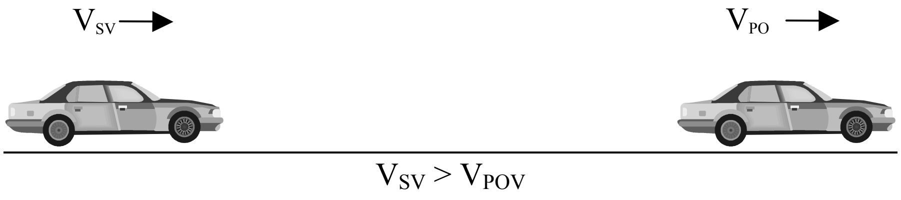


Figure 2-3 Constant **ΔV** Scenario

2.7.3 POV Stationary Cases

For this kinematic scenario, the POV is stopped at a distance down the road in the same lane. As the driver approaches at the prescribed target speed, the SV closes in on this stopped vehicle. Based on the given instruction, the SV driver either brakes in the same lane or steers to the left lane to avoid colliding with the stopped vehicle. This scenario is diagramed in Figure 2-4 below.

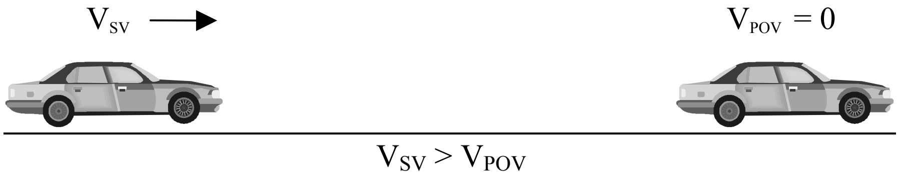


Figure 2-4 Stationary Scenario

2.7.4 Last-Second Braking and Steering Trials

Each participant completed 34 last-second braking trials on one day and 22 last-second steering trials on another day. Whether braking was done on the 1st day or the 2nd day was balanced across drivers. Of the 34 braking trials, they were evenly divided between "normal" (17) and "hard" (17) last-second braking instruction trials. Table 2-1 outlines the 17 kinematic braking conditions, including the shorthand notation for each condition used in tables and graphs in later sections of this document.

Table 2-1 Last-second Braking Kinematic Conditions

Kinematic Condition	Target SV Speed	Target POV Speed	POV Deceleration	Condition Shorthand Notation	Kinematic Groupings
1	30	30	0.15	30_30_15	POV Deceleration
2	30	30	0.28	30_30_28	
3	30	30	0.39	30_30_39	
4	45	45	0.15	45_45_15	
5	45	45	0.28	45_45_28	
6	45	45	0.39	45_45_39	
7	60	60	0.15	60_60_15	
8	60	60	0.28	60_60_28	
9	60	60	0.39	60_60_39	
10	30	20	0	30_20_0	Constant ΔV
11	30	10	0	30_10_0	
12	60	50	0	60_50_0	
13	60	30	0	60_30_0	
14	60	15	0	60_15_0	
15	30	0	0	30_0_0	POV Stationary
16	45	0	0	45_0_0	
17	60	0	0	60_0_0	

Of the 22 total last-second steering trials, they were evenly divided between normal (11) and hard (11) last-second steering trials. Table 2-2 outlines the 11 kinematic steering conditions, including the shorthand notation for each condition used in tables and graphs that follow. From this table, one will notice that in comparison to the above braking table, all conditions involving the *45 mph* speed or the *0.28 g* POV deceleration level have been eliminated. Hence, the primary focus of the last-second steering maneuvers was based only on the *anchor* speeds (i.e., *30 mph* and *60 mph*) and *anchor* POV deceleration cases (i.e., *0.15 g* and *0.39 g*).

Table 2-2 Last-Second Steering Kinematic Conditions

Kinematic Condition	Target SV Speed	Target POV Speed	POV Deceleration	Condition Shorthand Notation	Kinematic Groupings
1	30	30	0.15	30_30_15	POV Deceleration
2	30	30	0.39	30_30_39	
3	60	60	0.15	60_60_15	
4	60	60	0.39	60_60_39	
5	30	20	0	30_20_0	Constant ΔV
6	30	10	0	30_10_0	
7	60	50	0	60_50_0	
8	60	30	0	60_30_0	
9	60	15	0	60_15_0	
10	30	0	0	30_0_0	POV Stationary
11	60	0	0	60_0_0	

All 72 participants performed both types of driving maneuvers under both "normal" and "hard" conditions, for a total of 56 trials (17x2 for braking plus 11x2 for steering) completed over two days (braking done on one day and steering done on the next consecutive day (or visa versa) when possible).

3 Implementing the CAMP FCW Protocols at NADS

3.1 Overview

In replicating the CAMP closed-course study in the NADS, every effort was made to parallel as many aspects as possible of the previous study design. This included the test track environment, the vehicle dynamics, the number of participants, gender, and age group clusters, the kinematic conditions, the instructions to the drivers, data collection, data reduction, and computational methods. There were, of course, a few elements of the study that could not be directly paralleled. They included items like the vehicle cab and vehicle dynamics model used, initial headway conditions (driver-preferred versus fixed), and computation methods dealing with how SV steering onset was determined. In these cases, modifications were made to compensate for any shortcomings and best match the final outcome of the CAMP replication efforts. The details of how these CAMP FCW protocols were implemented in the NADS are covered in the following sections.

3.2 Simulated Environmental Conditions

Recreating the simulated environment for the Task 4 study was relatively straightforward. Similar to the TRC test track where CAMP Task 1 took place, the NADS driving database was a simple 3-lane straight piece of highway. All braking trials were set up and carried out in the center lane. All steering trials were set up in the right-most of the 3 lanes, where both the SV and the POV were positioned. As the steering trial was played out, the SV driver was told to steer only one lane to the left to avoid colliding into the POV. All trials took place in daylight and on dry pavement. The only vehicles present in the simulated driving scene were the SV and the POV.

3.3 Scenario Modeling

3.3.1 Kinematic implementation in NADS

The kinematic condition groupings were simulated in the NADS as described above, with the addition of the following details.

3.3.1.1 NADS POV Deceleration Implementation

As described previously, both the SV and the POV start out stopped in the same lane and separated by a few car lengths. Once the POV brake lights went off (simulated as a color and intensity change), the SV and the POV begin to accelerate from the stopped position to the same target speed. In the NADS, these two vehicles were initially "tied" (or artificially coupled) together at a 1.4 second time headway (based on the SV and POV target speeds) until the SV was within *20%* of the target POV speed (the necessity for coupling of the vehicles is explained in Section 3.3.3). At this point, the vehicles became autonomous and the SV driver is asked to maintain their “normal” headway, indicating they have done so by saying "Ready". Usually, within a 5-second window of the SV driver indicating their readiness, the POV began to decelerate at the constant target deceleration rate. In addition to the brake light simulation, a slight pitch of the lead vehicle to simulate brake dive accompanied the POV deceleration. The SV driver reacted to the POV braking by either braking in the same lane or steering to the left.

3.3.1.2 NADS Constant ΔV Implementation

In reference to Figure 2-3 above, the target speed of the POV is less than the target speed of the SV ($V_{POV} < V_{SV}$). Both the SV and the POV started out stopped in the same lane, separated by a large distance (the larger the target ΔV, the larger the initial separation). The SV and the POV begin to accelerate to target speeds. As the SV closed in on the POV, the SV avoided colliding into this vehicle by either braking in the same lane or steering to the left.

3.3.1.3 NADS POV Stationary Implementation

For this kinematic scenario, the POV is stopped in the distance (initially out of the driver's view in the NADS) down the road in the same lane. As the driver approached the prescribed target speed, the SV closes in on this stopped POV that has its brake lights on. Based on the given instruction, the SV driver either brakes in the same lane or steers to the left lane to avoid colliding with the stopped vehicle.

3.3.2 Separate File for Each Condition Run

At the end of each kinematic condition run, the driving data was stored for that trial in a separate file and the database was reinitialized for the next run.

3.3.3 Initial Headway Issue

For the POV moving implementations described above, in pre-piloting these trials in the NADS, it was observed that the lead car (the POV) was initially getting too far out in front of the SV while the SV driver began to establish their own rate of acceleration from the stopped position. Once this large headway gap was established, the SV drivers had a tendency to work from these long headways as they played out the trial run (a point which is discussed further below). The NADS initial time headway results were in the range of *3–4 seconds* on average as compared to *1.3–1.6 seconds* found in the CAMP closed-course research (see Table E-5). Without the NADS drivers at least starting out at a comparable initial time headway to those found in the CAMP closed-course study, it would severely handicap the comparison of the maneuver onset results. Hence, a solution to this lead car "runaway" issue was to initially "couple" the POV to the SV at a fixed distance (either *60, 90*, or *120 ft*) depending on the target speed (*30, 45*, and *60 mph*, respectively) until the SV reached approximately *85%* of its target speed. It is important to note that the SV driver was in complete control of their vehicle (including their speed) at all times and only the POV was initially constrained at a fixed headway until the SV reached *85%* of its target speed. After reaching this level, the POV became autonomous (uncoupled from the SV). For the POV DECELERATION trials, after reaching the target speed, then finding and maintaining a driver-preferred headway, the SV driver indicated their anticipation of the POV deceleration event by saying "Ready". By preventing the POV from initially getting too far ahead, and then allowing the SV driver to establish a "comfortable" headway after the POV became autonomous (uncoupled), initial headway times in the NADS were reduced to more reasonable numbers (*~1.6 seconds*) to compare the CAMP versus NADS last-second results.

Irrespective of the manner in which this headway issue was resolved in the current study, these results suggest careful attention must be paid in future NADS rear-end crash research to ensure that car-following behavior under NADS conditions is comparable to that found under actual driving conditions. This is of particular importance in rear-end crash research, where initial “steady state” headway conditions play a paramount role in any unfolding rear-end crash scenario.

3.4 Motion Tuning in the NADS

As with any motion-base simulator the accelerations that a driver feels in the NADS are not the same as the accelerations calculated by the vehicle dynamics model. A motion drive algorithm, sometimes called a 'washout' filter is used to transform calculated vehicle accelerations into motion system commands. The motion system hardware then responds to deliver the commanded accelerations within the limits of its physical performance.

Motion drive algorithms are typically highly adjustable [4] and rely on the selection of many parameters to determine their final performance. So it is not enough to simply note that a simulator has a motion capability or even to state the maximum physical limits of that capability. Something must be known about how the motion drive algorithm has been calibrated or tuned in order to meaningfully understand the motion cueing environment present during an experiment.

The motion algorithms used in the NADS at the time of this experiment applied two basic types of transformations to the vehicle accelerations: scaling and filtering. Scaling is the mathematical reduction of the desired acceleration by some fraction. Often, the fraction is fixed, but more advanced algorithms are capable of adjusting the scaling in various ways. Filtering seeks to remove the low-frequency portion of the vehicle's linear accelerations in order to limit the displacement of the simulator actuators. This is necessary to remain within the physical limits of the simulator hardware. In some cases additional filters are used to re-introduce the low-frequency accelerations through the judicious use of cabin tilt. The process is known as tilt-coordination.

3.4.1 Tuning Goals

There were three goals for the motion tuning used in the FCW trials:

1. **Maximize the scale factors for lateral and longitudinal motion.**

   The NADS has a unique motion system that is larger and more capable than any other simulator available. This is one of the reasons that the NADS appeared to be a useful test bed for the FCW trials. By maximizing the scale factors that were used in the trials we aimed to use the NADS at its full potential and to generate perceived vehicle accelerations that were as close as possible to an actual vehicle.

2. **Minimize the number of motion system aborts caused by momentarily exceeding the motion system capability.**

   When the NADS motion system exceeds its design limits, automatic-monitoring systems shut down the simulation to ensure the safety of the test participant and the simulator facility. These motions 'aborts' are disruptive to an experiment and unpleasant for the driver. It is only possible to eliminate motion aborts by operating the simulator far from its maximum limits. This would result in very small-scale factors that would not make use of the NADS capabilities. Balancing the desire to simultaneously increase the motion scaling and to minimize the aborts was a challenge that required the NADS motion system engineers to develop new methods for the FCW trials.

3. **Minimize false cues that lead to simulator sickness.**

   When a driver experiences vestibular cues that differ from the visual motion cues a ‘cue conflict’ is said to occur. Fixed simulators operate in a state of extreme cue conflict whenever any apparent acceleration is present. These cue-conflicts are thought to be the primary cause of simulator sickness [3]. Moving simulators like the NADS attempt to minimize cue conflict by ensuring that the visual and vestibular cues presented to the driver match as closely as possible. However, conflicts can and do exist even in moving simulators and these can actually be worse than having no motion at all [5]. Therefore, attention was given to minimizing any false cues that might trigger simulator sickness during the trials.

Motion algorithm parameters were selected by the NADS technical staff in accordance with these three goals.

3.4.2 NADS Washout Structure

An extremely abbreviated description of the NADS motion drive detailed in [6] is now presented in order to help the reader begin to appreciate the role of the key parameters.

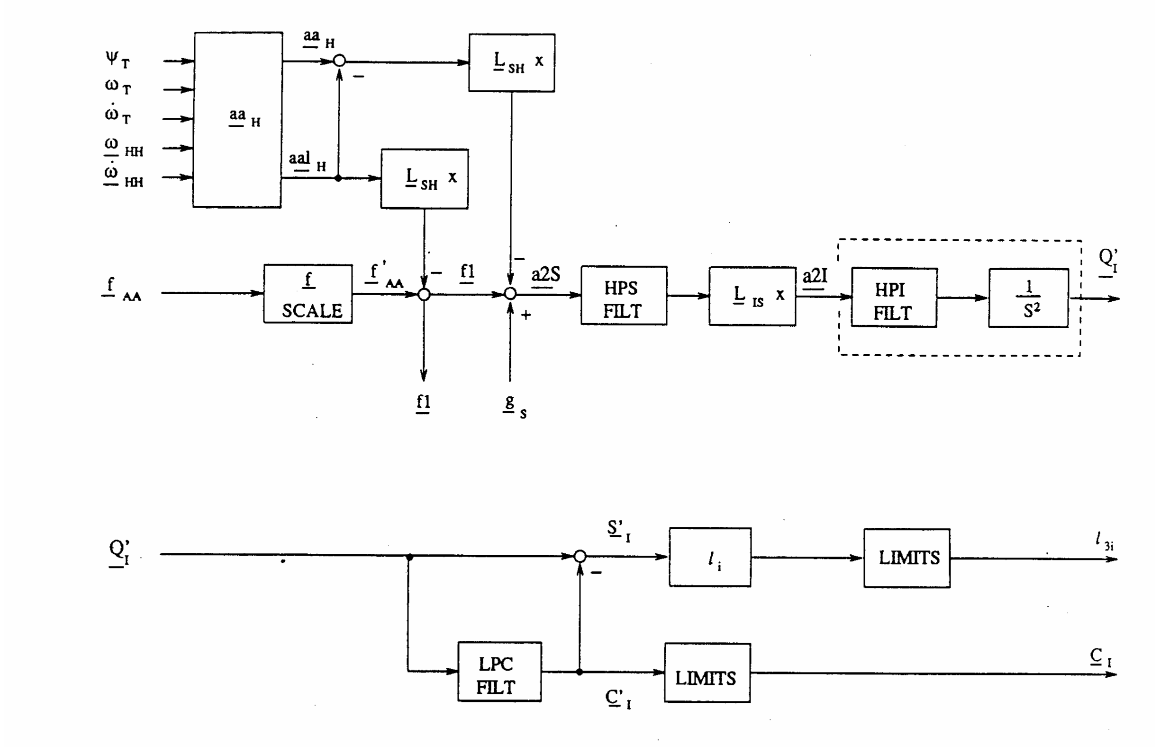


Figure 3-1 Translational Motion Control in NADS (from [6])

In Figure 3-1, linear accelerations from the vehicle model are transformed to specific forces* $\underline{f}_{AA}$ and become the input to the translational portion of the motion drive. They are scaled by the $\boxed{\underline{f}\text{ SCALE}}$ block and then are subject to high-pass filtering to limit the displacement of the motion system. After integration, the resulting linear displacements $\underline{Q}'_I$ are split by the

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* Specific force is measured in units of acceleration and is defined as $\mathbf{f} = \mathbf{a} - \mathbf{g}$

$\boxed{\begin{matrix}LPC\\FILT\end{matrix}}$ block into commands for the large-displacement X-Y carriage ($\underline{C}_I$) and commands for the six degree-of-freedom hexapod (l_{3i}).

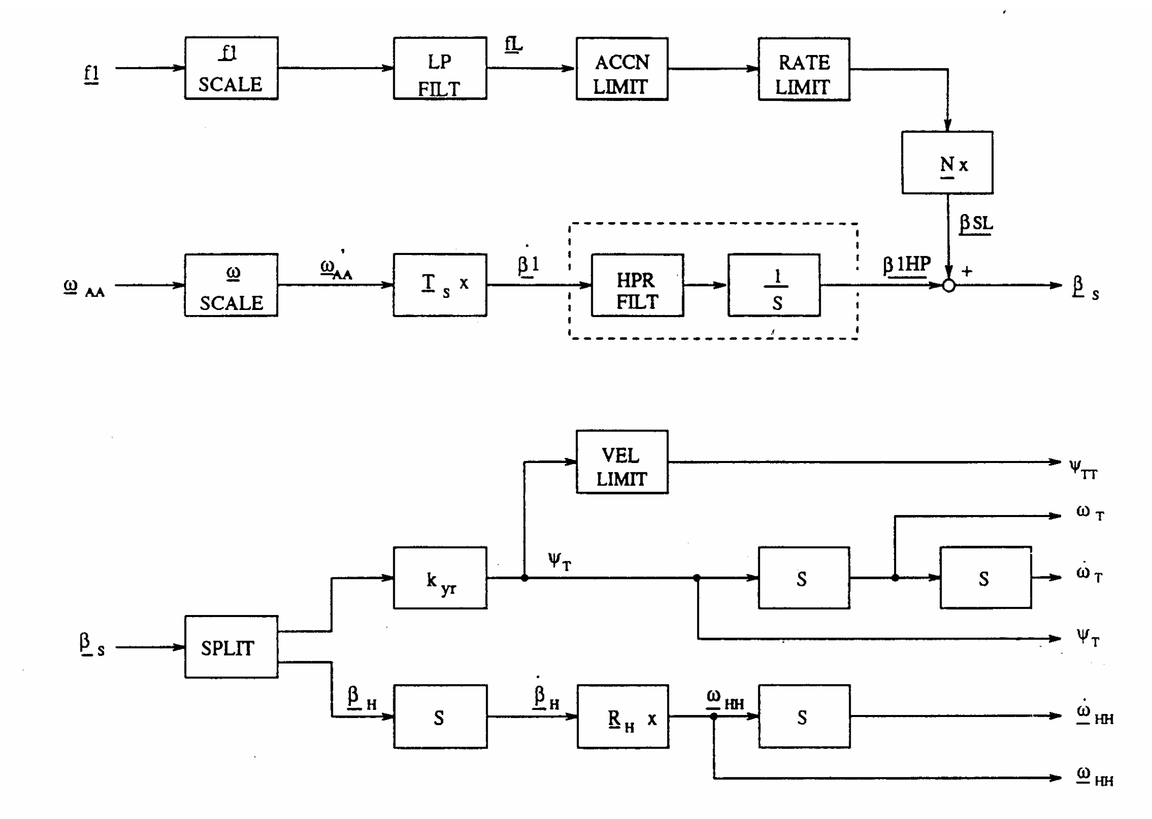

Figure 3-2 Rotational Motion Drive in NADS (from [6])

The angular velocities from the vehicle model $\underline{\omega}_{AA}$ also undergo scaling in the $\boxed{\omega\,\text{SCALE}}$ block as shown in Figure 3-2. The linear acceleration $\underline{f1}$, which has already undergone scaling in Figure 3-1, is further scaled by the $\boxed{f1\,\text{SCALE}}$ block. The resulting specific force is low-pass filtered in the $\boxed{\begin{matrix}LP\\FILT\end{matrix}}$ block.

This signal is added to the integrated angular velocities and used as tilt-coordination. The effect of this term is to substitute cabin tilt for low-frequency acceleration. The remaining portions of the angular channel deal with limiting and the effect of the unique NADS turntable. These terms will not be discussed here.

3.4.3 Scale Factors

The FCW steering trials, and to a lesser extent the braking trials, taxed the dynamic range of the conventional motion drive algorithm. The ratio between the largest and smallest peak lateral acceleration observed across all the steering trials was greater than *40:1*. For the braking trials the ratio between the largest and smallest peak decelerations was greater than *6:1*. These relatively large ratios meant that scale factors that would result in acceptable performance for mild maneuvers would likely cause motion system aborts in the most aggressive cases. To address this issue, the NADS technical staff developed a non-linear scaling technique.

Instead of holding $\boxed{\underline{f}\text{ SCALE}}$ constant, a curve was used where the value of the scale factor was a function of the specific force. When the specific force, expressed in *g's*, was near zero the scale factor was set to *1.0*. When the specific force was large, a value of *0.5* was used. In between these extremes a cosine taper was used to manage the transition. The resulting curve is shown in Figure 3-3.

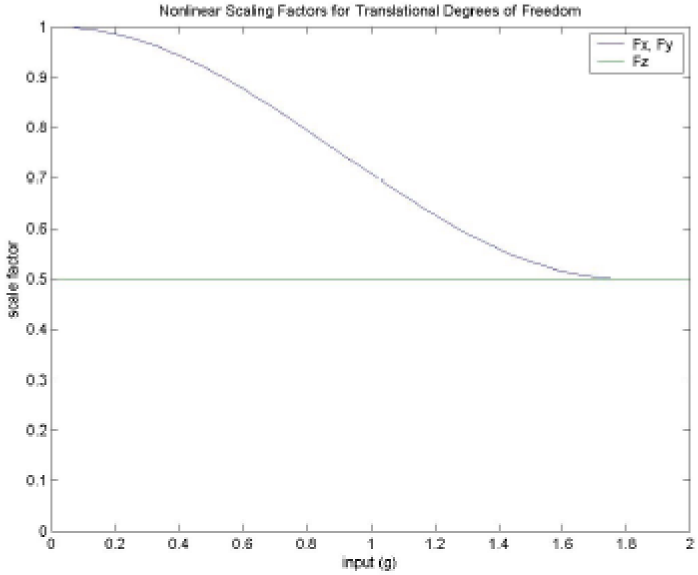

Figure 3-3 Translational Scale Factors in NADS

The scale factor for the vertical channel (*Fz*) was held constant at *0.5*. The effect of this strategy was to allow mild accelerations to be felt at near unity gain. Larger accelerations were still felt but were limited to *50%* of their original magnitude.

A similar strategy was adopted for the $\boxed{\omega\text{ SCALE}}$ block shown below in Figure 3-4. In the rotational case, non-linear scaling was used for all three degrees of freedom, although the overall scale factor was lower.

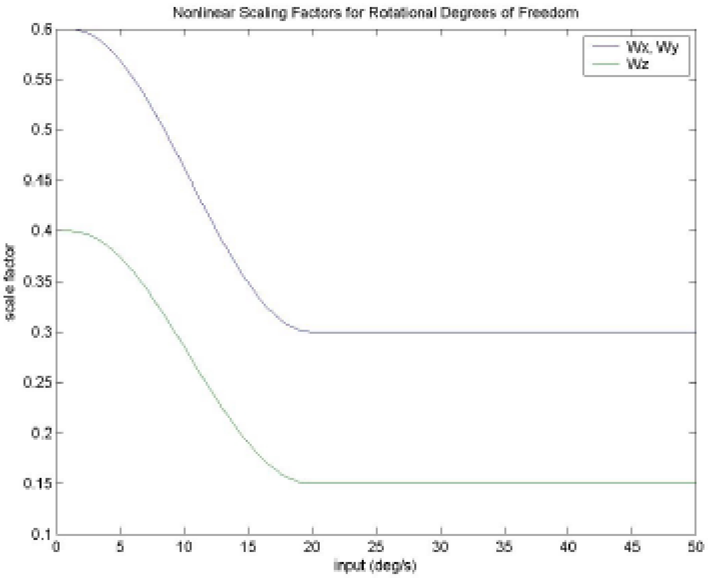

Figure 3-4 Rotational Scale Factors in NADS

Finally, the term $\boxed{f1\mathrm{SCALE}}$ was set to *0.15*. This provided only a *15%* contribution from tilt-coordination during the maneuvers. The effect of this term is that sustained accelerations were not simulated at the same level as the initial accelerations.

3.4.4 Filter Tuning

The $\boxed{\begin{matrix}LPC\\ FILT\end{matrix}}$ block was calibrated so that essentially all of the lateral and longitudinal accelerations were transmitted through the X-Y carriage. The six degree-of-freedom hexapod was used for the angular channels and for Z motion. High pass filtering for the translational motion was performed using the inertial frame filter[*]. The X, Y high pass cutoff frequencies in $\boxed{\begin{matrix}HPI\\ FILT\end{matrix}}$ were set to *0.185 rad/s*. The tilt-coordination onset filter for pitch in the $\boxed{\begin{matrix}LP\\ FILT\end{matrix}}$ block was set to *1.0 rad/s*. This low value further limited the amount of tilt-coordination used by the simulator so the damping coefficient for this block was changed to *2.0* to partially compensate for the slow onset of tilt-coordination. A complete list of the filter parameters for the braking and steering trials is given in Table 3-1 and Table 3-2

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[*] Because yaw angles were small for all of the FCW maneuvers there is essentially no difference between using the HPS or HPI filter blocks to limit the motion displacements.

Table 3-1 CAMP Braking Washout Parameters

Braking Parameter	**X**	**Y**	**Z**	**Roll**	**Pitch**	**Yaw**
$\boxed{\underline{f}\,\text{SCALE}}$	1-0.5	1-0.5	0.5	N/A	N/A	N/A
$\boxed{\omega\,\text{SCALE}}$	N/A	N/A	N/A	0.6-0.3	0.6-0.3	0.4-0.15
$\boxed{f1\,\text{SCALE}}$	N/A	N/A	N/A	0	0.15	N/A
HPI break freq (r/s)	0.185	0.185	1	0.05	0.05	0.01
HPI damping	2	2	2	0.707	0.707	0.707
LP break freq (r/s)	150	150	N/A	3	1	N/A
LP damping	2	2	N/A	2	2	N/A
LP aux freq (r/s)	150	150	N/A	100	100	N/A
LP vel lim	500 in/s	500 in/s	N/A	3.5 deg/s	3.5 deg/s	N/A
LP acc lim	500 G	500 G	N/ A	45 deg/s/s	45 deg/s/s	N/A

Table 3-2 CAMP steering washout parameters

Steering Parameter	**X**	**Y**	**Z**	**Roll**	**Pitch**	**Yaw**
$\boxed{\underline{f}\,\text{SCALE}}$	0.8-0.5	1-0.5	0.5	N/A	N/A	N/A
$\boxed{\omega\,\text{SCALE}}$	N/A	N/A	N/A	0.6-0.3	0.6-0.3	0.4-0.15
$\boxed{f1\,\text{SCALE}}$	N/A	N/A	N/A	0	0.6-0.5	N/A
HPI break freq (r/s)	0.185	0.185	1	0.05	0.05	0.01
HPI damping	2	2	2	0.707	0.707	0.707
LP break freq (r/s)	150	150	N/A	3	1	N/A
LP damping	2	2	N/A	2	2	N/ A
LP aux freq (r/s)	150	150	N/A	100	100	N/A
LP vel lim	500 in/s	500 in/s	N/A	3.5 deg/s	3.5 deg/s	N/A
LP acc lim	500 G	500 G	N/A	45 deg/s/s	45 deg/s/s	N/A

3.4.5 Braking Results

A typical example of mild braking is shown in Figure 3-5. The trace labeled MIF_Head_Point_Specific_F_0_ is the input to the motion drive algorithm. This is the level of specific force required to match the actual vehicle deceleration. The trace labeled MTS_Head_Point_Specific_F_0_ is the level of specific force actually attained by the NADS motion system during the deceleration. This is a deceleration trial (*30_30_15*), with the POV braking at *0.15 g's*. SV braking is taken to begin at approximately *69 seconds*[*].

Several features in Figure 3-5 are worth noting. Immediately after beginning to brake the driver in NADS experiences a very realistic onset cue that matches the vehicle specific force with only a slight reduction in magnitude. This onset cue is relatively brief and at about *70 seconds* it begins to decay away as a result of the high-pass filtering. The low value of $\boxed{f1\mathrm{SCALE}}$ results in only a small portion of the sustained deceleration being provided by tilt-coordination. At approximately *78 seconds*, the SV comes to a stop and the vehicle acceleration goes to zero. At this point, the trial is essentially over, but a moderately severe false cue is generated where the driver actually senses the vehicle accelerating forward after the visual scene stops moving. This false cue is a result of the interplay between the HPI high-pass filters and the low values chosen for $\boxed{f1\mathrm{SCALE}}$.

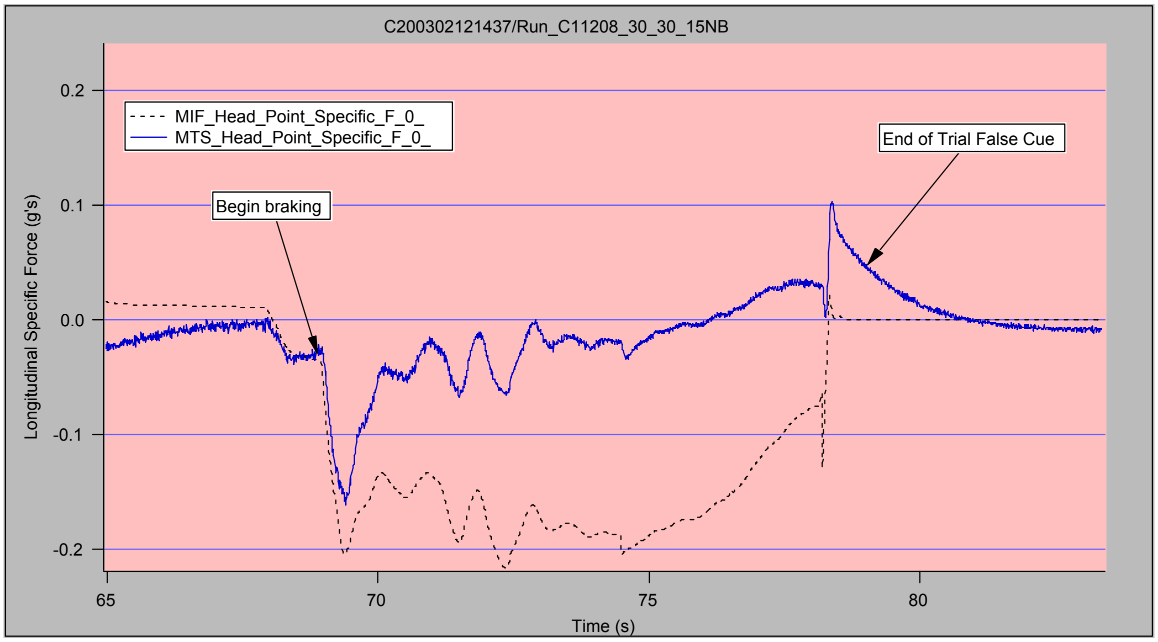

Figure 3-5. Mild Deceleration Case

The deceleration trial shown in Figure 3-6 is a shorter, more severe event. Here braking begins at approximately *38 seconds* and continues for less than *3 seconds* before the vehicle comes to a stop. The pattern of the NADS response is similar to the mild deceleration case. However, the combination of non-linear scaling, limiting and high-pass filtering reduces the magnitude of the onset cue to less than *50%* of the actual vehicle deceleration.

The false cue at the end of the trial is present here also. In this case the magnitude of the false cue is quite large and persists for a time period comparable to the deceleration event itself.

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[*] See the section on Data Reduction for an explanation of how the point of braking onset was determined.

