Subjective And Objective Vehicle Handling Behaviour

by

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The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others.

Abstract

This thesis presents results from a research project seeking to correlate subjective and objective measures of automobile handling. An underlying goal of the work was to demonstrate how a relatively simple lumped parameter model, suitable for effective use at the early stages of vehicle design, could be used to predict both the objective responses and subjective feel of the car. The work associated with the project was centred around sixteen configurations of a prototype saloon car. Objective evaluation included ISO defined steady state, step input, and frequency response testing. Subjective assessments were conducted by eight trained test drivers who supplied feedback in the form of numerical ratings on a questionnaire covering various aspects of handling. Examination of the two sets of data highlighted aspects of handling for which driver ratings correlated with objective data. It was also possible to quantify the average effect each objective response parameter had on driver ratings and thus to identify responses which most strongly influence subjective ratings. In addition a lumped parameter model allowing for lateral, yaw and roll degrees of freedom was validated against the experimental data. This validation demonstrated that the model was capable of accurate steady state and transient predictions both in the linear and non-linear range. The work concludes with a brief discussion about how the validated model, combined with the knowledge gained from the correlation work, could be used by engineers to streamline the design and development process.

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1. Introduction and Review of Previous Work

1.1 Definition of Objectives

Vehicle handling, the dynamic response of an automobile to driver inputs, can be described in terms of: i) subjective driver feedback, ii) measured objective data, and iii) mathematical predictions. Ambiguous links between these measures of vehicle handling have impeded the full use of mathematical handling models during the automotive design cycle. Although handling models of varying levels of sophistication are used by vehicle engineers, a great deal of development still centres itself around actual prototype testing due to the inability of the models to predict either the objective or subjective assessments of the final product. Recognising that increased efficiency and cost savings can be gained by reducing the amount of prototype-stage development the current research has been undertaken to improve the ability of relatively simple mathematical models to predict objective and subjective handling qualities through a co-ordinated program of data collection.

The first goal of the work was to correlate driver subjective opinions with objectively measurable vehicle responses. The second goal was to validate a vehicle handling model suitable for use by engineers during the design and development phases of vehicle production. By achieving these goals it would then be possible to utilise the predictive power of computer models to achieve better handling vehicles earlier in the design and development process.

The following sections review the current "state of the art" regarding the topic of vehicle subjective and objective evaluation of handling. First a formal definition of handling is given. The next sections then detail experimental objective methods of characterising vehicle handling, subjective assessment methods and finally mathematical modelling.

1.1.1 Definition of Subjective and Objective Handling

Vehicle handling can be defined as the dynamic performance of the driver-vehicle system during driving. Specific aspects are the vehicle directional response to steering, throttle and brake inputs. Also the vehicle's response to road or wind disturbances may also be considered especially in the context of how the driver responds to such inputs. Regardless of the exact wording of any definition of handling the common theme is always the driver's control of the vehicle. The two elements of the "system", the driver and the vehicle, logically lead to different ways of assessing vehicle handling: subjectively on the part of the driver and objectively when measurements are made of the vehicle.

Subjective handling refers to driver opinions of how the vehicle responds to his or her hand wheel, throttle and brake inputs while performing driving tasks. These opinions, by their nature, are best expressed in the form of words although it is a common practice to translate them into numerical quantities based on some kind of scale. For example one could describe the cornering stability of a car in emotive terms such as "*scythes through*" and "*the tail flicks just right*" or, alternatively, a person could simply rate "*Cornering Stability*" on a 1 to 10 scale. In the first case the terms were used in the review of a sports car in a popular motoring magazine. [1] The second example was sourced from a technical paper investigating subjective evaluation with lane change manoeuvres. [2] It will be seen that the need to quantify subjective impressions complicates the analysis of driver opinions.

Objective handling properties are more easily defined. They are measurements typically obtained from transducers fitted to a vehicle conducting some specified manoeuvre. An easily understood example is the peak lateral acceleration achieved after a sudden application of the hand wheel - a step input. The physically based output of an accelerometer gives measurements which are valid and repeatable which, naturally, makes such measurements the preferable method of assessing handling characteristics.

Clearly subjective and objective measures of handling are fundamentally different due to the driver dependence of the former. Tying the two together is important to automotive engineers since it is subjective handling which largely determines whether a car is satisfactory to a given driver but it is objective handling which can be analysed and designed for. Any research seeking such relationships in this thesis is referred to as *subjective-objective research* or *subjective-objective correlation*.

1.2 Objective Quantification of Vehicle Handling

The objective tests described in the literature for characterising the performance of a motor vehicle are defined clearly in a number of ISO standards or technical reports. Of particular interest to handling research are four distinct tests:

i) The steady state circular test, ISO 4138 - 1982 (E) [3]

ii) The step input test, ISO 7401: 1988 (E) [4]

iii) Frequency response test, ISO 7401: 1988 (E) [4]

iv) Severe lane change, ISO Technical Report 3888 [5]

Between these tests it is possible to obtain vehicle performance properties relating to both steady state and transient handling in the linear and non-linear ranges. The linear and non-linear handling ranges are normally delineated by lateral accelerations of approximately 0.3 g. Many papers make this definition in relation to various handling topics - reference [6] actually studies the differences of the two regimes in detail in addition to defining it. As the names imply the behaviour of the vehicle responses below 0.3 g tend to be a linear. The importance of this distinction relates to the added complications involved in accurately modelling vehicle handling beyond the linear range, as will be discussed later.

1.3 Subjective evaluation of vehicle handling and correlation with objective measures

In comparison with mathematical modelling and objective testing the topic of correlating subjective impressions of handling with objectively measurable responses has received little attention. To begin with there do not appear to be any technical papers detailing how subjective evaluation of vehicle handling is done. This situation exists in spite of the fact every vehicle manufacturer employs subjective assessment on the part of test drivers for development work. Considering research seeking to correlate driver opinions with objective responses “A Literature Survey on Subjective-Objective Correlation of Vehicle Handling”, written by the Motor Industry Research Association (MIRA), found only eleven references up to 1983 dealing with the subject. [7] Of these the author deemed only seven to be worthy of summary in the report. Since this time there has not been a significant increase in publications in this area. Only eleven additional references were found on the topic.

The discussion of these papers and subjective handling assessment is divided into the methodology pursued by various authors and the results.

1.3.1 Subjective Evaluation Methods

Although subjective-objective research methodologies are well documented in the technical literature, as will be discussed presently, there does not appear to be any published literature outlining subjective evaluation practices in industry. Specifically no references could be found which describe exactly how test drivers for automotive companies conduct evaluations during the course of vehicle development. Most information which the author has reviewed exists in the form of internal documents, produced by manufacturers or consulting companies for their own employees, and thus are not available for general use. However, the bulk of the information in these papers involves defining handling terms rather than with procedural issues and would not, in any case, contribute significantly to an overview of how subjective evaluations are conducted.

The author has been permitted to observe subjective vehicle testing at MIRA during the course of completing the current research and the following anecdotal observations are made to provide some perspective of how subjective handling evaluations are conducted.

Subjective evaluation during vehicle development is conducted either by experienced test drivers with specialist training in evaluating vehicles or by engineers familiar with the mechanical workings of the vehicle. By necessity both types of drivers have overlapping skills and knowledge so that they can communicate with each other. In fact in terms of improving the handling of a vehicle there is often little to distinguish between them. When conducting an overall evaluation of an unfamiliar vehicle a driver will typically conduct a series of manoeuvres on different circuits on the proving ground. At MIRA's proving ground a typical test may involve the use of the:

- *steering pad* for steady state evaluation. Also if the vehicle is truly new to the driver he may take advantage of the wide open space to conduct more severe manoeuvres.

- *general durability circuit* with track similar to a two lane motorway. Straight-line running characteristics and moderately severe cornering manoeuvres will be examined. The response of the vehicle to sudden throttle or brake applications will also be gauged.

- *closed handling circuit* where aggressive manoeuvres such as severe lane changes and sudden braking in a turn can be conducted. Other manoeuvres which might be attempted include ones involving reversals of the vehicle's path curvature such as "S" shaped turns or slaloming.

- *ride and handling circuit* with various discrete features (ridges, cambers, potholes etc.). The response of the vehicle to these disturbances often plays an important role in the drivers overall assessment.

- *high speed oval* circuit suitable for assessing stability at increased speeds.

During the various driving tasks indicated above the driver will note the feedback and response of the vehicle in terms of:

- hand wheel kickback due to suspension movement

- hand wheel torque feedback

- lateral acceleration, yaw rate, roll rate, roll angle

- pitching motion

This description is a very generalised overview of how a test driver typically evaluates a vehicle. The key elements to note are that drivers will tend to assess the vehicle over a number of manoeuvres of their choosing and that they focus on a variety of feedback and responses to formulate opinions of the vehicle.

1.3.2 Methodologies for Subjective-Objective Research

Papers focusing on subjective objective handling date back to the early 1970's. The majority of work has involved simple correlations of objective responses with either driver task performance measures or driver numerical ratings. Table 1-1 summarises the key papers in the literature dealing with the subject. By scanning down any of the columns in the summary table and it is easy to see that various ways have been tried in research.

Table 1-1 Summary of subjective-objective research

Ref	Vehicles	Subjective evaluation method/tasks	Drivers	Questions (phases in quotes are transcribed from the papers)	Rating Scale	Objective Vehicle Responses
[8]	1 vehicle in 5 configurations	Not stated	"5 expert drivers"	–"driving effort" –"ease of adaptation" –"precision of tracking" –"high speed handling" –"over all handling"	1 to 7 anchored by *Good* and *Poor*	-steady state yaw rate gain -yaw time constant -undamped yaw natural frequency (from 2 dof model) -yaw damping ratio (from 2 dof model)
[9]	2 pick-up trucks	lane changing	"most skilled drivers", unknown number	14 questions regarding: –"Straight running stability" –"Lane changing manoeuvrability" –"Cornering stability" –"Steering effort"	1 to 10 anchored by *bad, poor, fair, good, excellent*	-forward velocity -peak lateral acceleration ratios from lane change -peak yaw rate ratios from lane change -yaw rate frequency response gain
[10]	four "domestic and foreign vehicles"	–transient steering –braking in cornering –cornering across a single bump	10 evaluators from "various engineering activities" within Ford	Not explicitly stated	1 to 10	–"*sideslip acceleration coefficient*" –"*understeer angle increment*" –"*yaw velocity increment*"
[11]	8 "vehicles" in a simulator and 4 real vehicles	-Simulator: completion of a 10 km road course -Real vehicles: double lane change	-Simulator: "eight male test subjects" -Real vehicles: "eight unskilled drivers", for real vehicles (different pools of drivers were used)	5 questions relating to: –"...summary of your judgement of the vehicle" –"..result of a little inattention" –"...which manner does the vehicle react to a sudden steer input" –"...the necessary angle of steering wheel" –"...the steering torque"	1 to 5 with different descriptive anchors for each question	Simulator -time to complete simulated course -number of error made during simulator driving -yaw velocity: peak value and response time (from step input) -side slip angle: peak value, response time, and steady state value (from step input) -"TB" value = (peak yaw velocity response time)×(steady state side slip angle) -Real vehicles -yaw gain frequency response

Table 1-1 (continued)

Ref	Vehicles	Subjective evaluation method/tasks	Drivers	Questions (phases in quotes are transcribed from the papers)	Rating Scale	Objective Vehicle Responses
[12]	4 “vehicles” in a simulator	–completion of a 10 km road course –Real vehicles: double lane change	“three male test subjects”	–“...summary of your judgement of the vehicle” –“...which manner does the vehicle react to a sudden steer input” –“...the necessary angle of steering wheel”	1 to 5 with different descriptive anchors for each question	TB value (defined above) Steering ratio
[13]	–1 vehicle in 37 different steering, suspension and tyre set-ups for “expert driver” –4 vehicles for “typical drivers”	–straight-line driving in the presence of crosswinds –double lane change	–1 “expert test driver” –16 “typical subjects”	Not explicitly stated	1 to 10, divided into 3 segments: *“optimum to satisfactory”*, *“satisfactory performance, but unacceptable attentional demands and workload”*, *unsatisfactory performance and unacceptable workload”*	Steady state gain from yaw transfer function Effective time constant from yaw transfer function
[14]	1 vehicle in 8 different suspension, inertia and tyre set-ups. 1 reference vehicle.	lane change	“five development engineers”	Not explicitly stated	1 to 10	–Yaw velocity frequency response gain and phase –Lateral acceleration frequency response gain and phase –Hand wheel torque frequency response gain and phase

Table 1-1 (continued)

Ref	Vehicles	Subjective evaluation method/tasks	Drivers	Questions (phases in quotes are transcribed from the papers)	Rating Scale	Objective Vehicle Responses
[15]	Simulator: four Real vehicles: four	"Sudden lane change test"	Simulator: "seven drivers...ranging from a very skilled on e to a beginner" Real vehicles: "two experienced drivers....one with average...skill"	Not explicitly stated	Same as [13]	metric related to lateral acceleration phase
[16]	17 vehicles plus 1 reference	"ISO lane change"	"7 male subjects"	"Consider the...lane change manoeuvre...whether steering corrections were easy, medium, or difficult..."	1 to 10 with two levels of anchors for guiding user to ratings	Metrics derived from yaw rate, lateral acceleration, and roll angle frequency response functions : –steady state gain, H_o –equivalent time constant at 045° lag –bandwidth at $H=0.707H_o$ –maximum gain to steady state gain –average phase difference between yaw rate and lateral acceleration
[17]	5 configurations of a prototype "simulator vehicle"	lane changes	"ten drivers... experienced in evaluating steering performance"	"Response" "Stiffness" "Faithfulness"	1 to 5	lateral acceleration and yaw rate frequency response phase

1.3.2.1 Drivers

Opinion is divided on whether trained or untrained test drivers are more suitable for research. Untrained drivers on the one hand add realism to the experimental work since most drivers are not specially trained to assess handling. On the other hand they may be influenced by extraneous factors, such as vehicle appearances, thus giving feedback not based on the experimental factors. Trained drivers, it is argued, are better suited to providing reliable data because they are able to focus on the actual performance of the vehicle. However [9] argues that because they are usually highly skilled drivers as well as good assessors their car control abilities might bias them towards preferences different from "normal" drivers. In [13] the authors highlight differences in subjective opinion between an "expert" test driver and 16 ordinary ones indicating that the expert driver preferred a more responsive vehicle. The one problem with this observation is that the data for the expert driver was obtained under different circumstances than that of the normal drivers.

1.3.2.2 Driving Tasks and Subjective Rating Scales

By far the most common task which drivers used to evaluate vehicles is lane changing. Interestingly, despite the fact that an ISO standard exists for a severe lane change manoeuvre, only one of the references makes use of it. The rest appear to have utilised different variations of the theme. This fact among others makes it difficult to compare any of the studies with each other. Other factors which make comparisons difficult are the general lack of standardisation of the questions and rating scales. This point will be discussed in the next sub-section.

1.3.2.3 Discussion

Overall it is quite clear that many ideas exist as to how best to conduct subjective-objective research. As noted above the different driving tasks, questions, and rating scales strictly speaking make it impossible to compare any of the research with each other. This situation is somewhat unique in comparison to other areas of engineering where it seems natural to standardise testing as much as possible.

A separate, critical, observation of the previous work is that virtually none of the authors address the fact that by asking drivers to base their ratings strictly on specified manoeuvres, i.e. lane changes, the experimenters impose conditions on the subjective evaluation method which do not mirror how "real" drivers assess vehicles. The reason why specified manoeuvres are used of course, relates to the desirability of collecting data under controlled conditions. If all drivers are subject to the same vehicle responses they should give the same ratings. Recall that in section 1.3.1 that most test drivers base their assessments on a wide range of manoeuvres and tasks, all done at their discretion. The only paper to make a passing comment about the way subjective-objective research is conducted and the way it is actually done was [14] where it was noted that the lane change manoeuvre used forms part of the repertoire of tasks Ford test drivers use.

Thus it would seem that two possible avenues exist for improvement of subjective data collection. Either standardised driving tasks should be adopted so that results can be compared with each other or, the evaluation methods should more closely match realistic practices used by drivers.

1.3.3 Objective Vehicle Response Showing Correlation to Subjective Ratings

Despite the disparity in research methods there do appear to be some common features to the results. Examining the last column of Table 1-1 it can be seen that the majority of metrics correlated with driver ratings relate to either lateral acceleration or yaw rate. The level of successful correlation seen between ratings and objective data in all of the references is typically expressed in correlation coefficients of 0.7 to 0.9.

Given the apparent relationship between ratings and yaw and lateral responses it again seems interesting that little efforts have been made to conduct standardised tests. Admittedly the objective data collected must reflect characteristics which the investigators expect will show good results but nevertheless it would seem to be a useful idea to base more of the objective data collection on recognised standard tests.

1.4 Computer Handling Simulations and Modelling Strategies

Two issues are of particular interest to vehicle handling models. One the question of how detailed to make the model is one which has received attention from a number of authors. The second issue that of simulating tyre forces and moments.

1.4.1 Model complexity

In general most authors tend to advise caution when developing multi-degree of freedom handling models. [18] for example notes that "*A model must have sufficient complexity for a given application but should not be overly complicated*". It then proceeds to discuss various factors which may or may not be required of a vehicle model depending upon its intended use. In another reference [19] the authors note that in addition to its potential use, the improved accuracy of a more complex model should be set against the effects of errors in the additional model parameters. While a more sophisticated model might in theory give more realistic results the true accuracy of the simulation may be adversely affected by erroneous parameters. In such situations the addition of complexity to the model may in fact degrade its ability to provide accurate output.

The issue of how assessing how sensitive a model is to errors in its parameters is addressed comprehensively in [20]. In it the authors make a convincing case that the accuracy of model parameters should be considered when doing simulation and validation work.

From the view point of the engineer during the preliminary stages of vehicle design it is generally acknowledged that fairly simple, lumped parameter, models provide the most potential for use. These models have existed for decades and continue to find use today because of their simplicity and accuracy. Issues of vehicle dynamics which have been addressed by such models include i) roll control during severe manoeuvres, ii) tyre traction properties on directional behaviour, iii) manoeuvring in the presence of a flat tyre and iv) race car performance optimisation to name only a few. (Refer to [21], [22], [23], and [24])

As long ago as the 1950's Segel had demonstrated that a three degree of freedom model, allowing for side slip, yaw and roll motions, accurately represented the behaviour of automobiles in the linear operating region. [25] Later this model was extended by adding a degree of freedom associated with the steering system as shown in [26]. The assumptions made by the model include smooth roads, constant forward velocity, and no pitching motions. Today this basic representation of the automobile remains the basis for many handling models. Reference [27] for example recently discussed and demonstrated how its use can be extended into the non-linear region of handling by suitable application of small-disturbance theory and use of a non-linear tyre model. Returning to the vehicle design engineer, the author of [28] presented a five degree of freedom model which, when combined with a graphical user interface, could "*...be easily used by development engineers on a personal computer".*

Besides the advantage of simplicity and effectiveness of the lumped parameter approach, a number of factors tend to work against the use of more sophisticated models early in the design of an automobile. The complications to using, for example, multi-body systems are acknowledged in a number of papers. The authors of reference [28] note, for example, the need for specialists to run simulation codes such as *ADAMS* and *DADS* and reference [29] quotes cases where the complexity of computer models were so great that the vehicle being modelled was completed before the model. Given such scenarios it is clear that the use of lumped parameter models is potentially of greatest use - provided that their output can be related effectively to handling performance and evaluations.

1.4.2 Tyre Modelling

Arguably the most important but least understood element of the motor vehicle is the pneumatic tyre. As the primary force generating component on the vehicle the accuracy with which tyres are modelled must be considered critical to the validity of any handling simulation. The number of different approaches to modelling, both physical and empirical, reflect the complexity of how tyres generate forces and moments.

In general empirical approaches, where curves are fitted to experimentally collected data tend to find greater use in computer modelling in comparison with physical models. While helping to convey an understanding of the underlying mechanism of the tyre physically based models are generally not sufficiently accurate enough for vehicle modelling purposes according to [30]. Over the past decade an empirical approach to tyre modelling termed the "Magic Formula Tyre Model" has gained great acceptance in the field of vehicle dynamics. The model is built around a formula that represents tyre forces as a sine function with an arctangent function as its argument. In particular the basic formula is:

$$y = D\sin[C\arctan(Bx - E(Bx - \arctan(Bx)))] \qquad (1)$$

where

y = the lateral or longitudinal force or the self aligning moment of the tyre

B, C, D, E = shape factors which govern the exact shape of the curve; they are functions of the normal load and camber angle of the tyre

x = the slip angle of the tyre

Equation (1) was first presented in 1987 in reference [31] and has been the subject of much study and revision since then. A version of the formula supplied for the current research, for example incorporates extra constant terms to improve the fit of the model to real data. [32]

2. Experimental Data Collection

This chapter describes the experimental vehicle and instrumentation used in the research as well as the objective tests performed to characterise its handling. Sixteen vehicle set-ups were specified to maximise the range of handling responses for both the model validation and subjective-objective correlation work. It is important to test the model and to correlate subjective ratings over a wide range of operating conditions if broadly-based conclusions are to be drawn.

The first step in specifying the vehicle configurations was measuring suspension, mass, inertia, and tyre properties. Vehicle set-ups were then determined according to a factorial experiment where by each property was varied between two possible settings, depending upon the particular configuration.

Each vehicle set-up was subjected to five objective tests: steady state circular, step input, pseudo-random steer, impulse steer and lane change. The presentation of the results focuses on showing: i) typical results, ii) that a wide range of responses was obtained and iii) that the repeatability of the data was good.

2.1 Test Vehicle and Instrumentation

The experimental vehicle, pictured in Figure 2-1, was a prototype saloon car for which a variety of suspension components were available. This, in turn, allowed a broad range of handling characteristics to be achieved through different set-ups. Except for the wide variety of suspension development components available, the vehicle was typical of many front wheel drive cars with a manual transmission and a four cylinder engine. Appendix 2A details some basic vehicle specifications. The decision to use a single vehicle in different configurations rather than a pool of vehicles effectively allowed a wider range of vehicles (or more specifically vehicle configurations) to be tested. To have conducted the research by procuring multiple vehicles and the modelling data for each of them was not practical. Besides the additional costs, multiple vehicles would have complicated the subjective data collection with extraneous factors such as vehicle appearances and ergonomics.

Figure 2-1 The Experimental vehicle

The instrumentation consisted of a collection of transducers feeding into a digital data acquisition system. This set-up was consistent with the recommendations of the ISO standards applicable to the objective tests, described later in this chapter. All components were regularly maintained and calibrated to ISO standards by MIRA's Calibration Department. The transducers used are listed in Table 2-1. Recording of data during the experimental work was controlled by proprietary software written by the MIRA Vehicle Dynamics Department. In all testing, data was sampled at 40 Hz, well above the frequency range of interest in handling work.

Table 2-1 Instrumentation used for objective data collection

Response	Transducer Used
Lateral acceleration	Accelerometer installed at vehicle centre of gravity
Road wheel steer angle	Linear potentiometers
Roll and sideslip angle	Proprietary MIRA slip/roll trolley
Roll and yaw rate	Dual axis rate gyroscope
Handwheel angle and torque	Proprietary MIRA handwheel unit
Forward velocity	Non-contact speed sensor

2.2 Measurement and Specification of Vehicle Parameters

As noted in the previous section, the experimental vehicle was selected in part because a wide range of suspension components and wheels were available. In order to specify vehicle configurations which would yield a variety of handling responses a full set of suspension, inertia, damper and tyre characteristics were obtained. Examination of the data, detailed in the following sub-sections, led to eight vehicle parameters being selected for use in modifying vehicle configurations. Graphs depicting the actual characteristics of each parameter are not presented in this chapter since they are more appropriately examined in the context of the modelling work of Chapter 4.

2.2.1 Suspension Kinematic and Compliance - Front and Rear Roll Stiffnesses

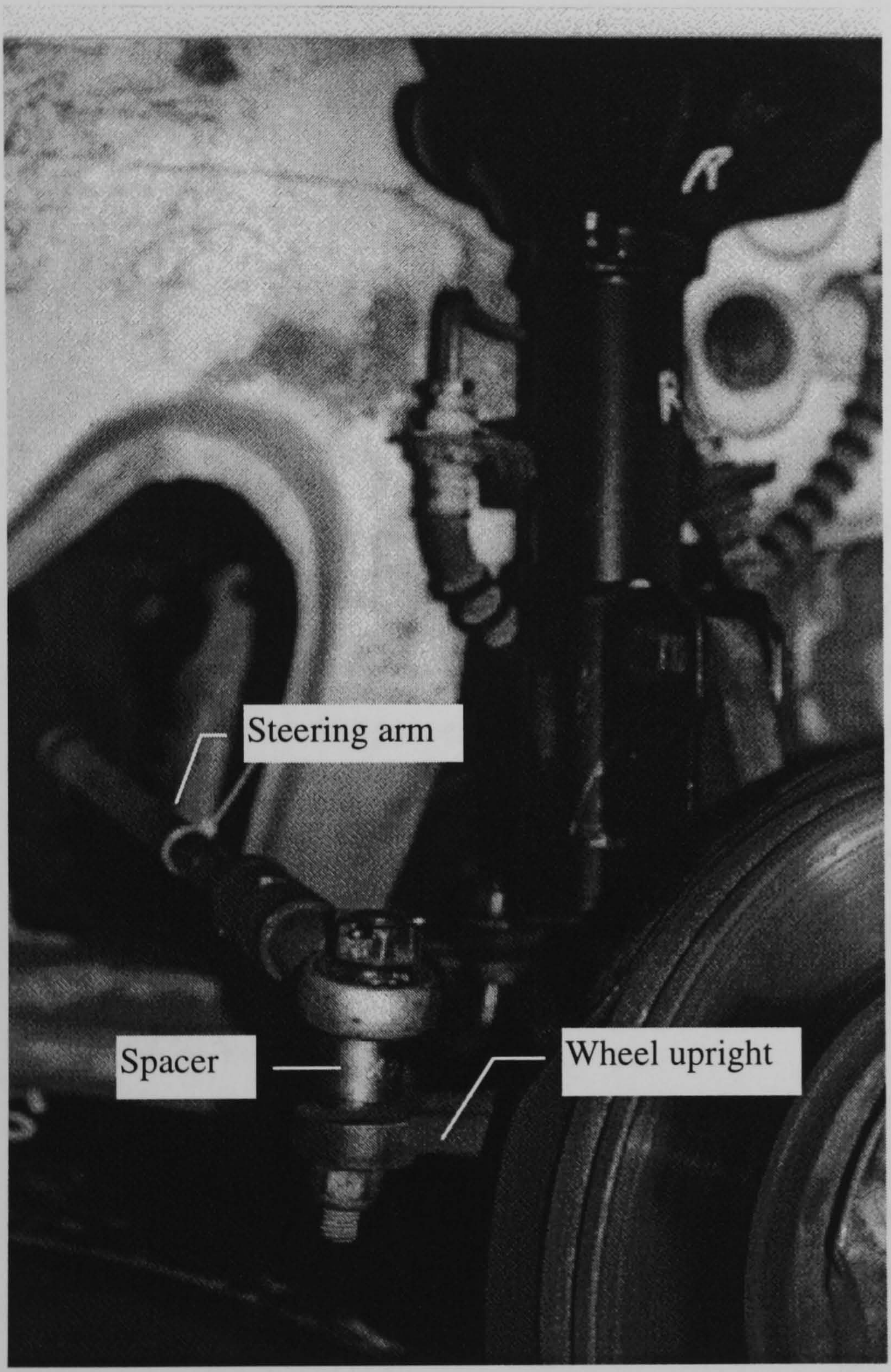
Suspension and steering characteristics were measured by Michelin at its Stoke-On-Trent facilities in England. Michelin does such measurements using a specialised rig on a day to day basis and was thus particularly suited to conducting the measurements. In total five configurations, incorporating a variety of springs and roll bars, were tested. The resulting kinematic and compliance characteristics for the front suspension, rear suspension and steering system were tabulated and graphed in a standard report. [1] Of particular interest here were the front and rear roll stiffnesses for which two levels, corresponding to the hardest and softest achievable settings, were selected. For the front suspension the selected stiffnesses were: 31 056 Nm/rad and 17 419 Nm/rad. For the rear suspension the values were: 20 398 Nm/rad and 16 788 Nm/rad.

2.2.2 Bump Steer

In addition to the suspension properties measured at Michelin one additional characteristic, the *bump steer* of the front suspension, was also modified and measured. Defined as the ratio of road wheel steer angle to vertical travel, *bump steer* had been noted in previous work with the vehicle to have a significant effect on the subjective and objective handling properties of the vehicle. [2] By varying the height of a spacer on the outboard end of the steering arms, the amount of road wheel steer angle caused by vertical travel was easily changed. (Figure 2-2) In total three spacer settings were examined and the corresponding steer vs. vertical travel curves plotted.

In the final experimental specification two settings were selected corresponding to a neutral characteristic and a roll oversteer characteristic. Using the slope at zero travel to differentiate between settings, the bump steer was set to 0.0439 deg/m or 0.0019 deg/m.

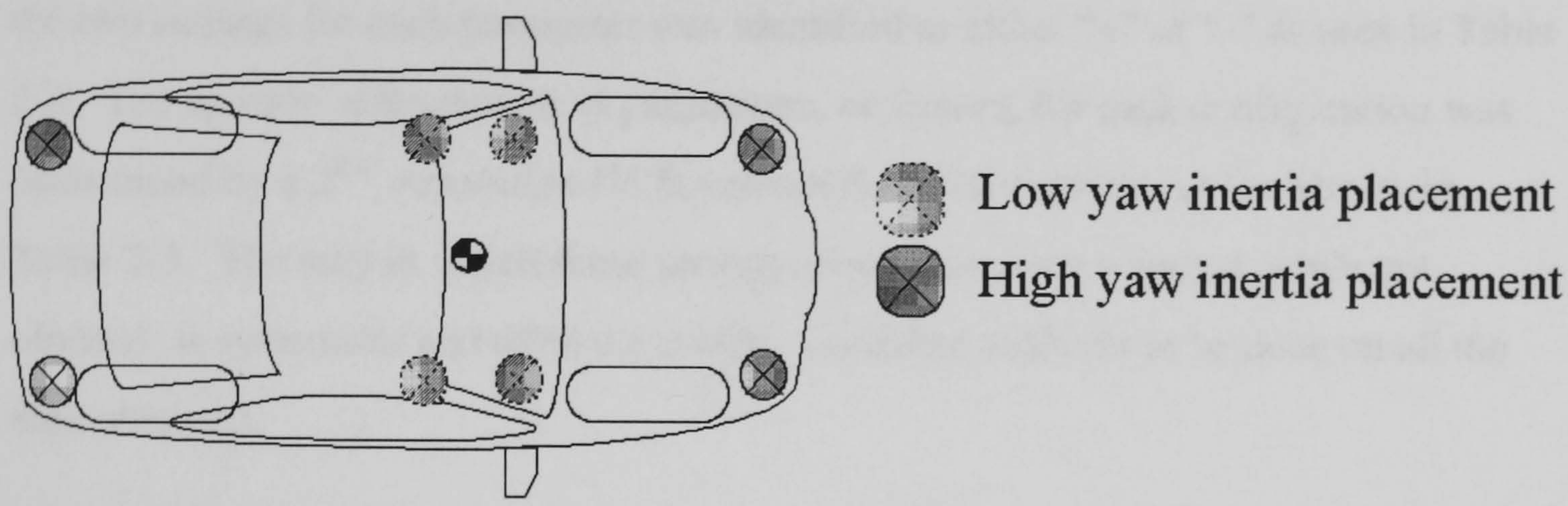
Figure 2-2 Spacers used to modify the front suspension bump steer characteristic



2.2.3 Inertial Properties

Inertial properties of the whole vehicle, wheels, and steering wheel were measured by a commercial laboratory which conducts such work on a day to day basis. After these measurements, ballast was added to the vehicle in order to change the yaw inertia between two experimental set-ups. The placement of ballast involved 20 kg bags of lead shot, located either at outboard or inboard positions as shown in Figure 2-3. This was done to maximise the change in yaw moment of inertia but to minimise changes in roll inertia and longitudinal weight distribution. The actual yaw inertia values were 2051 kgm^2 and 1746 kgm^2.

Figure 2-3 Placement of ballast in vehicle.



2.2.4 Front and Rear Damping

The dampers supplied for the vehicle were of the "take apart" variety which allow thousands of combinations of valves and springs to be fitted, giving almost any damping characteristic. Unlike the selection of roll stiffness, where measurements were done first, two damper settings for each of the front and rear suspensions were selected by assembling a "soft" setting and "hard" setting and measuring the characteristics afterwards. The damper measurements were done courtesy of the manufacturer. Using slopes at 0 m/s on the force vs. velocity curves to differentiate between settings, the front damping was either 2185 Ns/m or 790 Ns/m and the rears were 5188 Ns/m or 1785 Ns/m.

2.2.5 Front and Rear Tyres

Two tyres sizes, 175/70R13 and 185/60R14, were selected based on the wheel sizes available for the vehicle. The lateral force characteristics were provided by Michelin for the modelling work. In total four sets of each size were supplied.

2.3 Experimental Design - A Factorial Approach

A factorial approach was adopted in specifying the experimental configurations to accommodate the large number of possible combinations of vehicle parameters. The following sub-sections detail the vehicle set-ups and describe the calculation of factorial effects using this arrangement. The methodology underlying factorial experiments is described fully in reference [3].

2.3.1 Specification of Vehicle Configurations

The eight different vehicle parameters, identified in the previous section, were each varied between the two selected settings for a total of sixteen configurations. Each of the two settings for each parameter was identified as either "+" or "-" as seen in Table 2-2. The specific arrangement of parameters, or *factors*, for each configuration was determined by a 2^{8-4}, *resolution IV, fractional factorial experiment* [1] as shown in Table 2-3. The way in which these arrangements have been selected, while not obvious, is systematic and allows a number statistical analyses to be done on all the data obtained.

Tyre wear was accommodated by assigning sets of tyres to specific blocks, each with four configurations, and randomisation of the order of testing. Doing this, as well as restricting the severity of manoeuvres, assured that the systematic effects due to tyre wear were minimised.

Table 2-2 Vehicle parameters varied during experimental work

	Level	
Vehicle parameter	**+**	**-**
1. Front tyres	185/60 R14	175/70 R13
2. Rear tyres	185/60 R14	175/70 R13
3. Front damping	2185 Ns/m *	790 Ns/m *
4. Rear damping	5188 Ns/m *	1785 Ns/m *
5. Front roll stiffness	31 056 Nm/rad	17 419 Nm/rad
6. Rear roll stiffness	20 398 Nm/rad	16 788 Nm/rad
7. Yaw inertia	2051 kgm^2	1746 kgm^2
8. Bump steer	0.0439 deg/m *	0.0019 deg/m *

* These values are linearised quantities.

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[1] This compact description of the experimental design may be interpreted as follows. The 2^{8-4} denotes the fact that 8 factors were varied between 2 levels, but whereas a full examination of all possible factor combinations would involve 2^8 (= 256) configurations only a fraction of this number equal to 1/16 was done. (i.e. $(1/16) \times 2^8 = 2^{-4}2^8 = 2^{8-4}$ combinations). *Resolution IV* represents the fact the calculated effect each factor had on the vehicle response was not confounded with any interactive effects.

Table 2-3 Arrangement of vehicle parameters for sixteen test configurations

Config. #	Front roll stiffness	Rear tyres	Front damping	Rear damping	Front tyres	Rear roll stiffness	Yaw inertia	Bump Steer
1	-	-	-	+	+	+	-	+
2	+	-	-	-	-	+	+	+
3	-	+	-	-	+	-	+	+
4	+	+	-	+	-	-	-	+
5	-	-	+	+	-	-	+	+
6	+	-	+	-	+	-	-	+
7	-	+	+	-	-	+	-	+
8	+	+	+	+	+	+	+	+
9	+	+	+	-	-	-	+	-
10	-	+	+	+	+	-	-	-
11	+	-	+	+	-	+	-	-
12	-	-	+	-	+	+	+	-
13	+	+	-	-	+	+	-	-
14	-	+	-	+	-	+	+	-
15	+	-	-	+	+	-	+	-
16	-	-	-	-	-	-	-	-

2.3.2 Calculation of Effects

As stated in the previous sub-section the arrangement of parameters for each of the experimental configurations allowed statistical manipulation of the results. A specific example of such manipulation, involving a sensitivity analysis of the mathematical handling model, will be presented later in Chapter 4. However it is appropriate to describe the exact calculations here to clarify the "+" and "-" arrangement of parameters in the sixteen configurations.

Two steps are involved in the factorial analysis done in this work. The first is calculating the *main effect* that changing each factor from its "-" level to it "+" level has on the vehicle response. In the current context the "vehicle response" could be any objective or subjective measure obtained for the sixteen configurations. The second step involves examination of the *main effects* to see if any stand significantly apart from the rest.

Calculation of the *main effect* for a given parameter consists of averaging the responses obtained when the parameter was set at its "+" condition and subtracting the similarly obtained average response when the parameter was set at its "-" condition. For example, referring to Table 2-4, suppose sixteen side slip angles, measured at 0.4

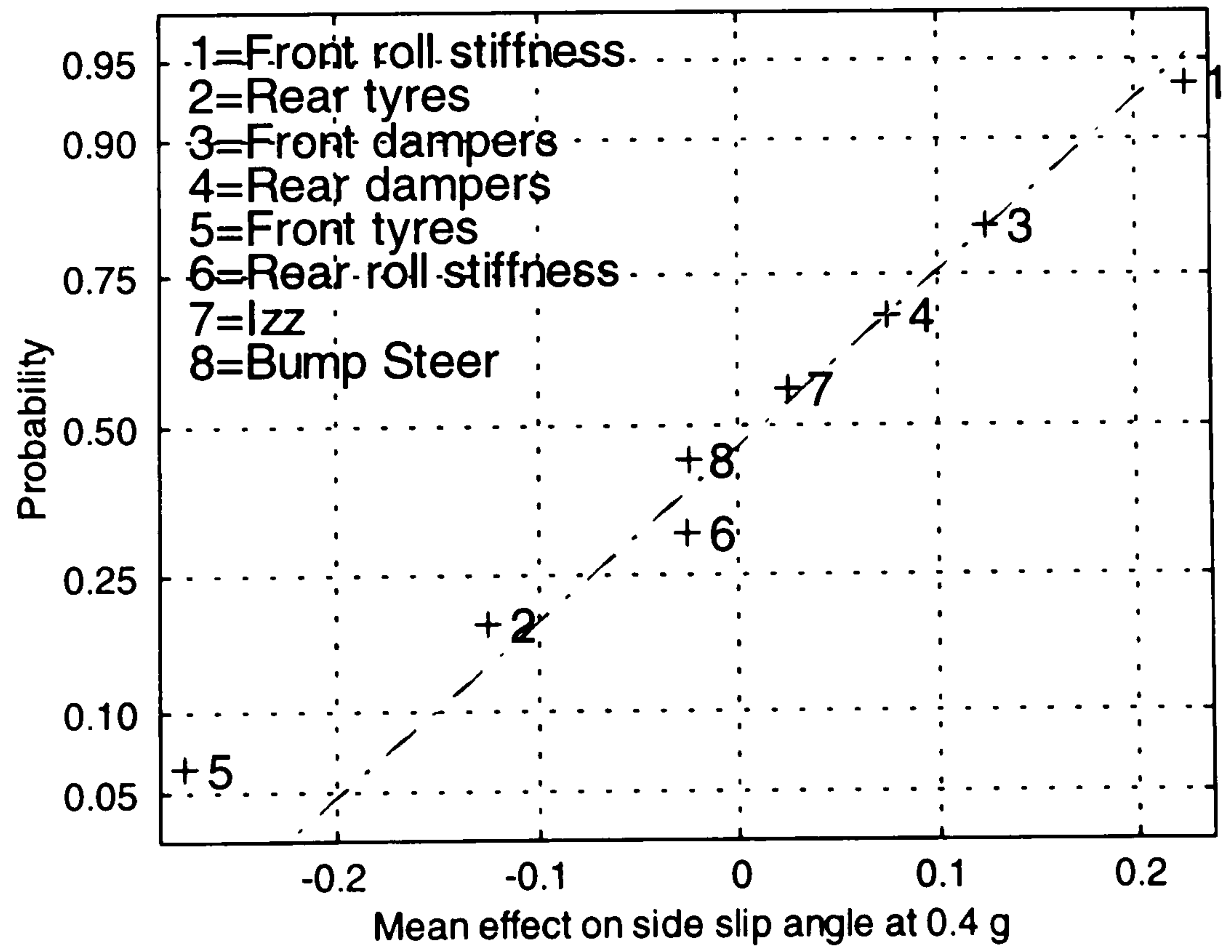
g during a steady state test, were obtained as shown in column 2. To estimate the *main effect* of front roll stiffness on this response, each slip angle value would first be multiplied by +1 or -1 depending upon the corresponding setting of roll stiffness setting. Column 3 is copied from Table 2-3. The products of this multiplication, shown in column 4, are summed together and divided by 8 giving 0.225. This result is the mean change in steady state lateral acceleration when roll stiffness is changed from its "-" condition to its "+" condition.

By performing the same calculations for the other parameters and plotting them on a normal probability plot, Figure 2-4, the relative effects of each parameter on the vehicle response can be seen. Of particular interest are factors whose effects do not lie on a straight line. The effects of such factors are significantly different from the rest in a statistical sense and thus may be important since their influence on the vehicle response is greatest. In the example shown in Figure 2-4 it appears that factor number 5, front tyres, might be significant in this way.

Table 2-4 Example factorial calculation

1	2	3	4
Configuration Number	Steady state slide slip at 0.4 g (deg)	Setting for Front roll stiffness	Column 2 × Column 3
1	4.8	-	-4.8
2	3.3	+	+3.3
3	3.5	-	-3.5
4	3.2	+	+3.2
5	4.9	-	-4.9
6	3.1	+	+3.1
7	3.6	-	-3.6
8	2.9	+	+2.9
9	5.3	+	+5.3
10	2.9	-	-2.9
11	4.3	+	+4.3
12	2.9	-	-2.9
13	4.5	+	+4.5
14	3.0	-	-3.0
15	3.7	+	+3.7
16	2.9	-	-2.9
		Main effect = Σ(Column 4)/8	0.225

Figure 2-4 Example normal probability plot for steady state slip angle



2.4 Objective Test Procedures

Five distinct tests, defined in ISO standards or technical reports, were used to characterise the handling performance of each vehicle configuration:

i) Steady state circular test procedure, ISO 4138 - 1982(E) [4]
ii) Step input, ISO 7401:1988(E) [5]
iii) Pseudo-random steer, ISO 7401:1988(E) [5]
iv) Impulse steer, ISO 7401:1988(E) [5]
v) Lane change, ISO technical report 3888 [6]

Table 2-5 details the speeds and lateral accelerations achieved during the measurements as well as the recorded responses and derived metrics. All of this testing as well as post-processing of the data was done according to standard practice as outlined in the relevant references. Because the tests are well documented in these papers a relatively brief description of them is given in the following sub-sections, along with details specific to the current work such as test speeds and handwheel inputs.

Table 2-5 Objective test program

Test	Description	Measured responses	Derived Metrics
Steady state steering pad	33 m radius, 0 to approx. 6 m/s^2 lateral acceleration clockwise and anti-clockwise.	Lateral acceleration Roll angle Yaw angle Roadwheel steer angle Handwheel steer angle Handwheel torque	d(hand wheel Angle)/d(lateral acceleration) d(road wheel angle)/d(lateral acceleration) d(front slip)/d(Lateral acceleration) d(side slip)/d(lateral acceleration) d(hand wheel torque)/d(lateral acceleration) d(roll angle)/d(lateral acceleration)
Step steer input	2 , 4, 6 m/s^2 lateral acceleration clockwise and anti-clockwise	Lateral acceleration Roll rate Yaw rate Road wheel steer angle Handwheel steer angle Handwheel torque	Peak lateral acceleration response time Peak road wheel steer angle and response time Peak roll rate and response time Peak yaw rate and response time Peak steering torque and response time
Impulse and Pseudo-random steer, (frequency response)	2 m/s^2 impulse inputs. Time histories transformed to frequency domain using handwheel angle as input.	Lateral acceleration Roll rate Yaw rate Road wheel steer angle Hand wheel steer angle Hand wheel torque	Lateral acceleration gain and phase Road wheel steer gain and phase Roll rate gain and phase Yaw rate gain and phase Steering torque gain and phase
Lane change	40 and 60 km/h runs through a pylon marked course	Lateral acceleration Roll rate Yaw rate Road wheel steer angle Handwheel steer angle Handwheel torque	No metrics used for quantitative analysis. Time histories used for qualitative comparison during model validation.

2.4.1 Steady State Circular Test

This test involves piloting the vehicle around a fixed radius circle at progressively higher speeds. Typically the test begins with the driver directing the vehicle around the circle at near zero speed and then incrementing the speed up in 2 km/h steps. At each increment a condition of steady state cornering is achieved, during which the vehicle response parameters are recorded. i.e. *Lateral acceleration, road wheel steer angles, roll angle, body side slip angle, handwheel angle, handwheel torque and speed.* In the current work the maximum speed reached in each test corresponded to a lateral acceleration of approximately 0.7 g on a 33 m radius circle. Although capable of greater cornering the maximum lateral acceleration was intentionally kept low to reduce tyre wear. Data was recorded in the clockwise and anti-clockwise directions. Postprocessing involved plotting the measured responses against lateral acceleration, fitting curves to this data and then calculating various gradients. i.e.

d(handwheel angle)/d(lateral acceleration),

d(road wheel angle)/d(lateral acceleration),

d(front slip angle)/d(lateral acceleration), d(sideslip angle)/d(lateral acceleration),

d(handwheel torque)/d(lateral acceleration).

2.4.2 Step Input Test

Commonly referred to as the *J-turn* test because of the shape of the path followed by the vehicle during testing, this procedure involves driving the car in a straight line at constant speed and then applying a step steer input. Vehicle responses are measured from before the input until after the vehicle has achieved a steady state. The test speed used in this work was set at 80 km/h and handwheel inputs were selected to give steady state lateral accelerations of ±0.2, ±0.4, and ±0.6 g. At least three repeat runs were made for each lateral acceleration. The measured vehicle responses were: *lateral acceleration, road wheel angles, roll rate, yaw rate, hand wheel angle, steering torque and speed.* Post-processing involved ensembling runs for each lateral acceleration and obtaining peak response values and response times for each vehicle response. Due to the lack of a distinct peak in many of the tested configurations the response time to achieve 90% of the steady state value was obtained as a more reliable indicator of dynamic performance.

2.4.3 Pseudo-random and Impulse Steer Tests

These procedures are similar in that they both yield responses in the frequency domain and the driving methodology is identical except for the shape of the handwheel input. In both tests the vehicle is driven in a straight line at a constant speed, while the driver applies either a sinusoidal input or a series of impulses to the hand wheel. In the current work the test speeds were specified as 100 km/h for the pseudo-random test and 80 km/h for the impulse. For each configuration the magnitude of the handwheel input was set so that the maximum lateral accelerations were ± 0.2 g - well within the linear response range for passenger cars. The measured responses were the same as the step input tests.

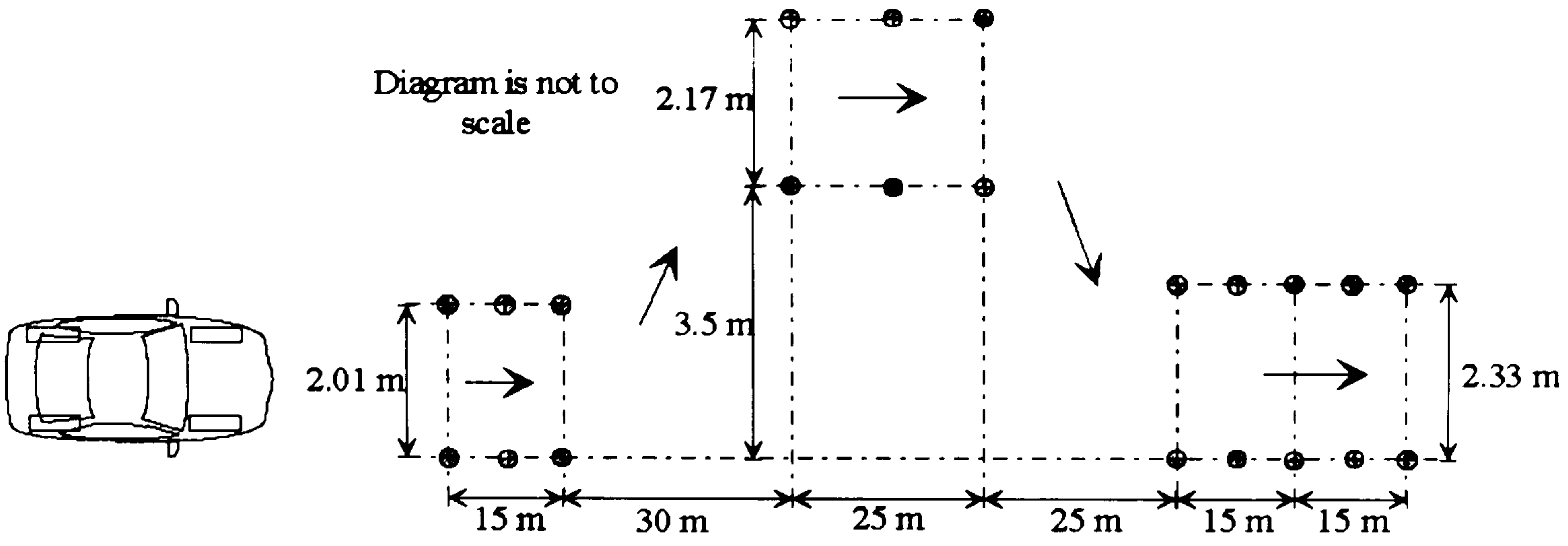
Post-processing of the data involved transformation of the time histories from each test into the frequency domain using Fast Fourier Transforms. Typically the hand wheel angle or road wheel angle is used as the input for these calculations and in the current work the former was used. The derived responses are in the form of gains and phases for each of the vehicle responses measured. i.e. *lateral acceleration, road wheel steer angle, roll rate, yaw rate, and steering torque.*

2.4.4 Severe Lane Change

This test differs from the others because it is a closed loop test in which the results depend on the driver input. It requires the driver to negotiate a pylon marked course (shown in Figure 2-5) at a constant speed without upsetting any of the pylons. Two speeds were specified for each set of tests - 50 km/h and 60 km/h. The responses measured were the same as for the step-input tests.

Because of the driver dependent nature of the results, the data collected from this test was unsuitable for subjective-objective correlation. However it was useful in the simulation validation due to the highly transient and severe nature of the input which provided a demanding test of the model.

Figure 2-5 Course layout for lane change tests



2.5 Results of Objective Testing

The presentation of the results is guided by the needs of the validation and correlation analyses which required tabulated metrics for comparison to simulated values and driver ratings. For each test, except lane changing, typical response curves are plotted to highlight the special features of each test. Because of the closed loop nature of the lane change responses the presentation of these results is left to Chapter 5 when model validation is addressed. The complete presentation of the test data is made in the appendices. In addition to simply presenting the results, selected steady state and transient responses are examined to highlight the wide range of handling characteristics achieved over the sixteen configurations. Data from both the linear and non-linear handling region are considerd. Finally, the repeatability of the steady state and frequency response data is considered in two case studies where repeat tests were conducted.

2.5.1 Steady State Circular Test

2.5.1.1 Raw Data and Derived Metrics

Figure 2-6 and Figure 2-7 depict typical results from the steady state test which were used in the validation and correlation analyses. The measured responses in Figure 2-6 show the *hand wheel angle, mean road wheel angle, roll angle, body slip angle* and *steer torque,* all plotted against *lateral acceleration.* The polynomial curves fitted to these data points yield the gradients, shown in Figure 2-7.

Appendix 2B tabulates, for the sixteen configurations, raw data and gradients corresponding to lateral accelerations of ±0.1 g, ±0.2 g, ±0.3 g, ±0.4 g, ±0.5 g.

Figure 2-6 Typical responses measured during a steady state circular test.

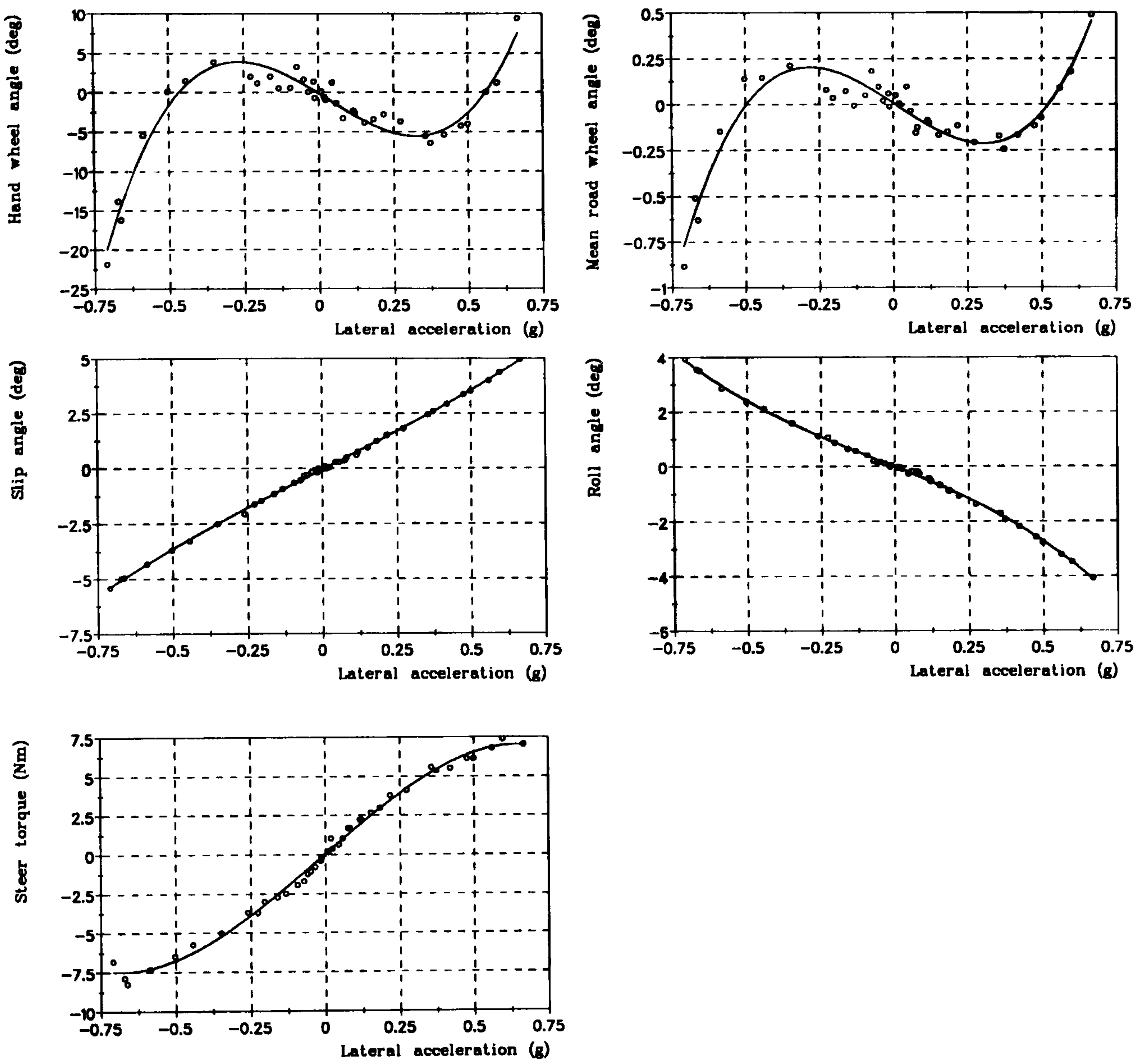
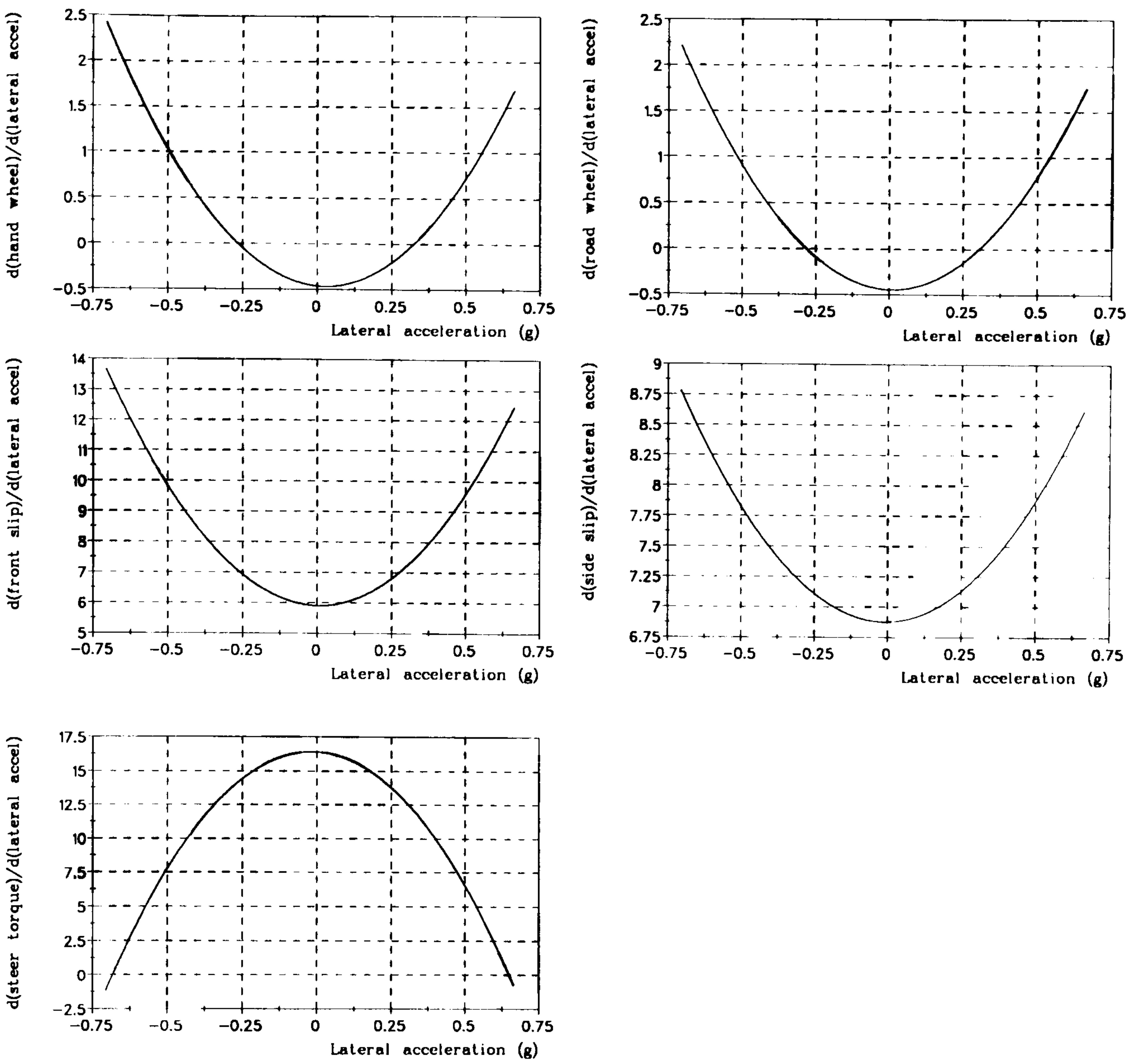


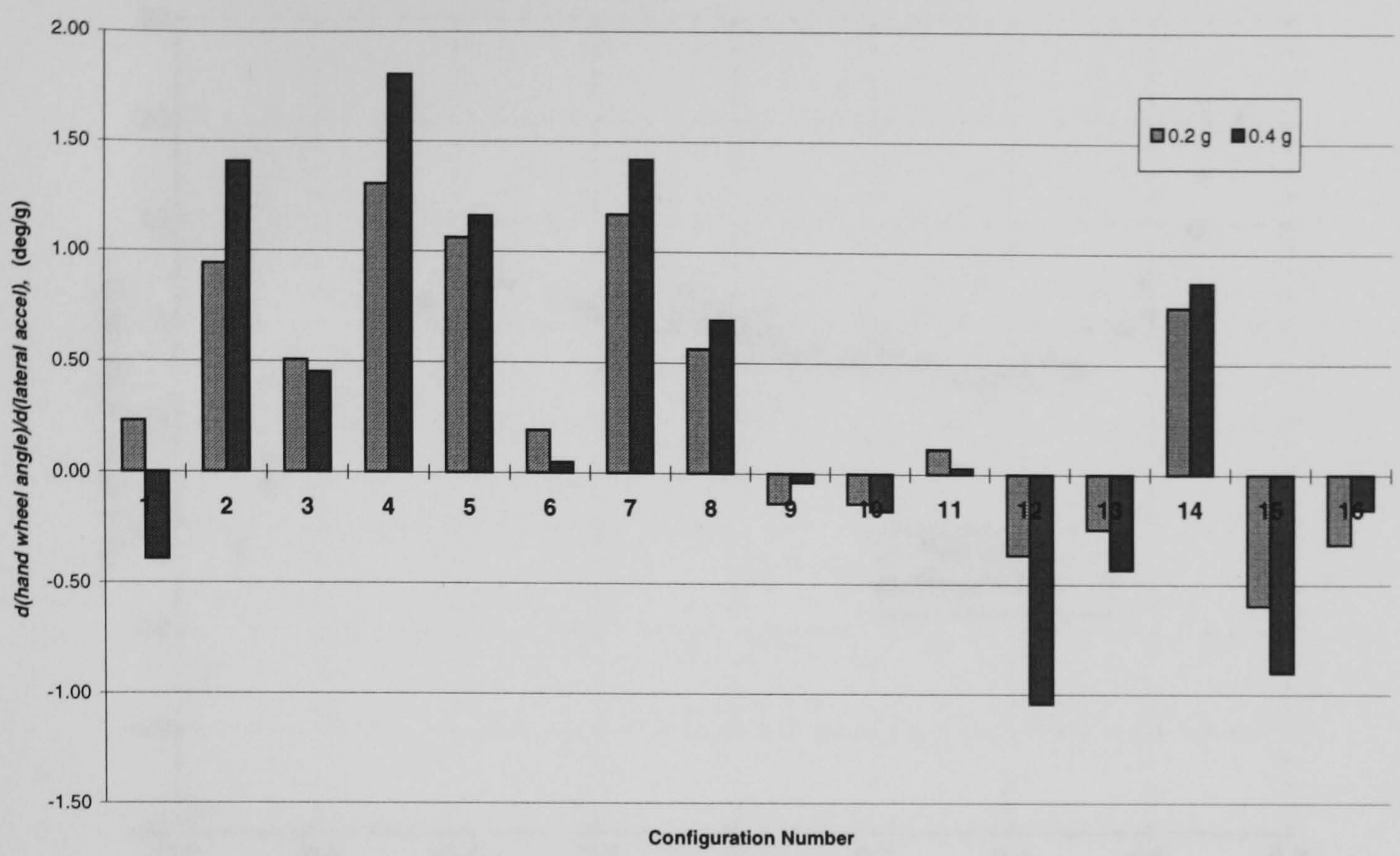
Figure 2-7 Typical steady state response gradients



2.5.1.2 Range of Steady State Responses

One of the important measures of handling relating the hand wheel input to cornering behaviour is the *d(hand wheel angle)/d(lateral acceleration)* gradient. Negative and positive values of this gradient respectively denote oversteering and understeering behaviour. Figure 2-8 shows the range of values obtained for this metric over sixteen configurations. For each configuration the average of the clockwise and anti-clockwise values at ±0.2 and ±0.4 g are shown. Note that 0.2 g is within the linear handling region, defined in Chapter 1, while 0.4 g is marginally outside of it. It can be seen from the values that both understeering and oversteering configurations, distributed over a wide range, were obtained. Similar statistics for the other gradients are tabulated in Appendix 2C.

Figure 2-8 *d(hand wheel angle)/d(lateral acceleration)* over sixteen configurations, each bar represents the average of the clockwise and anti-clockwise values



2.5.1.3 Repeatability of Steady State Results

During the experimental testing the opportunity was taken to assess the reliability of some of the collected data by conducting repeat tests and comparing the results. Figure 2-9 to Figure 2-13 show two steady state runs of configuration 10 which were recorded during a driver training exercise. The tests were conducted by different drivers, one of them a trainee engineer the other an experienced driver, at different times of the day. The "o"s denote the first test and the "+"s the second. The actual data can be found in Appendix 2D. It is quite clear from the figures that the results from the two runs are highly correlated. The differences between the data points are small and appear random. While this case study would ideally have been done with a greater separation in time and with more than one configuration it nonetheless demonstrates very good repeatabilty of the steady state results.

Figure 2-9 Repeatability of steady state test results: hand wheel angle

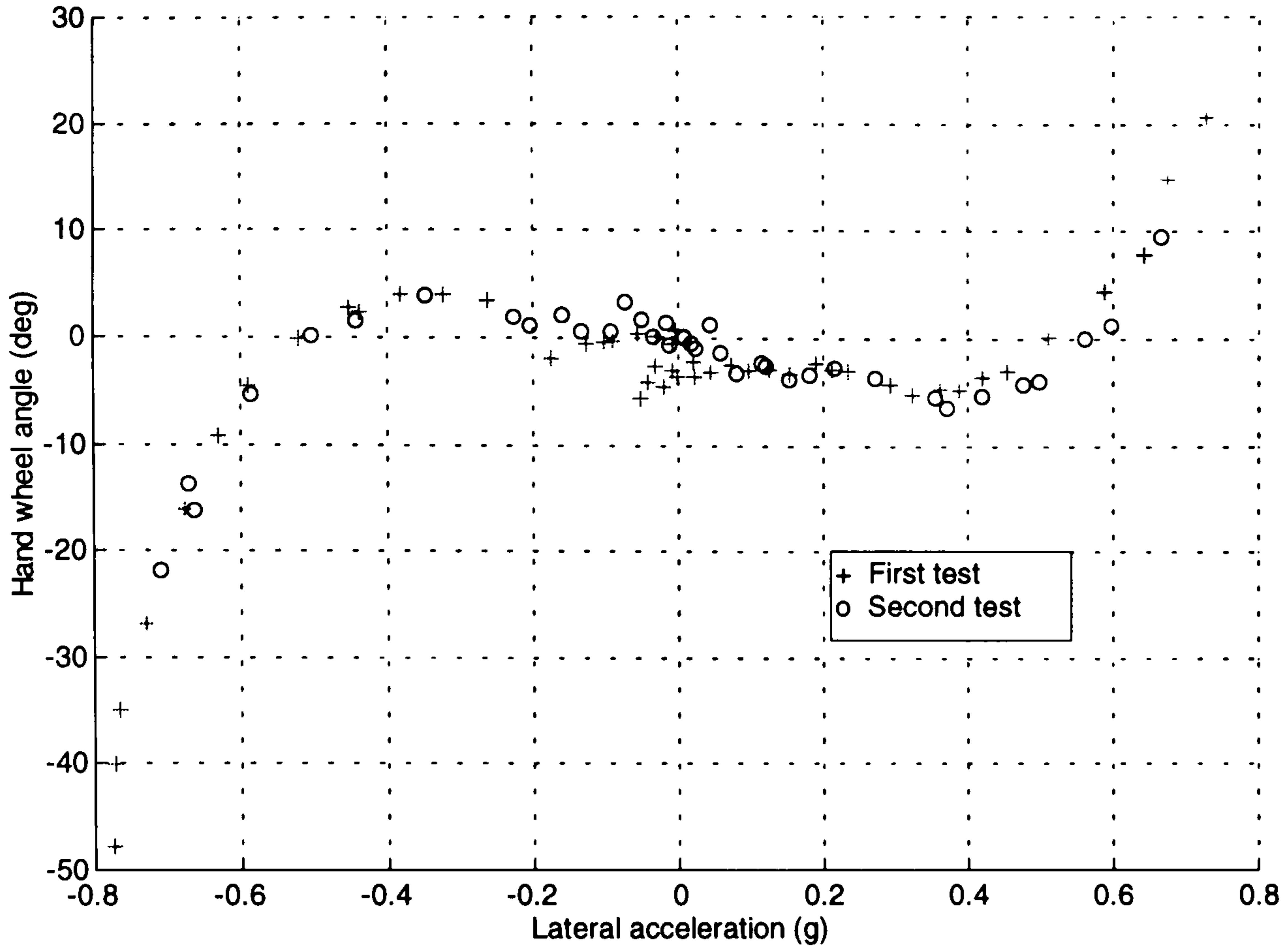


Figure 2-10 Repeatability of steady state test results: mean road wheel angle

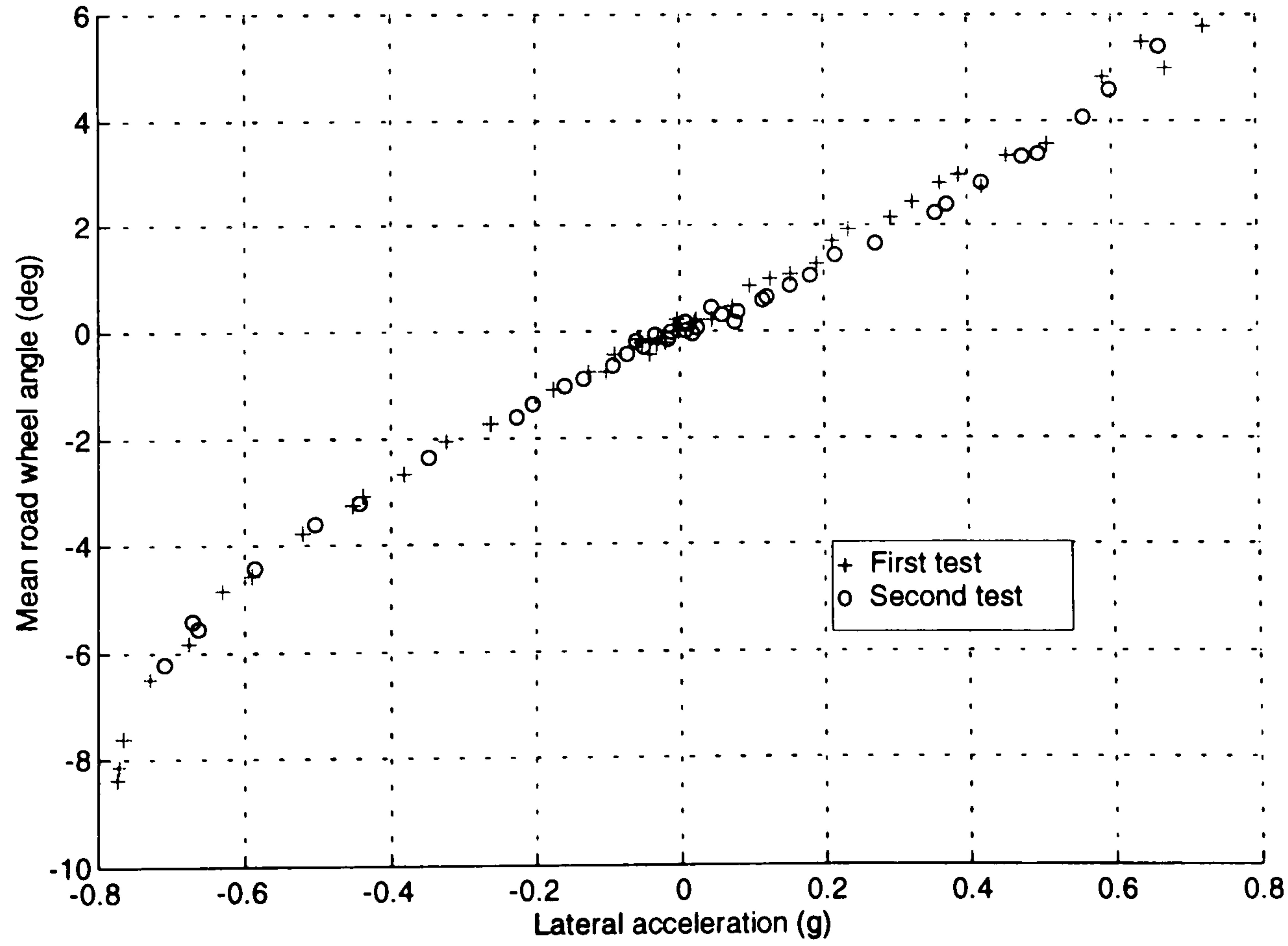


Figure 2-11 Repeatability of steady state test results: side slip angle

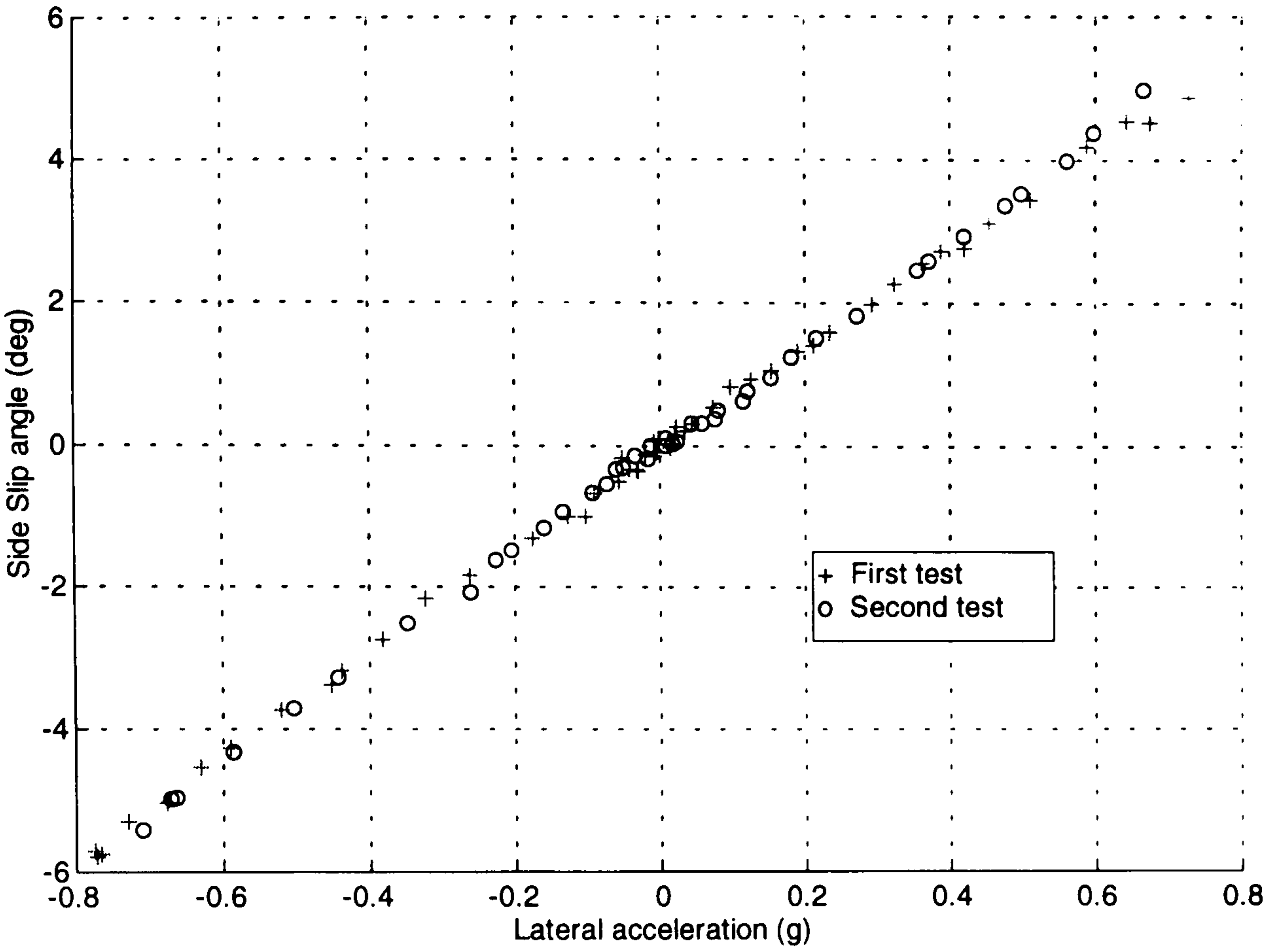


Figure 2-12 Repeatability of steady state test results: roll angle

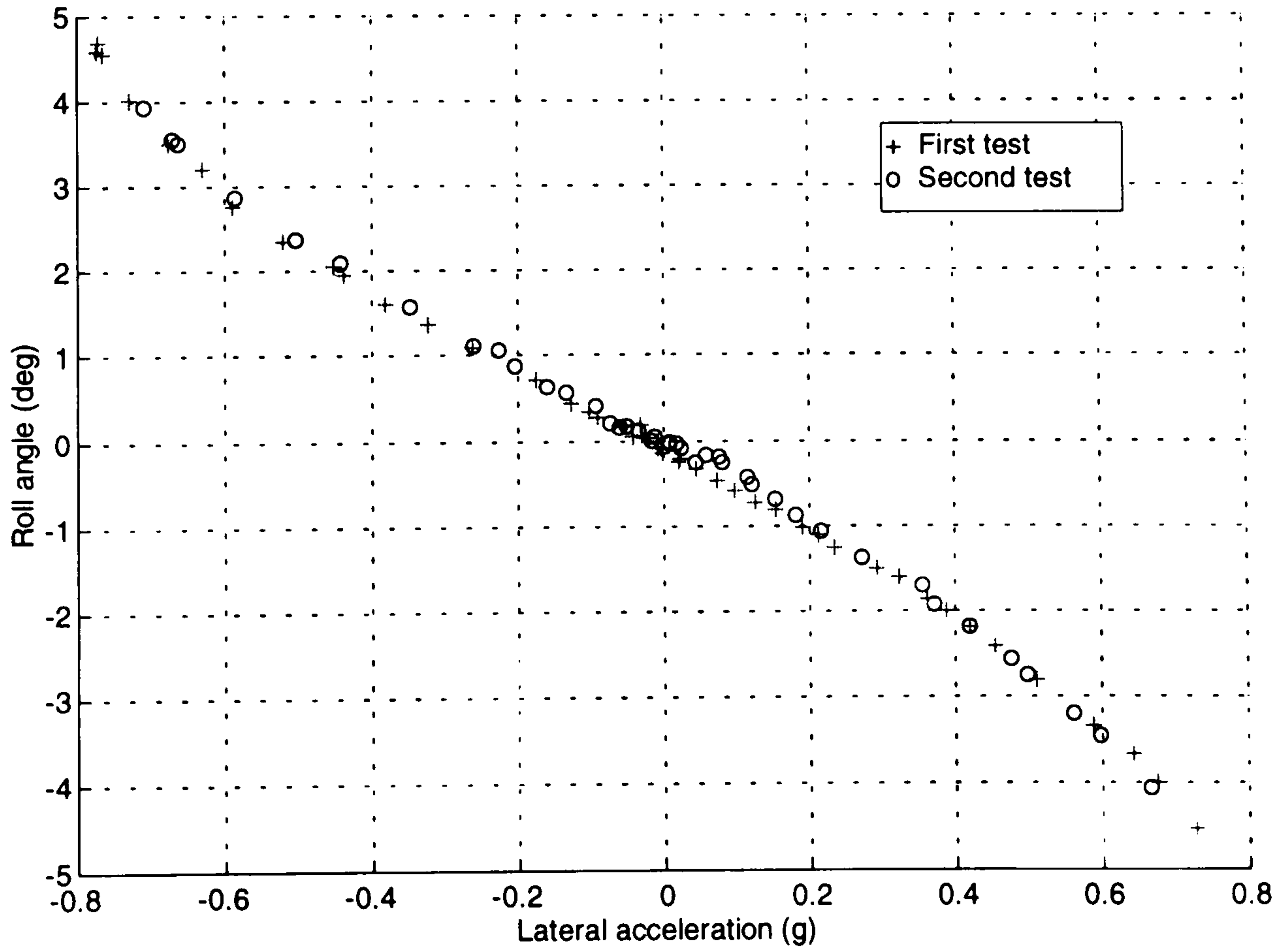
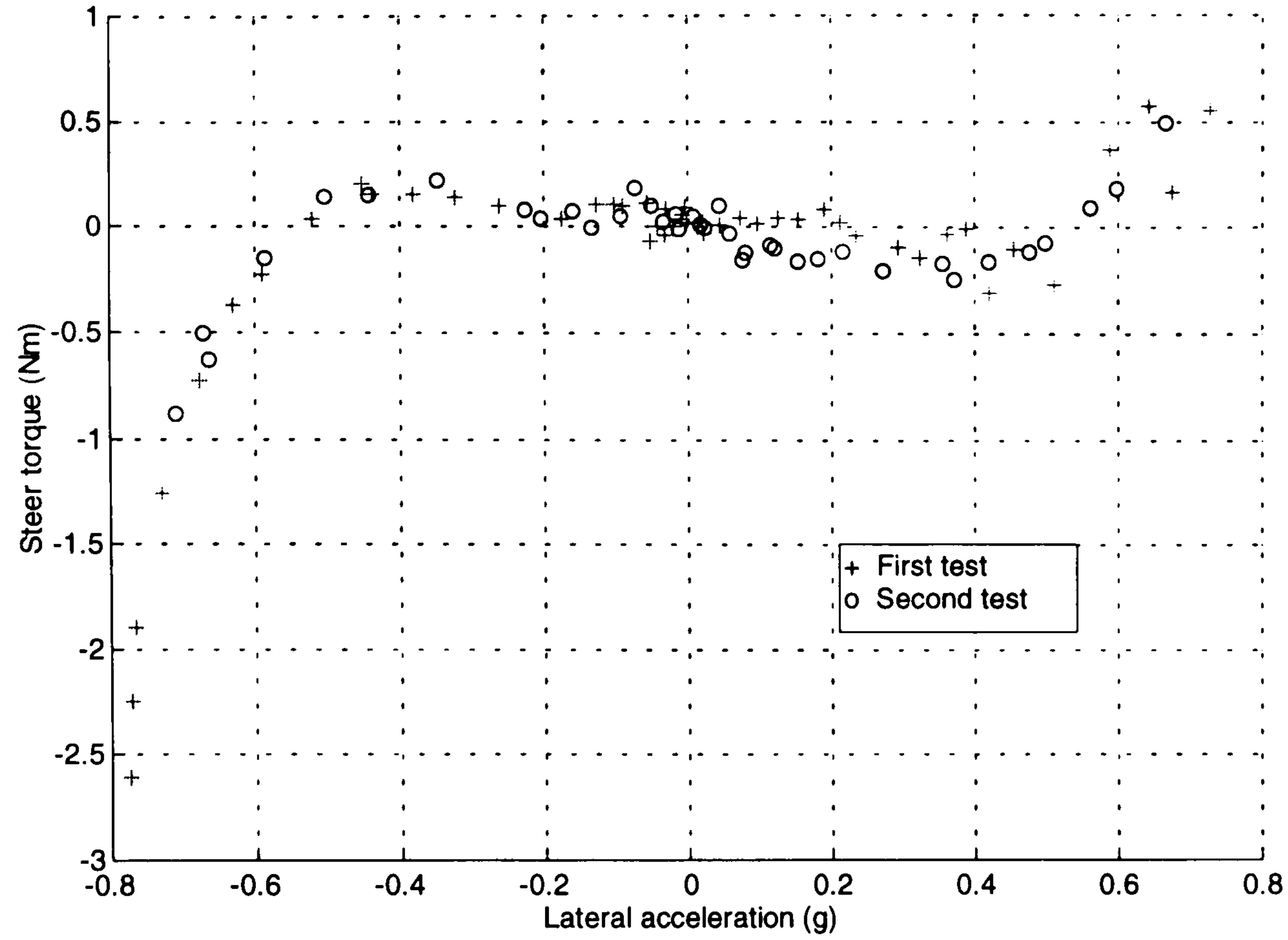


Figure 2-13 Repeatability of steady state test results: steer torque

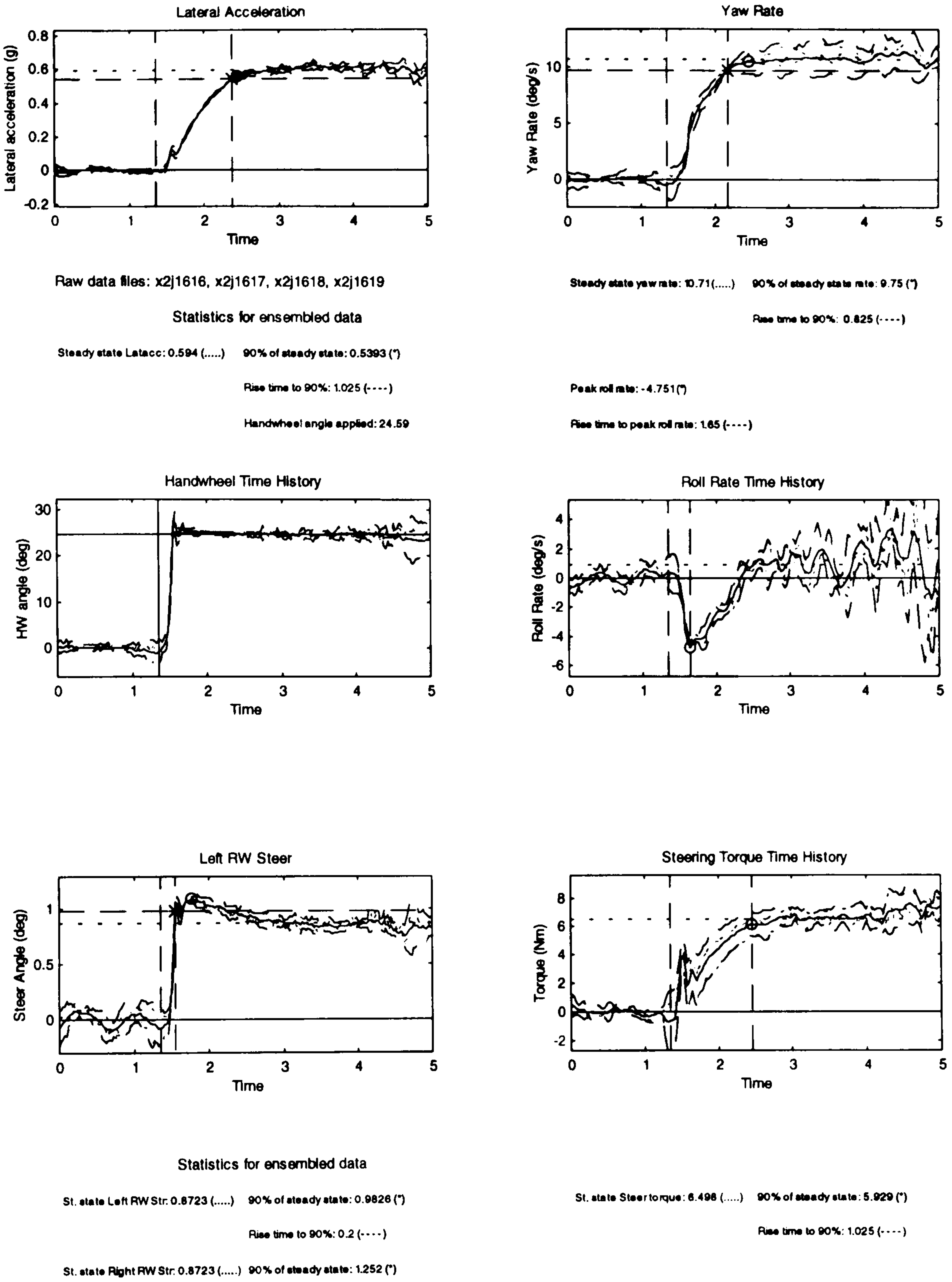


2.5.2 Step Input Test

2.5.2.1 Ensembled Data and Derived Metrics

Figure 2-14 shows individual and ensembled time histories for a 0.6 g j-turn as outputted by the computer program used to process the raw data. For each of *lateral acceleration, yaw rate, roll rate, road wheel angle and steer torque* the derived metrics relating to peak responses and response times are shown. A full presentation of the data from the sixteen configurations is assembled in Appendix 2E.

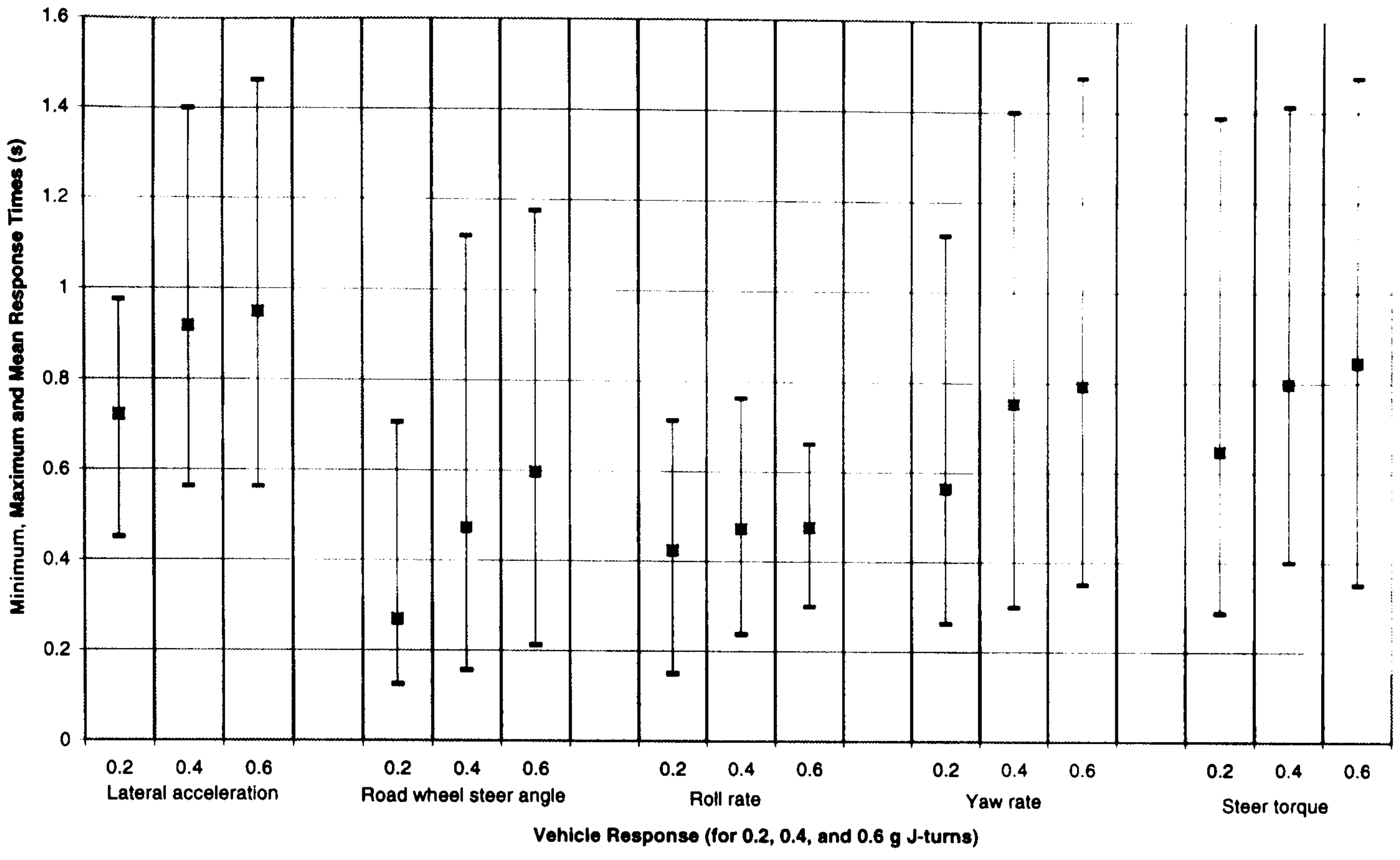
Figure 2-14 Ensembled response data and derived metrics from step-input test



2.5.2.2 Range of Responses Times

Using the response times as a simple measure of transient behaviour, Figure 2-15 was produced to show the range of values obtained for the various vehicle responses. As with the steady state data the clockwise and anticlockwise values were averaged together. It can be seen for each vehicle response that the percent change between the minimum and maximum values is typically greater than 100% - a good spread over sixteen configurations. Note also that these results are on both sides of 0.3 g lateral acceleration, which normally delineates between the linear and non-linear range of vehicle handling.

Figure 2-15 Response times obtained from step input tests



2.5.3 Frequency Response Tests

2.5.3.1 Bode Plots for Pseudo-Random Steer and Impulse Tests

Figure 2-16 to Figure 2-18 shows the frequency response, autospectral density, and coherence functions typically obtained from the two frequency domain tests. In particular Bode plots for *lateral acceleration, yaw rate and road wheel angle* are shown followed by the corresponding statistical plots. *Roll rate and steer torque* results were not used due to poor coherence in a significant number of configurations.

The important feature of the data in the figures is that the plotted gains and phases are valid for frequencies ranging from 0.1 to approximately 2.5 Hz. Note that the coherence function is close to 1.0 over this range for the three vehicle responses as shown in Figure 2-18. To ensure the use of reliable gains and phases, only values well within these limits, corresponding to 0.4, 0.7 and 1.0 Hz, were selected further analysis. Appendix 2F shows this data.

Figure 2-16 Frequency response gains and phase responses

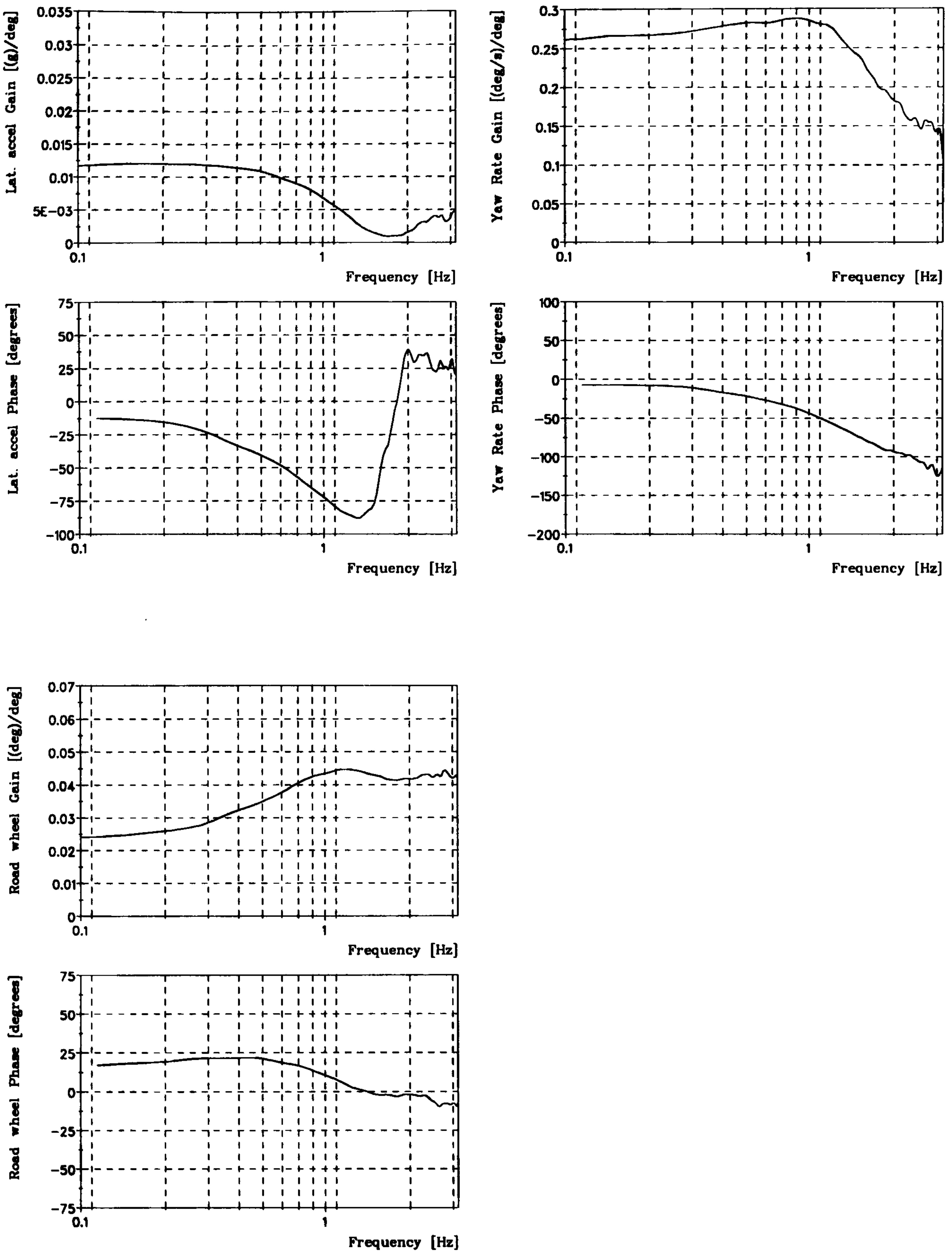


Figure 2-17 Autospectral densities from frequency response data

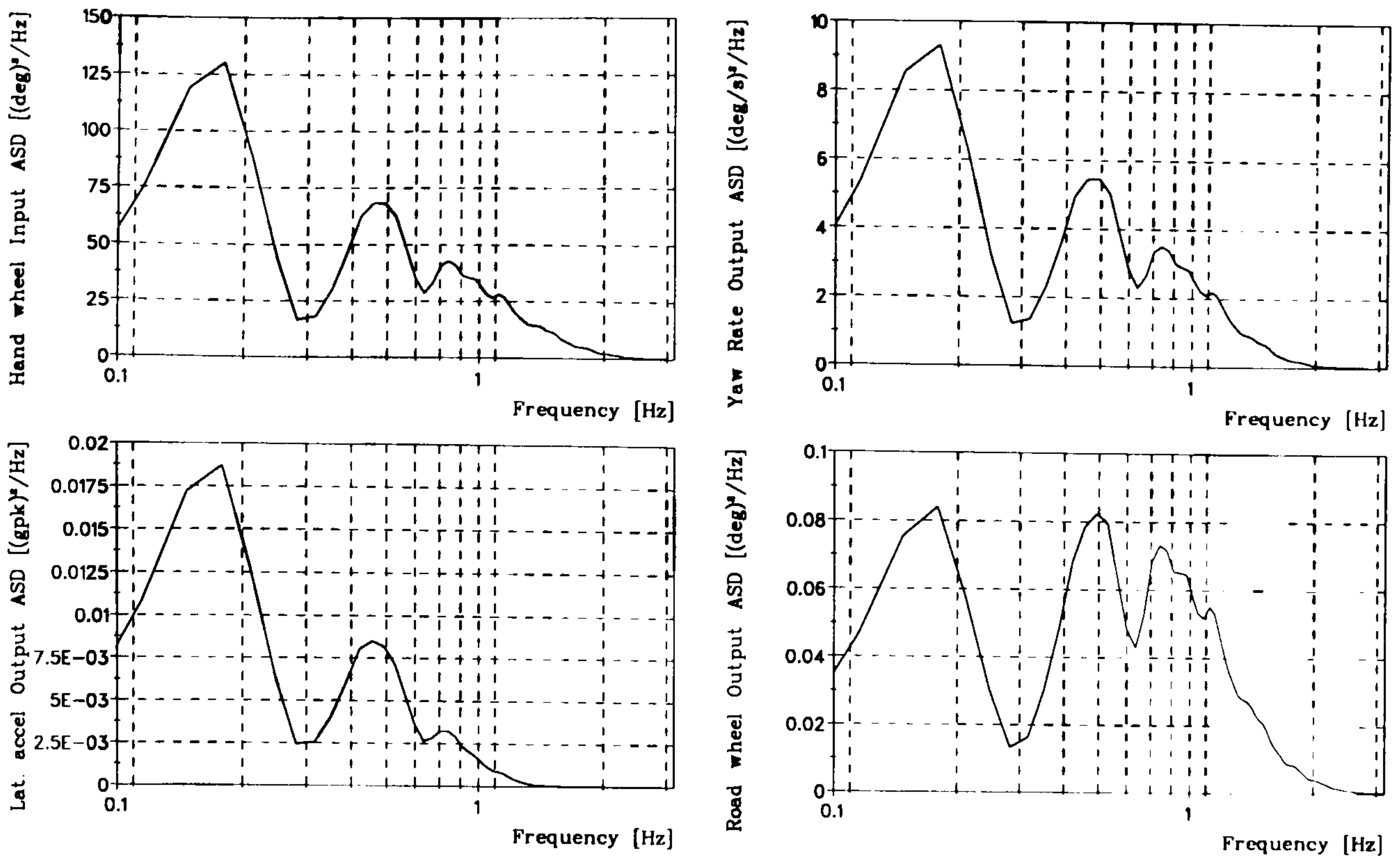
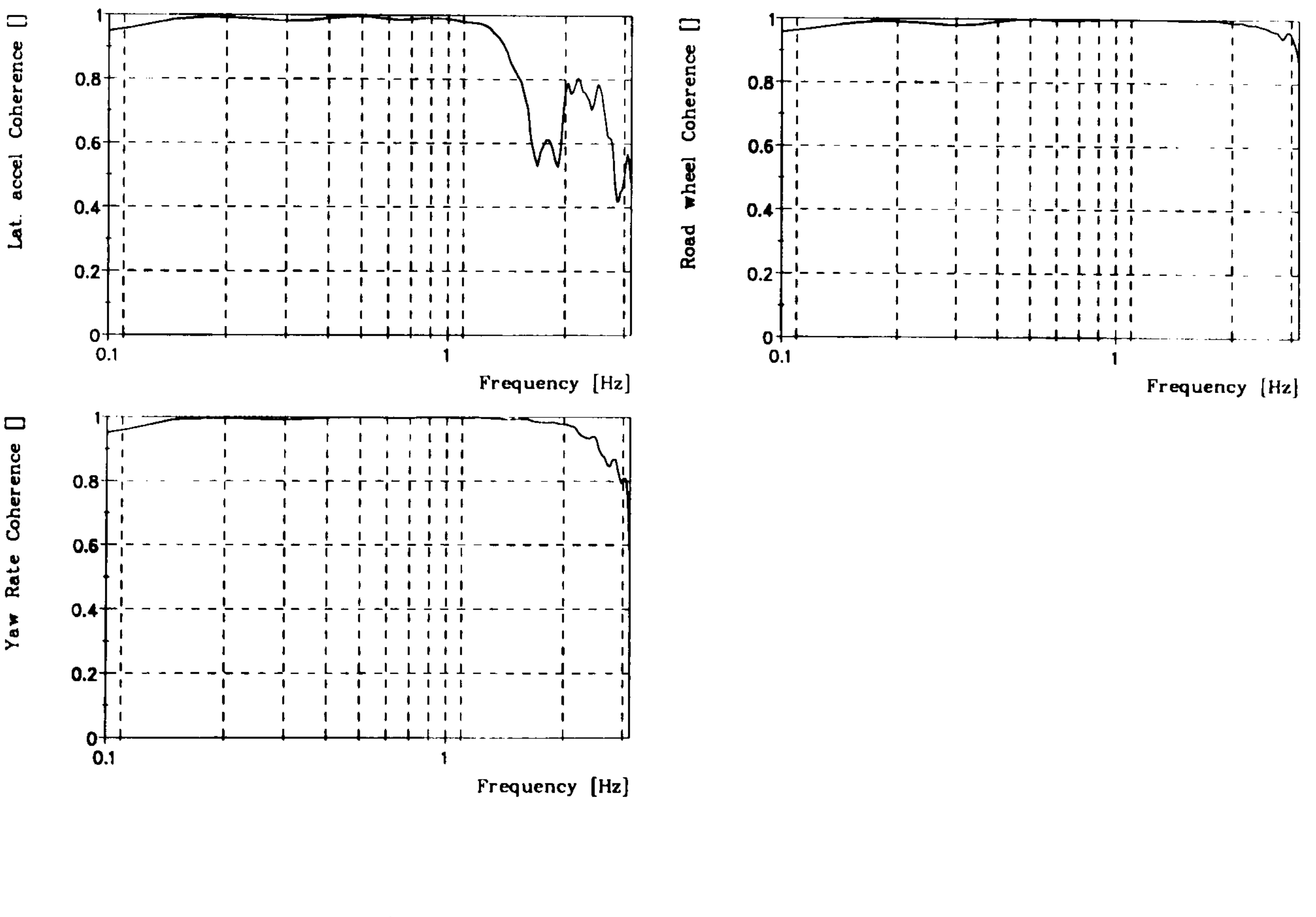


Figure 2-18 Coherence levels for frequency response data

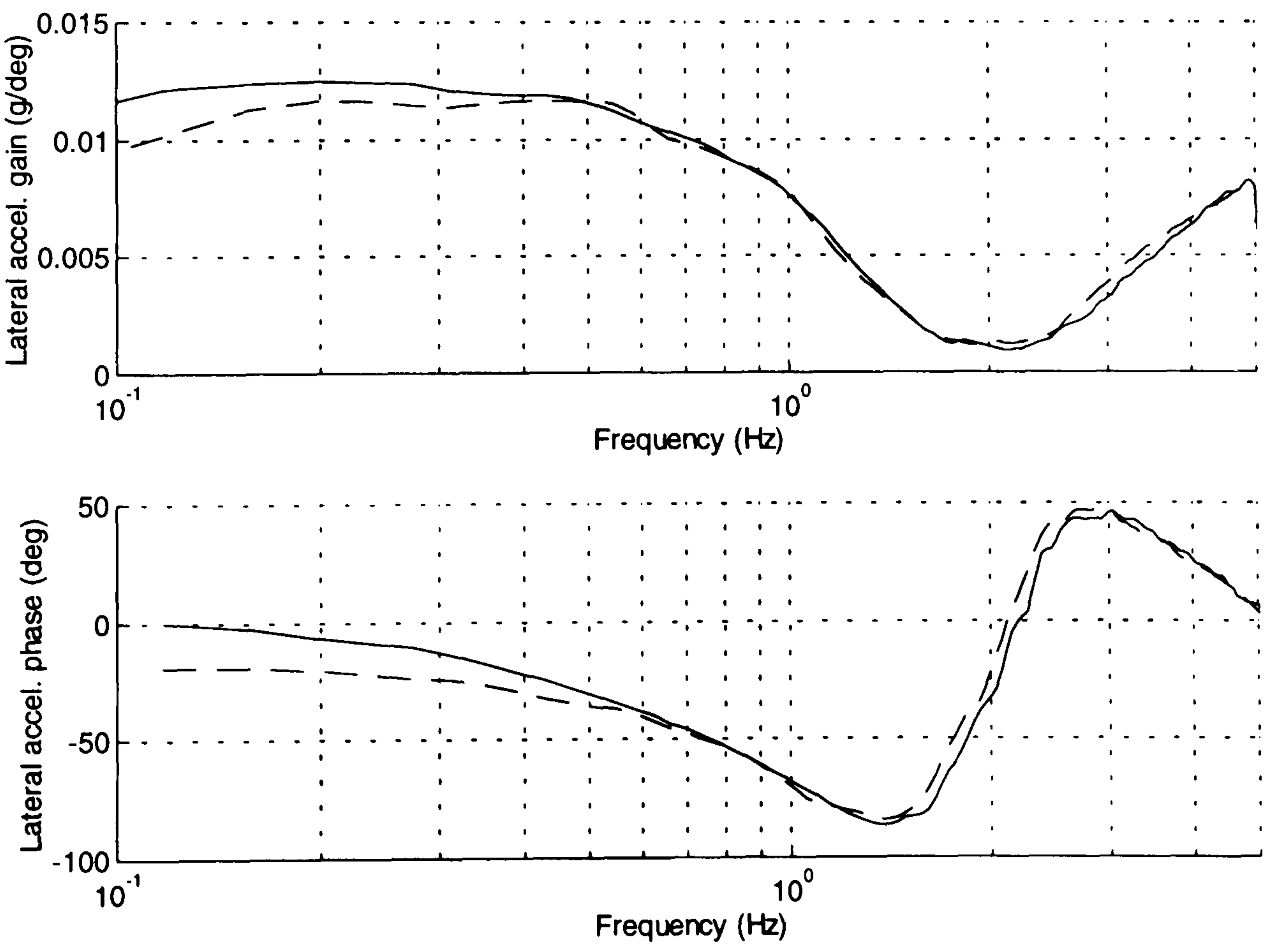


2.5.3.2 Repeatability of Frequency Response Results

In addition to the steady state repeatability study a similar exercise was done with the impulse test. Figure 2-19 to Figure 2-21 show the gains and phases obtained from tests conducted by different drivers on configuration 6, separated by almost four months. The solid line shows the first test and the dashed line the second.

Considering the length of time between tests the results compare quite well. Focusing on the range between 0.4 and 1.0 Hz (the range from which responses were selected for further analysis) it can be seen that except for yaw rate gain the agreement between the two runs is very good. It is difficult to determine the exact cause of the yaw rate gain discrepancy due to the fact that the vehicle set-up was changed and tested numerous times in the intervening period between tests. Even though a great deal of care was taken to assure that the vehicle was identical for the two tests, wear on the tyres and mechanical components may still have changed the yaw characteristics. However it is worth noting that the difference in gain values seen in Figure 2-21 is small in comparison to the deviation seen between vehicle configurations. For example at 0.7 Hz the difference between the repeat runs is 0.013 deg^2/s compared with a range of 0.14 deg^2/s and standard deviation of 0.04 between the sixteen configurations. [2] Thus even if the error seen is representative of the reliability of the yaw rate data it is still possible to distinguish between configurations with confidence.

Figure 2-19 Repeatability of frequency response results: Lateral acceleration



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[2] In Appendix I, Table 2I-1, the yaw gain difference at 0.7038 Hz is 0.2616 - 0.2483 = 0.01330 deg^2/s. In Appendix G, Table 2G- 2, the range is 0.3382 - 0.1978 = 0.1404 deg^2/s. The standard deviation of 0.04 is also obtained from the values in Table 2G- 2.

Figure 2-20 Repeatability of frequency response results: Road wheel angle

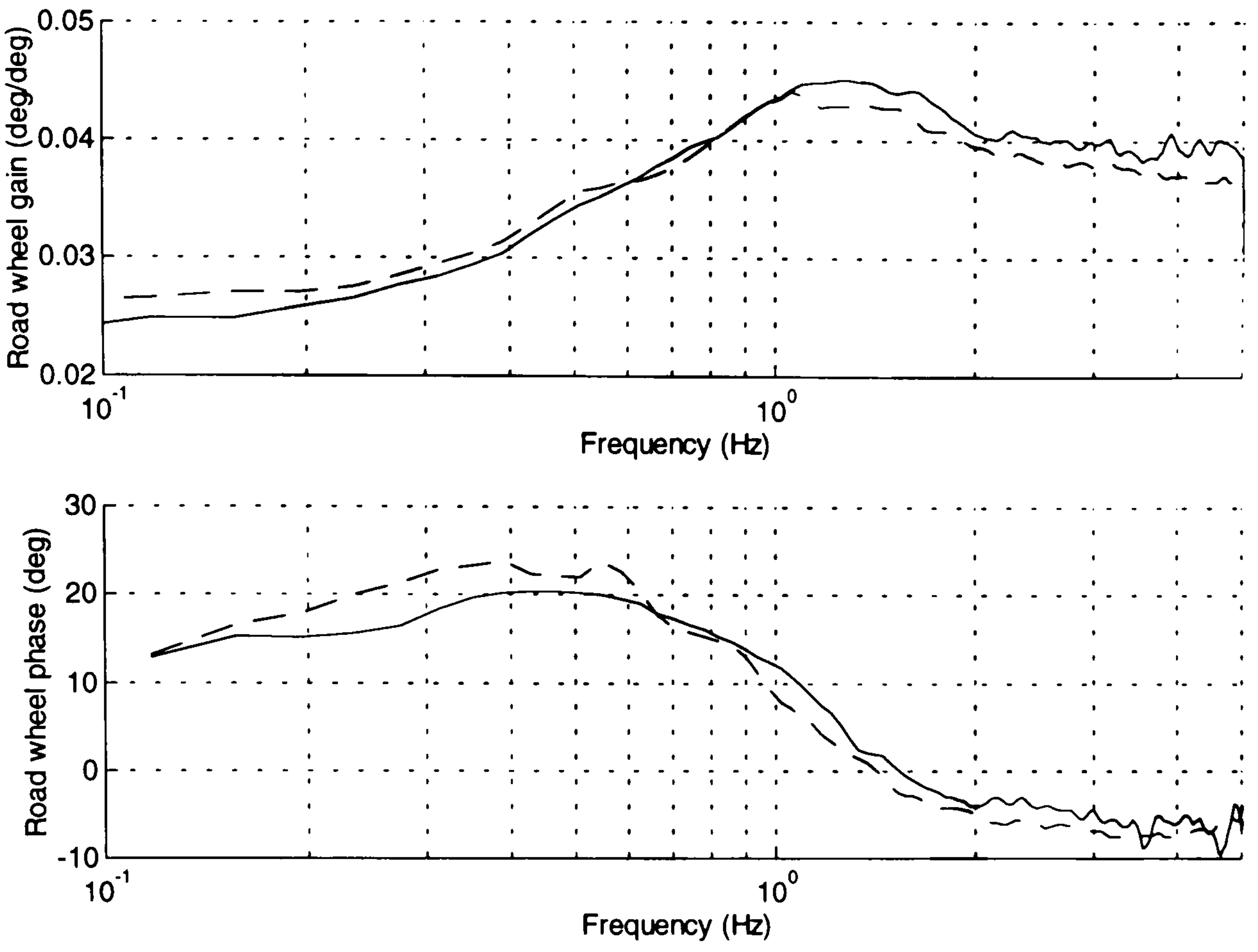
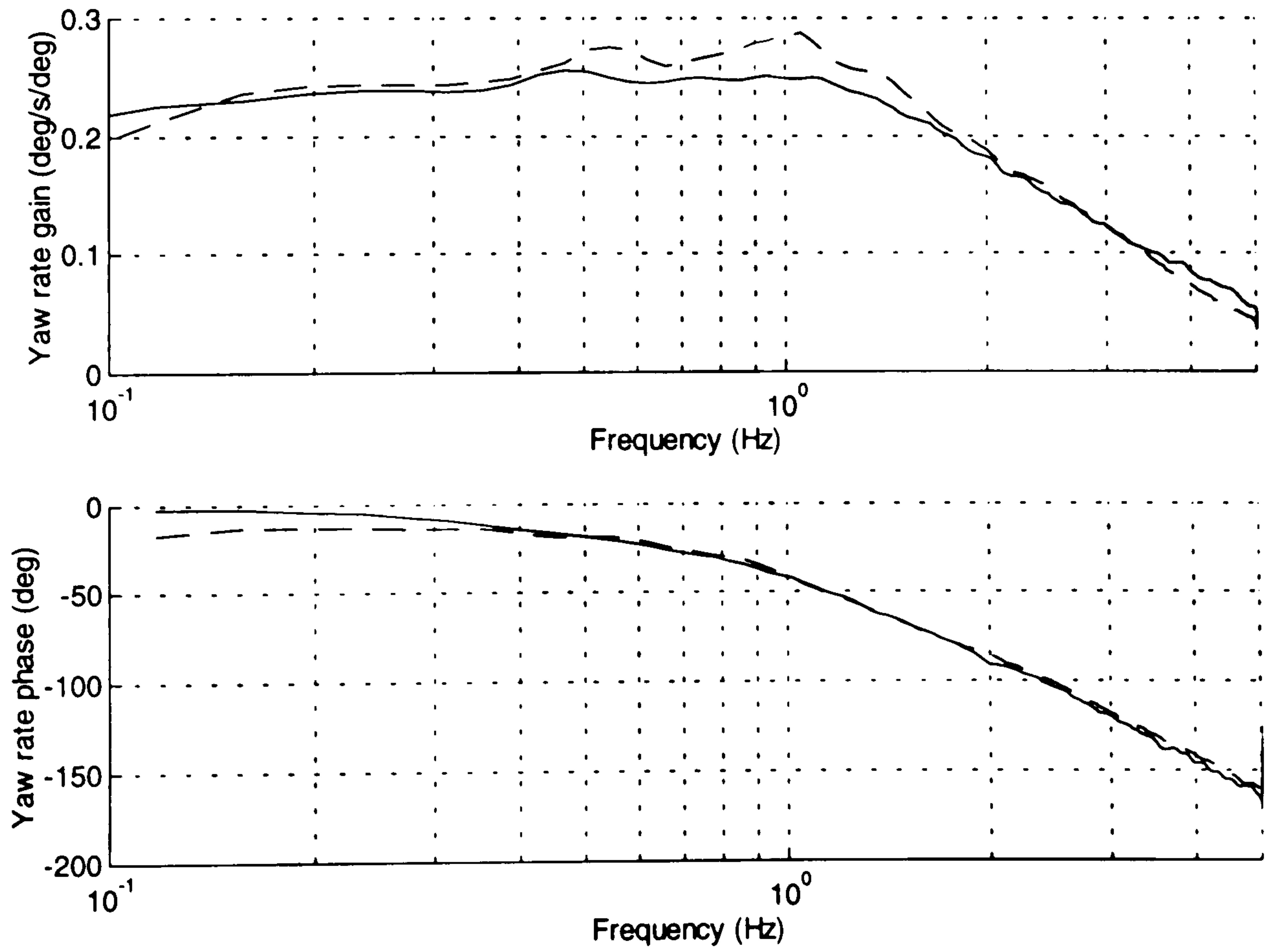


Figure 2-21 Repeatability of frequency response results: Yaw rate



2.6 Conclusions

For the purposes of model validation and subjective-objective correlation, the objective data collected is both wide ranging and reliable. The large scope of operating conditions should provide the basis for broadly-based conclusions in the research. Specific observations to support this conclusion are:

i) In the steady state tests, both understeering and oversteering characteristics were seen in the linear and non-linear handling region.

ii) Transient response times from the step input test showed percent changes of approximately 100% from minimum to maximum values. This data also spanned the linear and non-linear handling region.

iii) For the steady state tests the repeatability is very good. Differences between repeat runs were small and random.

iv) For the frequency response data the gains and phases between the repeat runs were also generally well correlated.

