UMTRI-85-7

REPORT ON THE STATUS OF ORGANIZATIONS WORKING IN THE FIELD OF VEHICLE HANDLING

L. SEGEL
A. GRIMM

FEBRUARY 1985

UMTRI The University of Michigan Transportation Research Institute

Technical Report Documentation Page

1. Report No. UMTRI-85-7	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle REPORT ON THE STATUS OF ORGANIZATIONS WORKING IN THE FIELD OF VEHICLE HANDLING		5. Report Date February 1985
		6. Performing Organization Code
7. Author(s) L. Segel, A. Grimm		8. Performing Organization Report No. UMTRI-85-7
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, Michigan		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address		13. Type of Report and Period Covered Final
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Organizations in the public and private sectors, both non-profit and for-profit (including motor vehicle and tire manufacturing firms) are identified and discussed with respect to their capabilities for (1) conducting investigations in the field of vehicle handling and (2) ensuring that a given motor car meets or exceeds a specified performance criterion.

17. Key Words vehicle handling studies; research resources; survey of capabilities; research capability assessment	18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price

PREFACE

The bulk of the data and documents used to produce this report were collected and provided by Mrs. A. Grimm, who is Coordinator, Research Information and Publications, University of Michigan Transportation Research Institute (UMTRI). The report, itself, was prepared by Mr. L. Segel, who is Head of UMTRI's Engineering Research Division and is a Professor of Mechanical Engineering and Applied Mechanics in The University of Michigan's College of Engineering

CONTENTS

I INTRODUCTION

The purpose of this document is to assemble, on behalf of the General Motors Corporation, information and data (residing within the files of the Transportation Research Institute of The University of Michigan) regarding organizations which have a capability for conducting analytical and experimental studies in the field of motor vehicle handling. To the extent that it has proved feasible to do so, this survey is international in scope. However, no attempt is made to interpret "motor vehicle" in its broadest sense; rather, emphasis is given to the motor car.

It is the author's understanding that General Motors has a twofold objective: (1) it would like to compile a comprehensive picture of the capabilities of organizations which constitute its competition in the automotive world; (2) it would like to obtain a comprehensive view of research organizations and personnel who constitute an external resource in the field of vehicle handling. This objective is indeed ambitious and to satisfy this objective, in an ideal manner, the following types of information should be obtained:

1) descriptive information
2) number of staff
3) computer facilities
4) test facilities
5) office and laboratory area
6) budget
7) billing rates
8) etc.

In practice, we found that our data resources (e.g., personal files, UMTRI Library) were not sufficiently detailed to provide information on each of the above listed items for each organization that is identified and surveyed in this report. In fact, the information gaps with respect to each of these objective entities are sufficiently large that the idea of presenting this survey in a tabular form was abandoned. Rather, the report consists of a summary narrative which directs the reader to more detailed information, as presented in a large number of appendices. For the benefit of the reader, the report opens with an "executive summary" which attempts to summarize, as briefly as possible, the status of the engineering and research enterprise which is currently addressing the topic of vehicle handling. This summary is followed by a narrative which is organized into seven categories, namely:

1.0 Motor Vehicle Manufacturers
2.0 Tire Manufacturers
3.0 University Affiliated Research Institutes
4.0 Private Research Organizations
5.0 Research Organizations Created by and Supported by the Motor Vehicle Industry
6.0 National Laboratories
7.0 Individual Academicians

The report concludes with copies of material selected both from personal files and the UMTRI Library, as called out in the preceding narrative.

II EXECUTIVE SUMMARY

The identification of resources in the field of vehicle handling is difficult, particularly within the private sector. In general, three observations appear to be worthy of being recorded here. One is that motor vehicle firms outside the U.S. appear to have different criteria than U.S. firms for deciding how much capital should be invested in laboratories and facilities which relate to obtaining a better understanding of the physics of the motor vehicle. In general, the European engineer and the Japanese engineer seem to be more generously supported than their typical U.S. counterparts. Whether this is a reflection of differences in U.S. and non-U.S. markets regarding customer demands for certain performance characteristics or a reflection of managerial and business philosophies is not clear to this writer.

The second observation is that the education of engineers in Europe differs from that of engineers elsewhere (i.e., in the U.S. and Japan), in that European educational practices encompass much more specialized training in automotive engineering and work towards producing a practitioner of the engineering profession rather than a graduate who has basic skills and knowledge. This practice is carried to the extreme in Germany where it is rather common for engineering students to obtain a doctorate in automotive engineering and for companies to utilize such graduates for providing engineering leadership in the managerial and executive ranks. Whether there are long-term implications of these differences in educational policies in regard to the competitive stance of G.M. vis-a-vis its European competition constitutes a question that is not answerable without serious inquiry and reflection.

Finally, it is possible to observe that vehicle handling research in the U.S. tended to be exclusively pursued within the private sector until the time that the motor vehicle industry became a regulated industry. Such was not the case in Europe, where technical universities provided a scholarly ambiance for research involving the motor vehicle, with ride, handling, and braking issues being addressed by academicians as well as engineers in the private sector. Further, it must be noted that the motor vehicle production enterprise was never as laissez faire in Europe as it was in the U.S. The historical record shows that motor vehicle design experienced regulatory constraints in Europe and Japan long before regulatory constraints were introduced in the U.S. on a national scale.

With regard to the possibilities of engaging an outside organization to provide external support on a project which requires expertise or test capabilities in the area of vehicle handling, the opportunities in the U.S. are different from those which exist abroad. Specifically, one finds that there are very few university-affiliated research organizations in the U.S., but, on the other hand, there exists a modest number of private research organizations. In Europe, however, there is a substantial number of university-affiliated research organizations, but a much smaller number of private firms. On the other hand, these private firms (e.g., Lotus and Porsche) are able to provide services that could not be matched by the remainder of the research community.

III INFORMATION SUMMARY BY CATEGORY

1.0 MOTOR VEHICLE MANUFACTURERS

Identifying the resources devoted by motor vehicle manufacturers to research, design, and development activities dedicated to achieving a product with good handling characteristics is almost impossible. Further, to obtain insight as to the extent to which the various motor vehicle manufacturing firms organize their engineering activities to ensure that adequate attention is given to handling properties is most difficult. Accordingly, most of what follows is based on a minimal amount of hard supporting data and tends to be rather anecdotal in nature.

1.1 Domestic

1.1.1 Ford Motor Company. Ford engineering personnel concerned with handling issues appear to be scattered throughout the organization and it is difficult to identify where the current and advanced engineering responsibilities lie. At the research end of the spectrum, it appears that their concern for various aspects of vehicle dynamic behavior (including ride) resides within a so-called "Vehicle Concepts Research Laboratory." This Laboratory includes three departments, viz., "Vehicle Methods and Components," "Vehicle Concepts," and "Vehicle Systems." The Laboratory is headed by a Dr. C.L. Magee whose specialized background is in the mechanics of structures. Reporting to the head of the Vehicle Methods and Components Department, however, are a number of engineers who could be labeled as "vehicle dynamicists" and who are concerned with ride and handling issues. Facts related to number of personnel, computer facilities, laboratory facilities, etc., are not available.

Because of UMTRI's strong highway safety orientation, we have been able to perceive that a portion of Ford's interest in vehicle handling resides within their "Automotive Safety Office" (Environmental and Safety Engineering Staff).

Although this group does experimental work requiring the measurement of vehicle responses to steering, they apparently have not seen fit to invest in a directional response measurement package, since they have elected to rent UMTRI's Humphrey unit on numerous occasions.

With respect to Ford's proving ground test facilities, it is known that their Arizona Proving Ground (see Appendix A) contains a 17-acre asphalt-paved surface for purposes of vehicle dynamics testing. We have heard Ford personnel refer to a handling track and a circular "skid pad" at their small test facility adjacent to their engineering center in Dearborn. It is possible that this latter facility has been described in an SAE publication, but we have been unable to locate such a document.

1.1.2 Chrysler Corporation. The absence of any organizational breakdown in their corporate telephone directory makes Chrysler even a bigger enigma than Ford. It is known that there are vehicle dynamics personnel both at the Proving Ground in Chelsea and at the engineering offices in Highland Park. However, the manner in which Chrysler divides up current engineering, advanced engineering, and longer-term research endeavors is not evident. The Company does appear to be highly centralized and apparently has all of its technical support personnel (including computing facilities plus other laboratories) under the direction of one manager (R. Brauberger). A recent meeting with seven Chrysler staff members gave UMTRI the impression that Chrysler goes to considerable effort to ensure that their staff remain abreast of the latest technological developments which impact on product design and manufacturing methods. It appears that Chrysler has been engaged in a major expansion of their central computing facilities which consists of CDC equipment.

Their vehicle dynamic test facility (see Appendix B) has an area of 18 acres. In general, this proving-ground facility appears to be in excess of the firm's needs, with the result that Chrysler makes this facility available to outside parties at rates quoted in an established fee schedule. (UMTRI, for example, has made use of their vehicle dynamics test area on numerous occasions.)

1.1.3 American Motors Corporation. Since no organization chart could be uncovered and the telephone directory has no departmental breakdown, we are unable to say anything substantive about the extent to which American Motors devotes resources to vehicle handling matters. Rather than speculate on this issue, we merely provide, in Appendix C, a layout of the American Motors Proving Ground in Burlington, Wisconsin, on which a skid pad and a ride and handling loop are identified.

1.2 European

1.2.1 Volkswagenwerk AG. The technical literature gives considerable evidence of VW's substantial interest in, and involvement with, vehicle handling topics. Their efforts in developing a driving simulator are well known and, given that Dr. Ernst Fiala (formerly, the professor in charge of the automotive engineering program at the Technical University of Berlin) has risen to the highest echelons of Company management, it is not surprising that research endeavors have been given a high priority.

Currently, the director of VW's Research and Development Division is Dr. Ulrich Seiffert. In 1977, at the ISATA Symposium on Automotive Technology and Automation, he described some of the facilities which VW has at their research and development center in Wolfsburg. It is clear that VW has a test track and a wind tunnel in close proximity to its safety test center, R & D test area, and "prototype factory." Of particular interest, is their vehicle dynamics test area (500 meters by 500 meters) which they claim makes it the largest facility of its kind in Europe. A detailed description of this facility, together with a description of the equipment which enables them to perform handling tests by remote control, is given in Appendix D. Data on number of staff devoted to vehicle handling engineering and/or research activities are not available.

1.2.2 Daimler Benz AG. The instrumentation and measurement methods used by Daimler Benz to evaluate the handling of automobiles is outlined in a lecture (see Appendix E) which was given by Dr. Adam Zomotor in 1981 at the International Center for Mechanical Sciences (Udine, Italy). In addition to this information, which can be directly compared with the methods employed by GM, we can note that Daimler Benz has a complement of wind tunnels (including a tunnel* large enough to conduct tests on full-scale automobiles) and crosswind test facilities (plus special pavement-imbedded instrumentation) to measure the lateral drift of a car in a sidewind. Details (in German) relating to this latter test capability will be found in Appendix F.

1.2.3 Volvo Car Corporation. No specific information has been found which speaks either to staff or facilities devoted to handling engineering and research by Volvo. It can only be noted that Volvo has seen fit to devote significant energies to vehicle handling studies, as have been disclosed and presented by Mr. Friedrich Jacksh at ESV conferences and in papers published in various journals.

Evidence also exists to indicate that the truck design and manufacturing portion of the Volvo group has been, and is currently, concerned with truck ride and handling issues. However, no definitive or objective statements can be made.

1.2.4 Saab-Scania AB. The variety and scope of Saab-Scania's product line suggest that it is, relatively speaking, a high-tech organization

---

*A. Kuhn, "Der grosse Daimler Benz Windkanal," ATZ 80 (1978) 1, p. 27.

as expected in view of its aircraft design and manufacturing activity. Whereas no data are available to indicate the breadth and depth of their activities and facilities relating to motor vehicle handling, it is known that, in the early- and mid-seventies, the computer simulation capabilities of the aircraft side of the Company were being brought to bear on issues faced by the motor car division.

More recently, Saab-Scania has sent engineers to a course on truck mechanics taught by UMTRI staff in the United Kingdom and has subsequently engaged UMTRI personnel to repeat this course at their facility. During this event, the quality and training of Saab-Scania staff (as perceived by UMTRI personnel) appeared to be excellent.

1.2.5 Other European Manufacturers. Unfortunately, no data could be found which speaks to the investments in staff and facilities being made by firms such as Renault, Citroen, Peugeot, Audi, BMW, Ford (overseas), Jaguar, Morris, Rover, Alfa Romeo, Ferrari, Fiat, and Lancia. Several firms (e.g., Porsche) are known to have invested heavily in tire dynamometers and one can presume that a portion of the motivation for this investment stems from their appreciation of the tire mechanics involved in handling maneuvers. Firms such as Porsche and Lotus provide engineering research and development services to other car-producing firms and thus are listed in Section 4.0--Private Research Organizations.

1.3 Japanese

1.3.1 Toyota Motor Company, Ltd. Information regarding the capabilities of Toyota in vehicle handling engineering and research derives primarily from personal observations made during my two-month stay (March/April 1975) in Japan under the auspices of the Japan Society for the Promotion of Science. The visit to Toyota was 2-1/2 days in length and the briefing effort reflected their gratitude for UMTRI's hosting of two young Toyota engineers during the years 1968-70.

The visit began with a tour of their Higashifuji Technical Center which contains their primary outdoor test facility. Although I do not have any quantitative data, my notes show that I was very impressed with their test facilities. With respect to making comparative judgments, my point of reference was the GM Proving Ground which I have toured on several occasions. It is sufficient to say that I was most impressed--they have a large vehicle dynamics test area and a large amount of laboratory space. It was clear that Toyota was influenced by UMTRI's work on limit maneuver measurements--they had a car with an automatic controller complete with an on-board function generator, telemetering system, etc. They also had a large mobile tire dynamometer and an inertia measurement device. The "Vehicle Testing and Research Department" at Higashifuji contained a:

Test Engineering Section
Test Operations Section
Vehicle Dynamics Laboratory
Vehicle Brake Performance Laboratory
Concept Engineering Laboratory
Vehicle Safety Research Laboratory

It should be noted that the Vehicle Dynamics Laboratory possessed a small wind tunnel and a very large crosswind-generating facility which was most impressive.

As was noted earlier in a letter to Mr. Eberle (then President of MVMA) dated June 26, 1975, in which I observed that the "engineering enterprise in Japan [appears to be] supported more liberally with capital expenditures than is true for the smaller motor vehicle firms in the U.S.," it appears that part (or perhaps all) of the reason for this state of affairs is that the Japanese carefully observe what others have done and are inclined to assume that if others have seen fit to create a particular facility, then their engineers should be given a similar facility, or perhaps an even better facility. Clearly, it is not possible to know whether their facility decisions reflect their own independent analyses, or whether they have been influenced by external events. Irrespective of whether the Japanese are leaders or followers, the

Toyota visit gave ample evidence that Toyota executives were inclined to be most generous in response to requests originating from their engineering departments.

As a final remark on Toyota, it should be noted that they saw fit to identify a laboratory as a "vehicle dynamics laboratory." This practice is also followed by other Japanese firms (as will be noted later) and appears to be in marked contrast with practices in which the title of a group or laboratory may imply that vehicle dynamic behavior is a matter of concern but does not explicitly so state.

1.3.2 Nissan Motor Company, Ltd. Again no hard data, but Nissan's concern with handling issues can be perceived on the basis of (1) discussions and (2) observation of their facilities. Two days were devoted to visiting Nissan, with the first day devoted to touring their proving ground, safety test laboratories, and central engineering laboratories. Their full-scale wind tunnel (see Appendix G) was most impressive and their test tracks, skid pads, etc., appeared to be well conceived--very compact, with everything adjacent to the factory. Nissan had seen fit to create four (or five) automatically controlled cars for test purposes. They used electric drive and, in my judgment, the engineering of these units was not very impressive. They also had a chase car equipped with a second set of controls (steering wheel, brake pedal, and accelerator) to generate the command signals sent by radio transmission to the test car. (The logic of this arrangement was not obvious.)

At the Central Engineering Laboratories, they had a number of driving simulators which had varying levels of complexity--with the most complete system being rather impressive. (I do not recall their rationale for creating these simulators, although it was clear that they were devoting considerable effort towards obtaining a better understanding of the driving process.)

On the second day at Nissan headquarters, movies were shown which revealed that they had designed a driver-vehicle study having some similarity to work that GM is reputed to have conducted. My notes state that these films "depicted a driver approaching a series of plastic mockups of the front end of a car which darted into the path of the [test] car. The plastic cars were pulled into the lane by bungee cords triggered by the test vehicle passing over a tape switch. The fake cars were triggered at random and sometimes did not get triggered at all. A variety of approach speeds were used which the driver was forced to maintain, requiring that he maneuver in order to avoid hitting the fake cars. A constant time interval was used in triggering the obstacle. In general, they found greater differences between drivers than between cars." My notes state that this work is continuing.

The personnel met during the visit in 1975 have advanced to positions of higher responsibility. It is of interest to observe that the chief of Nissan's Research and Development Office in 1975 had obtained his masters degree in mechanical engineering from The University of Michigan. Further, the person who currently is "General Manager, General Planning Department, Product Development Office" came to the U.S. as a young man in 1959 (approximately) to observe the vehicle dynamics research being conducted at the Cornell Aeronautical Laboratory. He stayed for a period of several months prior to enrolling as a graduate student at Princeton. This engineer originally had an intense interest in ride dynamics considered as a random process, but, at the time of my visit in 1975, was mainly occupied with the driver-vehicle studies referred to earlier.

1.3.3 Honda Motor Company, Ltd. This company is somewhat unique in that the research and development associated with various product lines is performed within an independent company under the name of Honda R & D Co., Ltd. As such, there are several Honda R & D centers, each devoted to a specific product line.

During my visit in 1975, emphasis was given to motorcycle dynamics. Nevertheless, I had some opportunity to see their test circuit and skid pad facilities which, at that time, were located in the vicinity of the Suzuka plant. Since then, Honda R & D has developed a full-blown proving ground facility at its Tochigi Center. Unfortunately, detailed data describing the Tochigi Center (acquired during a visit in 1982) has been misplaced. It can be stated, however, that the Tochigi Center, in conjunction with the other R & D Centers, constitutes a most modern test facility, fully equipped for conducting vehicle handling investigations.

During the 1975 visit, it was quite clear that Honda was concerned with handling issues. For example, demonstrations were conducted which included: (1) emergency lane-change comparisons of different cars, including a variable-steering car (a Pontiac Firebird); (2) a wireless-controlled car with servos mounted on the steering system, brake, and accelerator pedals; (3) additional task performance evaluations of the Honda ESV and other vehicles, with and without antiskid systems installed; and (4) evaluation of the performance of three different "run-flat" tires. In general, it can be stated that, whereas it was my impression in 1975 that Honda was not on a par with Toyota and Nissan (either with respect to facilities and experience in the area of vehicle dynamics), they appear to have corrected this state of affairs in a remarkably short period of time.

1.3.4 Mitsubishi Motors Corporation. A one-day visit to Mitsubishi did not provide for observations of their laboratory and outdoor test facilities. After viewing laboratories devoted mainly to durability testing and touring a truck assembly plant, Mitsubishi engineers (both car and truck) saw fit to conduct a broad-ranging discussion on a variety of handling issues and problems that they were encountering on both their car and truck product lines. Whereas it was not particularly unusual for car engineers to be discussing and pondering these issues, it was mind boggling to see truck engineers engaging in similar discussions. During this discussion, I learned that Mitsubishi had also developed a remote-control motor car for limit-maneuver testing. It should be recalled that, during 1975, Mitsubishi and all other Japanese firms exporting to the U.S. were heavily caught up in the effort to meet safety standards being promulgated by NHTSA.

1.3.5 Mazda Motor Company (formerly Toyo Kogyo Co., Ltd. No data are available regarding staff and facilities. A visit to the Toyo Kogyo Proving Ground was cancelled, in light of the five hours driving time required to make the round trip. Further, the absence of any prior contact with Toyo Kogyo personnel made this visit somewhat more stiff and formal, as compared to visits to other Japanese companies. The meeting did, however, reveal that they had a Testing and Research Division which included a "Safety Research Laboratory" and a "Vehicle Handling Research Section." Surprisingly, the personnel that I met did not include any of the authors of the 1973 SAE paper, entitled "Evaluation of Vehicle Handling and Stability by Computer Simulation at the First Stage of Vehicle Planning."

In general, Toyo Kogyo staff gave me the impression of having a sufficiently high level of confidence in their own abilities that they were not inclined to spend much effort to discern what others were doing. They were, however, keeping a wary eye on NHTSA's activities and, in common with other Japanese firms, seemed to be very concerned about the rollover problem.

1.3.6 Fuji Heavy Industries, Ltd. This Company began as an aircraft firm which was dissolved and reorganized after the war. It did not enter the four-wheel motor vehicle market until 1958 and, currently, in addition to the Subaru car, it produces industrial engines, railway rolling stock, buses, and aircraft. Its proving ground facility is located immediately adjacent to its main motor vehicle plant in Gunma. This facility included a high-speed track (one mile in length) and other road and surface areas, as needed for vehicle testing. A crosswind generator, consisting of three fans (plus vanes, etc., for control of airflow) was located on site. At that point in time, the Subaru was the only front-wheel-drive car built in Japan and tests were conducted for demonstrating the superiority of front-wheel drive in traversing a road bump while turning in a tight circle. (I don't recall that I was able to perceive the differences which they were demonstrating.)

The round-table discussions, conducted subsequent to the proving ground visit, revealed that Fuji was very much aware that their current car model rolls over when subjected to a very rapid lane-change maneuver. They showed films of this behavior without appearing to be self-conscious or embarrassed, prior to explaining the extent to which they were engaged in studying the rollover process, to the end that improvements in rollover immunity could be achieved.

1.3.7 Isuzu Motors, Ltd. Given that GM owns a portion of Isuzu's stock, it should have substantive information on their capabilities. Nevertheless, I was so impressed with the quality of Izuzu's staff that, at the risk of repeating what is already available to GM, I will include a few statements in this report.

Isuzu had (in 1975) a "Vehicle Dynamics Laboratory" which was part of their "Research and Experiment Department." This department had a total staff of 250 people, including 100 engineers. It was divided into light- and heavy-duty divisions, given their production of both cars and trucks. A test track was located immediately adjacent to the engineering offices, enabling them to demonstrate the lateral g that could be attained by the Gemini. A tour of the installation revealed that technical information was being exchanged with GM. All in all, they appeared to be a first-class outfit who had an excellent grasp of vehicle dynamics theory and practice.

2.0 TIRE MANUFACTURERS

It is known that tire companies supplying tires for passenger cars find it useful to conduct their own handling studies of prospective tire-vehicle combinations. Nevertheless, an identification of the resources devoted by tire companies to this particular topic is more problematical than is the case for motor vehicle firms. Accordingly, the statements which follow are based only on personal contacts and visits.

2.1 Domestic

2.1.1 Goodyear Tire and Rubber Company. I believe that GM has been briefed in some detail by Goodyear personnel regarding their activities in the tire-vehicle interaction area. The photographs provided in Appendix H give the reader some idea of the vehicle instrumentation and data processing capability that Goodyear has acquired fairly recently. The size of the group using this equipment and its relationship to tire research and/or development is not known to the author, however.

2.1.2 Firestone Tire and Rubber Company. It is only possible to state that, within the Central Research Laboratories of the Firestone Tire and Rubber Company, a decision has been made to develop an increased capability for analyzing, modeling, simulating, and measuring the directional behavior of tire-vehicle systems. In this connection, the laboratories have given Dr. Sunil Jha (formerly a senior researcher in the area of vibration and noise at the Institute of Sound and Vibration, University of Southhampton) responsibility for developing this capability. Although there was contact at the beginning of this endeavor, we are not currently informed on their progress.

2.1.3 Other Domestic Tire Companies. Uniroyal, going back to the time when Dr. Bull was the director of research, has had a long history of being concerned with the properties of the tire that influence its performance as a vehicle component. Judging by the nature of their publications, this interest continues today, but the extent to which they currently conduct a substantive effort to examine the handling of prospective tire-vehicle combinations, either by analysis or test, is not known.

Approximately the same remarks can be made with respect to the B.F. Goodrich Company and the Gencorp Company (formerly the General Tire and Rubber Company).

2.2 European

2.2.1 Societa Pneumatici Pirelli S.p.A. Pirelli produces a full line of tires for a broad spectrum of motor vehicles. By virtue of its investment in an automotive proving-ground facility (see Appendix I) comparable to what might be owned by a major vehicle manufacturer, and on the basis of the type of publications which originate from Pirelli staff (going back to the period of Dr. Chiesa), it appears that this company has made, and is still making, a major commitment towards developing an improved understanding of the statics and dynamics of tire-vehicle systems.

In June, 1984, I visited Pirelli in Milan. I saw their tire-mechanics laboratory and was briefed by several staff members. On the one hand, their equipment for measuring the quasi-static characteristics of tires seemed to be rather low budget in contrast to their investment in a proving ground. On the other hand, Pirelli seemed to be much more interested in the dynamic characteristics of tires than I would have expected. My recollection is that Pirelli had invested in tire dynamometers having a dynamic test capability to a greater extent than was invested in quasi-static test devices.

Pirelli appeared to be reasonably advanced in the use of computers for design and simulation and had several pieces of hardware which I had not seen before. (As an item of interest, I noted in a recent visit (September 1984) to the Tire Research Laboratory in Moscow that their computing facilities bore a great resemblance to what I saw in Milan. Later in the day, I learned that the Pirelli Company had provided technical assistance to the tire industry in the Soviet Union.)

As a final remark, I can state that Dr. P. Bandel (the director of research at Pirelli Tire) and his associates appear to have a substantive understanding of tire mechanics and the manner in which the tire influences the behavior of tire-vehicle systems. My guess is that vehicle manufacturers in Europe probably find Pirelli to be very helpful and productive in a car-development project.

2.2.2 Michelin. No information could be found which shows how and to what extent the parent company in France addresses the problem of matching tires to a vehicle to achieve good handling. Our only contact with Michelin personnel has involved staff assigned to their operations in the U.S. For example, Michelin has seen fit to send several engineers to The University of Michigan Engineering Summer Conference Course entitled "Mechanics of Heavy-Duty Trucks and Truck Combinations." On another occasion, I had an opportunity to meet with Michelin engineers engaged in defending the Company against plaintiffs in law suits and found their understanding of the directional mechanics of tire-vehicle systems to be rather pedestrian. I would speculate that Michelin staff in France are more solid individuals, but, given their reputation for secrecy, I doubt that it is possible to size them up, unless a buyer-supplier relationship exists.

2.2.3 Dunlop Limited. Detailed facilities and staffing data are lacking. Although I visited their operation in Birmingham in 1956, I do not recall any details other than seeing their cornering force measurement machine which was noteworthy because of its age. Dunlop, being the first company to make tires, has a long history of pioneering in the field of tire force-and-moment properties measurement. This history is well known because of the many publications which have been prepared by Dunlop personnel, most notably Eric Gough.

However, the extent to which Dunlop engages in activities devoted to advancing the handling of a tire-vehicle system is not immediately evident. A recent Dunlop technical presentation (see Appendix J) suggests that Dunlop takes very seriously the requirement to provide tire mechanics data to the vehicle manufacturer. This same publication also shows that the Tire Research Department of the Tire Technical Division of Dunlop Ltd. saw fit to develop a tire force and moment dynamometer capable of making dynamic measurements as well as quasi-static measurements. In this regard, Dunlop appears to have adopted a test posture which also appeared to exist at Pirelli.

2.3 Japanese

2.3.1 Bridgestone Tire Company, Ltd. In 1975, when I visited Bridgestone, this Company had approximately 50% of the tire business in Japan. Clearly, they were very successful and this success showed in the size of their technical center and the quality of the buildings devoted to engineering and development. Whether any portion of this success could be attributed to their technical arrangement with Goodyear is not known.

From my perspective, the total operation--factory and technical center, including the various test buildings and skid pad--was most impressive. It was all relatively new, with the factory dating from the early sixties and the technical center from the late sixties. Up-to-date and large amounts of computational equipment were in evidence. They had a very large flat-bed tire tester set up with three separate test frames which could be rolled into place on rails. This tester had a built-in calibrating system. They also used dead weights for loading the tire, thereby simplifying their load cell measuring system. As I recall, the Japanese made no effort to design this test facility so as to look attractive--they seemed to be concerned only with function.

Surprisingly, no efforts appeared to be underway to measure tire properties at speed on actual road surfaces. Bridgestone had an ASTM skid trailer and they used a tethered skid pad to determine the speed at which the rear driving wheels break loose on a wet surface. They were also using computer simulation to address handling topics. In particular, they had developed a driver model which could be used to close the loop in executing a lane-change maneuver. The details could not be grasped, but it was clear that the driver typically produces a steering input very similar to a sine wave and, further, this input is approximately two seconds in length. My reaction, at the time, was that Bridgestone staff are either brilliant or very lucky. It appeared that, in this simulation, they characterized the tire by a combination of friction-ellipse theory and the so-called Fiala model. Additional presentations were made regarding their tire mechanics studies which (1) struck me as impressive and (2) gave a favorable impression with respect to their professional capabilities.

2.3.2 Yokohama Rubber Company, Ltd. This is the number-two tire company in Japan, since, in 1975, it accounted for 23% of the tire business. In contrast with Bridgestone, who seemed to be doing their own thing, Yokohama seemed to be very much aware of and influenced by the research efforts of outside parties. For example, they appeared to be substantially influenced by the tire traction studies that were being performed at UMTRI (under MVMA sponsorship) in the early seventies. Accordingly, they had built separate longituidnal and lateral force dynamometers which were installed in a small bus. Since Goodrich (at that time) owned 33% of Yokohama, Yokohama personnel were completely informed on A. Veith's work in the field of tire traction.

Yokohama had a large number of tire dynamometers which included a capability for applying brake or drive torque. In addition, they had a large flat-bed with a pressure probe. For many years, they have had a belt machine which they were using sparingly, since it was worn. These dynamometer setups were huge and were either of their own design and construction or had been built by outside firms to their specifications.

3.0 UNIVERSITY-AFFILIATED RESEARCH INSTITUTES

The above title can be misleading. In general, it is an appropriate title for organizations in North America, but it is not an appropriate title for European organizations. The reason is that entities known as vehicle research institutes are an integral part of the teaching process in the technical universities which exist in Europe, both West and East. Contrary to the practice followed in the U.S., Canada, Australia, and Japan where the emphasis is on teaching major disciplines, such as mechanical engineering, European schools of engineering almost invariably offer students the opportunity to major in specialized fields, such as "automotive engineering." This is particularly true in Germany, where almost every engineering school has one or two professors who run an automotive engineering program which comprises the last two years of a five-year educational program. To the degree that these professors manage to develop a research program of sufficient substance as to give their institution a substantive reputation in the field of vehicle dynamics, these institutes, or institutions, are discussed below.

3.1 North America

3.1.1 UMTRI. When the Highway Safety Research Institute, the forerunner of UMTRI, was established in 1966, it was set up as a research organization within the University's Institute of Science and Technology. This arrangement resulted in UMTRI being detached from the various academic departments, and this independent research status, plus an absence of support from the general fund of the University, led to UMTRI's becoming a research organization dependent almost completely on grants and contractual awards from external sponsors. In this environment, the Engineering Research Division of UMTRI has, over time, acquired a capability, in terms of facilities and staff, for conducting research and solving problems in areas related to the mechanics and dynamics of tire-vehicle systems. The Division currently has eleven professional employees who are supported (currently) by a full-time staff of six people and a varying number of part-time students. These personnel are available to undertake research programs in areas in which the Division is particularly qualified, provided, of course, that ongoing project commitments permit them to do so.

An overview of laboratory facilities and a listing of staff members is provided in Appendix K. Research efforts involving these facilities and these personnel may be acquired by either of three methods: (1) a gift to the University, (2) a contractual award, and (3) a purchase order for services. The University does not have a vehicle test area of its own and therefore engages, as required, the test areas available at various proving-ground facilities in Michigan, Ohio, and Indiana.

3.1.2 Texas Transportation Institute. This Institute is an integral unit of Texas A&M University, but, similar to UMTRI, does not have a primary teaching mission, per se. Founded in 1950, it has developed into an organization whose main research thrust is in highway transportation and whose staff is, secondarily and in part, providing graduate instruction in highway, traffic, and transportation engineering and structural mechanics. The Institute is organized into eight Divisions (viz.: Economics and Planning; Transportation

Systems; Human Factors; Materials and Construction; Safety; Structural Systems; Accident Analysis; Special Programs) with a Safety Division organized, originally, to develop crashworthy hardware and safer roadside structures. Subsequently, the activities of the Safety Division were expanded to include studies related to tire-pavement interaction; vehicle handling, stability, and control; driver visibility; automobile fuel economy and engine emissions.

The total number of personnel comprising TTI staff is in the neighborhood of 250 people. They are housed both on the main campus of the University and at the Highway Safety Research Center (HSRC). Appendix L provides information with respect to TTI facilities located at the main campus and at the HSRC.

3.1.3 IIT Research Institute (IITRI). IITRI is a separately incorporated nonprofit research institute affiliated with the Illinois Institute of Technology. It has a staff in excess of 1600, including 675 professionals, who are supported by research contracts with U.S. government and industry. Its research activities cover a wide range of disciplines. In view of its capabilities in engineering mechanics (as can be applied to research in environmental and safety engineering), IITRI has, from time to time, become involved in studies related to the vehicle constraining performance of highway structures and the stability and controllability of multi-unit commercial vehicles. With respect to the latter endeavor, it can be stated that this activity is not a major thrust of the total IITRI program. In addition, it appears that this work has not been held in particularly high regard.

3.1.4 The Pennsylvania Transportation Institute (PTI). PTI is an integral unit of the Intercollege Research Program of The Pennsylvania State University. This program is administered by the Vice President for Research and Graduate Studies and tends to be applied to research directed at environmental or societal problems. The PTI is organized into seven major programs (viz.: Accident Analysis; Automotive Research; Public Transportation; Traffic Engineering; Transportation Pavement and Materials; Transportation Policy Analysis; and Transportation Systems). Its Automotive Research Program is concerned primarily with the interaction between pavements and vehicles. In support of this concern, the Institute has developed two outdoor test facilities, namely, a Skid Resistance Research Facility and a Pavement Roughness Research Facility (see Appendix M). In addition, PTI has developed a number of Tire/Pavement Laboratories which include a "Stone Polishing Laboratory," a "Moving Belt Friction Tester," a "Tire Energy Loss Test Facility," and a "Circular Track Apparatus" (see Appendix M). Appendix M also includes a description of the so-called "Penn State Road Friction Testers" and "Penn State GMR Profilometer."

PTI occupies three buildings which provide 20,000 sq. ft. of space for 83 personnel, comprising 41 faculty members, 3 research assistants, 22 graduate assistants, and 17 other staff members.

3.1.5 Concordia University Vehicle Dynamics & Systems Research Group. Although individual professors in engineering schools in the U.S. and Canada are known to pursue a vehicle dynamics research topic from time to time, it does not appear that, other than the "Vehicle Dynamics and Systems Research Group" in Concordia University in Montreal, mechanical engineering departments are inclined to single out this particular field of endeavor. The one exception, noted above, has announced that it is actively pursuing research and development work in the field of "vehicle suspension, handling, and ride control." A recent brochure lists eleven people as full-time personnel and two people as "part-time researchers." Appendix N identifies the research facilities possessed by this particular group. If further information is desired, it is recommended that one examine the Concordia University document entitled "Research and Development Activities in Vehicle Dynamics" available in UMTRI's library.

3.2 Europe

3.2.1 Vehicle Research Laboratory, Delft University of Technology (VRL). This Laboratory serves both a teaching and research function. It was founded in 1950, when H.C.A. van Eldik Thieme was appointed Professor Vehicle Engineering. By 1960, VRL had become a rather substantive research organization in view of the description of its research activities presented* by Professor van Eldik Thieme on the occasion of the 8th FISITA Congress. Whereas some of the research described in this paper was very likely conducted for outside sponsors, it is believed that a significant portion was supported by University funds. To a large extent, this situation appears to hold true today and is a rather remarkable state of affairs, given that the Netherlands cannot be considered to be a major motor vehicle producing country. However, it should be noted that this laboratory is responsible for teaching and research related to railway systems as well as motor vehicles.

A layout of the VRL building is provided in Appendix N. It can be seen that many of the identified test facililties are concerned with making measurements of the properties of tires. It would not be an exaggeration to say that this laboratory has attained a preeminent status in the tire mechanics measurement field. A visit and an examination of their publications provides ample evidence of the high level of expertise in design and construction of tire dynamometers which exists within this particular laboratory. Although VRL staff have not been prolific producers of technical papers in the open literature, it is obvious that they are knowledgeable and capable investigators in the area of vehicle dynamics, particularly in a laboratory setting. In addition, the current professor in charge of motor vehicle research (H.B. Pacejka) has developed an international reputation as a scholar in the field of tire-vehicle systems.

3.2.2 Institute for Motor Vehicle Research, Technical University of Braunschweig. This Institute serves both a teaching and research function. Although, in principle, it does research on railway vehicles as well as motor vehicles, the bulk of the research and most of their facilities apply to tire-vehicle systems.

As is true for comparable institutions in Germany, the research activities of the Institute at Braunschweig reflect the interests of the academicians who have served as its director. During the fifties and the sixties (and perhaps earlier), the director was Professor Paul Koessler, who, together with Professor Buschmann, is the author of a major German text entitled "Handbook of Motor Vehicle Technology" (previously, the "Handbook for the Motor Vehicle Engineer"). Professor Koessler is now deceased and his successor during

*H.C.A. Van Eldik Thieme, "Experimental and Theoretical Research on Mass-Spring Systems by the V.R.L. of the Technological University of Delft," Proceedings of the 8th FISITA Congress, 1960.

the seventies and the eighties is Professor Manfred Mitschke, who is the author of a more recent text entitled "The Dynamics of High-Speed Motor Vehicles."

These two academicians had, and still have, a strong interest in the dynamic behavior of motor vehicles. In 1970, the research activities of the Institute embraced the following areas: "brakes, vehicle vibrations, vehicle handling, tires, instrumentation and miscellaneous items." Brake research began as far back as 1939. In 1954, the Institute moved into its present building. The size of the current staff is not known. However, it employed approximately 30 people in 1970.

Although, with the information available, it is difficult to rank the various vehicle research institutions in Germany in regard to the substantiveness of their efforts in the area of vehicle handling, it is clear that Mitschke and his colleagues and students at Braunschweig have been major contributors to the vehicle dynamics research scene. Although I do not have any hard data revealing the size of their laboratories, photographs in a report entitled "The Institute and Its Activities" indicate that the research installation at Braunschweig is substantially larger than that which exists at Delft. It is possible to observe that Braunschweig has equipment which enables them to predict vehicle behavior as well as measure this behavior. Appendix O provides two photographic views of the Institute at Braunschweig.

3.2.3 Institute for Motor Vehicle Technology, Technical University of Berlin. In view of an absence of printed material, we must rely on memory to recall information gathered during visits in 1975, 1978, and 1979.

This Institute is at least as old as that at Braunschweig, if not older. Its physical plant is not as new as Braunschweig since some, if not all, of its laboratory space was built in the twenties. This estimate is based on my being shown the small drum on which Becker, Fromm, and Maruhn performed the pioneering tire measurements in the late twenties. It is still operational today, although used exclusively for student instruction. As is true for Braunschweig, the Institute in Berlin is responsible for the instruction that is given to fourth- and fifth-year students (specializing in Automotive Engineering) leading to the Dipl. Ing. degree.

Subsequent to the departure of Dr. Fiala from Berlin, two men took up the directorship of this Institute, viz.: Professor H. Appel and Professor H.P. Willumeit. In general, the former is mainly responsible for their research activities in "passive safety" (crashworthiness), with the latter primarily responsible for research in the field of active safety. Their interest in vehicle handling topics could be perceived by noting a substantial investment in driving simulators, in addition to what is indicated by their publications. It was my impression that the heads of this Institute deal directly with clients and run, in effect, a research business with little administrative support or control by the University. Further, as is generally true throughout Germany, the ties between the Institute and the motor vehicle industry are excellent.

3.2.4 Research Institute for Motor Vehicle Engineering and Engines, University of Stuttgart (FKFS). As both a research and teaching institute, FKFS was founded in 1930. Since its founding, it has had three directors, namely, W. Kamm (1930-1945), P. Riekert (1945-1971), and U. Essers (1971-present). Each of these men have put their own stamp on this Institute which is considerably broader in scope than that at Braunschweig and Berlin, in that engine research and wind-tunnel testing are major endeavors in Stuttgart, as well as research related to the remainder of the motor vehicle. An impression of the magnitude of its physical plant is given by a photograph of a model of the Institute (circa 1940) (see Appendix P). It also appears that this Institute was given a new building in 1978 and that its already substantial investment in wind-tunnel facilities has been augmented by the construction (1981-83) of a tunnel capable of testing full-scale motor vehicles. (For additional information, the reader is referred to an article in ATZ 83 (1981)1, pp. 9-14).

An ATZ article commemorating fifty years of research at FKFS contains figures and text showing that, notwithstanding the heavy emphasis given to internal combustion engines and vehicle aerodynamics, this Institute was, and is, concerned with the directional dynamics of tire-vehicle systems. The figure caption under a photograph of a tire side-force measurement facility indicates that this machine was built in 1954/55.

3.2.5 Institute of Internal Combustion Engines and Automotive

Engineering, Technical University of Vienna. Although the title of this Institute implies that it has a research program which extends beyond the field of I.C. engines, and an account of the work performed in Vienna from 1974-1984 states that they conduct "investigations in the field of vehicle dynamics," it is clear that, during the 1974-84 time period, very little attention has been given to vehicle dynamics issues. Presumably, the situation was different during the tenure of Dr. Robert Eberan-Eberhorst. However, during Dr. H.P. Lenz's tenure, the only paper which can be identified as being concerned with vehicle dynamics is a paper presented to the XX FISITA Congress in May 1984 (viz., E. Diem, "Systematic and Automatic Development of Vehicle-Dynamic Simulation Models"). Further, no chassis and tire measurement facilities are cited, thereby raising some questions as to whether the instruction in "Automotive Engineering," "Automotive Design," and "Design and Technology of Tires" is supported with laboratory demonstrations. Data on staff and size of the Institute are not available.

3.2.6 Additional European Institutes. Although hard data are not available, there are additional automotive research and test capabilities residing within European engineering schools. Within the Federal Republic of Germany, there should be mentioned, first, the Institute directed by Professor Gauss (recently retired) at the Technical University of Hanover. Deserving of mention, next, are the Technical Universities of Munich and Aachen, both of which train students in automotive engineering.

Five-year engineering programs with courses of instruction in automotive engineering (following the model existing in German schools and in Delft) are known to exist at technical universities in Belgium, Denmark, Sweden, and Finland. Because they (apparently) do little research nor publish their findings in the open literature, they are not well known in the English-speaking countries. In addition, there are a host of institutes (along the lines of the German institutions) existing within the socialist countries in Eastern Europe.

3.3 Japan

As far as this writer has been able to ascertain, engineering schools in Japan appear to follow the American model. I am not aware of any organizational entity in Japan which could be considered to be a university-affiliated research institute.

4.0 PRIVATE RESEARCH ORGANIZATIONS

4.1 Domestic

4.1.1 CALSPAN Corporation. Its Advanced Technology Center constitutes a large independent research and development organization whose origin was the Cornell Aeronautical Laboratory, Inc. (1946-1972). Beginning with a GM-sponsored project in 1953 on automotive stability and control, its research activities related to ground-supported vehicles grew steadily, leading to the formation of a Vehicle Dynamics Department in 1960 and the subsequent establishment of a Transportation Research Department in 1967. Subsequent to becoming the CALSPAN Corporation, a 33-acre proving ground (see Appendix Q) was built to facilitate vehicle crash tests, handling qualities tests and other transportation safety experiments. A laboratory tire force and moment dynamometer capable of testing car and truck tires at speeds up to 170 mph on a flat surface was also designed and developed.

Facilities and staff (400 professionals, 80 doctorates) are available to conduct research under contract to outside sponsors. Within the aeronautical and transportation engineering sector, CALSPAN has been active in (a) the development of more crashworthy vehicles, (b) crash testing as required to assess compliance with federal safety standards, (c) testing and simulation in the study of human occupant dynamics, and (d) studies concerned with the mechanical properties of tires and with the mechanics and dynamics of tire-vehicle systems. The maintenance of staff with qualifications in these latter areas has been difficult, however, in view of the erratic support received from government and industrial circles.

4.1.2 Milliken Research Associates. UMTRI files do not contain any material describing this organization. Mr. Milliken is, however, well known to many GM staff members as the single individual who was responsible for CALSPAN's entry into the automotive research field and who, subsequent to his retirement from CALSPAN, created his own consulting firm offering vehicle dynamics expertise to outside clients. It seems likely that GM staff have better information than we are in a position to supply.

4.1.3 Systems Technology, Inc. (STI). This California-based firm was established by its president, D.T. McRuer, to offer applied research and development capabilities in the broad field of control systems. Staffed originally by engineers who were concerned with stability and control issues arising within aeronautics, STI personnel subsequently became interested in automotive vehicles. At present, they identify the fields of research and development in automatic and manual control systems for all types of vehicles (aircraft, automobiles, and ships) as being their special area of expertise.

No hard data is available at UMTRI regarding the facilities which STI has designed and built in connection with their automotive research activities. However, it is known that STI has developed a driving simulator. Further, they have conducted a substantial number of field tests in the ride and handling area, with these tests incorporating a significant human factors component. Clearly, they have a strong instrumentation capability and they are able to draw upon technological developments in aerospace. In 1977, STI had a professional staff of 34 people, including 3 doctorates.

4.1.4 Failure Analysis Associates. This firm, which is headquartered in Palo Alto, California, claims to be the largest engineering and metallurgical consulting organization in the U.S. specializing in the analysis and prevention of engineering failures. Recently, they purchased the 156-acre test facility (in Phoenix, Arizona) which was previously owned by Dynamic Science, Inc. This facility (see Appendix R) includes a two-mile oval test track, a 10-acre vehicle dynamics test area, variable-coefficient braking surfaces, a 1200-foot powered crash rail, a 90-foot drop tower, and some miscellaneous test fixtures. The director of the Phoenix office is Dr. N.K. Cooperrider, who, previously, was a member of the mechanical engineering faculty of Arizona State University. His special area of expertise has been the dynamics of railway vehicles.

Whereas Failure Analysis Associates have traditionally provided consulting services primarily to industrial clients, the test facility in Phoenix was used by Dynamic Science in test programs performed (mainly) for government agencies. It can be assumed that Failure Analysis Associates will be most receptive to undertaking studies in the vehicle dynamics field, irrespective of the nature of the prospective client. Other than a knowledge of Dr. Cooperrider's background and experience, data are lacking with respect to other staff members. When Dynamic Science, Inc. operated the Phoenix facility, it had (in 1977) a professional staff of 30 people covering a range of disciplines, plus 50 technicians and auxiliaries.

4.1.5 Mechanical Dynamics, Inc. (MDI). This firm is located in Ann Arbor, Michigan and provides dynamic analysis services to a variety of clients, primarily industrial. It was established in 1977 by Dr. M.A. Chace to develop and market software which had been created by him and his doctoral students at The University of Michigan. The Company specializes in software which can describe and simulate the dynamic behavior of multi-degree-of-freedom, constrained, mechanical systems undergoing large displacements such that the system behaves in a highly nonlinear manner. This software has been applied to a number of motor vehicle design and/or analysis applications.

MDI does not appear to have any laboratory or field test capability. However, no hard data exists to confirm or negate the previous statement, nor is data in hand at UMTRI indicating the size of the organization, either in terms of personnel or space. It is likely that GM has such information.

4.1.6 MGA Research Corporation (MGA). This firm was established by Dr. P.M. Miller, formerly of CALSPAN Corporation, to provide engineering services both to the public and private sector. Staff expertise lies in the fields of vehicle dynamics, vehicle crashworthiness, test procedure design, instrumentation development, and engine and component development, as well as engine and vehicle noise abatement design. In-house laboratory capabilities appear to be limited, in that MGA typically obtains facilities (as needed) through subcontractual agreements. The firm, similarly, goes outside when necessary to obtain a large-scale computational capability. Small-scale computing is done in house on their own equipment.

In 1980, MGA consisted of seven full-time professionals assisted by a number of part-time consultants. Its staffing procedures, coupled with a minimal investment in costly laboratory facilities, apparently enable MGA to operate with a minimal overhead burden, leading to a research capability that is very attractive from a cost point of view.

4.1.7 Dynamic Research. This is a small firm which is mentioned here only because its principal staff member is Dr. David Weir, who developed considerable stature as a vehicle dynamicist while employed by Systems Technology, Inc. No data are available at UMTRI with regard to particulars such as staff and facilities.

4.1.8 Transportation Research Center of Ohio (TRC). This facility is a hybrid in that it was established by the State of Ohio, but is operated as a private business providing test services to clients within both the public and private sectors. TRC is an 8100-acre test facility, which reputedly makes it the "world's largest highway and transportation research complex." Ohio's initial investment to create this automotive proving ground facility was 30 million dollars. The Center presently contains a 7.5-mile high-speed oval track (with two 1.88-mile straightaways), a 50-acre vehicle dynamics test area (1800 ft by 1200 ft), and a braking test facility with test surfaces 2500 feet in length. (See Appendix S for a view of the general layout.)

TRC is primarily set up to provide a test facility to prospective clients rather than to provide professional assistance in studies addressing a broad spectrum of automotive development activities. It was created to make Ohio more attractive to automotive firms. Since its establishment roughly coincided with the increased involvement of the federal government in the development of safety standards, a significant portion of the budget has been devoted to creating "crash" test facilities. In addition, the National Highway Traffic Safety Administration established its Vehicle Research and Test Center (VRTC) at TRC. VRTC is a federally owned and operated laboratory which has been located on State of Ohio property in order to take advantage of the substantial capital investment which the State had already made.

It should also be noted that the close proximity of Ohio State University to TRC has led to joint working arrangements between OSU College of Engineering staff and TRC staff. More recently, similar working arrangements have been made with VRTC staff.

4.2 European

In contrast to the situation which exists in the U.S., there appears to be very little incentive for small private groups to offer research services to government agencies and industrial firms. On the other hand, there are at least two, if not more, automotive firms who can be engaged by other automotive firms to obtain assistance in a major research and/or development endeavor. The primary examples are Porsche in Germany and Lotus in England. A completely different type of organization, namely, "Technischen Uberwachungs-Verein" (TUV) exists in the Federal Republic of Germany to provide the various German states and the federal government with a wide variety of technical inspection services, including, for example, those needed for the annual inspection of motor vehicles and the motor vehicle type approval process. The TUV which services the State of Rheinland is located in Cologne and includes an entity known as the Institute for Traffic Safety. This Institute is unique in that it is not affiliated with a technical university. However, it is staffed with professionals (many with doctorates) who engage in vehicle handling research under the auspices (I believe) of the federal government.