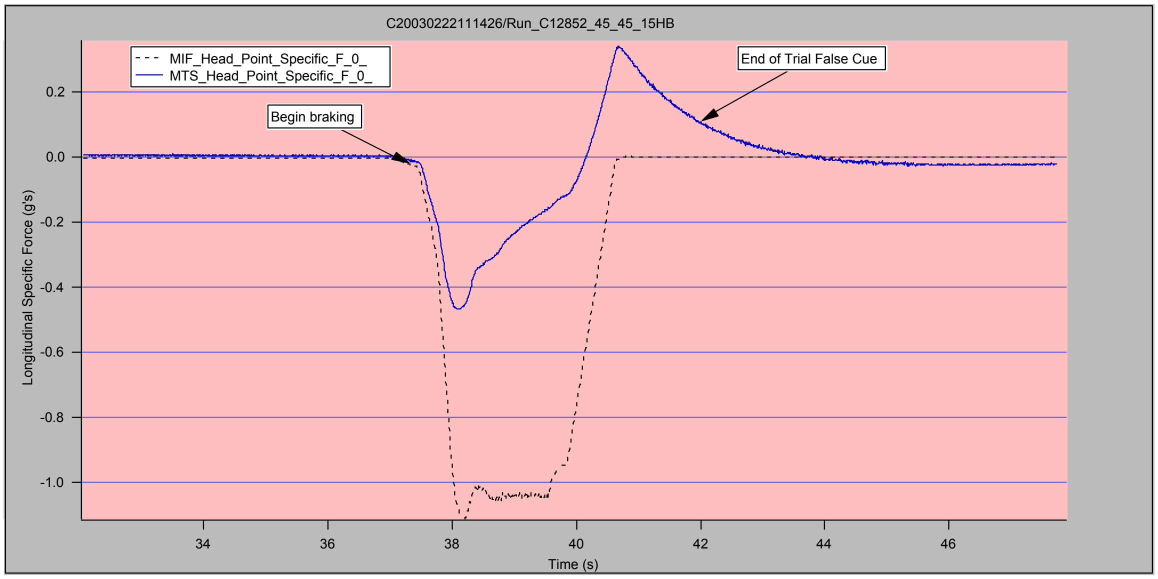


Figure 3-6. Aggressive Deceleration Case

3.4.5.1 Comments on Braking in NADS

The CAMP research team experienced the final NADS motion tuning prior to the start of the trials. The braking events experienced in the NADS were characterized by excellent initial braking onset cues, followed by less accurate cueing during the remaining deceleration event. Subjectively, our judgment was that the onset cues provided a realistic impression of vehicle braking. There was no detectable phase lag between the visual deceleration cues and the perception of the vehicle motion. The lack of motion cues during the deceleration event itself was subjectively masked by the strong visual impression derived from the high-resolution NADS display.

The false cue present at the end of the trials was both noticeable and uncomfortable. Although large simulator sickness scores did not result from this false cue, reducing or eliminating it for future experiments in the NADS would be advisable.

3.4.6 Steering Results

A typical example of mild steering is shown in Figure 3-7. Again, this is a deceleration trial (*60_60_15*) and although the instructions to the driver were to complete a "hard steering" maneuver, the peak lateral acceleration achieved was only about *0.1 g's*. For the steering case, MIF_Head_Point_Specific_F_1_ represents the lateral specific force requested by the simulation model and MTS_Head_Point_Specific_F_1_ is the lateral specific force actually experienced in the NADS.

Steering in NADS has a different character than braking. The onset cue in Figure 3-7 begins at approximately *51 seconds* when the driver begins the steering maneuver. The initial cue appears to noticeably lag the required acceleration, although this is primarily the result of scaling. After the peak lateral acceleration however, the situation changes and the NADS motion cues begin to *lead* the vehicle accelerations. There is also a substantial overshoot in the NADS motion response.

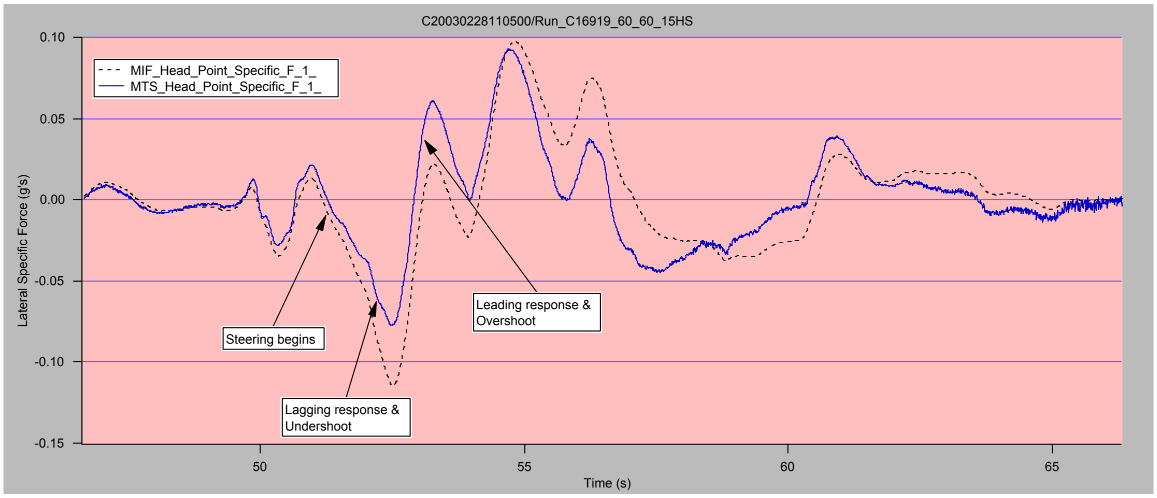


Figure 3-7 Mild Steering Case

A more severe steering trial is shown in Figure 3-8. Although this is the same kinematic condition and instruction as the case in Figure 3-7 (*60_60_15* Hard Steering), this driver responded much more aggressively to the situation.

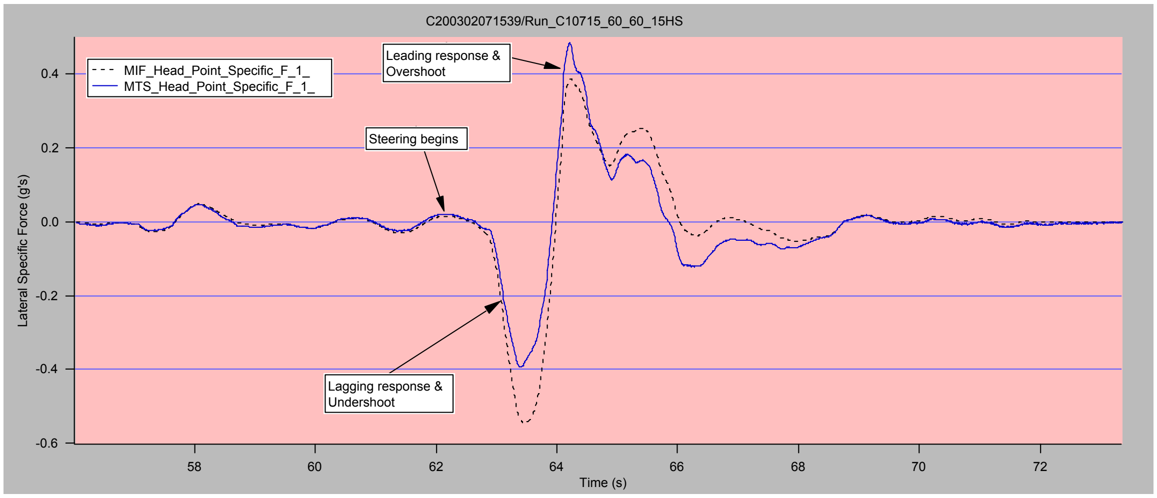


Figure 3-8. Aggressive steering case

3.4.6.1 Comments on Steering in NADS

Objectively, the lateral specific forces in the steering trials were a closer match to the vehicle specific forces than longitudinal specific forces were in the braking case. Subjectively, however, the impression was just the opposite. The false cues in the steering trials were more immediately perceptible than those in the braking trials, and the nature of the false cues made lateral control difficult. However, it is beyond the scope of this report to determine which features of the lateral specific force reproduction were responsible for this impression.

3.5 Vehicle Dynamics Modeling

The CAMP closed-course tests were performed using a 1997 Ford Taurus SHO as the subject vehicle [1, 2]. For the NADS comparison the original intention was to use the *NADSdyna*

Taurus model [7] along with the NADS Taurus cab. Although the *NADSdyna* Taurus model was based on a 1994 version of the Ford Taurus it represented the closest available match for the original closed course test conditions.

Unfortunately, the Taurus cab was unavailable for use in the NADS at the time the experiment was conducted. A Chevrolet Malibu cab was available; however it was not possible to use the Malibu cab with the Taurus dynamics model because of configuration issues in the NADS software. Because the Malibu and Taurus are both North American passenger sedans it was expected that their performance in the FCW trials would be similar enough that it would not introduce appreciable noise into the closed-course versus NADS comparison. To determine if this assumption was warranted, several comparisons were made between Taurus and Malibu responses.

The first comparison was between step-steer responses in both vehicles. We expected drivers to make abrupt steering inputs especially in the more severe kinematic conditions during the steering trials. We could not compare the published step-steer responses for the Malibu and Taurus directly because different test conditions were used in the two cases [8]. Instead we used a Ford-supplied Taurus model based on the *ADAMS* numerical code to generate data for the Taurus. We then compared the lateral response of the Taurus model with the Malibu *NADSdyna* model at two step-steer conditions:

Table 3-3 Malibu versus Taurus Lateral Conditions

Steering Input / Model	55° step @11.5 m/sec		168° step @11.5 m/sec	
	Steady state	Peak	Steady State	Peak
Malibu (Salaani, et. al.)	0.26 g	0.30 g	0.69 g	0.70 g
Taurus (ADAMS model)	0.22 g	0.26 g	0.65 g	0.64 g

The two models give similar results in these conditions. The Taurus response is generally lower than the Malibu for a given level of steering input by an amount that varies from *6% to 15%.*

To further validate the use of the Malibu model, VRTC [9] conducted a simulation of the Malibu and the Taurus in the *60_15_0* "hard steering", constant velocity condition. The steering input to the *NADSdyna* models was recorded during a test run in the NADS. Lateral acceleration (*Ay*), roll angle and yaw rate from these two models are plotted below in Figure 3-9 and Figure 3-10.

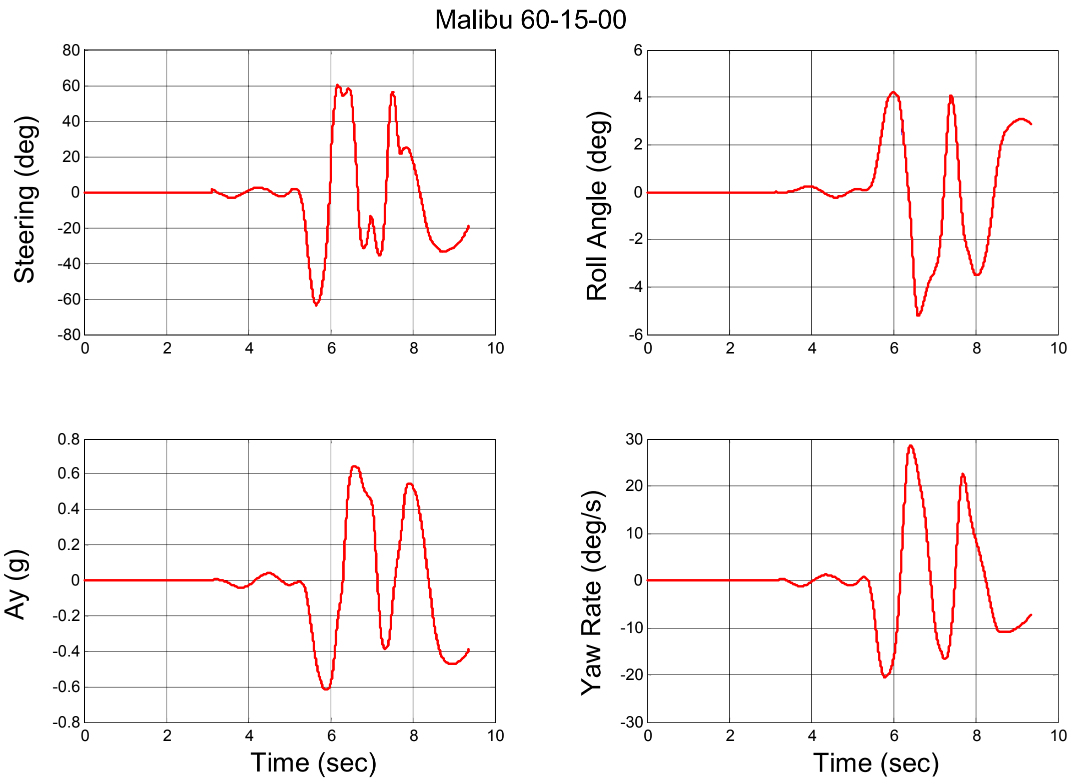


Figure 3-9 Malibu Steering Maneuver for *60_15_0* Condition

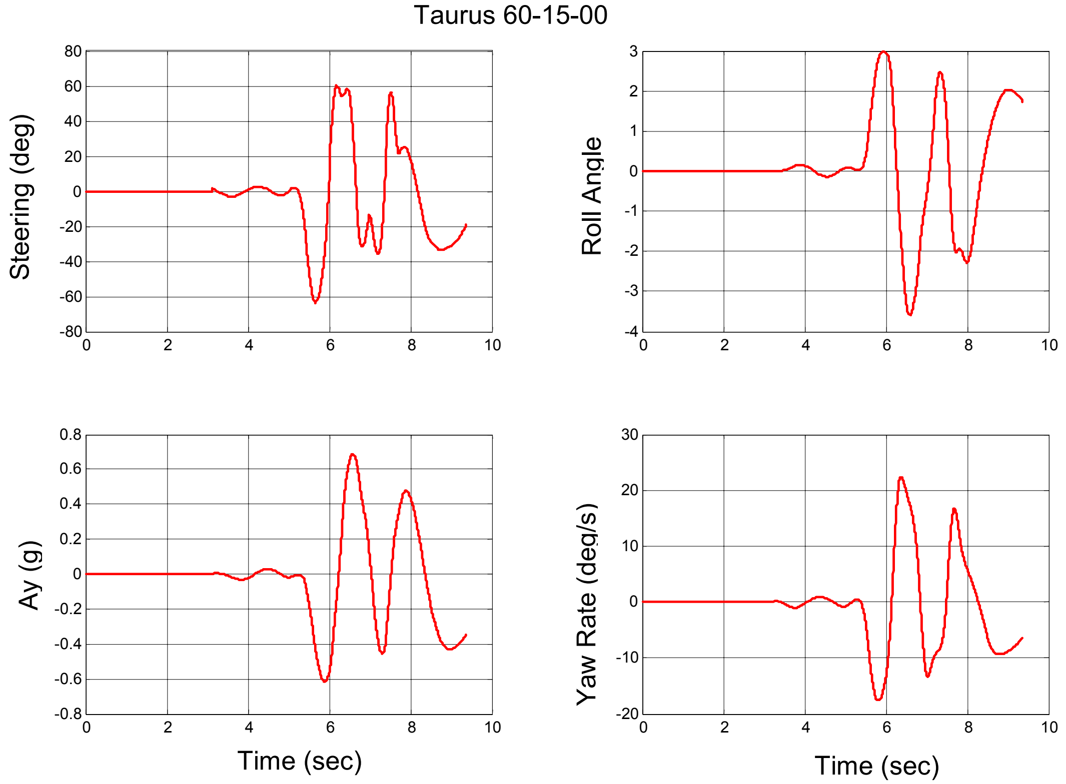


Figure 3-10 Taurus Steering Maneuver for *60_15_0* Condition

The two models give nearly identical results in this case. The Taurus generates less initial body roll than the Malibu but the lateral accelerations are quite comparable.

As a result of this analysis, it was concluded that the use of the Malibu cab along with the Malibu *NADSdyna* model was acceptable for the completion of the Task 4 trials.

4 Data Collection

There were various modes of data collection in the NADS. In addition to the 70 data channels used to collect a number of driver performance measures, digital video (DVCam) and audio data were also recorded for all trials and drivers. A single DVCam tape was made for each driver that contained both their braking and steering sessions.

4.1 NADS Video Data

The recorded video stream consisted of a quad-spilt screen (see Figure 4-1) that contained the following recorded perspectives:

Upper Left: An in-vehicle driver's face view.
Upper Right: An in-vehicle over-the-driver-shoulder view.
Lower Left: An in-vehicle foot-well view.
Lower Right: An in-dome forward-looking camera view (as approximately scene from the driver's perspective).

Figure 4-1 NADS Still Image of Video Stream

There was also a six-row text overlay in the lower right-hand corner of the quad-split video stream that had the following information:

Row 1: CAMP ID designation
Row 2: Subject number and Kinematic Condition
Row 3: Date and Time
Row 4: Frame number and Range (D)
Row 5: Brake Pressure (BP) and SV velocity (V)
Row 6: Throttle Pressure (TP) and Steering Wheel Angle (S).

An audio recording was also included on the DV tape. Input for the recording was obtained from:

- An in-vehicle microphone, recording the driver response and rear-seat experimenter's interaction with the driver.
- A simulator operator microphone, recording updates and instructions given to the rear-seat experimenter by the operator.
- Additional microphones that were in the NADS control room and on the rear-seat experimenter, also recorded any verbal exchanges that may have occurred pertaining to the experiment.

4.2 NADS Raw Data

For each kinematic condition run by each subject, a separate binary data file was saved. These files were approximately *10 Megabytes* in size depending on the duration of the trial run. In total, for all subjects, there were *4032 trials run,* totaling over *50 Gigabytes* of data for the entire experiment.

5 Data Reduction

The data from the NADS was provided to CAMP in raw, binary form. All computed measures presented in this report have been derived from the raw data by using data reduction routines developed at CAMP. There were *4032* experimental trials: *2,448* braking trials and *1,584* steering trials. Of these, *4023* were analyzed to produce the dependent measures. Nine files were not analyzed (representing less than *0.25%* of the total data), for the reasons listed in Table 5-1.

Table 5-1 Trials omitted from the data reduction phase

Run	**Reason omitted**
C11923_60_60_39NB	Missing from data CD's
C12227_30_0_0HB	Missing from data CD's
C13648_60_60_15HS	Missing from data CD's
C14226_60_30_0NB	Missing from data CD's
C14655_60_60_15HS	Missing from data CD's
C15156_60_30_0HS	Missing from data CD's
C16947_60_60_39HB	Missing from data CD's
C18040_30_30_15NS	Missing from data CD's
C19256_30_30_39HS	Data reduction error

Each experimental trial resulted in a separate data file. Each data file contained data channels sampled at *120 Hz*. The available data channels are listed in Table 5-2 along with a brief description of the data. On average, the data files were *12.4 Megabytes* in size. The total size of the binary dataset was *51.2 Gigabytes*.

Table 5-2 NADS Data channels supplied to CAMP

Channel Name	Data Description
CFS_Accelerator_Pedal_Position	**Accelerator pedal position** Closed throttle value = 0 Wide open throttle value = 1
CFS_Auto_Transmission_Mode	**Transmission mode** -2 = park -1 = Reverse 0 = Neutral 1 = First 2 = Second 3 = Third 4 = Overdrive
CFS_Brake_Pedal_Force	**Brake pedal force** Forces are measured at pedal face. Multiply value by 4 to get pounds, for CAMP data.
CFS_Steering_Wheel_Angle	**Steering wheel angle** Optical encoder mounted on steering actuator is used for steering wheel angle measurement. There is a 1:1 correlation between the steering wheel and the encoder rotation. Outputs 2048 counts/rotation so the resolution is 0.17578 degrees/count.
CFS_Steering_Wheel_Angle_Rate	**Steering wheel angle rate** Measured with hardware tachometer mounted to steering actuator shaft. Outputs 288.462 degrees/sec.
CFS_Steering_Wheel_Torque	**Steering wheel torque** Measured in the steering shaft using a reaction torque sensor (strain gauge bridge).
CIS_Cruise_Control	**Cruise control** 0 = not available 1 = Off 2 = On 3 = Set/Accel 4 = Resume 5 = Coast
MIF_Head_Point_Angular_Velocities	**Angular velocity commanded at the head point** 3-vector (roll, pitch, yaw) (Hexapod coordinate system)
MIF_Head_Point_Specific_Forces	**Specific forces commanded at the head point** 3-vector (x, y, z) (Hexapod coordinate system
MTS_Head_Point_Specific_Forces	**Achieved head point specific forces** 3-vector (x, y, z) (Hexapod coordinate system
MTS_Head_Point_Angular_Velocities	**Achieved head point angular velocity** 3-vector (roll, pitch, yaw) (Hexapod coordinate system
SCC_Lane_Deviation[0]	**Deviation from center of lane** 1 = SV on road -1 = SV in intersection 0 = can't be determined
SCC_Lane_Deviation[1]	**Deviation from center of lane** offset from center of lane or corridor. Positive is to right of center, and negative is to left.

Channel Name	Data Description
SCC_Lane_Deviation[2]	**Deviation from center of lane** width of lane, if on road. If on intersection shows 0.
SCC_Lane_Deviation[3]	**Deviation from center of lane** CVED lane ID, if on a road. CVED corridor ID, if on intersection.
SCC_DynObj_DataSize	**Indicates how many valid objects in SCC_DynObj Array** This variable lists the number of valid scenario objects. Valid objects are the closest objects to the SV, up to a maximum of 20.
SCC_DynObj_CvedId[0]	**CVED ID of Dynamic Scenario Objects** CVED id of dynamic scenario object, closest to SV
SCC_DynObj_CvedId[1 to 19]	**Cved IDs of Scenario Objects** CVED id of 2nd to 20th closest dynamic scenario objects
SCC_DynObj_SolId[0]	**Sol IDs of Scenario Objects** SOL id of dynamic scenario object, closest to SV
SCC_DynObj_SolId[1 to 19]	**Sol IDs of Scenario Objects** SOL id of 2nd to 20th closest dynamic scenario objects
SCC_DynObj_Name[0]	**Names of Scenario Objects** Scenario name of dynamic scenario object, closest to SV
SCC_DynObj_Name[1 to 19]	**Names of Scenario Objects** Scenario name of 2nd to 20th closest dynamic scenario objects
SCC_DynObj_Pos[0]	**Position of Scenario Objects** x coordinate of dynamic scenario object, closest to SV (CVED coordinates)
SCC_DynObj_Pos[1]	**Position of Scenario Objects** y coordinate of dynamic scenario object, closest to SV (CVED coordinates)
SCC_DynObj_Pos[2]	**Position of Scenario Objects** z coordinate of dynamic scenario object, closest to SV (CVED coordinates)
SCC_DynObj_Pos[3 to 39]	**Positions of Scenario Objects** x, y, and z coordinates of 2nd to 20th closest dynamic scenario objects
SCC_DynObj_Heading[0]	**Headings of Scenario Objects** Heading of dynamic scenario object, closest to SV (CVED coordinates)
SCC_DynObj_Heading[1 to 19]	**Headings of Scenario Objects** Heading of 2nd to 20th closest dynamic scenario objects.
SCC_DynObj_RollPitch[0]	**Dynamic Scenario Object Roll** Roll value of dynamic scenario object, closest to SV (CVED coordinates)
SCC_DynObj_RollPitch[1]	**Dynamic Scenario Object Pitch** Pitch value of dynamic scenario object, closest to SV (CVED coordinates)
SCC_DynObj_RollPitch[2 to 39]	**Dynamic Scenario Object Roll and Pitch** Roll and Pitch values of 2nd to 20th closest dynamic scenario objects
SCC_DynObj_AudioVisualState[0]	**Bit mask of Audio and Visual states** Indicates Audio/Visual state of dynamic scenario object closest to SV.
SCC_DynObj_AudioVisualState[1 to 19]	**Bit mask of Audio and Visual states** Audio/visual state of 2nd to 20th closest dynamic scenario objects

Channel Name	Data Description
SCC_DynObj_Vel[0]	**Velocity of Scenario Objects** Velocity of dynamic scenario object closest to SV (CVED coordinate system)
SCC_DynObj_Vel[1 to 19]	**Velocity of Scenario Objects** Velocity of 2nd to 20th closest dynamic scenario objects (CVED coordinate system)
SCC_OwnVehToLeadObjDist	**Distance to POV** Measured from bumper to bumper
VDS_Chassis_CG_Accel	**Chassis CG Acceleration** **3-vector** (SAE coordinate system)
VDS_Chassis_CG_Ang_Vel	**Chassis CG angular velocity** 3-vector (SAE coordinate system)
VDS_Chassis_CG_Orient	**Chassis CG orientation** 3-vector (SAE coordinate system)
VDS_Chassis_CG_Position	**Chassis CG position** 3-vector (SAE coordinate system)
VDS_Steering_Torque_Backdrive	**Commanded Steering Wheel Torque**

5.1 Dependent Measures

Seventeen dependent measures were calculated. The measures were calculated at specific times during the trial and each measure is associated with one and only one time period. There are three time periods of interest:

1) The moment of POV braking onset: This is only defined for the deceleration trials and corresponds to the initial conditions associated with the lead vehicle deceleration event.
2) The moment of SV braking or steering onset: This is the moment at which the driver begins a last-second braking or steering maneuver.
3) The (approach) conflict interval: This is the time period beginning at SV braking or steering onset and continuing until the SV has stopped. During this interval the driver is attempting to avoid crashing into the POV.

5.1.1 Measures Computed at POV Braking Onset

- **Initial Range** – the distance in feet between the SV and POV
- **Initial Headway** – the time required for the SV to travel a distance equal to Initial Range assuming its speed was held constant at POV braking onset
- **Initial Subject Vehicle Speed (SVSPDINIT)** – the SV speed at POV braking onset
- **Initial Principal Other Vehicle Speed (POVSPDINIT)** – the POV speed at POV braking onset

Note that these values are undefined for CONSTANT ΔV and POV STATIONARY trials.

5.1.2 Measures Computed at SV Braking/Steering Onset

- **Range** – the distance between the POV and SV.
- **Headway** – the time required for the SV to travel a distance equal to Range assuming its speed was held constant at SV braking/steering onset.
- **Required Deceleration** – the constant deceleration level at braking/steering onset for the SV driver to avoid the crash, assuming the current SV and POV speeds, and that the POV vehicle continues decelerating at the prevailing deceleration value. This is defined as the *longitudinal acceleration* to avoid crashes for both braking and steering conditions.

- **Time to Collision Case #1 (TTC1)** – the calculated time it would take the SV to collide with the POV assuming the current vehicle speeds at *SV onset*, as well as assuming SV and POV acceleration = 0 (at *SV onset*). Note that the prevailing deceleration at SV onset could be 0.
- **Inverse TTC1 (INVTTC1)** – 1/TTC1.
- **Time to Collision Case #2 (TTC2)** – the calculated time (in seconds) it would take the SV to collide with the POV assuming the current vehicle speeds at SV onset, assuming SV acceleration = 0 and the POV continues to decelerate at the current rate of slowing. Note that the prevailing deceleration at SV onset could be 0.
- **Subject Vehicle Speed (SVSPEED)** – the speed of the subject vehicle at braking/steering onset.
- **Principal Other Vehicle Speed (POVspeed)** – the speed of the POV at braking/steering onset.
- **Subject Vehicle Acceleration (SVaccel)** – the acceleration of the SV at braking/steering onset.
- **Principal Other Vehicle Acceleration (POVaccel)** – the acceleration of the POV at braking/steering onset.

5.1.3 Measures Computed during the Peak Conflict Interval

- **Minimum TTC Case #1 (minTTC1)** – the smallest value of TTC1 calculated at any point during the conflict interval (i.e., during the entire approach maneuver).
- **Minimum TTC Case #2 (minTTC2)** – the smallest value of TTC2 calculated at any point during the conflict interval.
- **Peak Deceleration** – the largest observed acceleration magnitude during the conflict interval. For braking trials this corresponds to the minimum longitudinal acceleration. For the steering trials this measure corresponds to the minimum lateral acceleration.

5.1.4 Computational Methods

The most critical issue in the data reduction for the FCW trials was the determination of the SV braking and steering onsets. The process was automated for both braking and steering using algorithms that will be described below. In the case of braking, the determination of onset was clear and unambiguous. However, for the steering onsets this was not always the case. No measure of "ground truth" exists for the steering onsets, especially for steering maneuvers that develop slowly. To ensure that the calculated steering onsets were plausible, the data underwent extensive manual review. Cases where the other dependent measures (e.g., TTC1 or Required Deceleration) were suspected of being outliers were all examined manually. In all cases the maneuver onset determined by the algorithm described here was found to be plausible, although the character of some slowly developing events is such that a unique 'best" onset does not exist.

5.1.5 Determination of SV Braking Onset

Braking onset was determined using an algorithm based on the braking onset algorithm described in [1]. Braking onset is not determined by pedal force but rather by deceleration. This prevents spurious brake activations from generating misleading onsets. The algorithm follows these steps:

1) Wait until the SV has reached *20 mph*.
   This avoids flagging early deceleration spikes sometimes generated by the *NADSdyna* software during a neutral/drive transition as brake onsets.
2) Find the time of the minimum longitudinal acceleration $T_{decel}^{\min}$.
3) Find the time of the last throttle closing prior to $T_{decel}^{\min}$. Call this time $T_f^{throttle}$.
4) Search the interval $\left[T_f^{throttle}, T_{decel}^{\min}\right]$ for the time T_{decel} at which longitudinal acceleration falls below *–0.1 g's*.
   If the driver brakes with the left foot, it is possible that the brake pedal force is non-zero at $T_f^{throttle}$. If this is the case, then the search interval is modified to become $\left[T_{decel}^{\min} - 5, T_{decel}^{\min}\right]$.
5) Define the brake onset time $T_0^{brake} = T_{decl} - 0.167$
   The *167-msec* offset, developed in [1], is designed to correspond to the point at which vehicle slowing occurs as a result of braking.

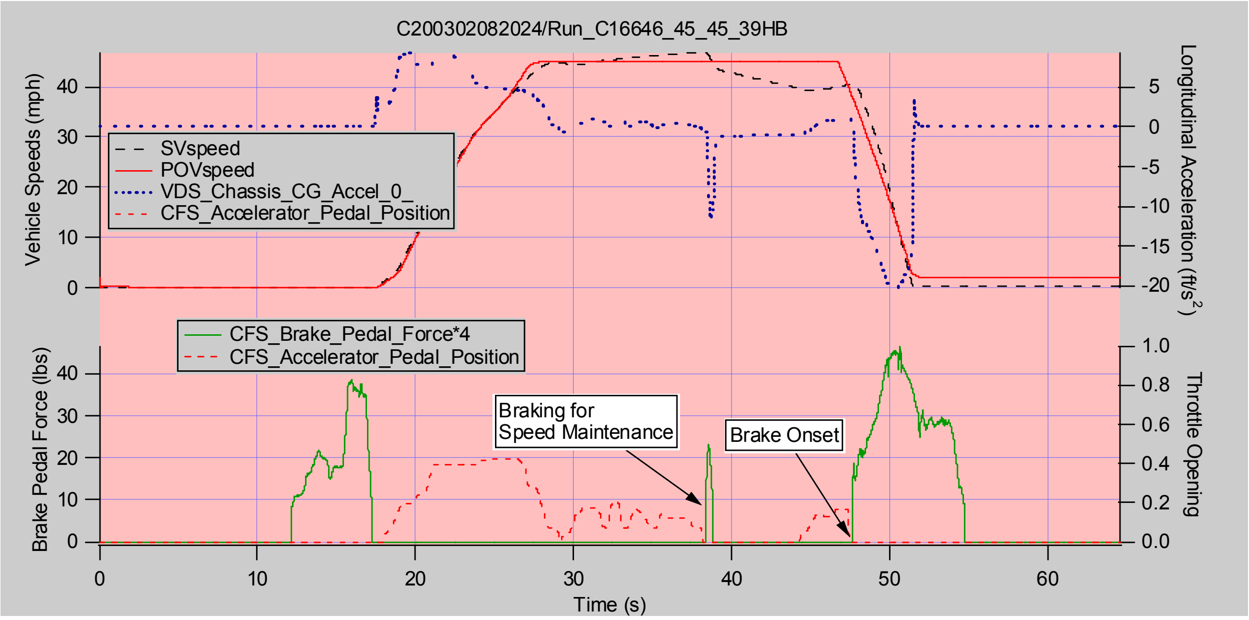


Figure 5-1 Determination of braking onset

Figure 5-1 provides a clear illustration during a *45_45_39* deceleration trial. Using this run as an example, the algorithm would function as follows:

1) *20 mph* is reached at approximately *22 seconds*.
2) $T_{decel}^{\min} = 50.38$ *seconds*
3) $T_f^{throttle} = 47.42$ *seconds* so the search interval is [47.42, 50.38]
4) $T_{decel} = 47.59$ *seconds*
5) $T_0^{brake} = 47.59 - 0.167 = 47.42$ *seconds*

In this example the driver makes a speed correction by tapping the brakes at approximately *39 seconds*. If the braking onset algorithm simply relied on pedal pressure exceeding some threshold this time might have been erroneously identified as the braking onset. Similarly, by restricting the search interval to $\left[T_f^{throttle}, T_{decel}^{\min}\right]$ the algorithm prevents the sharp deceleration at *39 seconds* from being misidentified as the point of braking onset.