3. Subjective Data Collection

Specifying the subjective data collection method required careful consideration on how best to obtain representative and analysable characterisations of driver opinion. Because the method proposed differed considerably from previous subjective-objective research a pilot study was conducted to assure that both the data collected and the method of collection would be suitable. Once this had been done eight drivers evaluated the sixteen experimental vehicle configurations providing a comprehensive database of ratings which, after checks for validity and reliability, were used in the subjective-objective correlation analysis.

3.1 The Scope of Subjective Data Collection

Although the ideal situation would have been to examine data from as wide a range of drivers and conditions as possible, practicality dictated that some constraints be placed on the scope of subjective data collection. Specifying the type of data collected and the collection methodology required a balance between imposing constraints for the sake of obtaining analysable data and allowing a realistic evaluation procedure. The practical consequences of the final balance was seen in the drivers used, the data collected and how and where the vehicle was tested.

3.1.1 Drivers For Subjective Evaluation

Only experienced trained test drivers were used to conduct the subjective evaluations. It was felt that this constraint was a reasonable one since the vehicle development process is initially limited to such drivers and engineers with specialist knowledge about test driving.

A pool of drivers was drawn from engineers and technicians at MIRA and from elsewhere to do the subjective appraisals. All of these people had training and experience in the testing and development of motor vehicles and, in general, were involved in such work on a day to day basis. Table 3-1 details the job description and experience of each driver.

Table 3-1 Details Of Subjective Evaluators

Driver	Job description	Relevant experience and training
A	Technician	10 years conducting objective tests
B	Consultant vehicle dynamics engineer	15 years handling development experience at MIRA and Michelin Doctorate in vehicle dynamics
C	Engineer	20 years conducting subjective and objective tests Responsible for instructing new test drivers at MIRA
D	Project engineer	10 years handling development experience at MIRA
E	Test driver	25 years tyre testing with Michelin and as a consultant test driver
F	Senior project engineer	10 years handling development experience at MIRA
G	Project engineer	5 years handling development experience at MIRA
H	Test driver	25 years consultant test driver

3.1.2 Nature Of The Subjective Data - Qualitative And Quantitative

Following the example of virtually all previous research the subjective data collection for different aspects of handling was centred around numerical ratings. The commitment to a qualitative paradigm of data collection was made with the recognition of the inherent deficiencies of numerical subjective ratings. By definition subjective impressions are not quantifiable phenomena. Having people convert their ideas of "good" and "bad" or "better" and "worse" into numbers naturally restricts their ability to express opinions. Terms such as "nervous", "positive feedback" and "sure footed" are only a few of hundreds if not thousands of descriptors which are used describe the handling of a car but whose essence can not be characterised by, for example, "1 to 10" ratings. Thus conclusions based on numerical ratings are by their nature limited by the inability to link them directly to the verbal feedback normally used by drivers. Setting such problems aside however the numerical paradigm still represents the most straightforward way of obtaining useful subjective-objective relationships since far more testing and analysis can be done compared to that which could be accomplished if qualitative methods, such as case studies, were used.

3.1.3 Testing Environment

All of the subjective evaluations were conducted on the MIRA proving ground. It was felt that conducting evaluations on the test tracks would eliminate confounding influences such as variable road conditions and traffic as well provide information collected under similar circumstances as the objective data. Additionally the proving ground allowed drivers to fully concentrate on the task of evaluation in relative safety.

Additional conditions placed on the evaluations included testing only on dry tracks in daylight and limiting manoeuvres to the low to medium lateral acceleration range. The restricted lateral accelerations were introduced primarily to conserve the tyres but also helped to narrow the scope of conditions from which the subjective data was obtained to that most often encountered on real roads.

No objective measurements were taken during driving thus restricting correlation of the ratings to the open loop test data only. While it was recognised that a driver's opinion may be influenced by the *way* he or she drives the vehicle it was not practical to obtain such information. i.e. Availability of transducers was limited by the need to share them with other projects and it was felt the presence of expensive, easily damaged, kit might restrict the freedom of the drivers to perform manoeuvres.

3.2 Development Of A Questionnaire And Driver Rating System

3.2.1 Pilot Study

Although previous research has pointed towards aspects of handling for which subjective ratings correlate with objective data, there does not seem to be any "standard" questions which demonstrably provide reliable, representative results. Considering the importance of obtaining such data a pilot study was conducted to assess both a subjective questionnaire and a method for conducting subjective evaluation.

In terms of the subjective testing method it was decided to examine whether reliable results could be obtained if a naturalistic method, duplicating real-world evaluations, was used as opposed to the common research method of soliciting feedback based on driving through specified, constrained, manoeuvres. It had been noted by the author during vehicle development activities at MIRA that subjective evaluation was done in a manner that was largely at the discretion of the driver. Although the test drivers would typically conduct a systematic evaluation involving steady state cornering, lane changing, straight-line directional stability etc. drivers were never explicitly instructed to base their feedback on specified standard manoeuvres. This practice does not appear unique to MIRA - at least one other reference, published by an author employed by Lotus engineering, notes a preferred evaluation method for vehicle handling based on a relatively unconstrained method which is at the discretion of the driver. [1] It was thus decided to investigate whether such an evaluation procedure could provide uniform, analysable results in conjunction with the questions to be asked in the questionnaire.

The questions in the questionnaire followed from the adoption a realistic evaluation method - since the drivers would test the vehicles in the "normal" way their feedback should also be expressed in terms that they normally used. A number of tasks were completed in order to compile a list of suitable questions for subjective ratings including:

i) Interviews with drivers regarding how they describe subjective aspects of handling.

ii) Observing on track evaluation of vehicles.

iii) Examination of a glossary defining standard terms used in the subjective evaluation of vehicle handling written by MIRA's vehicle dynamics department.

The draft questionnaire which resulted consisted of forty-one questions about various aspects of vehicle handling including steady state cornering, transient responses, straight-line cornering, and lane changing. In the end it was essentially the same as the final questionnaire, Table 3-2, and, therefore, is not reproduced here. A seven point rating scale was adopted for quantifying responses to each question. Three descriptive anchors, *worse, same, and better*, were used to label the *1*, *4* and *7* points respectively on the scale.

The vehicle obtained for the pilot study was a Lexus GS 300, selected because of its ready availability. The exact procedure for evaluating the vehicle and providing feedback was:

i) The driver was given the questionnaire before testing to give advanced notice of what feedback was required so that he could conduct suitable manoeuvres during the evaluation.

ii) The vehicle was then driven on the proving ground with the driver free to determine what circuits and manoeuvres to use without any particular time constraints.

iii) After completion of driving the draft questionnaire was completed. Ratings were given relative to another saloon car owned by MIRA which all of the drivers were familiar with.

Examination of the results from the survey indicated most of the ratings from four drivers who participated were in relatively good agreement. The spread of ratings on most questions was within three points between the drivers. On this basis it was decided that the draft questionnaire would be a satisfactory base for the final questionnaire.

3.2.2 Final Form Of The Questionnaire

Following the results of the pilot study additional detail questions were inserted into the original questionnaire expanding it to forty nine questions as shown in Table 3-2. The seven point scale was again specified for numerical ratings with one important addition - the provision for a “don’t know” rating. This extra option was incorporated to prevent guessing in instances where a driver genuinely could not provide a rating. An additional refinement to collecting ratings was also made by writing a computer program which automated the presentation of questions and recorded ratings and comments. The execution of the program was such that forty nine windows, each corresponding to one question, were presented sequentially to the driver who then entered the data required. As with a paper questionnaire, the driver was able answer the questions in any order and to edit his feedback by scrolling forwards and backwards through the windows. Figure 3-1 shows an example window from the program.

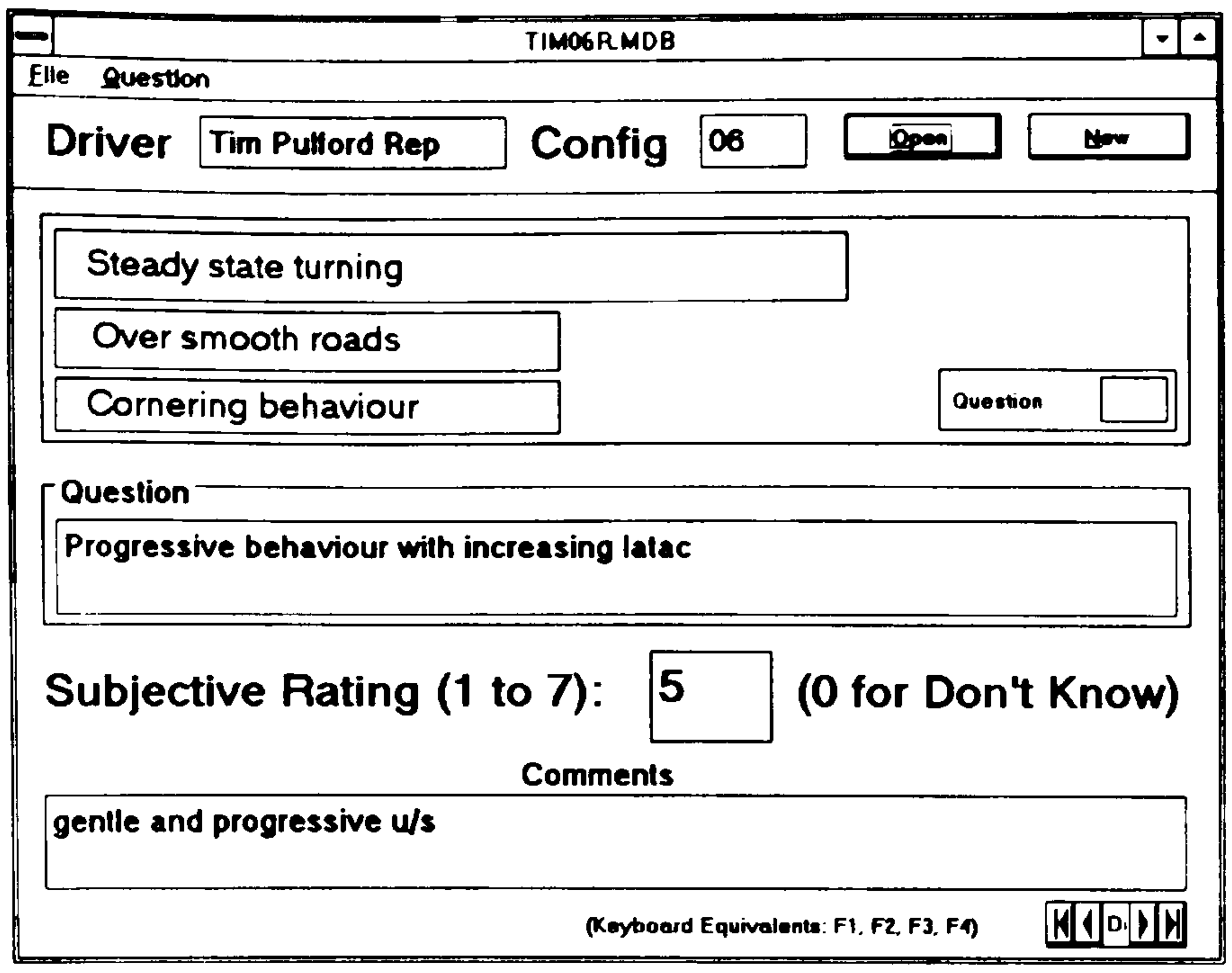
Table 3-2 Final form of the questionnaire

	Main Heading	Sub Heading	Sub Sub Heading	Question
01	Steady state turning	Over smooth roads	Cornering behaviour	Progressive behaviour with increasing lateral accel.
02	Steady state turning	Over smooth roads	Cornering behaviour	Ease with which line is held
03	Steady state turning	Over smooth roads	Cornering behaviour	Degree of body roll
04	Steady state turning	Over smooth roads	Cornering behaviour	Progressive behaviour with decreasing lateral accel.
05	Steady state turning	Over smooth roads	Steering torque feedback	Indication of available grip
06	Steady state turning	Over smooth roads	Steering torque feedback	Indication of magnitude of lateral acceleration
07	Steady state turning	Over smooth roads	Steering torque feedback	Magnitude of torque levels - LOW lock/HIGH lateral accel.
08	Steady state turning	Over smooth roads	Steering torque feedback	Magnitude of torque levels - HIGH lock/LOW lateral accel.
09	Steady state turning	Over smooth roads	Steering torque feedback	Progression of handwheel torque levels
10	Steady state turning	Over smooth roads	Steering torque feedback	Smoothness
11	Steady state turning	Over smooth roads	Steering torque feedback	Symmetry
12	Steady state turning	Over ROUGH roads	Cornering behaviour	Ease with which a line is held
13	Steady state turning	Over ROUGH roads	Cornering behaviour	Behaviour on uneven grip (wet patches)
14	Steady state turning	Over rough roads	Kickback on bumps	Kickback on bumps
15	Power change	Power on	Yaw response	Magnitude of response (state below whether over or under steer)
16	Power change	Power on	Yaw response	Progressiveness of yaw rate response
17	Power change	Power on	Yaw response	Yaw stability of vehicle at high lateral accel.
18	Power change	Power on	Steer torque feedback	Torque steer due to power change
19	Power change	Power OFF	Yaw response	Magnitude of response (state below whether over or under steer)
20	Power change	Power OFF	Yaw response	Yaw stability of vehicle at higher lateral accels.
21	Sudden braking in a turn			Yaw rate response (state tendency to spin or plough below)
22	Sudden braking in a turn			Roll stability
23	Sudden braking in a turn			Wheel lift
24	Sudden braking in a turn			Wheel lock up
25	Transient cornering	Turn in response		Turn in response and precision on smooth surfaces (low lateral accel.)
26	Transient Cornering	Turn in response		Turn in response and precision (medium lateral accel.)
27	Transient Cornering	Turn in response		Turn in response and precision (higher lateral accels.)
28	Transient cornering	Turn in response		Body roll ANGLE
29	Transient cornering	Turn in response		Body roll RATE
30	Transient cornering	Steering torque feedback		Steering catch-up

Table 3-2 (continued)

	Main Heading	Sub Heading	Sub Sub Heading	Question
31	Straight line directional stability	Constant throttle		Bump steer
32	Straight line directional stability	Constant throttle		Steer kickback
33	Straight line directional stability	Constant throttle		Over changing surface camber (state whether car wanders or pulls)
34	Straight line directional stability	Constant throttle		Over changing surface composition: ease with which a line is held
35	Straight line directional stability	Under acceleration		Torque steer
36	Straight line directional stability	Under acceleration		Tendency to pull to one side
37	Straight line directional stability	Under braking		Tendency to pull or weave
38	Obstacle avoidance	Single lane change	Trailing throttle	Turn in response
39	Obstacle avoidance	Single lane change	Trailing throttle	Recovery
40	Obstacle avoidance	Single lane change	Trailing throttle	Controllability
41	Obstacle Avoidance	Single lane change	Trailing throttle	Limiting factor (state below whether stability, grip, steering ratio)
42	Obstacle avoidance	Single lane change	Balanced throttle	Turn in response
43	Obstacle avoidance	Single lane change	Balanced throttle	Recovery
44	Obstacle avoidance	Single lane change	Balanced throttle	Controllability
45	Obstacle avoidance	Balanced throttle		Limiting factor (state below whether stability, grip, steering ratio)
46	Obstacle avoidance			Double lane change
47	Response to steering impulse			Oscillation of vehicle
48	Response to steering impulse			Oscillation of handwheel
49	Response to steering impulse			Level of damping

Figure 3-1 Sample window from subjective ratings computer program



Driver: Tim Pulford Rep

Config: 06

Steady state turning

Over smooth roads

Cornering behaviour

Question: Progressive behaviour with increasing latac

Subjective Rating (1 to 7): 5 (0 for Don't Know)

Comments: gentle and progressive u/s

3.3 Subjective Evaluation Procedure

After evaluating the pilot procedure as being satisfactory it was adopted for continued use in the actual research work. A vehicle of the same make and model was procured for use as a reference vehicle and fitted with tyres similar to those used in the experimental testing. The sixteen vehicle configurations specified in Chapter 2 were all evaluated by each of the eight drivers in a randomised order.

For each vehicle configuration, each driver first evaluated the reference vehicle and then the experimental one in any manner he wished on MIRA's proving ground subject to the restrictions of low to medium lateral accelerations. In all cases the driver was blind to the vehicle configuration and the initial condition of the vehicle was kept always the same. Specifically the experimental vehicle always started with greater than three quarters of a full fuel load and cool tyres.

Although each driver was free to conduct each test as he wished a typical evaluation involved use of the steady state steering pad, the inner durability track, the closed handling circuit, the ride and handling circuit and high speed circuit. Typically the evaluations consisted of one session lasting from 45 to 90 minutes although no specific restrictions were placed on time or number of outings.

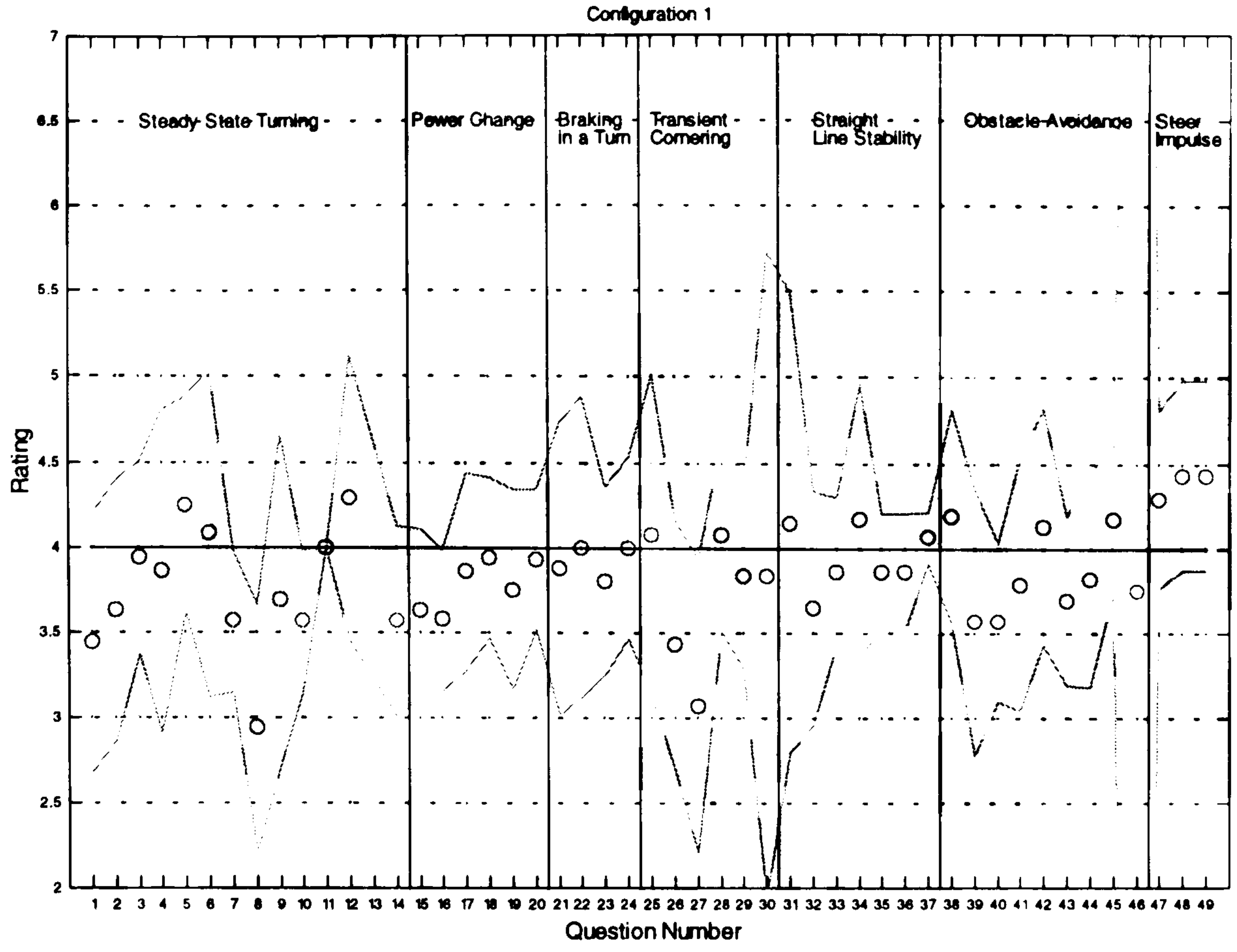
3.4 Results & Postprocessing of Data

Postprocessing of the data consisted of examinations for systematic errors which would suggest influences on the ratings other than the intended experimental factors. In particular time and block based effects dealing, respectively, with gradual drifts from the beginning to the end of testing and biases caused by different sets of tyres among the configurations were sought. Fortunately no such problems were evident allowing data analysis to proceed without the need for any corrective measures.

3.4.1 Results

The actual ratings along with summary statistics for each question (i.e. minimum, maximum, mean, median, standard deviation and range) are tabulated in Appendix 3B. In general they present an initially confusing picture. Figure 3-2, for example, shows for the forty nine questions corresponding to configuration 1 the mean ratings obtained from the drivers and 95% confidence interval. Note that the confidence interval encompasses both sides of the rating scale's mid-point highlighting, in most cases, that there was not even a consensus among drivers on whether the performance was better or worse than the reference. Close examination of the ratings and summary statistics showed no obvious patterns to explain this observation. In particular it did not appear to be a simple matter of offset driver references or scaling differences. i.e. it was not a matter of one driver always rating higher than the rest and one driver always rating lower than the rest; nor was it one driver's ratings being the same as another's except multiplied by a scaling factor.

Figure 3-2 Mean and 95% confidence interval of ratings for Configuration 1.



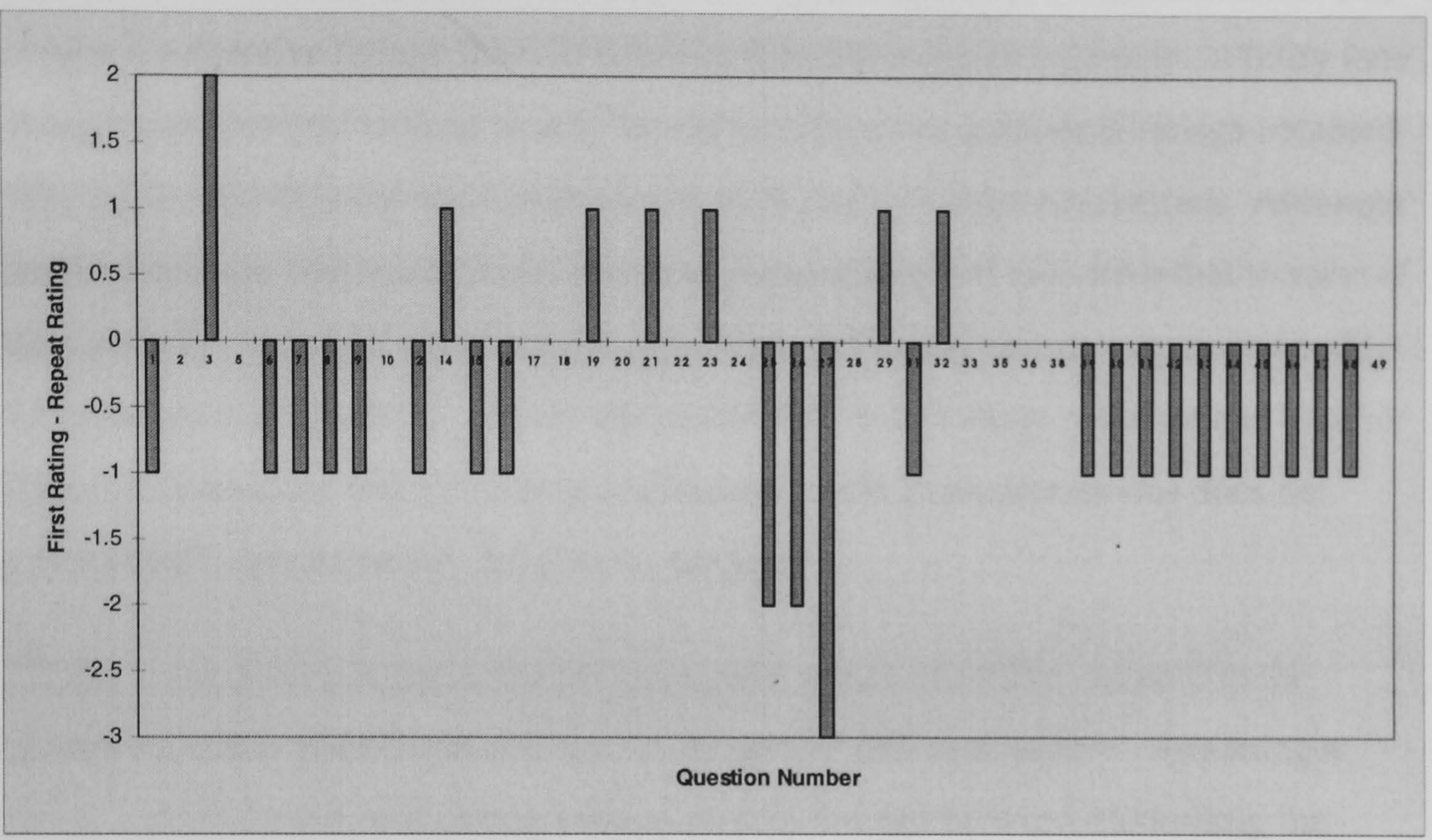
3.4.2 Repeatability of Driver Ratings: Case Study

Considering the variance seen between drivers in the ratings it is natural to query the reliability of each one's feedback.

Although time did not permit an extensive study of the issue, a case study involving driver G was done by having him test configuration 6 of the vehicle on separate occasions separated by two months. In both evaluations the standard procedure of section 3.3. was followed. Figure 3-3 shows the difference in ratings obtained from the two tests for the forty nine questions. The actual ratings and statistics are shown in Appendix 3C. Overall the repeatability is good. The average absolute difference between ratings from the first and repeat tests was 0.79. This is small in comparison with the corresponding range of ratings obtained from the sixteen configurations - the mean range was 3.08. More importantly in only four out of 49 questions did the difference exceed one rating point, (questions 3, 25, 26, 27). The only obvious feature of these questions is that numbers 25, 26, and 27 all dealt with turn-in response. Otherwise it is not clear why these four questions stood out from the rest.

While this single case does not conclusively demonstrate reliability of the ratings, it does at least suggest that the drivers are capable of providing it. If one assumes a comparable level of repeatability for all the drivers it is clear that the ratings variance between drivers cannot be entirely accounted for by poor repeatability.

Figure 3-3 Repeatability of ratings, Driver G, Configuration 3



3.4.3 Interpretation Of Rating Variance And Comparison With Previous Work

Assuming reliability of the ratings, three additional factors could explain the variance seen in the ratings. They relate to interpretation of the questions, the conditions under which the ratings were obtained, and the ability of the drivers.

In the first instance the possibility that questions had been interpreted differently by each driver is one which obviously would have given varied feedback. However to suppose that this significantly accounts for the spread of ratings one would have to believe that out of eight trained test drivers not a single question out of forty nine was interpreted in the same fashion by even a simple majority. Given that six of the eight drivers had worked for many years in the same vehicle dynamics department this is an unlikely scenario.

It may also be argued that different ratings will have resulted because, by the free nature of the subjective evaluation procedure, the vehicle configurations were in fact being evaluated based on different inputs and responses. The possibility of this cannot be discounted - only by more closely controlling or monitoring the testing could it be guaranteed that ratings had been obtained under identical circumstances. The reasons for why this was not done have already been discussed in Section 3.3. However it is instructive to examine previous research involving subjective - objective correlation under closely controlled conditions. In particular reference [2] obtained subjective ratings from five drivers piloting two pick-up trucks in thirty lane change manoeuvres. In their results the authors show the individual ratings obtained from each evaluation versus lateral acceleration and yaw response metrics. Although good correlation was achieved for the drivers as a group it is also clear that in spite of the carefully controlled experimental conditions individual ratings vary considerably for each test configuration . While the scatter seen in this study could be due to other factors it does show that restricting evaluations to identical manoeuvres does not automatically impart lower variances to ratings.

Finally a related argument to the previous point would ask if the variance in the ratings were due to different abilities on the part of different drivers. Assuming a driver's mental workload during a manoeuvre is divided between controlling the vehicle and evaluating it one could argue that less capable drivers will exhibit greater variance because less attention is paid to evaluating the vehicle and more to keeping control of the car. This idea needs to be considered against the fact that all of the evaluations took place in the low to medium lateral acceleration range in the safe environment of the proving ground. In no circumstance should the drivers' physical or mental workload have been overloaded. One would have to suppose that the majority of drivers were evaluating outside of their limits since no consistency was found between them over all the tested configurations. Based on this argument the effect of this possible source of error should also be considered minimal.

The interpretation of the variance of the results could easily be expanded beyond the simplistic points made here. However the fact remains that the ratings were all obtained from drivers accustomed to assessing cars using a method similar to that used for actual vehicle development work. In other words the ratings are representative of driver opinions obtained from realistic conditions and thus should be considered as valid data for further analysis.

3.5 Conclusions

The subjective data collection for the current work centred itself around eight trained test drivers who evaluated the experimental vehicle configurations using a forty nine question form. Unlike most previous research drivers were not constrained to specific tasks for their assessments - instead a more realistic procedure allowing the drivers to select their own manoeuvres on MIRA's proving ground was adopted. Feedback on steady state and transient manoeuvres was given in the form of ratings made on a seven point scale relative to a reference vehicle.

The results present a somewhat confused picture. In general there appeared to be little agreement between drivers on ratings. A number of possible sources of error relating to repeatability, interpretation of the questions and abilities of the drivers were considered and rebutted. With no obvious explanations for the wide spread of opinions but noting the realistic conditions under which they were obtained, the data was judged as valid and suited for further analysis.

4. Mathematical Modelling

This chapter presents the lumped parameter model used during the research. Besides considerations of simplicity as discussed in Chapter 1, attention was focused on making sure that all model parameters were based on experimentally obtained data. No parameters were assumed. The basic vehicle is modelled as a sprung and unsprung mass with roll, side slip and yaw degrees of freedom. The steering system and wheel motions were modelled based on data obtained from the suspension kinematics and compliance measurements. Non-linear tyre and damper forces were incorporated into the simulation using data supplied by the respective tyre and damper manufacturers.

The numerical solutions for the equations of motion were done by coding the mathematical model into a set of sub-routines. Once this was done, a sensitivity study of the model was done to assess the effect that model parameter errors would have on simulated responses. This exercise was important since the actual vehicle parameters during testing may not have been identical to the values used in the simulation. It also served to show that the eight experimental parameters did, in fact, exert the greatest influence on vehicle handling responses when set at their prescribed levels.

4.1 Basic Representation of the Vehicle

This section presents the mathematical representation of the vehicle and the experimentally measured parameters for it. To start, the basic modelling assumptions are shown followed by the derivation of equations of motion. The parameters and calculations related to the steering and suspension system, required for tyre forces, are then presented. Finally the actual vehicle parameters are tabulated to complete the description of the model.

4.1.1 Assumptions About the Vehicle and Its Operating Conditions

The basic assumptions made in the model about the vehicle and its environment were the commonly adopted ones, seen in the majority of mathematical handling models, as discussed in Chapter 1. In particular the following simplifications were made:

i) The vehicle operates on smooth flat roads only.

ii) It travels forward at a constant speed.

iii) It consists of two rigid bodies: a sprung mass and unsprung mass.

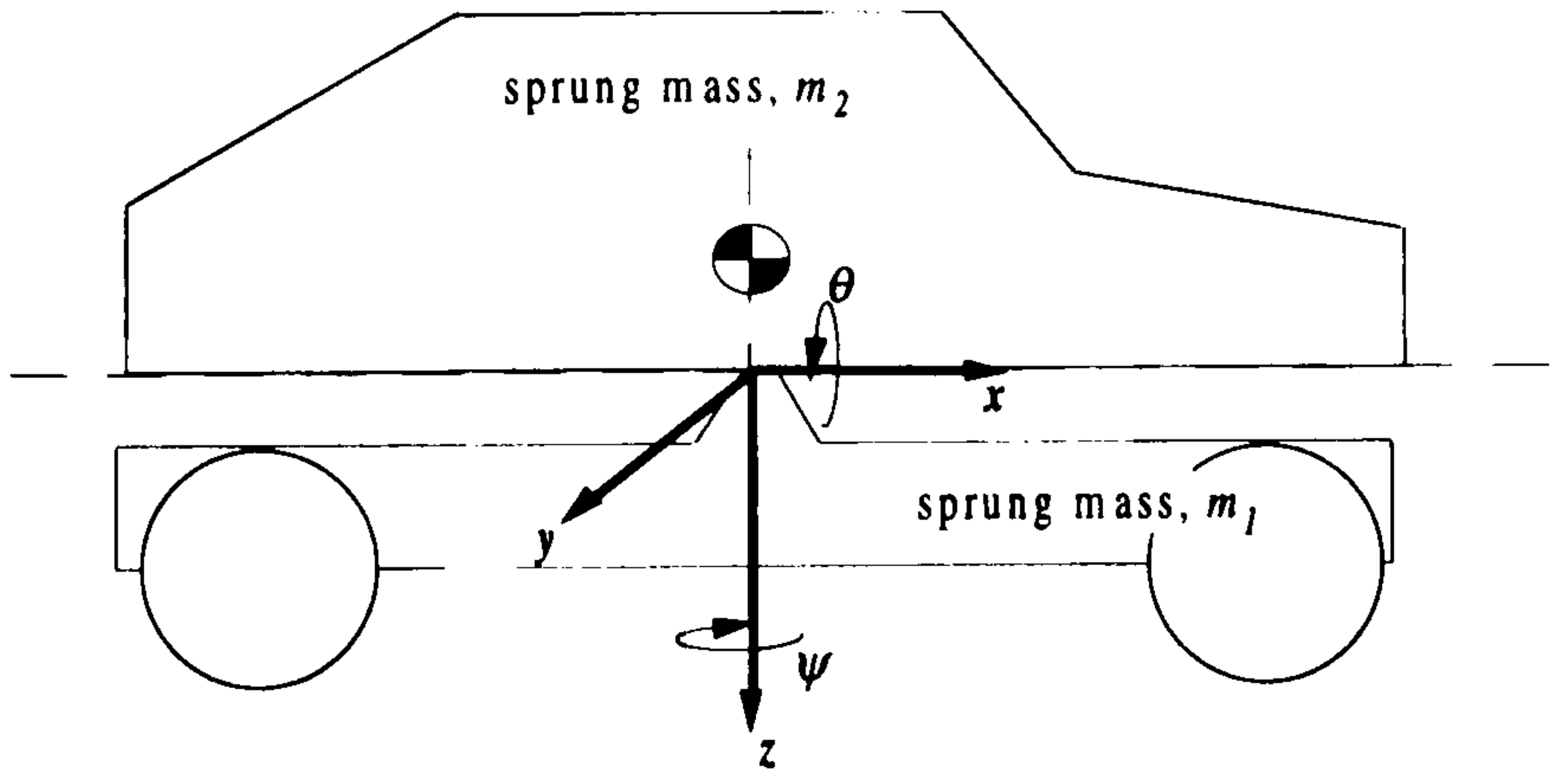
iv) No pitching motion occurs.

v) No aerodynamic forces act on the vehicle.

4.1.2 Sprung and Unsprung Masses - Equations of Motion

Figure 4-1 depicts the way in which the vehicle was represented. As stated in the previous sub-section the car was represented as an unsprung mass and a sprung mass. These are labelled as m_l and m_2 respectively. It can be seen that the sprung mass rode on the unsprung mass and was fixed to it through a horizontal roll axis. The height of the roll axis was determined by the intersection of a vertical line through the sprung mass centre of gravity and a line joining the front and rear kinematic roll centres. Roll motion is indicated as θ. The yaw motion of the sprung mass was constrained to be equal to that of the unsprung mass. Yaw is labelled as ψ. The unsprung mass, in addition to a yaw degree of freedom, was allowed a lateral, side slip, one - labelled y. With the forward motion, x, equal to a constant and vertical motion, z, equal to zero the basic vehicle model thus consisted of three degrees of freedom.

Figure 4-1 Vehicle representation and axis system



The linearised equations of motion for the vehicle system are as shown below in the system of equations (1). A first principles derivation, based on D'Alembert's principle as presented in [1], is given in Appendix 4A.

$$\begin{aligned} \Sigma F_y &= (m_1 + m_2)\ddot{y} + m_2 z_{roll}\ddot{\theta} + (m_1 + m_2)\dot{x}\dot{\psi} \\ \Sigma M_x &= m_2 z_{roll}\ddot{y} + I_{xx2}\ddot{\theta} \\ \Sigma M_z &= (I_{zz1} + I_{zz2})\ddot{\psi} \end{aligned} \tag{1}$$

where

m_1 and m_2 = unsprung and sprung masses, kg

z_{roll} = distance from vehicle roll axis to sprung mass centre of gravity, m

I_{xx2} = sprung mass roll inertia about the roll axis, kgm^2

I_{zz1}, I_{zz2} = unsprung and sprung mass yaw inertia, kgm^2

$\ddot{y}$ = lateral acceleration, m/s^2

$\ddot{\theta}$ = roll acceleration, rad/s^2

$\ddot{\psi}$ = yaw acceleration, rad/s^2

ΣF_y = the sum of the lateral forces, N

ΣM_x = the sum of the roll moments, N

ΣM_z = the sum of the yaw moments, N

4.1.3 Steering System and Suspension Kinematics and Compliance

In order to calculate the tyre forces and moments acting on the vehicle, detailed calculations of wheel motions and loading were required. The road wheel angle was calculated by superimposing the steer due to the hand wheel input, the bump steer contribution and compliance steer effect. This result was then used to determine the wheel slip angle. The other variables required for tyre modelling , normal loading and camber angle, were modelled as functions of roll angle.

4.1.3.1 Steering System

The steering system was modelled as a torsional spring connecting the handwheel to the road wheels through the steering gear as shown below in equation (2).

$$\delta_{road\ wheel} = (\delta_{hand\ wheel} - M_{z\,front\ tyres}/K_{steering\ column}) / ESR \tag{2}$$

where

$\delta_{road\ wheel}$ = road wheel steer angle, radians

$\delta_{hand\ wheel}$ = hand wheel steer angle, radians

$M_{z\,front\ tyres}$ = aligning moment from the front tyres, Nm

$K_{steering\ column}$ = steering column stiffness, Nm/radian

ESR = the effective steer ratio between the road wheels and hand wheel

Ideally the steering system would have been modelled as a spring-damper system thus adding a fourth degree of freedom to the model, however it was not possible to obtain steer damping characteristics for the experimental vehicle. While this limits the ability of the model to predict dynamic steer torque properties it does not appear to have affected steady state response as shown in Chapter 5.

4.1.3.2 Bump steer

The bump steer characteristics were modelled as non-linear functions of the wheel vertical displacement which, in turn, was calculated as the product of roll angle and half track width. Figure 4-2 to Figure 4-5 each show the experimentally obtained measurements for the port and starboard wheels in the "-" and "+" conditions. Also shown in the figures are the second order polynomials fitted to the data. The form in which they were incorporated into the model is shown in Table 4-1.

Figure 4-2 Port wheel bump steer in the "-" condition

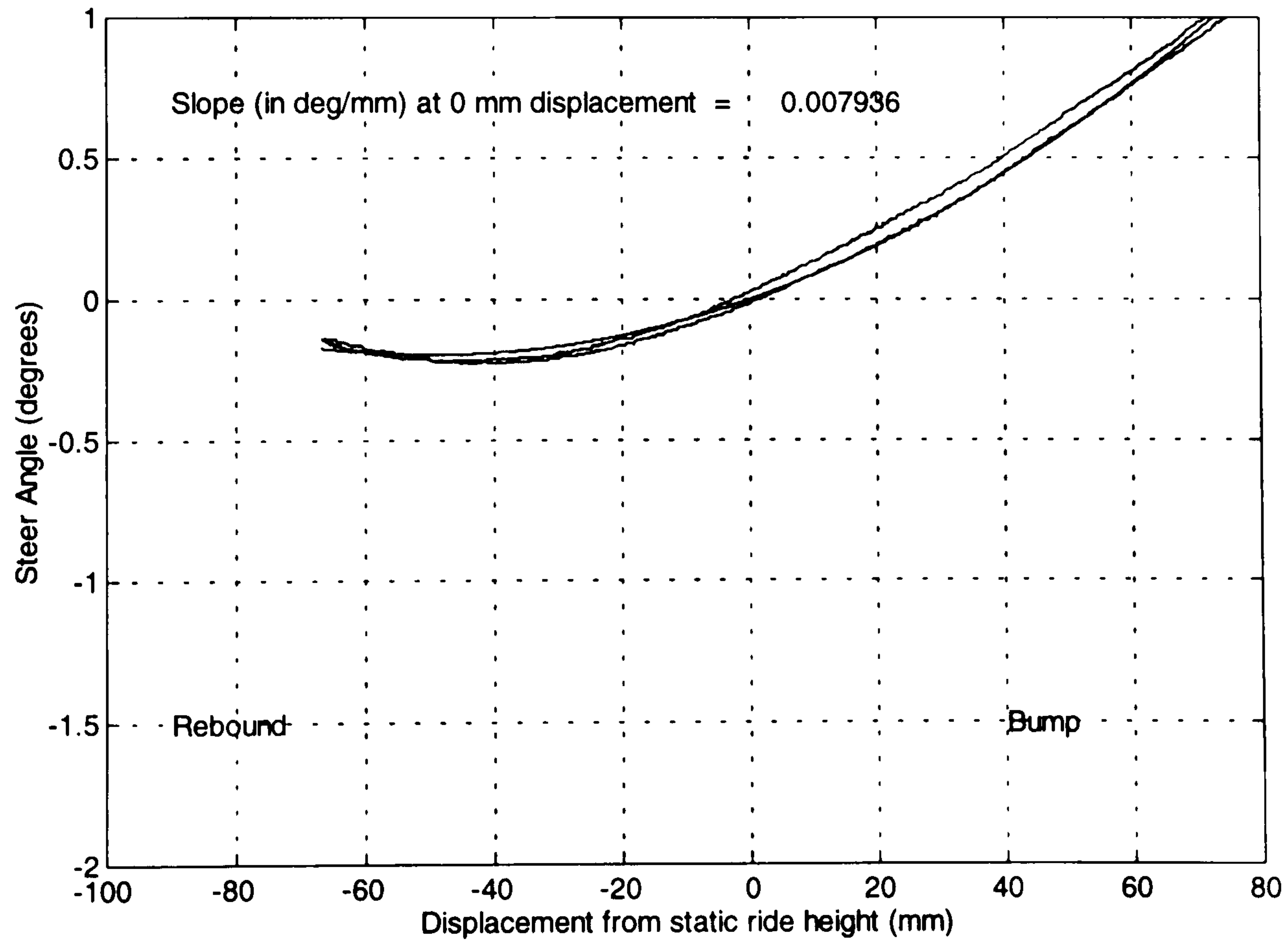


Figure 4-3 Starboard wheel bump steer in the "-" condition

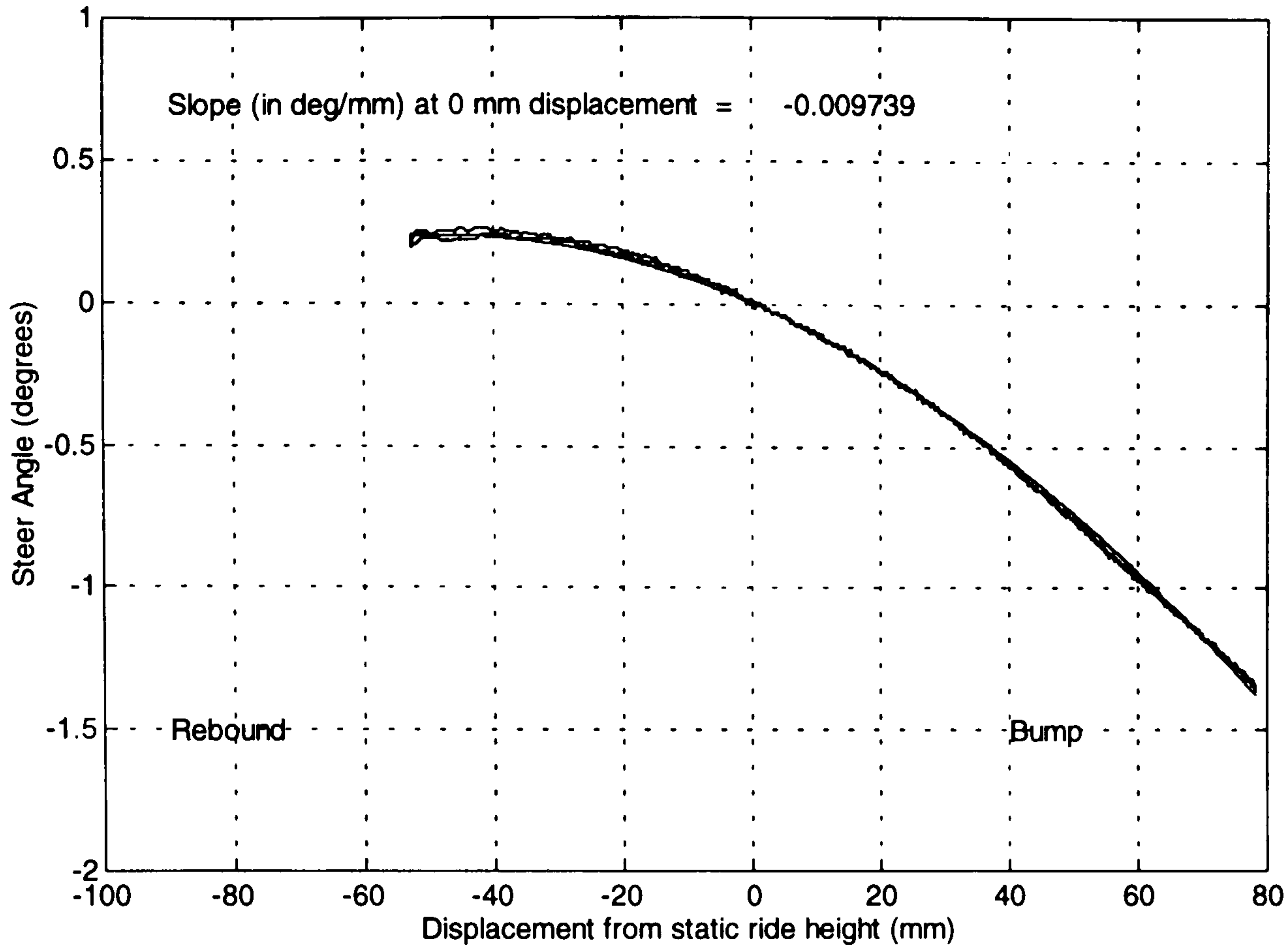


Figure 4-4 Port wheel bump steer in the "+" condition

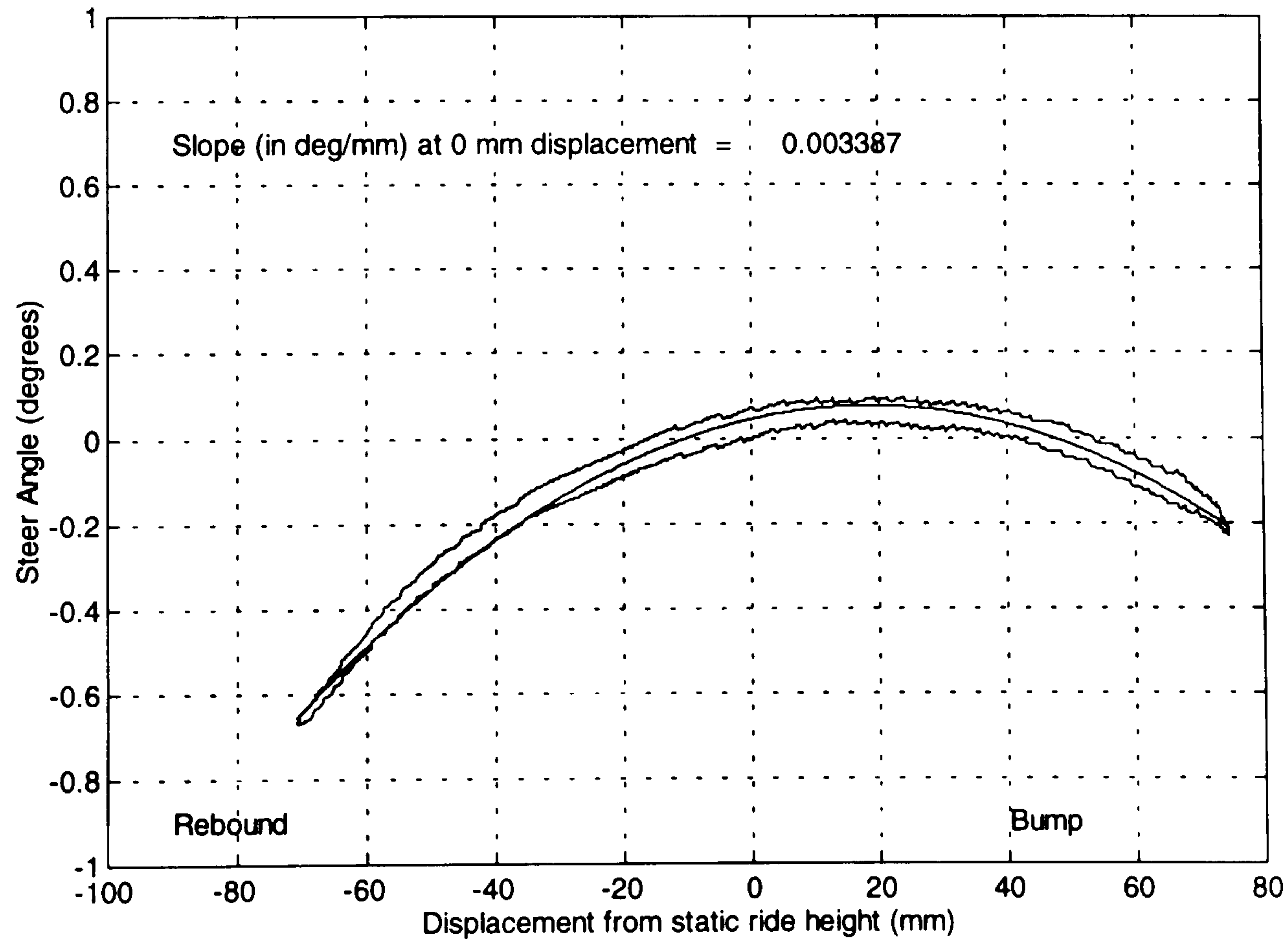


Figure 4-5 Starboard wheel bump steer in the "+" condition

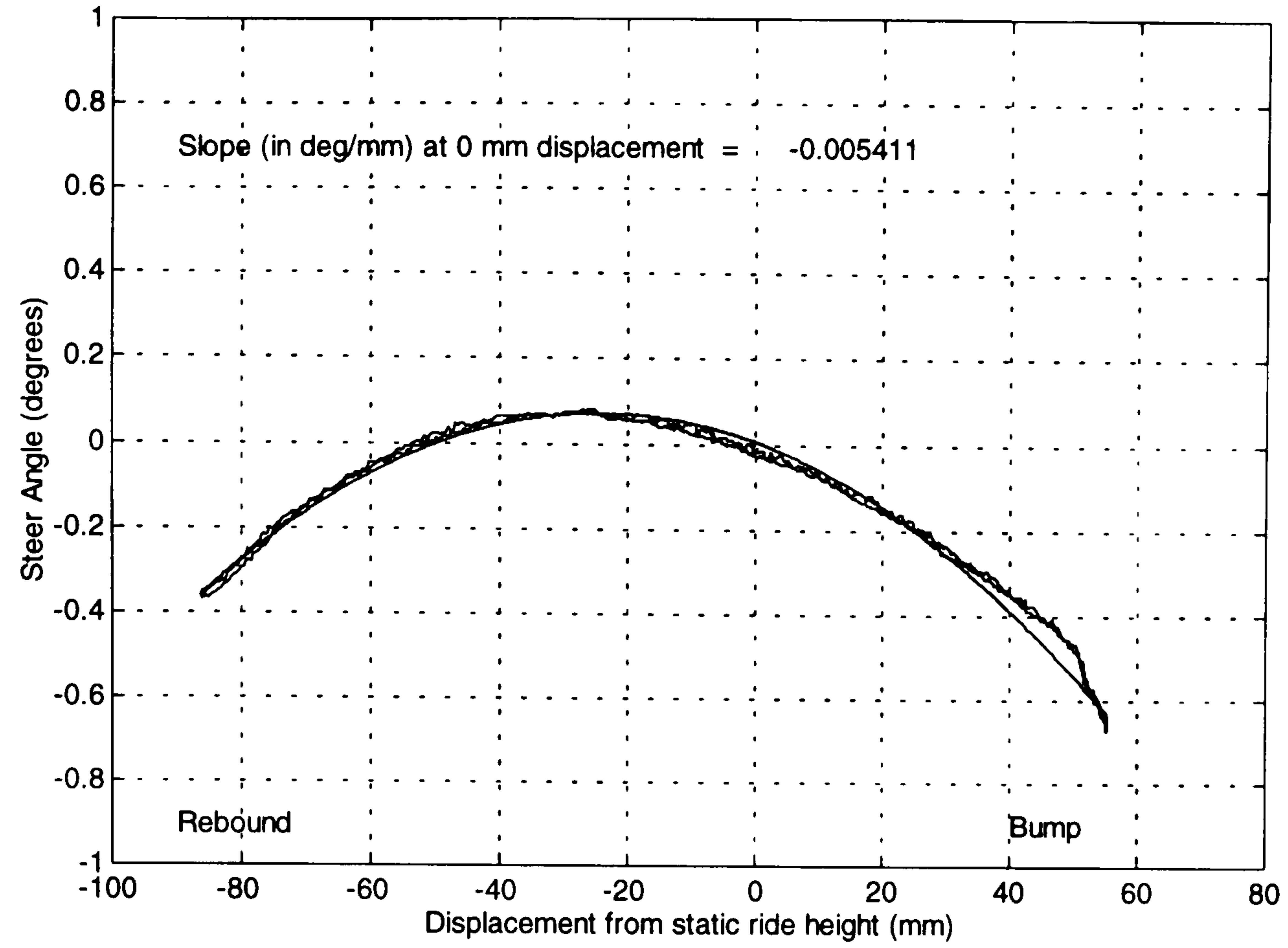


Table 4-1 Equations used to calculate bump steer contribution to road wheel angle, z_{wheel} is the vertical displacement of the wheel in mm.

	Bump steer setting	
	+	-
Port steer (deg) $\delta_{port\ bump\ steer}$	$-0.0001(-z_{wheel})^2 + 0.0034(-z_{wheel}) + 0.0439$ (3)	$0.0001(-z_{wheel})^2 + 0.0079(-z_{wheel}) - 0.0019$ (4)
Starboard steer (deg) $\delta_{starboard\ bump\ steer}$	$-0.0001(z_{wheel})^2 - 0.0054(z_{wheel}) + 0.0060$ (5)	$-0.0001(z_{wheel})^2 - 0.0097(z_{wheel}) + 0.0035$ (6)

4.1.3.3 Compliance Steer

Compliance steer for both the front and rear suspensions was modelled a function of aligning torque and a stiffness coefficient obtained from the kinematic and compliance measurements at Michelin. Specifically the compliance steer contribution for each wheel was calculated as:

$$\delta_{compliance\ steer} = (K_{compliance})^{-1}(M_{z\ tyre}) \qquad (7)$$

where

$K_{compliance}$ = the slope of the compliance steer vs. wheel torque graph, Nm/rad
$M_{z\ tyre}$ = the aligning moment of the tyre, Nm

4.1.3.4 Slip angle

The purpose of determining the road wheel steer angle was so that slip angles at each wheel could be calculated. For each wheel, the slip angle was determined as the difference between the direction of wheel travel and steer angle as shown below in equations (8) and (9).

$$\alpha_{front} = \frac{\dot{y} + a\dot{\psi}}{\dot{x}} - \delta_{\text{front wheel}} \tag{8}$$

$$\alpha_{rear} = \frac{\dot{y} - b\dot{\psi}}{\dot{x}} - \delta_{\text{rear wheel}} \tag{9}$$

where

α_{front}, α_{rear} = front and rear slip angles, rad

$\dot{y}, \dot{x}$ = lateral and forward velocities, m/s

a, b = distance from centre of gravity to the front and rear axle centre lines, m

$\dot{\psi}$ = yaw velocity, rad/s

$\delta_{front\ wheel} = \delta_{road\ wheel} + \delta_{bump\ steer} + \delta_{front\ compliance\ steer}$

$\delta_{rear\ wheel} = \delta_{rear\ compliance\ steer}$

4.1.3.5 Load transfer

Load transfer for each axle was calculated as a function of the lateral force, the height of the roll axis, roll stiffness and track width as shown below in equation (10). This equation is derived using Newton's second law to balance moments on the axle.

$$\Delta F_z = \frac{2F_y h_{roll}}{t} + \frac{2K_{roll}\theta}{t} \tag{10}$$

where

ΔF_z = load transfer, N

F_y = lateral force acting on the axle, N

h_{roll} = height of the roll axis, m

t = track width, m

K_{roll} = roll stiffness, Nm/radians

θ = roll angle, radians

4.1.3.6 Camber

Camber angle was modelled as a function of the body roll motion and a constant derivative term, again using data measured directly from the vehicle. Equation (11) shows this relation.

$$\gamma = \frac{d\gamma}{d\theta}\theta \qquad (11)$$

where
γ= camber angle, rad
θ = roll angle, rad

4.2 Forces and Moments

The forces and moments due to the tyres and suspension components where all modelled based on data supplied by the manufacturers or measured at Michelin. It is worth emphasising that the damper and tyre values apply specifically to the actual components used in the research. They were not general data sheets giving nominal characteristics. In the case of the tyre lateral forces and roll damping their contributions were modelled as non-linear elements. Roll moment due to the suspension springs was represented as a linear calculation. Yaw moment was a function of the tyre forces. Each of these are discussed below.

4.2.1 Tyre Forces and Moments

Information for representing the tyre lateral forces was supplied by the manufacturer in the form of *Magic tyre formulae*. These equations modelled the forces as a function of normal load, slip angle and camber angle. Figure 4-6 to Figure 4-9 illustrate the lateral force and aligning moment characteristics for the two tyre types used during the experimental work. Appendix 4B tabulates the exact form of the equations and the associated coefficients as provided on the manufacturer's data sheet. [2]

Figure 4-6 Lateral force vs. slip angle, 185/60R14 tyre, "+" level

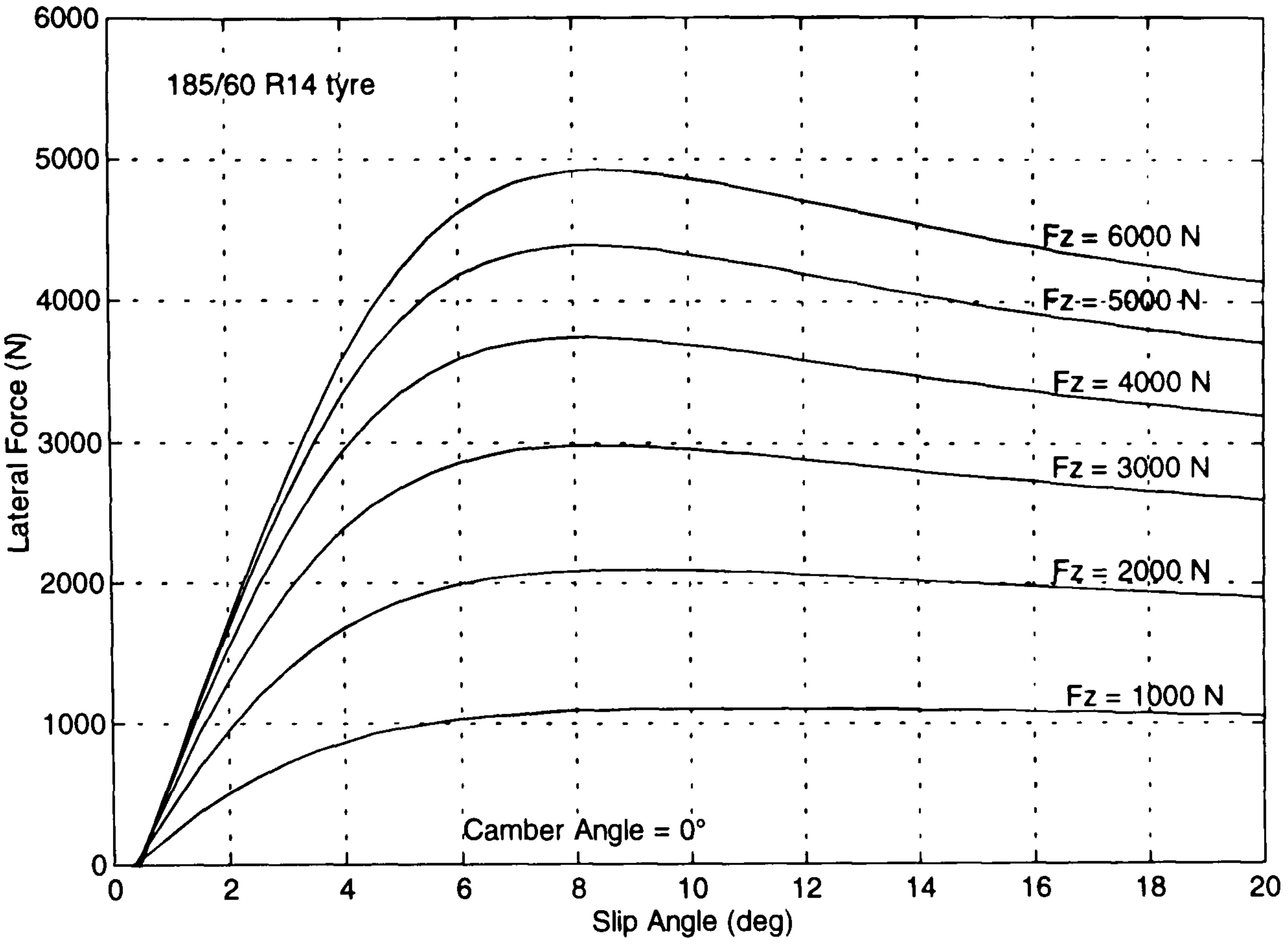


Figure 4-7 Lateral force vs. slip angle, 175/70R13 tyre, "-" level

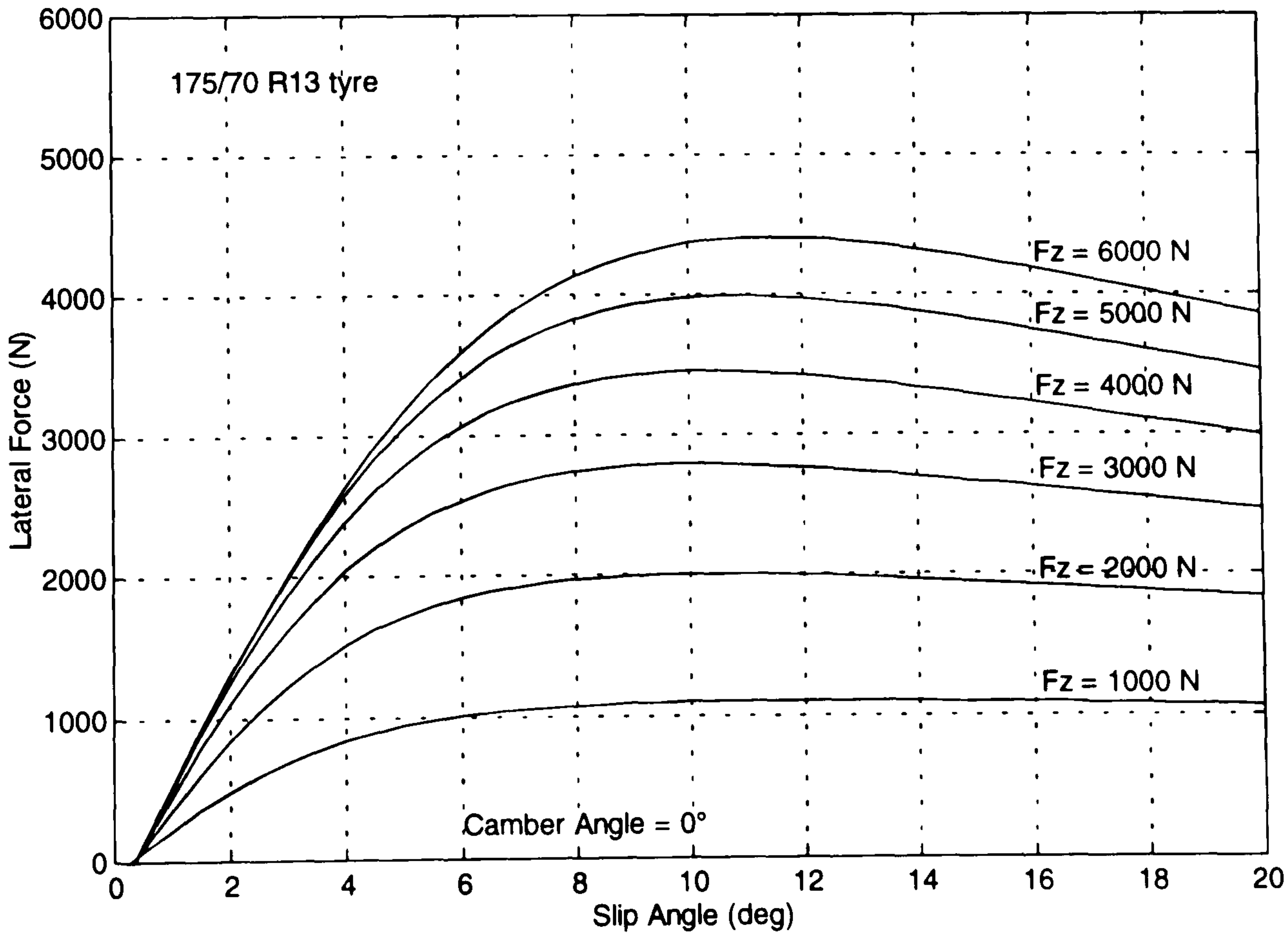


Figure 4-8 Aligning moment vs. slip angle, 185/60R14 tyre, "+" level

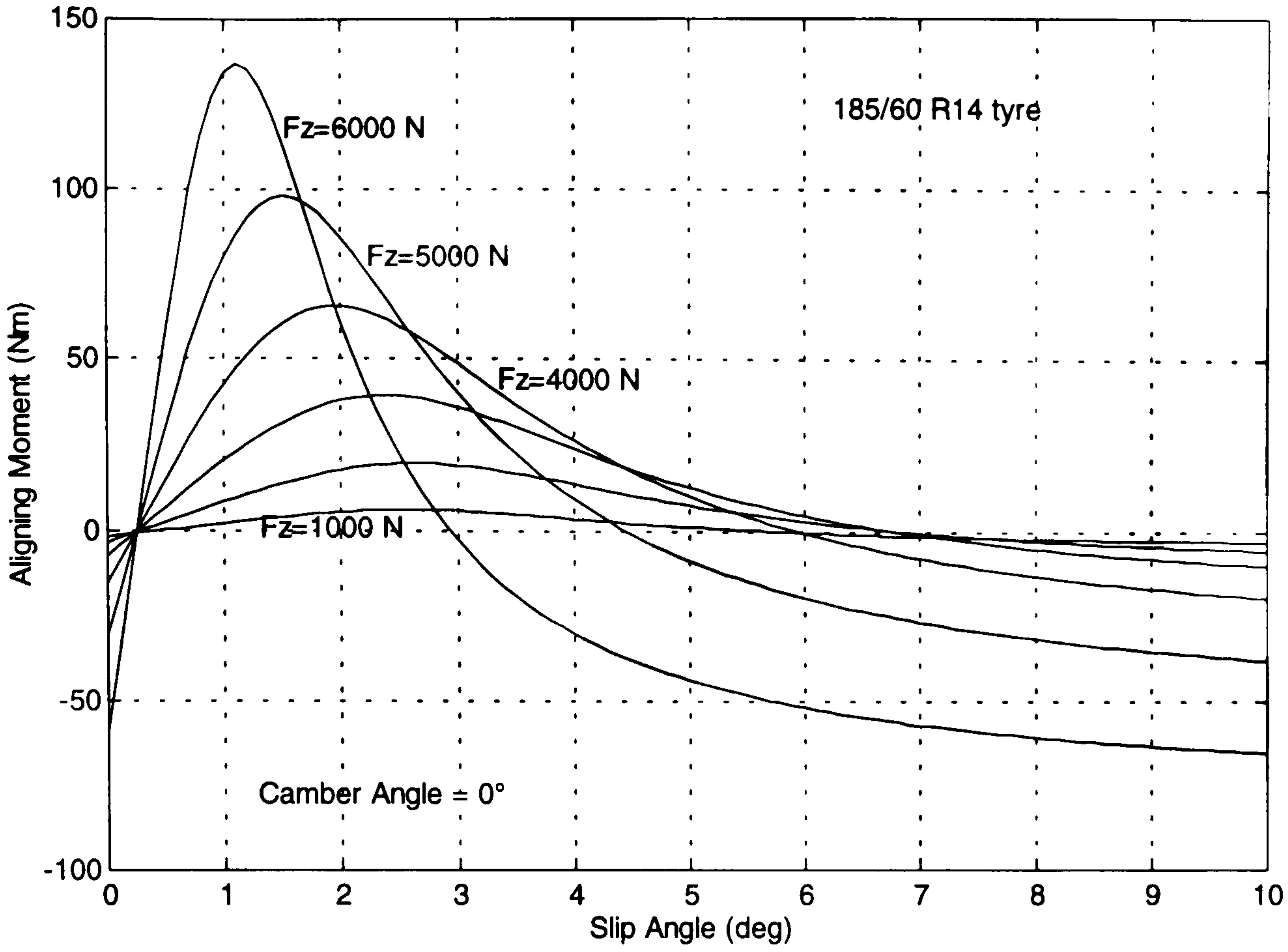
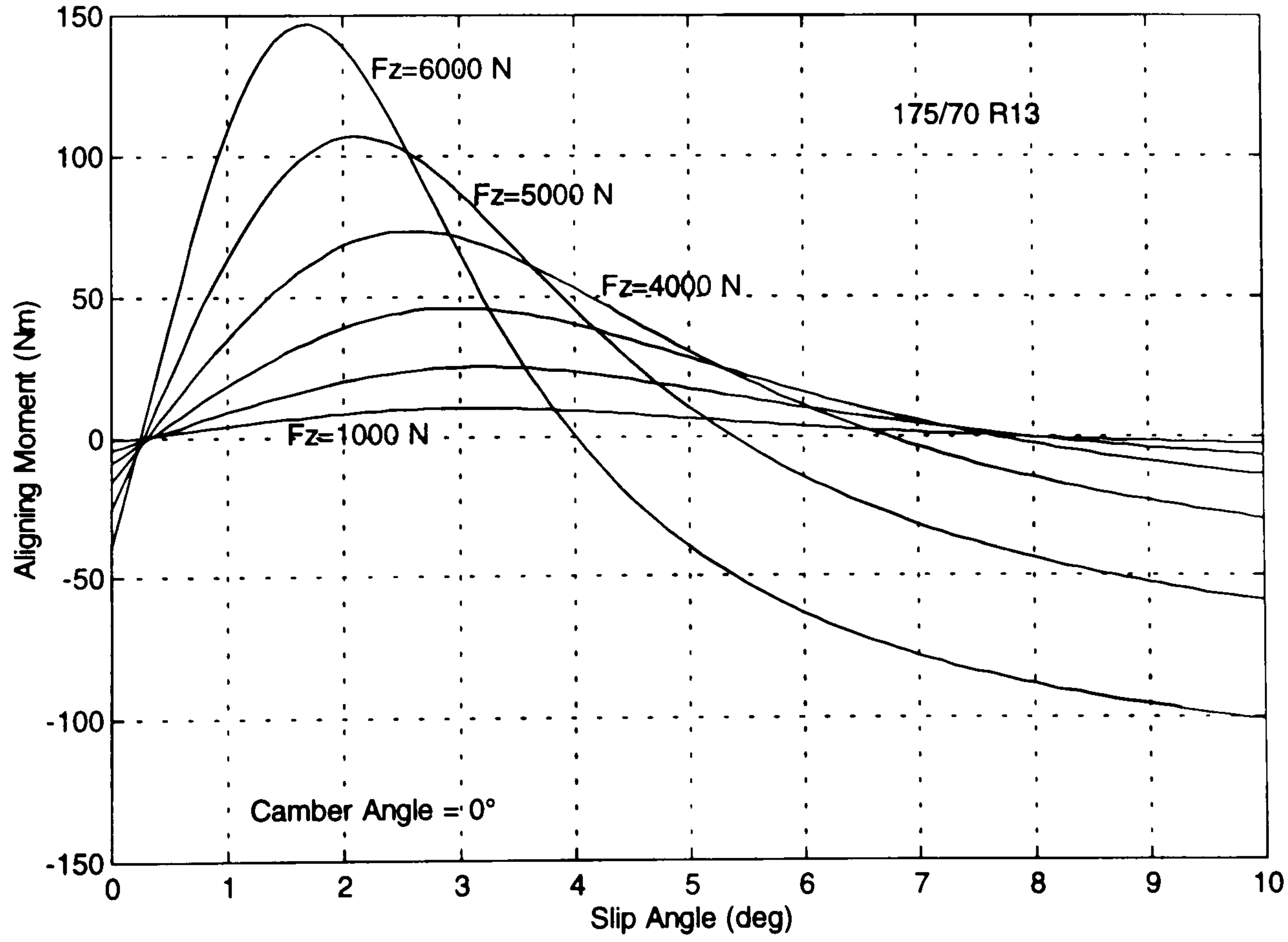


Figure 4-9 Aligning moment vs. slip angle, 175/70R13 tyre, "-" level



4.2.2 Damper Characteristics

Damper characteristics were measured courtesy of the manufacturer and provided in the form of data sheets tabulating forces and velocities. These values are reproduced in Appendix 4C. Polynomial curves were then fit to the bump and rebound data as shown in Figure 4-10 to Figure 4-13. The exact equations are tabulated in Table 4-2.

Figure 4-10 Front damping characteristics, "+" level

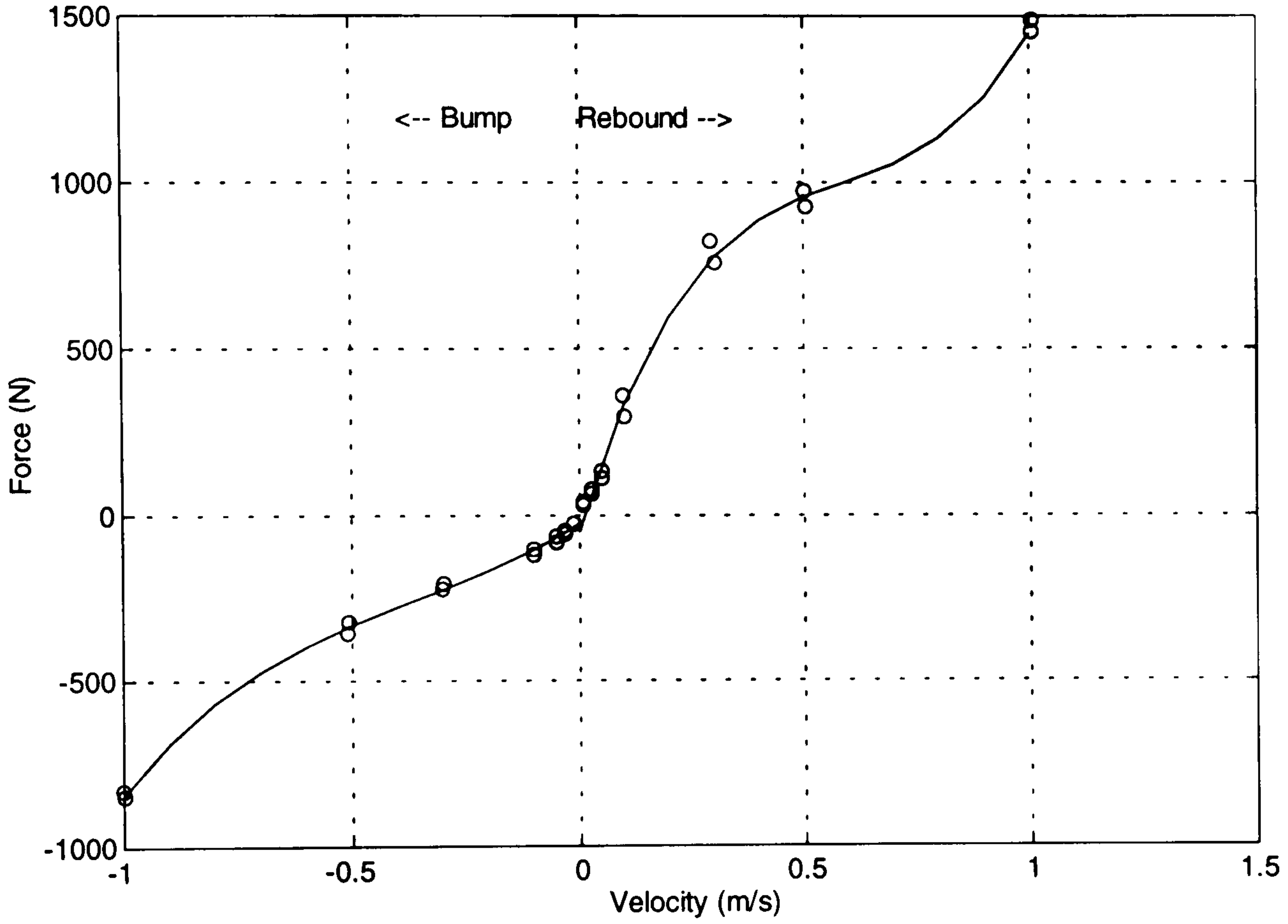


Figure 4-11 Front damping characteristics, "-" level

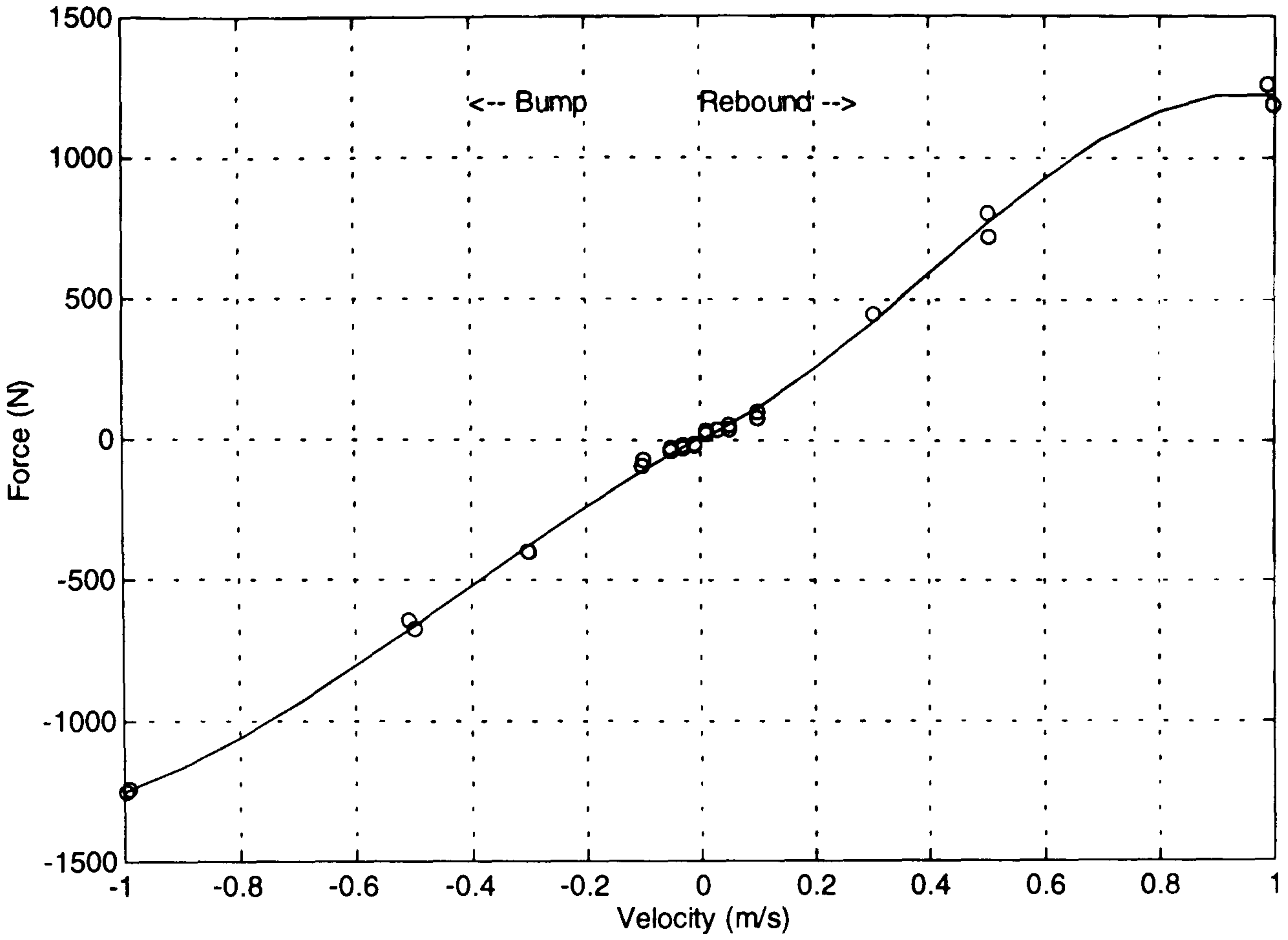


Figure 4-12 Rear damping characteristics, "+" level

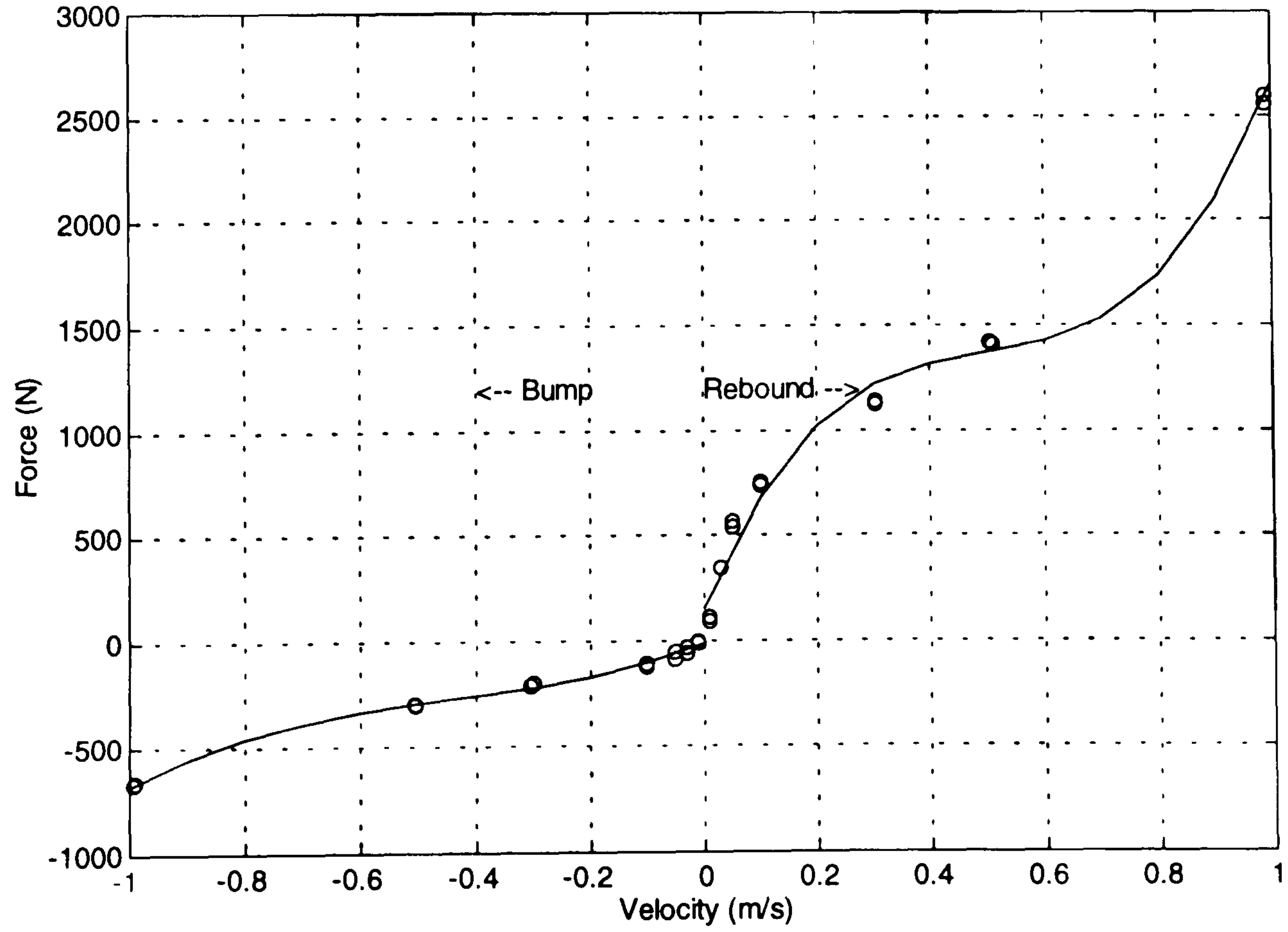


Figure 4-13 Rear damping characteristics, "-" level

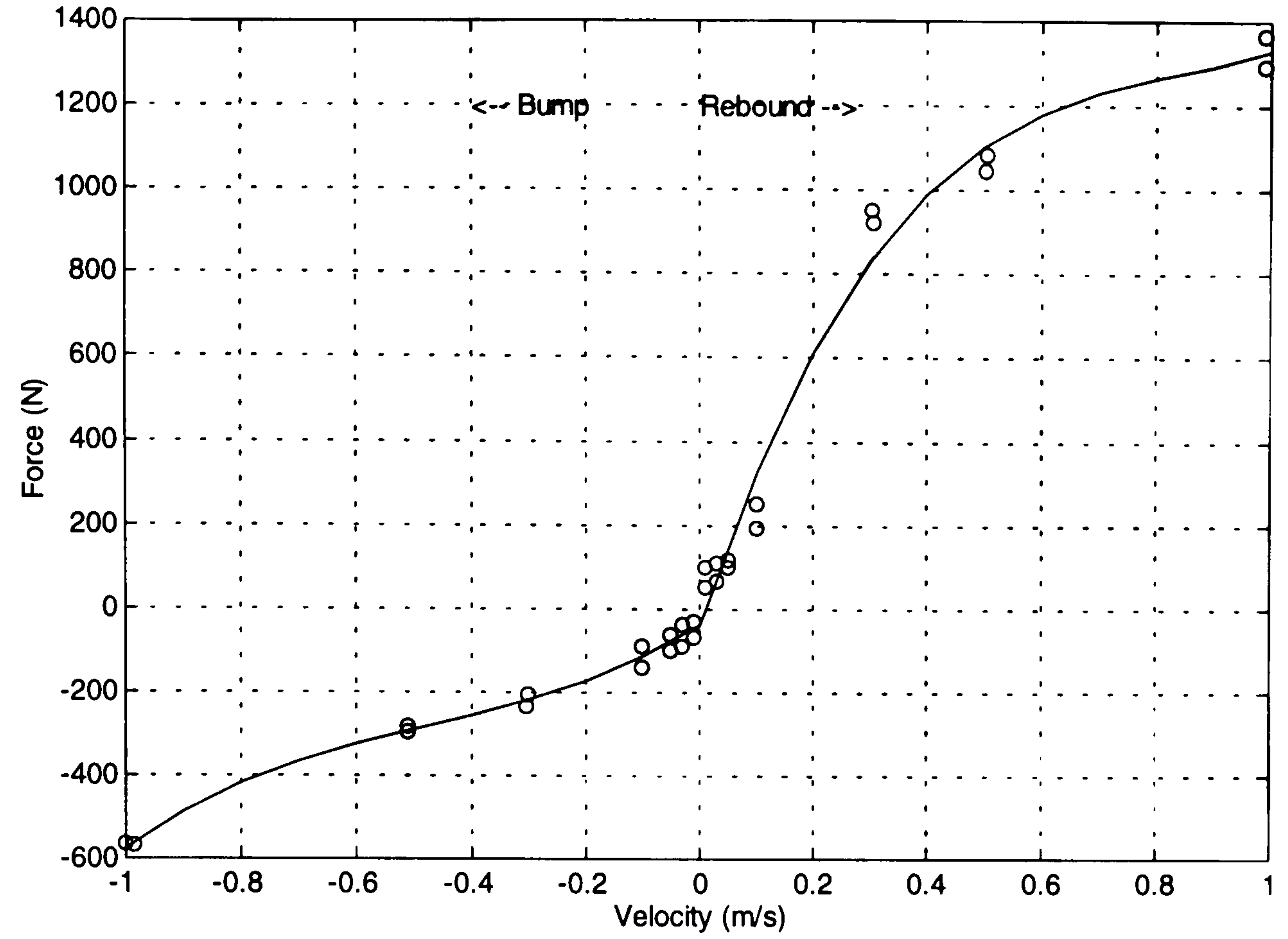


Table 4-2 Polynomials fitted to damper force vs. velocity data; x is the damper velocity in m/s

	Damper Characteristics	
	+	-
Damping force in bump (N)	$923.6x^3 + 974.2x^2 + 867.9x - 26.76$ (12)	$1195x^3 + 1576x^2 + 1044x - 16.94$ (13)
Damping force in rebound (N)	$3770x^3 - 6681x^2 + 4408x - 47.91$ (14)	$8162x^3 - (1.211e{+}004)x^2 + 6446x + 150.4$ (15)

4.2.2.1 Roll Moment Due to Suspension Springs

The roll moment caused by the suspension springs and roll bars was modelled as a simple function of roll angle. The suspension measurements at Michelin provided values which could be directly used in the following equation.

$$M_{roll\ stiff} = (K_{front\ roll} + K_{rear\ roll})\theta \qquad (16)$$

where

$M_{roll\ stiff}$ = roll moment contribution from suspension springs and roll bars, Nm

$K_{front\ roll}$, $K_{rear\ roll}$ = front and rear roll stiffnesses, Nm/rad

θ = roll angle, rad

4.2.2.2 Yaw Moment

Yaw moment was calculated based on the contributions of the tyre lateral forces acting about the vehicle centre of gravity and the aligning moments for each wheel. Specifically:

$$\begin{aligned} Mz_{total} = {} & a(Fy_{front\ port} + Fy_{front\ starboard}) - b(Fy_{rear\ port} + Fy_{rear\ starboard}) \\ & + Mz_{front\ port} + Mz_{front\ starboard} + Mz_{rear\ port} + Mz_{rear\ starboard} \end{aligned} \quad (17)$$

where

Mz_{total} = total yaw moment, Nm

a = distance from vehicle centre of gravity to front axle line, m

$Fy_{front\ port}$, $Fy_{front\ starboard}$, $Fy_{rear\ port}$, $Fy_{rear\ starboard}$ = Lateral forces, N

$Mz_{front\ port}$, $Mz_{front\ starboard}$, $Mz_{rear\ port}$, $Mz_{rear\ starboard}$ = aligning moments, Nm

4.2.3 Summary Of Model Parameters

Table 4-3 summarises the vehicle parameters used in the model and the source for each. As previously noted all of the values shown were based on experimentally measured data.

Table 4-3 Vehicle parameters used in simulation

Parameter	Abbreviation	Value used in simulation	Source
Vehicle body			
Distance from vehicle centre of gravity to front axle line	a	0.996 m	[4] Figure P16
Distance from vehicle centre of gravity to rear axle line	b	1.386 m	[4] Figure P16
Vehicle centre of gravity	cg_height	0.5 m	[5]
total mass	m_total	1314 kg	Measured at MIRA May 17,1994
Sprung mass roll inertia	Ixx	447.1 kgm^2	[5]
Yaw moment of inertia	Izz	1953 kgm^2 or 1648 kgm^2	[5]
Front suspension and steering			
Front roll stiffness	f_Kroll	31057 Nm/rad 17419 Nm/rad	[4] Figure R22,Config 3
Front half track width	f_track	0.703 m	[4] Figure P16
Front roll centre height	f_hroll	-0.054 m	[4] Figure Z5
Ratio of hand wheel angle to road wheel angle (Effective steer ratio)	ESR	21.3	[6] Table 1
Total steering stiffness between hand wheel and road wheels	K_total	1.174e4 Nm/rad	[4] Figure Y2, Handwheel locked
Front compliance steer coefficient	K_compliance	1.750e4 Nm/rad	[4] Figure Y2, Steer rack locked
Steering column torsional stiffness	K_column	3.57 e4 m/rad	[4] Figure Y2
Front mechanical trail	f_trail	0.035 m	Measured at MIRA May 17,1994
Static front port normal load	static_fp_fz	3750 N	Appendix D
Static front starboard normal load	static_fs_fz	3750 N	Appendix D
Static front camber angle	static_fp_camber	-1 degree	Measured at MIRA May 17,1994
Static front camber angle	static_fs_camber	-1 degree	Measured at MIRA May 17,1994
d(Camber)/*d*(Roll angle) suspension derivative	f_dCamber_dRoll	0.928 deg/deg	[4] Figure R4, Config 3
Rear Suspension			
Rear roll stiffness	r_Kroll	20913 Nm/rad 16789 Nm/rad	[4] Figure R22, Config 4
Rear half track	r_track	0.668 m	[4] Figure P16 Michelin
Rear roll centre height	r_hroll	-0.0080 m	Appendix D
Rear compliance steer coeffieient	K_R_steer	3.697e5 N/rad	[4] Figure P4
Static rear port normal load	static_rp_fz	2695 N	Appendix D
Static rear starboard normal load	static_rs_fz	2695 N	Appendix D
Static front camber angle	static_rp_camber	0.33 degrees	Measured at MIRA May 16,1994
Static front camber angle	static_rs_camber	-0.33 degrees	Measured at MIRA May 16,1994
d(Camber)/*d*(Roll angle) suspension derivative	r_dCamber_dRoll	0.986	[4] Figure R14
Roll axis height			
Distance from vehicle centre of gravity to roll axis	roll_axis_height	0.5348 m	Appendix D

4.3 Vehicle Simulation

Implementing the mathematical representation of the vehicle in simulation was done by coding the equations into a commercial data analysis package, Matlab. The basic operation of the simulation is shown in Figure 4-14. Figure 4-15 names the various sub-routines written and states what function each has in the simulation. A full listing of the programs are given in Appendix 4E. For each point in the simulation, the program read in experimental hand wheel and forward velocity inputs which were used to calculate the forces acting on the vehicle. Accelerations were then obtained from the equations of motion which, in turn, were sent to an integration subroutine. The outputs of the integration were then saved to disk and sent around for the next point in the simulation.

Figure 4-14 Block diagram of vehicle simulation

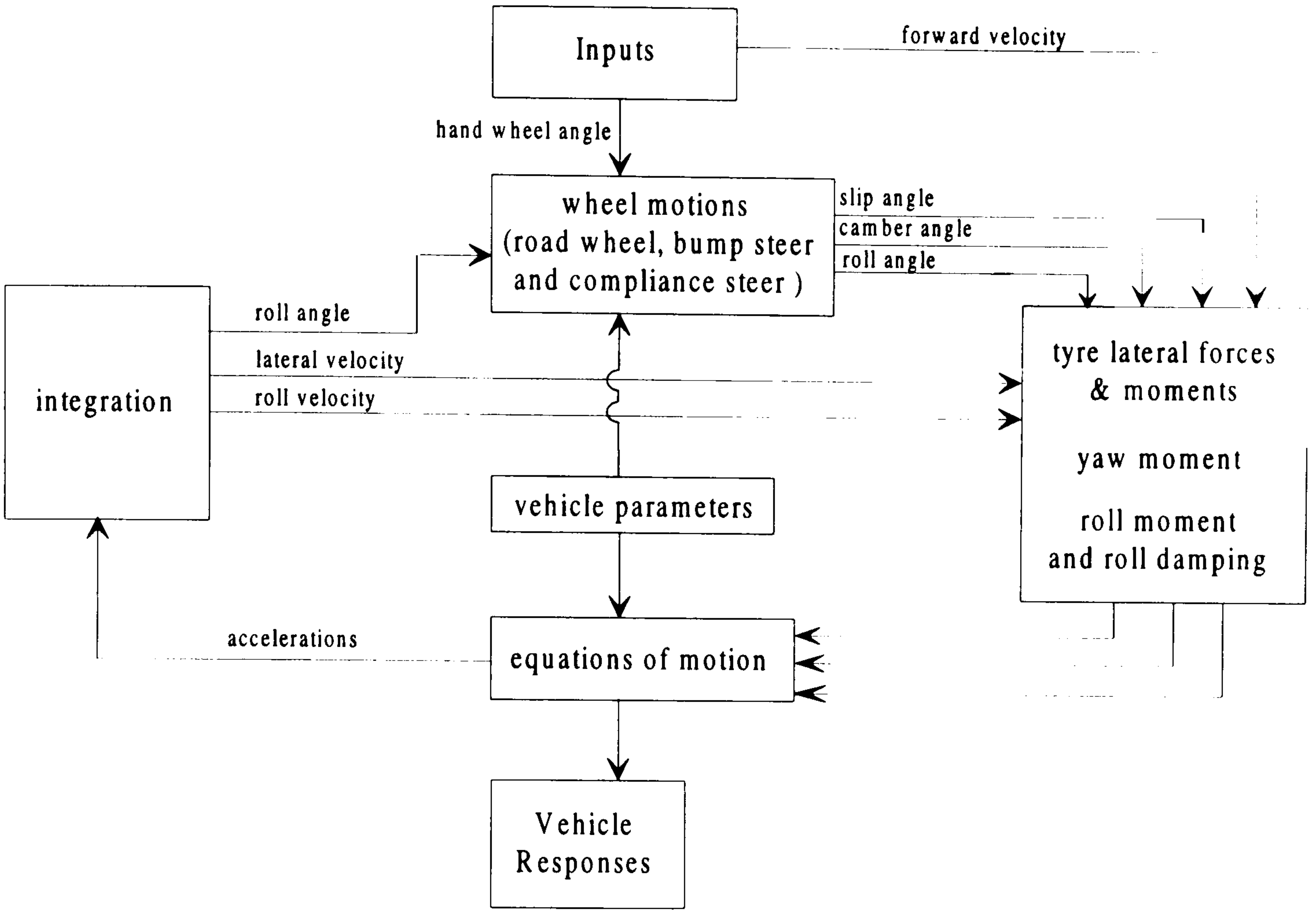
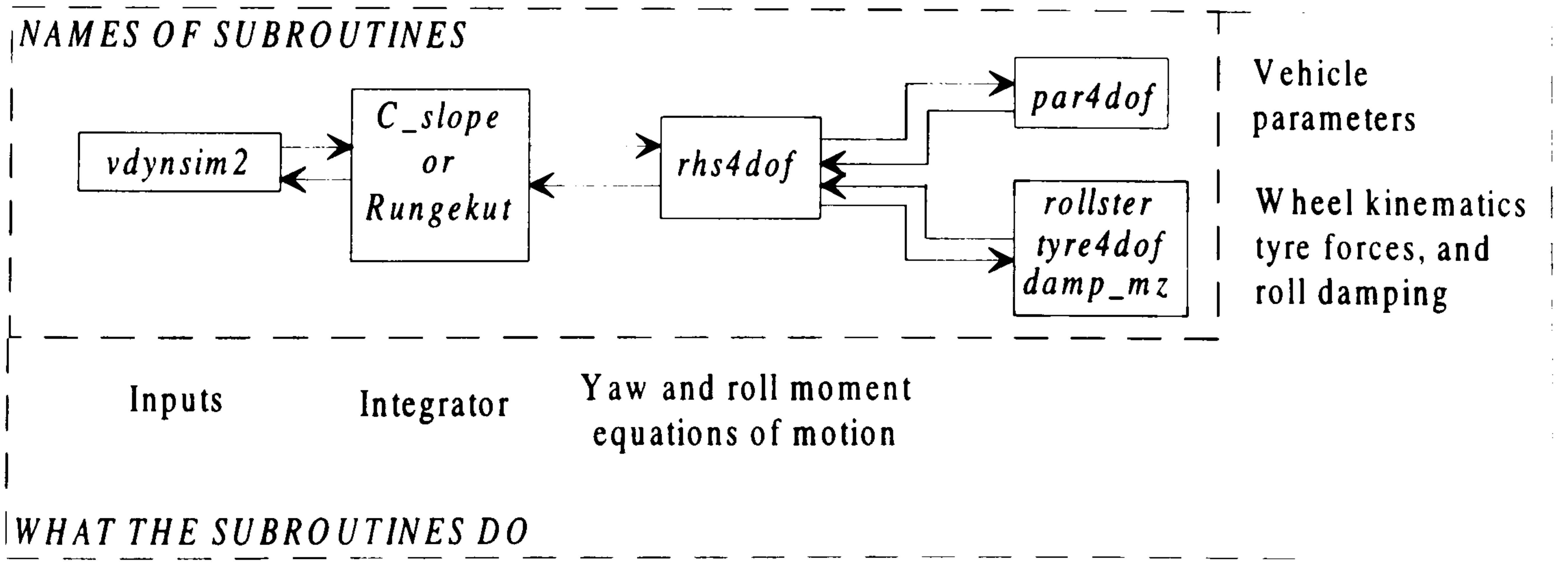


Figure 4-15 Subroutines and their function



4.3.1 Integration of the Equations of Motion

For each simulation run, one of two integration methods was used to solve the differential equations of motion. Initially solutions were sought using a *constant slope* integrator. This type of integration solves differential equations according to equation

(18) and is discussed fully in reference [3]. Simply put, each new solution is generated by: i) multiplying the slope at the previous time value by the time step and ii) adding this product to the previous solution. The advantages of this method are simplicity and fast solutions. The disadvantage is that in certain circumstances the errors of the approximate solutions build up, resulting in poor predictions. A check for such circumstances in the simulation was made by testing to see if the magnitudes of any of the predicted responses exceeded 200. This value was judged to be at least 20 times greater than the level of response expected in any of the solutions. In cases where the constant slope integrator was unsatisfactory a more sophisticated integration method was automatically selected.

$$y_{new} = y_{old} + \Delta t(slope_{old}) \tag{18}$$

where

y_{new} = the new solution for the current time value

y_{old} = the solution for the previous time value

Δt = time step between values

$slope_{old}$ = the acceleration or velocity from the previous time value

The more sophisticated integration method involved using a 4th order Runge-Kutta formula and, if necessary, increasing the number steps in each time interval. The Runge-Kutta method approximates each new solution by evaluating the function four times at different points in the time interval between the previous and current time values. Equation (19), shows the exact calculation. A full description of the method is given in [3] including a demonstration of its superiority to the constant slope method. After each new solution was obtained, its value was checked to determine if the difference between it and the previous solution exceeded a set tolerance of 0.001. If this was the case the time step was broken up into smaller steps and the function re-evaluated for each sub-interval. This process was repeated until the solution converged on one within the specified tolerance. Although computationally intensive this method was robust and reliable.

$$y(a+h) = c + \frac{1}{6}(m_1 + 2m_2 + 2m_3 + m_4)$$

where (19)

$$m_1 = hf(a,c), \quad m_2 = hf(a + \frac{1}{2}h, c + \frac{1}{2}m_1),$$

$$m_3 = hf(a + \frac{1}{2}h, c + \frac{1}{2}m_2), \quad m_4 = hf(a + h, c + m_3)$$

a = the old time value

h = the interval to the new time value

y = the new solution

c = the old solution

f = the differential equation being solved

4.4 Sensitivity Analysis

In order to address the possibility of inaccurate parameter values causing errors in the simulated results a sensitivity study was done using a factorial experiment. This experiment provided a gauge of how the model outputs might be affected by errors in the parameter set. It also confirmed that the eight experimental vehicle parameters selected in Chapter 2 did in fact play the most significant roles in modifying the vehicle handling behaviour.

Although all of the parameter measurements were done with care it is inevitable that their accuracy will have been affected by instrumentation or procedural errors. While it may seem pedantic to worry about the accuracy of measurements obtained from calibrated test rigs, staffed by experienced engineers, there is evidence to suggest that significant errors can occur. Reference [7], for example, notes that accuracies for inertial parameter measurements ranging from ±5% to ±15% are typical. In another reference, [8], the authors estimate that vehicle centre of gravity height measurements may vary by as much as ±51 mm. Even if the measurements were 100% accurate, this does not mean that the model will have been completely representative of the vehicle as tested on the proving ground. The true values of, for example, moments of inertia and centre of gravity position will have departed from the nominal values during testing due to fuel consumption. Alternatively, suspension kinematics may have varied slightly between set-ups due to the continual assembly and dissassembly of the suspension system. Clearly it is a worthwhile exercise to assess the sensitivity of the simulation output to any possible errors in the input parameters.

A true sensitivity analysis would involve differentiating the equations of motion with respect to each input parameter to give functions which indicate the effect that variations in the system inputs have on the outputs. To do this would have been a time consuming and mathematically intensive exercise and for this reason a pseudo-sensitivity study was done utilising a factorial experiment. This method was simple to implement using sub-routines already written for the validation analysis. Table 4-4 shows the contrast matrix for an experiment similar to that used for the sixteen experimental vehicle configurations but with a larger number of variables and more configurations. In total the effect of varying thirty-one model parameters on simulation outputs were investigated. In the case of the eight parameters used during the experimental testing, their "+" and "-" values were not changed. For the remaining vehicle parameters, each was assigned a "-" level equal to their nominal value and a "+" level 15% greater than the nominal. 15% was selected arbitrarily as a worst case error but it is consistent with the accuracy range quoted for inertial parameters in [7]. Each configuration was subjected to a step input test in which the handwheel angle went from 0 to 60 degrees in 0.5 second while travelling at 50 km/h. The derived responses were the same as for a conventional step input test. i.e. peak responses, response times, and steady state values. Appendix 4F tabulates these results.

Appendix 4G shows normal probability plots for the each vehicle parameter's main effect. (Refer to Chapter 2, Section 2.3.2 for a description of how main effects are calculated.) Overall it is quite clear that the eight experimental vehicle parameters would have the greatest effect on vehicle response even in the presence of the 15% variation of the other parameters. Recall that the experimental parameters were *front and rear roll stiffness, front and rear tyre size, front and rear roll damping, yaw inertia and bump steer setting*. These factors are labelled 1 to 8 as shown in Table 4-4. In the majority of cases where a factor deviated from a straight line, the factor was one of the experimental vehicle parameters. Most of the time, the effects attributed to the remaining vehicle parameters were small by comparision.

However three model parameters did, in some instances, have significant effects on the simulation output. Figure 4-16 to Figure 4-18 indicate that parameters 12, 21, and 29, the total vehicle mass, and front and rear normal loads could have a significant effect on results if their true values during testing deviated by the 15%. The affected responses are steady state lateral acceleration, yaw and steer torque. Fortunately errors of this magnitude are extremely unlikely to have happened during the experimental work. 15% of the total vehicle mass of 1314 kg is almost 200 kg - a change in vehicle mass of this amount simply could not have occured.

In summary even if the true values of the vehicle parameters differed from the modelled ones it is likely that the effects on the simulated responses would still be minimal in comparision to the effects of the experimental parameters.

Table 4-4 Factorial experiment to assess sensitivity of model parameters

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Configuration	f_Kroll	RearTyres	f_Croll	r_Croll	FrontTyres	r_Kroll	Izz	RollSteer	a	cg_height	m_sprung	m_total	Ixx	f_track	f_hroll	K_total	K_compliance	C_steer	f_trail	Izz_fw	static_fp_fz	static_fp_camber	f_dCamber_dRoll	r_track	r_hroll	K_R_steer	r_trail	Izz_rw	static_rp_fz	static_rp_camber	r_dCamber_dRoll
1	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	-
2	+	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	+	+
3	-	+	-	-	-	-	+	+	+	-	-	-	+	+	+	+	+	+	-	-	-	+	+	+	-	-	-	-	+	-	+
4	+	+	-	-	-	+	-	-	-	-	-	-	+	+	+	-	-	-	+	+	+	+	+	+	-	+	+	+	-	-	-
5	-	-	+	-	-	+	-	+	+	-	+	+	-	-	+	+	-	-	+	+	-	+	+	-	+	-	-	+	-	-	+
6	+	-	+	-	-	-	+	-	-	-	+	+	-	-	+	-	+	+	-	-	+	+	+	-	+	+	+	-	+	-	-
7	-	+	+	-	-	-	-	+	+	+	-	-	-	-	+	-	+	+	+	+	-	-	-	+	+	+	+	-	-	+	-
8	+	+	+	-	-	+	+	-	-	+	-	-	-	-	+	+	-	-	-	-	+	-	-	+	+	-	-	+	+	+	+
9	-	-	-	+	-	+	+	-	+	+	-	+	-	+	-	-	+	-	+	-	+	+	-	+	+	-	+	-	-	-	+
10	+	-	-	+	-	-	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	+	+	-	+	+	-	-
11	-	+	-	+	-	-	+	-	+	-	+	-	-	+	-	+	-	+	+	-	+	-	+	-	+	+	-	+	-	+	-
12	+	+	-	+	-	+	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	+	-	+	-	+	+	+
13	-	-	+	+	-	+	-	-	+	-	-	+	+	-	-	+	+	-	-	+	+	-	+	+	-	+	-	-	+	+	-
14	+	-	+	+	-	-	+	+	-	-	-	+	+	-	-	-	-	+	+	-	-	-	+	+	-	-	+	+	-	+	+
15	-	+	+	+	-	-	-	-	+	+	+	-	+	-	-	-	-	+	-	+	+	+	-	-	-	-	+	+	+	-	+
16	+	+	+	+	-	+	+	+	-	+	+	-	+	-	-	+	+	-	+	-	-	+	-	-	-	+	-	-	-	-	-
17	-	-	-	-	+	+	+	+	-	+	+	-	+	-	-	-	-	+	-	+	+	-	+	+	+	+	-	-	-	-	+
18	+	-	-	-	+	-	-	-	+	+	+	-	+	-	-	+	+	-	+	-	-	-	+	+	+	-	+	+	+	-	-
19	-	+	-	-	+	-	+	+	-	-	-	+	+	-	-	+	+	-	-	+	+	+	-	-	+	-	+	+	-	+	-
20	+	+	-	-	+	+	-	-	+	-	-	+	+	-	-	-	-	+	+	-	-	+	-	-	+	+	-	-	+	+	+
21	-	-	+	-	+	+	-	+	-	-	+	-	-	+	-	+	-	+	+	-	+	+	-	+	-	-	+	-	+	+	-
22	+	-	+	-	+	-	+	-	+	-	+	-	-	+	-	-	+	-	-	+	-	+	-	+	-	+	-	+	-	+	+
23	-	+	+	-	+	-	-	+	-	+	-	+	-	+	-	-	+	-	+	-	+	-	+	-	-	+	-	+	+	-	+
24	+	+	+	-	+	+	+	-	+	+	-	+	-	+	-	+	-	+	-	+	-	-	+	-	-	-	+	-	-	-	-
25	-	-	-	+	+	+	+	-	-	+	-	-	-	-	+	-	+	+	+	+	-	+	+	-	-	-	-	+	+	+	-
26	+	-	-	+	+	-	-	+	+	+	-	-	-	-	+	+	-	-	-	-	+	+	+	-	-	+	+	-	-	+	+
27	-	+	-	+	+	-	+	-	-	-	+	+	-	-	+	+	-	-	+	+	-	-	-	+	-	+	+	-	+	-	+
28	+	+	-	+	+	+	-	+	+	-	+	+	-	-	+	-	+	+	-	-	+	-	-	+	-	-	-	+	-	-	-
29	-	-	+	+	+	+	-	-	-	-	-	-	+	+	+	+	+	+	-	-	-	-	-	-	+	+	+	+	-	-	+
30	+	-	+	+	+	-	+	+	+	-	-	-	+	+	+	-	-	-	+	+	+	-	-	-	+	-	-	-	+	-	-
31	-	+	+	+	+	-	-	-	-	+	+	+	+	+	+	-	-	-	-	-	-	+	+	+	+	-	-	-	-	+	-
32	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Figure 4-16 Normal probability plot indicating a significant effect for factor number 21 and 29, static front and rear normal load.