4.2.1 Porsche. Information with respect to this firm's performance of research and development for outside sponsors has been gathered from the February 1984 issue of Car and Driver and from several issues of Porsche Panorama, a monthly publication of the Porsche Club of America.

In brief, Porsche, in addition to the R and D conducted on behalf of its own product line, conducts R and D for outside sponsors under contract. In the fiscal year ending July 31, 1984, it is reported that their annual billing to outside clients (numbering 40 to 45 organizations) reached 31 million dollars. It is estimated that over 80 percent of their clients are directly or indirectly related to the motor industry.

R and D is performed by Porsche at its Weissach experimental grounds which was opened between 1967 and 1970. At this center (see Appendix T), 1800 people are employed, constituting 29 percent of Porsche's entire labor force. As has been reported in the literature, Porsche has its own tire test facility consisting of a 20-foot drum on which they measure both wet and dry traction. They will shortly have their own full-scale wind tunnel.

Until 1974, their main external client was Volkswagen, with whom they had an exclusive consulting contract during the thirties and forties. Although it is Porsche's policy to keep their activities on behalf of their outside clients completely confidential, Car and Driver has been able to identify a few of Porsche's customers.

4.2.2 Lotus. No hard data are available, but we gather that GM is a client of Lotus and consequently should be relatively well informed.

4.2.3 Institute for Traffic Safety. As indicated earlier, this Institute is a part of TUV, Rheinland. As such, it maintains a motor vehicle laboratory which can conduct tests, as required, to secure type approval for a complete vehicle or a vehicle components. This technical service is provided to the Federal Republic of Germany to ensure that vehicles comply with ECE regulations in the areas of primary and secondary safety. In addition, it appears that the Institute is also charged with developing test procedures that relate to handling qualities evaluation. In this connection, Dr. K.

Rompe, the director of the Institute, has, on several recent occasions, authored papers which demonstrate the Institute's active interest in vehicle handling. Appendix U is a copy of a paper entitled "The Motor Vehicle Laboratory at the TUV, Rheinland" which appeared in ATZ in 1981.

5.0 RESEARCH ORGANIZATIONS CREATED BY AND SUPPORTED BY THE MOTOR VEHICLE INDUSTRY

Only two organizations are identified below as being in this category. However, it should be noted that UMTRI, which was identified earlier as a university-affiliated research organization, came into existence as a result of a financial gift made to The University of Michigan in 1965 by the General Motors Corporation, the Ford Motor Company, and the Motor Vehicle Manufacturers Association of the United States. Although UMTRI, in reality, was created (and partially supported) by the motor vehicle industry, this category is restricted to those organizations that owe their existence to a decision on the part of motor vehicle manufacturers (within a given country) to join forces in creating a research or proving ground organization that would serve their combined needs.

5.1 Motor Industries Research Association--U.K. (MIRA)

Research associations were first set up in the U.K. in 1919 by the government, with the collaboration of various trade associations. The intent was to stimulate manufacturing technology to enable the country to be more competitive after the First World War. MIRA was formed in 1946 as a classical research association funded by member's subscriptions and government aid. It continued to operate as such until 1970 when it was decided to change to contract funding as being more appropriate to the economic climate. This change was made over the period 1970-75 (see Appendix V), resulting in research and development contracts with a variety of clients (see Appendix V), accounting for the major portion of MIRA's current income (6.4 million dollars per annum).

Today, MIRA has a staff of over 200 people engaged in a wide variety of automotive research. It is located adjacent to a 600-acre proving ground (see Appendix V) containing some 26 miles of special test tracks.

Subsequent to the departure of Dr. F. Hales, who was the primary individual involved in establishing their vehicle handling research capability, MIRA has continued to maintain a vehicle handling assessment and analysis activity. MIRA has a significant instrumentation capability and is well known for its aerodynamic test facilities, which have included a wind tunnel sufficient in size to make aerodynamic measurements on full-scale cars since the early 1960's. A 1976 annual report identified nine research departments, viz., Noise, Aerodynamics, Instrumentation, Engines, Braking and Handling, Ride and Service Stresses, Safety, Crash Testing, Materials and Components. A visit to MIRA in 1981 by UMTRI staff gave a very favorable reading regarding its management and its capabilities.

5.2 Japan Automobile Research Institute (JARI)

JARI began as the Automotive High Speed Proving Ground, Inc., which was established in 1961, presumably under the auspices of the Japan Automobile Manufacturers Association (JAMA). In 1969, JARI came into being as a non-profit public research organization under the supervision of the Ministry of International Trade and Industry. The objective was to create a research institute which would reinforce the research and development capabilities of the Japan automobile industry, following the liberation in international trade in the late 1960's.

Currently, JARI is supported by a mix of clients, but it is believed that, over time, JARI will evolve into a contract research organization, such as has occurred at MIRA. For example, in 1982-1983, the JARI budget was just under 5,000,000,000 yen, with this amount being derived from the following sources:

	Percent
Grant in aid from government agencies:	2.2
Subscription from JAMA and others:	37.4
Contractual support:	21.5
Facility rentals:	11.2
Assoc. membership subscriptions:	0.9
Previous surplus:	2.2
Land sales:	2.6
Misc. income:	1.4
Loans:	20.4

(No explanation was provided as to why JARI saw fit to go into debt in that particular fiscal year.)

Twenty-four separate test facilities are identified and briefly described in Appendix W. The Institute has four research departments and one so-called experimental department. The research fields of the third and fourth departments, respectively, are (1) vibration, noise, dynamics, ride comfort and (2) tires, kinematics, controllability, stability, human engineering. The top administrator is called "President" and, invariably has been a former academician, beginning with Dr. Kondo, who was, in turn, succeeded by Drs. Watari and Ohigashi. It is worth noting that Drs. Kondo and Watari were both distinguished "vehicle dynamicists." Dr. Watari is now deceased and prior to becoming President of JARI was a professor of mechanical engineering at the University of Tokyo. Dr. Kondo, on the other hand, is a former aeronautical engineer, who after the war took up automotive stability and control as his primary field of interest. His two-volume text, entitled "Basic Automobile Engineering" (published in 1973 and 1974, respectively), remains, today, the standard reference work used by Japanese engineers concerned with the mechanics of tire-vehicle-driver systems.

Personal observations (made during a visit in 1975) include noting that "the facilities at JARI are most impressive." My notes go on to say that "the investment in engine test and combustion research equipment is fantastic, not to mention the tire mechanics laboratories and the electromagnetic radiation absorption chamber and the acoustic chamber used for calibrating acoustical instruments." At that point in time, JARI had completed building its large wind tunnel and was in the midst of calibrating this tunnel. My general impression was that JARI management was not particularly satisfied with their research productivity (in 1975) and was envious (rightly or wrongly) of rates of progress perceived as being made elsewhere.

The staff of 282 persons (June 1984) conducts research from which they produce three types of publications, viz., Technical Reports, Technical Memoranda, and Technical Notes. A listing of these publications indicates that very few research projects were completed and reported during the years of 1979, 1980, and 1981, for reasons that are not evident.

6.0 NATIONAL LABORATORIES (GOVERNMENT OWNED AND OPERATED)

6.1 NHTSA's Vehicle Research and Test Center (VRTC)

As indicated in Section 4.0, VRTC has a symbiotic relationship with TRC of Ohio and the Engineering College of Ohio State University. Its mission is defined as:

1) crash-avoidance research
2) crashworthiness research
3) pedestrian and biomechanics research
4) defect investigations, test, and evaluation

To accomplish this mission, the Center is organized into an "Engineering Test Facility" and a "Safety Research Laboratory."

It is not known how decisions are made and priorities are set regarding the research goals being pursued at VRTC. At the present time, the emphasis in the crash-avoidance area is on the mechanics of braking, particularly the braking performance of heavy-duty trucks and truck combinations. It can be speculated that NHTSA has concluded that the only reliable way of generating a revised heavy-duty truck braking performance standard which will stand up to external criticism is for VRTC staff to become more knowledgeable about the braking process than all other parties. Consequently, their current involvement with truck braking issues, including the interaction between braking and directional response and stability, has been sufficiently large so as to exclude staff from devoting any significant attention to the passenger car.

Total number of VRTC staff is not known. An inertial-type brake dynamometer of impressive size and test capabilities would appear to be their largest capital investment to date. The Center is equipped to instrument vehicles to conduct tests and is in possession of specialized tire dynamometers, as built under various NHTSA research contracts. There is reason to believe that the Center is currently in the process of designing and building its own laboratory facility for measuring the inertial, kinematic, and mechanical properties of motor cars.

6.2 Swedish Road and Traffic Research Institute (VTI)

This Institute is an independent government authority under the Swedish Ministry of Communications. Its activities are financed through government grants and commissions from other authorities, organizations, and private companies. Under its constitution, it bears responsibility for research and development work relating to roads, road traffic, and traffic safety. The Institute is also responsible for pursuing research and development related to other forms of transport and traffic when such tasks are compatible with its other work.

In support of this assignment, VTI is organized into (1) a Road Division, (2) a Road User and Vehicle Division, and (3) a Traffic Division. About 200 people are employed, supported by services provided by an Administrative Division. Multidisciplinary research projects are staffed by forming project groups with researchers from different divisions.

The Road Users and Vehicle Division has the following mission:

1) develop and apply methods for studying the function of vehicles and vehicle components in different traffic situations in order to improve the background data and information needed for codes (i.e., regulations) concerning vehicles, vehicle components, and traffic environment

2) develop and apply methods for the studies of human performance characteristics and behavior in different traffic situations in order to improve the background data and information needed for decisions concerning vehicles and traffic environment and measures relating to road users.

VTI was formed in 1971 and was relocated, in 1975, from Stockholm to Linkoping. At this latter site, it has created the following facilities:

1) a driving simulator with a wide-angle visual system and complete movement control system (see Appendix X)
2) computer programs for studying vehicle movements in standardized maneuvers
3) indoor and outdoor impact test track
4) dynamometer for measuring tire characteristics
5) on-road machine for studying the interaction between a tire and the pavement
6) other laboratories as needed to study traffic and pavement design and construction

A listing of R & D resources, as existed in 1981, can be found in Appendix X.

6.3 Transport and Road Research Laboratory--U.K. (TRRL)

TRRL was originally founded in 1933 as a Road Research Laboratory within the government Department of Scientific and Industrial Research. Over the years, it has been reorganized numerous times and located within various governmental units. It became the Transport and Road Research Laboratory in 1972 and currently retains that title in its mission to provide research services to the Department of the Environment and the Department of Transport. Its current responsibility is to provide technical and scientific advice and information to help these departments formulate, develop, and implement government policies relating to roads and transport, including their interaction with urban and regional planning.

TRRL laboratories and offices occupy a site of 250 acres. In 1979, its total staff numbered about 1000, approximately half being scientists and engineers. The organizational structure (at that time) is that shown in Appendix Y, namely, six departments forming a Transport Group, a Traffic and Safety Group, and an Engineering Group. Of particular interest to GM, is the Transport Systems Department (within the Transport Group) and the Safety Department (within the Traffic and Safety Group). It should be noted that in

1983, the Transport Systems Department was restructured to contain a Vehicle Engineering Division, formed from parts of the former Transport Engineering and Freight Divisions.

Currently, the Vehicle Engineering Division consists of five sections (viz., (1) Freight, (2) Noise and Vibration, (3) Vehicle Efficiency, (4) Vehicles for the Disabled, and (5) Dynamic Pavement Loads) employing 21 professional persons. The research emphasis is on commercial vehicles (i.e., trucks, buses, and taxis). Similar information is not available regarding the "Vehicle Safety Division." However, the literature gives evidence that this division has been and is concerned with handling issues as they impinge on the safety quality of the highway traffic system. A TRRL brochure prepared in 1979 states that the "Vehicle Safety Division is concerned with improving the accident-avoidance and road-user protection aspects of cars, commercial vehicles, motor cycles, and pedal cycles."

A "Technical Service Unit" controls the use of the research track (see Appendix Y for an aerial view of TRRL) and includes both workshops and garage services. A Research Services Unit provides computing, library, technical information, translating and interpreting services to the staff of the laboratory.

6.4 Australian Road Research Board (ARRB)

ARRB was founded in 1960 to serve as Australia's national road research center under the sponsorship of the National Association of Australian State Road Authorities and the Commonwealth Department of Transport. As such, it has a mission similar to that of TRRL. However, ARRB is much smaller than TRRL, having a staff of approximately 100 persons. Although ARRB does have a small research unit concerned with the mechanical attributes of motor vehicles, it does not have a road network and test area on which motor vehicle behavior can be studied. In recent years, ARRB's vehicle research unit has concentrated on the commercial vehicle, specifically, the pavement loading process and the mechanisms of rollover. This latter concern has led to the development of a tilt-table facility, which is installed adjacent to the ARRB complex at Vermont South, Victoria.

6.5 Traffic Safety and Nuisance Research Institute Japan (TSNRI)

TSNRI is the laboratory arm of the Motor Vehicle Department of the Road Transport Bureau, Ministry of Transport.

Under the provisions of the Road Vehicle Act, the Motor Vehicle Department is required to issue regulations for safety and pollution control. TSNRI, on the other hand, is charged with conducting the research which presumably leads to regulations. It is also charged with developing the test methods by which the compliance with a regulation can be assessed. In addition, this laboratory carries out the examinations which are part of the type-approval system used in Japan. In effect, this laboratory examines all new vehicle models for compliance with regulations governing dimensions, weights, braking system, steering performance, lighting equipment, exhaust emissions, etc., prior to their being approved for sale to the public.

In 1975, TSNRI had responsibility for safety and nuisance-control research for railway and aircraft traffic systems as well as the automotive system. To accomplish its mission, it was organized into three divisions, namely, a Traffic Safety Division, a Traffic Nuisance Division, and an Automobile Type Approval Test Division (see Appendix Z for identification of the sections making up each division).

Given the breadth of their mission and responsibilities, it was rather surprising to learn (during a visit in 1975) that the total staff consisted of 79 people (of which 45 were research personnel). It was possible to observe, however, that type-approval tests were expedited with the aid of company personnel accompanying the vehicle, such that TSNRI staff had need only to supervise and conduct the required tests. It is of interest to note that TSNRI became a separate laboratory only as recently as July 1970 when it was detached from the "Ship Research Institute." Prior to the establishment of the Ship Research Institute in April 1963, transportation research concerned with aviation, shipping, harbors, railways, and the automobile was performed within the "Transportation Technical Research Institute" which constituted the predecessor organization to TSNRI.

6.6 Transport Canada

This ministry (or governmental department) includes the "Road Safety and Motor Vehicle Regulation Directorate," which was reorganized in 1983 into the organization diagrammed in Appendix AA. The objective of this directorate is "to reduce deaths, severity of injuries, health impairment, property damage, and fuel consumption resulting from motor vehicle use in Canada." To this end, the Traffic Safety Standards and Research Branch is responsible for issuing safety standards under the authority of the Motor Vehicle Safety and Tire Safety Acts. In support of this branch and the compliance test activities of the Vehicle Safety Operations Branch, the directorate has established a Motor Vehicle Test Center (MVTC). In addition to supporting the directorate, this Center will also be a vehicle test resource for other units of government, industry, and private research agencies.

The MVTC was completed in 1979 at a total cost of 25.7 million dollars (Canadian). It is located on 550 hectares of federal land north of Montreal. As can be seen in an air view of the Center (see Appendix AA), it contains a triangular shaped vehicle dynamics area covering 9 hectares. Detailed information regarding the Vehicle Systems Section (see Appendix AA) and its capabilities for conducting instrumented vehicle tests with the aid of this facility are not available. Appendix AA contains a brief description of the various test facilitaies and laboratories that have been established at MVTC.

6.7 Other National Government Laboratories

It is presumed that national government laboratories, other than those identified above, exist in western European countries, in view of their type approval system. However, other than the organization in the Netherlands, known as TNO, little or no information was uncovered regarding the existence, location, and mission of these various type approval activities.

National government laboratories and research units concerned with the motor vehicle are also known to exist in eastern European countries, and in the Soviet Union and the People's Republic of China. For example, there is the

Central Research Institute for Automotive Engineering in Moscow (which I visited for two hours in 1984 without seeing any of their laboratories) and the Motor Vehicle Research Institute in Changchun, PRC. The latter institute has seen fit to send staff members abroad as visiting scholars, providing opportunity for people in the West to obtain impressions of the research interests and activities of this particular organization.

7.0 INDIVIDUAL ACADEMICIANS

Whereas this report has attempted to identify the organizational entities engaged either in vehicle dynamics research or having a vehicle test capability, it should be noted that there are individuals, who, by virtue of their expertise and training, should be considered as part of the worldwide community of technologists having specialized knowledge on vehicle handling topics. In general, these persons are academicians associated with engineering schools in a host of different countries. To a large extent, these persons reside outside the U.S. No listing is supplied, but people appropriate to a specific undertaking could be identified upon request.

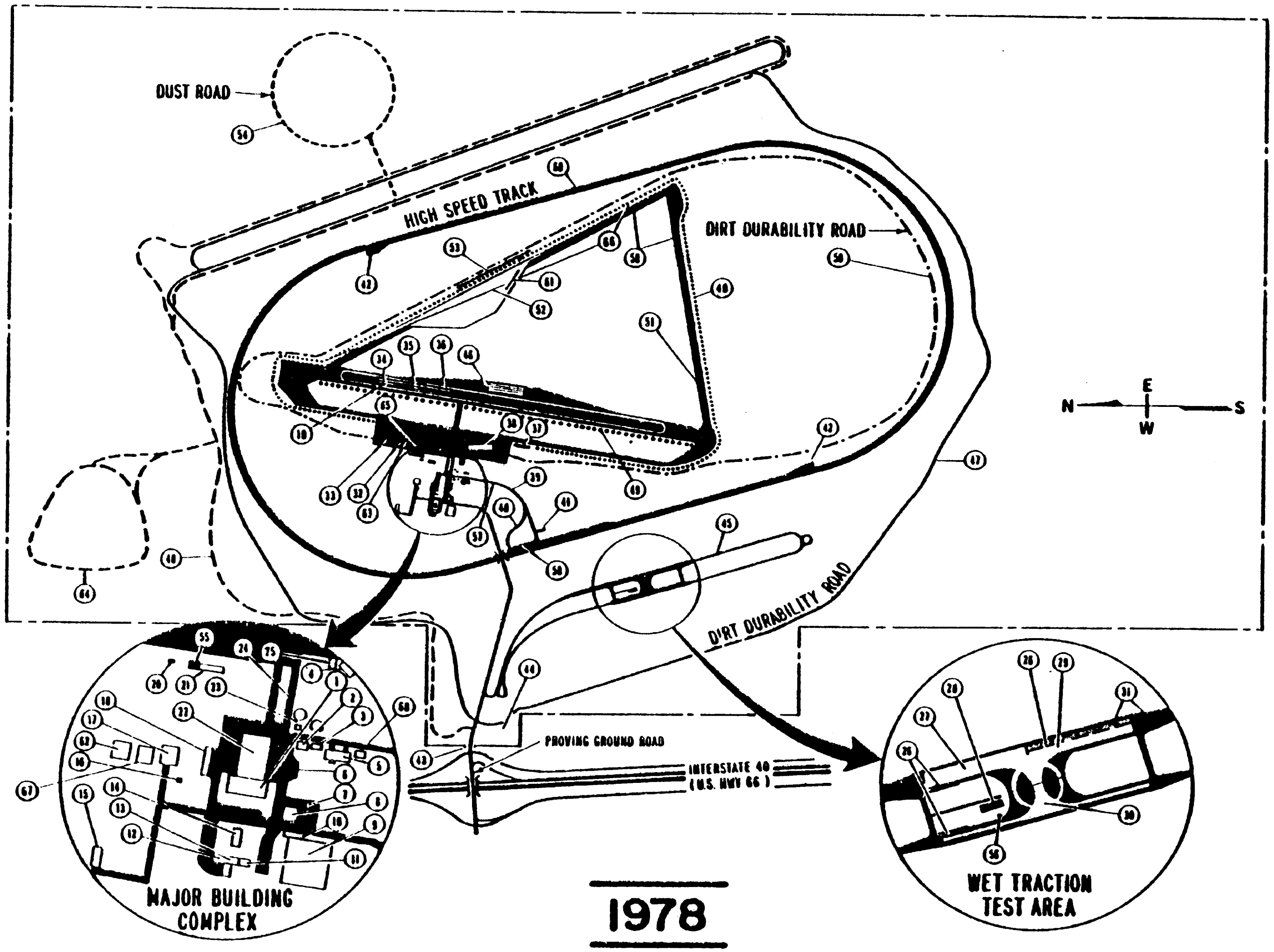
APPENDICES

Appendix A	Ford Motor Company, Arizona Proving Ground
Appendix B	Chrysler Corporation, Chelsea Proving Ground
Appendix C	American Motors Corporation, Burlington, Wisconsin Proving Ground
Appendix D	Volkswagenwerk AG, Wolfsburg, Research and Development Center
Appendix E	Daimler-Benz AG (Dr. Zomotor's lecture on measurement methods)
Appendix F	Daimler-Benz AG
Appendix G	Nissan Motor Company, Vehicle Test Department
Appendix H	Goodyear Tire and Rubber Company
Appendix I	Pirelli's tire test track at Vizzola Ticino
Appendix J	Dunlop tyre dynamics machine
Appendix K	University of Michigan Transportation Research Institute
Appendix L	Texas Transportation Institute
Appendix M	Pennsylvania Transportation Institute
Appendix N	Delft University of Technology, Vehicle Research Laboratory
Appendix O	Technische Universitat Braunschweig, Institut fur Fahrzeugtechnik
Appendix P	Stuttgart Research Institute for Motor Vehicle Engineering
Appendix Q	Calspan Corporation
Appendix R	Failure Analysis Associates
Appendix S	Transportation Research Center of Ohio
Appendix T	Porsche, Weissach test facility
Appendix U	TUV Rheinland Motor Vehicle Laboratory
Appendix V	Motor Industry Research Association
Appendix W	Japan Automobile Research Institute

Appendix X	Swedish Road and Traffic Research Institute (VTI)
Appendix Y	Transport and Road Research Laboratory
Appendix Z	Traffic Safety and Nuisance Research Institute, Japan Ministry of Transport
Appendix AA	Transport Canada

APPENDIX A

FORD MOTOR COMPANY
ARIZONA PROVING GROUND

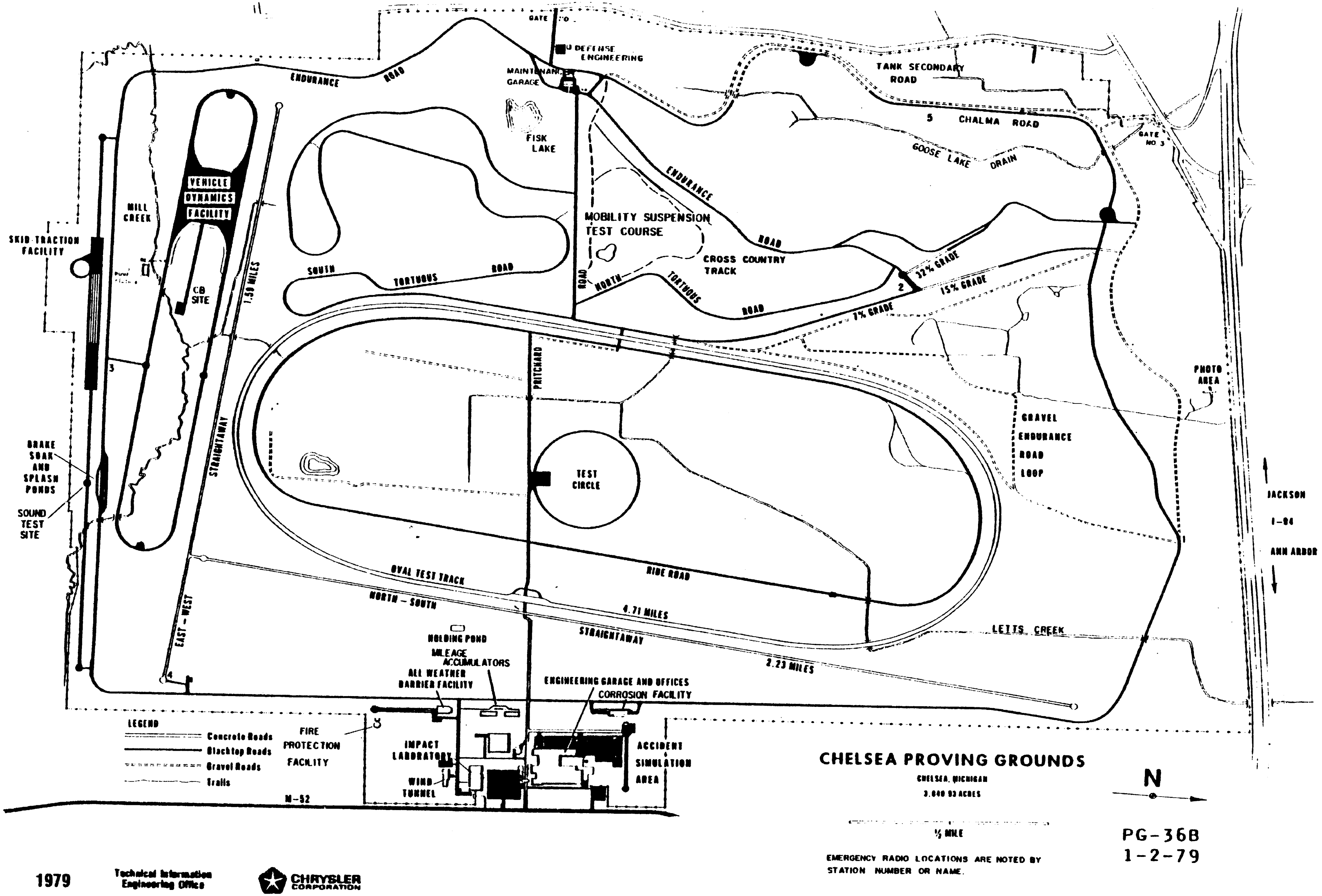


LEGEND

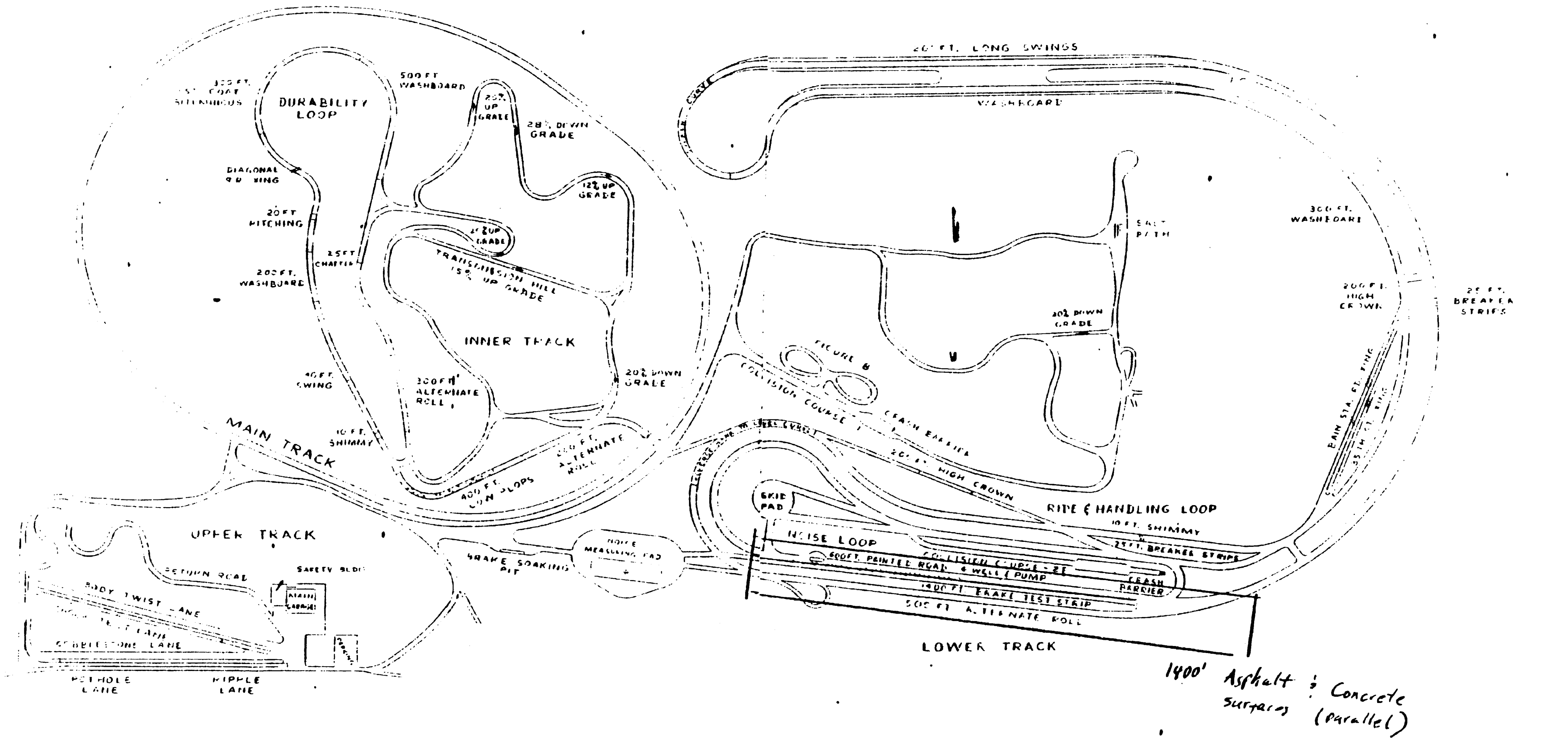
1 GENERAL OFFICES
2 FUEL ANALYSIS AND CARBURETOR FLOW LABORATORY
3 FUEL TANK QUICK DRAIN FACILITY
4 FUEL SPILLAGE TEST GRADES — 14% AND 30%
5 VEHICLE EMISSION AND DYNAMOMETER LAB
6 FUEL STATION
7 EMPLOYE PARKING LOT
8 COMMUNICATIONS AND SECURITY BUILDING
9 VEHICLE STORAGE COMPOUND
10 VISITOR PARKING
11 MANAGER'S OFFICE
12 ADMINISTRATIVE AND VISITING ENGINEER'S OFFICES
13 CAFETERIA AND SHIPPING AND RECEIVING
14 SWIMMING POOL
15 ENVIRONMENTAL EXPOSURE TEST FACILITIES
16 ELECTRICAL SUB STATION
17 NORTH STORAGE BARN
18 CARPORT
19 BRAKING AND ACCELERATION STRIP (ASPHALT)
20 OBSERVATION TOWER — SPECIAL EVENTS
21 EAST STORAGE BARN & SATELLITE GARAGE
22 VEHICLE SERVICES GARAGE
23 WATER TANK, RESERVOIR AND PUMP HOUSE
24 20% GRADE
25 BRAKE IMMERSION BATH
26 BROOMED CONCRETE
27 BURNISHED CONCRETE
28 UNDERGROUND WATER RESERVOIR
29 TROWELED CONCRETE
30 POLISHED PEBBLES
31 ASPHALT SHOULDER AND APPROACH ROAD
32 VEHICLE DYNAMICS TEST SURFACE — CONCRETE
33 TRAILER PARKING AREA
34 WEST BRAKING AND ACCELERATION STRIP (P C CONCRETE)
35 EAST BRAKING AND ACCELERATION STRIP (P C CONCRETE)
36 SAE AND CITY FUEL ECONOMY COURSE
37 SALT BATH
38 MUD BATH AND SALT HIGHWAY STRIP
39 HIGH SPEED TRACK ACCESS ROAD
40 BRAKE COOLER RETURN ROAD
41 30% GRADE
42 VEHICLE SOAK SHEDS
43 PROVING GROUND ENTRANCE
44 WATER WELL
45 WET TRACTION TEST AREA APPROACH ROADS
46 SKID REFERENCE SURFACES
47 DIRT DURABILITY ROAD
48 ALL-WHEEL DRIVE ROAD
49 CAR GRAVEL ROAD
50 DIRT DURABILITY ROAD FOR SALT CORROSION TESTS
51 ACCELERATED DURABILITY ROAD (P C CONCRETE)
52 VEHICLE DYNAMICS TEST SURFACE — ASPHALT
53 COBBLESTONE ROAD
54 DUST ROAD
55 HUMIDITY CHAMBERS
56 PARTS STORAGE BUILDING
57 DRUMMED FUEL STORAGE SHELTER
58 BRAKE COOLER
59 ASPHALTIC CONCRETE STRIPS
60 HIGH SPEED TRACK
61 SOUND LEVEL TEST SITE
62 TIRE STORAGE SHELTER
63 COLD ROOM
64 POWER HOP HILL
65 SALT SPRAY BOOTH
66 SILVER CREEK ROADS
67 CAR WASH
68 FUEL DRUM STORAGE

NOVEMBER, 1978

APPENDIX B


CHELSEA PROVING GROUNDS
CHELSEA, MICHIGAN
3,040 93 ACRES
½ MILE
EMERGENCY RADIO LOCATIONS ARE NOTED BY STATION NUMBER OR NAME.
PG-36B
1-2-79
N
JACKSON
I-94
ANN ARBOR
GATE NO 3
TANK SECONDARY ROAD
5 CHALMA ROAD
GOOSE LAKE DRAIN
DEFENSE ENGINEERING
MAINTENANCE GARAGE
FISK LAKE
ENDURANCE ROAD
MOBILITY SUSPENSION TEST COURSE
CROSS COUNTRY TRACK
NORTH TORTUOUS ROAD
SOUTH TORTUOUS ROAD
32% GRADE
15% GRADE
7% GRADE
PHOTO AREA
GRAVEL ENDURANCE ROAD LOOP
PRITCHARD
TEST CIRCLE
OVAL TEST TRACK
RIDE ROAD
4.71 MILES
NORTH – SOUTH
STRAIGHTAWAY
2.23 MILES
LETTS CREEK
EAST – WEST
1.59 MILES
VEHICLE DYNAMICS FACILITY
CB SITE
MILL CREEK
SKID-TRACTION FACILITY
BRAKE SOAK AND SPLASH PONDS
SOUND TEST SITE
HOLDING POND
MILEAGE ACCUMULATORS
ALL WEATHER BARRIER FACILITY
ENGINEERING GARAGE AND OFFICES
CORROSION FACILITY
FIRE PROTECTION FACILITY
IMPACT LABORATORY
WIND TUNNEL
ACCIDENT SIMULATION AREA
M-52
LEGEND
Concrete Roads
Blacktop Roads
Gravel Roads
Trails
1979
Technical Information Engineering Office
CHRYSLER CORPORATION

APPENDIX C



DURABILITY LOOP
500 FT. WASHBOARD
DIAGONAL
20 FT. PITCHING
25 FT. CHATTER
200 FT. WASHBOARD
40 FT. SWING
10 FT. SHIMMY
MAIN TRACK
INNER TRACK
28% DOWN GRADE
12% UP GRADE
TRANSMISSION HILL 15% UP GRADE
300 FT. ALTERNATE ROLL
20% DOWN GRADE
200 FT. ALTERNATE ROLL
400 FT.
UPPER TRACK
SAFETY BLDG.
RETURN ROAD
BODY TWIST LANE
COBBLESTONE LANE
POTHOLE LANE
RIPPLE LANE
BRAKE SOAKING PIT
NOISE MEASURING PAD
20 FT. LONG SWINGS
WASHBOARD
SALT PATH
300 FT. WASHBOARD
200 FT. HIGH CROWN
25 FT. BREAKER STRIPS
20% DOWN GRADE
FIGURE 8
COLLISION COURSE
CRASH BARRIER
HIGH CROWN
RIDE & HANDLING LOOP
10 FT. SHIMMY
25 FT. BREAKER STRIPS
SKID PAD
NOISE LOOP
600 FT. PAINTED ROAD & WELL & PUMP
CRASH BARRIER
1400 FT. BRAKE TEST STRIP
500 FT. ALTERNATE ROLL
LOWER TRACK
1400' Asphalt & Concrete surfaces (parallel)

134-A

8

APPENDIX D

4. AUTOMOBILE HANDLING TESTS

Numerous facilities are used for the purpose of testing vehicle handling. One of them is the vehicle dynamics test area. The dimensions of the maneuvering area of approximately 500 by 500 metres of flat and level surface make it the largest area for this purpose in Europe. Fig. 11 presents a horizontal plan of the facility.

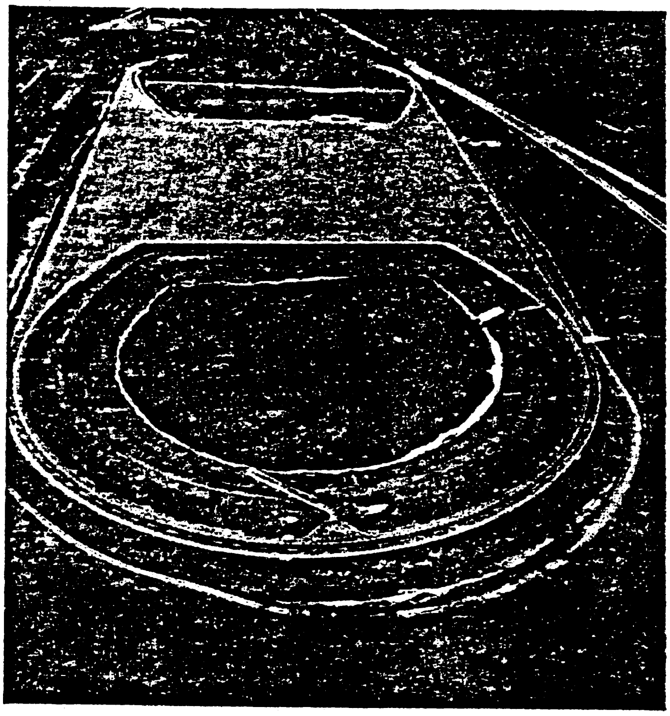


Fig. 11

The acceleration loops allow the operator to bring the test vehicle up to a predetermined high speed, if required, and to stabilize in this condition, before entering the actual maneuvering area. Besides conventional handling tests high speed tests up to and beyond the limits of control can be conducted safely without the risk of running out of braking distance.

Characteristical data of the vehicle dynamics test facility:

Overall length: 1550 metres
Overall width: 650 metres
Total area including the two acceleration loops: 307000 m²
Pavement: Fine grain asphalt concrete specified for heavy traffic
Inclination for water drainage: 1 %
Evenness: ± 2 millimetres per 4 metres in every direction
Leveled unpaved area within the larger acceleration loop: 115000 m²
Dimensions of the actual trapezoid shaped maneuvering area:
Basis 1: 540 metres
Basis 2: 450 metres
Height: 490 metres
Radius of the larger acceleration loop: 305 metres
Radius of the smaller acceleration loop: 205 metres.

Within the smaller loop a water storage basin is located for drainage purposes. The acceleration loops consist of two-lane super-elevated roads of a total width of 10 metres.
The funnel-shaped junctions with the maneuvering area are clothoids of 70 metres length with a design speed of 200 km/h. Besides testing by actual drivers, handling tests can be performed by remotely controlling the test vehicle from a follow car or from a monitoring and control centre (MC-centre). Fig. 12 shows a device which allows to control steering, brake and accelerator from a follow vehicle.

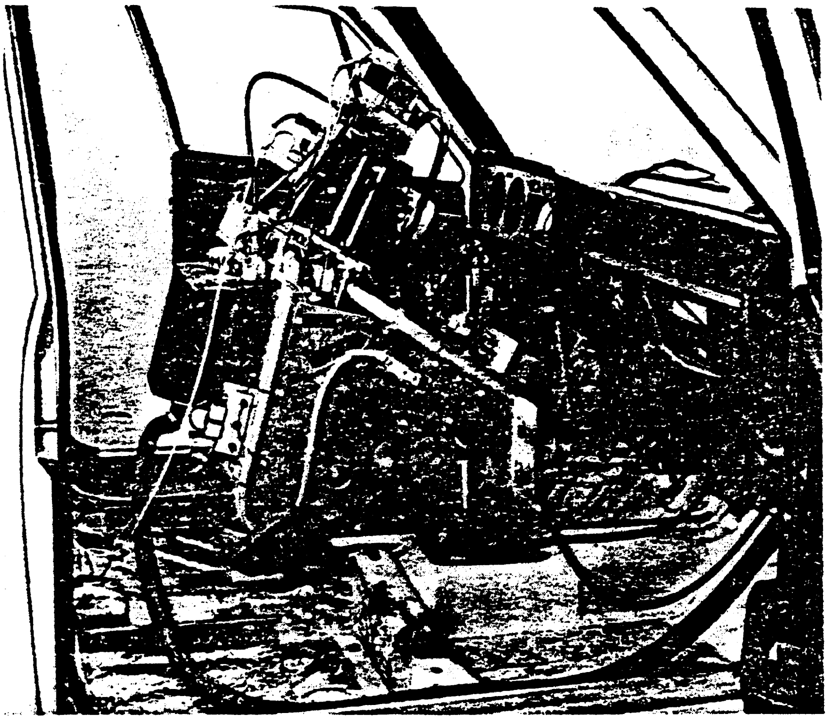


Fig. 12

The second possibility is the use of a remote control system from a stationary monitoring and control centre (MC-centre) with telemetric feedback from the test vehicle to the operator. Electronical and mechanical components installed in the test vehicle are designed to withstand impacts up to 80 km/h without damage to vital parts. Data are not only transmitted from the MC-centre to the test car; response data like steering angle, steering couple, brake line pressure, velocity and lateral acceleration will be telemetrically transmitted back to the MC-centre, where they serve as immediate information for the operator. Input and response data are recorded for evaluation.
An additional modification of the remote control system into a telemetric microprocessor-controlled driving-machine is in the planning stages. Reproducible input parameter variation will generate response data for further refined evaluation of automobile handling characteristics.

Fig. 13

Foreground: Antenna installation
Middleground: MC-Centre and test vehicle
Background: Maneuvering area

The picture presents the remote control system on the vehicle dynamics test area with stationary manual lock-on antenna installation. The MC-centre of the system is built into a Volkswagen LT Bus. In essence it simulates the driver's position and controls in an automobile.

Fig. 14: Driver's seat in the MC-centre with a view on steering wheel, TV-monitor and feedback instruments.

The test vehicle is controlled by steering angle, accelerator- and brake-inputs in the MC-centre. The steering torque of the test vehicle is fed back into the steering device in the MC-centre giving the operator sensible information of the attitude of the test car.

The TV-monitor enables the operator to drive the test car to any predetermined destination in distances up to one kilometer. Other important feedback data are indicated by instruments unterneath the monitor.

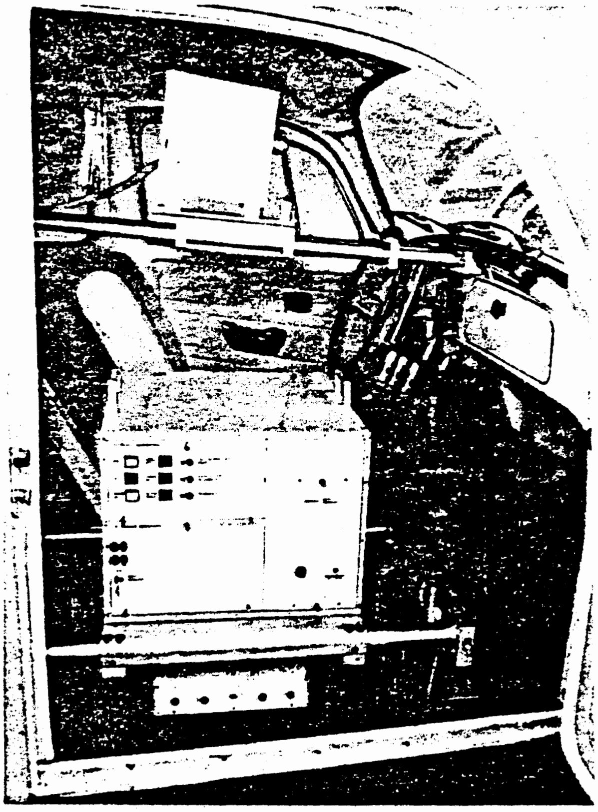


Fig. 15: View of steering and brake servo motors through the passenger door.

A view into the test vehicle shows the installation of electronic components as well as the servo motors for steering and brake. The TV-camera is mounted at driver's eye level,
Data generated by measuring instruments in the test car can be telemetrically transmitted to the MC-centre. They can be recorded on paper or on magnetic tape (see fig. 16).

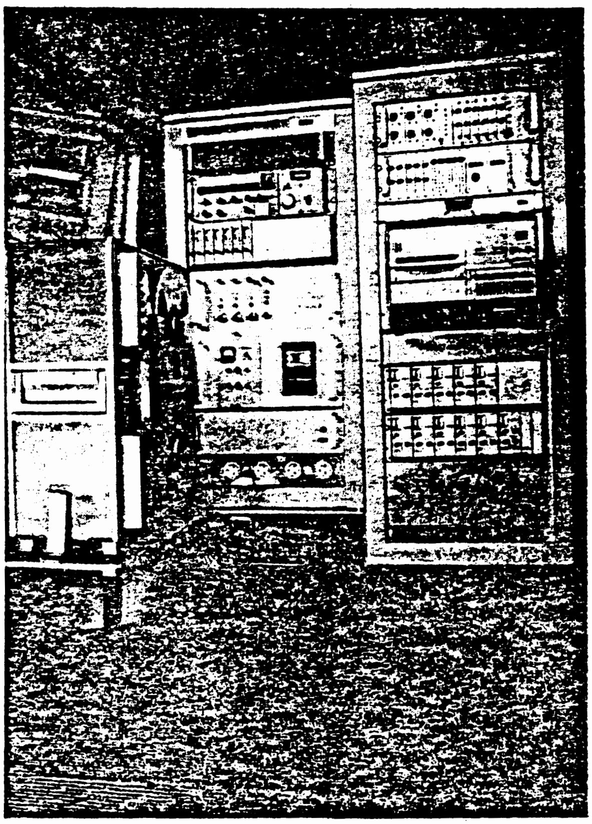


Fig. 16

External data recording decreases the weight of test vehicle installations and speeds up the running of extensive test programs.

APPENDIX E

HORIZONTAL MOTION OF AUTOMOBILES, VEHICLE HANDLING, MEASUREMENT METHODS AND EXPERIMENTAL RESULTS

Dr.-Ing. Adam Zomotor
Daimler-Benz AG
Postfach 2 02
7000 Stuttgart 60

INTRODUCTION

In addition to the subjective evaluation of vehicle handling, measurements of vehicle dynamic are more and more used as an aid in the development of vehicles. The general desire to retain the feeling of skilled test engineers in the shape of reproducible data for the purpose of obtaining the means for comparative improvements resulted especially during the past years in an increased application of measuring techniques. Based on this development, a number of test methods were established which cover important driving situations for vehicle evaluation. The same assignment and last but not least the cooperation between manufacturers of vehicles and the manufacturers of measuring instruments, as well as between institutes, resulted worldwide in a certain standardization of measuring methods and measuring instruments. The successful support of research and development by means of measurement requires that the measuring results of different variations are available as quickly as possible. Meeting such a demand assumes the use of computers for data input and evaluation. The following is a description of the measuring instruments now in general use for vehicle measurements.

MEASURING INSTRUMENTS FOR VEHICLE MEASUREMENTS

To cover the variables relevant to vehicle dynamic the manufacturers of measuring instruments, to a great extent in cooperation with the manufacturers of vehicles, have been developed special measuring data transducers and evaluation instruments.

Longitudinal and Lateral Acceleration

In most cases accelerations and decelerations in a horizontal level are measured with an accelerometer mounted on a stable platform, Fig. 1. Stabilizing excludes any influence

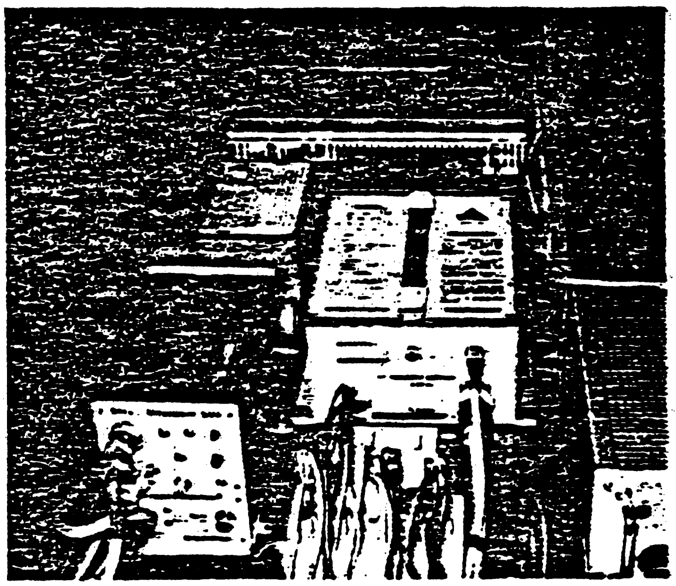


Fig. 1:
Stable Platform (Novotechnik)

on measuring results by components of gravity due to both the vehicle roll angle and pitch angle.

The measuring direction remains horizontal. However, influences caused by a road surface inclination have to be taken into consideration.

Accelerations can also be measured with transducers mounted directly on the sprung mass of the vehicle. In this case its output has to be corrected for the component of gravity on the accelerometer axis due to both the vehicle roll angle and pitch angle.

Forward and Lateral Velocity

Forward and lateral vehicle velocity are mainly measured with non-contact speed sensors. The Leitz sensors Correvit L and Q, Fig. 2 used for this purpose are working on account of optical correlation method with spatial frequency filtering. The surface structure of the road is reproduced on a grating

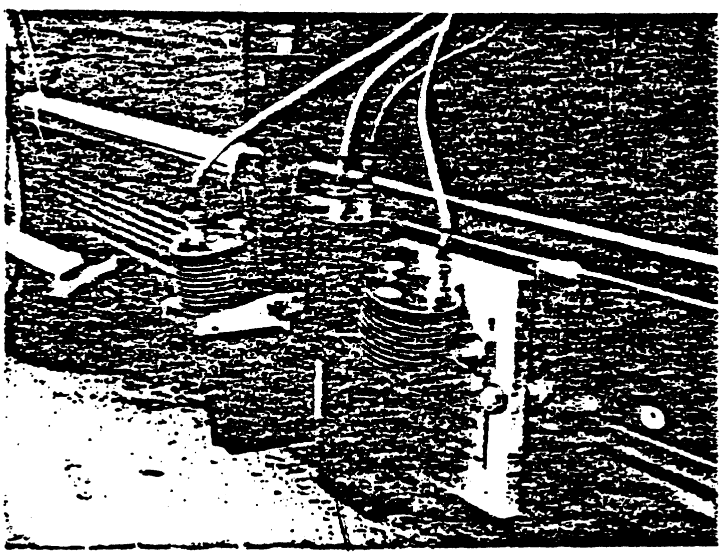


Fig. 2: Optical Speed Sensors on the Vehicle
Leitz Correvit L and Q

and the passing light is collected by a photographical recorder. The frequency of the received signal is proportional to the velocity at which the picture field is moved normal to the grid lines.

