# Crosswind Sensitivity of Passenger Cars and the Influence of Chassis

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**Abstract:**

Results of vehicle crosswind research involving both full-scale driver-vehicle tests and associated analyses are presented. The paper focuses on experimental crosswind testing of several different vehicle configurations and a group of seven drivers. Atest procedure, which utilized wind-generating fans arranged in alternating directions to provide a crosswind "gauntlet", is introduced and described. Driver preferences for certain basic chassis and aerodynamic properties aredemonstrated and linked to elementary system responses measured during the crosswind gauntlet tests. Based on these experimental findings and confirming analytical results, a two-stage vehicle design process is then recommended for predicting and analysing the crosswind sensitivity of a particular vehicle or new design.

**Keywords:** (A) vehicle dynamics considerations (e.g., weight distribution, tire, and suspension characteristics), (B) vehicle aerodynamic properties, (C) steering system characteristics (most notably steering system compliance, friction and torque assists), and (D) driver closed-loop steering behaviour.

## 1. Introduction

This paper is based on recent findings from a vehicle aerodynamics research project [1]sponsored by the Chrysler Motors Corporation at the University of Michigan Transportation Research Institute. The general thrust of that research was directed at the crosswind sensitivity of passenger cars, and specifically, the influence and interaction of chassis characteristics. The key elements considered in that study are outlined in Figure 1 and included: (A) vehicle dynamics considerations (e.g., weight distribution, tire, and suspension characteristics), (B) vehicle aerodynamic properties, (C) steering system characteristics (most notably steering system compliance, friction and torque assists), and (D) driver closed-loop steering behaviour and preferences obtained from experimental crosswind tests. This paper focuses on the experimental crosswind testing conducted during the project using several different vehicle configurations and a group of seven drivers. It reports on driver preferences for certain basic chassis and aerodynamic properties and demonstrates a linkage to elementary system responses measured during those crosswind tests.

The paper begins with an examination of previous research findings related tocrosswind sensitivity of passenger cars. A computer model, developed under this research program, is then briefly described. The use of that model at different stages of the research helped to identify and probe certain vehicle-related mechanisms identified as possibly significant contributors to the issue of crosswind sensitivity. As will be seen, the ability of the model to predict basic dynamic behaviour patterns, observed in experimental measurements of driver-vehicle systems operating in crosswinds, is an important factor for recommending it as a tool within the vehicle design process. The basis of the conclusions of this paper, however, rest upon experimental measurements and evaluations of a group of seven test drivers operating seven distinctly different vehicle configurations during nearly identical crosswind conditions. The crosswind tests were conducted using a set of eight fans (arranged in an alternating direction over a length of several hundred feet) to approximate a random-like crosswind "gauntlet" driven repeatedly by each driver.