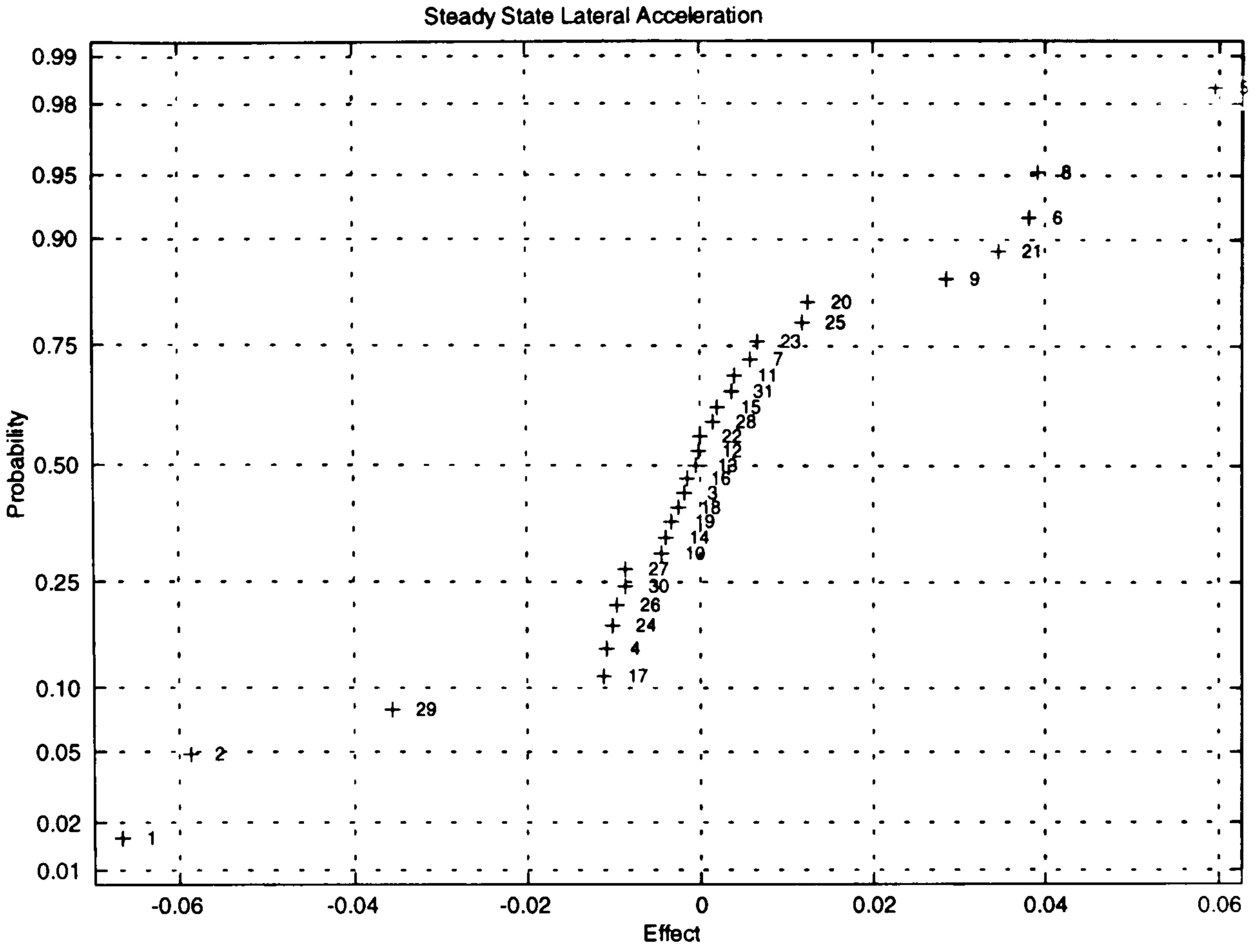


Figure 4-17 Normal probability plot indicating significant effects for factor number 21 and 29, static front rear normal load .

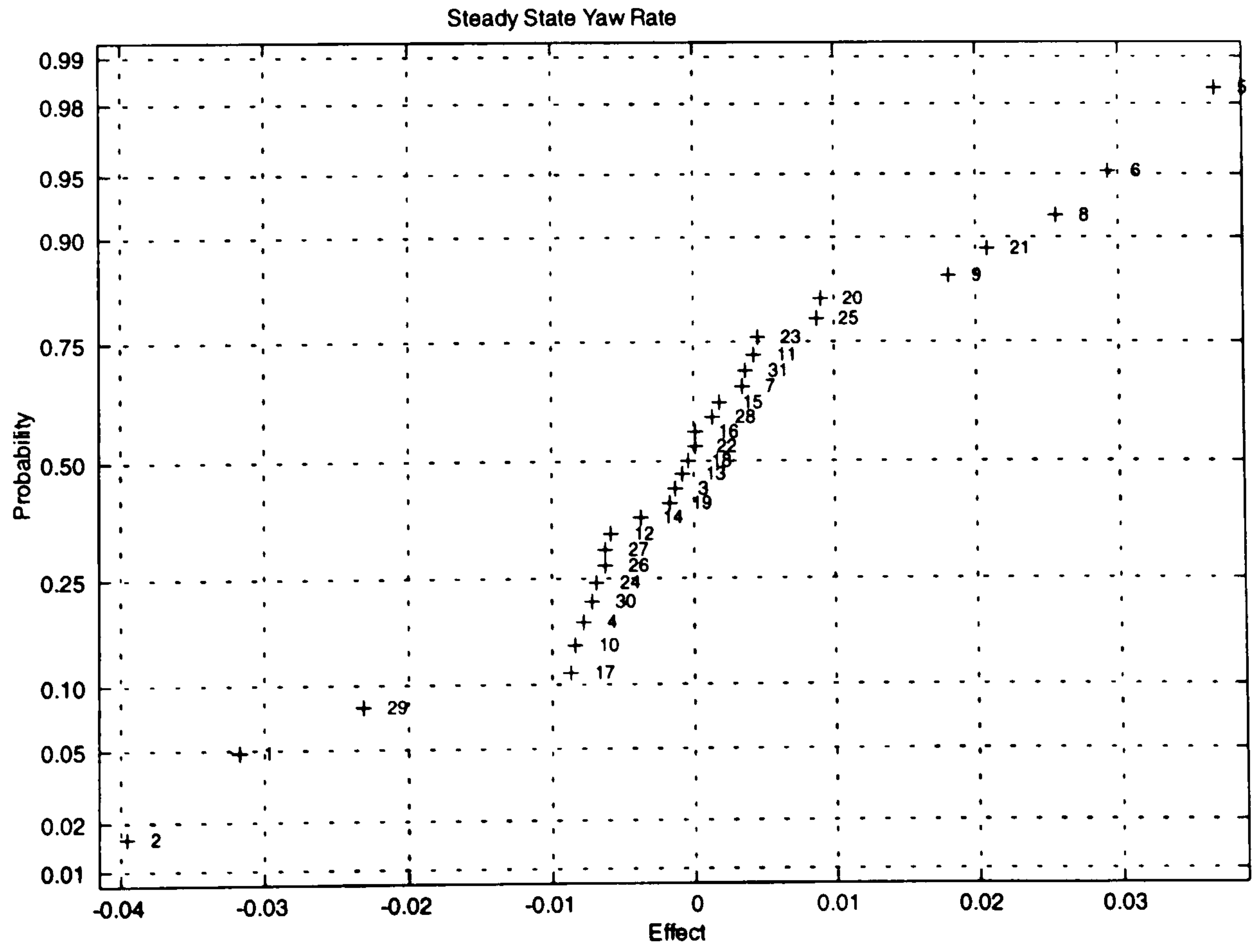
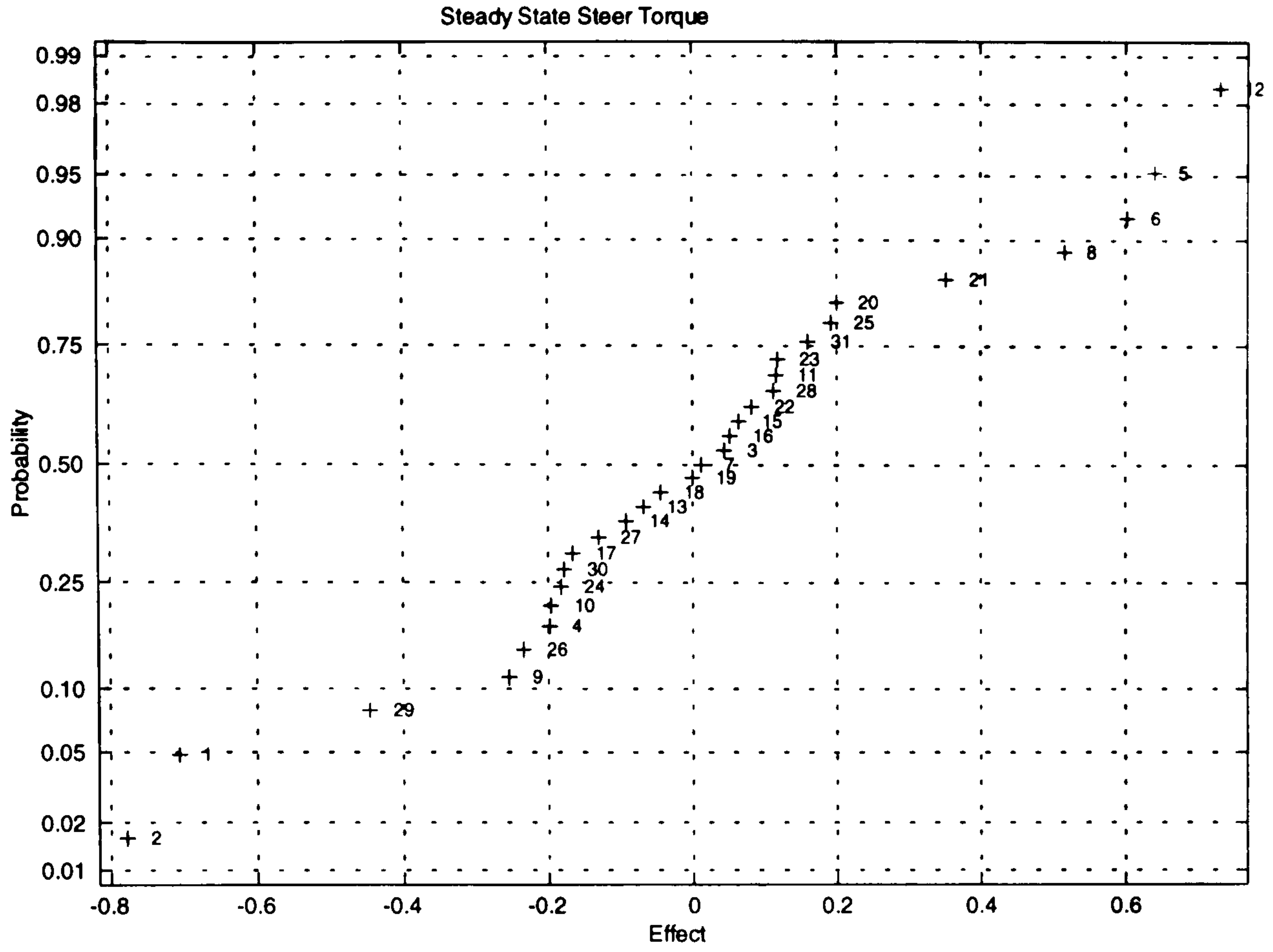


Figure 4-18 Normal probability plot indicating a significant effect for factor number 12, total vehicle mass



4.5 Conclusions

The most important feature of the model derived in this chapter was the fact that all of its parameters were obtained directly from, or were based on, experimental measurements - no values were assumed. The model allows for lateral, yaw and roll degrees of freedom and represents wheel motions as functions of hand wheel angle, roll and tyre aligning moment. Tyre and damping forces were incorporated into the simulation as non-linear functions.

In simulation it has been shown that the eight experimental vehicle parameters do in fact contribute most significantly handling responses, even in the presence of possible errors for the other parameters. A sensitivity analysis showed that if the model values were in error by as much as 15% their effects are generally small compared to that of the eight selected experimental parameters.

5. Validation of the Mathematical Model

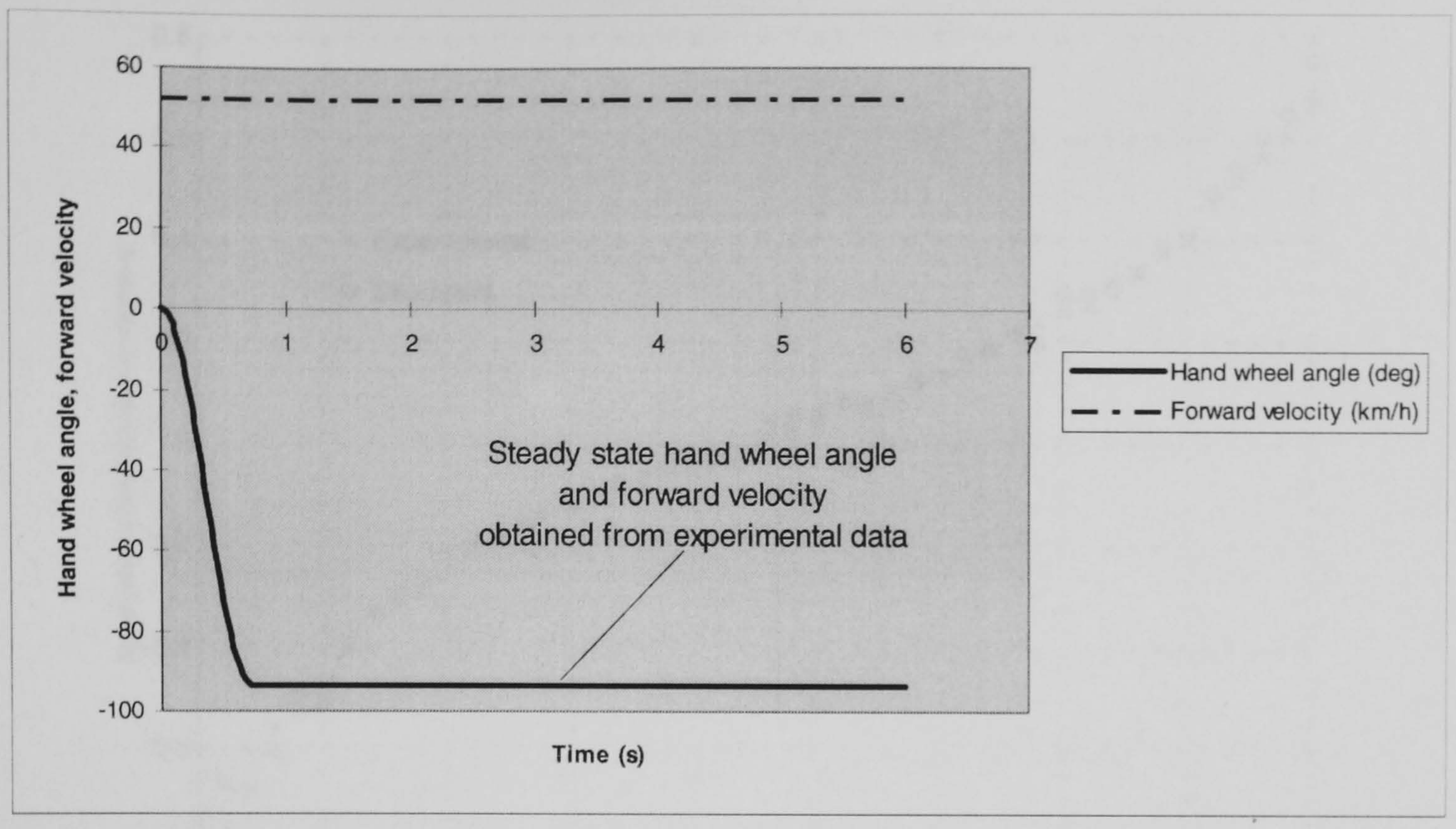
This chapter compares the simulated and experimental data to demonstrate the extent to which the mathematical model represents the actual vehicle. The methodology consisted of overlaying the simulated and experimental data for qualitative comparison and then quantifying errors by calculating the percent difference between them at specified lateral accelerations or frequencies.

The presentation in this chapter is organised by test type. For each test a typical comparison of simulated and experimental data is plotted along with tables or figures depicting the average percent errors seen across the sixteen experimental configurations.

5.1 Steady State

Figure 5-2 to Figure 5-4 overlay *lateral acceleration*, *roll angle* and *slip angle* data taken from experimental and simulated steady state data. Each simulated data point was generated individually based on the hand wheel angle and forward velocity corresponding to the experimental data point. Figure 5-1 shows the form of the hand wheel input and forward velocity input used to produce each point. The steady state hand wheel angle was taken from the experimental data point as was the forward speed. The end points of the response time histories using this input thus yielded the steady state responses.

Figure 5-1 Hand wheel and velocity input used to generate simulated steady state points.



The accuracy of the model was examined by comparing simulated and experimental values at points corresponding to the experimental lateral accelerations of -0.4, -0.2, 0.2, and 0.4 g. These are the lateral accelerations which were subsequently used in the subjective-objective correlation work. Table 5-1 shows for four measured responses the percent difference at each lateral acceleration averaged across all the experimental configurations. i.e. percent difference was calculated as:

100%×*(simulated value - experimental value)/experimental value.*

It can be seen that the overall accuracy is quite good. Figure 5-2 in particular highlights the fact that even at relatively high lateral accelerations - the non-linear region - the simulation values are accurate. Predicted lateral accelerations across the sixteen configurations averaged to approximately 5%. Roll angle, slip angle and steering torque also exhibit small errors although the confidence intervals are somewhat greater.

Figure 5-2 Experimental vs. simulated lateral acceleration, Configuration 9

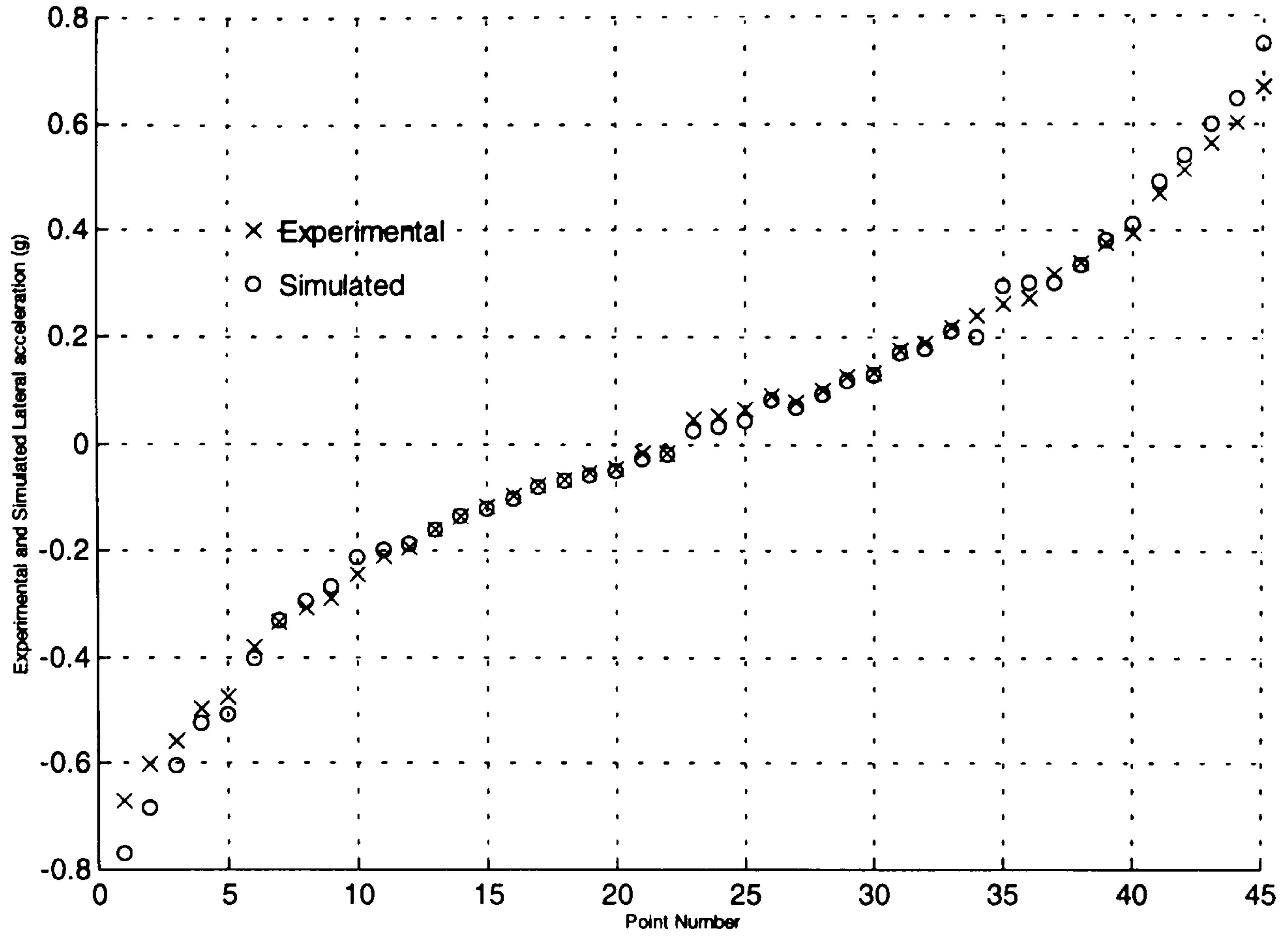


Figure 5-3 Experimental vs. simulated roll angle, Configuration 9

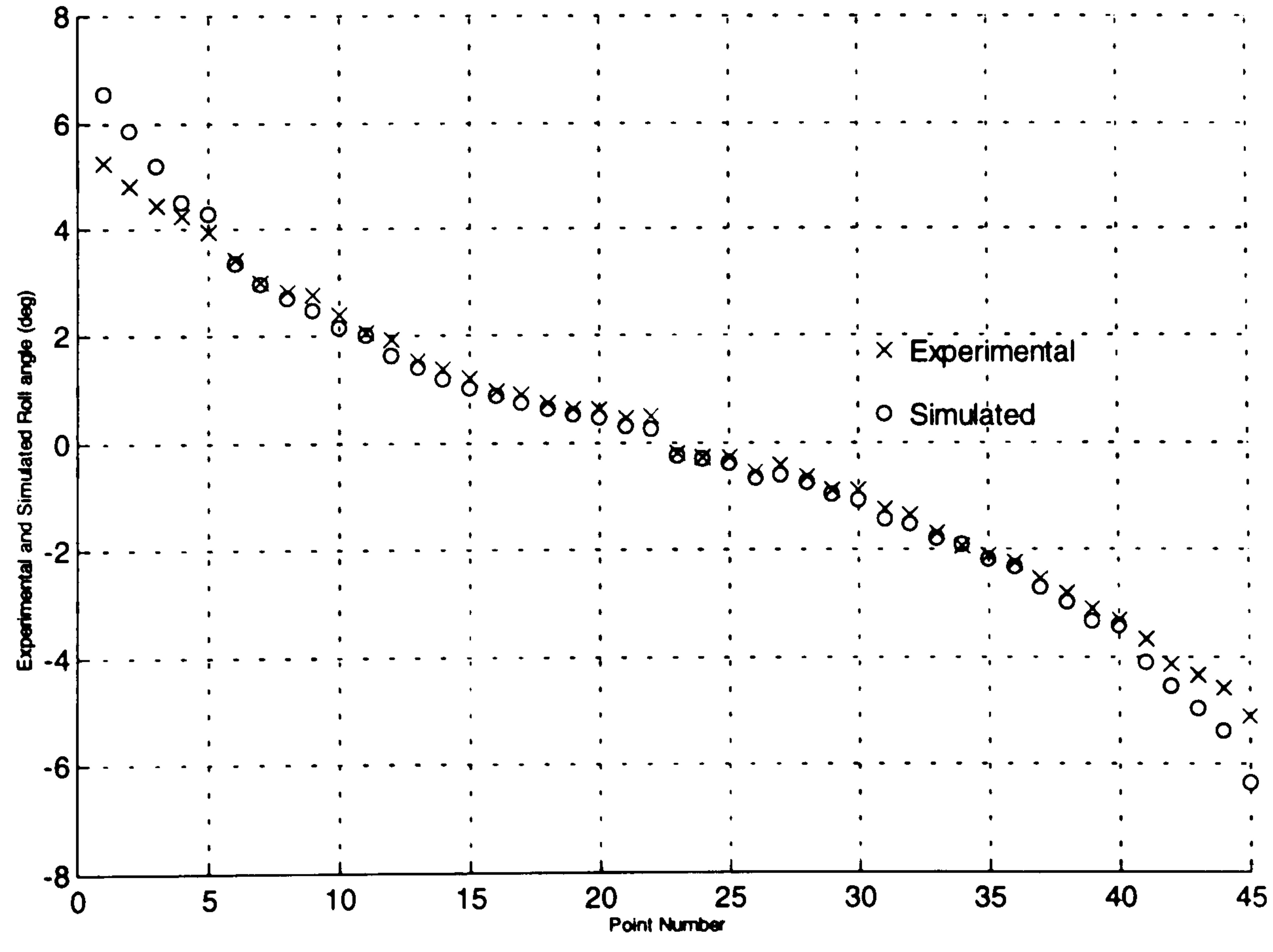


Figure 5-4 Experimental vs. simulated slip angle, Configuration 9

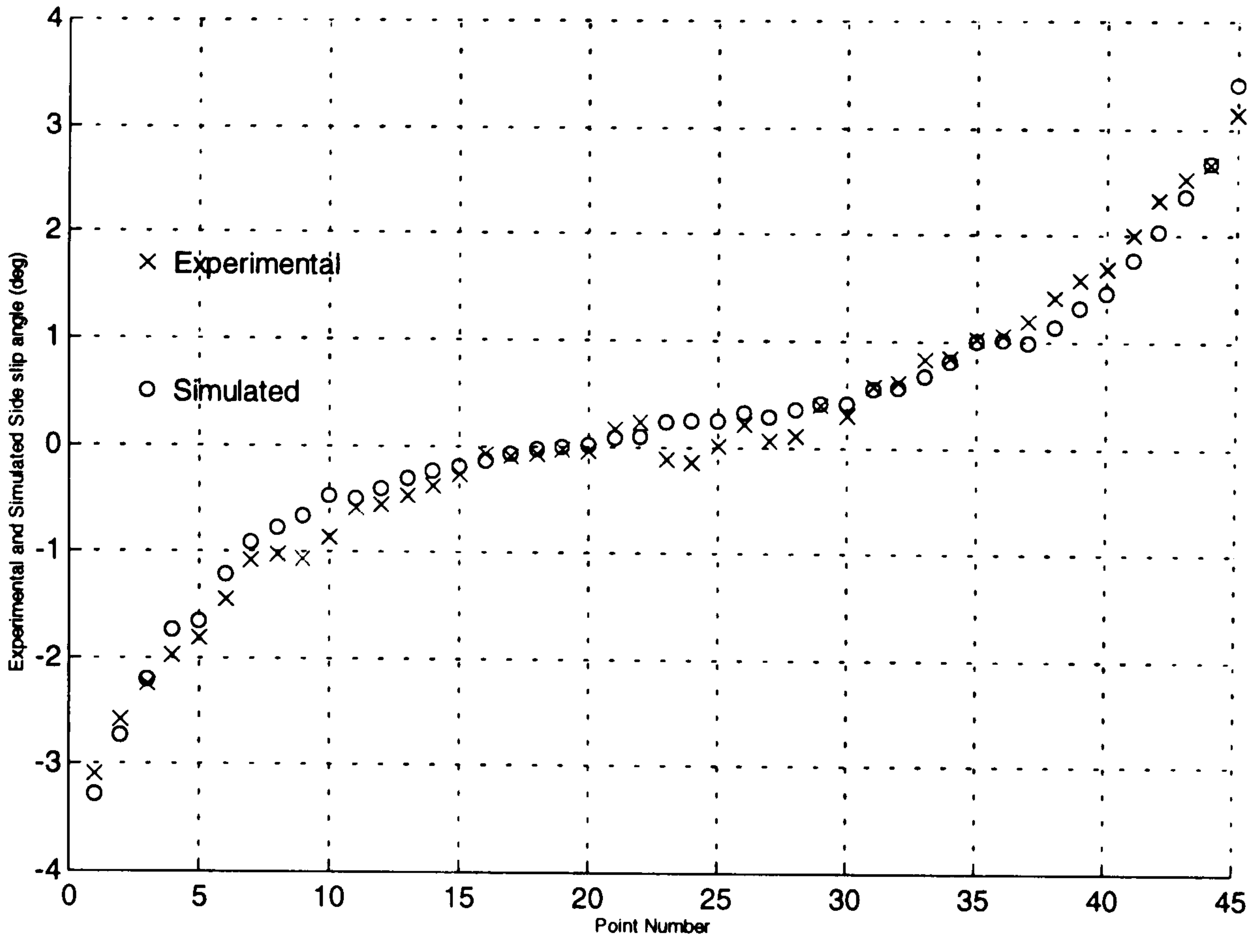


Table 5-1 Average percent errors for steady state predictions across all experimental configurations

Lateral Acceleration			Roll Angle		
Experimental Lateral acceleration	Mean Error (% difference)	± 95% Confidence Interval	Experimental Lateral acceleration	Mean Error (% difference)	± 95% Confidence Interval
-0.4	1.33	5.73	-0.4	4.15	5.87
-0.2	-5.61	6.25	-0.2	-2.39	5.71
0.2	-0.69	3.54	0.2	3.81	2.57
0.4	5.82	4.18	0.4	-0.38	3.12
Side Slip Angle			**Steering Torque**		
Experimental Lateral acceleration	Mean Error (% difference)	± 95% Confidence Interval	Experimental Lateral acceleration	Mean Error (% difference)	± 95% Confidence Interval
-0.4	0.76	10.88	-0.4	11.69	10.16
-0.2	14.99	15.88	-0.2	1.45	7.07
0.2	7.47	18.02	0.2	-1.01	6.58
0.4	29.82	9.95	0.4	12.31	10.37

5.2 Step Input

Figure 5-5 to Figure 5-7 compare measured and predicted *lateral acceleration, yaw rate and steering torque* step input responses for configuration 8. The simulated results were generated by reading in the experimental hand wheel angle and forward velocity as inputs to the model. Note that the roll rate signal obtained during testing was too noisy for comparison to the simulation - according to staff at MIRA this is a common problem. Figure 5-8 focuses on the transient response metrics obtained from the step input tests, namely the peak values and response times. Appendix 5B tabulates the data for each configuration along with confidence intervals.

Compared to the steady state results the transient characteristics are, on average, not as well predicted. The simulated peak values tend to differ by approximately 15% plus or minus approximately 5%. The difference in response times is slightly less, especially for lateral acceleration with values of 7% or less. However it can also be seen that of the model accuracy does not degrade in the non-linear, 0.6 g, range. In fact except for the peak steer torque the average percent error of each response metric is lower at 0.6 than it is at 0.2. Thus while the percent errors of the transient response predictions are subject to greater variability they appear to hold their accuracy into the non-linear range.

Figure 5-5 Experimental vs. simulated lateral acceleration for a step input test, Configuration 8.

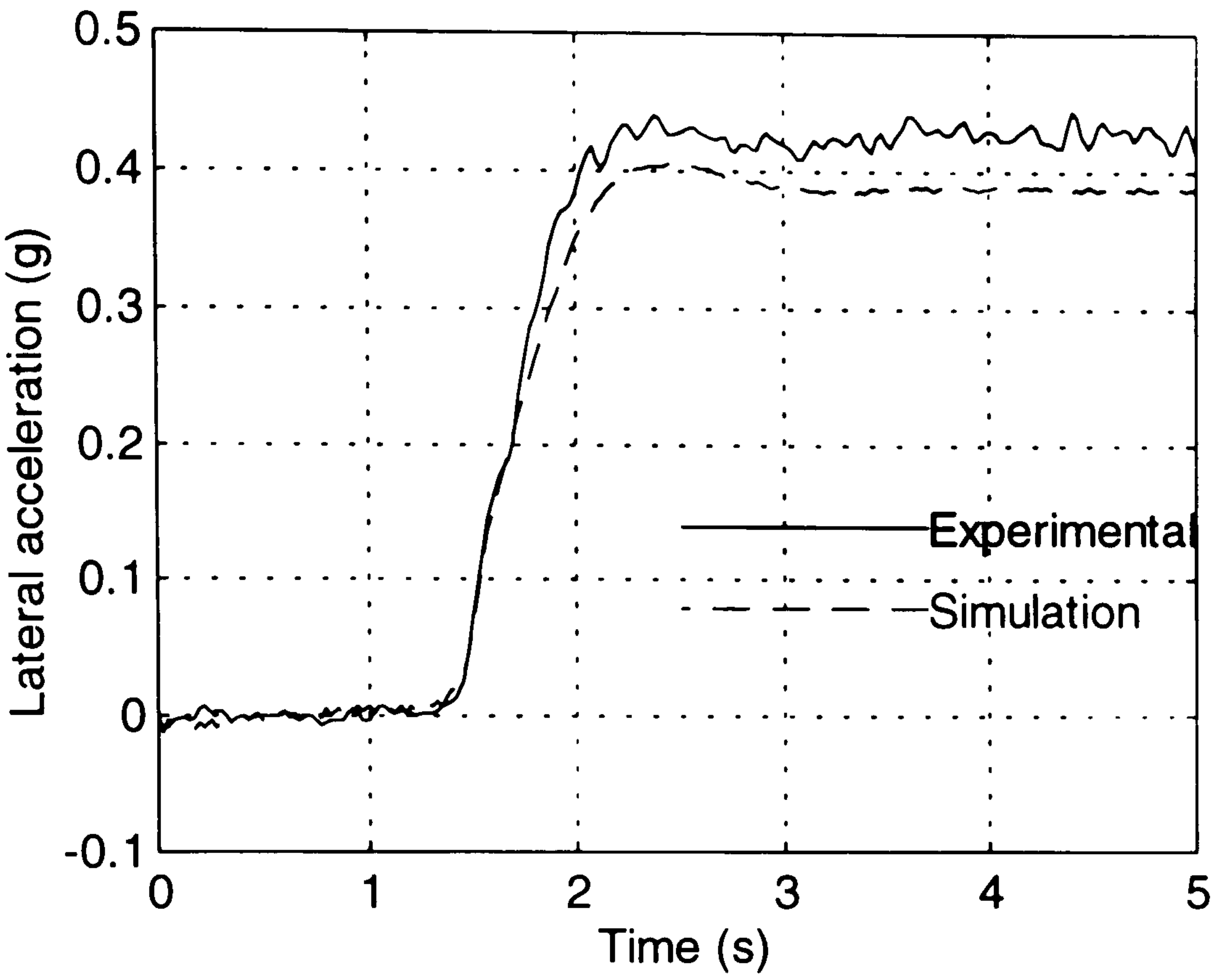


Figure 5-6 Experimental vs. simulated yaw rate for a step input test, Configuration 8.

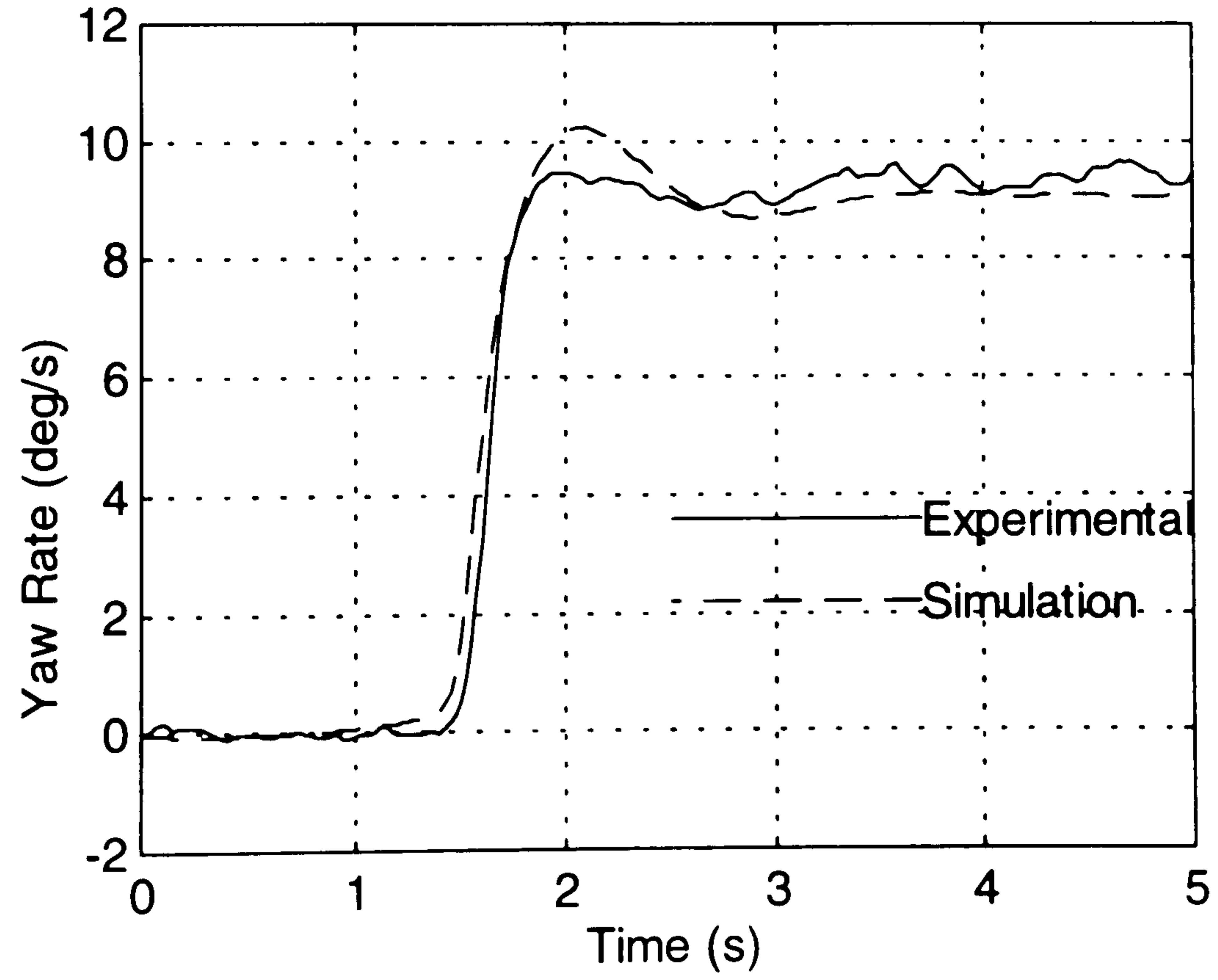


Figure 5-7 Experimental vs. simulated hand wheel torque for a step input test, Configuration 8.

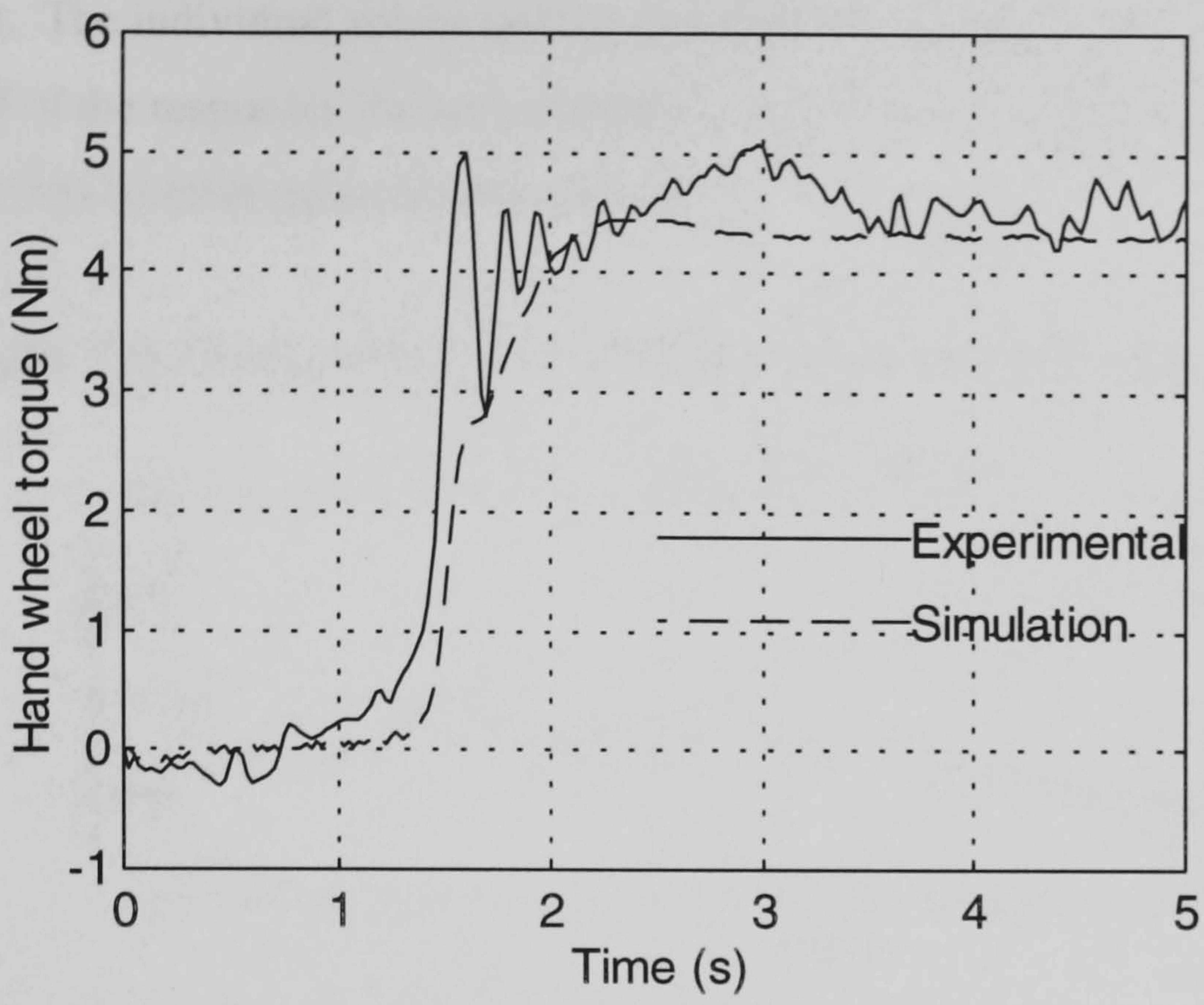
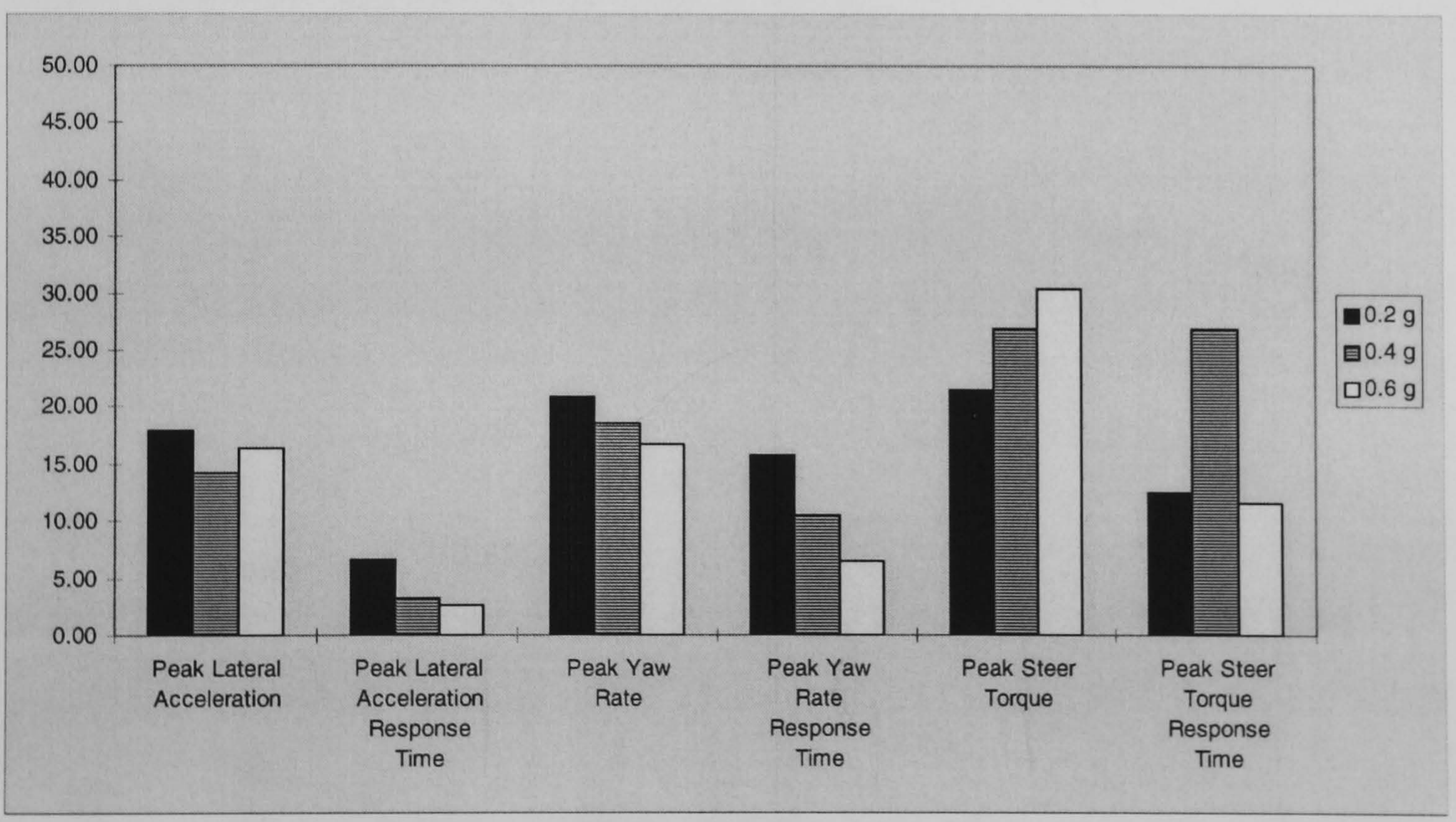


Figure 5-8 Percent difference between simulated and experimental step input results.



5.3 Frequency Response

Frequency response functions were generated by producing simulated time histories using the experimental hand wheel and forward velocities then transforming the results to the frequency domain. Lateral acceleration and yaw rate gains, with respect to hand wheel input, are shown in Figure 5-9 and Figure 5-10. Table 5-2 shows the percent difference between simulated and measured data at the three frequencies noted in Chapter 2 to be within the range where coherence is close to unity, 0.4, 0.7 and 1.0 Hz. The individual values used to calculate the means are shown in Appendix 5C. All of the responses shown in the table, except yaw rate gain at 1.0 Hz, exhibit average percent errors from 4 to 11%.

Figure 5-9 Experimental and simulated lateral acceleration gains

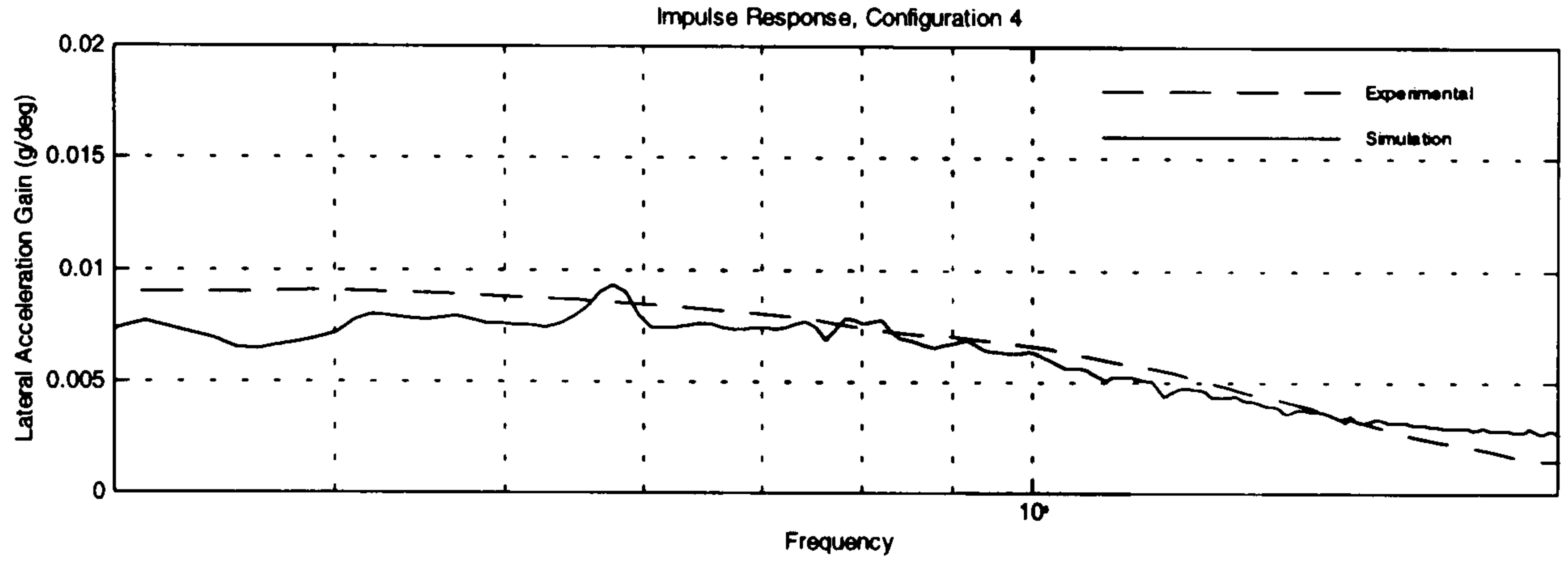


Figure 5-10 Experimental and simulated yaw gains

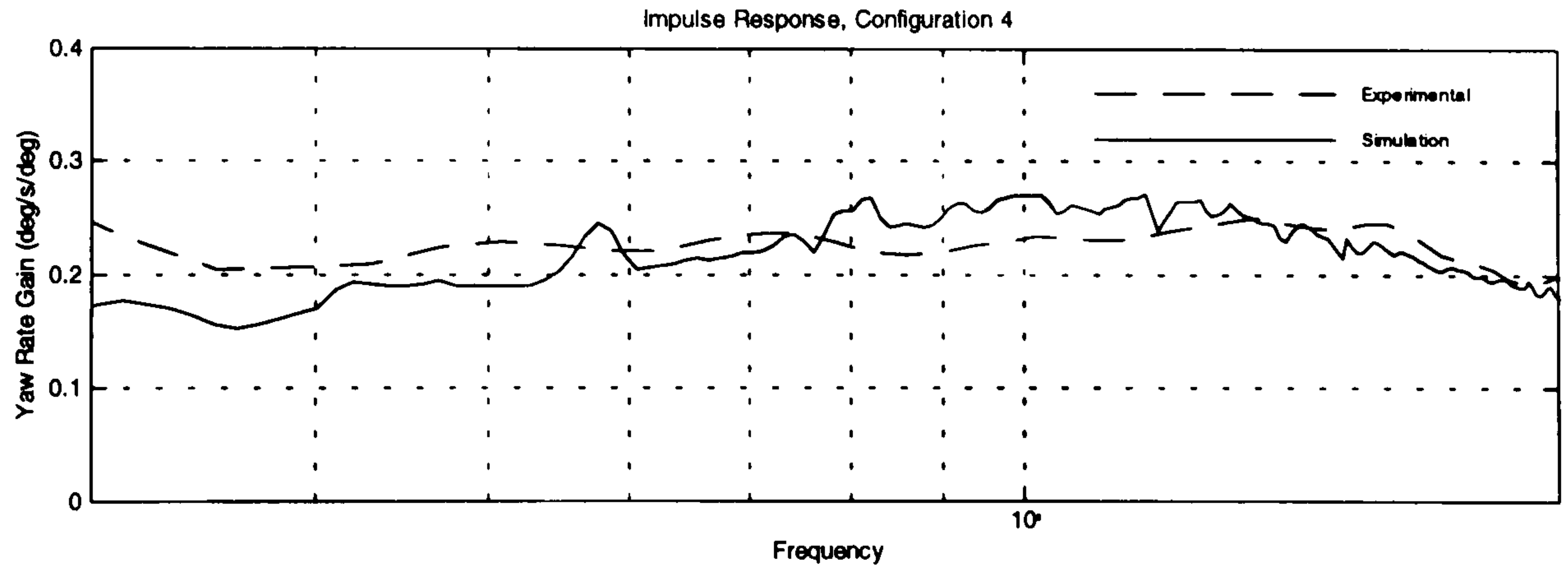


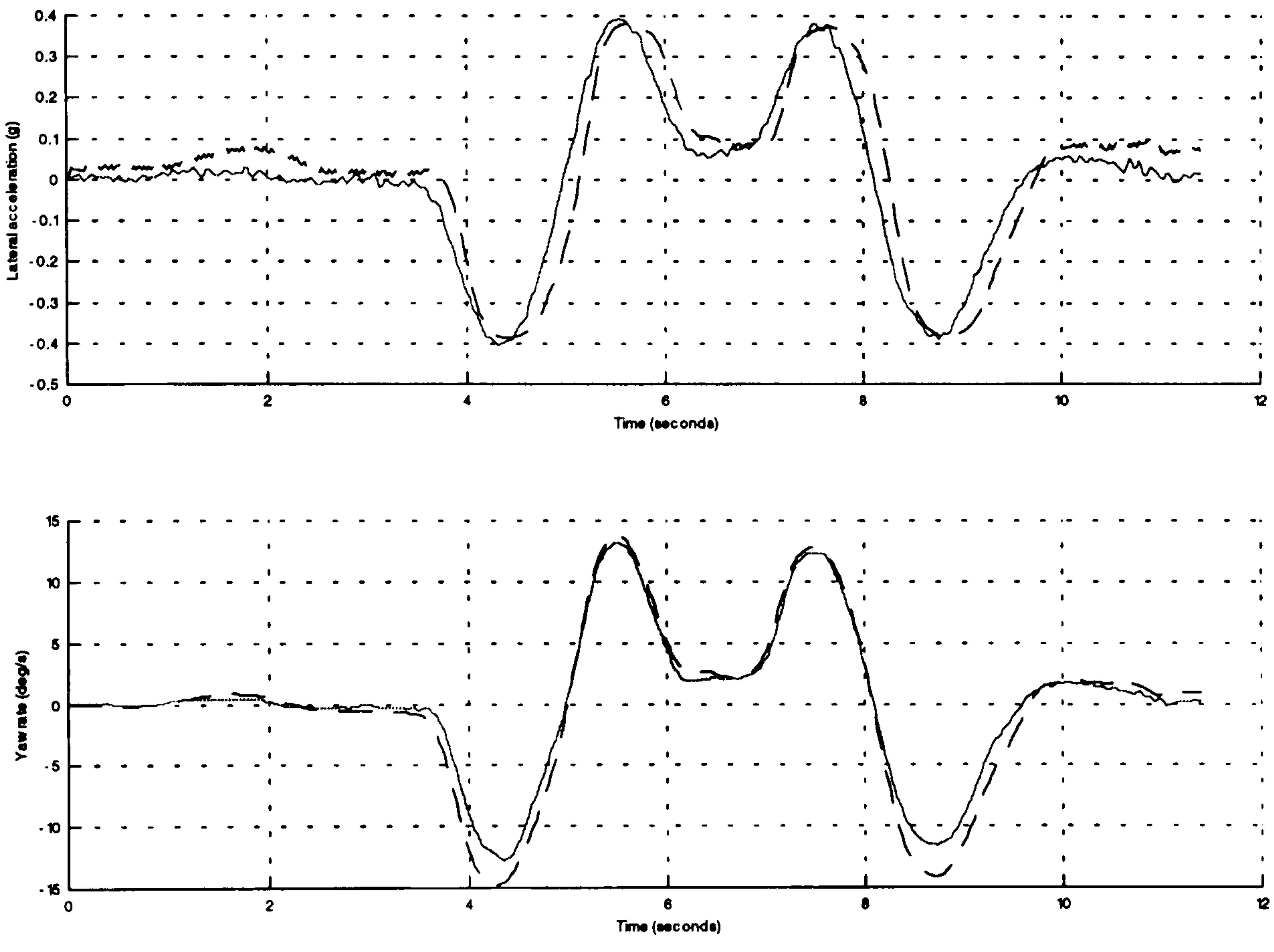
Table 5-2 Percent difference of frequency response gains at specific frequencies.

	Lateral Accel. Gain		Yaw Rate Gain	
Frequency	Mean Error	± 95% Confidence Interval	Mean Error	± 95% Confidence Interval
0.4	-6.04	3.17	-11.50	5.05
0.7	-4.22	1.53	-7.34	4.55
1	-11.90	2.25	-108.43	10.55

5.4 ISO Double Lane Change

As stated in Chapter 2, although the ISO double lane change manoeuvre is not suitable for subjective-objective correlation, it is a demanding test of a model's accuracy. Figure 5-11 shows that the simulated output - the dashed line - closely mirrors the solid experimental line for both lateral acceleration and yaw rate.

Figure 5-11 Experimental vs. simulated double lane change manoeuvre.



5.5 Conclusions

The ability of the model to predict experimental results in steady state and transient manoeuvres both in the linear and non-linear range of handling has been shown to be satisfactory. In particular:

- Steady state predictions of lateral acceleration, roll angle, slip angle and steering torque generally do not differ from the experiments by more than 10%.
- Predictions of transient behaviour - i.e. peak responses and response times for lateral acceleration, yaw rate and steering torque - exhibit percent errors of about 15% across the sixteen configurations.

- Frequency response results for lateral acceleration and yaw rate gains exhibit, for the most part, percent errors ranging from 4 to 11%.

- Lane changes simulations involving lateral accelerations in excess of 0.5 g mirror the experimental ones for both lateral acceleration and yaw rate responses.

6. Correlation Of Subjective and Objective Responses

This chapter brings together the subjective and objective data of previous chapters in order to:

i) Identify questions where good subjective - objective correlation exists. Such questions highlight aspects of handling for which test drivers are able to provide valid and reliable feedback based on objective performance.

ii) Identify the vehicle responses which contribute most to the drivers' formulation of ratings.

iii) Characterise the effect on driver ratings of increases (and decreases) in objective response parameters.

For a single driver these goals have a similar underlying theme. However when examining the drivers together the different objectives may not necessarily coincide. While drivers may all provide ratings correlating with objective data, the objective data itself may vary from driver to driver. For example one driver's ratings for "*lane change controllability*" might correlate with yaw response times while another's ratings might correlate equally well to lateral acceleration gains. This complication does not, however, preclude general conclusions on subjective-objective relationships as will be seen at the end of the chapter.

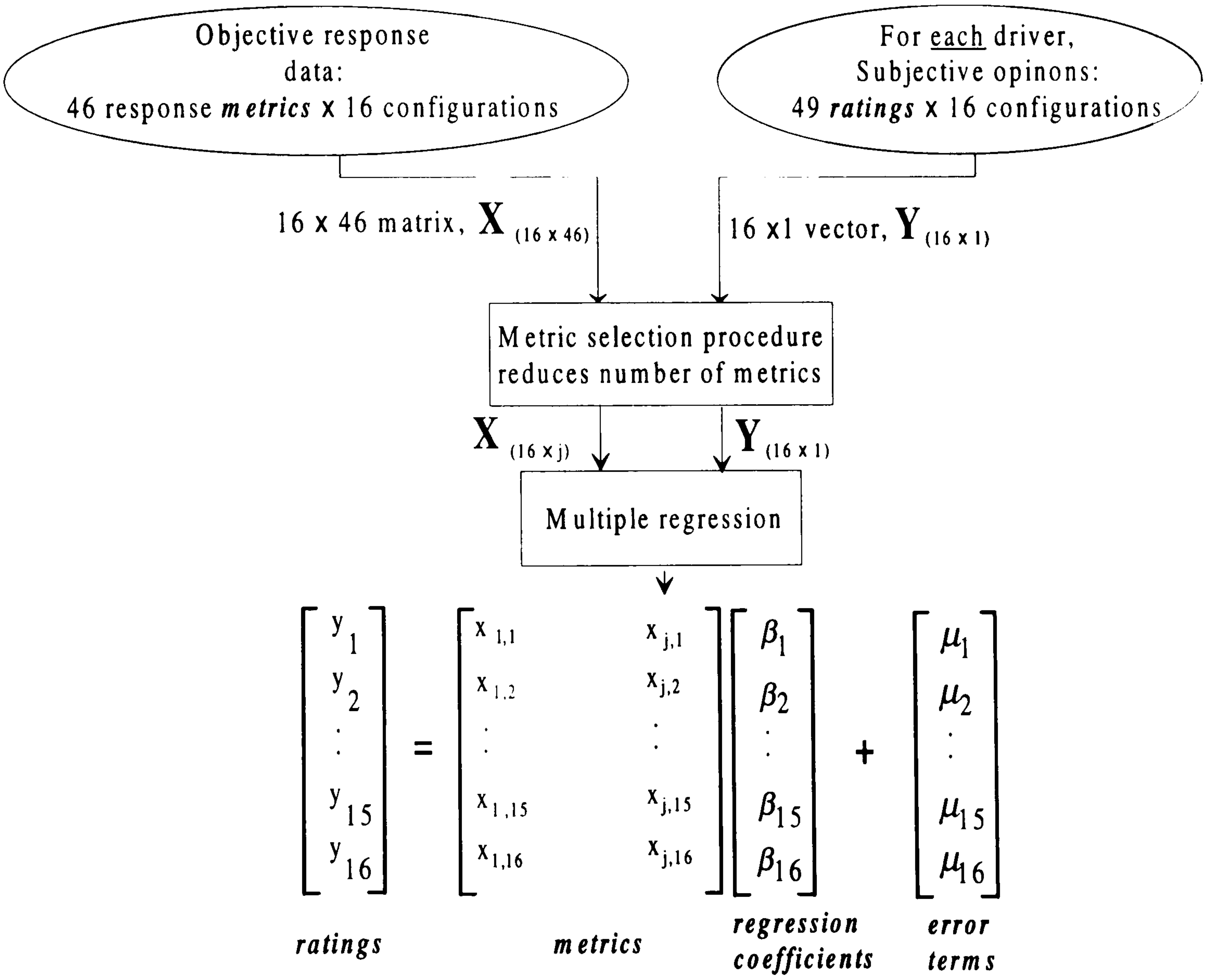
The method by which subjective-objective relationships were sought for each driver and their final form is illustrated in Figure 6-1. Forty-six sets of objective response parameters, or metrics, were compared with the sixteen ratings corresponding to a particular question. A selection process identified metrics likely to show correlation and sent them to a multiple regression procedure. If any correlation existed, a linear model of the driver's ratings for the question, based on the selected metrics, was produced. As an example of such a model consider the following equation.

$$Rating = 0.68(StMean/0.6) + 0.86(RollRtRespTime/0.6) - 0.3(d(storq)/0.2)$$

Definitions of the terms are given later in the chapter but it can still be seen that the predicted "*Rating*" for a given question is the sum of contributions from three different metrics.

The chapter begins with a summary of the data used in the correlation analysis followed by a description of the multiple regression techniques used. The analysis itself is presented in three sections starting with the correlation of ratings with the metrics grouped by test type. Next the investigation is expanded to one where metrics from all tests are pooled together. Finally the equations are re-interpreted to give a more generally applicable result where the average effect of each metric on ratings is estimated.

Figure 6-1 Correlation process gives a linear model of driver ratings in terms of objective metrics



6.1 Subjective And Objective Data Used In The Correlation Analysis

The data which was used in the current analysis was taken from the results of Chapter 2 and 3. Table 6-1 reproduces, from Chapter 3, the subjective questionnaire used to collect driver ratings. The ratings used in the regression are tabulated in Appendix 3B. For the objective data, forty six response metrics, named in Table 6-2 along with abbreviations used throughout the chapter, were selected as possible regressors for the correlation procedure. The basis for selecting these metrics was that they provided a valid, reliable and comprehensive characterisation of the vehicle's handling from low to medium lateral accelerations. Recall that this is nominally the same range of lateral accelerations over which the vehicles were subjectively evaluated. Note that the frequency response metrics are taken exclusively from the impulse test results since it was felt that they express information identical to the pseudo-random steer data. The actual data for each configuration is tabulated in Appendix 6A.

Table 6-1. Subjective Ratings Questionnaire, reproduced from Chapter 3.

	Main Heading	Sub Heading	Sub Sub Heading	Question
01	Steady state turning	Over smooth roads	Cornering behaviour	Progressive behaviour with increasing lateral accel.
02	Steady state turning	Over smooth roads	Cornering behaviour	Ease with which line is held
03	Steady state turning	Over smooth roads	Cornering behaviour	Degree of body roll
04	Steady state turning	Over smooth roads	Cornering behaviour	Progressive behaviour with decreasing lateral accel.
05	Steady state turning	Over smooth roads	Steering torque feedback	Indication of available grip
06	Steady state turning	Over smooth roads	Steering torque feedback	Indication of magnitude of lateral acceleration
07	Steady state turning	Over smooth roads	Steering torque feedback	Magnitude of torque levels - LOW lock/HIGH lateral accel.
08	Steady state turning	Over smooth roads	Steering torque feedback	Magnitude of torque levels - HIGH lock/LOW lateral accel.
09	Steady state turning	Over smooth roads	Steering torque feedback	Progression of handwheel torque levels
10	Steady state turning	Over smooth roads	Steering torque feedback	Smoothness
11	Steady state turning	Over smooth roads	Steering torque feedback	Symmetry
12	Steady state turning	Over ROUGH roads	Cornering behaviour	Ease with which a line is held
14	Steady state turning	Over rough roads	Kickback on bumps	Kickback on bumps
15	Power change	Power on	Yaw response	Magnitude of response (state below whether over or under steer)
16	Power change	Power on	Yaw response	Progressiveness of yaw rate response
17	Power change	Power on	Yaw response	Yaw stability of vehicle at high lateral accel.
18	Power change	Power on	Steer torque feedback	Torque steer due to power change
19	Power change	Power OFF	Yaw response	Magnitude of response (state below whether over or under steer)
20	Power change	Power OFF	Yaw response	Yaw stability of vehicle at higher lateral accel's
21	Sudden braking in a turn			Yaw rate response (state tendency to spin or plough below)
22	Sudden braking in a turn			Roll stability
23	Sudden braking in a turn			Wheel lift
24	Sudden braking in a turn			Wheel lock up
25	Transient cornering	Turn in response		Turn in response and precision on smooth surfaces (low lateral
26	Transient Cornering	Turn in response		Turn in response and precision (medium lateral accel.)
27	Transient Cornering	Turn in response		Turn in response and precision (higher lateral accel's)
28	Transient cornering	Turn in response		Body roll ANGLE
29	Transient cornering	Turn in response		Body roll RATE
30	Transient cornering	Steering torque		Steering catch-up
31	Straight line directional stability	Constant throttle		Bump steer
32	Straight line directional stability	Constant throttle		Steer kickback
33	Straight line directional stability	Constant throttle		Over changing surface camber (state whether car wanders or
34	Straight line directional stability	Constant throttle		Over changing surface composition: ease with which a line is held
35	Straight line directional stability	Under acceleration		Torque steer
36	Straight line directional stability	Under acceleration		Tendency to pull to one side
37	Straight line directional stability	Under braking		Tendency to pull or weave
38	Obstacle avoidance	Single lane change	Trailing throttle	Turn in response
39	Obstacle avoidance	Single lane change	Trailing throttle	Recovery
40	Obstacle avoidance	Single lane change	Trailing throttle	Controllability
41	Obstacle Avoidance	Single lane change	Trailing throttle	Limiting behaviour
42	Obstacle avoidance	Single lane change	Balanced throttle	Turn in response
43	Obstacle avoidance	Single lane change	Balanced throttle	Recovery
44	Obstacle avoidance	Single lane change	Balanced throttle	Controllability
45	Obstacle avoidance	Balanced throttle		Limiting behaviour
46	Obstacle avoidance			Double lane change
47	Response to steering impulse			Oscillation of vehicle
48	Response to steering impulse			Oscillation of handwheel
49	Response to steering impulse			Level of damping

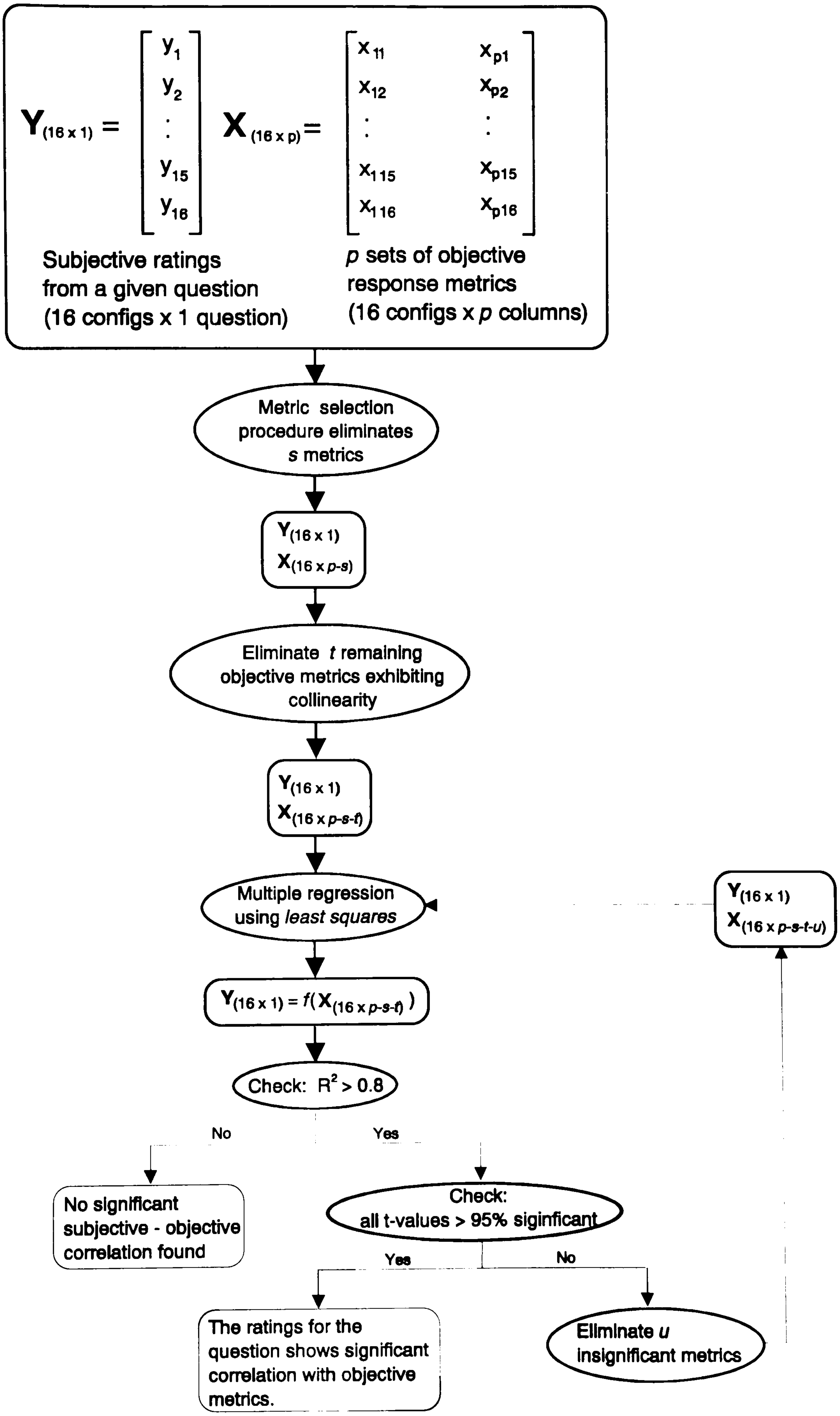
Table 6-2. Objective metrics used in the regression analysis.

Test	Metric	Abbreviation
Frequency response	Lateral acceleration gain at 0.4 Hz	LatacGain/0.4
	Lateral acceleration gain at 0.7 Hz	LatacGain/0.7
	Lateral acceleration gain at 1.0 Hz	LatacGain/1.0
	Lateral acceleration phase at 0.4 Hz	LatacPhase/0.4
	Lateral acceleration phase at 0.7 Hz	LatacPhase/0.7
	Lateral acceleration phase at 1.0 Hz	LatacPhase/1.0
	Roadwheel steer gain at 0.4 Hz	SteerGain/0.4
	Roadwheel steer gain at 0.7 Hz	SteerGain/0.7
	Roadwheel steer gain at 1.0 Hz	SteerGain/1.0
	Roadwheel steer phase at 0.4 Hz	SteerPhase/0.4
	Roadwheel steer phase at 0.7 Hz	SteerPhase/0.7
	Roadwheel steer phase at 1.0 Hz	SteerPhase/1.0
	Yaw rate gain at 0.4 Hz	YawGain/0.4
	Yaw rate gain at 0.7 Hz	YawGain/0.7
	Yaw rate gain at 1.0 Hz	YawGain/1.0
	Yaw rate phase at 0.4 Hz	YawPhase/0.4
	Yaw rate phase at 0.7 Hz	YawPhase/0.7
	Yaw rate phase at 1.0 Hz	YawPhase/1.0
Step Input	Lateral acceleration response time at 0.2 g	LatacRespTime/0.2
	Lateral acceleration response time at 0.6 g	LatacRespTime/0.6
	Peak, mean, road wheel steer angle at 0.2 g	StMean/0.2
	Peak, mean, road wheel steer angle at 0.6 g	StMean/0.6
	Peak, mean, road wheel steer angle response time at 0.2 g	StMeanRespTime/0.2
	Peak, mean, road wheel steer angle response time at 0.6 g	StMeanRespTime/0.6
	Peak roll rate at 0.2 g	RollRt/0.2
	Peak roll rate at 0.6 g	RollRt/0.6
	Peak roll rate response time at 0.2 g	RollRtRespTime/0.2
	Peak roll rate response time at 0.6 g	RollRtRespTime/0.6
	Peak yaw rate at 0.2 g	YawRt/0.2
	Peak yaw rate at 0.6 g	YawRt/0.6
	Peak yaw rate response time at 0.2 g	YawRtRespTime/0.2
	Peak yaw rate response time at 0.6 g	YawRtRespTime/0.6
	Peak steering wheel torque at 0.2 g	Storq/0.2
	Peak steering wheel torque at 0.6 g	Storq/0.6
	Peak steering wheel torque response time at 0.2 g	StorqRespTime/0.2
	Peak steering wheel torque response time at 0.6 g	StorqRespTime/0.6
Steady State	d(front slip)/d(lateral acceleration) at 0.4 g	d(fslip)/0.4
	d(front slip)/d(lateral acceleration) at 0.2 g	d(fslip)/0.2
	d(handwheel angle)/d(lateral acceleration) at 0.4 g	d(hw)/0.4
	d(handwheel angle)/d(lateral acceleration) at 0.2 g	d(hw)/0.2
	d(sideslip)/d(lateral acceleration) at 0.4 g	d(sslip)/0.4
	d(sideslip)/d(lateral acceleration) at 0.2 g	d(sslip)/0.2
	d(steer torque)/d(lateral acceleration) at 0.4 g	d(storq)/0.4
	d(steer torque)/d(lateral acceleration) at 0.2 g	d(storq)/0.2
	roll angle at 0.4 g	roll angle/0.4
	roll angle at 0.2 g	roll angle/0.2

6.2 Regression Methods

The selected method for correlating objective and subjective data involved a process in which the most important objective response metrics were matched to a given set of ratings, followed by ordinary least squares regression. The process, to be detailed in the following sub-sections, is depicted in Figure 6-2. The procedure accommodates the large number of possible *regressors* (i.e. objective metrics) and provides models in which the ratings are formulated as a linear function of them. A discussion of this modelling approach in terms of assumptions and implications completes the section.

Figure 6-2. Flow chart depicting the metric selection and regression procedure.



6.2.1 Metric Selection Process

The large number of response metrics which were available to correlate with driver ratings posed two problems when using multiple linear regression. First, with sixteen ratings per question and forty six corresponding objective metrics it was not possible to evaluate every possible multiple regression equation for statistically significant correlations. Second, the fact that some of the metrics effectively represented identical or interrelated vehicle characteristics meant that *multicollinearity*, could degrade the inferential and predictive characteristics of any regression equations. *Multicollinearity* refers to the situation where certain input *regressors* (i.e. objective metrics) exhibit strong relationships to one or more of the other responses. When using data sets exhibiting such a characteristic in multiple regression it becomes impossible to distinguish the true contribution to the system response of each regressor from the others.

The metric selection process used here is described in *Chatterjee and Price* [1] and involves the use of *ridge plots* to identify suitable data sets. The basis of these plots is the ridge regression method which is normally used to provide biased estimates of regression coefficients when collinear regressors are used. The first step in producing ridge plots was to standardise both subjective and objective data by subtracting from the elements of each data set its mean value and dividing by its standard error. This allows the coefficients in ridge and least squared regression equations to be compared with one another. Following this, each set of subjective data was regressed against the p sets of objective data by solving for $(\tilde{\beta}_1, \tilde{\beta}_2, \ldots \tilde{\beta}_p)$ in the following system of equations for values of k ranging from 0 to 1.

$$\begin{aligned}
(1+k)\tilde{\beta}_1 + r_{12}\tilde{\beta}_2 + \ldots\ldots\ldots + r_{1p}\tilde{\beta}_p &= r_{1y} \\
r_{12}\tilde{\beta}_1 + (1+k)\tilde{\beta}_2 + \ldots\ldots\ldots + r_{2p}\tilde{\beta}_p &= r_{2y} \\
r_{1p}\tilde{\beta}_1 + r_{2p}\tilde{\beta}_2 + \ldots\ldots\ldots + (1+k)\tilde{\beta}_p &= r_{py}
\end{aligned} \tag{1}$$

where

$(\tilde{\beta}_1, \tilde{\beta}_2, \ldots \tilde{\beta}_p)$ are estimated regression coefficients corresponding to each objective regressor

k is a bias factor

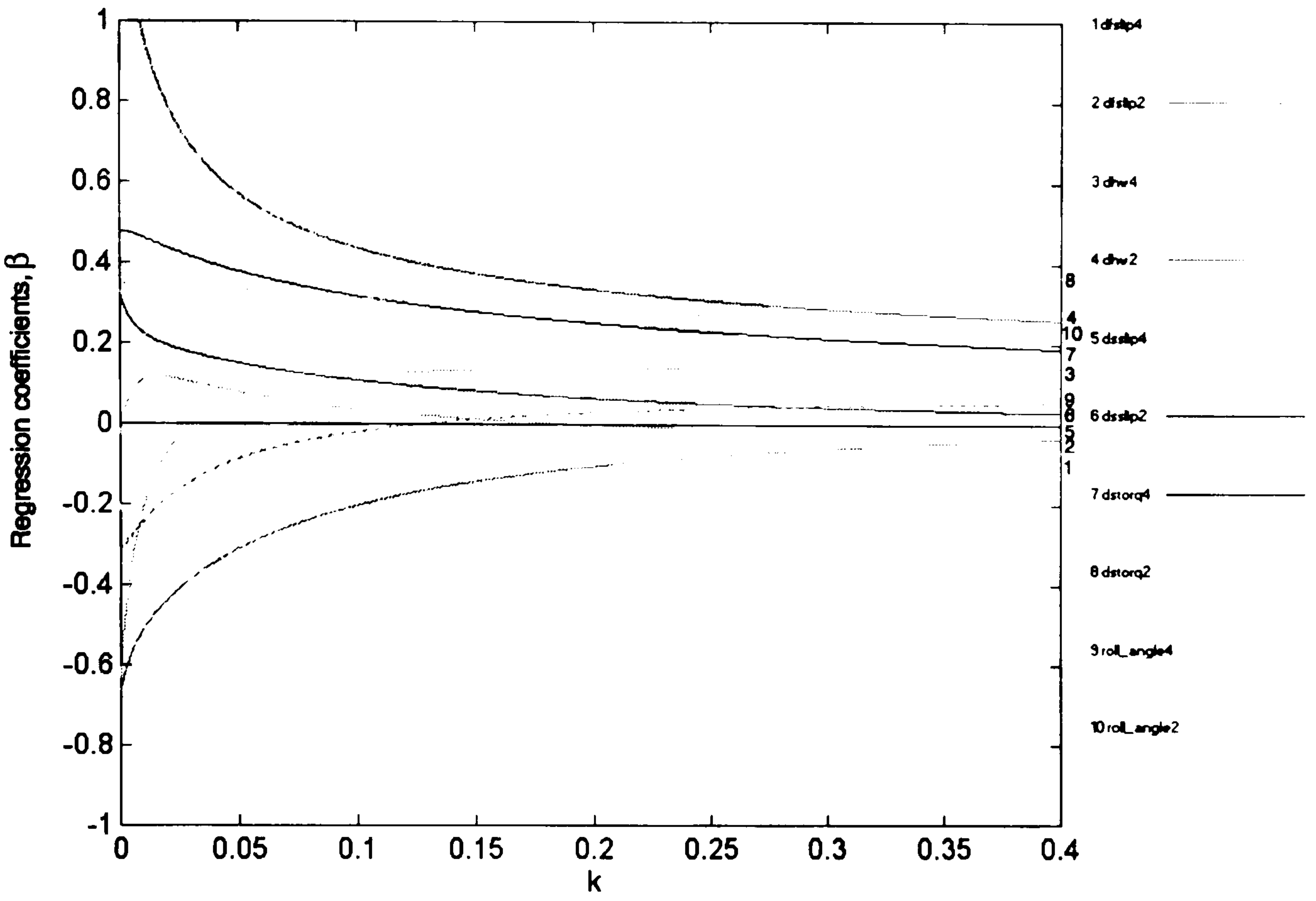
r_{iy}, $(i = 1..p)$ are the correlation coefficients of the ratings with the *pth* objective metrics

r_{ij},$(i,j = 1..p)$ are the correlation coefficients of the *ith* and *pth* objective metric

(Note: The notation used here follows that of [1].)

Each β in the solution for the above system gave an estimate of each regressor's contribution to the formulation of the ratings. By plotting them against k, the effects of multicollinearity could be seen and important regressors could be identified. Figure 6-3 shows a sample ridge plot. Each line represents the changing estimates of individual regression coefficients as a function of k. Significant regressors can be seen to be farther away from $\tilde{\beta}_i = 0$ than insignificant ones. The effects of multicollinearity can be seen in the way particular lines change their slope very suddenly near $k = 0$ indicating instability in the corresponding regression coefficient. Normally in ridge regression a solution is selected corresponding to a value of k in which the effects of multicollinearity are minimised. i.e. a value of k is selected in which the slopes of each line are minimal. In this work the slope of the lines was used to identify regressors to be eliminated.

Figure 6-3. Ridge plot used in variable selection. Each line depicts the regression coefficient, β_i, which would result, as a function of *k*, if the corresponding metric were included in multiple regression using the ridge method.



Once ridge plots were produced for each set of ratings three further steps were involved in this stage of the selection process:

i) Removal of regressors whose lines had flat, stable, slopes but which lay close to zero. This effectively deleted regressors whose effect on the ratings was negligible.

ii) Removal of regressors whose lines exhibited instability and tended to $\tilde{\beta}_i = 0$. This eliminated regressors whose influence declined with increasing *k*.

iii) Removal of one or more remaining unstable regressors to leave a subset of data suitable for least squares regression.

As an example, referring to Figure 6-3 the line labelled 5 would have been deleted in the first step; 2, 6, and 9 would have gone in the second step and 1, 3, and 4 in the last. The objective metrics corresponding to the remaining lines, 7, 8 and 10 would have been checked further and used in fitting a regression equation to the ratings.

Before being considered for regression the remaining data set was subject to an additional check for multicollinearity in the form the *Variance Inflation Factor* [1] defined as:

$$VIF(X_i) = \frac{1}{1 - R_i^2} \qquad (2)$$

where

$VIF(X_i)$ is the Variance inflation factor corresponding to the *ith* regressor

R_i^2 is the multiple regression coefficient when a least squares regression is done using X_i as the output and the remaining regressors as the input.

VIF's in excess of 10 are normally considered to indicate the presence of unacceptable multicollinearity. Any regressors with a high *VIF* remaining after the ridge procedure were also eliminated.

6.2.2 Multiple Regression

Once a suitable subset of objective regressors had been selected a "model" of the subjective ratings, for each question for each driver, was calculated using the method of least squares. This is the familiar regression method in which the resulting linear equations are of the form:

$$y_i = \tilde{\beta}_0 + \tilde{\beta}_1 x_{1i} + \tilde{\beta}_2 x_{2i} \cdots \tilde{\beta}_p x_{pi} + \mu_i \qquad (3)$$

where

y_i is the rating from a given question corresponding to the *i*th configuration

$\tilde{\beta}_p$ are regression coefficients corresponding to the *p*th objective regressor

x_{pi} are the objective data for the *p*th regressor for the *i*th configuration

μ_i is the residual (or error term) associated with the *i*th configuration

A detailed treatment of the calculations may be found in reference [1]. A number of diagnostic statistics were also calculated to be used as criteria for judging the degree of correlation and validity of the equations. These were:

i) R^2, the square of the multiple correlation coefficient interpreted as the amount of variability in the actual data accounted for by the regression equation.

ii) The *F- statistic* which quantifies the likelihood that the selected regressors are significant

iii) *t-values* for each regression coefficient - an indicator as to whether the corresponding regressor is statistically significant to the equation.

If the initial R^2 value was greater than or equal to 0.7 further refinements were made by iteratively eliminating any regressor which did not have a *t-value* significant to the 95% level. If after all insignificant regressors were eliminated more than three metrics remained, the ones with the lowest t-values were also deleted until only three remained. This ensured that only the most important metrics were considered in the analysis. If the R^2 value dropped below 0.7 it was assumed no correlation existed. This level of correlation is typical of that seen in the literature as discussed in Chapter 1.

6.2.3 Interpretation of Multiple Regression Models

It is worth noting and discussing the implicit assumptions made when using multiple linear regression about how drivers formulate ratings. Clearly the multiple linear model of equation (3) assumes each driver arrives at a numerical rating by weighing up a number of vehicle responses and superimposing their contributions. Thus each regression coefficient gives: i) the magnitude of the effect that the corresponding metric has on a driver's rating and ii) whether the effect is positive or negative in response to increases in the value of the metric. For example suppose a driver's ratings for a given question were modelled as :

$$Rating = 0.68(StMean/0.6) + 0.86(RollRtRespTime/0.6) - 0.3(d(storq)/0.2) \tag{4}$$

The magnitudes of the coefficients suggest *RollRtRespTime* has the largest influence followed by *StMean* then *d(storq)*. The signs suggest that increases to *StMean* and *RollRtRespTime* would result in increases in the driver's rating while increases to *d(storq)* would result in a lower rating.

Whether this simplistic multiple linear model truly approximates a driver's cognitive process is beyond the scope of this work. Given the complexity of the human thought process interactive effects or higher order formulations are obvious additions which could made. There is however minimal evidence to suggest that added complexity would result in substantial improvements to the model results. For example reference [2] did note improved correlation with higher order polynomial fits to subjective ratings but the degree of correlation indicated is no better than that achieved in the current work. Since no other studies were found which support the use of non-linear correlation and, following the principle that the simplest model is best, the linear formulation was considered appropriate.

6.3 Ratings vs. Metrics Organised By Test Type

Previous subjective-objective research, detailed in Chapter 1, has focused on correlating driver opinions with metrics from particular types of tests. (e.g. [2], [3], and [4]) These papers noted good correlations between subjective ratings and single or small sets of vehicle response parameters. In light of the success documented in such work, the ratings in the forty nine questions were initially regressed with data grouped according to test type. In this case three sets of metrics were used corresponding to the *steady state circular test*, the *step-input test*, and *frequency response test.* The metrics in each of these sets can be seen in Table 6-2 which organises the metrics according to test type.

This section begins by presenting the results of the correlation analysis followed by interpretation. It concludes with a comparison of this work with studies from the literature, highlighting the consistency of the results with those obtained by other authors.

6.3.1 Results

Table 6-3 to Table 6-5 indicate, for each driver the questions where ratings correlated with frequency response, step input and steady state data respectively. Additionally the mean ratings for all the drivers were correlated with the objective metrics and are shown in the final column of each table. The actual regression equations are listed in Appendix 6B. For the steady state and frequency responses (Table 6-3 and Table 6-5) the number of questions for a given driver showing correlation varies between zero and four. Slightly better results were obtained with the step-input data but even then the number of correlating questions for one driver ranges from a low of one (Driver H) to a high of seventeen (Driver A). In all three tables, no questions appear which are common to all drivers, nor do any single metrics appear in the regression equations of Appendix 6B more often than others.

Table 6-3 Questions where ratings correlated to frequency response test data.

	Driver								
	A	B	C	D	E	F	G	H	Mean
Questions where correlation was found	24	39	34	18	2	28	4	39	7
	44	49		41	6	29	26	41	23
	46			45	12		30		25
				48	17		31		29
				49	43		34		39
					49		38		40
							43		41
							44		43
							46		44
									46
									48
									49
Number of questions	3	2	1	5	6	2	9	2	12

Table 6-4. Questions where ratings correlated to step-input test data.

	Driver								
	A	B	C	D	E	F	G	H	Mean
Questions where correlation was found	7	11	1	5	16	12	5	37	10
	9	24	29	10	27	15	12		11
	10	28	34	17	29	27	14		12
	11	31		20	43	28	26		14
	14	32		30	48	32	30		16
	15	34		48		34	31		20
	18	37		49		44	32		23
	24	39					34		24
	26	40					39		25
	30	43					40		26
	32						41		27
	36						43		28
	40						44		29
	43						45		30
	44								31
	48								34
	49								35
									36
									39
									40
									41
									43
									44
									45
									46
									47
									48
									49
Number of questions	17	10	3	7	5	7	14	1	28

Table 6-5 Questions where ratings correlated to steady state circular test data.

	Driver								
	A	B	C	D	E	F	G	H	Mean
Questions where correlation was found	14	14		12	14		3		16
	18	24		39	19		6		30
	19	34		40	21		30		35
	44			43	43				
				44	44				
				45	48				
				49	49				
Number of questions	4	3	0	7	7	0	3	0	3

6.3.2 Interpretation

Two hypotheses can be made on the basis of the results of the previous sub-section:

i) No single test provides sufficient data to comprehensively reflect the ratings of all the drivers.

ii) Each driver formulates ratings in a unique manner in comparison to the other drivers.

The first point is based on the fact that in Table 6-3 to Table 6-5 very few "correlating questions" (i.e. questions where ratings correlated significantly with objective data) were found. The simplest explanation for this is that each set of test data does not provide sufficient coverage of a vehicle's handling envelope to allow more than occasional instances of correlation. This suggests that drivers formulate most of their opinions based on overall performance - e.g. steady state and transient characteristics at various points on the vehicle's handling envelope - not on single specific aspects of a vehicle's handling. Confirmation of this will be seen when correlation analysis involving all objective responses together is presented.

The second point is based on the observation that, in instances where correlation for a given question was found for two or more drivers, the metrics appearing in the equations differed depending upon the driver. Given the wide variance in driver ratings seen in Chapter 3 the idea that driver's were formulating ratings according to different responses or metrics is logical. The differences in ratings between two drivers could, for example, reflect that fact that one bases his ratings on yaw rate metrics while the other uses steer torque ones.

An important consequence of the second hypotheses is that averaging together driver ratings for analysis may result in the loss of information. Fundamentally the use of mean values implies that ratings are the result of a process in which the variance is assumed to be random. However if the drivers in this study had been basing their ratings on different formulations as suggested, then systematic bias would also contribute to the deviations seen in the ratings. Therefore, the averaged ratings could conceal important relationships underlying the formulation of driver ratings. Worse than hiding important relationships, averaged ratings may suggest incorrect ones. Consider Table 6-3. Of the correlating questions for average ratings, four questions

(7, 23, 25, 40) are ones which none of the drivers showed any correlation with at all. Of the remaining eight questions (29, 39, 41, 43, 44, 46, 48, 49) only one or two drivers showed correlation with them. A vehicle designed using such information is likely to be one which focuses on aspects of handling for which no true subjective-objective relationship exists for most drivers. Given the possibility of excluding important information and the difficulties in applying conclusions to individual drivers as just illustrated further analysis focused on individual driver ratings rather than averaged ones. The purpose of calculating them in Table 6-3 to Table 6-5 was to facilitate comparison with previous research.

6.3.3 Comparison With Previous Research

Although differences and ambiguities in the subjective evaluation procedures of studies seen in the literature make direct comparison impossible, the methodology of three of these projects ([2], [3], [4]) is similar enough that gross discrepancies between their results and the current results would be of concern. In each study, between five and eight drivers were asked to subjectively evaluate four to six vehicles or vehicle configurations. The results of this section are, at the very least, not inconsistent with these studies and, more generally, supported by observations and conclusions in these papers. The following paragraphs consider each paper in turn.

In reference [3] six "experienced development engineers" subjectively evaluated eight vehicles using a lane change manoeuvre. Ratings on a scale of 1 to 10 were given although no mention is made in the paper as to what handling quality drivers were asked to rate. Objective data was obtained in the form of frequency responses from "sinusoidal steering input tests". The main result with regard to subjective - objective correlation is the observation of good correlation between ratings and "handwheel torque phase difference" at 0.5 Hz. The lack of detail on what aspect(s) of handling were rated by the drivers is an omission which complicates comparison with the current work but does not prevent a cursory analysis. Consider Table 6-6 showing the correlation of the averaged lane change ratings with the *peak steer torque response time at 0.2 g*. This metric should be comparable to the phase lag of [3]. Note that reasonable correlations - R^2 values from 0.68 to 0.75 - were achieved. Interestingly in the correlation analysis with step input metrics, steering torque did not appear as a regressor in any of the regression equations. Instead, other metrics appear to have been better indicators of lane changing ratings.

Table 6-6 Regression Results Of Averaged Lane Change Ratings [1]

Questions			Metrics	Statistics	
Question #	Sub-Heading	Sub-Sub-Heading	StorqRespTime/0.2	R-squared	F
39	Trailing throttle	Recovery	-0.834	0.696	32.06
40	Trailing throttle	Controllability	-0.847	0.717	35.52
41	Trailing throttle	Limiting behaviour	-0.825	0.680	29.82
43	Balanced throttle	Recovery	-0.850	0.723	36.60
44	Balanced throttle	Controllability	-0.871	0.759	44.05
46		Double lane change	-0.844	0.713	34.75

In the second relevant study, [2], six configurations were tested by five "expert drivers". Details of the manoeuvres conducted during subjective assessment are not presented, but the drivers were apparently asked to provide ratings for at least sixteen aspects of handling. The objective data consisted of yaw characteristics obtained from transfer functions derived in the paper. Two useful pieces of information can be extracted which partially support the findings of this work. First in showing the results of their regression, the authors plot the ratings of individual drivers. As with the current work the variance present in the five questions is considerable. On the 1 to 7 scale used by the drivers, ratings for a given question appear to differ by as much as 6 points. Given this, it is not surprising that the correlation between yaw metrics and ratings for the 16 questions ranges from R values of 0.27 to 0.72. Interpreting this to mean that yaw related metrics from a single test cannot, on their own, account for a significant amount of the variance of driver ratings then at the very least [2] does not contradict the results of section 6.3.1. Although yaw related metrics occur in the successful regression equations of the previous section they are always accompanied by other metrics in order to make the correlation significant.

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[1] Each row in the table show a regression equation - the coefficients (actually there is only one in this case) are placed in columns according to the metric they are associated with. For example the first row for question 39 could be written in the longer form:
Subjective Rating = -0.834(*StorqRespTime/0.2*). $R^2 = 0.696$ *F-statistic* = 32.06

The final reference, by *Bergman* [4], presents results which partly contradict the results of section 6.3.1 but also contains some data which also supports it. In this study nine evaluators were selected from a pool of twenty on the basis of a pilot study which showed that they would be able to provided ratings which "represent a consensus judgement". Four vehicles were evaluated in three different objective tests: "Transient steering", "Braking in cornering", and "Cornering across a bump". For each test a single representative metric was derived, based on yaw responses, and very high degrees of correlation were shown with subjective ratings. i.e. In the three tests, the percent correlations, listed in the same order as above, were: 98%, 96%, 81%. Such high correlation coefficients obtained for ratings versus a singe metric clearly contradict the results of the current work. However, the preselection process used in the work places a limit on the general applicability of the conclusions. Strictly speaking, the subjective - objective relationships apply to a very specific group of drivers who were hand-picked from a larger one because they were shown to formulate ratings similarly. Had the evaluations been done with the original pool of drivers it is clear from data presented that correlation values would be much lower.

Interestingly, some supporting evidence is given for the current work by examining data given in the Table 4 of reference [4], reproduced below in Table 6-7. In it the mean ratings of the best and worst drivers are given. In his work, the author showed that the worst drivers' ratings do not correlate well with any single metric. However if multiple regression is done using the ratings and the objective metrics given in the paper in a manner similar to section 6.3.1 excellent correlation is achieved for the "Transient steering" and "Cornering across a single bump" manoeuvres. Note in Table 6-8 R^2 values of 0.99. Thus a possible re-interpretation of the so-called "worst" drivers is that they are formulating ratings based on more than a single objective aspect of the vehicle.

Table 6-7 Subjective and objective data presented in reference [4]

		Vehicles					
Manoeuvre	Test Criteria	1	2	3	4	Correlation Equation	Correlation Coefficient
Transient steering	Subjective rating of high ranking evaluators	6.94	7.79	6.60	8.47	y = 3.94 + 3.76X	0.992
	Measurement of sideslip acceleration coefficient	0.814	0.99	0.71	1.22		
	Subjective rating low ranking evaluators	6.12	7.13	6.62	6.80	y = 5.79 + 0.93X	0.361
Braking in cornering	Subjective rating of high ranking evaluators	4.40	6.61	7.96	8.13	y = 10.55 + 2.25X	0.931
	Measurement of normalised understeer angle increment	2.52	2.02	1.25	0.91		
	Subjective rating low ranking evaluators	5.77	7.81	7.47	6.96	y = 7.97 + 0.58X	0.401
Cornering across a single bump	Subjective rating of high ranking evaluators	6.26	5.67	5.75	7.51	y = 11.88 + 11.80X	0.858
	Measurement of yaw velocity increment	0.437	0.520	0.536	0.400		
	Subjective rating low ranking evaluators	6.13	5.94	7.13	8.15	y = 10.31 + 7.35X	0.408

Table 6-8 Subjective-Objective Multiple Regression For "Low Ranking Evaluators" [2]

	Regression Coefficients					
Manoeuvre	Sideslip acceleration coefficient	Normalised understeer angle increment	Yaw velocity increment	Constant term	Correlation Coefficient	F-Statistic
Transient steering	2.3		7.3	1.1	0.9997	969.9
Cornering across a single bump		-1.2	-5.9	11.7	.9877	20.0

6.4 Ratings vs. All Metrics, Aspects Of Handling Showing Correlation

This section begins, as the previous one did, by presenting the results of the correlation analysis. In this case all of the objective data was made available to the variable selection process. Unlike the previous section the number of correlating questions found as a result of this analysis is far greater, allowing an examination to be made of these questions in terms of their nature and in terms of the correlating objective responses. Finally further analysis is presented showing how the general effect of every metric on ratings can be quantified.

6.4.1 Results

Table 6-9 is a check list of questions summarising, in each column, the questions for which a particular driver provided objectively correlated ratings. The actual

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[2] Refer to Table 6-6 for an explanation on how to read this table.

regression equations are presented in Appendix 6C, organised by driver. The number of correlating questions for each driver ranged from eleven to twenty seven.

Next thirteen questions were identified for further detailed examination based on a simple majority of the eight drivers showing correlation for a given question. (These questions are reproduced in Table 6-10.) Each of these "best" questions was assumed to deal with an aspect of handling for which most drivers (i.e. at least 5 out of 8) were capable of providing objectively based ratings.

Table 6-9 Questions where ratings correlated with metrics selected from all objective tests

		Driver							
	Question #	A	B	C	D	E	F	G	H
Questions where correlation was found	1								
	2		x	x				x	
	3			x	x	x		x	
	4			x		x		x	
	5				x				
	6					x		x	
	7	x							
	8								
	9		x		x		x		
	10	x							
	11								
	12					x	x	x	
	14	x	x		x	x	x		x
	15								
	16					x		x	x
	17			x	x				
	18	x			x	x		x	x
	19	x		x	x	x			x
	20	x		x	x	x		x	
	21		x	x		x		x	
	22		x	x		x			
	23					x		x	x
	24	x	x						x
	25		x	x		x		x	x
	26	x		x				x	
	27					x			
	28		x	x			x	x	
	29			x	x	x	x	x	
	30	x			x				
	31	x	x		x	x		x	
	32	x	x			x	x	x	
	33		x		x	x	x	x	x
	34		x				x	x	
	35								
	36		x						x
	37		x		x	x			x
	38		x					x	x
	39		x		x	x	x	x	x
	40		x	x	x		x	x	
	41				x			x	x
	42				x				x
	43		x		x	x	x	x	x
	44		x		x	x		x	x
	45			x	x		x	x	x
	46							x	x
	47					x			
	48								
	49		x			x			
Number of Questions		11	20	14	20	24	12	27	18

Table 6-10 Questions where correlation was found for most drivers. ("Best" questions)

	Main Heading	Sub Heading	Sub Sub Heading	Question
14	Steady state turning	Over rough roads	Kickback on bumps	Kickback on bumps
18	Power change	Power on	Steer torque feedback	Torque steer due to power change
19	Power change	Power OFF	Yaw response	Magnitude of response
20	Power change	Power OFF	Yaw response	Yaw stability of vehicle at higher lateral accel's
29	Transient cornering	Turn in response		Body roll RATE
31	Straight line directional stability	Constant throttle		Bump steer
32	Straight line directional stability	Constant throttle		Steer kickback
33	Straight line directional stability	Constant throttle		Over changing surface camber (state whether car wanders or pulls)
39	Obstacle avoidance	Single lane change	Trailing throttle	Recovery
40	Obstacle avoidance	Single lane change	Trailing throttle	Controllability
43	Obstacle avoidance	Single lane change	Balanced throttle	Recovery
44	Obstacle avoidance	Single lane change	Balanced throttle	Controllability
45	Obstacle avoidance	Balanced throttle		Limiting behaviour

6.4.2 The Nature Of The Best Correlating Questions

Although there is no clear distinction between the eleven questions identified in Table 6-10 and the remaining questions from the questionnaire it is interesting to note that the majority of questions tend to deal with either a control related task or with control related feedbacks. Specifically lane changing has already been identified as a complex control task. If control related tasks provide the best correlation it is then not surprising that the remaining questions are dominated by hand wheel feedback responses since it is the primary instrument of control available to the driver.

6.4.3 Metrics Correlating With The Best Questions

Tables 11 to 24 show the regression equations found for each driver for the best questions. (Refer back to Table 6-6 for an explanation of how the information should be read.) An added feature of these tables is that coefficients with a positive value are highlighted in a dark grey and negative values are light grey. The purpose of this colour coding will become apparent during the analysis.

Table 6-11 Regression results for Question 14, (Steady state turning over rough roads - kickback on bumps)

Driver	LataccPhase/0.7	SteerGain/1.0	YawGain/0.7	LatacRespTime/0.2	StMean/0.6	RollRt/0.2	RollRtRespTime/0.6	d(fslip)/0.4	d(sslip)/0.2	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
A					0.68		0.86			-0.3			0.88	29
B						0.53	0.46		0.92		0.55		0.8	22.4
C														
D	0.99					0.31						-0.9	0.8	15.8
E							0.61	0.83		-0.5			0.83	18.1
F						-0.675		0.245		-0.794			0.756	12.37
G	0.9				-0.4			0.44					0.79	15.3
H		0.45	-0.9	0.69									0.72	9.47

Table 6-12 Regression results for Question 18, (Power on - torque steer due to power change)

Driver	LataccGain/1.0	YawPhase/1.0	RollRt/0.2	RollRtRespTime/0.6	YawRt/0.6	Storq/0.6	d(fslip)/0.4	d(fslip)/0.2	d(sslip)/0.2	roll angle/0.2	R-squared	F
A		0.51		0.58						0.34	0.74	10.2
B												
C												
D	0.65	0.56							0.6		0.82	17.3
E		0.51			0.56			0.49			0.75	12.2
F												
G			0.39			-0.3	0.87				0.79	12.7
H	0.49			-0.7			-0.4				0.78	13.9

Table 6-13 Regression results for Question 19, (Power off, magnitude of yaw response)

Driver	LataccGain/1.0	LataccPhase/1.0	SteerGain/1.0	SteerPhase/0.7	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	YawRt/0.6	Storq/0.2	Storq/0.6	d(fslip)/0.4	d(hw)/0.2	d(sslip)/0.4	d(storq)/0.2	roll angle/0.4	R-squared	F
A							0.71					0.78		0.48		0.9	31.3
B																	
C	0.72									0.51					-0.3	0.71	9.72
D					0.36			-0.4	-0.6							0.77	12.4
E			0.41	-0.4							0.68					0.81	17.3
F																	
G																	
H		0.68											-0.3			0.71	13.3

Table 6-14 Regression results for Question 20, (Power off, yaw stability)

Driver	LataccGain/0.7	LataccGain/1.0	LataccPhase/0.7	YawPhase/0.4	LatacRespTime/0.2	StMeanRespTime/0.2	StMeanRespTime/0.6	YawRt/0.2	Storq/0.2	d(fslip)/0.4	d(fslip)/0.2	d(sslip)/0.4	R-squared	F
A					-1	1.16						0.73	0.73	7.21
B														
C		0.65							-0.5	0.45			0.76	10.8
D			-0.6				-0.8	-0.8					0.74	7.59
E			0.95	-1.1						0.73			0.79	14
F														
G	0.68								-0.5		0.61		0.72	8.7
H														

Table 6-15 Regression results for Question 29, (Turn-in response, body roll rate)

Driver	LataccGain/1.0	LataccPhase/0.7	YawGain/0.7	YawGain/1.0	LatacRespTime/0.2	StMean/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.6	Storq/0.2	Storq/0.6	d(storq)/0.2	roll angle/0.2	R-squared	F
A															
B															
C					-0.974		-0.503						-0.459	0.758	12.55
D				1				0.68		-0.4				0.79	15.1
E		0.68							0.67		0.51			0.82	18.7
F	0.71		-0.7				-0.4							0.78	14.4
G	0.48					0.63						-0.5		0.72	8.67
H															

Table 6-16 Regression results for Question 31, (Straight line directional stability, bump steer)

Driver	LataccGain/1.0	LataccPhase/0.4	SteerPhase/0.4	SteerPhase/0.7	YawGain/0.4	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.6	YawRtRespTime/0.2	Storq/0.2	StorqRespTime/0.2	d(fslip)/0.2	d(storq)/0.2	R-squared	F
A		0.57					0.3					0.64		0.7	8.38
B			0.52		-0.6					-0.4				0.82	16.8
C															
D	-0.9								-1			-0.6		0.79	14.1
E				0.94				0.26					0.36	0.91	39.4
F															
G						-0.3	0.3				-0.8			0.81	17.5
H															

Table 6-17 Regression results for Question 32, (Straight line directional stability, steer kickback)

Driver	YawGain/0.7	StMean/0.2	StMean/0.6	StMeanRespTime/0.	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.6	YawRtRespTime/0.2	Storq/0.2	Storq/0.6	StorqRespTime/0.2	d(storq)/0.2	R-squared	F
A			0.59			0.56				-0.5			0.76	12.7
B				-1.2	0.39						1.07		0.8	10.6
C														
D														
E	-0.7					0.61						-0.6	0.71	8.97
F		0.32					-1.2				0.79		0.72	10.1
G						-0.2		-0.5	0.53				0.73	9.85
H														

Table 6-18 Regression results for Question 33, (Straight line directional stability over changing surface camber)

Driver	LatacGain/0.4	LataccGain/0.7	SteerPhase/0.4	YawGain/0.4	LatacRespTime/0.6	StMeanRespTime/0.	RollRt/0.2	YawRt/0.2	YawRt/0.6	Storq/0.2	d(fslip)/0.4	d(fslip)/0.2	d(sslip)/0.2	R-squared	F
A															
B		-0.4	0.41					-0.4						0.72	8.52
C															
D					-0.5				-0.4				-0.4	0.7	9.35
E				-0.9								-0.9		0.79	20.8
F				-0.6			-0.7					-0.9		0.82	15
G			0.65					-0.4		-0.4				0.76	12.5
H	-0.8					0.53					-0.7			0.72	6.99

Table 6-19 Regression results for Question 39, (Lane change, trailing throttle, recovery)

Driver	LatacePhase/1.0	SteerGain/0.7	SteerGain/1.0	SteerPhase/1.0	YawGain/0.4	YawRt/0.6	YawRtRespTime/0.2	Storq/0.2	d(sslip)/0.2	d(storq)/0.2	roll angle/0.2	R-squared	F
A													
B							-0.9	-0.3				0.8	20.6
C													
D				0.92					-0.7		-0.8	0.86	22.9
E	0.41				-0.6							0.81	21.9
F		-0.7			-0.4			-0.5				0.78	14.6
G			-0.5			-0.7		-0.2				0.92	40.3
H					-0.7			0.25		0.67		0.88	23.4

Table 6-20 Regression results for Question 40, (Lane change, trailing throttle, controllability)

Driver	LataccGain/0.7	LataccGain/1.0	SteerGain/1.0	SteerPhase/1.0	YawGain/0.7	StMean/0.2	StMeanRespTime/0.2	StMeanRespTime/0.	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.2	R-squared	F
A								-1	0.72							0.7	15.4
B	-0.467			0.242						-0.552						0.773	11.36
C		0.425			-0.712								-0.325			0.7	9.316
D				0.842								-0.685			-0.907	0.864	23.23
E				0.398		0.495					-0.534					0.769	11.08
F						0.497	-0.776							0.299		0.706	9.623
G			-0.652				-0.755									0.798	23.67

Table 6-21 Regression results for Question 43, (Lane change, balanced throttle, recovery)

Driver	LataccGain/1.0	SteerGain/1.0	SteerPhase/0.4	YawGain/0.7	StMeanRespTime/0.	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.6	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.2	R-squared	F
A					-1.2	0.34	0.7									0.74	10.4
B			0.359					-0.706								0.707	14.49
C	0.603									-0.766					-0.483	0.659	7.731
D						-0.733						-0.464	-0.447			0.731	10.87
E	0.482			-0.786									0.307			0.875	25.6
F									-0.74		0.369		-0.327			0.758	11.51
G		-0.441						-0.352	-0.594							0.81	17.09
H			0.423	-0.502										0.618		0.801	16.09

Table 6-22 Regression results for Question 44, (Lane change, balanced throttle, controllability)

Driver	LataccGain/0.7	SteerGain/0.7	SteerGain/1.0	SteerPhase/1.0	YawGain/0.7	StMean/0.2	StMeanRespTime/0.2	YawRt/0.2	YawRt/0.6	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.2	roll angle/0.4	R-squared	F
A				0.839										0.704	23.8
B	-0.739					-0.35		-0.572						0.811	15.7
C			0.288		-0.613							0.619		0.771	12.35
D		-0.649									-0.753		-0.664	0.794	14.12
E						0.495			-0.659	-0.398				0.735	10.18
F							-0.784							0.614	20.71
G			-0.444				-0.936			-0.24				0.855	23.53

Table 6-23 Regression results for Question 45, (Lane change, limiting behaviour)

Driver	LataccGain/1.0	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	StMean/0.2	StMeanRespTime/0.2	YawRt/0.6	Storq/0.6	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
A															
B															
C	0.504	0.765											-0.333	0.742	11.47
D			-1.013				-0.523					-0.255		0.864	16.89
E															
F						-0.591		-0.762		0.364				0.719	6.813
H			-0.74								0.54			0.719	14.07
G									-0.896		0.387			0.915	54.09

Examining the regression equations corresponding to each driver for a given question it is again clear that each one's ratings are best modelled using different sets of objective responses. Although the metrics which appear in each table tend to form a substantially smaller subset of the original set of handling responses there are no patterns which could serve to define a unifying subjective-objective relationship which would apply to all or even most drivers.

While it is disconcerting that so many metrics, some seemingly unrelated to the question, should play a part in driver ratings the high degree of significance associated with each metrics' regression coefficient reasonably counters the possibility of false matches. Therefore the signs and magnitudes of each regression coefficient should give valid information about how each metric affects driver ratings for a given question.

Note, for each question, with the help of the colour coding, the signs of the regression coefficients associated with a given metric tend to be consistently positive or negative for all drivers. For example in question 14, Table 6-11, it can be seen that the metrics *RollRtRespTime/0.6, d(fslip)/0.4, and d(storq)/0.2* each appear in three drivers' regression equations - and the sign for the first two is always positive while sign for the third is always negative. Although in the same table the situation for *RollRt/0.2* is not as clear (2 positive, 1 negative) the general pattern for each question is that the effect each metric has on ratings is always positive or always negative.