In another often used method the forward velocity is determined by the spin velocity of the wheel. For this purpose, an inductive impulse transducer is used in combination with a toothed disk which rotates with the wheel. A brake disk, for example, is suitably prepared for this purpose, Fig. 3. The impulses are then processed by a frequency to voltage converter.

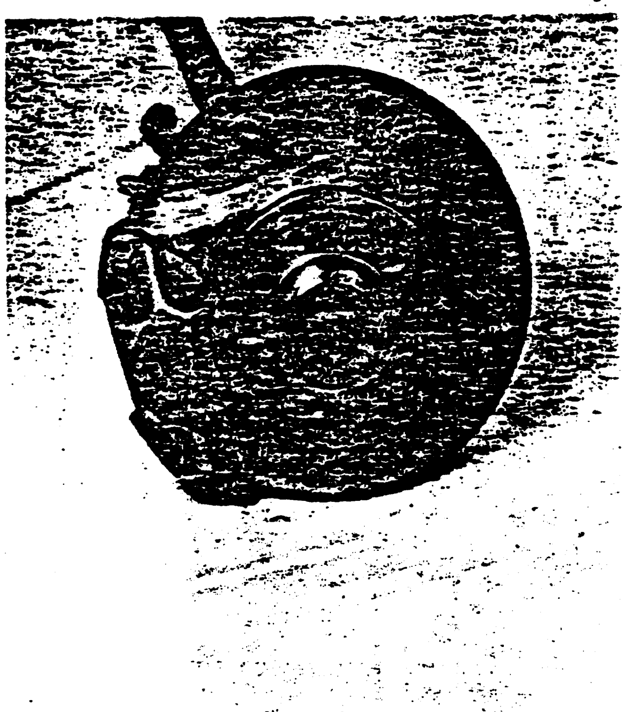


Fig. 3:
Impuls Transducer and toothed brake disk for measuring forward velocity

Yaw Angle, Yaw Velocity

For yaw angle measuring a directional gyro stabilized in a vertical plane may be used, Fig. 4. The turning of the gyro housing attached to the vehicle in relation to gyro is obtained by a potentiometer. A built-in differentiator can also be used to derive the yaw velocity.

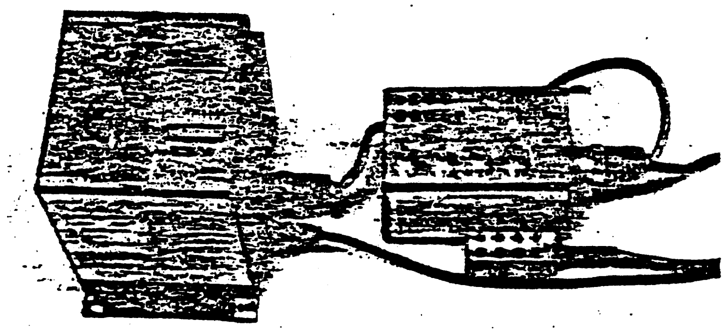


Fig. 4: Directional Gyro for obtaining yaw angle and yaw velocity (Novotechnik)

Another possibility for direct measurement of the yaw velocity is the spring restrained rate gyro, Fig. 5. The control current for restraining the gyro is proportional to the yaw velocity.

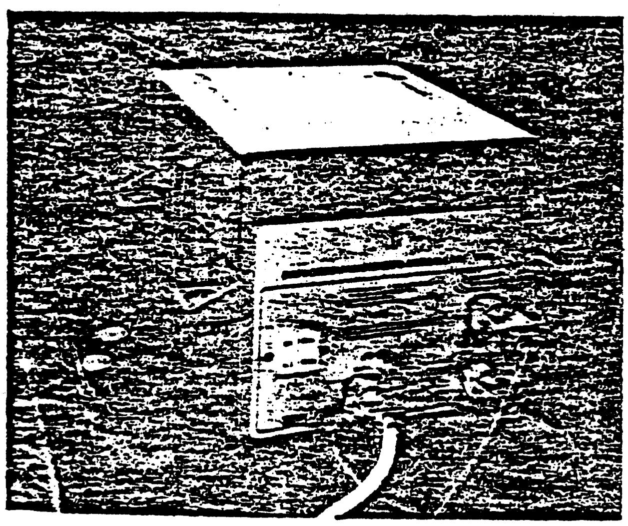


Fig. 5:
Spring Restrained Rate Gyro (Novotechnik)

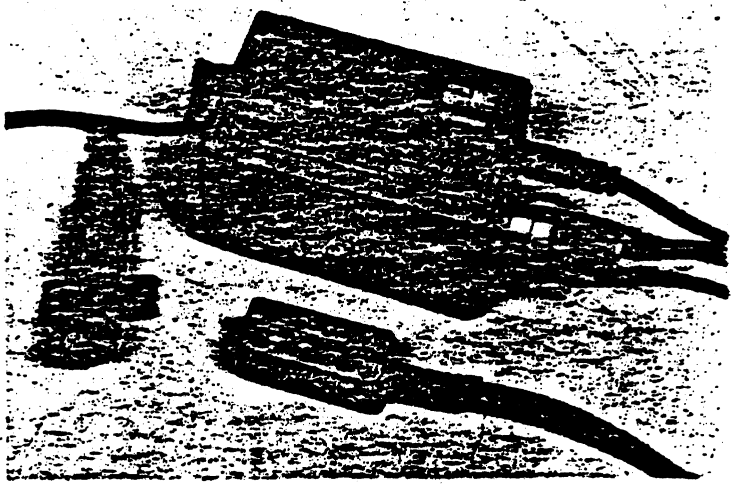


Fig. 6: Rate Sensor (Novotechnik)

For direct measurement of the yaw velocity the so-called rate sensor is often used, Fig. 6. The principle is based on the fact that during the rotation of the housing a gas jet is diverted by the Corriolis force. This diversion is proportional to the angular velocity. The small dimensions and the robustness of the instrument are of advantage. There are no sensitive bearings in contrast to the gyro.

Steering Wheel Angle, Front Wheel Angle

Special measuring steering wheels are used for measuring the steering wheel angle, Fig. 7. The angles are transferred to a potentiometer by means of a gear wheel transmission. A torsion measuring hub with a strain gages bridge is integrated in the measuring steering wheel for measuring the torque.

A number of devices has been developed for measuring the front wheel angle in relation to the vehicle body. The device for measuring the front wheel lock while driving consists of

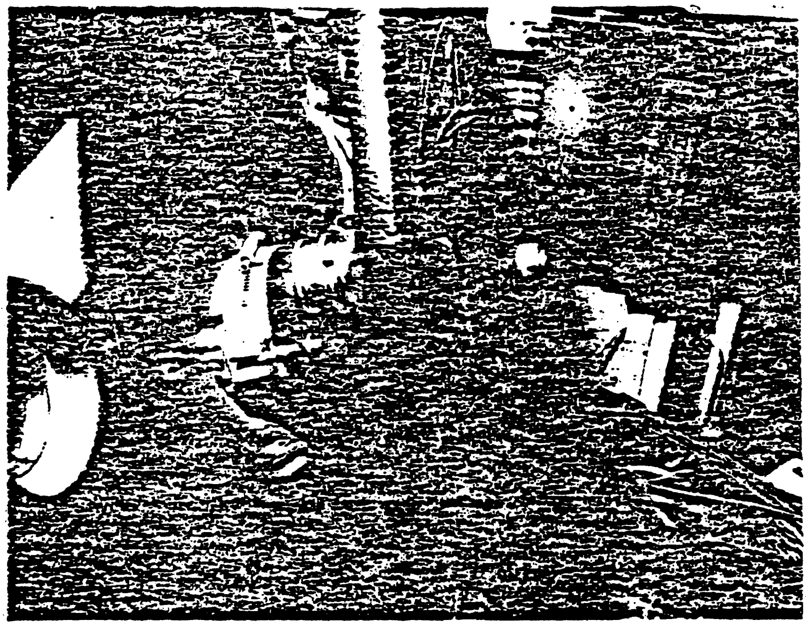


Fig. 7: Measuring Steering Wheel for obtaining steering wheel angle and torque

a lever mechanism which presses a sensor against a face plate on the wheel. The face plate is attached to the hub stud and is not rotating with the wheel. The steering angle of the front wheel is transmitted to an electric angle transducer. Changes in track width and camber are compensated by guiding on a parallelogram. This can be attached to the vehicle body by means of a frame, Fig. 8.

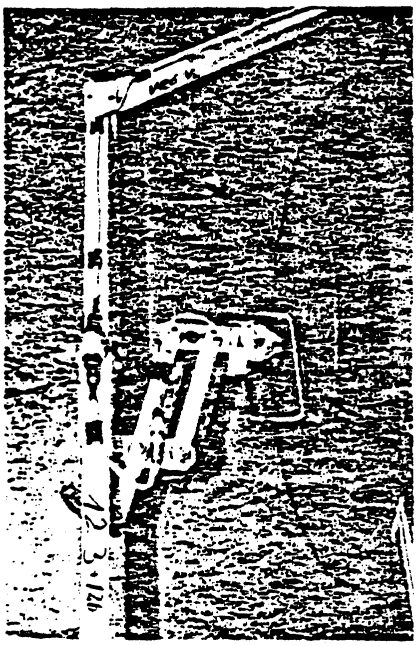


Fig. 8: Device for measuring front wheel lock angle

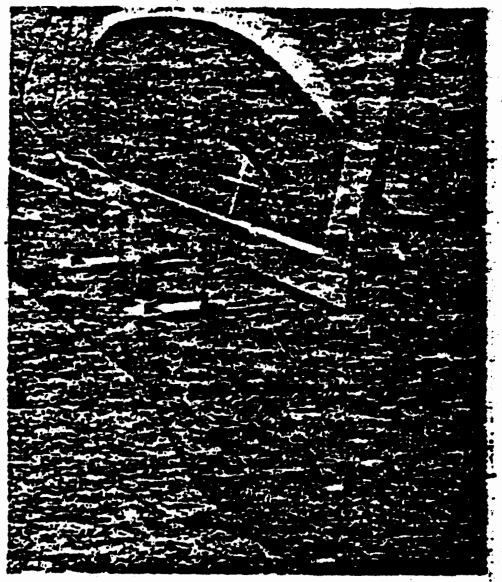


Fig. 9:

Inductive Transducers for measuring wheel toe changes on the rear axle

While driving the vehicle, changes of the rear wheel toe angle in relation to the body, can be obtained with the same device. The face plate is rotatably mounted on the rear wheel rim and held by means of an arm in relation to the vertical axis, so that the face plate is not rotating with the wheel. Since the angles on the rear axle are only small, simple inductive transducers can here also be used, Fig. 9.

Sideslip Angle, Slip Angle

Sideslip and slip angles can be computed from the measured forward and lateral velocity or can be directly determined by a rotatably suspended trolley wheel. The measuring instruments can be attached to the vehicle body for measuring the Sideslip angle, see Fig. 2. For measuring the slip angle, these measuring instruments are attached to the wheel. For this purpose, the optical forward and lateral speed sensor Fig. 10 may be used or a trolley wheel may be attached to the hub stud, Fig. 11. The rotatably mounted trolley wheel arm adjusts itself in direction of the movement. A potentiometer measures the angle in relation to the wheel plane, the

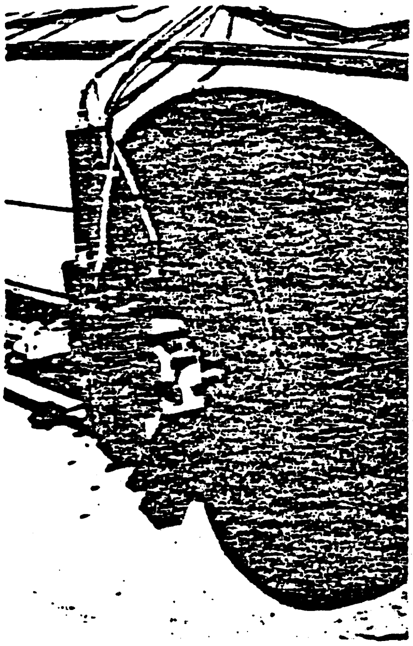


Fig. 10:
Leitz Sensors on the wheel for measuring slip angle

slip angle. A second potentiometer permits determining the camber, that is the inclination of the wheel plane to the road surface.

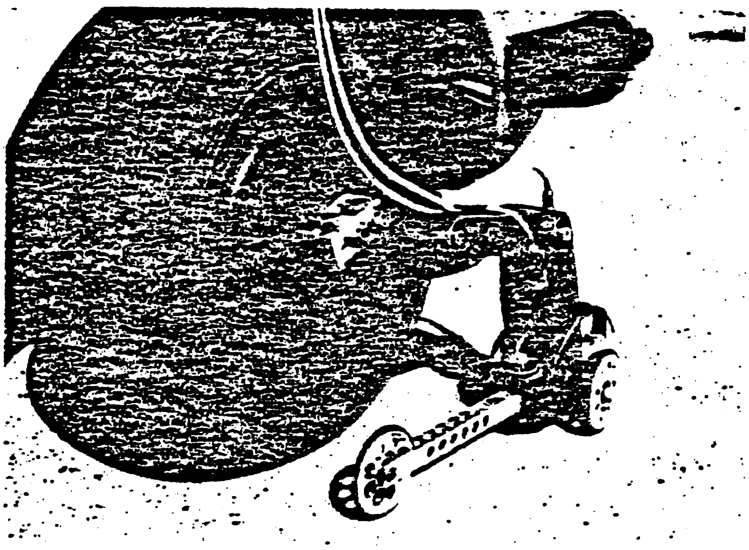


Fig. 11: Trolley Wheel for measuring slip angle (Eng. School Offenburg)

Roll Angle, Pitch Angle

The stable platform (refer to Fig. 1) is also suitable for measuring the roll or pitch angle of the vehicle. The swivel movement of the instrument housing firmly attached to the vehicle as compare to the always horizontally stabilized platform is obtained by a potentiometer. Another possibility is the non-contact measuring of the ground distance at three points of the vehicle by optical distance sensors, Fig. 12. Roll and pitch angle can be computed from the ground distances and the geometric dimensions of the locating points of the three sensors on the vehicle body.

Brake Pressure

The oil pressure in the braking system is obtained by means of a pressure transducer, which is installed at the master cylinder output.

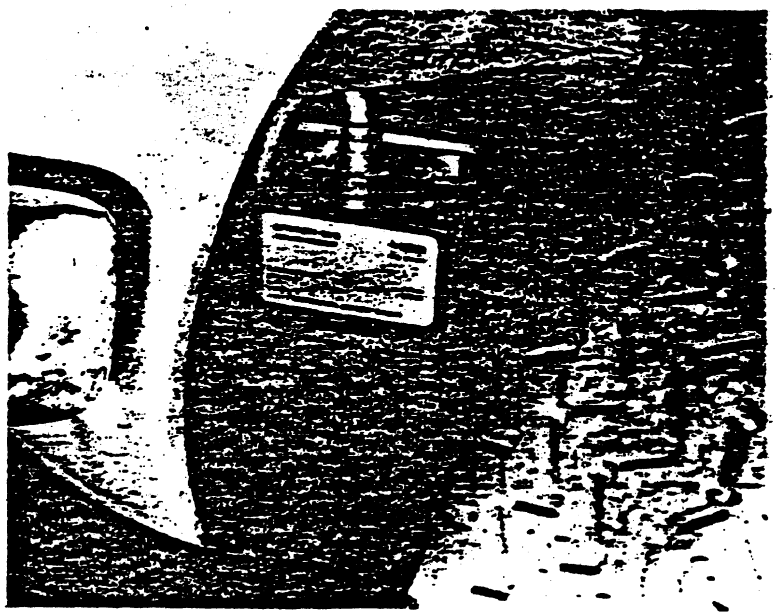


Fig. 12: Optical Distance Sensor for obtaining roll and pitch angle (Novotechnik)

RECORDING AND EVALUATION METHODS

In practical measuring techniques, a few methods and instruments for recording and evaluation of pertinent data have been extracted. Depending on assignment and equipment the following methods can be applied in general:

Direct Recorder

The most simplified method is the use of a directly writing oscillograph for recording if few measuring variables and short measuring periods are involved, Fig. 13. The time functions are immediately displayed while measuring. Evaluations are made by measuring amplitudes manually. The method is less suited for fast vibrations where very many data are coming up. In such cases it will nevertheless be useful to observe basic connections if the signals recorded on magnetic tape are made visible on an oscillograph.

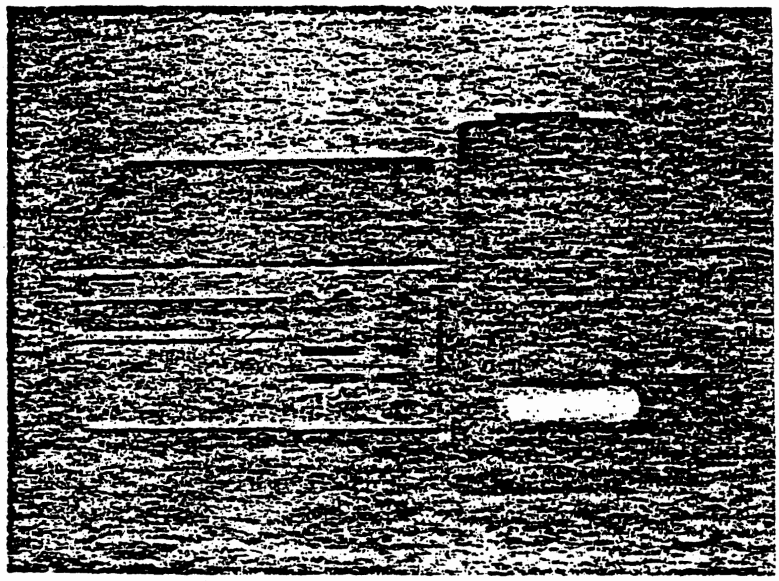


Fig. 13: Directly Recording Oscillographs
Visicorder (Honeywell)

FM Magnetic Tape

For long measuring periods and quick processes, the recording with frequency modulation on a tape recorder has proven its worth, Fig. 14. The frequency modulated analog tapes are subsequently digitalized for evaluation by a computer. The conversion of the tapes requires additional time and computer capacity, for this reason the method should be used where results are not required immediately. The number of channels is limited.

With an 1/2" tape seven tracks and one voice track are available. A disadvantage is that fluctuations of tape speed will show up as measuring faults and therefore very accurate synchronization is required. Only a few tape recorders are available to withstand any acceleration suitable for use in the vehicles; they are in addition relatively large and are consequently rather heavy.

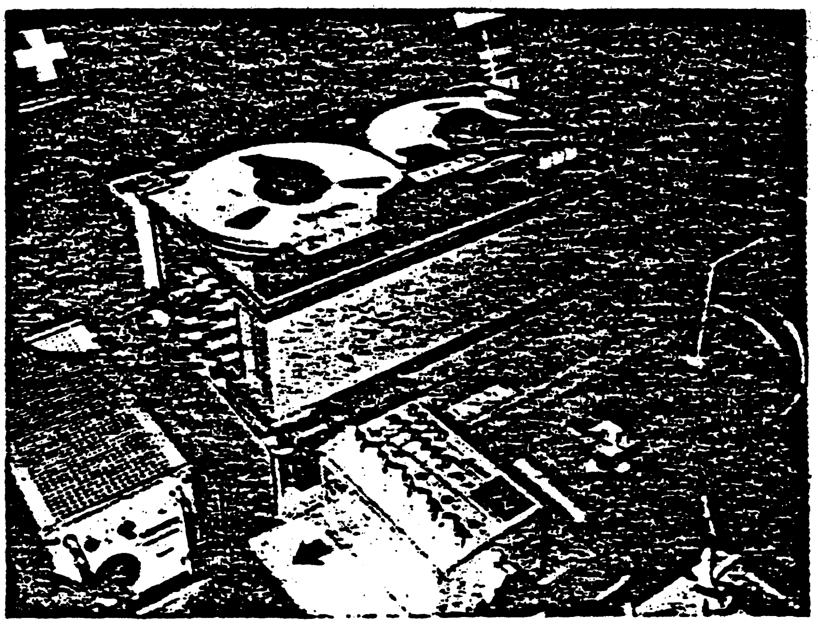


Fig. 14: FM-Tape Recorder, Frequency Modulation, (Honeywell)

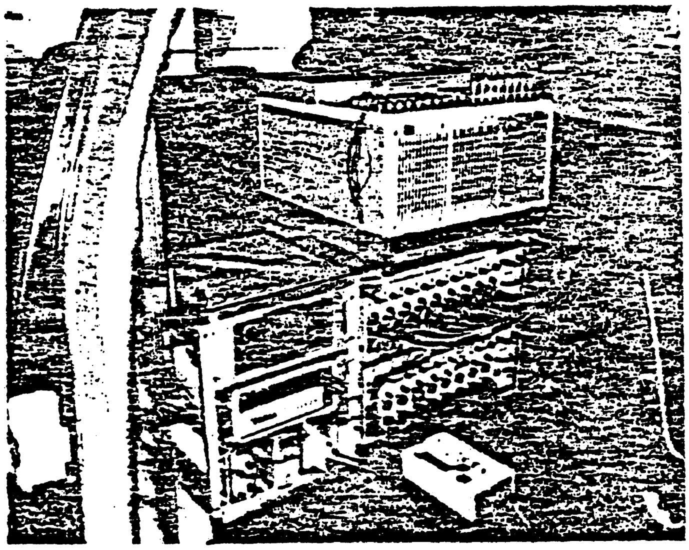


Fig. 15: PCM Measuring System, Pulse-Code-Modulation, (Lennartz and Hewlett-Packard)

PCM Method

The recording of measuring signals with a PCM system (pulse-code-modulation) permits the storage of large quantities of data at low space requirements for the unit, Fig. 15. For this method regular samples are taken from analog signals and are shown as a binary digit on the magnetic tape. The time-equivalent samples of different functions are recorded on a tape by a multiplex system one after the other. This system permits the recording of eight functions on one track. Upon conversion these measuring variables can directly be evaluated by a computer. A disadvantage is that the measuring signals are not visible and that the evaluation cannot be made at the test site.

Mobile, Computer-Aided Measuring and Evaluation System

The high demands of today's practical research and the need to quickly obtain large volumes of data for immediate evaluation at the test site lead to the development of a mobile, computer-aided measuring and evaluation system. The measuring data recording system comprises the respectively required analog amplifiers, a process computer with operating terminal and a digital cassette mechanism for intermediate storage of the recorded data. The evaluation system includes a desk computer (e.g. HP 9845 B) with an additional cassette mechanism and a four-colour plotter of DIN A 3 size to issue the final diagrams. For a combination of the two systems there are basically two possibilities available, the "OFF LINE" and the "ON LINE" data connection, Fig. 16.

In most cases, the "OFF LINE" data transfer performed by a digital cassette is used in practice. For this purpose the data collecting unit with signal processing, storage and operating terminal is installed in the test car, Fig. 17 as shown in Fig. 16 too. The evaluation equipment is housed in a separate vehicle acting as a mobile computer center, Fig. 18.

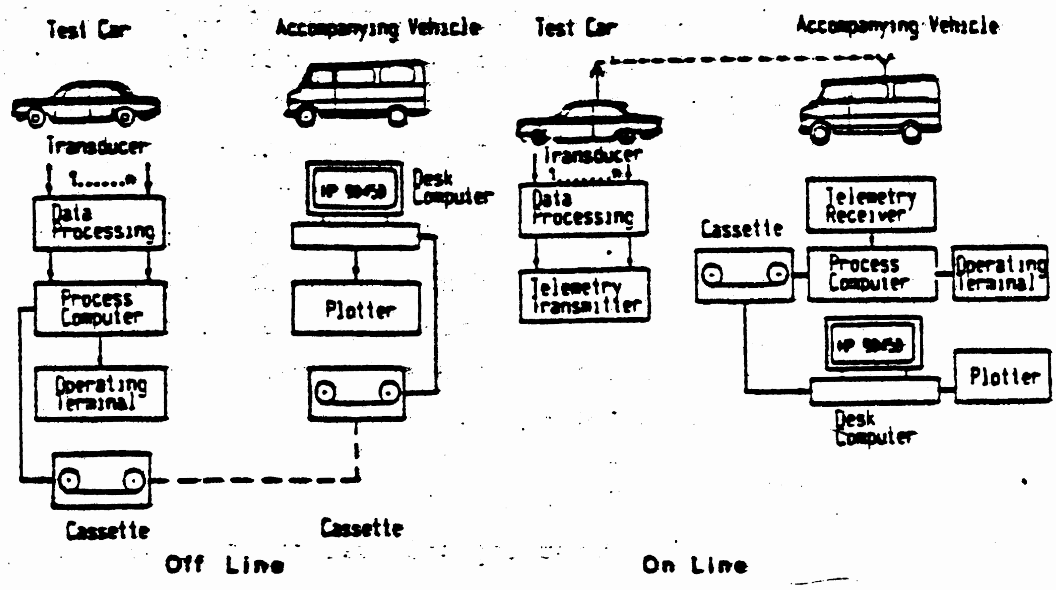


Fig. 16: Mobile Measuring and Evaluation Systems

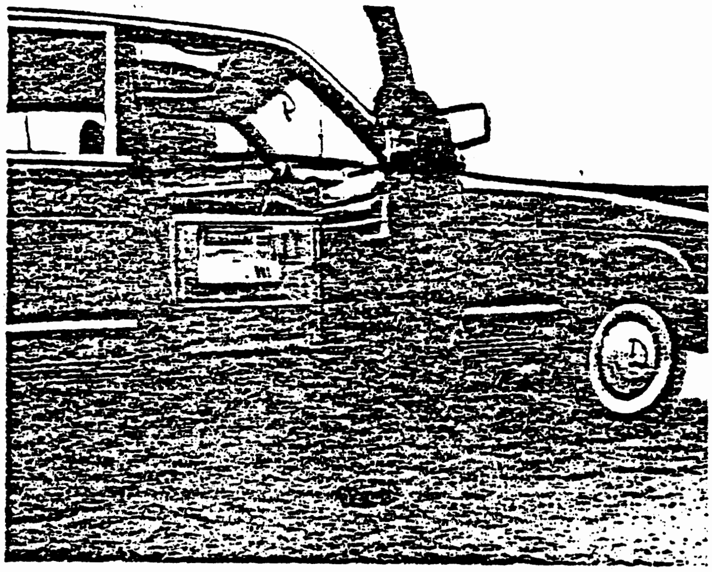


Fig. 17: Measuring Equipment VCS 102 installed in the test car

Following one or several measuring series the data cassette and the printout are taken from the test car and the evaluation

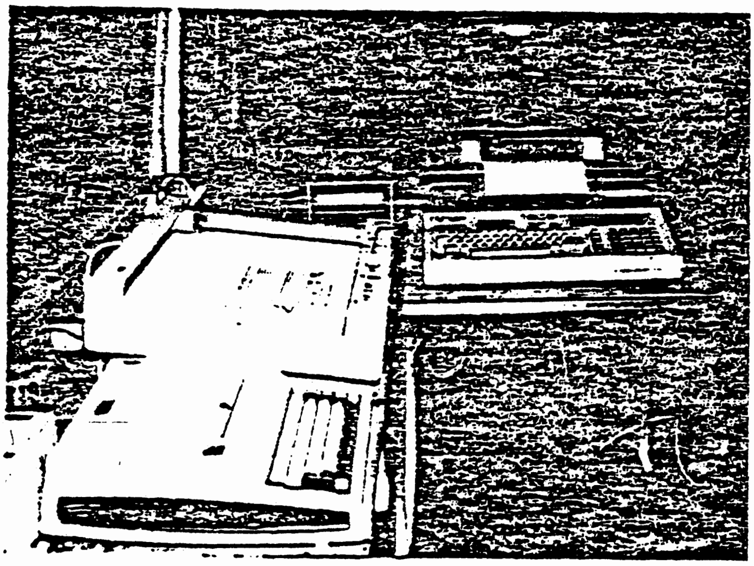


Fig. 18: Evaluation Equipment with desk computer, plotter and operating terminal installed in the accompanying vehicle

in the mobile computer center will start. Measuring will go on in the test car with a second cassette, while the first cassette is evaluated.

For the "ON LINE" data transfer the data are transferred from the test car by telemetry into the accompanying vehicle, Fig. 16. If, on account of technical reasons only a few instruments can be installed in the test car, this system is preferred. The test car will then hold only the required transducers with the respective data processing (analog amplifier and telemetry transmitter).

However, experience has shown that this measuring method can only be used if the accompanying vehicle can be positioned close to the test track with visual contact to the test car, if possible, since otherwise during telemetry transmission disturbances may occur depending on the environment.

TEST METHODS AND MEASUREMENT PROCEDURES FOR VEHICLE DYNAMICS

Today, on the basis of experience selected individual disciplines are usually examined in open loop to obtain technical measurements of the vehicle handling. Measurements in closed loop, driver/vehicle/environment have shown that the determination of an absolute measuring assessment is not possible due to the large variation of the driver characteristic An attempt is therefore being made to find a correlation between the measurement results in open loop and the subjective evaluation of skilled test engineers in closed loop. Due to the large number of possible driving manoeuvres and operating conditions objective measurement of the entire vehicle handling is not possible, only subsectors can be recorded and compared for different vehicles.

Measurement of the Tractive Resistances

The rolling resistance and aerodynamic drag are primary factors for the fuel consumption of a passenger car. For this reason many attempts have been made in the past to measure these variables under realistic conditions using various methods.

One possibility is the measurement of the drive torque with the aid of highly sensitive torque measurement hubs. This allows the total tractive resistance without the losses in the drive train to be recorded. Due to the sensitivity of the measurement hubs such tests can only be accomplished on a blocked track while avoiding sharp starting, braking and turning manoeuvers.

To determine the rolling resistance the vehicle to be tested can be pulled by a second vehicle or with a cable winch, whereby the tractive forces in the tow cable are measured. The disadvantages of this method are that the measurements can only be accomplished at very low speed to eliminate the aerodynamic drag and that strong disturbances resulting from oscillation of the cable are superimposed on the measurement values. An improvement to the towing method is achieved by protecting the vehicle from the aerodynamic drag with a large trailer, Fig. 19. The tractive force between the trailer and the protected vehicle is measured with a special tow bar. The measured force corresponds to the pure rolling resistance. The measurement can also be accomplished at higher speeds. This method is, however, a large-scale affair due to the required trailer.

The coast-down test which has already been in use for some time offers the possibility to measure the entire tractive resistance and subdivide it into aerodynamic drag and rolling resistance. Experience has shown that, above all, to separate the aerodynamic and rolling resistance an extremely high degree of accuracy is required in measuring the values. The previous measuring techniques did not assure this degree of accuracy.

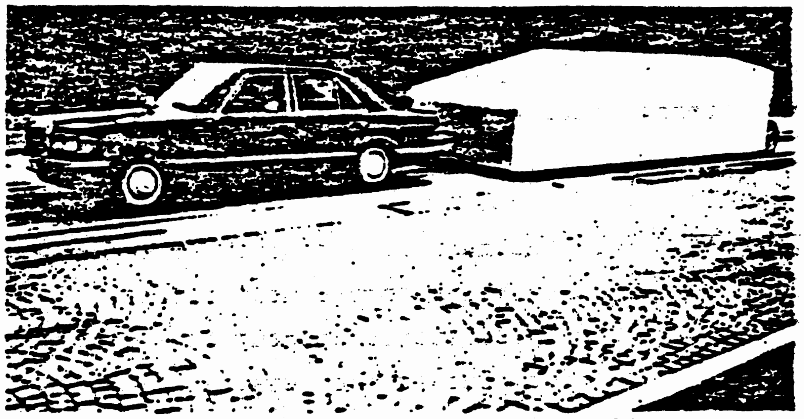


Fig. 19: Rolling Resistance Measurement by towing behind a trailer to eliminate Aerodynamic Drag

Only in the recent past it has become possible to accomplish such measurements with the required degree of accuracy using modern sensor and calculation technology. Various methods were also examined for the coast-down test. The method, which led to the best results will be shown here.

Up to driving speeds of approximately 150 km/h the following applies for the deceleration resulting from tractive resistances on an even track without wind:

$$a_x = A v_x^2 + B v_x + C$$

The aerodynamic drag is proportional to the square of speed:

$$W_L = m A \cdot v_x^2 \quad \text{where} \quad A = c_w \cdot F \cdot \frac{\rho}{2}/m$$

or solved for the drag coefficient:

$$c_w = \frac{A \cdot m}{F\ \rho/2}$$

where the air density equals

$$\rho\,(kg/m^3) = 0.465\ \frac{P\ (Torr)}{273 \cdot T\ (^{\circ}C)}$$

The rolling resistance consists of one term which is proportional to the speed and one constant term:

$$W_R = (B\ v_x + C)\ m$$

where the speed-dependent coefficient of rolling resistance:

$$f_R\ (v) = v_x \frac{B}{g} + \frac{C}{g}$$

a_x = vehicle longitudinal acceleration
v_x = vehicle speed
m = vehicle mass
F = frontal area of the vehicle
p = air pressure
T = air temperature
g = natural gravity

The linear statement for the rolling resistance only applies to approximately 150 km/h depending upon the make of the tire.

At higher speeds terms of a higher order have also to be taken into consideration.

In coast-down tests either the deceleration or the speed can be measured. Very high requirements are placed upon the accuracy of the measurement, because all methods react very sensitively to measurement inaccuracies. In the tests the speed was measured with optical Leitz sensors and the acceleration curve ascertained through numerical differentiation.

In measuring the speed, the road surface inclination is also included (a gradient of 0.1 % results in a speed deviation of 1 m/s for a measurement duration of 100 s; coast-down time from 120 km/h to stand-still approximately 170 s).

Therefore measurement is only possible on a road with a known gradient. Correction of the measured speed:

$$v\ (t) = v_m\ (t) + \int_0^t b\ (t)\ dt$$

where

$$b(t) = g \cdot \sin \vartheta_s (t) \qquad \vartheta_s = \text{angle of inclination}$$

Starting at a fixed point each individual position, the associated angle of inclination and therefore the interfering acceleration can be determined from the road profile through integration of the measured speed. The tractive resistances are determined by direct regression. Other solution strategies gave no usable results.

In a statement according to equation (1) a polynomial regression of the second order can be accomplished for the acceleration using the speed. The regression calculation leads directly to the coefficients A, B, and C, from which the aerodynamic drag and rolling resistance W_L and W_R or the coefficients c_w and f_R (v) can be calculated. The vehicle mass, the frontal area of the vehicle and the air pressure and air temperature in terms of the air density are fully considered in the calculation of the coefficients. Measurement errors for these variables therefor result in corresponding coefficient errors. Usabe results have already been achieved with this statement, Fig. 20.

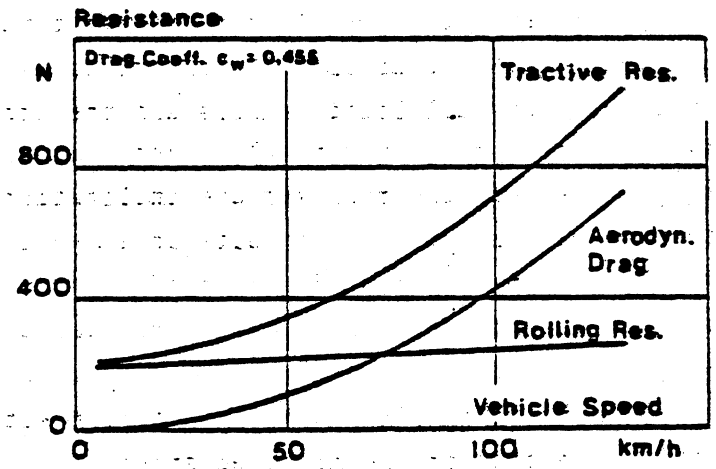


Fig. 20: Results of Coast-Down Test: Aerodynamic Drag and Rolling Resistance

Steady State Turning

One of the oldest test methods in vehicle dynamics is the steady state turning. It supplies basic comparative data for the development of vehicles. In addition to the maximum acceleration this data also include the curve of various vehicle dynamic variables using the lateral acceleration on a circular track with a constant radius. Other methods where the steering wheel angle or the driving speed remain constant are used less often because they require a very large test surface.

In the steady state turning test the lateral acceleration, steering wheel angle and moment, side slip angle and roll angle are measured. The vehicle is accelerated to the desired speed on a circular track usually with a radius between 30 and 50 m. When the steady state condition is reached, the data shall be recorded. The speeds can be run in steps or the vehicle can be accelerated in a quasi-steady state from the lowest speed up to the limit range, whereby the measured variables are recorded during the entire procedure.

The evaluation is accomplished by a computer program. The recorded tape is continuously read and checked whether the measured lateral acceleration is within certain limits; if so, all measured values are simultaneously coordinated to this lateral acceleration interval. This program allows the range from minus 10 to plus 10 m/s^2 to be evaluated in 100 classes. The class width then corresponds to 0.2 m/s^2. The mean value, standard deviation and peak values are calculated and recorded from the adjoined variables measured. These values can be given in tabular form. Presentation of the measured values as a function of the lateral acceleration is also possible. Fig. 21 shows the steering wheel angle, steering wheel torque, sideslip angle and roll angle. The lateral forces on the wheels can also be measured with special measurement hubs, Fig. 22.

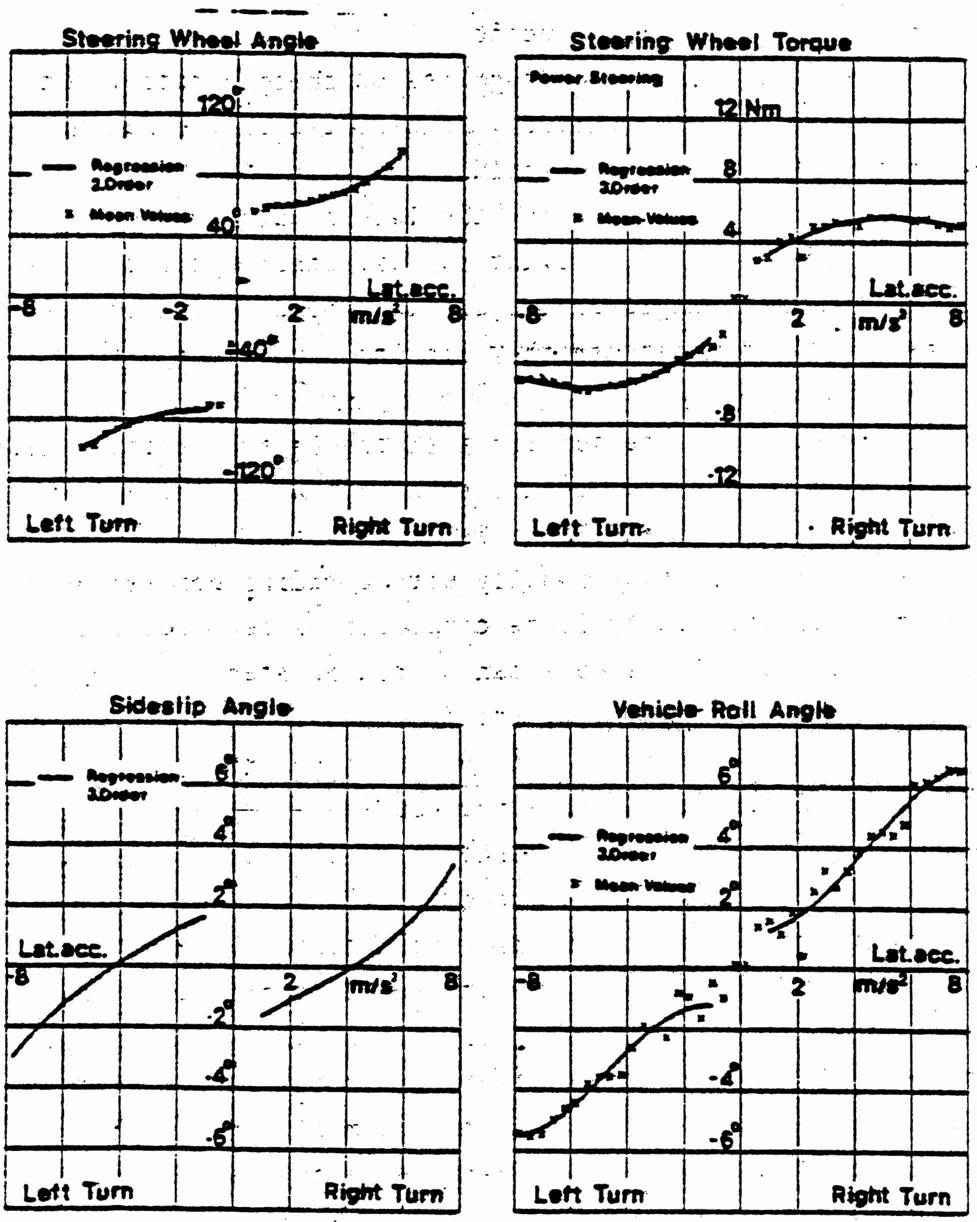


Fig. 21: Steering Wheel Angle, Steering Wheel Torque, Side Slip Angle and Roll Angle versus lateral Acceleration in Steady State Turning (Radius: 42,5 m)

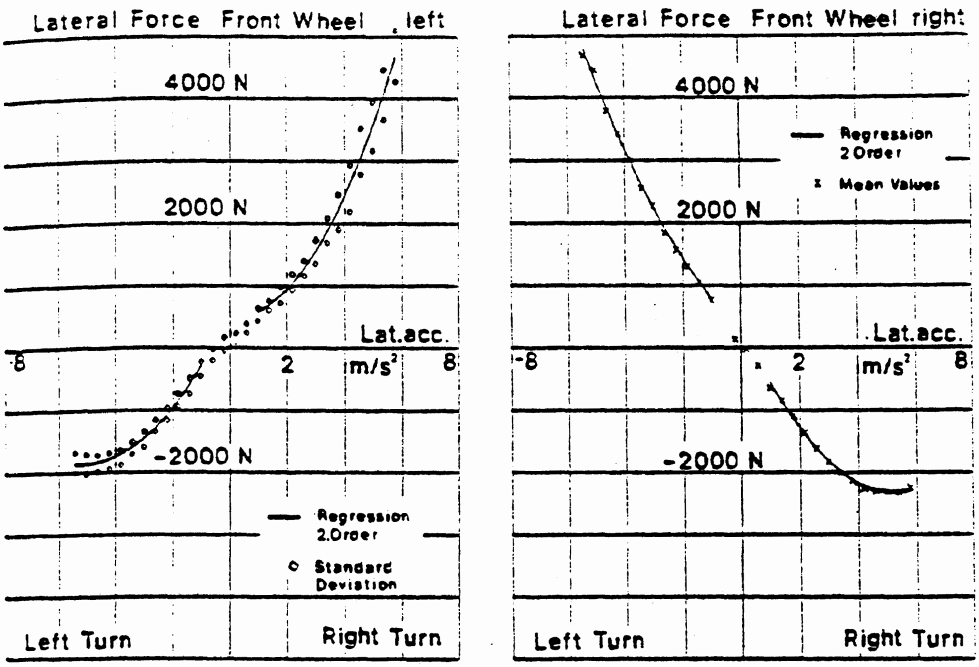


Fig. 22: Lateral Force on the front wheels in
Steady State Turning (Radius: 42,5 m)

For determination of the steer properties the elasto-kinematic characteristics of the wheel suspension are used in addition. Essential information can be obtained for the steer properties from the changes in the steer angle of the individual wheels due to the lateral force and during vehicle roll. For this reason the wheel angles are recorded versus lateral acceleration on a circular path, Fig. 23.

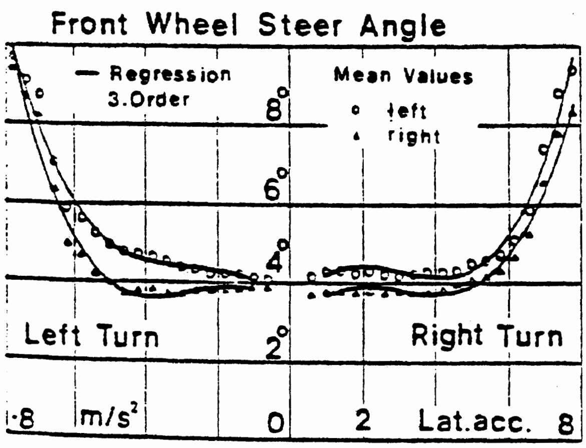


Fig. 23:
Front wheel steer angle versus lateral acceleration in steady state turning (Radius 42,5 m)

Transient Response

To investigate the vehicle handling it is also necessary to determine the transient response of the vehicle in addition to the steady state steer properties. Various test methods have been developed to measure the transient response. The methods used most often in practice, the step input and the frequency response method, are explained in the following.

Step Input

For the step input method the most important input and output variables for the

- steering wheel angle and
- yaw velocity

as well as the following reference variables are measured:

- steering wheel angle velocity
- forward velocity
- lateral acceleration.

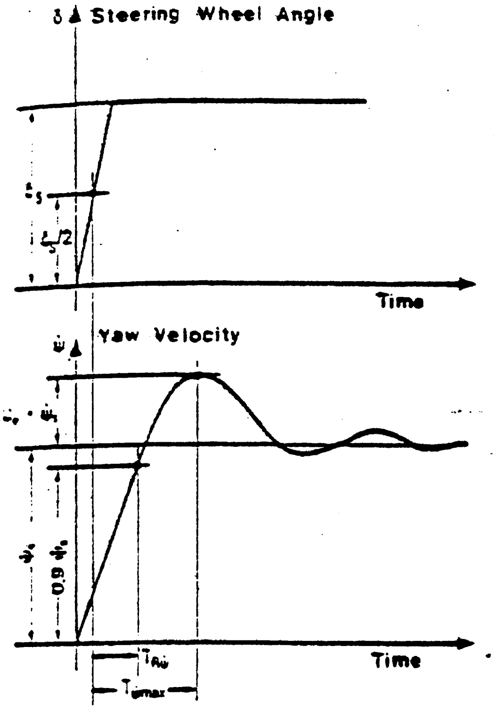
For comparison with the subjective evaluation the

- sideslip angle and
- roll angle

are recorded in addition.

At the given speed, generally between 80 and 120 km/h, the vehicle is moved from a straight path into a circular path with a given lateral acceleration (4 and 6 m/s^2) with the quickest possible ramp form steering wheel angle input. During this procedure the steering wheel angle velocity should be between 200 and 500 $^o/s$.

Parameters are determined from the time functions of the recorded variables for characterization of the transient response. Evaluation is accomplished with a program system resulting in the following characteristic values:



90 % - Response time of yaw velocity $T_{R\dot\psi}$

Peak response time of yaw velocity $T_{\dot\psi max}$

Maximum overshoot of yaw velocity $U_{\dot\psi}$

Yaw Rate response gain (yaw velocity divided by steady state steering wheel angle) $(\dot\psi/\delta)_s$

Fig. 24:

Definition of Several Characteristic Values for transient response test Step Input

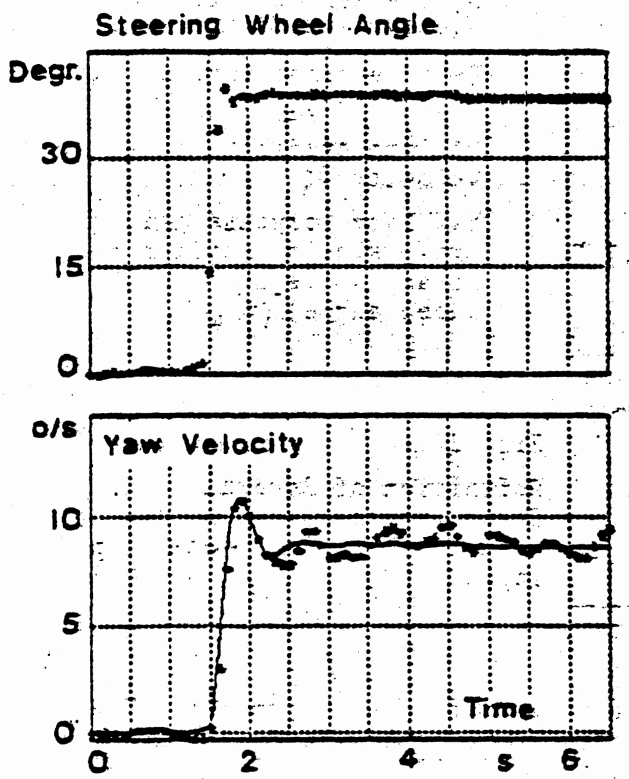
See Fig. 24 for the definition of these parameters. The time at which the steering angle reaches 50 % of its final value is chosen as the initial point for determination of the response time.

Moreover the model time functions are determined using a simple vehicle model of the second order with an identification routine. The vehicle yaw motion is determined by the transfer function

$$\frac{\dot\psi}{\delta} = \left(\frac{\dot\psi}{\delta}\right)_s \frac{1 + T_Z \cdot s}{1 + \frac{2D}{\nu_n} s + \frac{1}{\nu_n^2} s^2}$$

Using this model the measured data can be approximated well in most cases. The model serves as a mathematical aid for evaluation of measured transfer functions. The program calculates the model parameters:

- numerator time constant T_Z
- damping ratio D
- undamped natural frequency ν_n



Steering Wheel Angle	38.4	Degr.
90 % - Response Time	.179	s
Peak Response Time	.336	s
Overshoot	25.5	%
Steering Wheel Velocity	211	Degr/s
Yaw Rate Response Gain	.211	1/s
Numerator Time Constant	.0924	s
Damping Ratio	.453	-
Und. Natural Frequency	1.34	Hz

Fig. 25:

Evaluation of Step Input as it is supplied by the computer

An additional evaluation variable is the vehicle factor TB, which also shows a good correlation with the subjective evaluation. The TB factor is the product of the peak response time and the steady state sideslip angle, $TB = T_{\dot{\psi}max} \cdot \beta_s$.