5.1.6 Determination of SV Steering Onset

In contrast to the method of determining braking onset as described above, the method used to determine steering onset was completely different than the method used in FCW Task 1 [2]. In the Task 1 CAMP closed-course trials, manual analysis of video data was used to determine the time at which the test subject began the lane change maneuver. At the point that onset was determined to have occurred, the simulation time was read from a video overlay. This video overlay was synchronized with the data acquisition system so that the steering onset determined from the video analysis could be accurately related to the raw data stream.

In the NADS experiment this method was not feasible. The video overlay used by the NADS facility is not designed to support deterministic data collection. The update rate of the video overlay was observed to vary from greater than *4 Hz* to less than *0.6 Hz*. The slow average update rate and the lack of determinism in the update times made it impossible to accurately relate the simulation frame numbers shown on the overlay with the raw data being collected on the NADS computers.

Consequently, an algorithm had to be developed to automatically determine the steering onsets. This process contains inherent ambiguities. Consider the event shown in Figure 5-2. This is a rather gentle lane change that occurs between *34* and *38 seconds*.

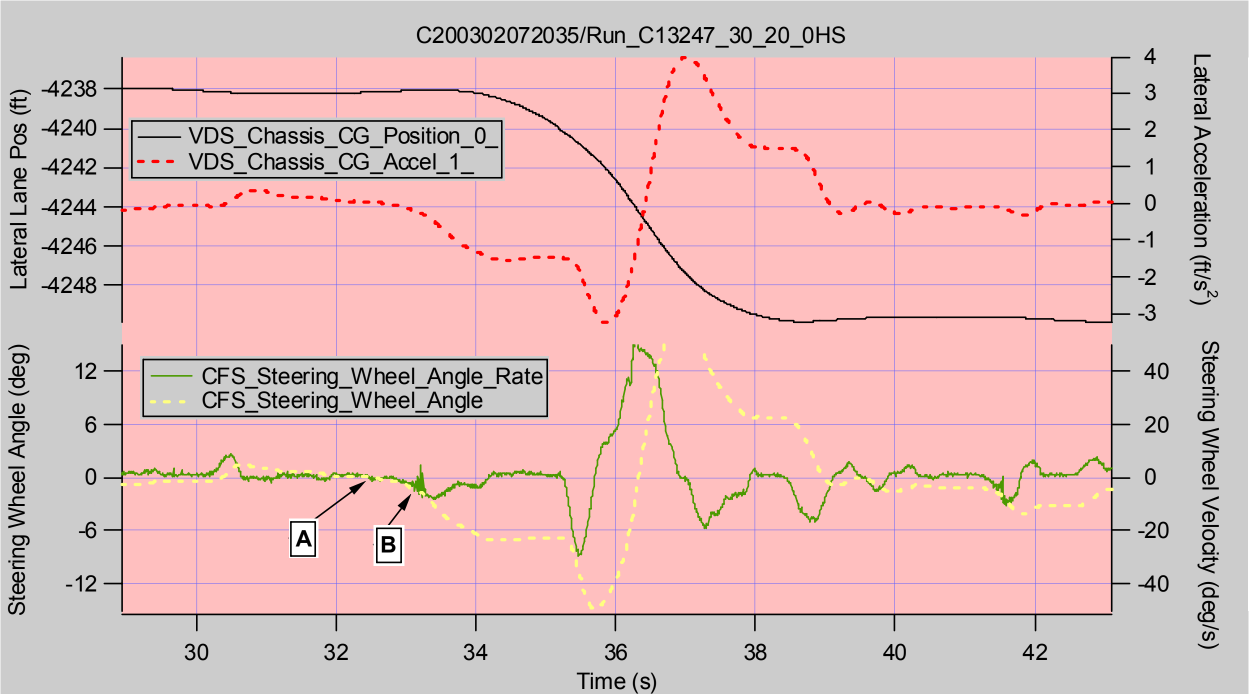


Figure 5-2 A slowly developing lane change

In this event, where is the steering onset? Does it occur near point ***A***, when the steering wheel angular velocity crosses zero? Or, does it occur near point ***B*** when the steering wheel velocity suddenly increases? The problem is compounded in the face of noise factors. Some drivers, as shown in Figure 5-3, exhibited significant high-frequency (*~1 Hz*) steering input during normal lane-keeping.

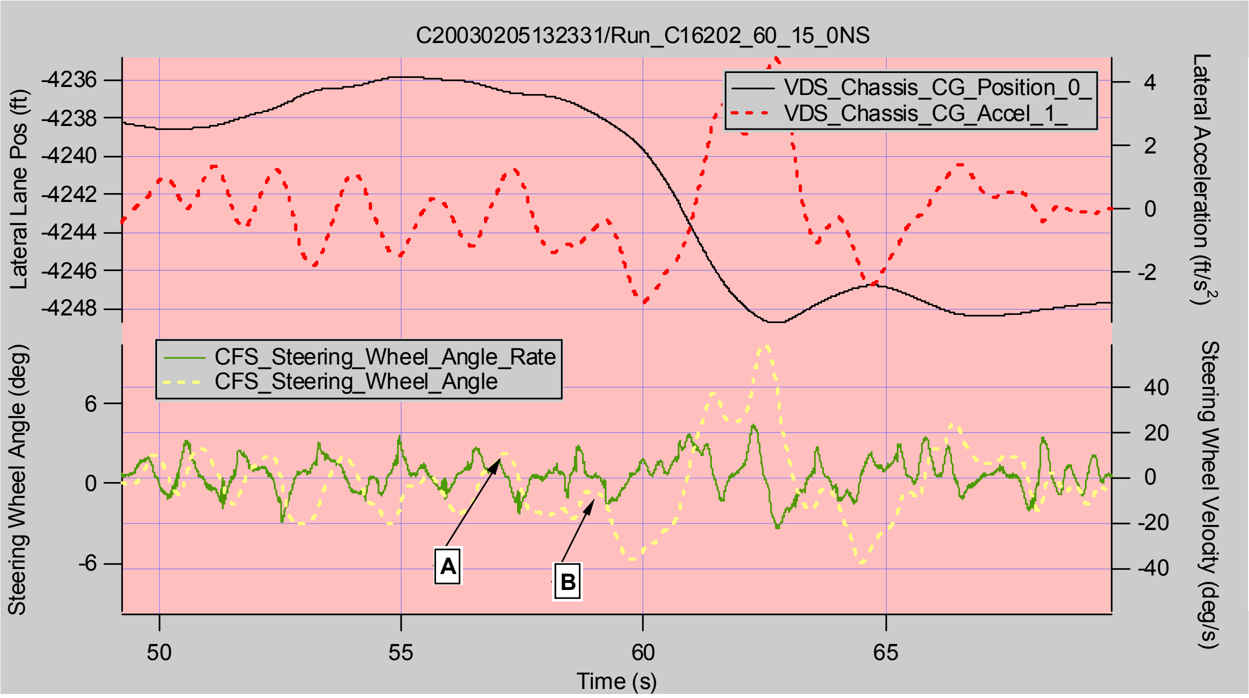


Figure 5-3 Lane change with high-frequency steering input

Again, there is some uncertainty in determining the steering onset. Does it occur near point ***A*** when the steering wheel angle begins its longest run of values below zero? Or, does it begin near point ***B*** when the steering wheel angle begins its descent toward a minimum value?

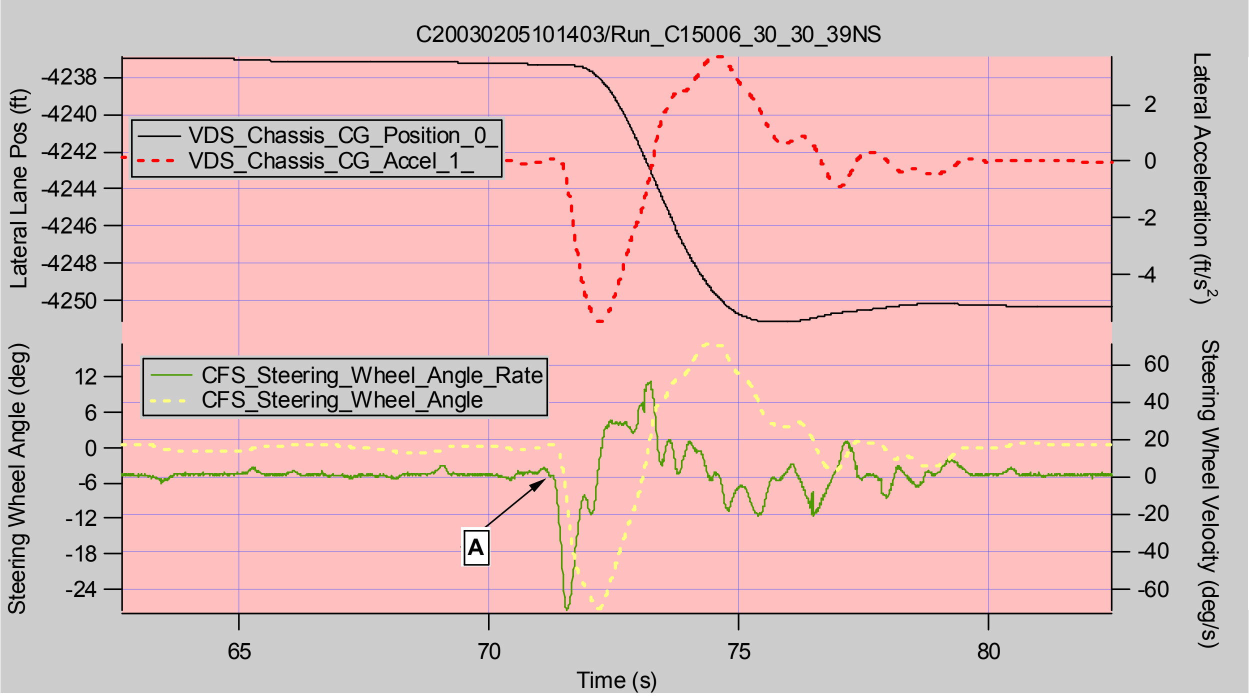


Figure 5-4 Unambiguous steering onset

Not all cases present these difficulties. Figure 5-4 shows an example with a sharp, clearly defined steering onset and little noise. There is no doubt that the steering onset occurred near point ***A***. The challenge in determining the steering onsets was to develop an algorithm that would generate plausible values for all possible cases, which will now be described.

5.1.6.1 The Steering Onset Algorithm

1) Determine the time at which the lane change is observed to be *60%* complete. This time is called T_{60}.
2) Search for the minimum lateral acceleration found in the range $\left[T_{60}-7, T_{60}\right]$. The time at which the minimum occurs is labeled $T_{\min accel}$.
3) Smooth the steering wheel angular velocity using a *5 Hz*, zero-phase, low-pass filter.
4) Search backward in time from $T_{\min accel}$ until the following two conditions are simultaneously met:
    a. The smoothed steering wheel velocity crosses zero from below.
    b. The steering wheel angle is greater than *-2.5 degrees.*

5.1.6.2 Examples of the Steering Onset Determination

Figure 5-5 shows the results of applying the onset algorithm to the three cases discussed above. Each of these solutions is plausible. Extensive manual review of the steering onset determinations has been performed and no cases where the steering onset was obviously in error have been discovered.

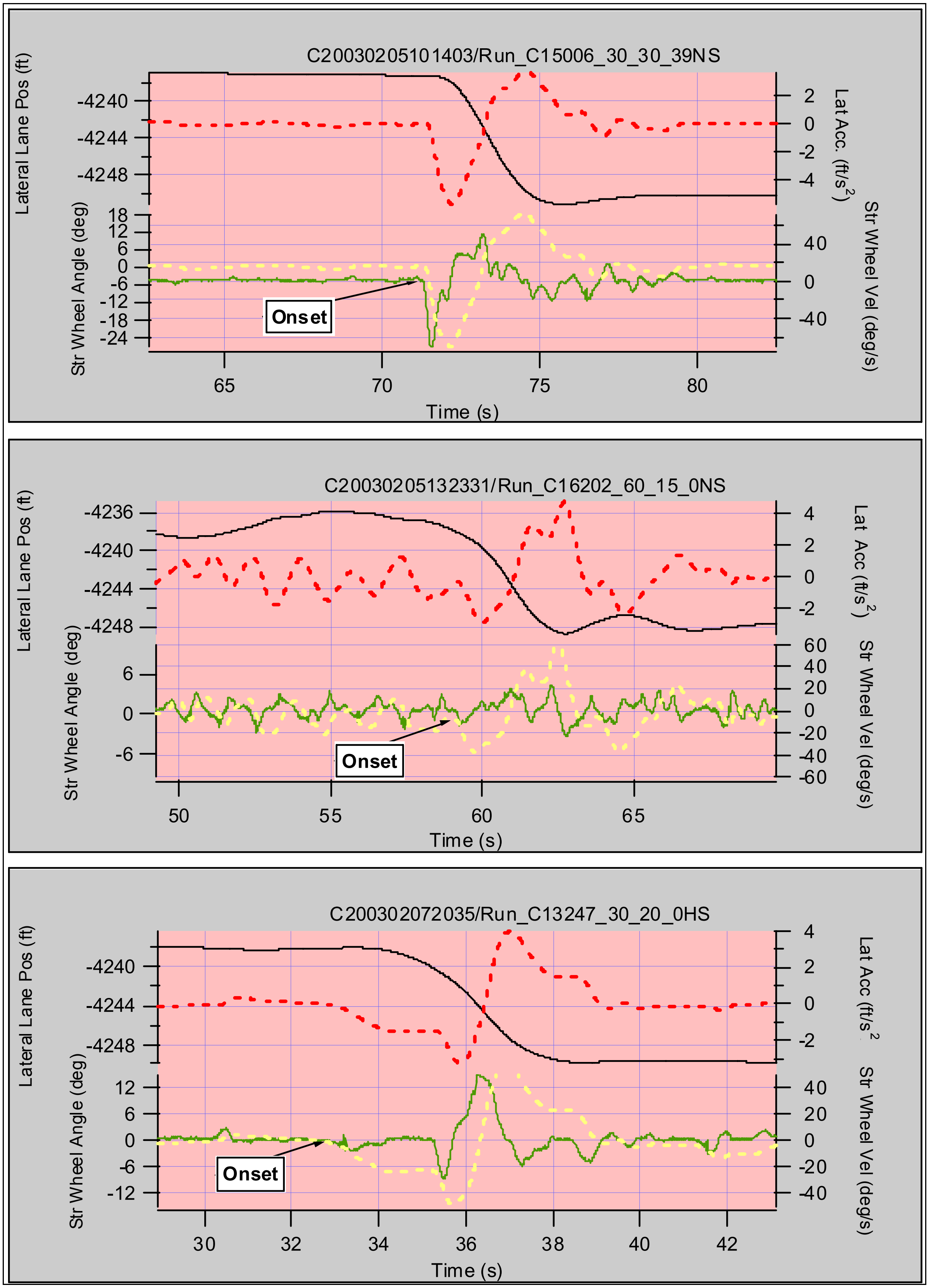


Figure 5-5 Steering onsets determined by the automated algorithm

5.1.7 Key Formulas

Key measurement formulas, namely required deceleration and TTC2, used in the data reduction computation algorithms can be found in Table 5-3.

Table 5-3 Key Formulas

Measure	**Formula**	**Comments**
Required Deceleration	If $V_{POV} = 0, a_{POV} = 0$: $a_{required} = \frac{V_{SV}^2}{-2R}$ If $V_{POV} \neq 0, a_{POV} = 0$: $a_{required} = \frac{(V_{POV} - V_{SV})^2}{-2R}$ If $a_{POV} \neq 0$: $a_{required} = \frac{V_{SV}^2}{-2\left(R - \frac{V_{POV}^2}{2a_{POV}}\right)}$	R = Range, the distance between the SV and POV at the moment of computation
Time to Collision Case #1	$TTC_1 = \frac{R}{(V_{SV} - V_{POV})}$	TTC < 0 is the no-crash condition
Time to Collision Case #2	If $a_{POV} = 0$ then : $TTC_2 = TTC_1$ If the POV stops moving prior to a colllision : $TTC_2 = \frac{1}{V_{SV}}\left(R - \frac{V_{POV}^2}{2a_{POV}}\right)$ If both vehicles are moving : $TTC_2 = \frac{(V_{SV} - V_{POV}) \pm \sqrt{(V_{SV} - V_{POV})^2 - 2a_{POV}R}}{a_{POV}}$	The smallest root which is greater than zero is taken as the solution of the quadratic equation.

6 CAMP vs. NADS Comparison

The following discussion is aimed at providing the reader a closer look at the various higher-order interactions observed between the kinematic-oriented variables across performance measures. These variables play a paramount and fundamental role in determining appropriate crash alert timing. For POV STATIONARY trials, these key kinematic-oriented variables include speed and braking instruction. For POV DECELERATION and CONSTANT ΔV trials, these key kinematic-oriented variables include speed, braking instruction, and POV braking profile.

In this vein, the same "kinematic figure" format described in [1] was used in this report to compare the CAMP versus NADS results for the key dependent measures that follow. On these kinematic figures, the major groupings from left to right are: POV DECELERATION, CONSTANT ΔV, and POV STATIONARY (as shown in Figure 6-1). Within the kinematic groupings, the conditions are clustered left to right by increasing speed (*30, 45, 60*, or *30, 60*). Within each speed faction for POV DECELERATION, the lowest deceleration level is on the left (*0.15 g*); the highest is on the right (*0.39 g*). For CONSTANT ΔV cases, the smallest ΔV (within a speed group) is on the left (e.g., *30 mph – 20 mph = 10 mph*) increasing up to the largest ΔV being on the right (e.g., *60 mph – 15 mph = 45 mph*).

In the following sections, a discussion and comparison of the trends observed across conditions for the NADS versus CAMP datasets is provided. This discussion is based on visual inspection (rather than statistical analyses), whereas Section 7 provides a statistically-based comparison of the NADS versus CAMP last-second braking onsets using a regression modeling approach. Given that models of last-second braking onset have particular relevance for developing FCW timing approaches, and taking into account the more limited last-second steering closed-course dataset [2], all Section 7 modeling efforts were focused on characterizing last-second braking onsets in the NADS versus CAMP datasets. The braking onset models developed for the NADS and CAMP datasets allow the most direct and appropriate comparison of these datasets, since these models provide a more "holistic" account of performance across all testing conditions (relative to an approach which is more focused on "micro" comparisons across each of the maneuver instruction by kinematic condition combinations) and address the issue that initial (pre-last second maneuver) conditions varied somewhat across the NADS versus CAMP datasets.

6.1 Maneuver Onset Variables

6.1.1 Required Deceleration

The last-second braking and steering results are plotted separately for the required deceleration measure in Figure 6-1. The results are further divided into "normal" and "hard" maneuver intensity instructions. In general, the NADS drivers appeared to be more conservative than the CAMP drivers in their maneuver onsets (i.e., NADS drivers had earlier maneuver onsets).

For the last-second braking conditions, the following observations are noted. For the POV DECELERATION case, the data trends are similar, with the exception that there is no overall speed effect in the NADS data (which is present in the CAMP dataset). In addition, the congruency of these data trends is stronger for the lower speed cases (*30* and *45 mph*) than for the *60 mph* conditions, and a trend toward greater congruence in the "hard" braking instruction condition when the lead vehicle braked harder (with the greatest congruency when higher braking was combined with higher speeds). For the CONSTANT ΔV case, the data trends when comparing NADS to CAMP are quite similar. In contrast, for the POV STATIONARY case, braking onsets are distinctly more conservative in the NADS dataset (with the exception of the *60 mph* "hard" braking instruction condition), data congruency is higher for the highest approach speed (*60 mph*), and there is greater NADS-CAMP data resemblance in the "hard" braking instruction condition.

For the corresponding last-second steering results shown in Figure 6-2, the following observations are noted. Relative to the last-second braking data, there is a distinctly more pronounced and consistent trend for NADS drivers to be more conservative than the CAMP drivers under both "normal" and "hard" maneuver intensity instructions. For the POV DECELERATION case, the data trends are similar (as was the case with the last-second braking data), although there is a distinct tendency toward greater equivalence in the lower speed (*30 mph*) condition. For the CONSTANT ΔV case, there is a trend such that for a given SV speed, the congruency of the data trends increases as relative speed decreases. For the POV STATIONARY case, steering onsets (as in the last-second braking data) are once again distinctly more conservative in the NADS dataset.

Overall, these results suggest that the congruency between the NADS and CAMP last-second maneuver datasets is highly dependent on the kinematic (or vehicle-to-vehicle) approach condition (as well as maneuver intensity instruction condition), and that there is generally a stronger correlation across datasets for the last-second braking (relative to last-second steering) data. In addition, it appears that the greatest divergence for last-second braking between these two datasets occurs in the POV STATIONARY case.

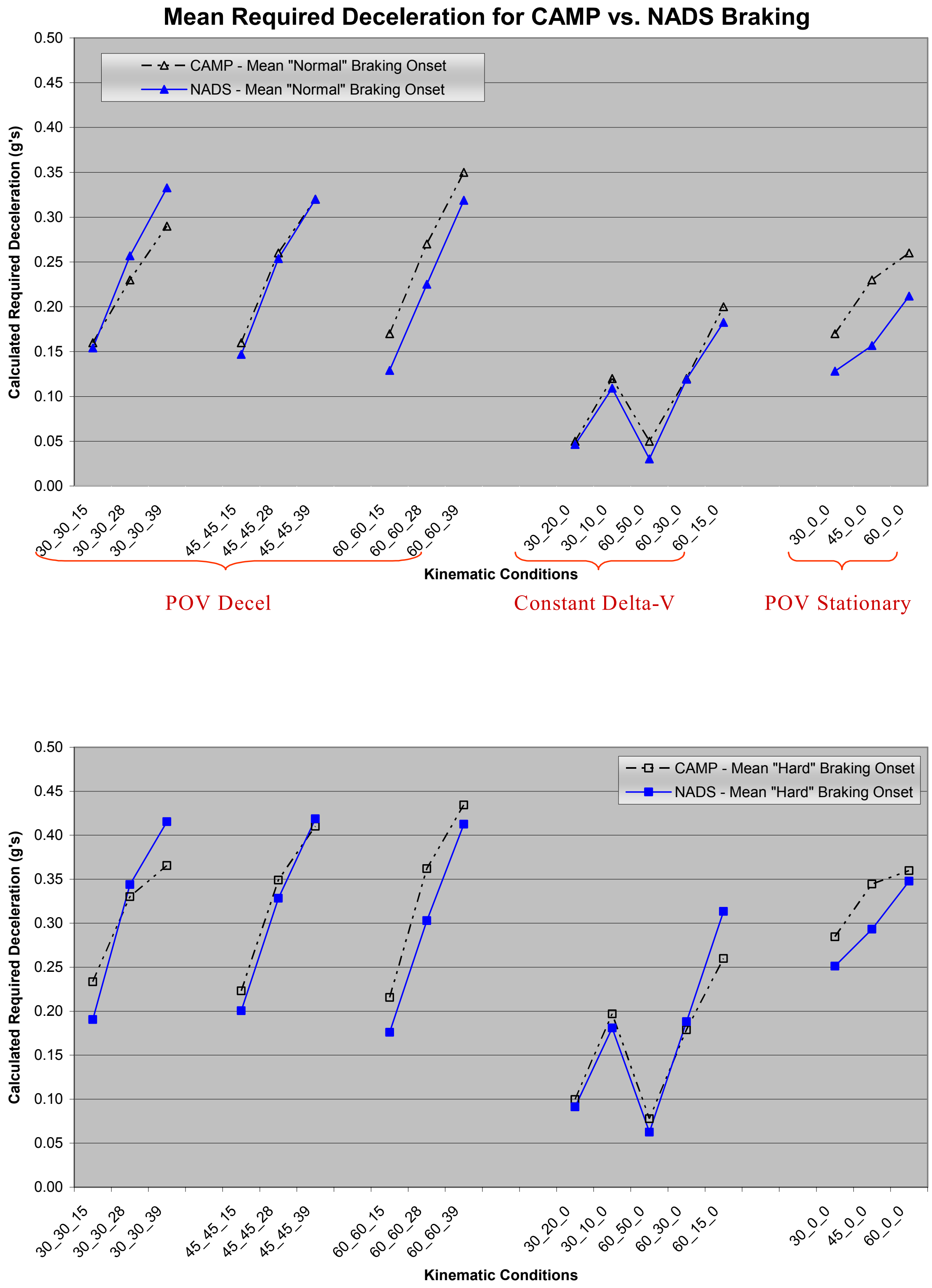


Figure 6-1. Required Deceleration Braking Results

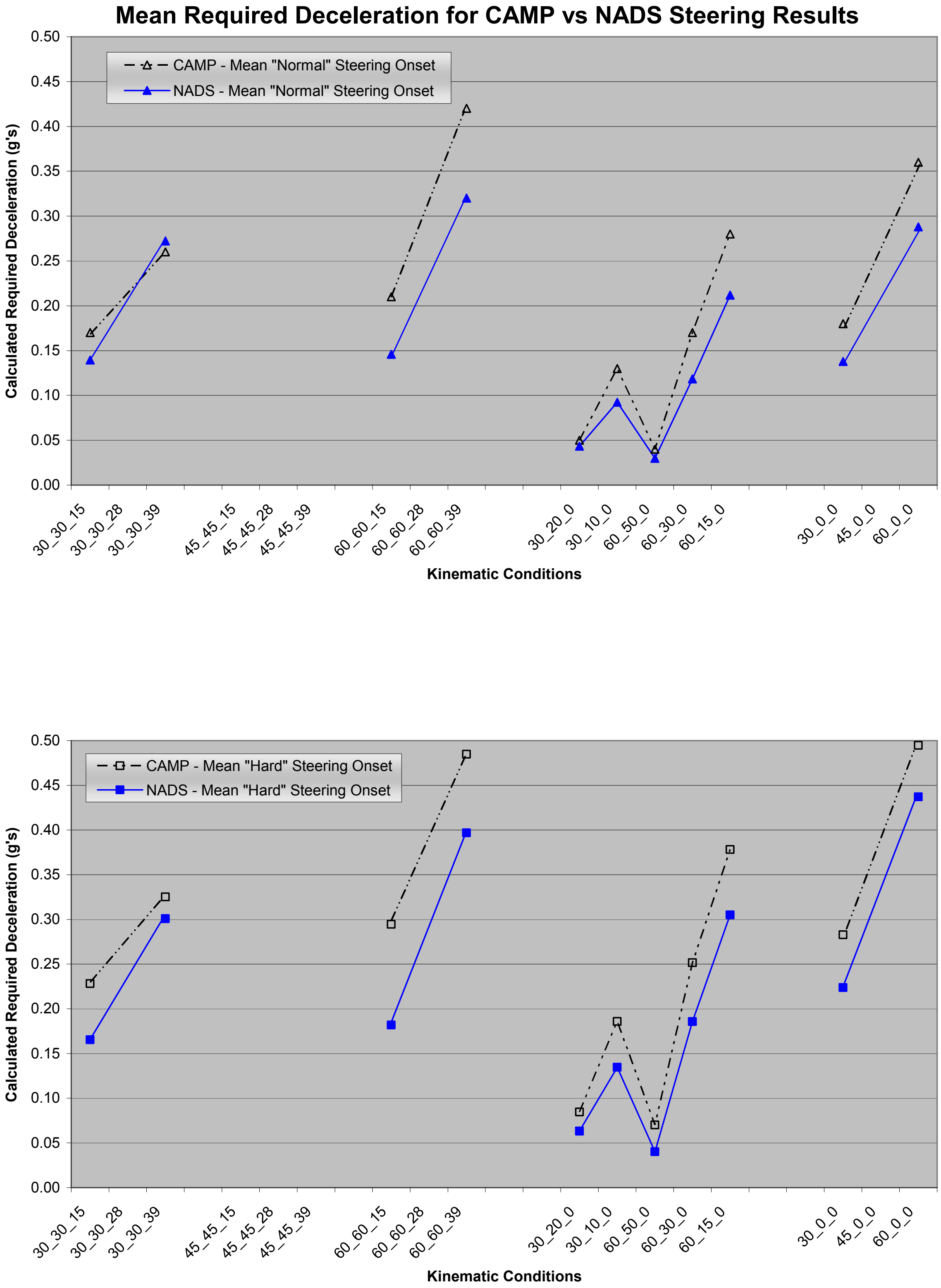

Mean Required Deceleration for CAMP vs NADS Steering Results

Figure 6-2. Required Deceleration Steering Results

6.1.2 TTC2

For the TTC2 measure, shown in Figures 6-3 and 6-4, the NADS drivers appeared to be once again be generally more conservative than the CAMP drivers in their performance.

For both the last-second braking and steering data, for the POV DECELERATION cases, the harder the POV braked during either "hard" last-second braking or steering instructions, the closer the NADS performance approached the CAMP closed-course results. This trend became more prevalent as the SV and POV speeds increased from *30* to *60 mph*. For CONSTANT ΔV cases, there is a distinct trend such that for a given SV speed, the congruency of the data trends increases as relative speed increases. In contrast, for the POV STATIONARY case, maneuver onsets are once again distinctly more conservative in the NADS condition, and there is once again greater NADS-CAMP data congruence in the "hard" maneuver intensity instruction condition.

Overall, as with the required deceleration measure these results suggest that the correspondence between the NADS and CAMP last-second maneuver datasets is highly dependent on the kinematic condition, and that there is generally a stronger match across datasets for the last-second braking (relative to last-second steering) data.