Thus it appears that when analysing the handling characteristics addressed by a specific question it is not possible to predict if a given vehicle metric will influence a particular driver but it is possible to state whether it has a positive or negative effect when it **does** play a role in that driver's formulation. This hypothesis that the effect of each metric is unequivocally positive or negative make intuitive sense in so much as drivers can be expected to have identical responses, in terms of mental workload and opinion, to specific vehicle behaviour characteristics. For example slower response times should always be perceived as a subjectively poor characteristic.

An additional observation leads to an extension of this idea: when a given metric plays a role in more than one of the questions in tables 6-11 to 6-24, it's sign is also consistent between questions. e.g. *LatacGain/1.0* appears in Tables 6-12 - 6-16, 6-21, 6-22, and 6-24. In every single occurrence in these tables its sign is positive. The implication of this is that the general effect a given vehicle response has on ratings is independent of the particular question posed. Thus it should be possible to produce a summary table which suggests whether or not an increase or decrease in a vehicle response metric will produce a beneficial change to the general subjective feel of the automobile's handling. An examination of this hypothesis is made in detail in the next section.

6.5 The General Effect Of Metrics On Driver Ratings

This section takes up the idea proposed in the previous section that the sign of the effect that a metric has on subjective ratings is the same regardless of driver or question and extends it to show that the magnitude of the effect can be quantified. A multi-step process was used where:

i) Regression equations were re-derived leaving in all statistically significant regressors

ii) It was demonstrated that for a given driver the usual effect of a specific metric over all his correlating questions was not only of the same sign but its magnitude was normally distributed about a mean value

iii) The mean effects for all the drivers were averaged to estimate the general effect that each response metric had in the formulation of ratings. Statistics of confidence were then used to identify the most reliable metrics.

6.5.1 Multiple Regression Models With All Significant Regressors

In the analysis of section 6.4 the final step of the variable selection process involved paring the number of metrics used in the regression equations to three even at the cost of eliminating statistically significant regressors. Since the intent here was to examine the characteristics of any objective metrics which contribute significantly to the ratings this final constraint was removed producing a set of multiple correlation equations in which all statistically significant regressors were included in the analysis. This typically resulted in equations containing between two and eight regressors with much higher levels of correlation. The improved levels of correlation coefficients allowed a higher cut-off value of R^2 equal to 0.8 instead of 0.7 (used in the previous section) to be applied thus increasing confidence in the results. Appendix 6D shows the results of the expanded analysis.

Examining the tables in Appendix 6D the pattern seen in Section 6.4.3 is repeated where the signs of the regression coefficients associated with a specific response metric tend to be consistent. In other words it can be seen that, in general, increases (or decreases) in the level of each response metric will effect consistently higher or lower ratings. Given this it seemed reasonable to investigate if the magnitude of each effect could be characterised by a mean value and variance. Demonstrating this would open the possibility of prioritising metrics in terms of their influence on subjective ratings.

6.5.2 Mean Effects Of Metrics On Individual Driver's Ratings

Figures 6-4 to 6-8 show normal probability plots each depicting the distribution of regression coefficients corresponding to a particular column in the table for Driver A. (Appendix 6D) In other words each graphed point depicts an instance where the corresponding metric affected ratings. Similar graphs for the other drivers are given in Appendix 6E. In order to discern actual trends these graphs were produced only in cases where a metric appeared ten or more times in a driver's correlating equations. It can be seen that in almost every case that the regression coefficients are reasonably characterised by a normal distribution - departures from normality tend to be isolated to one or two outlying points.

Proceeding on the assumption that the regression coefficients associated with each metric are satisfactorily described by the mean and standard deviation Table 6-24 was produced which, for each driver, displays the mean and 95% confidence interval for each metric.

Figure 6-4 Distribution of *LataccGain/1.0* regression coefficients, Driver A

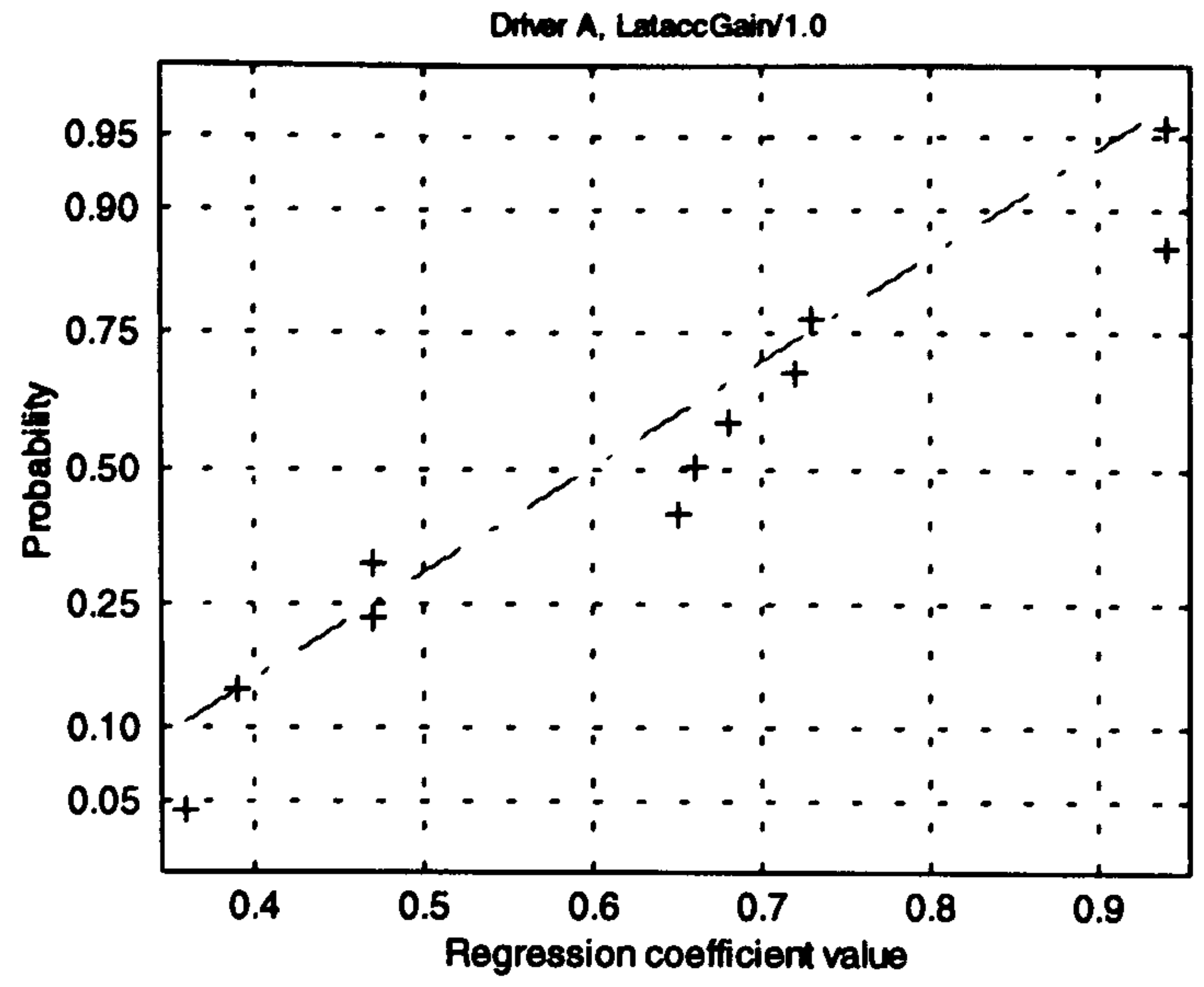

Figure 6-5 Distribution of *RollRtRestpTime/0.6* regression coefficients, Driver A

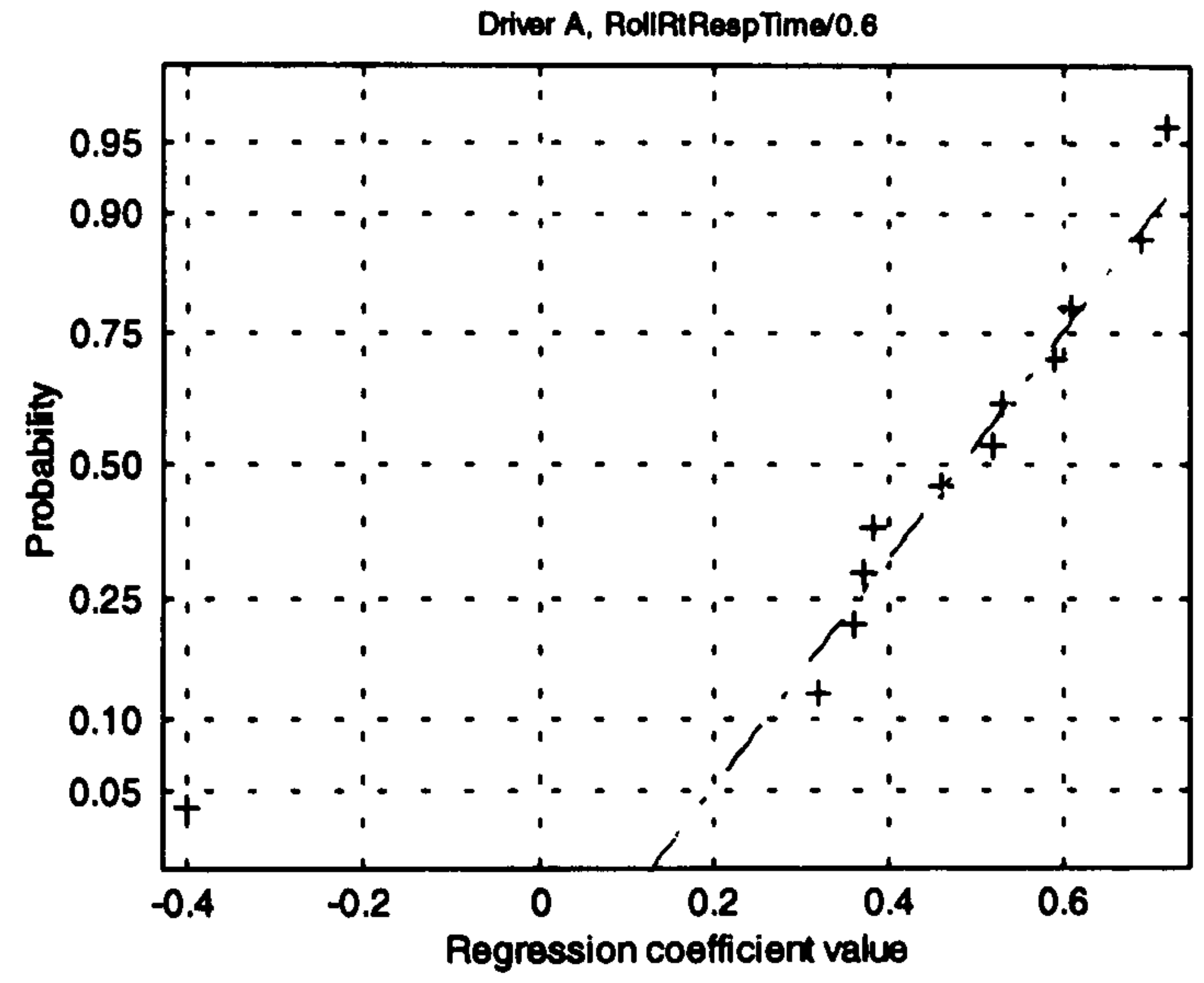

Figure 6-6 Distribution of *Storq/0.2* regression coefficients, Driver A

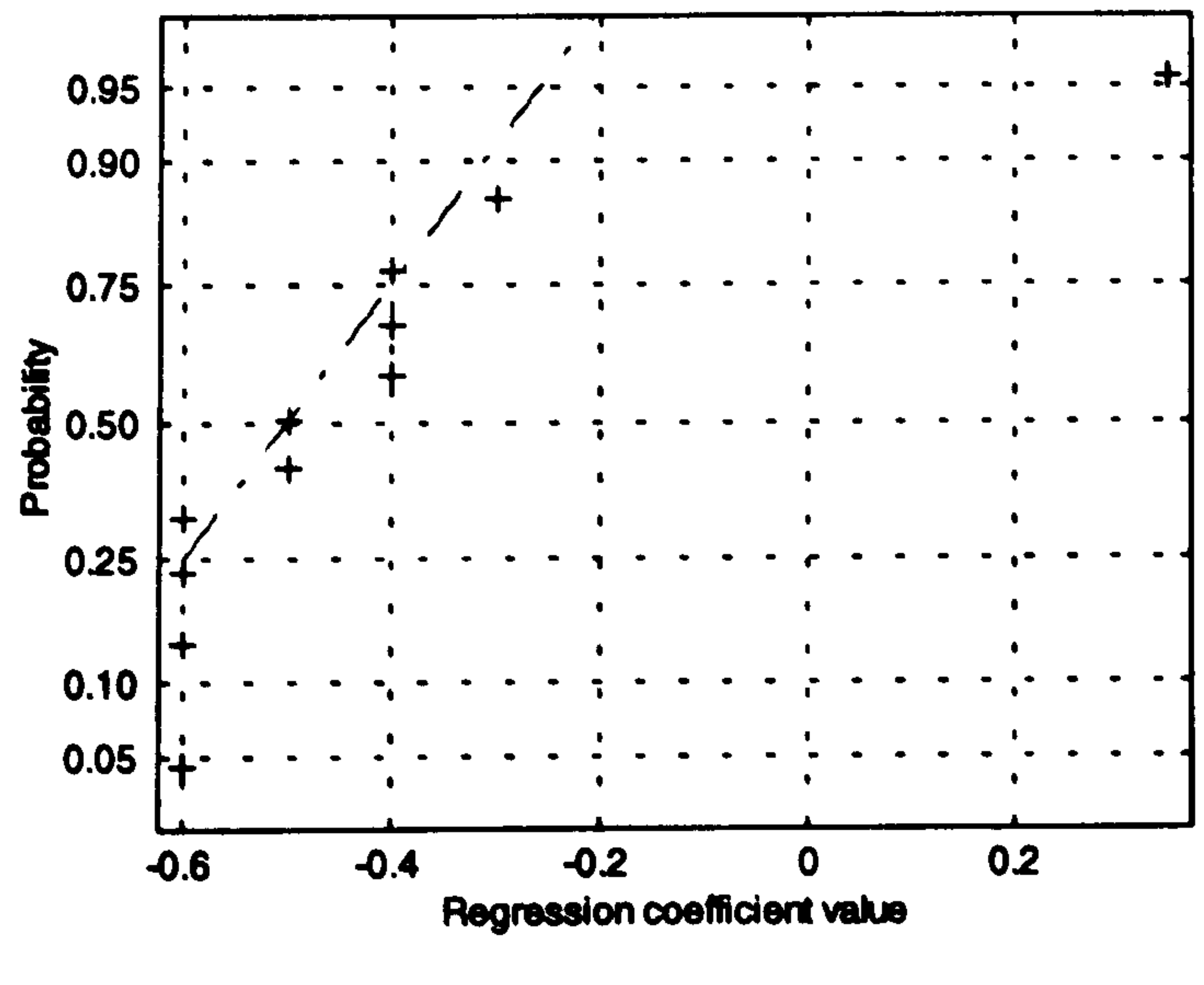

Figure 6-7 Distribution of *Storq/0.6* regression coefficients, Driver A

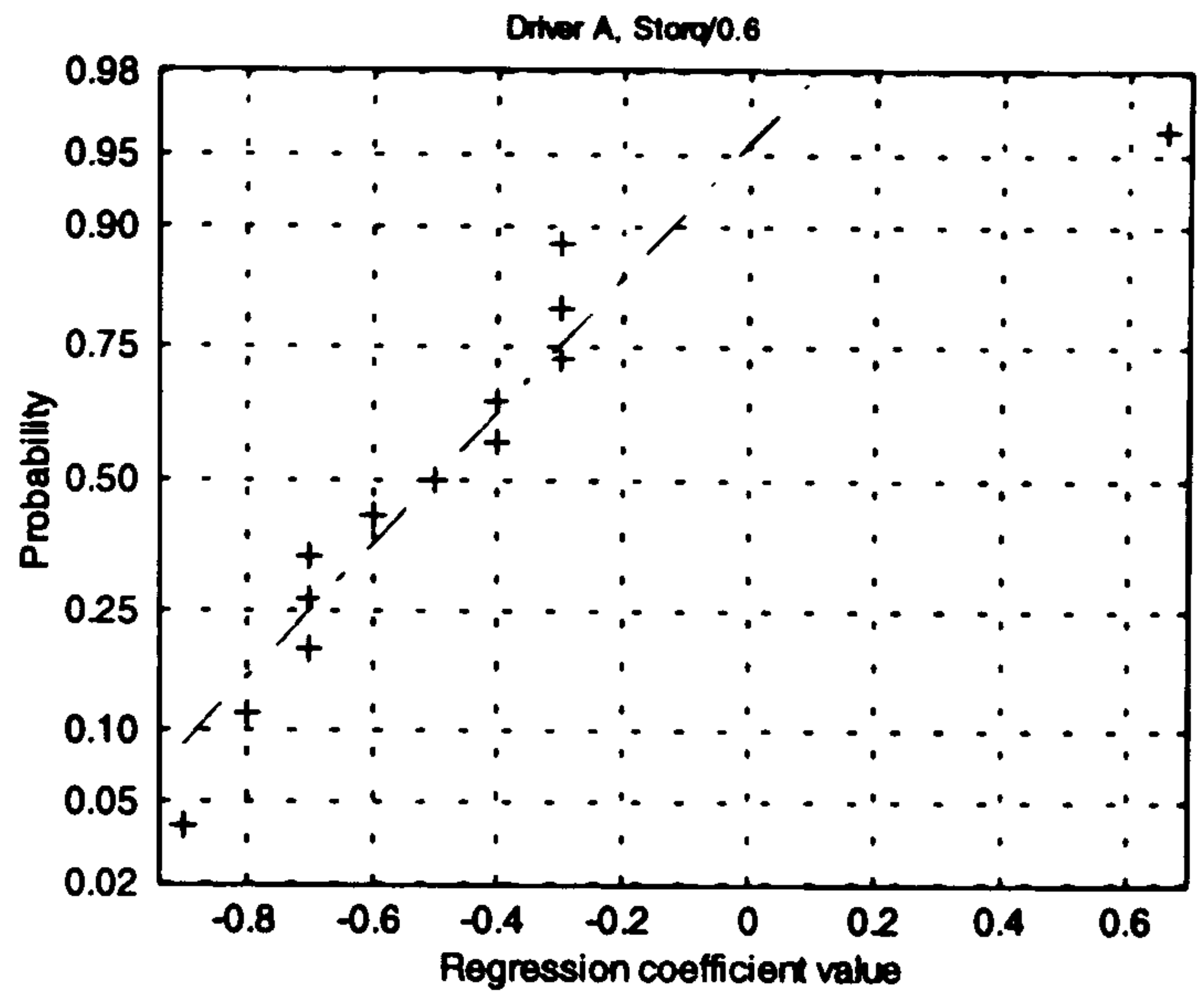

Figure 6-8 Distribution of *d(sslip)/0.4* regression coefficients, Driver A

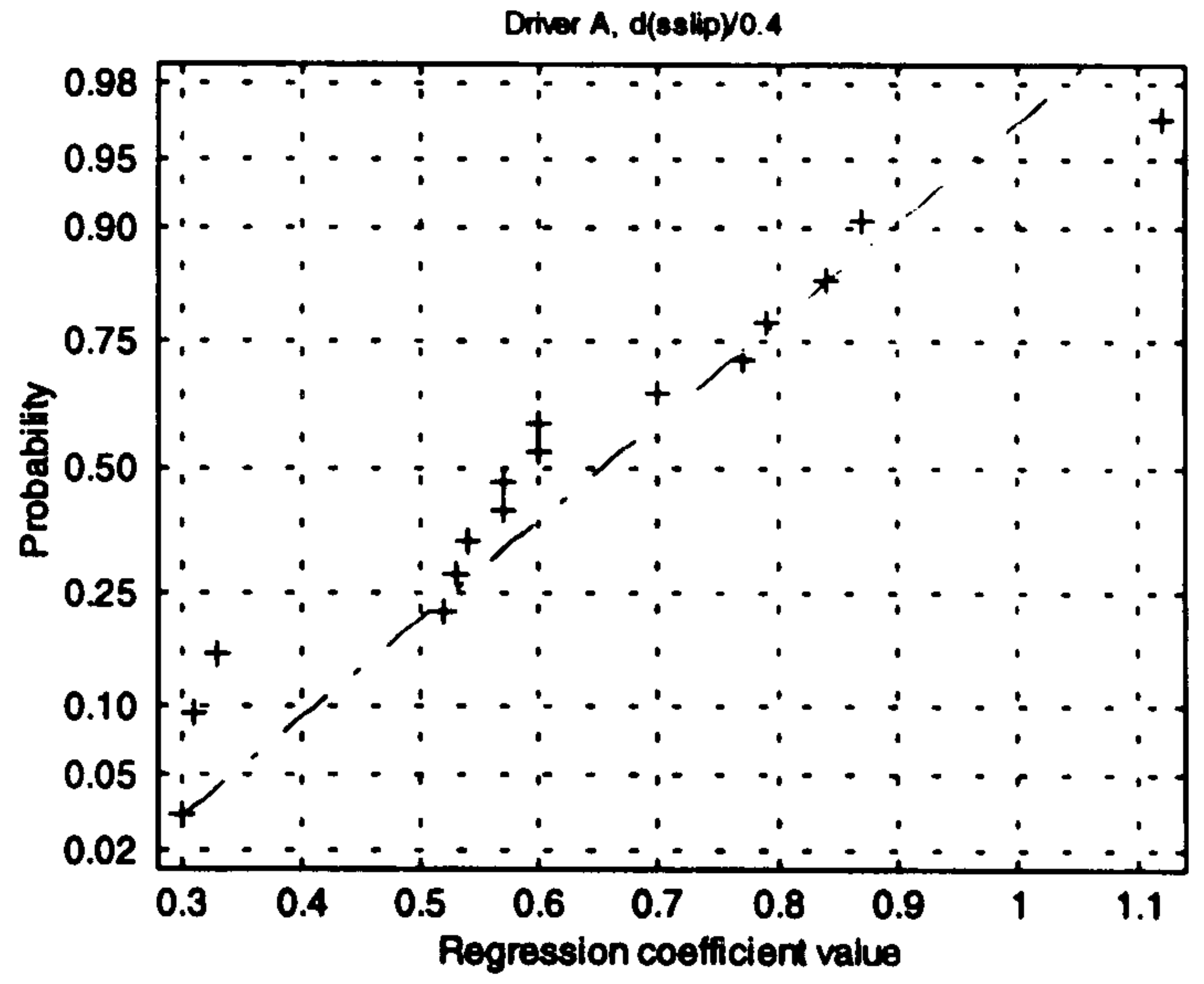

Table 6-24 Mean effect of metrics on each driver. Where no value is given the corresponding metric was not used by the driver.

		Driver															
		A		B		C		D		E		F		G		H	
	Metric	Mean Effect	± 95% Confidence Interval	Mean Effect	± 95% Confidence Interval	Mean Effect	± 95% Confidence Interval	Mean Effect	± 95% Confidence Interval	Mean Effect	± 95% Confidence Interval	Mean Effect	± 95% Confidence Interval	Mean Effect	± 95% Confidence Interval	Mean Effect	± 95% Confidence Interval
1	LatacGain/0.4			-0.9						-0.6333	0.6252						
2	LataccGain/0.7	-0.55	0.2054	-0.7	1.271	0.54						-0.08	9.148	-0.355	0.7488	0.21	2.043
3	LataccGain/1.0	0.405	0.3177	0.3345	0.3003	0.6141	0.1164	0.5123	0.09807	0.346	0.6681	0.6373	0.1336	0.235	0.6845	0.4173	0.2712
4	LataccPhase/0.4			0.34				-0.5		0.94		0.56		-0.8		0.52	
5	LataccPhase/0.7																
6	LataccPhase/1.0			0.655	1.334					0.535	1.334					-0.6	0
7	SteerGain/0.4					-0.5	2.541										
8	SteerGain/0.7	-0.7	0	0.55		-0.335	0.3638			0.08	0.671	0.17	8.513	-0.295	0.6096	-0.3	
9	SteerGain/1.0	-0.1025	0.4256	0.00375	0.4011	-0.4889	0.08968	-0.2	1.138	0.206	0.2522	-0.2017	0.5907	-0.045	0.3071	-0.4118	0.201
10	SteerPhase/0.4	0.48	0.1771	0.725	1.207	0.49		0.774	0.1649	0.51		0.76	0.5082	0.7	1.652	-0.015	6.163
11	SteerPhase/0.7			0.22	9.148							0.72		0.535	1.461	-0.7	
12	SteerPhase/1.0	0.58		0.48	0.624	0.7		0.6275	0.2096	-0.08	1.874	-0.7	0	0.59	0.311		
13	YawGain/0.4	-0.1783	0.7819	-0.6		-0.65	0.3788	-0.5	1.271	-0.78	0.5511	-0.5333	0.3795	-0.2533	1.1	-0.1367	1.783
14	YawGain/0.7	-0.625	0.2387	-0.5155	0.3387	-0.57	0.1264	-0.7333	0.2868	-0.7273	0.2976	-0.6	0.1215	-0.4	0.5192	-0.4475	0.814
15	YawGain/1.0	0.46		-0.5	0	0.025	5.4	0.36						0.68			
16	YawPhase/0.4	-0.4		-0.54	0.3117	-0.5375	0.2045	-0.4		-0.9		0.455	0.6988	-0.003333	1.778	-0.15	1.526
17	YawPhase/0.7									1.58							
18	YawPhase/1.0	0.71		0.3117	0.5933	0.035	0.8098	0.435	0.3379	0.45	0.5082			0.2	1.293	-0.5	0.8605
19	LatacRespTime/0.2	-0.5225	1.508			-0.22	2.971	0.085	9.974	0.366	1.233	-0.66	0.2256			-0.6833	0.277
20	LatacRespTime/0.6							-1.1						-0.8			
21	StMean/0.2	-0.27	0.6003	0.5533	0.2129	-0.4		-0.55	0.2756	-0.62	0.2692	0.14	0.6809	0.155	0.4792	0.07889	0.4816
22	StMean/0.6			1.41								0.545	1.207			0.73	
23	StMeanRespTime/0.2	-0.04889	0.5136	-0.52	0.2221	-0.875	0.5719	-0.06	1.683	0.3933	0.5108	0.7167	0.3173	-0.5	0.6572	-0.272	0.369
24	StMeanRespTime/0.6	-0.8	0.5663			-1.467	1.12	-0.8	0.4303					-0.9		0.24	1.779
25	RollRt/0.2	-0.06833	0.6279	0.118	0.3359	-0.5833	0.07583	0.1729	0.5005	0.5458	0.2564	0.5633	0.6403	0.3575	0.7015	0.02222	0.3534
26	RollRt/0.6	-0.22	1.23	-0.1067	1.692	-0.6	2.541	-0.7		-0.6333	0.5737			0.54		0.66	2.287
27	RollRtRespTime/0.2			0.39	1.144	0.3375	0.5822	0.405	0.5718	0.4767	0.4933	0.64	13.21	-0.52	0.204	0.3633	1.65
28	RollRtRespTime/0.6	0.5425	0.1515	0.3129	0.5383	-0.224	0.7321	-0.03667	0.6339	-0.25	0.5843	0.4292	0.1858	0.01857	0.5947	-0.06429	0.4558
29	YawRt/0.2	-0.5909	0.1424	-0.1867	1.607	0.59	1.398	-0.4167	0.1227	-0.48	0.136	-0.56	0.2575	-0.331	0.1798	-0.247	0.3271
30	YawRt/0.6	0.5433	0.09896	0.1163	0.5587	0.1336	0.4374	0.07556	0.3395	-0.2429	0.6183	0.2117	0.6395	0.07571	0.5025	-0.2612	0.4069
31	YawRtRespTime/0.2			-1.3		-0.55	3.177			-0.5				-0.6		-1.2	
32	YawRtRespTime/0.6			-0.3				-0.9						-0.6			
33	Storq/0.2	-0.02647	0.2604	-0.5375	0.1544	-0.51	0.1037	-0.4429	0.08387	0.02556	0.3641	-0.4136	0.184	-0.3633	0.2672	-0.3109	0.2012
34	Storq/0.6	-0.5	0.4303	0.215	0.4227	0.42	0.2103	-0.006	0.5993	0.014	0.3982	-0.4569	0.2367	-0.525	0.1986	-0.4	0.2484
35	StorqRespTime/0.2					0.99				-0.55	0.6353			-0.7		-0.5	
36	StorqRespTime/0.6																
37	d(fslip)/0.4			0.136	0.839	0.085	4.892	-0.4667	0.7589	-0.19	0.5694			0.535	0.953	0.1325	1.209
38	d(fslip)/0.2	0.27	0.4383	-0.5714	0.1029	-0.3433	0.459	-0.6	0.2096	-0.03429	0.4399	0.435	0.1075	-0.4622	0.2639	0.63	
39	d(hw)/0.4	0.62															
40	d(hw)/0.2	0.1067	1.118	-0.4				-0.6								-0.7	
41	d(sslip)/0.4	0.504	0.1941	-0.01818	0.4099	0.5418	0.1282	0.3471	0.4468	-0.3875	0.1298	0.6225	0.1177	0.3309	0.2024	0.1086	0.2995
42	d(sslip)/0.2	0.885	4.002	-0.3783	0.4745	-0.1033	1.537	-0.4129	0.5109	-0.45	0.6353	-0.4	0.4303	-0.2043	0.2475	-0.62	0.2964
43	d(storq)/0.4	0.28	0.5464	0.2738	0.404	-0.5		-0.2862	0.4072	-0.01455	0.2822	0.4171	0.4174	-0.0375	0.6277	0.238	0.6072
44	d(storq)/0.2	-0.1633	0.3452	0.22	0.2326	-0.3967	0.4433	-0.1514	0.4294	0.4556	0.07796	-0.185	0.4439	-0.2275	0.4676	0.07875	0.4383
45	roll angle/0.4	-0.065	6.798	0.3		-0.2		-0.8333	0.3795	-0.4		0.505	0.186	-0.176	1.264	-0.06	5.591
46	roll angle/0.2	-0.65	1.906	0.02286	0.5572	0.1067	1.095	-0.6	0.1066	0.22	0.6838	-0.346	0.5832	-0.5692	0.1314	0.11	0.6328

6.5.3 Mean Effects of Metrics On All Drivers' Ratings

Having established that each metric's effect on each driver was normally distributed the results for all eight drivers were averaged together to estimate the relative effect each metric would have in a more general sense. Figure 6-9 summaries the mean values, sorted in ascending order, and confidence intervals for all the metrics. (The data is tabulated in Appendix 6F.)

Of particular interest are metrics who's effects have a narrow confidence interval and those which do not cross the zero effect line. In other words attention should be drawn to metrics for which: i) there is good, uniform, agreement among the drivers as to the true value of the effect and ii) the effect is unequivocally positive or negative regardless of the question asked. The lines corresponding to twelve metrics meeting the first criteria of *uniform agreement*, where the width of the 95% confidence interval is less than 0.6, are drawn in a bold typeface. Of these, five metrics are potentially of greater importance because the 95% confidence interval does not encompass the zero effect line indicating an *unequivocal* (i.e. always positive or always negative) effect. These metrics are: *LataccGain/1.0, SteerPhase/0.4, YawGain/0.4, YawGain/0.7, and Storq/0.2.* Two additional metrics, *SteerGain/1.0* and *d(sslip)/0.4* only slightly impinge upon the zero effect line and could practically be considered together with the just mentioned metrics to yield a group of seven metrics for which their effects can be said to be uniform and unequivocal.

Table 6-25 completes the categorisation of all the metrics according to whether their effect is uniform and/or unequivocal. A close look at the metrics appearing in each column suggest some general patterns.

Starting with the first column, (unequivocal and uniform effect), it can be seen that five out of seven metrics are derived from frequency response data with the remaining two being derived from the remaining tests. For metrics which are unequivocal but not necessarily uniform, four out of five were derived from the step input test. Considering the metrics in these two columns together it is thus interesting to note that with the single exception of *d(sslip)/0.4* all of the metrics relate to transient aspects of handling response. This is certainly consistent with the appearance of many transient handling questions, such as lane changing, as highly correlated in section 6.4.2 . In particular yaw related ones appear more often then others and in all cases tend to have a negative effect. This is perhaps what one would expect - increasing magnitudes of yaw response implies a vehicle configuration which will be more difficult to control. For time response an increase suggests a slower response to the input - again something generally acknowledged to be a subjectively poor quality.

Moving to metrics which are uniform but equivocal in their effect it can be seen that they are from the step input and steady state tests. Except for a small majority of the metrics being related to steering torque feedback there are no obvious explanations for why the metrics in this column have mixed effects on the drivers. In the case of the steer torque metrics it is reasonable to expect that the greater effort which might be linked to increased feedback through the column will be preferable in some manoeuvres whereas for others circumstances the opposite will be true.

Figure 6-9 Mean Effect Of Each Response Metric On All Drivers. Bold lines show where the 95% confidence interval is less than 0.6

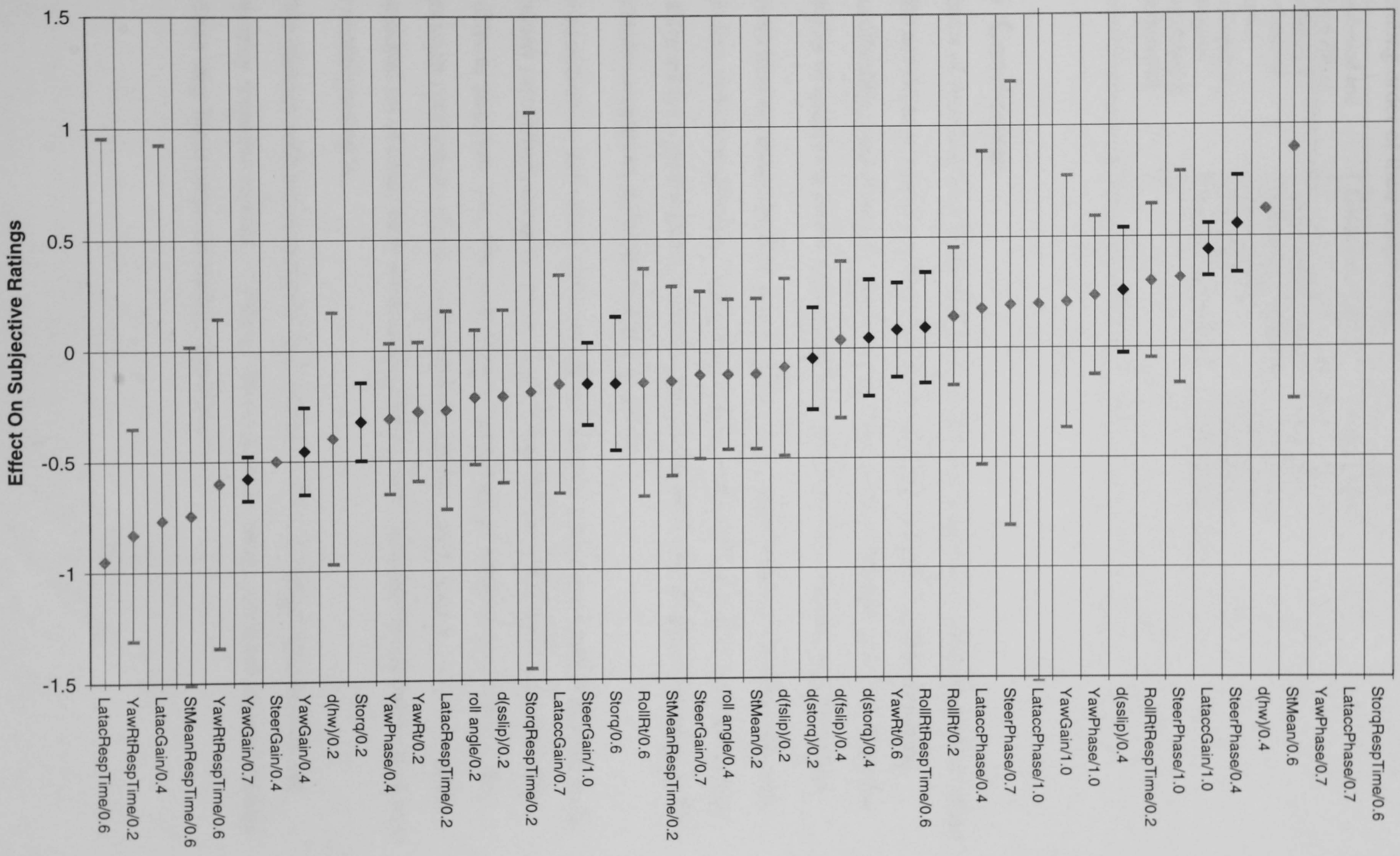

Table 6-25 Nature of the effects each metric has on ratings. Metrics are listed in ascending order of their mean effect.

Unequivocal and Uniform Effect	Unequivocal Effect	Uniform Effect
YawGain/0.7 YawGain/0.4 Storq/0.2 SteerGain/1.0 d(sslip)/0.4 LataccGain/1.0 SteerPhase/0.4	YawRtRespTime/0.2 StMeanRespTime/0.6 YawPhase/0.4 YawRt/0.2 RollRtRespTime/0.2	Storq/0.6 d(storq)/0.2 d(storq)/0.4 YawRt/0.6 RollRtRespTime/0.6

6.6 Conclusions

Aspects of handling which showed good subjective-objective correlation tend to relate to the activities or responses involving control of the vehicle. i.e. lane changing controllability, lane changing recovery, and handwheel feedback questions form the majority of questions where correlation was established for the majority of drivers.

Drivers tend to formulate their ratings for a given aspect of handling using different objective vehicle responses. In instances where subjective objective correlation was established for a given question for more than one driver the metrics appearing in the regression equations differ from driver to driver.

The contribution individual metrics make to a driver's ratings formulation tends to be normally distributed around a mean value. Often the contribution is unequivocally positive or negative. i.e. For each driver's set of ratings regression equations, the regression coefficient values associated with a given metric tend to form a normally distributed set of data. In most cases the values were distributed on either side of zero not encompassing it.

Of the metrics with an unequivocal and uniform effect on ratings the majority are frequency response metrics. Of those whose effect is unequivocal but not necessarily uniform step-input response metrics predominate.

Figure 6-4 Distribution of *LataccGain/1.0* regression coefficients, Driver A

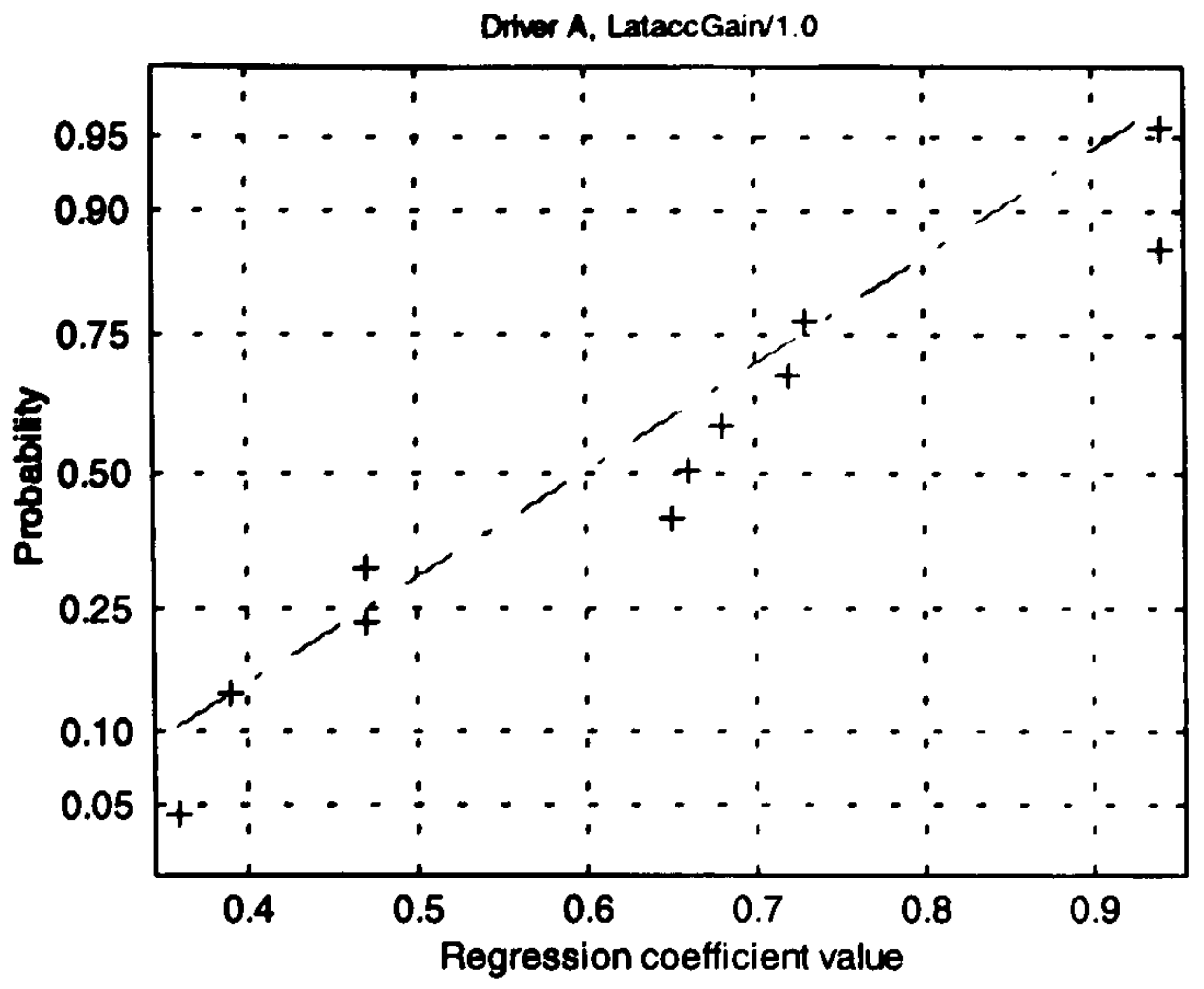

Figure 6-5 Distribution of *RollRtRestpTime/0.6* regression coefficients, Driver A

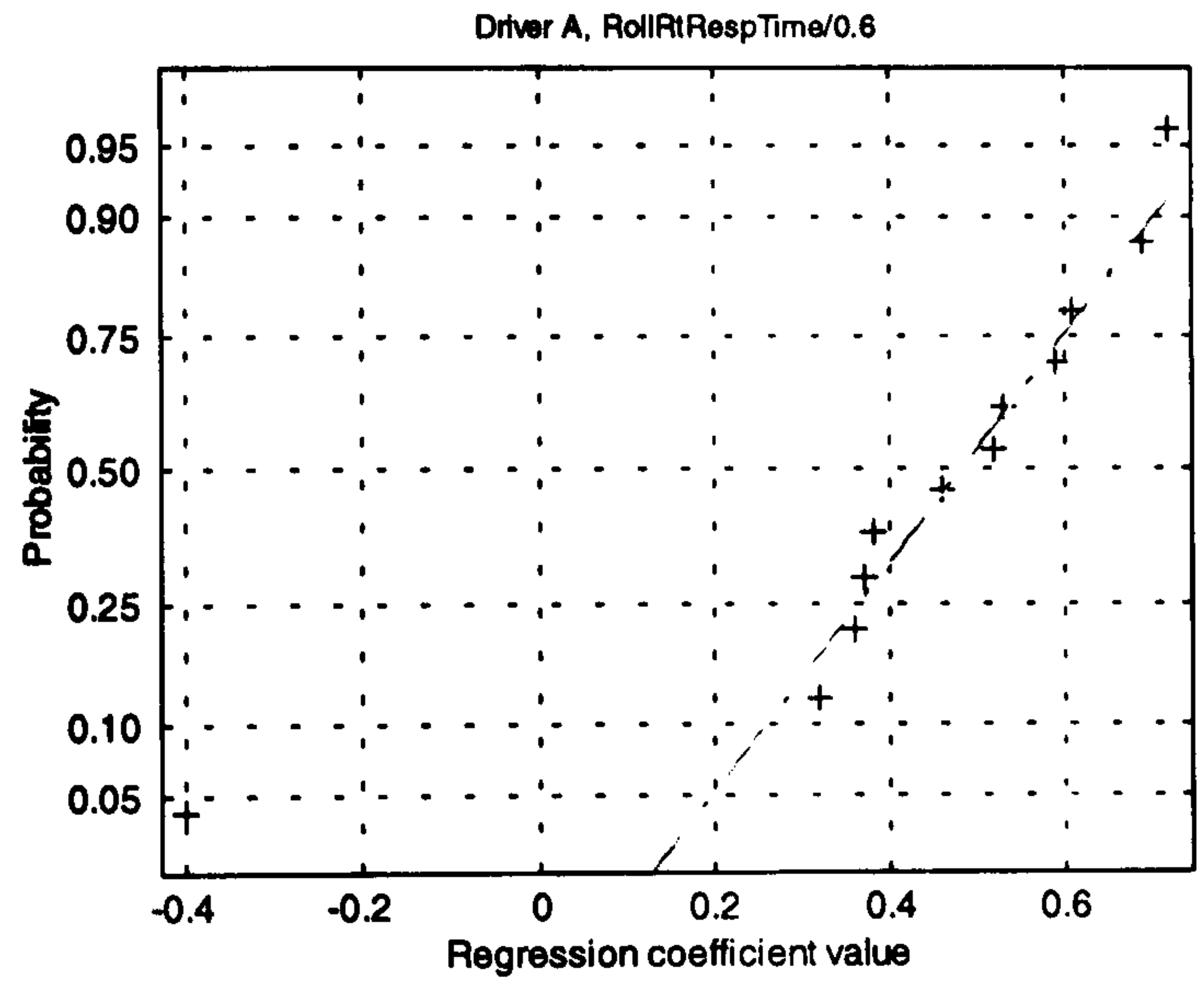

Figure 6-6 Distribution of *Storq/0.2* regression coefficients, Driver A

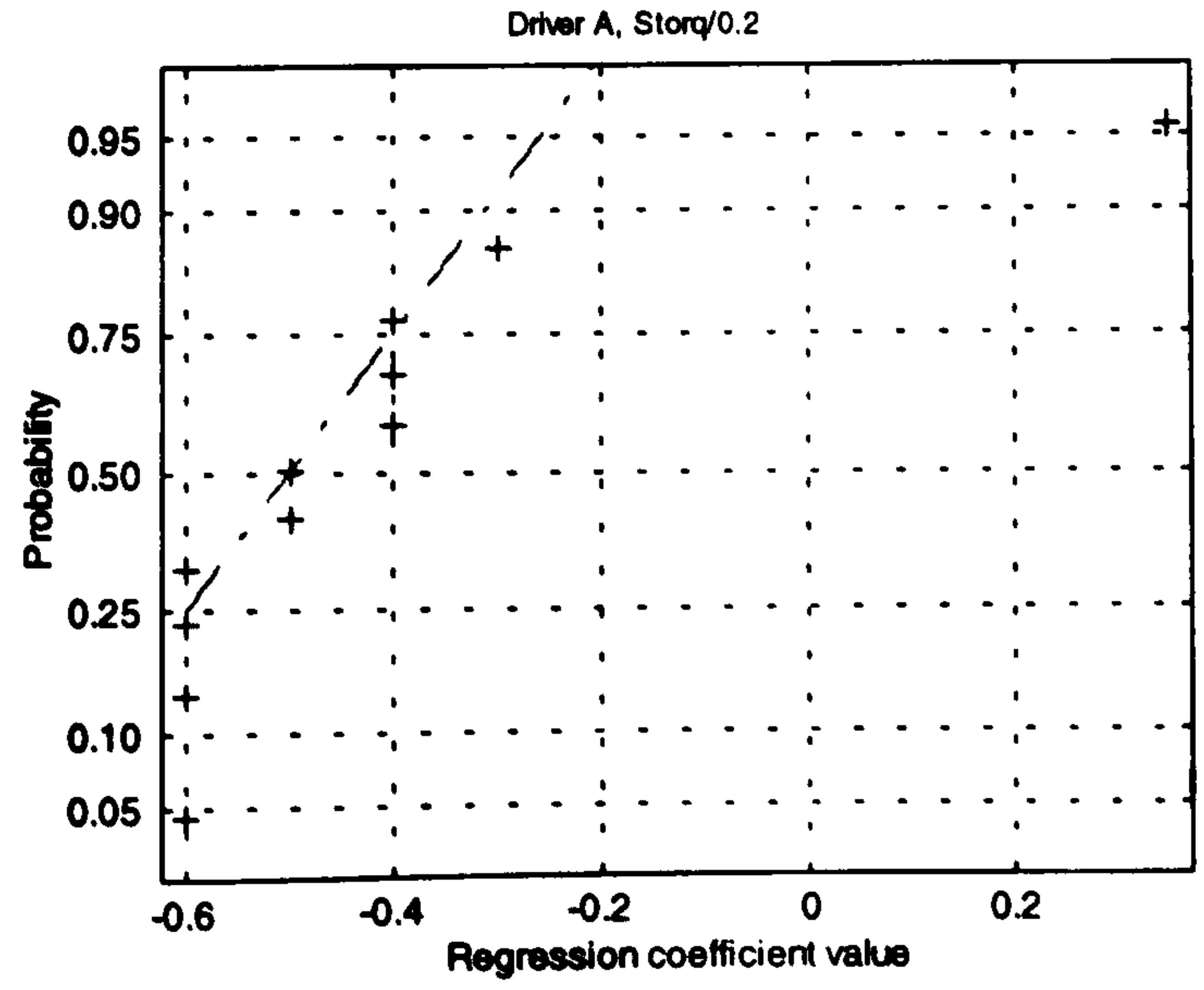

Figure 6-7 Distribution of *Storq/0.6* regression coefficients, Driver A

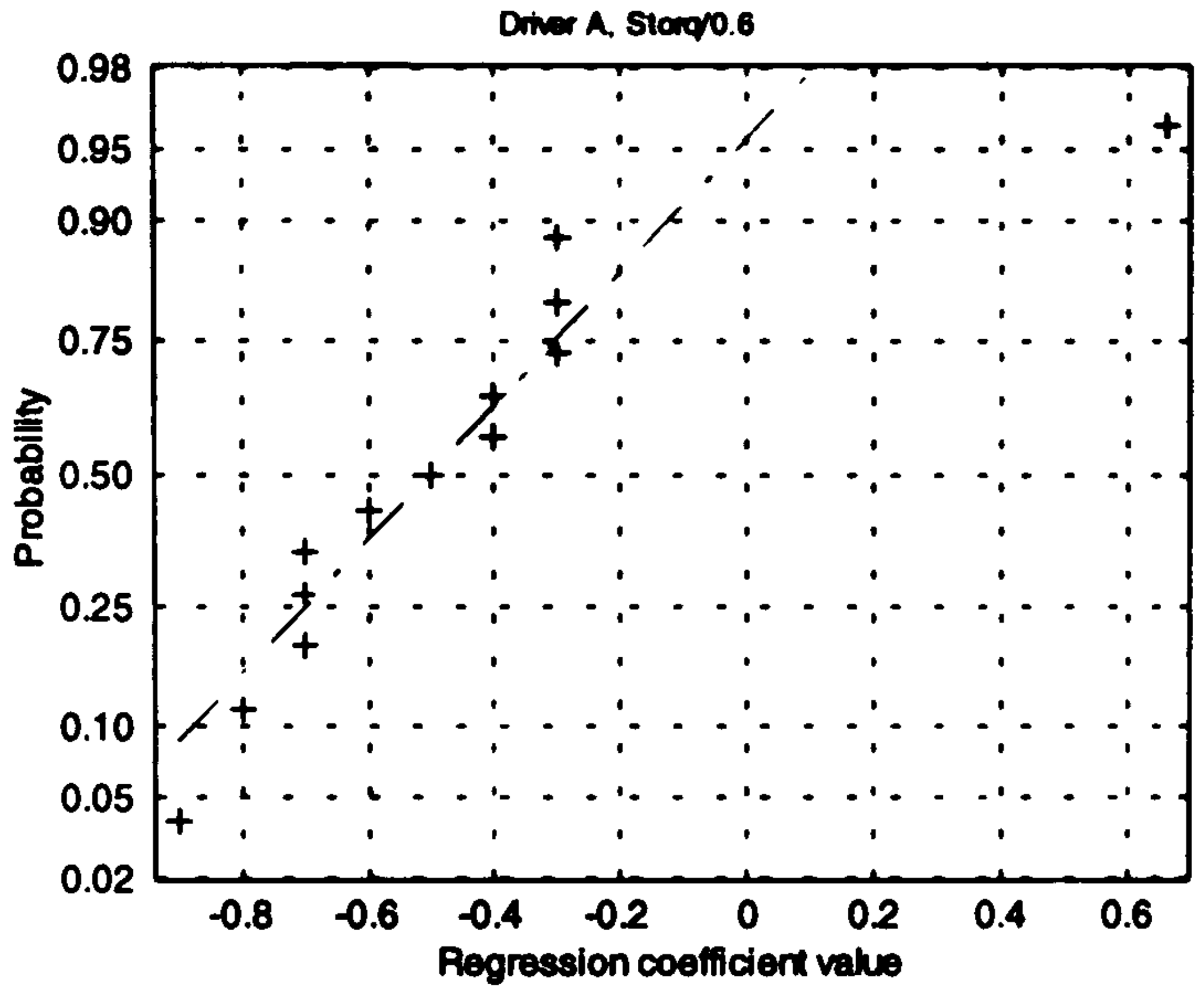

Figure 6-8 Distribution of *d(sslip)/0.4* regression coefficients, Driver A

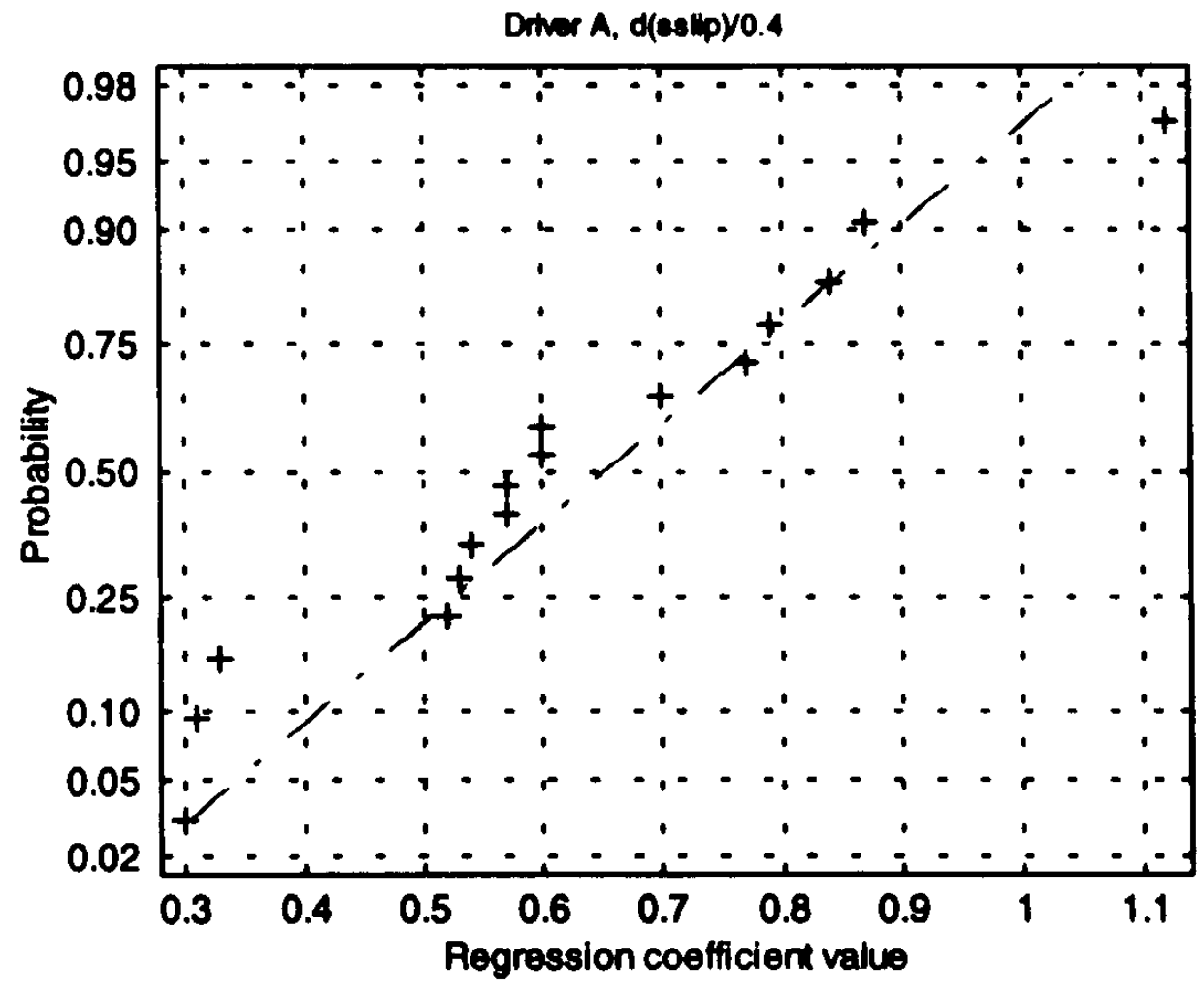

Table 6-24 Mean effect of metrics on each driver. Where no value is given the corresponding metric was not used by the driver.

	Driver															
	A		B		C		D		E		F		G		H	
Metric	Mean Effect	± 95% Confidence Interval	Mean Effect	± 95% Confidence Interval	Mean Effect	± 95% Confidence Interval	Mean Effect	± 95% Confidence Interval	Mean Effect	± 95% Confidence Interval	Mean Effect	± 95% Confidence Interval	Mean Effect	± 95% Confidence Interval	Mean Effect	± 95% Confidence Interval
1 LatacGain/0.4			-0.9						-0.6333	0.6252						
2 LataccGain/0.7	-0.55	0.2054	-0.7	1.271	0.54						-0.08	9.148	-0.355	0.7488	0.21	2.043
3 LataccGain/1.0	0.405	0.3177	0.3345	0.3003	0.6141	0.1164	0.5123	0.09807	0.346	0.6681	0.6373	0.1336	0.235	0.6845	0.4173	0.2712
4 LataccPhase/0.4			0.34				-0.5		0.94		0.56		-0.8		0.52	
5 LataccPhase/0.7																
6 LataccPhase/1.0			0.655	1.334					0.535	1.334					-0.6	0
7 SteerGain/0.4					-0.5	2.541										
8 SteerGain/0.7	-0.7	0	0.55		-0.335	0.3638			0.08	0.671	0.17	8.513	-0.295	0.6096	-0.3	
9 SteerGain/1.0	-0.1025	0.4256	0.00375	0.4011	-0.4889	0.08968	-0.2	1.138	0.206	0.2522	-0.2017	0.5907	-0.045	0.3071	-0.4118	0.201
10 SteerPhase/0.4	0.48	0.1771	0.725	1.207	0.49		0.774	0.1649	0.51		0.76	0.5082	0.7	1.652	-0.015	6.163
11 SteerPhase/0.7			0.22	9.148							0.72		0.535	1.461	-0.7	
12 SteerPhase/1.0	0.58		0.48	0.624	0.7		0.6275	0.2096	-0.08	1.874	-0.7	0	0.59	0.311		
13 YawGain/0.4	-0.1783	0.7819	-0.6		-0.65	0.3788	-0.5	1.271	-0.78	0.5511	-0.5333	0.3795	-0.2533	1.1	-0.1367	1.783
14 YawGain/0.7	-0.625	0.2387	-0.5155	0.3387	-0.57	0.1264	-0.7333	0.2868	-0.7273	0.2976	-0.6	0.1215	-0.4	0.5192	-0.4475	0.814
15 YawGain/1.0	0.46		-0.5	0	0.025	5.4	0.36						0.68			
16 YawPhase/0.4	-0.4		-0.54	0.3117	-0.5375	0.2045	-0.4		-0.9		0.455	0.6988	-0.003333	1.778	-0.15	1.526
17 YawPhase/0.7									1.58							
18 YawPhase/1.0	0.71		0.3117	0.5933	0.035	0.8098	0.435	0.3379	0.45	0.5082			0.2	1.293	-0.5	0.8605
19 LatacRespTime/0.2	-0.5225	1.508			-0.22	2.971	0.085	9.974	0.366	1.233	-0.66	0.2256			-0.6833	0.277
20 LatacRespTime/0.6							-1.1						-0.8			
21 StMean/0.2	-0.27	0.6003	0.5533	0.2129	-0.4		-0.55	0.2756	-0.62	0.2692	0.14	0.6809	0.155	0.4792	0.07889	0.4816
22 StMean/0.6			1.41								0.545	1.207			0.73	
23 StMeanRespTime/0.2	-0.04889	0.5136	-0.52	0.2221	-0.875	0.5719	-0.06	1.683	0.3933	0.5108	0.7167	0.3173	-0.5	0.6572	-0.272	0.369
24 StMeanRespTime/0.6	-0.8	0.5663			-1.467	1.12	-0.8	0.4303					-0.9		0.24	1.779
25 RollRt/0.2	-0.06833	0.6279	0.118	0.3359	-0.5833	0.07583	0.1729	0.5005	0.5458	0.2564	0.5633	0.6403	0.3575	0.7015	0.02222	0.3534
26 RollRt/0.6	-0.22	1.23	-0.1067	1.692	-0.6	2.541	-0.7		-0.6333	0.5737			0.54		0.66	2.287
27 RollRtRespTime/0.2			0.39	1.144	0.3375	0.5822	0.405	0.5718	0.4767	0.4933	0.64	13.21	-0.52	0.204	0.3633	1.65
28 RollRtRespTime/0.6	0.5425	0.1515	0.3129	0.5383	-0.224	0.7321	-0.03667	0.6339	-0.25	0.5843	0.4292	0.1858	0.01857	0.5947	-0.06429	0.4558
29 YawRt/0.2	-0.5909	0.1424	-0.1867	1.607	0.59	1.398	-0.4167	0.1227	-0.48	0.136	-0.56	0.2575	-0.331	0.1798	-0.247	0.3271
30 YawRt/0.6	0.5433	0.09896	0.1163	0.5587	0.1336	0.4374	0.07556	0.3395	-0.2429	0.6183	0.2117	0.6395	0.07571	0.5025	-0.2612	0.4069
31 YawRtRespTime/0.2			-1.3		-0.55	3.177			-0.5				-0.6		-1.2	
32 YawRtRespTime/0.6			-0.3				-0.9						-0.6			
33 Storq/0.2	-0.02647	0.2604	-0.5375	0.1544	-0.51	0.1037	-0.4429	0.08387	0.02556	0.3641	-0.4136	0.184	-0.3633	0.2672	-0.3109	0.2012
34 Storq/0.6	-0.5	0.4303	0.215	0.4227	0.42	0.2103	-0.006	0.5993	0.014	0.3982	-0.4569	0.2367	-0.525	0.1986	-0.4	0.2484
35 StorqRespTime/0.2					0.99				-0.55	0.6353			-0.7		-0.5	
36 StorqRespTime/0.6																
37 d(fslip)/0.4			0.136	0.839	0.085	4.892	-0.4667	0.7589	-0.19	0.5694			0.535	0.953	0.1325	1.209
38 d(fslip)/0.2	0.27	0.4383	-0.5714	0.1029	-0.3433	0.459	-0.6	0.2096	-0.03429	0.4399	0.435	0.1075	-0.4622	0.2639	0.63	
39 d(hw)/0.4	0.62															
40 d(hw)/0.2	0.1067	1.118	-0.4				-0.6								-0.7	
41 d(sslip)/0.4	0.504	0.1941	-0.01818	0.4099	0.5418	0.1282	0.3471	0.4468	-0.3875	0.1298	0.6225	0.1177	0.3309	0.2024	0.1086	0.2995
42 d(sslip)/0.2	0.885	4.002	-0.3783	0.4745	-0.1033	1.537	-0.4129	0.5109	-0.45	0.6353	-0.4	0.4303	-0.2043	0.2475	-0.62	0.2964
43 d(storq)/0.4	0.28	0.5464	0.2738	0.404	-0.5		-0.2862	0.4072	-0.01455	0.2822	0.4171	0.4174	-0.0375	0.6277	0.238	0.6072
44 d(storq)/0.2	-0.1633	0.3452	0.22	0.2326	-0.3967	0.4433	-0.1514	0.4294	0.4556	0.07796	-0.185	0.4439	-0.2275	0.4676	0.07875	0.4383
45 roll angle/0.4	-0.065	6.798	0.3		-0.2		-0.8333	0.3795	-0.4		0.505	0.186	-0.176	1.264	-0.06	5.591
46 roll angle/0.2	-0.65	1.906	0.02286	0.5572	0.1067	1.095	-0.6	0.1066	0.22	0.6838	-0.346	0.5832	-0.5692	0.1314	0.11	0.6328

6.5.3 Mean Effects of Metrics On All Drivers' Ratings

Having established that each metric's effect on each driver was normally distributed the results for all eight drivers were averaged together to estimate the relative effect each metric would have in a more general sense. Figure 6-9 summaries the mean values, sorted in ascending order, and confidence intervals for all the metrics. (The data is tabulated in Appendix 6F.)

Of particular interest are metrics who's effects have a narrow confidence interval and those which do not cross the zero effect line. In other words attention should be drawn to metrics for which: i) there is good, uniform, agreement among the drivers as to the true value of the effect and ii) the effect is unequivocally positive or negative regardless of the question asked. The lines corresponding to twelve metrics meeting the first criteria of *uniform agreement*, where the width of the 95% confidence interval is less than 0.6, are drawn in a bold typeface. Of these, five metrics are potentially of greater importance because the 95% confidence interval does not encompass the zero effect line indicating an *unequivocal* (i.e. always positive or always negative) effect. These metrics are: *LataccGain/1.0, SteerPhase/0.4, YawGain/0.4, YawGain/0.7, and Storq/0.2.* Two additional metrics, *SteerGain/1.0* and *d(sslip)/0.4* only slightly impinge upon the zero effect line and could practically be considered together with the just mentioned metrics to yield a group of seven metrics for which their effects can be said to be uniform and unequivocal.

Table 6-25 completes the categorisation of all the metrics according to whether their effect is uniform and/or unequivocal. A close look at the metrics appearing in each column suggest some general patterns.

Starting with the first column, (unequivocal and uniform effect), it can be seen that five out of seven metrics are derived from frequency response data with the remaining two being derived from the remaining tests. For metrics which are unequivocal but not necessarily uniform, four out of five were derived from the step input test. Considering the metrics in these two columns together it is thus interesting to note that with the single exception of *d(sslip)/0.4* all of the metrics relate to transient aspects of handling response. This is certainly consistent with the appearance of many transient handling questions, such as lane changing, as highly correlated in section 6.4.2 . In particular yaw related ones appear more often then others and in all cases tend to have a negative effect. This is perhaps what one would expect - increasing magnitudes of yaw response implies a vehicle configuration which will be more difficult to control. For time response an increase suggests a slower response to the input - again something generally acknowledged to be a subjectively poor quality.

Moving to metrics which are uniform but equivocal in their effect it can be seen that they are from the step input and steady state tests. Except for a small majority of the metrics being related to steering torque feedback there are no obvious explanations for why the metrics in this column have mixed effects on the drivers. In the case of the steer torque metrics it is reasonable to expect that the greater effort which might be linked to increased feedback through the column will be preferable in some manoeuvres whereas for others circumstances the opposite will be true.

Figure 6-9 Mean Effect Of Each Response Metric On All Drivers. Bold lines show where the 95% confidence interval is less than 0.6

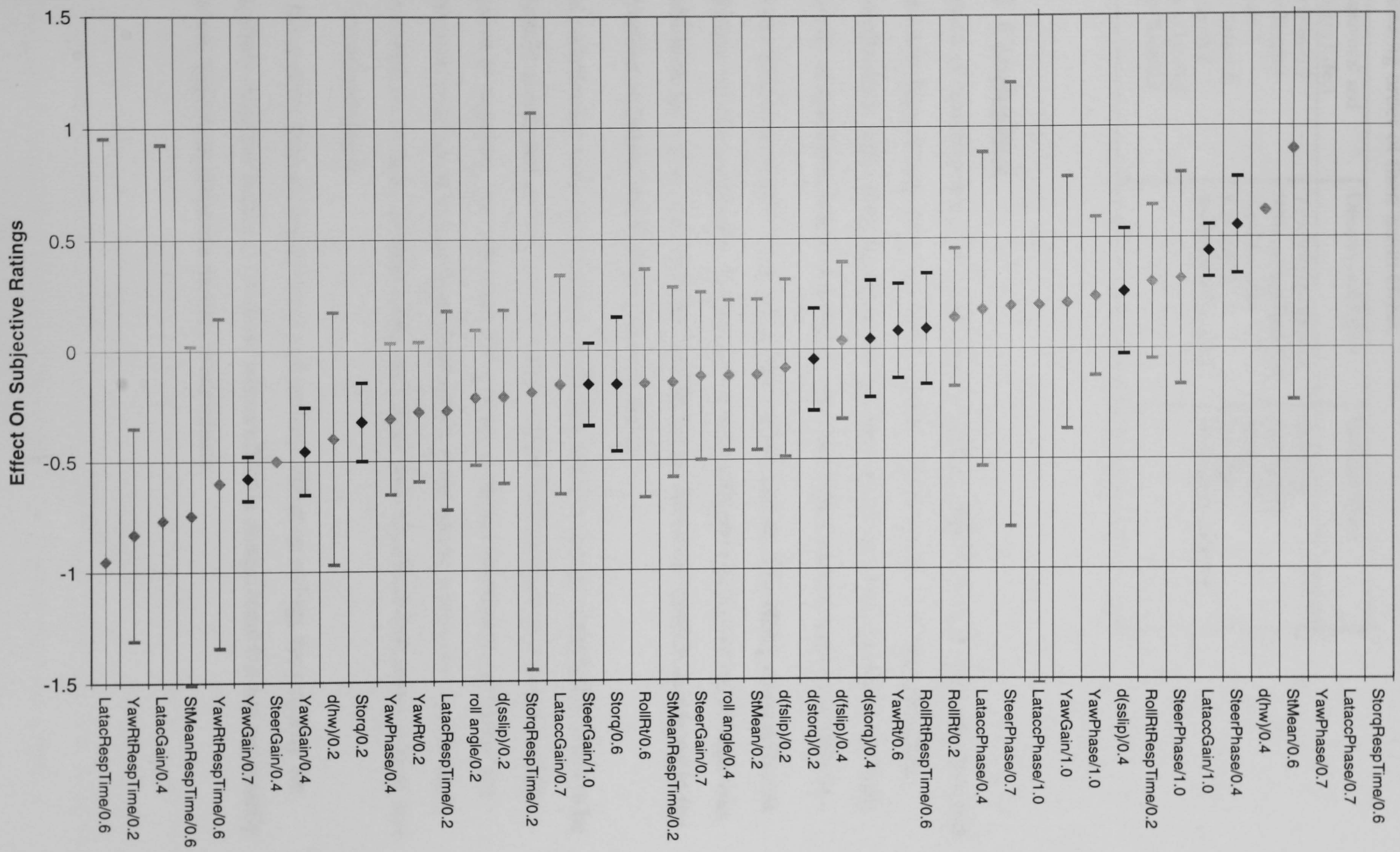

Table 6-25 Nature of the effects each metric has on ratings. Metrics are listed in ascending order of their mean effect.

Unequivocal and Uniform Effect	Unequivocal Effect	Uniform Effect
YawGain/0.7	YawRtRespTime/0.2	Storq/0.6
YawGain/0.4	StMeanRespTime/0.6	d(storq)/0.2
Storq/0.2	YawPhase/0.4	d(storq)/0.4
SteerGain/1.0	YawRt/0.2	YawRt/0.6
d(sslip)/0.4	RollRtRespTime/0.2	RollRtRespTime/0.6
LataccGain/1.0		
SteerPhase/0.4		

6.6 Conclusions

Aspects of handling which showed good subjective-objective correlation tend to relate to the activities or responses involving control of the vehicle. i.e. lane changing controllability, lane changing recovery, and handwheel feedback questions form the majority of questions where correlation was established for the majority of drivers.

Drivers tend to formulate their ratings for a given aspect of handling using different objective vehicle responses. In instances where subjective objective correlation was established for a given question for more than one driver the metrics appearing in the regression equations differ from driver to driver.

The contribution individual metrics make to a driver's ratings formulation tends to be normally distributed around a mean value. Often the contribution is unequivocally positive or negative. i.e. For each driver's set of ratings regression equations, the regression coefficient values associated with a given metric tend to form a normally distributed set of data. In most cases the values were distributed on either side of zero not encompassing it.

Of the metrics with an unequivocal and uniform effect on ratings the majority are frequency response metrics. Of those whose effect is unequivocal but not necessarily uniform step-input response metrics predominate.

7. Application of Research Results to Vehicle Design and Development

Having established subjective-objective relationships and demonstrated validity of the lumped parameter mathematical model - the two necessary elements for effective use of computer handling modelling - it is appropriate to consider their potential utility in practice. Two aspects of the design and development phase are considered, the preliminary, pre-prototype phase, and the prototype testing and development phase.

7.1 Preliminary Design

As noted in Chapter 1 lumped parameter models of the type validated in this research are particularly advantageous due to the parsimonious need for model parameters. An additional advantage of the results of this work is that the identification of important objective responses was based on a wide variety of handling qualities, not specific ones. i.e. in Chapter 6 the identification of important metrics was made by combining results from all of the subjective rating questions. Therefore the designer using the model would be relieved of the need to consider vehicle performance characteristics in specific contexts such as transient manoeuvring or steady state cornering. He or she could experiment with parameter combinations and assess the relative suitability of different combinations by focusing on the "unequivocal" frequency response and step input metrics identified in Chapter 6.

7.2 Testing and Development

In a testing and development context two possible uses of the results of this work present themselves. The first relates to benchmarking activities or work otherwise aimed at comparing the handling performance of various vehicles.

Having identified the metrics with appear to relate most strongly to overall driver opinion, attention can be focused on collection and analysis of these values. Ultimately, with further validation of the model, it may be possible to combine its use with measurement rigs which directly supply the model parameters. An efficient and validated system combining the use of such rigs and mathematical modelling could be faster and more consistent than conducting experimental measurements. Thus in situations where a number of different prototype modifications were possible the use of a kinematics and compliance rig might help guide development engineers towards the best configurations to do proving ground work with.

To illustrate the ideas of the previous paragraph consider a hypothetical example. Suppose that a vehicle prototype development team was tasked with evaluating various suspension and wheel set-ups with the overall aim of optimising handling performance. A common scenario might have one prototype delivered with various springs, roll bars, dampers and wheels, permitting a wide range of set-ups. To test each possible combination even with skilled selection of vehicle characteristics by test drivers would be a time consuming and costly task. On the other hand if various suspension combinations could be testing in the lab on a measurement rig, where weather and access to a proving ground were not an issue, a computer model could quickly predict the performance metrics related to subjective handling. Armed with this information the number of possible set-ups could be narrowed down allowing the "best" set-ups to be evaluated immediately on test tracks.

Another possible use of the subjective objective results in addition to benchmarking could be to clear up confusion as to the source of improvements or worsening of subjective handling. Test drivers on occasion are uncertain as to why one car feels different from another. The vehicle may have changed in an unexpected way after modifications or even changed subjectively without any apparent cause. In such cases the measurement of the important metrics might help to identify the underlying causes of the changed perception of the vehicle.

8. Conclusions

The objectives of this research were first to correlate subjective driver opinions of vehicle handling with objective measurements and second to validate a handling model suitable for the early stages of vehicle design. These goals followed from the acknowledged need to identify subjective-objective relationships if computer modelling is to play a significant role during vehicle development.

Studies dating back to the early 1970's have suggested that, in general, driver ratings can be correlated with various lateral and yaw response related parameters. However differences in the individual test methodologies make it difficult to compare results. Both subjective and objective data collection methods tend to be customised to each study. There does not appear to be any widespread use of standard test methods for either the driver assessment tasks or for objective data collection.

Data collection for the correlation work in this research **did** make use of standardised tests in combination with a representative subjective evaluation procedure. In particular, experimental data collection was based around ISO defined tests. A total of sixteen vehicle configurations of a prototype car were subjected to steady state and transient manoeuvres, yielding a wide range of handling characteristics. The subjective data collection involved eight trained test drivers and allowed them to evaluate the vehicle in a realistic manner, similar to that normally done. The subjective questionnaire returned results which were initially confusing - there was little agreement between the drivers' ratings for all aspects of handling.

The vehicle handling model established for conducting computer simulations allowed for lateral, yaw and roll degrees of freedom. A special effort was made to assure that every parameter used by the model was experimentally obtained. This included obtaining tyre modelling data for the tyres from their manufacturer. As a result of these efforts the comparison of experimental and simulated data showed good general agreement in both the linear and non-linear handling regimes. Across sixteen configurations steady state predictions were within 10% of the experimental, transient behaviour was accurate to 15% and frequency response simulations differed by 4 to 11%.

Examination of the subjective-objective regression equations showed that the questions showing the best correlation concerned control tasks or hand wheel related feedback such as *lane change recovery* and *controllability*, *steering kickback,* and *torque steer.*

It was noted, however, that each driver appeared to formulate their ratings for a given aspect of handling in a manner different from the others. i.e. although driver ratings correlated strongly with objective data the specific responses showing correlation differed from driver to driver. But by re-examining the regression equations it was possible to identify the mean effect each response metric had on subjective ratings. By averaging results a number of metrics were identified which appeared to have unequivocal effects on all drivers. Of these metrics frequency response and step input ones appeared most often. In particular the frequency response *gains* for *lateral acceleration, yaw rate, and road wheel steer angle,* and the *phases* for *yaw rate* had well defined effects on driver opinions. *Peak response times* for *yaw rate, steering torque and roll rate* from step input tests also had definite influences on ratings. Thus, although drivers considered different objective responses in formulating opinions, the contribution of each objective response to the overall rating was roughly the same.

With the validated mathematical model and the subjective-objective relationships developed in this work some progress has been made towards the goal of predicting subjective qualities based on computer modelling. In the early stages of the design process, engineers may begin to benefit from the broadly based subjective-objective relationships which have been developed. Also, the use of computer simulations during prototype development to suggest desirable configurations or to clarify uncertainties regarding driver feedback follows from the results of the research. In conclusion then, some of the elements to close the loop between subjective evaluation, experimental measurements and computer simulation exist, have been clarified, and can potentially be applied to the vehicle design and development process.

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Appendix 2A Specifications for the Experimental Vehicle

Table 2A- 1

Make and Model	Hyundai X2
Total mass	1213 kg
Front track	1.406 m
Rear track	1.336 m
Wheelbase	1.4 m
Weight distribution (front/rear)	60/40
Engine capacity/number of cylinders	1468 cc / 4 in-line
Transmission	Manual 5 speed
Driver	Front wheels
Front suspension	MacPherson Strut
Rear suspension	trailing arms
Steering system	Un-assisted rack and pinion

Appendix 2B Steady State Circular Test Results

Table 2B- 1 Steady state responses for Configuration 1

Configuration 1						
Lateral acceleration	Left road wheel angle	Right road wheel angle	Roll angle	Side slip angle	Hand wheel angle	Steer torque
-0.6966	0.5915	1.662	6.868	-4.825	2.092	-9.798
-0.6498	0.6996	1.752	6.547	-3.956	4.015	-9.724
-0.5864	0.5673	1.596	6.241	-3.19	0.5102	-9.923
-0.5363	0.4756	1.482	5.904	-2.72	-2.27	-9.126
-0.472	0.4803	1.372	5.379	-1.953	-2.716	-7.55
-0.4006	0.3876	1.209	4.863	-1.426	-4.088	-7.05
-0.3459	0.2353	0.9609	3.715	-1.63	-6.385	-6.328
-0.3268	0.2722	0.9207	3.182	-1.456	-5.156	-6.102
-0.2599	0.1431	0.5936	2.303	-1.32	-6.369	-5.605
-0.2399	0.1358	0.5184	2.161	-1.177	-6.132	-4.553
-0.2174	0.1696	0.5122	2.008	-0.9947	-4.937	-4.662
-0.183	0.1437	0.3592	1.484	-0.7866	-5.016	-4.958
-0.1638	0.1497	0.2956	1.301	-0.7331	-4.278	-4.339
-0.1456	0.1246	0.2371	1.183	-0.6221	-4.1	-3.213
-0.1199	0.1455	0.2202	1.054	-0.4888	-3.263	-3.92
-0.09801	0.1154	0.1761	0.8849	-0.4011	-2.882	-3.248
-0.0896	0.0741	0.1377	0.7184	-0.3533	-3.481	-3.466
-0.07815	-0.005254	0.05884	0.4066	-0.3265		-2.688
-0.06154	-0.01202	0.01325	0.4021	-0.2957		-1.788
-0.05528	0.08441	0.09806	0.3813	-0.1767	-2.03	-2.199
-0.04963	0.06304	0.08419	0.238	-0.1684	-2.437	-1.57
-0.06134	-0.05272	-0.041	0.08879	-0.1301		-2.228
-0.03098			0.187	-0.2518		-1.229
-0.02833	0.07496	0.0724	0.0917	-0.0336	-1.021	-2.259
-0.02127	-0.03113	-0.02744	0.07278	-0.08059		-0.7781
-0.01043			0.1228	0.3134		-0.8509
0.01042	0.02363	0.03411	-0.02105	0.1921	1.245	0.6983
0.02161			-0.1266	0.4664		1.034
0.03503	0.06626	0.02921	-0.2635	0.3252	2.815	1.029
0.0597	0.1373	0.094	-0.445	0.5526	4.783	0.7257
0.07745	0.08001	0.05404	-0.5796	0.6066	4.701	2.521
0.09692	0.1482	0.1101	-0.6904	0.6501	6.919	2.423
0.1234	0.1828	0.1802	-0.8838	0.8609	8.862	3.741
0.1218	0.1089	0.08868	-0.9429	0.7927	7.345	3.386
0.1513	0.1051	0.09233	-1.326	1.058	8.457	4.04
0.1869	0.1174	0.1327	-1.541	1.317	9.923	4.342
0.2188	-0.0118	0.08701	-1.88	1.481	10.37	5.703
0.2502	-0.1357	-0.02869	-1.96	1.56	8.777	5.279
0.3054	-0.2347	0.01732	-2.537	1.991	10.85	6.721
0.3269	-0.4474	-0.1738	-2.878	2.067	7.363	5.972
0.3963	-0.5833	-0.1765	-3.473	2.74	7.793	7.18
0.4393	-0.6845	-0.2129	-3.773	3.11	7.184	8.166
0.4775	-0.8132	-0.3218	-4.03	3.468	5.351	8.172
0.5441	-0.918	-0.3581	-4.668	4.248	4.771	8.555
0.5862	-1.136	-0.5311	-4.955	4.695	1.846	9.494
0.6263	-1.215	-0.5937	-5.227	5.235	0.5212	9.625
0.6728	-1.278	-0.5944	-5.709	6.084	-0.1723	9.954
0.7889	-1.167	-0.4743	-6.403	8.416	-0.2983	8.611

Table 2B- 2 Steady state responses for Configuration 2

Configuration 2						
Lateral acceleration	Left road wheel angle	Right road wheel angle	Roll angle	Side slip angle	Hand wheel angle	Steer torque
-0.6459	0.007054	-0.3459	4.937	-4.703	-54.24	-10.46
-0.5602		0.3858	4.401	-3.631	-35.52	-10.04
-0.5542	-0.2279		4.428	-3.447	-39.87	-8.164
-0.4661		0.6304	3.663	-2.538	-22.37	-8.221
-0.454	-0.2399	0.4466	3.645	-2.596	-24.82	-7.893
-0.4666	-0.4163	0.2829	3.7	-2.701	-28.41	-7.258
-0.4262	-0.2643	0.2669	3.199	-2.518	-24.89	-7.633
-0.33		0.4716	2.364	-1.764	-13.67	-6.135
-0.3193	-0.003078	0.3689	2.342	-1.775	-15.47	-5.759
-0.3179	-0.2254	0.1612	2.475	-1.856	-19.33	-5.745
-0.2932	-0.1514	0.1617	2.263	-1.668	-17.22	-5.34
-0.2668	0.006636	0.2562	2.044	-1.328	-12.53	-4.438
-0.23	0.03442	0.237	1.644	-1.037	-10.75	-4.521
-0.2119	-0.01133	0.1571	1.573	-1.138	-11.21	-3.936
-0.2047	0.1179	0.2299	1.461	-1.052	-8.733	-3.56
-0.1757	0.1859	0.2651	1.151	-0.8339	-5.806	-3.219
-0.161	0.08477	0.1204	1.117	-0.8062	-6.896	-2.435
-0.1317	0.101	0.1036	0.9017	-0.6289	-5.537	-2.793
-0.09586	0.2781	0.2089	0.7354	-0.351	0.05535	-2.081
-0.0802	0.1817	0.09678	0.5057	-0.3694	-1.142	-1.201
-0.06108	0.1676	0.06986	0.4405	-0.2552	-0.7129	-2.034
-0.05654	0.1088	0.02863	0.2997	-0.2532	-1.109	-1.335
-0.04801	0.1198	0.04835	0.2754	-0.2123	-0.3987	-1.298
-0.02465	0.09114	-0.01779	0.1421	-0.1191	-0.8283	-1.123
-0.02432		-0.0604	0.0278	-0.1992	-1.751	-0.0239
-0.01621	0.06033	0.02301	0.006393	-0.09758	0.3874	-0.644
0.01005			-0.1817	0.2631		1.452
0.008446			0.02046	0.1892		
0.0195	0.07122	0.09897	-0.2884	0.005884	-0.7725	1.429
0.02546	0.09305	0.09632	-0.2585	0.08119	-1.384	-0.09373
0.03459	0.1733	0.1666	-0.3833	0.1181	0.7162	1.093
0.05306	0.2158	0.2373	-0.3136	0.2548	2.293	1.216
0.06817	0.1664	0.2165	-0.5306	0.3087	2.356	1.388
0.0824	0.2353	0.3379	-0.7867	0.4273	5.474	1.821
0.1003	0.2478	0.2979	-0.8531	0.5631	5.935	2.942
0.1159	0.2305	0.3444	-0.8134	0.6599	7.356	3.583
0.1406	0.1432	0.2514	-1.041	0.7608	6.719	3.095
0.1657	0.2006	0.3652	-1.263	0.9518	9.765	3.895
0.1868	0.1189	0.3139	-1.5	1.009	9.715	4.887
0.2094	-0.1142	0.143	-1.729	1.019	7.046	5.11
0.251	-0.03648	0.3625	-2.002	1.381	12.55	5.253
0.2838	-0.1663	0.3201	-2.176	1.466	12.62	5.559
0.3427	-0.2151	0.5436	-2.529	1.99	18.24	7.035
0.3635	-0.4387	0.498	-2.754	2.081	18.33	6.348
0.4015	-0.681	0.4909	-3.075	2.337	18.75	6.161
0.4335	-0.8044	0.6662	-3.52	2.651	22.64	6.773
0.4865	-0.7068	0.9731	-3.73	3.114	29.18	7.626
0.5327	-0.8037	1.011	-4.007	3.475	30.4	8.117
0.5422	-0.8661	1.051	-4.177	3.679	31.97	7.806
0.6258	-0.4116	1.642	-4.542	4.515	44.16	9.553

Table 2B- 3 Steady state responses for Configuration 3

Configuration 3						
Lateral acceleration	Left road wheel angle	Right road wheel angle	Roll angle	Side slip angle	Hand wheel angle	Steer torque
-0.4749	-0.03365	0.7798	6.738	-1.447	-11.21	-7.779
-0.4504	-0.01848	0.7592	6.683	-1.236	-10.91	-7.499
-0.4422	-0.06539	0.7041	6.562	-1.149	-11.6	-7.347
-0.4287	-0.02171	0.7264	6.493	-0.9839	-10.58	-6.619
-0.4042	0.05608	0.7619	6.371	-0.8205	-8.581	-5.999
-0.3823	-0.0471	0.6769	6.245	-0.7756	-10.33	-6.385
-0.3727	-0.06292	0.6484	5.831	-0.866	-10.37	-6.935
-0.3476	0.003895	0.6694	4.936	-1.093	-8.271	-5.012
-0.32	-0.02386	0.6023	4.605	-1.066	-8.358	-4.55
-0.2699	0.05866	0.6504	4.989		-6.652	-3.733
-0.2702	-0.001054	0.5274	3.512	-1.304	-6.662	-3.588
-0.2342	0.02961	0.4642	2.999	-1.215	-5.111	-2.481
-0.201	0.08835	0.3945	2.746	-0.8622	-3.613	-2.152
-0.1821	0.08168	0.2961	2.373	-0.8191	-3.203	-3.257
-0.1658	0.08351	0.2611	2.156	-0.8072	-2.592	-2.674
-0.1295	0.1169	0.2344	1.675	-0.6309	-0.8332	-2.327
-0.1318	0.01336	0.153	1.731	-0.7319	-2.748	-1.142
-0.1089	0.1075	0.2052	1.429	-0.5588	-0.2121	-1.227
-0.1438	-0.001054	0.1657	1.752	-0.7753	-3.803	-1.688
-0.1144	0.04435	0.1572	1.435	-0.5711	-2.156	-1.163
-0.1135	-0.03365	0.0633	1.357	-0.5972	-4.085	-1.905
-0.1008	0.03682	0.118	1.27	-0.5054	-1.886	-1.692
-0.07919	0.005293	0.06319	1.152	-0.4344	-1.94	-0.6053
-0.0662	-0.01364	0.005963	0.937	-0.3532	-1.799	-1.336
-0.04694	0.06425	0.08314	0.7899	-0.1738	0.5898	-0.9823
-0.03179	-0.01493	-0.003436	0.6082	-0.1301	-0.3627	-0.7161
0.03574	0.04387	0.04204	0.003042	0.1802	1.524	0.6373
0.05707	0.001591	-0.01362	-0.000361	0.2774	1.305	0.5655
0.06447	-0.06156	-0.08307	-0.08196	0.2947	0.4107	1.656
0.06713	-0.04586	-0.07095	-0.25	0.275	0.8036	1.259
0.07916	0.005248	-0.01279	-0.2107	0.3627	2.065	1.969
0.09198	-0.02068	-0.04589	-0.4117	0.4186	1.97	1.956
0.1185	-0.0352	-0.04547	-0.5616	0.4555	2.667	2.343
0.124	-0.01315	-0.03304	-0.6981	0.5185	3.23	2.54
0.145	-0.07222	-0.05623	-0.8308	0.6504	3.283	2.875
0.1557	-0.07265	-0.04056	-1.016	0.7537	3.938	2.539
0.1708	-0.05812	-0.007352	-1.085	0.8316	5.339	2.995
0.1843	-0.07631	-0.01007	-1.267	0.9038	5.66	3.002
0.202	-0.08932	0.007999	-1.301	1.052	6.256	3.423
0.2224	-0.1163	0.04215	-1.641	1.205	7.561	4.392
0.2428	-0.2256	-0.05404	-1.765	1.161	5.919	3.453
0.2552	-0.2601	-0.06155	-1.803	1.177	6.232	4.345
0.2771	-0.2307	-0.01613	-1.96	1.368	7.51	4.228
0.2934	-0.2905	-0.0462	-2.35	1.467	7.118	3.996
0.3025	-0.2605	-0.01884	-2.453	1.506	7.856	5.266
0.3266	-0.2751	-0.000564	-2.648	1.651	8.399	4.245
0.3441	-0.3138	0.04288	-2.923	1.784	9.238	4.504
0.3748	-0.2983	0.0952	-3.108	1.944	10.27	6.167
0.3922	-0.3434	0.0671	-3.312	2.055	9.455	6.57
0.396	-0.3723	0.0315	-3.448	2.046	8.465	6.002
0.4137	-0.3231	0.09645	-3.525	2.281	9.583	4.766
0.4199	-0.2716	0.1537	-3.507	2.372	10.81	5.5
0.441	-0.309	0.1393	-3.719	2.488	10.53	6.152
0.4629	-0.3109	0.1761	-4.042	2.695	11.09	5.885
0.4919	-0.3031	0.2122	-4.257	2.89	11.82	6.889
0.4995	-0.3526	0.1488	-4.288	2.952	10.83	5.866
0.5255	-0.3471	0.1811	-4.412	3.11	11.35	6.742
0.5243	-0.318	0.2444	-4.609	3.236	12.35	6.433

Table 2B- 4 Steady state responses for Configuration 4

Configuration 4						
Lateral acceleration	Left road wheel angle	Right road wheel angle	Roll angle	Side slip angle	Hand wheel angle	Steer torque
-0.511	-1.669	-0.3798	4.417	-1.855	-48.31	-8.957
-0.5417	-1.901	-0.5474	4.565	-1.993	-52.95	-10.16
-0.4542	-1.183	-0.04389	3.949	-1.47	-37.02	-7.3
-0.4762	-1.443	-0.2723	4.09	-1.635	-42.7	-7.025
-0.4321	-1.229	-0.1962	3.882	-1.445	-37.76	-6.683
-0.4049	-1.145	-0.2201	3.456	-1.331	-35.59	-6.586
-0.3756	-0.9826	-0.1565	3.151	-1.12	-31.44	-7.624
-0.3395	-0.8243	-0.08268	2.932	-0.9675	-27.47	-6.196
-0.305	-0.6973	-0.03275	2.711	-0.8108	-24.53	-5.831
-0.263	-0.6112	-0.05682	2.356	-0.6674	-21.81	-5.248
-0.2581	-0.6072	-0.09138	2.23	-0.6175	-21.55	-5.193
-0.2345	-0.7556	-0.2859	2.116	-0.6626	-24.46	-5.528
-0.1992	-0.5182	-0.1193	1.848	-0.3802	-18.18	-3.481
-0.1839	-0.4263	-0.09191	1.648	-0.3248	-16.06	-3.879
-0.1738	-0.4026	-0.07145	1.711	-0.2214	-15.26	-4.072
-0.17	-0.6025	-0.3336	1.617	-0.3761	-19.55	-3.636
-0.1514	-0.443	-0.1789	1.42	-0.3576	-15.24	-2.993
-0.1433	-0.2719	-0.04102	1.276	-0.3145	-11.8	-3.372
-0.1262	-0.09831	0.0828	1.159	-0.154	-7.63	-2.582
-0.124	-0.2224	-0.07632	0.9745	-0.3295	-10.18	-3.32
-0.1113	-0.3099	-0.1527	0.7997	-0.4765	-11.27	-2.511
-0.09751	-0.1163	-0.02035	0.6154	-0.2902	-7.347	-2.677
-0.08692	-0.1572	-0.04283	0.3611	-0.3706	-7.4	-1.558
-0.08017	-0.1376	-0.04908	0.4347	-0.3334	-6.594	-0.9468
-0.06926	-0.0424	0.01633	0.1431	-0.2009	-3.22	-1.044
-0.05823	-0.1682	-0.1272	0.1733	-0.2892	-5.393	-1.477
-0.04372	-0.07678	-0.02321	0.002908	-0.1619	-3.179	-2.122
-0.0314	-0.1385	-0.1044	0.0722	-0.1635	-4.229	-1.669
-0.0213	0.08792	0.1264	0.1138	0.01901	1.314	-0.4473
-0.01964	-0.03121	-0.006888	-0.05915	-0.0644	-1.103	-0.7191
-0.02644	-0.1048	-0.08162	-0.07951	-0.073	-2.447	-0.839
-0.03543	0.003376	0.06308	0.1592	-0.1203	-0.6867	-0.009081
-0.02171	0.2755	0.3385	0.08532	0.1412	4.418	-1.678
0.0106	-0.2361	-0.241	-0.2869	-0.2151	-4.32	2.272
0.02443	0.1706	0.1741	-0.2653	0.1489	3.88	2.177
0.02025	0.1314	0.1292	-0.3589	0.08201	2.931	0.8022
0.03208	0.0386	0.01297	-0.3156	0.07557	1.335	1.978
0.04079	0.01143	-0.01703	-0.4005	0.155	1.037	1.345
0.05164	0.08688	0.06852	-0.4166	0.2556	3.177	2.194
0.07532	0.1203	0.0858	-0.592	0.4007	4.295	2.328
0.07547	0.003594	-0.0254	-0.7279	0.1094	1.982	3.083
0.09094	-0.02201	-0.06113	-0.7904	0.1836	1.728	2.907
0.09457	0.04028	0.003641	-0.986	0.04805	3.511	2.582
0.1111	0.1851	0.156	-1.088	0.1504	7.253	3.294
0.1113	0.1271	0.09693	-1.214	0.1286	5.898	2.887
0.1276	0.2051	0.1692	-1.306	0.1576	8.477	4.238
0.1337	0.1026	0.06767	-1.385	0.1043	7.26	4.637
0.1539	0.0664	0.03438	-1.483	0.2274	6.746	3.795
0.1784	0.1833	0.1702	-1.695	0.3833	10.89	4.392
0.1837	0.1114	0.09163	-1.698	0.3747	9.167	5.324
0.2069	0.3067	0.3363	-1.904	0.589	14.76	4.553
0.2321	0.2408	0.2784	-2.114	0.5727	14.25	4.661
0.2449	0.09253	0.1139	-2.152	0.5541	11.62	5.957
0.2512	0.1094	0.1458	-2.272	0.6405	12.66	4.974
0.2993	0.2151	0.2963	-2.466	0.947	16.64	5.665
0.297	0.08845	0.1623	-2.546	0.7722	14.33	5.757
0.3333	0.2188	0.3707	-2.846	1.197	19.19	6.238
0.3795	0.2358	0.4749	-3.134	1.348	22.07	7.96
0.4368	0.4028	0.8065	-3.784	1.76	28.93	8.132
0.4015	0.1866	0.4628	-3.526	1.469	22.59	8.579
0.4281	0.2987	0.6836	-3.759	1.693	26.93	7.27
0.4699	0.3787	0.8534	-4.103	1.898	30.28	7.28
0.4901	0.4368	0.9144	-4.218	2.006	32.08	8.203
0.5221	0.7052	1.306	-4.432	2.396	39.15	8.565

Table 2B- 5 Steady state responses for Configuration 5

Configuration 5						
Lateral acceleration	Left road wheel angle	Right road wheel angle	Roll angle	Side slip angle	Hand wheel angle	Steer torque
-0.5748	-1.313	-0.2221	7.153	-3.154	-40.27	-10.25
-0.5155	-0.9445	0.07387	6.664	-2.428	-32.33	-11.09
-0.4661	-0.8713	0.101	6.305	-2.069	-30.65	-9.488
-0.4182	-0.5822	0.2698	5.802	-1.601	-24.84	-7.484
-0.3868	-0.5964	0.2631	5.741	-1.44	-24.62	-8.471
-0.3431	-0.367	0.3777	5.192	-1.076	-19.92	-6.698
-0.3111	-0.375	0.3388	4.883	-0.8617	-19.51	-6.599
-0.2879	-0.4535	0.2573	4.926	-0.775	-20.73	-7.103
-0.2461	-0.3446	0.3167	4.358	-0.4656	-17.55	-5.108
-0.222	-0.3862	0.2173	4.063	-0.3217	-17.9	-5.284
-0.1926	-0.1393	0.3175	3.741	-0.0441	-11.03	-3.896
-0.1607	-0.1138	0.2105	3.011	-0.06015	-8.923	-3.454
-0.1359	-0.1234	0.1082	2.715	-0.03044	-8.102	-4.325
-0.1105	-0.01883	0.1491	2.363	0.1267	-5.246	-3.293
-0.1052	-0.007129	0.1121	1.793	-0.3503	-4.679	-3.557
-0.06856	0.1426	0.22	1.379	-0.1331	-0.2478	-2.89
-0.05808	0.09917	0.1457	1.24	-0.1087	-0.4667	-2.235
-0.05233	-0.06082	-0.01309	1.074	-0.191	-3.401	-1.605
-0.04336	-0.242	-0.1918	1.318	-0.2806	-6.758	-2.002
-0.03775	-0.06919	-0.03929	1.115	-0.177	-2.712	-1.276
-0.03159	-0.01679	0.0343	0.8411	-0.1075	-0.9102	-0.5414
-0.02549	-0.009491	0.02073	0.6436	-0.01094	-0.8086	-2.104
-0.02094	-0.1534	-0.1331	0.9603	-0.1314	-3.914	-0.9489
-0.01063	0.09659	0.1258	0.8294	0.1687	1.722	-1.572
-0.0132	-0.191	-0.1937	0.6328	-0.0447	-3.437	-0.284
-0.01506	0.02991	0.02689	0.6473	0.151	0.7098	-1.777
0.0129	-0.02968	-0.002702	0.519	0.01066	-0.9314	1.05
0.03356	-0.275	-0.2633	0.5315	0.04091	-4.362	1.572
0.03835	0.04688	0.07173	0.4333	0.2752	2.589	0.5693
0.04452	-0.1436	-0.1413	0.415	0.1879	-0.6612	0.6436
0.06758	0.07147	0.06672	-0.04785	0.1834	4.528	1.246
0.06878	0.2129	0.2241	-0.09933	0.3236	7.731	0.9687
0.09749	0.01553	0.02767	-0.34	0.2904	5.014	2.185
0.1135	0.01799	0.03279	-0.3973	0.391	5.897	2.532
0.1256	-0.004661	0.02329	-0.8795	0.3377	6.581	2.747
0.1549	-0.03881	0.02924	-1.138	0.6002	7.26	3.054
0.1644	-0.2357	-0.1689	-1.448	0.4148	4.396	3.904
0.2052	-0.1261	0.008675	-1.782	0.7674	8.901	3.73
0.2167	-0.145	0.01796	-1.975	0.7484	9.858	3.747
0.2537	-0.123	0.1194	-2.152	0.9554	12.7	4.743
0.2775	-0.1406	0.1517	-2.742	1.099	14.33	4.99
0.3033	-0.1944	0.148	-2.966	1.246	14.79	6.257
0.34	-0.2234	0.1418	-3.402	1.572	15.44	5.875
0.386	-0.1353	0.2921	-3.928	1.952	18.76	7.068
0.4088	-0.1421	0.3088	-3.956	2.088	19.02	7.888
0.4114	-0.08981	0.383	-4.118	2.181	20.62	6.426
0.4631	-0.03569	0.5064	-4.492	2.618	22.32	6.635
0.5163	0.0326	0.6562	-4.921	3.044	24.85	8.499
0.5787	0.2112	1.003	-5.598	3.771	30.05	8.783

Table 2B- 6 Steady state responses for Configuration 6

Configuration 6						
Lateral acceleration	Left road wheel angle	Right road wheel angle	Roll angle	Side slip angle	Hand wheel angle	Steer torque
-0.5362	0.3931	1.272	4.95	-2.756	-3.405	-8.292
-0.5107	0.4149	1.268	4.821	-2.508	-2.762	-8.354
-0.4783	0.4032	1.211	4.767	-2.28	-2.992	-7.911
-0.473	0.4124	1.187	4.581	-2.182	-2.51	-6.726
-0.4564	0.4011	1.138	4.458	-2.082	-2.593	-6.213
-0.4355	0.386	1.067	4.298	-1.962	-2.967	-6.527
-0.398	0.4045	0.9728	4.004	-1.718	-2.556	-6.121
-0.3967	0.3432	0.9209	4.031	-1.721	-3.519	-6.369
-0.3802	0.3736	0.8816	3.877	-1.593	-2.882	-5.945
-0.3321	0.4185	0.7797	3.475	-1.265	-1.692	-5.461
-0.3046	0.3801	0.6882	3.244	-1.09	-2.176	-5.265
-0.2806	0.3954	0.6143	3.039	-0.9185	-1.955	-6.916
-0.2291	0.3834	0.5153	2.81	-0.6949	-1.376	-4.715
-0.2362	0.4328	0.577	2.958	-0.6464	-0.03265	-6.155
-0.2053	0.3937	0.4706	2.567	-0.5483	-0.2537	-5.01
-0.189	0.3627	0.4034	1.97	-0.7129	-0.01961	-4.03
-0.1562	0.3484	0.3464	1.831	-0.548	0.2051	-4.22
-0.137	0.1123	0.1125	1.459	-0.7445		-3.309
-0.1195	0.3392	0.2877	1.348	-0.5955	0.8262	-3.002
-0.1108	0.2916	0.2314	1.269	-0.5953	0.2508	-3.51
-0.1011	0.2675	0.1984	1.079	-0.5524	-0.1446	-3.68
-0.09077	0.2222	0.1424	0.7582	-0.6533	-0.2574	-3.407
-0.07201	0.1448	0.03962	0.6429	-0.6202		-2.736
-0.06213	0.2462	0.1416	0.6844	-0.4955	0.5847	-2.495
-0.05121	0.002922	-0.08939	0.5435	-0.5707		-1.496
-0.04654	0.05102	-0.05244	0.5484	-0.511		-2.581
-0.02845	0.1151	0.005284	0.303	-0.3618		-1.249
-0.02774	0.2184	0.132	0.3555	-0.2549	1.883	-1.061
-0.02486	0.1552	0.03827	0.3225	-0.284	0.2079	-1.326
-0.01846	0.07411	-0.04085	0.2962	-0.3241		-1.34
0.0302	-0.003055	-0.01476	0.1224	0.0151		2.044
0.04064	-0.03301	-0.04805	-0.004102	0.04965		1.09
0.05687	0.1292	0.1286	0.05603	0.2172	2.993	1.403
0.06617	0.08187	0.07407	-0.1922	0.2838	2.295	2.277
0.07892	0.07221	0.05789	-0.2942	0.3149	2.391	2.108
0.09841	0.04408	0.03034	-0.3887	0.4081	2.242	1.983
0.1115	0.07854	0.07731	-0.5443	0.4514	3.884	2.969
0.1307	0.07844	0.06019	-0.5797	0.56	4.459	3.056
0.1408	0.08208	0.07845	-0.7383	0.715	4.994	3.226
0.1479	-0.009283	-0.02248	-0.7572	0.7098	2.998	2.469
0.1748	0.005425	0.03608	-0.88	0.8672	5.06	4.267
0.1887	-0.04471	-0.02582	-1.099	0.9619	4.298	4.509
0.2138	-0.1001	-0.06475	-1.349	1.105	4.281	4.538
0.2243	-0.1777	-0.1175	-1.422	1.116	3.318	4.964
0.262	-0.2035	-0.1091	-1.677	1.312	4.424	5.17
0.2981	-0.3086	-0.1825	-1.805	1.558	3.844	4.845
0.3201	-0.3351	-0.1502	-1.904	1.716	4.881	6.24
0.3563	-0.4006	-0.185	-2.131	1.994	4.817	7.14
0.4002	-0.5094	-0.1851	-2.483	2.355	5.163	7.392
0.4188	-0.5715	-0.1907	-2.694	2.546	5.143	7.233
0.4547	-0.6786	-0.2256	-2.993	2.77	4.597	6.353
0.4864	-0.7653	-0.2252	-3.241	3.082	4.583	6.57
0.502	-0.8381	-0.2546	-3.35	3.175	3.814	7.252
0.5301	-0.8165	-0.2335	-3.553	3.43	4.549	6.927
0.5587	-0.8618	-0.2351	-3.707	3.715	4.741	8.454

Table 2B- 7 Steady state responses for Configuration 7

Configuration 7						
Lateral acceleration	Left road wheel angle	Right road wheel angle	Roll angle	Side slip angle	Hand wheel angle	Steer torque
-0.6247	-0.122	-0.8642	5.472	-4.072	-59.47	-12.47
-0.5374		-0.09777	4.619	-3.004	-39.07	-11.77
-0.4784		0.1402	4.33	-2.583	-31.76	-10.4
-0.4704	0.02014	0.1086	4.138	-2.578	-32.37	-11.07
-0.4099	-0.2495	0.2502	3.897	-2.086	-26.9	-10.37
-0.4026	-0.2697	0.2154	3.841	-2.044	-26.72	-11.18
-0.3682	-0.1989	0.2587	3.421	-1.806	-23.33	-10.08
-0.2945	-0.00324		2.768	-1.511	-16.93	-8.173
-0.2889	0.02651		2.751	-1.383	-15.4	-8.005
-0.261	-0.1761	0.2227	2.382	-1.44	-17.98	-6.261
-0.2533	-0.04008	0.2682	2.23	-1.288	-14.82	-6.977
-0.2246	0.006989	0.2556	1.956	-1.138	-12.94	-6.789
-0.2108	-0.01785	0.1866	1.934	-1.108	-12.6	-6.118
-0.1977	-0.171	0.02843	1.737	-1.107	-14.44	-5.429
-0.1727	0.09884	0.2193	1.422	-0.7411	-8.426	-5.12
-0.1465	0.02557	0.1723	1.36	-0.6605	-7.909	-4.611
-0.123	-0.144	0.0546	1.109	-0.6099	-9.075	-4.372
-0.1173	0.07181	0.1076	1.032	-0.4629	-5.688	-4.775
-0.0858	-0.07348	-0.05846	0.7504	-0.3749	-6.875	-4.285
-0.07104	-0.05532	0.02525	0.6722	-0.3365	-4.769	-2.699
-0.05246	-0.1693	-0.1604	0.4248	-0.2951	-7.569	-4.064
-0.04871	0.05625	0.0758	0.3403	-0.1527	-1.428	-2.873
-0.02368	-0.08799	0.02907	0.2683	-0.1275	-1.676	-2.198
-0.01758	0.3645	0.3354	0.1323	0.1667	5.384	-3.033
-0.01105	-0.233	-0.0911	-0.01567	-0.1467	-2.548	-1.256
-0.003163	-0.01733	0.05863	-0.07456	-0.009961	1.001	-1.238
0.01546	-0.008425	-0.1271	-0.2341	-0.08464	-1.603	-1.336
0.03096	0.112	0.05639	-0.3375	0.1219	2.311	-1.544
0.0343	0.2122	0.1548	-0.5108	0.1963	4.86	-1.321
0.04875	0.2571	0.2554	-0.4862	0.3091	7.469	-0.8022
0.06055	0.1497	0.1821	-0.773	0.3309	6.42	-0.4315
0.08096	-0.03515	-0.01493	-0.8116	0.3065	2.913	0.05461
0.1045	0.04929	0.1173	-1.045	0.4109	6.502	0.5426
0.1114	0.1088	0.2399	-1.037	0.5147	9.193	0.7799
0.1241	0.003056	0.08288	-1.239	0.452	6.773	1.569
0.1458	0.02142	0.1879	-1.398	0.6691	9.993	2.52
0.1667	-0.1669	0.1384	-1.508	0.7664	9.635	1.739
0.194	-0.2187	0.1905	-1.807	0.9591	11.83	2.857
0.2079	-0.2324	0.293	-2.063	1.073	14.38	4.417
0.2266	-0.2682	0.2609	-1.983	1.172	14.83	2.586
0.2631	-0.362	0.3235	-2.306	1.407	16.6	2.071
0.2887	-0.5891	0.2112	-2.399	1.44	15.26	2.88
0.3276	-0.604	0.4302	-2.617	1.714	20.65	3.254
0.354	-0.7222	0.4545	-2.994	1.933	22.28	4.08
0.3897	-0.717	0.5917	-3.471	2.196	25.35	3.797
0.4113	-0.7257	0.6664	-3.587	2.376	27.06	4.93
0.4581	-0.6298	0.8067	-3.947	2.658	30.6	5.398
0.5099	-0.5233	0.9918	-4.302	2.918	34.73	7.794
0.5364	-0.53	1.048	-4.613	3.151	36.21	8.84
0.577	-0.4665	1.146	-4.768	3.452	38.45	8.748
0.5949	-0.3388	1.255	-4.693	3.648	40.85	8.345
0.642	0.1891	1.895	-5.198	4.174	53.6	9.774

Table 2B- 8 Steady state responses for Configuration 8

Configuration 8						
Lateral acceleration	Left road wheel angle	Right road wheel angle	Roll angle	Side slip angle	Hand wheel angle	Steer torque
-0.598	-0.6005	0.483	5.456	-2.105	-24.62	-9.717
-0.5596	-0.5389	0.4847	5.267	-1.854	-23.32	-10.97
-0.5169	-0.3604	0.5702	4.88	-1.495	-19.56	-9.552
-0.4568	-0.2282	0.5652	4.485	-1.091	-16.76	-8.389
-0.4077	-0.1178	0.4976	4.099	-0.834	-14.26	-7.306
-0.3663	-0.03571	0.4692	3.767	-0.6008	-12.36	-7.715
-0.3069	0.04265	0.4251	3.313	-0.3585	-9.974	-6.796
-0.2992	0.03212	0.3866	3.115	-0.3221	-10.21	-6.53
-0.2278	0.0462	0.2358	2.67	-0.02171	-8.922	-5.421
-0.1884	0.01879	0.1589	2.305	0.1083	-8.512	-4.917
-0.1315	0.05835	0.1145	1.928	0.3521	-6.67	-5.228
-0.1084	0.09436	0.09877	1.259	0.04628	-5.041	-4.025
-0.09847	0.01879	0.03059	1.144	0.1372	-6.121	-3.879
-0.08605	0.01911	-0.00136	0.4539		-2.967	-2.898
-0.04688	0.05663	0.04135	0.01262	-0.05066	-0.5319	-3.187
-0.01294	0.00288	-0.004282	0.03652	-0.04444	-0.4691	-1.612
0.02268	0.01971	0.02152	-0.5441	-0.03286	1.605	0.8963
0.05329	-0.04759	-0.04426	-0.5657	0.1413	1.533	1.831
0.07328	-0.04082	-0.04113	-0.7574	0.2487	2.451	1.713
0.1093	-0.05092	-0.03486	-0.8085	0.3935	3.503	2.673
0.1327	-0.04189	-0.01283	-0.9936	0.5237	4.888	4.069
0.1828	-0.1458	-0.08665	-1.38	0.7008	4.476	4.605
0.2362	-0.1215	-0.01367	-1.679	0.9289	7.246	5.062
0.2927	-0.1806	-0.02275	-2.132	1.192	8.646	6.305
0.3255	-0.2078	0.01829	-2.379	1.393	10.44	7.918
0.3867	-0.2531	0.1037	-2.825	1.717	12.36	8.209
0.442	-0.3189	0.117	-3.169	2.04	12.87	8.142
0.4887	-0.2952	0.2352	-3.408	2.345	15.13	8.772
0.5314	-0.3129	0.2751	-3.916	2.66	16.05	9.93
0.5653	-0.2472	0.4077	-4.073	2.973	18.72	9.442
0.612	-0.1606	0.5445	-4.335	3.323	21.33	10.79