The measured characteristic variables and the calculated model parameters of various vehicles correlated with the subjective evaluation of numerous test drivers in comprehensive test series. It has been shown that at least two characteristic variables are required to characterize the transient response; one of these variables is the yaw rate response gain under steady state conditions. The additional characteristic values should represent the most important frequency-dependent characteristics of the dynamic vehicle behaviour.

The yaw rate response gain $(\dot{\psi} / \delta)_s$ for the yaw velocity has been clearly identified as a suitable steady state characteristic value. The yaw rate response gain shows a correlation with the subjective evaluation on a curvy path for more than 0.8. The greater $(\dot{\psi}/\delta)_s$ was, the better the vehicle was evaluated. Above all the damping D, the peak response time $T_{\dot{\psi}max}$ and the factor TB proved to be the suitable dynamic characteristic values for the evaluation of the vehicle based on the correlation. The greater the damping and the smaller $T_{\dot{\psi}max}$ and TB were, the better the evaluation of the vehicles.

To compare different vehicles in regard to their transient response based on the step input measurements the characteristic values given here, above all, must be examined more closely in addition to the time history of the individual variables.

Frequency Response

A further possibility for evaluating the transmission characteristics of a vehicle is the measurement and charting of the frequency response. Here the input and output variables are collated with one another at various sinusoidal excitation frequencies, as is usual in control technology. These transmission characteristics change according to amplitude and phase over the steer frequency.

The advantage in relation to the step input measurement is that a large test surface is not required; a long straight path with corresponding width is sufficient. At constant driving speed the steer frequency is increased in steps. It has proven practical to use an automatic steering machine for these measurements. Fig. 26 shows an electrohydraulic steering machine installed in a vehicle. The tests were performed with a driver who accelerated the test vehicle to the correct test speed and held this speed constant during the measurement procedure.

During the measurement period the driver removes his hands from the steering wheel and actuates two push buttons which start the steering machine. The steer angle input is then

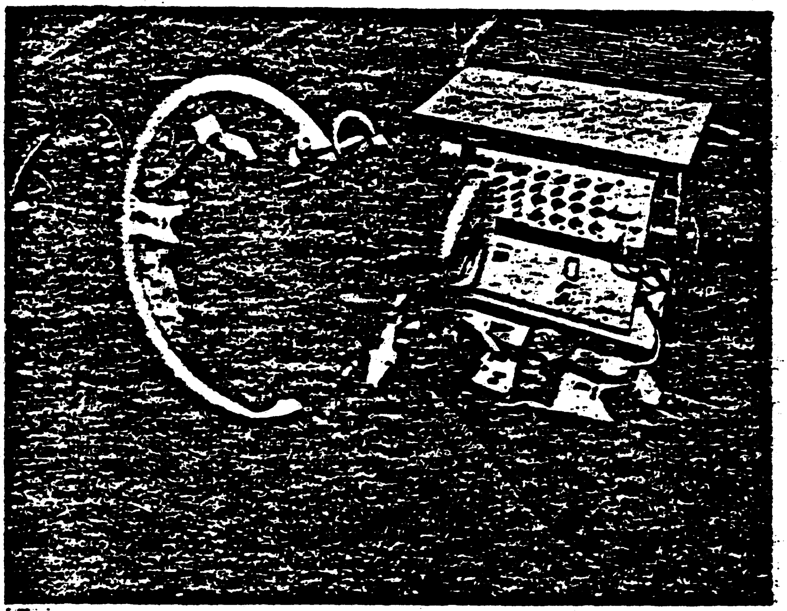


Fig. 26: Steering machine for frequency response measurements installed in the vehicle

accomplished automatically according to previously set values.

The automatic mechanism is switched off by releasing the push buttons and the driver can reassume manual control of the steering wheel in order to drive the vehicle to the starting position for the next test. In these tests the data are transmitted to the accompanying vehicle by telemetry, where the test run is evaluated immediately.

The following variables are measured:

- steering wheel angle
- yaw velocity
- lateral acceleration
- sideslip angle
- roll angle

The amplitude characteristics and phase angles are calculated and plotted from the measured time history using a program. Fig. 27 shows the amplitude and phase curve for the yaw velocity and the lateral acceleration for a vehicle with

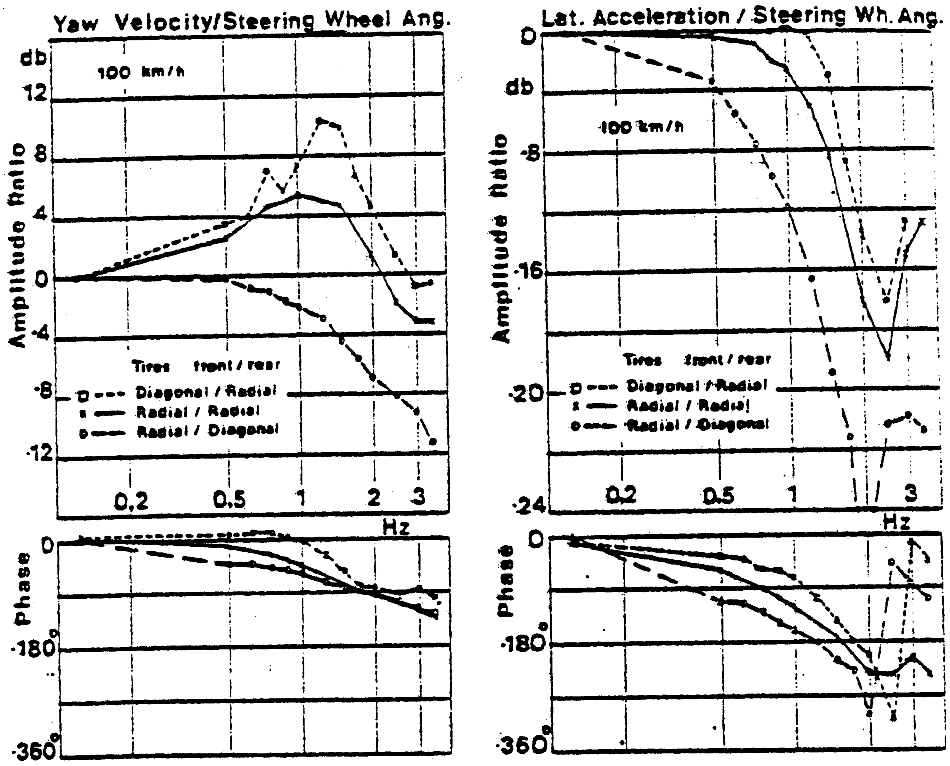


Fig. 27: Frequency Response of Yaw Velocity and Lateral Acceleration for three Several Vehicle Lay-Outs

different steer properties varied through the tires.

The yaw velocity shows a marked resonance hump at 1.5 Hz, which increases with increasing understeer. This hump also increases with the forward velocity. The differences in the vehicle lay-out can also be seen clearly from the frequency response of the lateral acceleration. The oversteer already shows a decrease of 12 dB at 1 Hz steering frequency. The high degreee of understeer is still not subject to any decrease in the lateral acceleration response at this point. On the basis of such frequency response measurements the various vehicles can be compared and evaluated in regard to their transmission characteristics.

Braking in a Turn

An important, practice-related driving manoeuvre is braking in a turn. During this manoeuvre the vehicle should not deviate from the initial path, if possible, nor should it spin. While the tests considered up to this point could only be performed in the open loop procedure due to their character, for braking in a turn a closed loop test, i.e. with the influence of the driver, is also possible. In the closed loop test the vehicle path is usually given in the form of a marked lane, and the driver manipulates the steering angle and deceleration so that the vehicle remains in the lane and stops within a given distance. The test is very close to practice, however, the results are dependent upon the driver so that a number of drivers have to be used. Such tests are well suited for a subjective comparison of vehicles.

On the other hand, if the vehicle motion is to be recorded and evaluated on the basis of objective characteristic values, the open loop procedure have to be used. The goal of this test is to determine the effect of braking upon the directional behaviour of the vehicle whose steady state turning is disrupted only by the braking procedure. The steering wheel is kept fix during the test. The following variables are measured:

- steering wheel angle
- brake pressure
- lateral acceleration
- longitudinal deceleration
- forward velocity
- yaw velocity
- sideslip angle

It has been determined that the differences between various vehicles can best be determined using an initial circle with a diameter of 100 m at an initial lateral acceleration value with a minimum of 5 m/s^2.

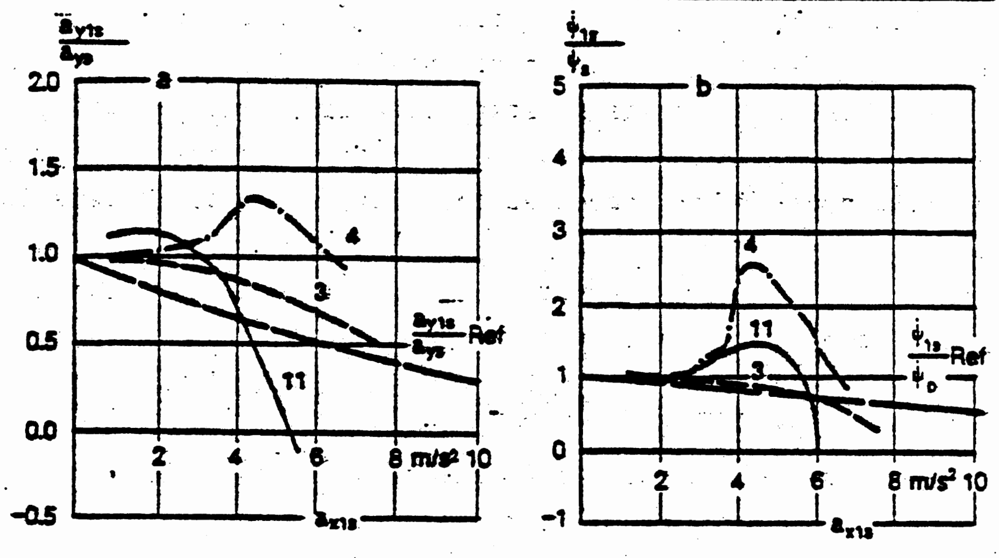
This corresponds to an initial vehicle speed of 80.5 km/h. The vehicle is braked at an incrementally increasing longitudinal deceleration from the steady state circular turning. During this procedure the brake pedal is actuated as quickly as possible. The brake pressure is increased this far, until all wheels lock up.

The recorded measurement variables are processed further using a computer. In this procedure the following additional variables are calculated:

- reference yaw velocity
- reference lateral acceleration
- yaw angle deviation from initial circle

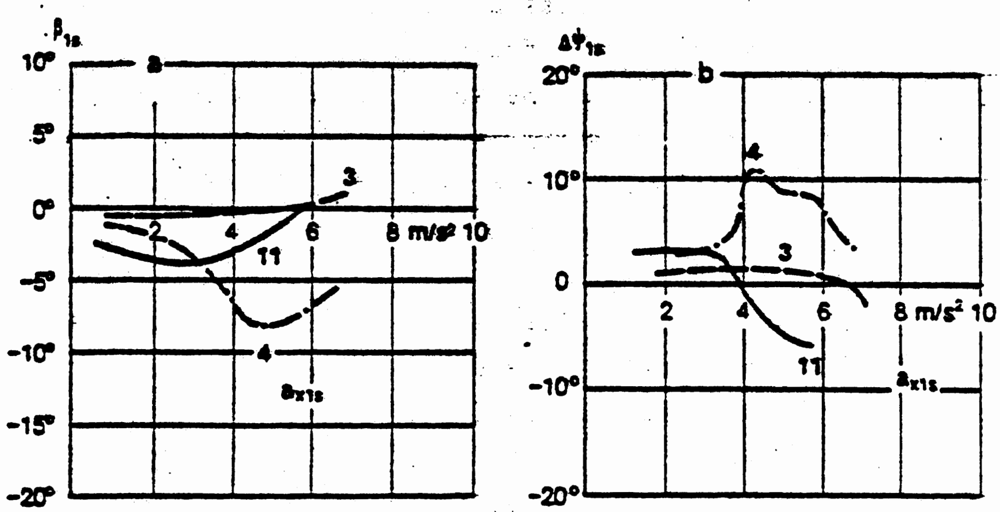
The reference condition is the condition of the vehicle slowing down with the same longitudinal deceleration time history as the test vehicle without any deviation of the vehicle center of gravity from the initial circular trajectory. In addition the steady state values from the beginning of the braking procedure, mean values and maximum values as well as values at the time 1 s after braking begins are determined from the time history of the measured variables for each test. The time 1 s was therefore chosen, because this period corresponds approximately to the reaction time of the driver. When the driver after this period desires to initiate a correction the vehicle motion should still be under his control. The mean values, maximum values and the 1 second values are standardized in part to the steady state values or the reference values in order to avoid differences through dispersion in the initial conditions.

The curves for three different vehicles are shown here to illustrate the behaviour characteristics obtained from a large number of tests. Due to the fact that the vehicle handling changes at variously high degrees of deceleration, the curves are charted in relation to the deceleration. The 1 s values are graphed versus the 1 s value for the deceleration and the mean values versus the mean deceleration value.



a Lateral Acceleration b Yaw Velocity

Fig. 28: Related Time Values 1 s after braking begins versus the associated time value of the longitudinal deceleration for 3 various vehicles no. 3, 4 and 11



a Sideslip Angle b Yaw Angle Deviation

Fig. 29: Time values 1 s after braking begins versus the associated time value of the longitudinal deceleration for 3 various vehicles no. 3, 4 and 11

Fig. 28 and 29 show characteristic variables at the time 1 s after braking begins. Moreover in Fig. 28a and 28b the reference lines for exact keeping of the nominal circular trajectory are indicated. The presentation of the initial values based on the lateral acceleration in Fig. 28a shows that vehicle 3 comes relatively close to the desired reference curve for exact keeping of the trajectory. The relatively high values for vehicle 4 in the middle deceleration range show the entry into the circle. Vehicle 11 also allows the observation that turning into the circle at slight deceleration, while the point of intersection with the reference line indicates the begin of sliding out of the trajectory at a deceleration of approximately 4 m/s^2. The point at which the lateral acceleration crosses the zero axis at a deceleration of approximately 5.5 m/s^2 means that the limit of steerability has been reached for this vehicle. The vehicle then skids tangentially out of the circular trajectory.

The corresponding handling properties can also be seen in the curve of the initial values in relation to the yaw velocity in Fig. 28b. The related yaw motion, e.g. for vehicle 4, is approximately twice as great as the related lateral acceleration. The reason for this is that an increase in the sideslip angle in addition to a decrease in the radius driven is expressed in the value of the yaw velocity. The associated sideslip angle is charted in Fig. 29a. Fig. 29b shows the difference between the actual und the calculated yaw angle for keeping the nominal circular trajectory 1 s after braking begins. These curves can also be used for evaluation of the vehicle handling. The driver also visually recognizes the deviation in the yaw angle. A greater angle to the vehicle longitudinal axis in relation to the nominal path tangent after braking for 1 s would frighten the driver more than a smaller deviation. The mean values and maximum values of this characteristic variable supply the same information so that it is not necessary to explain them here.

CORRELATION BETWEEN MEASURED VALUES AND SUBJECTIVE EVALUATION OF THE VEHICLE HANDLING

The relationship between the characteristic values determined in the open loop procedure and the actual traffic situations as well as to the accident causes is unknown. However, the goal of vehicle development is to improve the handling characteristics so that these improvements contribute to the reduction of the number of accidents resulting from the handling characteristics and therefore increase the active safety. The manner in which the driver masters the handling characteristics of his vehicle in actual traffic situations can only be determined through subjective evaluation of several skilled drivers while driving under normal traffic conditions. The test results can often only be interpreted in terms of feelings based on experience. Therefore the correlation between objective criteria and the subjective evaluation is important. Today, correlation studies are performed for every test method used.

A questionnaire is filled in for each test procedure for subjective evaluation of the vehicle, in which the driver can evaluate the vehicles according to a certain scale. At least 7 possible grades can be given:

1 for "poor" and 7 for "very good". The selection and formulation of the questions asked play a primary roll for the success of the evaluation.

The goal of the study is to find the objective criteria from the measured variables, which are best suited for describing the subjective evaluation. The stepwise multiple regression analysis method has proven itself suitable to connect the objective and subjective data. With this method an analytic relationship is determined between the dependent variables, the subjective evaluation points and the independent measurement values, i.e. the perception of the driver is interpreted by a weighted combination of the individual test values. Since the multiple regression assumes variables independent of one another, the objective characteristic values, which correlate highly with one another and are therefore interchangeable with one another, have to be reduced. Following this data reduction only those characteristic variables are used in the calculation and compared with the subjective evaluations in the corresponding criteria, which on one hand show the highest possible correlation with the subjective evaluations and which on the other hand have a low correlation between one another.

In numerous studies it has been shown that the subjective evaluation can be described best by a linear regression model. For this reason the linear relationship

$$y = a_0 + a_1 \cdot x_1 + a_2 \cdot x_2 + \ldots + a_n \cdot x_n$$

has been assumed as a model for the stepwise multiple regression analysis. With this y is the dependent variable (evaluation point number), x_1, x_2 ... x_n are the independent variables and a_0, a_1 ... a_n are the coefficients sought. In stepwise multiple regression a regression equation results in the following manner for each calculation step by adding a new variable:

$$y = a_0 + a_1x_1$$

$$y = a_0' + a_1'x_1 + a_2x_2$$

$$y = a_0'' + a_1''x_1 + a_2'x_2 + a_3x_3$$

... etc.

In this procedure that variable is inserted into the calculation in each case, which effects the greatest possible improvement of the multiple correlation coefficients. The results are indicated by the computer in tabular form and recorded in a plotter diagram with the measurement values.

An example of the subjective evaluation of the transient response with 8 vehicles in comparison to the measurement values from the step input is shown in Fig. 30. The criterion given here is an inquiry regarding the ability of the vehicle for rapid driving over a curvy path. The table shows that the yaw response gain $\dot{\psi}/\delta$ was inserted into the regression as the first variable. The second variable inserted, the damping ratio D improved the multiple correlation coefficient from 0.821 (initial value) to 0.858. By stepwise inserting the peak response time $T_{\dot{\psi}max}$, the response time of the lateral acceleration T_{Ray} and the numerator time constant T_Z a multiple correlation coefficient of 0.897 is finally achieved.

Calculation Step	Variable inserted into the calculation	Multiple Correlation Coefficient
1	$\dot{\psi}/\delta$	0,821
2	D	0,858
3	$T_{\dot{\psi}max}$	0,882
4	T_{Ra_y}	0,891
5	T_z	0,897

Fig. 30: Stepwise Multiple Regression Analysis with 8 vehicles from the values of the subjective evaluation and the step input measurement

REFERENCES

1. Vehicle Dynamics Terminologie. SAE J 670 e, 1978

2. A. Zomotor: Ein korrelationsoptisches Verfahren zur direkten Messung von instationären Schwimm- und Schräglaufwinkeln an Kraftfahrzeugen. (An Optical Correlation Method for the Direct Measurements of Transient Sideslip and Slip Angles of Motor Vehicles). ATZ 1975, Nr. 7-8.

3. R. Rönitz, H.H. Braess, A. Zomotor: Verfahren und Kriterien zur Bewertung des Fahrverhaltens von Personenkraftwagen. (Methods and Criteria for the Evaluation of Handling and Road-Holding Properties of Passenger Cars - State-of-the-Art and Problems). Automobilindustrie 1977, Heft 1 und 3.

4. A. Zomotor: Meßverfahren bei der Auslegung des Fahrverhaltens. (Measuring Procedures for the Evaluation of Vehicle Handling). Automobilindustrie 1978, Heft 2.

5. T.P. Yasin: The Analytical Basis of Automobile Coastdown Testing. SAE 780334.

6. ISO/TC 22/SC 9: Road Vehicles - Steady State Circular Test Procedure. Draft ISO Standard, DIS 4138.2, 1980.

7. E. Bisimis, H.D. Beckmann, R. Rönitz, A. Zomotor: Lenkwinkelsprung und Übergangsverhalten von Kraftfahrzeugen. (Steer Step Input and Transient Response of Motor Vehicles). ATZ 1977, Nr. 12

8. A. Zomotor, A. Horn, K. Rompe: Bremsen in der Kurve - Untersuchung eines Testverfahrens. (Braking in a Turn - Investigation of a Testprocedure). ATZ 1980, Nr. 9.

9. H.-U. Lücke, W. Renz: Mobiles rechnergesteuertes Meßdatenerfassungs- und -auswertesystem für den Fahrzeugeinsatz. Messen und Prüfen, Juli/August 1981.

APPENDIX F

a.T.Z., Feb. 1968, Vol. 70, No. 2.

Dipl.-Ing. H. Steinbrenner, Dipl.-Ing. H.-J. Florus, Ing. H. Groesner, Stuttgart

Some Special Techniques for Testing Vehicles on Test Tracks.

Einige spezielle Methoden für Messungen an Fahrzeugen auf der Versuchsbahn

Mitteilung aus der Abteilung Versuchs-Meßhaus der Daimler-Benz AG, Stuttgart

Bei der Untersuchung und Bewertung von Fahrzeugen hinsichtlich des Fahrverhaltens und anderer charakteristischer Größen sind Messungen erforderlich, welche z. B. über die Straßenlage, das Beschleunigungsvermögen oder über Bremswege Auskunft geben. Es soll auch untersucht werden, wie sich Fahrzeuge in kritischen Situationen, z. B. beim Überholen, verhalten.

Deshalb wurden für die Einfahrbahn der Firma Daimler-Benz AG einige Meßverfahren entwickelt, die an bestimmte Streckenabschnitte gebunden sind und daher nur auf einer werkseigenen Bahn angewendet werden können, dafür aber wenig Rüstzeit am Fahrzeug benötigen und das Ergebnis möglichst schnell anzeigen, also insgesamt die Entwicklung von Fahrzeugen erheblich erleichtern. Einige dieser Meßverfahren sollen hier behandelt werden.

1. Geschwindigkeitsmessung

1.1 Messung des Geschwindigkeitsverlaufs

Zur Gewinnung des üblichen Geschwindigkeits-Zeitdiagramms existieren verschiedene Verfahren. Bei einem Verfahren wird ein 5. Rad eingesetzt, welches im allgemeinen einen elektrischen Impulsgeber betätigt. Diese Wegimpulse werden in eine geschwindigkeitsproportionale Gleichspannung umgesetzt, welche meist über der Zeit aufgezeichnet wird. Bei einem anderen Verfahren wird entlang einer Teststrecke mittels Radar die Geschwindigkeit gemessen und ebenfalls durch einen Linienschreiber aufgezeichnet [1]. Die nachfolgend genannten Möglichkeiten sollen diese Meßverfahren ergänzen.

1.2 Verfahren zur Messung der Geschwindigkeit über einen definierten Streckenabschnitt

Vielfach ist die Messung der Geschwindigkeit eines Fahrzeugs über eine bestimmte Fahrstrecke, z. B. während eines gewissen Fahrzustandes, erforderlich. In anderen Fällen soll die Geschwindigkeit an einer bestimmten Stelle einer Teststrecke (z. B. am Beginn derselben) ermittelt werden. Daher sind bei Daimler-Benz auf der Versuchsbahn an mehreren Stellen derartige Meßeinrichtungen geschaffen worden, und zwar über Strecken von 10, 100 oder über 1000 m. Die dabei angewandte Technik soll an einem Beispiel beschrieben werden.

Die Bestimmung der Geschwindigkeit geschieht durch Messung der Zeit über eine Fahrstrecke definierter Länge. Wegen der erforderlichen Genauigkeit müssen hierbei elektronische Zeitmesser (Zählgeräte) eingesetzt werden. Das Starten und Stoppen derselben erfolgt über elektrische Impulse, die z. B. fotoelektrisch gewonnen werden können. Der Nachteil solcher Lichtschranken ist, daß sie im allgemeinen aus der Fahrbahn herausragen und dadurch bei einem Ausbrechen von Fahrzeugen Unfallgefahr bedeuten. Werden sie aber versenkt angebracht, dann besteht Verschmutzungsgefahr und Gefahr der Störung durch herabfallende Blätter und dergleichen. Ähnliches gilt für Schranken, die mit Ultraschall arbeiten.

Aus diesen Gründen findet ein induktives Verfahren mit Drahtschleifen Verwendung, **Bild 1**. Bei dieser Einrichtung befindet sich im Fahrzeug ein kleiner Generator, welcher eine Wechselspannung mit einer Frequenz von z. B. 5 kHz erzeugt. Am Fahrzeug, z. B. an der hinteren Stoßstange, wird eine Sendespule mit Ferritkern angebracht. Diese Antenne erzeugt ein magnetisches Wechselfeld. In die Fahrbahn ist eine Drahtschleife eingelassen, welche den zu messenden Abschnitt genau definiert. Überfährt das Fahrzeug die Drahtschleife, so entsteht ein kurzes Impulspaket (mit der Sendefrequenz). Man erhält also am Beginn und am Ende des Streckenabschnittes je eine solche Impulsfolge in die Drahtschleife induziert. An diese ist ein Empfänger angeschlossen, welcher auf die Sendefrequenz abgestimmt ist und dadurch Störimpulse unterdrückt. Der Empfänger ist mit einem Impulsformer verbunden, welcher seinerseits den elektronischen Zeitmesser steuert. Aus der so gemessenen Zeit läßt sich nach der Beziehung

$$v = 3{,}6 \cdot s/t$$

dabei ist v = Geschwindigkeit in km/h, s = Weg in m, t = Zeit in s, die Geschwindigkeit errechnen. Bei sich oft wiederholenden Messungen ist die Umrechnung umständlich. Vielfach wird bei gewissen Messungen auch verlangt, daß das Ergebnis dem Fahrer sofort, z. B. durch Tafeln, angezeigt wird. Für diesen Fall ist eine elektronische Umrechnung der gemessenen Zeit in die Geschwindigkeit erforderlich. Dies geschieht mit einem von der Firma Paul E. Klein, Tettnang, entwickelten Gerät. Bei diesem Gerät wird die elektronisch gemessene Zeit digital nach der oben genannten Beziehung umgerechnet und sofort auf Ziffernanzeigenröhren dargestellt. Das Gerät ist dabei so aufgebaut, daß bei einer Streckenlänge von 10 m die dreistellige Anzeige in 1/10 km/h angezeigt wird, während bei einer 100 m-Strecke die Anzeige direkt in km/h erfolgt.

1.2.1 Anwendung dieses Geschwindigkeits-Meßverfahrens beim Wedeltest. Bei der Untersuchung des Fahrverhaltens liefert der sog. Wedeltest, welcher den Überholvorgang auf der Straße nachahmt, eine wichtige Aussage. Bei diesem Test wird eine abgesteckte Strecke durchfahren, **Bild 2 und 3**. Dabei ist es notwendig, die Ge-

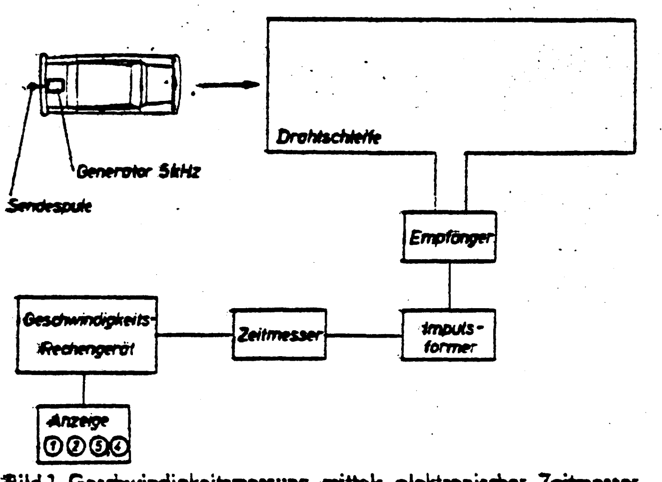


Bild 1. Geschwindigkeitsmessung mittels elektronischer Zeitmesser und Drahtschleifen in der Fahrbahn

Bild 2 Fahrzeug beim Wedeltest

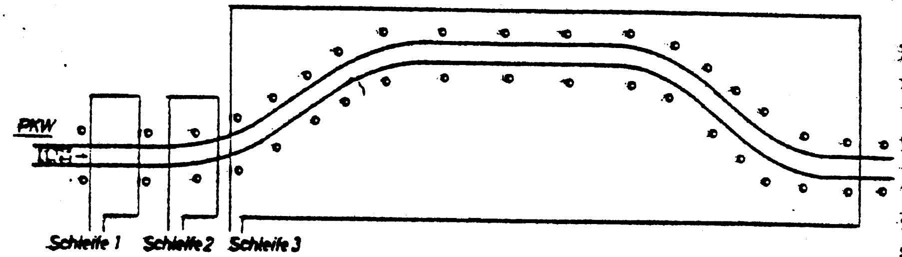


Bild 3. Drahtschleifenanordnung in der Fahrbahn für den Wedeltest

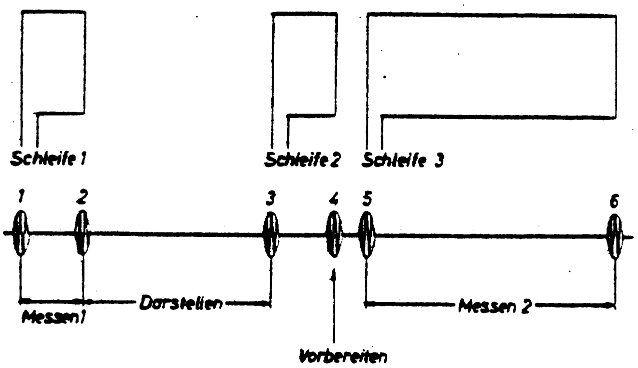


Bild 4. Impulse am Ausgang der Schleifen für den Wedeltest

schwindigkeit beim Einfahren in die Wedelstrecke und außerdem die während des gesamten Wedelvorganges vorhandene mittlere Geschwindigkeit zu messen. Aus diesem Grunde sind, wie Bild 3 zeigt, auf der Strecke drei Schleifen vorgesehen; die erste Schleife dient dazu, die Einfahrgeschwindigkeit zu bestimmen; die zweite Schleife wird dazu benutzt (wie noch genau beschrieben wird), um die Anlage weiterzuschalten, und die dritte Schleife ermittelt die mittlere Durchfahrgeschwindigkeit während des Wedeltests. Alle Schleifen sind in der Praxis hintereinandergeschaltet. Damit ergibt sich am Ausgang der hintereinandergeschalteten Schleifen der in Bild 4 gezeichnete Impulsplan.

Jeweils beim Überfahren eines der eingelassenen Drähte entsteht ein Impulspaket. Dies wird in dem Impulsformer, der dem Empfänger nachgeschaltet ist, zu einem Steuerimpuls verarbeitet. Diese Impulse gelangen in dem zur Anlage gehörenden Steuergerät auf einen sogenannten Ringzähler. Dieser steuert nun seinerseits mit den Impulsen 1 und 2 direkt das elektronische Geschwindigkeits-Meßgerät, so daß beim Durchfahren der Schleife 1 gezählt und sofort die Geschwindigkeit errechnet und angezeigt wird. Impuls 3 wird zum Löschen der Anzeige der Einfahrgeschwindigkeit verwendet. Impuls 4 dient zur Vorbereitung für eine neue Messung. Impuls 5 leitet die neue Messung ein, und Impuls 6 beendet diese. Es kommt dann noch Durchfahren der Schleife 3 die mittlere Geschwindigkeit während des Wedelvorganges zur Anzeige. Dieses Ergebnis bleibt angezeigt, bis es durch Drücken einer Taste am Gerät wieder gelöscht wird. Damit ist auch ein neuer Meßzyklus vorbereitet. Die Abstände zwischen der Schleife 1 und 2, d. h. zwischen den Impulsen 2 und 3, sind so gewählt, daß auch bei den höchsten Geschwindigkeiten, die bei der Messung vorkommen, noch eine Ablesezeit von 0,5 s verbleibt.

1.2.2 Genauigkeit der Geschwindigkeits-Meßanordnung. Die Meßunsicherheit des Gerätes selbst ergibt sich aus der Unsicherheit der Zeitmessung und dem Rechenfehler bei der Ermittlung der Geschwindigkeit. Die Meßgenauigkeit der Zeitmessung und der Umrechnung ist recht hoch, der Fehler beträgt ±0,1‰. Weiterhin geht in die Genauigkeit die Unsicherheit der Wegmessung ein. Diese ist einmal durch den geometrischen Abstand der Drähte und zum anderen durch die Genauigkeit der Ansprechschwelle, mit der das Impulspaket beim Überfahren mit der Lage des Schleifendrahtes übereinstimmt, gegeben. Die Schleife kann auf 1 cm genau verlegt werden. Damit bleibt die Meßunsicherheit hierdurch unter 0,1‰ (bei 100 m).

Durch die beim Überfahren der Schleifendrähte entstehenden Impulspakete spricht im Gerät ein Impulsformer an. Dazu ist eine bestimmte magnetische Feldstärke erforderlich. Daher kommt es schon kurz vor Erreichen der Drahtschleife zum Ansprechen. Diese Entfernung ist von der Höhe der Sendespule über der Fahrbahn abhängig, weil sich mit dem Abstand auch die Feldstärke ändert. Hat man bei der Einfahrt und bei der Ausfahrt genau dieselben Höhenverhältnisse der Sendespule, dann entsteht kein Meßfehler. Da die Meßspule jedoch aus Bequemlichkeitsgründen an der Karosserie, d. h. an der Stoßstange, festgemacht wird, können durch Bewegungen der Karosserie beim Abbremsen oder Beschleunigen Höhenunterschiede zwischen Einfahrt und Ausfahrt auftreten. Diese Einflüsse wurden untersucht.

Bei einer Höhe der Spule von 100 mm spricht der Impulsformer 200 mm vor Erreichen des Schleifendrahtes an. Ändert sich die Spule in ihrer Höhe um ±50 mm — ein in der Praxis selten vorkommender Wert —, dann ändert sich der vorher genannte Ansprechwert um ±25 mm. Die Ein- bzw. Ausfahrmarken sind also mit einer Unsicherheit von ±25 mm vorhanden. Damit ergibt sich eine Meßunsicherheit von ±0,5%. Diese Genauigkeit ist im allgemeinen vollkommen ausreichend. Falls es aber erforderlich ist, die Fehler kleiner zu machen, kann das durch Befestigen der Spule an der Achse durchaus erreicht werden.

2. Messung der Seitenwindempfindlichkeit von Fahrzeugen

Zur Erfassung der Seitenwindempfindlichkeit von Fahrzeugen ist auf einer Teststrecke der Versuchsbahn der Firma Daimler-Benz eine Anzahl von Gebläsen quer zur Fahrbahn aufgebaut [2], an welchen das Fahrzeug vorbeifährt. Zur Beurteilung muß die Abdrift des Fahrzeuges beim Vorbeifahren an den Gebläsen gemessen werden. Die Anlage ist in Bild 5 mit einem Versuchsfahrzeug während einer bestimmten Entwicklungsphase zu sehen.

Die einfachste Methode zur Messung der Abdrift besteht nun darin, mit Hilfe von Preßluft Wasser während des Durchfahrens auf die Straße zu spritzen. Es kann dann nach der Fahrt an Hand der Wasserspur die Abdrift ermittelt werden. Dieses Verfahren ist einfach, allerdings zeitaufwendig und bei Regenwetter nicht durchführbar. Außerdem führt es auch bei mehreren Fahrten, die hintereinander durchgeführt werden, zu Unsicherheiten.

Es bestand daher für den Elektroniker die Aufgabe, die Position des Fahrzeuges am Anfang und am Ende der Teststrecke festzustellen und sofort anzuzeigen. Dazu muß außerdem noch die Geschwindigkeit gemessen werden. Dies wird nach dem vorher beschriebenen Verfahren durchgeführt und liegt als Digitalanzeige vor. Es war daher naheliegend, auch die Abdrift digital anzuzeigen.


Bild 5. Abdrift eines Fahrzeuges durch Seitenwind

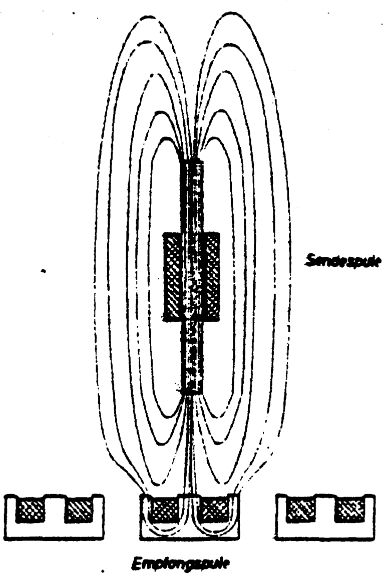


Bild 6. Meßprinzip zur Erfassung der Abdrift eines Fahrzeuges

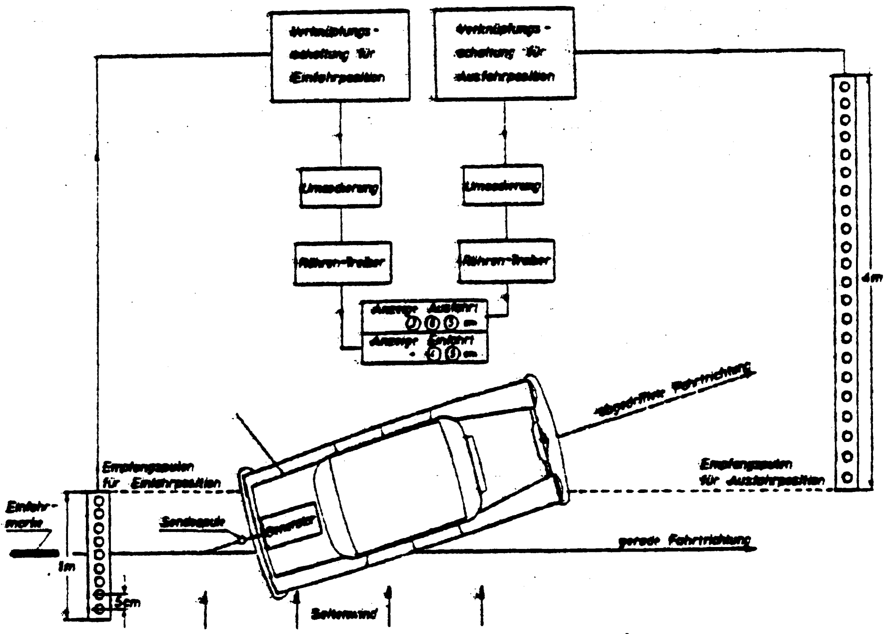


Bild 9. Gesamtschaltung zur Driftmessung

2.1 Meßverfahren

Entsprechend Bild 6 wird die induktive Kopplung zweier Spulen als Meßprinzip benutzt. Am Fahrzeug befindet sich eine Sendespule, die von einer Wechselspannung kleiner Leistung, die im Fahrzeug erzeugt wird, erregt wird. Die Spule besteht im Prinzip aus einem Ferritstab, der mit einer Wicklung versehen ist, so daß sich ein magnetisches Feld ergibt. In der Fahrbahn eingelassen sind eine Reihe von Empfangsspulen. Es handelt sich dabei um offene Topfspulen, deren Joche ebenfalls aus Ferritmaterial bestehen. Steht die Sendespule genau über einer Empfangsspule, so sind diese beiden Spulen am engsten gekoppelt. Am Ausgang dieser Empfangsspule entsteht dann die höchste Spannung. Die danebenliegenden Spulen werden zwar noch vom Streufeld der Sendespule erfaßt, geben aber kleinere Spannungen ab. Beim Überfahren der Empfangsspulen mit der Sendespule am Fahrzeug entstehen je nach Geschwindigkeit an den Spulen kürzere oder längere Impulspakete. Die in die Spulen induzierte Wechselspannung wird gleichgerichtet, Bild 7. Diese Gleichspannung lädt einen Kondensator auf. Da an der Spule, welche der Antenne am nächsten ist, die größte Spannung entsteht, ist an dieser zuerst ein definierter Spannungswert erreicht und dadurch die Stelle markiert, an welcher das Fahrzeug die Spulenreihe überfahren hat.

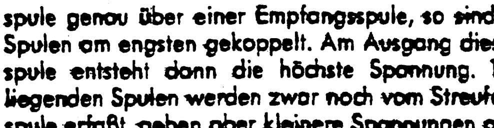


Bild 7. Beschaltung der Empfangsspule

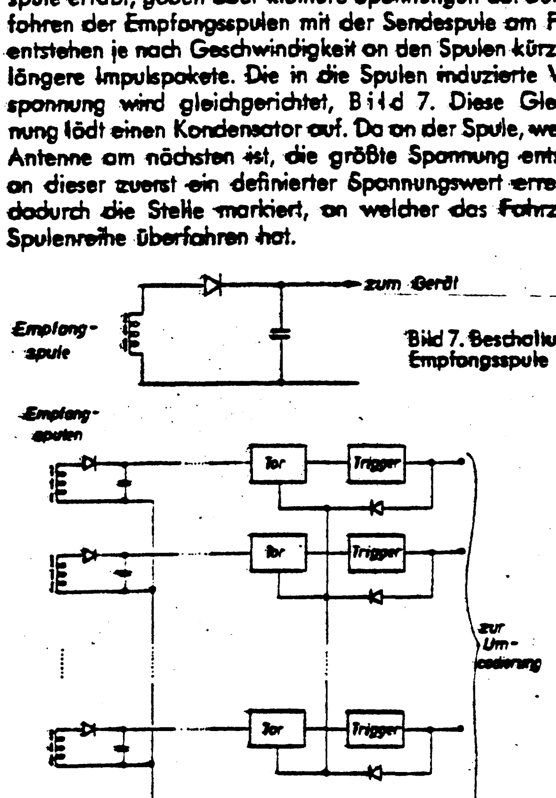


Bild 8. Verknüpfungsschaltung für die Driftmessung

Aus den vielen in der Fahrbahn eingelassenen Spulen muß also diejenige ausgesucht werden, welche zuerst einen bestimmten Spannungspegel erreicht. Die dazu notwendige Verknüpfungsschaltung ist in Bild 8 zu sehen. Die an den Spulen anstehenden Spannungen gelangen zu einer Torschaltung. Zunächst sind die Tore alle geöffnet, und die Spannungen können die danach folgenden Trigger beeinflussen. Unter Trigger versteht man dabei eine Schaltung, die bei einer genau definierten Eingangsspannung umkippt und dabei am Ausgang ein elektrisches Signal abgibt. Der Verknüpfer ist so aufgebaut, daß, wenn ein Trigger umgekippt ist, alle Tore und damit auch alle anderen Trigger gesperrt sind.

Wird nun beim Überfahren mit der Sendespule bei einer Empfangsspule der Triggerpegel erreicht, so spricht nur der zu dieser Empfangsspule gehörende Trigger an. Ein Ausgangssignal entsteht also nur an diesem Trigger. Das vorhandene Signal kann nun z. B. auf einem Tableau angezeigt werden, welches die Nummer der überfahrenen Spule trägt. Die Ausgangssignale der Trigger können auch umcodiert werden, so daß eine Anzeige den tatsächlichen Abständen entsprechend erfolgt.

2.2 Ausgeführte Meßanlage

Bei der ausgeführten Anlage, Bild 9, betragen die Spulenabstände 5 cm. In der Ausfahrposition sind Spulen über eine Länge von 4 m quer zur Fahrbahn in diese eingelassen worden. Diese Strecke reicht für die vorkommenden Werte der Abdrift aus. Bei den Messungen soll zwar an einer genau gekennzeichneten Stelle eingefahren werden, was jedoch nicht immer exakt eingehalten werden kann. Infolgedessen ist es notwendig, auch auf der Einfahrseite Spulen in der Fahrbahn unterzubringen, welche die Einfahrposition kennzeichnen. Hier kommen nie größere Abweichungen als ±50 cm vor, so daß Spulen über 1 m Länge in der Fahrbahn anzuordnen sind. Die beiden Spulensätze sind mit je einer Verknüpfungsschaltung verbunden. Ist die Teststrecke von einem Fahrzeug, welches mit Generator und Sendespule bestückt ist, durchfahren worden, so ist in den Verknüpfungsschaltungen die Einfahr- bzw. Ausfahrposition durch ein Signal markiert. Da die Abweichung in cm angezeigt werden soll, werden die Signale umcodiert. Wenn z. B. die 7. Spule überfahren worden ist, dann soll nicht der Wert 7 sondern die Zahl 35 erscheinen. Da die Anzeige mit Glimmzifferröhren erfolgt, ist nach der Umcodierung jeweils noch ein Röhrentreiber erforderlich. Die Ziffernanzeige der Ein- und Ausfahrposition wird zweckmäßigerweise untereinander angebracht, wie im Bild 9 dargestellt.

Bei der ausgeführten Anlage schließen die Spulen auf der Ausfahrseite an die Verlängerung der Spulen auf der Einfahrseite an, Bild 9. In der Ausfahrposition wird in Richtung der Abdrift gezählt. Auf der Einfahrseite wird entgegengesetzt gezählt. Damit ergibt sich die Abdrift als Summe der beiden angezeigten Werte und nicht wie bei einer Zählung in gleicher Richtung als deren Differenz.

2.3 Genauigkeit des Meßverfahrens

Bei einem genügend scharf gebündelten Feld ist der Fehler ±½ Spulenabstand, d. h. ±25 mm. Bei der praktischen Ausführung wurden Schalenkerne mit 36 mm ∅ angewendet und in der Fahrbahn verlegt. Die Sendespule wurde auf einen Ferritstab mit ca. 200 mm Länge gewickelt. Bei Abständen von 70 mm zwischen Sendespule und Empfangsspule ergibt sich damit die vorher angegebene Genauigkeit, da das Feld noch genügend stark gebündelt ist. Werden größere Abstände verwendet, geht die Genauigkeit zurück. Befestigt man die Sendespule der Einfachheit halber an der hinteren Stoßstange des Fahrzeuges, muß sie mit ca. 150 mm Bodenfreiheit montiert werden. Die Unsicherheit beträgt dann ±50 mm, d. h. einen Spulenabstand.

Da bei kleinen Abständen von der Fahrbahn die Gefahr besteht, daß die Spule beschädigt wird, nimmt man lieber die verkleinerte Meßgenauigkeit in Kauf und verwendet den größeren Spulenabstand.

Da im allgemeinen Abdriften von einigen Metern (2 bis 4 m) vorkommen, beträgt im letzteren Falle die Meßunsicherheit immer noch ±2,5% vom Meßwert. Eine Erhöhung der Meßgenauigkeit ist im allgemeinen nicht erforderlich, auch schon deshalb, weil eventuelle Winkelfehler bei der Einfahrt in weit stärkerem Maße im Ergebnis enthalten sind.

3. Messung des dynamischen Rollradius r_{dyn}

Der dynamische Rollradius ist definiert als der Halbmesser eines Rades, der sich beim Fahren einstellt. Er ist proportional der zurückgelegten Wegstrecke, geteilt durch die Umdrehungszahl des Rades. Der dynamische Rollradius nimmt wegen der auf das Rad wirkenden Fliehkräfte mit der Geschwindigkeit zu. Durch den mit der Drehzahl stärker anwachsenden Schlupf bei den angetriebenen Rädern kann er sich bei diesen Rädern wieder verkleinern.

3.1 Meßmethode

Entsprechend der vorher gegebenen Definition wird über eine genau bestimmte Strecke, z. B. 100 m, möglichst genau die Anzahl der Umdrehungen des zu untersuchenden Rades ermittelt.

Die Strecke ist wiederum wie bei der Geschwindigkeitsmessung durch eine in die Fahrbahn eingelassene Drahtschleife definiert. Zur exakten Bestimmung der Umdrehungszahl des Rades wird aber nicht nur ein Impuls pro Umdrehung zur Messung benützt, sondern n Impulse. Die Radimpulse werden mit einem elektronischen Zähler gezählt. Die Zählbereitschaft des Gerätes wird hierzu wieder, ähnlich wie bei der Geschwindigkeitsmessung, durch die Impulse der Schleife gesteuert. Auf der Strecke s sollen nun in den Zähler A Impulse eingezählt werden. Dann ergibt sich:

$$s = \underbrace{A \cdot \frac{1}{n}}_{\text{Radumdrehung}} \cdot \underbrace{2\pi \cdot r_{dyn}}_{\text{Umfang}}$$

und daraus $r_{dyn} = \dfrac{n \cdot s}{2\pi A}$

Wählt man n = 63, so ergibt sich mit guter Annäherung für eine 100 m-Strecke

$$r_{dyn} = \frac{1000}{A} \quad [\text{m}].$$

3.2 Meßaufbau, Bild 10

In dem zu untersuchenden Fahrzeug wird wieder ein Generator und eine Sendespule untergebracht; außerdem ist das interessierende Rad mit einem Impulsgeber mit 63 Impulsen versehen. Die Signale des Impulsgebers werden über einen im Fahrzeug befindlichen Telemetrie-Sender und einen Empfänger auf den im Meßraum stehenden Zähler übertragen. Befindet sich das Fahrzeug außerhalb der Schleife, dann ist der Zähler noch gesperrt, und es werden keine Impulse gezählt. Beim Einfahren des Fahrzeuges in die Schleife entsteht, wie bei der Geschwindigkeitsmessung, ein Impulspaket, welches über den Impulsformer das Startsignal gibt.

Die von dem Rad drahtlos ankommenden Impulse werden im Zähler gezählt, und zwar so lange, bis die Sendespule am Fahrzeug die Schleife wieder verläßt; dann kommt über den Impulsformer der Stoppimpuls. Nach dem Durchfahren steht im Zähler die Zahl A, und es kann daraus, wie vorher beschrieben, der dynamische Rollradius errechnet werden. Dieser Wert stellt einen Mittelwert des Halbmessers über der durchfahrenen Strecke dar. Parallel dazu erfolgt eine absolute Geschwindigkeitsmessung mit Hilfe derselben Schleife, wie unter Abschnitt 1.2 beschrieben, da man immer die zu dem gemessenen dynamischen Rollradius gehörende Geschwindigkeit kennen will.

Wenn es nicht unbedingt erforderlich ist, das Ergebnis sofort nach dem Durchfahren außerhalb des Fahrzeuges zu besitzen, kann das Verfahren auch abgewandelt werden. In diesem Fall wird der Zähler im Fahrzeug untergebracht. Der Telemetrie-Sender entfällt. Der Generator speist nun die Schleife. Die Spule am Fahrzeug wirkt als Empfangsspule und startet bzw. stoppt den Zähler über einen Impulsformer.

3.3 Genauigkeit

Das Ergebnis im Zähler ist mit einer Unsicherheit von ±1 Impuls behaftet. Bei der Anwendung von 63 Impulsen pro Umdrehung, bei einer Fahrstrecke von 100 m und bei einem Radumfang von ungefähr 2 m ergibt sich damit eine Meßunsicherheit von ±0,3‰. Die erzielbare Genauigkeit ist also durch die Anwendung der elektronischen Methode recht gut.