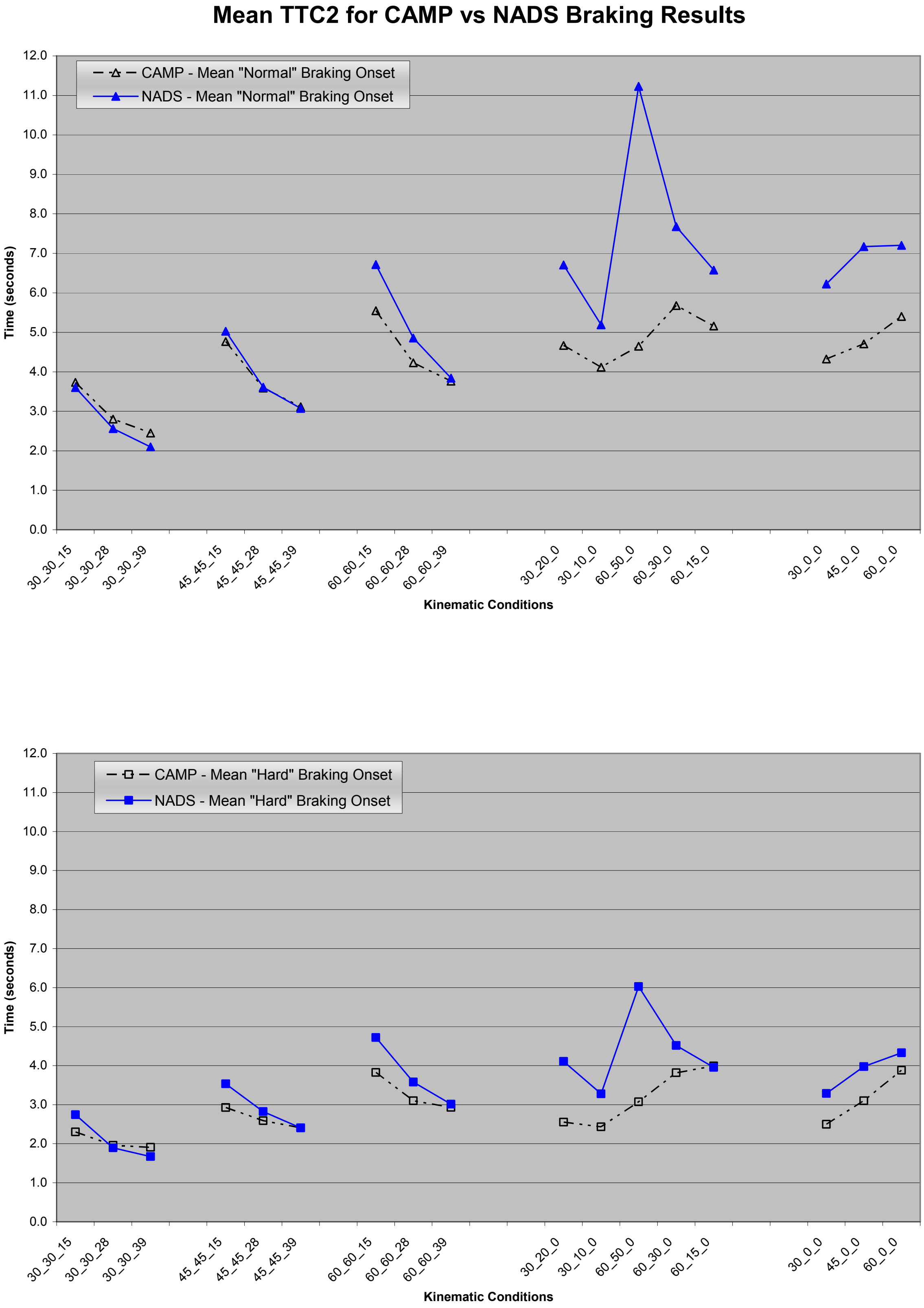
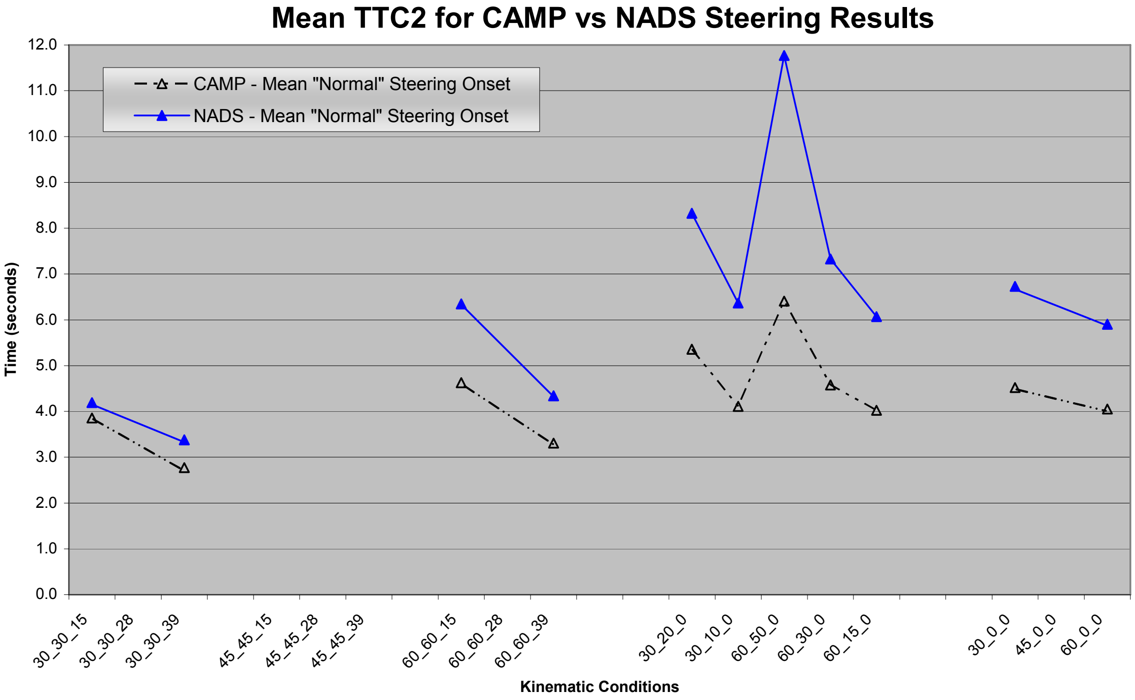


Figure 6-3. TTC2 Braking Results



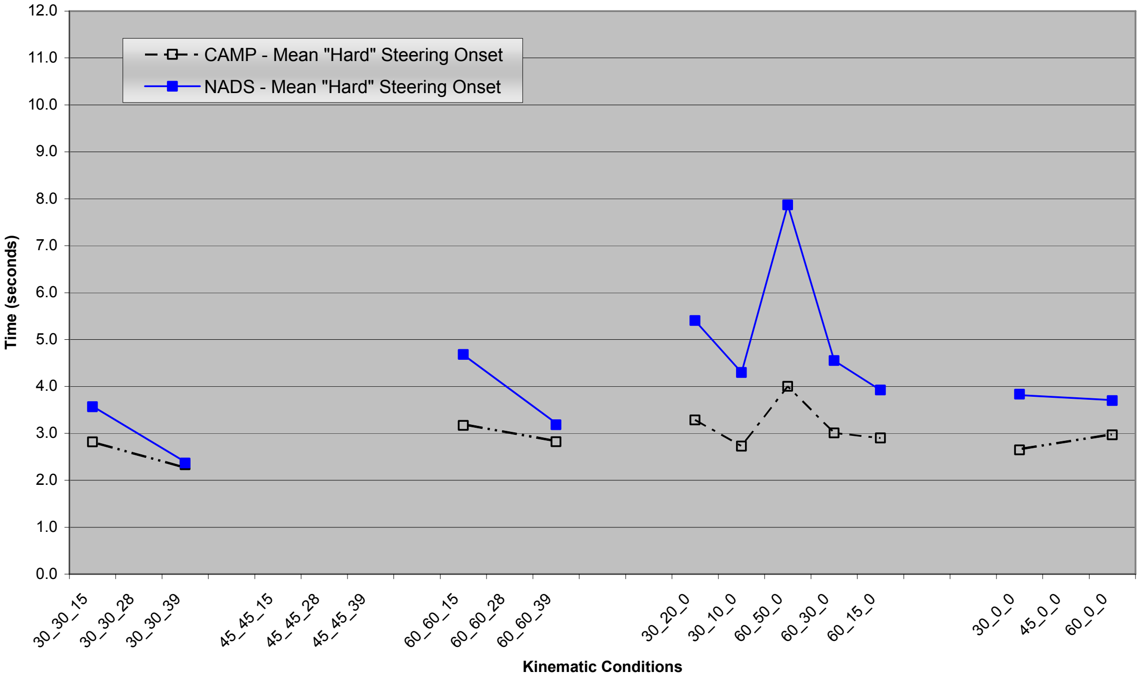


Figure 6-4. TTC2 Steering Results

6.1.3 TTC1

TTC1 results for braking and steering are shown in Figure 6-5 and Figure 6-6, respectively. As mentioned earlier, the TTC1 measure assumes SV and POV acceleration is equal to zero at SV onset. Hence, though the pattern of the results are very similar to TTC2, the relatively simplicity of this measure makes it inherently more unstable (see [2] for a detailed discussion on this topic), especially in cases where SV and POV speeds were nearly equal at SV onset (which leads to extremely large values). For this reason, there are two sets of TTC1 plots. The first set, Figure 6-5 and Figure 6-6, plots all the data, excluding only one outlier (where TTC1 ≥ 44,000 seconds). The second set, Figure 6-7 and Figure 6-8, excludes outlier values greater than the *97.5th percentile*. The exclusion of these data points primarily affected the steering results. (This TTC1 outlier issue will be discussed further in Appendix F). An examination of either set of the plots (with and without outliers) reveals that basically the same trends reported above for the TTC2 measure apply to the TTC1 measure.

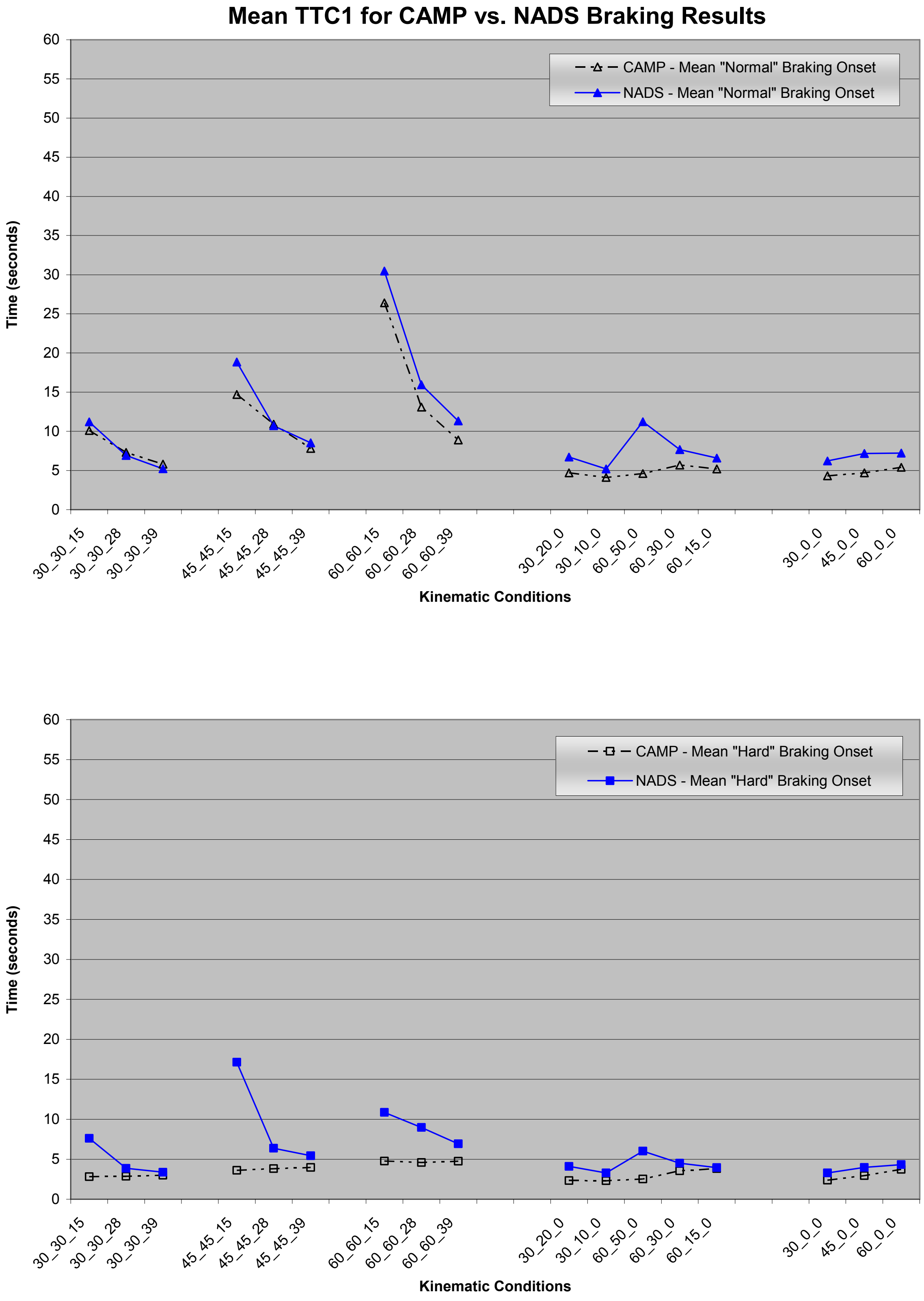


Figure 6-5. TTC1 Braking Results

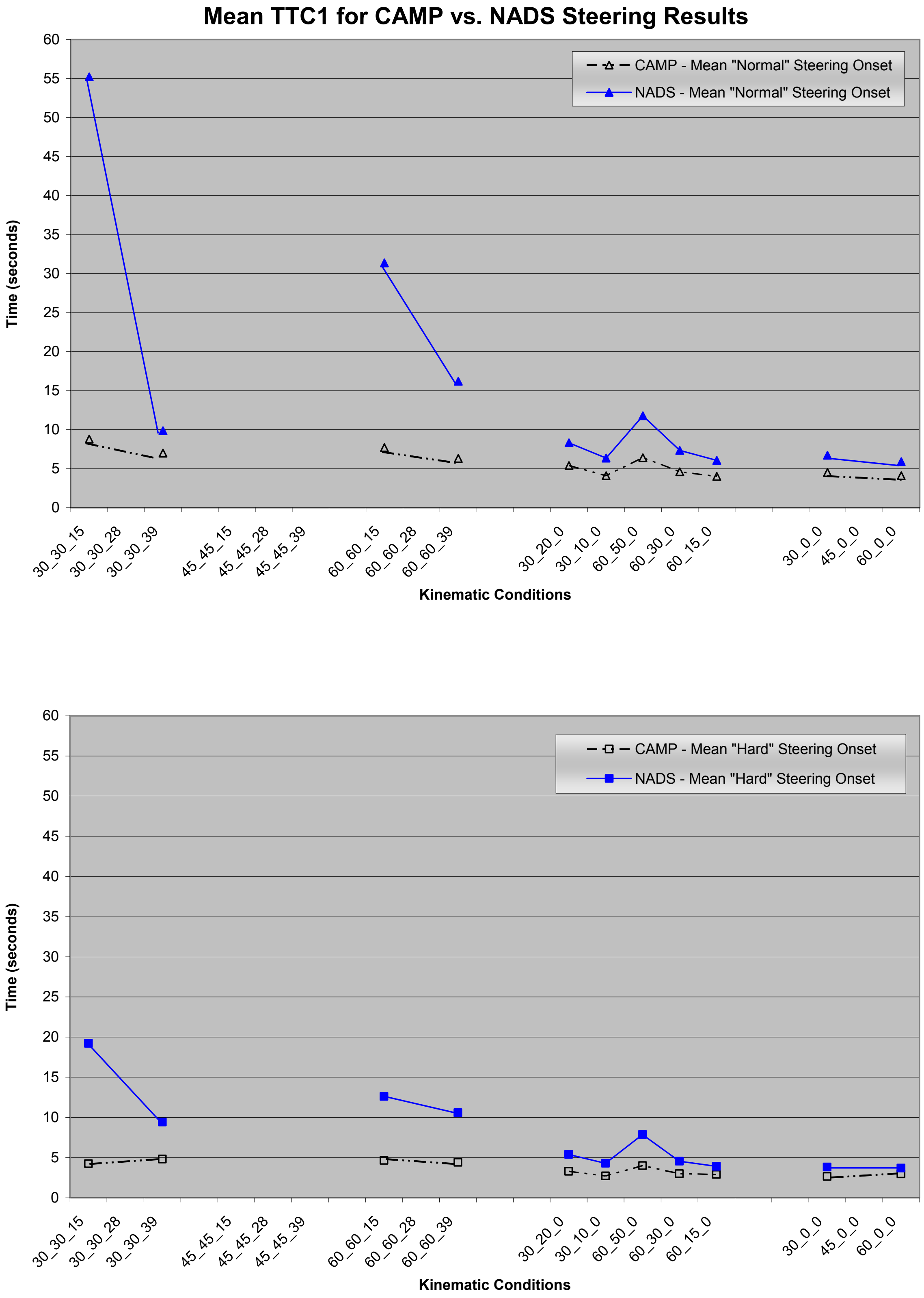


Figure 6-6. TTC1 Steering Results

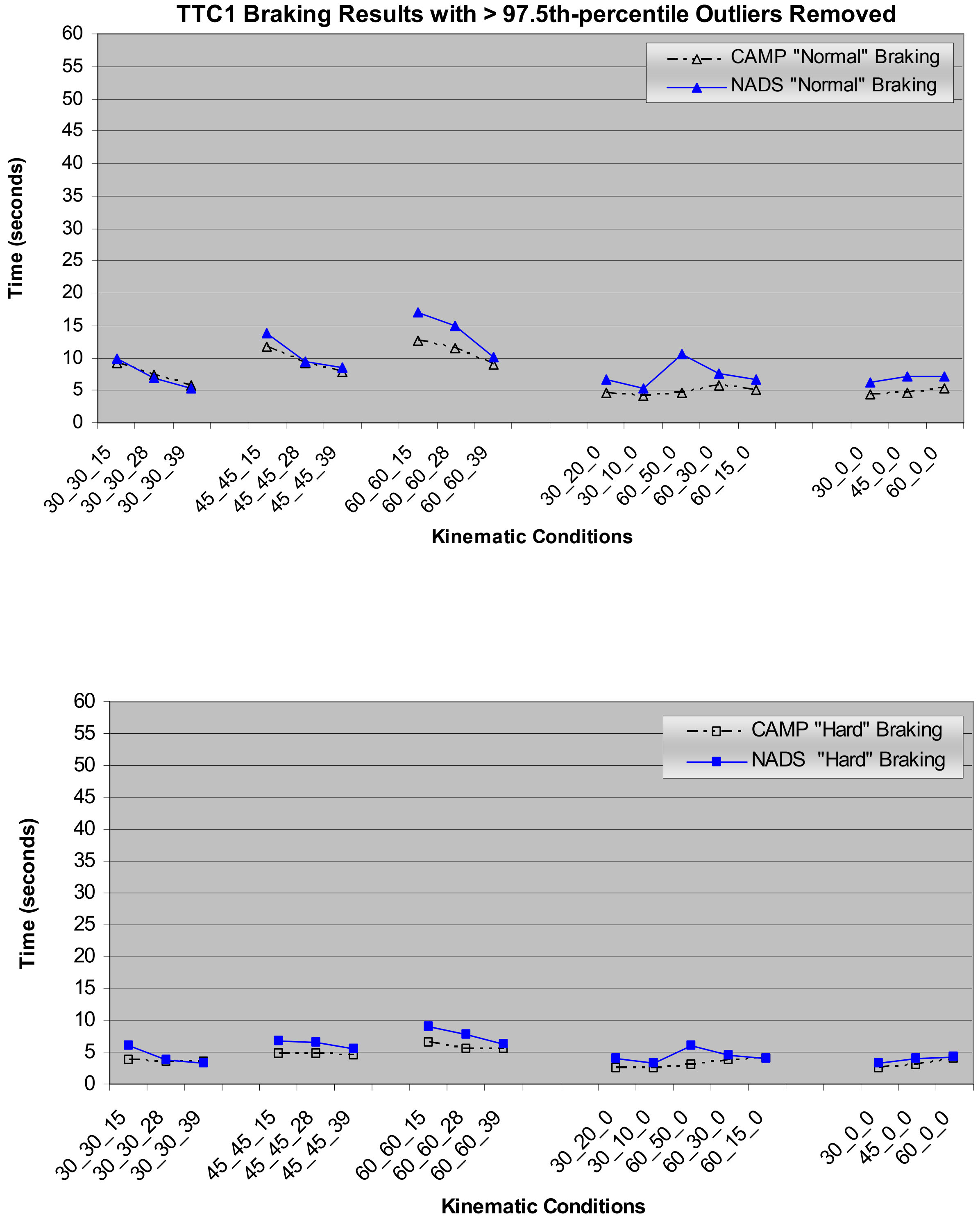


Figure 6-7. TTC1 Braking Results with Outliers Removed

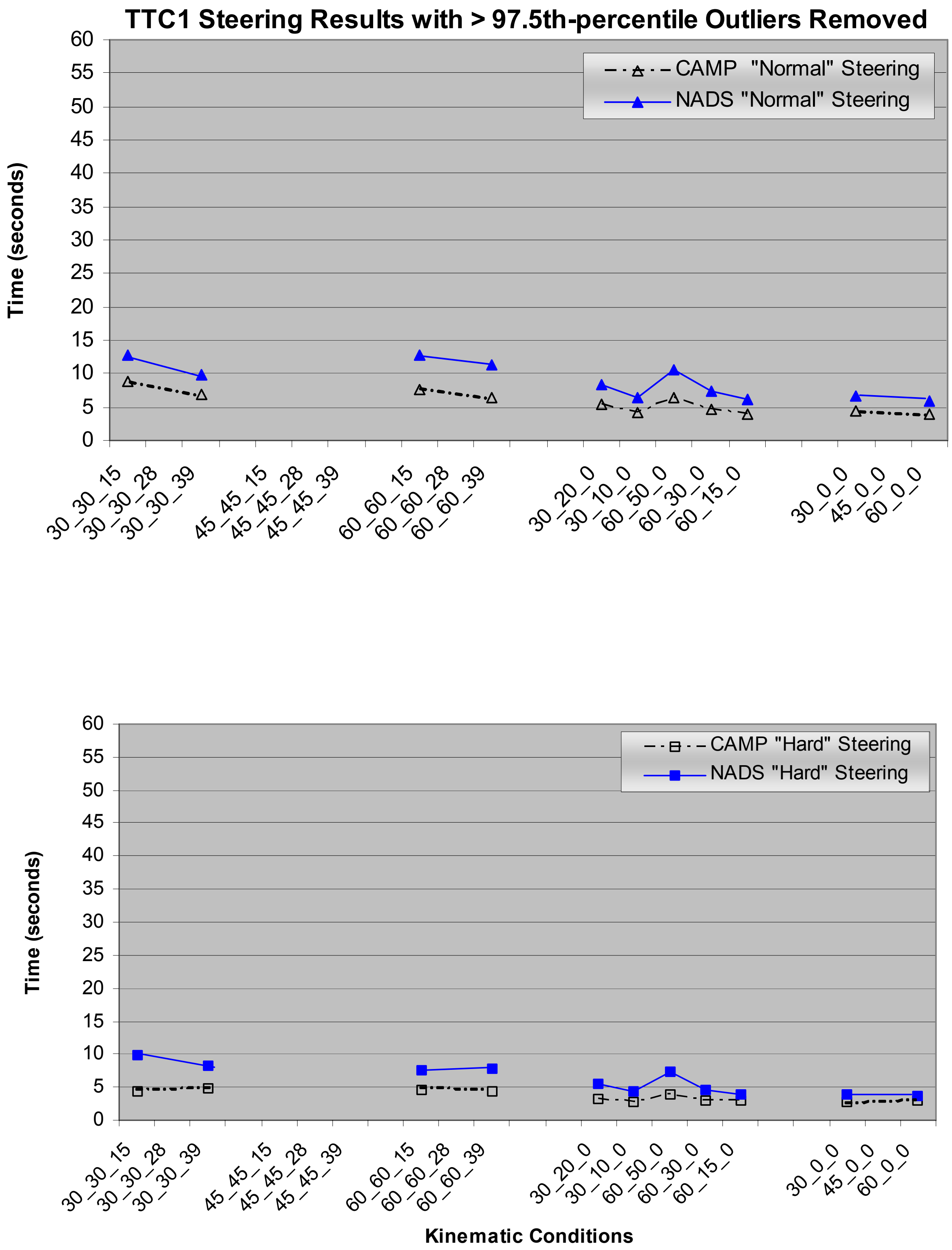


Figure 6-8. TTC1 Steering Results with Outliers Removed

6.1.4 Inverse TTC1

As has been clearly demonstrated in the previous CAMP Task 1 work [2], the inverse TTC1 measure appears to play a primary role in driver decision-making about whether they are in a "normal" or "hard" maneuver onset condition (this measure will be discussed further in Section 7). Hence, from a driver perception perspective, this measure appears to be of considerable importance, even though it has the same weaknesses as the TTC1 measure in terms of precisely characterizing the kinematic conditions surrounding a vehicle-to-vehicle approach. Taking the inverse of TTC1 has the effect of compressing the scale (between *0.0–1.0*) and substantially minimizing any outlier effects. In comparing the NADS results to the CAMP results for *InvTTC1*, as shown in Figures 6-9 and 6-10, the same trends reported above for the TTC1 and TTC2 measure are evident for this measure, as is to be expected given the relationship of these three variables. The reader needs to keep in mind the inverse nature of the relationship between InvTTC1 relative to TTC1 and TTC2 when comparing across these time-based measures.

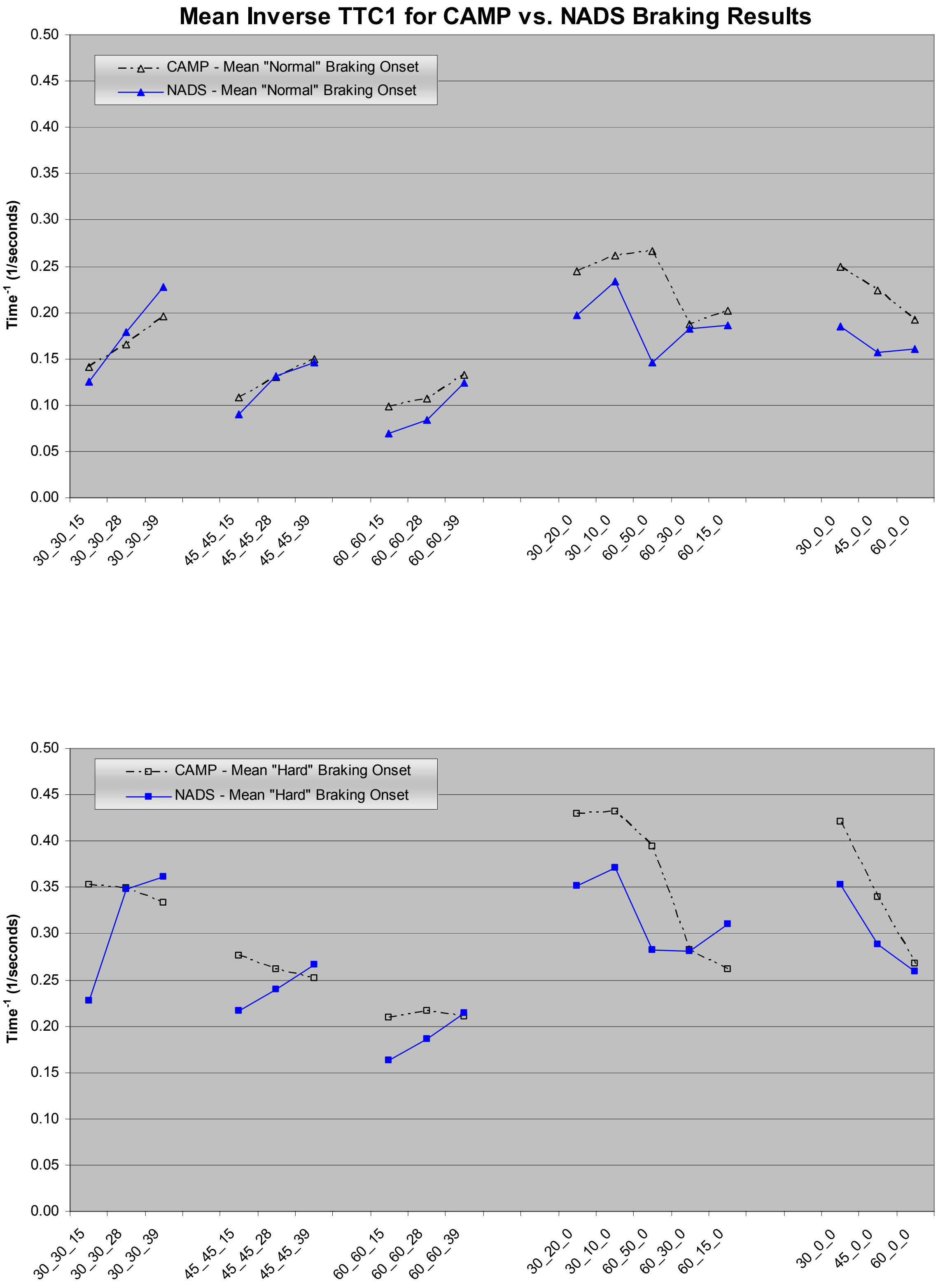
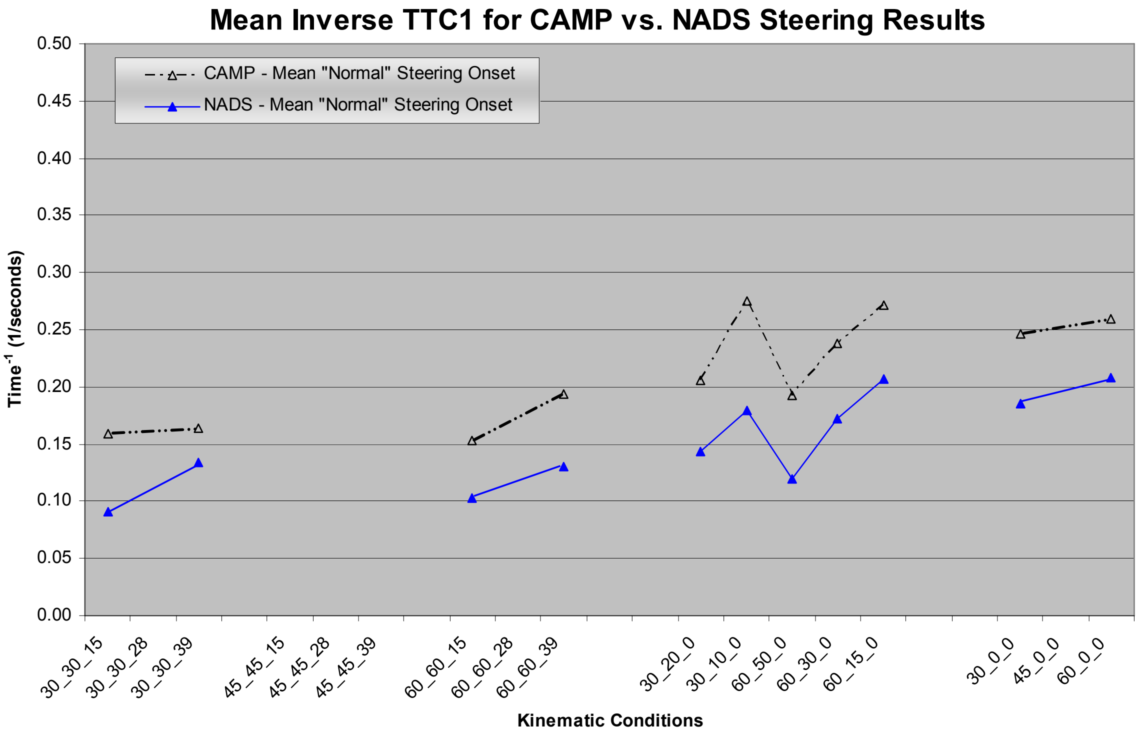


Figure 6-9. InverseTTC1 Braking Results



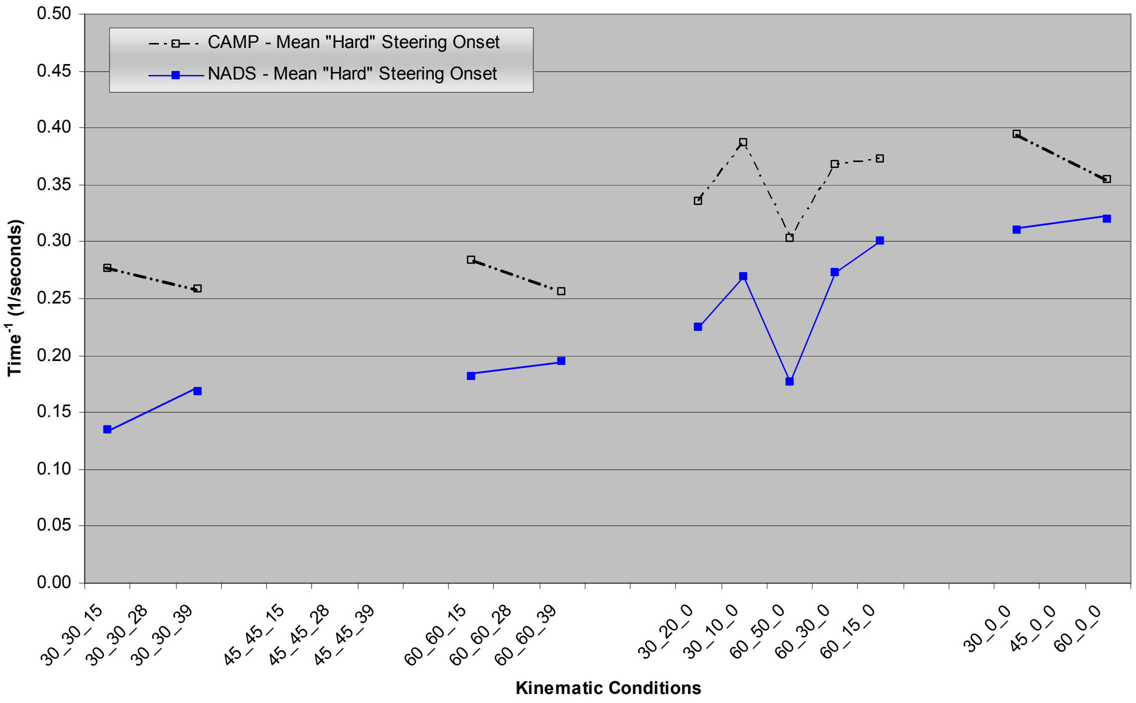


Figure 6-10. InverseTTC1 Steering Results

6.2 Peak Conflict Variables throughout Maneuver

The results that follow examine peak conflict measures throughout the entire approach (as opposed to the kinematic conditions at braking onset). Overall, as with braking onset measures described earlier, the results which will now be described suggest that the correspondence between the NADS and CAMP last-second maneuver datasets for peak conflict are once again highly dependent on the kinematic condition.