Table 2B- 9 Steady state responses for Configuration 9

Configuration 9						
Lateral acceleration	Left road wheel angle	Right road wheel angle	Roll angle	Side slip angle	Hand wheel angle	Steer torque
-0.5903	-2.179	-0.05238	4.746	-3.372	-22.94	-9.455
-0.5289	-1.602	0.2356	4.316	-2.859	-14.53	-10.69
-0.4895	-1.219	0.3812	3.949	-2.532	-8.628	-8.834
-0.4317	-1.154	0.2803	3.744	-2.263	-9.324	-8.768
-0.4152	-0.9489	0.3367	3.452	-2.093	-7.24	-8.668
-0.3298	-0.8196	0.1899	2.917	-1.73	-8.049	-7.135
-0.2904	-0.4714	0.3442	2.481	-1.368	-3.169	-7.429
-0.2655	-0.528	0.211	2.322	-1.312	-5.258	-6.722
-0.2504	-0.5898	0.1254	2.257	-1.343	-6.362	-5.003
-0.2113	-0.4651	0.1028	1.894	-1.141	-5.16	-4.344
-0.1842	-0.2243	0.2334	1.553	-0.8679	-0.9075	-2.927
-0.1701	-0.3746	0.02353	1.404	-0.8455	-4.238	-3.504
-0.1424	-0.3991	-0.04013	1.028	-0.7647	-5.239	-2.688
-0.1207	-0.1699	0.08814	0.8618	-0.6616	-1.496	-1.522
-0.1062	-0.2336	-0.02201	0.6974	-0.5516	-3.115	-1.707
-0.09067	-0.06054	0.07715	0.4456	-0.357	-0.1276	-1.726
-0.07064	-0.02445	0.08364	0.3815	-0.3898	0.6768	-1.54
-0.06258	-0.1987	-0.1041	0.2191	-0.3609	-3.026	-0.8068
-0.05291	-0.1054	-0.01238	0.1111	-0.3202	-1.221	-0.9202
-0.04395	-0.3004	-0.2053	0.1169	-0.3344	-5.503	-0.8237
-0.01944	-0.0924	-0.05898	-0.04826	-0.1238	-1.364	-0.2018
-0.0174	-1.07E-05	0.03442	-0.03068	-0.05874	0.3923	-0.8897
0.02346	0.04585	0.1407	-0.3346	0.007925	2.378	0.3931
0.02762	-0.08387	0.001008	-0.4354	-0.02365	-0.354	0.1156
0.03992	-0.1133	-0.03888	-0.4375	0.1275	-0.7806	0.3293
0.06095	0.1289	0.2027	-0.7058	0.3299	4.414	0.5618
0.05217	-0.1574	-0.1145	-0.5714	0.1808	-1.865	0.9514
0.06937	-0.1099	-0.07564	-0.7929	0.2286	-0.9571	1.588
0.09036	0.1464	0.1908	-1.032	0.5078	4.311	1.584
0.09855	0.01171	0.02739	-1.019	0.4178	1.544	2.196
0.1338	0.1327	0.1449	-1.4	0.6836	3.943	2.1
0.1447	-0.07954	-0.08674	-1.511	0.7303	-0.5109	2.382
0.1711	-0.02108	-0.008207	-1.843	0.9555	0.7546	2.457
0.1895	-0.09407	-0.08914	-2.091	0.9694	-0.5501	3.536
0.2065	-0.1251	-0.1134	-2.234	1.143	-1.251	3.298
0.2166	-0.2954	-0.2756	-2.374	1.178	-4.685	3.719
0.2539	-0.346	-0.2941	-2.685	1.317	-5.872	4.298
0.2731	-0.3658	-0.2734	-2.95	1.537	-5.936	4.046
0.3042	-0.4909	-0.336	-3.245	1.701	-7.348	5.34
0.3201	-0.5504	-0.3447	-3.465	1.809	-8.001	4.748
0.3874	-0.649	-0.2996	-3.812	2.12	-9.109	5.806
0.4225	-0.6067	-0.09993	-4.28	2.452	-7.029	6.198
0.4709	-0.6858	-0.05344	-4.477	2.645	-7.598	7.516
0.5043	-0.7977	-0.04412	-4.718	2.777	-8.722	7.734
0.5612	-0.5832	0.4985	-5.251	3.249	-2.713	8.134

Table 2B- 10 Steady state responses for Configuration 10

Configuration 10						
Lateral acceleration	Left road wheel angle	Right road wheel angle	Roll angle	Side slip angle	Hand wheel angle	Steer torque
-0.6131	-0.5228	0.5397	5.528	-2.357	-0.4743	-10.75
-0.5849	-0.3963	0.5538	5.455	-2.149		-11.23
-0.5238	-0.1824	0.5959	5.075	-1.722	2.83	-9.607
-0.4895	-0.05546	0.5995	4.731	-1.451	3.503	-10.65
-0.4405	-0.0331	0.457	4.319	-1.17	2.627	-10.73
-0.4109	0.05955	0.4904	4.135	-0.9588	3.876	-9.002
-0.3568	0.07341	0.3714	3.241	-1.005	3.019	-8.995
-0.3298	0.09093	0.3456	3.232	-0.6286	2.86	-8.591
-0.2973	0.07427	0.2735	2.181	-1.086	2.225	-7.623
-0.2562	0.01258	0.1964	2.195	-0.7805	0.9923	-7.109
-0.2094	0.02655	0.1512	1.718	-0.6104	0.7897	-6.248
-0.1661	-0.007305	0.07271	1.071	-0.7541	0.05989	-5.058
-0.1274	-0.01268	0.03825	0.9307	-0.6207	-0.04838	-5.333
-0.08406	-0.006874	0.01977	0.4915	-0.4487	0.4453	-4.344
-0.06231	-0.04471	-0.03494	0.09488	-0.3665	-0.3797	-3.59
-0.03588			0.1107	-0.08503		-3.11
0.01464	0.0008024	-0.005799	-0.09866	0.05637	0.1063	0.9082
0.0422	0.02552	0.02458	-0.3542	0.1848	0.7821	1.336
0.06077	-0.04219	-0.05017	-0.6032	0.2021	-0.4238	1.272
0.08843	-0.02123	-0.01655	-0.6127	0.3247	0.3014	1.791
0.109	-0.04864	-0.03503	-0.9065	0.4347	-0.1531	2.314
0.1499	-0.03875	-0.01133	-1.034	0.5837	0.1829	3.18
0.1848	-0.06787	-0.0224	-1.431	0.7606	-0.1587	3.611
0.2426	-0.1468	-0.05247	-1.861	0.9383	-0.9791	5.208
0.2614	-0.1856	-0.07262	-2.049	1.046	-1.492	5.396
0.3468	-0.2725	-0.04401	-2.556	1.515	-2.08	5.723
0.3648	-0.2663	0.009968	-2.754	1.745	-1.32	5.605
0.4072	-0.308	0.05945	-3.062	2.115	-1.299	6.219
0.4675	-0.4093	0.1016	-3.565	2.447	-2.012	6.885
0.5289	-0.4951	0.1831	-3.966	2.784	-2.556	7.412
0.566	-0.4763	0.3392	-4.393	3.025	-1.095	8.111

Table 2B- 11 Steady state responses for Configuration 11

Configuration 11						
Lateral acceleration	Left road wheel angle	Right road wheel angle	Roll angle	Side slip angle	Hand wheel angle	Steer torque
-0.57	-0.4324	0.4485	5.398	-3.182	-0.427	-9.646
-0.5109	-0.3547	0.3578	5.045	-2.651	-1.094	-8.762
-0.4672	-0.2879	0.3311	4.884	-2.236	-0.7393	-8.314
-0.4192	-0.205	0.2889	4.559	-1.818	0.06144	-6.441
-0.3788	-0.107	0.2647	4.101	-1.445	0.8827	-6.765
-0.3601	-0.07182	0.2584	3.967	-1.312	1.274	-7.639
-0.3249	-0.1733	0.1221	3.792	-1.147	-0.8185	-4.914
-0.3266	-0.2458	0.01873	3.599	-1.151	-2.718	-5.421
-0.2952	-0.2111	-0.01573	3.31	-0.9299	-2.487	-5.092
-0.2655	-0.1501	-0.05847	2.973	-0.6018	-2.129	-5.662
-0.2312	-0.1507	-0.08795	2.144	-1.096	-2.63	-3.409
-0.2008	-0.1191	-0.09113	1.545	-0.9932	-1.399	-3.63
-0.1863	-0.005808	0.02	1.395	-0.8504	0.8417	-3.152
-0.1536	0.05988	0.06889	0.9637	-0.6501	1.892	-2.532
-0.1278	0.09017	0.08703	0.7876	-0.5226	2.356	-3.257
-0.09552		-0.2778	0.4572	-0.6073	-4.96	-1.268
-0.0725	0.1043	0.09965	0.2416	-0.2246	3.094	-1.148
-0.05465	0.03127	0.02234	0.1293	-0.1538	1.146	-2.07
-0.03953	-0.05834	-0.04299	0.1529	-0.1487	-0.441	-1.349
-0.02681	0.1102	0.09975	0.123	0.05614	3.014	-1.133
-0.0166		-0.08477	-0.2329	-0.08533	-1.256	-0.4718
0.002332	0.01646	-0.03892	-0.05373	0.04124	-1.197	0.03167
0.0174		0.1779	-0.163	0.2901	2.806	-0.7468
0.02295	0.1225	0.06097	-0.231	0.2475	1.346	0.8958
0.0327	0.1266	0.07466	-0.147	0.3078	1.314	0.1521
0.05877	0.09781	0.06309	-0.3719	0.4125	0.6438	0.1572
0.06689	0.1148	0.08261	-0.6503	0.4446	0.8358	0.3941
0.09158	0.1481	0.1403	-0.6126	0.5254	1.741	1.127
0.1136	0.1112	0.09088	-1.032	0.6652	0.9057	1.585
0.1504	0.01155	0.0492	-1.297	0.8786	-1.164	1.618
0.186		0.3041	-2.23	0.5482	3.685	1.319
0.1895		0.3606	-2.446	0.5927	5.031	1.696
0.2265	0.1733	0.3293	-2.642	0.6838	3.598	2.193
0.2324	0.07233	0.2591	-2.974	0.7198	2.138	2.709
0.2911	0.048	0.314	-3.244	1.075	2.369	4.046
0.3135	0.08079	0.4238	-3.573	1.324	3.781	4.599
0.3322	-0.02271	0.3887	-3.837	1.456	2.49	5.208
0.3648	-0.07754	0.3843	-4.105	1.67	1.827	6.131
0.3862	-0.07326	0.4667	-4.196	1.895	2.93	5.755
0.4242	-0.1184	0.5693	-4.794	2.321	3.038	5.298
0.4624	-0.1635	0.6241	-4.946	2.647	2.933	5.562
0.5011	-0.1826	0.7619	-5.296	3.061	3.479	6.317
0.546	-0.2039	0.9442	-5.597	3.543	4.491	7.091

Table 2B- 12 Steady state responses for Configuration 12

Configuration 12						
Lateral acceleration	Left road wheel angle	Right road wheel angle	Roll angle	Side slip angle	Hand wheel angle	Steer torque
-0.6513	0.5738	1.623	5.836	-3.825	20.82	-8.787
-0.5814	0.701	1.544	5.431	-3.027	20.89	-8.217
-0.5286	0.6686	1.355	5.119	-2.558	18.91	-7.408
-0.4512	0.6695	1.153	4.583	-1.874	16.66	-7.949
-0.4072	0.4922	0.9006	4.2	-1.649	12.87	-6.264
-0.3668	0.4069	0.7184	3.918	-1.387	10.44	-6.133
-0.308	0.4026	0.6286	3.49	-0.9907	9.371	-5.581
-0.28	0.3216	0.4988	3.216	-0.7677	6.883	-4.802
-0.2272	0.3021	0.3727	2.356	-0.7249	6.823	-4.382
-0.1782	0.2388	0.2612	1.452	-0.858	5.099	-3.848
-0.1188	0.3108	0.2643	1.299	-0.2528	6.244	-3.343
-0.1098	0.1805	0.1365	0.6868	-0.7045	4.288	-1.657
-0.06894	0.07092	0.0004585	0.3423	-0.4215	2.087	-1.479
-0.04017	0.06545	-0.01728	0.1247	-0.3024	2.004	-1.414
0.003585	0.01678	0.00387	-0.344	0.001542	1.22	1.048
0.0207	0.0009113	0.009503	-0.3813	0.05821	2.118	0.5378
0.04527	0.01807	0.01816	-0.5839	0.1968	2.677	1.46
0.08554	-0.02032	-0.0267	-0.9069	0.2208	1.99	2.821
0.1203	-0.06773	-0.04528	-1.194	0.5041	1.645	2.807
0.1672	-0.1699	-0.1267	-1.73	0.6722	0.2421	3.919
0.2182	-0.1877	-0.1126	-2.096	0.8944	0.4092	4.664
0.2535	-0.3528	-0.223	-2.289	1.055	-1.994	5.611
0.3059	-0.462	-0.2494	-2.673	1.509	-3.179	5.997
0.3304	-0.5244	-0.2855	-2.787	1.68	-4.069	6.465
0.3687	-0.6328	-0.3074	-3.248	2.007	-5.361	7.432
0.4018	-0.8315	-0.4319	-3.694	2.244	-8.63	7.692
0.4609	-0.9754	-0.4617	-3.907	2.713	-10.3	7.436
0.5063	-1.19	-0.5322	-4.301	3.118	-13.12	8.633
0.5489	-1.268	-0.4807	-4.636	3.566	-13.54	8.048
0.5857	-1.307	-0.3719	-4.955	4.052	-13.01	8.642

Table 2B- 13 Steady state responses for Configuration 13

Configuration 13						
Lateral acceleration	Left road wheel angle	Right road wheel angle	Roll angle	Side slip angle	Hand wheel angle	Steer torque
-0.7585	-1.255	0.1603	6.763	-4.988	-2.45	-9.232
-0.7189	-0.7438	0.5754	6.384	-4.327	4.967	-9.978
-0.6137	-0.3236	0.7433	5.561	-3.258	7.921	-10.09
-0.5823	-0.1715	0.792	5.233	-2.941	9.305	-9.676
-0.5268	-0.03279	0.7941	5.092	-2.526	9.131	-9.538
-0.4954	-0.002371	0.716	4.64	-2.27	8.048	-8.938
-0.4467	0.01353	0.5796	4.422	-1.995	6.112	-8.591
-0.4042	0.07866	0.5362	4.015	-1.754	5.625	-7.841
-0.3552	0.1715	0.4797	3.599	-1.541	5.364	-7.332
-0.3072	0.1002	0.2925	3.123	-1.322	3.2	-6.302
-0.2457	0.06082	0.1459	2.561	-1.096	1.583	-5.713
-0.1882	0.1264	0.1169	1.988	-0.6988	2.326	-4.043
-0.1563	0.1025	0.0799	1.6	-0.5534	1.778	-4.002
-0.1302	0.07673	0.06131	1.556	-0.4646	1.257	-3.429
-0.09724	0.03782	0.01662	1.281	-0.3284	0.5523	-2.792
-0.06952	0.06157	0.01359	0.9776	-0.1671	1.004	-2.724
-0.04727	0.07544	0.01808	0.744	-0.06216	1.23	-1.911
-0.02202	-0.0589	-0.1298	0.4632	-0.03429	-1.352	-0.5322
0.01531	0.02097	0.05873	0.2445	0.04356	0.3805	0.2094
0.04639	-0.03609	0.009449	-0.1963	0.1328	-0.3066	1.106
0.06973	-0.07887	-0.03827	-0.2324	0.1777	-1.107	1.346
0.09021	-0.08478	-0.04683	-0.5351	0.1903	-1.103	1.872
0.1205	-0.03083	0.03378	-0.6861	0.3901	0.2423	2.532
0.1526	-0.07736	0.01906	-0.9675	0.5423	-0.4	2.903
0.1811	-0.08155	0.04976	-1.784	0.2694	-0.7071	4.273
0.2376	-0.2449	-0.03795	-1.447	1.005	-2.289	5.643
0.3044	-0.295	-0.0012	-2.145	1.269	-2.647	5.615
0.3482	-0.3271	0.1366	-3.125	1.213	-2.012	6.837
0.3913	-0.4582	0.1284	-3.762	1.28	-3.667	7.704
0.4326	-0.6623	0.0863	-4.001	1.649	-6.433	7.52
0.4813	-0.6616	0.2367	-4.531	1.94	-5.606	7.696
0.5469	-0.7308	0.4505	-5.013	2.515	-5.723	7.642
0.5769	-0.7491	0.5455	-5.269	2.775	-5.432	8.772

Table 2B- 14 Steady state responses for Configuration 14

Configuration 14						
Lateral acceleration	Left road wheel angle	Right road wheel angle	Roll angle	Side slip angle	Hand wheel angle	Steer torque
-0.4764	-1.206	-0.4917	4.049	-1.579	-21.55	-10.47
-0.4376	-1.134	-0.4801	3.828	-1.501	-20.32	-8.176
-0.4324	-0.9777	-0.3326	3.848	-1.33	-16.87	-9.004
-0.4519	-1.148	-0.4769	3.894	-1.456	-19.73	-7.798
-0.3922	-0.8854	-0.359	3.429	-1.102	-15.74	-6.845
-0.3179	-0.642	-0.2661	2.792	-0.7334	-11.61	-6.781
-0.2991	-0.7742	-0.4073	2.688	-0.7822	-14.21	-5.094
-0.2741	-0.5624	-0.2407	2.451	-0.548	-10.23	-5.965
-0.2513	-0.5577	-0.2865	2.403	-0.5258	-10.77	-5.583
-0.2365	-0.6103	-0.3628	2.122	-0.6231	-11.97	-3.975
-0.2027	-0.4143	-0.1999	1.911	-0.369	-8.118	-3.899
-0.191	-0.2696	-0.08963	1.623	-0.3435	-5.481	-3.727
-0.1938	-0.3739	-0.2051	1.676	-0.3865	-7.781	-4.069
-0.1965	-0.5192	-0.3334	1.741	-0.4476	-10.69	-5.138
-0.1791	-0.3983	-0.2562	1.665	-0.3116	-8.215	-3.706
-0.1672	-0.1814	-0.06291	1.429	-0.258	-4.386	-4.412
-0.137	-0.1597	-0.09366	1.124	-0.3795	-3.201	-3.475
-0.1235	-0.03805	-0.001298	0.8978	-0.3345	-0.1339	-3.864
-0.08852	-0.2031	-0.2012	0.6986	-0.3705	-3.218	-3.005
-0.06906	0.0215	-0.02855	0.6005	-0.1213	1.862	-1.583
-0.07209	-0.1831	-0.2407	0.2762	-0.2202	-3.001	-1.93
-0.06901	-0.4241	-0.4737	0.5676	-0.3203	-8.529	-2.18
-0.05511	-0.1131	-0.1957	0.4284	-0.1586	-1.263	-1.235
-0.03591	-0.003785	-0.1189	0.119	0.009326	0.8839	-1.882
-0.02592	-0.2735	-0.3734	-0.1604	-0.1195	-4.064	-0.773
-0.04548	0.2445	0.1127	0.2961	0.1593	5.552	-1.91
-0.01739	-0.1828	-0.3276	0.08216	-0.04634	-3.316	-2.058
0.02428	0.1481	0.1237	0.03215	0.3914	2.391	0.9255
0.02877	0.0272	-0.003563	0.02689	0.3277	0.193	2.023
0.04169	0.07735	0.03949	0.0413	0.3965	0.9654	1.548
0.05932	0.2677	0.2291	-0.2137	0.5577	4.908	1.786
0.06491	0.2545	0.2286	-0.1007	0.4393	4.772	2.189
0.07075	0.3137	0.2752	-0.6981	0.1364	6.457	2.27
0.08684	0.3211	0.2907	-0.8307	0.1472	7.747	2.081
0.08874	0.3236	0.2772	-0.989	0.07823	7.807	3.483
0.1148	0.33	0.3094	-1.022	0.2123	7.903	3.174
0.1437	0.1783	0.1718	-1.248	0.2561	5.486	3.138
0.1611	0.1937	0.196	-1.32	0.3796	5.872	2.998
0.1823	0.4015	0.4356	-1.581	0.5696	10.34	3.975
0.1955	0.2634	0.2894	-1.705	0.5527	7.565	3.873
0.2258	0.2764	0.3206	-1.869	0.6328	8.117	5.139
0.2429	0.3328	0.3884	-2.041	0.7434	9.278	4.787
0.2892	0.4813	0.5833	-2.317	1.074	12.62	5.425
0.2915	0.3896	0.4916	-2.353	1.039	11.02	5.995
0.3269	0.463	0.6272	-2.633	1.325	13.23	6.349
0.3436	0.416	0.5976	-2.77	1.435	12.7	6.364
0.3667	0.4799	0.6952	-2.883	1.561	14.49	6.13
0.4289	0.4913	0.8566	-3.342	1.927	16.21	8.338
0.4479	0.6159	1.024	-3.605	2.118	19.15	9.525
0.4881	0.5765	1.115	-3.914	2.301	19.59	7.27
0.5372	0.7237	1.386	-4.131	2.522	23.92	10.91
0.5367	0.6685	1.382	-4.107	2.594	23.46	9.408

Table 2B- 15 Steady state responses for Configuration 15

Configuration 15						
Lateral acceleration	Left road wheel angle	Right road wheel angle	Roll angle	Side slip angle	Hand wheel angle	Steer torque
-0.6879	-0.7731	0.9392	8.708	-3.5	13.2	-6.972
-0.5744	-0.2373	1.194	7.887		17.06	-8.214
-0.4809	0.07588	1.228	7.245	-0.8777	16.96	-9.692
-0.3976	0.07599	0.959	6.533	-0.2143	12.39	-9.974
-0.3693	0.05923	0.8627	5.693	-0.5491	11.37	-8.368
-0.3242	0.06664	0.6824	3.893	-1.005	9.922	-6.296
-0.2946	0.008426	0.4964	2.846	-1.234	7.266	-5.887
-0.2437	-0.009941	0.3577	2.277	-1.052	5.85	-4.801
-0.2059	-0.09619	0.1815	1.548	-0.8775	3.048	-4.206
-0.1686	-0.1335	0.09804	1.04	-0.8508	1.991	-3.676
-0.1387	-0.1452	0.02613	0.7145	-0.7024	1.3	-3.131
-0.1056	-0.1703	-0.00747	0.3779	-0.5748	0.6423	-2.738
-0.08024	-0.1961	-0.02302	-0.007325	-0.4501	-0.0634	-1.889
-0.05821	-0.1787	-0.02385	-0.02492	-0.2954	-0.0886	-1.552
-0.01808	-0.1752	-0.0393	-0.3676	-0.007678	-0.07179	-1.129
0.01742	-0.1905	0.002734	-0.1804	0.0715	-4.927	0.3592
0.05686	-0.003632	0.1929	-0.5899	0.2932	-1.174	0.08618
0.07761	-0.05153	0.137	-0.956	0.2993	-2.527	0.993
0.1266	-0.07731	0.1288	-1.23	0.5636	-3.195	2.063
0.1816	-0.2075	0.03936	-1.75	0.9283	-5.258	2.725
0.2444	-0.2971	0.03446	-2.078	1.278	-6.555	4.427
0.3043	-0.4665	0.021	-2.957	1.64	-9.043	4.52
0.3616	-0.6093	-0.06238	-3.249	2.062	-11.27	4.712
0.4218	-0.8326	-0.08263	-3.973	2.56	-14.7	4.495
0.4992	-0.9962	0.04896	-4.694	3.322	-16.06	6.766
0.579	-1.23	0.04876	-5.386	4.115	-20.42	6.882
0.6404	-1.4	0.08695	-5.943	4.892	-24.05	7.033
0.7346	-1.304	0.5845	-7.186	6.908	-24.46	8.274

Table 2B- 16 Steady state responses for Configuration 16

Configuration 16						
Lateral acceleration	Left road wheel angle	Right road wheel angle	Roll angle	Side slip angle	Hand wheel angle	Steer torque
-0.588	-1.125	0.3593	4.334	-3.869	-15.64	-8.127
-0.5454	-0.7032	0.6377	4.029	-3.373	-7.578	-8.526
-0.5134	-0.6484	0.6034	3.754	-3.281	-7.347	-7.589
-0.4649	-0.3123	0.7651	3.483	-2.743	-1.479	-7.943
-0.4251	-0.1176	0.8003	2.9	-2.354	1.492	-7.272
-0.3934	-0.2731	0.5488	2.741	-2.377	-2.075	-5.593
-0.3617	-0.1375	0.5971	2.501	-2.001	0.08824	-5.577
-0.2955	-0.2138	0.3631	1.947	-1.663	-2.577	-5.377
-0.2621	-0.09252	0.4179	1.735	-1.346	-0.3946	-5.092
-0.2345	-0.07602	0.3459	1.519	-1.233	-0.6606	-4.122
-0.1889	-0.004255	0.3321	1.172	-0.9452	0.7239	-3.297
-0.1914	-0.1074	0.2362	1.259	-0.9756	-1.523	-3.366
-0.1663	0.03699	0.2986	1.025	-0.7704	0.9061	-3.395
-0.1508	-0.00601	0.215	0.9116	-0.7339	0.5366	-2.758
-0.1306	-0.01591	0.1605	0.7943	-0.6587	0.3051	-2.344
-0.09283	0.06401	0.1424	0.5715	-0.4871	1.074	-1.132
-0.09082	-0.1625	-0.06896	0.4378	-0.4865	-3.518	-1.087
-0.06626	0.03555	0.05867	0.2555	-0.3887	0.1671	-0.702
-0.0582	0.05885	0.06454	0.1936	-0.2511	0.7337	-0.9739
-0.04845	-0.1362	-0.1141	0.07216	-0.3428	-3.366	-0.137
-0.02777	0.1436	0.1314	0.09434	-0.06881	2.108	-0.05736
-0.01369	-0.07365	-0.08541	-0.08632	-0.04451	-2.237	-0.09965
0.01969	-0.1226	-0.1908	-0.1828	0.04625	-3.761	0.1268
0.03101	0.2182	0.1498	-0.1567	0.2646	3.216	1.087
0.04538	0.262	0.1868	-0.2749	0.4317	4.197	0.7939
0.04233	0.05884	-0.02616	-0.2558	0.2965	0.5309	1.997
0.06126	0.1227	0.04961	-0.5557	0.5016	1.142	1.228
0.08216	-0.05469	-0.16	-0.5728	0.3756	-2.144	2.261
0.08932	0.04255	-0.03684	-0.6995	0.4731	-0.1589	2.06
0.1044	0.09668	0.01419	-0.7686	0.6563	0.8562	1.518
0.1304	0.0443	-0.05026	-0.9571	0.7598	-0.2228	2.189
0.1565	0.02399	-0.07897	-1.119	0.9423	-0.5431	2.816
0.1676	-0.0518	-0.1636	-1.365	1.104	-2.031	2.209
0.1993	-0.07665	-0.1887	-1.46	1.208	-2.568	3.22
0.2301	-0.1172	-0.211	-1.708	1.383	-3.199	4.212
0.2598	-0.1745	-0.2366	-2.047	1.604	-4.165	4.065
0.285	-0.329	-0.3644	-2.461	1.609	-7.377	4.067
0.3358	-0.3611	-0.3864	-2.831	1.79	-8.077	4.697
0.3617	-0.5458	-0.5364	-3.111	2.001	-11.19	5.303
0.3875	-0.5428	-0.4922	-3.373	2.175	-10.98	6.032
0.446	-0.5088	-0.3598	-3.575	2.723	-9.146	5.589
0.5031	-0.5987	-0.3398	-4.079	3.041	-9.87	7.53
0.5696	-0.4104	0.04531	-4.541	3.553	-4.258	8.301

Table 2B- 17 *d(hand wheel)/d(lateral acceleration)* values at various lateral accelerations

	Lateral Acceleration (g)									
Config.	-0.5	-0.4	-0.3	-0.2	-0.1	0.1	0.2	0.3	0.4	0.5
1	-0.6879	-0.3338	0.02776	0.2697	0.4577	0.797	0.1884	-0.2054	-0.452	-0.6229
2	2.18	1.519	1.149	0.9837	0.9206	0.8792	0.8981	1.006	1.3	1.868
3		0.4992	0.5595	0.5238	0.4692	0.4513	0.4851	0.4948	0.401	
4	2.617	1.921	1.69	1.646	1.586	1.167	0.9647	1.029	1.686	3.484
5	1.52	1.364	1.28	1.219	1.156	0.9875	0.9048	0.8795	0.9629	1.228
6	0.08457	0.1143	0.1743	0.2328	0.2678	0.2228	0.1484	0.05856	-0.02034	-0.05254
7	2.467	1.579	1.21	1.162	1.224	1.255	1.176	1.127	1.256	1.805
8	1.332	0.8216	0.3624	0.5088	1.018	0.4786	0.6155	0.634	0.5614	0.6933
9	1.339	0.4117	0.2518	0.3739	0.4465	-0.1204	-0.6446	-0.9129	-0.4905	1.241
10	0.1871	-0.1904	-0.2566	-0.1765	-0.0749	-0.02281	-0.09653	-0.1732	-0.1483	0.1011
11	-0.08995	-0.01482	0.04582	0.09199	0.1237	0.1439	0.133	0.1075	0.06767	0.01331
12	-0.9241	-1.046	-0.6818	-0.2456	-0.5928	-0.2797	-0.4907	-0.7287	-1.042	-0.7092
13	-0.3755	-0.5116	-0.4328	-0.2689	-0.1265	-0.1105	-0.2277	-0.3481	-0.3558	-0.09014
14		0.9411	0.8792	0.9019	0.9111	0.7427	0.6151	0.5849	0.7935	
15	-0.5888	-0.9213	-0.9039	-0.721	-0.5127	-0.358	-0.4698	-0.6726	-0.8845	-0.9794
16	1.389	0.2205	-0.07482	0.01681	0.1195	-0.2505	-0.652	-0.9018	-0.536	0.9935

Table 2B- 18 *d(road wheel angle)/d(lateral acceleration)* values at various lateral accelerations

	Lateral Acceleration (g)									
Config.	-0.5	-0.4	-0.3	-0.2	-0.1	0.1	0.2	0.3	0.4	0.5
1	-0.836	-1.018	-0.9896	-0.805	-0.6372	-0.06963	-0.6884	-0.9075	-0.9748	-0.9841
2	0.1756	0.1447	0.2586	0.245	-0.2636	-0.02372	-0.5314	-0.3468	-0.1106	0.5481
3		-0.1435	-0.4353	-0.4108	-0.2709	-0.09877	-0.1158	-0.1265	0.01461	
4	1.939	1.021	0.658	0.5686	0.5236	0.2652	0.1725	0.3489	1.105	2.98
5	1.473	0.7704	0.3268	0.05404	-0.07616	-0.08698	0.03411	0.2603	0.6446	1.256
6	-0.1832	-0.6654	-0.7863	-0.7152	-0.5808	-0.4373	-0.4876	-0.5842	-0.6518	-0.5752
7	0.8087	0.2777	-0.01114	-0.1524	-0.2339	-0.3647	-0.3487	-0.1754	0.3234	1.345
8	0.5641	0.03109	-0.1979	-0.2678	-0.2539	-0.1656	-0.1192	-0.03605	0.1299	0.49
9	1.557	0.4951	0.2469	0.3159	0.3614	-0.1911	-0.6725	-0.8716	-0.3429	1.544
10	0.2572	-0.07382	-0.267	-0.349	-0.3487	-0.2016	-0.1061	-0.03172	-0.00515	-0.04779
11	-0.2749	-0.1143	0.01761	0.1209	0.1955	0.2587	0.249	0.2107	0.1438	0.04817
12	-1.041	-1.169	-0.8328	-0.485	-0.8668	-0.47	-0.6328	-0.8731	-1.138	-0.6998
13	-0.08389	-0.3893	-0.4367	-0.3501	-0.2434	-0.1939	-0.2478	-0.2751	-0.1589	0.264
14		0.8955	0.6671	0.6333	0.6556	0.6153	0.5605	0.5853	0.8196	
15	-0.2646	-0.8533	-0.9041	-0.6929	-0.4272	-0.2191	-0.3485	-0.5673	-0.7399	-0.6622
16	1.207	-0.09564	-0.3791	-0.205	-0.00425	-0.2542	-0.6514	-0.9175	-0.5496	1.053

Table 2B- 19 *d(front slip angle)/d(lateral acceleration)* values at various lateral accelerations

	Lateral Acceleration (g)									
Config.	-0.5	-0.4	-0.3	-0.2	-0.1	0.1	0.2	0.3	0.4	0.5
1	4.41	1.865	1.93	3.114	4.349	5.613	5.588	5.574	6.152	7.986
2	9.749	7.669	6.485	5.876	5.53	5.064	5.138	5.811	7.606	10.92
3		1.345	-1.184	0.9653	3.066	3.549	3.928	5.825	8.52	
4	10.57	7.239	5.239	4.2	3.637	3.485	4.154	5.797	9.012	14.96
5	13.06	10.48	7.081	3.351	0.4131	2.967	4.564	7.206	10.24	13.16
6	6.295	6.867	3.216	-0.4448	-0.4074	5.33	4.004	5.041	6.851	7.665
7	8.976	5.603	4.502	4.691	5.198	5.521	5.291	5.39	6.718	10.59
8	7.391	5.505	4.216	0.9526	-2.412	4.01	3.529	4.736	6.75	9.086
9	10.81	7.126	5.645	5.294	5.305	4.834	4.356	4.323	5.506	9.008
10	7.003	2.852	-0.2659	-0.1077	4.869	3.076	4.382	5.483	6.48	7.238
11	10.58	7.293	2.387	2.655	5.752	1.847	2.406	7.191	10.73	11.17
12	6.517	4.296	1.998	0.1451	0.8208	2.106	3.953	5.618	5.582	7.594
13	5.812	3.921	3.841	4.215	3.272	3.569	3.846	2.798	3.914	8.571
14		6.498	5.962	4.414	2.378	0.604	5.824	9.128	7.816	
15	3.005	-2.147	-2.244	0.1845	3.233	6.705	6.452	5.468	4.978	6.839
16	11.21	7.527	5.495	4.588	4.143	3.646	3.617	4.149	5.745	9.165

Table 2B- 20 *d(sideslip angle)/d(lateral acceleration)* values at various lateral accelerations

Config.	-0.5	-0.4	-0.3	-0.2	-0.1	0.1	0.2	0.3	0.4	0.5
1	6.732	4.476	4.151	4.611	5.194	6.011	6.363	7.08	8.391	10.62
2	8.891	7.078	5.926	5.326	5.096	5.282	5.663	6.369	7.544	9.278
3		0.9969	-0.6171	2.544	5.057	4.686	4.435	5.927	8.248	
4	5.28	5.044	3.921	2.723	1.884	2.291	3.524	5.112	6.575	7.246
5	9.491	8.776	6.102	2.783	0.7424	3.082	4.602	6.739	8.727	9.819
6	6.614	8.155	4.932	1.374	1.479	5.602	5.584	6.726	8.107	8.755
7	8.074	6.296	5.258	4.821	4.754	5.152	5.496	5.921	6.575	7.591
8	5.628	5.77	5.063	1.318	-2.063	4.412	4.21	5.026	6.066	7.198
9	6.911	5.492	4.878	4.793	5.024	5.673	5.896	5.97	5.931	5.846
10	6.366	3.411	0.9081	0.8238	4.563	3.553	4.401	6.15	7.29	6.106
11	10.96	8.003	2.673	2.098	5.565	0.9908	2.383	7.199	10.1	10.15
12	8.268	6.767	4.357	1.714	2.43	3.496	5.592	7.432	7.983	9.456
13	6.285	4.978	4.752	4.97	4.505	3.913	4.434	3.64	4.448	7.98
14		4.909	3.867	2.853	2.215	2.975	4.236	5.614	6.45	
15	3.893	0.1477	-0.1468	1.375	3.476	6.442	6.815	6.778	7.076	8.85
16	8.399	6.738	5.993	5.798	5.788	5.696	5.6	5.668	6.2	7.605

Table 2B- 21 *d(hand wheel torque)/d(lateral acceleration)* values at various lateral accelerations

	Lateral Acceleration (g)									
Config.	-0.5	-0.4	-0.3	-0.2	-0.1	0.1	0.2	0.3	0.4	0.5
1	7.305	9.695	13.89	18.77	22.45	24.34	21.96	17.27	11.61	5.668
2	12.39	11.9	14.99	18.98	21.72	20.53	16.78	11.95	8.398	8.894
3		21.13	16.26	15.09	15.52	15.72	14.15	11.47	8.39	
4	25.53	10.84	11.22	17.79	24.21	23.94	17.07	9.69	7.659	20.38
5	15.75	13.68	15.88	19.77	22.78	22.55	18.84	14.25	10.45	10.02
6	23.19	5.214	5.572	14.03	23.07	26.06	18.53	8.856	3.201	10.46
7	11.34	16.41	20.37	22.46	22.68	18.76	15.96	14.14	14.46	18.89
8	12.07	6.774	10.91	18.44	25.75	28.4	23.38	15.66	9.485	9.332
9	6.572	18.42	22.96	23.04	20.77	16	14.86	14.59	14.31	12.62
10	4.655	13.53	19.86	23.82	25.57	23.58	20.05	15.07	8.837	1.979
11	14.55	16.25	18.39	16.47	13.44	4.611	20.2	22.56	3.299	12.72
12	7.182	9.12	13.61	18.12	21.52	21.98	18.84	14.16	9.111	5.357
13	8.4	12.85	17.04	20.34	22.49	22.59	20.25	16.18	10.34	2.726
14		21.58	12.43	15.7	22.3	24.36	17.97	11.13	11.44	
15	-8.159	19.66	30.06	18.73	10.96	19.25	15.94	9.049	6.019	8.798
16	8.55	12.77	16.52	18.63	19.03	15.36	12.63	10.78	11.77	17.49

Appendix 2C Steady State Circular Test Summary Statistics

		Summary Statistics				
Metric	Lateral Accel.	Minimum	Maximum	Mean	Median	Standard Deviation
d(HandWheel)/d(Latac), (deg/g)	0.1	-0.4362	1.3764	0.418	0.3528	0.5744
	0.2	-0.5954	1.3054	0.3146	0.2098	0.602
	0.3	-0.7883	1.3596	0.2268	0.0966	0.7058
	0.4	-1.044	1.8033	0.296	0.0367	0.854
	0.5	-0.8166	3.0502	0.6936	0.5783	1.2093
d(Steer Torque)/d(Latac), (Nm/g)	0.1	9.0281	27.072	20.6968	22.1449	4.5877
	0.2	14.6197	21.9375	18.3622	18.4074	1.9874
	0.3	7.2139	20.4741	14.899	14.4754	3.4653
	0.4	4.2076	16.5093	11.5183	11.3888	3.2505
	0.5	0.3197	22.9565	10.5232	10.6705	5.9017
d(RoadWheel)/d(Latac), (deg/g)	0.1	-0.6684	0.6354	-0.1284	-0.1973	0.3291
	0.2	-0.7467	0.5969	-0.2009	-0.239	0.359
	0.3	-0.9486	0.6262	-0.2304	-0.2151	0.4693
	0.4	-1.1535	1.0629	-0.0743	-0.0124	0.6302
	0.5	-0.9101	2.4594	0.4235	0.2333	0.9855
d(Front Slip)/d(Latac), (deg/g)	0.1	0.7991	5.3597	3.471	3.68	1.5019
	0.2	1.7797	5.507	3.5976	3.994	1.2411
	0.3	1.612	7.5449	4.495	4.6325	1.6304
	0.4	1.4156	10.3598	6.142	6.2382	2.1749
	0.5	4.9221	13.1109	8.9057	9.0112	2.463
d(Side Slip)/d(Latac), (deg/g)	0.1	1.1746	5.7421	3.9052	4.1333	1.4401
	0.2	2.2407	5.6988	4.0362	3.6727	1.1324
	0.3	2.6551	6.4205	4.9803	5.2345	1.0914
	0.4	3.612	9.0533	6.336	6.1759	1.4999
	0.5	6.2357	10.5547	7.796	7.7581	1.4107

Appendix 2D Repeatability of Steady State Results

Table 2D- 1

First Test							Second Test					
Lateral acceleration (g)	Hand wheel angle (deg)	Mean road wheel angle (deg)	Side slip angle (deg)	Roll angle (deg)	Steer Torque (Nm)		Lateral acceleration (g)	Hand wheel angle (deg)	Mean road wheel angle (deg)	Side slip angle (deg)	Roll angle (deg)	Steer Torque (Nm)
-0.7096	-21.8694	-6.2395	-5.4114	3.9375	-0.8851		-0.7709	-40.0988	-8.1327	-5.7975	4.6947	-2.2482
-0.671	-13.7967	-5.4315	-4.9814	3.551	-0.5104		-0.7737	-47.793	-8.3834	-5.7032	4.5823	-2.6072
-0.662	-16.1971	-5.5742	-4.9574	3.5059	-0.6305		-0.765	-35.0568	-7.6071	-5.7555	4.5597	-1.8978
-0.5858	-5.4524	-4.4326	-4.332	2.8582	-0.1473		-0.7295	-26.801	-6.5106	-5.297	4.0138	-1.2561
-0.5024	0.078	-3.6208	-3.7025	2.3627	0.1393		-0.6775	-16.1706	-5.8302	-5.0251	3.5107	-0.7249
-0.4431	1.4407	-3.2184	-3.2818	2.0977	0.1454		-0.6304	-9.2867	-4.8602	-4.5284	3.2051	-0.372
-0.3483	3.8397	-2.3837	-2.5126	1.5769	0.2118		-0.5898	-4.6201	-4.5642	-4.2583	2.7655	-0.2242
-0.2596			-2.066	1.1126			-0.5215	-0.1915	-3.7734	-3.7193	2.3568	0.0341
-0.2263	1.9748	-1.6235	-1.6265	1.0586	0.0794		-0.4535	2.7568	-3.2453	-3.3768	2.0498	0.204
-0.2037	1.1416	-1.3802	-1.4741	0.8676	0.035		-0.4379	2.2791	-3.0874	-3.1619	1.9472	0.1566
-0.1602	1.9992	-1.0613	-1.1587	0.6368	0.0719		-0.3826	3.9532	-2.668	-2.7334	1.6154	0.153
-0.1328	0.4931	-0.9163	-0.9384	0.5598	-0.007		-0.323	3.9303	-2.0573	-2.1596	1.3767	0.1378
-0.0939	0.548	-0.6701	-0.6622	0.4042	0.0496		-0.2618	3.4343	-1.7257	-1.8228	1.0964	0.1007
-0.0723	3.2445	-0.4384	-0.5458	0.2005	0.1822		-0.176	-1.9969	-1.1133	-1.3036	0.7108	0.0337
-0.0606		-0.1887	-0.3381	0.148			-0.1274	-0.5914	-0.7756	-1.0046	0.4337	0.1077
-0.0495	1.604	-0.3069	-0.32	0.1702	0.0957		-0.1021	-0.3946	-0.7799	-0.9937	0.3305	0.1019
-0.0347	0.0551	-0.0805	-0.1591	0.1109	0.0209		-0.0907	-0.3458	-0.4567	-0.6745	0.2698	0.0986
-0.0163	1.3599	-0.1727	-0.1888	-0.0116	0.0581		-0.057	0.431	-0.1671	-0.5145	0.1642	0.1098
-0.013	-0.743	-0.0331	-0.0185	0.0484	-0.0119		-0.0305	0.1182	-0.1302	-0.3515	0.0595	0.0874
0.0084	0.0245	0.0003	-0.0092	-0.0184	0.0497		-0.0317	-2.5799	-0.2641	-0.3466	0.1822	-0.0387
0.0083	0.0687	0.1613	0.0829	-0.0374	0.0492		-0.0074	-0.5884	0.1144	-0.1604	-0.0064	0.0368
0.0184	-0.6043	-0.0563	0.0164	-0.0434	0.0067		-0.0044	0.6935	0.2174	-0.0843	-0.0888	0.0922
0.0236	-0.9583	0.0571	0.0449	-0.0962	-0.0032		0.0134	NaN	NaN	-0.0375	NaN	NaN
0.045	1.2316	0.429	0.3017	-0.2664	0.0964		0.0138	NaN	NaN	0.0022	NaN	NaN
0.0585	-1.3917	0.3066	0.2975	-0.1836	-0.0345		0.0335	NaN	NaN	0.2041	NaN	NaN
0.0758		0.158	0.3584	-0.1955	-0.1544		-0.053	-5.6632	-0.2144	-0.1728	0.1832	-0.0642
0.081	-3.2993	0.3592	0.4807	-0.2751	-0.1256		-0.042	-4.1311	-0.4491	-0.3507	0.0505	0.0034
0.1156	-2.3546	0.5689	0.6045	-0.4415	-0.0862		-0.02	-4.5798	-0.2371	-0.1294	0.0271	-0.0006
0.1203	-2.666	0.6276	0.7546	-0.5299	-0.1018		-0.0072	-3.0171	0.118	0.0426	-0.0925	0.0546
0.1527	-3.8486	0.8379	0.9433	-0.6895	-0.1666		-0.0015	-3.5467	-0.0065	0.0912	-0.1463	0.0124
0.1828	-3.4442	1.0428	1.2362	-0.8892	-0.1489		0.0204	-2.2419	0.1617	0.1419	-0.2558	0.0199
0.217	-2.8048	1.4371	1.5001	-1.0821	-0.1153		0.0225	-3.5711	0.2185	0.251	-0.2168	-0.031
0.273	-3.7204	1.6386	1.8063	-1.3773	-0.2067		0.0445	-3.2094	0.2251	0.302	-0.3376	0.0076
0.356	-5.573	2.2219	2.4414	-1.713	-0.1714		0.073	-2.5547	0.4784	0.5216	-0.4689	0.0423
0.3727	-6.4429	2.386	2.579	-1.9314	-0.2448		0.0969	-3.0065	0.8401	0.8063	-0.5907	0.0184
0.4194	-5.399	2.8139	2.9197	-2.189	-0.1661		0.1258	-2.9119	0.9757	0.9168	-0.7255	0.0419
0.4758	-4.2728	3.3021	3.3634	-2.5735	-0.1155		0.1538	-3.2766	1.0828	1.0483	-0.8253	0.0366
0.4987	-4.0286	3.3623	3.5154	-2.763	-0.0727		0.1905	-2.3838	1.2694	1.3063	-1.0316	0.0846
0.5608	0.0214	4.0522	3.984	-3.2117	0.0882		0.2112	-2.8768	1.6946	1.3963	-1.115	0.0243
0.597	1.1888	4.5585	4.3628	-3.4762	0.1778		0.2344	-2.9927	1.9122	1.5821	-1.2716	-0.0425
0.6674	9.4187	5.3984	4.9624	-4.0749	0.4884		0.293	-4.2273	2.1317	1.9777	-1.5037	-0.0912
							0.3237	-5.2803	2.4564	2.2568	-1.6177	-0.1411
							0.3622	-4.7293	2.8082	2.5408	-1.8733	-0.031
							0.387	-4.8468	2.9607	2.7224	-2.0021	-0.0033
							0.4199	-3.6641	2.7116	2.7517	-2.1993	-0.3054
							0.4555	-3.1026	3.3384	3.0994	-2.41	-0.1
							0.5111	0.1616	3.5509	3.4446	-2.8201	-0.2661
							0.5887	4.4253	4.8087	4.1778	-3.3491	0.3636
							0.6415	7.833	5.4676	4.5328	-3.6782	0.5731
							0.6747	14.8222	4.9936	4.517	-4.0041	0.1687
							0.7271	20.6012	5.7815	4.8645	-4.5406	0.5502

Appendix 2E Results From Step Input Tests

Table 2E- 1

	Response times for lateral acceleration					
	Steady state lateral acceleration achieved during test (g)					
Config.	-0.2	-0.4	-0.6	0.2	0.4	0.6
1	0.8	1.4	1.4	0.775	1.075	1.35
2	0.6	0.65	0.875	0.625	0.65	0.65
3	0.425	0.475	0.5	0.5	0.65	0.625
4	0.4	0.55	0.525	0.5	0.6	0.675
5	0.55	1.175	0.95	0.625	0.675	0.8
6	0.575	0.6	0.6	0.625	0.875	0.75
7	0.6	0.675	0.8	0.5	0.525	0.6
8	0.65	0.725	0.8	0.65	0.675	0.875
9	0.75	0.65	0.625	1.15	1.125	0.875
10	0.625	1.15	1.3	0.65	1.075	1.25
11	0.975	1.25	1.15	0.95	1	1
12	0.825	1.55	1.375	0.925	1.25	1.3
13	0.925	1.075	1.275	0.825	1.35	1.225
14	0.625	0.6	0.8	0.675	0.625	0.675
15	0.975	1.3	1.425	0.975	1.325	1.5
16	0.675	0.825	0.8	1.15	1.225	1.025

Table 2E- 2

	Mean road wheel angles					
	Steady state lateral acceleration achieved during test (g)					
Config.	-0.2	-0.4	-0.6	0.2	0.4	0.6
1	-0.384	-0.8125	-1.0603	0.3454	0.2806	0.7606
2	-0.6118	-1.4011	-2.0516	0.5406	1.1054	1.3179
3	-0.7713	-1.4398	-1.9686	0.5867	0.7903	1.105
4	-0.8449	-1.4643	-2.613	0.868	1.4581	2.1492
5	-0.7772	-1.4391	-2.3082	0.6543	1.218	1.6597
6	-0.4637	-0.9446	-1.6918	0.4368	0.5203	0.9306
7	-0.9572	-1.4136	-2.2596	0.7117	1.4417	1.8306
8	-0.7102	-1.1956	-1.9057	0.4718	1.004	1.4357
9	-0.5614	-1.1676	-2.0732	0.5265	0.7367	1.5543
10	-0.4441	-0.9385	-1.4312	0.5228	0.9987	1.3749
11	-0.5648	-1.1798	-1.505	0.6683	0.9501	1.5666
12	-0.3608	-0.6642	-0.7178	0.3544	0.5443	0.8208
13	-0.4935	-0.7421	-1.1037	0.4506	0.8637	1.4335
14	-0.8172	-1.5725	-2.5555	0.673	1.5513	2.2054
15	-0.3986	-0.6248	-1.244	1.1256	0.5993	1.1373
16	-0.5494	-0.884	-1.4183	0.3961	0.6242	1.1172

Table 2E- 3

	Response times for mean road wheel angle					
	Steady state lateral acceleration achieved during test (g)					
Config.	-0.2	-0.4	-0.6	0.2	0.4	0.6
1	0.3	0.6	0.65	0.35	0.2	0.3625
2	0.225	0.275	0.475	0.15	0.2125	0.2125
3	0.15	0.2	0.25	0.125	0.1375	0.1875
4	0.175	0.25	0.275	0.225	0.3125	0.3625
5	0.2	0.775	0.5	0.1625	0.225	0.3125
6	0.2	0.2	0.275	0.125	0.1125	0.15
7	0.25	0.375	0.5	0.175	0.2	0.25
8	0.275	0.325	0.4	0.1625	0.225	0.4
9	0.55	0.725	0.7	0.15	0.1125	0.5125
10	0.275	0.925	1.3	0.2875	0.65	0.8625
11	0.225	0.9	1.225	0.425	0.5375	0.5375
12	0.275	1.325	1.35	0.275	0.2625	0.6
13	0.325	0.85	1.35	0.375	0.85	0.8125
14	0.3	0.225	0.5	0.2375	0.1875	0.375
15	0.2375	1.65	1.45	1.175	0.5875	0.9
16	0.15	0.55	0.6	0.1	0.175	0.4875

Table 2E- 4

	Yaw rates					
	Steady state lateral acceleration achieved during test (g)					
Config.	-0.2	-0.4	-0.6	0.2	0.4	0.6
1	-3.435	-8.848	-12.34	3.956	6.932	10.19
2	-4.232	-8.715	-9.926	3.649	5.561	7.683
3	-3.502	-8.013	-10.62	3.702	6.858	10.85
4	-3.751	-7.294	-9.981	2.194	6.503	8.836
5	-4.551	-7.226	-12.45	4.409	7.846	10.7
6	-3.939	-7.465	-10.96	3.812	7.175	10.59
7	-4.789	-6.315	-9.654	3.416	7.14	9.642
8	-2.697	-5.622	-9.175	4.61	8.312	10.94
9	-3.788	-7.758	-12.04	4.408	7.099	12.39
10	-2.837	-7.142	-9.781	3.448	6.604	11.08
11	-4.589	-7.618	-11.94	3.514	6.912	11.25
12	-3.557	-8	-8.538	3.379	6.601	9.346
13	-4.075	-7.242	-11.41	4.546	6.722	11.59
14	-3.241	-6.137	-10.47	3.169	8.241	12.01
15	-3.391	-7.698	-14.49	7.397	6.759	13.78
16	-3.659	-7.109	-9.728	3.949	6.243	9.75

Table 2E- 5

	Response times for yaw rate					
	Steady state lateral acceleration achieved during test (g)					
Config.	-0.2	-0.4	-0.6	0.2	0.4	0.6
1	0.525	1.1	1.275	0.6	0.65	0.875
2	0.425	0.45	0.625	0.375	0.4	0.4
3	0.25	0.3	0.325	0.275	0.3	0.375
4	0.3	0.375	0.35	0.275	0.4	0.45
5	0.375	0.9	0.625	0.35	0.4	0.5
6	0.35	0.375	0.35	0.35	0.675	0.4
7	0.4	0.475	0.6	0.325	0.325	0.375
8	0.325	0.4	0.475	0.35	0.425	0.6
9	0.55	0.725	0.7	1.025	1.025	0.875
10	0.375	1.125	1.3	0.4	1.1	1.225
11	0.9	1.05	1.225	0.9	0.85	0.825
12	0.675	1.625	1.4	0.9	1.075	1.175
13	0.95	1.05	1.375	0.75	1.275	1.225
14	0.5	0.4	0.6	0.65	0.4	0.475
15	0.7	1.65	1.45	1.55	1.15	1.5
16	0.375	0.575	0.6	1	1.075	0.825

Table 2E- 6

	Roll rates					
	Steady state lateral acceleration achieved during test (g)					
Config.	-0.2	-0.4	-0.6	0.2	0.4	0.6
1	2.899	3.717	4.901	-3.061	-3.548	-3.427
2	4.547	8.044	7.682	-3.264	-5.601	-6.058
3	10.75	13.37	11.11	6.194	-9.913	-15.16
4	3.488	6.103	10.76	-4.037	-8.99	-12.06
5	5.798	8.305	12.35	-5.02	-7.805	-8.392
6	8.486	6.411	13	-4.456	-8.023	-9.154
7	4.167	6.809	10.28	-3.043	-6.885	-10.34
8	4.06	5.128	7.694	-3.688	-5.093	-6.498
9	4.866	6.71	10.47	-9.332	-6.986	-10.78
10	2.865	4.482	6.059	-2.435	-5.345	-6.857
11	2.508	5.42	5.942	-3.606	-3.948	-5.039
12	2.129	4.296	3.081	-1.635	-2.59	-3.747
13	3.509	3.851	6.147	-3.97	-5.855	-8.538
14	3.829	5.87	9.652	-2.628	-6.212	-9.143
15	2.387	2.764	5.024	-2.313	-3.171	-4.665
16	2.414	3.625	5.331	-2.088	-2.513	-4.751

Table 2E- 7

	Response times for roll rate					
	Steady state lateral acceleration achieved during test (g)					
Config.	-0.2	-0.4	-0.6	0.2	0.4	0.6
1	0.5	0.6	0.65	0.55	0.7	0.475
2	0.325	0.5	0.575	0.25	0.3	0.325
3	0.2	0.25	0.325	0.1	0.225	0.475
4	0.25	0.35	0.35	0.3	0.5	0.5
5	0.475	0.95	0.625	0.6	0.575	0.45
6	0.525	0.275	0.35	0.425	0.775	0.25
7	0.35	0.475	0.6	0.425	0.3	0.375
8	0.6	0.375	0.55	0.3	0.325	0.475
9	0.225	0.275	0.3	0.325	0.45	0.3
10	0.45	0.525	0.725	0.4	0.5	0.6
11	0.45	0.85	0.7	0.55	0.475	0.525
12	0.725	0.9	0.6	0.7	0.575	0.325
13	0.425	0.4	0.375	0.625	0.75	0.625
14	0.525	0.325	0.575	0.425	0.25	0.35
15	0.35	0.35	0.725	0.6	0.525	0.575
16	0.425	0.25	0.3	0.2	0.25	0.3

Table 2E- 8

	Steer torques					
	Steady state lateral acceleration achieved during test (g)					
Config.	-0.2	-0.4	-0.6	0.2	0.4	0.6
1	-3.343	-5.546	-7.825	3.019	3.652	4.824
2	-3.256	-5.671	-8.18	3.781	5.31	5.278
3	-4.355	-6.832	-8.294	3.931	6.178	6.745
4	-2.983	-5.368	-7.657	2.277	4.521	6.434
5	-3.212	-6.054	-7.172	2.18	3.439	6.895
6	-3.343	-5.344	-7.261	3.738	5.207	7.611
7	-3.999	-5.71	-9.193	1.678	4.959	6.647
8	-3.44	-6.239	-8.741	3.566	4.501	5.469
9	-3.583	-7.051	-8.473	2.154	4.705	7.477
10	-2.799	-5.624	-7.656	2.323	4.801	5.877
11	-3.643	-6.517	-8.9	2.825	3.996	6.124
12	-2.947	-6.335	-8.166	2.554	4.713	6.432
13	-3.343	-5.491	-8.088	3.663	4.437	6.978
14	-3.481	-4.873	-8.397	1.86	5.931	7.353
15	-3.024	-5.745	-7.547	3.481	4.347	6.058
16	-3.348	-6.288	-8.254	2.657	4.242	5.929

Table 2E- 9

	Response times for steer torque					
	Steady state lateral acceleration achieved during test (g)					
Config.	-0.2	-0.4	-0.6	0.2	0.4	0.6
1	0.65	1.1	1.275	0.6	0.65	0.875
2	0.45	0.525	0.625	0.55	0.45	0.4
3	0.25	0.3	0.325	0.475	0.525	0.375
4	0.3	0.425	0.35	0.275	0.4	0.475
5	0.425	1.025	0.8	0.35	0.4	0.625
6	0.6	0.4	0.35	0.525	0.725	0.675
7	0.475	0.475	0.725	0.475	0.325	0.375
8	0.45	0.65	0.475	0.4	0.45	1.025
9	0.65	0.725	0.7	1.025	1.025	0.875
10	0.525	1.125	1.3	0.5	1.1	1.225
11	0.9	1.25	1.225	0.9	0.85	0.825
12	0.725	1.625	1.4	0.9	1.075	1.175
13	0.95	1.05	1.375	0.75	1.275	1.225
14	0.525	0.525	0.775	0.675	0.4	0.475
15	1.225	1.65	1.45	1.55	1.175	1.5
16	0.6	0.725	0.725	1.1	1.125	1.025

Appendix 2F Summary statistics for step input test

Note that the values in each row represent the average of clockwise and anticlockwise data.

Table 2F- 1

		Summary Statistics				
Metric	Lateral Accel.	Minimum	Maximum	Mean	Median	Standard Deviation
Lateral Acceleration Response Time (s)	0.2	0.45	0.975	0.7211	0.65	0.1816
	0.4	0.5625	1.4	0.9172	0.9062	0.2899
	0.6	0.5625	1.462	0.9492	0.8562	0.3006
Peak Roadwheel Steer Angle (deg)	0.2	0.3576	0.8565	0.5951	0.5836	0.1579
	0.4	0.5465	1.562	1.018	1.017	0.3258
	0.6	0.7693	2.381	1.572	1.536	0.4686
Roadwheel Steer Angle Response Time (s)	0.2	0.125	0.7062	0.2691	0.2438	0.1378
	0.4	0.1562	1.119	0.473	0.3813	0.2909
	0.6	0.2125	1.175	0.5977	0.4719	0.3287
Peak Roll Rate (deg/s)	0.2	1.882	8.47	4.046	3.672	1.872
	0.4	2.968	11.64	5.856	5.576	2.261
	0.6	3.414	13.14	7.94	7.219	2.977
Roll Rate Response Time (s)	0.2	0.15	0.7125	0.4242	0.4625	0.1373
	0.4	0.2375	0.7625	0.4727	0.4312	0.1671
	0.6	0.3	0.6625	0.4766	0.475	0.1153
Peak Yaw Rate (deg/s)	0.2	2.972	5.394	3.862	3.84	0.5845
	0.4	6.676	7.89	7.178	7.209	0.3184
	0.6	8.805	14.14	10.75	10.75	1.361
Yaw Rate Response Time (s)	0.2	0.2625	1.125	0.5641	0.4812	0.2618
	0.4	0.3	1.4	0.7531	0.7375	0.367
	0.6	0.35	1.475	0.793	0.6375	0.3837
Peak Steer Torque (Nm)	0.2	2.561	4.143	3.118	3.092	0.4425
	0.4	4.599	6.505	5.301	5.27	0.4474
	0.6	6.325	7.975	7.248	7.202	0.4705
Steer Torque Response Time (s)	0.2	0.2875	1.388	0.6484	0.5812	0.2786
	0.4	0.4	1.412	0.7977	0.7938	0.3459
	0.6	0.35	1.475	0.8445	0.7688	0.3539

Appendix 2G Processed Data From Impulse Tests

Table 2G- 1

	Lateral acceleration gain (g/deg)			Lateral acceleration phase (deg)		
	Frequency			Frequency		
Config.	0.4	0.7	1	0.4	0.7	1
1	0.01162	0.009548	0.006572	-28.97	-50.95	-73.55
2	0.00889	0.007379	0.005089	-27.26	-52.94	-77.62
3	0.009624	0.008633	0.006501	-21.28	-39.81	-62.31
4	0.009057	0.008012	0.006497	-15.82	-36.78	-51.79
5	0.009416	0.007841	0.004845	-25.55	-52.92	-71.66
6	0.01191	0.01005	0.007439	-21.62	-46.32	-69.17
7	0.008744	0.007507	0.005761	-24	-43.18	-64.62
8	0.009573	0.008415	0.006705	-22.62	-37.35	-54.51
9	0.01218	0.007847	0.004314	-60.53	-70.91	-80.29
10	0.01351	0.01034	0.007669	-31.26	-50.59	-65.11
11	0.01392	0.009163	0.005319	-42.2	-69.4	-82.67
12	0.01452	0.01103	0.005982	-41.73	-68.03	-89.16
13	0.01443	0.01074	0.006889	-37.62	-59.95	-78.32
14	0.009703	0.008563	0.006335	-24.91	-46.91	-66.61
15	0.01584	0.009769	0.005434	-53.82	-76.52	-91.55
16	0.0124	0.009337	0.005545	-45.17	-72.7	-89.78

Table 2G- 2

	Yaw rate gain (deg/s/deg)			Yaw rate phase (deg)		
	Frequency			Frequency		
Config.	0.4	0.7	1	0.4	0.7	1
1	0.2752	0.2824	0.2844	-14.2	-28.91	-44.82
2	0.2216	0.2247	0.2267	-14.25	-31.49	-49.53
3	0.1908	0.1978	0.2119	-12.71	-23.28	-38.39
4	0.2054	0.2358	0.2328	29.63	1.021	-13.72
5	0.2064	0.2295	0.2258	-16.31	-31.13	-50.21
6	0.244	0.2483	0.2485	-13.79	-27.74	-42.83
7	0.2063	0.2026	0.219	-15.52	-22.82	-38.72
8	0.1893	0.2093	0.236	-6.93	-13.84	-26.35
9	0.2696	0.2335	0.2093	-43.38	-48.21	-57.63
10	0.2985	0.2657	0.2479	-26.61	-37.43	-48.23
11	0.331	0.2602	0.2274	-27.52	-46.88	-53.53
12	0.3894	0.3382	0.2654	-30.32	-57.26	-70.58
13	0.3087	0.2595	0.2369	-21.89	-39.06	-47.01
14	0.1688	0.2115	0.2224	14.21	-9.512	-26.42
15	0.351	0.272	0.2303	-39.87	-51.82	-60.57
16	0.278	0.2649	0.2344	-32.51	-49.49	-59.34

Table 2G- 3

	Road wheel angle gain (deg/deg)				Road wheel angle phase(deg)		
	Frequency				Frequency		
Config.	0.4	0.7	1		0.4	0.7	1
1	0.03068	0.0386	0.04358		21.52	17.93	9.954
2	0.02999	0.03746	0.0409		14.02	13.87	6.55
3	0.02987	0.03611	0.04318		16.61	17.46	12.15
4	0.03494	0.03787	0.04221		3.385	4.758	5.394
5	0.0335	0.04175	0.04545		13.72	11.6	4.326
6	0.03046	0.03854	0.04369		20.22	17.27	11.68
7	0.02971	0.03663	0.04314		18.4	20.06	13.68
8	0.03248	0.03845	0.04267		13.63	12.63	7.397
9	0.0444	0.04286	0.0424		-3.135	-0.9776	-1.502
10	0.03841	0.03959	0.0401		1.377	-0.1182	-2.173
11	0.04787	0.04229	0.0425		-8.33	-8.129	-5.308
12	0.04465	0.0459	0.04389		3.634	-4.618	-7.488
13	0.04321	0.0433	0.0427		-6.824	-7.386	-6.832
14	0.04476	0.04381	0.04393		-1.405	-1.817	-5.524
15	0.04297	0.04135	0.04117		-4.076	-2.847	-2.249
16	0.0379	0.04085	0.04064		1.773	-2.472	-2.591

Appendix 2H Processed Data And Summary Statistics From Pseudo-Random Tests

Table 2H- 1

	Lateral acceleration gain (g/deg)				Lateral acceleration phase (deg)		
	Frequency				Frequency		
Config.	0.4	0.7	1		0.4	0.7	1
1	0.01552	0.01176	0.007581		-32.99	-59.23	-85.18
2	0.01112	0.008518	0.005502		-29.39	-60.82	-88.35
3	0.01003	0.008705	0.006182		-23.71	-45.24	-66.12
4	0.01012	0.009383	0.007765		-20.99	-39.09	-61
5	0.01169	0.009349	0.005506		-33.14	-64.61	-88.89
6	0.01539	0.01208	0.008235		-30.95	-56.87	-80.58
7	0.01042	0.009259	0.006957		-25.08	-44.82	-71.55
8	0.01232	0.01037	0.007608		-23.99	-44.23	-66.15
9	0.01611	0.009485	0.005328		-54.73	-78.17	-90.37
10	0.01877	0.0123	0.008611		-40.55	-60.45	-73.08
11	0.01614	0.009908	0.006218		-55.15	-76.44	-89.7
12	0.0219	0.01125	0.005771		-63.12	-89.24	-99.35
13	0.01985	0.01293	0.008336		-49.53	-70.14	-82.2
14	0.01236	0.01002	0.007131		-33.43	-56.78	-79.83
15	0.01836	0.008689	0.005274		-77.92	-90.54	-98.17
16	0.01741	0.01126	0.00624		-62.52	-87.52	-102.5

Table 2H- 2

	Yaw rate gain (deg/s/deg)				Yaw rate phase (deg)		
	Frequency				Frequency		
Config.	0.4	0.7	1		0.4	0.7	1
1	0.3013	0.3015	0.3074		-14	-29.94	-46.78
2	0.2223	0.2435	0.2499		-10.92	-30.3	-52.21
3	0.2026	0.21	0.2121		-15.98	-25.94	-39.63
4	0.1513	0.1891	0.2282		16.53	3.598	-20.11
5	0.2445	0.2631	0.2649		-14.68	-36.66	-60.03
6	0.3507	0.3072	0.2872		-21.7	-37.68	-48.55
7	0.1876	0.2096	0.2178		-8.516	-15.81	-35.13
8	0.2383	0.2583	0.2688		-9.993	-23.09	-39.72
9	0.2928	0.2511	0.2335		-36.54	-47.84	-58.7
10	0.3123	0.2505	0.2256		-26.43	-37.94	-46.54
11	0.3292	0.2723	0.2569		-35.72	-47.42	-56.12
12	0.3846	0.2619	0.2156		-45.88	-58.05	-65.42
13	0.3019	0.2664	0.2378		-26.63	-34.42	-36.52
14	0.1766	0.2115	0.2513		-3.993	-16.92	-26.02
15	0.3725	0.2667	0.2391		-54.77	-57.09	-64.54
16	0.3054	0.2511	0.221		-40.09	-51.2	-61.56

Table 2H-3

	Road wheel angle gain (deg/deg)				Road wheel angle phase(deg)		
	Frequency				Frequency		
Config.	0.4	0.7	1		0.4	0.7	1
1	0.02842	0.03808	0.04525		30.3	24.65	12.89
2	0.02593	0.0371	0.04225		23.72	18.91	8.11
3	0.02924	0.03657	0.04216		12.58	18.04	13.6
4	0.03194	0.03625	0.0429		8.444	11.72	12.75
5	0.03158	0.04219	0.047		19.84	15.79	5.667
6	0.0301	0.03894	0.04538		24.37	21.07	14.17
7	0.02531	0.03418	0.0426		23.94	25.71	16.95
8	0.0266	0.03542	0.04144		21.8	21.5	14.51
9	0.03957	0.04113	0.04108		-1.097	0.7258	-0.5283
10	0.03802	0.0385	0.03861		1.431	1.971	0.1782
11	0.04671	0.04313	0.04164		-10.22	-11.59	-12.15
12	0.04051	0.04057	0.04015		7.786	2.841	-1.505
13	0.04466	0.04095	0.04098		-6.444	-6.352	-6.625
14	0.04135	0.0421	0.04304		0.4326	-1.386	-5.112
15	0.04003	0.04002	0.04131		-4.669	0.838	-2.235
16	0.04155	0.03863	0.03836		-7.541	-9.328	-10.15

Appendix 2I Repeatability of Frequency Response Results

Table 2I- 1

	Lateral accel gain (g/deg)		Lateral accel. phase (deg)		Road wheel gain (deg/deg)		Road wheel phase (deg)		Yaw rate gain (deg/s/deg)		Yaw rate phase (deg)	
Frequency	First Test	Second Test	First Test	Second Test	First Test	Second Test	First Test	Second Test	First Test	Second Test	First Test	Second Test
0.1173	0.01213	0.01019	-0.2412	-19.03	0.02484	0.02663	12.83	13.13	0.225	0.2122	-2.642	-17.22
0.1564	0.01238	0.01124	-2.766	-19.25	0.02489	0.02712	15.39	16.69	0.2304	0.2366	-2.535	-13.13
0.1955	0.01249	0.01162	-6.561	-20.37	0.02585	0.02712	15.22	17.96	0.2358	0.2427	-4.306	-12.74
0.2346	0.01245	0.01163	-8.538	-22.29	0.02667	0.02759	15.57	20.08	0.2382	0.244	-5.295	-13.47
0.2737	0.01235	0.01147	-10.9	-23.9	0.0277	0.02854	16.52	21.31	0.2392	0.244	-7.193	-14.2
0.3128	0.01208	0.01136	-14.38	-24.73	0.02847	0.02951	18.33	22.77	0.2373	0.2431	-9.224	-13.74
0.3519	0.01196	0.0115	-18.1	-26.95	0.02941	0.03042	19.69	23.35	0.2393	0.2463	-11.54	-14.28
0.391	0.01191	0.01162	-21.62	-29.6	0.03046	0.03135	20.22	23.83	0.244	0.2489	-13.79	-15.35
0.4301	0.0119	0.01164	-24.62	-32.86	0.032	0.03291	20.43	22.35	0.2522	0.256	-15.44	-17.63
0.4692	0.01176	0.01163	-28.25	-34.63	0.03338	0.03429	20.35	22.16	0.2561	0.2626	-17.34	-18.68
0.5083	0.01152	0.0116	-31.61	-36.06	0.03443	0.03563	20.25	22.07	0.2543	0.2725	-18.77	-19.06
0.5474	0.01119	0.0115	-34.71	-37.02	0.0352	0.03597	20.05	23.83	0.2493	0.2756	-20.32	-18.53
0.5865	0.01086	0.01106	-37.36	-39.47	0.03598	0.03643	19.61	22.7	0.2456	0.2732	-21.8	-19.68
0.6256	0.01054	0.01048	-40.1	-42.28	0.03678	0.03648	19	20.47	0.2448	0.264	-23.62	-22.02
0.6647	0.01029	0.01001	-43.42	-45.49	0.0377	0.03707	17.99	17.67	0.2466	0.2599	-25.89	-24.56
0.7038	0.01005	0.009766	-46.32	-48.12	0.03854	0.03767	17.27	16.34	0.2483	0.2616	-27.74	-26.52
0.7429	0.009823	0.009612	-49.04	-50.54	0.03932	0.03853	16.57	15.79	0.2496	0.2661	-29.37	-27.87
0.782	0.009496	0.009394	-51.46	-52.43	0.03979	0.03929	16.1	15.28	0.2486	0.2684	-30.59	-29.08
0.8211	0.009149	0.009139	-54.48	-54.78	0.04026	0.04018	15.34	14.79	0.2475	0.2708	-32.49	-30.35
0.8602	0.008795	0.008864	-57.65	-57.66	0.04101	0.04113	14.67	14.2	0.2477	0.274	-34.54	-31.94
0.8993	0.00852	0.008609	-60.73	-61.15	0.04193	0.04203	13.79	12.96	0.2496	0.2786	-36.97	-34.35
0.9384	0.008256	0.008325	-63.7	-64.46	0.04269	0.04249	13.07	11.19	0.2505	0.2804	-39.12	-37.02
0.9775	0.007895	0.007999	-66.5	-68.13	0.04322	0.04309	12.32	9.29	0.2497	0.2842	-40.99	-39.93
1.017	0.007439	0.007514	-69.17	-72.07	0.04369	0.04356	11.68	7.872	0.2485	0.2858	-42.83	-42.77
1.056	0.006967	0.006945	-71.86	-75.65	0.04425	0.04413	10.66	7.123	0.2489	0.2873	-44.96	-45.58
1.095	0.006553	0.006305	-74.56	-77.42	0.0447	0.04377	9.512	6.13	0.2501	0.2805	-47.52	-48.17
1.134	0.006146	0.005782	-77.15	-78.45	0.04487	0.04333	8.451	5.28	0.2489	0.2732	-49.6	-50.25
1.173	0.005656	0.005268	-79.3	-79.06	0.04489	0.04278	7.543	4.154	0.2455	0.2645	-51.34	-52.23
1.212	0.005152	0.00483	-81.39	-80.28	0.04501	0.04284	6.616	3.398	0.2408	0.261	-52.86	-54.21
1.251	0.004678	0.004361	-83.22	-81.06	0.04508	0.04285	5.113	2.544	0.2376	0.2575	-55.36	-56.43
1.29	0.004274	0.004005	-84.67	-82.02	0.04514	0.04295	3.693	1.961	0.2358	0.2561	-58.18	-58.3
1.329	0.003895	0.003644	-85.75	-83	0.04499	0.04293	2.377	1.481	0.2339	0.2548	-61.02	-60.09
1.369	0.003524	0.003351	-86.47	-84.32	0.04496	0.04297	2.053	1.002	0.2312	0.254	-62.78	-61.77
1.408	0.003197	0.003053	-86.44	-84.35	0.0448	0.04285	1.946	0.3283	0.2274	0.251	-64.08	-63.61
1.447	0.002893	0.002844	-85.14	-83.6	0.0445	0.04277	1.709	-0.6091	0.2235	0.2463	-65.5	-65.33
1.486	0.002606	0.002598	-83.43	-81.42	0.04418	0.04274	0.8842	-1.626	0.2193	0.2402	-67.61	-67.26
1.525	0.002299	0.002292	-82.75	-79.45	0.04403	0.04278	0.06161	-2.427	0.2161	0.2343	-69.74	-69.33
1.564	0.002013	0.002002	-82.08	-76.27	0.04418	0.04256	-0.5773	-2.783	0.2138	0.2285	-71.59	-71.39
1.603	0.001789	0.001794	-80.46	-71.46	0.04424	0.04201	-1.023	-2.883	0.2124	0.2232	-72.97	-72.84
1.642	0.00163	0.00168	-75.45	-65.41	0.04406	0.0414	-1.515	-3.133	0.2101	0.2176	-74.51	-74.23
1.681	0.001458	0.001542	-69.89	-59.34	0.04369	0.04097	-1.803	-3.577	0.2062	0.2125	-76.03	-75.71
1.72	0.001302	0.001413	-64.08	-54.29	0.04325	0.04084	-2.176	-4.005	0.2025	0.208	-77.79	-77.55
1.76	0.001229	0.001335	-60.49	-48.91	0.04294	0.04082	-2.533	-4.232	0.1997	0.2048	-79.41	-79.07
1.799	0.001266	0.001296	-56.15	-44.03	0.04248	0.04079	-2.944	-4.262	0.1966	0.202	-81.16	-80.29
1.838	0.001328	0.00125	-50.79	-40.07	0.0421	0.04061	-3.016	-4.281	0.1923	0.1997	-82.5	-81.44
1.877	0.001303	0.001172	-43.97	-37.66	0.04162	0.0403	-3.227	-4.338	0.187	0.1971	-84.39	-82.73
1.916	0.001242	0.001144	-38.59	-34.31	0.04128	0.03995	-3.536	-4.413	0.1845	0.1944	-86.68	-83.82
1.955	0.001155	0.001176	-35.41	-28.94	0.04092	0.03967	-3.948	-4.678	0.1835	0.1913	-89.33	-84.88
1.994	0.001126	0.001249	-32.9	-22.14	0.04058	0.03952	-4.154	-4.997	0.1829	0.188	-91.29	-85.84
2.033	0.001059	0.00127	-28.8	-15.04	0.04042	0.03943	-3.945	-5.53	0.1796	0.1837	-91.82	-87.37
2.072	0.001002	0.00127	-21.79	-8	0.04023	0.03932	-3.585	-5.74	0.1745	0.1788	-92.27	-88.95
2.111	0.000918	0.001247	-13.64	-1.379	0.04017	0.03914	-3.08	-5.92	0.1695	0.174	-92.61	-90.32
2.151	0.0009179	0.001249	-5.018	4.805	0.04008	0.03889	-2.971	-5.971	0.166	0.1709	-93.8	-91.54
2.19	0.0009562	0.001246	-0.9203	9.298	0.04036	0.03869	-3.313	-6.13	0.1653	0.169	-94.79	-92.6
2.229	0.00101	0.001257	1.377	14.77	0.04068	0.03864	-3.744	-6.01	0.1655	0.1677	-96.02	-94.06
2.268	0.001059	0.001304	3.231	20.39	0.04091	0.03879	-3.719	-5.827	0.1647	0.166	-96.84	-95.27
2.307	0.00112	0.001346	11.32	27.02	0.04074	0.03893	-3.299	-5.641	0.1616	0.1642	-98.05	-96.54
2.346	0.001235	0.00143	20.82	31.75	0.04047	0.03894	-2.962	-5.68	0.1571	0.1624	-99.1	-97.6
2.385	0.001309	0.001478	27.69	36.1	0.04039	0.03877	-3.442	-5.736	0.1545	0.1607	-101	-98.85
2.424	0.001369	0.001556	29.59	39.17	0.04035	0.03862	-3.945	-5.796	0.1523	0.1592	-102.3	-100
2.463	0.001433	0.001595	30.71	42.35	0.04032	0.03842	-4.358	-5.995	0.1506	0.1571	-103.6	-101.3
2.502	0.001595	0.001692	33.53	42.49	0.04	0.03821	-4.093	-6.253	0.1467	0.1543	-104.2	-102.4
2.542	0.001775	0.001865	37.48	42.38	0.03992	0.03807	-3.984	-6.513	0.1443	0.1504	-105.2	-103.7
2.581	0.00191	0.00209	40.4	41.69	0.0399	0.0381	-3.966	-6.478	0.1424	0.1469	-106.5	-104.7
2.62	0.002001	0.002321	42.16	43.93	0.04005	0.0383	-4.293	-6.248	0.1422	0.1446	-108.3	-105.8
2.659	0.002058	0.002484	43.3	45.6	0.04011	0.03825	-4.459	-6.08	0.1413	0.1427	-110.1	-107
2.698	0.002139	0.002641	43.48	47.16	0.04014	0.03815	-4.499	-6.032	0.1397	0.1405	-111.4	-108.4
2.737	0.002189	0.00278	43.55	46.68	0.04008	0.03793	-4.408	-6.176	0.1372	0.1374	-112.5	-109.9
2.776	0.002303	0.002944	42.93	46.68	0.03986	0.03804	-4.473	-6.322	0.1339	0.135	-113.5	-111.2
2.815	0.002429	0.003112	43.49	46.53	0.03946	0.03811	-4.931	-6.465	0.1305	0.133	-115.3	-112.4
2.854	0.002644	0.003285	43.25	46.99	0.03931	0.03828	-5.458	-6.591	0.1275	0.1318	-117	-113.5

Table 2I- 2 Summary statistics for pseudo-random steer data.

		Summary Statistics				
Metric	Frequency	Minimum	Maximum	Mean	Median	Standard Deviation
Corrected Lateral Acceleration Gain (g/deg)	0.3	0.0093	0.024	0.0146	0.0143	0.0046
	0.4	0.0089	0.0203	0.0134	0.0139	0.0034
	0.7	0.0075	0.0114	0.0093	0.0093	0.0014
	1.0	0.0046	0.0081	0.0062	0.0061	0.0011
	1.3	0.0025	0.0056	0.0037	0.0038	0.001
Corrected Lateral Acceleration Phase (deg)	0.3	-70.7647	-11.9306	-32.0294	-24.7016	17.2128
	0.4	-76.3134	-16.9608	-38.7379	-30.6717	17.7144
	0.7	-87.4496	-35.8161	-60.774	-58.406	16.5765
	1.0	-100.0913	-56.2189	-78.0123	-78.5385	12.7152
	1.3	-101.8022	-70.7907	-86.4979	-85.0048	10.5545
Lateral Acceleration Gain (g/deg)	0.3	0.0101	0.0258	0.016	0.0157	0.005
	0.4	0.01	0.0219	0.0148	0.0155	0.0038
	0.7	0.0085	0.0129	0.0103	0.01	0.0014
	1.0	0.0053	0.0086	0.0068	0.0066	0.0012
	1.3	0.0028	0.0059	0.004	0.004	0.001
Lateral Acceleration Phase (deg)	0.3	-72.0595	-16.2572	-34.2578	-27.7574	16.299
	0.4	-77.9226	-20.9864	-41.0738	-33.2845	17.2017
	0.7	-90.542	-39.0862	-64.0119	-60.6371	16.6694
	1.0	-102.4782	-60.9988	-82.6869	-83.6879	12.4931
	1.3	-105.7204	-76.257	-92.5647	-91.7426	9.8249
Roll Angle Gain (deg/deg)	0.3	0.0554	0.2153	0.1078	0.0859	0.048
	0.4	0.0563	0.1677	0.0973	0.089	0.0334
	0.7	0.0507	0.0975	0.0665	0.0644	0.013
	1.0	0.0292	0.0723	0.0478	0.0455	0.011
	1.3	0.0175	0.0534	0.0311	0.0293	0.0097
Roll Angle Phase (deg/deg)	0.3	-19.5498	153.5622	103.9254	118.321	48.957
	0.4	73.5642	147.2818	112.7651	115.4299	20.8906
	0.7	39.1929	114.2328	88.019	89.9217	19.915
	1.0	16.6246	82.993	59.4324	61.24	18.9376
	1.3	2.8195	70.3966	40.1198	42.1375	16.625
Roll Rate Gain ((deg/s)/deg)	0.3	0.0828	0.337	0.1966	0.1767	0.077
	0.4	0.14	0.363	0.2307	0.222	0.0727
	0.7	0.2198	0.4261	0.2924	0.2868	0.0532
	1.0	0.1859	0.4587	0.3009	0.2919	0.0698
	1.3	0.1419	0.4304	0.2514	0.223	0.0781
Roll Rate Phase (deg)	0.3	-173.9116	50.0731	-117.8763	-135.6024	58.5799
	0.4	-174.3808	134.9812	-106.1284	-141.7165	94.7201
	0.7	-173.3769	175.7349	-0.1341	-3.7309	163.0606
	1.0	47.3103	173.4821	137.4137	149.3973	30.9827
	1.3	98.9485	147.5927	127.2097	129.0374	13.6524
Roadwheel Steer Gain (deg/deg)	0.3	0.0236	0.0486	0.0346	0.0345	0.0083
	0.4	0.0253	0.0467	0.0351	0.035	0.0072
	0.7	0.0342	0.0431	0.039	0.0388	0.0026
	1.0	0.0384	0.047	0.0421	0.0419	0.0023
	1.3	0.038	0.048	0.0429	0.043	0.0029
Roadwheel Steer Phase (deg)	0.3	-8.8249	29.6937	8.529	7.8913	12.862
	0.4	-10.2163	30.2967	9.0421	8.1149	13.4824
	0.7	-11.5908	25.7062	8.4441	7.2796	12.5972
	1.0	-12.1485	16.951	3.7829	2.9228	9.6945
	1.3	-11.8291	8.6475	-0.5974	-0.6485	6.0535
Steer Torque Gain (Nm/deg)	0.3	0.1531	0.3641	0.2491	0.2322	0.0706
	0.4	0.1605	0.3006	0.2262	0.2258	0.0496
	0.7	0.0951	0.1808	0.1429	0.1438	0.0262
	1.0	0.0619	0.128	0.0959	0.0936	0.0202
	1.3	0.0721	0.1314	0.0881	0.0852	0.0155
Steer Torque Phase (deg)	0.3	-54.2869	18.1232	-9.7065	-7.5496	19.1112
	0.4	-53.3051	17.874	-10.8397	-4.6249	18.8741
	0.7	-41.969	29.5559	-12.7363	-13.6454	17.6425
	1.0	-30.2406	45.9444	-0.6708	-2.3382	19.7549
	1.3	-3.2901	60.6936	19.292	17.883	15.4578
Yaw Angle Gain (deg/deg)	0.3	0.0695	0.2334	0.149	0.1578	0.048
	0.4	0.0631	0.1657	0.1146	0.1226	0.0305
	0.7	0.0478	0.0702	0.0577	0.0575	0.0064
	1.0	0.0286	0.0479	0.0382	0.0382	0.0047
	1.3	0.0245	0.0354	0.0294	0.029	0.0034
Yaw Angle Phase (deg)	0.3	-142.9442	-76.0117	-108.8128	-103.3826	17.1102
	0.4	-144.7448	-76.2884	-111.7864	-107.7879	17.5233
	0.7	-147.9075	-85.1756	-123.511	-123.4929	16.8897
	1.0	-157.62	-108.2373	-137.7123	-137.5569	14.5953
	1.3	-165.5864	-121.175	-149.1005	-152.2585	12.9052
Yaw Rate Gain ((deg/s)/deg)	0.3	0.1412	0.4387	0.2825	0.3002	0.0897
	0.4	0.1513	0.3846	0.2734	0.297	0.0717

Appendix 2J Processed Data And Summary Statistics From Impulse Tests

Summary statistics for impulse steer data.

		Summary Statistics				
Metric	Frequency	Minimum	Maximum	Mean	Median	Standard Deviation
Corrected Lateral Acceleration Gain (g/deg)	0.3	0.0077	0.0154	0.0111	0.0108	0.0026
	0.4	0.0077	0.0142	0.0106	0.0103	0.0022
	0.7	0.0065	0.0107	0.0083	0.0082	0.0012
	1.0	0.0039	0.0071	0.0056	0.0058	0.0009
	1.3	0.0023	0.005	0.0034	0.0034	0.0008
Corrected Lateral Acceleration Phase (deg)	0.3	-51.1122	-10.003	-23.3668	-19.4083	11.7355
	0.4	-69.8187	-13.7997	-30.4479	-26.5654	14.5205
	0.7	-73.1195	-33.4495	-51.273	-48.352	12.7544
	1.0	-86.8568	-48.0136	-68.1589	-67.537	11.7507
	1.3	-91.0766	-61.1242	-76.8203	-76.3331	9.3748
Lateral Acceleration Gain (g/deg)	0.3	0.0088	0.0169	0.0119	0.012	0.0026
	0.4	0.0087	0.0158	0.0116	0.0118	0.0024
	0.7	0.0074	0.011	0.009	0.0089	0.0012
	1.0	0.0043	0.0077	0.0061	0.0062	0.0009
	1.3	0.0026	0.0053	0.0037	0.0037	0.0008
Lateral Acceleration Phase (deg)	0.3	-48.3457	-10.4644	-25.9893	-21.4098	10.9954
	0.4	-60.5298	-15.8151	-32.7719	-28.1166	12.7667
	0.7	-76.5172	-36.782	-54.7042	-51.9355	13.2381
	1.0	-91.5494	-51.7895	-73.0436	-72.6004	12.0518
	1.3	-95.8671	-66.3661	-82.3869	-81.8208	9.3221
Roll Angle Gain (deg/deg)	0.3	0.05	0.2693	0.0938	0.0722	0.0573
	0.4	0.0429	0.2568	0.0833	0.0664	0.0523
	0.7	0.0319	0.0852	0.056	0.0524	0.0137
	1.0	0.0306	0.0711	0.0419	0.0396	0.0106
	1.3	0.0165	0.0421	0.0271	0.0254	0.0077
Roll Angle Phase (deg/deg)	0.3	-28.6124	162.5512	92.9378	96.8616	54.7387
	0.4	1.7984	148.7334	103.1707	113.2986	41.9265
	0.7	41.4243	119.7468	92.4413	99.2576	22.2688
	1.0	19.7687	84.8876	64.9263	70.3054	17.3056
	1.3	-0.4863	68.9444	45.8411	50.0835	18.063
Roll Rate Gain ((deg/s)/deg)	0.3	0.089	0.3703	0.1664	0.1372	0.0875
	0.4	0.0852	0.4563	0.1908	0.1619	0.0927
	0.7	0.1449	0.3576	0.2418	0.2333	0.0514
	1.0	0.1995	0.4282	0.262	0.2492	0.0592
	1.3	0.1343	0.3645	0.2139	0.211	0.0585
Roll Rate Phase (deg)	0.3	-161.222	155.4402	-61.5842	-112.301	98.1657
	0.4	-163.326	156.4416	-88.9043	-125.8	88.1201
	0.7	-172.699	172.6682	-42.0749	-139.85	143.0179
	1.0	54.7199	170.8532	144.9624	151.1238	29.315
	1.3	93.4045	152.4429	134.9284	136.3673	15.6937
Roadwheel Steer Gain (deg/deg)	0.3	0.0272	0.0503	0.0364	0.0348	0.0074
	0.4	0.0297	0.0479	0.0372	0.0364	0.0065
	0.7	0.0361	0.0459	0.0403	0.0402	0.0028
	1.0	0.0401	0.0454	0.0426	0.0427	0.0014
	1.3	0.0403	0.0451	0.043	0.0428	0.0016
Roadwheel Steer Phase (deg)	0.3	-9.1139	21.4709	6.2886	4.2141	9.9592
	0.4	-8.3302	21.5227	6.5327	3.5094	10.16
	0.7	-8.1287	20.057	5.4501	2.3199	10.0695
	1.0	-7.4876	13.6764	2.3415	1.4117	7.34
	1.3	-9.0182	7.0115	-1.1255	-1.7558	4.6216
Steer Torque Gain (Nm/deg)	0.3	0.0981	0.3192	0.1852	0.1817	0.061
	0.4	0.106	0.2659	0.1788	0.1816	0.0525
	0.7	0.1124	0.184	0.1437	0.1408	0.0207
	1.0	0.0755	0.1365	0.1094	0.1128	0.017
	1.3	0.0814	0.1323	0.1057	0.1078	0.012
Steer Torque Phase (deg)	0.3	-36.3406	37.405	-6.3737	-5.585	17.8939
	0.4	-39.4799	24.9068	-10.1526	-6.8502	17.774
	0.7	-38.0618	5.5857	-14.2784	-12.3655	13.7333
	1.0	-24.128	15.881	-2.4025	-2.6165	12.0698
	1.3	-8.5418	37.0284	13.0366	13.5211	14.333
Yaw Angle Gain (deg/deg)	0.3	0.0862	0.2112	0.1405	0.1311	0.0383
	0.4	0.0673	0.1603	0.1079	0.1053	0.0266
	0.7	0.0449	0.0764	0.0559	0.0559	0.0083
	1.0	0.0326	0.0445	0.0371	0.0366	0.003
	1.3	0.0234	0.0327	0.0276	0.0274	0.0022
Yaw Angle Phase (deg)	0.3	-128.882	-64.8012	-103.146	-103.484	17.0887
	0.4	-131.131	-64.1348	-106.938	-105.69	17.5338
	0.7	-147.82	-88.8442	-122.449	-121.688	16.2268
	1.0	-161.292	-103.744	-135.477	-137.071	14.8273
	1.3	-159.61	-51.2759	-141.503	-147.334	26.4109
Yaw Rate Gain ((deg/s)/deg)	0.3	0.1628	0.3904	0.2601	0.2444	0.0713
	0.4	0.1688	0.3894	0.2584	0.2568	0.0648

Appendix 3A Driver Ratings

Table 3A-1 Ratings And Statistics For Driver A

	Configuration																Statistics					
Question Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Minimum	Maximum	Mean	Median	Standard Deviation	Range
1	4	4.5	3	3.5	4	3.5	4	3.5	3	4.5	4	3	3	4	3.5	3	3	4.5	3.63	3.5	0.53	1.5
2	4	4.5	3	3.5	3.5	3.5	4	3.5	3	5	3.5	3	3.5	4.5	3.5	3	3	5	3.66	3.5	0.60	2
3	4	4.5	4	4	4	4.5	4	3.5	3	4.5	4.5	3	3	5	3	3	3	5	3.84	4	0.68	2
4	4.5	4	4	4	4	4	4	4	3.5	4	4	4	4	4	4	3	3	4.5	3.94	4	0.31	1.5
5	3.5		4.5	4	5	4.5	4	3.5	4	5	4.5	3	3	5.5	4.5	3	3	5.5	4.10	4	0.78	2.5
6	4		3.5				4.5		3	4.5		3			3.5	4	3	4.5	3.75	3.75	0.60	1.5
7	4	3.5	3	4	3.5	3	3	3.5	3	4.5	3	3	3		3.5	3	3	4.5	3.37	3	0.48	1.5
8	3.5	3	3	3.5	3	3	3	3	3	4	3	3	2.5	3	3.5	3	2.5	4	3.13	3	0.34	1.5
9	3.5	3.5	3	4	3.5	3	3	3	3	4.5	3	3	3	3	3.5	3	3	4.5	3.28	3	0.45	1.5
10	4	3.5	2.5	4	4	3	3	3.5	3	4	3	3	3	3.5	3.5	3	2.5	4	3.34	3.25	0.47	1.5
11	4	4	3				3	3.5	3.5	3.5		3	3	4	3	3	3	4	3.38	3.25	0.43	1
12	4.5	4.5	3.5	3	4.5	5	4.5	4.5	2.5	4.5	3	3	3	4	4.5	2.5	2.5	5	3.81	4.25	0.85	2.5
14	3.5	4	3.5	4	4	3	4	3.5	3	4	4	3	3	4.5	4	2.5	2.5	4.5	3.59	3.75	0.55	2
15	4		3.5	3.5	4	4	4	4	3	4	4	3	3	4	3.5	3	3	4	3.63	4	0.44	1
16	3.5						4	4	3	4			3.5		4	3	3	4	3.63	3.75	0.44	1
17			3				4	4	3		4	3			3.5	3	3	4	3.44	3.25	0.50	1
18	3.5		4	4	4	3	3.5	4	3	4	3.5	3.5	3.5	4	3.5	3	3	4	3.60	3.5	0.39	1
19	4	4	3.5	4	4	3.5	4	4	4	4		3.5		4	4	3	3	4	3.82	4	0.32	1
20	4	4	4			4.5	4	4	4	4		4	3.5		4	3	3	4.5	3.92	4	0.36	1.5
21	4	4.5	4	4	4	4	4	4	3	4	3.5	4	4	4	4	3	3	4.5	3.88	4	0.39	1.5
22	4.5	4.5	4	4		5	4.5	3.5	3	4.5	4	4		4	4	3.5	3	5	4.07	4	0.51	2
23	4	4	4	4		4		4		4	4		4		4		4	4	4.00	4	0.00	0
24	4		4			4	4	4	3	4	4	3.5	4	4	4	3.5	3	4	3.85	4	0.32	1
25		4	3.5	3.5	3	5	4.5	4	2.5	4	4.5	3	3	5.5		3	2.5	5.5	3.79	3.75	0.87	3
26			3.5	4		5	4.5	4	2.5	4	4	3	3	5.5		3	2.5	5.5	3.83	4	0.89	3
27			3	3.5		5	4.5	3.5	2.5	4	3.5	3	3	5.5		2.5	2.5	5.5	3.63	3.5	0.96	3
28		4.5	4	4	4	5	4.5	4	2.5	4	4.5		3	5		3	2.5	5	4.00	4	0.76	2.5
29		4	4	4		4.5	4	3.5	2.5	4	4.5	3	3.5	5.5		3	2.5	5.5	3.85	4	0.77	3
30	3	3.5	3	3.5				3.5		3.5	3	3	3		3.5	3	3	3.5	3.23	3	0.26	0.5
31	4	4.5	3.5	4		3.5	4	3	3	3.5	3.5	3	3	4.5	3.5	3	3	4.5	3.57	3.5	0.53	1.5
32	4	4	3.5	4	4	3.5	3.5	3.5	3	4	4	3	3.5	4	4	3	3	4	3.66	3.75	0.40	1
33	4.5	4.5	2.5	4.5	5	3.5	4	3	3	4	3.5	4	2.5	4.5	3.5	3	2.5	5	3.72	3.75	0.77	2.5
34	4	4.5		3.5	3	4	4	3.5	3	4		3.5		4	3.5		3	4.5	3.71	3.75	0.45	1.5
35	3	3	3	4	4	3	3	3.5	2.5	3.5	3	4	3	4	3.5	3	2.5	4	3.31	3	0.48	1.5
36	3	3	3	4	4	3	3	3.5	2.5	3.5	3	3	3	4	3.5	3	2.5	4	3.25	3	0.45	1.5
37	4	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4	3	4	3.94	4	0.25	1
38	4	4.5	3.5	4	2.5	3.5	4	4	2.5	4	3	3	3	4.5	3.5	2.5	2.5	4.5	3.50	3.5	0.68	2
39	4.5	4.5	4	3.5	4	4	4.5	4	3	4	3.5	3	3	5	3	2.5	2.5	5	3.75	4	0.71	2.5
40	4.5	4	4	4	4.5	4.5	4.5	3.5	3	4	3.5	3	2.5	4.5	3	2.5	2.5	4.5	3.72	4	0.73	2
41	4	4.5	4.5	3.5	4	4.5	4	3	3	4	3.5	3	2.5	4.5	3	3	2.5	4.5	3.66	3.75	0.68	2
42	4	4.5	4	3.5	4	4	4.5	4	2.5	4	3.5	3	3	5	3.5	3	2.5	5	3.75	4	0.66	2.5
43	4.5	4	4	4		4.5	4	4	2.5	4	3.5	3	3	5	3	3	2.5	5	3.73	4	0.70	2.5
44	4.5	4.5	4	4	4	4.5	4		2.5			3	3		3	3	2.5	4.5	3.67	4	0.72	2
45	4	4.5	4.5	4	3.5	4.5	4	4	2.5	4	3.5	3.5	3	5	3	3	2.5	5	3.78	4	0.68	2.5
46	4.5	4.5	4	3.5		4.5	4.5	4	3	4	3	7	2.5	5.5	3	2.5	2.5	7	4.00	4	1.20	4.5
47	3.5	4.5	4	3	4	4	4.5	4	3.5	3.5	3.5	3.5	2.5	5.5	3	3	2.5	5.5	3.72	3.5	0.73	3
48	3.5	4.5	4.5	4	5.5	4	4	4	3.5	3.5	4		2	5.5	3	2.5	2	5.5	3.87	4	0.95	3.5
49	3.5	5	4.5	4	5.5	4.5	4.5	4	3.5	3	4.5		2	6	3	2.5	2	6	4.00	4	1.10	4

Table 3A-2 Ratings And Statistics For Driver B

	Configuration																Statistics					
Question Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Minimum	Maximum	Mean	Median	Standard Deviation	Range
1	4	3	5	3	3	4	4	3	3	5	4	3	3	4	4	4	3	5	3.69	4	0.70	2
2	5	5	5	3	4	5	5	5	5	5	4	2	4	5	4	5	2	5	4.44	5	0.89	3
3	3	3	3	4	3	3	4	3	2	4	3	2	3	5	3	3	2	5	3.19	3	0.75	3
4	4	4	4	4	4	4	4	4	4	5	4	3	4	4	4	4	3	5	4.00	4	0.37	2
5	5	5	4	5	4	4	5	4	4	5	3	4	4	4	4	4	3	5	4.25	4	0.58	2
6		5	4	3	4	4	5	4	4	5	4	4	4	4	4	4	3	5	4.13	4	0.52	2
7	4	3	3	2	3	3	3	3	2	2	3	2	3	2	2	2	2	4	2.63	3	0.62	2
8	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2.13	2	0.34	1
9	3	4	2	3	3	3	3	3	2	2	3	2	2	2	2	2	2	4	2.56	2.5	0.63	2
10	3	4	2	2	3	2	3	2	2	2	3	2	2	2	2	2	2	4	2.38	2	0.62	2
11	4	4	4			3	3		3	3	4	2	2	4	2	2	2	4	3.08	3	0.86	2
12	5	5	5	5		3	5		5	5	2	2	1	5	2	3	1	5	3.79	5	1.53	4
14	4	3	3	2	3	3	3		3	2	2	2	3		3	3	2	4	2.79	3	0.58	2
15	4	4	4	5		4	4	4	4	4	4	4	4	4	4	4	4	5	4.07	4	0.26	1
16	4	4	4	5		4	4	4	4	4	4	4	4	4	4	4	4	5	4.07	4	0.26	1
17	4	4	4	5		4	4	4	4	4	4	4	4	4	4	4	4	5	4.07	4	0.26	1
18	4	4	4		4	4	4	4	4	4	4	4	4	4	4	4	4	4	4.00	4	0.00	0
19	4	4	4	5	4	4	4	4	4	4	4	4	4	5	4	4	4	5	4.13	4	0.34	1
20	4	4	4	5		4	4	4	4	4	4	4	4	5	4	4	4	5	4.13	4	0.35	1
21	5	4	5	5	5	4		4	4	5	6	5	5	5		3	3	6	4.64	5	0.74	3
22	4	4	4	4	4			5	4	4		3	3	6		4	3	6	4.08	4	0.79	3
23		5	5	5	3			3	4	4	5	4		4		3	3	5	4.09	4	0.83	2
24	5	5		5	3			5	4	5	5	4	5	6		3	3	6	4.58	5	0.90	3
25	3	3	4	3	3	3	4	4	3	4	2	3	3	4	2	3	2	4	3.19	3	0.66	2
26	3	3	3	3		3	4	3	3	3	3	2	2	3	2	4	2	4	2.93	3	0.59	2
27	2	2	3	3		3	5	3	3	3	2	2	1	5	1	5	1	5	2.87	3	1.30	4
28	4	3	3	5	3	3	4	3	2	4	4		3	5	2	4	2	5	3.47	3	0.92	3
29	4	3	3	5	5	3	3	5	2	4	3	3	2	5	2	4	2	5	3.50	3	1.10	3
30												3										0
31	4	4	4	4		4	4	4	4	4	1	2	1	4	1	3	1	4	3.20	4	1.26	3
32	4	3				4	3	3	3	2		3	3	4	4	4	2	4	3.33	3	0.65	2
33	4	5	4	4		4	5	4	4	4		4	1	4	2	4	1	5	3.79	4	1.05	4
34		5	4	5		4	5	5	5	5		4		5	2	3	2	5	4.33	5	0.98	3
35	4	4	4	4	4	4	4	4	4	4		4			4		4	4	4.00	4	0.00	0
36	4	4	4	4	4	4	4	4	4	4		2			4		2	4	3.83	4	0.58	2
37	4	3	4	4	4	4	4	4	4	4		2	4		4		2	4	3.77	4	0.60	2
38	4		3	2		3	3	3	3	3	2	2	1	3	1	5	1	5	2.71	3	1.07	4
39	4		5	5		4	5	5	3	5	2		1	5	1	5	1	5	3.85	5	1.57	4
40	4		5	5		4	5	5	5	5	2	2	1	5	1	5	1	5	3.86	5	1.61	4
41	4					4	5	4			2	2		5			2	5	3.71	4	1.25	3
42	3	2	3	3	3	3	3	3	3	3	3	2	1	3	1	5	1	5	2.75	3	0.93	4
43	4	3	5	5	4	4	5	5	3	5	3		1	5	1	5	1	5	3.87	4	1.41	4
44	5	5	5	5	5	4	5	5	5	5	3		1	5	1	5	1	5	4.27	5	1.44	4
45	4	3				4	5	4				2		5			2	5	3.86	4	1.07	3
46								5				3		5			3	5	4.33	5	1.15	2
47	5	3	5		5	3	5	5		3	4	2	2	5	2	4	2	5	3.79	4	1.25	3
48	5	4	5		5	4	5	5		4	4	2	2	5	2	4	2	5	4.00	4	1.18	3
49	5		5		5	3	5	5		3	4	1	2	5	2	4	1	5	3.77	4	1.42	4

Table 3A-3 Ratings And Statistics For Driver C

	Configuration																Statistics					
Question Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Minimum	Maximum	Mean	Median	Standard Deviation	Range
1	2	3	4	4	2	4	2.5	3	4	3	2	2.5	1	4	2	4	1	4	2.94	3	0.98	3
2	3	2.5	4	4	4	4.5	2.5	4	4	4	3.5	4	2	4	2.5	4	2	4.5	3.53	4	0.76	2.5
3	4	4	2.5	4.5	1	3.5	5	2	2	4.5	3	3.5	2	2	2	3	1	5	3.03	3	1.16	4
4	2	3	4	4	4	4.5	3	4	3.5	3.5	4	3.5	2.5	4	2.5	3.5	2	4.5	3.47	3.5	0.69	2.5
5	5	2.5	3.5	3.5	3	5	3	6	3	5	5	4	2	3	3	4	2	6	3.78	3.5	1.13	4
6	3	3	4	3	2	3.5	2.5	5	2	4.5	4	3	1	2	3	5	1	5	3.16	3	1.14	4
7	3	3	4.5	4	1	3.5	3	3	2.5	3	3	3.5	2	2	3.5	3	1	4.5	2.97	3	0.83	3.5
8	2	2	4	2	1	3	2	2	2.5	3	2.5	2	1.5	2	2.5	2	1	4	2.25	2	0.68	3
9	2	2	2.5	2.5	2	3.5	2	2	2.5	2.5	2.5	2.5	2	2	3	2	2	3.5	2.34	2.25	0.44	1.5
10	4	4	3	4	3	4	3	4	3	4	3	4	4	4	4	4	3	4	3.69	4	0.48	1
11	4	4	4	4	4	4	4	4	4	4	4	3	4	3	4	4	3	4	3.88	4	0.34	1
12		3	2.5	3.5	3	4	4	4	3	5	3	4	2	4	2	3	2	5	3.33	3	0.84	3
14	4	4	3	4	3	4	4	3	4	4.5	4	4	2	4	3	4	2	4.5	3.66	4	0.65	2.5
15	3	3	3	4	5	5	2	3	4	5	5	3	3	4	3	4	2	5	3.69	3.5	0.95	3
16		4	3.5	4.5	4	5	3.5	4	4	4	3	4	3	4	3	3.5	3	5	3.80	4	0.56	2
17	4	3	2.5	4.5	3	4.5	4	4	3	4	4	4	3		2	3	2	4.5	3.50	4	0.76	2.5
18	4	3	4	4	3	4	3	4	3.5	3.5	4	4	3.5	4	3.5	4	3	4	3.69	4	0.40	1
19	3	2.5	3	4	3	4.5	4	4	3.5	4	4	3	4.5	4	3	3.5	2.5	4.5	3.59	3.75	0.61	2
20	4	3	2	4.5		4.5	4	4	3	4.5	4	3.5	4		2.5	4	2	4.5	3.68	4	0.77	2.5
21	5	3	4.5	4	2	5.5	3	4	3.5	5.5	4.5	4.5	3.5	5	4.5	5	2	5.5	4.19	4.5	0.98	3.5
22	5	4	3.5	4	2	4	5	3	2.5	4	3	4	2	3	3	3.5	2	5	3.47	3.5	0.90	3
23						6	3			6				4		5	3	6	4.80	5	1.30	3
24	4	4	4		4	6	3	5	4.5	6	4	5	1	5	4	5	1	6	4.30	4	1.22	5
25	5	5	2.5	3	3	4.5	3	5	4.5	5	5	5	3	3	2	3	2	5	3.84	3.75	1.11	3
26	3	4	2.5	3		4	3	5	4	4	4	3.5	2.5	3	2	3	2	5	3.37	3	0.79	3
27	2	3	2	2.5		4.5	2	6	3	4	3	4	2	4	2	2	2	6	3.07	3	1.21	4
28	4	5	3	4	1	4	5	3	2	3.5	4		2	3	2.5	2.5	1	5	3.23	3	1.13	4
29	3	5	2.5	4.5	2	3	5	4	2	4	2	4	2.5	4	2.5	3	2	5	3.31	3	1.05	3
30		4					3	3				5					3	5	3.75	3.5	0.96	2
31	4	5	4	4.5	3	4	4	4	4	3.5	4	4	3	4	3	3	3	5	3.81	4	0.57	2
32	4	3.5	3		3	4.5	4	4	4	4	4	3	4	4	3.5	4	3	4.5	3.77	4	0.46	1.5
33	4	3	3.5	3.5	3	4	3	6	4	4.5	3.5	3.5	2.5	4	2.5	3	2.5	6	3.59	3.5	0.86	3.5
34	4	3	3	4	4	4	3	4	3.5	4.5	3	4	3.5	4	2	2.5	2	4.5	3.50	3.75	0.68	2.5
35	4	3	4	4	3	4	4	5	4.5	4	4	4	4	4	4	2	2	5	3.84	4	0.68	3
36	4	3	4	4	3	4	4	5	4.5	4	4	2.5	4	4	4	2.5	2.5	5	3.78	4	0.68	2.5
37	4	4	4	4	4	4	4	4	4	4	4	4	3.5	3	4	4	3	4	3.91	4	0.27	1
38	5	3	2.5	2.5	3	5	2	5	3	5	3.5	3.5	2.5	2	2	3.5	2	5	3.31	3	1.12	3
39	2	3	3	5	2	5	5	5	2.5	4	3	3.5	2	5	2	2	2	5	3.38	3	1.27	3
40	3	4	4	5	3	6	4.5	5	3.5	4.5	3	2.5	3	5	2	3.5	2	6	3.84	3.75	1.09	4
41	2	3	3.5	5	2	5.5	5	5	2.5	4.5	3	4	2.5		2	2.5	2	5.5	3.47	3	1.26	3.5
42	5	3.5	3	3	3	5.5	3.5	5	3.5	5	4.5	4	2	3	2.5	4	2	5.5	3.75	3.5	1.02	3.5
43	4	3	3	5.5	3	5.5	5.5	5	3	4	3.5	3.5	2	5	2.5	3.5	2	5.5	3.84	3.5	1.14	3.5
44	4	3.5	4	5	3	6	6	5	3.5	4.5	4	3	1.5	5	2.5	3.5	1.5	6	4.00	4	1.22	4.5
45	5	3.5	4	5	3	6	5.5	5	3	4.5	3.5	3.5	2	4	2.5	3	2	6	3.94	3.75	1.14	4
46	3	4	2.5	5.5	3	5.5	5		3.5	5	4	3	2		2.5		2	5.5	3.73	3.5	1.20	3.5
47	5	5	2.5	3	3	4	4.5		2.5	4.5	4	3	1	5	2	2.5	1	5	3.43	3	1.24	4
48	5	5	3	3.5	3	3	6		2.5	4	3	3.5	1	5	2	3	1	6	3.50	3	1.31	5
49	5	5	2	3	2	3	5		2.5	3.5	4	2.5	2.5	5	2	3	2	5	3.33	3	1.18	3