Bei der Berechnung des dynamischen Rollradius mit der vorher angegebenen Näherungsformel ergibt sich außerdem noch ein systematischer Fehler aus 6,3/2π, entsprechend 0,3‰. Dieser ist, falls erforderlich, durch exakte Berechnung vermeidbar.

4. Messung des Geradeauslaufs

Bei der Entwicklung von Fahrzeugen ist es wichtig zu erfahren, wie gut ein Fahrzeug unter der Einwirkung von Fahrbahnunebenheiten geradeausläuft. Es ist also die Abweichung von einer auf der Fahrbahn gedachten Geraden meßtechnisch zu erfassen. Zur Beurteilung dieses Ergebnisses ist es außerdem noch erforderlich, zu erfahren, wie groß die zugehörigen Lenkradbewegungen sind. Daher werden auch die Lenkraddrehwinkel gemessen. Das Geradeauslaufverhalten ergibt sich dann aus der Beurteilung dieser beiden Vorgänge. Man könn-

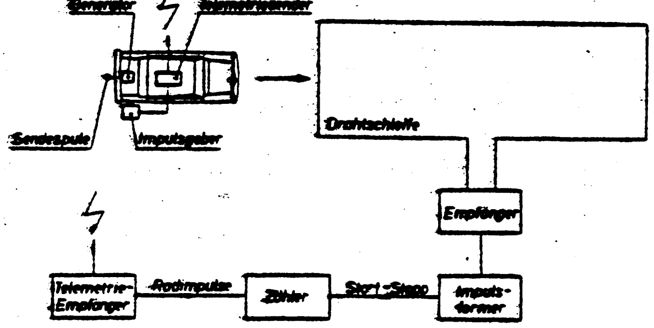


Bild 10. Meßanordnung zur Messung des dynamischen Rollradius

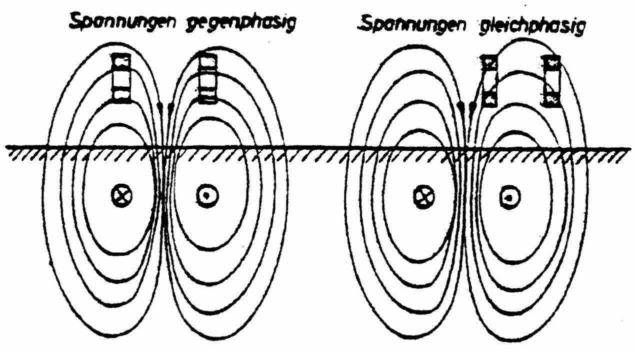


Bild 11. Meßprinzip zur Erfassung der Abweichung eines Fahrzeuges von einer Geraden

te nun beides mit Hilfe eines Oszillographen aufzeichnen und dann bewerten, und zwar nach Größe und nach der Häufigkeit der vorhandenen Ausschläge. Es ist recht zeitraubend, diese Ergebnisse aus einem Oszillogramm zu gewinnen. Daher besteht der Wunsch, das Meßverfahren so zu gestalten, daß die Ergebnisse bereits klassiert erscheinen.

4.1 Meßverfahren

Als Meßprinzip bei der Erfassung der Abweichung des Fahrzeuges von einer Geraden auf der Straße wird wiederum die induktive Kopplung zwischen einer Drahtschleife und Spulen ausgenützt. Zu diesem Zweck wird in der Meßstrecke, auf welcher die Messungen stattfinden sollen, eine Doppelleitung ausgelegt, die wiederum mit einer Wechselspannung gespeist wird. Am Fahrzeug befinden sich Empfangsspulen. Die in der Fahrbahn befindliche Doppelleitung besitzt einen magnetischen Feldverlauf, wie auf Bild 11 dargestellt. Zur Ortsbestimmung des Fahrzeuges werden diesmal Spulenpaare angewendet. Befindet sich je eine Spule des Paares rechts und links der Symmetrieebene des magnetischen Feldes und damit auch rechts und links der Doppelleitung, so werden sie von gegensinnigen Feldlinien durchsetzt, und man erhält damit an den Spulen gegenphasige Wechselspannungen.

Ist das Spulenpaar (rechts oder links) außerhalb der Symmetrieachse der Leitung, so werden die Spulen von Kraftlinien gleicher Richtung geschnitten. Es entstehen damit an den Ausgängen der Spulen gleichphasige Spannungen. Die Ausgänge der beiden Spulen führen auf eine Entscheideeinheit, welche ein Signal abgibt, wenn sich die Symmetrieachse zwischen den Spulen befindet (Zustand L), im anderen Fall entsteht kein Signal (Zustand O). Damit ist eine bestimmte Breite in der Abweichung des Fahrzeuges und damit eine Klasse definiert. Will man, wie es für ein Häufigkeitskollektiv erforderlich ist, mehrere Klassen, dann benötigt man mehrere Spulensätze, wobei sich diese kombinieren lassen, so daß sich die Gesamtzahl der Spulen reduziert und nur so viel Spulen benötigt werden, wie Klassen vorgesehen sind.

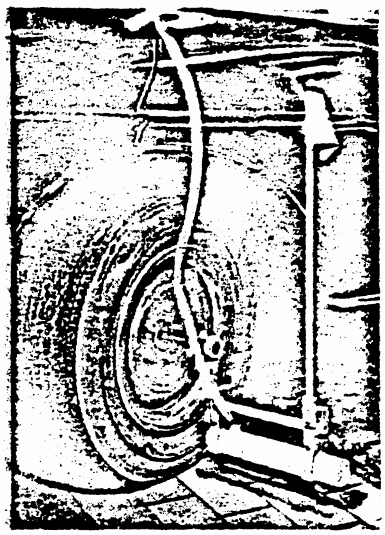


Bild 13. Spulensatz am Fahrzeug

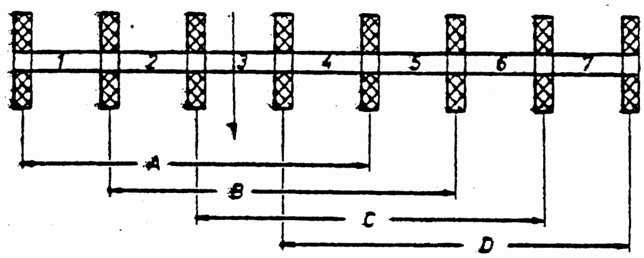


Bild 14. Spulenanordnung zur Erfassung der Abweichung eines Fahrzeuges von einer Geraden

4.2 Meßanlage

4.2.1 Klassierung der Abweichung. In Bild 12 ist eine Übersicht über die ausgeführte Meßanlage gegeben. Am Achsschenkel eines Vorderrades sind 8 Spulen angebracht und in einem Gehäuse vereinigt, wie Bild 13 zeigt. Diese Spulen müssen sich während der Meßfahrt über der ausgelegten Doppelleitung befinden. Die Abstände der Spulen untereinander entsprechen der zu klassierenden Breite, sie betragen 3 cm.

Die Paarung der Spulen ist gemäß Bild 14 vorgenommen und mit A bis D bezeichnet. Jedem dieser Buchstaben entspricht eine Entscheideeinheit. Fährt das Fahrzeug beispielsweise, siehe Pfeil in Bild 14, so, daß sich die Symmetrieachse der Leitung in der Klasse 3 befindet, dann gilt:

A = L, B = L, C = L, D = O.

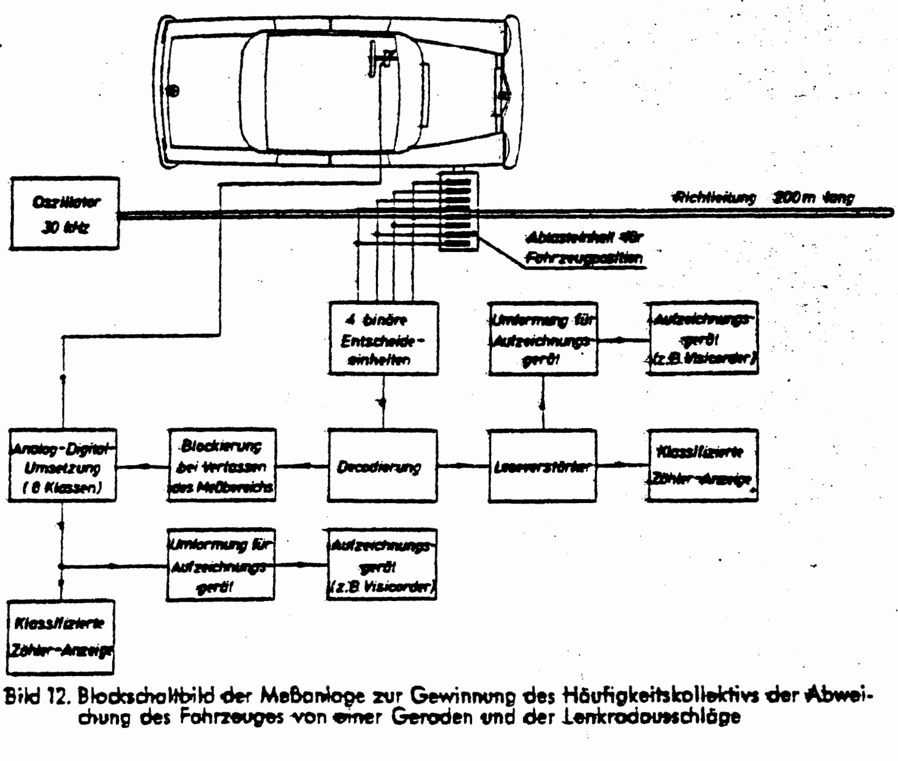


Bild 12. Blockschaltbild der Meßanlage zur Gewinnung des Häufigkeitskollektivs der Abweichung des Fahrzeuges von einer Geraden und der Lenkradausschläge

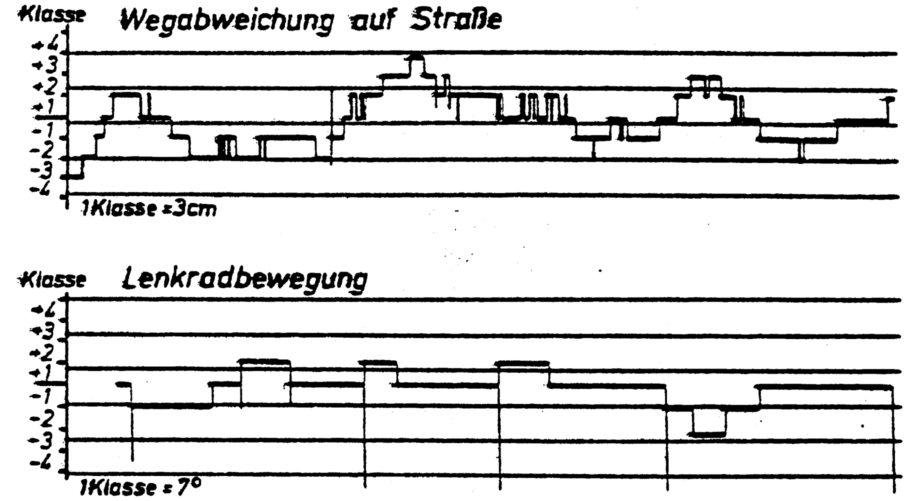


Bild 15. Aufzeichnung des klassierten Verlaufs der Abweichung des Fahrzeugs und des Lenkradwinkels über der gefahrenen Strecke

Über die mit Decodierung im Bild 12 bezeichnete Verknüpfungsschaltung wird in diesem Falle über einen Leseverstärker das Zählwerk der Klasse 3 angesteuert. Insgesamt sind 7 Klassen vorgesehen. Außer den Signalen für die einzelnen Klassen liefert die Decodierung noch ein Signal, wenn sich das Fahrzeug bzw. der Spulensatz nicht mehr über der Doppelleitung befindet. Dieses Signal wird dazu verwendet, die Lenkraddrehwinkelklassierung zu sperren, weil bei der Geradeauslaufklassierung dann nicht mehr gezählt wird.

4.2.2. Lenkrad-Drehwinkelklassierung. Zur Erfassung des Lenkraddrehwinkels wird mit dem Lenkrad ein Potentiometer mechanisch verbunden und mit einer konstanten Gleichspannung versorgt. Die am Potentiometer stehende Spannung geht nun auf so viele Fensterverstärker, wie Klassen vorgesehen sind, d. h. im ausgeführten Gerät auf 8 Fensterverstärker, deren Ausgänge auf die Zählwerke führen. Bekanntlich sind Fensterverstärker Einrichtungen, welche ein Signal abgeben, wenn die Eingangsspannung zwischen zwei genau definierten Werten liegt. Die Fensterverstärker haben eine Klassenbreite von 7° und schließen aneinander an. Es kann aber durch Wahl der Übersetzung zwischen Lenkrad und Potentiometer die Klassenbreite beliebig variiert werden.

4.2.3 Darstellung des Ergebnisses. Beim Durchfahren durch die Meßstrecke wird in beiden Klassiergeräten jeweils dann um eine Einheit weitergezählt, wenn die Klassengrenzen von oben oder unten herkommend überschritten werden. Nach Durchfahren der Meßstrecke hat man nach Ablesen der einzelnen Zähler sofort die gewünschte Häufigkeitsverteilung. Es handelt sich dabei um das am einfachsten zu gewinnende Häufigkeitskollektiv der Schwellwertüber- und -unterschreitung.

Zu bemerken ist noch, daß die Geradeauslaufzähler keine definierte Nullklasse haben, da diese vom zufälligen Einfahren in die Meßstrecke abhängt. Bei der Auswertung wird die am häufigsten auftretende Klasse zur Nullklasse bestimmt. Der Lenkraddrehwinkel dagegen besitzt eine Nullage. Sie ist definiert durch die Geradeausstellung der Vorderräder.

Der Vergleich der Häufigkeiten beim Durchfahren mit mehreren Fahrzeugen (oder bei Variationen am zu untersuchenden Fahrzeug) bildet direkt das Ergebnis. In manchen Fällen ist es aber auch zweckmäßig, die zeitliche Reihenfolge der Klassenüberschreitungen zu erfahren, um Zusammenhänge zwischen der Lenkradbewegung und den Abweichungen auf der Straße kennenzulernen. Aus diesem Grunde wird in der mit „Umformung für die Aufzeichnung" bezeichneten Schaltung von Bild 12 eine Ausgangsspannung erzeugt, die der Klassenhöhe proportional ist. Damit läßt sich auf einem Oszillographen der klassierte Verlauf der Abweichungen zeitlich darstellen, Bild 15.

4.3 Genauigkeit der Anordnung

Höhenabweichungen der Spule durch Einfedern des Rades führen im Gegensatz zu den vorher beschriebenen Meßverfahren zu keiner Meßunsicherheit, da die Symmetrielinie der in die Fahrbahn eingelassenen Doppelleitung höhenunabhängig ist. Die Lenkradeinschläge dagegen ergeben einen Meßfehler, weil sich die Achse der Spulen mit dem Radeinschlag schräg stellt und damit nicht mehr senkrecht zu der in die Fahrbahn eingelassenen Leitung ist. Diese Einflüsse sind jedoch sehr unbedeutend, da nur kleine Radeinschläge vorkommen. So hängt die insgesamt vorhandene Meßgenauigkeit im wesentlichen von der Fertigungsgenauigkeit der Spulensätze und der Genauigkeit ab, mit welcher die 200 m lange Doppelleitung verlegt werden kann. Eine Genauigkeit auf 2 bis 3% ist damit ohne weiteres erreichbar.

5. Betriebserfahrungen

Die beschriebenen Anlagen sind nun schon mehr als ein Jahr in Betrieb. Dabei konnten einige Erfahrungen gesammelt werden. Durch Witterungseinflüsse und Temperaturschwankungen wurden anfänglich die Schleifen zerstört. Durch entsprechende Verlegung der Drähte und durch Verwendung von Leitungen mit hochwertiger Isolation ist es gelungen, diesen Schwierigkeiten Herr zu werden. Meistens werden die Messungen auf Betonpisten mit Stoßfugen ausgeführt. Damit müssen auch die Schleifen in der Betonpiste verlegt werden. Ist eine Schleife so lang, daß sie mehrere Betonplatten umfaßt, so können bei anhaltenden Regenfällen Schwierigkeiten durch die Leitfähigkeit des Materials in den Stoßfugen auftreten. Man erhält dann auch an den Fugen innerhalb der Schleife Impulse. Allerdings sind diese Spannungen kleiner (etwa 1/10), so daß sie durch entsprechende Einstellung am Impulsformer unterdrückt werden können.

Die Spulen für die Driftmessung mußten ebenfalls nach dem ersten Winter ausgewechselt werden, da die Vergußmasse an einigen Stellen Risse bekommen hatte, so daß Wasser eindringen konnte, was durch die Eisbildung zu einer Sprengung geführt hat. Durch Einsatz einer geeigneten Vergußmasse ließen sich diese Schwierigkeiten beheben

Die angeführten Beispiele zeigen, daß es mit Hilfe von elektronischen Schaltungen unter Ausnützung bekannter physikalischer Effekte gelingt, recht einfache und genaue Meßverfahren zu schaffen, die bei der Entwicklung von Fahrzeugen von Nutzen sind.

Schrifttum

[1] Steinbrenner, H. und Florus, H.J.: Über neue Methoden zur Messung von Beschleunigungs-Vorgängen an Fahrzeugen. ATZ Heft 1, Januar 1965

[2] Engels, R.: Untersuchungen über Fahrtrichtungshaltung. Z. VDI, Februar 1964

APPENDIX G

Vehicle Test Department
Nissan Motor Company Co., Ltd.

NISSAN FULL-SCALE WIND TUNNEL

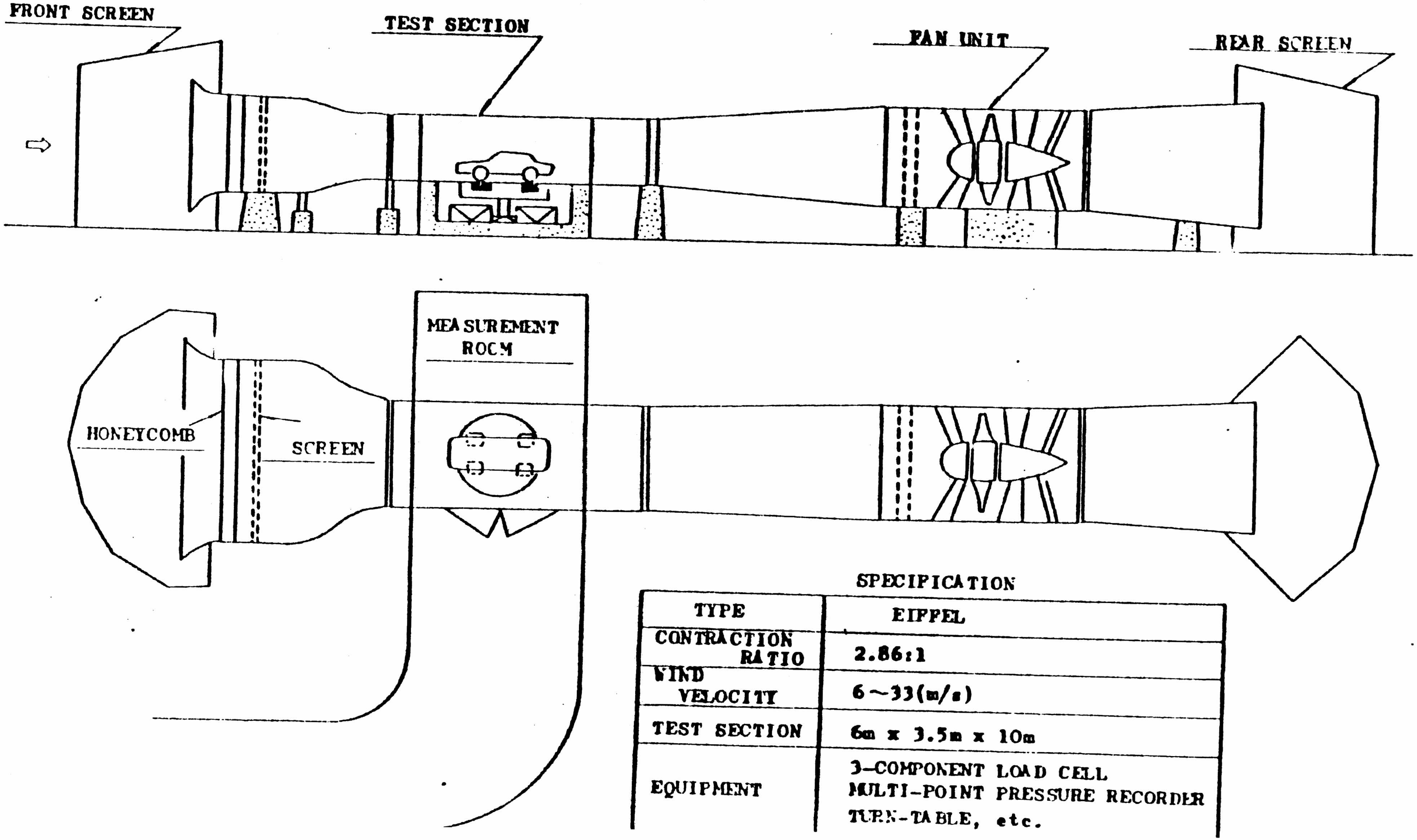
In the development of high-speed automotive vehicles, the wind resistance and vehicle stability characteristics, particularly aerodynamic lift and side force effects, must be better understood.

For this and othor purposes, Nissan Motor Company has constructed a new full scale wind tunnel, in 1968, now in operation at our Oppama Proving Ground.

Nissan Full Scale Wind Tunnel is of the Eiffel type, with a contraction ratio of 2.86 and a maximum wind velocity of 33meters per second.

The test section is closed, and its dimensions are ; width 6meters, height 3.5meters, and length 10meters. Equipment cosists of 3-component load cell, multi-point pressure recorder, turn table, data reduction system, etc.

FULL SCALE WIND TUNNEL

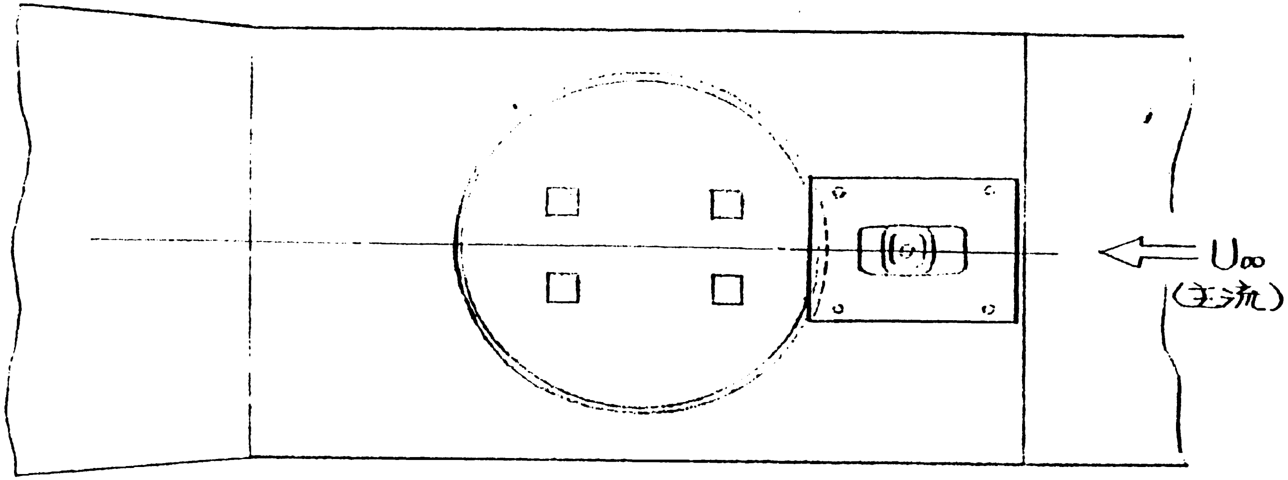


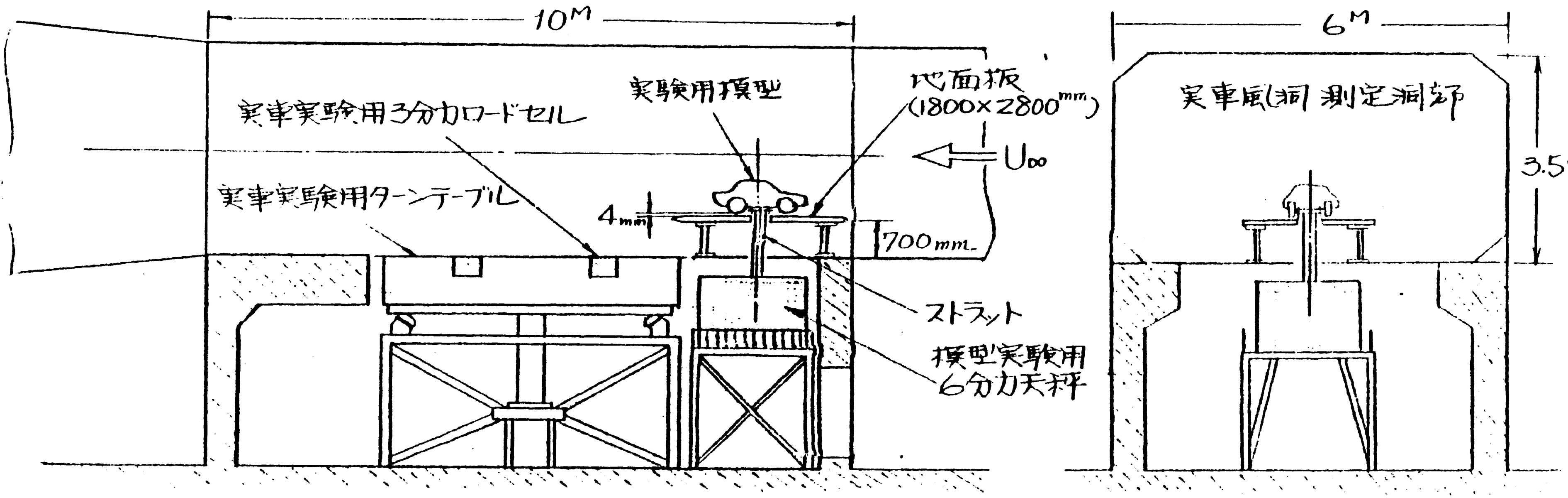
SPECIFICATION

TYPE	EIFFEL
CONTRACTION RATIO	2.86:1
WIND VELOCITY	6~33(m/s)
TEST SECTION	6m x 3.5m x 10m
EQUIPMENT	3-COMPONENT LOAD CELL MULTI-POINT PRESSURE RECORDER TURN-TABLE, etc.

模型実験用6分力天秤主要仕様

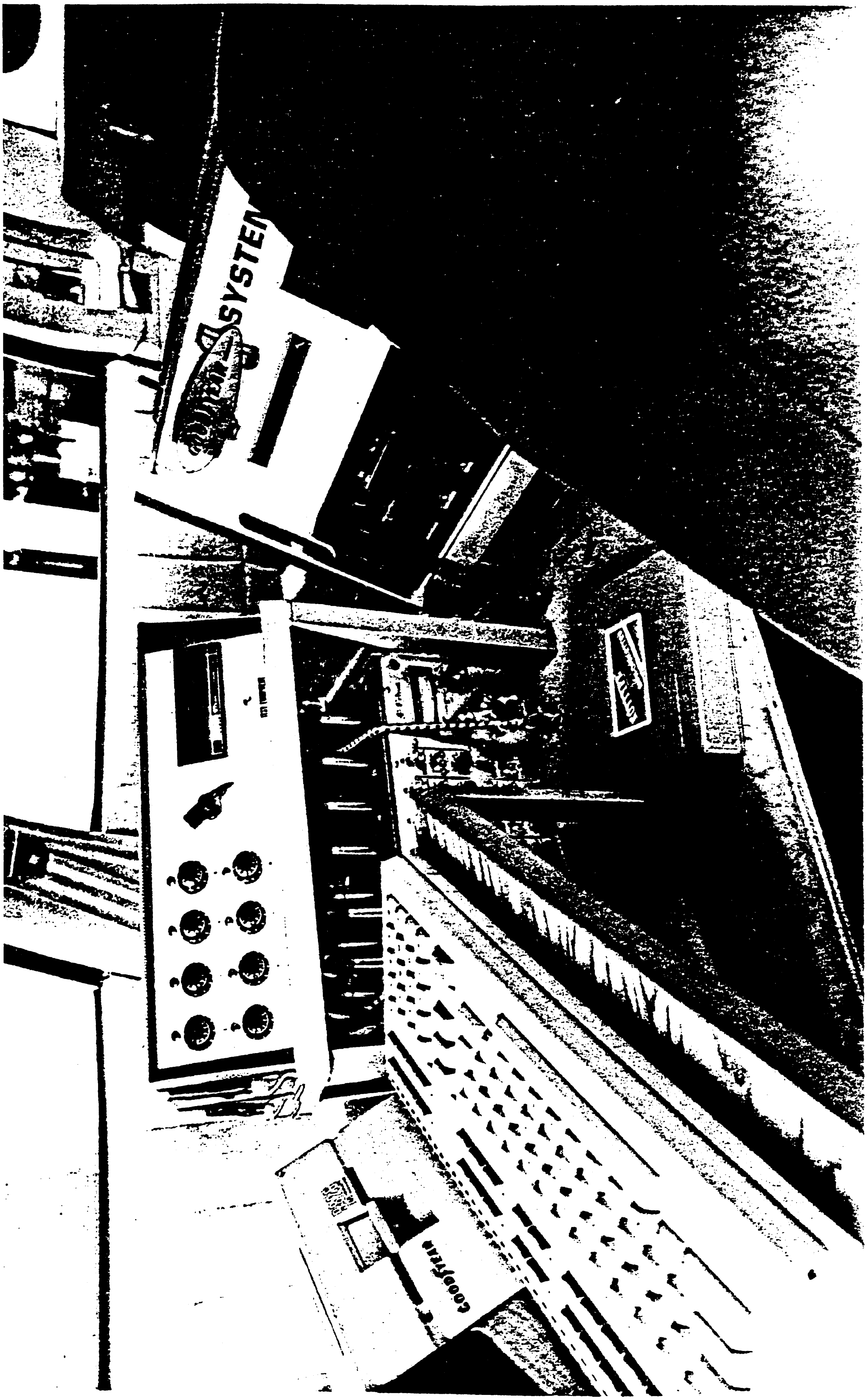
型式	：ピラミッド型 ストラット式
測定量	：抗力，揚力，横力 縦揺モーメント，偏揺モーメント 横揺モーメント
容量	：3分力 0～±10 kg モーメント 0～±5 kg·m
自重キャンセル範囲	：0～50 kg
精度	：±0.5％
その他	：偏揺角自動調節装置付

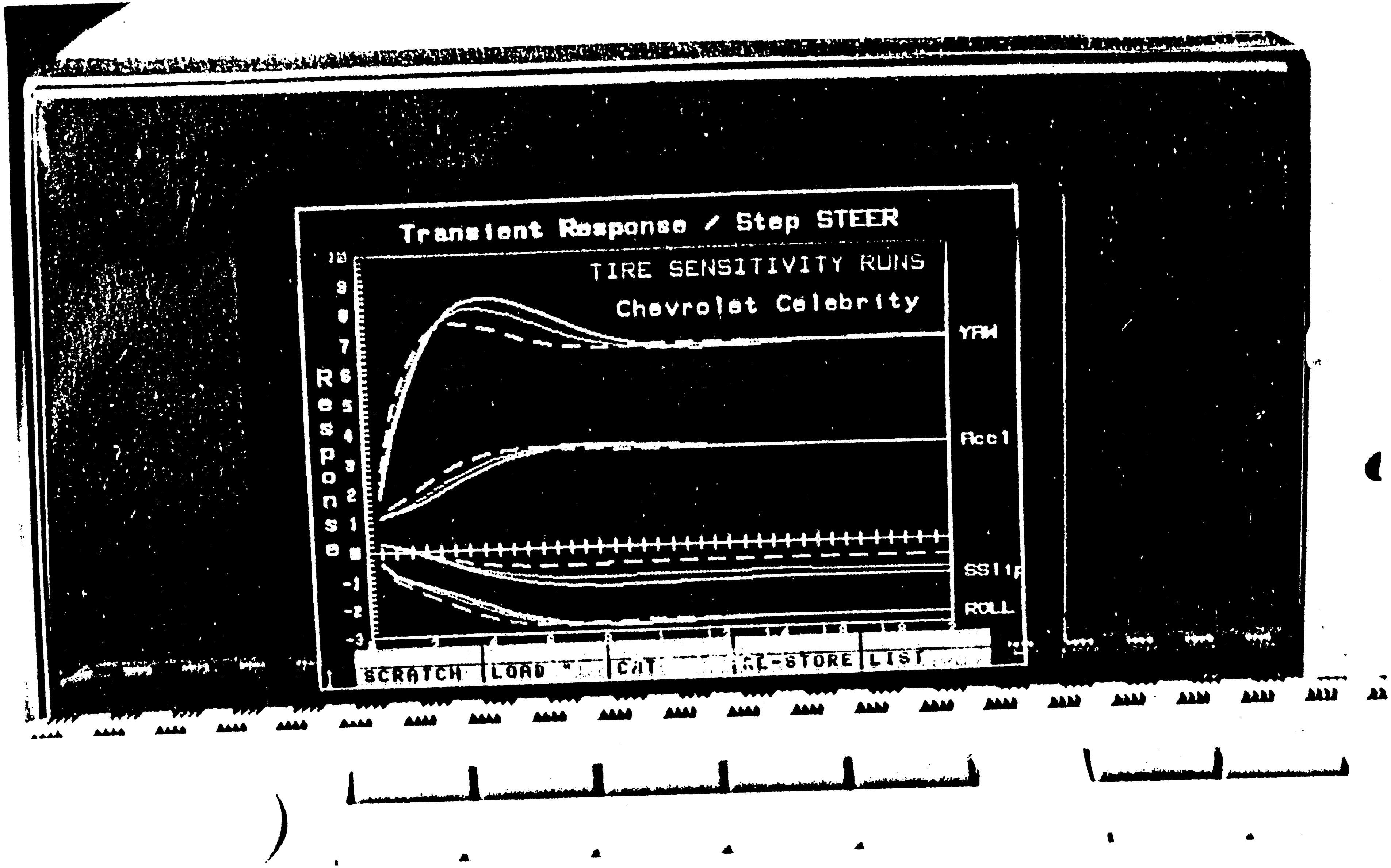


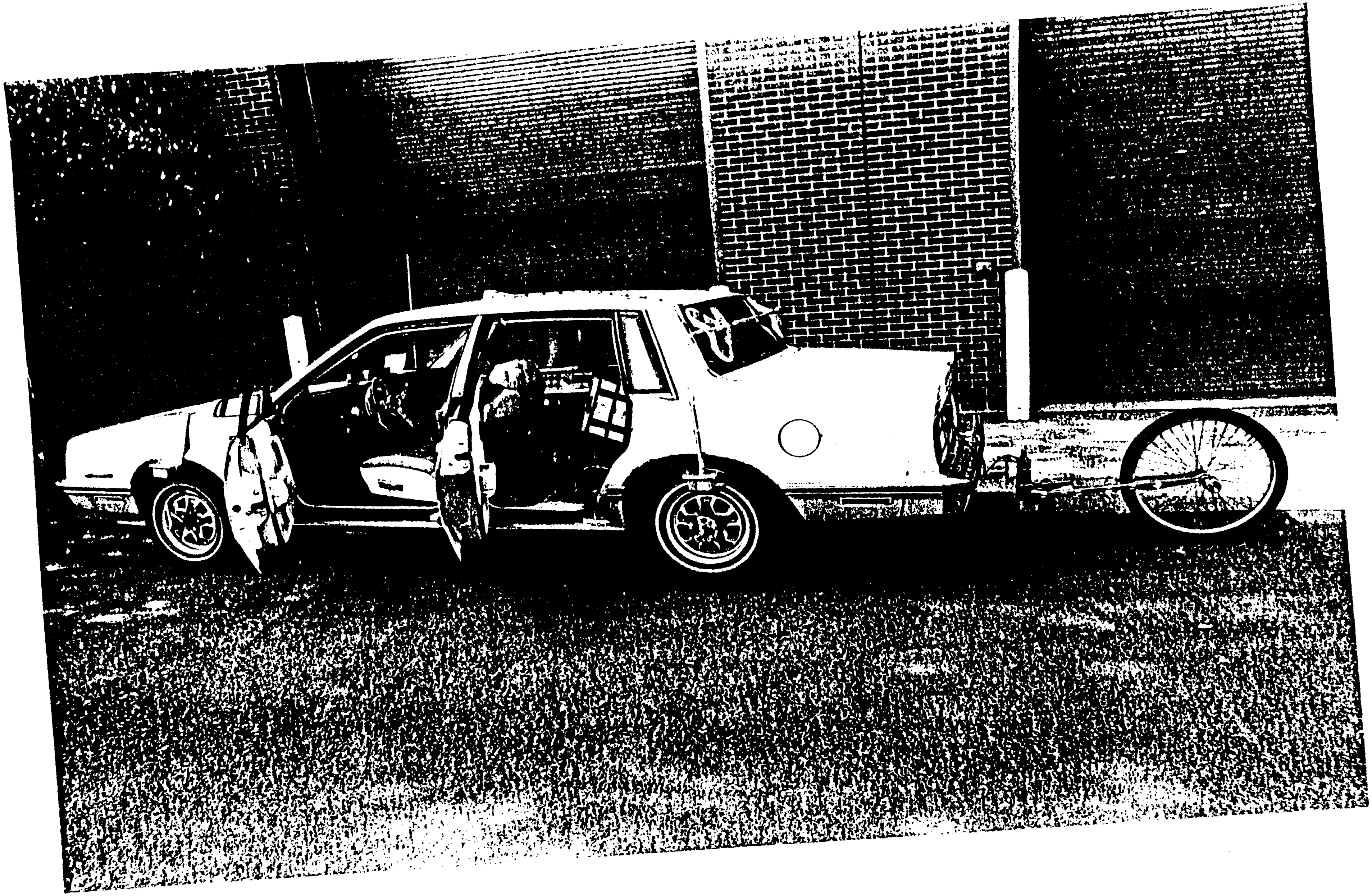


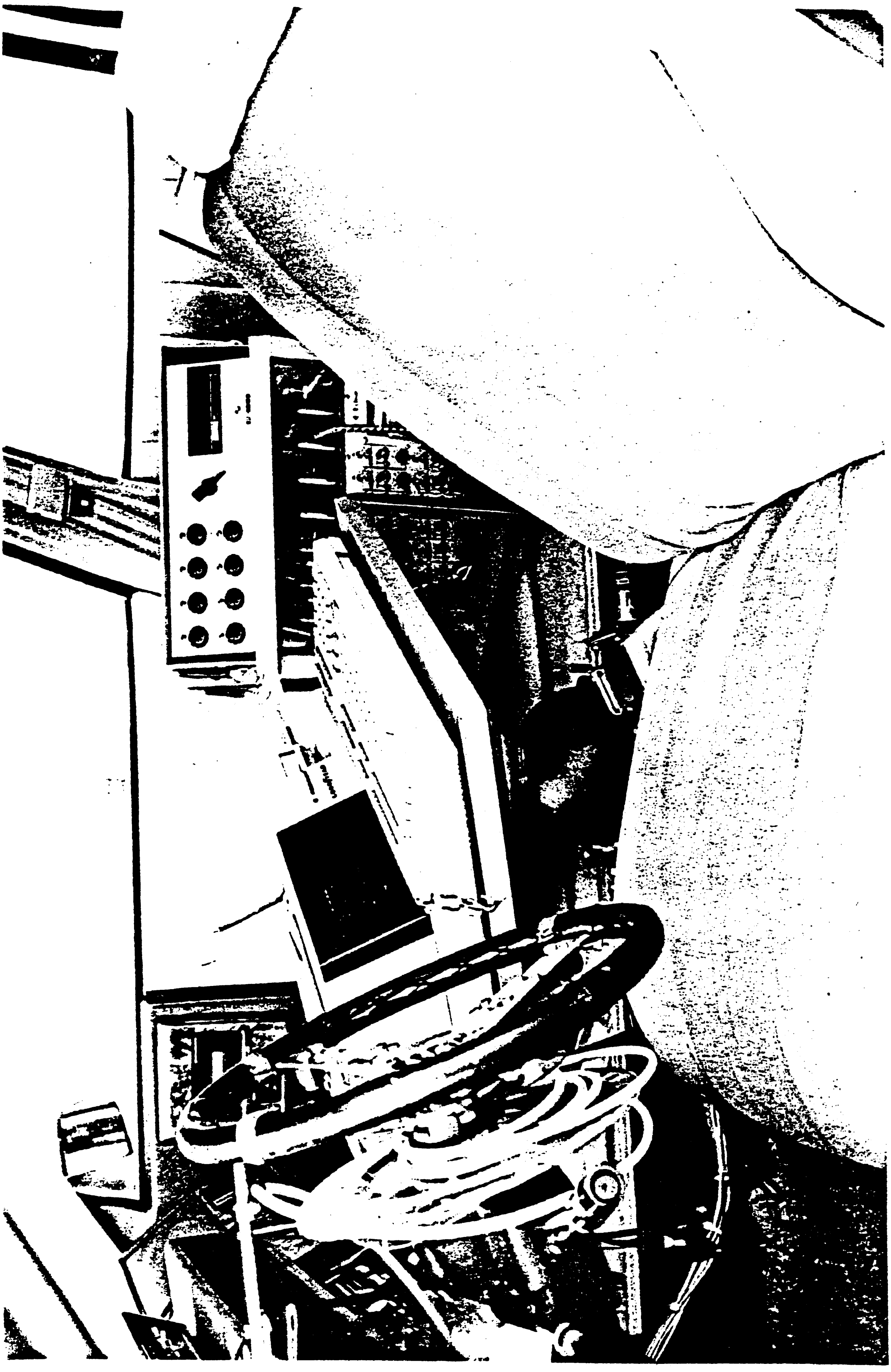
実験装置

APPENDIX H


Goodyear


Transient Response / Step STEER
TIRE SENSITIVITY RUNS
Chevrolet Celebrity
Response
YAW
Accl
ROLL
SCRATCH
LOAD
CAT
LIST





APPENDIX I

The tyre test track in Vizzola Ticino

APPENDIX J

THE DUNLOP TYRE DYNAMICS MACHINE

D. J. Osborne

Dunlop Limited, U.K.

1. Introduction

During the last decade, increasing emphasis has been placed upon vehicle safety by both the tyre and vehicle manufacturer.

The tyres play an important role from the point of view of wet and dry grip performance, control under deflated conditions, and high speed stability and response. The tyre designer is continually optimising the tyre construction in an endeavour to satisfy these constraints. In the case of vehicle handling, the designer must first determine the critical components before such modifications can be made.

On the other hand, the vehicle manufacturer, while not being concerned about the basic tyre mechanics, demands performance characteristics of tyres for use in mathematical models of vehicle and suspensions. These models were originally based upon steady-state tyre data, which proved adequate for models relating to normal driving conditions involving low frequency manoeuvres. However, for the study of events arising from rapid wheel movements, as in the case of shimmy or accident avoidance situations, it is necessary to account for the transient characteristics of tyres.

To provide information of this type, the Dunlop Tyre Dynamics Machine has been developed. This equipment permits four independent transient motions to be applied to the tyre, namely vertical and lateral displacements, together with steer and camber rotations. Potentiometers which record the instantaneous wheel position, and a strain-gauged force transducer system, enable the resulting six components of tyre force and moments to be evaluated at the contact patch as a function of wheel orientation and time.

2. Description of Machine

2.1. Frameworks

The Tyre Dynamics Machine comprises a large diameter smooth cast iron drum upon which rolls a tyre/wheel assembly supported by moveable frames. The frames are three interconnected structures shown schematically in Figure 1. The wheel hub is supported by the six strain-gauged links mounted in a cube arrangement. Such a system allows the forces in the links to be resolved into three forces and three moments with respect to mutually perpendicular axes. The "cube" is attached by means of linear bearings to the steer (slip) angle framework. This allows the wheel axle to be moved vertically relative to the slip angle frame thus giving variation in axle height and tyre load.

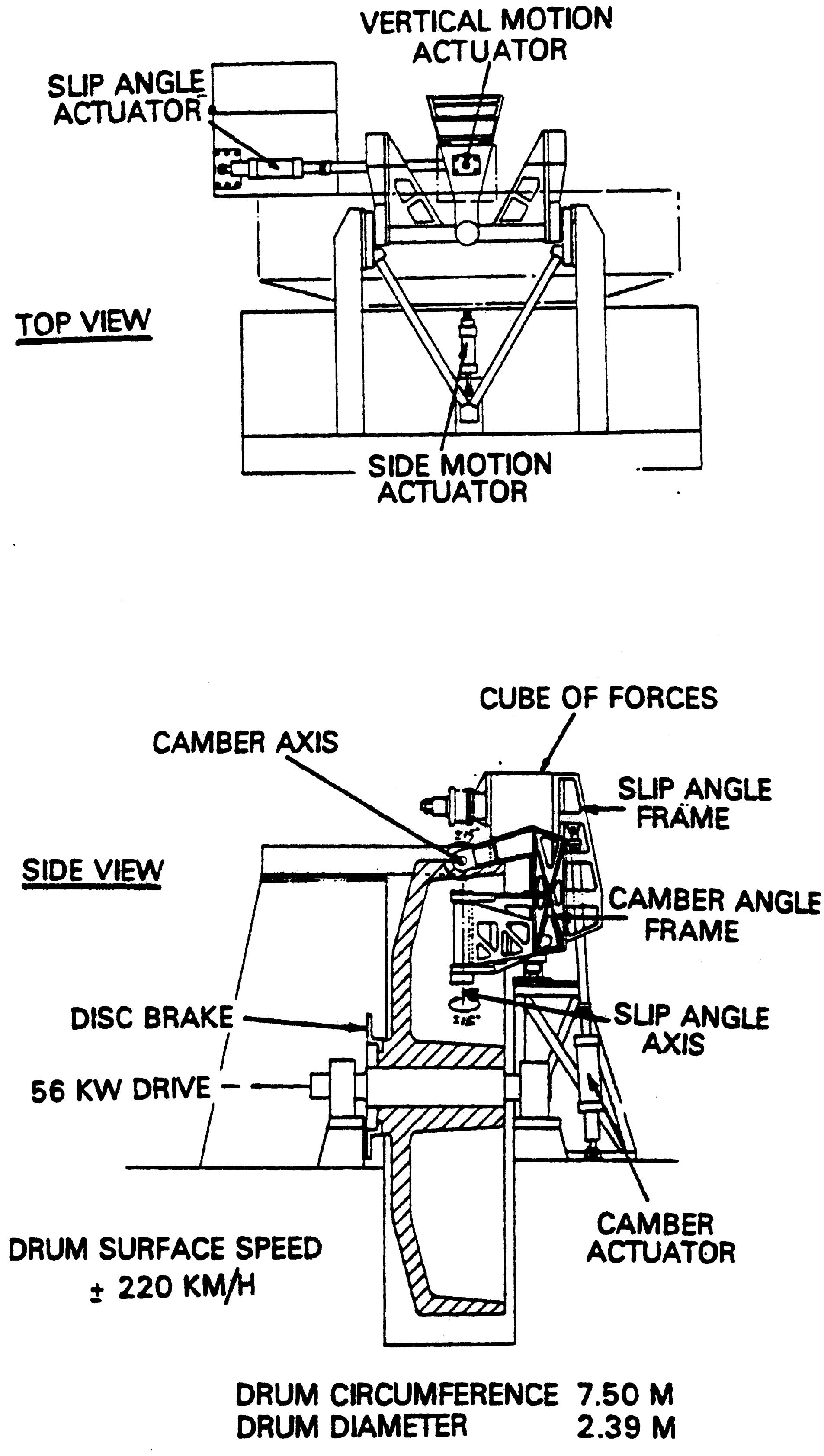


Figure 1

CONFIGURATION OF DUNLOP TYRE DYNAMICS MACHINE

The steer framework pivots around two taper bearings which are positioned so that the king pin inclination relative to the wheel plane is zero and the steer offset at the drum surface is small. This is achieved by locating the king pin inside the drum. The king pin also forms part of the framework that allows camber motion. The camber axis has been chosen to be tangential to the drum surface and intersects the axis of the king pin at right angles.

The vertical, steer and camber frames are supported on two pedestals which house the linear bearings necessary for the lateral motion of the entire assembly. The interconnection of the frames has been designed so that each of the four motions can be applied independently or in any combination.

2.2. Control System

The force required to move the frames is supplied by four electro-hydraulic actuators operating at 140 kg/cm^2.

The actuators are controlled electrically using standard modular systems. The main components of the control system are an input signal, a transducer, a closed loop controller and error level detection networks. A typical example is shown in Figure 2.

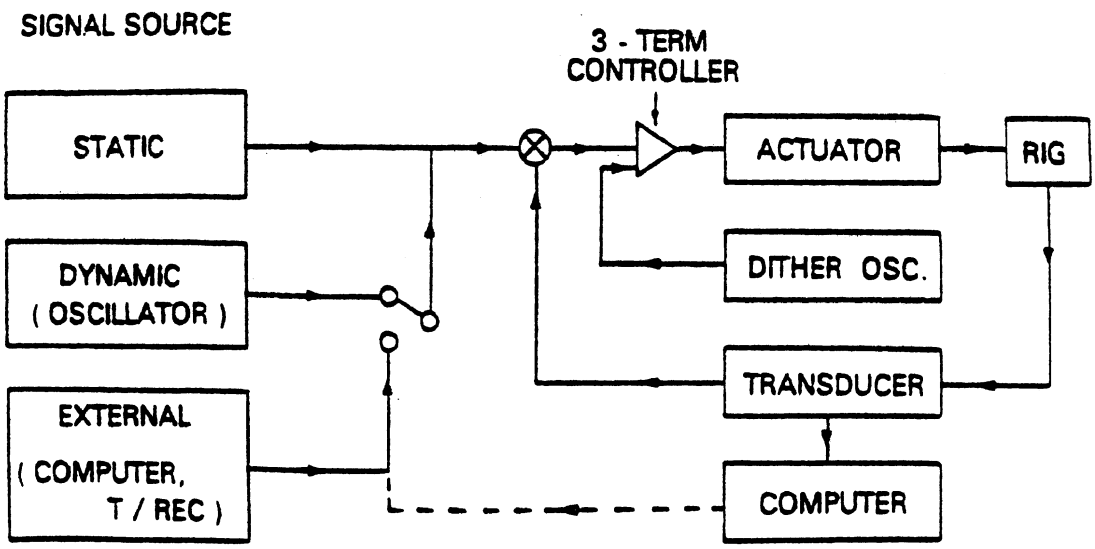


Figure 2

TYPICAL CONTROL SYSTEM FOR TYRE DYNAMICS MACHINE

2.2.1. Input Signal

The displacement of the actuator is proportional to the applied signal level. The input can be generated in three ways:

(a) A static D.C. level input, which displaces the actuator a fixed amount. This type of input is used to determine steady state tyre properties.