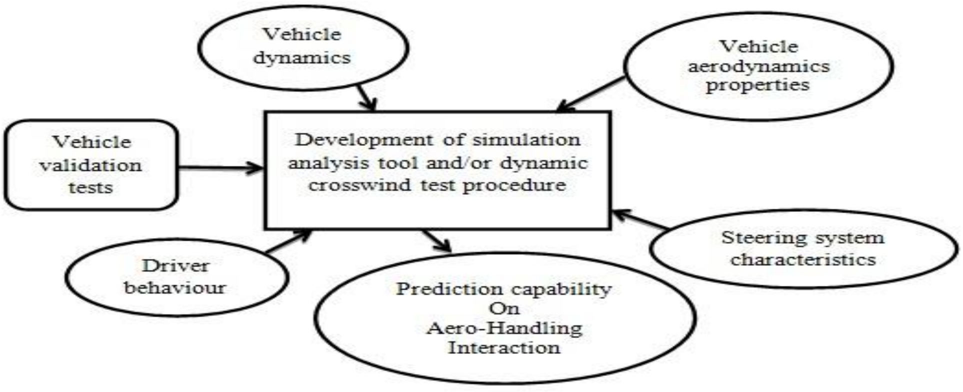



**Fig. 1. Key Elements in Vehicle Crosswind Stability.**

## 2. Previous Research

The trends during the last decade or so to lighter, more fuel efficient cars in response to changing energy policies, combined with more recent trends toward higher performance passenger cars, have led to increased interest in aerodynamic styling as a means for providing low drag configurations and for mitigating any high-speed crosswind sensitivities. In many cases, attempts at streamlining passenger cars for minimizing drag have led to unwanted increases in crosswind sensitivity. As noted in such comprehensive texts such as Hucho [2]and Scibor-Rylski [3],this tradeoff was observed as early as **1933** by Kamm [4]out of which arose the well-known truncated rear-end design ("Kamm-back") which helped to offset much of the crosswind susceptibility introduced from streamlining. More recent observations, such as Kohri and Kataoka [5]or Hucho [2],have contributed to improved understandings on the subtle influences relating to A-and C-pillar styling designs and their importance in affecting crosswind sensitivity of passenger cars. Studies such as Noguchi [6]have also noted the importanceof certain suspension properties (e.g., roll steer and lateral force compliances) as elements not to be discounted when considering a vehicle's crosswind sensitivity. Other studies relating to crosswind sensitivity of passenger cars have been compiled in such documents as Kobayashi and Kitoh [7],which was primarily concerned with literature related to the crosswind sensitivity of light weight cars.

### Wind Measurement Technology

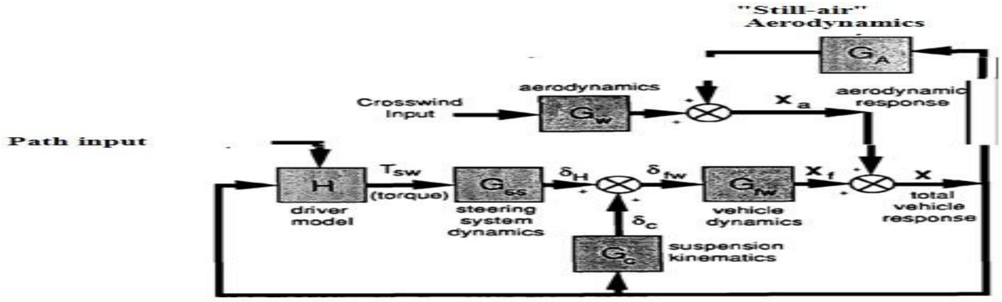
In addition to the studies cited above, a number of technological advancements in on-board wind measurement capabilities have also occurred in the last two decades which have helped to promote further understanding of the nature of crosswinds acting on vehicles in open areas, as well as in the vicinity of fixed roadway objects and other moving vehicles. Smith in 1972 [8] described a MIRA wind measurement device (utilizing anemometers) and its use in measuring a number of different crosswind profiles. More recently, Tran [9] presented a pressure transducer system for measuring the wind forces and moments acting on a vehicle by recording the pressures at approximately 10 points along the circumference of a vehicle and then combining this information with a uniform flow model. A wind transducer developed by the Chrysler Corporation aerodynamics department utilizing a strain-gauged sphere in combination with an inertial mass compensating accelerometer, is described by Pointer in [10]. This latter device was also used during the crosswind testing described subsequently in this paper.

## 3. A Driver-Vehicle Crosswind Model

A computer model for predicting the interaction between vehicle and driver during crosswind conditions is introduced and outlined briefly in this section. Its use as an advanced tool that can be used in place of, or in conjunction with, certain types of dynamic random crosswind test procedures is subsequently being recommended as part of a total crosswind sensitivity design process. The model was developed during this research and was used to help identify and separate different mechanisms of the driver-vehicle system contributing significantly to the crosswind sensitivity of the system. Figure 2shows a block diagram outlining the principal components of the crosswind driver/vehicle model. The technical details of the computer model can be found in Sayers et a1 [11].The four primary components of the model are described briefly in the following.