6.2.1 Peak Longitudinal Deceleration

For the last-second braking conditions shown in Figure 6-11, the following observations are noted for the peak longitudinal deceleration measure. For the POV DECELERATION case, the basic data trends are somewhat similar, with the exception that (similar to the braking onset data) there is no overall speed effect in the NADS data. In addition, unlike the results from the braking onset measures reported earlier, there is a marked divergence between the data trends associated with the "normal" and "hard" braking instruction results (which is in marked contrast to the previous CAMP results). In the "hard" braking instruction condition, the NADS peak deceleration values are generally lower than was observed in the CAMP results, and there is a trend toward greater data matching when the lead vehicle braked harder. In sharp contrast, under "normal" braking instructions, the NADS peak deceleration values are generally higher than was observed in the CAMP results, and there is a trend toward greater data congruency under lower lead vehicle deceleration conditions.

For the POV STATIONARY case, braking onsets are overall distinctly more conservative in the NADS dataset (with the exception of the *60 mph* "hard" braking instruction condition), and there is markedly more correspondence at higher approach speeds and under the "hard" braking (relative to "normal" braking) instruction conditions. These same trends were observed in the variables examining kinematic conditions at last-second braking onset.

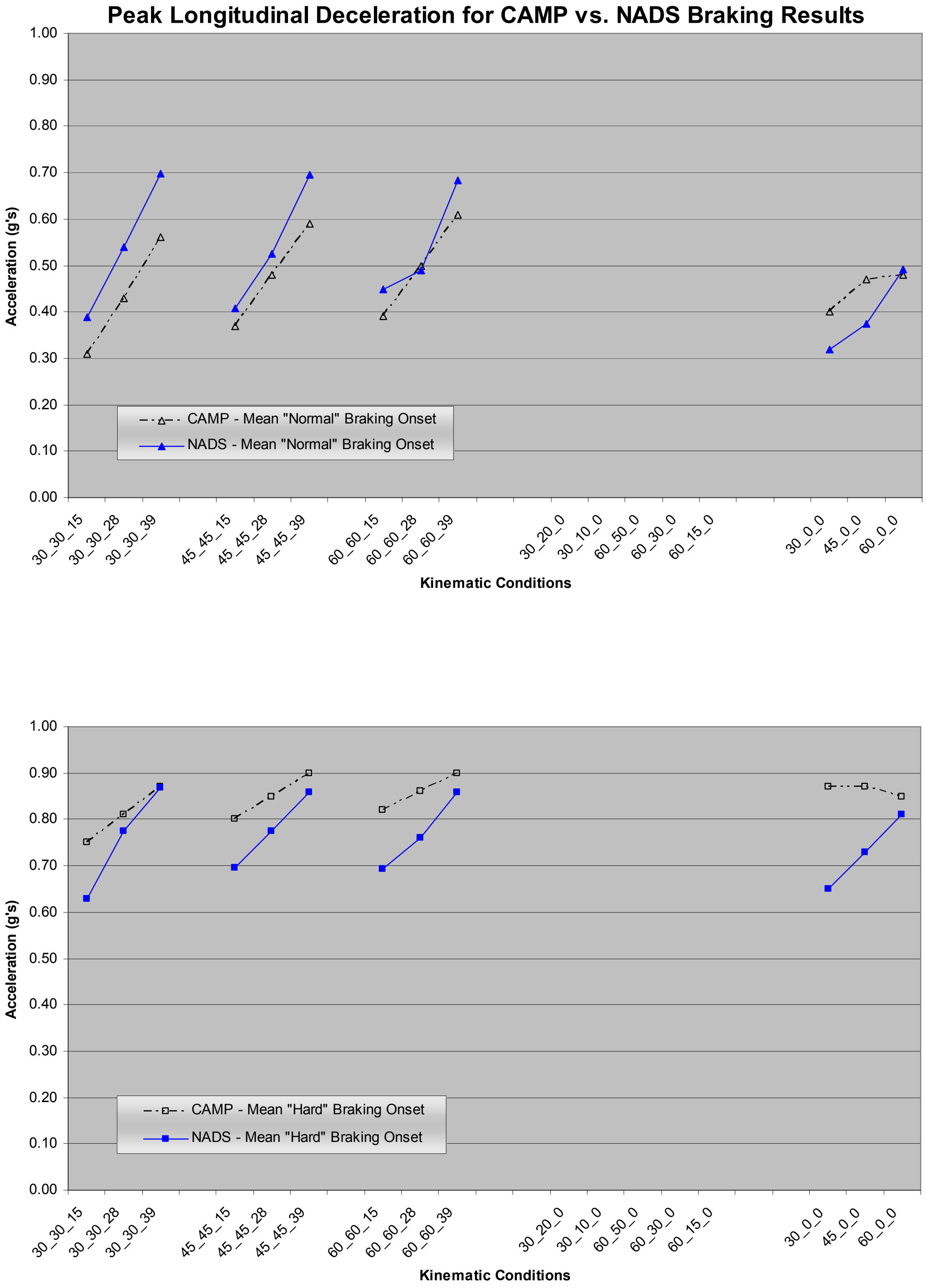


Figure 6-11. Peak Longitudinal Braking Results

6.2.2 Peak Lateral Acceleration

For the last-second steering conditions, the following observations are noted for the peak lateral deceleration measure, which are shown in Figure 6-12. Unlike the data reported above for the peak longitudinal deceleration under last-second braking conditions (and consistent with the last-second maneuver onset data), there is more of a consistent trend for NADS drivers to be more conservative than the CAMP drivers under both "normal" and "hard" maneuver intensity instructions.

For the POV Deceleration case, the general data trends are somewhat similar. In both the Constant ΔV and POV Stationary cases, the trend for NADS drivers to be more conservative than the CAMP drivers appears generally more pronounced than in the POV Deceleration case. In addition, for the POV Stationary cases, as was observed for the peak longitudinal measure, there is markedly more correspondence at higher approach speeds.

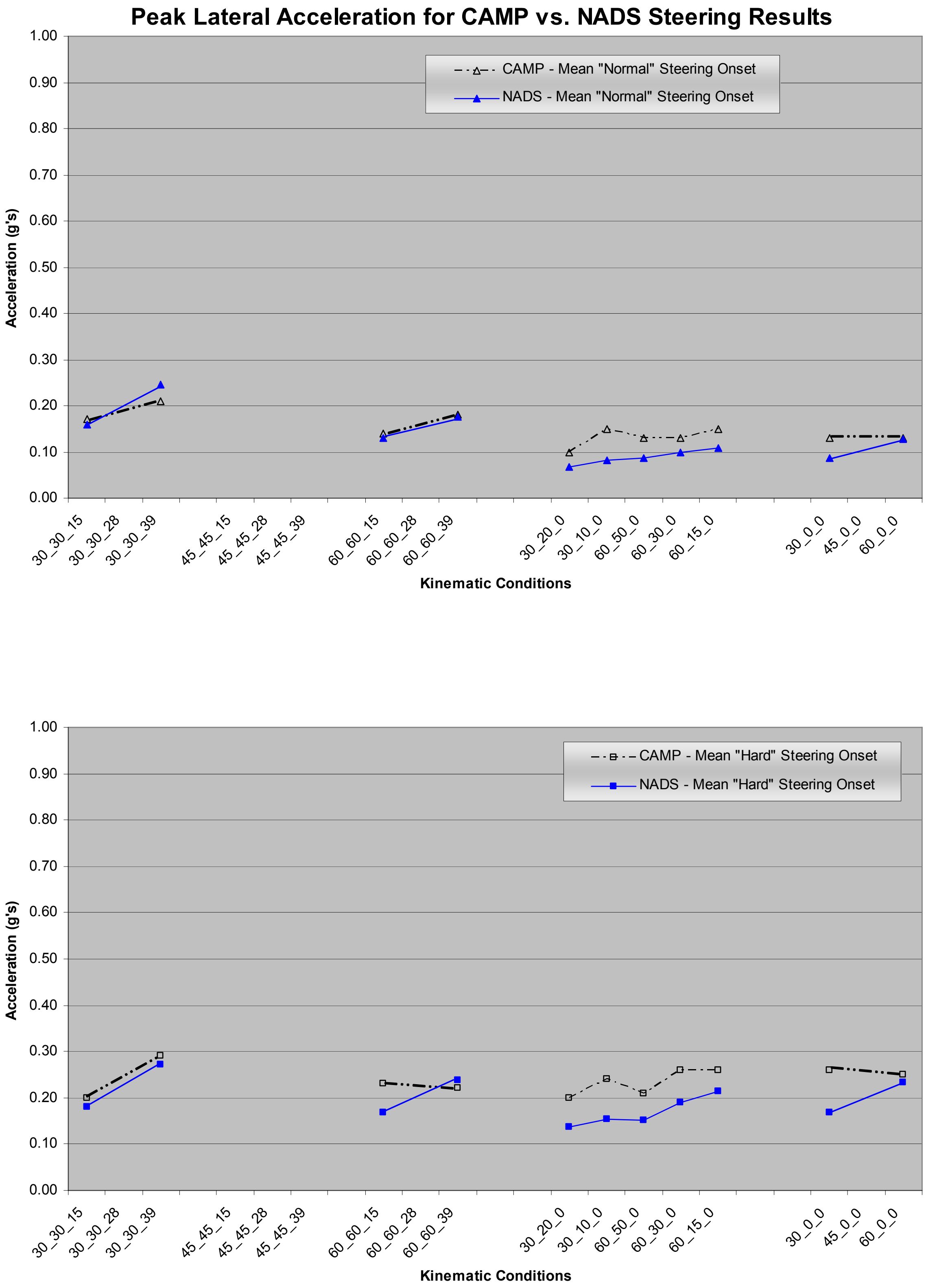


Figure 6-12. Peak Lateral Steering Results

6.2.3 MinTTC2 and MinTTC1

The results for minTTC2 and minTTC1 measures for last-second braking can be found in Figure 6-13 and Figure 6-14, respectively. The following observations are noted for these measures.

Across all kinematic conditions, we again see the trend of NADS performances being more analogous to the CAMP results when under "hard" maneuver intensity instruction conditions.

For the POV DECELERATION case, minTTC2 is generally more aggressive (i.e., lower) under NADS conditions, whereas the opposite is true for the minTTC2 measure. For the minTTC2 measure, at the lowest deceleration level, the results are comparable across CAMP and NADS conditions. At the higher deceleration levels for the minTTC2 measure, the NADS performance data is generally more aggressive. Interestingly, these effects of lead vehicle deceleration are essentially reversed for the minTTC1 measure.

For the POV STATIONARY case, the minTTC2 and minTTC1 measures (which are equivalent for this case) are distinctly more conservative in the NADS, particularly in the “normal” maneuver intensity instruction condition.

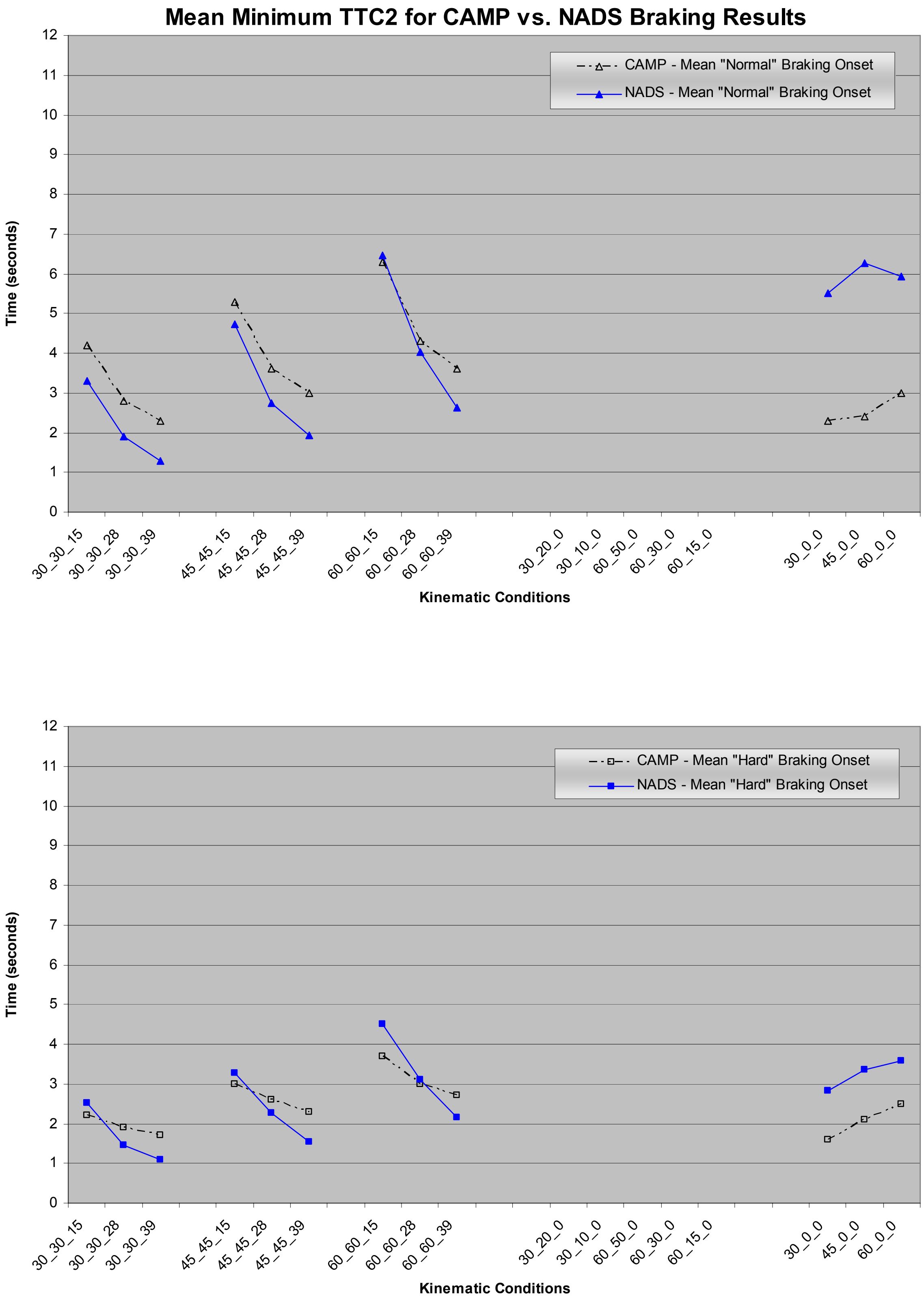


Figure 6-13. MinTTC2 Braking Results

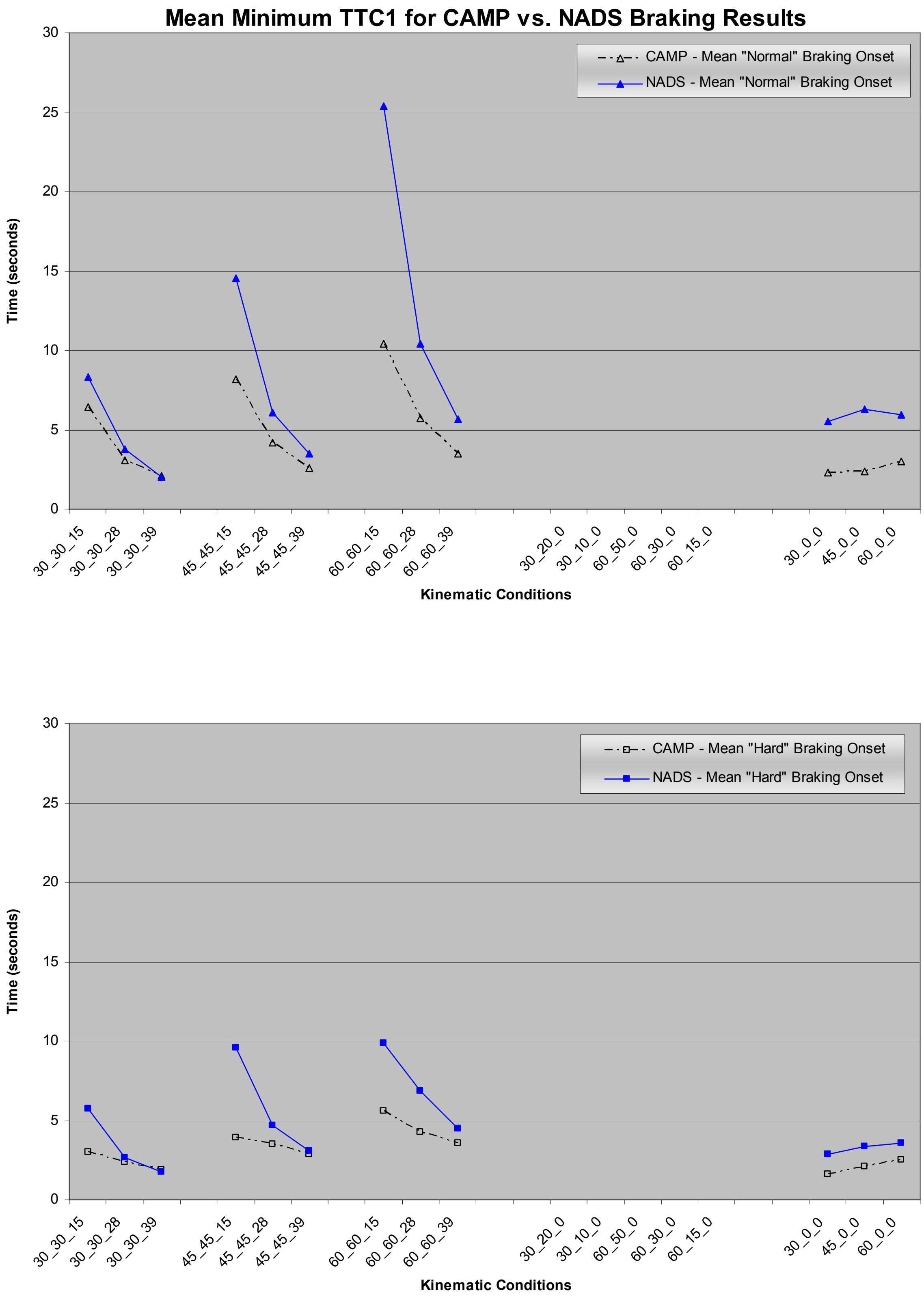


Figure 6-14. MinTTC1 Braking Results

7 An Inverse TTC Model of Last-Second Braking Onset

The modeling efforts were focused on last-second braking judgment trials. Half of the last-second braking trials were conducted under normal braking instruction conditions, with the remaining half of trials conducted under hard braking instruction conditions. The goal of this effort was to develop a model to characterize driver's last-second braking onsets under NADS conditions. This model was developed from the following data available at last-second braking onset: SV speed, POV speed, POV deceleration, and the range between the following driver's vehicle and the surrogate lead vehicle. Logistic regression was used to predict whether or not a specific braking onset scenario was a normal or hard, last-second braking onset scenario. This modeling approach has the distinct advantage of employing both the normal and hard braking instruction data, whereas a linear regression approach employs only the hard braking instruction data for the purpose of predicting driver deceleration behavior in response to a FCW alert (see [1] or [2] for an example of such an approach).

A best-fitting equation was generated for a dimensionless variable, x, which was forced to map onto a logistic function ($p=1/(1+e^{-X})$) ranging from 0 to 1. Note that for any given value of the "hardness of braking" index, x, the corresponding probability p that the existing kinematic conditions are a hard (rather than a normal) braking onset scenario can be determined. Hence, with this approach, the designer can a priori select a probability value of hard braking onset, referred to as p^*, which is compared to the *p value* the driver is currently experiencing. If the observed *p value* is higher than the designer-selected *p* value*, the conditions are "alert appropriate" from a braking onset perspective.

As was found with the CAMP closed-course data [2], inverse TTC (i.e., 1/TTC or $\Delta V/Range$) turned out to be the single most important predictor of whether or not a braking onset scenario was a normal or hard, last-second braking onset scenario. Inverse TTC is of importance for a number of reasons. First, inverse TTC corresponds to the angular speed of the approaching object divided by its angular size, and hence, is directly tied to the visual looming properties of the lead vehicle [10, 11]. As the driver approaches a distant lead vehicle traveling at a constant speed, the visual angle subtended by this vehicle ahead will steadily increase prior to undergoing a rapid expansion prior to a collision [12]. Note that just as the visual angle subtended by the lead vehicle becomes "optically explosive" immediately prior to a collision [12,13], changes in the inverse TTC measure (unlike the TTC measure) become more prominent as TTC diminishes to low TTC values. Second, the inverse TTC measure appears as a term in the time derivative of required deceleration. Third, the *Evans and Rothery* in-traffic study [14] found inverse TTC to be a robust measure for describing driver's relative motion judgments of whether the spacing to the lead vehicle was closing or opening under near threshold relative speed conditions. Together, these and the current findings suggest an inverse TTC model provides an efficient heuristic for characterizing driver perception during rear-end approach scenarios.

For the inverse TTC model approach, as was done in [2], three separate equations were developed for lead vehicle moving and braking, lead vehicle moving and not braking, and lead vehicle stationary cases. These correspond to the POV DECELERATION, CONSTANT ΔV, and the POV STATIONARY trials, respectively, in this data set. The resulting equations for this approach are shown below (where *ΔVelocity* and *Range* need to be expressed in common units):

Table 7-1 Inverse TTC model from Task 1 Closed-Course Data [2]

If lead vehicle moving and braking: $x = -3.415 + 10.786(\Delta V / Range) + 0.0340(SV\ speed\ in\ MPH)$
If lead vehicle moving and not braking: $x = -3.415 + 7.558(\Delta V / Range) + 0.0340(SV\ speed\ in\ MPH)$
If lead vehicle stationary: $x = -5.640 + 17.063(\Delta V / Range) + 0.0340(SV\ speed\ in\ MPH)$

Fit statistics for this logistic regression model (based on the NADS dataset) included a χ^2 value of *15.823* (df=8, $p<0.05$) and a Nagelkerke R^2 value of *0.323* (see *Hosmer and Lemeshow*, [15]). The three corresponding equations associated with the inverse TTC model previously developed from the closed-course comparison dataset [2], which are identical in form to the equations above developed from the current NADS dataset, are shown below:

Table 7-2 Inverse TTC Model from NADS Data

If lead vehicle moving and braking: $x = -6.092 + 18.816(\Delta V / Range) + 0.0534(SV\ speed\ in\ MPH)$
If lead vehicle moving and not braking: $x = -6.092 + 12.584(\Delta V / Range) + 0.0534(SV\ speed\ in\ MPH)$
If lead vehicle stationary: $x = -9.073 + 24.225(\Delta V / Range) + 0.0534(SV\ speed\ in\ MPH)$

Note that in comparing these three equations within each of the two datasets, different slopes for the inverse TTC component are required, whereas the speed component remains constant. These equations imply that for given inverse TTC and SV speed levels, required decelerations are generally highest in the lead vehicle stationary case, second highest in the lead vehicle moving and braking case, and lowest in the lead vehicle moving and not braking case. Furthermore, the lower values of coefficients in the NADS inverse TTC model equations in Table 7-2 relative to the corresponding CAMP-based equations from Table 7-1 suggests that, in general, changes in inverse TTC and speed values under NADS conditions have a smaller change in the estimated probability that a driver is in a hard braking onset scenario than under the on-road conditions [2]. Put in another way, changes in inverse TTC and speed under NADS conditions causes a smaller change in the driver's perception of rear-end crash threat than under on-road conditions (however, in both cases, inverse TTC appears to play a dominant role).

A comparison of NADS versus closed-course inverse TTC model predictions of the probability of a hard braking onset scenario is provided in Figure 7-1. This comparison is shown separately for the lead vehicle moving and braking (POV Deceleration), lead vehicle moving and not braking (Constant ΔV), and lead vehicle stationary (POV Stationary) cases. In this figure, each data point represents an individual braking onset trial from either the NADS or closed-course database. These results suggest that for each of the three general kinematic cases the degree of correspondence in predictions for the probability of hard braking onset between these models (and hence, the degree to which NADS braking onset results emulate those found under closed-course conditions) generally increases as the predicted probability of a hard braking onset scenario increases. The pattern of results in Figure 7-1 also suggests that prior to reaching a high probability of a hard braking onset during an approach to a vehicle ahead, the driver's perception of rear-end crash threat is fundamentally different, and thus, the perception of threat evolves in an inherently different manner and time-course as the driver approaches high probability of a hard braking onset levels in NADS relative to the CAMP on-road conditions.

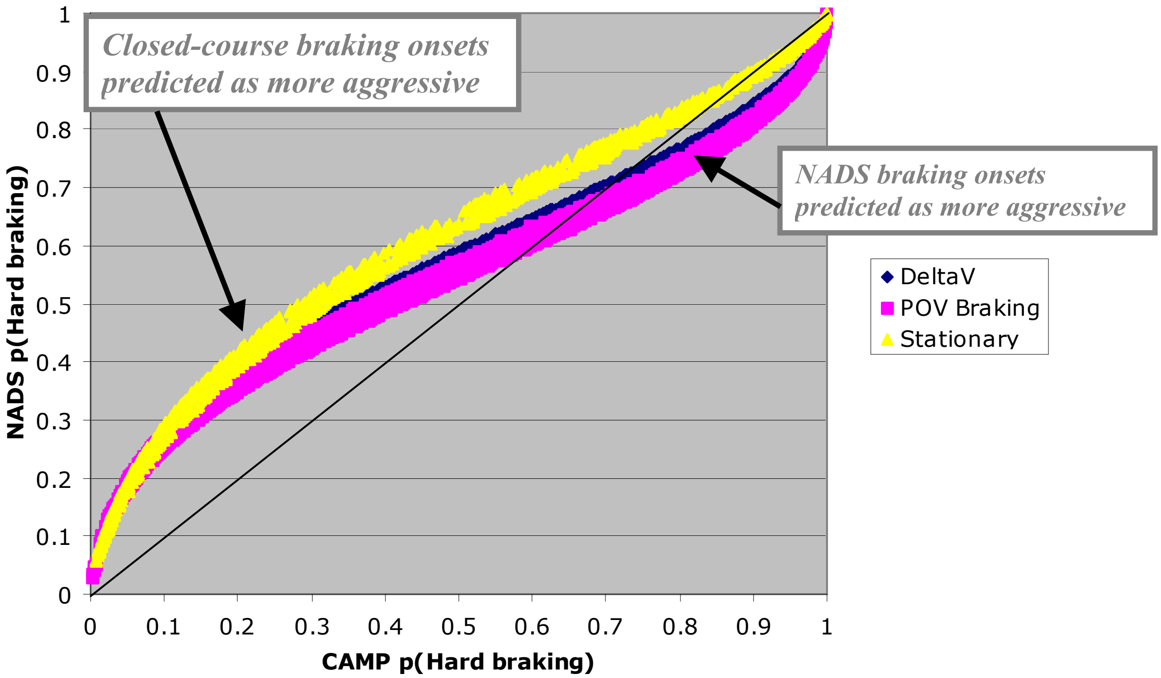


Figure 7-1. A comparison of NADS versus closed-course inverse TTC model predictions of the probability of a hard braking onset scenario for the POV moving and braking (POV DECELERATION), POV moving and not braking (CONSTANT ΔV), and lead vehicle stationary cases (POV STATIONARY). Each data point represents an individual braking onset trial from either the NADS or *Kiefer et al.,* database.

For a driving simulator facility, the approach outlined above can be used as an effective means of comparing last-second braking onset data under driving simulator conditions to that obtained by *Kiefer et al.* [1, 2] under closed-course, on-road conditions. That is, once a facility has gathered a last-second braking dataset similar to that obtained here, the simulator data can be modeled using logistic regression (see [2] for a more detailed discussion of this regression method). The resulting equations for the three general kinematic cases (lead vehicle moving and braking, lead vehicle moving and not braking, and lead vehicle stationary) can than be compared to those reported in [2], and the corresponding Figure 7-1 can be generated. Furthermore, should important simulator changes occur at a given driving simulator facility (e.g., improvements/degradations in the visual scene), this process can be repeated to better understand the impacts of these changes on driver's braking onset behavior, and hence, the driver's perception of rear-end crash threat. In addition, repeating this process would provide important knowledge on the impact of simulator characteristics on driver's perception of rear-end crash threat, which could also be obtained by simply manipulating the characteristics of a driver simulator within an experiment.

8 Summary of Key Findings

There were many consistent trends in the data presented above, which will now be summarized below. Overall, these results suggest, first, that that the congruency between the NADS and CAMP last-second maneuver datasets in terms of either maneuver onset or peak conflict measures are highly dependent on the kinematic (or vehicle-to-vehicle approach) condition. This implies that a constant scale factor cannot be applied to transfer from NADS to the CAMP (closed-course) data, and indeed, the relationship between the degree and time course of a crash threat a driver experiences in the NADS relative to closed-course conditions appears to be inherently complex. In addition, there is generally greater congruence under last-second "hard" (rather than “normal”) maneuver intensity conditions. Hence, the latter data will be the focus of the discussion below, in part because it has considerably more relevance for conducting rear-end crash research on the NADS (as well as other simulators).

8.1 Maneuver Onset Findings

The primary trends for maneuver onset differences observed between the NADS and the CAMP data can be summarized as follows:

For last-second “hard" braking judgments, the NADS results more closely matched the CAMP closed-course results under the following conditions:

- Under POV DECELERATION conditions – when both the POV was braking harder **and** the speed conditions were higher.
- Under POV STATIONARY conditions – at the higher SV closing speed.
- Under CONSTANT ΔV conditions – when the difference in speeds between vehicles was larger (It should be noted that this trend was somewhat dependent on the braking onset measure employed).

Overall, braking onsets were generally more conservative in the NADS than under corresponding CAMP closed-course conditions.

For last-second “hard" steering judgments, the NADS results more closely matched the CAMP closed-course results under the following conditions:

- Under POV DECELERATION conditions – when both POV was braking harder **and** the speed conditions were lower (i.e., the *30_30_39* kinematic condition). It should be noted that correspondence between datasets was generally weak across all remaining kinematic conditions examined.

Overall, NADS steering onset results were markedly and consistently more conservative than under corresponding CAMP closed-course conditions. Hence, NADS last-second "hard" braking performance matched the corresponding results from the CAMP closed-course data better under last-second braking relative to last-second steering conditions.