Table 3A-4 Ratings And Statistics For Driver D

	Configuration																Statistics					
Question Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Minimum	Maximum	Mean	Median	Standard Deviation	Range
1	3.5	3	3.5	3.5	3	4	3.5	4	4	4.5	5	3.5	2	5	3	4.5	2	5	3.72	3.5	0.80	3
2	3	4	4.5	3	4	4.5	4	4	4	4.5	5	3	2.5	4.5	3	4	2.5	5	3.84	4	0.72	2.5
3	4	3.5	3.5	4	4	3.5	4	3.5	3	4	3.5	3.5	3.5	3.5	3.5	3.5	3	4	3.63	3.5	0.29	1
4	4	4	4	4	4	4	4	4	4	4	4	3.5	3	4		4	3	4	3.90	4	0.28	1
5	4.5	5	4.5	5	4.5	5	5	5	4.5	4.5	4	4	3	5	3.5	4.5	3	5	4.47	4.5	0.59	2
6	4.5	5	4.5	5	4	5	5	5	4.5	4.5	5	4	3	5	3.5	4.5	3	5	4.50	4.5	0.61	2
7	3.5	4	3.5	3	2	3.5	4	3.5	3.5	3.5	3.5	3	3.5	4	3	3.5	2	4	3.41	3.5	0.49	2
8	3	3	3	2	3	3	3	3	3	4	2	3	2	3	3	3	2	4	2.88	3	0.50	2
9	5	4.5	5	5	5	5	5	5.5	4.5	4.5	5	3.5	2	5	2	4.5	2	5.5	4.44	5	1.05	3.5
10	3.5	3.5	3	3.5	3	3.5	3.5	3	3.5	3.5	3	3	2	4	2	3	2	4	3.16	3.25	0.54	2
11	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	3	4	3.94	4	0.25	1
12	2.5	4.5	4.5	6	3.5	4.5	4	4.5	4.5	4.5	5.5	3	2	4.5	2	4	2	6	4.00	4.5	1.14	4
14	4	4	4	4.5	2.5	4	4	4	3.5	3.5	4	3	3	4	3	3.5	2.5	4.5	3.66	4	0.54	2
15	3	4	4	4		4	4	4	4	4	3.5	4.5	3	4	3.5	4	3	4.5	3.83	4	0.41	1.5
16	3	4	4	4		4	4	4	4	4	4	4	4	4		4	3	4	3.93	4	0.27	1
17	4	4	4	4			4	4	4	4	5	4	4			4	4	5	4.08	4	0.29	1
18	4	4	4	4		4	4	4	3.5	4	3.5	3.5	4	4	3.5	4	3.5	4	3.87	4	0.23	0.5
19	3	4	3	5	4.5	3.5	4.5	4	4	4	4	4.5	2.5	4		4	2.5	5	3.90	4	0.66	2.5
20	4	4	4	4		4	3.5	4	4	4		4	3			4	3	4	3.88	4	0.31	1
21	3.5	4	4.5	6	4.5	4	3.5	3.5	4	5		5	3	4		4	3	6	4.18	4	0.77	3
22	4	3.5	4	4	4	3.5	3.5	3.5	3.5	4.5	4	3.5	3.5	3.5	3	3.5	3	4.5	3.69	3.5	0.36	1.5
23	4	4	4	4	4	4	4	4	4	4		4	4	4		4	4	4	4.00	4	0.00	0
24	4	4.5	4.5	6	4.5	4	3.5	3.5	4	4.5		4	3.5	4		4.5	3.5	6	4.21	4	0.64	2.5
25	3	4.5	3.5	4	3.5	4.5	4	4.5	3	4.5	4	3	2	4	3	3	2	4.5	3.63	3.75	0.74	2.5
26	3	4	3.5	3.5		5	3.5	4.5	3	4.5	3.5	3.5	1	4	2.5	3	1	5	3.47	3.5	0.95	4
27	3	4	4	3		4.5	3.5	4	3.5	4.5	3	3	2	4	2.5	3.5	2	4.5	3.47	3.5	0.72	2.5
28	4	3.5	3.5	4	4	3.5	3.5	3.5	3	4	4	2	3.5	3.5	3	3.5	2	4	3.50	3.5	0.52	2
29	4	3	3	4	3.5	3.5	3.5	3	3	4	2.5	4	3.5	3	2.5	3	2.5	4	3.31	3.25	0.51	1.5
30	4	4	4	4	5.5	4.5	4	5	2.5	4	3	3.5	1	3.5	1	2	1	5.5	3.47	4	1.28	4.5
31	2	4	4	4		4	4	4	4	4	3.5	3.5	1	3	2	4	1	4	3.40	4	0.97	3
32	4	4	4	4	3	4	4	4	4	3.5	4.5	3.5	2	4	3	4	2	4.5	3.72	4	0.60	2.5
33	3	4	4	4	3.5	4	4	4	4	4	4	4	3	4	3	3.5	3	4	3.75	4	0.41	1
34	4	4.5	4.5	4		5	4	4.5	4	4.5	5	4	2	5	3.5	4.5	2	5	4.20	4.5	0.75	3
35	4	4	4	4		4	4	4	4	4	4	4	4	4	4	4	4	4	4.00	4	0.00	0
36	4	4	4	4	4	4	4	4	4	4	4	3.5	4	4	4	4	3.5	4	3.97	4	0.13	0.5
37	4	4	3.5	4		4	4.5	4	4	4		2.5	4	4	3.5	4	2.5	4.5	3.86	4	0.46	2
38	3	4	3.5	5	3.5	4.5	3	4.5	3.5	4	4	2.5	2	3		4.5	2	5	3.63	3.5	0.83	3
39	3.5	4.5	4	6	3	4.5	4.5	4.5	4	4.5	5	2.5	1	3		3	1	6	3.83	4	1.21	5
40	3.5	4.5	4	6	3	4.5	5	4.5	4.5	4.5	5.5	3.5	1	3.5		3.5	1	6	4.07	4.5	1.18	5
41	4	4	4	4	3	4	4	4		4		3		4		4	3	4	3.83	4	0.39	1
42	3	3.5	4.5	4.5	3.5	5	3	4.5	3.5	4	3.5	3	2.5	3.5	3	4.5	2.5	5	3.69	3.5	0.73	2.5
43	3	4	4.5	6	3	5	4.5	5	4	4.5	5	3	2.5	3	3	3.5	2.5	6	3.97	4	1.01	3.5
44	3	4	4.5	6	3	5	4.5	5	4.5	4.5	5.5		2.5	3.5	2.5	3.5	2.5	6	4.10	4.5	1.07	3.5
45	4	4	4	4		4	4	4		4		3		4	2.5	4	2.5	4	3.79	4	0.50	1.5
46		4	5			4.5	4	4.5				3		3		3.5	3	5	3.94	4	0.73	2
47	4	4	3.5	4	4.5	4	4	4	3.5	4	4.5	2	2.5	3	2	3.5	2	4.5	3.56	4	0.79	2.5
48	5	5	4	5	5	4.5	4.5	4.5	3	3.5	3.5	3	2	4.5	2	3	2	5	3.88	4.25	1.04	3
49	5	5	4	5	5	4.5	5	4.5	3	3	4	3	2.5	4.5	2.5	3.5	2.5	5	4.00	4.25	0.95	2.5

Table 3A-5 Ratings And Statistics For Driver E

	Configuration																Statistics					
Question Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Minimum	Maximum	Mean	Median	Standard Deviation	Range
1	3	2.5	5	4	4	5.5	5	5.5	6	5	4	3	4	5	3	4	2.5	6	4.28	4	1.05	3.5
2	3	3.5	5	3	5.5	4	5.5	5	6	3.5	4	2.5	5	3	4	3.5	2.5	6	4.13	4	1.07	3.5
3	4.5	3	6	5	5	3	6	5.5	2	5.5	4.5	2.5	4	6	4	3	2	6	4.34	4.5	1.33	4
4	3	4	5	4	5	4	4	5	5	4	4	3.5	4	5	4	4	3	5	4.22	4	0.60	2
5	3	3	4	4	3.5	5	4	5.5	5	6	2.5	3.5	3	4	4	2.5	2.5	6	3.91	4	1.04	3.5
6	3	3	4			5	4	5.5	4	6	4	3	4		4	3	3	6	4.04	4	0.97	3
7	4	3	3	2	3	4		3.5		4	2	4	3	3	4	4	2	4	3.32	3.25	0.72	2
8	4	4	3	3	3	4		3.5		4	2	4	3	3	4	4	2	4	3.46	3.75	0.63	2
9	3	3	3	3	4	4	3	4	4	3	3	3	3	3	4	3	3	4	3.31	3	0.48	1
10	3	3	3	4	4.5	4	3	4	5	4	3	4	3	3.5	4	4	3	5	3.69	4	0.63	2
11	4	4	6	4	3	4	4	4	1	4	4	4	4	4	4	4	1	6	3.88	4	0.96	5
12	5	4	5.5	3.5	5	4.5	6	5.5	5	4.5	2	2.5	4	3	3	4	2	6	4.19	4.25	1.15	4
14	3.5	5		5	5	4	4	4	3	4	5	4	3	5	3.5	4	3	5	4.13	4	0.72	2
15	4.5	2	3	3	5	4	5	3	3.5	5	5	4	4	5	4.5	4	2	5	4.03	4	0.92	3
16	3	4.5	4	5	5	4	5	4	4	5	4	2	3	5	3.5	3	2	5	4.00	4	0.91	3
17	2.5	4.5	5	3.5	5	4	4	6	5	5	4	3	3		3.5	2.5	2.5	6	4.03	4	1.04	3.5
18	5	3.5	4	5	4	3	4	3	4	3	4	2.5	4	5	4.5	3	2.5	5	3.84	4	0.79	2.5
19	3	3.5	4	5	6	3.5	4	4	5	3	5	4	4	5	3	4	3	6	4.13	4	0.87	3
20	3	4	4	4	6	4.5	5	5	5.5	5		3	3.5	3	2	3	2	6	4.03	4	1.13	4
21	3	2.5	5	5.5	4	5.5	3.5	6.5	3	6.5	5.5		5	5	3	6	2.5	6.5	4.63	5	1.36	4
22	4	2.5	5	5	4	4	5	6	2.5	6	4	3	4	6	4	4	2.5	6	4.31	4	1.12	3.5
23	4	4	5	5	4	4.5	4	6.5	4	6.5	5	4	4.5	6	4	4	4	6.5	4.69	4.25	0.91	2.5
24	4	4	6	5	4	5	5	6.5		6.5	5	5	4	5.5	4	5	4	6.5	4.97	5	0.88	2.5
25	5	3	3.5	5	5	4	5	4	3	5	2	3.5	4	4.5	2.5	3	2	5	3.88	4	0.99	3
26	5	3	3	5	5	4	4	3.5	2.5	5	2	2.5	4	4.5	2.5	3	2	5	3.66	3.75	1.04	3
27	3	2.5	3	5	5	3.5	5	3	3.5	6	2	2.5	3.5	4.5	2	2.5	2	6	3.53	3.25	1.22	4
28	4	2.5	5	4.5	5	3	6	5.5	2	5.5	4		3	6	3.5	3	2	6	4.17	4	1.30	4
29	4	2.5	5	5	5	3	6	5	2	5	4.5	3	5	6	3	2.5	2	6	4.16	4.75	1.30	4
30												3					3	3	3.00	3	#DIV/0!	0
31	7	5	5	4	6.5	6	5.5	6	4	4.5	2	3	4	3.5	4	2.5	2	7	4.53	4.25	1.43	5
32	3.5	5		4.5	5	4	4	4	3.5	4	5	2.5	3	5	4	4	2.5	5	4.07	4	0.75	2.5
33	3.5	3.5		4	4	6	4	6		4	4	3	3	4	4	3	3	6	4.00	4	0.94	3
34	3	4.5		4	4	4.5	5	5.5	5	6	3	4	3.5	3	3	4	3	6	4.13	4	0.95	3
35	4	3	4.5	5	4	3	4	3	4	3	4	3.5	4		5	3.5	3	5	3.83	4	0.67	2
36	4	3	4.5	5	4	4	5	4	4.5	4	4	4	4	5	4	3	3	5	4.13	4	0.59	2
37	4	5	3	4	4	5	4	5	4	5	4	2	3	3.5	2.5	3	2	5	3.81	4	0.93	3
38	5	2		3.5	4.5	4	5.5	2.5		5.5	5	2.5	4.5	3	2	2.5	2	5.5	3.71	3.75	1.30	3.5
39	3	3		5	4	3.5	6	5		3	2		2	4.5	2	2.5	2	6	3.50	3	1.31	4
40	3	4.5		5	4	4	6	5		3	2	4	3	4	3	3	2	6	3.82	4	1.07	4
41												2.5					2.5	2.5	2.50	2.5	#DIV/0!	0
42	5	2	2.5	3.5	4.5	4	3	2.5	2	5	5	3	5	3	2	2.5	2	5	3.41	3	1.17	3
43	3	3	6	4.5	4	3	6	5	3	3.5	2		3.5	5	2	3	2	6	3.77	3.5	1.28	4
44	3	4	5	5	4	3	6	5	3	3.5	2		4	4	3	3.5	2	6	3.87	4	1.04	4
45												2					2	2	2.00	2	#DIV/0!	0
46				5								2		5			2	5	4.00	5	1.73	3
47	4		4	5	4.5	4	6	5.5	3	5	2.5	2	2.5	6	3	3	2	6	4.00	4	1.31	4
48	4		4		4.5	4	6	5	2.5	4	3	3	3	5	4	3	2.5	6	3.93	4	0.98	3.5
49	4		4	5	4.5	3	5.5	5.5	2.5	3	2.5	2	2	6	2	2.5	2	6	3.60	3	1.42	4

Table 3A-6 Ratings And Statistics For Driver F

	Configuration																Statistics					
Question Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Minimum	Maximum	Mean	Median	Standard Deviation	Range
1	5	4	3	4	3	6	4	5.5	4	5	3	1	1	3.5	1	6	1	6	3.69	4	1.65	5
2	5	3.5	3.5	4	5	6	5	5.5	4	5	4	3	3	5	2	6	2	6	4.34	4.5	1.15	4
3	5	3.5	3.5	4.5	3	5	4	6	2.5	6	3	4	3.5	3.5	3	6	2.5	6	4.13	3.75	1.16	3.5
4	5	4	3.5	4	4	6	4	5.5	4	5	4	2	2	3.5	2	6	2	6	4.03	4	1.28	4
5	5	3.5	3.5	4	3	5	5	5.5	3	3	3	3	4.5	4	4	5	3	5.5	4.00	4	0.89	2.5
6	5	4	4	4	3	5	4	5.5	3	4	4	3	4	4	5	5	3	5.5	4.16	4	0.77	2.5
7	3	2	2	3	2	3	3	2	1	3	2	2	2	2.5	2	3	1	3	2.34	2	0.60	2
8	2	1	1.5	2	1	2	3	1	1	2	1	2	2	2	2	2.5	1	3	1.75	2	0.61	2
9	5	3.5	3	4.5	3	5	5	5	1	3	4	4	3.5	4	4	3	1	5	3.78	4	1.06	4
10	4	3	3	4.5	3	4	4	3	1.5	3	3	3	3	3.5	3	4	1.5	4.5	3.28	3	0.71	3
11	4	4	4	4	4	4	4	4	5.5	4	4	4	4	4	3	5	3	5.5	4.09	4	0.52	2.5
12	4	5	4.5	4	5	5	5	5	3	5	4	6	3.5	4.5	2	5	2	6	4.41	4.75	0.97	4
14	2	3	2	3	2	3	2	2	1.5	2	3	2	2	3	3	4	1.5	4	2.47	2	0.67	2.5
15	4	4	2	3	5	5	4	4.5	1.5	4	3	4	4	3.5	3	6	1.5	6	3.78	4	1.13	4.5
16	4	4	4	4	5	5	5	5.5	5.5	2	4	5	4	4	4	6	2	6	4.44	4	0.95	4
17	4	4	4	3.5	4	5	5	6	6.5	6	4	5	4	4	4	7	3.5	7	4.75	4	1.08	3.5
18	4	4	4	3.5	4	5	5	4	3	6	5		3	4	4	4	3	6	4.17	4	0.79	3
19	5	3	2	3.5	5	5	5	6	1.5	2	5	5	5	3.5	3	7	1.5	7	4.16	5	1.56	5.5
20	4	5	6	4.5	5	6	6	5.5	6.5	6	5	5	5	5	5	7	4	7	5.41	5	0.78	3
21	2	5	6	5	5	6	4	5	6.5	6	5	4	4	5	5	6	2	6.5	4.97	5	1.10	4.5
22								5	5.5								5	5.5	5.25	5.25	0.35	0.5
23																						
24																						
25	5	3	3	3.5	5	5	4	3.5	1.5	3	4	5	2	4.5	3	4.5	1.5	5	3.72	3.75	1.09	3.5
26	4	3	3	3.5	5	5	4	3.5	2.5	4	3	4	2	4.5	2	5	2	5	3.63	3.75	0.99	3
27	4	2.5	3	4	5	5	4	3	2.5	5	2	4	3	4	1	5	1	5	3.56	4	1.20	4
28	5	3.5	3.5	4.5	3	5	3.5	5	1.5	6	2		3.5	3.5	3	3.5	1.5	6	3.73	3.5	1.19	4.5
29	3.5	4	3.5	4.5	3	4	4	5	1.5	5	2	2	4	3.5	3	3.5	1.5	5	3.50	3.5	1.02	3.5
30												3					3	3	3.00	3	#DIV/0!	0
31	4	4	4	3.5	5	6	5	6.5	1.5	5	5	2	4	4	4	3	1.5	6.5	4.16	4	1.30	5
32	2	4	3	4	2	3	3	3	2.5	3	3	5	2	3.5	3	4	2	5	3.13	3	0.83	3
33	4	4	4	4	4	5	4	5.5	2.5		5		3	4	4	4	2.5	5.5	4.07	4	0.76	3
34	5	5	3.5	4	5	5	5	5.5	3		5		4	4	4	5	3	5.5	4.50	5	0.73	2.5
35	4	4	4	4	5	5	5	4.5	2.5	6	5		4	4	4	4	2.5	6	4.33	4	0.79	3.5
36	4	4	4	4	5	5	5	4.5	3	5	5	2	4	4	4	4	2	5	4.16	4	0.81	3
37	4	4	4	4	5	6	5	4.5		6	5	2	4	4	4	3.5	2	6	4.33	4	0.99	4
38	5	3	3	5	4	5	3	3	1.5	6	5	2	3.5	4.5	3	5	1.5	6	3.84	3.75	1.27	4.5
39	5	5	4.5	6	5	6	6	5	4	6	4	2	3.5	5	3	5	2	6	4.69	5	1.15	4
40	4	5	4.5	6	6	6	6.5	5	3	6	4	2	3.5	5.5	2	5	2	6.5	4.63	5	1.43	4.5
41	4		4.5	3.5	5	6	6	5		6	4	2	4		3	6	2	6	4.54	4.5	1.28	4
42	5	3.5	3.5	5	3	5	3	3.5	1.5	6	5	2	3.5	4.5	3	6	1.5	6	3.94	3.5	1.33	4.5
43	4	5	4.5	6	5	7	6	5	4.5	6	4		3.5	5	2	5	2	7	4.83	5	1.21	5
44	4	5	5	6	6	7	6.5	5	4	5	4		4	5.5	3	6	3	7	5.07	5	1.12	4
45		4	4.5	3.5		6	6	5		5	5		4	4.5	3	6	3	6	4.71	4.75	0.99	3
46																						
47							5	6	2.5			2					2	6	3.88	3.75	1.93	4
48							5	5.5	1.5			2					1.5	5.5	3.50	3.5	2.04	4
49							5	6	1.5			1					1	6	3.38	3.25	2.50	5

Table 3A-7 Ratings And Statistics For Driver G

	Configuration																Statistics					
Question Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Minimum	Maximum	Mean	Median	Standard Deviation	Range
1	3	3	4	3	4	3	3	4	2	4	4	2	3	4	4	4	2	4	3.38	3.5	0.72	2
2	3	4	4	4	3	4	4	4	3	5	2	2	3	4	3	3	2	5	3.44	3.5	0.81	3
3	3	3	5	3		5	3	3	3	3	5	5	3	5	4	5	3	5	3.87	3	0.99	2
4		4	4	3	4	4	4	4	3	3	4			4			3	4	3.73	4	0.47	1
5	4	3	5	5	6	4	5	5	4	5	5	2	3	5	2	5	2	6	4.25	5	1.18	4
6	5	3	5	3	5	4	5	5	5	5	3	5	6	5	6	5	3	6	4.69	5	0.95	3
7	3	4	3	4	2	3	4	3	3	3	1	2	3	2	6	3	1	6	3.06	3	1.12	5
8	2	3	2	2	3	2	3	3	3	3	1	3	3	3	4	4	1	4	2.75	3	0.77	3
9	5	4	4	4	5	4	5	4	4	5	3	5	5	3	4	5	3	5	4.31	4	0.70	2
10	4	4	4			4	4	4	4	5							4	5	4.13	4	0.35	1
11	4	4	4	4	4	2	4	4	4	3	4	4	3	4	4	4	2	4	3.75	4	0.58	2
12	5	4	4	4	5	4	4	4	2	5	2	2	2	4	1	2	1	5	3.38	4	1.31	4
14	4	4	4	5	4	5	4	4	3	4	3	3	3	3	2	3	2	5	3.63	4	0.81	3
15	3	3	4	3	4	3	3	4	3	5	4		3	4	3	4	3	5	3.53	3	0.64	2
16	4	4	4	4	4	4	4	4	4	5	4			4	3	4	3	5	4.00	4	0.39	2
17	4	4	5	4	4	4	5	4	4	5	4		5	4	2	4	2	5	4.13	4	0.74	3
18	3	4	3			4	3	3	4	3	4	3	2	3	2	3	2	4	3.14	3	0.66	2
19	4	4	3	2	5	5	5	3	4	5	4		5	5	3	5	2	5	4.13	4	0.99	3
20		4	3	6	5	4	5	3	4	5	4		6	5	5	5	3	6	4.57	5	0.94	3
21	4	5	5	6	3	5	5	4	4	7	5		5	5	4	5	3	7	4.80	5	0.94	4
22	2	4	3	5	4	4	4		5	6	4	5	4	5	4	5	2	6	4.27	4	0.96	4
23	3	4	5	6	3	5	5	4	3	6	5	5	6	5	4	5	3	6	4.63	5	1.02	3
24	3	4	5	6	3	4	5	4	5	6	5	5	6	5	4	5	3	6	4.69	5	0.95	3
25	3	3	3	5	2	3	3	4	2	4	2	4	5	3	3	4	2	5	3.31	3	0.95	3
26	3	3	3	4		3	3	4	3	5	3	5	4	4	2	3	2	5	3.47	3	0.83	3
27	3	3	3	3		2	2	4	3	5	3	5	3	3		3	2	5	3.21	3	0.89	3
28	3	3	3	5	4	4	3	3	3	3	5	3	2	5	3	3	2	5	3.44	3	0.89	3
29		3	3	4		4	3	3	2	3	3	2	2	5	3	3	2	5	3.07	3	0.83	3
30		3	4				4		2	5	2	3	3	4	1	1	1	5	2.91	3	1.30	4
31	4	4	4	5	4	4	4	4	3	5	3	2	3	4	2	3	2	5	3.63	4	0.89	3
32	4	4	5		3	5	4	5	4	3	3	3	3	3	3	3	3	5	3.67	3	0.82	2
33	4	3	4	4	4	4	4	4	4	4	2	4	2	4	2	3	2	4	3.50	4	0.82	2
34	5	4	4	4	4	4	4		3	3	4	4	3	5	2		2	5	3.79	4	0.80	3
35	4	4	4	4	4	4	4	4	4	4	4		4	4	5	4	4	5	4.07	4	0.26	1
36	4	4	4	4	4	4	4	4	4	4	4	4	4	3	5	4	3	5	4.00	4	0.37	2
37	4	4	4	4		4	4	4	4	4	4	4		4		4	4	4	4.00	4	0.00	0
38	4	2		5	3	4	2	4	2	5	5	4	5	4	3	4	2	5	3.73	4	1.10	3
39	3	5		5	2	3	5	4	3	6	3	4	3	3	1	6	1	6	3.73	3	1.44	5
40	3	5		5	2	3	5	4	2	6	2	3	2	3	1	6	1	6	3.47	3	1.60	5
41	4	5		3		3	5		2	6	3	2	2	3	1		1	6	3.25	3	1.48	5
42	4	3	3	5	3	3	3	4	3	5	5	2	5	4	1	4	1	5	3.56	3.5	1.15	4
43	3	5	5	6	2	3	5	4	3	6	3	2	3	4	1	3	1	6	3.63	3	1.45	5
44	3	5	5	7	2	3	5	4	2	6	2	2	3	3	1	2	1	7	3.44	3	1.71	6
45	4	5		5		3	5		2	5	3	5	3	3	1	3	1	5	3.62	3	1.33	4
46		3		6		3	5	4	2	6	3	4	3	3	1	2	1	6	3.46	3	1.51	5
47	4	2	3	5	2	3	4	6	4	4	2	6	3	5	2	2	2	6	3.56	3.5	1.41	4
48	4	4	4	4	2	4	5	6	3	3	2	3	3	5	1	3	1	6	3.50	3.5	1.26	5
49	4	2	3	4	3	3	3	6	3	3	2	2	2	5	3	2	2	6	3.13	3	1.15	4

Table 3A-8 Ratings And Statistics For Driver H

	Configuration																Statistics					
Question Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Minimum	Maximum	Mean	Median	Standard Deviation	Range
1	3	3	3	3	4	5	3	4.5	4	5	4	3	3.5	4	3	4	3	5	3.69	3.75	0.73	2
2	3	3	3	4	3.5	4.5	4	4.5	5	5	4	3	3.5	4	3.5	4	3	5	3.84	4	0.68	2
3	4	5	3	2.5	3.5	5	4	5	5	4.5	3	3	4	4	3	4	2.5	5	3.91	4	0.84	2.5
4	4.5	4	3	5	4	5	5	4	4	5	5	4	4.5	4	4	4	3	5	4.31	4	0.57	2
5	4	5	5	5	4.5	5	3.5	5	4	5	4	4.5	4	4	3.5	4.5	3.5	5	4.41	4.5	0.55	1.5
6		5		6	4	5	3.5	5			4			4			3.5	6	4.56	4.5	0.82	2.5
7	4	4	4.5	4	4.5	5	3.5	4.5	4.5	4.5	4	4	4	5	3.5	3.5	3.5	5	4.19	4	0.48	1.5
8	4	5	4.5	5	3.5	5	3.5	4.5	4.5	4.5	4	4	4	6	4	3.5	3.5	6	4.34	4.25	0.68	2.5
9	3	3	4	2	4	5	4.5	4.5	4.5	4.5	3	3.5	4	5.5	3	4.5	2	5.5	3.91	4	0.92	3.5
10	3	4	3.5	5	4	5	4.5	4.5	5	4	3	3.5	3.5	5.5	3.5	4	3	5.5	4.09	4	0.76	2.5
11		4	4	4	4	4	4	4	4	4	4	4	4	4		4	4	4	4.00	4	0.00	0
12	4	5	5	3	3	4.5	4	4.5	5	4	2.5	3	3	4	3	2.5	2.5	5	3.75	4	0.89	2.5
14	3.5	3		3	4	3	4.5	4	4	3	4	3	3.5	4	3.5	3.5	3	4.5	3.57	3.5	0.50	1.5
15	3.5	5		5	4	4.5	3.5	4	4	4	3	3.5		4	3.5	3	3	5	3.89	4	0.63	2
16	3.5	3		3	3.5	4	4.5	5	4	4		3.5		4	3.5	3	3	5	3.73	3.5	0.60	2
17	4.5	3	4	3	3.5	3	4.5	5	4	4	3	3	4	3	2.5	3	2.5	5	3.56	3.25	0.73	2.5
18	4	4	4	4	3	5	3.5	4	4	4	3	4	4	4	4	4	3	5	3.91	4	0.46	2
19	4	3.5		5	3.5	4	4.5	4	3.5	4	3	3.5	4	4		3.5	3	5	3.86	4	0.50	2
20	4.5	4.5	4	5	4	4	3.5	5	3.5	4	2.5	3.5	3	4	3	3	2.5	5	3.81	4	0.73	2.5
21	4.5	3		5	4	3	3	3.5	4	4.5	2.5	3	4	4	3.5	3	2.5	5	3.63	3.5	0.72	2.5
22	4.5	3	3.5	3	4	3	4	4.5	4	4	2.5	3	4	5	3	2	2	5	3.56	3.75	0.81	3
23	4	2.5	4			3	3	3.5	4	4		3.5			2.5	3	2.5	4	3.36	3.5	0.60	1.5
24	4	2.5	4			3	3	3.5	4	4		3.5			2.5	3	2.5	4	3.36	3.5	0.60	1.5
25	4.5	4.5	3.5	5	3.5	3.5	3.5	5	3.5	4	5	3	3.5	5	3	3.5	3	5	3.97	3.5	0.74	2
26	3	4	3.5	3	3.5	3.5	3.5	5	3.5	4	3	3	3.5	4	3	3	3	5	3.50	3.5	0.55	2
27	4.5	3	4	3	3.5	3	3.5	5	3	3.5	2	3	3	4	2.5	2.5	2	5	3.31	3	0.77	3
28	4.5	4.5	3	3	4	4.5	4	5	3.5	4.5	3	3	4	4	2.5	4	2.5	5	3.81	4	0.73	2.5
29	4.5	4.5	3.5	3	3.5	3.5	4	4	3	4.5	3	3.5	4	4	2.5	4	2.5	4.5	3.69	3.75	0.60	2
30	4.5	3	4	3	4	4.5	3.5	5	3	4.5	4	3	4.5	4	3	4	3	5	3.84	4	0.68	2
31		3.5	5	4	3.5	5	4.5	5	5	4.5	4	3		4		3	3	5	4.15	4	0.75	2
32		4	3.5	3	4	3	4.5	4	4	3	4	3.5		4		3	3	4.5	3.65	4	0.52	1.5
33		4		3	3	3.5	4.5	5	5	3.5	2.5	4		4		2.5	2.5	5	3.71	3.75	0.86	2.5
34		4.5		4	4	3.5	4.5	4.5	5	4.5	2.5	4		4		3	2.5	5	4.00	4	0.71	2.5
35		3.5	4	4	3.5	4	3	4	3.5	3.5	3	4	4	3		2	2	4	3.50	3.5	0.59	2
36		4	4	4	3.5	4	3	4	3.5	3	3	3		3		2	2	4	3.38	3.5	0.62	2
37	4.5	4	5	4	4	4	4	4	5.5	5	4	2.5	3.5	4		3	2.5	5.5	4.07	4	0.75	3
38	3.5	4.5		5	3.5	4.5	3.5	5	3	4	5	2.5		3.5	2.5	3.5	2.5	5	3.82	3.5	0.87	2.5
39	3.5	3.5		3	3.5	3.5	4	5	3.5	4	2.5	2.5		3.5	2.5	2.5	2.5	5	3.36	3.5	0.72	2.5
40	3.5	3		3	3.5	3.5	3.5	5	4	3.5	3	3		4	2.5	2.5	2.5	5	3.39	3.5	0.66	2.5
41	4.5	3			4	3.5	3.5	5	4	3.5	3.5	2.5			2.5	2.5	2.5	5	3.50	3.5	0.80	2.5
42	4	4.5	3.5	5	3.5	4.5	4.5	5	3.5	4	4	2.5	4	3.5	2.5	3.5	2.5	5	3.88	4	0.74	2.5
43	4	3	3.5	3	3.5	3	4.5	5	3.5	4	2	2.5	3	3.5	2.5	2.5	2	5	3.31	3.25	0.79	3
44	4	3	3.5	3	4	3	4.5	5	3.5	3.5	2.5		3	4	2.5	2.5	2.5	5	3.43	3.5	0.75	2.5
45	4	3	3.5		4	3	3.5	5	3.5	3.5	2	2.5	3		2.5	2.5	2	5	3.25	3.25	0.78	3
46		3	4		4	3	4.5	5			2	4	3	3.5			2	5	3.60	3.75	0.88	3
47	4.5	3	3.5	3	4	3	3.5	5	3.5	3.5	2	4	3	3.5	2	2.5	2	5	3.34	3.5	0.81	3
48	4.5	4	4.5	3		4	3.5	5	4	3.5	4	2.5	4	4	3	3.5	2.5	5	3.80	4	0.65	2.5
49	4.5	3	3.5	3	4	3	3.5	5	3.5	4	7	2	4	5	2	3	2	7	3.75	3.5	1.24	5

Appendix 3B Repeatability Of Subjective Ratings: Case Study

Question Number	First Evaluation (August 1, 1997)	Repeat Evaluation (October 10, 1997)	Difference	abs(Difference)
1	4	5	-1	1
2	4	4	0	0
3	5	3	2	2
5	4	4	0	0
6	4	5	-1	1
7	3	4	-1	1
8	2	3	-1	1
9	4	5	-1	1
10	4	4	0	0
12	4	5	-1	1
14	5	4	1	1
15	3	4	-1	1
16	4	5	-1	1
17	4	4	0	0
18	4	4	0	0
19	5	4	1	1
20	4	4	0	0
21	5	4	1	1
22	4	4	0	0
23	5	4	1	1
24	4	4	0	0
25	3	5	-2	2
26	3	5	-2	2
27	2	5	-3	3
28	4	4	0	0
29	4	3	1	1
31	4	5	-1	1
32	5	4	1	1
33	4	4	0	0
35	4	4	0	0
36	4	4	0	0
38	4	4	0	0
39	3	4	-1	1
40	3	4	-1	1
41	3	4	-1	1
42	3	4	-1	1
43	3	4	-1	1
44	3	4	-1	1
45	3	4	-1	1
46	3	4	-1	1
47	3	4	-1	1
48	4	5	-1	1
49	3	3	0	0
	Mean		-0.42	0.79
	Standard Deviation		0.96	0.67

Appendix 4A Derivation Of Equations Of Motion

The equations of motion for a simple vehicle model as used in the current work can be found by application of D'Alembert's principle. In particular the following form of the principle, for N rigid bodies characterised by j generalised co-ordinates, $q_{1\text{-}j}$, can be used. A full derivation of this equation can be found in reference [1] from Chapter 4's references.

$$\sum_{1}^{N}\left[m_i(\dot{\vec{v}}_i+\dot{\vec{\rho}}_{ci})\cdot\vec{\gamma}_{ij}+(\bar{I}_i\cdot\dot{\vec{\omega}}_i+\vec{\omega}_i\times\bar{I}_i\cdot\vec{\omega}_i+m_i\vec{\rho}_{ci}\times\dot{\vec{v}}_i)\cdot\vec{\beta}_{ij}\right]=Q_j \qquad (4A-1)$$

$$(j=1,2,\ldots n)$$

where

m_i = mass of the ith body

$\vec{v}_i$ = velocity of m_i

$\vec{\rho}_{ci}$ = a vector from the body centre of gravity to a reference point

$\vec{\gamma}_{ij}$ = the *velocity coefficient* defined as $\dfrac{\partial\vec{v}_i}{\partial q_i}$

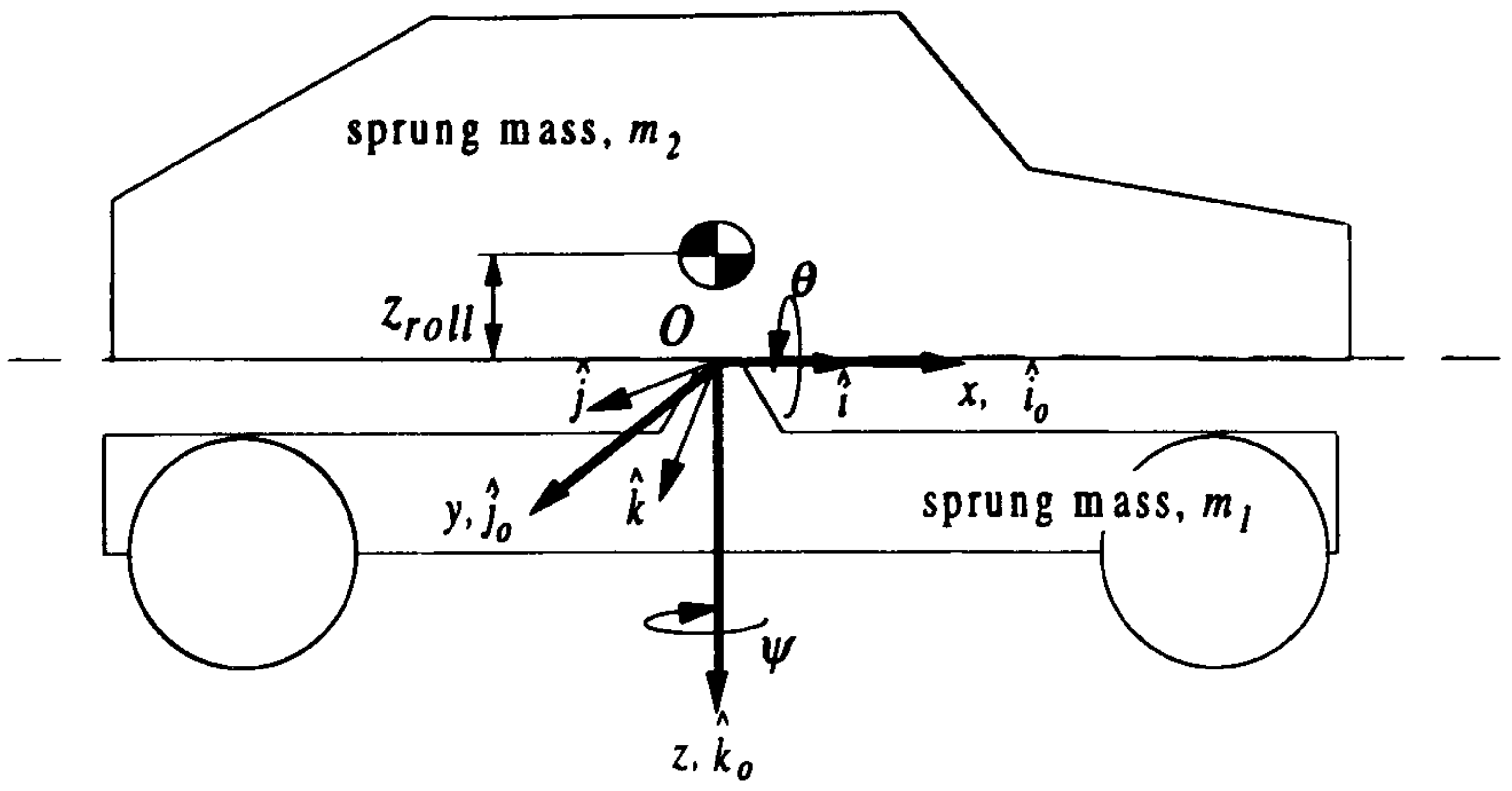
$\bar{I}_i$ = the inertia dyadic of the ith body

$\vec{\omega}_i$ = the angular velocity of the mass

$\vec{\beta}_{ij}$ = the *angular velocity coefficient* defined as $\dfrac{\partial\vec{\omega}_i}{\partial q_i}$

The vehicle is assumed to consist of two masses - a sprung mass, m_2, fixed about a horizontal roll axis to the unsprung mass, m_1, which moves forward at a constant speed but is free to side slip and yaw in response to lateral forces generated by the tyres. Referring to Figure 4A-1 assume that axes, $(\hat{i}_0, \hat{j}_0, \hat{k}_0)$ are fixed to the unsprung mass at the point O defined by the intersection of the roll axis and a vertical line passing through the unsprung mass centre of gravity. A second set of axes, $(\hat{i},\hat{j},\hat{k})$, are fixed to the sprung mass also at O. The generalised co-ordinates of the system are defined x, y, θ, *and* ψ, which denote the forward, lateral, roll and yaw displacements as shown in the figure.

Figure 4A-1 Vehicle representation in the model



Based on the generalised co-ordinates, the following generalised velocities and angular velocities are defined

$$u_1 = \dot{x} \tag{4A - 2}$$

$$u_2 = \dot{y}$$

$$u_3 = \dot{\theta}$$

$$u_4 = \dot{\psi}$$

The sprung and unsprung mass have the same velocity

$$\bar{v}_1 = \bar{v}_2 = u_1\hat{i}_o + u_2\hat{j}_o \tag{4A - 3}$$

Thus the velocity coefficients are:

$$\gamma_{11} = \hat{i}_o,\ \gamma_{12} = \hat{j}_o,\ \gamma_{21} = \hat{i}_o,\ \gamma_{22} = \hat{j}_o \tag{4A - 4}$$

(the remaining coefficents are 0)

The angular velocities are:

$$\bar{\omega}_1 = u_4\hat{k}_o \tag{4A - 5}$$

$$\bar{\omega}_2 = u_3\hat{i} + u_4\sin(\theta)\hat{j} + u_4\cos(\theta)\hat{k} \tag{4A - 6}$$

Thus the angular velocity coefficients are:

$$\beta_{14} = \hat{k}_o,\ \beta_{23} = \hat{i},\ \ \beta_{23} = \hat{i},\ \beta_{24} = \ \sin(\theta)\hat{j} + \cos(\theta)\hat{k} \tag{4A - 7}$$

(the remaining coefficients are 0)

Now evaluate the terms of equation (4A - 1) [1].

$$\dot{v}_1 = \frac{dv_1}{dt} + \omega_1 \times v_1 = (\dot{u}_1 - u_4u_2)\hat{i}_o + (\dot{u}_2 + u_4u_1)\hat{j}_o \tag{4A - 8}$$

---

[1] Note that the derivation shown here is was originally done using a symbolic maths package, *Maple*. *Maple* output, however, could not be "cut and pasted" into directly into this document. To minimise errors the equations were transcribed directly from the *Maple* output. This is why some terms in the equations have awkward signs and, in some instances, terms have not been collected together.

$$m_1 \dot{\bar{v}}_1 \cdot \bar{\gamma}_{11} = m_1\left[(\dot{u}_1 - u_4 u_2)\hat{i}_o + (\dot{u}_2 + u_4 u_1)\hat{j}_o\right] \cdot \hat{i}_o = m_1(\dot{u}_1 - u_4 u_2) \tag{4A - 9}$$

$$m_1 \dot{\bar{v}}_1 \cdot \bar{\gamma}_{12} = m_1((\dot{u}_1 - u_4 u_2)\hat{i}_o + (\dot{u}_2 + u_4 u_1)\hat{j}_o) \cdot \hat{j}_o = m_1(\dot{u}_2 + u_4 u_1) \tag{4A - 10}$$

$$\dot{\bar{\omega}}_2 = \dot{u}_3 \hat{i} + [\dot{u}_4 \sin\theta + u_4 \cos\theta\dot{\theta}]\hat{j} + [\dot{u}_4 \cos\theta - u_4 \sin\theta\dot{\theta}]\hat{k} \tag{4A - 11}$$

$$\dot{\bar{\omega}}_2 \times \bar{\rho}_{c2} = \left[-(\dot{u}_4 \sin\theta + u_4 \cos\theta\, u_3)\, z_{roll}\right]\hat{i} + \dot{u}_3 z_{roll} \hat{j} \tag{4A - 12}$$

$$\begin{aligned}\bar{\omega}_2 \times (\bar{\rho}_{c2} \times \bar{\omega}_2) = {} & -u_4 \cos\theta\, u_3 z_{roll} \hat{i} - u_4^2 \cos\theta \sin\theta\, z_{roll} \hat{j} \\ & + \left[u_3^2\, z_{roll} + u_4^2 \sin^2\theta\, z_{roll}\right]\hat{k}\end{aligned} \tag{4A - 13}$$

$$\begin{aligned}\ddot{\rho}_{c2} = \dot{\bar{\omega}}_2 \times \bar{\rho}_{c2} + \bar{\omega}_2 \times (\bar{\rho}_{c2} \times \bar{\omega}_2) = {} & \left[-(\dot{u}_4 \sin\theta + u_4 \cos\theta\, u_3)\, z_{roll} - u_4 \cos\theta\, u_3 z_{roll}\right]\hat{i} \\ & + \left[\dot{u}_3 z_{roll} - u_4^2 \cos\theta \sin\theta\, z_{roll}\right]\hat{j} + \left[\dot{u}_3^2\, z_{roll} + u_4^2 \sin^2\theta\, z_{roll}\right]\hat{k}\end{aligned} \tag{4A - 14}$$

$$\begin{aligned}m_2(v_2 + \ddot{\bar{\rho}}_{c2}) = m_2[{} & [\dot{u}_1 - (\dot{u}_4 \sin\theta\, u_4 \cos\theta\, u_3)\, z_{roll} - u_4 \cos\theta\, u_3 z_{roll}]\hat{i} \\ & + \left[\dot{u}_2 - u_4^2 \cos\theta \sin\theta\, z_{roll}\right]\hat{j} + \left[\dot{u}_3^2\, z_{roll} + u_4^2 \sin^2\theta\, z_{roll}\right]\hat{k}\ ]\end{aligned} \tag{4A - 15}$$

$$m_2(v_2 + \ddot{\bar{\rho}}_{c2}) \cdot \gamma_{21} = -m_2[-\dot{u}_1 + u_4 u_2 + z_{roll} \dot{u}_4 \sin\theta + u_4 \cos\theta\, u_3 z_{roll}]\hat{i} \tag{4A - 16}$$

$$m_2(v_2 + \ddot{\bar{\rho}}_{c2})\gamma_{22} = m_2[\ \dot{u}_2 + u_4 u_1 + \dot{u}_3 z_{roll} - u_4^2 \cos\theta \sin\theta\, z_{roll}\ ] \tag{4A - 17}$$

$$\dot{\bar{\omega}}_1 = \dot{\bar{u}}_4 \tag{4A - 18}$$

$$\bar{I}_1 \cdot \dot{\bar{\omega}}_1 = I_{zz1} \dot{u}_4 \tag{4A - 19}$$

$$m_1(\bar{\rho}_{c1} \times \dot{v}_1) = m_1\left[-L(\dot{u}_2 + u_4 u_1)\hat{i} + (\dot{u}_1 + u_4 u_2)\hat{j}\right] \tag{4A - 20}$$

$$\bar{I}_1 \cdot \bar{\omega}_1 + m_1(\bar{\rho}_{c1} \times \dot{v}_1) = -m_1 L(\dot{u}_2 + u_4 u_1)\hat{i} + m_1 L(\dot{u}_1 + u_4 u_2)\hat{j} + I_{zz1} \dot{u}_4 \hat{k} \tag{4A - 21}$$

$$\left[\bar{I}_1 \cdot \bar{\omega}_1 + m_1(\bar{\rho}_{c1} \times \dot{\bar{v}}_1)\right] \cdot \beta_{14} = I_{zz1} \dot{u}_4 \tag{4A - 22}$$

$$\bar{I}_2 \cdot \dot{\bar{\omega}}_2 = I_{xx2} \dot{u}_3 \hat{i} + I_{yy2}[\dot{u}_4 \sin\theta + u_4 \cos\theta\, u_3]\hat{j} + I_{zz2}[\dot{u}_4 \cos\theta - u_4 \sin\theta\, u_3]\hat{k} \tag{4A - 23}$$

$$\begin{aligned}\dot{\bar{\omega}}_2 \times \bar{I}_2 \cdot \dot{\bar{\omega}}_2 = {} & [-I_{yy2} u_4^2 \sin\theta \cos\theta + I_{zz2} u_4^2 \cos\theta \sin\theta]\hat{i} + \\ & [\ I_{xx2} u_3 u_4 \cos\theta - I_{zz2} u_4 \cos\theta\, u_3]\hat{j} \\ & [\ -I_{xx1} u_3 u_4 \sin\theta - I_{yy2} u_4 \sin\theta\, u_3]\hat{k}\end{aligned} \tag{4A - 24}$$

$$m_2\,\rho_{c2}\times\dot{\vec{v}}_2 = m_2\left[\dot{u}_2\,z_{roll}\,\vec{i} - \dot{u}_1\,z_{roll}\,\vec{j}\right] \tag{4A - 25}$$

$$\vec{I}_2\cdot\dot{\vec{\omega}}_2 + \dot{\vec{\omega}}_2\times\vec{I}_2\cdot\dot{\vec{\omega}}_2 + m_2\,\rho_{c2}\times\dot{\vec{v}}_2 = \tag{4A - 26}$$

$$\left[I_{xx2}\dot{u}_3 - I_{yy2}\,u_4{}^2\,\sin\theta\cos\theta + I_{zz2}\,u_4{}^2\,\cos\theta\sin\theta + m_2\,\dot{u}_2\,z_{roll}\right]\vec{i}$$

$$\left[I_{yy2}\left[\dot{u}_4\sin\theta + u_4\cos\theta\,u_3\right] + I_{xx2}u_3\,u_4\cos\theta - I_{zz2}\,u_4\cos\theta\,u_3 - m_2\dot{u}_1\,z_{roll}\right]\vec{j}$$

$$\left[I_{zz2}\left[\dot{u}_4\cos\theta - u_4\sin\theta\,u_3\right] - I_{xx1}u_3\,u_4\sin\theta - I_{yy2}\,u_4\sin\theta\,u_3\right]\vec{k}$$

$$\left(\vec{I}_2\cdot\dot{\vec{\omega}}_2 + \dot{\vec{\omega}}_2\times\vec{I}_2\cdot\dot{\vec{\omega}}_2 + m_2\,\rho_{c2}\times\dot{\vec{v}}_2\right)\cdot\beta_{23} = \tag{4A - 27}$$

$$I_{xx2}\dot{u}_3 - I_{yy2}\,u_4{}^2\,\sin\theta\cos\theta + I_{zz2}\,u_4{}^2\,\cos\theta\sin\theta + m_2\,\dot{u}_2\,z_{roll}$$

$$\left(\vec{I}_2\cdot\dot{\vec{\omega}}_2 + \dot{\vec{\omega}}_2\times\vec{I}_2\cdot\dot{\vec{\omega}}_2 + m_2\,\rho_{c2}\times\dot{\vec{v}}_2\right)\cdot\beta_{24} = \tag{4A - 28}$$

$$\left[I_{yy2}\left[\dot{u}_4\sin\theta + u_4\cos\theta\,u_3\right] + I_{xx2}u_3\,u_4\cos\theta - I_{zz2}\,u_4\cos\theta\,u_3 - m_2\dot{u}_1\,z_{roll}\right]\sin\theta$$

$$+\left[I_{zz2}\left[\dot{u}_4\cos\theta - u_4\sin\theta\,u_3\right] - I_{xx1}u_3\,u_4\sin\theta - I_{yy2}\,u_4\sin\theta\,u_3\right]\cos\theta$$

Finally assemble the terms and set them equal to the sums of forces and moments. To give the final form shown in Chapter 4, linearisation can be done by dropping second order terms and assuming small angles, i.e. $\cos\theta \approx 1$ and $\sin\theta \approx 0$. The linear terms carried through to the final form are shown in a bold type face.

(4A - 8) and (4A - 16)

$$\sum \boldsymbol{F_x} = \boldsymbol{m_1(\dot{u}_1 - u_4 u_2) - m_2[-\dot{u}_1} + u_4 u_2 + z_{roll}\dot{u}_4\sin\theta + u_4\cos\theta\,u_3\,z_{roll}] \tag{4A - 29}$$

(4A - 8) and (4A - 27)

$$\sum \boldsymbol{F_y} = \boldsymbol{m_1(\dot{u}_2 + u_4 u_1)}\quad \boldsymbol{+ m_2[\ \dot{u}_2} + u_4 u_1 + \dot{u}_3\,z_{roll} - u_4{}^2\cos\theta\sin\theta\,z_{roll}\ ] \tag{4A - 30}$$

(4A - 27)

$$\sum \boldsymbol{M_x} = \boldsymbol{I_{xx2}\dot{u}_3} - I_{yy2}u_4{}^2\sin\theta\cos\theta + I_{zz2}u_4{}^2\cos\theta\sin\theta + \boldsymbol{m_2\dot{u}_2 z_{roll}} \tag{4A - 31}$$

(4A - 19) and (4A - 28)

$$\begin{aligned}\sum \boldsymbol{M}_z = \boldsymbol{I}_{zz1}\dot{\boldsymbol{u}}_4 + [\,I_{yy2}[\dot{u}_4 \sin\theta + u_4 \cos\theta\, u_3] + \\ I_{xx2} u_3 u_4 \cos\theta - I_{zz2} u_4 \cos\theta\, u_3 - m_2 \dot{u}_1 z_{roll}]\sin\theta \\ + [\,\boldsymbol{I}_{zz2}[\dot{\boldsymbol{u}}_4 \cos\theta - u_4 \sin\theta\, u_3] - I_{xx1} u_3 u_4 \sin\theta - I_{yy2} u_4 \sin\theta\, u_3]\cos\theta\end{aligned} \tag{4A - 32}$$

Appendix 4B *Magic Formulas* for Lateral force and Aligning Moment

Tables 4B-1 and 4B-2 detail magic formula coefficients and formulas for lateral force and aligning moment for the two tyre types used in the research. The information is transcribed directly from a data sheet supplied by the tyre manufacturer.

Table 4B-1 Coefficients and *Magic tyre formulas* for lateral force

Coefficients for 175/70R13 tyres	Coefficients for 185/60R14 tyres	*Magic tyre formulas* for lateral force Y= lateral force (N) Delta = slip angle (deg) Z = normal load (kN) Gamma = camber angle (deg)
a0r = 1.5459 a1r = -59.7229 a2r = 1224.48 a3r = 1170.26 a4r = 6.62746 a5r = 0.00507213 a6r = -.376828 a7r = 0.81875 a8r = -.0231471 a9r = -0.00877666 a10r = -.0560763 a111r = -15.4746 a112r = 0.71115 a12r = -3.84307 a13r = 7.61327	a0f = 1.77925 a1f = -62.2526 a2f = 1175 a3f = 842.105 a4f = 5.28384 a5f = 0.00365843 a6f = -.232336 a7f = 0.999990 a8f = -.00110557 a9f = 0.076567 a10f = -.312481 a111f = -17.1426 a112f = 0.436313 a12f = -16.3378 a13f = 85.0246	SV0 = a12 × Z +a13; SV = SV0 + (a112 × (Z^2) +a111 × Z)×Gamma SH0 = a9×Z+a10 SH = SH0 + a8×Gamma E = a6 * Z+a7 C = a0 D = a1×(Z.*Z)+a2×Z BCD0 = a3×sin(2*atan(Z/a4)) BCD = BCD0 × (1-a5×abs(Gamma)) B = BCD/(C×D) PHI=(1-E)×(Delta+SH)+E/B×atan(B×(Delta+SH)) Y = D × sin(C×atan(B*PHI)) + SV

Table 4B-1 Coefficients and *Magic tyre formulas* for lateral force

Coefficients for 175/70R13 tyres	Coefficients for 185/60R14 tyres	*Magic tyre formulas* for aligning moment N= aligning moment (Nm) Delta = slip angle (deg) Z = normal load (kN) Gamma = camber angle (deg)
c0 = 2.62018 c1 = -3.14438 c2 = -6.61594 c3 = 0.465960 c4 = -3.91150 c5 = -0.337224 c6 = 0.103519e-2 c7 = -0.162817 c8 = 1.31159 c9 = -3.76028 c10 = 0.236082e-3 c11 = -0.130090e-1 c12 = 0.14062e-1 c13 = -0.292237 c14 = 0.967801e-1 c15 = -0.880200 c16 = 1.28033 c17 = -1.64998	c0 = 2.40963 c1 = -3.16795 c2 = -3.61196 c3 = 0.329674 c4 = -2.58216 c5 = -.465324 c6 = 0.0075275 c7 = -0.31213 c8 = 2.81783 c9 = -7.69007 c10 = -0.0443184 c11 = -0.000937470 c12 = 0.00202554 c13 = -0.269418 c14 = 0.074818 c15 = -0.934123 c16 = -0.446931 c17 = 1.23908	SV0 = c16 × Z +c17 SV = SV0 + (c14 × (Z^2) +c15 × Z)×Gamma SH0 = c12×Z+c13 SH = SH0 + c11×Gamma E0 = c7 × (Z.^2) + c8 × Z +c9 E = E0 × (1 - c10 ×abs(Gamma)) C = c0 D = c1×(Z^2)+c2×Z BCD0 = c3×(Z^2) +c4×Z/exp(c5×Z) BCD = BCD0 × (1-c6×abs(Gamma)) B = BCD/(C×D) PHI=(1-E)×(Delta+SH)+E/B×atan(B×(Delta+SH)) N = D × sin(C×atan(B×PHI)) + SV

Appendix 4C Damper Test Data

+							
Front				Rear			
Port		Starboard		Port		Starboard	
Velocity	Force	Velocity	Force	Velocity	Force	Velocity	Force
1.009	1453	1.008	1488	0.989	2551	0.989	2594
0.504	977	0.505	926	0.509	1406	0.504	1414
0.295	824	0.303	762	0.303	1121	0.304	1133
0.1	359	0.101	297	0.101	734	0.1	750
0.05	133	0.05	109	0.05	566	0.05	535
0.03	74	0.03	62	0.03	344	0.03	340
0.01	39	0.01	27	0.01	90	0.011	105
-0.011	-27	-0.011	-27	-0.011	-16	-0.011	-12
-0.031	-59	-0.03	-47	-0.031	-62	-0.031	-39
-0.05	-82	-0.05	-66	-0.05	-90	-0.05	-59
-0.101	-121	-0.101	-105	-0.101	-125	-0.101	-109
-0.303	-227	-0.3	-207	-0.303	-215	-0.299	-203
-0.512	-359	-0.507	-324	-0.505	-297	-0.505	-305
-0.997	-848	-0.999	-833	-0.99	-664	-0.992	-668
-							
Front				Rear			
Port		Starboard		Port		Starboard	
Velocity	Force	Velocity	Force	Velocity	Force	Velocity	Force
0.997	1187	0.988	1259	0.99	1367	0.991	1293
0.506	719	0.502	805	0.505	1082	0.503	1047
0.302	445	0.302	445	0.303	953	0.305	922
0.1	74	0.1	94	0.1	191	0.1	250
0.05	31	0.05	51	0.05	117	0.05	98
0.03	31	0.03	31	0.03	109	0.03	66
0.01	27	0.01	16	0.01	98	0.01	51
-0.011	-23	-0.011	-20	-0.011	-70	-0.011	-31
-0.031	-35	-0.03	-23	-0.031	-90	-0.031	-39
-0.05	-43	-0.051	-35	-0.051	-102	-0.05	-62
-0.1	-98	-0.099	-74	-0.102	-141	-0.101	-90
-0.301	-398	-0.299	-398	-0.303	-234	-0.301	-207
-0.497	-672	-0.507	-645	-0.51	-297	-0.509	-285
-0.994	-1254	-0.989	-1242	-0.985	-570	-1	-566

Appendix 4D Derived Parameters for Vehicle Model

Parameter	Abbreviation	Value	Calculation
Static front port normal load	static_fp_fz	3750 N	(m_total×(b/(a+b))×9.81/2)/1000
Static front starboard normal load	static_fs_fz	3750 N	(m_total×(b/(a+b))×9.81/2)/1000
Rear roll centre height	r_hroll	-0.0080 m	r_track x dtrack/dz = .668m × [(-.006 - 0.006)/2]mm/mm
Static rear port normal load	static_rp_fz	2695 N	(m_total×(a/(a+b))×9.81/2)/1000
Static rear starboard normal load	static_rs_fz	2695 N	(m_total×(a/(a+b))×9.81/2)/1000
Distance from vehicle centre of gravity to roll axis	roll_axis_height		cg_height-(((f_hroll-r_hroll)/(a+b))×b + r_hroll)

Appendix 4E Vehicle Simulation Subroutines Written for *Matlab*

```
% Vehicle Dynamic Simulation Program
% This program implements a four dof (sideslip, roll, yaw,RW Steer) model in which
% Handwheel angle and fwdvel are used as parameters to calculate the tyre forces

%clear all;


% GET THE INPUT DATA
%Input_Data = loadraw2('c:\dave_c\m-files\jturns\jrespons\x2j012ae.txt');

% INITIAL CONDITIONS

% y dot
% roll dot
% yaw dot
% y
% roll
% yaw

y=zeros(6,1);

clear Answers Out;
[Answers,Out] = c_slope(y,Input_Data,'rhs_4dof',Config);
if (max(max(abs(Answers))) > 200 | isnan(max(max(abs(Answers)))))
  disp('Using Runge Kutta Integrator')
  [Answers,Out]  = RungeKut(y,Input_Data,'rhs_4dof',Config);
end


%Output Data for transient response tests
Output_Data=...
[Input_Data(:,1),...
 Out(4,:)/9.81,...
 Out(1,:)'*57.3,...
 Out(2,:)'*57.3,...
 Answers(2,:)'*57.3,...
 Answers(3,:)'*57.3',...
 Input_Data(:,7),...
 Out(3,:)',...
 Input_Data(:,9)];



%Output Data for steady state response tests
%Output_Data=...
%[Out(4,:)./9.81,...
% Out(1,:)'*57.3,...
% Out(2,:)'*57.3,...
% Answers(7,:)'*57.3,...
% Out(6,:)',...
% Input_Data(:,7),...
% Out(3,:)',...
% Input_Data(:,9)];

clear y dy dt vdot w_cross_v ;
```

```
function [solutions,Other_Outputs]=RungeKut(y,Input,rhs_function,ConfigNo)


noh(1)=0;
ierr=0;

old_f_force=0; old_r_force=0; % These are used to calculate the load transfer and slip in "rhs"
old_MZFport=0; old_MZFstar=0; old_MZRport=0; old_MZRstar=0;
n=size(Input,1)-1;  % number of data points in the simulation
x=Input(:,1);        % the first column should contain the time indices for the steer input
y=[y,zeros(length(y),n)]; % preallocate y for extra speed
tol=0.01;
knt=12;
neqn=size(y,1)

% main step loop from x(1) to x(n)


for m=1:n
  %if (rem(m,50)==0) | m==1; disp(['This is point ',num2str(m)]); end;
  disp(['This is point ',num2str(m)]);
  % save initial values for this main step forward

  xo=x(m);
  xn=x(m+1);
  yo=y(:,m);

  % stepsize reduction loop within this main step from xo to xn

  kmx=knt+1;
  for k=1:kmx
    ns=2^(k-1);
    h=(xn-xo)/(ns);
    xx=xo;
    ys=yo;


    %  march 4th order Runge-Kutta from xo to xn

    for i=1:ns
      eval(['[a,old_f_force,old_r_force,old_MZFport,old_MZFstar,old_MZRport,old_MZRstar,Other] = '...
          rhs_function '(ys, m, old_f_force,
                  old_r_force,old_MZFport,old_MZFstar,old_MZRport,old_MZRstar,Input,ConfigNo);'])
      ybs=ys+0.5*h*a;

      xx=xx+0.5*h;
      eval(['[b,old_f_force,old_r_force,old_MZFport,old_MZFstar,old_MZRport,old_MZRstar,Other] = '...
          rhs_function '(ys, m, old_f_force,
old_r_force,old_MZFport,old_MZFstar,old_MZRport,old_MZRstar,Input,ConfigNo);'])
      yds=ys+0.5*h*b;

      eval(['[c,old_f_force,old_r_force,old_MZFport,old_MZFstar,old_MZRport,old_MZRstar,Other] = '...
          rhs_function '(ys, m, old_f_force,
old_r_force,old_MZFport,old_MZFstar,old_MZRport,old_MZRstar,Input,ConfigNo);'])
      yts=ys+1.0*h*c;

      xx=xx+0.5*h;
      eval(['[d,old_f_force,old_r_force,old_MZFport,old_MZFstar,old_MZRport,old_MZRstar,Other] = '...
          rhs_function '(ys, m, old_f_force,
old_r_force,old_MZFport,old_MZFstar,old_MZRport,old_MZRstar,Input,ConfigNo);'])

      ys=ys+h*(a./6 + b ./3 + c./3 + d./6);

    end %(for i...)

    % check for convergence of y at xn

    if (k == 1)
      yold=ys;
    else
      ichk=0;
      dif=abs(ys-yold);
      for j=1:neqn
```

```
     % if (ys(j) .ne. 0.) dif=abs(dif/ys(j))
     if (j == 1) & (k > 10)
      disp(['x dot difference is', num2str(dif)]);
      disp(['y old =' num2str(yold(1)) ' y new =' num2str(ys(1))]);
     end %(if (ys(j)...)
     if (dif(j) > tol)
      %disp(['y(' num2str(j) ') is greater than tol'])
      ichk=1;
      yold=ys;
     end %(if dif >..)
    end %(for j..)
    if (ichk == 0)
     % store final solution at xn in array y
     y(:,m+1)=ys;
     noh(m+1)=k-1;
     break;
    else
     yold=ys;
     %break;
    end
   end %(if k...)
  disp(num2str(k))
  end %(for k)

  if ((k==kmx) & (ichk ==1))
   ierr=1;
noh(m+1)=knt ;
  end %(if ((k==kmx))

  Other_Outputs=[Other_Outputs,Other];
end %(for m...)
Other_Outputs=[zeros(size(Other_Outputs,1),1),Other_Outputs]; % this is so that each column of Other_Outputs matches y
solutions=y;
```

```
% This function performs a simulation based on the system given in "rhs_function"
% using the Constant slope (Euler's) method for integrating refer to
% Spiegel, "Applied differential equations, 3rd ed", Chapter 9 of any other
% diffeq's text for more info
%
% y is the state variables
% Input is an nx9 matrix of experimental data whos columns are: Time,Latacc,STL,STR,RollRt,Yaw Rate,HW,Storq,Speed
% ConfigNo is a number 1 to 16 corresponding to one of the experimental config's


function [solution,Other_Outputs]=c_slope(y,Input,rhs_function,ConfigNo)

old_f_force=0;  old_r_force=0; ; % These are used to calculate the load transfer and slip in "rhs"
old_MZFport=0;  old_MZFstar=0;  old_MZRport=0;  old_MZRstar=0;

n=size(Input,1)-1;    % number of data points in the simulation
x=Input(:,1);         % the first column should contain the time indices for the steer input
y=[y,zeros(length(y),n)]; % preallocate y for extra speed
disp(rhs_function);

for m=1:n;
  if (rem(m,50)==0) | m==1; disp(num2str(m)); end;
  xo=x(m);   % x old
  xn=x(m+1);  % x new
  ys=y(:,m);
  eval(['[a,old_f_force,old_r_force,old_MZFport,old_MZFstar,old_MZRport,old_MZRstar,Other] = '...
       rhs_function '(ys, m, old_f_force, old_r_force,old_MZFport,old_MZFstar,old_MZRport,old_MZRstar,Input,ConfigNo);'])
  y(:,m+1)=y(:,m)+a.*(xn-xo);
  Other_Outputs=[Other_Outputs,Other];
end;
Other_Outputs=[zeros(size(Other_Outputs,1),1),Other_Outputs]; % this is so that each column of Other_Outputs matches y
solution = y;
```

```
function [f,f_force,r_force,MZFport,MZFstar,MZRport,MZRstar,OtherOutputs] =
rhs_4dof(y,m,old_f_force,old_r_force,old_MZFport,old_MZFstar,old_MZRport,old_MZRstar,Inputs,Config)

f=zeros(length(y),1);

LatVel =   y(1);
RollRate=  y(2);
YawRate=   y(3);
LatDisp=   y(4);
RollAngle= y(5);
YawAngle=  y(6);

par_4dof

% INPUTS
HW_Angle = Inputs(m,7);
FwdVel = Inputs(m,9)*.27778; %(n.b. convert from km/h to m/s)

RW_Angle_port = ((HW_Angle/57.3-old_MZFport/(K_column)) / ESR) + (old_f_force/2)*f_trail/K_compliance + RollSteer;
RW_Angle_star = ((HW_Angle/57.3-old_MZFstar/(K_column)) / ESR) + (old_f_force/2)*f_trail/K_compliance + RollSteer;;

R_RW_Angle = -old_r_force/(K_R_steer);


%  FORCES AND MOMENTS

tyre4dof;

Lat_Force = (FYFport + FYFstar + FYRport + FYRstar) - m_total*YawRate*FwdVel;
% Note in the following equation that the sign of the damping moments are determined by damp_mz.m
RollMoment =  - f_Kroll * RollAngle - r_Kroll * RollAngle...
        + f_damp_moment  + r_damp_moment...
        - (FYFport+FYFstar) * (roll_axis_height)...
        - (FYRport+FYRstar) * (roll_axis_height)...
        - roll_axis_height*sin(RollAngle)*m_sprung*9.81;


YawMoment =  a*FYFport + a*FYFstar - b*FYRport - b*FYRstar...
        + MZFport + MZFstar + MZRport + MZRstar;  % Note the signs of Mz are determined by tyre4dof


%  FIND ACCELERATIONS
mm=zeros(length(y)/2,length(y)/2);
mm(1,1) = m_total;
mm(1,2) = m_sprung * roll_axis_height;
mm(2,1) = m_sprung * roll_axis_height;
mm(2,2) = Ixx;
mm(3,3) = Izz;

fv(1,1)= Lat_Force;
fv(2,1)= RollMoment;
fv(3,1)= YawMoment;

rh=mm\fv;

f(1,1) =rh(1);
f(2,1) =rh(2);
f(3,1) =rh(3);
f(4,1) =y(1);
f(5,1) =y(2);
f(6,1) =y(3);

% OUTPUTS

f_force = FYFport + FYFstar;
r_force = FYRport + FYRstar;
Storq=  MZFport+MZFstar;


OtherOutputs=...
[RW_Angle_port;...
 RW_Angle_star;...
 Storq;...
```

```
 (f_force+r_force)/m_total;...
 RollAngle;...
 -57.3*((LatVel- b * YawRate)/FwdVel);
];
```

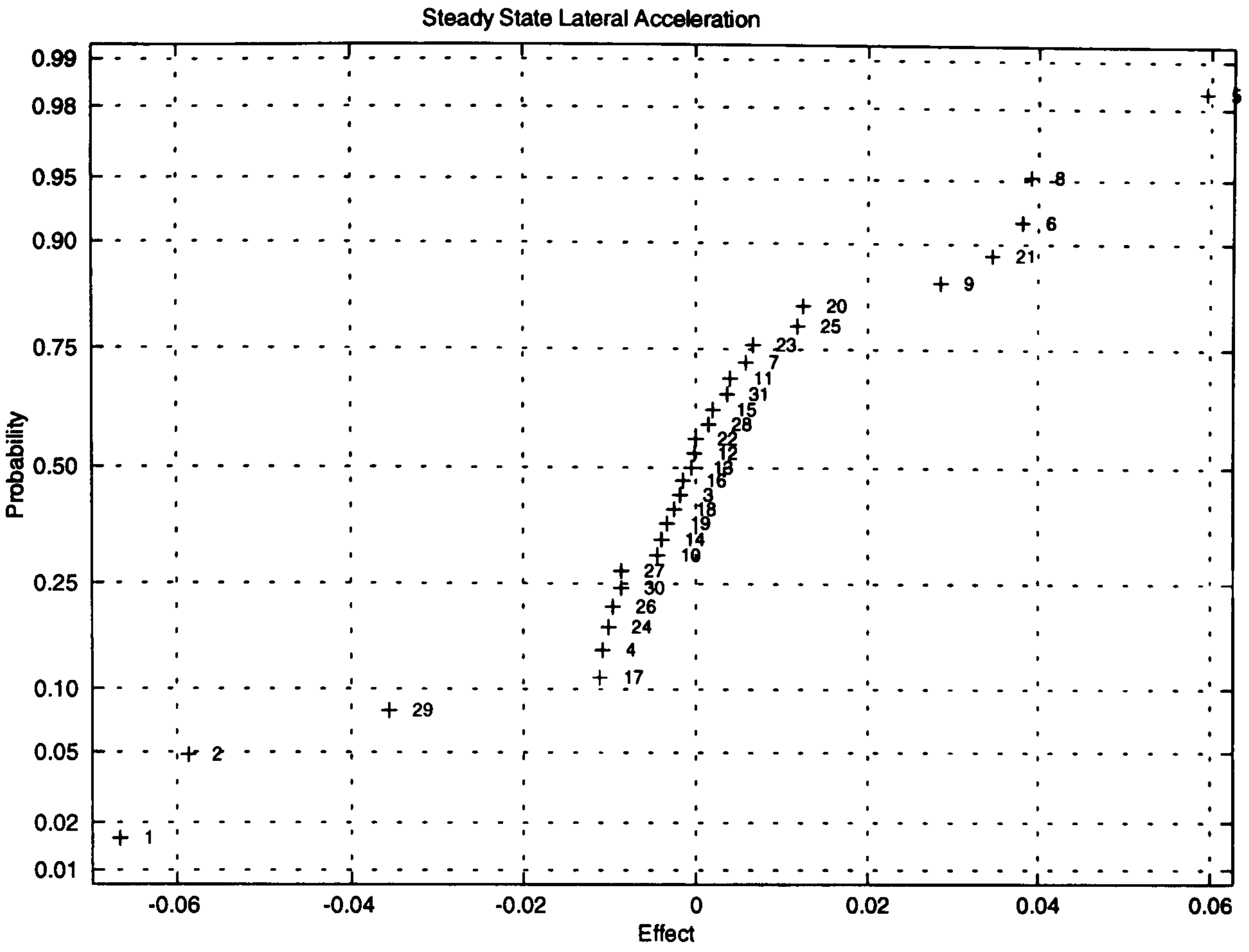
```
%
%           FKroll|RTyre|FDamp|RDamp|FTyre|RKroll|Izz|B_Steer
ContrastMatrix= [  -1  -1  -1   1   1   1  -1   1;
                 1  -1  -1  -1  -1   1   1   1;
                -1   1  -1  -1   1  -1   1   1;
                 1   1  -1   1  -1  -1  -1   1;
                -1  -1   1   1  -1  -1   1   1;
                 1  -1   1  -1   1  -1  -1   1;
                -1   1   1  -1  -1   1  -1   1;
                 1   1   1   1   1   1   1   1;
                 1   1   1  -1  -1  -1   1  -1;
                -1   1   1   1   1  -1  -1  -1;
                 1  -1   1   1  -1   1  -1  -1;
                -1  -1   1  -1   1   1   1  -1;
                 1   1  -1  -1   1   1  -1  -1;
                -1   1  -1   1  -1   1   1  -1;
                 1  -1  -1   1   1  -1   1  -1;
                -1  -1  -1  -1  -1  -1  -1  -1];


% VEHICLE BODY
a = 0.996;     % m    P16 Michelin
b = 2.382-a;    % m    P16 Michelin
cg_height = 0.5;  % m    0.35 + 0.15, from Cranfield plus estimate of distance from lower edge of sill seam
m_sprung = 1002;  % kg
m_total = 1314;  % kg    from measurments @ MIRA May 17 + 2*75kg passengers
Ixx = 447.1;     % kgm^2  338.7 from Cranfield  ((2*25kg+2*23.5) * 0.5^2m^2) from lead shot
            %     2*75kg*0.5^2m^2  from 2 passengers
            %     (12.2+11.6)kg * 1.4^2 m^2  from batteries+kit (All measurments May 17 @ MIRA)


% FRONT SUSPENSION AND STEERING
f_track = 0.703;  % m    1.406 m /2  P16 Michelin
f_hroll = -0.054;  % m    f_track * dtrack/dz = 0.703m * [(-0.031 -0.046)/2]mm/mm dtrack/dz = avg of two wheels, Config 3
vert. tests p Z5 Michelin

ESR = 21.3;         % MIRA-90-244596/1 Table 1
K_total = 1.174e4;    % Nm/rad [0.5*(1/0.121+1/0.187)kN/deg] * 0.03m * 1000 N/kN * 57.3 deg/rad  Fig Y2 Michelin:
Handwheel locked
K_compliance = 1.750e4; % Nm/rad [0.5*(1/.074+1/.146)kN/deg] * 0.03m * 1000 N/kN * 57.3 deg/rad   Fig Y2 Michelin:
Steer rack locked
K_column = K_total*K_compliance/(K_compliance-K_total);
f_trail= 0.035;  % mechanical trail = wheel radius*tan(castor) = 0.145m * tan(2°) + 0.025 pneumatic trail
Izz_fw = 0.51607;  % kgm^2 Cranfield

static_fp_fz = (m_total*(b/(a+b))*9.81/2)/1000;  % kN
static_fs_fz = (m_total*(b/(a+b))*9.81/2)/1000;  % kN
static_fp_camber= 1;  % degrees Measured before tests
static_fs_camber=-1;  % degrees Measured before tests
f_dCamber_dRoll=.928; % (0.918+0.938)/2  Config 3 Roll test, Fig R4, Camber Change (Ground Rel) v. Body Roll, Michelin

% REAR SUSPENSION
r_track= 0.668;     % m    1.336m / 2 P16 Michelin
r_hroll= -0.0080;    % m    r_track * dtrack/dz = .668m * [(-.006 - 0.006)/2]mm/mm
K_R_steer= 3.697e5;   % N/rad (1/0.155 deg/kN)* 1000 N/kN * 57.3 deg/rad  Fig P4 Michelin
%C_R_steer= 360; %420;  % Nms/rad
r_trail= 0.03;      % m
r_trail_arm = .1;    % m
Izz_rw = 0.63;      % kgm^2 Cranfield

static_rp_fz = (m_total*(a/(a+b))*9.81/2)/1000;  % kN
static_rs_fz = (m_total*(a/(a+b))*9.81/2)/1000;  % kN
static_rp_camber= 0.33; % degrees Measured May 16 @ MIRA
static_rs_camber= -0.33; % degrees Measured May 16 @ MIRA
r_dCamber_dRoll=.986  ; % (0.979+0.994)/2  Config 3 Roll test, Fig R14, Camber Change (Ground Rel) v. Body Roll,
Michelin


% ROLL AXIS HEIGHT
% n.b. in calculating the roll axis height (for use in determining roll moments) c.g. and roll centre height are relative to ground,
+'ve up
% the roll axis is a horizontal line at the intersection of the c.g. vertical and the kinematic roll axis
```

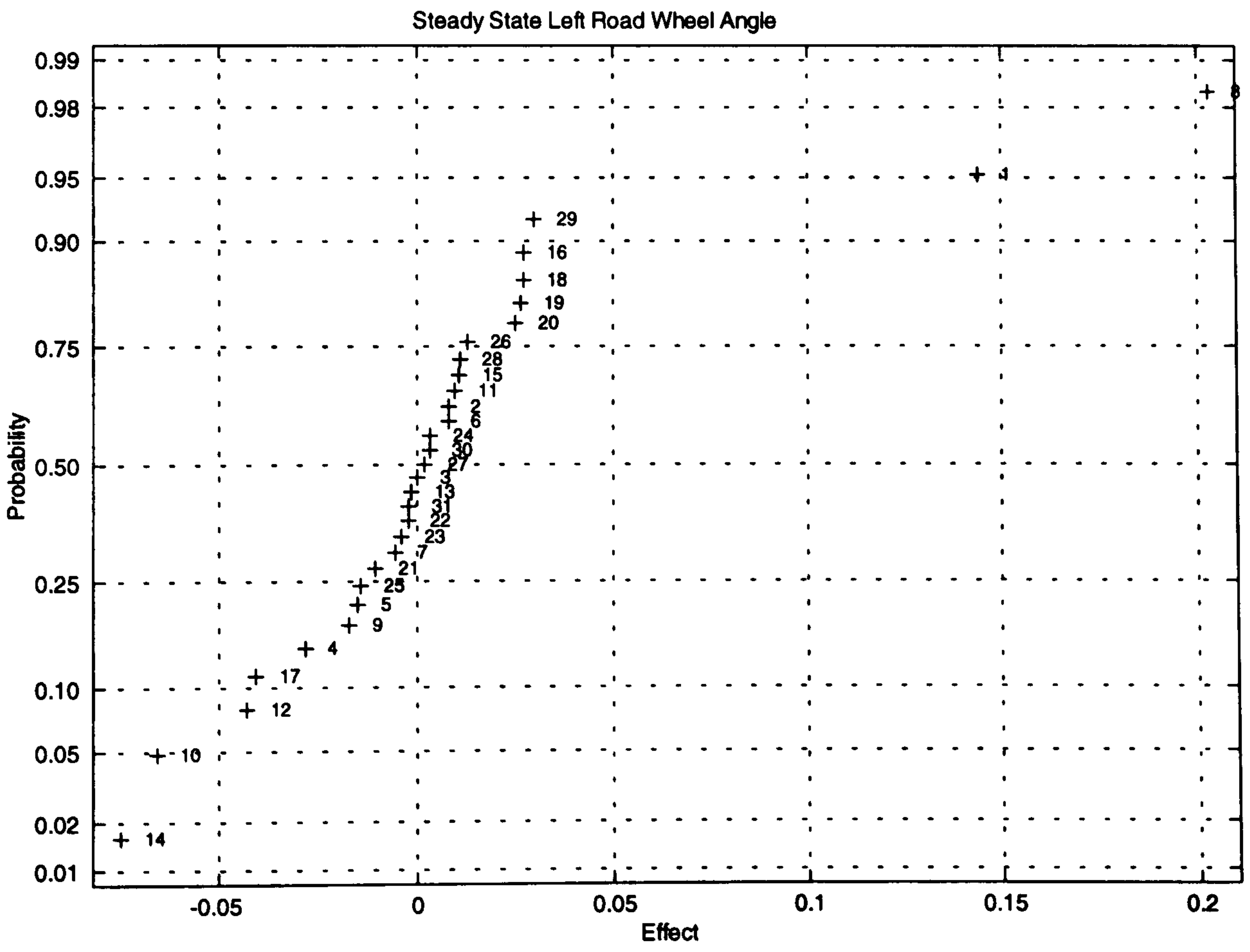
```
roll_axis_height = cg_height-(((f_hroll-r_hroll)/(a+b))*b + r_hroll);


if ContrastMatrix(Config,1) == 1
 f_Kroll = 31057; % 542Nm/deg * 57.3deg/rad  Config 3 Roll test, Fig R22, Roll Moment v. Body Roll Angle, Michelin
else
 f_Kroll = 17419; % 304Nm/deg * 57.3deg/rad  Config 4 Roll test, Fig R22, Roll Moment v. Body Roll Angle, Michelin
end
if ContrastMatrix(Config,2) == 1
 RearTyres ='L';
else
 RearTyres ='S';
end
if ContrastMatrix(Config,3) == 1
 f_damp_moment=damp_mz(RollRate,+1,'F',f_track);
else
 f_damp_moment=damp_mz(RollRate,-1,'F',f_track);
end
if ContrastMatrix(Config,4) == 1
 r_damp_moment=damp_mz(RollRate,+1,'R',r_track);
else
 r_damp_moment=damp_mz(RollRate,-1,'R',r_track);
end
if ContrastMatrix(Config,5) == 1
 FrontTyres = 'L';
else
 FrontTyres = 'S';
end
if ContrastMatrix(Config,6) == 1
 r_Kroll =20913; % 365Nm/deg * 57.3deg/rad  Config 3 Roll test, Fig R22, Roll Moment v. Body Roll Angle, Michelin
else
 r_Kroll =16789; % 293Nm/deg * 57.3deg/rad  Config 4 Roll test, Fig R22, Roll Moment v. Body Roll Angle, Michelin
end
if ContrastMatrix(Config,7) == 1
 Izz = 1953;  %  1540 kgm^2  from Cranfield
            %  2*(25kg * (1.5^2+0.7^2)m^2) + 2*(23.5kg * (1.9^2+0.7^2)m^2) from lead shot
            %  2*75kg*0.5^2m^2   from 2 passengers
            %  (12.2+11.6)kg * 1.4^2 m^2  from batteries+kit (All measurments May 17 @ MIRA)
else
 Izz = 1648;  %  1540 kgm^2  from Cranfield
            %  2*(25kg * 0.5^2m^2) + 2*(23.5kg * 0.7^2m^2) from lead shot
            %  2*75kg*0.5^2m^2   from 2 passengers
            %  (12.2+11.6)kg * 1.4^2 m^2  from batteries+kit (All measurments May 17 @ MIRA)
end
if ContrastMatrix(Config,8) == 1
 [STL,STR]=rollster(RollAngle,f_track,+1);
 RollSteer=(STL+STR)/2;
else
 [STL,STR]=rollster(RollAngle,f_track,-1);
 RollSteer=(STL+STR)/2;
end
```

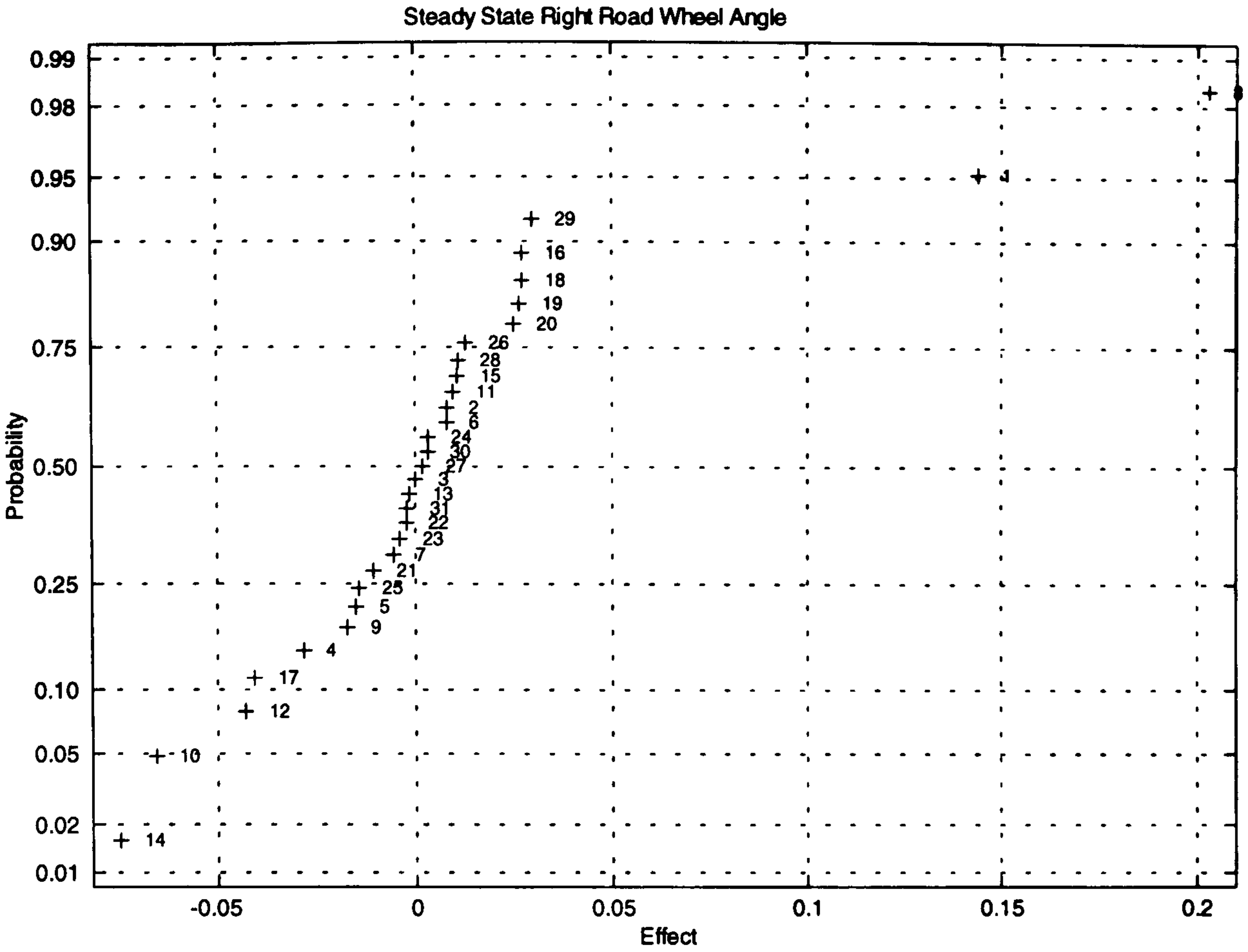
Appendix 4F Results from the Pseudo-sensitivity Analysis

Configuration	Steady State Lateral Acceleration	Steady State Left Road Wheel Angle	Steady State Right Road Whee Angle	Steady State Yaw Rate	Steady State Steer Torque	Peak Lateral Acceleration	Peak Left Road Wheel Angle	Peak Right Road Wheel Angle	Peak Roll Rate	Peak Roll Rate Response Time	Peak Yaw Rate	Peak Steer Torque	Lateral Acceleration Response Time to 90% of Steady State	Left Road Wheel Angle Response Time to 90% of Steady State	Right Road Wheel Angle Response Time to 90% of Steady State	Yaw Rate Response Time to 90% of Steady State	Steer Torque Response Time to 90% of Steady State
1	0.559	2.819	2.819	0.333	6.093	0.5457	3.022	3.022	-0.1562	1.625	0.3296	6.088	2.125	1.625	1.625	1.9	1.9
2	0.4652	2.772	2.772	0.2818	6.615	0.4711	2.893	2.893	-0.1546	1.6	0.29	6.696	1.9	1.65	1.65	1.775	1.775
3	0.4731	2.898	2.898	0.2848	4.512	0.4822	3	3	-0.1545	1.65	0.2884	4.585	1.9	1.65	1.65	1.775	1.775
4	0.4452	2.895	2.895	0.2806	5.732	0.4475	2.938	2.938	-0.1347	1.6	0.2829	5.768	1.85	1.65	1.65	1.775	1.775
5	0.6529	2.975	2.975	0.4084	9.126	0.601	3.079	3.079	-0.1243	1.65	0.3837	8.778	2.375	1.65	1.65	2.225	2.225
6	0.4402	2.853	2.853	0.2708	5.52	0.4475	2.92	2.92	-0.1186	1.6	0.2784	5.606	1.925	1.65	1.65	1.775	1.775
7	0.4862	2.921	2.921	0.2873	5.247	0.4991	3.024	3.024	-0.1414	1.65	0.2971	5.394	1.9	1.65	1.65	1.75	1.75
8	0.4217	2.884	2.884	0.2617	4.643	0.4257	2.934	2.934	-0.1193	1.6	0.2664	4.691	1.825	1.65	1.65	1.775	1.775
9	0.5812	2.471	2.471	0.3455	7.306	0.562	2.891	2.891	-0.1329	1.65	0.3408	7.335	2.175	1.6	1.6	1.9	1.9
10	0.4311	2.992	2.992	0.2612	5.322	0.4448	3.045	3.045	-0.1357	1.6	0.2727	5.423	1.85	1.65	1.65	1.75	1.75
11	0.5054	2.707	2.707	0.3053	5.572	0.5176	2.925	2.925	-0.2275	1.675	0.3075	5.716	1.8	1.625	1.625	1.8	1.8
12	0.4235	3.005	3.005	0.2676	4.743	0.5195	3.04	3.04	-0.2658	1.675	0.2788	5.313	1.65	1.675	1.675	1.75	1.75
13	0.5418	2.701	2.701	0.3246	5.91	0.545	2.919	2.919	-0.1151	1.675	0.3265	5.982	2.05	1.625	1.625	1.825	1.825
14	0.4549	3.072	3.072	0.2794	6.577	0.4665	3.088	3.088	-0.1092	1.625	0.2928	6.682	1.95	1.675	1.675	1.775	1.775
15	0.4731	2.722	2.722	0.2802	4.487	0.494	2.907	2.907	-0.1392	1.65	0.2916	4.627	1.85	1.625	1.625	1.725	1.725
16	0.43	3.032	3.032	0.2672	5.471	0.4332	3.039	3.039	-0.1129	1.6	0.2715	5.519	1.875	1.675	1.675	1.775	1.775
17	0.7	2.907	2.907	0.4343	7.719	0.6367	3.053	3.053	-0.1708	1.6	0.4034	7.858	2.425	1.65	1.65	2.3	2.3
18	0.4817	2.832	2.832	0.2969	5.475	0.4981	2.923	2.923	-0.1219	1.6	0.3156	5.576	1.875	1.65	1.65	1.75	1.75
19	0.587	2.883	2.883	0.3483	7.106	0.5793	3.023	3.023	-0.2311	1.65	0.3464	7.106	2.025	1.65	1.65	1.875	1.875
20	0.4674	2.901	2.901	0.2904	6.095	0.4708	2.942	2.942	-0.1709	1.625	0.2951	6.141	1.825	1.65	1.65	1.75	1.75
21	0.6106	2.974	2.974	0.3771	7.725	0.5996	3.092	3.092	-0.1257	1.625	0.373	7.722	2.1	1.65	1.65	1.9	1.9
22	0.5151	2.788	2.788	0.3216	5.094	0.5246	2.915	2.915	-0.09042	1.6	0.3342	5.2	2	1.65	1.65	1.8	1.8
23	0.5276	2.773	2.773	0.3047	7.153	0.5926	3.091	3.091	-0.3844	1.725	0.3195	8.192	1.7	1.625	1.625	1.75	1.75
24	0.5143	2.753	2.753	0.3146	5.736	0.5199	2.927	2.927	-0.17	1.625	0.3248	5.812	1.95	1.625	1.625	1.775	1.775
25	0.5611	2.717	2.717	0.3398	6.996	0.5466	2.901	2.901	-0.1789	1.6	0.3334	7.053	2.15	1.625	1.625	1.95	1.95
26	0.5751	2.995	2.995	0.3546	5.624	0.5836	3.046	3.046	-0.1548	1.6	0.3635	5.713	2	1.65	1.65	1.8	1.8
27	0.4606	2.798	2.798	0.2723	6.398	0.4805	2.947	2.947	-0.19	1.625	0.2799	6.612	1.8	1.625	1.625	1.75	1.75
28	0.5591	3.006	3.006	0.3478	6.34	0.5691	3.04	3.04	-0.1498	1.625	0.3538	6.445	1.95	1.65	1.65	1.775	1.775
29	0.5775	2.659	2.659	0.3573	6.471	0.5572	2.906	2.906	-0.125	1.625	0.347	6.455	2.175	1.625	1.625	1.975	1.975
30	0.583	3.009	3.009	0.3646	6.648	0.5892	3.068	3.068	-0.1051	1.6	0.3692	6.747	2.05	1.65	1.65	1.85	1.85
31	0.4962	2.523	2.523	0.2854	5.83	0.5145	2.918	2.918	-0.1505	1.65	0.3059	6.054	1.875	1.6	1.6	1.725	1.725
32	0.5213	2.962	2.962	0.3191	6.71	0.5381	3.063	3.063	-0.1265	1.625	0.3319	6.901	1.9	1.65	1.65	1.75	1.75

Appendix 4G Normal Probability Plots for the Sensitivity Study






Steady State Right Road Wheel Angle
Probability
0.99
0.98
0.95
0.90
0.75
0.50
0.25
0.10
0.05
0.02
0.01
Effect
-0.05
0
0.05
0.1
0.15
0.2
14
10
12
17
4
9
5
25
21
7
23
22
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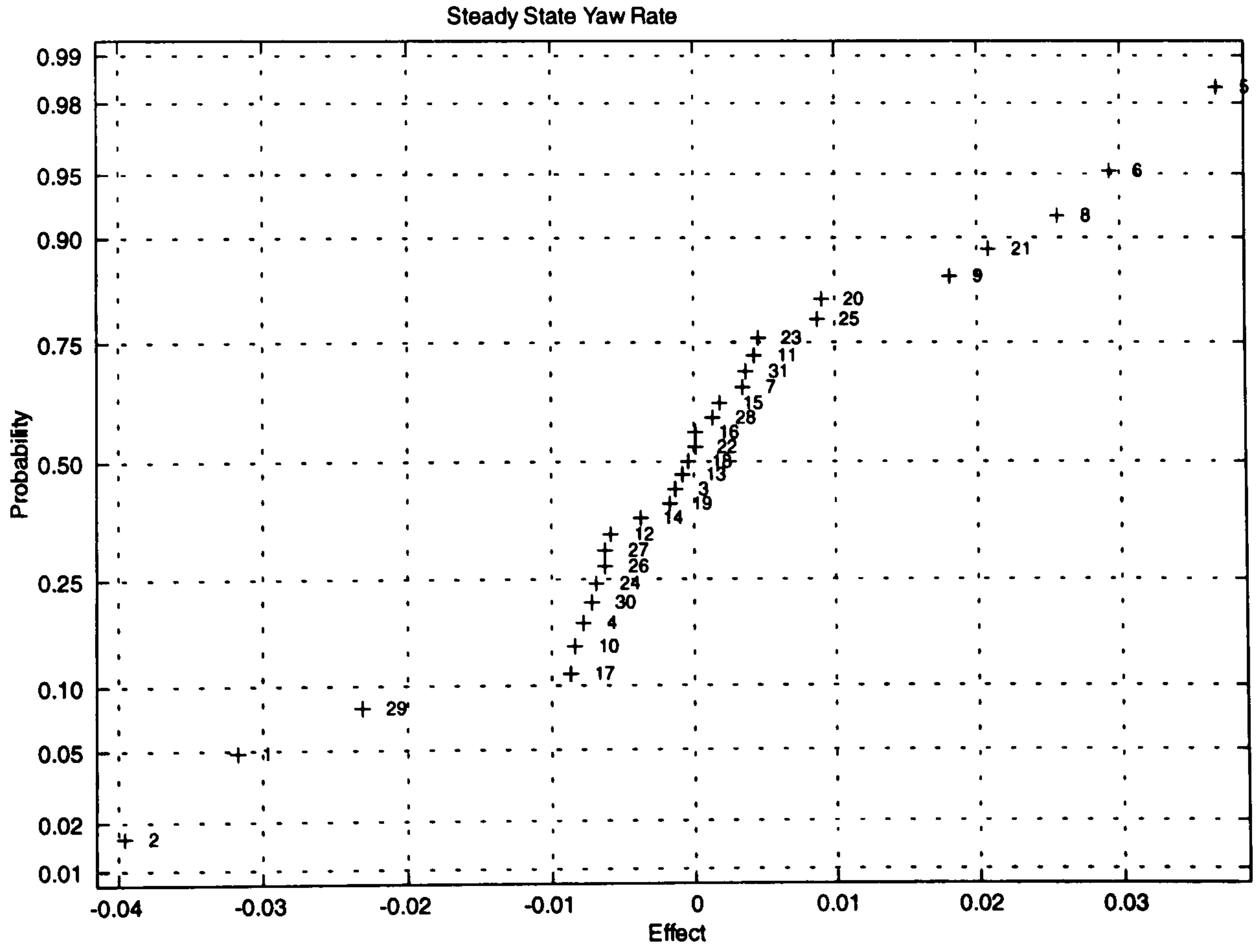
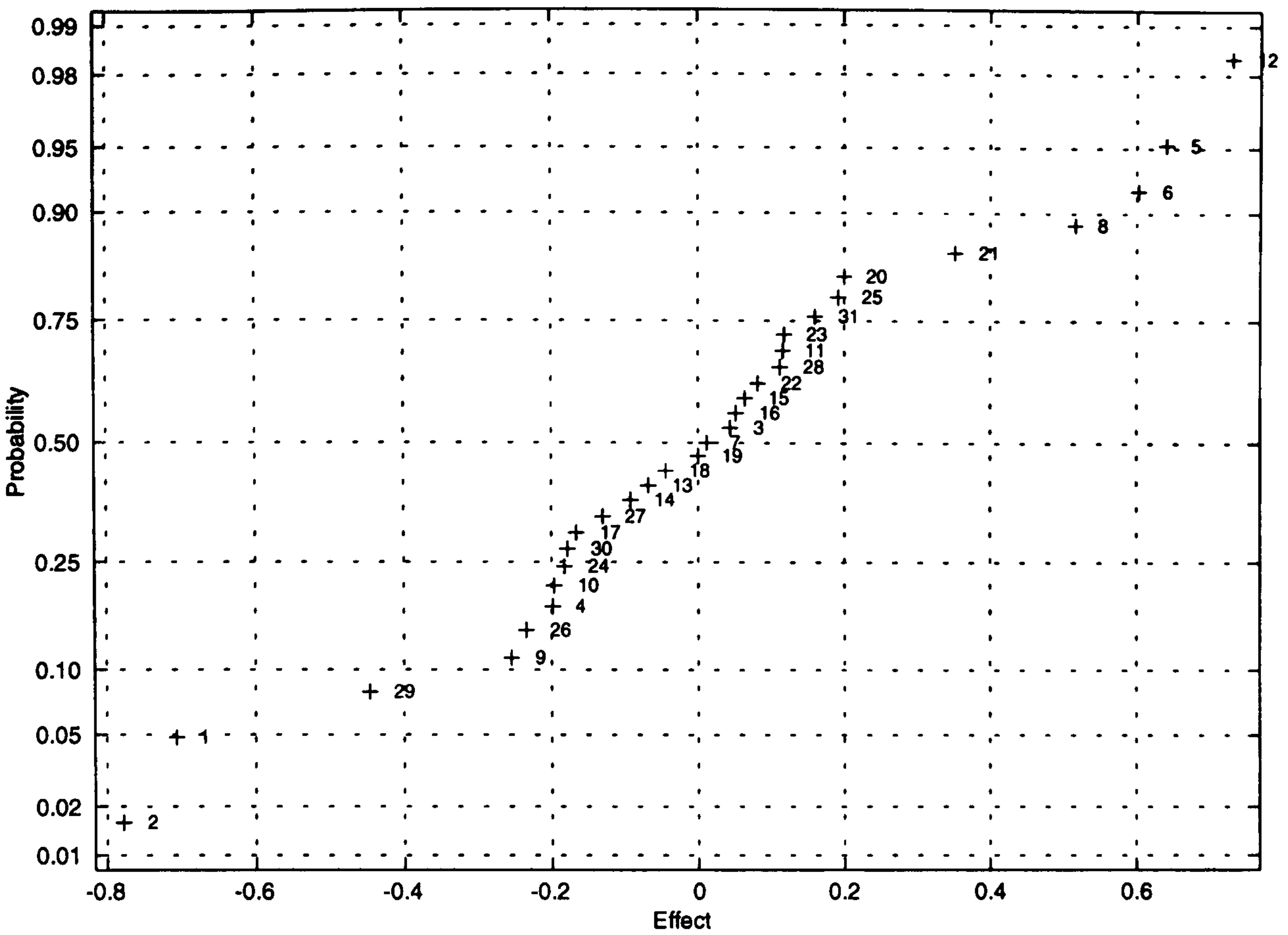
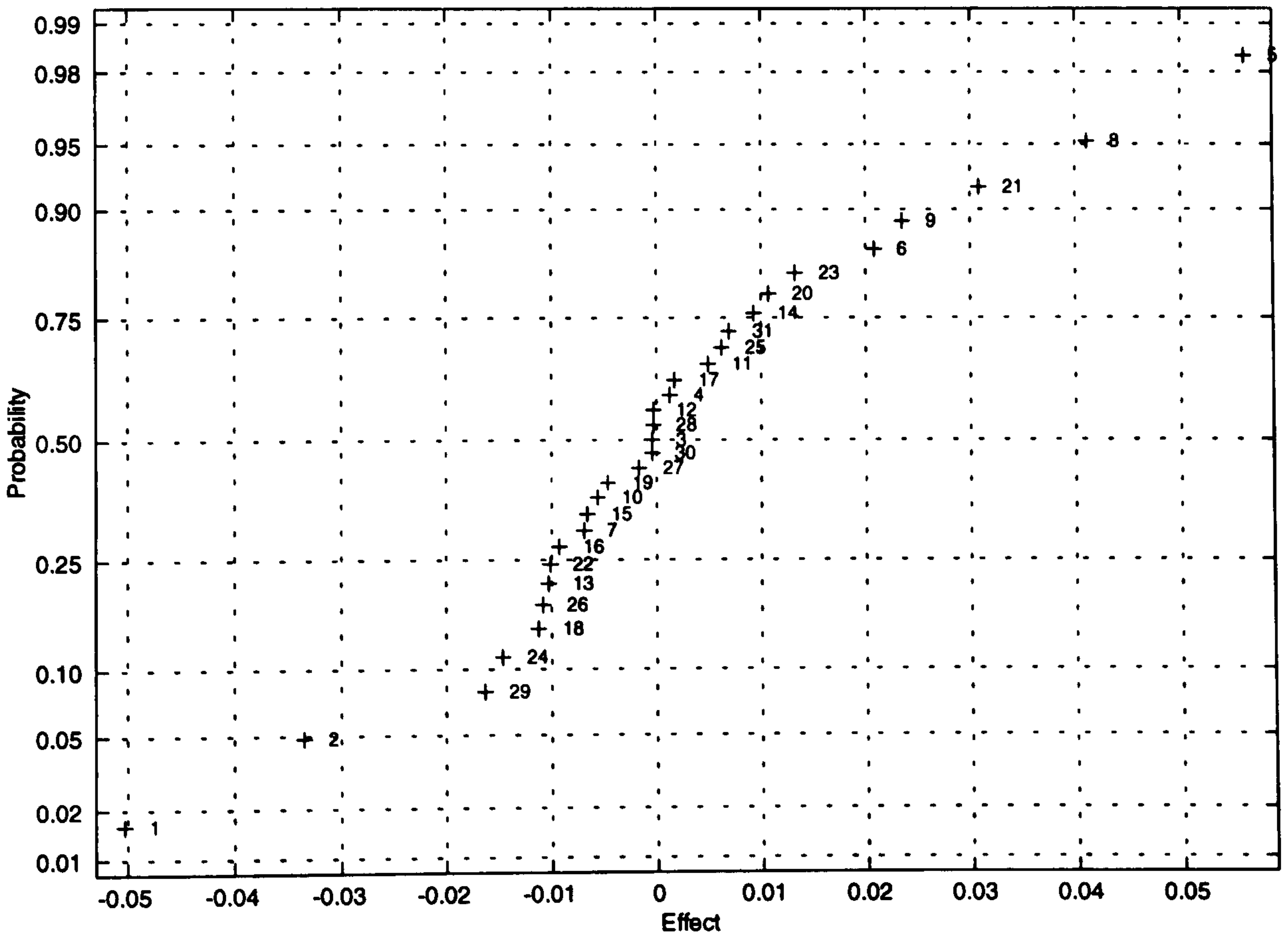
6
2
11
15
28
26
20
19
18
16
29
1
8

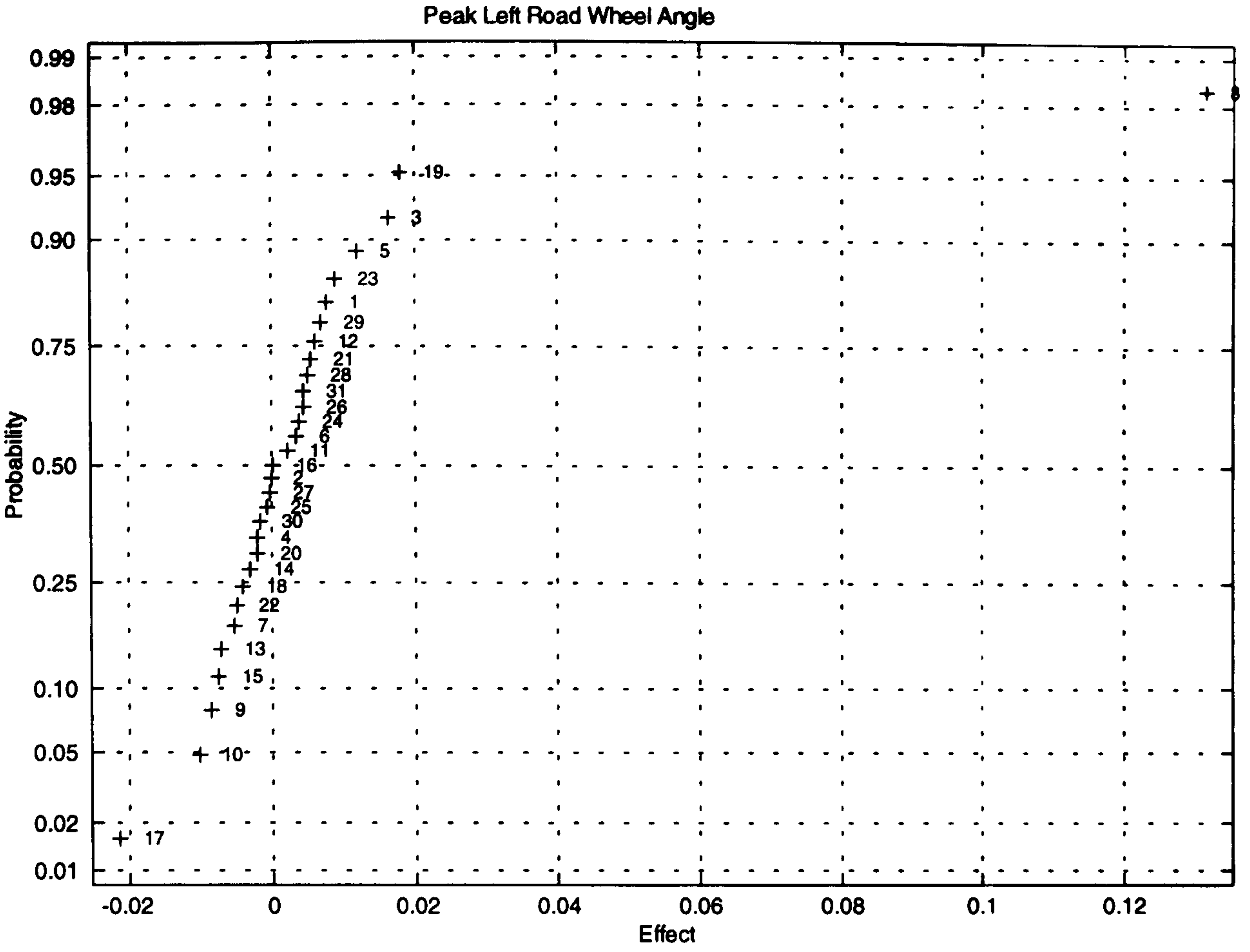

Steady State Yaw Rate
Probability
0.99
0.98
0.95
0.90
0.75
0.50
0.25
0.10
0.05
0.02
0.01
Effect
-0.04
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
2
1
29
17
10
4
30
24
26
27
12
14
19
3
13
18
22
16
28
15
7
31
11
23
25
20
9
21
8
6
5