(b) A dynamic input. This signal is obtained from a function generator and is added to any D.C. signal that has been set. The function generator provides a wide range of dynamic signals together with a single cycle and quarter cycle facility for special purpose tests. Frequencies from .001 Hz to 100 Hz are available in sinusoidal, square, ramp and sawtooth waveforms. The oscillator is common to all four actuators, although the amplitudes are independently controlled.

The sinusoidal input is of particular interest in the study of tyre transfer functions, whereas the quarter cycle square wave can be used to generate step inputs.

(c) External inputs. Selecting the external input facility disconnects the function generator and allows the static input to be summed with some external source. This may be from another oscillator, tape recorder or a mini-computer. The latter facility enables tests to be performed under computer control with the computer effectively forming part of the machine control loop, and enables more rapid and accurate settings to be made than using manual control.

It is thus possible to program the computer to perform automatic tyre testing, both for steady state and transient manoeuvres.

2.2.2. Transducers

Conductive plastic potentiometers having infinite resolution are used to measure the attitude of the machine. Rectilinear potentiometers allowing a measurement better than .1 mm are used for the vertical and lateral displacements, and rotary potentiometers measuring to within .05^{o} are used for the slip and camber angles. A supplementary potentiometer is mounted on the steer angle frame and driven through a 5:1 gear mechanism in order to increase the accuracy of measurement in the small slip angle region.

A load cell mounted between the vertical actuator and the hub frame gives an approximate auxilliary measurement of tyre load. This measurement will be affected by camber, and consequently the true vertical tyre load is computed from the "cube" transducers.

2.2.3. Closed Loop Control

The input signal to the actuator and the output signal from the transducer are compared using a three-term controller. Adjustments can be made to the controller to optimise the stabilisation of the system.

The control of the axle position differs slightly from that of steer, camber, and lateral motions, in that two forms are available. The first is using 'position' mode, whereby the output from the axle height potentiometer provides the feedback signal. Secondly, under 'force' control, the load cell is used and the potentiometer isolated. Position control is used for the majority of tyre tests since this has the higher frequency response and ensures a fail-safe situation in the case of sudden tyre deflation.

2.2.4. Error (level) Detection

The values of the controlled variables are continuously monitored by level detectors to ensure that the signal levels are within a pre-set safe operating range. In the event of any displacement or rotation exceeding the specified safety limits, the error detector automatically retracts the tyre from the drum surface.

2.3. Performance Characteristics

The response of the four motions can be measured either in terms of frequency/amplitude characteristics or by defining the maximum rate of change of position resulting from a step input. These parameters are summarised in Figure 3 together with the absolute range of each motion.

PARAMETER	RANGE	RESPONSE	
		SINUSOIDAL	STEP
SLIP	± 15°	± 1.5° AT 5 HZ ± 0.5° AT 10 HZ	20°/SEC
CAMBER	± 15°	± 1.5° AT 4 HZ ± 0.3° AT 8 HZ	45°/SEC
AXLE HEIGHT	380 TO 230 MM 300 TO 150 MM	± 10 MM AT 6 HZ ± 2.5 MM AT 12 HZ	350 MM/SEC
LATERAL	± 100 MM	± 20 MM AT 4 HZ ± 4 MM AT 8 HZ	200 MM/SEC

Figure 3

TYRE DYNAMICS MACHINE PERFORMANCE

Two ranges of axle height are available by using an alternative hub mounting. This allows model and small aircraft tyres to be tested as well as the full range of car tyres. The tyres roll on a smooth drum (2.39 m diameter) capable of surface speeds of $\pm$220 km/h. Lateral force coefficients in excess of .7 can be achieved on this surface. At the present time only dry interface conditions without driving or braking are available.

3. Computer System

The study of transient tyre properties requires a measurement system that is both fast and accurate. This is achieved using a digital computer system, as described in Figure 4.

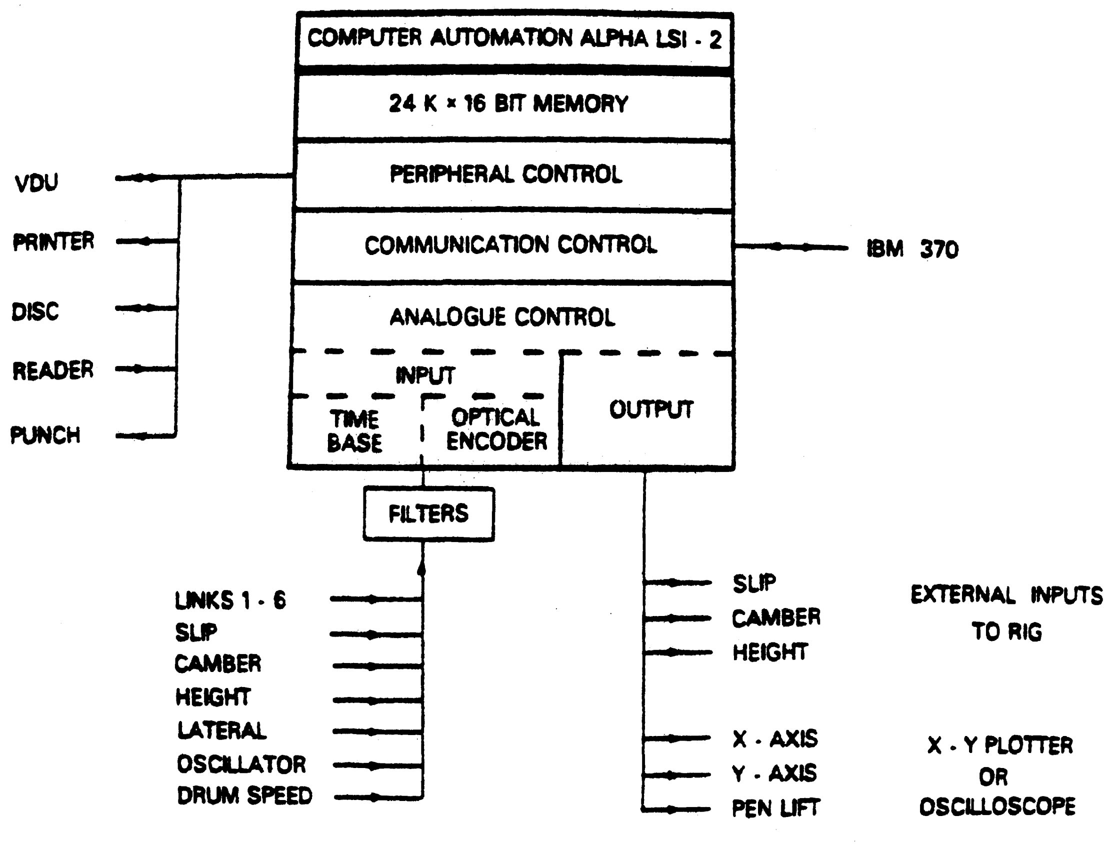


Figure 4

TYRE DYNAMICS MACHINE COMPUTER SYSTEM

The computer performs four main functions, namely data acquisition, computation and display, machine control, and teleprocessing.

By using a parallel-sample technique all input channels are sampled simultaneously. The required speed and accuracy is obtained using 14 bit ADC's having a maximum sampling rate of 50 kHz per channel. Prior to sampling all signals are passed through low pass filters to remove high frequency noise. The actual sampling rate can either be controlled by a clock to give selectable frequencies in the range 1 to 5000 Hz over all channels or, alternatively, measurements can be made at equi-spaced positions around the rotating tyre in the range 1 to 512 samples per revolution. The latter facility is achieved using an optical encoder mounted on the wheel axle. This dual sampling method gives a convenient way of studying either time or distance dependent phenomena.

The raw data is stored in memory until all the required samples have been obtained. The computer then performs the necessary scaling, transformation of axes, and corrections arising from calibration, so as to obtain the three forces and moments acting at the contact patch, according to the S.A.E. sign convention. The calibration of the machine was obtained by applying known static forces and moments and calculating errors due to cross-coupling. This generates a 6 x 6 matrix of correction constants which is approximately a unit matrix.

The computed values can then be displayed on a number of output devices. The mini-computer is linked to an IBM 370, which handles long-term data storage, together with more complex data processing such as smoothing and automatic graphical output.

A suite of programs are available to perform a wide variety of tests. These include steady state analysis, impulse and sinusoidal frequency response, and simulation of wheel motions to reproduce in-service conditions. All programs are written in either Assembler or Fortran and can be readily modified to incorporate any specific test requirements.

4. Tyre Testing

Mathematical models relating to some aspects of transient tyre properties have been developed by a number of authors. In particular, Pacejka (1), and Segel (2) have given solutions for the steer response of tyres based upon the analogy of a stretched string on an elastic foundation, corresponding to the tread and carcass regions respectively. The Tyre Dynamics Machine provides a practical means of evaluating the validity of such theories. Of particular interest are the generation of tyre forces associated with a step input of steer angle, as arises during emergency manoeuvres, and secondly the more general frequency response characteristics of the tyre expressed as an amplitude and phase relationship to the applied motions.

4.1. Response to a Step Input

When the tyre is subjected to a step change of steer angle, the lateral force generated by the tyre rolls a finite distance before attaining a new steady state condition. The mathematical model differentiates between two regions. When the distance rolled is less than the contact length, the build-up of lateral force is proportional to the distance travelled, and beyond this region the curve becomes exponential.

Figure 5 gives the experimental results from the Dynamics Machine of such a step input.

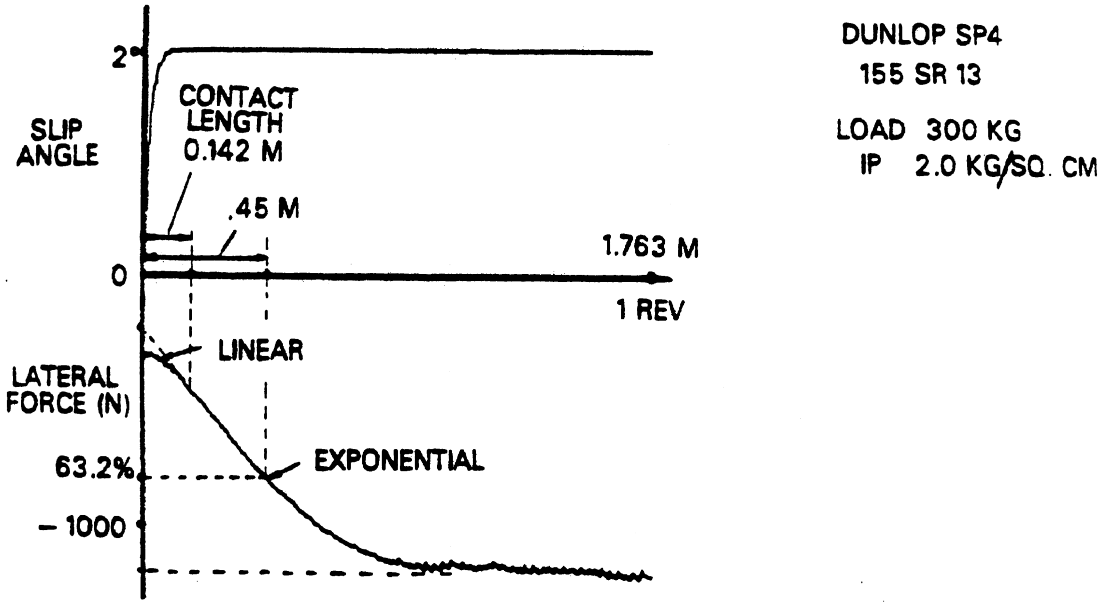


Figure 5

BUILD UP OF LATERAL FORCE DUE TO STEP INPUT OF SLIP ANGLE

The two regions can be readily distinguished, thus validating the use of the mathematical model.

4.2. Frequency Response

The transfer function of a system generally involved applying a sinusoidal input of known amplitude and frequency and measuring the relative amplitude and phase of the output. When this technique is applied to measurements on tyres, it is necessary to make allowances for tyre non-uniformities, inertia of the moving mass and gyroscopic effects, particularly at the higher excitation frequencies and drum speeds. A typical set of results is shown in Figure 6 for the lateral force and aligning torque response of a radial tyre over a range of steer frequencies and drum speeds. Once again, these results provide confirmation of the published data based upon mathematical models.

5. Conclusions

The Tyre Dynamics Machine can provide information necessary to support or modify existing theories on transient tyre behaviour. This will enable vehicle designers to make more realistic representations of tyres in future development studies.

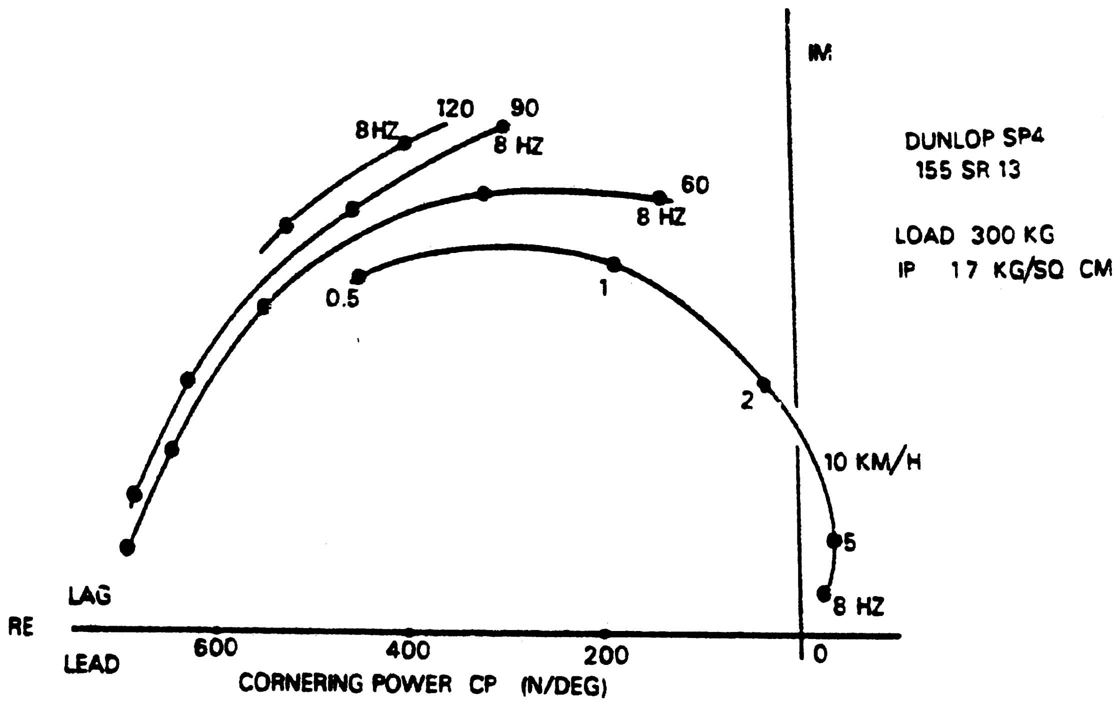
Tyre Research and Development is based upon quantifying the effect of small differences in design.

Historically, this work has been largely empirical, but with the advent of test machines of the type described, future advances will be possible by detailed analysis of the tyre components and the part each plays in the generation of tyre forces.

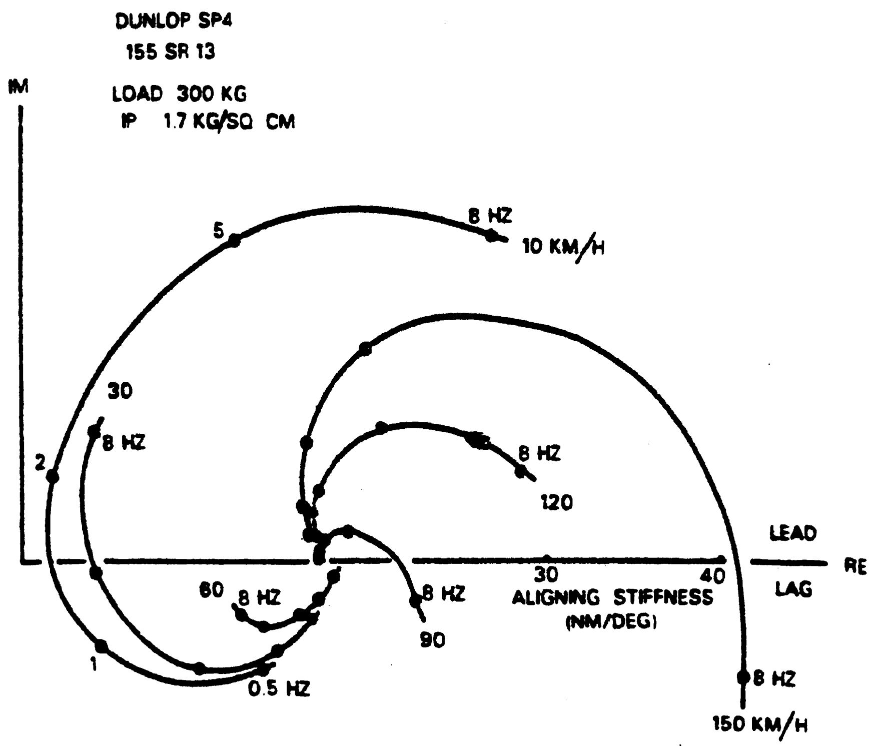
References

(1) Pacejka H. B.
Analysis of the dynamic response of a rolling string-type tyre model to lateral wheel-plane vibrations.
Vehicle System Dynamics (1972).

(2) Segel L.
Force and moment response of pneumatic tyres to lateral motion inputs.
Journal of Engineering for Industry (1965).



DYNAMIC RESPONSE OF LATERAL FORCE TO STEER

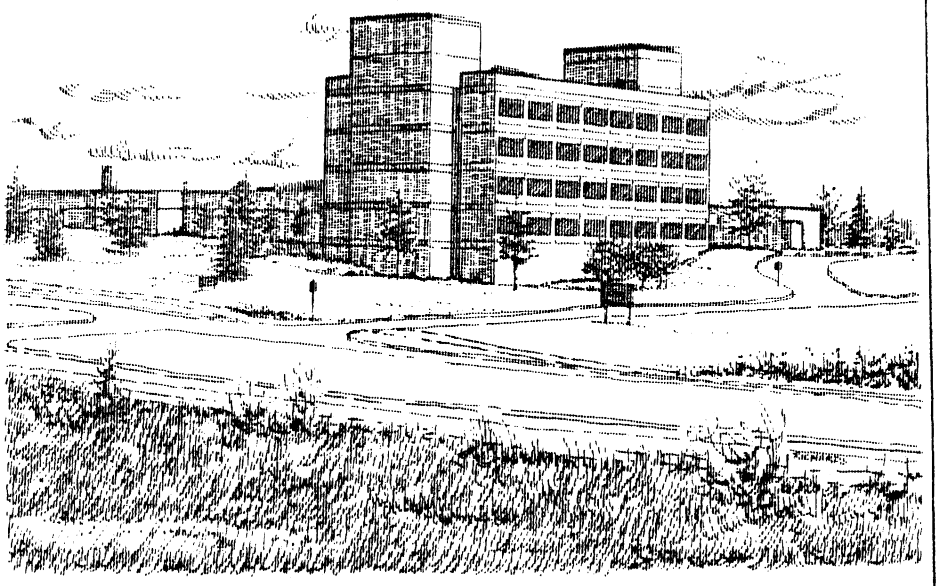


DYNAMIC RESPONSE OF ALIGNING TORQUE TO STEER

Figure 6

APPENDIX K

UMTRI RESEARCH FACILITIES



The UMTRI Building

The building was constructed in 1969 on the North Campus of The University of Michigan. It provides 68,000 square feet of laboratories and other facilities specifically designed to support research on all aspects of transportation systems and their problems. The building contains laboratories for vehicle research, impact-sled tests, biomedical studies, and engineering and human factors research, as well as a library, conference rooms, office space, and microcomputers for U-M and visiting faculty and staff members engaged in the multidisciplinary research programs.

The UMTRI Library

This facility provides a specialized information service for the institute staff and other members of the transportation research community. Its collection includes more than 57.000 cataloged documents and more than 225 periodical titles. The subject areas of the collection reflect the many different ways in which transportation problems can be approached. with materials drawn from the literature of engineering, physics, medicine, public health, law, economics, psychology, sociology, statistics, computer science, and other fields. The library concentrates on obtaining the most current information on transportation problems and making it readily accessible to the research staff. The library also employs its unique classified subject file to conduct retrospective literature searches, and it provides UMTRI staff with access to all other University of Michigan library resources.

Computing Equipment

UMTRI maintains a variety of terminals for ready access to the University's AMDAHL 5860 computer. Microcomputers at the Institute include Apples, IBM PC's, and Zenith Z-100's for data processing and word processing. A Data General Eclipse S/250 computer is employed in the motorcycle tire dynamometer for on-line calculations and automatic control of its test procedures. Also, small and portable digital systems have been developed for use in experiments requiring automated data acquisition and programmed test procedures. These small computer systems are typically employed in tests conducted at vehicle proving grounds.

Automated Data Access and Analysis System

The UMTRI Automated Data Access and Analysis System (ADAAS) is an integrated set of computer programs used to access, manipulate, and analyze more than 350 accident-related data sets maintained by UMTRI. The system is resident on the University of Michigan's AMDAHL 5860 computer, and may be operated in either batch or conversational mode through remote terminals, via a telephone line.

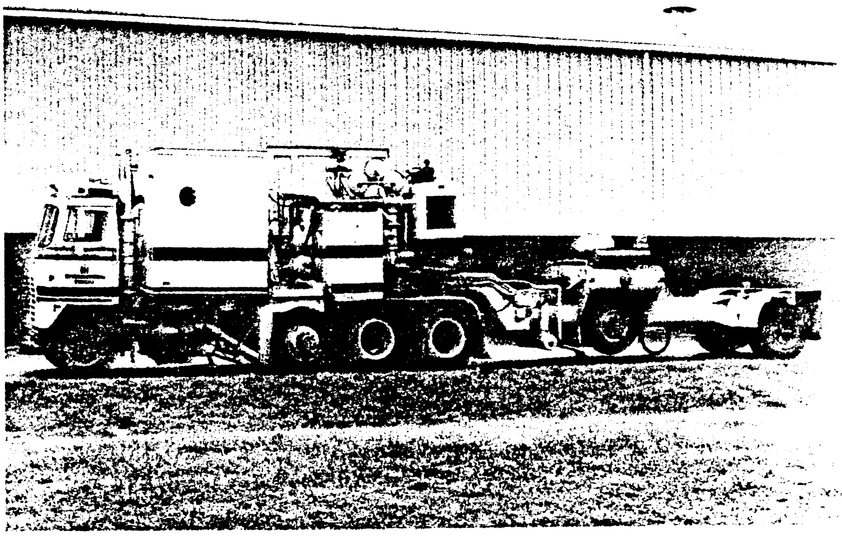
Data access is provided by a keyword unique to each data set. All physical file manipulations (for example, uses of magnetic tapes) are performed by the system. Six simple data manipulation/analysis operations are provided to handle most preliminary data search functions. The data sets can also be accessed by OSIRIS, SPSS, or MIDAS, so that more sophisticated analytic operations may be performed.

The system is largely self-documentary and self-describing, so that novice users can quickly become familiar with its operations. Because the system offers a simple technique for using accident data in important safety-related research questions and decisions, it is employed about 35 times a day by government, industry, and university researchers in the U.S. and Canada. Current users include persons in the NHTSA, the Canadian Ministry of Transport, the Michigan Department of State, the Missouri Highway Patrol, member companies of the Motor Vehicle Manufacturers Association, and staff members in several universities and private research organizations.

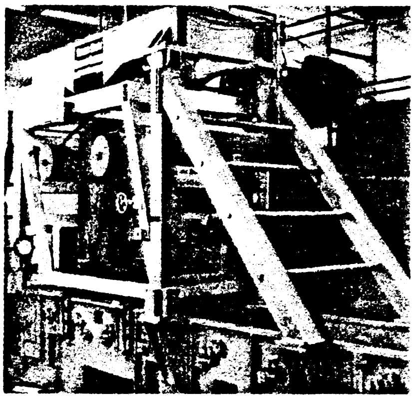
Mobile Truck Tire-Brake Tester

Constructed by UMTRI under MVMA sponsorship, this over-the-road apparatus is a six-axle, 36-ton tractor-semitrailer specially designed and instrumented to measure the longitudinal and lateral shear-force properties of truck tires under realistic braking and cornering conditions on all types of roadway surfaces, under various loads, at velocities up to 70 mph. Test tires are mounted on test stations located on both the tractor and the semitrailer. The braking and cornering behavior of the test tire is measured with the aid of load cells and recorded at an onboard operator's module. The mobile system carries its own hydraulic, pneumatic, and electrical power services, and also provides a water-delivery capability for tests on wet roadways.

The Mobile Tire-Brake Tester is also used as a dynamometer for measuring the torque characteristics of commercial vehicle brakes. The load cell that measures longitudinal force also measures the torque produced by the brake installed on the test wheel located on the semitrailer.

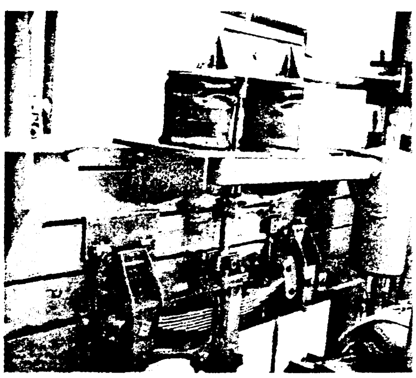


Flat-Bed Tire Tester



The flat-bed tester is used to obtain precise measurements of the mechanical characteristics of rolling and standing tires. It accommodates passenger-car and truck tires ranging from 24 to 44 inches in diameter and can apply vertical loads of up to 10,000 lbs. The device is designed for low-speed tests at steer angles between ±90° and camber angles between ±20°, and is instrumented to measure the three forces and three moments developed by the tire. Automatic data scanning and logging by on-line analog-to-digital converters and digital tape-recording equipment provide efficient data recording for rapid processing on the UMTRI PDP 11/45 computer.

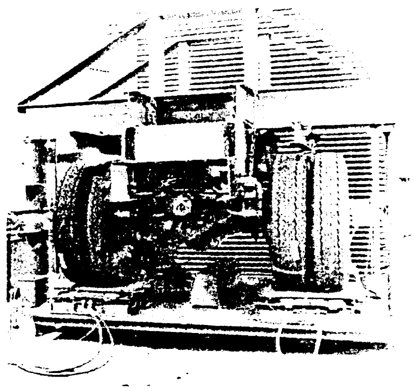
Leaf Spring Tester



An electrohydraulic stroking device built into a versatile mounting plate assembly permits measurement of the force/deflection properties of leaf springs at stroking frequencies of up to 15 H_z. Sample springs are mounted with all of their peripheral components, such as frame saddles, shackles, torque rods, equalizer links, etc., to establish authentic force reactions at the spring ends. With this device, spring properties relating to braking and handling as well as ride responses of vehicles can be measured.

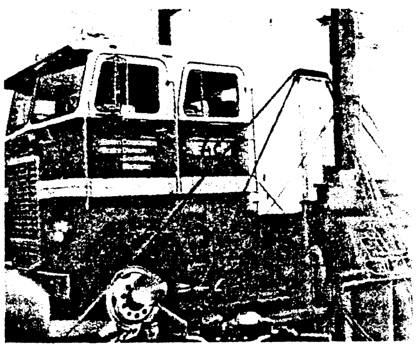
Suspension Properties Tester

The UMTRI facility for testing suspension properties of heavy vehicles is capable of measuring virtually all of the compliance, kinematic, and Coulomb friction properties of suspension and steering systems as they react to vertical force, roll moment, lateral force, brake force, and aligning moment. The facility can accept single-axle and tandem-axle suspensions (maximum tandem spread 70 inches) of all common, on-highway track widths. Suspensions can be tested in their normal configuration (mounted on a vehicle), or as mounted on an abbreviated frame section. All measurements are performed at steady-state or quasi-steady-state; that is, the facility is not intended for dynamic testing.

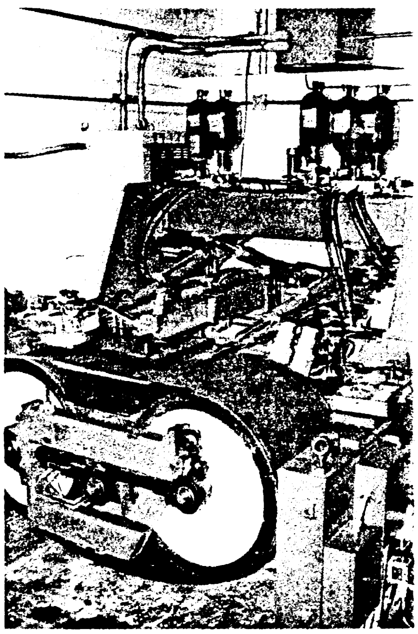


Pitch-Plane Inertial Properties Tester

The UMTRI Pitch-Plane Inertial Properties swing is used to measure the pitch moment of inertia and center-of-gravity position in the pitch-plane (i.e., side view) of motor vehicles. The tester, designed primarily for heavy vehicles, can handle two- and three-axle trucks weighing up to 30,000 lbs. The vehicle properties measured with this device are important determinants of motor vehicle behavior during braking.



Honda/UMTRI Motorcycle Tire Dynamometer



This dynamometer, designed and constructed by UMTRI under sponsorship of the Honda Research and Development Company, provides a research capability found nowhere else in the world. Unlike conventional dynamometers, this one provides complete flexibility for testing traction under dynamic operating conditions.

The facility is unique in its physical design, in that it employs a small, light tire-mounting head positioned by a mechanically simple system of hydraulic cylinders. During tire testing these cylinders are under the control of a digital computer. One thousand times each second the computer takes measurements of the tire position and loading and performs the complex calculations necessary to reposition the test tire dynamically.

Tires may be tested at speeds to 100 mph., slip angles of more than ±15 degrees, inclination angles to ±45 degrees, and at path curvatures of 0 to .035 feet. All position control variables have band widths extending beyond 10 H_z.

Vehicle Dynamics Simulation Programs

Several computer programs for simulating vehicle dynamics were developed at UMTRI for use in predicting the longitudinal and directional responses of passenger cars, passenger-car-and-trailer combinations, trucks, tractor-semitrailers, doubles, and triples combinations.

These simulation models range from relatively simple ones concerned with motions in one plane to more complex models that simulate all types of motions during steering, braking, or combined maneuvers. The programs contain provisions for representing various tandem suspensions, brake systems, antilock systems, tire shear-force characteristics, steering system compliance and kinematics, and various fifth-wheel or hitch designs. Although the more complex programs deal with equations and models having many degrees of freedom, including wheel-rotation dynamics, special techniques have been developed to make them economical to run.

Professional Staff and Program Participants

Alem, Nabih M.
Ph.D., Mechanical Engineering
Associate Research Scientist

Barhydt, Wendy H.
B.S., Special Education
Research Assistant

Bennett, Robert O.
M.S., Physics
Senior Research Associate

Benson, Joseph B.
M.S., Bioengineering
Senior Research Associate

Boissonneault, Joseph F.
Foreman

Bowman, Bruce M.
Ph.D., Engineering Mechanics
Associate Research Scientist

Bowman, Marion J.
Research Associate

Bunch, Howard M.
C.M.A., M.B.A., Marketing and Transportation
Research Scientist and Head, Marine Systems Division
Associate Professor of Transportation Management

Businski, Karen L.
B.S., Social Work
Accident Investigator

Campbell, John D.
M.S., Information and Control Engineering
Senior Research Associate

Campbell, Kenneth L.
Ph.D., Mechanical Engineering
Associate Research Scientist

Carsten, Oliver M.
Ph.D., History
Research Associate

Cleveland, Donald E.
Ph.D., Civil Engineering
Professor of Civil Engineering

Cole, David E.
Ph.D., Mechanical Engineering
Head, Office for the Study of Automotive Transportation
Associate Professor, Mechanical Engineering and Applied Mechanics

Compton, Charles P.
M.S., Biology
Programmer Analyst

Cooley, Peter
B.S., Electrical Engineering
Research Scientist

Crequé, Denise M.
Administrative Associate

Dallas, Andrew
B.S., Naval Architecture and Marine Engineering, Physical Oceanography
Research Associate

Davinich, Alice R.
M.P.H., Health Planning
Accident Investigator

Ervin, Robert D.
M.S., Mechanical Engineering
Research Scientist

Fancher, Paul S.
M.S., Instrumentation Engineering
Research Scientist

Filkins, Lyle D.
M.S., Industrial Engineering
Research Scientist

Flora, Jairus D.
Ph.D., Statistics
Research Scientist
Professor of Biostatistics

Gattis, R. Guy
M.A., Library Science
Assistant Coordinator, Research Information and Publications

Gillespie, Thomas D.
Ph.D., Mechanical Engineering
Research Scientist

Gordus, Jeanne P.
Ph.D., Economic History
Assistant Research Scientist

Green, Charles P.
M.S., Civil Engineering
Research Associate

Green, John A.
Ph.D., Physics
Research Scientist

Green, Paul A.
Ph.D., Industrial and Operations Engineering, Psychology
Assistant Research Scientist

Green, Richard C.
B.A., English
Assistant Director, UMTRI

Grimm, Ann C.
M.A., Library Science
Coordinator, Research Information and Publications

Hagan, Michael R.
B.S., Electrical Engineering
Engineer in Research

Haney, James E.
M.A., English
Senior Science Writer

Harbeck, Lawrence T.
M.A., Business Administration
Associate Research Scientist

Hess, Robert L.
Ph.D., Engineering Mechanics
Professor of Mechanical Engineering and Applied Mechanics

Huelke, Donald F.
Ph.D., Anatomy
Professor of Anatomy

Jessup, John E.
B.S., Naval Architecture and Marine Engineering
Research Associate

Kadlubowski, James W.
B.S., Psychology
Accident Investigator

Kaiker, Patricia S.
B.A., English, Spanish
Engineer in Research

Lehman, Richard J.
B.A., Psychology
Research Associate

Lux, Paula
B.A., Applied Art
Research Associate

MacAdam, Charles C.
M.S., Aerospace Engineering
Assistant Research Scientist

Mackenzie, James R.
B.Sc., M.D., C.M.
Associate Professor of Surgery
Medical School

Melvin, John W.
Ph.D., Theoretical and Applied Mechanics
Research Scientist and Head, Biosciences Division
Associate Professor of Mechanical Engineering

Minahan, Daniel J.
B.S., Civil Engineering
Staff Consultant

Moore, Joseph A.
Administrative Associate

Mumemasa, Fuse
Visiting Scientist
Nissan Motor Company

Nusholtz, Guy S.
M.S., Bioengineering
Assistant Research Scientist

O'Day, James
M.S., Physics
Research Scientist and Head, Systems Analysis Division
Acting Director, UMTRI

O'Keefe, Brian J.
B.A., Geography
Research Assistant

Olson, Paul L.
Ph.D., Industrial/Experimental Psychology
Research Scientist and Head, Human Factors Division

Owings, Clyde L.
M.D., Ph.D., Bioengineering
Associate Professor of Pediatrics and Communicable Diseases
Associate Professor of Electrical and Computer Engineering

Perrin, Nancy A.
Conference Assistant

Pettis, Leslie C.
B.S., History
Research Assistant

Pflug, Melissa A.
M.A., Physical Anthropology
Research Associate

Pollock, William T.
Ph.D., Psychology
Research Scientist

Ricci, Leda L.
B.A., English, Sociology
Research Assistant

Richards, Kathleen C.
M.A., Elementary Education
Senior Graphic Artist

Robbins, Delmar H.
Ph.D., Engineering Mechanics
Research Scientist

Sayers, Michael W.
M.S., Mechanical Engineering
Senior Research Associate

Scher, Robert M.
M.S., Naval Architecture and Marine Engineering
Research Associate

Schneider, Lawrence W.
Ph.D., Bioengineering
Research Scientist

Scott, Robert E.
M.S., Electrical Engineering
Research Scientist

Segel, Leonard
M.S., Engineering
Research Scientist and Head, Engineering Research Division
Professor of Mechanical Engineering and Applied Mechanics

Sherman, Harold W.
B.S., Electrical Engineering
Senior Research Associate

Siegel, Marilyn C.
B.A., French
Technical Library Assistant

Sivak, Michael
Ph.D., Psychology
Associate Research Scientist

Snyder, Richard G.
Ph.D., Physical Anthropology, Zoology
Research Scientist
Professor of Anthropology

Spenny, Curtis H.
Ph.D. Engineering and Applied Physics
Visiting Scientist
Transportation Systems Center, U.S. Department of Transportation
Lecturer, Mechanical Engineering and Applied Mechanics

Vickers, Paul W.
M.S., Naval Architecture and Marine Engineering
Research Associate

Wagenaar, Alexander C.
Ph.D., Public Health
Assistant Research Scientist

Watanabe, Yoshinori
Visiting Research Engineer
Honda R & D Ltd.

Weber, Kathleen
M.A., Library Science
Senior Research Associate

Winkler, Christopher B.
M.S., Mechanical Engineering
Associate Research Scientist

Wolf, Arthur C.
Ph.D., Political Science
Associate Research Scientist

APPENDIX L

FACILITIES ON THE MAIN CAMPUS

Office Facilities

Having outgrown the original building that served as its administrative headquarters for more than 25 years, the Institute moved to new facilities in the newly completed Academic and Agencies Building in mid-1981. This building provides facilities for the administration, two complete TTI research divisions, and significant portions of three more divisions. These elements of the Institute now occupy 28,800 square feet on the fourth and fifth floors of the new building. For the first time in recent years a major portion of the TTI staff is housed in the same building, substantially increasing the efficiency of the overall administrative and research operations of the Institute. TTI research divisions also occupy some 10,000 additional square feet in several main campus buildings shared with various departments of the University.

Research Facilities and Services

Laboratories: Available to and extensively used by the Institute are fully equipped laboratories for research on materials, soils, and pavements. These laboratories are shared with the Civil Engineering Department of the University. Principal among these facilities are the:

- McNew Materials Laboratory
- Bituminous Pavement Laboratory
- Asphalt Rheology Laboratory
- Synthetic Aggregate Laboratory
- Geotechnical Laboratories

These laboratories provide a full capability for asphalt and concrete materials testing required by the Materials & Construction Division. Such testing ranges from standard quality control tests to more sophisticated tests such as beam fatigue, overlay shear, and resilient modulus. The laboratories are staffed by skilled technicians, well-trained in operating a wide selection of testing equipment and instrumentation. Included in the laboratories' inventory is equipment which permits researchers to conduct extensive field testing such as surface texture measurements, construction monitoring, coring, and dynaflect measurements.

Automatic Data Processing: Readily accessible automatic data processing services are provided by the Texas A&M University Data Processing Center (DPC). The DPC is a centralized computing facility operated by the Texas Engineering Experiment Station that provides computational support and data processing services to all components of the Texas A&M University, other universities, and state agencies. The DPC campus network, serving the academic, research and administrative needs of the University is one of the most complete and extensive local networks of any college or university.

Research projects account for about 40% of the DPC computer usage. Highly qualified DPC personnel are available to assist researchers with the computer-related aspects of research projects. Plotting, analog-to-digital conversion, statistical analysis, and other services can be provided to researchers.

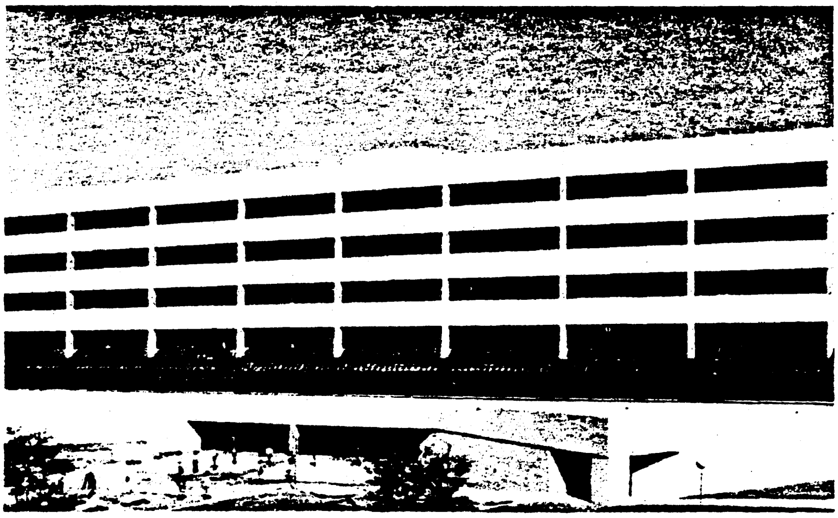
The DPC has two computers in the Amdahl 470 series which are fully program-compatible with the IBM 370 line. The system has an on-line storage capability of over 24,000 megabytes of information and machine cycle times of 32.5 or 26.0 nanoseconds. The two computers, combined with extensive and sophisticated peripheral equipment, provide a capability to handle any data processing task with great speed and efficiency. To supplement the available central computing services of the DPC and to increase the efficiency with which it can meet its ever expanding need for data processing, the Institute has, over the past five years, steadily increased its own inventory of mini- and micro-computers, word processors, and terminal equipment and accessories.

Library: The resources of the Texas A&M University Library, one of the major libraries in the Southwest, are fully available to the Institute's staff. Present holdings of this library are approximately 1,300,000 volumes and 1,800,000 microforms in all collections. The Library subscribes to 15,000 journals, including 5,000 from foreign countries. The University Library is designated a depository for U.S. Government publications and receives 90% of its publications.

The Library has available all major indexing and abstracting publications. In addition, its Automated Information Retrieval Service offers access to 200 on-line bibliographic and statistical data bases. Materials retrieved by the system cover the many disciplines of TTI research and include reports and articles, both domestic and foreign.

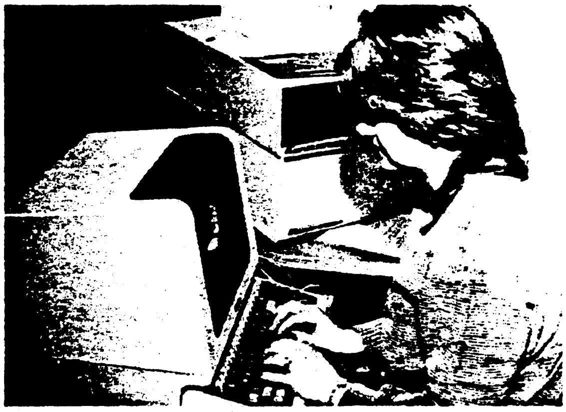
The Library's Technical Reports Center has comprehensive holdings in all facets of the transportation field, representing reports from universities engaged in transportation research, the highway departments of various states, national and international transportation organizations.

The Institute has on its staff a full-time Research Librarian who is officed in the University Library. He is on call to conduct intensive literature searches for researchers when needed.



TTI Administrative Headquarters and a sizable number of the Institute's researchers are now housed in the Academic and Agencies Building.

Word processors have streamlined the production process for TTI's many technical reports and other written communications.



Microcomputers have increased the economy and efficiency of the Institute's many data processing tasks.

Left: Making asphalt concrete samples in gyratory compactor.

Right: Preparing pavement core sample for laboratory tests.

FACILITIES AT THE BRYAN RESEARCH AND EXTENSION CENTER

The Highway Safety Research Center (HSRC) of the Texas Transportation Institute is located on this 2000 acre complex of research and training facilities. The site is a former Air Force Base, and its extensive concrete runways and parking aprons are ideally suited to experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, and the durability and efficacy of highway pavements and structural systems. The potential for expansion of research and testing activities to other problem areas in transportation is almost unlimited.

Some of the more notable facilities present on the HSRC Proving Grounds, where nearly all full-scale experimentation is conducted, are:

- Crash test facilities for evaluation of crashes at varying impact angles and speeds.
- Hydroplaning trough for studying the phenomenon of vehicle hydroplaning.
- Rain simulator capable of simulating rainfall rates up to five inches per hour on a 200-foot roadway section.
- Test tract of 3½ miles that will permit simulation of freeway traffic conditions at speeds up to 70 miles per hour.
- Special pads designed for the conduct of tire skid tests on road surfaces of various textures.
- Special track configured for research and training in the development of special driving skills for drivers of emergency vehicles.
- Pavement test facility consisting of sections of different materials and thickness that can be nondestructively tested for strength and other parameters. Careful control of the material and thickness of the sections also permits use of this facility to calibrate certain test equipment.
- Rotary kiln used for research in and testing of synthetic aggregates.
- Impact sled facility for testing vehicle occupant restraint systems at speeds up to 30 mph.
- Vehicle Emissions and Fuel Economy Laboratory (VEL), including a Clayton Dynamometer and computer controlled exhaust analyzing equipment. (More fully described below.)

An important facility located at the HSRC and administered and operated by TTI is the Federal Highway Administration (FHWA) Central/Western Field Test Center. This is the first field test and evaluation center developed for the FHWA for the calibration, correlation, and evaluation of skid measurement systems on a nationwide basis. The Field Test Center serves 26 central and western states and other public agencies in providing technical advisory services, precision static and dynamic calibrations traceable to standards of the National Bureau of Standards, and standardized services for skid measurement equipment.

This self-watering diagonal braking vehicle was developed by TTI to provide an economical system for cities and counties to make skid resistance measurements on their streets and roadways. Identical water spray devices are mounted ahead of left front and right rear wheels.

In May 1979, TTI commenced test operations in its Vehicle Emissions and Fuel Economy Laboratory (VEL). The VEL, representing an investment of some $320,000, is the only facility of its kind in southeast Texas. Up-to-date state-of-the-art technology in vehicle emissions and fuel economy measurement is exemplified in the sophisticated instrumentation and layout of the laboratory. The VEL capabilities include the following levels of testing:

- EPA Certification constant volume sampling (CVS) tests
- Continuous modal (raw or dilute) tests
- Continuous monitoring of up to 32 additional engine parameters during the above tests, with second-by-second print-out
- Fuel economy determination

At the present time, the laboratory is not equipped for evaporative emissions measurement. Upgrading of the equipment capabilities to include this function is planned for the near future.

The analytical instrumentation and dynamometer are controlled by the operator through a computer interface which enhances the accuracy and efficient conduct of the testing. The dynamometer is a Clayton Type CTE-50, which is a split-roll configuration adaptable to wider tract medium-duty and multipurpose vehicles. The analytical instrumentation is exclusively Horiba Instruments, all EPA approved, and the controlling computer is a Hewlett Packard Model 45 HP 1000, recently upgraded to include a sophisticated graphics output capability.

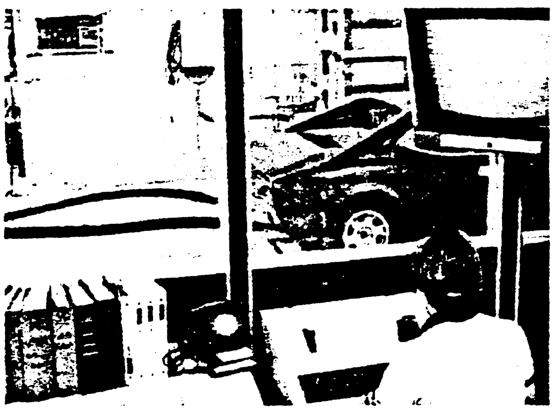
The Vehicle Emissions and Fuel Economy Laboratory provides TTI with a base for the development of substantial new research and evaluation programs. The facility is ideally located to test foreign-made vehicles entering the United States through the Port of Houston. Its continuous modal monitoring capability makes possible research directed toward improved automotive engine components such as catalytic converters, fuel injection systems, and computerized engine controls.

Research Instrumentation Facilities: Well-equipped instrumentation laboratories and shops are an integral part of TTI's Proving Grounds Research Program. Manned by highly-skilled personnel, these activities design, fabricate, assemble and install sophisticated mechanical, electronic, and photographic instrumentation in test vehicles and on test ranges for the collection of data generated by experimental research projects.

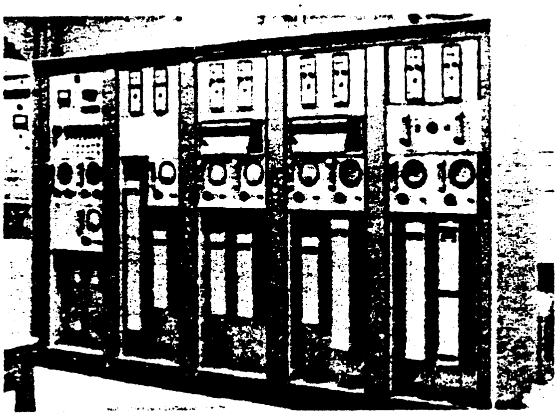
Mechanical instrumentation requirements include the design of electrohydraulic mechanical systems and the manufacture, calibration and maintenance of control devices for a variety of transportation systems. Although some instrumentation system components are available commercially, many components must be designed and fabricated using machine shop and automotive laboratory facilities. The technicians within this group have met these unique requirements with great skill and versatility. The mechanical instrumentation laboratory/shop is fully equipped for the complete maintenance and repair of automotive vehicles.

The *electronic instrumentation* laboratory is often called upon to provide instrumentation for highly specialized experiments where appropriate measuring and recording equipment is not available commercially. The capability of the electronic instrumentation group to design and fabricate nonstandard measurement equipment allows quick development of prototype systems necessary for the solution of research problems. Typical of such nonstandard systems are: (1) a digital data acquisition system designed for the Texas State Department of Highways and Public Transportation for use on their highway friction units; (2) field research instrumentation for Brown & Root, Inc., in connection with offshore oil platforms in the North Sea; and (3) aircraft control instrumentation for the Aerospace Department of Texas A&M University for aircraft research work.

The capabilities of the *photographic instrumentation* group include: (1) photo-instrumentation and photography used as a technique for the collection and storage of data; (2) production of sound-motion pictures to document research



Vehicle emissions tests are computer-controlled.