8.2 Peak Conflict Findings

For last-second “hard" braking judgments, the NADS results more closely matched the CAMP closed-course peak conflict results under the following conditions:

- Under POV DECELERATION conditions – when the POV was braking harder.
- Under POV STATIONARY conditions – at the higher SV closing speed.

Overall, peak conflict measures were markedly more conservative in the NADS than under corresponding CAMP closed-course conditions.

For last-second “hard" steering judgments, the NADS results more closely matched the CAMP closed-course peak conflict results under the following conditions:

- Under POV DECELERATION conditions – when the POV was braking harder.
- Under POV STATIONARY conditions – at the higher SV closing speed.

Overall, once again, peak conflict measure tended to be more conservative in NADS than under corresponding CAMP closed-course conditions suggesting there are inherent problems with interpreting peak conflict data in the NADS (with the most extreme form of peak conflict being a collision).

8.3 Summary of CAMP Inverse TTC Model

These data were used to develop a model to characterize driver's last-second braking onsets under NADS conditions. A wide range of potential time-based and deceleration-based predictors was explored. As was found with the closed-course dataset [2], the most promising approach developed was an inverse TTC model. This model assumes that the driver deceleration response in response to the crash alert is based on an inverse TTC threshold that decreases linearly with driver speed. The key component of this model is the inverse TTC term, defined as the difference in speed between the lead and following vehicles divided by the range between these two vehicles (or Δ*Velocity/Range*).

A comparison of model predictions from the inverse TTC model developed here and the corresponding model reported in [2] suggests that, for a given set of kinematic conditions, the degree to which NADS braking onset results emulate those found under closed-course conditions generally increases as the predicted probability of a hard braking onset scenario increases. The methodological and modeling approach reported in this paper can be used as an effective means of comparing and understanding driver's last-second braking onset judgments (and hence, driver's perception of rear-end crash threat) under driving simulator conditions relative to those obtained under closed-course, on-road conditions.

8.3.1 Comparing 'Crashes' in the NADS trials with 'Crashes' in the Closed-Course trials

During the closed-course trials, the front-seat passenger-side test experimenter could override braking if necessary to help avoid crashes with the surrogate target lead vehicle. No such auxiliary braking took place at NADS. Consequently, it is not possible to make a direct comparison between crashes at NADS and crashes in the closed-course trials. Nevertheless, some worthwhile observations can be made, which will now be discussed.

Combining the two previous datasets of CAMP closed-course FCW last-second braking trials [1,2], there were six total impacts found over the 3,536 last-second braking trials conducted. It is interesting to note that four of the six impacts occurred in the *30_30_39* kinematic condition. It was also interesting to note that these particular impacts occurred as a result of a failure to execute appropriate braking by both the driver and experimenter (the latter who had access to add-on brakes).

In the NADS trials, 'crashes' were not determined by real-time collision detection between the SV and POV. This makes it difficult to determine if the SV and POV actually collided during the complex geometry of the steering trials. However, the braking trials can be analyzed simply by noting how often the distance between the SV and POV became less than zero.

In the 2,448 braking trials, the distance between the SV and the POV became less than zero on 32 occasions. These are presumed to represent a 'crash' condition. Table 8-1 lists the conditions under which these crashes were observed. Similar to the closed-course data, it appears there is a greater tendency for crashes to occur when the lead vehicle was braking at the hardest lead vehicle deceleration level examined (i.e., *0.39 g's*). Indeed, *68%* of NADS crashes occurred in the *0.39-g* lead vehicle deceleration condition.

Condition	Crashes	Percent of total
30_30_39NB	6	18.75%
45_45_39HB	6	18.75%
60_60_39HB	4	12.50%
45_45_39NB	3	9.38%
60_15_0HB	3	9.38%
60_60_39NB	2	6.25%
30_30_28HB	1	3.13%
30_30_28NB	1	3.13%
30_30_39HB	1	3.13%
45_45_28HB	1	3.13%
45_45_28NB	1	3.13%
60_0_0NB	1	3.13%
60_30_0NB	1	3.13%
60_60_28NB	1	3.13%

Table 8-1 Kinematic conditions associated with crashes. Steering cases are not included and all cases resulting in zero crashes are omitted

8.4 Explanation of the differences

There were numerous potential confounding factors that make it difficult to specify the underlying reasons for the observed differences between the NADS versus the CAMP results (e.g., visual cues, braking and steering cues, existence of a "real" crash threat). A common simulator issue that did not play a major role was simulator sickness issues (see results in Appendix G). A couple of the more notable differences will be discussed below.

8.4.1 NADS Braking & Steering Cues

NADS motion simulation details for braking and steering were discussed in Section 3.4.6 of the report. The trends correspond to what might be expected based on the motion simulation subjective assessment performed by CAMP researchers. Namely, braking feel at onset and throughout the maneuver was assessed to be relatively realistic in the NADS (particularly compared to steering feel, which was considered poor), and this expert opinion assessment was apparently validated in terms of the generally greater congruency in last-second braking (relative to last-second steering) data. It seems entirely possible that drivers in the NADS may have felt less confidence in their ability to steer (rather than brake) when attempting last-second approach maneuvers. If this is the case, this may explain why NADS drivers were consistently more conservative than the CAMP closed-course drivers when executing a steering maneuver.

8.4.2 NADS Visual Cues

Although the NADS employed a state-of-the-art visual display, the visual cues available to the driver are not perfect. Even with the NADS high-resolution inset display the subjective impression is that the visual scene is not as clear in the simulator as it is during real-world driving. To the extent that the visual information available to the driver is degraded, driver's ability to decide when to make and perform last-second maneuvers is impaired.

The NADS data matches the closed-course data most closely when the looming of the lead vehicle tends to be more pronounced (i.e., when the lead vehicle was braking harder, and when approaching a parked vehicle at a high relative speed), and as the results in Section 7 indicate, under conditions when the probability of "hard" braking onsets is higher. This trend strongly suggests that the primary factor controlling the degree of correspondence between the NADS and the CAMP closed-course data may be the quality of the visual display. It also suggests that when drivers cannot see the lead vehicle under driving simulator conditions as well as they can during real-world driving, they may have a tendency to make more cautious judgments in order to avoid the possibility of a collision.

8.5 Recommendation for Scenarios in Future NADS Research

Overall, in order to get the best correspondence between NADS and closed-course data when examining rear-end (and possibly other) crash scenarios, these results suggest using all of the following general recommendations/strategies:

- Scenarios need to pay careful attention to ensure initial headway conditions prior to the critical approach event correspond to those that are typically experienced in real world driving. More generally, scenarios should have real-world validation.
- Scenarios should emphasize high lead vehicle decelerations. The *0.39-g* deceleration levels gave the best results, particularly for the TTC measures. These levels have been used in previous CAMP surprise trial research.
- Scenarios should emphasize cases where the relative speed differential is high, particularly when the lead vehicle is stationary.
- Scenarios should emphasize last-second hard braking or hard steering over last-second “normal” maneuvers.
- Crash rates should not be used as a metric, and instead, attention should be focused on the interpretation of last-second maneuver onset behavior.

9 Acknowledgements

Much effort went into making this study a successful endeavor. For this reason, the authors would like to thank the following teams and individuals for their support and attention to detail.

Beginning with the NADS Team, we would like to thank L.D. Chen, Ginger Watson, Tim Brown, Yiannis Papelis, Judith Wightman, Cheryl Benn, Matt Schikore, Scott Egerton, Twila Finkelstein, Tad Gates, Chris Schwartz, Shannon Guest, Larry Hynes, Mary Bender, and Sue Ellen Alisbury for their efforts in working with CAMP to fine tune, design, implement, and execute this study.

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Finally, we would like to acknowledge Tom Reed & Associates, Ltd. for their assistance with summarizing the NADS Interim report's experimental methods section for this report.

10 Appendices

Appendix A Non-Compliant and Dropped Participant Descriptions

Gender	**Group**	**Participant Number**	**Notes**
Male	Young	6	Participant ran into the lead vehicle in 8 of the 17 normal braking trials. Participant did not respond to requests to brake at the last second possible "to avoid colliding with the lead vehicle" using normal braking pressure. When told it is important not to collide with other vehicles, he responded that he couldn't avoid colliding with a vehicle ahead using normal braking pressure at his normal following distance. For hard brakes, participant seemed averse to getting near the lead vehicle.
Male	Middle	13	Withdrew due to simulator sickness.
Male	Middle	14	Did not run on two consecutive days. Participant had to come in a third day to complete trials 42-56.
Male	Middle	20	Unable to complete drives due to motion problems and scheduling constraints.
Male	Middle	24	Did not run on two consecutive days.
Male	Older	32	Participant usually brakes with two feet. Broke with left foot on two trials. Did not run on two consecutive days.
Female	Young	40	Withdrew due to simulator sickness.
Female	Young	41	Withdrew due to simulator sickness.
Female	Young	48	Withdrew due to simulator sickness.
Female	Middle	51	Completed remaining braking trials from day 1 on day 2 due to simulator problems and scheduling constraints. Did not complete last steering trial (60_30_0 HS).
Female	Middle	52	Withdrew due to simulator sickness.
Female	Middle	53	Completed remaining trials from day 1 on day 2 due to simulator problems.
Female	Middle	56	Participant dropped due to four consecutive E-Stops.
Female	Middle	57	Withdrew due to simulator sickness.
Female	Middle	59	Did not run on two consecutive days.
Female	Older	62	Had a glass of wine the night before day 1. BAC administered prior to drive registered 0.000
Female	Older	66	Did not run on two consecutive days.
Female	Older	70	Did not run on two consecutive days.

Appendix B In-Vehicle Experimental Protocol

[Give basic introduction on video, audio monitoring, overhead safety console, seat belt and resting position]
[As dome is prepared to go out to center read the following:]
Before we begin, I would like to give you an overview of what you will be doing today. I am going to ask you to drive at speeds ranging from 30 to 60 MPH while you are following or approaching another vehicle. We refer to this vehicle as the “lead vehicle.” The lead vehicle is equipped with working brake lights. Throughout your drive today, the lead vehicle will be parked, moving at a constant speed, or braking to a stop. For trials in which the lead vehicle brakes to a stop, it will do so with varying braking intensities, ranging from normal to relatively hard braking.
For each trial it is important that you accelerate quickly to reach the designated speed and drive in the same lane as the lead vehicle.
On one set of trials, you will be asked to brake in order to avoid colliding with the lead vehicle in your lane. It is important to stay in the same lane as the lead vehicle. You will be asked to brake at the LAST SECOND POSSIBLE using either NORMAL braking pressure or HARD braking pressure. Please keep your foot on the accelerator pedal until you are ready to brake, and then quickly move your foot from the accelerator to the brake pedal.
On other trials, you will be asked to make a lane change at the LAST SECOND YOU NORMALLY WOULD or a lane change at the LAST SECOND POSSIBLE in order to go around the lead vehicle in your lane. When you make your lane change, you should only move one lane to the left. It is important that you do not brake until you are finished completing your lane change maneuver.
Do you have any questions so far?
When I tell you to begin, put your foot on the brake and shift into DRIVE. Remember to accelerate quickly to the target speed. At the end of each drive, I will ask you to brake to a complete stop. When the speedometer indicates ZERO, please shift into PARK. When you are not driving, please avoid resting your foot on the pedals or touching the steering wheel or shifter.
[Go to first set of instructions next page] [Continue with first set of instructions.]

NORMAL BRAKING

Decel

For the first nine drives, wait until the lead vehicle’s brake lights go off, then quickly accelerate to maintain what you consider to be your normal following distance behind the lead vehicle. Let me know when you’ve reached your normal following distance by saying “READY.” The lead vehicle will brake at some point after that. You should maintain your speed and brake at the last second possible to avoid colliding with the lead vehicle using NORMAL braking intensity or pressure. Keep your foot on the accelerator pedal until you are ready to brake, and then quickly move your foot to the brake pedal.

Trial 1:

Trial 2:

Trial 3:

Trial 4:

Trial 5:

Trial 6:

Trial 7:

Trial 8:

Trial 9:

NOTES

When the brake lights go off, you may begin driving; the lead vehicle will accelerate to ____ miles per hour.

Brake to a complete stop and shift the car into park.

Constant Speed

For the next five drives, you will be traveling at a speed greater than the lead vehicle, which will travel at a constant speed. For these drives you should quickly accelerate to the target speed. Then maintain your speed and brake at the last second possible to avoid colliding with the lead vehicle using NORMAL braking intensity or pressure.

Trial 10: 30

Trial 11: 30

Trial 12: 60

Trial 13: 60

Trial 14: 60

NOTES

Stopped

For the next three drives, the lead vehicle will be stopped ahead in the lane. For these drives you should quickly accelerate to the target speed. Then maintain your speed and brake at the last second possible to avoid colliding with the lead vehicle using NORMAL braking intensity or pressure.

Trial 15: 30

Trial 16: 45

Trial 17: 60

NOTES

You may begin driving; the target speed is ____ miles per hour.

Brake to a complete stop and shift the car into park.

HARD BRAKING

Decel

For the next nine drives, wait until the lead vehicle's brake lights go off, then quickly accelerate to maintain what you consider to be your normal following distance behind the lead vehicle. Let me know when you've reached your normal following distance by saying "READY." The lead vehicle will brake at some point after that. You should maintain your speed and brake at the last second possible to avoid colliding with the lead vehicle using HARD braking intensity or pressure. Keep your foot on the accelerator pedal until you are ready to brake, and then quickly move your foot to the brake pedal.

Trial 18: 30

Trial 19: 30

Trial 20: 30

Trial 21: 45

Trial 22: 45

Trial 23: 45

Trial 24: 60

Trial 25: 60

Trial 26: 60

NOTES

When the brake lights go off, you may begin driving; the lead vehicle will accelerate to ___ miles per hour.

Brake to a complete stop and shift the car into park.

Constant Speed

For the next five drives, you will be traveling at a speed greater than the lead vehicle, which will travel at a constant speed. For these drives you should quickly accelerate to the target speed. Then maintain your speed and brake at the last second possible to avoid colliding with the lead vehicle using HARD braking intensity or pressure.

Trial 27: 30

Trial 28: 30

Trial 29: 60

Trial 30: 60

Trial 31: 60

NOTES

Stopped

For the next three drives, the lead vehicle will be stopped ahead in the lane. For these drives you should quickly accelerate to the target speed. Then maintain your speed and brake at the last second possible to avoid colliding with the lead vehicle using HARD braking intensity or pressure.

Trial 32: 30

Trial 33: 45

Trial 34: 60

NOTES

You may begin driving; the target speed is ___ miles per hour.

Brake to a complete stop and shift the car into park.

NORMAL LANE CHANGING

For some of the drives, you will be asked to maintain a target speed. For other drives, you will be asked to maintain whatever speed allows you to keep your comfortable following distance behind the lead vehicle.

Decel

For the first four drives, wait until the lead vehicle's brake lights go off, then quickly accelerate to maintain what you consider to be your normal following distance behind the lead vehicle. Let me know when you've reached your normal following distance by saying "READY." The lead vehicle will brake at some point after that. You should maintain your speed and change lanes at the last second you NORMALLY would to avoid the lead vehicle.

Trial 35: 30

Trial 36: 30

Trial 37: 60

Trial 38: 60

NOTES

When the brake lights go off, you may begin driving; the lead vehicle will accelerate to ____ miles per hour.

Brake to a complete stop and shift the car into park.

Constant Speed

For the next five drives, you will be traveling at a speed greater than the lead vehicle, which will travel at a constant speed. For these drives you should quickly accelerate to the target speed. Then maintain your speed and change lanes at the last second you NORMALLY would to avoid the lead vehicle.

Trial 39: 30

Trial 40: 30

Trial 41: 60

Trial 42: 60

Trial 43: 60

NOTES

Stopped

For the next two drives, the lead vehicle will be stopped ahead in the lane. For these drives you should quickly accelerate to the target speed. Then maintain your speed and change lanes at the last second you NORMALLY would to avoid the lead vehicle.

Trial 44: 30

Trial 45: 60

NOTES

You may begin driving; the target speed is ___ miles per hour.

Brake to a complete stop and shift the car into park.

RAPID LANE CHANGING

Decel

For the next four drives, wait until the lead vehicle's brake lights go off, then quickly accelerate to maintain what you consider to be your normal following distance behind the lead vehicle. Let me know when you've reached your normal following distance by saying "READY." The lead vehicle will brake at some point after that. You should maintain your speed and change lanes at the LAST SECOND possible to avoid colliding with the lead vehicle.

Trial 46: 30

Trial 47: 30

Trial 48: 60

Trial 49: 60

NOTES

When the brake lights go off, you may begin driving; the lead vehicle will accelerate to ____ miles per hour.

Brake to a complete stop and shift the car into park.

Constant Speed

For the next five drives, you will be traveling at a speed greater than the lead vehicle, which will travel at a constant speed. For these drives you should quickly accelerate to the target speed. Then maintain your speed and change lanes at the LAST SECOND possible to avoid colliding with the lead vehicle.

Trial 50: 30

Trial 51: 30

Trial 52: 60

Trial 53: 60

Trial 54: 60

NOTES

Stopped

For the next two drives, the lead vehicle will be stopped ahead in the lane. For these drives you should quickly accelerate to the target speed. Then maintain your speed and change lanes at the LAST SECOND possible to avoid colliding with the lead vehicle.

Trial 55: 30

Trial 56: 60

NOTES

You may begin driving; the target speed is ___ miles per hour.

Brake to a complete stop and shift the car into park.

Appendix C Randomization Procedure

MASTER ORDER #1

TRIAL	BLOCK 1 - NORMAL		BLOCK 2 - HARD		BLOCK 3 - NORMAL		BLOCK 4 - HARD	
1	Delta V	60 / 30	Stat	60	Braking	60 / 60 / 0.39	Delta V	30 / 10
2	Delta V	60 / 50	Stat	45	Braking	60 / 60 / 0.28	Delta V	30 / 20
3	Delta V	60 / 15	Stat	30	Braking	60 / 60 / 0.15	Delta V	60 / 30
4	Delta V	30 / 10	Braking	45 / 45 / 0.15	Braking	45 / 45 / 0.28	Delta V	60 / 15
5	Delta V	30 / 20	Braking	45 / 45 / 0.28	Braking	45 / 45 / 0.15	Delta V	60 / 50
6	Stat	45	Braking	45 / 45 / 0.39	Braking	45 / 45 / 0.39	Braking	45 / 45 / 0.15
7	Stat	30	Braking	60 / 60 / 0.28	Braking	30 / 30 / 0.15	Braking	45 / 45 / 0.39
8	Stat	60	Braking	60 / 60 / 0.39	Braking	30 / 30 / 0.28	Braking	45 / 45 / 0.28
9	Braking	60 / 60 / 0.39	Braking	60 / 60 / 0.15	Braking	30 / 30 / 0.39	Braking	30 / 30 / 0.39
10	Braking	60 / 60 / 0.15	Braking	30 / 30 / 0.39	Stat	30	Braking	30 / 30 / 0.28
11	Braking	60 / 60 / 0.28	Braking	30 / 30 / 0.15	Stat	45	Braking	30 / 30 / 0.15
12	Braking	30 / 30 / 0.15	Braking	30 / 30 / 0.28	Stat	60	Braking	60 / 60 / 0.28
13	Braking	30 / 30 / 0.28	Delta V	30 / 20	Delta V	60 / 50	Braking	60 / 60 /0.15
14	Braking	30 / 30 / 0.39	Delta V	30 / 10	Delta V	60 / 15	Braking	60 / 60 / 0.39
15	Braking	45 / 45 / 0.28	Delta V	60 / 15	Delta V	60 / 30	Stat	45
16	Braking	45 / 45 / 0.39	Delta V	60 / 50	Delta V	30 / 20	Stat	60
17	Braking	45 / 45 / 0.15	Delta V	60 / 30	Delta V	30 / 10	Stat	30

MASTER ORDER #2

TRIAL	BLOCK 1 - NORMAL		BLOCK 2 - HARD		BLOCK 3 - NORMAL		BLOCK 4 - HARD	
1	Delta V	60 / 50	Braking	60 / 60 / 0.39	Stat	60	Delta V	30 / 10
2	Delta V	60 / 15	Braking	60 / 60 / 0.15	Stat	45	Delta V	30 / 20
3	Delta V	60 / 30	Braking	60 / 60 / 0.28	Stat	30	Delta V	60 / 50
4	Delta V	30 / 20	Braking	30 / 30 / 0.15	Braking	45 / 45 / 0.15	Delta V	60 / 30
5	Delta V	30 / 10	Braking	30 / 30 / 0.28	Braking	45 / 45 / 0.28	Delta V	60 / 15
6	Braking	30 /30 / 0.39	Braking	30 / 30 / 0.39	Braking	45 / 45 / 0.39	Stat	30
7	Braking	30 / 30 / 0.28	Braking	45 / 45 / 0.28	Braking	60 / 60 / 0.28	Stat	45
8	Braking	30 / 30 / 0.15	Braking	45 / 45 / 0.39	Braking	60 / 60 / 0.39	Stat	60
9	Braking	45 / 45 / 0.39	Braking	45 / 45 / 0.15	Braking	60 / 60 / 0.15	Braking	60 / 60 / 0.39
10	Braking	45 / 45 / 0.15	Stat	45	Braking	30 / 30 / 0.39	Braking	60 / 60 / 0.28
11	Braking	45 / 45 / 0.28	Stat	30	Braking	30 / 30 / 0.15	Braking	60 / 60 / 0.15
12	Braking	60 / 60 / 0.15	Stat	60	Braking	30 / 30 / 0.28	Braking	45 / 45 / 0.28
13	Braking	60 / 60 / 0.28	Delta V	30 / 10	Delta V	60 / 15	Braking	45 / 45 / 0.15
14	Braking	60 / 60 / 0.39	Delta V	30 / 20	Delta V	60 / 30	Braking	45 / 45 / 0.39
15	Stat	30	Delta V	60 / 30	Delta V	60 / 50	Braking	30 / 30 / 0.15
16	Stat	60	Delta V	60 / 15	Delta V	30 / 20	Braking	30 / 30 / 0.28
17	Stat	45	Delta V	60 / 50	Delta V	30 / 10	Braking	30 / 30 / 0.39

MASTER ORDER #3

TRIAL	BLOCK 1 - NORMAL		BLOCK 2 - HARD		BLOCK 3 - NORMAL		BLOCK 4 - HARD	
1	Stat	45	Delta V	30 / 10	Braking	60 / 60 / 0.39	Stat	45
2	Stat	60	Delta V	30 / 20	Braking	60 / 60 / 0.28	Stat	30
3	Stat	30	Delta V	60 / 50	Braking	60 / 60 / 0.15	Stat	60
4	Delta V	60 / 15	Delta V	60 / 30	Braking	45 / 45 / 0.28	Braking	45 / 45 / 0.15
5	Delta V	60 / 30	Delta V	60 / 15	Braking	45 / 45 / 0.15	Braking	45 / 45 / 0.28
6	Delta V	60 / 50	Braking	45 / 45 / 0.15	Braking	45 / 45 / 0.39	Braking	45 / 45 / 0.39
7	Delta V	30 / 20	Braking	45 / 45 / 0.39	Braking	30 / 30 / 0.15	Braking	60 / 60 / 0.28
8	Delta V	30 / 10	Braking	45 / 45 / 0.28	Braking	30 / 30 / 0.28	Braking	60 / 60 / 0.39
9	Braking	30 / 30 / 0.28	Braking	30 / 30 / 0.39	Braking	30 / 30 / 0.39	Braking	60 / 60 / 0.15
10	Braking	30 / 30 / 0.15	Braking	30 / 30 / 0.28	Stat	60	Braking	30 / 30 / 0.39
11	Braking	30 / 30 / 0.39	Braking	30 / 30 / 0.15	Stat	45	Braking	30 / 30 / 0.15
12	Braking	60 / 60 / 0.15	Braking	60 / 60 / 0.28	Stat	30	Braking	30 / 30 / 0.28
13	Braking	60 / 60 / 0.39	Braking	60 / 60 / 0.15	Delta V	60 / 30	Delta V	30 / 20
14	Braking	60 / 60 / 0.28	Braking	60 / 60 / 0.39	Delta V	60 / 50	Delta V	30 / 10
15	Braking	45 / 45 / 0.39	Stat	30	Delta V	60 / 15	Delta V	60 / 15
16	Braking	45 / 45 / 0.28	Stat	45	Delta V	30 / 10	Delta V	60 / 50
17	Braking	45 / 45 /0.15	Stat	60	Delta V	30 / 20	Delta V	60 / 30

MASTER ORDER #4

TRIAL	BLOCK 1 - NORMAL		BLOCK 2 - HARD		BLOCK 3 - NORMAL		BLOCK 4 - HARD	
1	Stat	60	Braking	45 / 45 / 0.15	Delta V	30 / 10	Stat	60
2	Stat	45	Braking	45 / 45 / 0.28	Delta V	30 / 20	Stat	30
3	Stat	30	Braking	45 / 45 / 0.39	Delta V	60 / 30	Stat	45
4	Braking	60 / 60 / 0.39	Braking	60 / 60 / 0.28	Delta V	60 / 15	Delta V	60 / 50
5	Braking	60 / 60 / 0.28	Braking	60 / 60 / 0.39	Delta V	60 / 50	Delta V	60 / 15
6	Braking	60 / 60 / 0.15	Braking	60 / 60 / 0.15	Braking	60 / 60 / 0.39	Delta V	60 / 30
7	Braking	45 / 45 / 0.28	Braking	30 / 30 / 0.39	Braking	60 / 60 / 0.15	Delta V	30 / 20
8	Braking	45 / 45 / 0.15	Braking	30 / 30 / 0.15	Braking	60 / 60 / 0.28	Delta V	30 / 10
9	Braking	45 / 45 / 0.39	Braking	30 / 30 / 0.28	Braking	30 / 30 / 0.15	Braking	30 / 30 / 0.39
10	Braking	30 / 30 / 0.15	Stat	30	Braking	30 / 30 / 0.28	Braking	30 / 30 / 0.28
11	Braking	30 / 30 / 0.28	Stat	45	Braking	30 / 30 / 0.39	Braking	30 / 30 / 0.15
12	Braking	30 / 30 / 0.39	Stat	60	Braking	45 / 45 / 0.28	Braking	45 / 45 / 0.39
13	Delta V	30 / 10	Delta V	60 / 15	Braking	45 / 45 / 0.39	Braking	45 / 45 / 0.15
14	Delta V	30 / 20	Delta V	60 / 30	Braking	45 / 45 / 0.15	Braking	45 / 45 / 0.28
15	Delta V	60 / 50	Delta V	60 / 50	Stat	45	Braking	60 / 60 / 0.15
16	Delta V	60 / 30	Delta V	30 / 20	Stat	60	Braking	60 / 60 / 0.28
17	Delta V	60 / 15	Delta V	30 / 10	Stat	30	Braking	60 / 60 / 0.39

MASTER ORDER # 5

TRIAL	BLOCK 1 - NORMAL		BLOCK 2 - HARD		BLOCK 3 - NORMAL		BLOCK 4 - HARD	
1	Braking	45 / 45 / 0.15	Delta V	60 / 50	Stat	45	Braking	60 / 60 / 0.39
2	Braking	45 / 45 / 0.39	Delta V	60 / 15	Stat	30	Braking	60 / 60 / 0.15
3	Braking	45 / 45 / 0.28	Delta V	60 / 30	Stat	60	Braking	60 / 60 / 0.28
4	Braking	30 / 30 / 0.39	Delta V	30 / 20	Braking	45 / 45 / 0.15	Braking	30 / 30 / 0.15
5	Braking	30 / 30 / 0.28	Delta V	30 / 10	Braking	45 / 45 / 0.28	Braking	30 / 30 / 0.28
6	Braking	30 / 30 / 0.15	Stat	60	Braking	45 / 45 / 0.39	Braking	30 / 30 / 0.39
7	Braking	60 / 60 / 0.28	Stat	45	Braking	60 / 60 / 0.28	Braking	45 / 45 / 0.28
8	Braking	60 / 60 / 0.15	Stat	30	Braking	60 / 60 / 0.39	Braking	45 / 45 / 0.39
9	Braking	60 / 60 / 0.39	Braking	60 / 60 / 0.39	Braking	60 / 60 / 0.15	Braking	45 / 45 / 0.15
10	Delta V	30 / 10	Braking	60 / 60 / 0.28	Braking	30 / 30 / 0.39	Stat	30
11	Delta V	30 / 20	Braking	60 / 60 / 0.15	Braking	30 / 30 / 0.15	Stat	60
12	Delta V	60 / 30	Braking	45 / 45 / 0.28	Braking	30 / 30 / 0.28	Stat	45
13	Delta V	60 / 15	Braking	45 / 45 / 0.15	Delta V	30 / 20	Delta V	60 / 30
14	Delta V	60 / 50	Braking	45 / 45 / 0.39	Delta V	30 / 10	Delta V	60 / 50
15	Stat	30	45	30 / 30 / 0.15	Delta V	60 / 15	Delta V	60 / 15
16	Stat	45	60	30 / 30 / 0.28	Delta V	60 / 50	Delta V	30 / 10
17	Stat	60	30	30 / 30 / 0.39	Delta V	60 / 30	Delta V	30 / 20

MASTER ORDER #6

TRIAL	BLOCK 1 - NORMAL		BLOCK 2 - HARD		BLOCK 3 - NORMAL		BLOCK 4 - HARD	
1	Braking	45 / 45 / 0.15	Stat	45	Delta V	30 / 10	Braking	30 / 30 / 0.28
2	Braking	45 / 45 / 0.28	Stat	60	Delta V	30 / 20	Braking	30 / 30 / 0.15
3	Braking	45 / 45 / 0.39	Stat	30	Delta V	60 / 50	Braking	30 / 60 / 0.39
4	Braking	60 / 60 / 0.28	Braking	60 / 60 / 0.39	Delta V	60 / 30	Braking	60 / 60 / 0.15
5	Braking	60 / 60 / 0.39	Braking	60 / 60 / 0.28	Delta V	60 / 15	Braking	60 / 60 / 0.39
6	Braking	60 / 60 / 0.15	Braking	60 / 60 / 0.15	Stat	30	Braking	60 / 60 / 0.28
7	Braking	30 / 30 / 0.39	Braking	45 / 45 / 0.28	Stat	45	Braking	45 / 45 / 0.39
8	Braking	30 / 30 / 0.15	Braking	45 / 45 / 0.15	Stat	60	Braking	45 / 45 / 0.28
9	Braking	30 / 30 / 0.28	Braking	45 / 45 / 0.39	Braking	45 / 45 / 0.15	Braking	45 / 45 / 0.15
10	Stat	60	Braking	30 / 30 / 0.15	Braking	45 / 45 / 0.39	Delta V	60 / 15
11	Stat	30	Braking	30 / 30 / 0.28	Braking	45 / 45 / 0.28	Delta V	60 / 30
12	Stat	45	Braking	30 / 30 / 0.39	Braking	30 / 30 / 0.39	Delta V	60 / 50
13	Delta V	30 / 20	Delta V	60 / 30	Braking	30 / 30 / 0.28	Delta V	30 / 20
14	Delta V	30 / 10	Delta V	60 / 50	Braking	30 / 30 / 0.15	Delta V	30 / 10
15	Delta V	60 / 15	Delta V	60/15	Braking	60 / 60 / 0.28	Stat	60
16	Delta V	60 / 50	Delta V	30 /10	Braking	60 / 60 / 0.15	Stat	45
17	Delta V	60 / 30	Delta V	30 / 20	Braking	60 / 60 / 0.39	Stat	30

Appendix D Participant Documentation

Participant screening and processing forms used for this study are included in this appendix as referenced from the NADS report to CAMP [16]. They are ordered as follows:

1. Screening Procedures,
2. Informed Consent Document,
3. CAMP/NADS Driving Survey,
4. Simulator Sickness Questionnaire,
5. Post-Study Reaction Survey,
6. Payment Voucher.