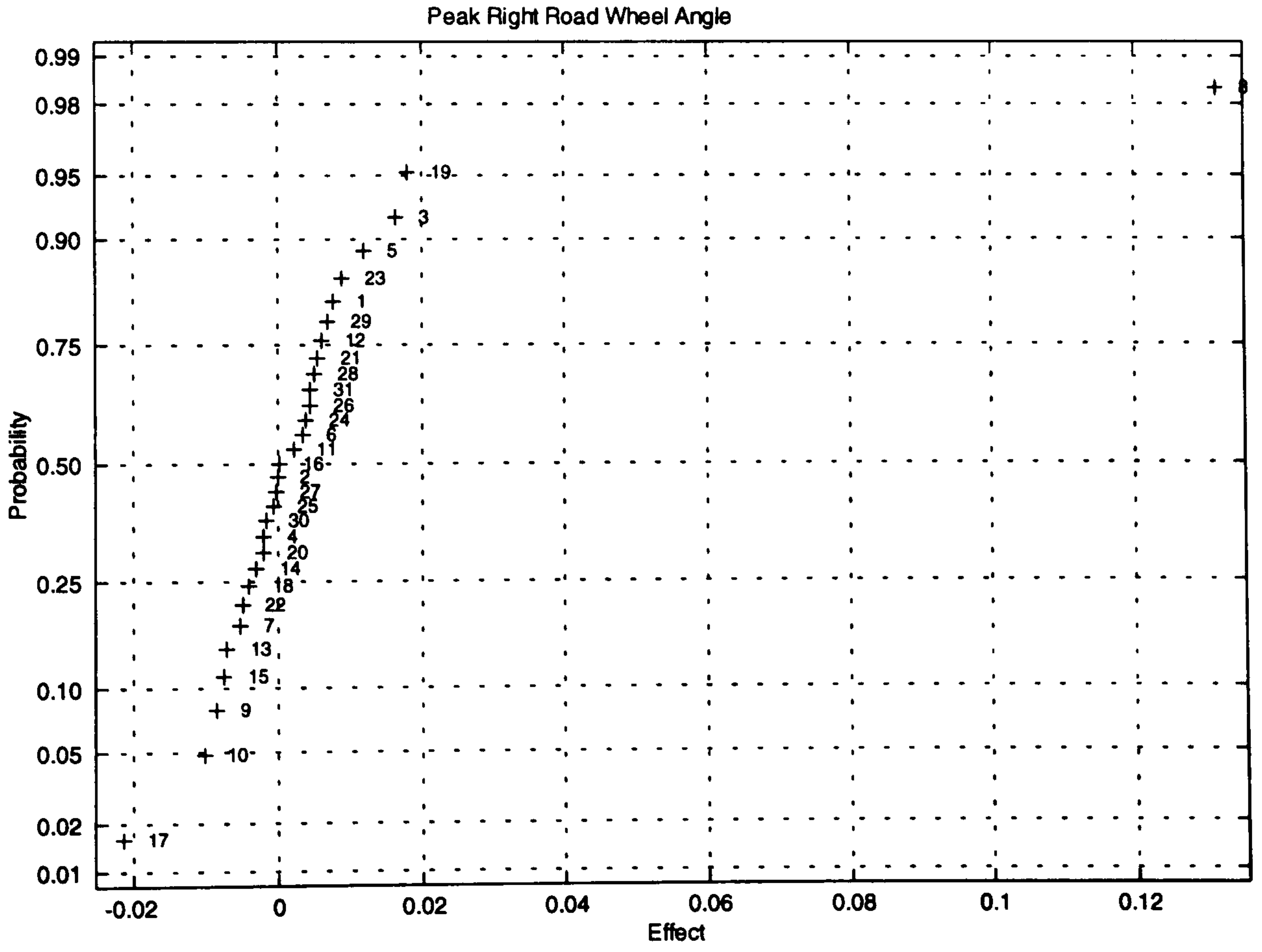
Steady State Steer Torque

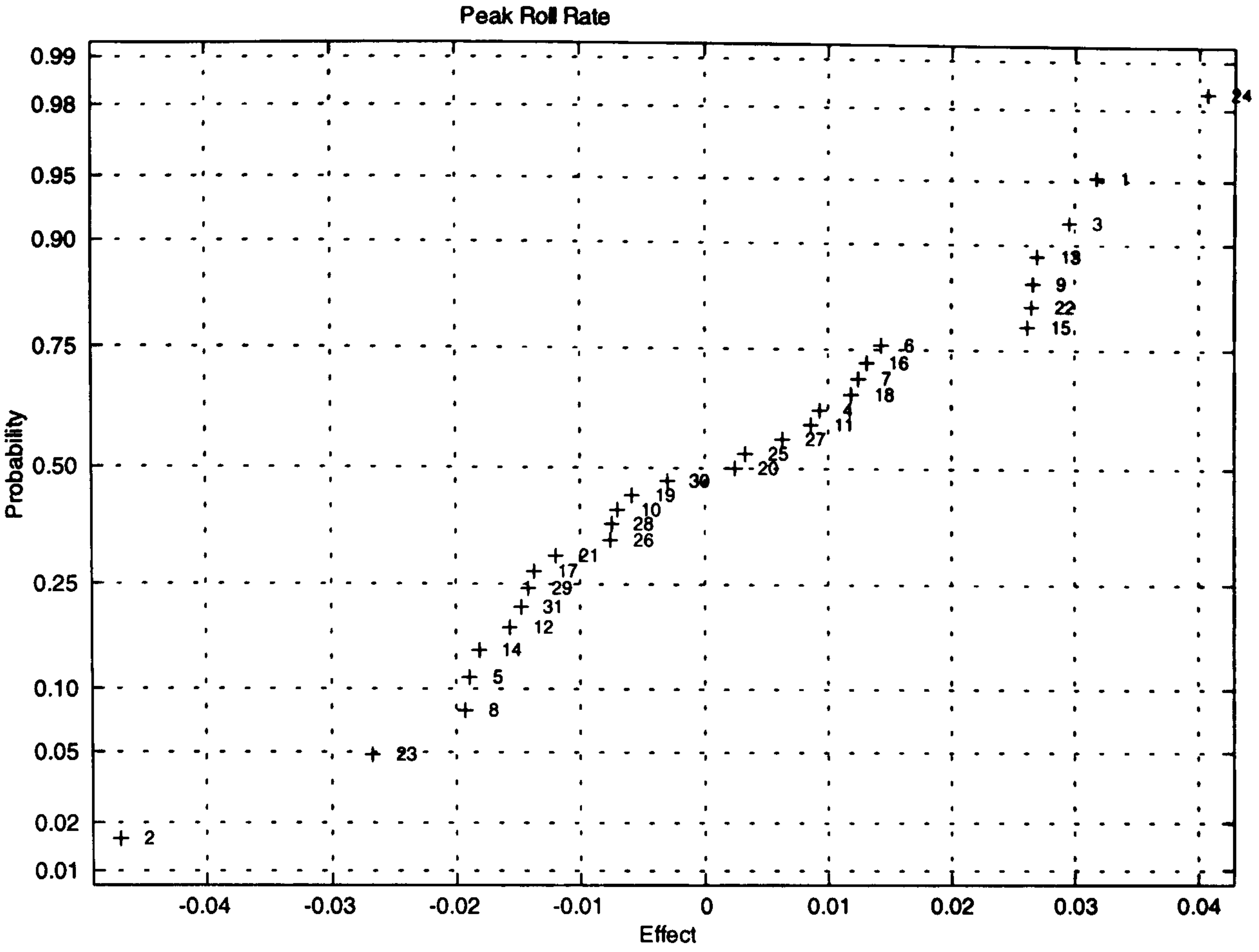


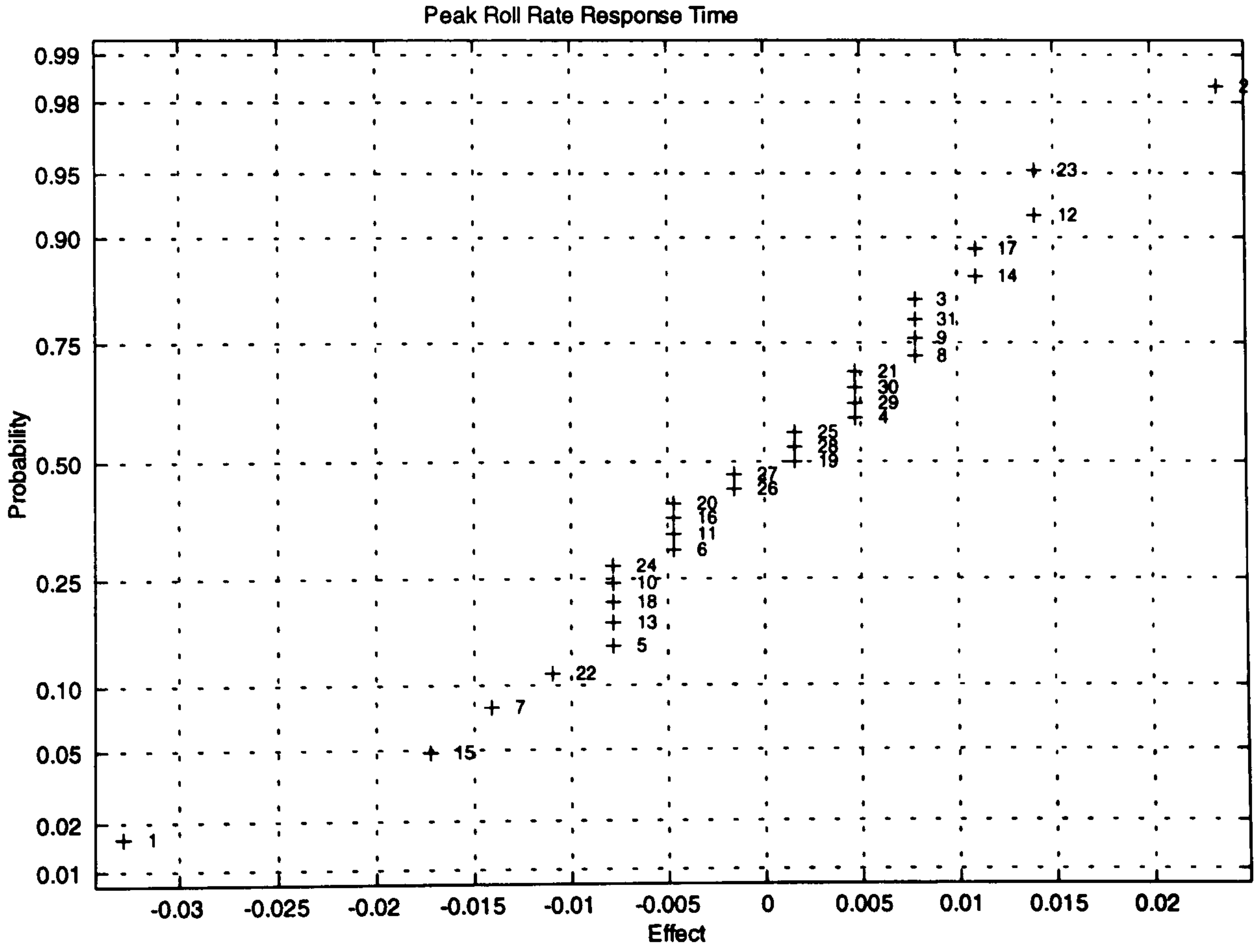
Peak Lateral Acceleration

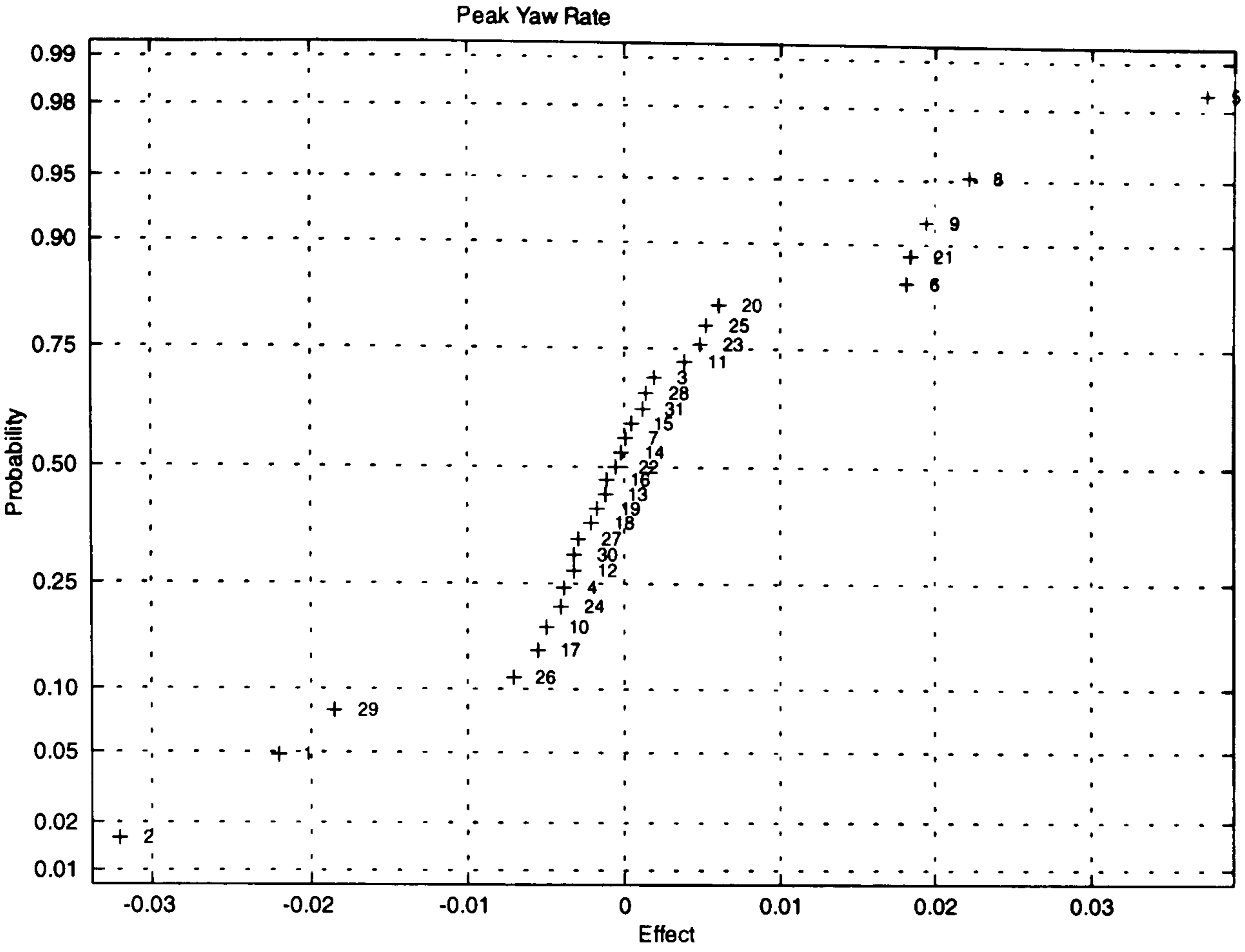


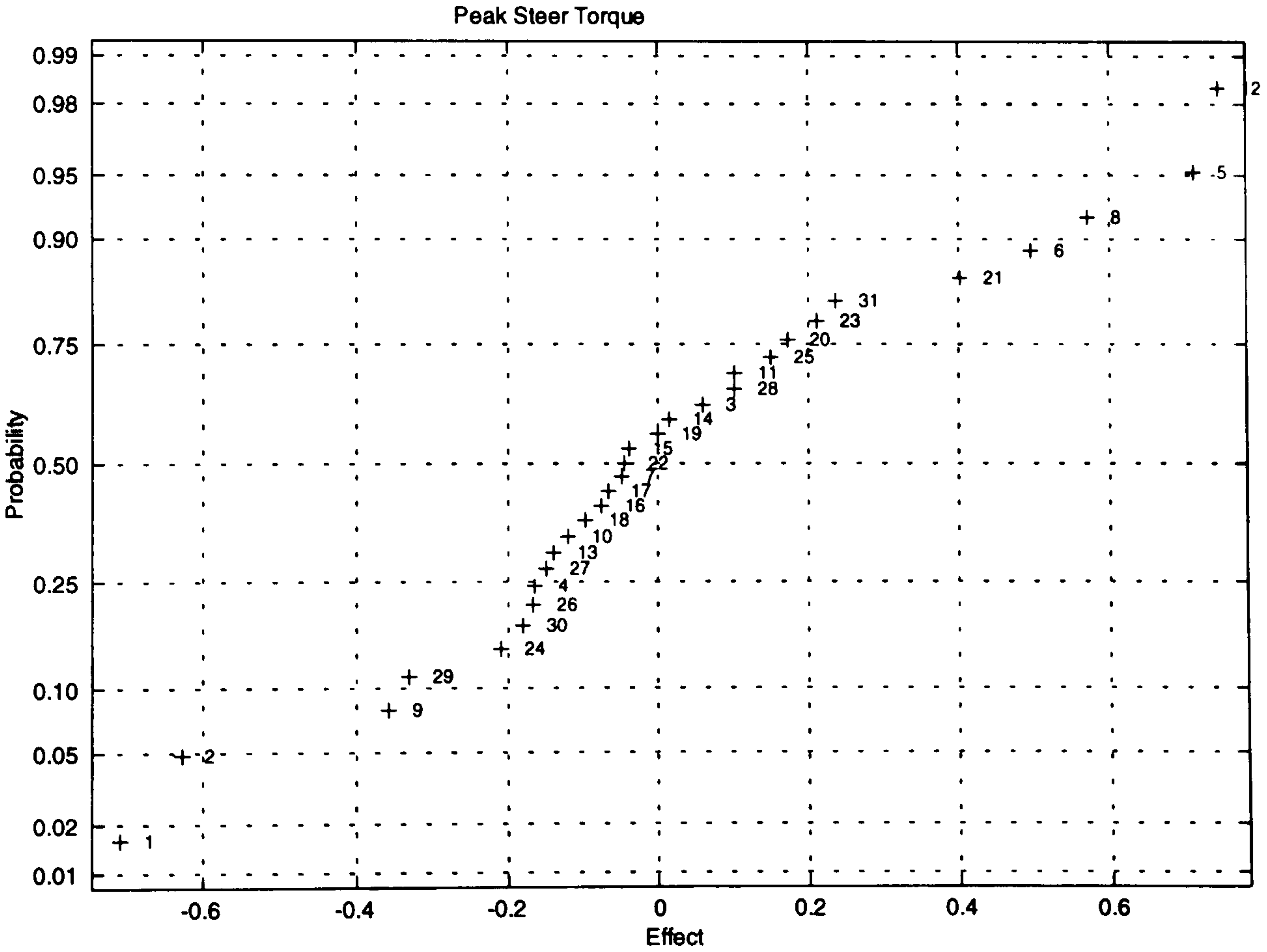

Peak Left Road Wheel Angle
Probability
0.99
0.98
0.95
0.90
0.75
0.50
0.25
0.10
0.05
0.02
0.01
-0.02
0
0.02
0.04
0.06
0.08
0.1
0.12
Effect
8
19
3
5
23
1
29
12
21
28
31
26
24
6
11
16
2
27
25
30
4
20
14
18
22
7
13
15
9
10
17


Peak Right Road Wheel Angle
Probability
0.99
0.98
0.95
0.90
0.75
0.50
0.25
0.10
0.05
0.02
0.01
-0.02
0
0.02
0.04
0.06
0.08
0.1
0.12
Effect
8
19
3
5
23
1
29
12
21
28
31
26
24
6
11
16
2
27
25
30
4
20
14
18
22
7
13
15
9
10
17


Peak Roll Rate


Peak Roll Rate Response Time


Peak Yaw Rate
Probability
0.99
0.98
0.95
0.90
0.75
0.50
0.25
0.10
0.05
0.02
0.01
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
Effect
5
8
9
21
6
20
25
23
11
3
28
31
15
7
14
22
16
13
19
18
27
30
12
4
24
10
17
26
29
1
2


Peak Steer Torque
Probability
0.99
0.98
0.95
0.90
0.75
0.50
0.25
0.10
0.05
0.02
0.01
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
Effect
12
5
8
6
21
31
23
20
25
11
28
3
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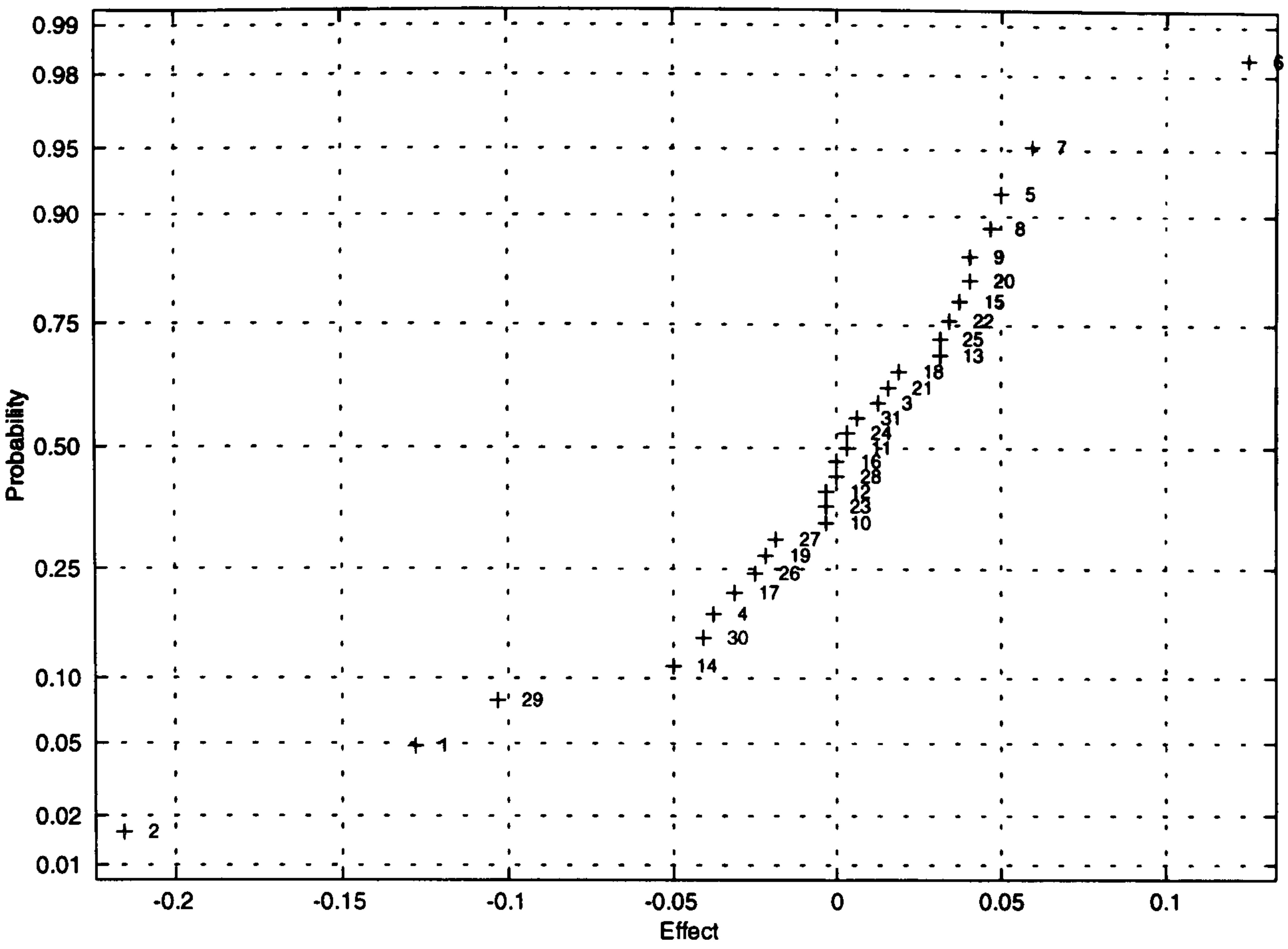
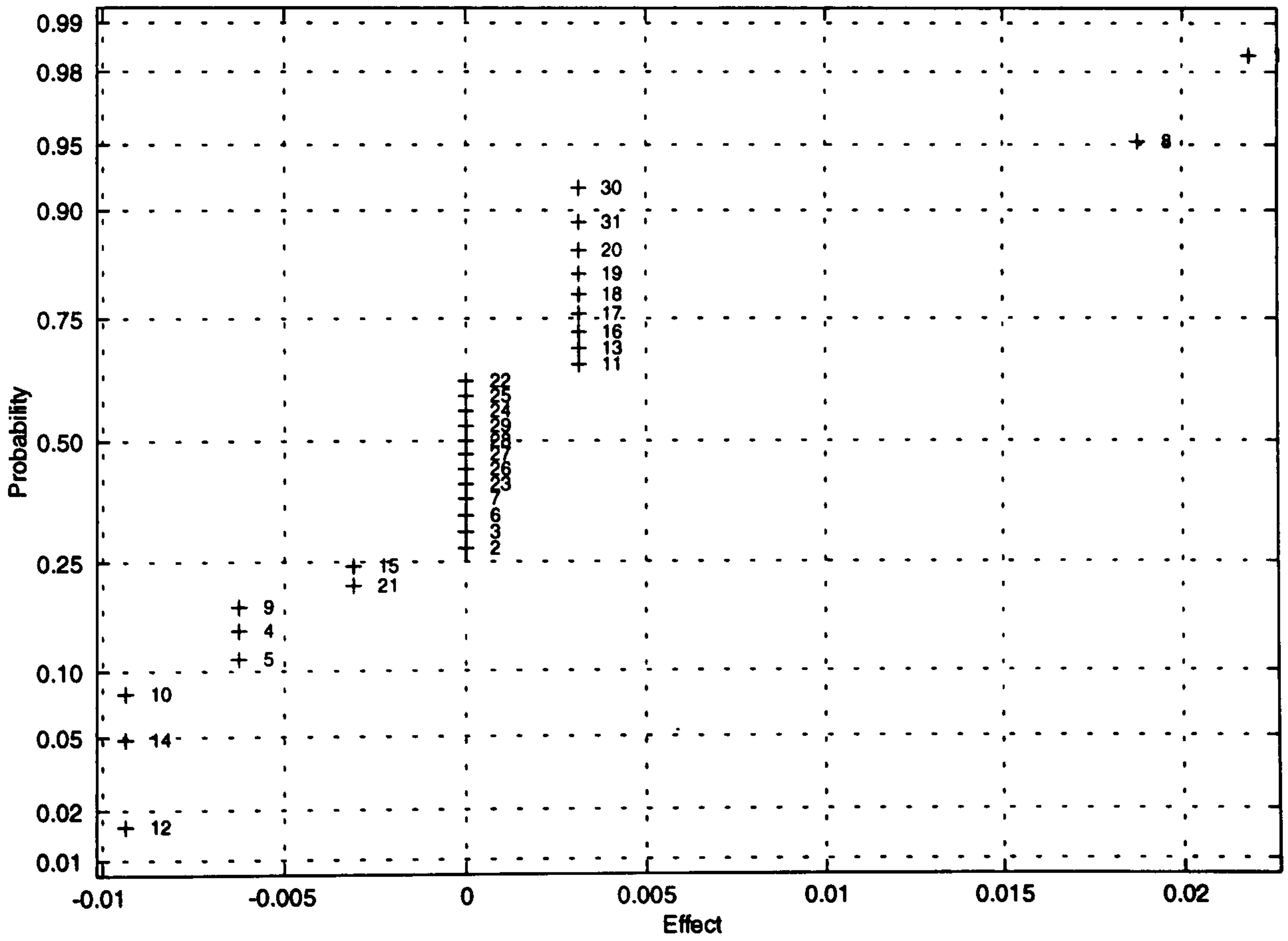
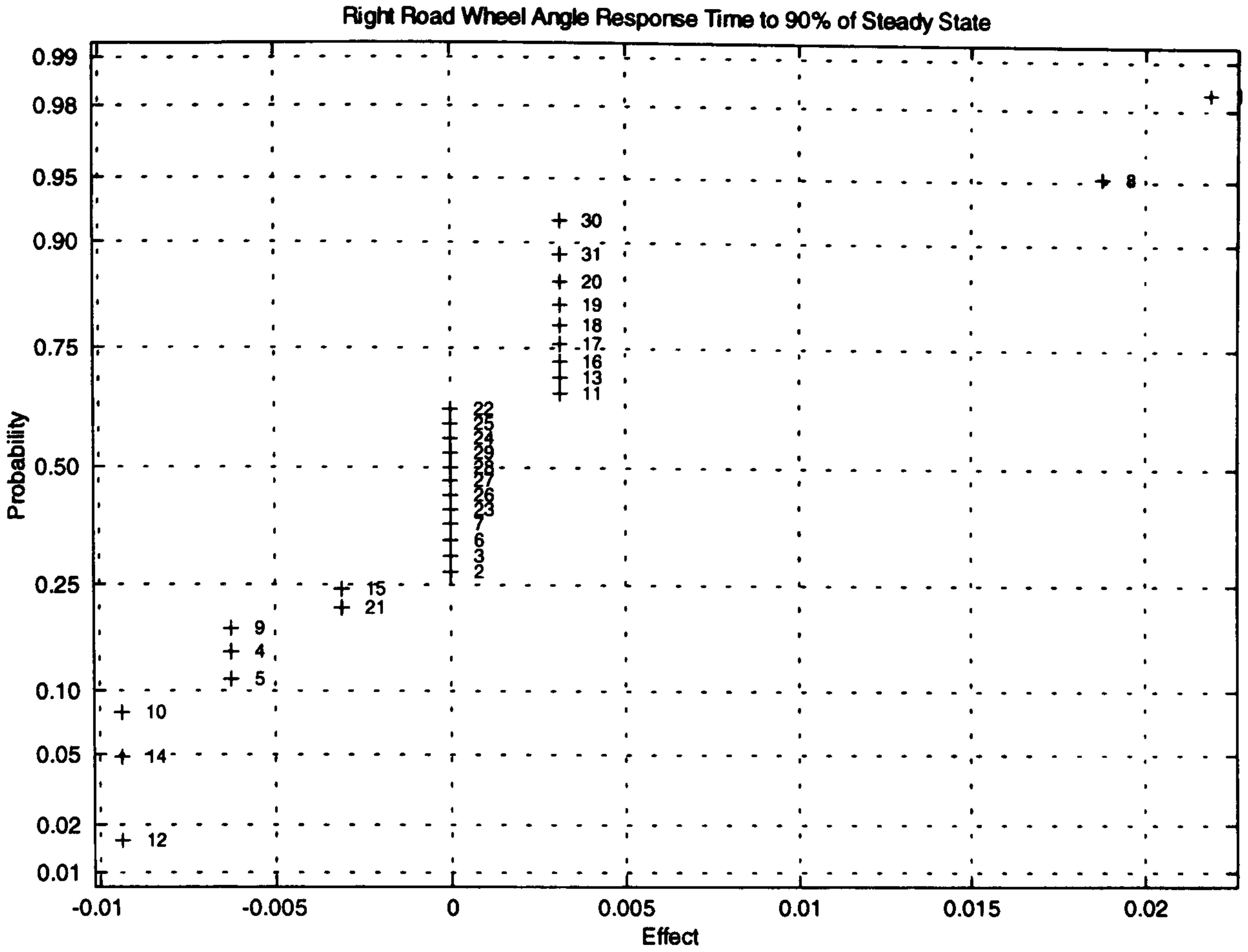
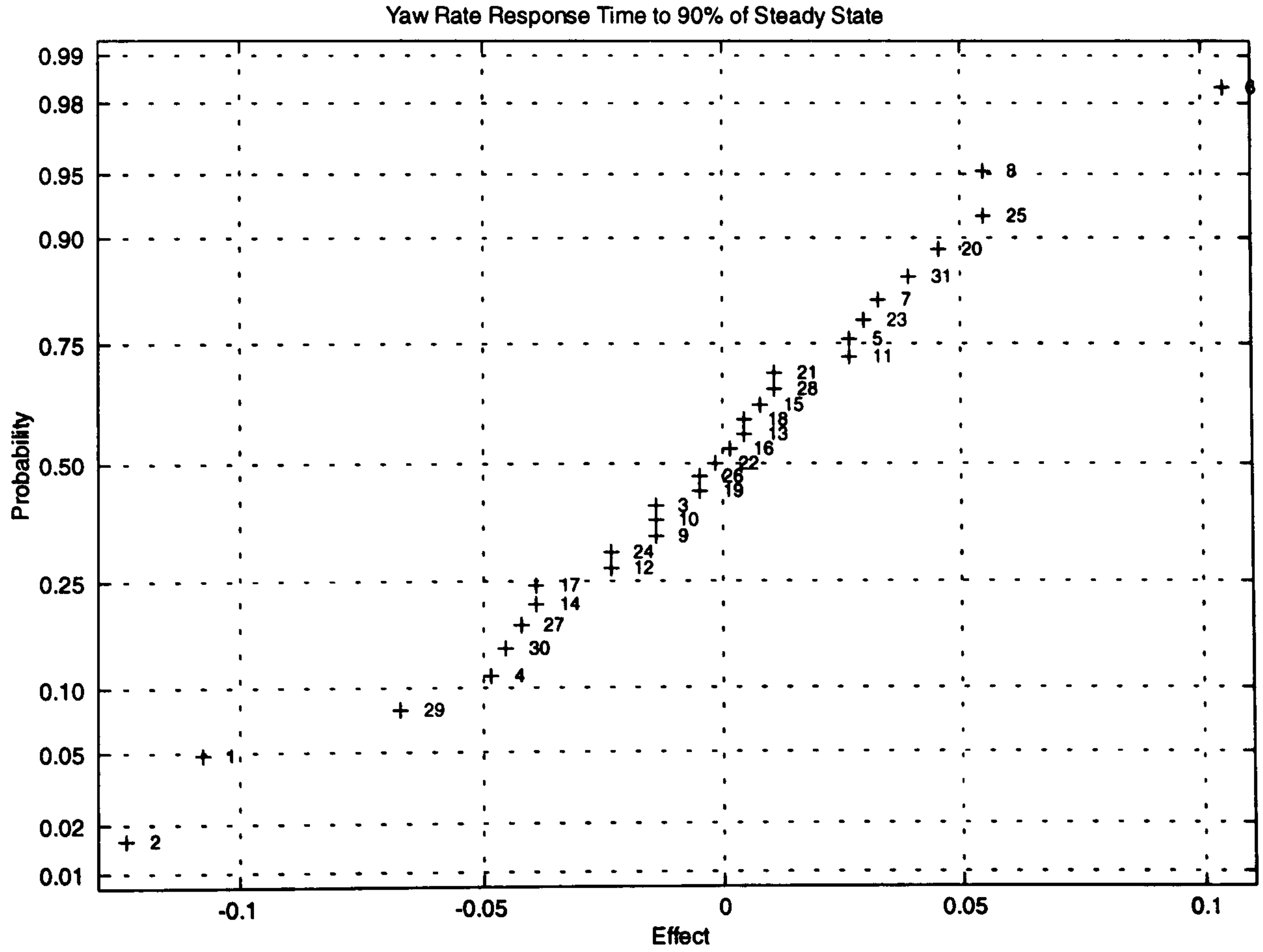
22
17
16
18
10
13
27
4
26
30
24
29
9
2
1


Lateral Acceleration Response Time to 90% of Steady State

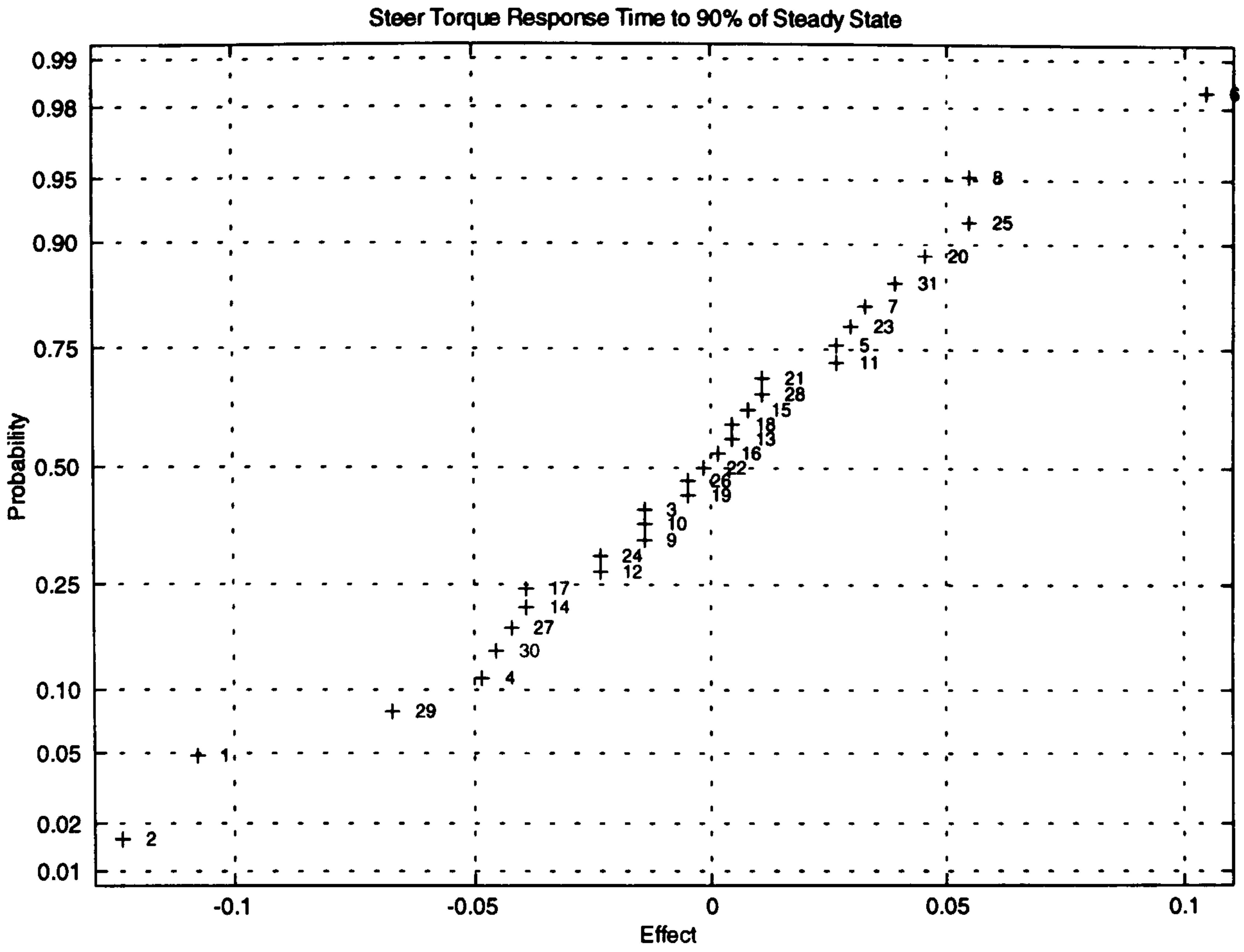

Left Road Wheel Angle Response Time to 90% of Steady State



Right Road Wheel Angle Response Time to 90% of Steady State



Yaw Rate Response Time to 90% of Steady State


Steer Torque Response Time to 90% of Steady State
Probability
0.99
0.98
0.95
0.90
0.75
0.50
0.25
0.10
0.05
0.02
0.01
-0.1
-0.05
0
0.05
0.1
Effect
8
25
20
31
7
23
5
11
21
28
15
18
13
16
22
26
19
3
10
9
24
12
17
14
27
30
4
29
1
2

Appendix 5A Percent Errors Between Experimental and Simulated Steady State Data

Table 5A-1

	Lateral acceleration percent error			
Config	-0.4	-0.2	0.2	0.4
1	-34.97	19.92	-6.64	-15.19
2	-5.56	10.67	-1.91	-12.21
3	-4.95	138.05	12.59	-2.47
4	5.62	-2.19	2.34	6.80
5	-13.27	-14.84	2.03	3.06
6	3.49	-3.24	1.84	12.24
7	-15.64	-22.02	11.11	17.51
8	-1.97	-16.76	3.20	9.00
9	6.28	1.61	-0.13	9.55
10	9.79	-1.79	-9.20	3.61
11	-0.18	-0.53	-5.16	-4.68
12	4.21	0.66	-3.84	8.29
13	4.02	-9.98	-2.01	-1.52
14	13.11	9.25	-6.69	-1.29
15	-24.41	-31.20	8.77	15.97
16	14.25	7.50	-5.51	11.80
Mean Error	1.33	-5.61	-0.69	5.82
± 95% C.I.	5.73	6.25	3.54	4.18

Table 5A-2

	Roll angle percent error			
Config	-0.4	-0.2	0.2	0.4
1	-38.68	9.58	-4.19	-13.91
2	-2.92	-0.92	4.93	-5.18
3	-8.93	-0.29	-3.95	-8.77
4	7.44	9.16	4.45	-3.06
5	4.45	15.74	9.14	4.11
6	5.73	1.08	-1.82	-4.30
7	-3.85	1.61	3.56	1.18
8	2.67	0.58	-1.28	2.98
9	-8.49	-0.30	-2.92	-8.74
10	12.70	-23.57	4.28	1.88
11	13.83	-9.26	11.68	2.22
12	23.64	-12.65	7.05	11.45
13	-8.19	9.21	-7.10	4.34
14	5.28	-3.23	7.71	-1.00
15	2.11	-6.37	2.51	-5.16
16	10.11	9.27	-6.68	-1.63
Mean Error	4.15	-2.39	3.81	-0.38
± 95% C.I.	5.87	5.71	2.57	3.12

Table 5A-3

	Side slip angle percent error			
Config	-0.4	-0.2	0.2	0.4
1	-184.80	-9.11	23.18	1.00
2	4.54	25.48	3.28	-6.61
3	-0.53	0.65	-9.91	6.25
4	-4.78	7.45	-36.19	17.28
5	8.50	32.13	-12.42	18.36
6	-11.15	-37.85	37.80	47.16
7	28.23	22.90	44.94	52.13
8	-1.96	1.86	-14.62	18.39
9	38.87	4.95	36.41	45.39
10	-22.88	23.66	-9.28	28.04
11	-8.16	49.21	-7.11	4.33
12	-9.67	41.43	-22.20	25.43
13	-3.46	4.17	-4.45	1.14
14	4.20	-8.15	-8.77	6.16
15	10.22	2.23	13.33	41.26
16	-3.92	4.75	-12.28	-3.75
Mean Error	0.76	14.99	7.47	29.82
± 95% C.I.	10.88	15.88	18.02	9.95

Table 5A-4

	Steering torque percent error			
Config	-0.4	-0.2	0.2	0.4
1	-1.57	29.77	25.19	16.72
2	22.40	1.85	4.91	23.66
3	-2.92	4.28	11.68	7.05
4	18.78	8.75	8.62	26.94
5	4.84	6.56	5.12	9.49
6	-16.17	8.56	2.81	26.39
7	24.96	-3.10	-4.05	-32.79
8	3.50	20.08	4.76	29.51
9	37.15	8.36	10.32	13.74
10	30.61	-13.18	-12.73	-2.43
11	-3.29	-13.41	-14.29	31.74
12	5.73	6.66	-8.15	21.77
13	-12.64	-1.47	6.23	9.79
14	29.04	-15.83	-4.11	-2.39
15	0.78	-3.67	-3.79	8.24
16	-5.18	-8.77	-4.05	4.20
Mean Error	11.69	1.45	-1.01	12.31
± 95% C.I.	10.16	7.07	6.58	10.37

Appendix 5B Percent Errors Between Experimental and Simulated Step Input Data

The following tables show, for each configuration, the absolute percent difference observed between experimental and simulated data. Clockwise and anti-clockwise values were averaged to give the numbers shown.

Table 5B-1 0.2 g

	Absolute Percent Difference Between Simulated and Expermental Data							
Configuration	Peak Lateral Acceleration	Peak Lateral Acceleration Response Time	Peak Road Wheel Angle	Peak Road Wheel Angle Response Time	Peak Yaw Rate	Peak Yaw Rate Response Time	Peak Steer Torque	Peak Steer Torque Response Time
1	32.58	3.78	37.61	34.59	15.02	12.00	3.18	6.02
2	15.21	8.90	8.67	51.36	24.32	18.20	35.51	12.29
3	17.99	21.15	22.45	48.39	36.01	36.14	26.82	11.77
4	11.56	8.94	15.61	40.39	8.11	18.53	26.63	22.87
5	31.22	8.89	12.22	37.44	7.60	25.83	9.96	12.64
6	26.55	6.20	18.54	55.78	19.75	28.95	19.79	16.67
7	20.01	15.98	11.33	44.44	16.50	36.11	21.07	38.66
8	3.02	1.05	15.24	25.40	6.77	22.09	27.07	10.11
9	16.56	2.09	10.73	43.27	14.56	2.13	18.80	1.04
10	20.17	2.69	8.94	43.36	32.57	20.66	14.68	3.27
11	9.28	1.04	5.82	19.61	18.27	1.56	20.05	11.01
12	9.61	5.49	5.95	34.78	30.86	2.69	24.15	3.26
13	18.80	5.49	5.17	22.62	31.64	10.91	24.69	6.84
14	0.85	9.68	10.18	33.59	31.61	5.75	23.34	10.71
15	30.00	3.78	18.02	25.38	28.30	3.85	11.34	1.04
16	22.92	1.03	11.63	38.70	11.55	6.98	37.26	31.37
Mean	**17.90**	**6.64**	**13.63**	**37.44**	**20.84**	**15.77**	**21.52**	**12.47**
± 95% Confidence Interval	**4.66**	**2.75**	**3.95**	**5.12**	**4.88**	**5.79**	**4.35**	**5.19**

Table 5B-2 0.4 g

	Absolute Percent Difference Between Simulated and Expermental Data							
Configuration	Peak Lateral Acceleration	Peak Lateral Acceleration Response Time	Peak Road Wheel Angle	Peak Road Wheel Angle Response Time	Peak Yaw Rate	Peak Yaw Rate Response Time	Peak Steer Torque	Peak Steer Torque Response Time
1	20.67	2.13	29.67	12.84	26.90	3.26	17.94	17.94
2	5.44	4.36	11.62	38.21	23.22	5.31	30.36	30.36
3	31.25	10.34	20.75	25.46	28.64	28.05	19.88	19.88
4	9.71	3.13	17.70	33.18	9.20	6.29	35.80	35.80
5	19.41	2.13	13.73	37.59	11.91	29.81	10.57	10.57
6	11.96	2.13	18.23	48.98	9.04	10.45	23.38	23.38
7	14.03	12.88	14.10	27.78	25.96	36.37	17.91	17.91
8	11.27	3.71	10.55	35.01	8.07	23.01	17.93	17.93
9	19.07	3.17	11.29	42.39	13.47	4.44	46.84	46.84
10	7.65	2.08	8.89	25.22	9.82	5.61	32.38	32.38
11	1.02	0.52	10.38	25.93	29.08	0.00	17.40	17.40
12	10.62	0.00	5.46	26.77	10.28	0.00	34.16	34.16
13	5.04	1.04	11.72	23.79	29.38	0.00	17.04	17.04
14	17.31	3.16	16.49	29.85	19.92	14.77	37.64	37.64
15	11.83	0.00	12.02	27.27	21.32	0.00	21.77	21.77
16	29.96	0.52	11.85	30.76	20.37	1.09	49.42	49.42
Mean	**14.14**	**3.21**	**14.03**	**30.69**	**18.54**	**10.53**	**26.90**	**26.90**
± 95% Confidence Interval	**4.14**	**1.75**	**2.77**	**4.16**	**3.98**	**5.95**	**5.63**	**5.63**

Table 5B-3 0.6 g

	Absolute Percent Difference Between Simulated and Expermental Data							
Configuration	Peak Lateral Acceleration	Peak Lateral Acceleration Response Time	Peak Road Wheel Angle	Peak Road Wheel Angle Response Time	Peak Yaw Rate	Peak Yaw Rate Response Time	Peak Steer Torque	Peak Steer Torque Response Time
1	12.20	2.69	30.20	18.16	67.66	5.57	12.50	3.26
2	18.51	2.64	9.84	26.56	16.18	2.53	28.43	34.11
3	10.30	6.57	19.99	17.80	12.49	22.78	23.71	27.14
4	23.68	3.52	21.10	28.14	2.75	1.39	37.04	17.83
5	6.82	1.58	13.17	35.02	14.31	12.50	22.31	0.52
6	13.75	3.71	17.42	29.20	9.95	11.06	26.37	5.17
7	3.44	7.90	13.19	31.14	14.89	15.75	30.73	24.84
8	14.05	2.78	13.28	23.15	12.76	2.45	27.74	39.52
9	26.82	1.58	19.39	27.38	20.00	0.55	39.98	3.85
10	23.48	2.13	12.84	21.82	9.56	10.91	36.17	3.32
11	11.67	0.00	13.52	21.79	15.27	2.13	31.16	0.52
12	12.96	0.00	11.13	23.41	12.17	0.00	41.50	2.13
13	7.17	0.00	18.05	23.98	14.74	0.00	26.30	0.52
14	30.73	4.73	23.44	20.25	12.42	4.31	40.02	16.11
15	11.48	0.00	19.46	26.99	8.46	0.00	21.06	3.78
16	34.69	2.04	15.47	23.43	21.99	10.55	42.54	1.56
Mean	**16.36**	**2.62**	**16.97**	**24.89**	**16.60**	**6.41**	**30.47**	**11.51**
± 95% Confidence Interval	**4.43**	**1.13**	**2.58**	**2.29**	**7.02**	**3.32**	**4.19**	**6.48**

Appendix 5C Comparison of Simulated and Experimental Frequency Response Gains

Percent Errors Between Experimental and Simulated Frequency Responses						
Config.	Latac Gain			Yaw Gain		
	0.4 Hz	0.7 Hz	1.0 Hz	0.4 Hz	0.7 Hz	1.0 Hz
1	0.0642	-0.0796	-0.173	0.0203	-0.0536	-1.2638
2	-0.0161	0.047	-0.1158	0.175	-0.0091	-0.7788
3	-0.0107	0.0222	-0.4426	0.1847	0.4412	-0.8961
4	-0.2675	-0.0788	-0.0399	-0.6094	-0.1706	-0.4661
5	0.0571	-0.1764	-0.0113	0.0094	-0.5192	-2.2326
6	0.0532	0.0062	-0.1776	-0.0757	0.0505	-0.8092
7	-0.2411	-0.097	-0.0433	-0.364	-0.0626	-0.7543
8	-0.038	-0.003	-0.0585	0.0554	-0.2484	-1.4517
9	-0.5398	-0.069	0.1601	-0.176	-0.1036	-0.9921
10	0.0239	0.0514	-0.0723	-0.3613	-0.1339	-1.0693
11	-0.2866	-0.1538	-0.0694	-0.0578	-0.3648	-1.5465
12	0.154	-0.0932	-0.2428	-0.2983	-0.4118	-1.9684
13	0.0796	0.1527	-0.0383	0.1862	0.4705	0.0595
14	0.0805	0.0058	-0.2216	0.0741	0.0176	-1.0131
15	-0.0478	-0.1798	-0.2388	0.0341	-0.2051	-1.9118
16	-0.0316	-0.03	-0.1192	-0.1802	0.1291	-0.2545
Mean	-6.04	-11.50	-4.22	-7.34	-11.90	-108.43
± 95% Confidence Interval	3.17	5.05	1.53	4.55	2.25	10.55

Appendix 6A Response Metrics Selected For Use In Multiple Regression

	Response Metric											
Configuration	LatacGain/0.4	LatacGain/0.7	LatacGain/1.0	LatacPhase/0.4	LatacPhase/0.7	LatacPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0
1	0.0116	0.0095	0.0066	-28.9700	-50.9500	-73.5500	0.0307	0.0386	0.0436	21.5200	17.9300	9.9540
2	0.0089	0.0074	0.0051	-27.2600	-52.9400	-77.6200	0.0300	0.0375	0.0409	14.0200	13.8700	6.5500
3	0.0096	0.0086	0.0065	-21.2800	-39.8100	-62.3100	0.0299	0.0361	0.0432	16.6100	17.4600	12.1500
4	0.0091	0.0080	0.0065	-15.8200	-36.7800	-51.7900	0.0349	0.0379	0.0422	3.3850	4.7580	5.3940
5	0.0094	0.0078	0.0048	-25.5500	-52.9200	-71.6600	0.0335	0.0418	0.0455	13.7200	11.6000	4.3260
6	0.0119	0.0101	0.0074	-21.6200	-46.3200	-69.1700	0.0305	0.0385	0.0437	20.2200	17.2700	11.6800
7	0.0087	0.0075	0.0058	-24.0000	-43.1800	-64.6200	0.0297	0.0366	0.0431	18.4000	20.0600	13.6800
8	0.0096	0.0084	0.0067	-22.6200	-37.3500	-54.5100	0.0325	0.0385	0.0427	13.6300	12.6300	7.3970
9	0.0122	0.0078	0.0043	-60.5300	-70.9100	-80.2900	0.0444	0.0429	0.0424	-3.1350	-0.9776	-1.5020
10	0.0135	0.0103	0.0077	-31.2600	-50.5900	-65.1100	0.0384	0.0396	0.0401	1.3770	-0.1182	-2.1730
11	0.0139	0.0092	0.0053	-42.2000	-69.4000	-82.6700	0.0479	0.0423	0.0425	-8.3300	-8.1290	-5.3080
12	0.0145	0.0110	0.0060	-41.7300	-68.0300	-89.1600	0.0447	0.0459	0.0439	3.6340	-4.6180	-7.4880
13	0.0144	0.0107	0.0069	-37.6200	-59.9500	-78.3200	0.0432	0.0433	0.0427	-6.8240	-7.3860	-6.8320
14	0.0097	0.0086	0.0063	-24.9100	-46.9100	-66.6100	0.0448	0.0438	0.0439	-1.4050	-1.8170	-5.5240
15	0.0158	0.0098	0.0054	-53.8200	-76.5200	-91.5500	0.0430	0.0414	0.0412	-4.0760	-2.8470	-2.2490
16	0.0124	0.0093	0.0055	-45.1700	-72.7000	-89.7800	0.0379	0.0409	0.0406	1.7730	-2.4720	-2.5910

	Response Metric											
Configuration	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	YawPhase/0.7	YawPhase/1.0	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6
1	0.2752	0.2824	0.2844	-14.2000	-28.9100	-44.8200	0.7875	1.3750	0.3647	0.9104	3.2500	5.0620
2	0.2216	0.2247	0.2267	-14.2500	-31.4900	-49.5300	0.6125	0.7625	0.5762	1.6850	1.8750	3.4380
3	0.1908	0.1978	0.2119	-12.7100	-23.2800	-38.3900	0.4625	0.5625	0.6790	1.5370	1.3750	2.1880
4	0.2054	0.2358	0.2328	29.6300	1.0210	-13.7200	0.4500	0.6000	0.8565	2.3810	2.0000	3.1880
5	0.2064	0.2295	0.2258	-16.3100	-31.1300	-50.2100	0.5875	0.8750	0.7157	1.9840	1.8120	4.0620
6	0.2440	0.2483	0.2485	-13.7900	-27.7400	-42.8300	0.6000	0.6750	0.4503	1.3110	1.6250	2.1250
7	0.2063	0.2026	0.2190	-15.5200	-22.8200	-38.7200	0.5500	0.7000	0.8345	2.0450	2.1250	3.7500
8	0.1893	0.2093	0.2360	-6.9300	-13.8400	-26.3500	0.6500	0.8375	0.5910	1.6710	2.1880	4.0000
9	0.2696	0.2335	0.2093	-43.3800	-48.2100	-57.6300	0.9500	0.7500	0.5439	1.8140	3.5000	6.0620
10	0.2985	0.2657	0.2479	-26.6100	-37.4300	-48.2300	0.6375	1.2750	0.4835	1.4030	2.8120	10.8100
11	0.3310	0.2602	0.2274	-27.5200	-46.8800	-53.5300	0.9625	1.0750	0.6166	1.5360	3.2500	8.8120
12	0.3894	0.3382	0.2654	-30.3200	-57.2600	-70.5800	0.8750	1.3380	0.3576	0.7693	2.7500	9.7500
13	0.3087	0.2595	0.2369	-21.8900	-39.0600	-47.0100	0.8750	1.2500	0.4720	1.2690	3.5000	10.8100
14	0.1688	0.2115	0.2224	14.2100	-9.5120	-26.4200	0.6500	0.7375	0.7451	2.3800	2.6880	4.3750
15	0.3510	0.2720	0.2303	-39.8700	-51.8200	-60.5700	0.9750	1.4620	0.7621	1.1910	7.0620	11.7500
16	0.2780	0.2649	0.2344	-32.5100	-49.4900	-59.3400	0.9125	0.9125	0.4728	1.2680	1.2500	5.4380

	Response Metric											
Configuration	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6
1	2.9800	4.1640	5.2500	5.6250	3.6960	11.2700	5.6250	10.7500	3.1810	6.3250	6.2500	10.7500
2	3.9050	6.8700	2.8750	4.5000	3.9400	8.8050	4.0000	5.1250	3.5180	6.7290	5.0000	5.1250
3	8.4700	13.1400	1.5000	4.0000	3.6020	10.7400	2.6250	3.5000	4.1430	7.5190	3.6250	3.5000
4	3.7620	11.4100	2.7500	4.2500	2.9720	9.4090	2.8750	4.0000	2.6300	7.0450	2.8750	4.1250
5	5.4090	10.3700	5.3750	5.3750	4.4800	11.5800	3.6250	5.6250	2.6960	7.0330	3.8750	7.1250
6	6.4710	11.0800	4.7500	3.0000	3.8760	10.7700	3.5000	3.7500	3.5400	7.4360	5.6250	5.1250
7	3.6050	10.3100	3.8750	4.8750	4.1030	9.6480	3.6250	4.8750	2.8380	7.9200	4.7500	5.5000
8	3.8740	7.0960	4.5000	5.1250	3.6530	10.0600	3.3750	5.3750	3.5030	7.1050	4.2500	7.5000
9	7.0990	10.6200	2.7500	3.0000	4.0980	12.2200	7.8750	7.8750	2.8680	7.9750	8.3750	7.8750
10	2.6500	6.4580	4.2500	6.6250	3.1420	10.4300	3.8750	12.6300	2.5610	6.7670	5.1250	12.6300
11	3.0570	5.4900	5.0000	6.1250	4.0520	11.6000	9.0000	10.2500	3.2340	7.5120	9.0000	10.2500
12	1.8820	3.4140	7.1250	4.6250	3.4680	8.9420	7.8750	12.8800	2.7510	7.2990	8.1250	12.8800
13	3.7390	7.3420	5.2500	5.0000	4.3110	11.5000	8.5000	13.0000	3.5030	7.5330	8.5000	13.0000
14	3.2280	9.3980	4.7500	4.6250	3.2050	11.2400	5.7500	5.3750	2.6710	7.8750	6.0000	6.2500
15	2.3500	4.8440	4.7500	6.5000	5.3940	14.1400	11.2500	14.7500	3.2520	6.8030	13.8800	14.7500
16	2.2510	5.0410	3.1250	3.0000	3.8040	9.7390	6.8750	7.1250	3.0030	7.0910	8.5000	8.7500

	Response Metric									
Configuration	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2
1	4.0080	4.3510	-0.3929	0.2291	6.4330	5.4870	1.0650	2.0370	0.4907	0.0550
2	7.6380	5.5070	1.4090	0.9409	7.3110	5.4950	1.0150	1.7880	-0.0246	-0.0770
3	4.9320	2.4460	0.4501	0.5044	4.6220	3.4900	1.4760	1.4620	1.3330	0.6876
4	8.1260	4.1770	1.8030	1.3050	5.8090	3.1240	0.9250	1.7430	0.0344	-0.0622
5	10.3600	3.9570	1.1630	1.0620	8.7520	3.6920	1.2060	1.9310	0.9495	0.8131
6	6.8590	1.7800	0.0470	0.1906	8.1310	3.4790	0.4208	1.6280	0.7995	0.4581
7	6.1600	4.9910	1.4180	1.1690	6.4350	5.1580	1.5440	1.9210	0.1001	-0.0320
8	6.1270	2.2410	0.6915	0.5621	5.9180	2.7640	0.8129	2.0910	0.5616	0.4273
9	6.3160	4.8250	-0.0394	-0.1354	5.7120	5.3440	1.6360	1.8950	-0.3319	-0.2683
10	4.6660	2.1370	-0.1694	-0.1365	5.3500	2.6120	1.1180	2.1940	0.2727	0.0394
11	9.0140	2.5300	0.0264	0.1125	9.0530	2.2410	0.9773	1.8330	-0.0414	-0.3241
12	4.9390	2.0490	-1.0440	-0.3681	7.3750	3.6530	0.9116	1.8480	0.3402	-0.0042
13	3.9170	4.0310	-0.4337	-0.2483	4.7130	4.7020	1.1600	2.0290	0.1314	0.2754
14	7.1570	5.1190	0.8673	0.7585	5.6800	3.5450	1.6510	1.6830	0.1341	0.0448
15	1.4160	3.3180	-0.9029	-0.5954	3.6120	4.0950	1.2840	1.7340	1.0240	-0.2176
16	6.6360	4.1020	-0.1577	-0.3176	6.4690	5.6990	1.2270	1.5630	-0.2969	-0.1743

Appendix 6B Regression Equations For Ratings vs. Metrics Organised By Test Type

Table 6B-1 Correlation With Frequency Response

Driver	Question #	LatacGain/0.4	LataccGain/0.7	LataccGain/1.0	LataccPhase/0.4	LataccPhase/0.7	LataccPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	YawPhase/0.7	YawPhase/1.0	R-squared	F
A	24	0.896			0.794														0.649	0.776	10.39
	44				0.475						0.543									0.887	35.43
	46				0.481				1.135		0.921									0.695	8.363
B	39	-1.03								-0.44										0.8	20.03
	49		-1	0.289																0.819	22.67
C	34						0.994		0.638							0.483				0.81	17.09
D	18			0.504										-0.62						0.736	16.71
	41									-0.75				-0.97		0.551				0.751	8.053
	45	-0.78		0.406																0.752	13.63
	48	-0.99														0.41				0.873	44.53
	49		-0.83		0.483											0.486				0.911	41.11
E	2						0.755									-0.53	-0.89			0.706	9.623
	6	0.795					1.181													0.753	15.27
	12						0.789	-0.57									-0.77			0.802	16.23
	17						1.116									-0.34	-0.8			0.704	8.725
	43														-1.08	0.377				0.763	19.36
	49	-0.9																		0.816	57.55
F	28			0.692												0.304				0.795	23.3
	29			0.564				-0.48		-0.3										0.756	12.39
G	4				0.924		-1.01								-0.51					0.705	5.589
	26						1.084						-0.65		0.638					0.741	10.49
	30		0.326				1.001													0.868	26.3
	31						0.858													0.736	39.1
	34	-0.68								0.333						0.477				0.727	8.866
	38				0.75						-1.06					0.68				0.827	17.49
	43						0.828			-0.49										0.768	21.54
	44						0.863			-0.43										0.785	23.78
	46						1.118								0.602					0.75	15.03
H	39						1.315										-0.75			0.76	17.39
	41				-0.51					0.434									1.087	0.777	9.308
Mean	7			0.423						-0.51		0.66								0.788	14.86
	23		0.528				0.909				-0.53									0.74	11.4
	25				0.749											0.348				0.728	17.42
	29				0.856															0.732	38.28
	39	-0.5					0.517			-0.23										0.821	18.36
	40	-0.6					0.406			-0.25										0.814	17.52
	41			0.42										-0.75						0.784	23.59
	43	-0.3					0.678													0.837	33.38
	44	-0.43					0.569													0.863	40.95
	46					0.854														0.729	37.64
	48	-0.87																		0.751	42.3
	49													-0.96		0.293				0.765	21.14

Table 6B-2 Correlation With Steady State Circular

Driver	Question #	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
A	14		1.191				-1.09			0.368		0.769	13.35
	18				0.535	-0.44	-0.59					0.719	9.382
	19		0.8				-0.62		0.566			0.729	8.96
	44				0.689			-0.41		0.278		0.755	8.224
B	14						0.918			0.546		0.803	22.35
	24	-0.88	1.209				-1.4					0.781	9.51
	34	0.773						0.237	0.582			0.819	12.08
D	12		-0.74	0.894						-0.56		0.757	12.43
	39		-0.8	1.011							-0.63	0.77	12.27
	40		-0.82	0.957							-0.79	0.81	15.63
	43		-0.96	1.069							-0.57	0.828	19.27
	44		-0.92	0.936							-0.63	0.808	15.42
	45									-1.01	1.032	0.733	12.33
	49			0.713		0.337						0.725	17.1
E	14				0.631		-0.45		-0.39			0.726	9.714
	19	0.814						0.365				0.722	16.84
	21		-0.91							-0.84	0.492	0.712	9.077
	43			0.682		-0.48					0.41	0.72	9.415
	44			0.809		-0.57					0.275	0.809	15.53
	48	-0.6		1.103								0.745	16.08
	49			0.837								0.7	30.34
G	3			-0.42			-0.35		-0.8			0.799	14.62
	6	-0.68						0.411			0.409	0.71	9.816
	30				0.48				0.571		0.607	0.813	10.16
Mean	16		-0.45	0.95								0.707	15.71
	30		-0.64		0.876				0.251			0.768	13.22
	35	-0.87			0.594		-0.71					0.769	13.29

Table 6B-3 Correlation With Step Input

Driver	Question #	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	R-squared	F
A	7	-0.31														-0.37	-0.7			0.762	11.72
	9	-0.76					0.675										-0.52			0.696	9.166
	10				0.448											-0.42	-0.86			0.884	30.54
	11			-0.73	1.362												-0.82			0.757	8.293
	14				0.689						0.704									0.829	31.52
	15						-0.91				0.986									0.745	17.5
	18	-0.67									0.597									0.713	14.88
	24	-0.48									0.688					0.335				0.74	8.523
	26									0.702	0.508								-1.16	0.696	6.114
	30	-1.77						-1.13				0.964								0.848	13
	32				0.587						0.556						-0.45			0.761	12.75
	36				0.989					0.494							-0.57			0.722	10.41
	40						-1.03				0.718									0.704	15.43
	43						-1.2			0.337	0.704									0.739	10.39
	44						-1.13			0.278	0.523									0.833	13.27
	48				0.419		-0.77				0.571									0.733	10.07
	49				0.401		-0.76				0.488									0.7	8.567
B	11						-1				0.765	-0.21								0.714	7.489
	24					0.474						-0.8				0.536				0.696	6.097
	28			0.265				-0.46				-0.76								0.813	15.93
	31						-0.43							-0.55		-0.28				0.817	16.41
	32						-1.17			0.385								1.069		0.799	10.6
	34			-0.61	1.059								-0.3							0.745	7.771
	37												1.065	-0.87						0.73	13.52
	39													-0.87		-0.26				0.805	20.62
	40									-0.43				-0.62		-0.34				0.822	15.36
	43											-0.46		-0.48						0.718	15.31
C	1									-0.37	-0.45	-0.37								0.737	11.21
	29	-0.5				0.908							-1.19							0.848	22.36
	34									0.584		-0.5		-0.44						0.735	11.08
D	5						-0.9									-0.35				0.787	24.03
	10						-0.55					-0.4				-0.39				0.748	11.87
	17										1.03			1.338					-1.22	0.83	13.05
	20			-0.56			-0.7					-0.68								0.728	7.12
	30					-0.5	-0.68				0.646									0.744	11.64
	48						-0.53										-0.26	-0.43		0.827	19.15
	49						-0.97			0.304										0.745	18.98
E	16				0.755						0.304			-0.32						0.859	24.47
	27	-0.77											0.255			-0.65				0.793	15.29
	29	-0.64									0.726						0.543			0.755	12.33
	43	-0.75															0.394			0.716	15.11
	48	-1.14				0.37		-0.42												0.769	11.1

Table 6B-3 (continued)

Driver	Question #	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	R-squared	F
F	12					-0.59				0.422			-0.42							0.886	31.03
	15					-1.04		-0.78				0.651								0.698	9.26
	27				-0.33	-0.8										-0.57				0.748	11.9
	28	-1.01			-0.65			-0.49												0.743	10.59
	32			0.318									-1.16					0.785		0.716	10.08
	34								-0.94	0.552					-1.08					0.803	13.58
	44							-0.35			-0.5			-0.74						0.724	9.609
G	5					-1.47					0.463		0.826							0.719	10.24
	12												0.312				-0.3	-1.05		0.863	25.28
	14																	-0.86		0.733	38.41
	26						0.614					-0.95								0.813	26.13
	30	-0.96					0.514					-0.37								0.908	23.04
	31									-0.26	0.297							-0.83		0.814	17.48
	32										-0.21			-0.48		0.533				0.729	9.847
	34						-0.79			0.554		-0.41								0.793	12.75
	39						0.393			-0.48			-0.91							0.872	24.92
	40					-0.65		-0.59		-0.54										0.827	17.47
	41										0.516			-0.92						0.787	16.59
	43									-0.4		-0.47		-0.28						0.763	12.88
	44	-1.01					0.518			-0.37										0.785	14.61
	45										0.411		-0.77					-0.33		0.964	80.48
H	37					0.918				-0.68				-0.64						0.739	10.37
Mean	10														-0.69	-0.58	-0.49			0.698	9.264
	11						-0.9				0.585	-0.3								0.728	10.72
	12													-0.91						0.826	66.47
	14				0.326		-0.82	-0.61												0.755	12.32
	16		-0.6											-0.34		-0.35				0.784	14.56
	20				0.275									-0.55		-0.49				0.8	16.02
	23						0.703		0.537			-0.81								0.707	9.642
	24			0.267								-1.11	0.344							0.853	23.14
	25									0.459		-0.45		-0.63						0.85	22.61
	26									0.356				-0.93		-0.31				0.859	24.3
	27									0.288				-0.86		-0.41				0.826	19.03
	28						-0.72				0.74	-0.48								0.745	11.67
	29	-0.84						-0.51				-0.21								0.847	22.23
	30									0.466			0.317					-1.15		0.873	27.62
	31													-0.9						0.809	59.48
	34			-0.63	0.545									-0.66						0.729	10.74
	35	-1				0.952				0.348										0.79	15.05
	36					0.743							0.557	-1.27						0.8	15.99
	39			0.27								-0.36		-0.62						0.875	28
	40									-0.25				-0.82		-0.26				0.903	37.31
	41	-0.84																		0.702	33.04
	43											-0.26		-0.73						0.819	29.49
	44													-0.92						0.847	77.67
	45	-0.74					-0.39	-0.4												0.849	22.54
	46	-0.72										-0.3				-0.29				0.914	42.38
	47						-0.85				0.638	-0.38								0.746	11.73
	48						-1.12				0.629									0.826	30.92
	49				0.249		-0.92				0.64									0.815	17.61

Appendix 6C Regression Equations For Ratings vs. All Metrics

Table 6C-1

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46		
Driver	Question #	LatacGain/0.4	LataccGain/0.7	LataccGain/1.0	LataccPhase/0.4	LataccPhase/0.7	LataccPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	YawPhase/0.7	YawPhase/1.0	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
A	7																											-0.38							-0.7										0.54			0.8	14.6
	10																						0.45											-0.42	-0.86													0.88	30.5
	14																						0.68						0.86																-0.27			0.88	29
	15																								-0.91				0.99																			0.74	17.5
	18																		0.51										0.58																		0.34	0.74	10.2
	19																							0.71																	0.78				0.48			0.9	31.3
	20																			-0.99				1.16																		0.73						0.73	7.21
	24								-0.34								0.5												0.59																			0.78	10.4
	26			0.47										-0.73																												0.63						0.76	8.65
	30																			-1.77						-1.13				0.96																		0.85	13
	31				0.57																								0.3										0.64									0.7	8.38
	32																						0.59						0.56						-0.45													0.76	12.7
	36																						0.99					0.49							-0.57													0.72	10.4
	40																								-1.03				0.72																			0.7	15.4
	43																								-1.2			0.34	0.7																			0.74	10.4
	44	0.9			0.79														0.65																													0.78	10.4
	48																						0.42		-0.77				0.57																			0.73	10.1
	49																						0.4		-0.76				0.49																			0.7	8.57

Table 6C-2

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46		
Driver	Question #	LatacGain/0.4	LataccGain/0.7	LataccGain/1.0	LataccPhase/0.4	LataccPhase/0.7	LataccPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	YawPhase/0.7	YawPhase/1.0	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
B	2									-0.28					-1.07							-0.68																										0.72	10.1
	9																																						0.44	0.49				-0.76				0.74	11.4
	11																								-1				0.77	-0.21																		0.71	7.49
	14																									0.53			0.46														0.92			0.55		0.8	22.4
	21																							0.56					1.03																-0.82			0.79	12.4
	22														-0.98											-0.81																		0.41				0.73	7.22
	24																							0.47						-0.8				0.54				-0.88	1.21				-1.4					0.78	9.51
	25			0.65																											-0.52													0.72				0.72	10.1
	28									0.36																-0.62				-0.77																		0.85	20.3
	31										0.52			-0.58																				-0.38														0.82	16.8
	32																								-1.17			0.39								1.07												0.8	10.6
	33		-0.43								0.41																			-0.41																		0.72	8.52
	34																																			-0.74									0.41			0.77	14.9
	36								-0.88																						0.58							0.77						0.24	0.58			0.82	12.1
	37																		0.79												0.78														0.15			0.83	15
	38									-0.52												-0.55			-0.93																							0.7	7.65
	39																															-0.87		-0.26														0.8	20.6
	40																											-0.43				-0.62		-0.34														0.82	15.4
	43																													-0.46		-0.48																0.72	15.3
	44		-0.74																			-0.35								-0.57																		0.81	15.7
	49		-1	0.29																																												0.82	22.7

Table 6C-3

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46		
Driver	Question #	LatacGain/0.4	LataccGain/0.7	LataccGain/1.0	LataccPhase/0.4	LataccPhase/0.7	LataccPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	YawPhase/0.7	YawPhase/1.0	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
C	1																											-0.37	-0.45	-0.37																		0.74	11.2
	2																								-0.68									-0.56					-0.77									0.72	10.1
	3												0.5																		-0.5																-0.62	0.7	9.14
	4																																-0.6										-0.63					0.76	20.8
	17			0.68																														-0.36								0.56						0.72	9.42
	19			0.72																															0.51											-0.33		0.71	9.72
	20			0.65																														-0.53				0.45										0.76	10.8
	21			0.84																																									-0.36		-0.51	0.7	9.31
	22										0.95																			-0.29																	-0.77	0.82	18.6
	25		-0.79																			-1.26																					-0.55					0.76	12.6
	26		-1.09																			-1.14																					-0.78					0.78	13.3
	28			0.42								0.82																																			-0.91	0.76	11.3
	29																			-0.97						-0.5																					-0.46	0.76	12.6
	34																											0.58		-0.5		-0.44																0.73	11.1
	40			0.42											-0.71																													-0.32				0.7	9.32
	45			0.5									0.77																																		-0.33	0.74	11.5

Table 6C-4

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46		
Driver	Question #	LatacGain/0.4	LataccGain/0.7	LataccGain/1.0	LataccPhase/0.4	LataccPhase/0.7	LataccPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	YawPhase/0.7	YawPhase/1.0	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
D	3												0.69																0.52					-0.55														0.71	9.59
	5																								-0.9									-0.35														0.79	24
	9																								-0.56					-0.35												0.3						0.77	13.5
	10																								-0.55					-0.4				-0.39														0.75	11.9
	12																																						-0.74	0.89						-0.56		0.76	12.4
	14					0.99																				0.31																					-0.93	0.8	15.8
	17																												1.03			1.34					-1.22											0.83	13.1
	18			0.65															0.56																								0.6					0.82	17.3
	19																					0.36									-0.4			-0.61														0.77	12.4
	20					-0.64																			-0.76					-0.83																		0.74	7.59
	29															1											0.68							-0.4														0.79	15.1
	30										0.91																							-0.33									-0.49					0.85	22.8
	31			-0.89																												-1							-0.58									0.79	14.1
	33																				-0.49										-0.39												-0.42					0.7	9.35
	37								-0.89																						0.53															-0.8		0.75	10.2
	39												0.92																														-0.69				-0.79	0.86	22.9
	40												0.84																														-0.68				-0.91	0.86	23.2
	41									-0.75				-0.97		0.55																																0.75	8.05
	42																												-1						-0.51								-0.78					0.76	13
	43																											-0.73															-0.46	-0.45				0.73	10.9
	44								-0.65																																		-0.75			-0.66		0.79	14.1
	45													-1.01								-0.52																								-0.26		0.86	16.9
	48	-0.99														0.41				0.87	44.5	0																										0.87	44.5
	49		-0.83		0.48											0.49				0.91	41.1	0																										0.91	41.1

Table 6C-5

	F	9.62	13.9	16	10.6	9.15	18.1	24.5	8.73	12.2	17.3	14	15.3	10.3	9.21	9.82	20.4	18.7	39.4	8.97	20.8	9.76	21.9	25.6	10.2	12.6	11.1	40.6
	R-squared	0.71	0.78	0.8	0.78	0.7	0.83	0.86	0.7	0.75	0.81	0.79	0.81	0.72	0.7	0.71	0.84	0.82	0.91	0.71	0.79	0.71	0.81	0.87	0.74	0.77	0.77	0.92
46	roll angle/0.2			0.46												0.55												
45	roll angle/0.4																											
44	d(storq)/0.2					0.31	-0.47												0.36	-0.62		0.44						
43	d(storq)/0.4		0.3																			-0.58		0.31				
42	d(sslip)/0.2				-0.46										-0.6													
41	d(sslip)/0.4					-0.23																			-0.4			
40	d(hw)/0.2																											
39	d(hw)/0.4																											
38	d(fslip)/0.2									0.49			-0.65								-0.89							
37	d(fslip)/0.4						0.83				0.68	0.73																
36	StorqRespTime/0.6																											
35	StorqRespTime/0.2																											
34	Storq/0.6																	0.51										
33	Storq/0.2													-0.37		-0.67	-0.72											
32	YawRtRespTime/0.6																											
31	YawRtRespTime/0.2							-0.32																				
30	YawRt/0.6									0.56									0.26						-0.66			
29	YawRt/0.2														-0.36													
28	RollRtRespTime/0.6		0.5				0.61	0.3										0.67		0.61								
27	RollRtRespTime/0.2																											
26	RollRt/0.6																0.58											
25	RollRt/0.2																										-0.42	-0.39
24	StMeanRespTime/0.6																											
23	StMeanRespTime/0.2												-0.64														0.37	
22	StMean/0.6				0.5			0.76																		0.77		
21	StMean/0.2																								0.49			
20	LatacRespTime/0.6																											
19	LatacRespTime/0.2																										-1.14	
18	YawPhase/1.0		0.7							0.51																		
17	YawPhase/0.7																											
16	YawPhase/0.4	-0.89							-0.8			-1.06																
15	YawGain/1.0	-0.53		-0.78					-0.34																			
14	YawGain/0.7													-0.66	-0.27					-0.72		-0.75		-0.79				-0.28
13	YawGain/0.4																				-0.87		-0.56					
12	SteerPhase/1.0					0.8																						
11	SteerPhase/0.7										-0.4		-0.56						0.94									
10	SteerPhase/0.4																									0.62		
9	SteerGain/1.0										0.41															-0.29		
8	SteerGain/0.7			0.22																								
7	SteerGain/0.4																											
6	LataccPhase/1.0	0.76							1.12														0.41					
5	LataccPhase/0.7											0.95						0.68										
4	LataccPhase/0.4																											
3	LataccGain/1.0				0.53									0.72		0.4	0.41							0.48				
2	LataccGain/0.7																											
1	LatacGain/0.4																											-0.85
	Question #	2	3	4	6	12	14	16	17	18	19	20	21	22	23	25	27	29	31	32	33	37	39	43	44	47	48	49
	Driver	E																										

Table 6C-6

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46		
Driver	Question #	LatacGain/0.4	LataccGain/0.7	LataccGain/1.0	LataccPhase/0.4	LataccPhase/0.7	LataccPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	YawPhase/0.7	YawPhase/1.0	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
F	9												0.86													-0.56		0.42																				0.7	9.43
	12																							-0.59				0.42			-0.42																	0.89	31
	14																									-0.67												0.25							-0.79			0.76	12.4
	27																						-0.33	-0.8										-0.57														0.75	11.9
	28			0.75																												-0.28																0.8	23.4
	29			0.71											-0.66											-0.42																						0.78	14.4
	32																					0.32									-1.16					0.79												0.72	10.1
	33													-0.57												-0.66													-0.93									0.82	15
	34																										-0.94	0.55					-1.08															0.8	13.6
	39								-0.68					-0.36																				-0.45														0.78	14.6
	40			0.48											-0.7																											0.49						0.71	9.92
	43																															-0.74			0.37									-0.33				0.76	11.5
	44																									-0.35			-0.5			-0.74																0.72	9.61
	45															0.59								-0.76											0.36													0.72	6.81

Table 6C-7

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46		
Driver	Question #	LatacGain/0.4	LataccGain/0.7	LataccGain/1.0	LataccPhase/0.4	LataccPhase/0.7	LataccPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	YawPhase/0.7	YawPhase/1.0	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
G	2									-0.47					-0.19					-0.73																												0.79	14.7
	3						-0.45																																				-0.52		-0.69			0.79	13.8
	4														-0.52													0.79						0.67														0.84	12.6
	5																							-1.47					0.46		0.83																	0.72	10.2
	6																																					-0.68						0.41			0.41	0.71	9.82
	12																														0.31				-0.3	-1.05												0.86	25.3
	14					0.9																	-0.4															0.44										0.79	15.3
	16																		-0.55											-1.07															0.36			0.84	17.9
	18																									0.39									-0.33			0.87										0.79	12.7
	20		0.68																															-0.51					0.61									0.72	8.7
	21			0.52						-0.73																	0.38																					0.73	10
	23			0.68							-0.68													-0.41																								0.7	9.55
	25																														-0.54											-0.82		-0.49				0.72	10.4
	26								0.37																					-0.72															0.37			0.81	15.2
	28																0.76														0.49											0.59						0.7	9.37
	29			0.48																			0.63																						-0.45			0.72	8.67
	30																			-0.96					0.51					-0.37																		0.91	23
	31																											-0.26	0.3							-0.83												0.81	17.5
	32																												-0.21			-0.48		0.53														0.73	9.85
	33										0.65																			-0.42				-0.38														0.76	12.5
	34																								-0.79			0.55		-0.41																		0.79	12.7
	38				0.75						-1.06					0.68																																0.83	17.5
	39									-0.49																					-0.75			-0.22														0.92	40.3
	40																							-0.65		-0.59		-0.54																				0.83	17.5
	41																-0.43												0.52			-1.19																0.9	23
	43									-0.44																				-0.35		-0.59																0.81	17.1
	44									-0.44														-0.94																		-0.24						0.85	23.5
	45																												0.41		-0.77					-0.33												0.96	80.5
	46																														-0.53			-0.38											0.45			0.72	7.89

Table 6C-8

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Driver	Question #	LatacGain/0.4	LataccGain/0.7	LataccGain/1.0	LataccPhase/0.4	LataccPhase/0.7	LataccPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4
H	14									0.45					-0.9		
	16																
	18			0.49													
	19						0.68										
	23									0.41							
	24									0.41							
	25																
	33	-0.77															
	36																
	37																
	38								-0.63								
	39													-0.65			
	41																
	42								-0.49								
	43										0.42				-0.5		
	44									0.29					-0.61		
	45													-0.74			
	46						0.65			0.55							

		17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Driver	Question #	YawPhase/0.7	YawPhase/1.0	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6
H	14			0.89													
	16																
	18												-0.66				
	19																
	23													-0.88			
	24													-0.88			
	25		0.85														
	33							0.53									
	36									0.54							
	37									1.2			0.64				
	38																
	39																
	41	1.1		0.67													
	42		0.49														
	43																
	44																
	45																
	46														-0.68		

		33	34	35	36	37	38	39	40	41	42	43	44	45	46		
Driver	Question #	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
H	14															0.72	9.47
	16	0.47	0.79										0.78			0.8	11.8
	18					-0.44										0.78	13.9
	19									-0.33						0.71	13.3
	23									-0.7						0.77	7.99
	24									-0.7						0.77	7.99
	25									0.37					-0.42	0.7	9.33
	33					-0.69										0.72	6.99
	36			-0.45								-0.39				0.75	9.05
	37														-0.56	0.74	10.4
	38					0.43					-0.48					0.8	13.4
	39	0.25											0.67			0.88	23.4
	41												0.42			0.83	12.7
	42													-0.39		0.76	12.6
	43												0.62			0.8	16.1
	44												0.62			0.77	12.4
	45												0.54			0.72	14.1
	46															0.81	8.72

Appendix 6D Regression Equations Including All Significant Regressors

Table 6D-1 Driver A

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46		
Question	LatacGain/0.4	LataccGain/0.7	LataccGain/1.0	LataccPhase/0.4	LataccPhase/0.7	LataccPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	YawPhase/0.7	YawPhase/1.0	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
1			0.39						-0.32					-0.32														0.69										0.50			0.77						0.83	7.59
5			0.65																									-0.40		0.77			-0.58								0.54	-0.62	0.84		0.38		0.93	8.7
7																											-0.42						-0.28	-0.78										0.45			0.86	15.6
8			0.47																						0.84			0.38					-0.6	-0.69												-0.62	0.86	9.21
9									-0.46										-0.49				0.31		0.33								-0.61	-0.59													0.90	13.4
10																						0.45											-0.42	-0.86													0.88	3.54
11		-0.77														0.40					-0.52		0.93						-0.80					-0.30				0.32									0.98	25
12									-0.72		0.72			-0.61													1.68																		0.33		0.88	14.6
14																						0.64						0.61	-0.26									0.30			0.30				0.72	-0.47	0.96	24.7
15			0.36											-0.70														0.59													0.57						0.83	1.25
18																												0.53	-0.42													-0.33	0.41			0.47	0.86	11.3
19																							0.75		0.21															0.75				0.54			0.94	34.9
20																			-0.50				1.17		0.52																1.12	-0.34	0.24	0.24	0.24		1.00	16.9
24		0.64						-0.49								0.51					0.40							0.36																			0.93	18.3
25			0.79										-1.15								-0.46							0.39						0.49							0.73					-0.63	0.92	9.47
26			0.77										-0.66																				-0.35	0.49							0.62						0.94	18.6
27			0.94										-0.46																				-0.47	0.66							0.52						0.96	31.6
28			0.94											-0.52														0.37										0.41			0.87			-0.35			0.92	11.4
29			0.73										-0.38															0.72		0.32								0.55			0.57			-0.60			0.95	12.8
30									-0.68										-0.79				0.68																				-0.50				0.94	23.4
31				0.56																								0.52										0.67						-0.38			0.80	9.74
32																			-0.93									0.46		0.66				-0.28							0.31					-0.44	0.86	8.56
33																			-0.64				0.52										-0.46	-0.34				0.39			0.60						0.93	19.2
35												-0.67									0.33									-0.59			-0.59												0.91		0.85	11.7
36												-0.65	-0.69								0.33												-0.44	-0.43											0.51		0.90	13.2
39			0.68											-0.57																				-0.43							0.7		0.67				0.65	3.7
40										0.80																		0.32	-0.68	0.62								0.34			0.33						0.81	6.57
41			0.72											-0.46																				-0.51							0.84		0.72	-0.4			0.71	3.71
43			0.66						0.4					-0.62																				-0.68							0.6		0.54				0.86	8.13
44			0.47						0.59					-0.83																			0.35	-0.66							0.53					-0.67	0.96	14.8
46								0.84		0.72																				-0.49			-0.42												0.57		0.83	8.74
48														-0.76									0.69						-0.58												0.79				0.38		0.82	8.89

Table 6D-2 Driver B

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46		
Question	LatacGain/0.4	LataccGain/0.7	LataccGain/1.0	LataccPhase/0.4	LataccPhase/0.7	LataccPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	YawPhase/0.7	YawPhase/1.0	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
2			0.38						-0.61	0.43				-0.83							-0.59									0.54											0.45		0.52				0.95	15.4
3			0.43										-0.65															0.56					-0.53											-0.47			0.82	9.34
5									-0.26										-1.22				0.33			-0.43							-0.29									0.57					0.89	12.5
6										0.86				-0.47							-1.38							0.92										0.51								-0.55	0.84	6.95
7									0.69			0.58																0.62					0.72												-0.65		0.85	11.4
9																							0.33										0.30					0.37	0.62		0.44		-0.54				0.89	12.3
10																												0.51					0.46					0.75			0.73						0.87	17.7
11		-0.71																										0.42	-0.87	0.36			0.48														0.86	8.44
12		-0.36								0.32															0.47				-0.30				-0.42	-0.45									0.39				0.96	23.3
14																			-0.51											0.66								-0.43				1.20					0.85	13
21													0.57								0.46		0.72					0.56												0.26				-0.53	0.47		0.99	72.6
23													0.96						-1.20				0.44							0.32			0.59							0.46				-0.39		-0.78	0.99	26
24																							0.44					0.44	-0.83				0.51					0.46									0.88	9
25			0.62											-0.35																-0.47													0.56				0.82	12.3
27														-0.74									-0.55										-0.75							-0.42				-0.28			0.83	8.86
28									0.40																-0.74				-0.78															-0.28			0.92	27.5
29									0.39					-0.55									-0.67		-0.74				-0.56	0.59				-0.45													0.86	7.16
31										0.43			-0.78								-0.29												-0.47														0.87	17.7
32															0.46									-0.46						0.57														-0.69			0.89	14.4
33		-0.54								0.60						-0.45													-0.53				-0.33														0.98	15.9
34																									0.59			0.31	-0.59									0.56			0.32			0.52			0.98	34.6
36								-0.75																		0.34				0.58														0.38			0.90	15.3
37																		0.71							0.33					0.72														0.33			0.91	18.3
38									-0.53												-0.55			-1.33		-0.56																	0.45				0.94	27.4
39									-0.46	0.39			-0.58																-0.39																		0.94	31.1
40									-0.39				-0.65								-0.40			-0.57									-0.35														0.97	15.6
42								-0.69											0.81				-1.34							0.55			-0.58														0.82	9.9
43																							-0.23	-0.83	-0.45				-0.26				-0.26					-0.68					0.54				0.97	37.5
44		-0.57								0.33											-0.30								-0.48				-0.24														0.93	16.8
49																					0.98								-0.85				0.69	-0.7				0.61			0.58						0.96	27.4

Table 6D-3 Driver C

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46		
Question	LatacGain/0.4	LataccGain/0.7	LataccGain/1.0	LataccPhase/0.4	LataccPhase/0.7	LataccPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	YawPhase/0.7	YawPhase/1.0	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
2				-0.54																				-0.96					-0.49	0.28			-0.47					-0.79									0.92	17.8
3			0.41									0.57																		-0.43																-0.76	0.84	14.7
4																												-0.7													0.21	-0.88					0.90	35.6
5												0.46												-0.75		-0.74														-0.59		-0.79					0.88	8.47
7												0.57																		-0.29							-0.38	-0.54						-0.44		-0.52	0.87	9.9
8			0.49																						0.82									-0.34				-0.67					0.49	-0.28		-0.72	0.92	13.1
9																							0.72		0.65								-0.42										-0.78	-0.49			0.79	7.63
10																									-0.63			-0.33													-0.59		-0.64				0.79	10.2
12			0.26							0.66			-0.44								-0.51												-0.64									-0.46				-0.56	0.95	18.2
14										0.63													-0.37										-0.34									-0.34				-0.98	0.82	9.34
15			0.51						-0.56																0.54					0.60			-0.56								0.93						0.85	6.18
17			0.75									0.34																					-0.33								0.60					-0.37	0.85	9.51
18															0.36			0.73	0.87										-0.43									-0.45						-0.55			0.96	35.4
19			0.99															0.28											0.51					0.48											-0.54		0.85	1.96
20			0.79															0.28							-0.25					0.28											0.39				-0.67		0.94	18.9
21			0.66																		-0.36								-0.35	0.46														-0.43		-0.44	0.89	12.6
22										0.95																			-0.29																	-0.77	0.82	18.6
24														-0.76														-0.72					-0.78	-0.74				-1.03								-0.45	0.81	5.78
25		-0.89																			-1.12																					-0.53	-0.19	0.24		-0.35	0.94	23.3
26			-0.46											-0.53							-0.39							-0.61						-0.35							0.35	-0.75		0.71			0.92	9.23
29																			-0.75						-0.34					-0.43							-0.23									-0.47	0.88	14.6
32			0.36															0.45												0.56													-0.42		-0.96		0.83	8.62
34									0.3																0.3				-0.55				-0.26										-0.28	0.48			0.92	17.6
38									-0.25												-0.54			-0.66														-0.51						0.56			0.89	17
40			0.44											-0.85																			-0.35										-0.44				0.83	11.2
41																				-1.12								0.54		-0.35			-0.47	0.44			-0.79	-0.17					-0.67				0.98	48.9
42										0.78			-0.58			-0.36					-0.77																					-0.85				-0.82	0.92	16.4
43			0.56									0.35															0.45					-0.89	-0.40													-0.57	0.93	2.84
44			0.31									0.96																					-0.35	0.36								-0.35				-0.42	0.86	8.94
45			0.63									0.85																					-0.27	0.17							0.28					-0.34	0.92	18.3
46												0.92																					-0.40					-0.69							-0.80		0.80	7.84
48										0.85								0.28					-0.54					0.36	0.35														0.42			-0.80	0.92	11.4
49			0.49											-0.6														0.59	-0.36												0.62	0.71				-0.57	0.87	6.77

Table 6D-4 Driver D

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46		
Question	LatacGain/0.4	LatacGain/0.7	LatacGain/1.0	LatacPhase/0.4	LatacPhase/0.7	LatacPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	YawPhase/0.7	YawPhase/1.0	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
3		0.28										0.70											-0.39					0.67					-0.57														0.84	1.61
5											0.65		-0.86								-0.37												-0.29									-0.34				-0.56	0.90	13.5
6										0.57				-0.56															-0.35												0.32	-0.33				-0.76	0.95	29.3
8									-0.57				-0.97			-0.63					-0.63												-0.84												0.82		0.83	7.42
12									-0.41												0.45				0.51				-0.55												0.53	-0.22				-0.27	0.97	37.3
14												0.35						0.53											-0.40				0.43								0.17					-0.69	0.98	65.8
15			-0.57																									-0.52		-0.62			-0.61									-0.46			0.70		0.83	6.46
17								0.22																				0.68		0.48							0.46				0.27			-0.48			0.97	3.7
18			0.77											-0.58									-0.32		-0.3																	0.49					0.96	46.3
19			-0.44																		0.42									-0.44			-0.63					-0.43									0.94	3.67
20				-0.85																				-0.92					-0.59					-0.42				-0.34									0.99	12
21									-0.4					1.1							0.95				0.61								-0.32	-0.36								-0.42		-0.3			0.97	22.6
24													1.45			0.79											-0.82							-0.24			0.61										0.91	17.1
26									-0.44				-0.64																				-0.64								0.95				0.94		0.84	9.46
28			0.57															0.47									-0.47			0.51				-0.56							0.96		0.55				0.82	5.14
29													0.63		0.68											0.54							-0.34		-0.71							0.22					0.93	19.2
30		-0.25								0.83																							-0.29									-0.53					0.95	26.2
31			-0.61						-0.20							-0.23															-0.62	-0.62	-0.45					-0.65									0.99	68.3
32		-0.58									0.42																		-0.39									-0.58						-0.25		-0.72	0.85	8.19
33																		-0.36		-0.79										-0.38												-0.65				-0.38	0.87	12.9
37			0.55					-0.68	0.15					-0.36															0.29	0.45															-1.67		0.98	34.7
38														-0.57							0.54							-0.61						-0.89				-0.84								-0.65	0.87	9.08
39												0.79															-0.38														0.22	-0.67				-0.67	0.94	3.62
40		-0.77						-0.28																					-0.33									-0.66			0.25					-0.58	0.95	26.3
41			0.72						-0.22					-0.49														-0.12										0.34			-0.3	0.44	-0.25				0.99	66.6
42									-0.33				-0.60															-0.73						-0.34				-0.39				-0.43					0.94	24.3
43								-0.37																			-0.47															-0.55	-0.33			-0.32	0.83	1.97
44									0.31												0.45				0.61				-0.22	-0.54								-0.64					-0.23	0.19		-0.96	0.99	47.8
45													-1.13								-0.52																								-0.26		0.86	16.9
47												0.52											-0.77				-0.40	0.68		0.59											0.45				-0.45		0.94	18.6
48									0.56					-0.8															-0.42					-0.69							0.33					-0.31	0.94	23.6
49									0.63					-0.8							0.35								-0.42					-0.68				-0.39			0.44	0.49				-0.43	0.97	19.4

Table 6D-5 Driver E

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46		
Question	LatacGain/0.4	LataccGain/0.7	LataccGain/1.0	LataccPhase/0.4	LataccPhase/0.7	LataccPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	YawPhase/0.7	YawPhase/1.0	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
1														-0.73														-0.62		0.29			-0.32	0.26				-0.64						0.44			0.93	14.8
2									-0.34			0.33																	0.54					0.75										0.39		0.45	0.84	7.74
3																		0.59					-0.39					0.77															0.36				0.86	17.3
4		-0.79						0.55							-0.47																							-0.43			-0.40					0.43	0.91	15.2
6			0.44											-0.6																			-0.45									-0.55					0.83	10.1
7										0.63						-0.51																	-0.48				-0.59										0.82	9.92
10			-0.86																									-0.44					-0.91					-0.54			-0.7		-0.52			0.4	0.84	5.94
12												0.77				-0.33							-0.41																		-0.31		0.26	0.38		0.20	0.95	2.57
14				0.34																								0.59									0.69							-0.52			0.95	23.7
15			0.79																						-0.50					0.79											0.97		0.87				0.88	14.6
16			0.18						-0.28					-0.84											0.36			0.35					-0.6								0.28						0.94	17
17		-0.59														-0.32									0.46																	-0.60		0.36			0.83	8.94
19			-0.51						0.39		-0.54							0.42																			0.42									0.25	0.95	31.2
20						0.76										-0.83									0.21												0.68							0.29			0.98	72.9
21											-0.53							0.32					-0.59		-0.25													-0.70									0.95	36.3
22			0.44											-0.68				0.46								-0.54							-0.36					-0.59					0.45				0.96	3.7
23			0.23											-0.93												-0.52			-0.44											-0.38		-0.57					0.93	21.6
24													-0.63			-0.82													-0.75													-0.57					0.86	1.36
25		-0.42	0.78																														-0.72									0.35				0.52	0.93	23.3
26			0.62																							0.23							-0.55	-0.35				0.50								0.45	0.95	3.59
27			0.34																							0.68							-0.62											0.32			0.91	28.3
28			0.4						0.36					-0.58											-0.5									-0.31								-0.45	0.52				0.90	8.77
29																		0.52					-0.42					0.88						0.50													0.88	2.78
31											0.94																			0.26														0.36			0.98	39.4
32														-0.57														0.60						-0.23			0.51							-0.55			0.94	29.5
33														-0.59																		-0.32						-0.73							0.30		0.96	2.4
34															-0.48			-0.77													-1.28							-0.46			-0.59						0.83	9.47
35									0.15					0.93				0.78			0.45									0.42													0.63	-0.39			0.96	24.9
36			0.65						0.75												0.69				0.51																			0.24		-0.86	0.89	11.6
37									-0.34					-0.77																											0.37		-0.43	0.44			0.83	9.94
38			0.49																						0.69					0.56			-0.56	0.28							0.66	0.53		0.9		-0.77	0.94	6.89
39						0.55						0.34									0.39																										0.86	19.8
40																					0.90				0.55		0.30			-1.20							-0.61										0.92	18.1
42			0.62																											0.41											0.62			0.36			0.69	6.09
43									0.37												0.39		-0.78																		-0.68						0.87	16.5
44																					0.50									-0.64											-0.43					0.38	0.88	17.6
47									-0.65	0.82												1.41					0.48																				0.89	19.5
49	-0.85													-0.28											-0.39																						0.92	4.57

Table 6D-6 Driver F

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46		
Question	LatacGain/0.4	LataccGain/0.7	LataccGain/1.0	LataccPhase/0.4	LataccPhase/0.7	LataccPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	YawPhase/0.7	YawPhase/1.0	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
1			0.70						-0.47							-0.45			0.52					-1.50									-0.50														0.88	11.2
2			0.74											-0.34		-0.63			0.42				-0.78	-1.92	-0.57					0.57			-0.56														0.97	18.9
6			0.82											-0.68										-1.00		-0.85									0.99												0.85	11.5
7			0.57					-0.57																	-0.44								-0.49											-0.38			0.85	11.5
9												0.70						0.47							-0.52		0.53																				0.83	13.1
10								-0.33							0.45			0.47							-0.49																			-0.52			0.80	7.86
12																							-0.59				0.42			-0.42																	0.89	31.3
14			0.19						-0.56				-0.37												-0.67					0.35											0.52			-0.82			0.94	19.2
17													-0.90			-0.98									-0.75			-0.88										-0.48						0.42			0.85	8.58
19									0.32														-0.87		-0.83				0.62																		0.7	6.37
20									-0.48				-0.75			-0.79												-0.42					-0.29	0.29				-0.44									0.94	19.6
21									-0.37						-0.44	-0.36												-0.62														-0.62					0.86	12.7
25									0.44	0.44															-0.71																0.32			-0.38			0.87	13.8
26			0.27							0.51			-0.84												-0.22								-0.67							-0.85	0.62			-0.35			0.96	2.75
27			0.72																														-0.58				0.47					0.59				0.40	0.84	1.43
28			0.75																												-0.28																0.80	23.4
29			0.49				-0.30		-0.35					-0.47											-0.54																					0.32	0.95	27.9
31			0.85											-0.63														0.33	0.48												0.59						0.92	22.9
32								0.29																						-0.82							-0.25					-0.33		-0.49		-0.38	0.88	11.5
33													-0.53												-0.64													-0.88			0.29						0.99	2.45
34																										-0.35	0.60			-0.81								-0.31									0.82	1.11
35		0.54																-0.47	-1.64						-0.48			0.45						0.33							0.44						0.93	9.34
36			0.46					-0.45						-0.64											-0.48					0.66											0.69						0.86	9.39
37			0.76						-0.37					-0.87		-0.34														0.55			-0.31								0.82						0.92	11.3
38			1.03						-0.49																					0.48								0.44			0.86						0.7	4.78
39			0.47					-0.70						-0.44																0.23			-0.45								0.35				-0.25		0.94	18.2
40			0.45					-0.34						-0.63																			-0.49								0.43						0.92	23.9
41							-0.72		-0.70					-0.44		-0.39																									0.61						0.84	7.48
42			0.45						-0.48														-1.4		-0.73					1.13																	0.83	9.55
43			0.22															-0.33									-0.24				-0.77		-0.53	0.49									-0.51				0.96	25.5
44			0.77											-0.67							-0.36								0.7	-0.55			-0.84								0.36			-0.61			0.95	14.7
45										0.49						-0.43							-0.71		-0.75									0.57				-0.43									0.97	2.39

Table 6D-7 Driver G

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46		
Question	LatacGain/0.4	LataccGain/0.7	LataccGain/1.0	LataccPhase/0.4	LataccPhase/0.7	LataccPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	YawPhase/0.7	YawPhase/1.0	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
2			0.35						-0.39					-0.83				-0.30	-0.81		-0.47		0.40										-0.36														0.98	47.7
3						-0.64																	-0.40																			-0.59		-0.59			0.85	14.3
4				0.52		-0.62								-0.57													0.68						0.48														0.98	47.1
6																									-0.45															-0.68			0.66			0.78	0.86	11.4
7									-0.54										-0.87				0.88					-0.44	0.39																		0.85	11.3
8									-0.43																-0.64			-0.64	0.64				-0.53								-0.43					0.68	0.83	5.65
12			-0.17										-0.55						-0.94		-0.77							0.41		0.19			-0.26														0.97	35.8
14			0.51																		0.35		-0.39		0.39									-0.38							0.33						0.83	7.35
15																-0.57							-0.74		-0.47																	-0.92	0.48				0.82	8.13
16			0.34															-0.95			0.44		-0.42						-0.93															0.50			0.97	36.9
18																		-0.29							0.47									-0.32			0.92										0.87	14.6
20		0.90																			0.38												-0.42					0.63									0.82	1.43
21			0.67						-0.56																	0.48																				-0.42	0.81	1.83
22									-0.52																			-0.46					-0.69									-0.45					0.82	11.1
23			0.84							-0.50			0.69								0.69		-0.74																								0.94	18.9
24		0.43																						0.93		0.84	-0.36			-0.48															-0.46		0.89	11.6
25										-0.42															-0.27					-0.64											-0.77		-0.45			0.33	0.89	12.6
26														0.49															-0.43	-0.44				0.34							-0.4	-0.3		0.37			0.95	18.7
27			-0.43																		-0.88								-0.25	-0.54											-0.34	-0.83	0.36	0.32			1.00	183
28																0.55													-0.13	0.48			-0.17				0.17				0.42	-0.32		-0.32		-0.37	0.99	116
29			0.43						-0.55				-0.55									0.73					0.81			0.24											0.30			-0.75			0.97	2.38
30																					0.46								-0.64															0.57		0.5	0.97	43
31			0.42											-0.73											0.27				-0.25				-0.43	-0.49							0.17						0.95	23
32		-0.72																					-0.39		0.51												-0.87						-0.65				0.90	15.6
33										0.47																		-0.32	-0.44				-0.54												0.38		0.86	12.6
34									0.47															-0.52				0.38	-0.52																		0.88	9.47
38			0.85								-0.67																										0.34										0.83	16.8
39									-0.59														-0.35							-0.47			-0.22														0.95	52.5
40								-0.32	-0.48														-0.65		-0.27								-0.26														0.96	46.1
41																-0.45												0.56			-1.19										0.24		0.29				0.96	3.94
43									-0.47										-0.63										-0.38																		0.87	26.8
44									-0.46										-0.65					0.29											-0.55												0.90	24.2
45																			-0.24											-0.77														0.38			0.95	61.2
46			0.78											0.31							0.59				0.36					-0.73														0.46		-0.5	0.99	71.3

Table 6D-8 Driver H

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46		
Question	LatacGain/0.4	LatacGain/0.7	LatacGain/1.0	LataccPhase/0.4	LataccPhase/0.7	LataccPhase/1.0	SteerGain/0.4	SteerGain/0.7	SteerGain/1.0	SteerPhase/0.4	SteerPhase/0.7	SteerPhase/1.0	YawGain/0.4	YawGain/0.7	YawGain/1.0	YawPhase/0.4	YawPhase/0.7	YawPhase/1.0	LatacRespTime/0.2	LatacRespTime/0.6	StMean/0.2	StMean/0.6	StMeanRespTime/0.2	StMeanRespTime/0.6	RollRt/0.2	RollRt/0.6	RollRtRespTime/0.2	RollRtRespTime/0.6	YawRt/0.2	YawRt/0.6	YawRtRespTime/0.2	YawRtRespTime/0.6	Storq/0.2	Storq/0.6	StorqRespTime/0.2	StorqRespTime/0.6	d(fslip)/0.4	d(fslip)/0.2	d(hw)/0.4	d(hw)/0.2	d(sslip)/0.4	d(sslip)/0.2	d(storq)/0.4	d(storq)/0.2	roll angle/0.4	roll angle/0.2	R-squared	F
2									-0.28					-0.76														-0.74		0.4			-0.6					-0.8						0.58		-0.34	0.96	18.6
5												-0.34													0.82					-0.75				-0.64								-0.37					0.91	18.3
9			0.51										-1.49			-0.95											0.41							0.48													0.81	8.64
10													-0.84										0.56					-0.66					-0.56										-0.27				0.84	1.29
14									0.58					-1.91					0.74						-0.37																						0.81	1.87
15												-0.72							-1.36				0.79		0.90					-0.74			0.32	-0.36				0.19									0.97	18.9
16														-0.46													0.32						0.34	0.62				-0.31			-0.24			0.55			0.96	17.4
17												0.76						0.41	0.73				-0.48															-0.42					0.63	0.75			0.92	12.6
18													-0.31															-0.59									-0.79						-0.53				0.82	12.9
19			0.9																		0.77																					0.47					0.80	13.5
20									0.3					-0.55															-0.52					-0.68													0.76	8.67
21																									0.53								-0.59	-0.54							-0.55						0.80	6.12
22														-0.90													0.70		-0.63	0.39							-0.48	0.29						0.32			0.89	8.89
23									0.33												-0.55				0.33				-0.49												-0.58		0.32	0.31			0.98	27.5
24									0.33												-0.55				0.33				-0.49												-0.58		0.32	0.31			0.98	27.5
25																		1.39			-0.38							0.29													0.38					-0.44	0.82	9.76
28														-0.83							-0.66					-0.47					-0.46													0.30			0.82	8.87
29				0.94					-0.23					-0.37							-0.89					-0.49												0.23					0.45				0.93	14.5
30			0.99											-0.52					0.99																		0.38									0.60	0.83	9.52
31			0.37						-0.33					-0.28											0.66									0.6									-0.29	0.45			0.99	55
32	-0.39		-0.52																									0.55						0.58													0.82	8.99
33	-0.93							0.56															0.29		0.31								0.37				-0.83							0.24			0.97	18.4
34								0.29																	0.43										-0.49		-0.65	0.55						0.43			0.96	18.1
35			0.36						0.36														0.83		0.89					-0.78													-0.32				0.87	7.49
36																							0.39		0.57										-0.63								-0.46				0.85	11.7
37																									1.18				-0.3					-0.31									0.32	0.55		-0.41	0.88	9.67
38								-0.54																									0.27				0.46					-0.50					0.87	13.9
39													-0.65																				0.25											0.67			0.88	23.4
40						0.43		0.55					-0.58								-0.27												0.48	0.36							-0.29			0.58			0.99	41.6
41									0.27								1.58		0.77																									0.43			0.89	14.6
42								-0.48										0.49																									-0.34	0.20	-0.40		0.93	25.2
43										0.51				-0.44																											-0.29			0.62			0.88	19.8
45	-0.57																																								-0.30			0.53		0.35	0.84	11.6
46						0.64			0.69																			0.35		-0.81											-0.31						0.97	19.6
48														-0.88												-0.93		-0.39		0.61							0.53							0.38		0.85	0.86	6.24