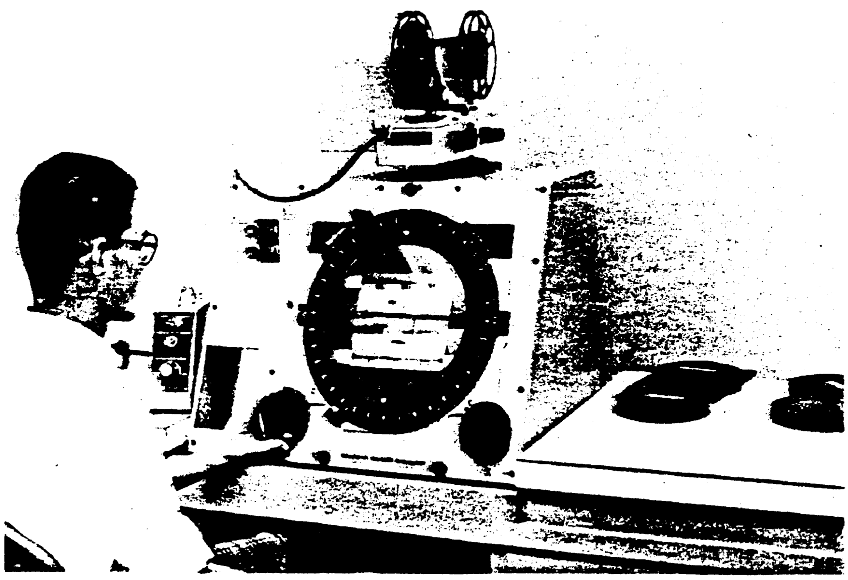


Analytical equipment in Vehicle Emissions and Fuel Economy Laboratory.

projects and to transmit results of these projects to the ultimate user: and (3) still photography for a wide range of uses. The group also maintains an extensive film library, and is equipped with an extensive inventory of precision high speed, standard movie and still cameras plus accessorial equipment.

The facilities and capabilities of the *engineering and construction* group are extensive and flexible. The main complex contains approximately 50,000 square feet of floor space with an additional 2,000 square feet of offices and drafting areas. Included within this complex are machine, welding, and woodworking shops. A portable shop completely equipped with all necessary equipment gives this group mobile capability. A. structural testing area contains hoists, loading frames, and anchors which will accommodate large structural elements. Examples of these test elements are 15,000 lb. prestressed concrete piles and segments of highway crash cushions. A versatile pendulum test facility was designed and constructed by this section for use in a variety of dynamic tests of automobiles at speeds up to 25 mph. Other examples of the accomplishments of this section are the design and fabrication of structures such as breakaway luminaire and sign supports, crash cushions, pendulum and vehicle crash testing facilities, and rainfall simulators.

Research Evaluation and Reporting: Also an integral part of the Proving Grounds Research Program is the Research Evaluation and Reporting Section. This group provides an interdisciplinary approach to experimental design, testing, data reduction and analysis, and report writing. Its staff includes individuals with backgrounds in mathematics, engineering, and physics. They are well-versed in the analysis of electronically recorded data. Equiment includes a Gerber Digital Data Reduction System, a Southwest Technical Products Model 6800 computer, a Hewlett Packard Model HP85 micro-computer including graphics tablet and plotter, plus several terminals for access to the University's Amdahl computers. Analysis of high speed film is also an area where this section is highly skilled. Vanguard Motion Analyzers are used extensively for analysis of film exposed at speeds of 100 to 11,000 frames per second. The Research Evaluation and Reporting Section occupies a central position in the pursuit of research objectives and provides the essential elements for technical reports covering a wide spectrum of highway safety research.



Analysing high speed motion picture film.

APPENDIX M

Skid Resistance Research Facility

The Skid Resistance Research Facility is located on a separate lane adjacent to one tangent of the experimental highway. The lane is 15 ft wide and 1,150 ft long, with an approach that allows vehicle speeds up to 60 mph. The instrumentation permits precise measurement of vehicle speeds and lateral placements throughout the test area.

Each test surface is 6 ft wide by 200 ft long. The area includes six different surfaces: two dense-graded asphalt friction courses, one with a polishing limestone aggregate and one with a nonpolishing aggregate; two open-graded asphalt friction courses, also with polishing and nonpolishing limestone aggregates; a dense-graded asphalt friction course with a jennite surface treatment; and a dense-graded asphalt course with a sand-epoxy treatment. The various surface textures are based on maximum aggregate sizes ranging from 0.033 in. (sand-epoxy) to 0.25 in. (open-graded asphalt friction course). The skid resistances of the test surfaces are monitored routinely, and skid numbers range from 15 to 60.

Originally constructed in 1972, the facility was rebuilt in 1982. It has been used extensively for skid resistance research, tire noise and pavement texture studies, hydroplaning research, and an evaluation of methods of skid resistance measurement other than the locked-wheel method. Current research at the facility includes the development of high-speed, noncontact macrotexture measurement methods and a study of the effects of weather conditions on pavement materials.

Pavement Roughness Research Facility

The Pavement Roughness Research Facility is a pavement lane constructed adjacent to the Skid Resistance Research Facility at the lower tangent of the experimental highway. It consists of two troughs. 2 ft wide by 4 in. deep by 800 ft long, located where the wheel paths for automobiles and light trucks would normally be. Interchangeable concrete molded inserts provide a choice of running surfaces with a variety of roughness characteristics. These pavement surfaces exhibit roughness within a range of values significant for routine testing.

Tire/Pavement Laboratories

Stone Polishing Laboratory

The Stone Polishing Laboratory is used for studying the techniques of polishing so that the properties that pavements and aggregates require for adequate skid resistance can be defined more precisely. Equipment includes:

1. The Penn State reciprocating pavement polisher (RPP) on which pavement cores or stone samples are polished by a sliding rubber pad. The RPP may also be transported to actual pavements for in situ operation. The resulting decrease in friction is measured by a pendulum friction tester.
2. A drum polisher on which ten individual particles of an aggregate sample are polished by a rotating rubber-coated drum. The decrease in average friction is measured by a special device directly attached to the machine.
3. The Penn State circular track, which can be used for polishing samples mounted in the wheel tracks. Here friction can be measured either continuously by the torque-measuring system or periodically by other methods.

Related experimental work in the Stone Polishing Laboratory includes the measurement of pavement surface texture, which affects friction between tire and pavement. The texture measurement facility includes two portable profile tracers for macrotexture and microtexture measurement: these tracers can also be used on pavements in the field. The macrotexture tracer measures asperity sizes down to 0.5 mm, and the microtexture tracer from .01 mm to 0.5 mm. The composition and structure of stones are investigated by means of petrographic analysis, chemical analysis, X-ray spectroscopy, and light and scanning electron microscopy.

Moving Belt Friction Tester

The Penn State moving belt friction tester (MBFT) is a laboratory apparatus used for evaluating tire performance under varying test conditions. The MBFT consists of a continuous stainless steel belt (0.016 in. thick) running on two steel drums, each 15 in. in diameter. One of the drums is driven by a gasoline engine. The test tire is supported on a frame resting on the middle of the belt span, and the belt is supported underneath by a teflon plate. A vertical load of up to 1,500 lb can be applied on the tire. Test-tire speeds corresponding to vehicle speeds of up to 80 mph can be achieved. Wet and flooded road conditions are simulated by applying water tangentially on the belt; and, by controlling the amount of water flow, effective water film thicknesses of up to 0.25 in. can be obtained.

The tester can measure belt speed, water flow, vertical load on the tire, friction force in the contact patch between tire and belt, vertical motion of the tire during hydroplaning, and water film thickness under the tire during hydroplaning. Instrumentation is also available to measure tire deformation in the contact patch during locked-wheel tests. Among the various operating conditions that can be simulated on the MBFT are smooth tire and smooth pavement surface, smooth tire and fine-textured pavement surface, and transition from a dry surface to a flooded pavement.

Tire Energy Loss Test Facility

The major components of the Penn State Tire Energy Loss Test Facility are a moving-belt machine, a 50-hp SCR-controlled DC electric motor and driving-cycle generator, and a microprocessor system for data collection and reduction.

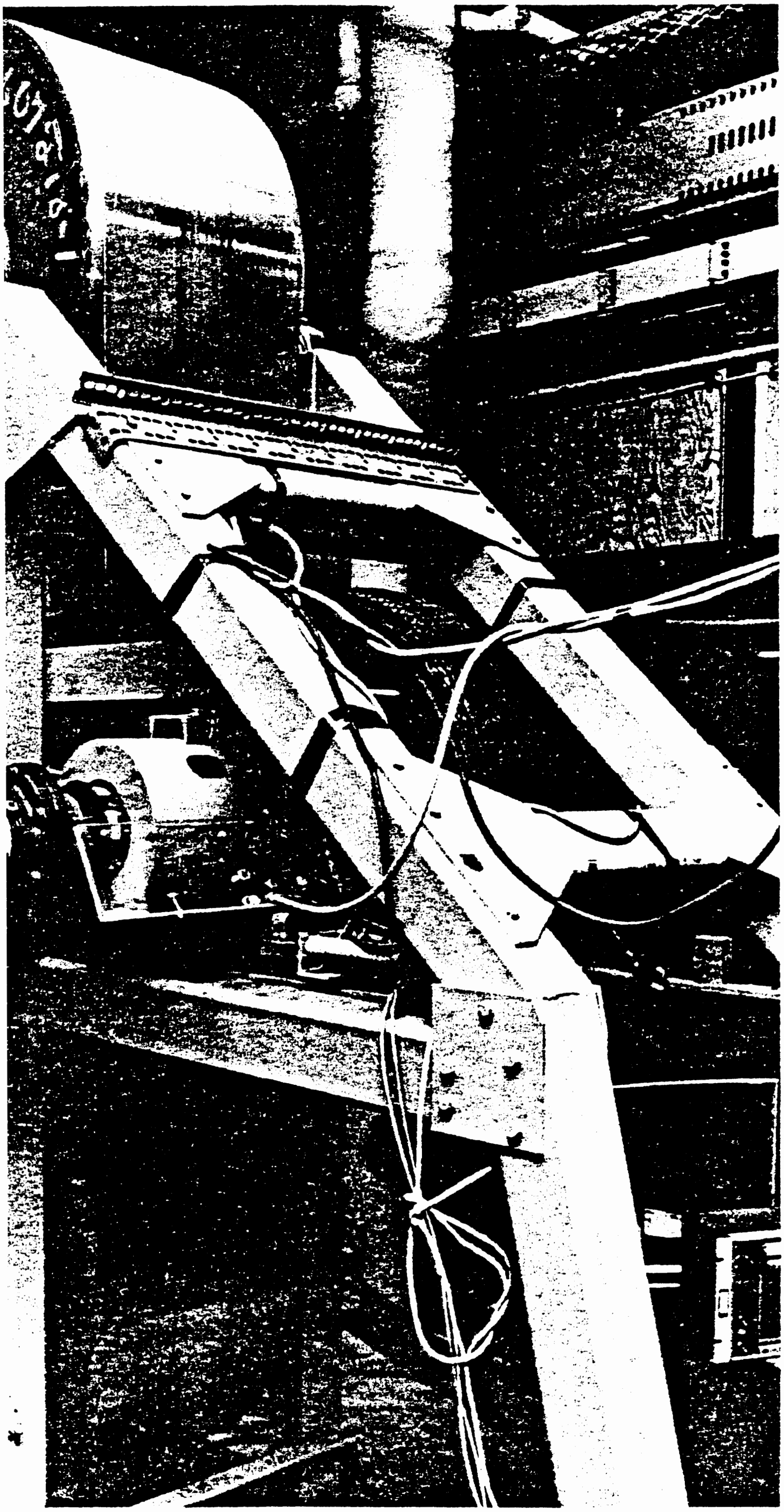
The moving-belt machine has essentially the same design as the Penn State moving belt friction tester (MBFT), except that the tire-support bearing is replaced by a second tire. The two tires are loaded across the belt and are mutually supporting. One of the tires is driven by the DC motor, while the other is free-rolling; the machine therefore simulates half of a two-wheel-drive car. The inertial load on the driving tire is supplied by the machine drums and can be supplemented by removable discs driven through a gearbox. Vertical and longitudinal tire forces are measured by strain-gauged force transducers. Other instrumentation measures input torque, driving-wheel and drum speed, and tire-rolling radius.

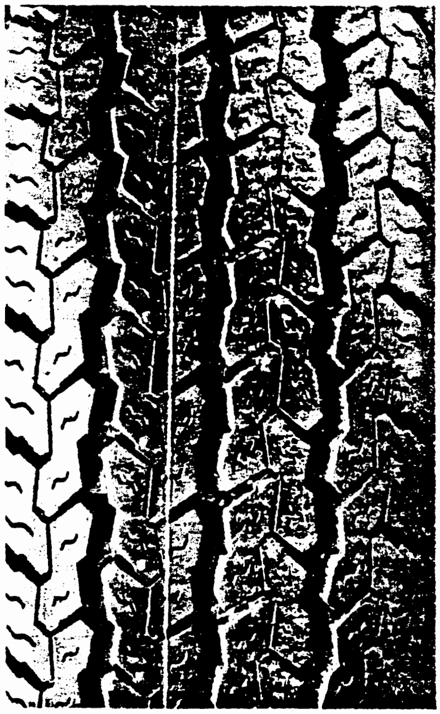
Instantaneous power consumed by the tires is measured through analog processing of the force and speed transducer signals. Digital integration of the power signals then gives the total energy consumed by the tires during a test cycle. A separate speed control system allows the machine to be programmed to follow various driving cycles. The speed profile of the driving cycle of interest is stored in erasable ROMs, read out sequentially at one-second intervals, converted to an analog signal, and passed to the SCR controller. The present system allows sequences lasting up to 45 minutes.

Circular Track Apparatus

The Penn State circular track apparatus is designed for research on tire-pavement interaction and tire characteristics. Investigations conducted on the apparatus include the effects of a tire on the surface finish of aggregates, the measurement of the distortion that a tire undergoes when braked, and the effects of nonuniform tire temperatures on frictional performance.

The apparatus has two concentric annular tracks. The inner track has a very high friction surface, whereas the outer track can be varied. Normally the outer track has a lower friction surface than the inner track. Two tires, one running on each track, with their wheels connected through shafts, gears, and an infinitely variable transmission, are rolled along the tracks by a motor-driven, rotating support structure. In addition, the outer tire is suspended on an automotive front-wheel-drive, front-end suspension and can be locked as a rigid mounting or run as a

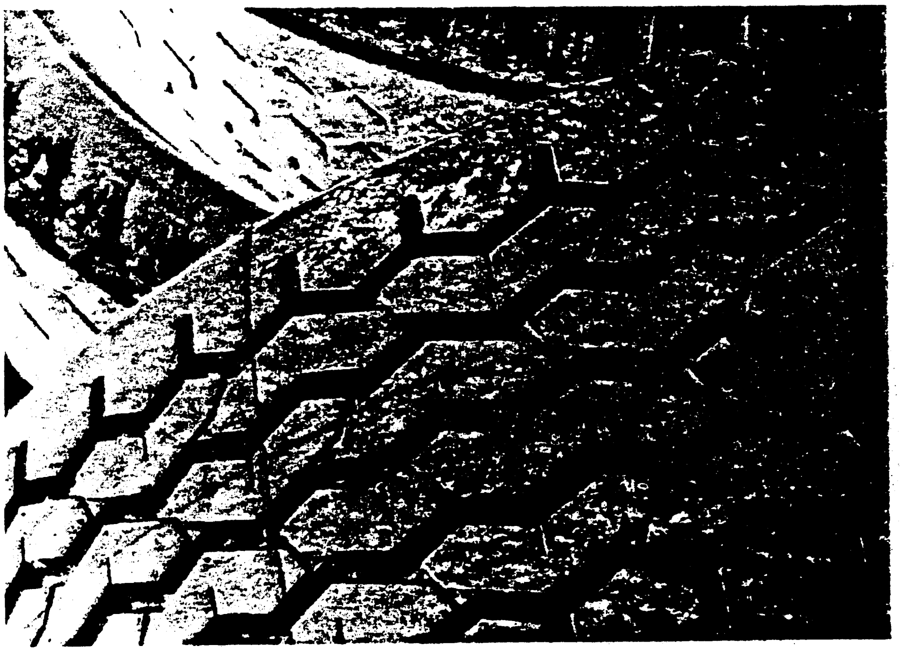




The Tire Energy Loss Facility.

normal suspension. The outer or test tire can be made to roll at any speed up to 20 mph and can be made to skip through changes of the transmission setting: thus it is forced to rotate more slowly than it would in pure rolling. The friction is measured as torque on the drive shaft. Different tires can be used, and the vertical load on them changed over a wide range. Tests can be conducted on flat roadways or on wavelengths up to 10 ft at amplitudes of 5 in.

Removable concrete sections with pre designed profiles can be placed in the outer tracks. Four sets are currently ava able with amplitudes of 0.25 and 0.5 in. and wavelengths between 32 and 16 in. These sections are used in conjunction with front-wheel-drive car suspension ar wheel assemblies to study the loss of tra tion induced by roughness. Toronado ar Phoenix suspensions may both be fittec to the machine so that the effects of veh cle size on traction loss can be determined.



Penn State Road Friction Testers

The Penn State road friction testers are high-speed vehicles for measuring, with a slipping or sliding full-size tire, the friction between tire and pavement. Each light truck carries all instrumentation and a water tank for wetting the pavement in front of the test wheel, which is carried on a sprung parallelogram outrigger attached to the rear of the truck. The outrigger can be moved laterally so that tests can be made in or out of the wheel paths even while the tester is operating in heavy traffic. The test wheel is retarded and eventually locked up by controlled actuation of a brake.

The testers satisfy the requirements of ASTM Method E274 for measuring pavement skid resistance; in fact, the design of these testers has played an instrumental role in developing and refining this method. The Penn State testers are used extensively for research on pavements, tires, and brakes. One tester has been used for hydroplaning research and for determining the effects of water film thickness on skid resistance measurements. This tester performs locked-wheel friction measurements with variable water film thicknesses up to five times the requirement of ASTM Method E274. The brake torque is measured as an indication of the friction between tire and pavement. Another tester can measure the side forces on a wheel operating in yaw and the friction force of a slipping wheel, as well as perform locked-wheel tests according to ASTM Method E274. All three force components and the three torque components acting at the hub of the test wheel are measured with this tester. Pavement temperature and tire-tread temperatures can also be monitored continuously.

These road friction testers have on-board computers which automatically control the test sequencing and data collection. The data are processed on-board to provide comprehensive information on pavement friction as a function of speed.

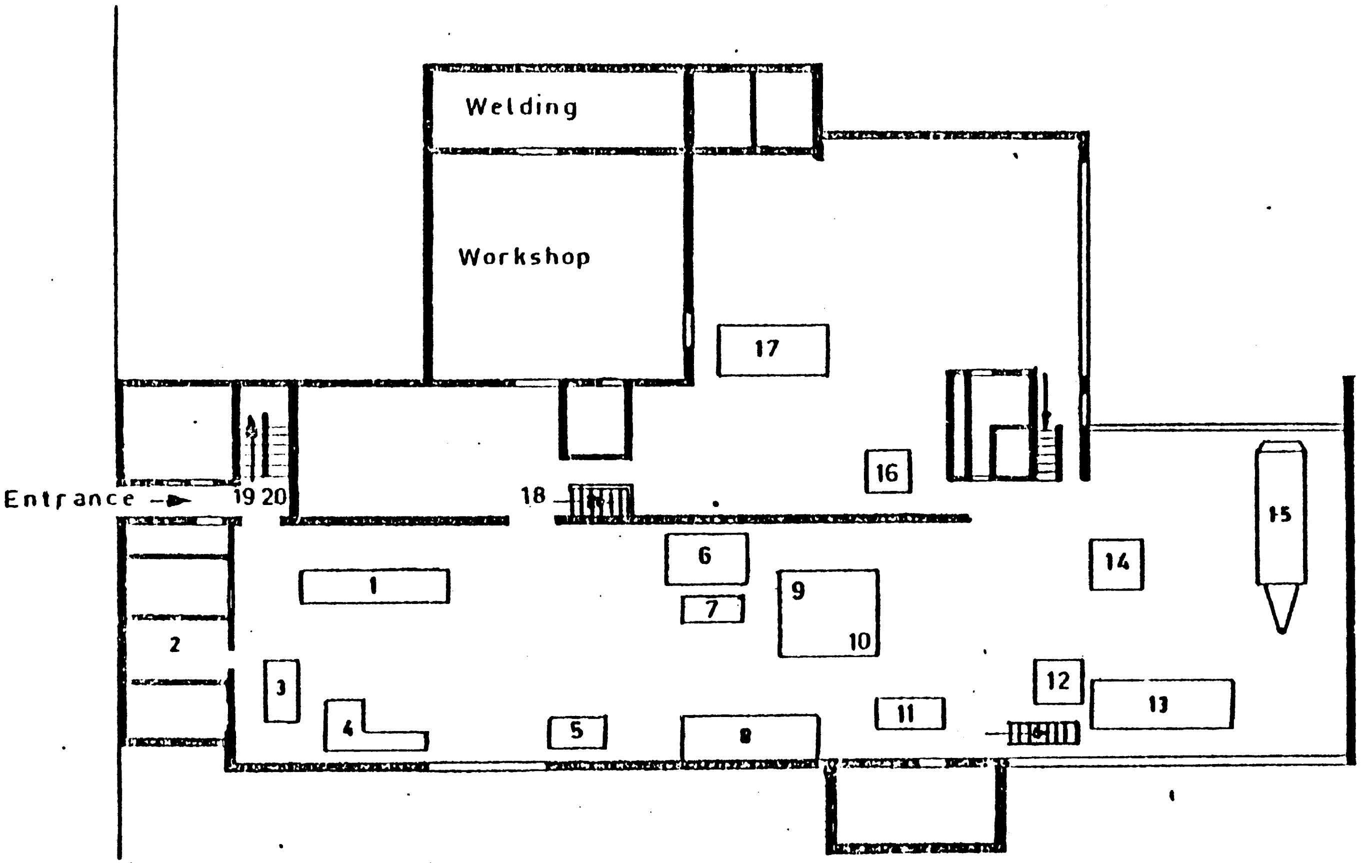
Penn State GMR Profilometer

PTI's profilometer is a K.T. Law Model 690 Surface Dynamics, GMR-type. It uses two spring-loaded, road-following wheels, instrumented with a linear potentiometer, to measure and record road surface profiles for studies of road roughness characteristics, pavement evaluation methods, and vehicle vibration. The profilometer can calibrate response-type measurement systems and record road profiles. Both analog and digital data acquisition and processing can be performed.

Skid tests are conducted on a variety of pavement surfaces at the Skid Resistance Research Facility.

APPENDIX N

Vehicle Research Laboratory



GROUND FLOOR

1. Inertia brake dynamometer - anti skid systems
2. Viscoelastic friction
3. Movable platform tire tester
4. Shock absorber testapparatus
5. Tire tread drainage measuring device
6. Tire nonuniformity
7. Steering system dynamics
8. Balancing
9. Seat suspension
10. Rubberspring characteristics
11. Suspendid drivers cabin
12. One-wheel truck tire tester
13. Truck
14. Measuring wheel
15. Test-trailer passenger car tires
16. Road waviness measuring system
17. Three-mass minibus suspension system

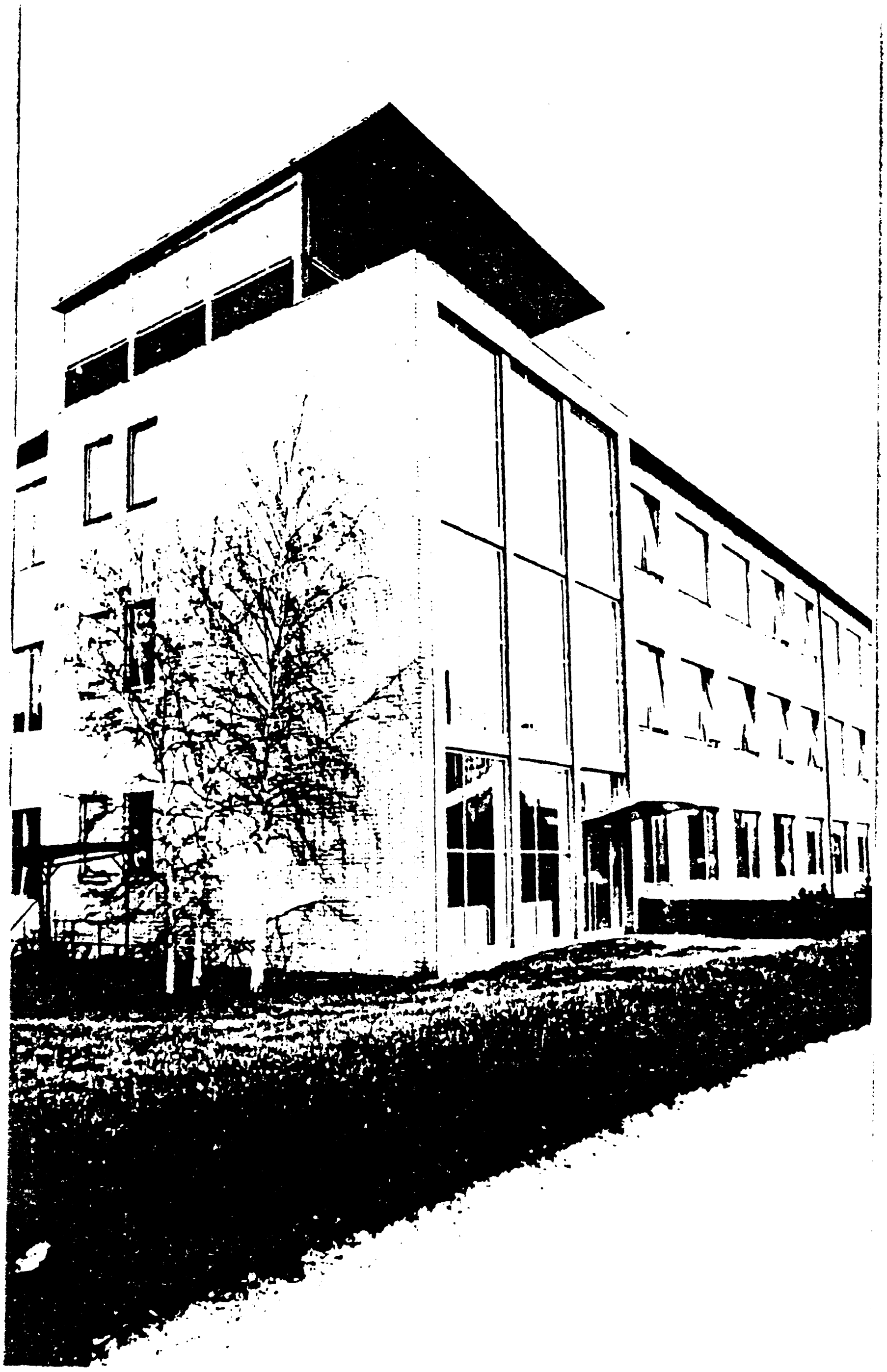
BASEMENT

18. Large inertia brake dynamometer

1^e FLOOR

19. Comfort-vibration analyser
20. Analogue computer

APPENDIX O



APPENDIX P

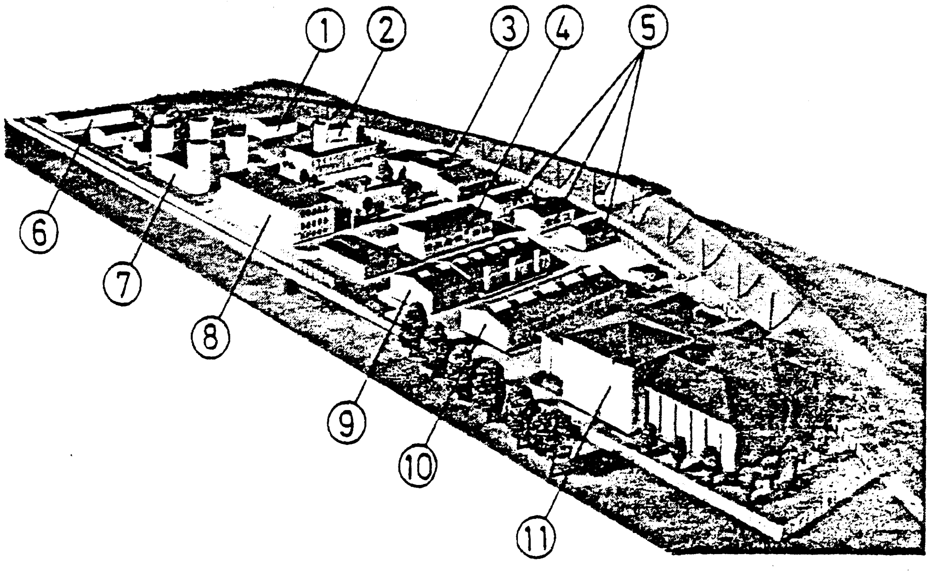
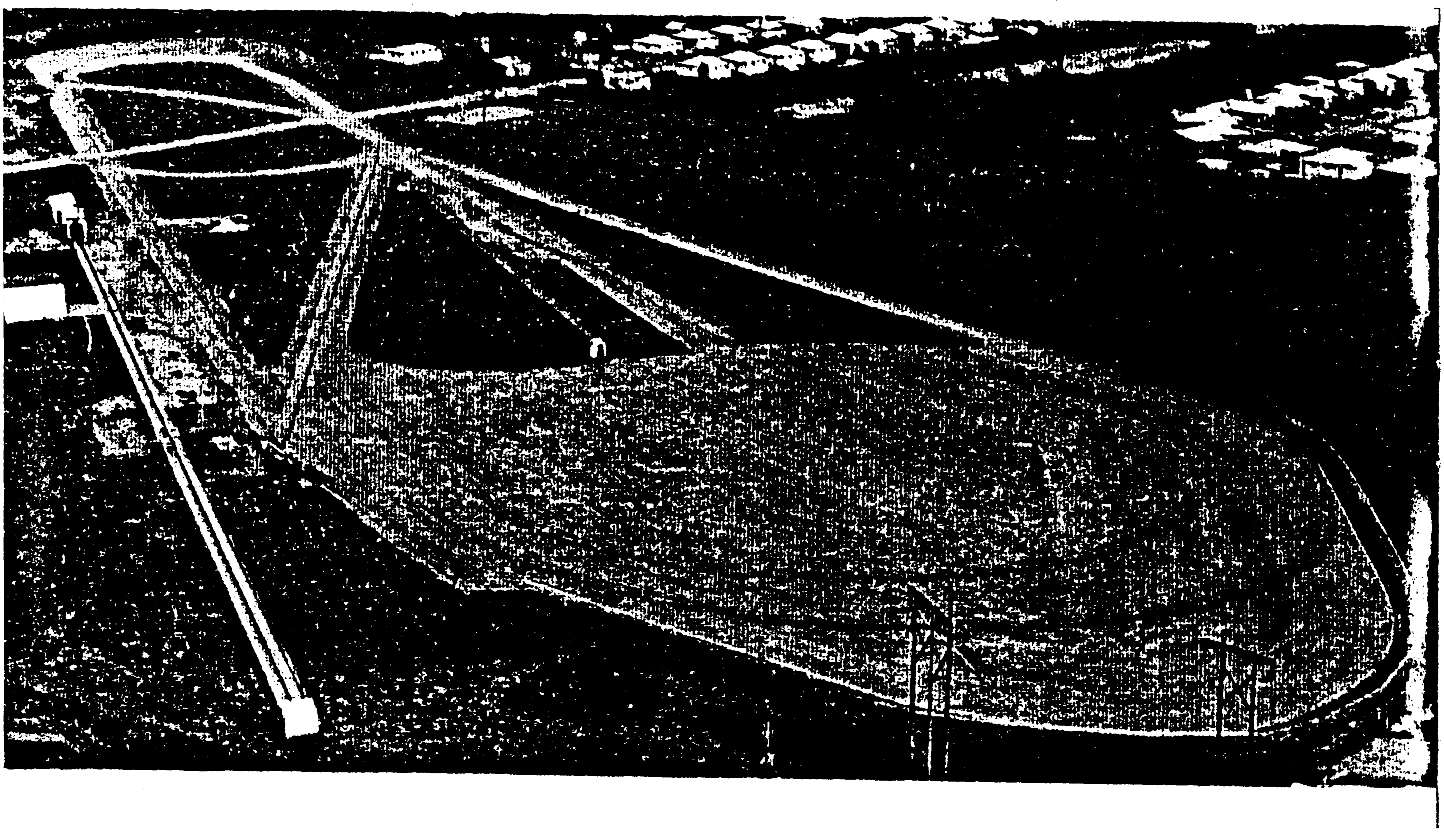
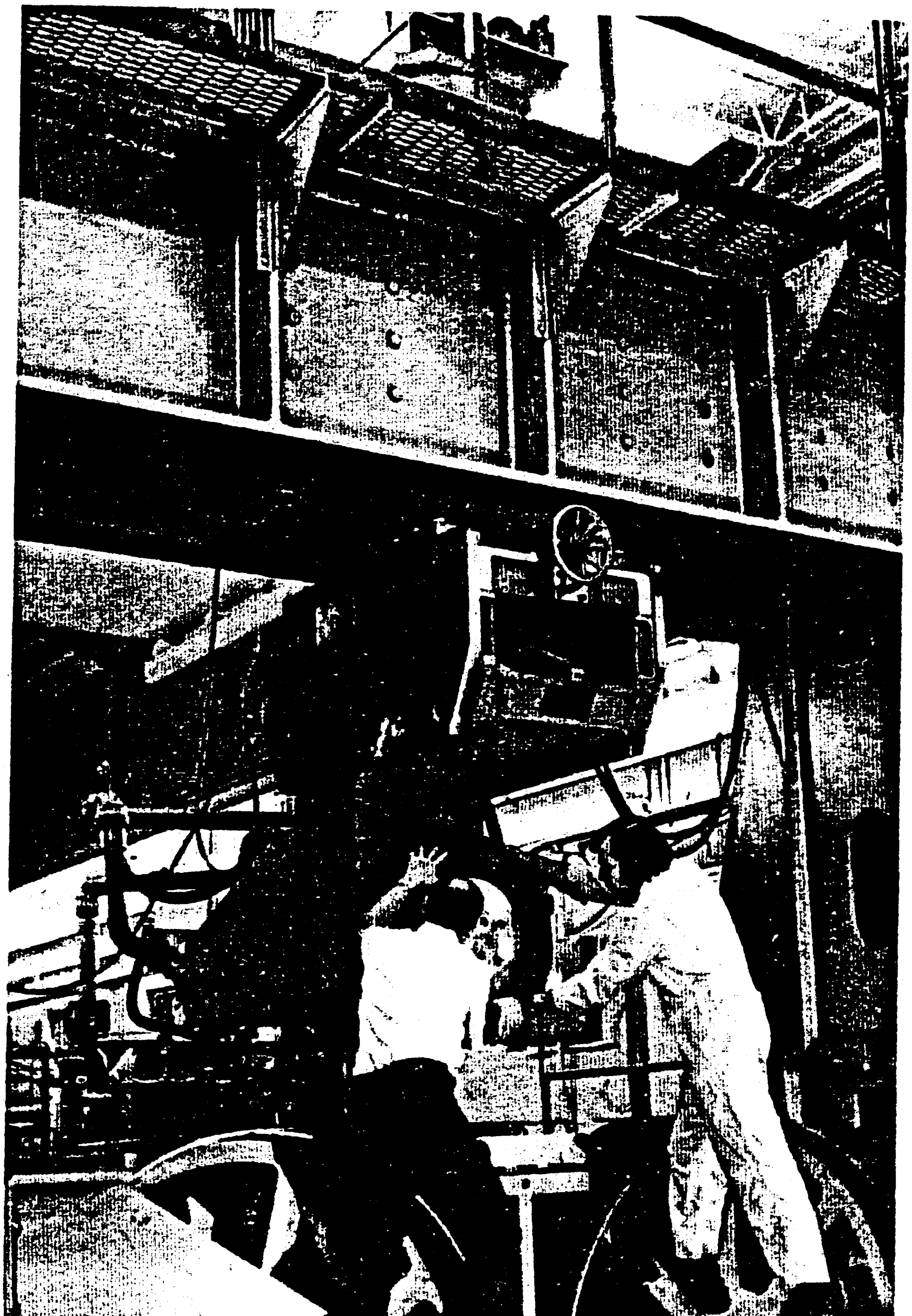


Bild 5. Ausbaustand des Instituts 1940 (Modellbild)
1 Motorenprüffeld
2 Flugmotoren-Windkanal
3 Stammgebäude
4 Lehrgebäude
5 Werkstätten und Lager
6 Schwingungsprüffeld
7 Flugmotoren-Höhenprüfstand
8 Verwaltungs- und Laboratoriumsgebäude
9 Fahrzeugmotorenprüfstände und Modellfahrbahn
10 Kraftwagenprüfstand und Modellwindkanäle
11 Kraftwagen-Vollprüffeld

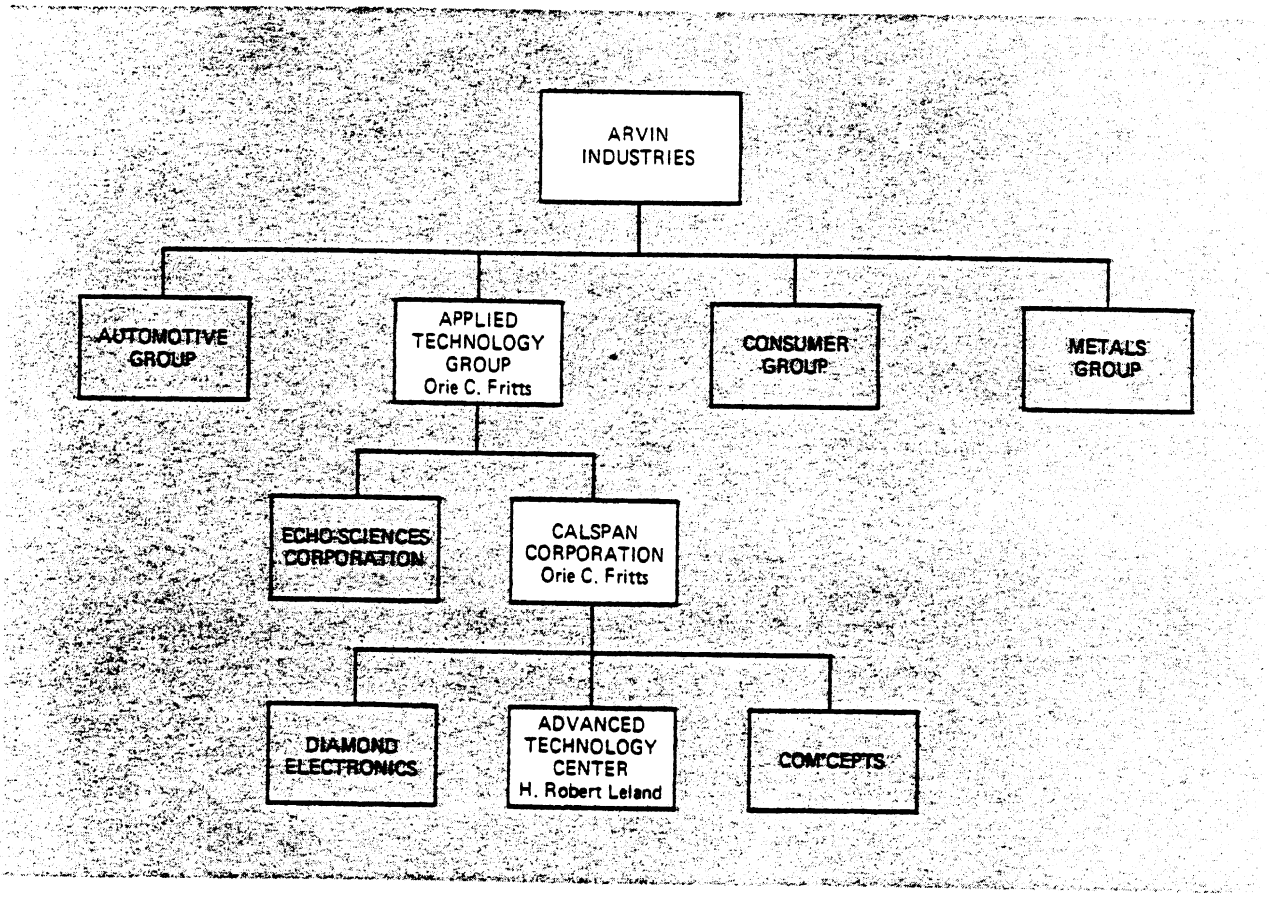
APPENDIX Q

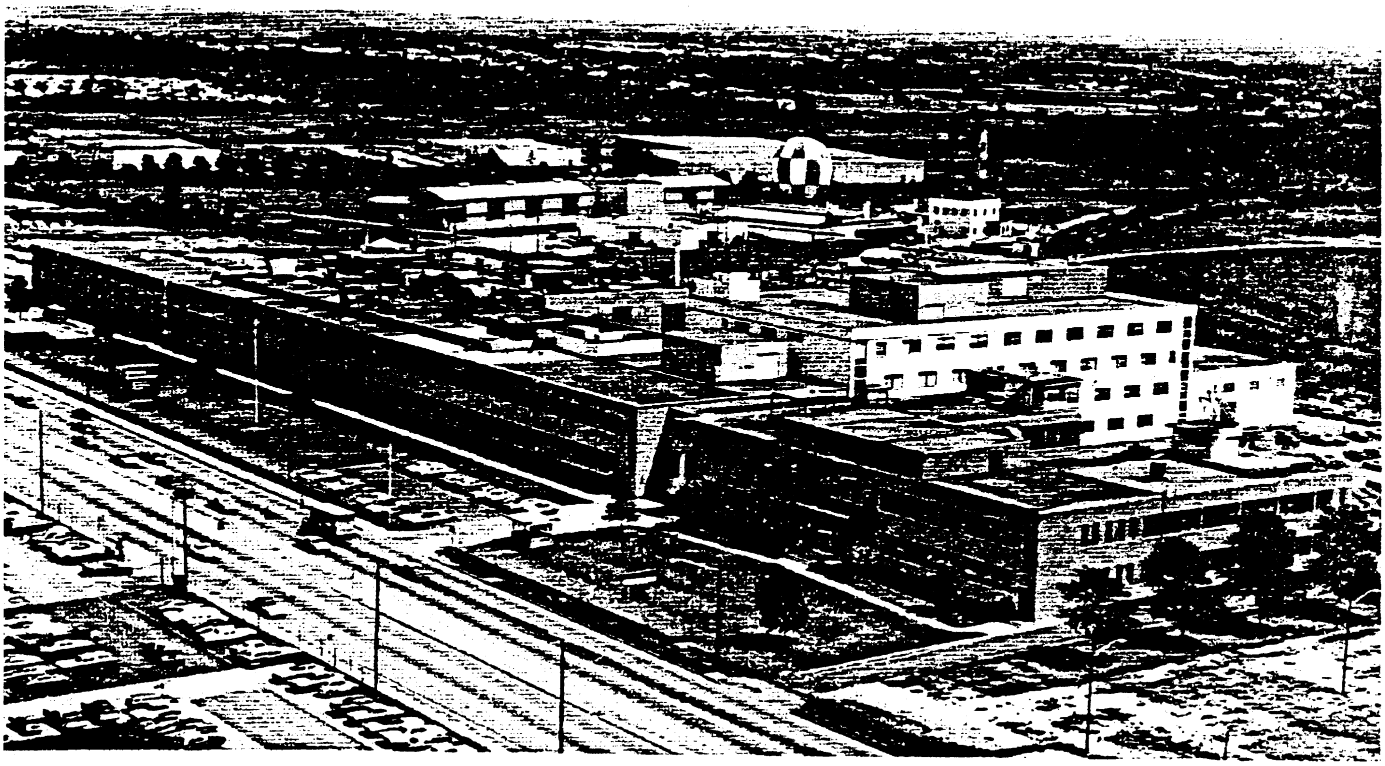
. A 33-acre automotive proving ground is used extensively for vehicle crashes, handling qualities tests, rollovers and other transportation safety experiments.





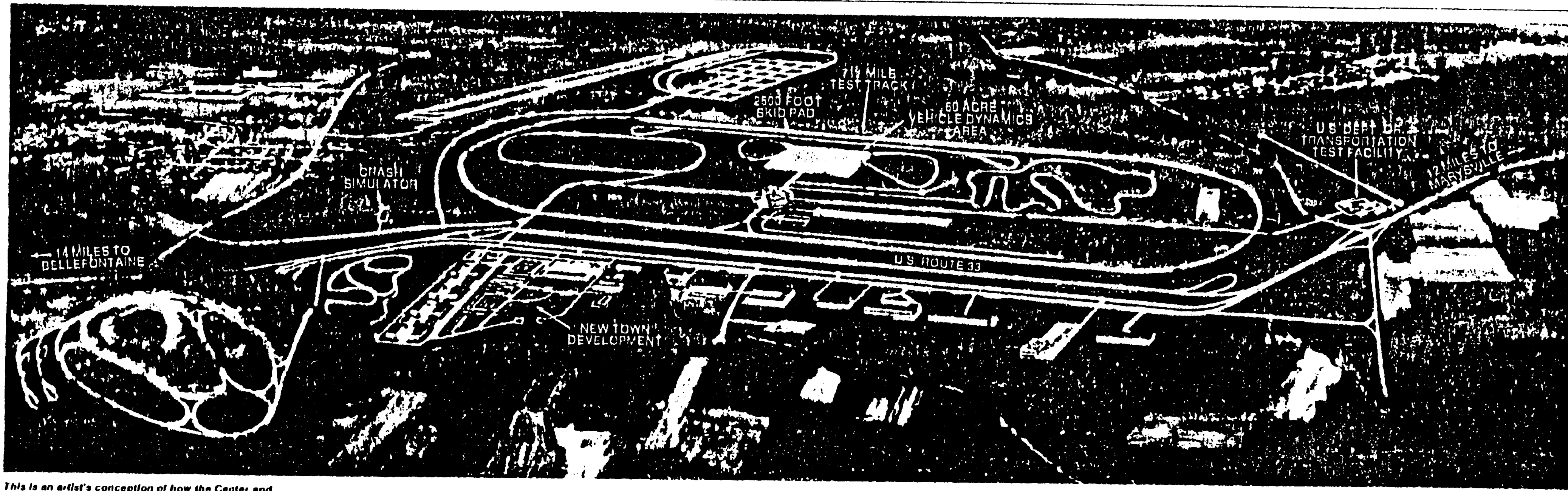
1


ARVIN INDUSTRIES
AUTOMOTIVE GROUP
APPLIED TECHNOLOGY GROUP
Orie C. Fritts
CONSUMER GROUP
METALS GROUP
ECHO SCIENCES CORPORATION
CALSPAN CORPORATION
Orie C. Fritts
DIAMOND ELECTRONICS
ADVANCED TECHNOLOGY CENTER
H. Robert Leland
COMCEPTS



APPENDIX R

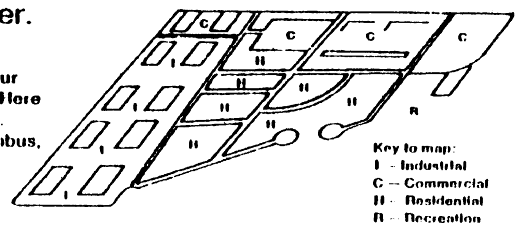
APPENDIX S



This is an artist's conception of how the Center and its environs will appear by year-end 1975.

"New Town" adjoins the Research Center.

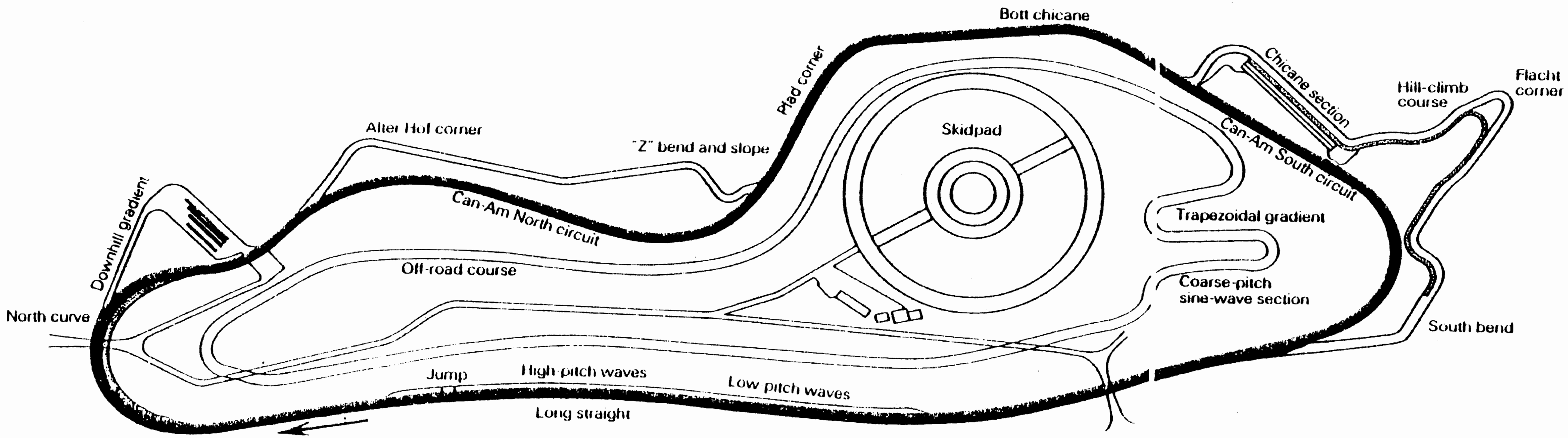
"New Town" will be close to metropolitan centers, within 30 minutes driving time of four large lakes, and five miles from a ski slope. Here is country style living with city convenience. Developers are Showe Builders, Inc., Columbus, Ohio.



U. S. Department of Transportation Motor Vehicle Compliance Center.

This $9.6 million facility to be constructed and operated by the National Highway Traffic Safety Administration, is scheduled for completion in 1974. It will be operated by a staff of 250 engineers, technicians and support personnel.

APPENDIX T



PHOTOGRAPHY BY MARTYN GODDARD

APPENDIX U

Sonderdruck aus ATZ Automobiltechnische Zeitschrift · 83. Jahrgang · Nr. 1/1981 · Franckh'sche Verlagshandlung Stuttgart

Klaus Rompe und Peter Wiegner

Das Kraftfahrzeuglabor des TÜV Rheinland

Bevor neue Fahrzeuge oder Fahrzeugteile zum Straßenverkehr zugelassen werden können, muß das Gutachten einer Technischen Prüfstelle die Übereinstimmung mit den geltenden Vorschriften bescheinigen. Hierzu sind zum Teil umfangreiche Prüfungen notwendig, für die insbesondere im Rahmen internationaler Genehmigungen von dem jeweils beauftragten Technischen Dienst komplexe Prüfeinrichtungen vorzuhalten sind. Die im Kraftfahrzeuglabor des TÜV Rheinland in Köln vorhandenen Einrichtungen und ihre Einsatzmöglichkeiten sollen hiermit der interessierten Fachwelt vorgestellt werden.