### Vehicle Model

The vehicle model is characterized by five degrees of freedom for the sprung mass, constant forward speed, and massless suspension/wheel assemblies. Tire and suspension compliances are also included. Tire lateral force is treated as largely linear except for cornering stiffness dependency on vertical load. The basic dynamics of the vehicle are very similar to that developed by Segel [12].High speed test data, collected during the course of the aerodynamic crosswind stability research program at UMTRI [1],were used to validate the baseline model behaviour through direct comparisons with model predictions. Test track handling measurements and aerodynamic wind tunnel measurements of a baseline passenger car, in several different aerodynamic configurations, were conducted at nominal speeds of 50 and 100 mph to validate the model. As part of the model validation process, a stable platform and a variety of transducers were used to measure all body motions. Steering wheel displacement and torque measurements, front wheel rotations, and other steering system functions (power boost pressures, pitman arm motion, and tie rod forces) were also recorded and utilized in the model validation.



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| $\delta_H$ | front wheel angle contribution from steering command and compliance |
| $\delta_C$ | front wheel angle contribution from suspension kinematics |
| $\delta_{fw}$ | total front wheel steer angle |
| $X_f$ | non-aerodynamic vehicle response |

**Fig. 2. Chrysler/UMTRI Crosswind Vehicle Model.**

## 4. Experimental Crosswind Measurements

The results of experimental crosswind tests of driver-vehicle systems conducted during the research program are presented in this section. All full-scale testing was performed on the vehicle dynamics facility at the Chrysler Proving Grounds in Chelsea, Michigan. The vehicle crosswind testing results were obtained with the use of eight U.S. Government-owned wind generating fans described in detail by Klein and Jex in [13].

The use of fan-generated crosswinds in this research program was based upon several needs. One need was to obtain crosswinds of sufficient magnitude that the test drivers would be given a definite subjective impression of the different vehicle configurations being driven, and, that would also produce a system response that could be readily measured by on-board instrumentation. Test speeds of 90-100 mph were selected so that the aerodynamic inputs provided by sizeable crosswinds (25 mph or so) would still permit a linear-regime characterization of the vehicle aerodynamics. A second need was to have available a generally repeatable set of crosswind conditions so that different drivers could be exposed to more or less the same crosswind experiences at widely varying times during the test program. And finally, there was the practical need to be able to schedule test drivers on a regular basis and be guaranteed that sufficient crosswind test conditions would be available.

Against this back-drop of perceived needs was the clear observation, wellreported in the literature, that fan-generated crosswinds were generally insufficient for obtaining reliable subjective evaluations from test drivers. Since nearly all of the previous uses of fans for subjective evaluations were for short duration drive-by scenarios, in which drivers attempted to regulate the lateral path in response to a short-term pulse of crosswind, a different approach was considered for this research program. It was decided that the traditional, closely-grouped fan arrangement, which provides a short-duration pulse of crosswind, would be used only to evaluate the passive (non-driver) vehicle response. Anew arrangement of the fans, in the form of a crosswind "gauntlet" course, would be used, instead, to expose the test drivers to the fan-generated crosswinds over a longer period of time for collecting their subjective evaluations.

**Test Procedures**

Two basic test maneuverers were used to evaluate the response of the various driver-vehicle configurations. The first maneuverer was a fixed steering wheel drive-by of a constant pulse of fan-generated crosswind. It was used to primarily characterize and verify differences in the passive crosswind behaviour of the different vehicle configurations. The second maneuverer, serving to evaluate the active (driver and vehicle) crosswind system behaviour, employed the same fans spread out over a longer distance but arranged in alternating directions. Active steering for path regulation by each driver was required during this latter test. All tests were conducted for vehicle speeds of 90-100 mph. Further descriptions of these two test procedures follow.

***Crosswind** Pulse. This maneuverer was conducted with the eight fan units grouped togetherand facing perpendicular to the test track as seen in Figure 3. Fixed steering wheel drive-by tests were then performed for each vehicle configuration to evaluate their respective passive (no regulatory driver steering) wind behaviour. Each test vehicle was driven in a straight line at 100 mph from the ambient environment past the fans whereupon it encountered an approximately constant 25 mph crosswind for a period of nearly 0.7 seconds. A pulse-like vehicle response due to entering and then exiting the crosswind stream was recorded by on-board instrumentation. The resulting peak yaw rate and lateral acceleration responses observed for each vehicle configuration were then used to confirm that significant and distinctly measurable differences in the vehicle aerodynamic andchassis configurations were