APPROVED BY IRB-02 (Behavioral)
IRB ID No.: **200204070**
APPROVAL DATE: ***4/23/2003***
EXPIRATION DATE: ***4/23/2004***

Appendix D.1 Screening Procedure

Telephone Screening

For a participant to be eligible for this study, they must be able to participate when the study is scheduled, meet all inclusion criteria,

Introduction

Inform the person contacted about the nature of the study and when it will run. Determine if they can and are willing to participate.

"Hello, ________. My name is _____________ with the National Advanced Driving Simulator. I am contacting you because you had contacted us with an interest in participating in a study. The purpose of this research study is to investigate last second braking and steering behavior in a variety of conditions.

"This research involves a time commitment of approximately 4 hours over two days that requires you to come to the National Advanced Driving Simulator located on the Oakdale Campus. The appointment will require completion of a questionnaire regarding driving experience and general health questions and signing a consent form. You will receive instructions on the simulator cab and the study drive. After driving the simulator for a series of trials of approximately 2 to 3 minutes each, you will be asked to fill out questionnaires regarding your driving experience. Compensation for participating in this study will be $25 per hour.

"Is this a study in which you would be willing to participate?"

- If NO, "Would you like us to keep you on our list of participants?"

  Make a notation concerning wish to remain on list of participants.

  "Thank you for your time."

- If YES, proceed to Inclusion Criteria.

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IRB ID No.: **200204070**
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EXPIRATION DATE: ***4/23/2004***

Inclusion Criteria

If a participant fails to meet one of the criteria, stop, skip the Heath Screening and proceed to the Closing.

If all inclusion criteria are meet proceed to Health Screening.

"There are several criteria that must be met for participation in this study. I will need to ask you several questions to determine your eligibility."

1) **Do you possess a valid driver's license within the United States?**

   [Exclude if no current valid driver's license.]

2) **How long have you been a licensed driver?**

   [Exclude if less than two years.]

3) **How many miles per year do you drive?**

   [Exclude if less than 3,000 miles per year and less than 5 days per week.]

4) **Can you operate an automatic vehicle without special equipment?**

   [Exclude if no.]

5) **Have you participated in a simulator study within the past 12 months? If so, what was the nature of the study?**

   [Exclude if yes, make notation of type of study]

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EXPIRATION DATE: ***4/23/2004***

General Health Exclusion Criteria

If a participant fails to meet one of the criteria, stop and proceed to the Closing.

"Because of pre-existing health conditions, some people are not eligible for participation in this study. I need to ask you several health-related questions before you can be scheduled for a study session. Your response is voluntary and all responses are confidential. This means that you can refuse to answer any questions that you choose and that only a record of your motion sickness susceptibility will be kept as part of this study. No other responses will be kept. Please answer yes or no to the following questions:"

1) **If the subject is female:**
   Are you, or is there a possibility that you are pregnant?

   [Exclude if there is any possibility of pregnancy.]

2) **Have you been diagnosed with a serious or terminal illness?** If yes, is the condition still active? Are there any lingering effects? If yes, do you care to describe?

   [Exclude if there is any current serious condition.]

3) **Do you have Diabetes?** Have you been diagnosed with hypoglycemia? If yes, do you take insulin or any other medication for blood sugar?

   [Exclude if insulin is taken for this condition.]

4) **Do you suffer from a heart condition such as disturbance of the heart rhythm or the experience of a heart attack?** If yes, please describe.

   [Exclude if there has been a heart attack within the past 6 months, or if there is a history of ventricular flutter or fibrillation, or systole requiring cardioversion. Potential participants with atrial fibrillation may be acceptable, given that their heart rhythm is now stable following medical treatment or pacemaker implants.]

5) **Have you ever suffered brain damage from a stroke, tumor, head injury, or infection?** If yes, what are the resulting effects? Do you have visual loss, blurring, or double vision; weakness, numbness, or funny feelings in the arms, legs, or face; trouble swallowing; slurred speech; uncoordination or loss of control; trouble walking; trouble thinking, remembering, talking, or understanding?

   [Exclude if there has been a stroke within the past 3 months, there is an active tumor, or if there are lingering effects.]

6) **Have you ever been diagnosed with seizures or epilepsy?** If yes, how frequently and what type?

[Exclude if there has been a seizure within the past 12 months.]

7) **Do you suffer from inner ear, dizziness, vertigo, or balance problems?** If yes, please describe. Do you have Meniere's disease?

[Exclude if there is any recent history of inner ear, dizziness, vertigo, or balance problem.]

8) **Do you ever suffer from motion sickness?** If yes, on what mode of transportation and what were the conditions (e.g., rough sea, back seat, etc.)? What symptoms did you experience? How old were you when this occurred?

[Record responses then say, "When we complete this list of questions, I will need to ask you specific questions about your motion sickness history. Until then, let me continue with this list." DO INCLUDE OR EXCLUDE AT THIS TIME.]

9) **Do you suffer from a respiratory disorder such as asthma or chronic bronchitis?** If yes, please describe.

[Exclude if disorder results in obvious or continuous shortness of breath or if the subject requires chronic medical therapy such as theophylline, inhalers, steroid medications, and especially oxygen therapy.]

10) **Have you ever been diagnosed with a mood problem or a psychiatric disorder? If yes, are you taking medication? Please describe.**

[Exclude if there is any diagnosed psychiatric disorder. This includes schizophrenia, depression, mania, personality disorder, dependency, or abuse of psychoactive of illicit drugs or alcohol, chronic fatigue syndrome, agoraphobia, hyperventilation, or anxiety attacks.]

11) **Do you have a migraine or tension headaches?** If yes, what is the nature of this pain? How often and when was the last headache? Are you currently taking medication for these headaches? If so, what are you taking?

[Exclude if headaches occur greater than 2 times a month, if there has been a headache in the past 48 hours, or if the subject takes chronic daily or narcotic medications.]

12) **Are you currently taking any medications?** If yes, what is the medication and what is it for?

[Exclude if medication if for motion sickness, psychiatric disorder, or any of the conditions mentioned above that indicates a problem mentioned above that may have been incorrectly denied previously.]

Closing

If participant **MEETS ALL** criteria **(Driving Inclusion and General Health Exclusion Criteria):**

- **Inform the participant to refrain from alcohol and non-prescription drug intake for the 24 hours preceding the session.**
- **Schedule the appointment.**
- **Give directions** to the National Advanced Driving Simulator, explain where to park and ask them to check in at the front desk inside the main entrance.
- **Stress the importance of attending the session.**
  Tell the participant to contact study personnel at 335-4313 at least 24 hours in advance if they cannot attend the session.

If the person **does NOT** meet one or more of these criteria, explain that this study requires meeting all of these conditions, thank the person for their time, and, if reasonable (i.e., they may qualify for a study at another time), ask if they wish to remain on the list of participants for other National Advanced Driving Simulator studies.

APPROVED BY IRB-02 (Behavioral)
IRB ID No.: 200204070
APPROVAL DATE: 4/23/2003
EXPIRATION DATE: 4/23/2004

Appendix D.2 Informed Consent Document

Project Title: **Forward Collision Warning**
Investigator(s): **Ginger Watson, Ph.D., Timothy Brown, Ph.D., Judith Wightman, M.A., Shannon Guest, Ph. D., Cheryl Benn, B.S.**

PURPOSE

The purpose of this research study is to prepare for a study that will investigate drivers' braking and steering maneuvers. We are inviting you to participate in this research study because you are between the ages of 20 and 70, have a valid, unrestricted U.S. driver's license (except for corrective eyeglasses and contact lenses), have a minimum of 2 years driving experience, and are in good general health.

If you agree to participate, you will be asked to sign this Informed Consent Document indicating that you have read the following document and have been told about the goals of this study.

PROCEDURES

If you agree to participate, your involvement will last for approximately 4 hours over two days. A total of no more than three hours in the simulator should be required. The visit will proceed as follows:

Upon arrival at the simulator facility, you will be briefed on the experimental procedure and participant rights, and will be asked to read and sign this Informed Consent Document. You will be asked to fill out a questionnaire regarding your driving history. The experimenter will then escort you to the simulator, brief you on the simulator cab, and explain the procedures for your drives.

As a participant, you will be asked to drive the simulator vehicle at speeds ranging from 30 to 60 miles per hour behind a simulated lead vehicle. While following the lead vehicle, you will be asked to make "last-second" braking and steering judgments in order to avoid the simulated vehicle, which will be either stationary or moving.

After completing your drives for the day, you will be asked to complete two additional questionnaires about your experience in the simulator.

The remainder of the drives will be completed on a subsequent day for which you have already been scheduled.

<u>All driving trials will be recorded on video</u>.

The simulator contains sensors that measure certain aspects of vehicle operation, vehicle motion, and driver actions. The system also contains video cameras that capture images of driver actions (e.g., driver's hand position on the steering wheel, forward road scene). These sensors and video cameras are located in such a manner that they will not affect your driving, the vehicle's performance, or obstruct your view while driving. The information collected using these sensors and video cameras is recorded onto data storage media for subsequent analysis by research staff.

RISKS

The possible risks associated with participating in this research project are as follows. The risk to you, if you actually drive the simulator, is discomfort associated with simulator disorientation. Previous studies with similar driving intensities and simulator setups have produced mild to moderate disorientation effects such as slight uneasiness, warmth, or eyestrain for a small number of participants. These effects are believed to last for only a short time, usually 10-15 minutes, after leaving the simulator. If you ask to quit driving as a result of discomfort, you will be allowed to quit at once. You will be asked to sit and rest before leaving, while consuming a beverage and a snack. This time may coincide with completion of the questionnaires. There is no evidence that driving ability is hampered in any way; therefore, if you show few or no signs of discomfort, you should be able to drive home. If you experience anything other than slight effects, transportation will be arranged through other means. If you are driven home, a follow-up call will be made 24 hours later to ensure that you are not feeling ill effects. Most people enjoy driving in the simulator and do not experience any discomfort.

An experimenter will be present in the back seat of the simulator cab with you to ensure your safety while driving the simulator.

BENEFITS

There may be no personal benefit to you for participating in this study. However, many participants do find driving in a simulator of this type to be an exciting and unique experience. However, it is hoped that society could benefit from this study by gaining useful information regarding last-second braking and steering maneuvers to better understand how collisions might be avoided in the future.

COSTS AND COMPENSATION

You will not incur any costs for participating in this research project.

Should you agree to participate in this study, your compensation will be $25 per hour and your participation is expected to last approximately 4 hours. Payment will be made by check. Please note that in the event that the test lasts less than 1 hour, your minimum payment for participation will be $25.

CONFIDENTIALITY

Records of participation in this research project will be kept confidential to the extent permitted by law. However, federal government regulatory agencies and the University of Iowa Institutional Review Board (a committee that reviews and approves research studies) may inspect and copy records pertaining to this research. It is possible that these records could contain information that personally identifies you, especially where video data are concerned. Participants in the study will be assigned a number to which they will be referred, thereby reducing personal identification of participants. In the event of any report or publication from this study, your name and responses to questionnaire items will not be disclosed. Results will be reported in a summarized manner in such a way that you cannot be identified. Please note that general health information obtained from you during the screening process is not retained in study records.

The **engineering data** collected and recorded in this study (including any performance scores based on these data) will be analyzed along with data gathered from other participants. These data may be publicly released in final reports or other publications or media for scientific (e.g., professional society meetings), educational (e.g., educational campaigns for members of the general public), outreach (e.g., nationally televised programs highlighting traffic safety issues), legislative (e.g., data provided to the U.S. Congress to assist with law-making activities), or research purposes (e.g., comparison analyses with data from other studies). Engineering data may also be released individually or in summary with that of other participants, but will not be presented in a way that permits personal identification, except when presented in conjunction with video data.

The **video data** (video image data recorded during your drive) recorded in this study includes your video-recorded likeness and all in-vehicle audio including your voice (and may include, in some views, superimposed performance information). Video and in-vehicle sounds will be used to examine your driving performance and other task performance while driving. Video image data (in continuous video or still formats) and associated audio data may be publicly released, either separately or in association with the appropriate engineering data for scientific, educational, outreach, legislative, or research purposes (as noted above). By initialing in the space provided, you verify that you have been told that audio/visual recordings will be generated during the course of this study.

_______________ Participant’s initials

VOLUNTARY PARTICIPATION

Taking part in this research study is voluntary. You may choose not to take part at all. If you agree to participate in this study, you may stop participating at any time. If you decide not to take part, or if you stop participating at any time, your decision will not result in any penalty or loss of benefits to which you may otherwise be entitled.

Under certain circumstances, your participation in this research study may be ended without your consent. This might happen if you fail to operate the research vehicle in accordance with the instructions provided, or if there are technical difficulties with the driving simulator.

APPROVED BY IRB-02 (Behavioral)
IRB ID No.: 200204070
APPROVAL DATE: 4/23/2003
EXPIRATION DATE: 4/23/2004

RESEARCH-RELATED INJURY

In the event of research-related injury, medical treatment is available at the University of Iowa Hospitals and Clinics. No compensation for treatment of research-related injury is available from the University of Iowa unless the injury is proven to be the direct result of negligence by a University employee. Should a research-related injury occur, the cost of treatment must be paid for by you and/or your medical or hospital insurance carrier.

QUESTIONS

Questions are encouraged. If you have any questions about this research project, please contact: **Dr. Timothy Brown, (319) 335-4785, or Dr. Ginger Watson, (319) 335-4679.** If you have questions about the rights of research participants or research-related injury, please contact the Human Subjects Office, 300 College of Medicine Administration Building, The University of Iowa, Iowa City, Iowa, 52242, (319) 335-6564, or e-mail irb@uiowa.edu.

DISPOSITION OF INFORMED CONSENT

Investigators at the University of Iowa will retain a signed copy of this Informed Consent Document. A copy of this document will also be offered to you at the time you begin your participation in this study.

INFORMED CONSENT STATEMENT

Your signature indicates that you have read this document and that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this document.

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Participant's Name (printed)

Signature of Participant	Date

APPROVED BY IRB-02 (Behavioral)
IRB ID No.: 200204070
APPROVAL DATE: 4/23/2003
EXPIRATION DATE: 4/23/2004

VIDEO DATA RELEASE STATEMENT

I, ________________________, grant permission to use, publish or otherwise disseminate video image data (including continuous video and still photo formats derived from the video recording) and associated in-vehicle audio data collected about me in this study, either separately or in association with the appropriate engineering data for scientific, educational, outreach, legislative, and research purposes or to demonstrate the fidelity of the National Advanced Driving Simulator. I understand that such use may involve widespread distribution to the public and may involve dissemination of my likeness in video or still photo formats, but will not result in release of my name or other identifying personal information.

I may withdraw the permissions granted in this video data release by contacting Ginger Watson at (319) 335-4679 or g-watson@uiowa.edu. Withdrawal of this video data release may only be accomplished **within seven days (1 calendar week)** of the date recorded on this consent. The ability to withdraw video data does not extend to the ability to withdraw engineering data.

Signature of Participant	Date

INVESTIGATOR STATEMENT

I have discussed the above points with the participant or, where appropriate, with the participant's legally authorized representative, using a translator when necessary. It is my opinion that the participant understands the risks, benefits, and procedures involved with participation in this research study.

Signature of Investigator	Date

Initials of Witness	Date

Study: CAMP I
Date: ____________
Participant #: ____________

Appendix D.3 CAMP/NADS Driving Survey

As part of this study, it is useful to collect information describing each participant. The following questions ask about you and your health, your personal vehicle, and your driving patterns. Please read each question carefully. If something is unclear, ask the research assistant for help. Your participation is voluntary and you have the right to omit questions if you choose.

Background Information

1) What is your birth date? ______ / ______ / ______
Month Date Year

2) What is your gender?

☐ Male

☐ Female

3) What was your total household income last year? (Check only one)

☐ 0 - $4,999
☐ $5,000 - $9,999
☐ $10,000 - $14,999
☐ $15,000 - $19,999
☐ $20,000 - $29,999
☐ $30,000 - $39,999
☐ $40,000 - $49,999
☐ $50,000 or more

4) Of which ethnic origin(s) do you consider yourself? (Check all that apply)

☐ American Indian/Alaska Native
☐ Asian
☐ Black/African American
☐ Hispanic/Latino
☐ Native Hawaiian/Other Pacific Islander
☐ White/Caucasian
☐ Other

5) What is the highest level of education you have completed? (Check only one)

☐ Primary School
☐ High School Diploma or Equivalent
☐ Technical School or Equivalent
☐ Some College or University
☐ Associate’s Degree
☐ Bachelor’s Degree
☐ Some Graduate or Professional School
☐ Graduate or Professional Degree

6) What is your present employment status? (Check only one)

☐ Unemployed

☐ Retired

☐ Work part-time

☐ Work full-time

☐ None of the above

7) What type of work do you do (e.g., teacher, law enforcement official, homemaker)?

____

Driving Experience

1) How old were you when you started to drive?

_______ years of age

2) How often do you drive? (Check the most appropriate category)

☐ Less than once weekly

☐ At least once weekly

☐ At least once daily

3) In which environment do you most frequently drive? (Check only one)

☐ Rural highway (e.g., Highway 1, Highway 6, Highway 218)

☐ Small town (e.g., Solon, West Branch)

☐ Suburban (e.g., Iowa City, Marion)

☐ City (e.g., Cedar Rapids, Des Moines)

☐ High-density city (e.g., Chicago, Los Angeles)

☐ Highway/freeway (e.g., Interstate 80)

4) What speed do you typically drive on the highway when the speed limit is 55 miles per hour?

☐ Below 45

☐ 45 – 49

☐ 50 – 54

☐ 55

☐ 56 – 60

☐ 61 – 64

☐ 65 – 69

☐ 70 – 74

☐ Above 74

5) What speed do you typically drive on the highway when the speed limit is 65 miles per hour?

☐ Below 55

☐ 55 – 59

☐ 60 – 64

☐ 65

☐ 66 – 70

☐ 71 – 74

☐ 75 – 79

☐ 80 – 84

☐ Above 84

6) When the following conditions or situations occur, how frequently do they keep you from driving? (Check the most appropriate answer for each condition)

	Never	Rarely	Occasionally	Frequently	Not Applicable
Nighttime/darkness	☐	☐	☐	☐	☐
Fog	☐	☐	☐	☐	☐
Rain	☐	☐	☐	☐	☐
Snow or sleet	☐	☐	☐	☐	☐
Rush hour/high traffic levels	☐	☐	☐	☐	☐
Highway/freeway	☐	☐	☐	☐	☐

7) Have you ever participated in any special driving schools (e.g., AARP or insurance courses, racing school, or as part of law enforcement training)?

☐ No

☐ Yes (Please describe):

____

____

8) How do you usually feel when driving? (Check only one)

☐ Afraid

☐ Nervous

☐ Neutral

☐ Confident

9) How comfortable do you feel when you drive in the following conditions or perform the following maneuvers? (Check the most appropriate answer for each condition)

	Very Uncomfortable	Slightly Uncomfortable	Slightly Comfortable	Very Comfortable	Not Applicable
Nighttime/darkness	☐	☐	☐	☐	☐
Fog	☐	☐	☐	☐	☐
Rain	☐	☐	☐	☐	☐
Snow or sleet	☐	☐	☐	☐	☐
Rush hour/high traffic levels	☐	☐	☐	☐	☐
Highway/freeway	☐	☐	☐	☐	☐
While smoking	☐	☐	☐	☐	☐
After drinking alcohol	☐	☐	☐	☐	☐
With children	☐	☐	☐	☐	☐
High-density traffic	☐	☐	☐	☐	☐
Passing other cars	☐	☐	☐	☐	☐
Changing lanes	☐	☐	☐	☐	☐
Making left turns at uncontrolled intersections	☐	☐	☐	☐	☐
Using wireless phone	☐	☐	☐	☐	☐
Eating	☐	☐	☐	☐	☐
Engaging in personal grooming activities (e.g., combing hair, applying makeup)	☐	☐	☐	☐	☐

Personal Vehicle

1) What type of automobile do you drive most often?

Year	Make (e.g., Ford, Toyota)	Model (e.g., Escort, Celica)
___ ___ ___ ___	______________________________	__________________________________

2) Which of the following features does this automobile have? (Check all that apply)

☐ None of these

☐ Air Bag

☐ Anti-Lock Brakes

☐ Automatic Transmission

☐ CB Radio

☐ CD/Cassette Player

☐ Cruise Control

☐ Power Brakes

☐ Power Steering

☐ Radar Detector

☐ Sunroof/Moonroof

☐ Other technologies (e.g., trip computer, moving-map display, vehicle information center)

Please list: ____

Violations and Accidents

1) Within the past five years, how many moving violations have you received?

☐ 0

☐ 1 – 2

☐ 3 – 4

☐ 5 or more

☐ Not sure

2) Within the past five years, have you received a ticket for any of the following? (Please check No or Yes for each)

	No	Yes
Speeding	☐	☐
Going too slowly	☐	☐
Failure to yield right of way	☐	☐
Disobeying traffic lights	☐	☐
Disobeying traffic signs	☐	☐
Improper passing	☐	☐
Improper turning	☐	☐
Reckless driving	☐	☐
Following another car too closely	☐	☐
Driving while intoxicated	☐	☐
Other (please specify) ________________________________		

3) In the past five years, how many times have you been the driver of a car involved in an accident?

☐ 0 (Go to question # 4)

☐ 1

☐ 2

☐ 3

☐ 4 or more

Please provide the following information for each accident:

Accident 1

	No	Yes
Was another vehicle involved?	☐	☐
Was a pedestrian involved?	☐	☐
Were you largely responsible for this accident?	☐	☐

Weather Condition: ______________________________
Month/Year: ______________________________
Brief Description: ______________________________
____

Accident 2

	No	Yes
Was another vehicle involved?	☐	☐
Was a pedestrian involved?	☐	☐
Were you largely responsible for this accident?	☐	☐

Weather Condition: ______________________________
Month/Year: ______________________________
Brief Description: ______________________________
____

Accident 3

	No	Yes
Was another vehicle involved?	☐	☐
Was a pedestrian involved?	☐	☐
Were you largely responsible for this accident?	☐	☐

Weather Condition: ______________________________
Month/Year: ______________________________
Brief Description: ______________________________
____

Accident 4

	No	Yes
Was another vehicle involved?	☐	☐
Was a pedestrian involved?	☐	☐
Were you largely responsible for this accident?	☐	☐

Weather Condition: ______________________________
Month/Year: ______________________________
Brief Description: ______________________________
____

4) If you were to be involved in a traffic accident within the next five years, what do you think is most likely to be the cause? (Check only one)

☐ Mistake by self

☐ Mistake by other drivers

☐ External conditions (e.g., weather or road)

Health Status

1) Do you have any disabilities?

☐ No

☐ Yes (Please describe)

____

____

2) What type of prescription glasses or contact lenses are you wearing as you drive in today's study? (Check only one)

☐ None (Go to question # 3)

☐ Single Lens Glasses

☐ Bifocals

☐ Trifocals

☐ Contact Lenses

How many years ago did you obtain your current pair of glasses/contact lenses? (Check only one)

☐ 0 – 3

☐ More than 3

What type of visual problem do you have? (Check only one)

☐ Distance - can only see items that are near without correction

☐ Near - can only see items that are far away without correction

☐ Distance and Near - cannot see items that are near or far without correction

3) Have you ever had the following eye surgeries? (Check all that apply)

☐ None

☐ Lens implant (one eye)

☐ Lens implant (both eyes)

☐ Reattachment of detached retina

☐ Surgery for vision correction

☐ Other (Please list) ____

4) Do you suffer from any of the following hearing losses? (Check only one)

☐ None

☐ Partial hearing loss - one ear only

☐ Partial hearing loss - both ears

☐ Complete hearing loss - one ear only

☐ Complete hearing loss - both ears

5) Do you currently use a hearing aid? (Check only one)

☐ No

☐ Yes

6) How often do you experience motion sickness? (Check only one)

☐ Never

☐ Rarely

☐ Occasionally

☐ Frequently

If you take medication for motion sickness, please list: ______________________________

____

7) Have you taken any medication in the past 48 hours? (Check only one)

☐ No

☐ Yes (Please list all) ____

____

8) Have you consumed any alcohol or other drugs in the past 24 hours? (Check only one)

☐ No

☐ Yes (Please list all) ____

____

Computer Experience

1) How would you rate your frequency of computer use? (Check only one)

☐ Infrequent or non-user

☐ Occasional user

☐ Frequent user

2) For which of the following purposes do you regularly use a computer? (Check all that apply)

☐ Do not use a computer

☐ Word processing

☐ Spreadsheets

☐ Computer programming

☐ Games

☐ Internet/email

☐ Other (Please specify) ____

3) How often do you play computer or video games? (Check only one)

☐ Do not play

☐ Less than once monthly

☐ At least once monthly

☐ At least once biweekly

☐ At least once weekly

☐ At least once daily

Appendix D.4 Simulator Sickness Questionnaire

Study: CAMP I
Maneuver: ____________
Date: ____________
Participant #: ____________

Directions: Circle the option for each symptom to indicate whether that symptom applies to you right now.

1. General Discomfort None_____Slight_____Moderate_____Severe_____
2. Fatigue None_____Slight_____Moderate_____Severe_____
3. Headache None_____Slight_____Moderate_____Severe_____
4. Eyestrain None_____Slight_____Moderate_____Severe_____
5. Difficulty Focusing None_____Slight_____Moderate_____Severe_____
6. Increased Salivation None_____Slight_____Moderate_____Severe_____
7. Sweating None_____Slight_____Moderate_____Severe_____
8. Nausea None_____Slight_____Moderate_____Severe_____
9. Difficulty Concentrating None_____Slight_____Moderate_____Severe_____
10. "Fullness of Head" None_____Slight_____Moderate_____Severe_____
11. Blurred Vision None_____Slight_____Moderate_____Severe_____
12. Dizzy - with Eyes Open None_____Slight_____Moderate_____Severe_____
13. Dizzy - with Eyes Closed None_____Slight_____Moderate_____Severe_____
14. *Vertigo None_____Slight_____Moderate_____Severe_____
15. **Stomach Awareness None_____Slight_____Moderate_____Severe_____
16. Burping No ______Yes_______ If yes, no. of times _______
17. Vomiting No ______Yes_______ If yes, no. of times _______
18. Other ____

---

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort that is just short of nausea.

Appendix D.5 POST-DRIVE REACTION STUDY

Study: CAMP I
Maneuver: ____________
Date: ____________
Participant #: ____________

REACTION SURVEY

For each of the following items, circle the number that best indicates how closely the simulator resembles an actual car in terms of appearance, sound, and response. If an item is not applicable, circle NA.

		Not at all like a real car					Completely like a real car	
1)	Response of the seat adjustment levers	0	1	2	3	4	5	6	NA
2)	Response of the mirror adjustment levers	0	1	2	3	4	5	6	NA
3)	Response of the door locks and handles	0	1	2	3	4	5	6	NA
4)	Response of the gear shift	0	1	2	3	4	5	6	NA
5)	Response of the fans	0	1	2	3	4	5	6	NA
6)	Response of the brake pedal	0	1	2	3	4	5	6	NA
7)	Response of the speedometer	0	1	2	3	4	5	6	NA
8)	Response of the steering wheel while driving straight	0	1	2	3	4	5	6	NA
9)	Feel when accelerating	0	1	2	3	4	5	6	NA
10)	Feel when braking	0	1	2	3	4	5	6	NA
11)	Feel when passing other cars or swaying	0	1	2	3	4	5	6	NA
12)	Feel when driving straight	0	1	2	3	4	5	6	NA
13)	Feel of approximate speed when driving 30 mph	0	1	2	3	4	5	6	NA
14)	Feel of approximate speed when driving 45 mph	0	1	2	3	4	5	6	NA
15)	Feel of approximate speed when driving 60 mph	0	1	2	3	4	5	6	NA
16)	Appearance of car interior	0	1	2	3	4	5	6	NA
17)	Appearance of roadside scenery	0	1	2	3	4	5	6	NA
18)	Appearance of roads and road markings	0	1	2	3	4	5	6	NA
19)	Appearance of signs	0	1	2	3	4	5	6	NA
20)	Appearance of other vehicles	0	1	2	3	4	5	6	NA
21)	Appearance of rear-view mirror image	0	1	2	3	4	5	6	NA
22)	Sound of your car	0	1	2	3	4	5	6	NA
23)	Sound of other vehicles	0	1	2	3	4	5	6	NA

For each of the following items, circle the number that best describes the similarity between driving the simulator and driving an actual car. If an item is not applicable, circle NA.

		Not at all like real driving						Completely like real driving	
24)	Ability to read road and warning signs	0	1	2	3	4	5	6	NA
25)	Ability to respond to other vehicles	0	1	2	3	4	5	6	NA
26)	Ability to keep straight in your lane	0	1	2	3	4	5	6	NA
27)	Ability to stop the vehicle	0	1	2	3	4	5	6	NA

Overall Impressions

For each of the following items, circle the number that best indicates your overall impression of the simulator.

		Not at all like a real car						Completely like a real car	
28)	Overall feel of the car when driving	0	1	2	3	4	5	6	NA
29)	Overall appearance of driving scenes	0	1	2	3	4	5	6	NA

		Not at all like real driving						Completely like real driving	
30)	Overall similarity to real driving	0	1	2	3	4	5	6	NA

Appendix D.6 CAMP/NADS PAYROLL VOUCHER

NADS Participant Payroll Voucher Information

Department Name: NADS & Simulation Center
Contact Person:
Campus Address:
Campus Phone:

SECTION 1: PAYEE INFORMATION

Name: ______________________________
LAST FIRST MIDDLE INITIAL

Social Security Number: ☐☐☐ – ☐☐ – ☐☐☐☐

Address: ______________________________
STREET ADDRESS

______________ ______ ☐☐☐☐☐
CITY STATE ZIP

SECTION 2:

IS THE ABOVE PAYEE:		
Full Time Federal Employee	☐ YES	☐ NO
Primarily a UI Student	☐ YES	☐ NO
University of Iowa Employee	☐ YES	☐ NO
State of Iowa Employee (not UI)	☐ YES	☐ NO
Relative of the Project Director	☐ YES	☐ NO

SECTION 3:

IS THE ABOVE PAYEE:

A U.S. citizen or resident of the U.S. or U.S. territories? ☐ YES ☐ NO

If NO, complete the following information:

VISA Type: ______________________ Date of Birth: ☐☐ / ☐☐ / ☐☐☐☐

Tax Residency Country: ______________________

Permanent Foreign Address: ______________________
____

SECTION 4:

Start Date: ☐☐ / ☐☐ / ☐☐☐☐ Stop Date: ☐☐ / ☐☐ / ☐☐☐☐

Description: Research participant in _CAMP, Phase I________________________ study.

Amount $ ____________________

Appendix E   ANOVA Results

Appendix E.1   Age and Gender Findings

An analysis of variance (one-way ANOVA) was performed for a few of the dependent variable (DV) measures. The data were analyzed by maneuver type (braking and steering) and by kinematic condition groupings (POV Stationary, POV Deceleration, and Constant ΔV) and can be found in Tables E-1 through E-4. For each of these tables, the between-subjects factors were *Age* and *Gender*. The significance coding level used in the following tables is as follows, $p < 0.01 \equiv$ {*} or {#}; $p < 0.001 \equiv$ {**} or {##}; and $p < 0.0001 \equiv$ {***} or {###}. Asterisks are used for the current data set and the pound signs are used to indicate results previous CAMP results [1]. The discussion below will concentrate on general differences between the current NADS and previous CAMP (closed-course) database for the last-second braking trials only.

Tables E-1 and E-2 compare available CAMP results from the 1999 report [1] to the NADS results for the last-second braking data. For the POV Stationary trial comparison shown in, one notable difference between datasets is that *Age* effects for brake onset measures are prevalent for the CAMP drivers (under which younger drivers were less conservative) and are not generally found with the current dataset. For the POV Deceleration comparison shown in Table E-2, *Age* and *Gender* effects were prevalent for the NADS drivers, whereas no such effects occurred in the closed-course results. In the NADS study, older drivers and female drivers were found to be more conservative than younger and male drivers, respectively.