Appendix 6E Distribution Of Regression Coefficients

Figure 6E-1 Distribution of *YawRt/0.2* regression coefficients, Driver B

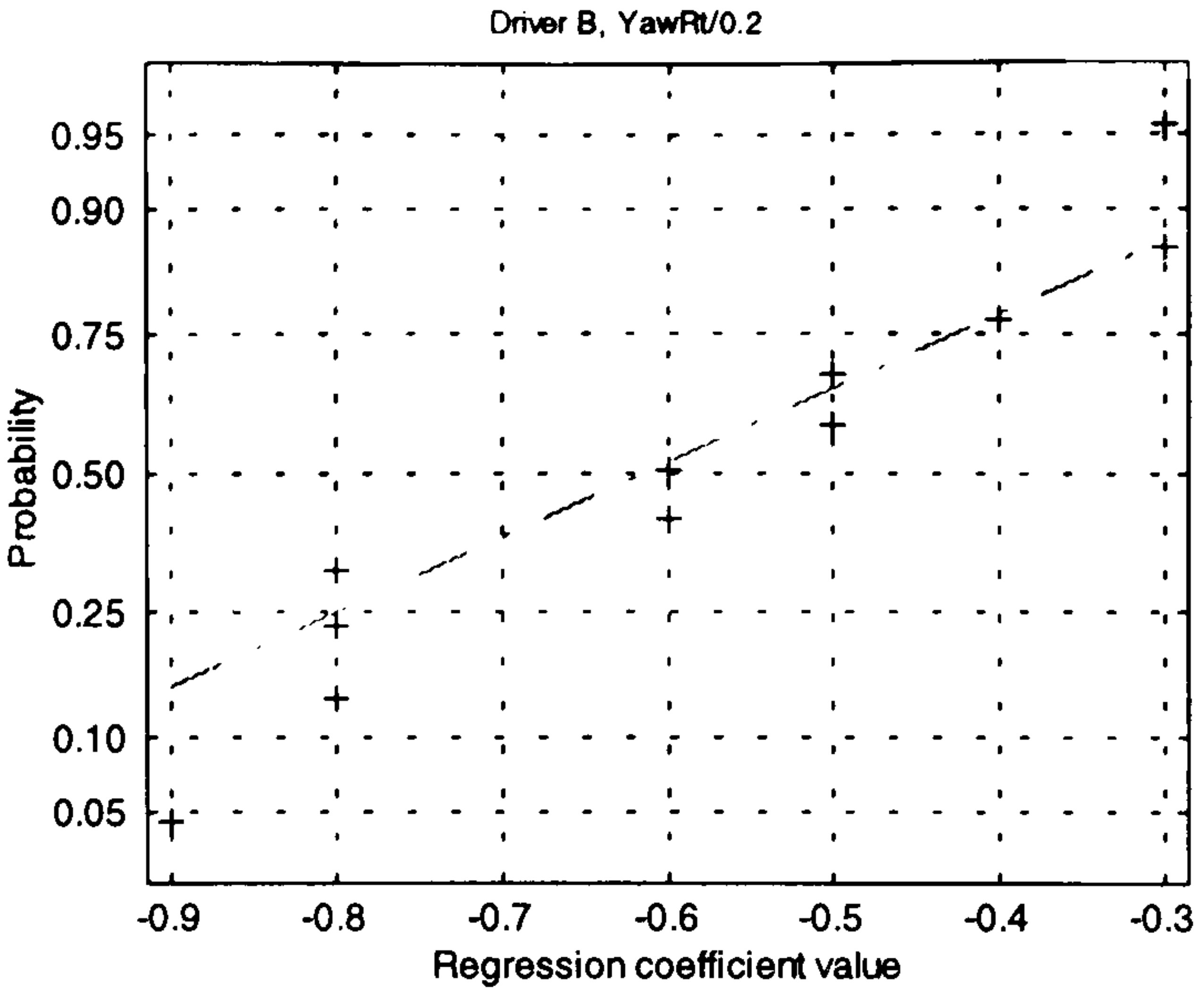


Figure 6E-2 Distribution of *Storq/0.2* regression coefficients, Driver B

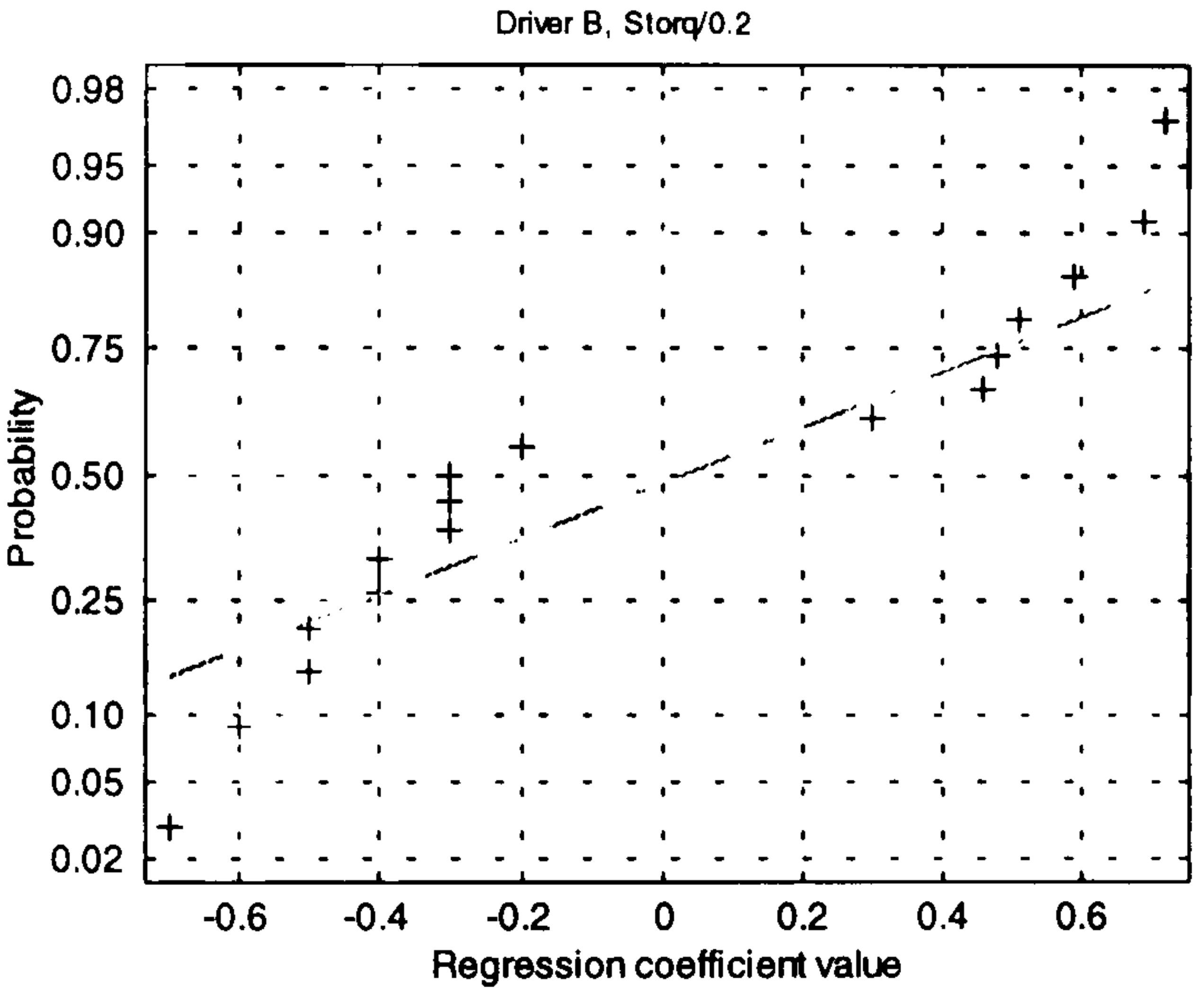


Figure 6E-3 Distribution of *LataccGain/1.0* regression coefficients, Driver C

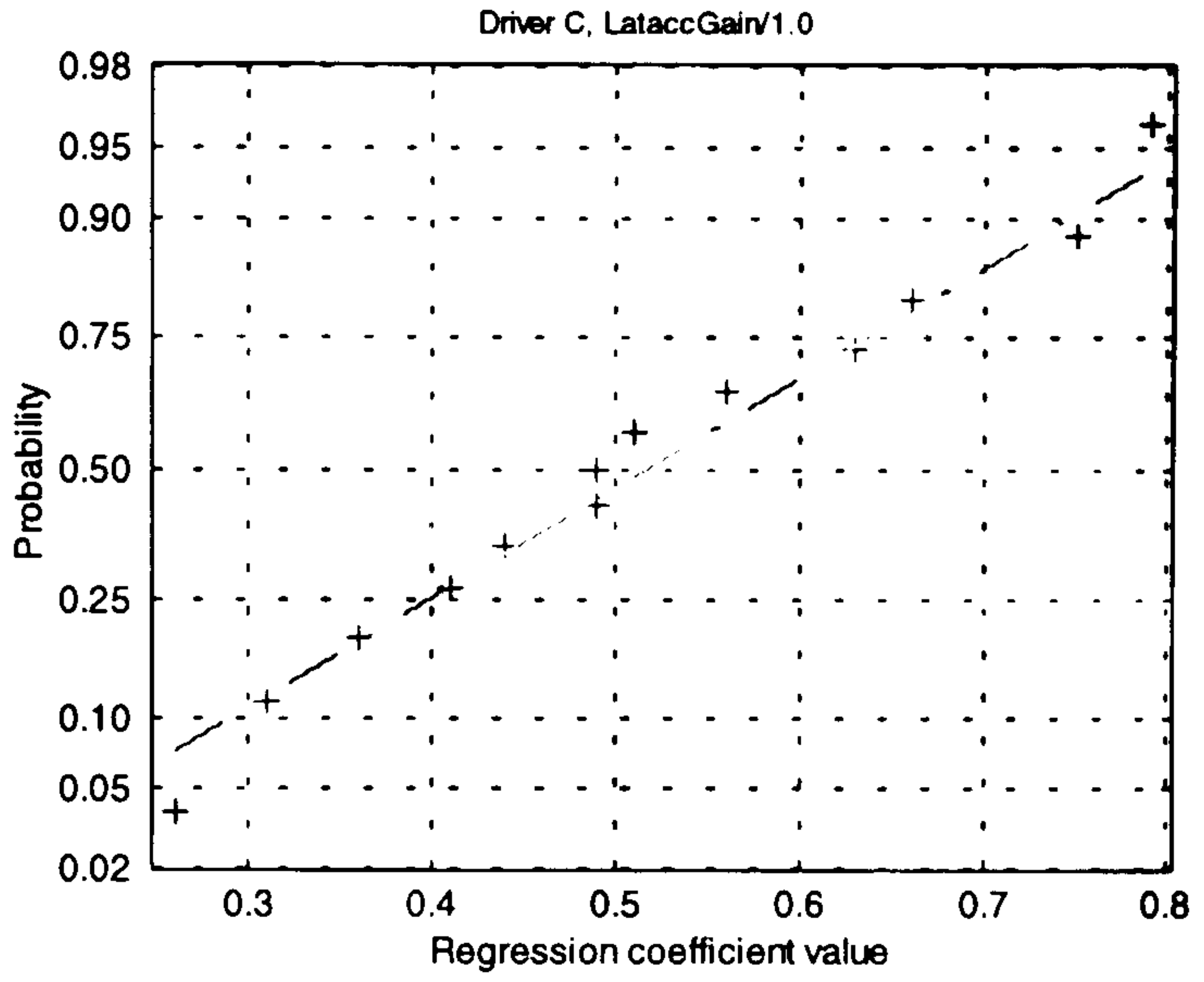


Figure 6E-4 Distribution of *Storq/0.2* regression coefficients, Driver C

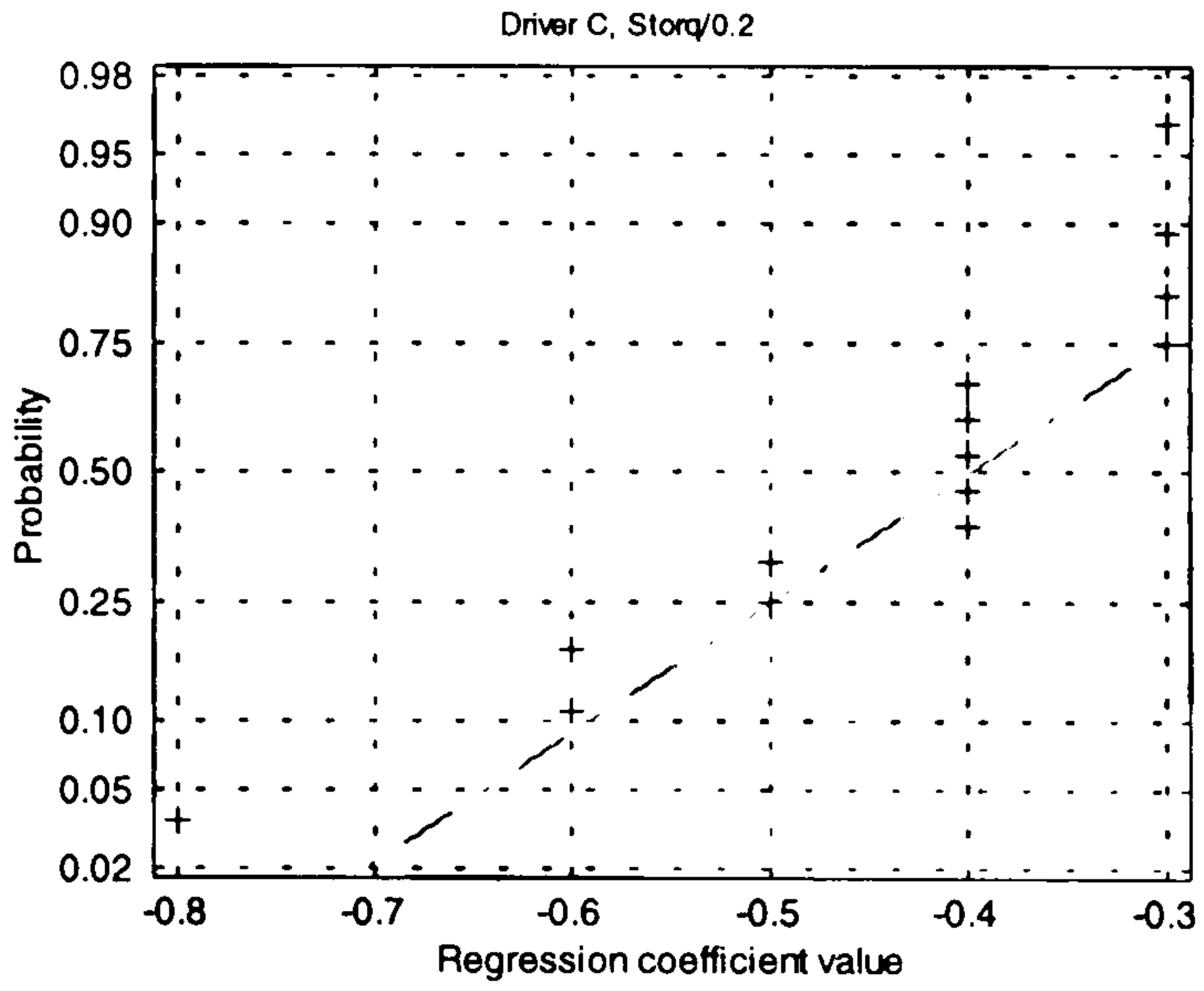


Figure 6E-5 Distribution of *RollAngle/0.2* regression coefficients, Driver C

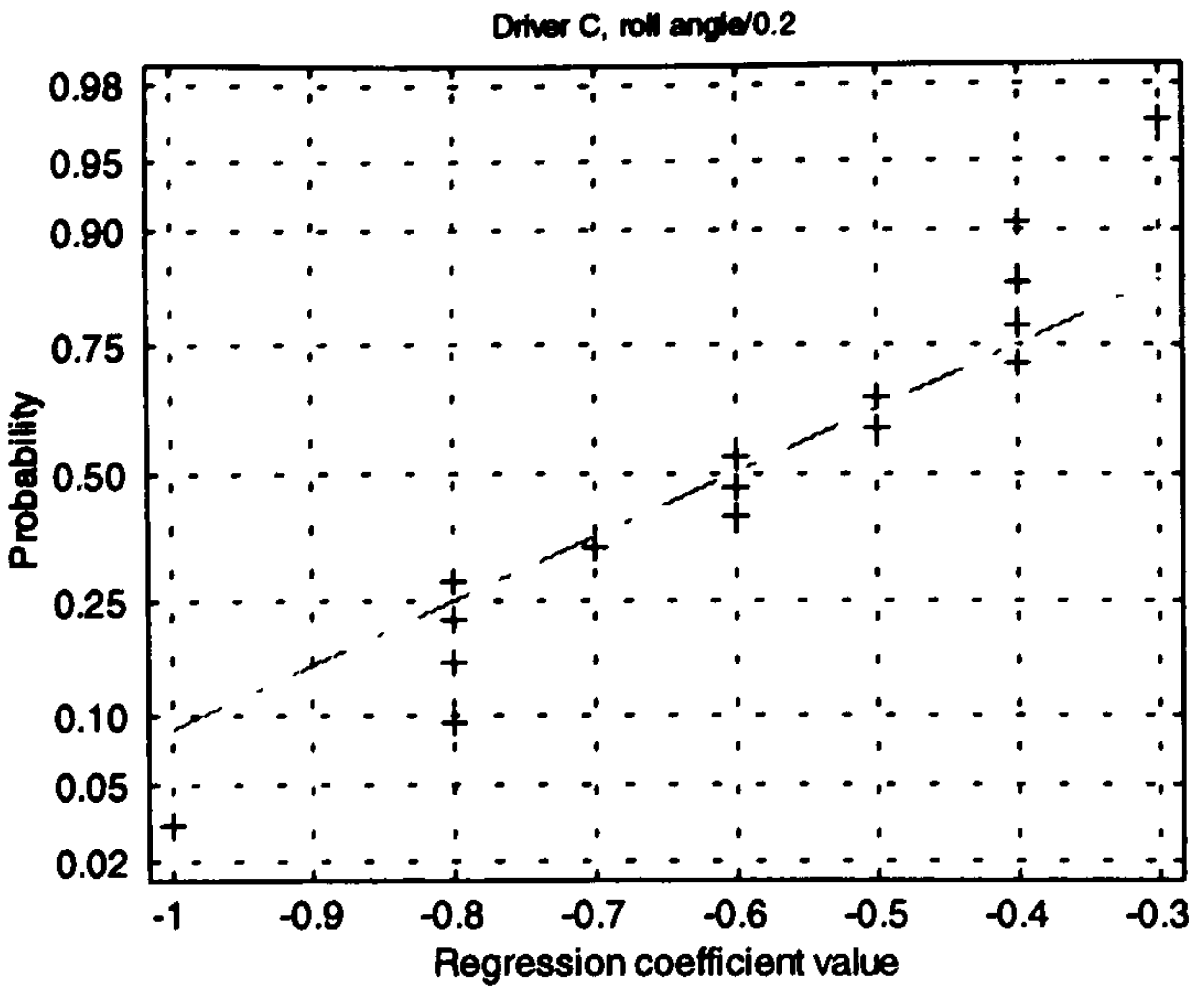


Figure 6E-6 Distribution of *LataccGain/1.0* regression coefficients, Driver D

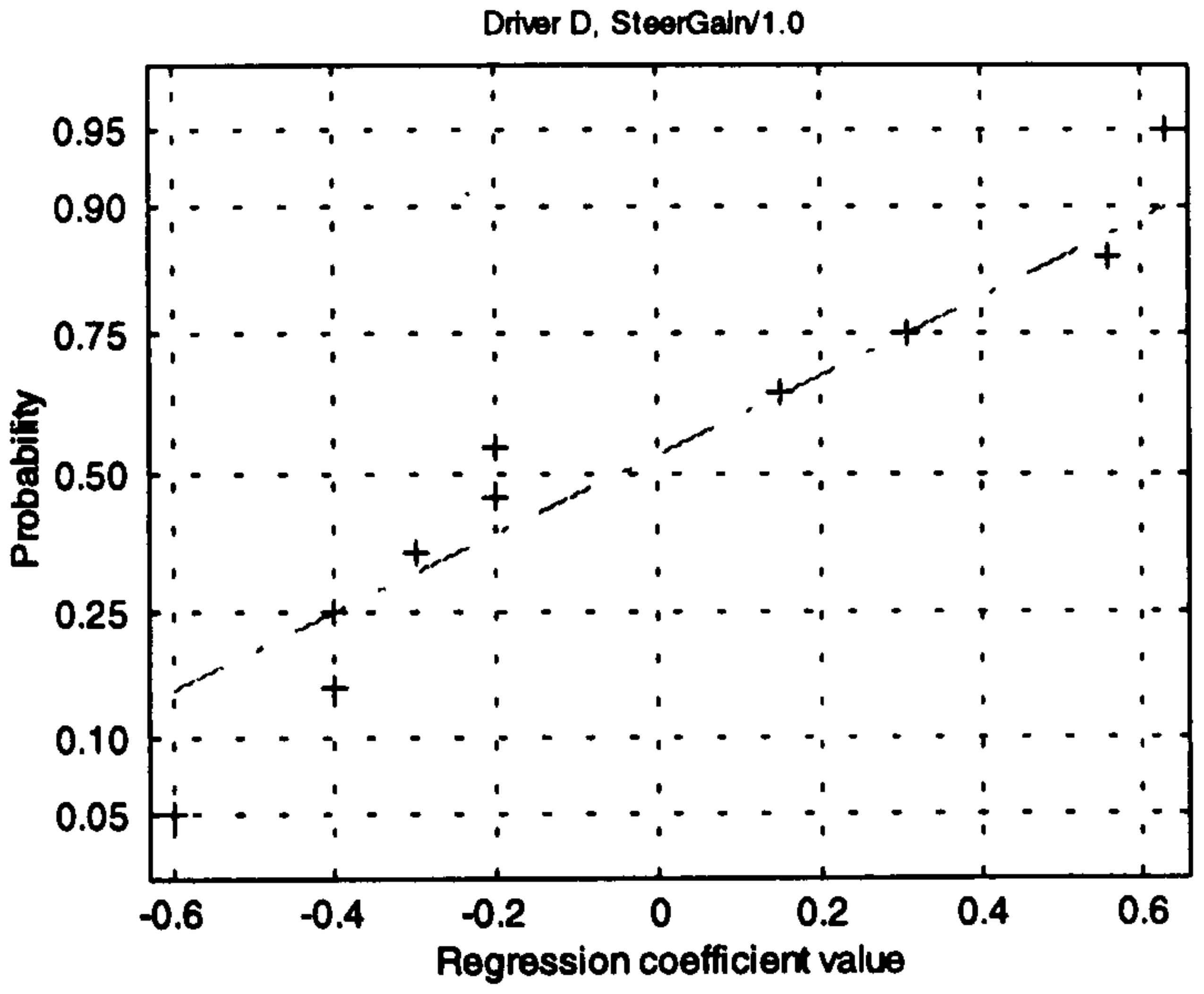


Figure 6E-7 Distribution of *YawRt/0.2* regression coefficients, Driver D

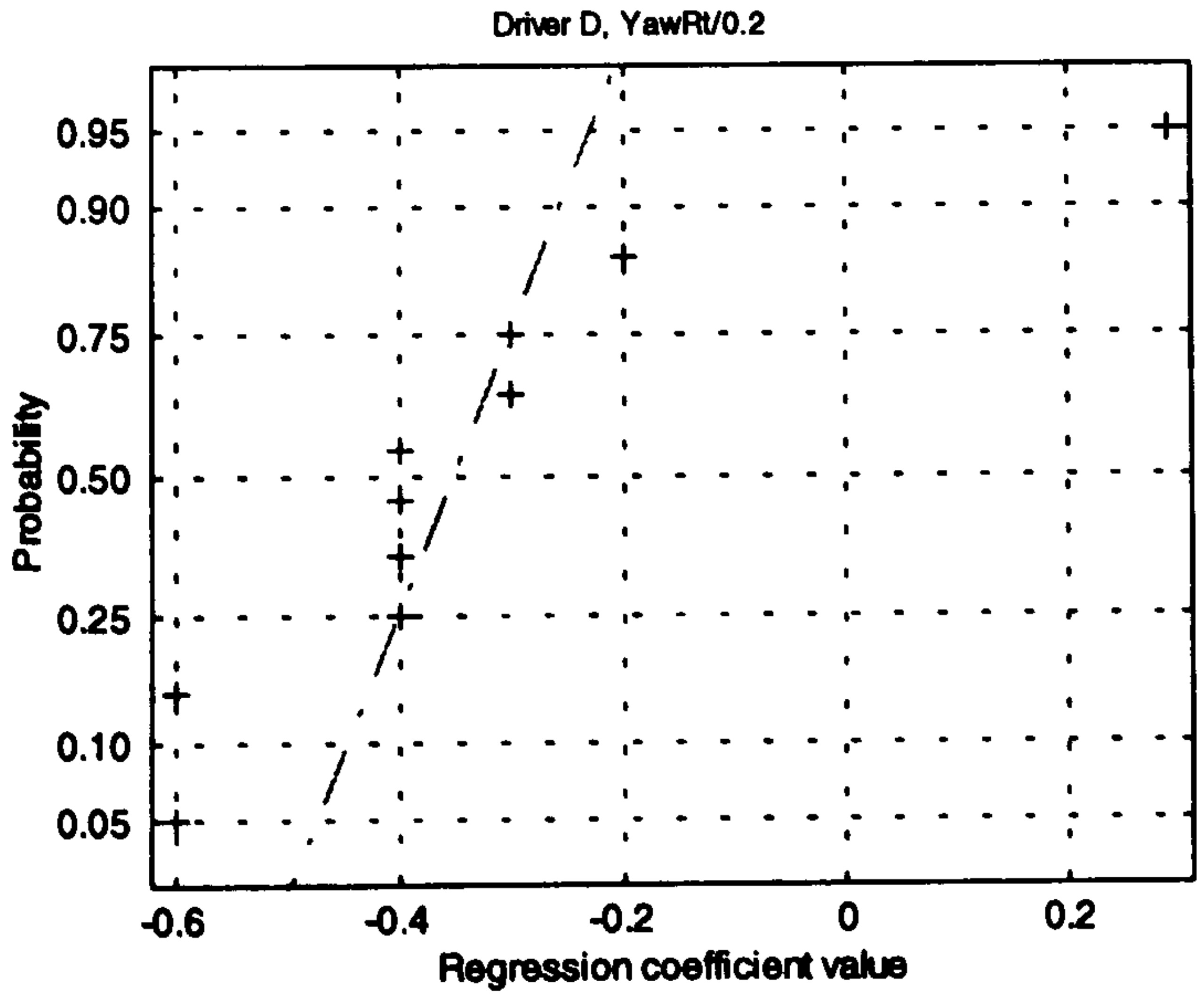


Figure 6E-8 Distribution of *d(sslip)/0.4* regression coefficients, Driver D

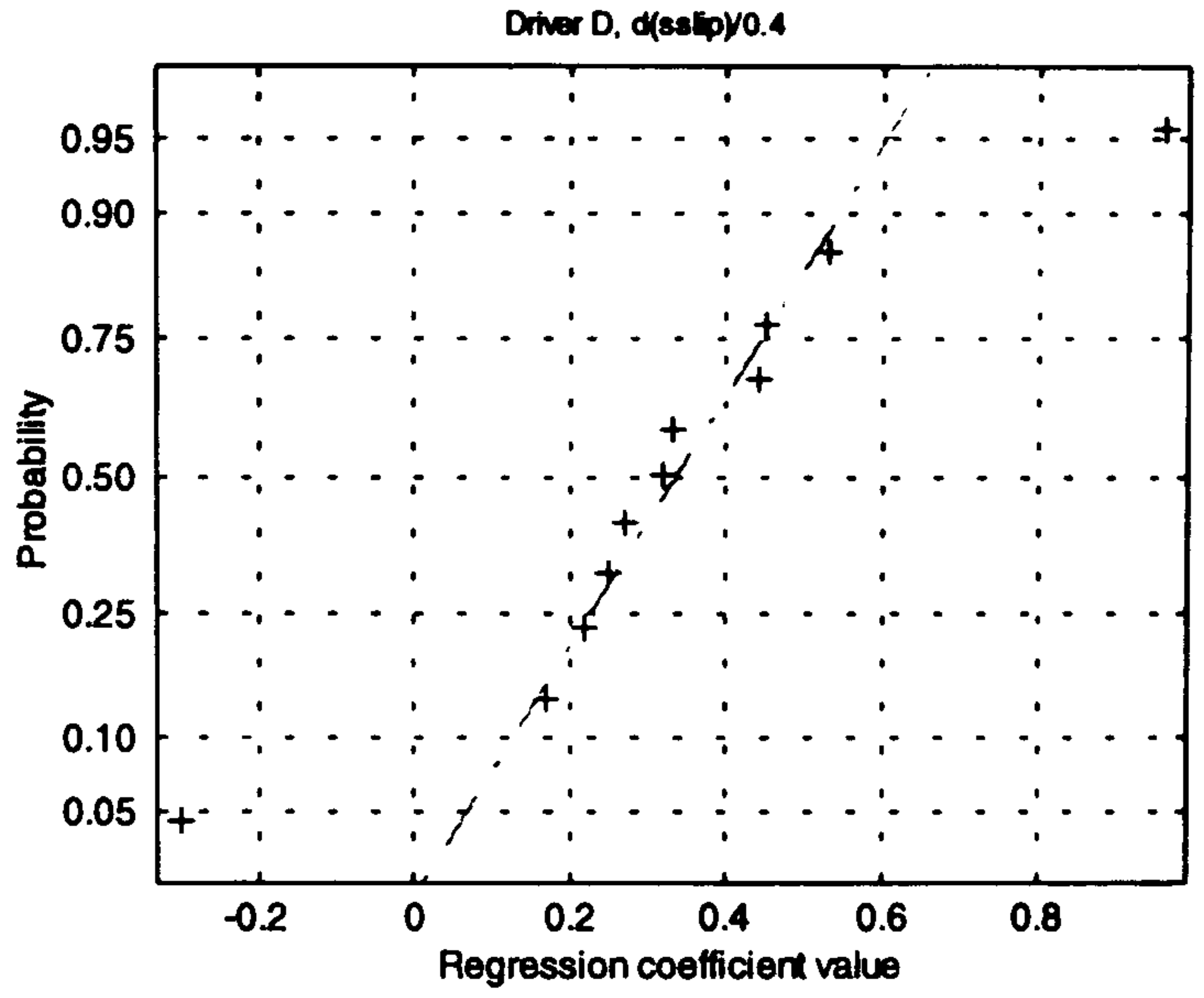


Figure 6E-9 Distribution of *d(sslip)/0.2* regression coefficients, Driver D

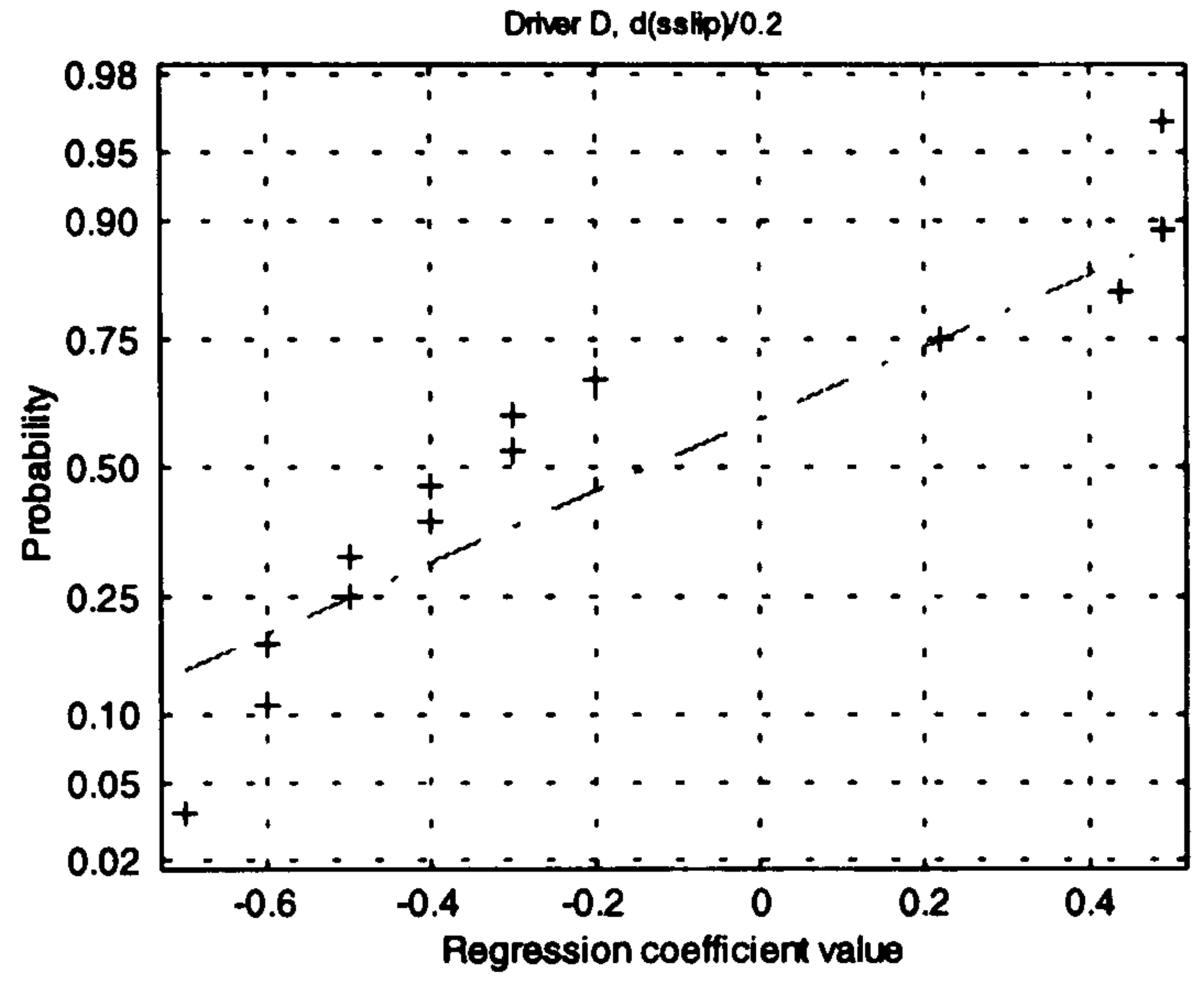


Figure 6E-10 Distribution of *RollAngle/0.2* regression coefficients, Driver D

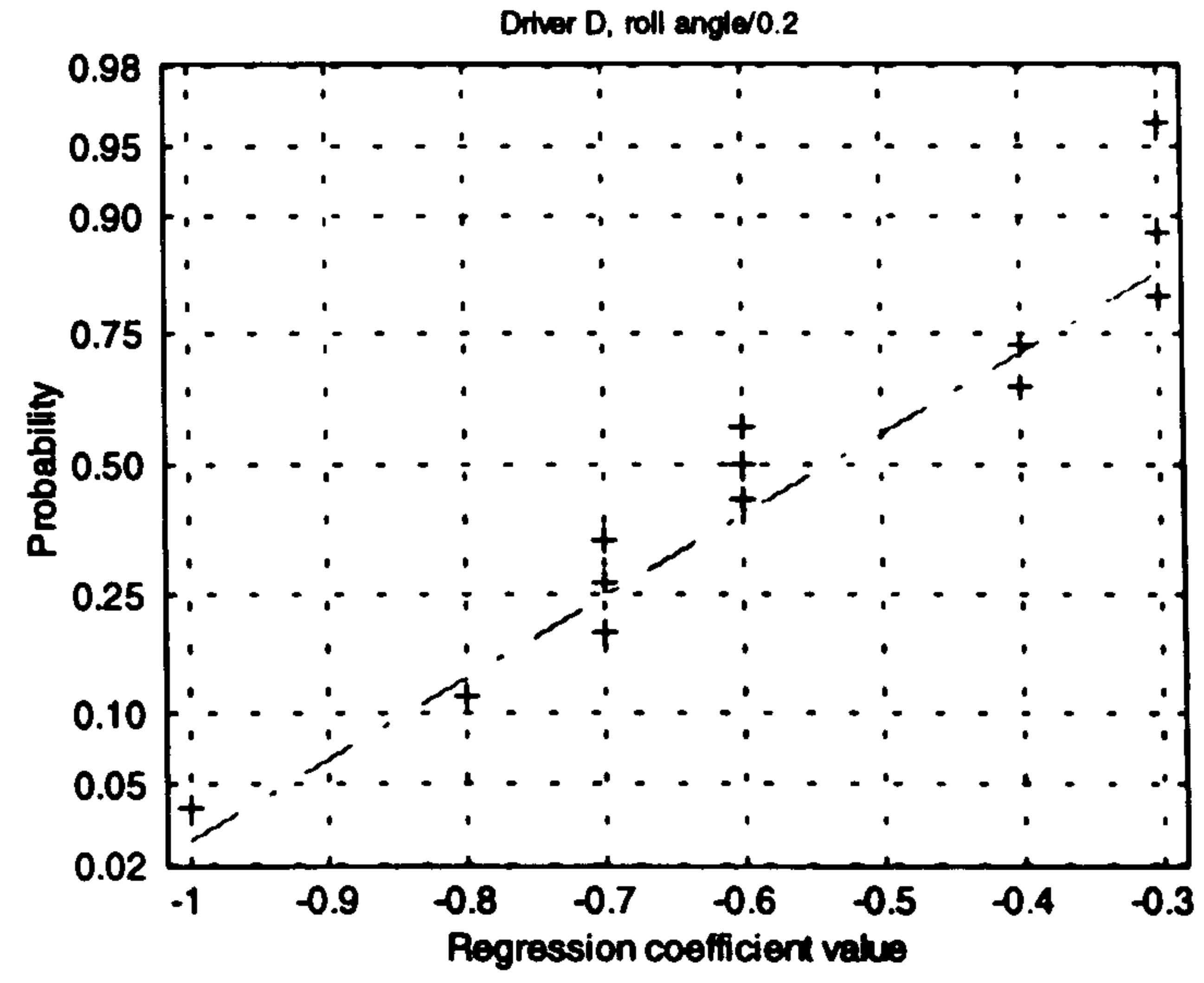


Figure 6E-11 Distribution of *LataccGain/1.0* regression coefficients, Driver E

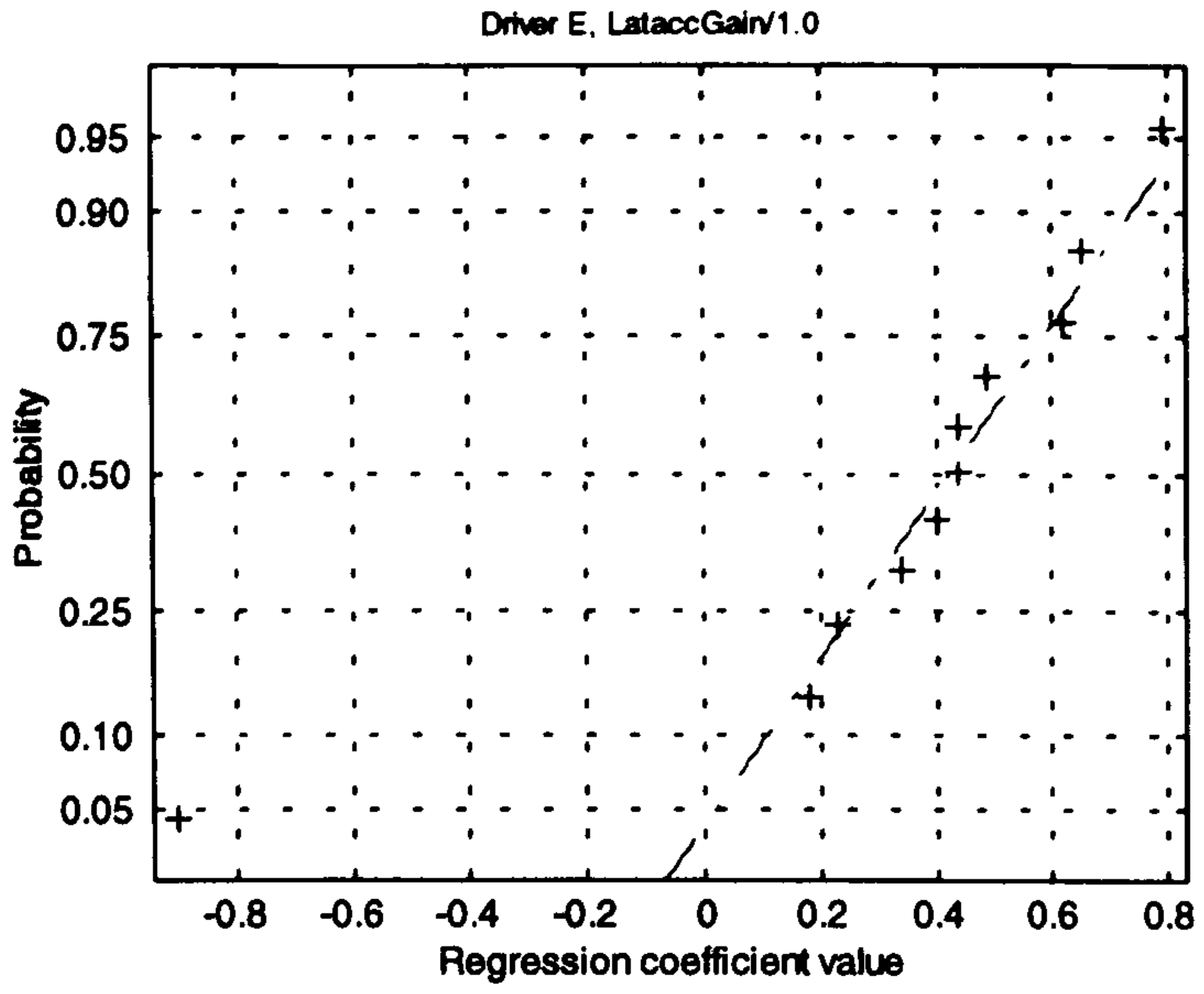


Figure 6E-12 Distribution of *YawGain/0.7* regression coefficients, Driver E

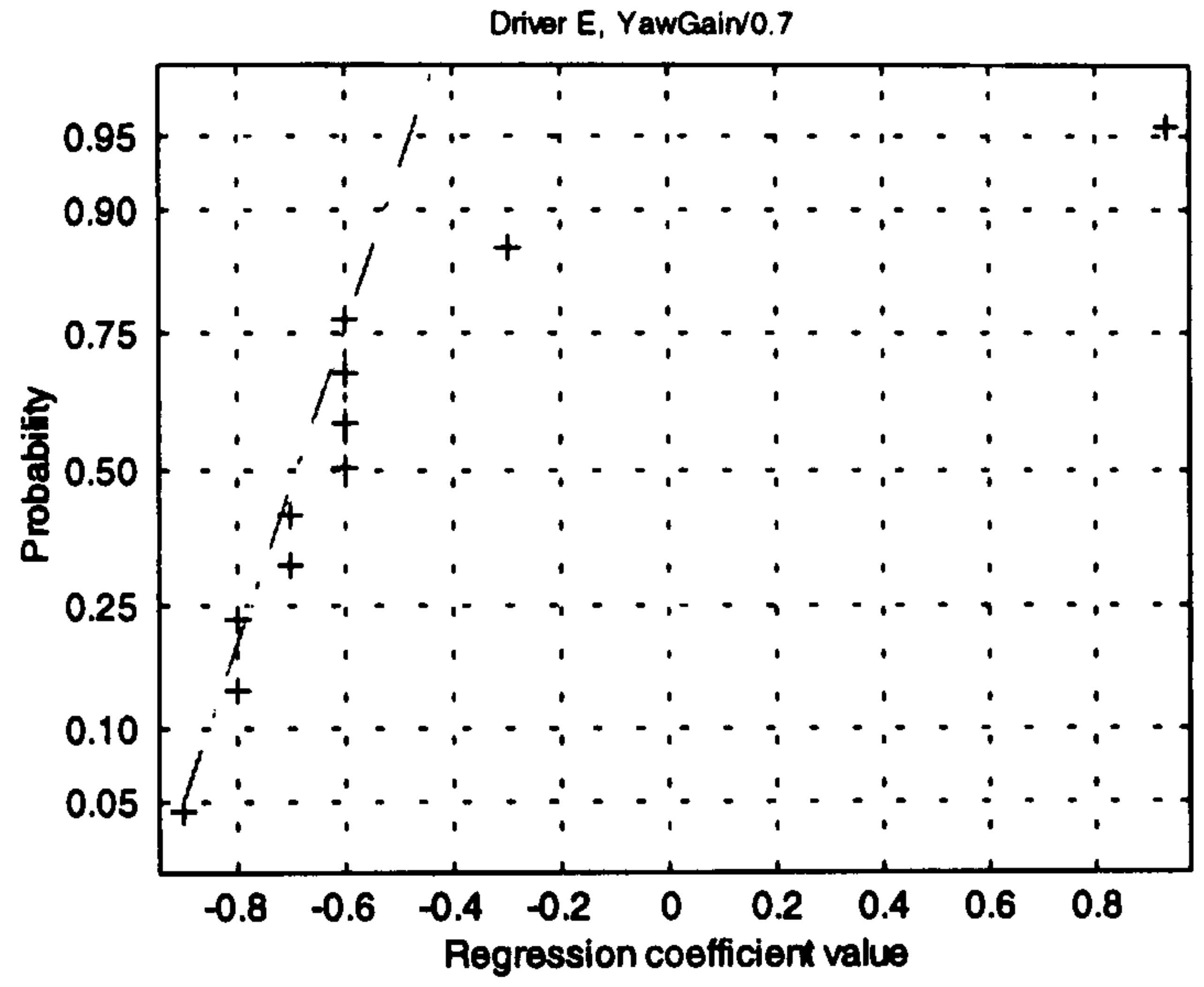


Figure 6E-13 Distribution of *RollRt/0.2* regression coefficients, Driver E

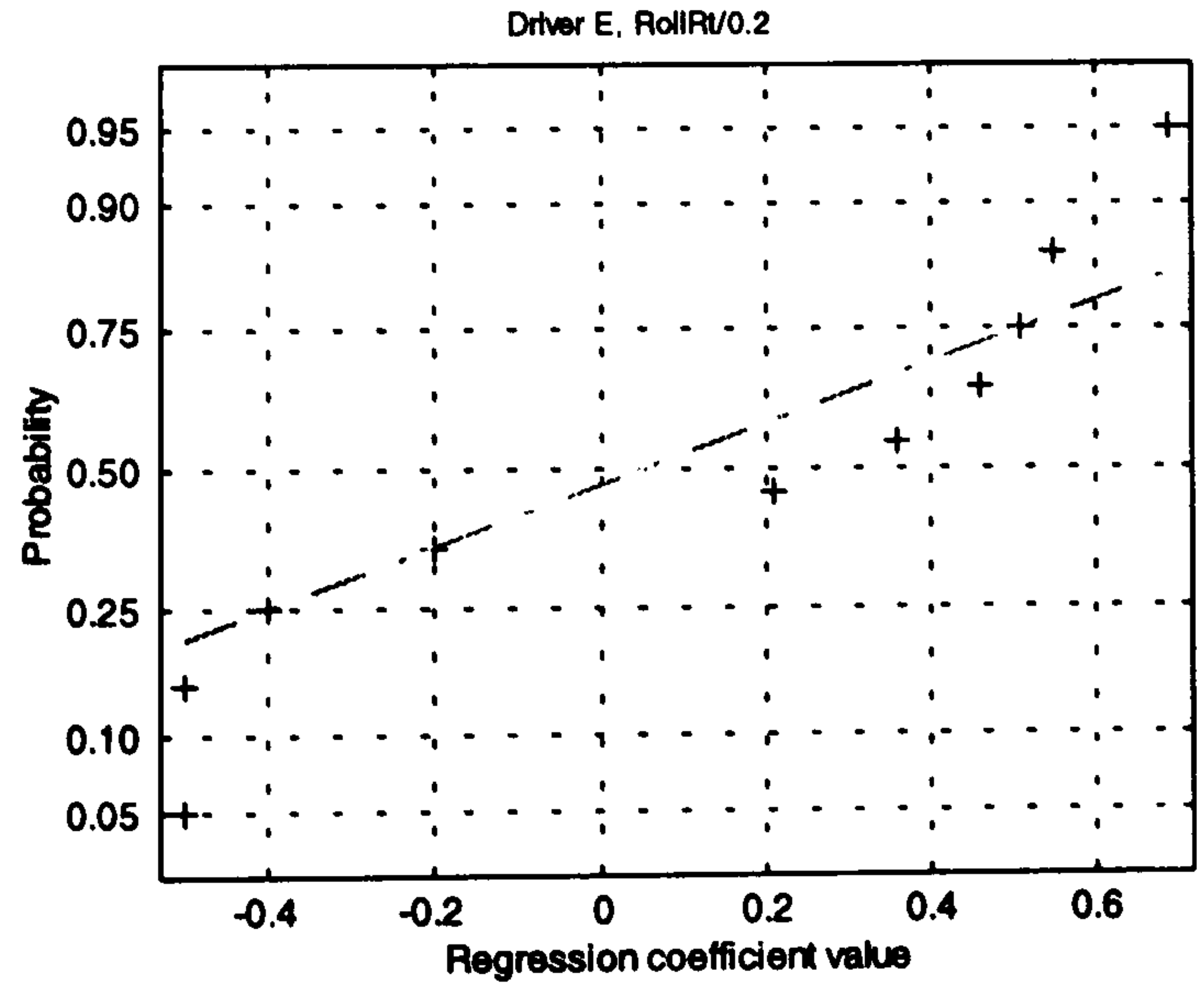


Figure 6E-14 Distribution of *d(sslip)/0.4* regression coefficients, Driver E

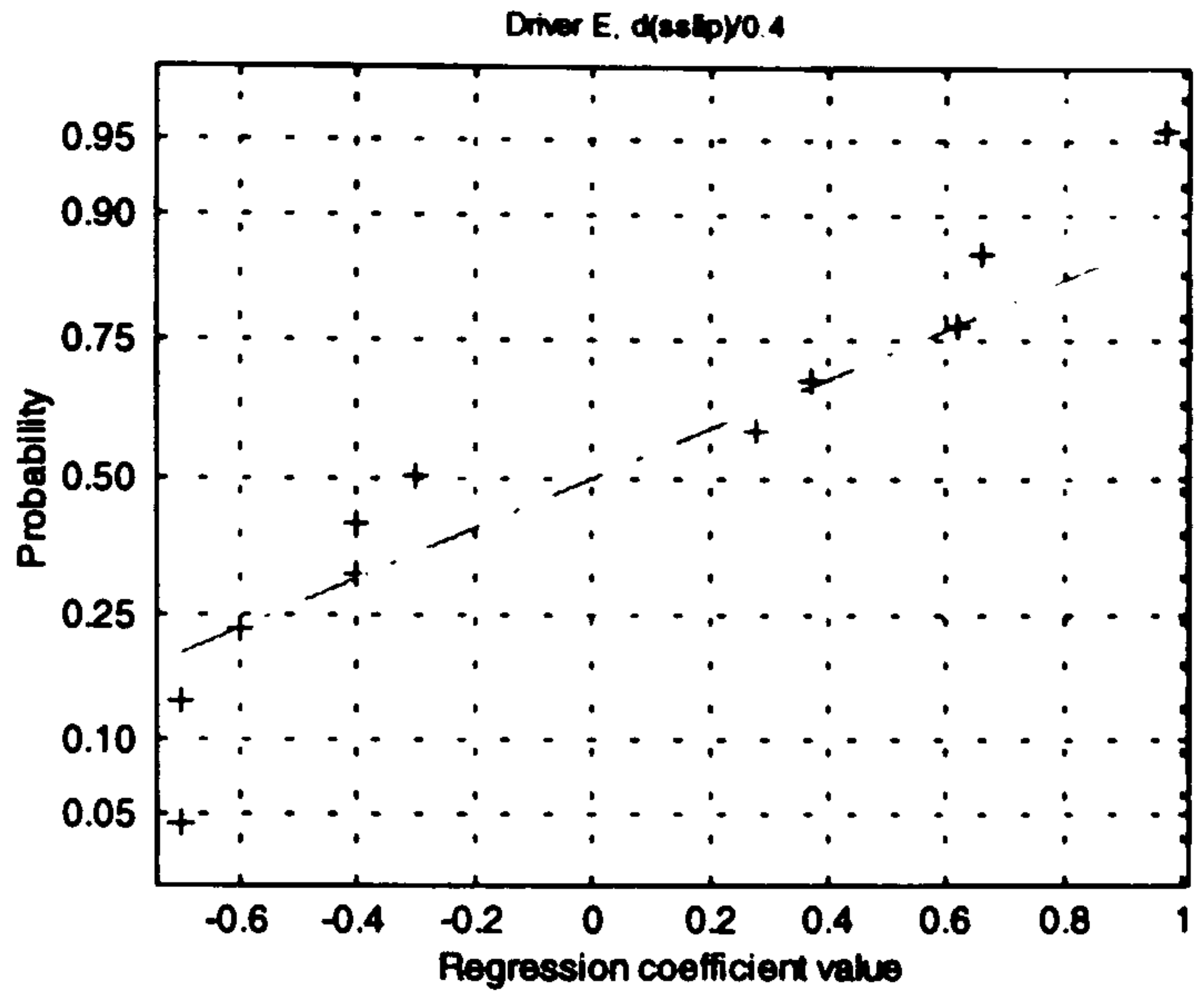


Figure 6E-15 Distribution of *d(storq)/0.2* regression coefficients, Driver E

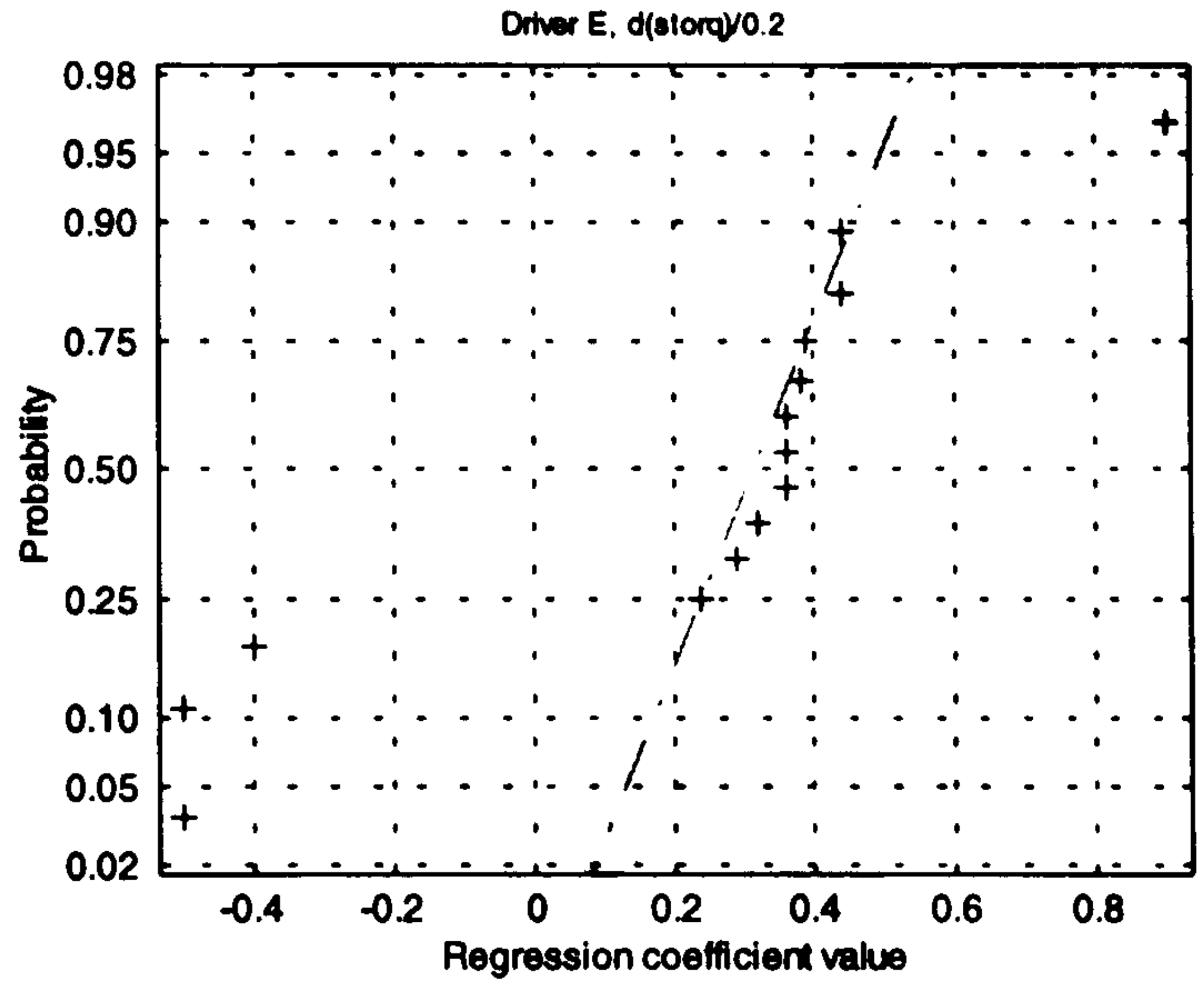


Figure 6E-16 Distribution of *LataccGain/1.0* regression coefficients, Driver F

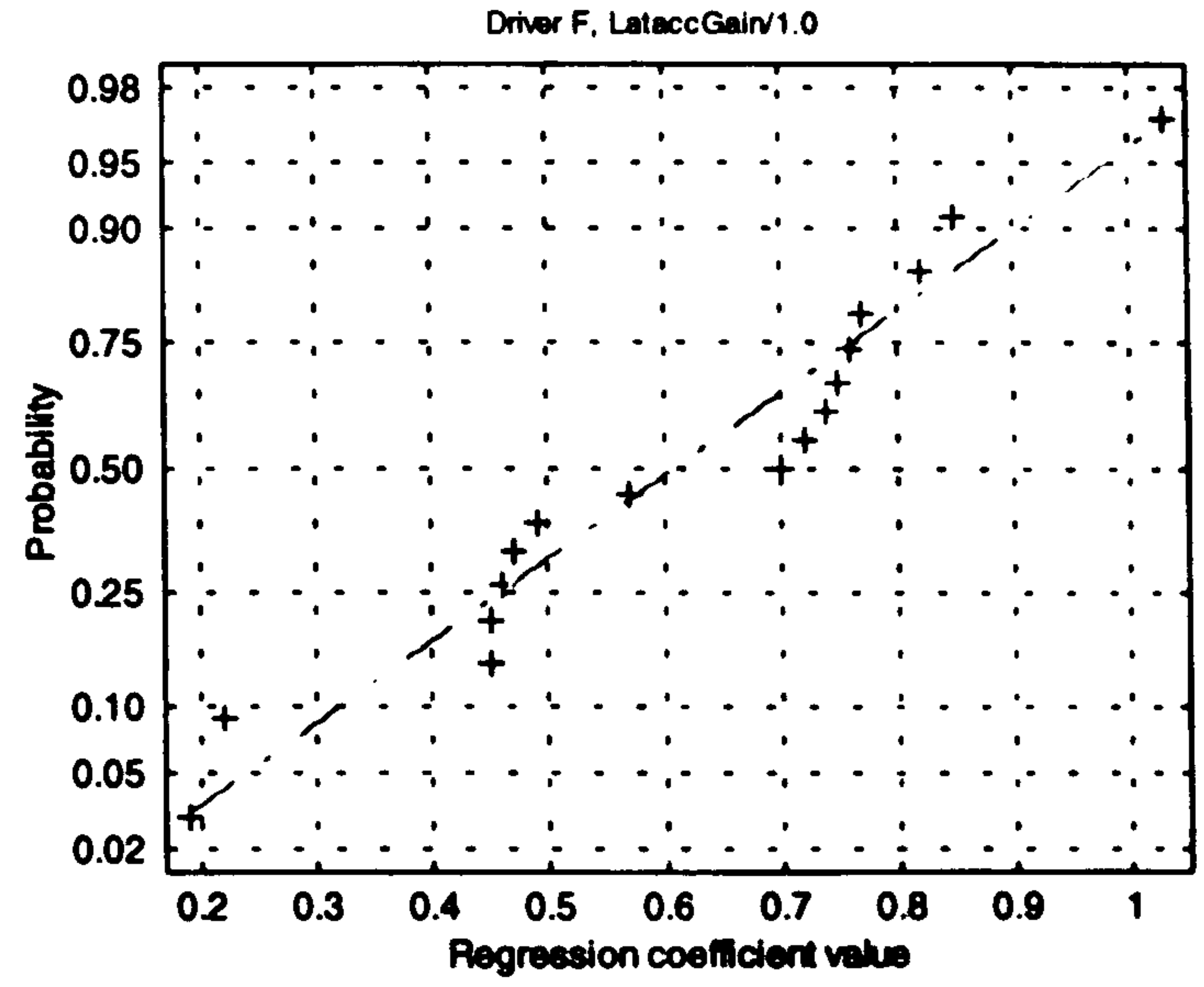


Figure 6E-17 Distribution of *YawGain/0.7* regression coefficients, Driver F

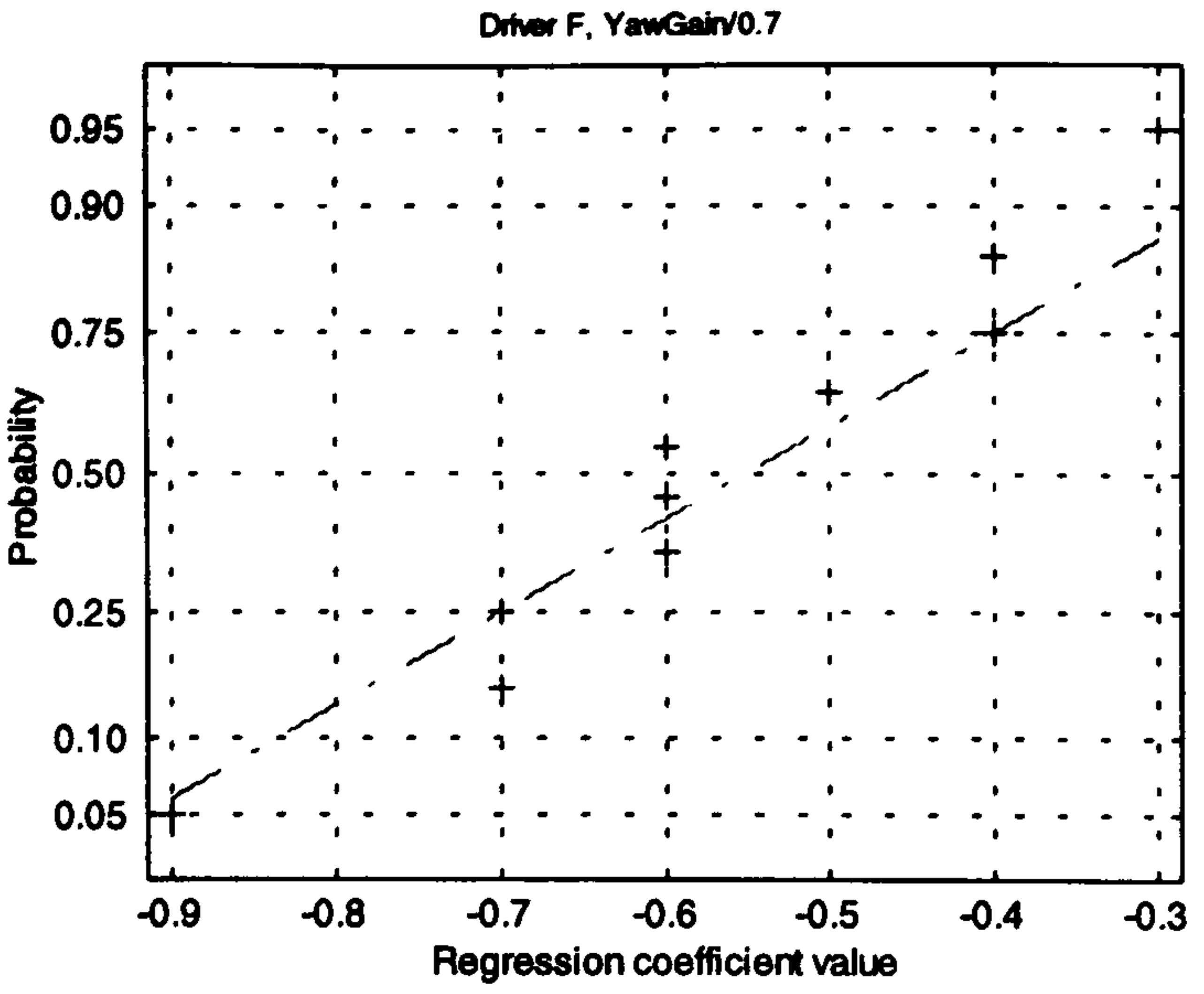


Figure 6E-18 Distribution of *RollRt/0.2* regression coefficients, Driver F

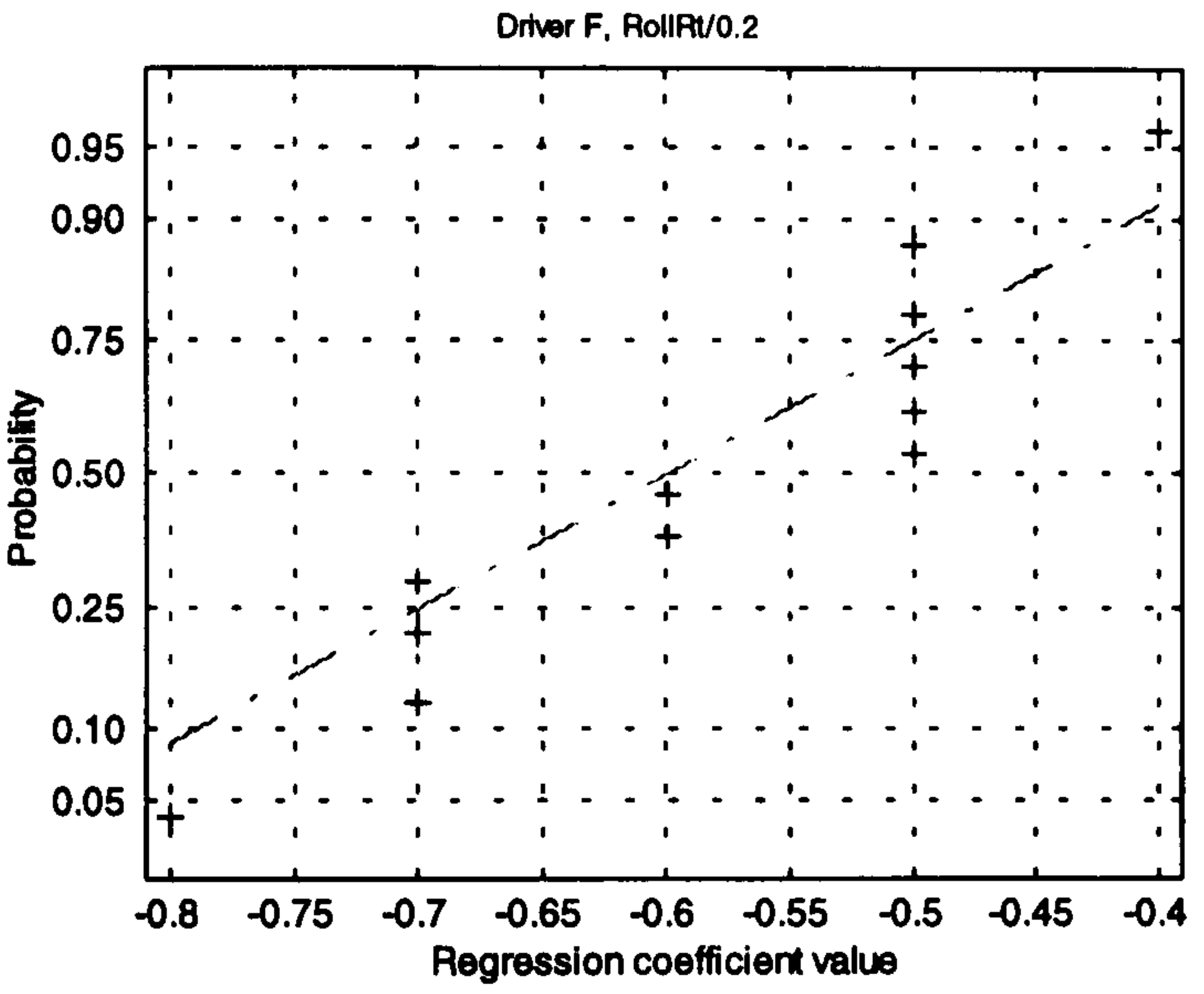


Figure 6E-19 Distribution of *YawRt/0.6* regression coefficients, Driver F

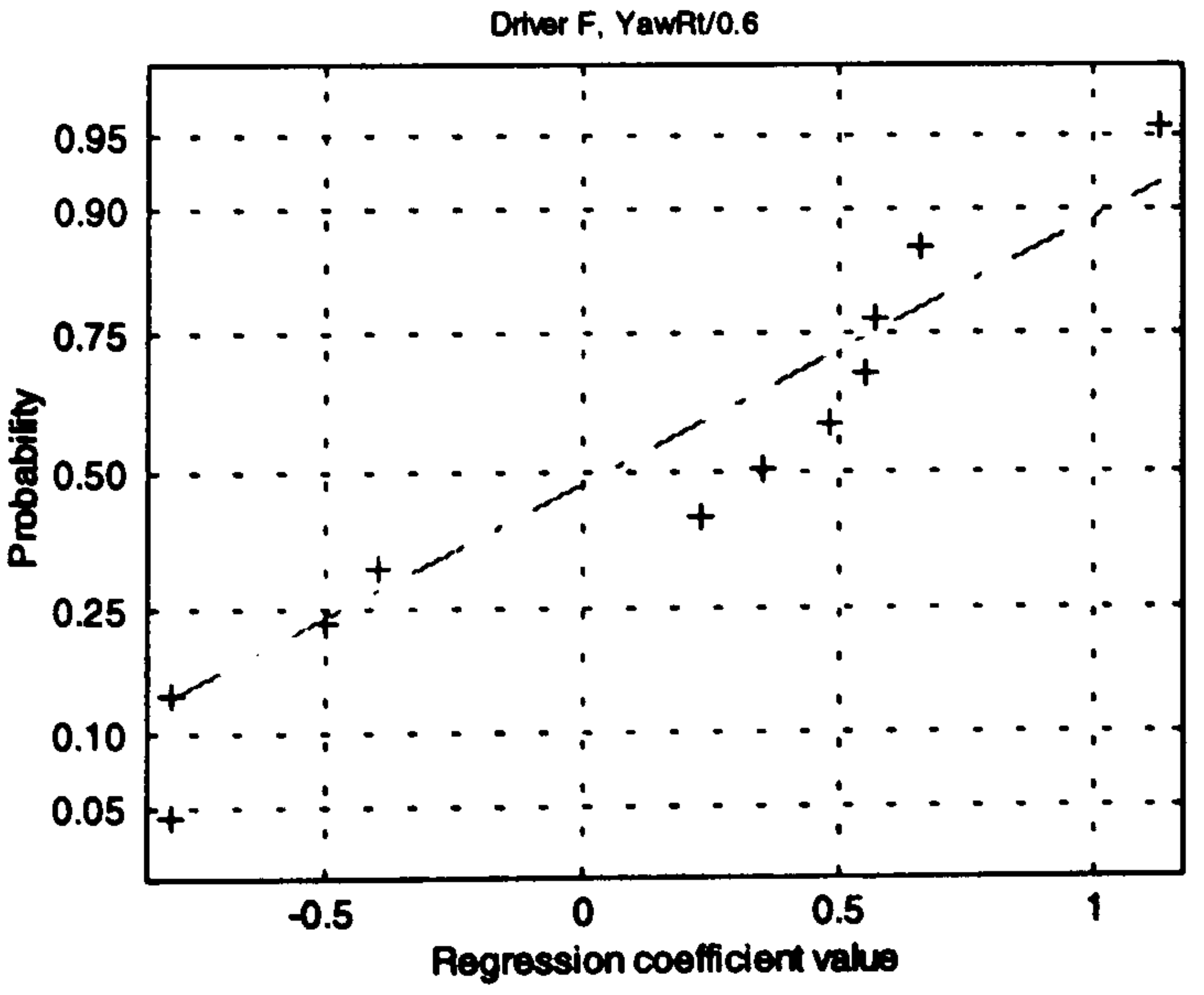


Figure 6E-20 Distribution of *Storq/0.2* regression coefficients, Driver F

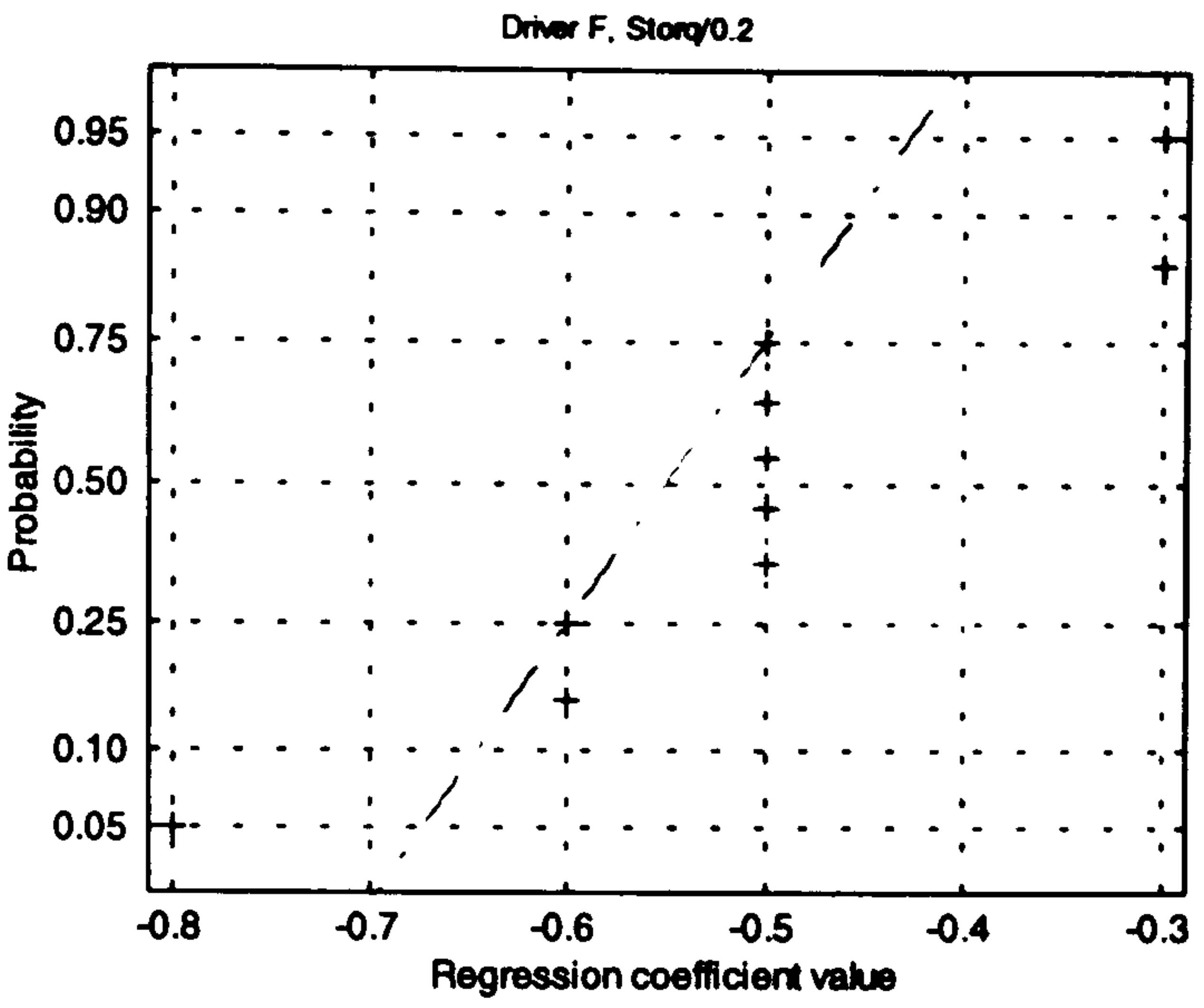


Figure 6E-21 Distribution of *d(sslip)/0.4* regression coefficients, Driver F

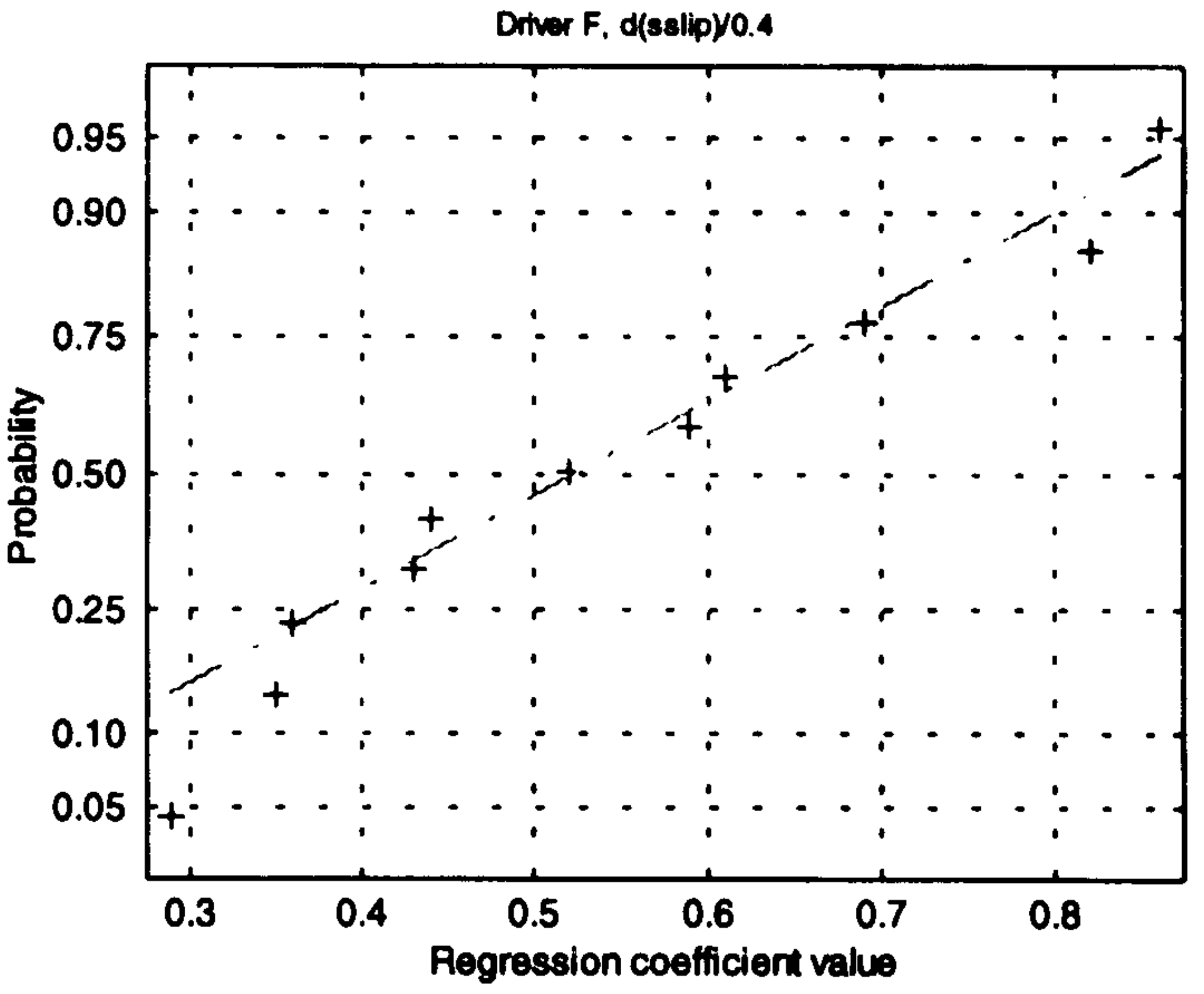


Figure 6E-22 Distribution of *LataccGain/1.0* regression coefficients, Driver G

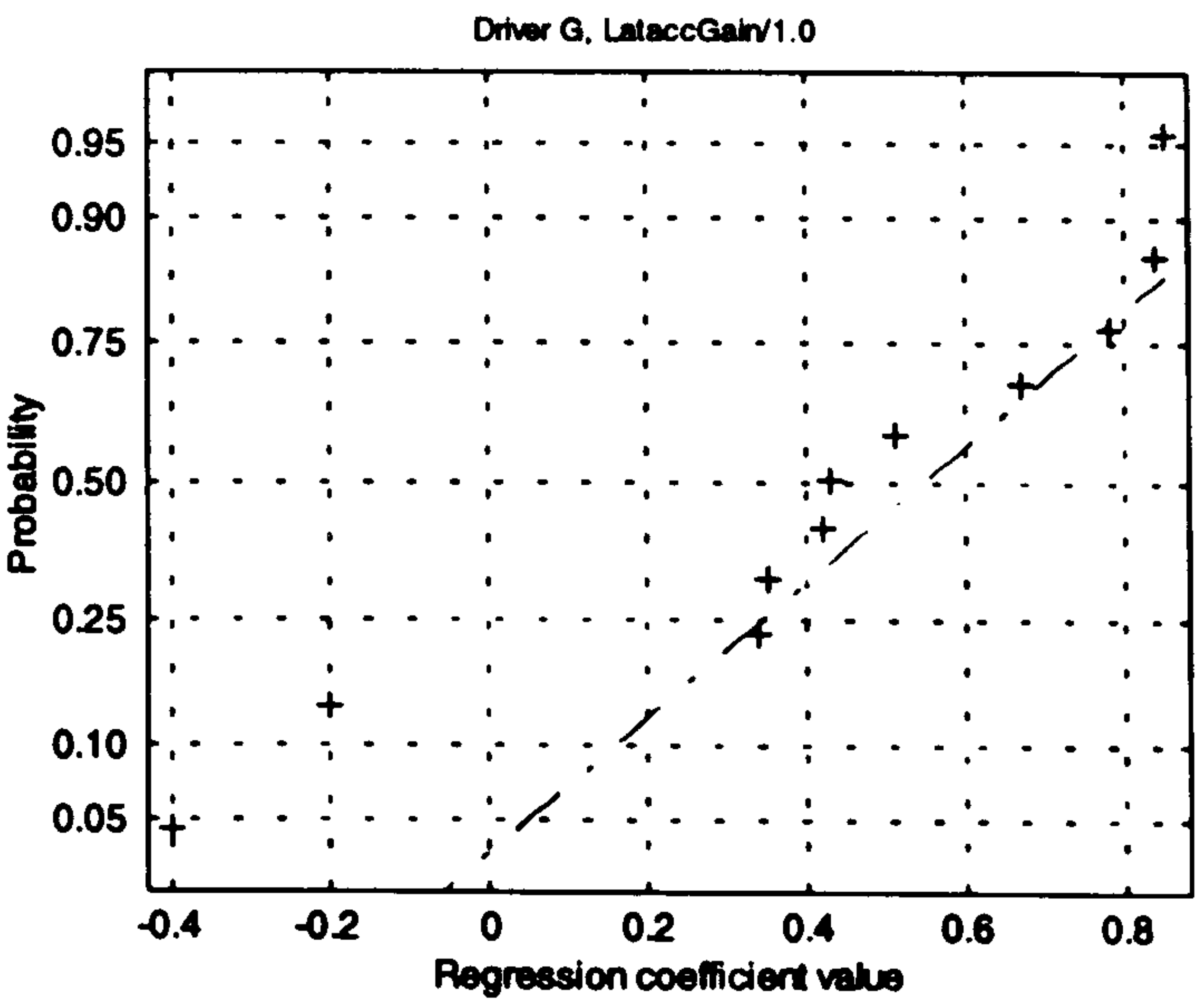


Figure 6E-23 Distribution of *LataccGain/1.0* regression coefficients, Driver G

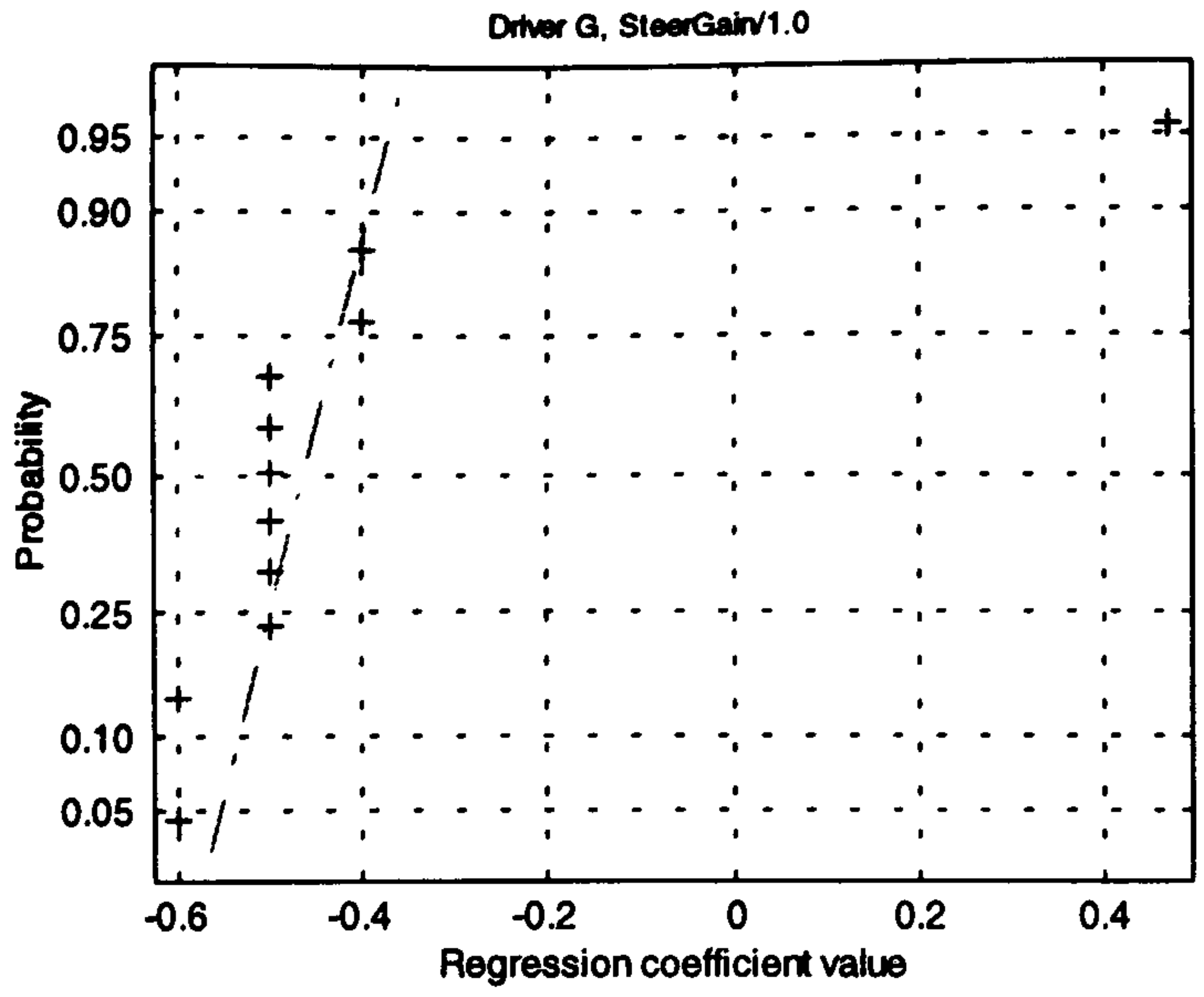


Figure 6E-24 Distribution of *StMeanRespTime/0.2* regression coefficients, Driver G

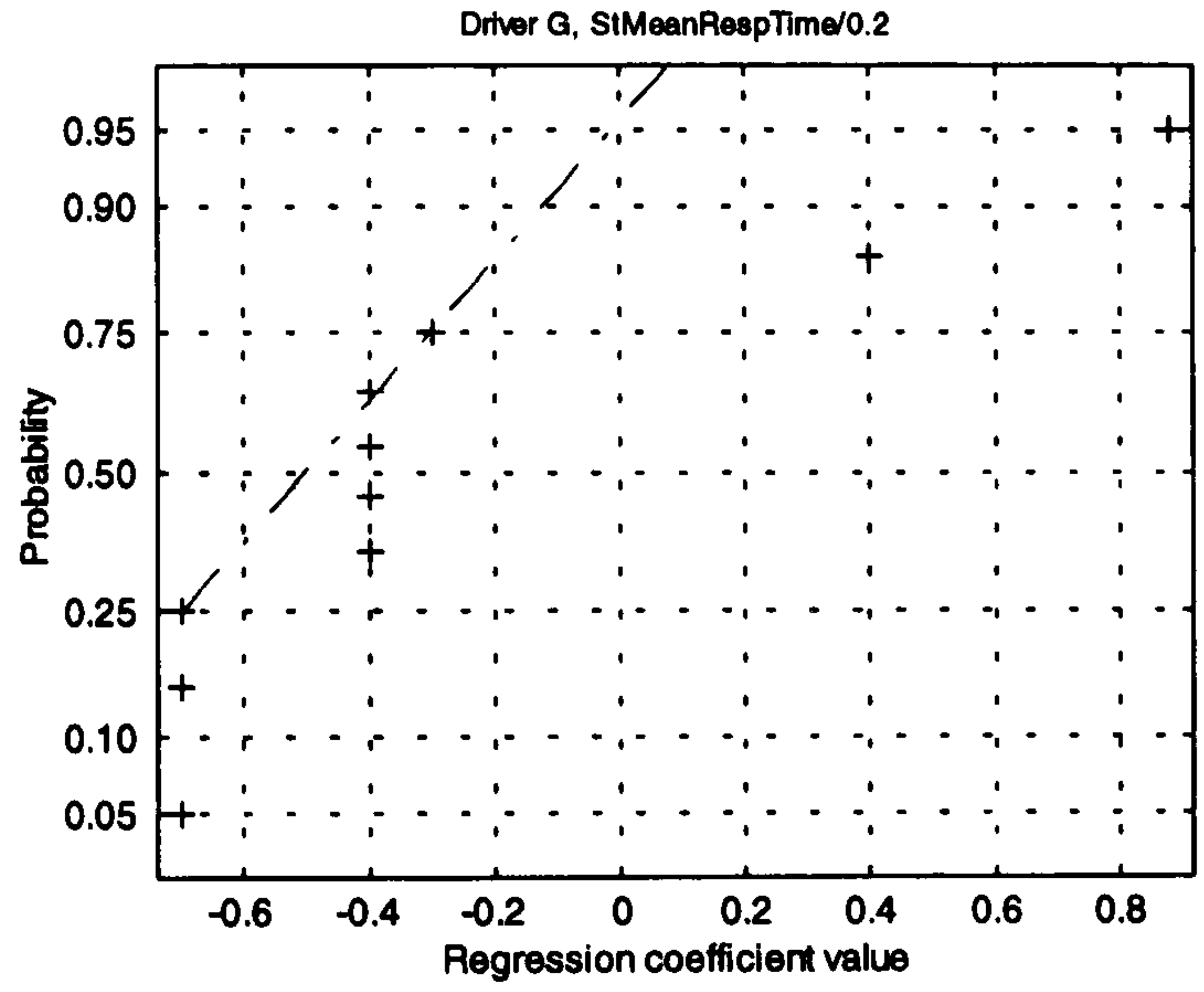


Figure 6E-25 Distribution of *YawRt/0.2* regression coefficients, Driver G

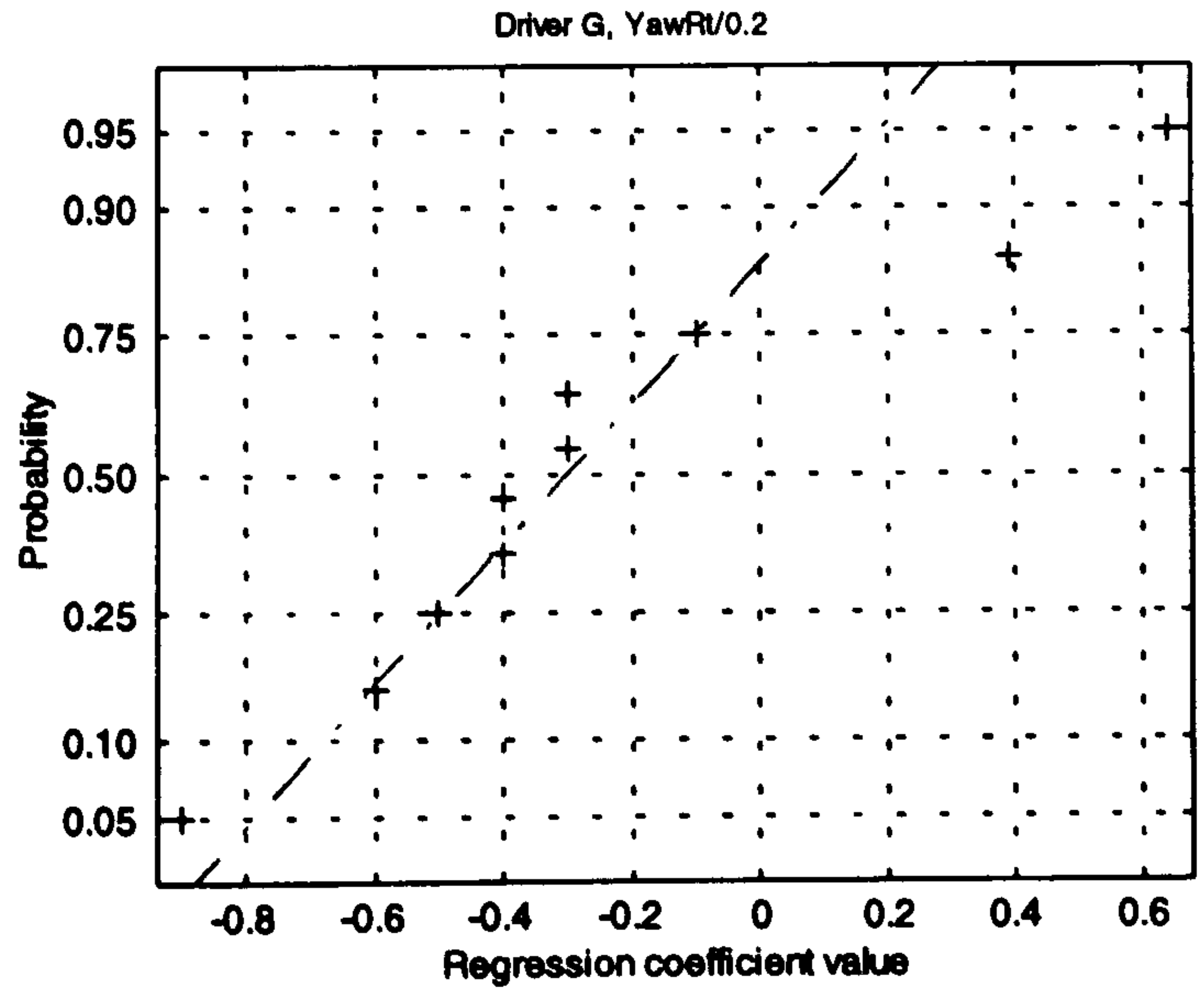


Figure 6E-26 Distribution of *Storq/0.2* regression coefficients, Driver G

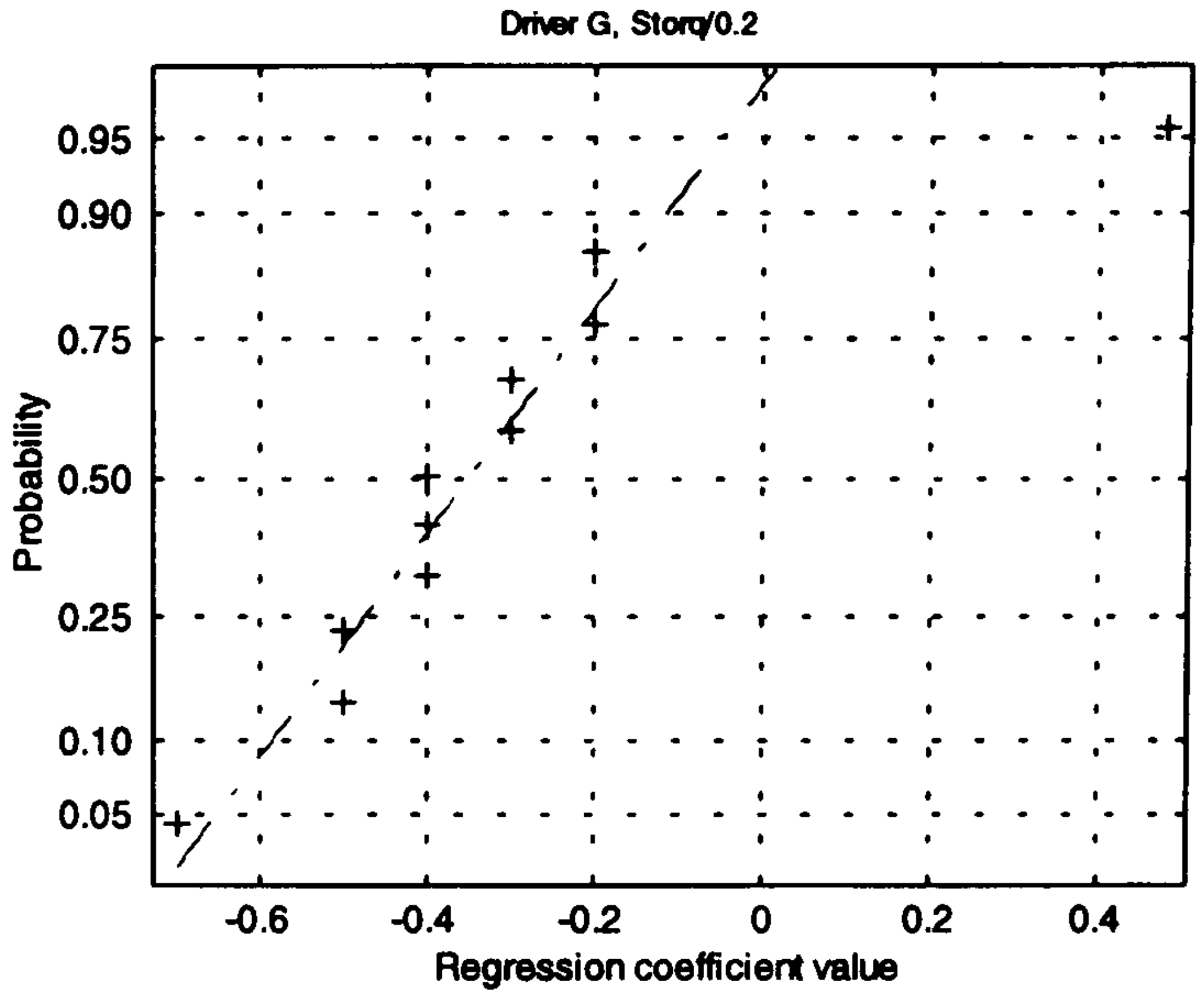


Figure 6E-27 Distribution of *SteerGain/1.0* regression coefficients, Driver H

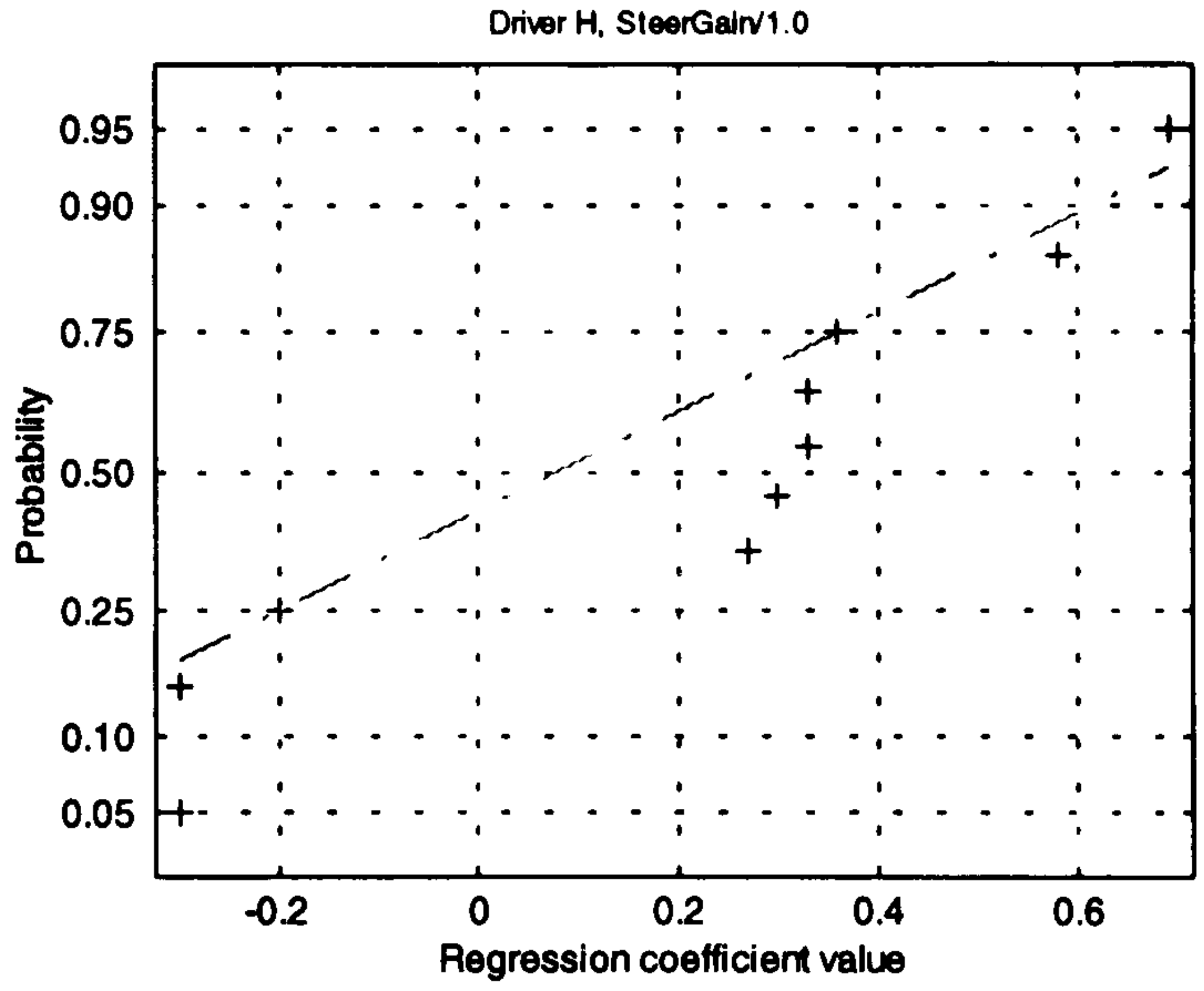


Figure 6E-28 Distribution of *YawGain/0.7* regression coefficients, Driver H

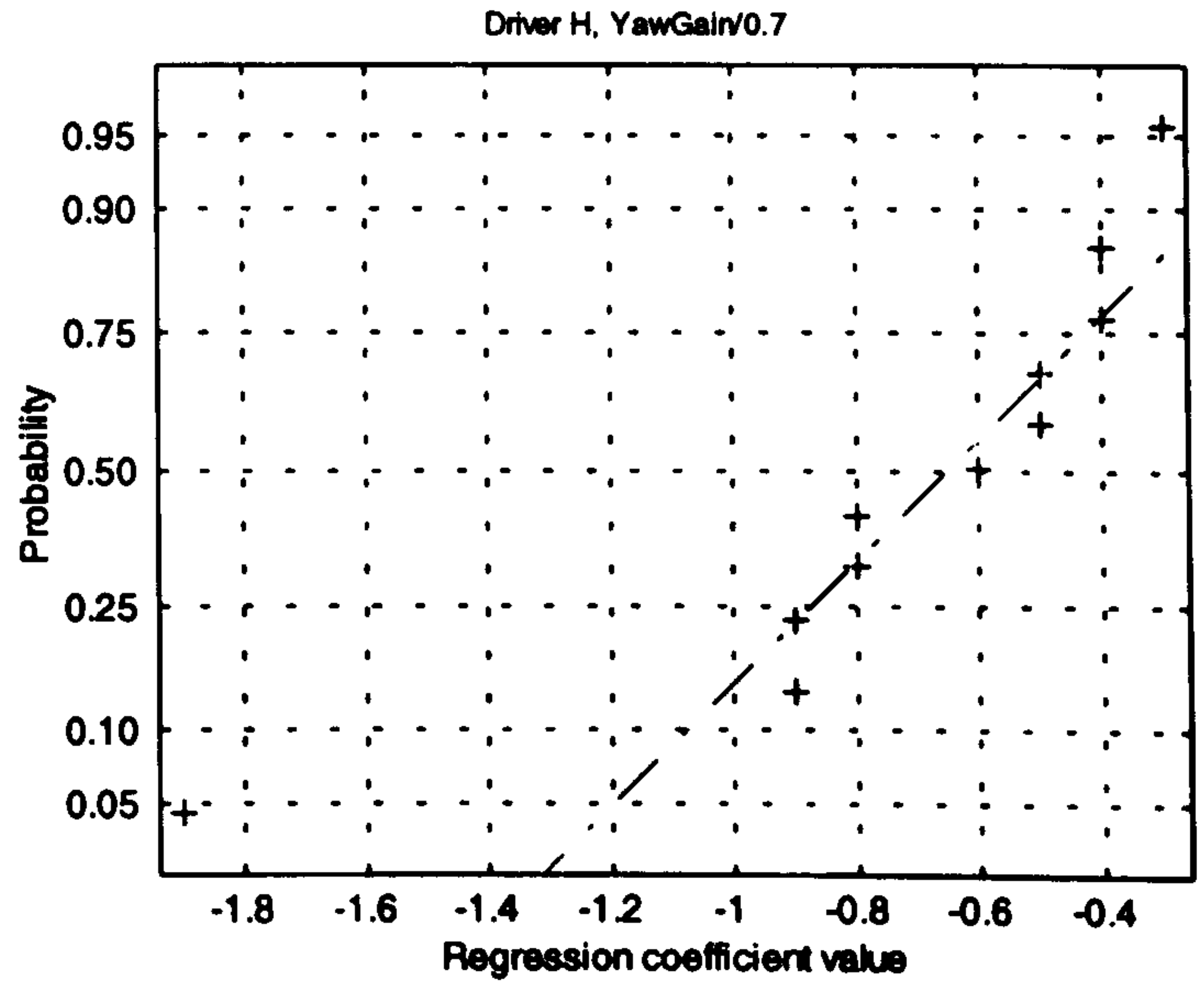


Figure 6E-29 Distribution of *RollRt/0.2* regression coefficients, Driver H

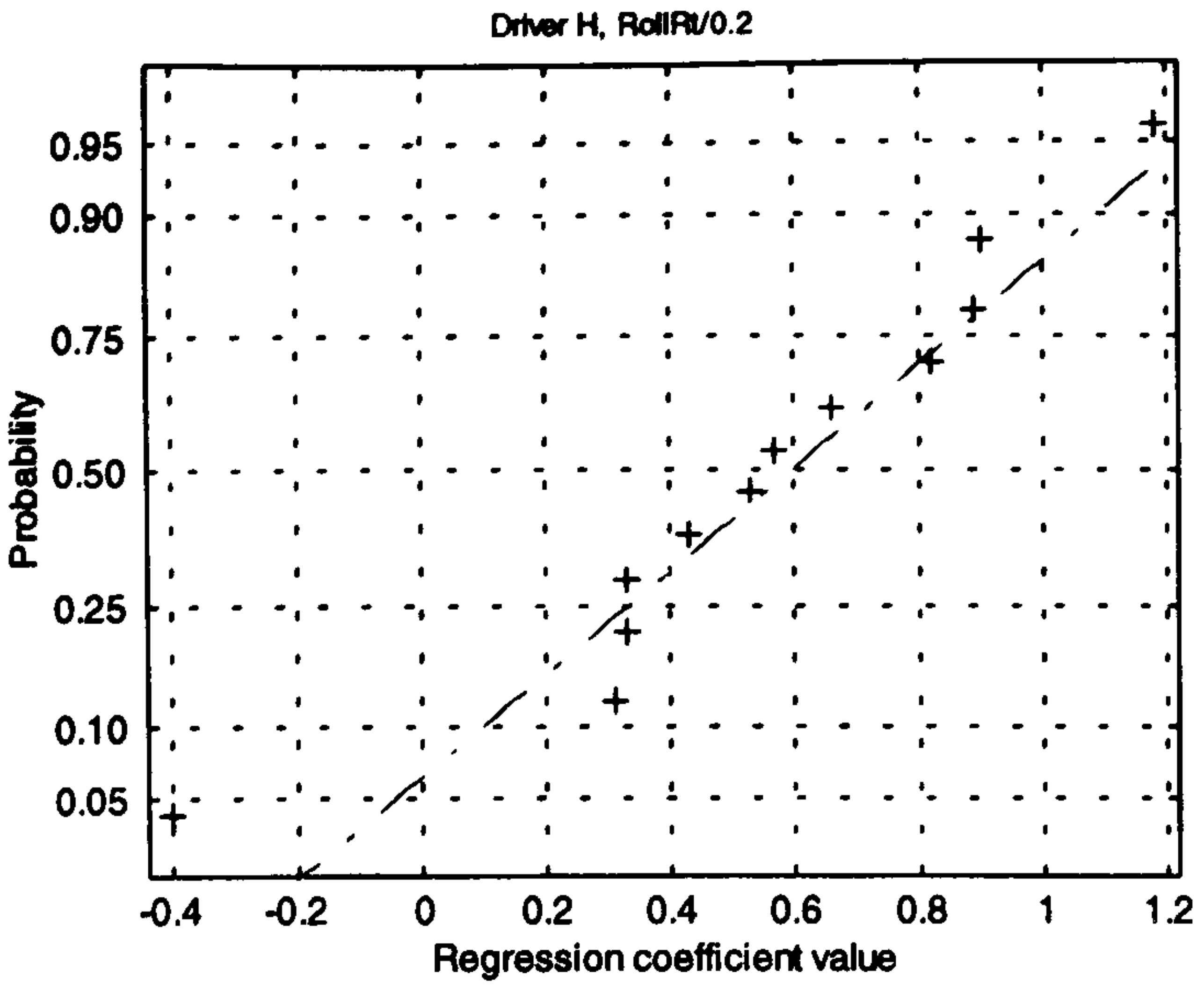


Figure 6E-30 Distribution of *Storq/0.6* regression coefficients, Driver H

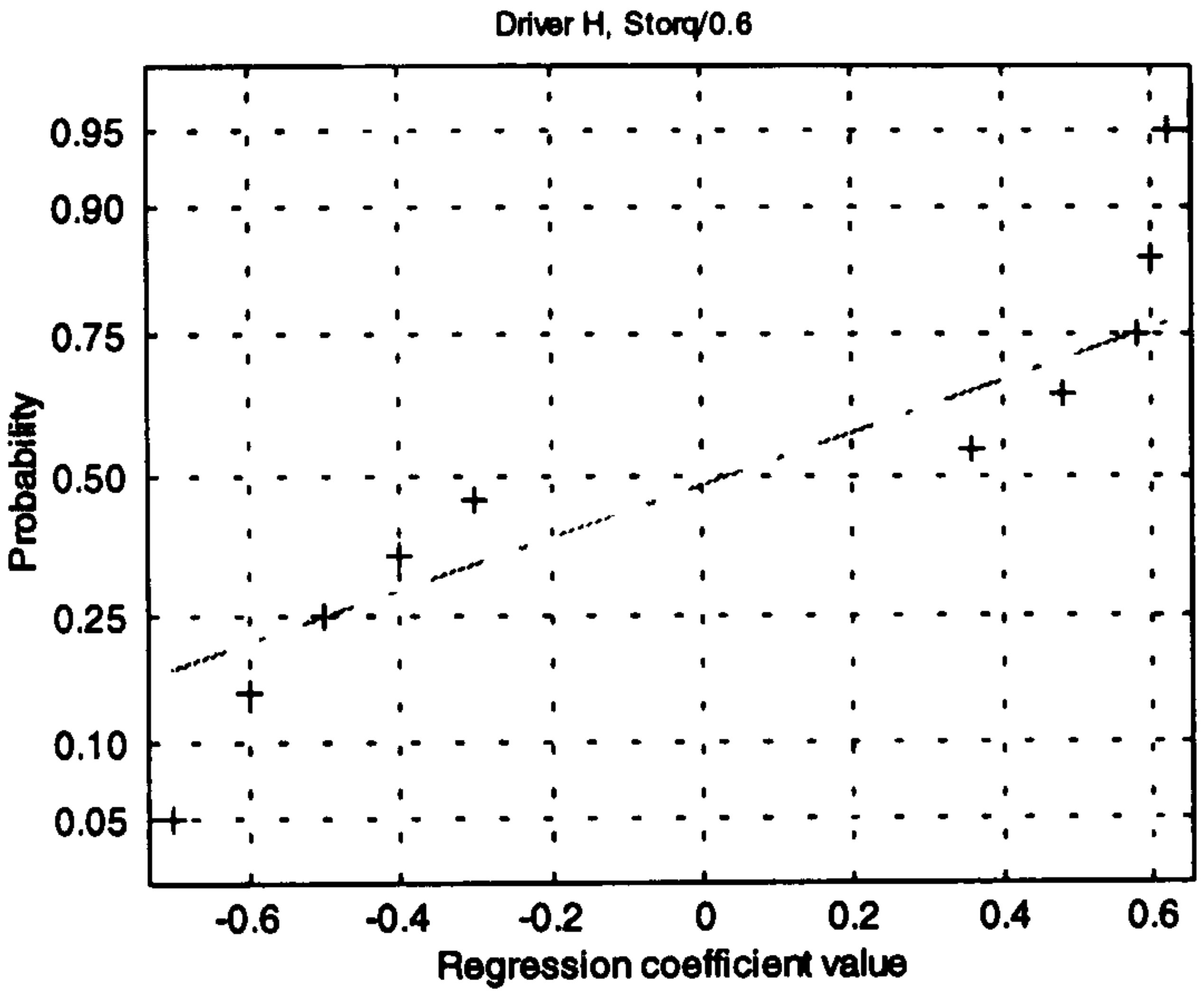


Figure 6E-31 Distribution of *d(storq)/0.4* regression coefficients, Driver H

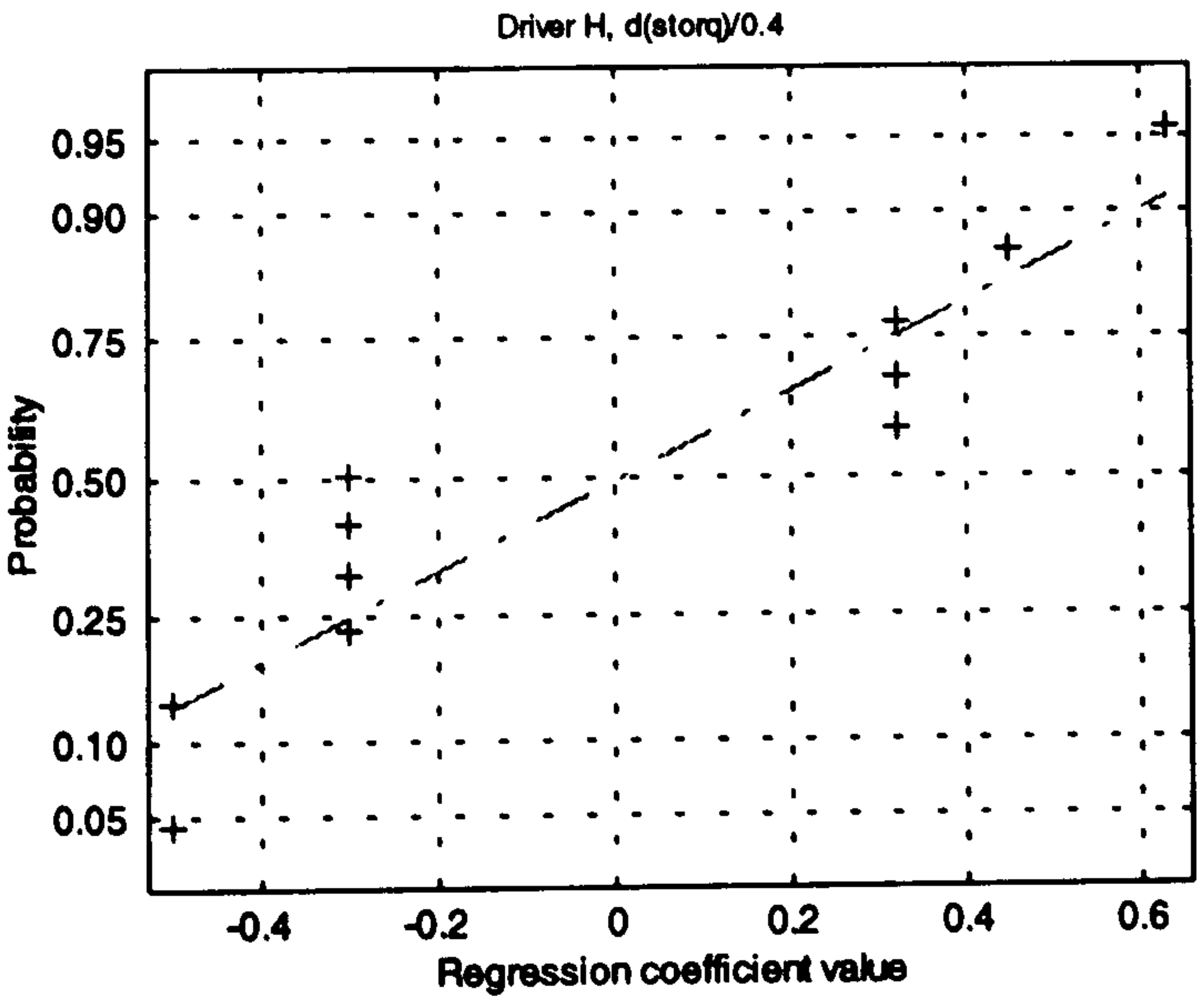
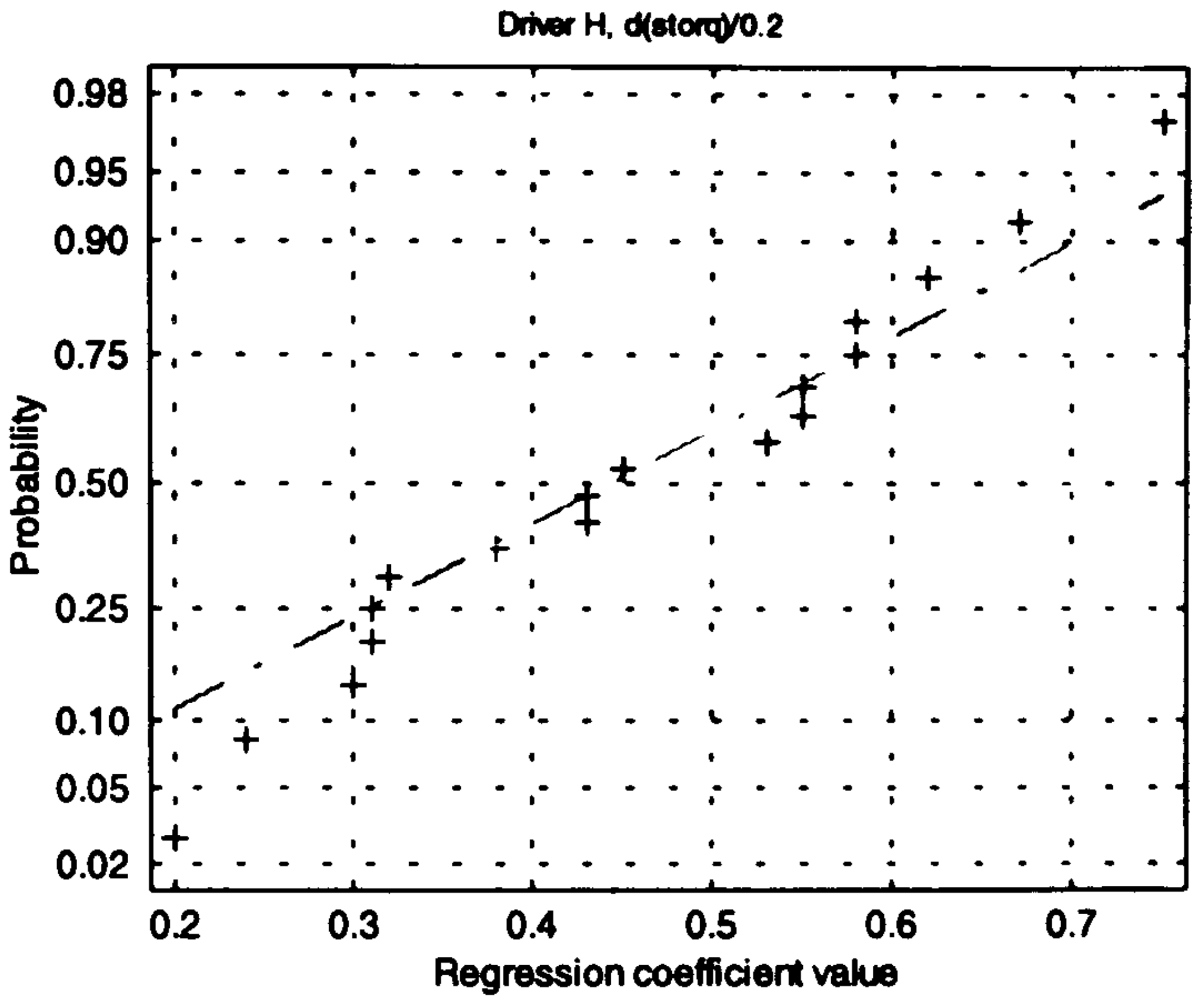


Figure 6E-32 Distribution of *d(storq)/0.2* regression coefficients, Driver H



Appendix 6F Mean Effect Of Metrics On All Drivers

Metric	Mean Effect	Lower 95% Confidence Interval	Upper 95% Confidence Interval
LatacRespTime/0.6	-0.95	-2.8559	0.9559
YawRtRespTime/0.2	-0.83	-1.3101	-0.3499
LatacGain/0.4	-0.7667	-2.4608	0.9275
StMeanRespTime/0.6	-0.7453	-1.511	0.0204
YawRtRespTime/0.6	-0.6	-1.3452	0.1452
YawGain/0.7	-0.5773	-0.6781	-0.4765
SteerGain/0.4	-0.5		
YawGain/0.4	-0.454	-0.6516	-0.2563
d(hw)/0.2	-0.3983	-0.9696	0.173
Storq/0.2	-0.3224	-0.4997	-0.1451
YawPhase/0.4	-0.3095	-0.6518	0.0329
YawRt/0.2	-0.2778	-0.5942	0.0387
LatacRespTime/0.2	-0.2725	-0.7226	0.1776
roll angle/0.2	-0.2132	-0.5188	0.0923
d(sslip)/0.2	-0.2105	-0.6028	0.1819
StorqRespTime/0.2	-0.19	-1.449	1.069
LataccGain/0.7	-0.1558	-0.6514	0.3397
SteerGain/1.0	-0.155	-0.3425	0.0325
Storq/0.6	-0.1549	-0.4588	0.1491
RollRt/0.6	-0.1514	-0.6688	0.3659
StMeanRespTime/0.2	-0.1457	-0.5772	0.2857
SteerGain/0.7	-0.1186	-0.4996	0.2625
roll angle/0.4	-0.1162	-0.458	0.2257
StMean/0.2	-0.1141	-0.4561	0.2279
d(fslip)/0.2	-0.0845	-0.4869	0.3178
d(storq)/0.2	-0.0462	-0.278	0.1856
d(fslip)/0.4	0.0386	-0.3171	0.3943
d(storq)/0.4	0.0463	-0.2181	0.3108
YawRt/0.6	0.0815	-0.1321	0.2951
RollRtRespTime/0.6	0.091	-0.1595	0.3415
RollRt/0.2	0.141	-0.1707	0.4527
LataccPhase/0.4	0.1767	-0.5329	0.8862
SteerPhase/0.7	0.1938	-0.8096	1.1971
LataccPhase/1.0	0.1967	-1.5237	1.917
YawGain/1.0	0.205	-0.3654	0.7754
YawPhase/1.0	0.2345	-0.1235	0.5926
d(sslip)/0.4	0.2562	-0.0269	0.5392
RollRtRespTime/0.2	0.2989	-0.0479	0.6457
SteerPhase/1.0	0.3139	-0.1644	0.7923
LataccGain/1.0	0.4377	0.3202	0.5551
SteerPhase/0.4	0.553	0.3348	0.7712
d(hw)/0.4	0.62		
StMean/0.6	0.895	-0.2365	2.0265
YawPhase/0.7	1.58		
LataccPhase/0.7			
StorqRespTime/0.6			