**Vehicle trajectory**

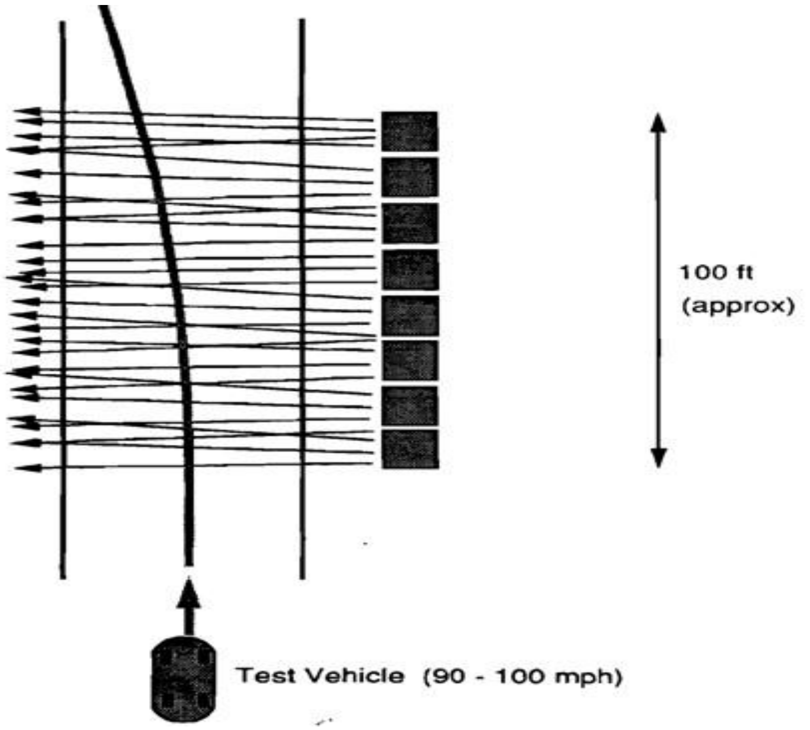


**Fig. 3. Crosswind Pulse, Fixed Steering Wheel Test.**

present in the passive crosswind behaviour of eachvehicle. (The short duration of the crosswind pulse at these speeds did not permitthe vehicle to fully establish itself in a steady-state turning condition.)

***Crosswind "Gauntlet" Maneuvre.** For this set of tests, the eight fan units were located, in an alternating manner, along opposite sides of a straight-line testcourse (single lane width) and distributed over a longitudinal travel distance of approximately 350 feet. See Figure 4. This arrangement presented the driver-vehicle system with a series of fluctuating pulses of crosswind from one side and then the other in a repeating sequence. The spacing between the fans was approximately 52 feet. Wind output from each fan was set at an approximate level of 25 mph and the test course was driven at speeds of 90 to 100 mph. An inner lane width of approximately 8 to 9 feet was defined by a series of traffic cones along the centre of the course in order to require each driver to regulate the vehicle path (without undue demand) within those bounds during traversal of the crosswind course. All of the subjective evaluations collected during the test program were obtained from this crosswind test procedure.

Impressions of several drivers who drove past the fans in both arrangements(Crosswind Pulse versus the Crosswind Gauntlet) noted significant differences. The closely grouped pulse arrangement had a very small effect on a driver's subjective and objective response as the crosswind pulse was encountered. The primary inputs to the drivers were reported to be sound (from wind noise) and a mild change in direction as the fans were passed. Drivers also commented that the experience was too brief. In contrast, the driving experience through the crosswind gauntlet generally made a much'stronger impression on the test drivers. This was most likely due to the longer length of time of crosswind exposure provided by the gauntlet course and significantly increased driver-vehicle system responses during this test. For the same levels of fan wind output, the gauntlet course produced noticeably amplified system responses compared to those obtained from simple drive-bys of the closely-spaced pulse arrangement. The alternating pulses and their input frequency during the gauntlet test produced a more resonating dynamic response that further contributed to subjective driver impressions. The on-board measurements, as well as simple visual observation of the different vehicle configurations traversing the gauntlet, confirmed the amplifying qualities of the gauntlet test procedure. As an example, in a few of the worst-case vehicle configurations, peak lateral accelerations greater than 0.6g were recorded at the driver head position and more than 0.45g's on the stabilized platform. Levels approximately half these would have been recorded in the crosswind pulse test for the same fan output. Drivers Seven different drivers were utilized in the test program to provide subjective evaluations of each of the vehicle configurations during the crosswind gauntlettests. Objective measurements of the total driver-vehicle system responses werealso collected for four of these test drivers to obtain representative system responses during the gauntlet tests. All of the drivers were males with backgrounds as engineers or technicians ranging in age from 25 to 55. All drivers, but one, were associated to varying degree with the crosswind research program. (Other drivers also participated intermittently during the testing but were not included in these results because of not having driven each of the different vehicle configurations, or, because their chosen speeds fell significantly outside the nominal 90-100 mph range.)