Table E-1. Overview of Statistically Significant Effects for POV Stationary Braking Trials

NADS (***) vs. [CAMP (###)]

		At SV Braking Onset		Throughout Braking	
Ref. Row	**Effect / DV**	**TTC**	**Required Decel.**	**Peak Decel.**	**Minimum TTC**
1	**Age (A)**			***	
	[CAMP Results]	[#]	[#]		[#]
2	**Gender (G)**	*	**		**
	[CAMP Results]		[#]		
3	**A x G**				

Table E-2 Overview of Statistically Significant Effects for POV DECELERATION Braking Trials

NADS (***) vs. No CAMP Significant Results

		Initial Conditions		At SV Braking Onset			Throughout Braking		
Ref. Row	Effect / DV	Initial Headway	Initial POV Speed	TTC1	TTC2	Req Decel	Peak Decel	Min TTC1	Min TTC2
1	Age (A)	***	***				***		*
2	Gender (G)				*	***			*
3	A x G								

The following tables coincide with Table E-1 and illustrate mean performances for a few of the various DVs across *Age Groups* and *Gender*, respectively, for the POV STATIONARY braking trials. In Table E-3, as indicated earlier, *Age* effects for braking onset measures were prevalent for the CAMP drivers (under which younger drivers were less conservative) and are not found with the current NADS dataset.

Table E-3 An *Age Group* Comparison of Mean Results for Various Dependent Variables at SV Braking Onset for POV STATIONARY Trials

	At SV Braking Onset		Throughout Maneuver	
	TTC (seconds)	Req Decel (g's)	Peak Decel (g's)	MinTTC (seconds)
Age Group	Braking Only			
Young (20 – 30) [CAMP Result]	5.4 [3.4]	-0.23 [-0.31]	-0.49 ---	4.4 [2.0]
Middle (40 – 50) [CAMP Result]	5.4 [3.8]	-0.23 [-0.29]	-0.56 ---	4.6 [2.5]
Older (60 – 70) [CAMP Result]	5.3 [3.8]	-0.24 [-0.28]	-0.63 ---	3.9 [2.4]

Table E-4 illustrates <u>NADS *Gender* means only</u> for the same DVs shown in Table E-3.

Table E-4 A NADS *Gender* Comparison of Mean Results for Various Dependent Variables at SV Braking Onset for POV STATIONARY Trials

	At SV Braking Onset		Throughout Maneuver	
	TTC (secs)	Req Decel (g's)	Peak Decel (g's)	MinTTC (secs)
Gender	Braking Only			
Female	5.74	-0.21	-0.42	5.1
Male	4.99	-0.26	-0.57	4.07

Tables E-5 and E-6 coincide with Table E-2 above and illustrate mean performances for various DVs across *Age Groups* and *Gender*, respectively, for the POV DECELERATION braking trials.

Table E-5 A NADS *Age Group* Comparison of Mean Results for Various Dependent Variables at SV Braking Onset for POV DECELERATION Trials

	Initial Conditions		At SV Braking Onset			Throughout Maneuver		
	Headway (secs)	POV Speed (mph)	TTC1 (secs)	TTC2 (secs)	Req Decel (g's)	Peak Decel (g's)	MinTTC1 (secs)	MinTTC1 (secs)
Age Group	**Braking Only**							
Young	1.76	44.9	10.1	3.47	-0.28	-0.57	6.40	2.61
Middle	1.52	44.9	10.7	3.51	-0.26	-0.65	7.50	2.98
Older	1.45	44.9	10.7	3.32	-0.28	-0.74	7.35	2.88

Table E-6 A NADS *Gender* Comparison of Mean Results for Various Dependent Variables at SV Braking Onset for POV DECELERATION Trials

	Initial Conditions		At SV Braking Onset			Throughout Maneuver		
	Initial Headway	Initial POV Speed	TTC1 (secs)	TTC2 (secs)	Req Decel (g's)	Peak Decel (g's)	MinTTC1 (secs)	MinTTC1 (secs)
Gender	**Braking Only**							
Female	1.56	44.9	11.2	3.51	-0.26	-0.65	7.75	2.96
Male	1.59	44.9	9.73	3.35	-0.28	-0.66	6.40	2.69

Appendix E.2 Participant Compliance with Instructions

Drivers were instructed by the in-vehicle experimenter to maintain speeds of either *30*, *45*, or *60 mph*, depending upon the trial. Participant compliance with the instructions administered was checked by comparing the actual average speed of the subject vehicle (SV) at onset and the desired target speeds.

Table E-7 shows substantial compliance with the instructions, as was the case in the previous CAMP dataset (as indicated below). Although compliance was high for both the braking and steering trials, the participants tended to drive slightly faster in the steering trials than they did in the braking trials.

Table E-7 Participant Compliance with Instructions

	POV Stationary Trials		POV Moving Trials			
			Constant ΔV		POV Deceleration	
	SV Speed @ SV Onset		SV Speed @ SV Onset		SV Speed @ SV Onset	
Target Instruction Speed	Braking	Steering	Braking	Steering	Braking	Steering
Maintain 30 mph (CAMP Result)	31.0 (29.8)	32.2	30.9	32.6	30.4 (30.3)	30.5
Maintain 45 mph (CAMP Result)	44.3 (44.6)	---	---	---	44.3 (45.6)	---
Maintain 60 mph (CAMP Result)	58.5 (58.0)	60.5	58.9	60.2	58.8 (60.8)	59.6

Table E-8 shows a comparison of the initial time headways maintained by participants at POV braking onset for the NADS braking and steering trials versus the CAMP braking trials for the POV DECELERATION trials. For the *30* and *45 mph* NADS braking trials, the time headways are substantially equivalent to the data obtained in the original CAMP last-second braking experiments. NADS participants kept slightly (*0.2 second*) longer headways at *60 mph* than did their counterparts on the CAMP test track. For the steering trials, participants kept slightly (*0.1 second*) longer headways at *30 mph* and about the same headways at *60 mph* compared to the braking trials in the simulator. These results indicate that the experimental attempts to create equivalent initial conditions (by artificially coupling the vehicle in NADS) across the NADS and CAMP datasets were largely successful, which enable a more direct comparison between the two datasets.

Table E-8 Comparison of Initial Time Headways at POV Braking Onset between NADS and CAMP Results

	Average Time Headway (seconds)		
Target Speed	**NADS**		**CAMP (Braking Only)**
	Braking	**Steering**	
30 mph	1.3	1.4	1.3
45 mph	1.6	-	1.6
60 mph	1.8	1.7	1.6

Appendix F   NADS TTC1 Outlier Discussion

Appendix F.1   TTC1 Outlier Issues

When comparing the NADS TTC1 results with those from the CAMP study, based on how the TTC1 calculation is defined (*Range/[*$V_{SV} - V_{POV}$*]*), it is possible to get both negative values (which are undefined, since TTC is infinite) and positive values. In *25* out of *4024* trials, TTC was negative and hence undefined (and eliminated from further analysis). The frequency of extreme positive values for NADS TTC1 greater than *100 seconds* occurred almost five times more frequently than it occurred in the CAMP data (24 NADS occurrences versus 5 CAMP occurrences). In the NADS dataset, over *90%* of these extreme events occurred in the low POV DECELERATION condition (*0.15 g*), and 75% of these event happened under "normal" maneuver intensity instructions.

Several approaches were taken to statistically identify the TTC1 outliers in the NADS data, including confidence intervals and least-square mean fitting. No particular method appeared to provide any more of a benefit than just selecting a TTC1 threshold, by reviewing histogram results. Since the CAMP analysis did not remove extreme TTC1 values in their analysis, in the end, these data also remained a part of the NADS data set and used in Inverse TTC modeling results discussed later in this report. To facilitate a less biased comparison to the CAMP results, a *42-second* threshold was chosen for the NADS TTC1 data, representing the *97.5*th*–percentile* boundary and all outliers beyond this value were removed. These results can be found in Figure F-1 and Figure F-2.

Overall, the trends in the data remain the same as they were for the data that included the outliers. Most notable were the comparison improvements for the POV DECELERATION conditions *30_30_15* and *60_60_15*.

Appendix F.2   POV Initial Conditions

Based on the TTC1 equation, there are only two ways to get extremely large TTC1 values: either the *range* (distance between SV and POV at SV onset) is quite large and/or the SV and the POV speeds are nearly equal (ΔV is extremely small) at the time of SV braking onset. From Table E-8 it was illustrated that initial headways (at POV onset) appear comparable to the CAMP results. So, large values for *range* as it relates to initial headway can be ruled out as a primary cause for these extreme values. For a large majority of these extreme cases, it was found that ΔV was extremely small at SV onset. Based on this finding, a closer look was taken at V_{SV} and V_{POV} prior to and at SV onset.

Figure F-1 illustrates what was occurring when ΔV was extremely small at SV onset. The results of a *30_30_15* normal steering trial are displayed in this figure. First note that the SV driver speed (the flat horizontal line at *~29.3 mph*) never reaches the target speed of *30 mph* prior to POV beginning its deceleration (the dotted vertical line). POV speed (from the left, the top mostly horizontal line), which is automated, is right at *30 mph*. When the POV begins to decelerate (referred to as POV onset), its speed must cross through the under speed SV. It turns out that this "speed cross over," where $\Delta V=0$, happens to occur at the same time the SV driver begins to react to the POV decelerating (referred to as SV onset). This "SV under speed" condition prior to POV onset was a common occurrence for the extreme TTC1 values.

Figure F-2 summarizes $\Delta V = V_{SV} - V_{POV}$ *at POV braking onset* for the entire dataset and separately for just the TTC1 outliers. In these box plots, the centerline of each box represents the median value of ΔV and the edges of the boxes are the upper and lower quartiles. The TTC1 outliers predominantly occur when $\Delta V < 0$, whereas the entire dataset is distributed evenly around $\Delta V = 0$. This confirms that the SV under speed condition shown in Figure F-1 is the root cause for the large TTC1 values observed in the dataset.

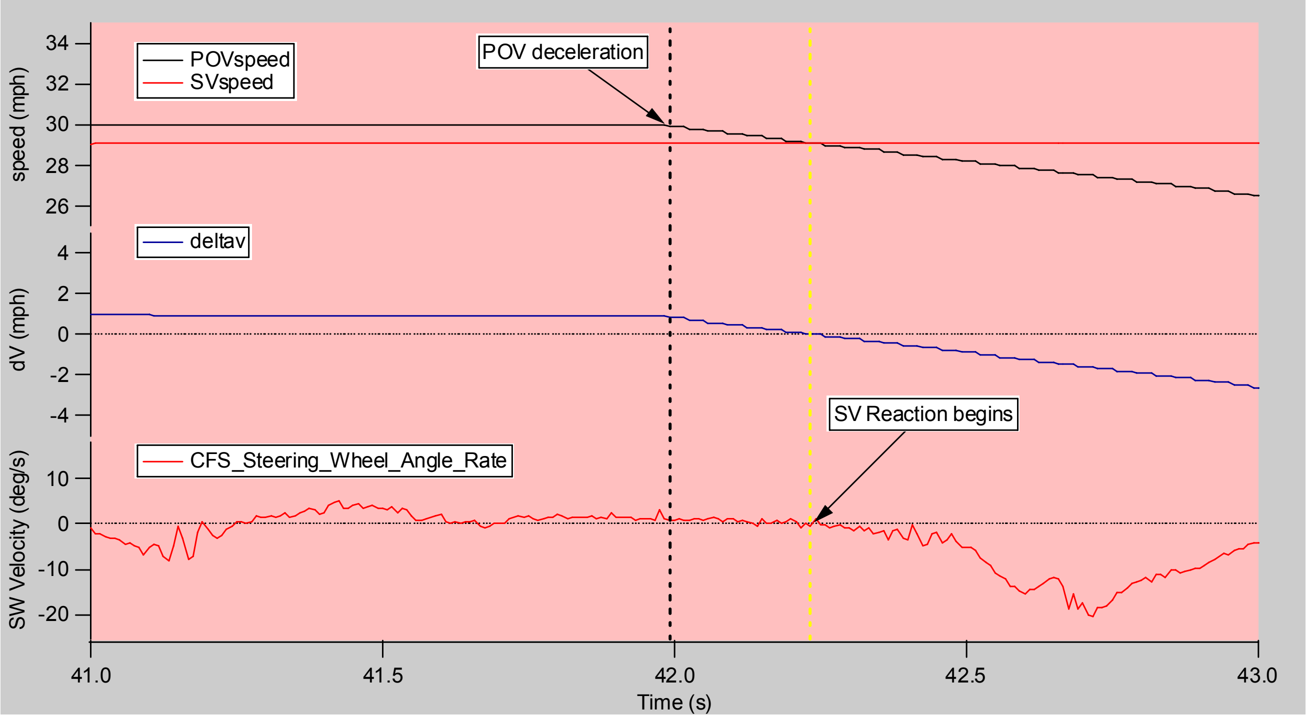

Figure F-1 SV under target speed illustration

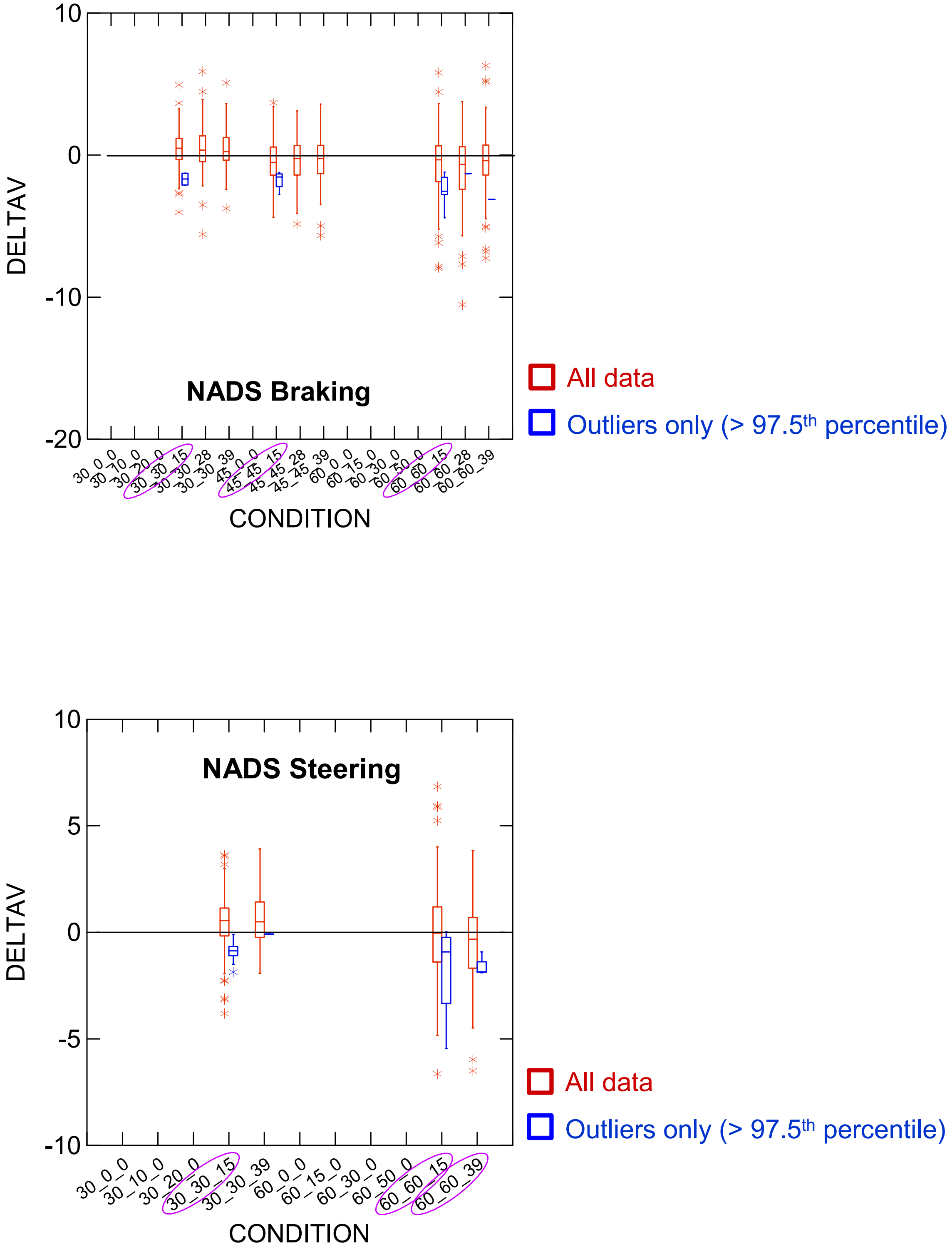

Figure F-2. ΔV Box Plots: All data vs. Outliers Only data.
In these plots, ΔV is calculated at POV braking onset.

Appendix G NADS SSQ Results

Simulator sickness is a well-known phenomenon associated with high-fidelity virtual simulation. Kennedy *et al.* [3] extensively studied the occurrence of this phenomenon in flight simulators, leading them to create the simulator sickness questionnaire (SSQ). The SSQ is the most widely accepted method for both quantifying the severity of post-event simulator sickness effects and diagnosing general areas where the simulator technology or utilization methodology is less than desired. As mentioned in the Experimental Design section above, cumulative SSQ results were recorded after each driving session per participant. The NADS SSQ exposure findings were generally very positive for this study.

In completing the study, a total of six of the 80 recruited subjects dropped out of the study due to simulator sickness issues. Thus, a greater than *90%* retention rate was achieved for a large study such as this one where the drivers experienced aggressive last-second maneuvers.

The SSQ tool itself provides an uncomplicated scoring method, structured such that its symptom clusters can be used as a diagnostic mechanism for identifying systemic shortcomings (see SSQ form in Appendix D). The system cluster components of the SSQ score identify how the subjects are affected by the exposure and consist of the following descriptors: *Nausea*, *Oculomotor*, and *Disorientation*. The cumulative score, termed *Total Severity*, is a weighted sum of these three components. Mean cumulative scores for all the NADS participants were very low (normalized sickness scores under 3.0 are considered very good) [3], indicating that sickness was not a problem as it affects how participants interact with the simulated vehicle environment. These results are illustrated by *Age Group*, *Gender*, *Maneuver Type*, *Day of Exposure* and, trial blocking *Order* (see Appendix C) and can be found in Figure G-1 through Figure G-5.

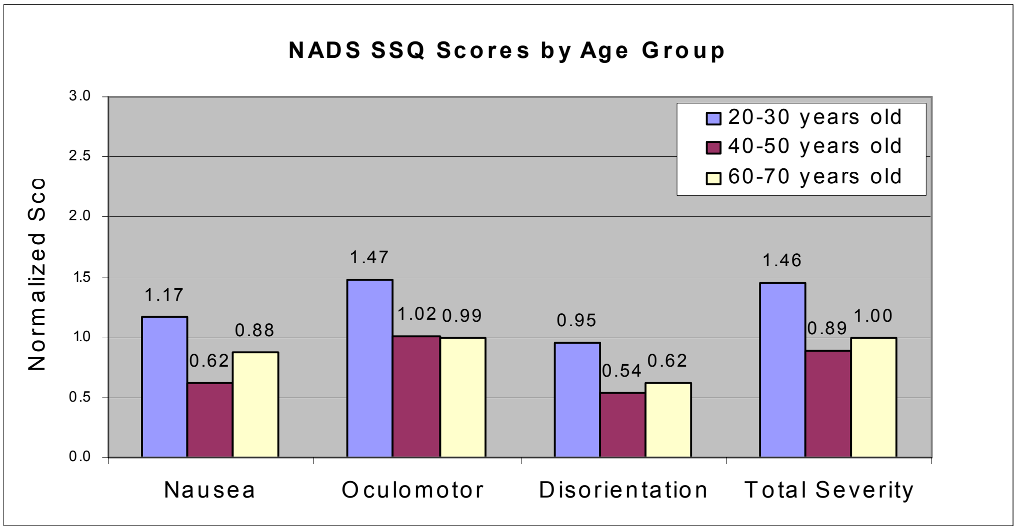

Figure G-1 NADS SSQ Scores by *Age Group*

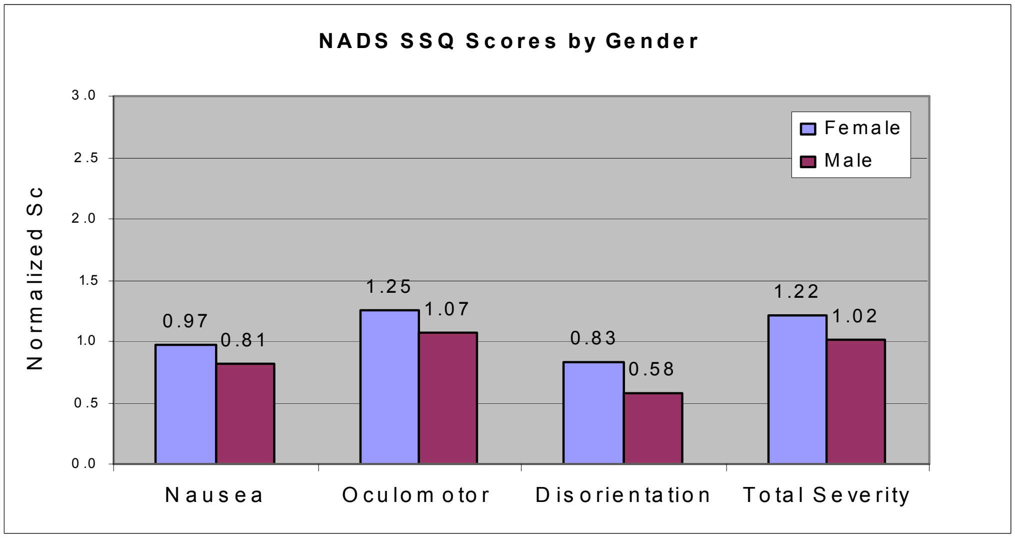

Figure G-2 NADS SSQ Scores by *Gender*

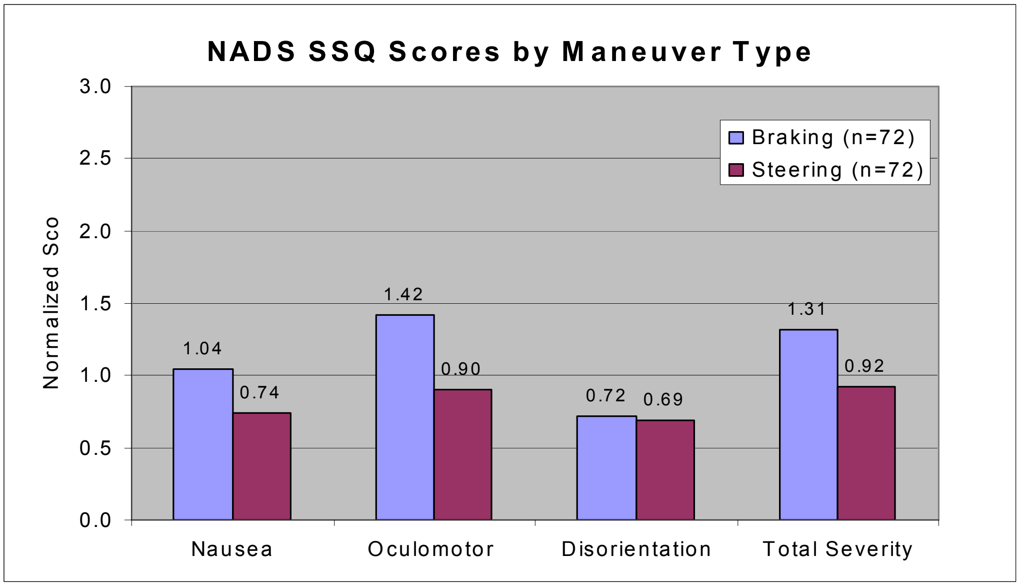

Figure G-3 NADS SSQ Scores by *Maneuver Type*

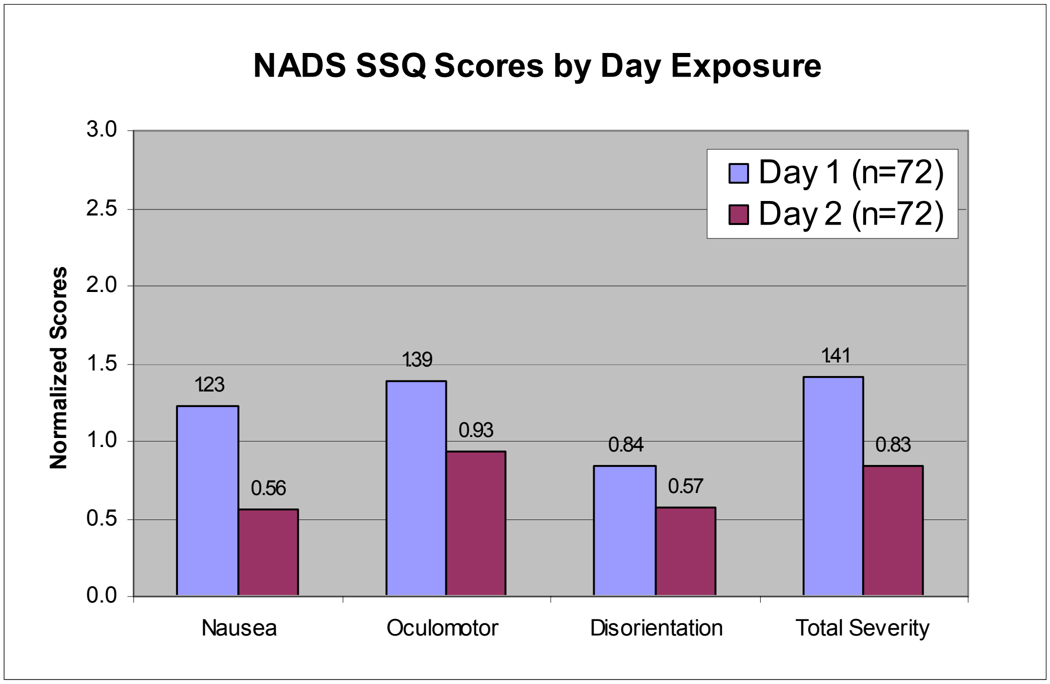

Figure G-4 NADS SSQ Scores by *Day of Exposure*

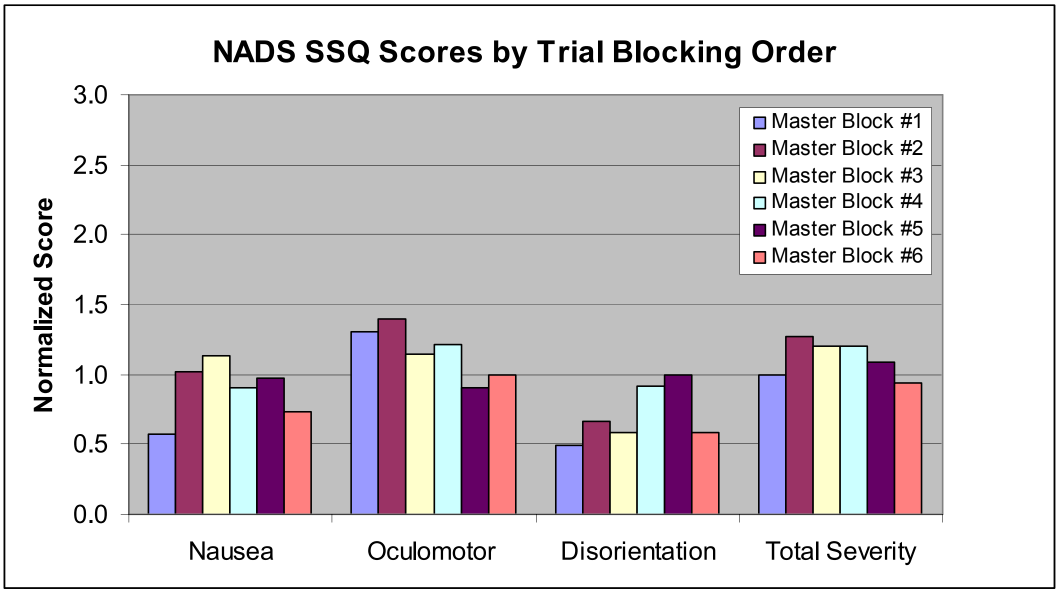

Figure G-5 NADS SSQ Scores by *Trial Blocking Order*

It should be noted that during the early stages of the study, due to a NADS equipment problem that was later identified as a faulty track sensor error, a small number of participants experienced one or more emergency stops (E-stops) during their driving session. There was concern after experiencing such an event, whether this would affect their driving performance, hence, tainting their results. At CAMP's request, a NADS analysis was done to compare subjects that had experienced 1 or more E-stops to those who had experience none. No significant difference was found when comparing the SSQ scores of these two groups of subjects. Only subjects who had experienced 2 or more consecutive E-stops were replaced (1 subject).

References

[1] Kiefer, R., LeBlanc, D., Palmer, M., Salinger, J., Deering, R., & Shulman, M. (1999). *Development and Validation of Functional Definitions and Evaluation Procedures for Collision Warning Avoidance Systems* (Final DTNH22-95-H-07301). Washington DC: Crash Avoidance Metrics Partnership. http:__www-nrd.nhtsa.dot.gov_pdf_nrd-12_acas_HS808964_Report-1999-08.pdf

[2] Kiefer, R.J., Cassar, M.T., Flannagan, C.A., LeBlanc, D.J., Palmer, M.D, Deering, R.K., and Shulman, M.A. (2003), *Forward Collision Warning Requirements Project: Refining the CAMP Crash Alert Timing Approach by Examining "Last-Second" Braking and Lane Change Maneuvers Under Various Kinematic Conditions,* (NHTSA: DOT HS 809 574). Washington, DC. http:__www-nrd.nhtsa.dot.gov_pdf_nrd-12_HS809574Report.pdf

[3] Kennedy, R.S. and Lane, N.E. (1993), *Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness.* International Journal of Aviation Psychology, 3(3), 203-220. Lawrence Erlbaum Associates, Inc.

[4] Grant, P.R. and Reid, L.D. (1997), *Motion Washout Filter Tuning: Rules and Requirements.* Journal of Aircraft, 34 (2).

[5] Kennedy, R. S., Dutton, B., Ricard, G. L., Frank, L. H., *Simulator sickness – a survey of flight simulators for the Navy,* SAE Paper No. 841597, Warrendale PA

[6] Reid, L. D. and Grant, P.R. *Motion Algorithm for Large-Displacement Driving Simulator*, Transportation Research Record, No. 1403, pp 98-106, Mar. 1993, Washington DC

[7] Salaani, M. K., Heydinger, G. J., and Guenther, D. A.(1997), "Validation Results from Using NADSdyna Vehicle Dynamics Simulation," SAE Paper No. 970565, Warrendale, PA

[8] Salaani, M. K., Keydinger, G. J., Grygier, P. A., (2001), "Parameter determination and vehicle dynamics modeling for the NADS of the 1998 Chevrolet Malibu," SAE Paper No. 2001-01-0140, Warrendale PA

[9] *"VRTC Analysis of Reverse Steer Maneuvers"*, VRTC memo, 9/12/2002

[10] Lee, D.N. (1976). *A theory of visual control of braking based on information about time-to-collision*. Perception, 5, 437-459.

[11] Summala, H., Lamble, D., and Laakso, M. (1998). *Driving experience and perception of lead car's braking when looking at in-car targets.* Accident Analysis and Prevention, 30, 401-407

[12] Groeger, J. (2000). *Understanding driving: Applying cognitive psychology to a complex everyday driving task.* Taylor & Francis, Inc.: Philadelphia

[13] Schiff, W., and Detwiler, M. (1979). *Information used in judging impending collision.* Perception, 8, 647-658

[14] Evans, L., and Rothery, R. (1974). *"Detection of the sign of relative motion when following a vehicle."* Human Factors, 16, 161-173

[15] Hosmer, D.W., and Lemeshow, S. (2000). *Applied Logistic Regression*. New York: Wiley & Sons

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[16] Brown, Timothy L., Wightman, Judith A., Watson, Ginger S., Benn, Cheryl A., Salisbury, Sue Ellen (2005). Report for the Crash Avoidance Metrics Partnership (CAMP) forward collision warning study on the NADS: Human subjects materials and questionnaires used in the replication of closed course testing (NADS No. N05-001). Iowa City, IA: National Advanced Driving Simulator.

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