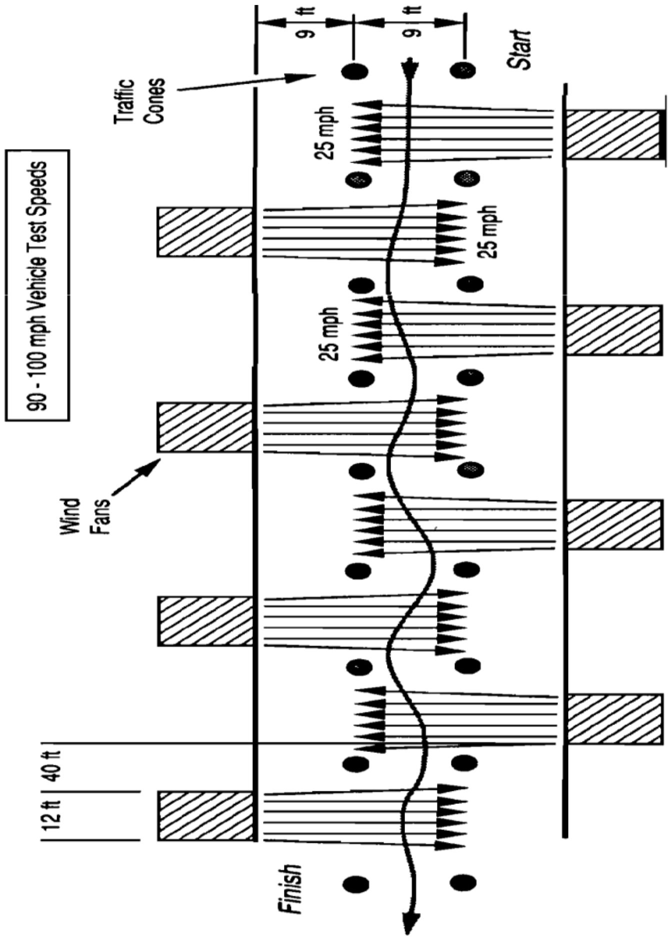


**Fig. 4. Crosswind Gauntlet Test Course Used in Study**

## 5. Conclusions

The results of the full-scale driver-vehicle crosswind tests presented above, in combination with static turning analyses of vehicles in constant crosswinds and more complete dynamic crosswind simulations, suggest the following conclusions:

- A vehicle's static turning response due to a constant crosswind input and fixed steering wheel angle is a useful, first-stage predictor of driver's likely subjective evaluation of a vehicle's crosswind sensitivity.
- That same static turning measure will also frequently predict a vehicle's likely ranking of RMS responses obtained during dynamic crosswind maneuvers.
- A more reliable and accurate method for predicting subjective evaluations ofvehicle crosswind sensitivity is with RMS yaw rate values obtained from fullscale testing or comprehensive dynamic simulation of driver-vehicle systems during dynamic, random-like or natural crosswind conditions.
- Increased roll motion due to decreased suspension roll stiffness was associated with lower driver subjective evaluations of vehicle crosswind sensitivity.
- At vehicle speeds of 90-100 mph, variations in fore-aft weight distributionplayed as important a role as comparable variations in aerodynamic canter-of-pressurelocation in influencing both subjective and objective evaluations ofvehicle crosswind sensitivity.
- A two-stage vehicle design process is recommended for analysing the crosswind sensitivity of a potential vehicle or new design: (1) A preliminaryscreening of candidate vehicle designs for crosswind sensitivity, based uponthe simplified statics analysis of Equations (3) or (4),should first be conductedto screen out ineligible candidate designs having unsuitable vehicle properties(e.g., relative locations of mass canter, neutral steer point, and aerodynamicCP that promote high passive crosswind sensitivity). (2) conduct a more in-depthand comprehensive analysis of the "final round" candidate designs usingdynamic analysis (such as the crosswind model described above). The dynamicmodel should employ random-like, natural crosswind inputs to examine likelydriver-vehicle responses to systematic variations of vehicle chassis properties(suspension, steering system, and weight distributions particularly) and differentaerodynamic designs. RMS values of system responses (e.g., yaw rate) can beused to evaluate the influence of alternate designs.

- The dynamic crosswind model developed under this work can be used to further explain and analyse the crosswind sensitivity of driver-vehicle systems in a dynamic context, particularly for driving scenarios involving active driver steering control during representative random crosswind conditions. Its use as a tool to systematically examine the influences of vehicle sub-components on crosswind stability is especially useful.
- Further man-machine research into likely driver preferences regarding body roll motion and driver-cantered motion experiences deriving from aerodynamic crosswind forces and moments is recommended.
- Re-examination by other parties of the crosswind gauntlet test procedure (orsimilar procedures) utilizing wind-generating fans is also recommended. Basedon the experiences reported here, this type of crosswind test procedure appearsto offer significant promise for collecting driver-based subjective data of vehiclecrosswind sensitivities. Whether such procedures can effectively replacenatural crosswind testing as a reliable method for collecting driver subjectiveinformation remains to be seen.

## References:

[1]. Vehicle Crosswind Stability. Chrysler Challenge Fund Project - #2000533, UMTRI, Sponsored by the Chrysler Motors Corporation, 1987-1990.
[2]. W. Hucho, **Aerodynamics of Road Vehicles.** Butterworths, 1987.
[3]. A. J. Scibor-Rylski, **Road Vehicle Aerodynamics.** Revised by D.M. Sykes ed. Wiley, New York, 1984.
[4]. W. Kamm, Anforderungen an Kraftwagen bei Dauerfahrten. ZVDI. vol77, 1933.
[5]. I. Kohri and T. Kataoka, Research on Improvement of Cross-Wind Properties of Passenger Cars. **JSAEReview,** Vol. 10, No. 3, 1989. pp. 46-51.
[6]. H. Noguchi, Crosswind Stability and Suspension Properties. MIRA Translation by G. Wood, Rept No. Translation 2/87. 1987.
**[7].** T. Kobayashi and K. Kitoh, Cross-Wind Effects and the Dynamics of Light Cars. **Int. J. of Vehicle Design.** Vol. No. Special Publication SP3, 1983. pp. 142-157.
[8]. J. P. Smith. Wind Gusts Measured on High-Speed Roads. The Motor Industry Research Association, Rept No. 197217, May, 1972.
[9]. V. T. Tran, Determining the Wind Forces and Moments Acting on Vehicles by Means of Pressure Transducers. SAE Paper No. 900313, 1990.
[10]. J. D. Pointer, On-Road Calibration of the Dynamic Pressure Vector System. 10/17/88. Memorandum to G. Romberg. Chrysler Motors Corporation. 1988.
[11]. M. Sayers, C. C. MacAdam and Y. Guy, Chrysler/UMTRI Wind-Steer Vehicle Simulation. User's Manual, Version 1.0, vols I and 11, Report No. UMTRI-89-811-2, 1989.
[12]. L. Segel, On the Lateral Stability and Control of the Automobile as Influenced by the Dynamics of the Steering System. **Journal Engineering for Industry,** Vol. **66,** No. 8, 1966. pp.
[13]. R. H. Klein and H. R. Jex, Development and Calibration of an Aerodynamic Disturbance Test Facility. SAE Paper No. 800143, 1980.