The Motor Vehicle Laboratory at the TÜV Rheinland, Cologne

Abstract

To get the type approval for a new vehicle or vehicle part the manufacturer needs in many cases a test certificate of the Technical Service. The TÜV Rheinland is the Technical Service for the FRG, for some of the ECE- or EG-Regulations in the field of primary or secondary safety.

Therefore, the association has to keep ready the corresponding facilities for carrying out crash tests with complete vehicles or components, for testing spare steering wheels, seats, head restraints, safety-belt anchorages, protection helmets, safety glass, drivers' field of view, and vehicle vibration and handling characteristics.

The aim of this article is to give a survey on the test facilities of this laboratory and to show the possibilities of use to interested experts.

1. Aufgaben des Kraftfahrzeuglabors

Bei der Beantragung einer nationalen Allgemeinen Betriebserlaubnis werden von den Fahrzeug- und Fahrzeugteileherstellern in zunehmendem Maße Genehmigungen nach internationalen Regelungen und Richtlinien verwendet, die in allen der ECE bzw. der EG angehörenden Ländern Gültigkeit besitzen. Zur Erzielung einer rationellen Arbeitsteilung und um die notwendigen Investitionen für Prüfanlagen in Grenzen zu halten, ist für die Prüfung nach einer bestimmten Regelung oder Richtlinie im allgemeinen in jedem Land nur eine Institution als zuständiger Technischer Dienst benannt. In der Bundesrepublik hat der Bundesverkehrsminister für eine Reihe von ECE-Regelungen und EG-Richtlinien auf den Gebieten der passiven und aktiven Sicherheit den TÜV Rheinland mit dieser Aufgabe betraut, *Tafel 1*.

Diese Benennung macht es notwendig, entsprechende Prüfeinrichtungen zu entwickeln und bereitzustellen, damit auch solche Hersteller z. B. von Zubehörteilen, die keine entsprechenden Einrichtungen besitzen, die Möglichkeit zur Prüfung an neutraler und unabhängiger Stelle haben.

Tafel 1. Technische Dienste des TÜV Rheinland

	ECE-Regelung	EG-Richtlinie
Verhalten der Lenkanlage bei Unfallstößen	12	74/297/EWG
Verankerungen der Sicherheitsgurte	14	76/115/EWG
Widerstandsfähigkeit der Sitze und ihrer Verankerungen	17	74/408/EWG
Innenausstattung	21	74/60/EWG 78/632/EWG
Kopfstützen	25	78/932/EWG
Sichtfeld		77/649/EWG
Entfrostungs- und Trocknungsanlagen für Scheiben		78/317/EWG
Scheibenwischer und Scheibenwascher		78/318/EWG
Unterfahrschutz		70/221/EWG
Sichtfeld bei land- oder forstwirtschaftlichen Zugmaschinen		74/347/EWG

Mit dieser Verpflichtung zur Vorhaltung solcher Anlagen ist jedoch keineswegs auch – sozusagen automatisch – die Zuweisung eines bestimmten Prüfvolumens zur Nutzung dieser Anlagen verbunden. So machen Hersteller aus der Bundesrepublik unter anderem von der Möglichkeit Gebrauch, diese internationalen Prüfungen in anderen Ländern durchführen zu lassen. Hier besteht daher ein freier Wettbewerb, der allerdings in manchen Ländern durch ein insgesamt beschleunigtes Prüf- und Genehmigungsverfahren zusätzliche Anreize erhält.

Bei den großen Fahrzeugherstellern werden die entsprechenden Prüfungen aus Kostengründen auf den herstellereigenen Anlagen von den TÜV-Sachverständigen durchgeführt. Um diese Tätigkeit wahrnehmen zu können, muß der Sachverständige jedoch mit derartigen Prüf- und Meßverfahren als Experte umgehen können, und diese Erfahrung kann er nur auf eigenen Anlagen gewinnen. Weiterhin werden insbesondere die Sachverständigen der Technischen Dienste von den Vertretern der zuständigen Behörden als Berater herangezogen zu allen Fragen, welche die spezielle Richtlinie oder Regelung betreffen. Dies setzt ebenfalls umfangreiche, selbst erarbeitete Prüferfahrungen voraus. Darüber hinaus sind die Technischen Dienste naturgemäß zur Mitarbeit bei der Verbesserung der Prüfgrundlagen und -verfahren im Sinne höherer Reproduzierbarkeit und größerer Objektivität aufgefordert und werden dazu auch mit der Durchführung entsprechender Forschungsaufgaben betraut.

Ein weiteres Aufgabengebiet des Kraftfahrzeuglabors des TÜV Rheinland sind vergleichende Untersuchungen an Fahrzeugteilen, z. B. im Auftrage von Verbraucherorganisationen. Jedoch auch für die einzelnen Teilehersteller bietet der TÜV Rheinland die Ausarbeitung und Durchführung eines aussagekräftigen Prüfprogramms zur Ermittlung von Sicherheit und Qualität an. Über diese Prüfung wird ein Zertifikat erteilt, und der Hersteller kann die Kunden über ein entsprechendes Prüfzeichen darauf hinweisen.

Schließlich werden die Prüfanlagen verbunden mit dem Know-how des Personals im Rahmen von Entwicklungsaufträgen von den Fahrzeug- und Fahrzeugteileherstellern in Anspruch genommen.

2. Prüfeinrichtungen

Die nachfolgende Beschreibung soll einen kurzen Überblick über die Einrichtungen dieses Labors geben und Hinweise für die Anwendbarkeit aufzeigen. Auf einer Gesamtfläche von etwa 1000 m² sind neben den verschiedenen Prüfanlagen eine kleine Mechanische Werkstatt zur Vorbereitung der Versuche und meßtechnische Prüf- und Arbeitsplätze zur Entwicklung und Anpassung der Meßgeräte und Prüfeinrichtungen untergebracht.

2.1. *Crashanlage*

Die vom Flächenbedarf her aufwendigste Einrichtung ist die im vergangenen Jahr neu in Betrieb genommene Crashanlage, *Bild 1 und 2*. Über ein Endlosseil wird das Fahrzeug auf einer 60 m langen Strecke beschleunigt. Der Aufprallblock mit einer Masse von 200 t entspricht den einschlägigen SAE- und

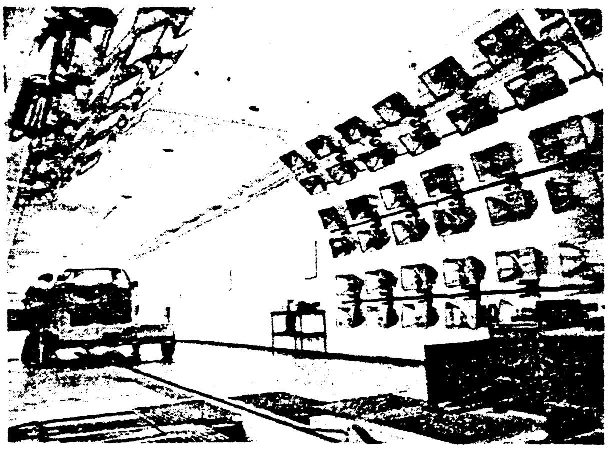


Bild 1. Beschleunigungsstrecke der Crashanlage

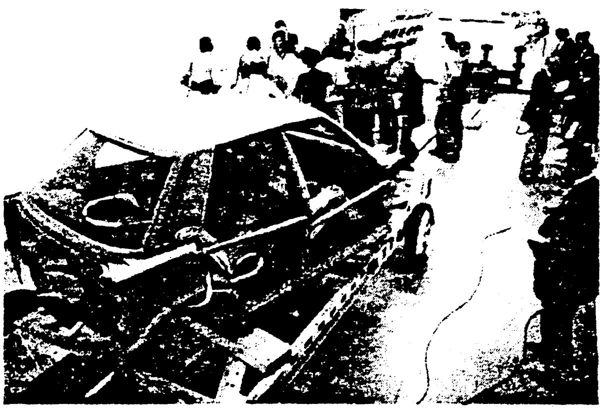


Bild 2. Versuchsträger mit schräggestellter Karosse in der Crashanlage

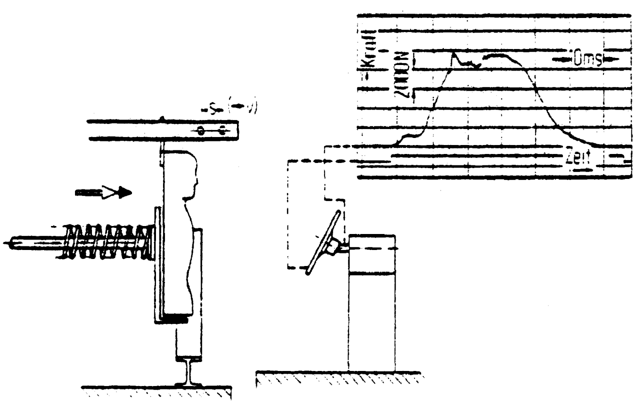


Bild 3. Schema des Aufprallprüfstandes für Sonderlenkräder

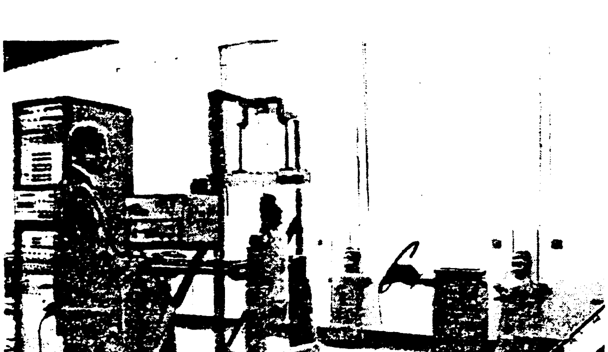


Bild 4. Ansicht des Aufprallprüfstandes

ISO-Richtlinien. Der Antrieb des Seils erfolgt aus einem Hydrospeicher über einen Hydromotor.

Der Speicher enthält ein Ölvolumen von 100 l und ein Gasvolumen von 200 l. Die Anlage wird mit einem Betriebsdruck von 200 ... 300 bar gefahren. Damit ergibt sich für den Antriebsmotor bei einem Druck von z. B. 250 bar eine Antriebsleistung von 500 kW. Mit dieser Leistung kann ein Fahrzeug mit der Masse von 2000 kg auf eine maximale Aufprallgeschwindigkeit von 90 km/h gebracht werden. Bei einer Verdoppelung der Fahrzeugmasse sinkt die mögliche Aufprallgeschwindigkeit auf 54 km/h. Diese Aufprallgeschwindigkeit kann mit einer Genauigkeit von weniger als ± 1 % geregelt werden. Die Schwankungen der Fahrzeugbeschleunigung in der Antriebsphase können kleiner als ± 0.05 m/s² gehalten werden. Die Übertragung der Meßdaten wie Beschleunigung und Kräfte vom Fahrzeug zur Meßwarte erfolgt nach dem Verfahren der Puls-Code-Modulation entweder über ein koaxiales Schleppkabel oder telemetrisch. Die Übertragungsrate beträgt derzeit 500 kbit. Ein Ausbau auf 2000 kbit ist vorgesehen. Hochgeschwindigkeits-Filmaufnahmen halten den Bewegungsablauf fest.

Die Crashanlage ermöglicht die Simulation typischer Kollisionen ganzer Fahrzeuge wie Frontal-, Schräg-, Mauer- oder Pfahlaufprall z. B. zur Ermittlung der Eindringtiefe des Lenkrades sowie Zweirad- und Fußgängerkollisionen. Über einen speziellen Versuchsträger, wie ihn die Bilder 1 und 2 zeigen, in Verbindung mit einer Blechstreifenbremse kann die Fahrzeugverzögerung zerstörungsfrei aufgebracht werden zur Prüfung von Fahrzeugkomponenten wie z. B. Kindersicherungssysteme oder Fahrzeugsitze [1]. Durch die quer zur Fahrtrichtung angeordnete Karosse kann damit auch ein Seitenaufprall dargestellt werden.

2.2. *Prüfanlagen für Sonderlenkräder*

Zur Prüfung des Energieaufnahmevermögens von Sonderlenkrädern z. B. nach ECE-Regelung 12 wird ein Torso mit einer Masse von 36.3 kg in Fahrtrichtung auf das Lenkrad geschossen. Die Aufprallgeschwindigkeit muß 24.1 km/h betragen. Über ein Federkatapult, das über einen Druckluftzylinder vorgespannt wird, kann der Torso auf diese Geschwindigkeit beschleunigt werden, *Bild 3 und 4*. Als Bewertungskriterien dienen die beim Aufprall auf das Lenkrad entstehende Horizontalkraft und die Ausbildung eventueller Splitter und Kanten.

Zusätzliche Prüfungen beziehen sich auf die Lenkradfestigkeit bei Temperaturen von -22 °C bis + 80 °C. Neben den notwendigen Kühl- und Heizeinrichtungen stehen dazu Prüfstände zur Aufbringung von tangential und senkrecht zum Lenkradkranz wirkenden Kräften in unterschiedlicher Frequenz und Höhe zur Verfügung.

2.3. *Sitzprüfstände*

In den Prüfverfahren für Sitze sind statische und dynamische Prüfungen vorgesehen. Bei den dynamischen Prüfungen werden die Sitze auf dem Versuchsträger der Crashanlage einer Verzögerung von 20 g über einen Zeitraum von mehr als 30 ms ausgesetzt. Die Auswirkungen auf die Sitzverankerungen und die Verriegelungseinrichtungen werden beobachtet.

Bei den statischen Prüfungen wird über eine Rückenschale eine senkrecht zur Lehne wirkende Kraft aufgebracht, *Bild 5*.

Bild 5. Statischer Sitzprüfstand

Die Größe der Kraft ist als Moment um den sogenannten H-Punkt festgelegt, der unter vorgegebenen Bedingungen mit einer Meßpuppe zu bestimmen ist und etwa der Lage des Hüftdrehgelenks des Insassen entspricht.

2.4. Prüfung von Kopfstützen

Ähnliche Bedingungen sind für die statische Prüfung der Festigkeit der Verankerung von Kopfstützen vorgesehen. Auch hier ist die senkrecht zur Kopfstütze angreifende Kraft durch ein Moment um den H-Punkt festgelegt. Bewertet wird die Rückwärtsverlagerung unter Einwirkung dieser Kraft. *Bild 6.*

Zusätzlich ist das Energieaufnahmevermögen der Kopfstütze nachzuweisen. Dazu wird über einen Fallgewichtsprüfstand ein mit Beschleunigungsaufnehmern ausgerüsteter Prüfkopf mit der Masse von 6.8 kg senkrecht auf die Kopfstütze fallen gelassen. Bewertet wird die gemessene Verzögerung des Prüfkopfes bei einer Aufprallgeschwindigkeit von 24.1 km/h.

2.5. Prüfstand für Gurtverankerungen

Zum Nachweis der Festigkeit der Verankerungspunkte von Sicherheitsgurten in Personen- und Lastwagen ist ein Prüfstand nach *Bild 7* vorgesehen [2]. Sechs hydraulisch betätigte Zugzylinder mit einer maximalen Zugkraft von 30 kN dienen zum Aufbringen der entsprechenden Kräfte in Schulter- und Beckengurt. Ein über Servoventile elektronisch geregeltes Hydraulikaggregat bewirkt den vorgeschriebenen Kraftanstieg und sorgt für die Konstanz der Haltekraft bei einem Nachgeben von Gurt und Gurtverankerung. Die Fahrzeugkarosserie ist während dieses Versuchs auf einer 4 × 2 m großen Aufspannungsplatte festgezurrt. *Bild 8.*

Diese Versuchseinrichtung wird auch bei anderen quasistatischen Zugversuchen an Fahrzeugteilen wie z. B. Sitzen oder Ladungssicherungssystemen verwendet.

2.6. Prüfung von Schutzhelmen

Verschiedene Einrichtungen sind für die Prüfung von Schutzhelmen vorgesehen. Die Stoßdämpfung bei Aufschlag eines Schlagkörpers und die Durchdringfestigkeit wird auf dem bereits bei den Kopfstützen erwähnten Fallgewichtsprüfstand ermittelt.

Auf einem speziellen Prüfstand wird die zum seitlichen Zusammendrücken des Helmes erforderliche Kraft und damit die Seitensteifigkeit gemessen. An einem Prüfkopf werden die Koordinaten des Sichtfeldes und die Öffnungswinkel festgestellt. Eine weitere Prüfeinrichtung dient zur Ermittlung der Festigkeit des Kinnriemens bei statischer Beanspruchung.

2.7. Vermessungseinrichtung

Zur Vermessung der Lage der Gurtverankerungspunkte und zur Ermittlung von innerhalb des Koordinatensystems des Fahrzeugs festgelegten Punkten, auf die sich verschiedene Prüfvorschriften beziehen, wie z. B. den Sitz-Referenz-Punkt oder H-Punkt, steht eine Vermessungseinrichtung zur Verfügung. Auf einer 2 × 6 m großen Grundplatte mit einer Unebenheit von weniger als ± 0.14 mm ist eine dreidimensionale Meß- und Anreißvorrichtung angebracht. *Bild 9.*

Der Anzeigeweg beträgt in Längsrichtung 5430 mm, in Querrichtung 1600 mm und in der Höhe 2250 mm. Die Ablesegenauigkeit beträgt 0.1 mm. Diese Einrichtung wird unter anderem auch für die Beurteilung der Sichtverhältnisse auf die Instrumente bei Einbau eines Sonderlenkrades verwendet. Dazu wird eine Kamera in dem Augenpunkt des Fahrers positioniert, um die Verdeckungen auszuwerten.

2.8. Sichtfeldmeßverfahren

Zur Vermessung des Fahrersichtfeldes, unabhängig von der umgebenden Helligkeit, wurde ein spezielles Laser-Sichtfeldmeßgerät entwickelt [3]. Mit der erwähnten Vermessungseinrichtung wird dazu ein Helium-Neon-Laserrohr kleinster Leistung z. B. in die Augenpunkte des Fahrers ge-

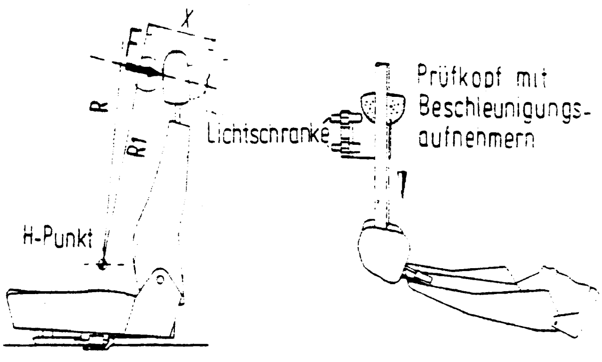


Bild 6. Prüfeinrichtung für Kopfstützen:
links: statisch
rechts: dynamisch durch Aufprall eines Prüfkopfes

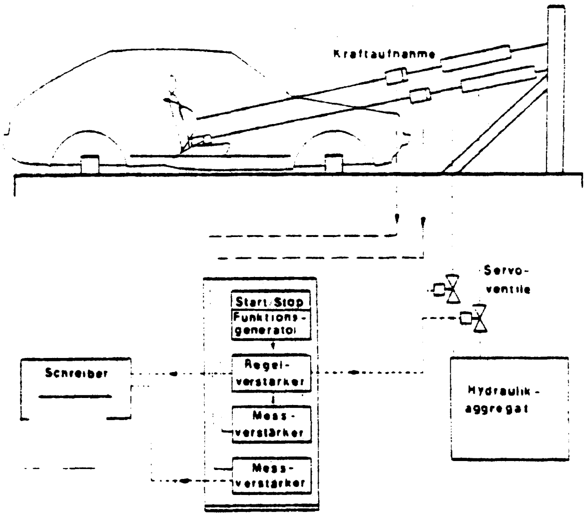


Bild 7. Schema des Prüfstandes für die Verankerungen von Sicherheitsgurten

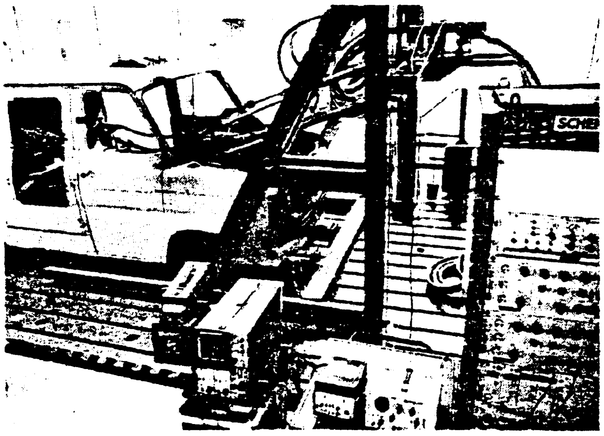


Bild 8. Prüfung der Gurtverankerungen

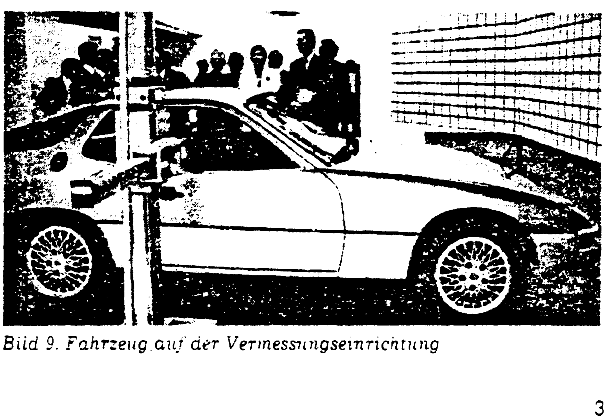


Bild 9. Fahrzeug auf der Vermessungseinrichtung

Bild 10. Das Laser-Sichtfeldmeßgerät im Einsatz

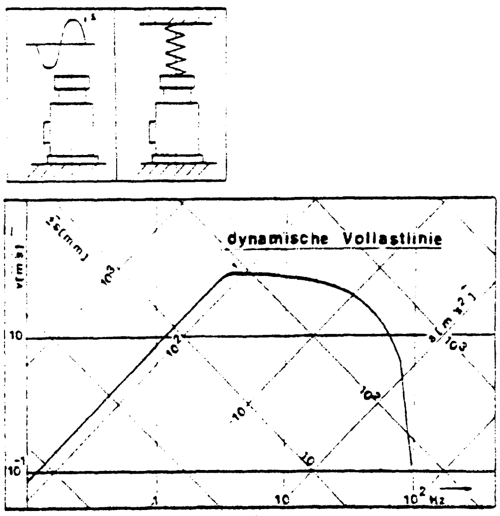


Bild 11. Schema und Kennfeld der Hydropulsanlage

Bild 12. Versuchsfahrzeug und Meßbus für Fahrverhaltensuntersuchungen

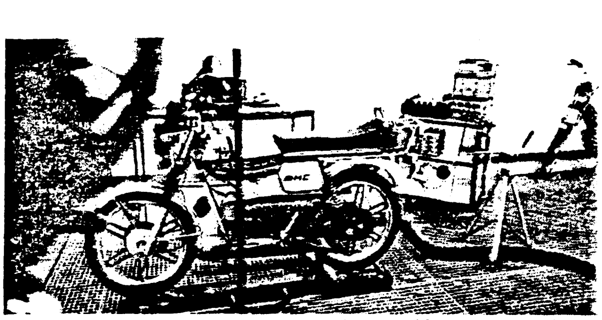


Bild 13. Prüfung von Höchstgeschwindigkeit und Lärmemission bei einem Kleinkraftrad

bracht. Ein digitales Anzeigesystem erlaubt nun die im Sichtfeld liegenden Verdeckungen horizontal und vertikal mit einer Einstellgenauigkeit von ± 0,1 Winkelgrad zu ermitteln. *Bild 10.* Ein zusätzlich vorgesehener Strahlenteiler ermöglicht die Bewertung der gleichzeitigen Sicht aus beiden Augenpunkten, wobei ein Divergenzwinkel zwischen beiden Augenstrahlen von 0 bis 12° einstellbar ist. Damit kann der sogenannte ambinokulare Verdeckungswinkel ermittelt werden.

Weiterhin von Wichtigkeit ist die Entfernung des verdeckenden Gegenstandes z. B. bei fahrbaren Arbeitsmaschinen. Hierzu wurde ein ebenfalls aufsteckbarer Mischbildentfernungsmesser mit einem Meßbereich von 300 bis 12 000 mm entwickelt. Das Sichtfeldmeßgerät ist sowohl für die Vermessung des direkten Fahrersichtfeldes als auch für die Ermittlung des indirekten Sichtfeldes durch Innen- oder Außenspiegel geeignet [4].

2.9. *Prüfeinrichtungen für Sicherheitsglas*

Für Sonderprüfungen an Sicherheitsglas und glasähnlichen Stoffen in Anlehnung an nationale und internationale Anforderungen stehen die notwendigen Einrichtungen zur Verfügung. Mit einem speziell 14 m hohen Fallprüfstand werden Kugelfall-, Pfeilfall- und Phantomfallversuche zur Prüfung der Splittersicherheit durchgeführt. Zur Ermittlung der optischen Eigenschaften werden das Schräglinien- und Zebrastreifenverfahren angewandt und der Transmissionsgrad sowie der Streulichtanteil ermittelt. Weitere Prüfeinrichtungen berücksichtigen die thermische Beständigkeit, die Abriebfestigkeit und die Entflammbarkeit. Auch bei der Prüfung der mechanischen Beständigkeit von Kunststoffteilen wie z. B. Spoilern, Kraftradverkleidungen oder Sonnendächern kommen die Prüfeinrichtungen zum Einsatz.

2.10. *Schwingungsprüfung*

Schwingungsprüfungen werden einerseits zur Bewertung der Festigkeit von Bauteilen bei hohen Lastwechselzahlen oder bei stoßartiger Beanspruchung eingesetzt und andererseits zur Beurteilung der Schwingbeanspruchung des Fahrers, z.B. auf dem Sitzplatz von größeren Rasenmähern. Hierzu steht ein Hydropuls-Zylinder mit einer Nennkraft von 16 kN und einem Hub von 250 mm zur Verfügung, mit dem Wechsellasten mit Frequenzen bis etwa 100 Hz aufgebracht werden können, *Bild 11.* Entsprechende Auswerteprogramme zur Durchführung von Frequenzanalysen bei den mit dem Prüfstand erregten Schwingsystemen liegen vor. Für die Zukunft ist ein Ausbau auf eine Vier-Zylinder-Anlage geplant.

2.11. *Fahrverhaltensmeßeinrichtung*

Für die Ermittlung der Änderungen der Fahreigenschaften von Kraftfahrzeugen gegenüber dem Neuzustand durch den Anbau von Zusatz- oder Austauschteilen wie z.B. Spoilern oder speziellen Aufbauten oder durch Verschleiß von Teilen wie z.B. Stoßdämpfern, werden im Kraftfahrzeuglabor verschiedene Meßgeräte vorgehalten [5, 6].

Außer einem speziellen Meßlenkrad zur Messung von Lenkradwinkel und Lenkmoment mit variablen Rasten und Anschlägen stehen z.B. eine kreiselstabilisierte Plattform mit dreiaxialem Beschleunigungsaufnehmer, Kurskreisel, Meßgeräte für die Längs- und Quergeschwindigkeit sowie Längenmeßsysteme für Federwege oder Knickwinkelgeber für Untersuchungen mit Anhängern zur Verfügung. Die Meßdaten werden entweder mit einem Magnetband im Versuchsfahrzeug registriert oder per Telemetrie in einen Meßbus übertragen, in dem sofort erste Auswertungen und Überprüfungen vorgenommen werden können. *Bild 12.*

2.12. *Sonstige Prüfeinrichtungen*

Eine Anzahl von kleineren Prüfeinrichtungen mit vorwiegend pneumatischen Kraftzylindern dient der Prüfung der Dauerfestigkeit von Fahrzeugteilen wie z. B. Sonderlenkern für Motorräder. Zur Überprüfung von Austauschschalldämpfern stehen entsprechende Schallpegel-Meß- und Registriereinrichtungen zur Verfügung. Die Ermittlung der Motorleistung bei Kraftfahrzeugen oder der Höchstgeschwindigkeit von kleineren motorisierten Zweirädern, *Bild 13*, ist ebenfalls möglich.

Da das Kraftfahrzeuglabor weiterhin für die Wartung und Kalibrierung der im Rahmen der Fahrzeugreihenuntersuchung und der Typprüfung verwendeten Meßgeräte zuständig ist, z. B. für die Scheinwerfereinstellung, die Emission von CO im Abgas oder die Ermittlung der Fahrzeugverzögerung, wurden auch hierzu entsprechende Prüf- und Kalibriergeräte entwikkelt.

3. Meßdatenerfassung und -verarbeitung

Die Datenaufzeichnung erfolgt im allgemeinen auf Bandspeichern. Für die Fahrversuche stehen FM-Analog-Bandgeräte oder PCM-Bandgeräte zur Verfügung. Weiterhin ist die telemetrische Datenübertragung an Versuchsträgern in die Meßwarte oder den Meßbus vorgegeben. Zur anschließenden Weiterverarbeitung werden die Daten digital oder analog von einem Prozeßrechner, der mit zwei Plattenspeichern und einer Bandstation ausgerüstet ist, übernommen. Für die Auswertung der üblichen Crash- und Fahrversuche wurden spezielle Auswertungsprogramme entwickelt. Die Ergebnisse werden dann in Tabellenform über einen Drucker oder analog zur Aufzeichnung auf einen XY-Schreiber ausgegeben. Der Prozeßrechner dient darüber hinaus auch direkt zur Steuerung von Einrichtungen wie der Crashanlage und der Hydropulsanlage.

4. Ausblick

Im Rahmen einer Neubaumaßnahme des TÜV Rheinland wurden die verschiedenen Kraftfahrzeugprüfeinrichtungen zu einem Kraftfahrzeuglabor zusammengefaßt. Obwohl eine große Zahl der Prüfeinrichtungen speziell zur Erfüllung der Anforderungen der geltenden Regelungen und Richtlinien erstellt werden, ergeben sich in vielen Fällen zahlreiche weitere Anwendungsmöglichkeiten im Rahmen der Weiterentwicklung von Fahrzeugen, Fahrzeugteilen und Prüfverfahren. Interessierte Hersteller und Behörden auf diese Möglichkeiten hinzuweisen, ist das Ziel dieser Darstellung.

Schrifttum

[1] Hirschberger, H. G., Rompe, K. und Tupova, J.: Untersuchung zur Belastung von Nutzfahrzeugen bei Auffahrunfällen. Automobilindustrie (1977), 2, S. 41–48

[2] Hirschberger, H. G. und Felten, G.: Anforderungen an Gurtverankerungen. Technische Überwachung (1978) 7/8, S. 215–218

[3] Engel, G.: Meßverfahren für das Sichtfeld aus Kraftfahrzeugen. Kolloquiumsbericht „Sicht aus Kraftfahrzeugen" TÜV Rheinland 1979, S. 189–205

[4] Rompe, K., Reimann, S. und Engel, G.: Zweckmäßigkeit eines rechten Außenspiegels bei Personenkraftwagen. Jahrestagung der Deutschen Gesellschaft für Verkehrsmedizin e. V., Frankfurt, 9. 4. 1978

[5] Rompe, K. und Grunow, D.: Fahrbahngriffigkeit und Fahrverhalten von Pkw beim Bremsen in der Kurve. 18. Internationaler FISITA-Congreß, 5.–8. 5. 1980, Hamburg

[6] Burow, K. und Grunow, D.: Beurteilung des Fahr- und Bremsverhaltens von Pkw-Wohnanhänger-Zügen. 18. Internationaler FISITA-Congreß, 5.–8. 5. 1980, Hamburg

Anschrift der Verfasser:

Privatdozent Dr.-Ing. Klaus Rompe
Vordersten Büchel 41a, 5064 Rösrath-Hoffnungsthal

Dr.-Ing. Peter Wiegner
Werheider Straße 21, 5000 Köln 80

APPENDIX V

FIG 1 THE ORGANISATION OF MIRA

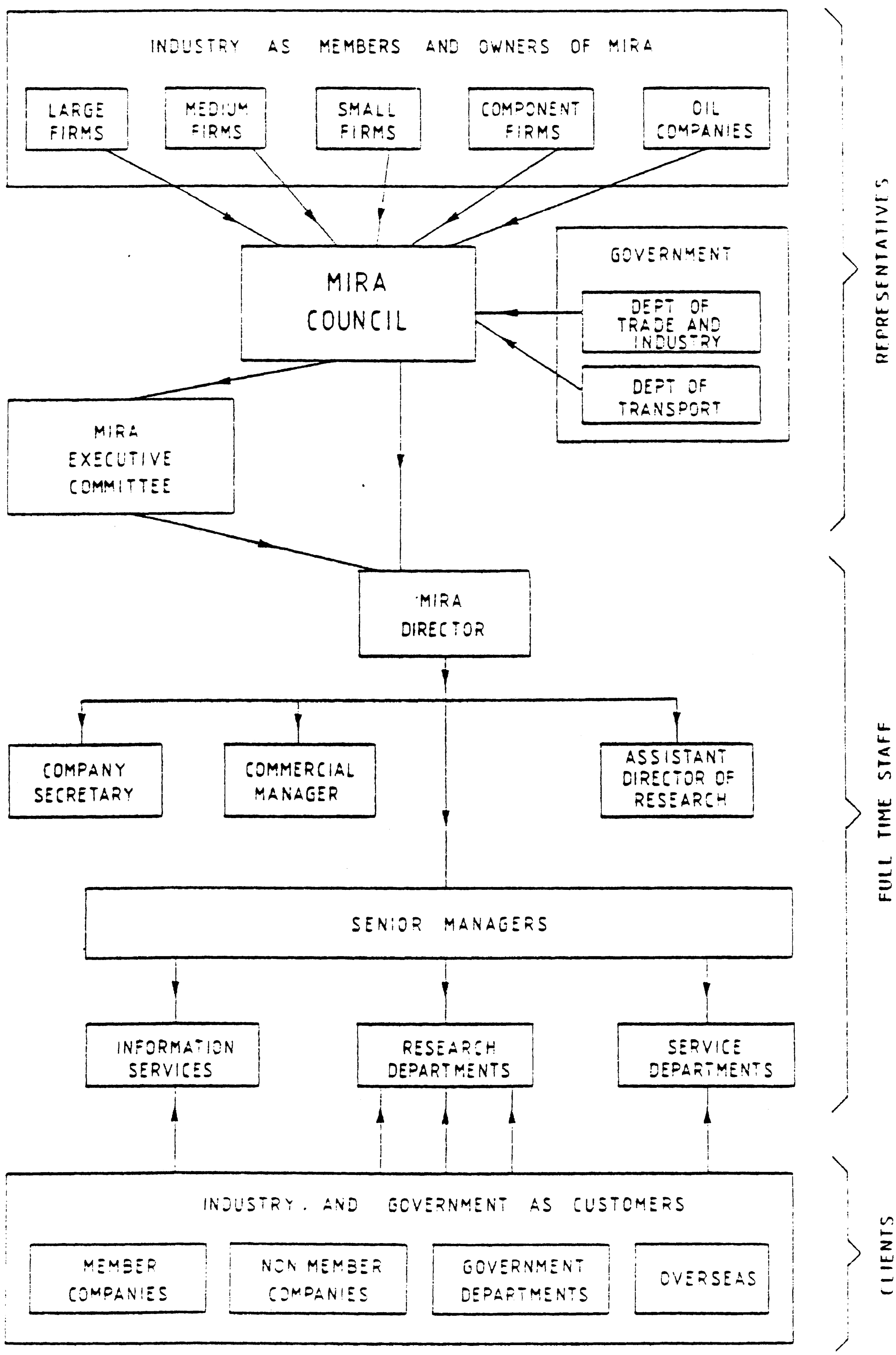
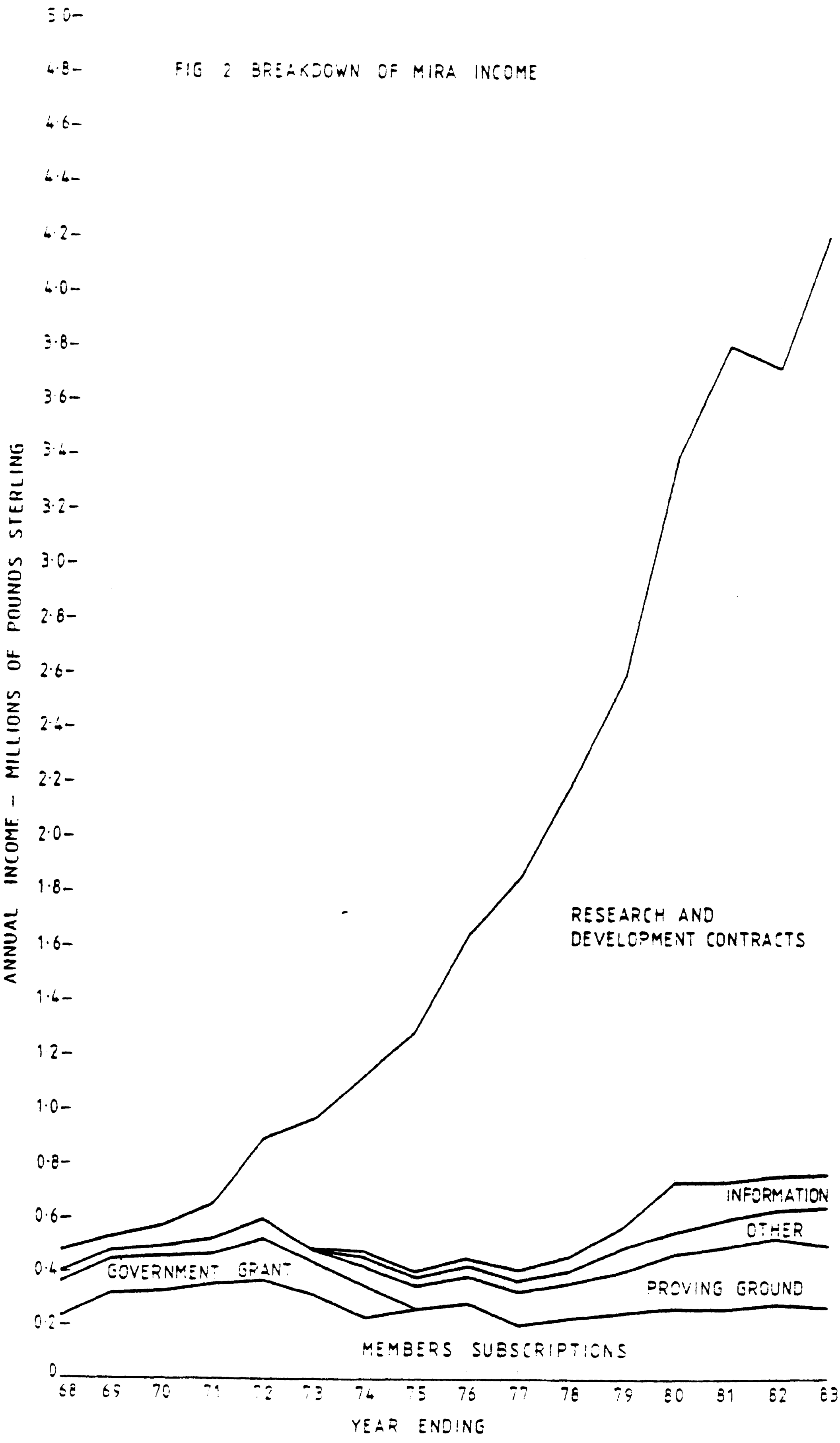


FIG 2 BREAKDOWN OF MIRA INCOME



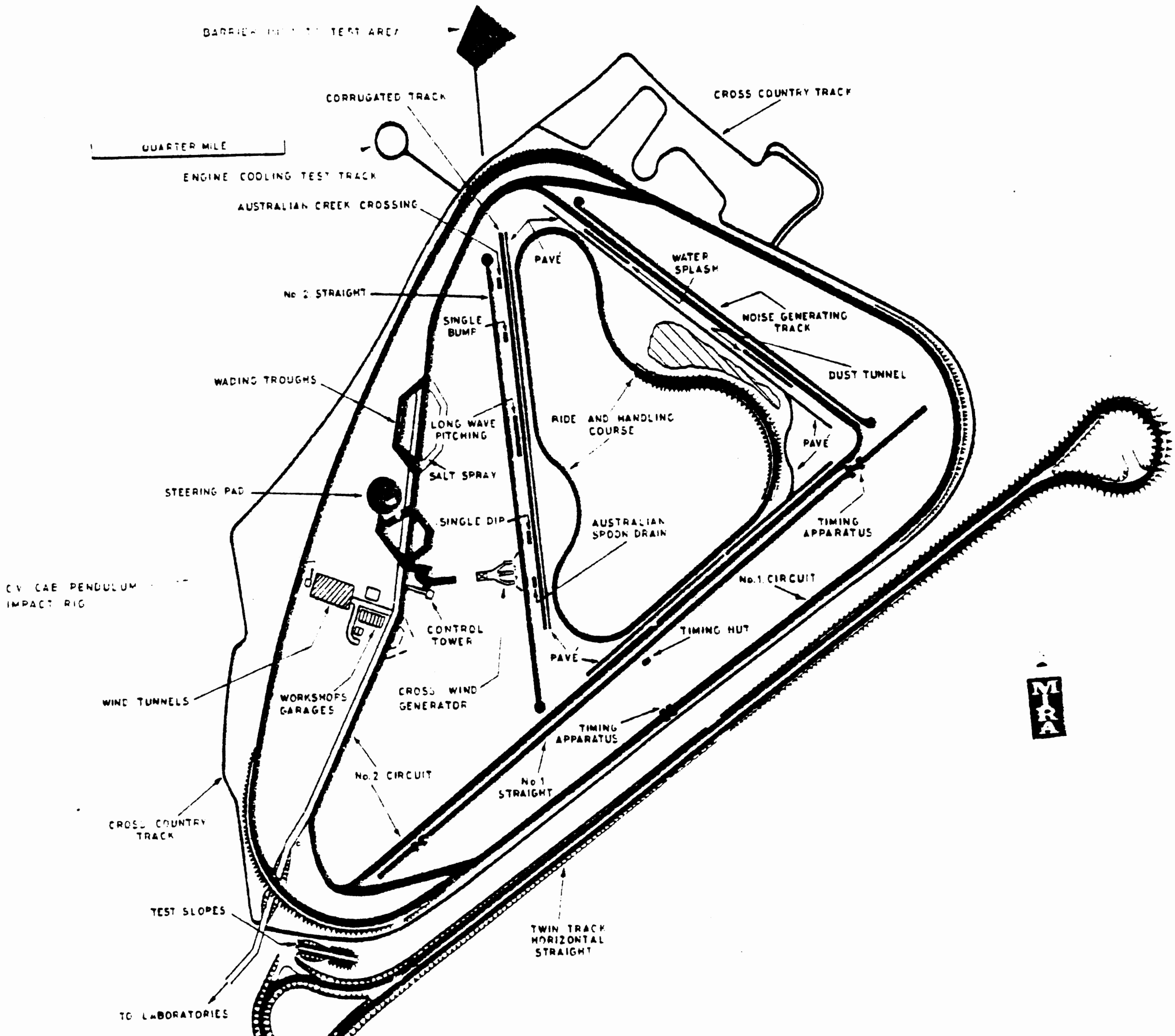


Fig. 14 - MIRA Proving Ground

APPENDIX W

LAYOUT OF JAPAN AUTOMOBILE RESEARCH INSTITUTE, INC.

Proving Ground Facilities

High Speed Circuit,
5,500 m long, 12 m wide concrete pavement

Outer Circuit,
7,000 m long, asphalt pavement

Multipurpose Test Track,
500 m long, 30 m wide and 500 m long, 45 m wide, Total length 1,000 m, asphalt pavement

Slippery Test Track,
450 m long, 30 m wide, polished concrete pavement

Skid Pad,
100 m in diameter, asphalt pavement

Steering & Handling Test Ground,
with area of 72,000 m², asphalt pavement

Standard Uneven Road,
300 m long, 4.5 m wide, granite block pavement

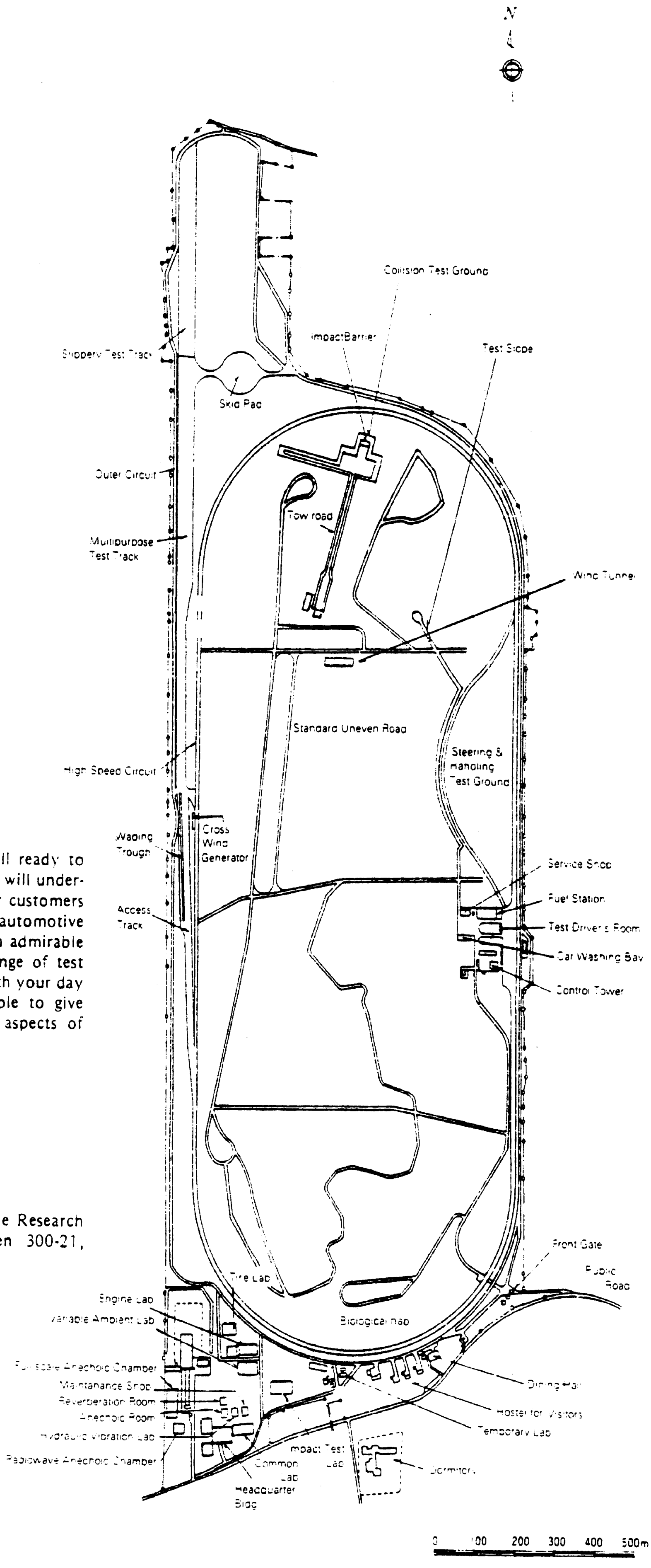
Test Slop
10 m long, grade 30%

A Guide to Customers

With excellent and unique facilities, we are well ready to handle problems on automotive technologies. We will undertake specific work for manufacturers and other customers on a strictly confidential basis on all aspects of automotive technologies. Our long-term activities provide an admirable background for consultative work while our range of test facilities are available at short notice to assist with your day to day problems. Our staff are always available to give advice and to discuss specific projects on all aspects of testing and research on automobiles.

Address your initial inquiry to;

Technical Information Center, Japan Automobile Research Institute, Yatabe-cho, Tsukuba-gun, Ibaraki-ken 300-21, Japan

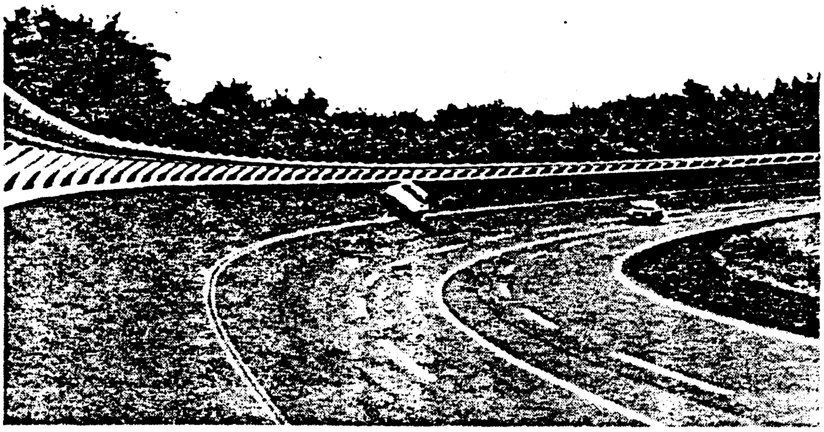


6. JARI PROVING GROUND AND TEST FACILITIES

Our well-combined research activities and an excellent and versatile array of testing facilities and technology are the bases of JARI operations. The JARI was built in the site extending over an area of nearly 2.4 million square meters (586 acres). Various research laboratories and excellent purpose-built facilties are well arranged in the extensive site, which is surrounded with a natural beautiful scenery on the foot of Mt. Tsukuba. Proving ground and research facilities include varied and flexible testing capabilities, which are available for leasing to on-site customers.

1. High-speed Test Circuit, 5,500 meters long

The high-speed oval track, asphalt-paved, is one of the longest of its type in Japan. The 5,500 meter ovel circuit has a straight course about 1,500 meters long and 12 meters wide. The banked corner, which allows neutral speed of up to 190 kilometers per hour, has a maximum slop of 45 degrees. The lane for vehicles travelling at the design speed is marked in yellow. This circuit is used for a variety of tests including endurance, braking, vehicle aerodynamics, lubricant effectiveness and automatic control. The inside lane is for slow-speed and outside two lanes are for high-speed.



High-speed test circuit, 5,500 meters long

2. Outer Circuit

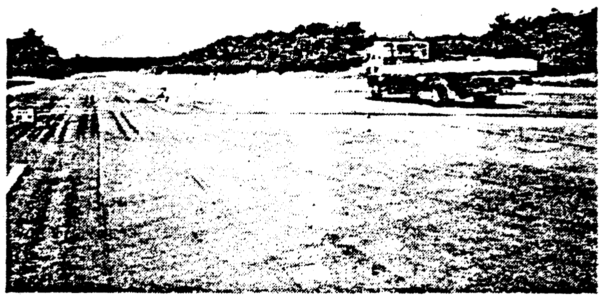
The asphalt-paved circuit is on the outer side of the high-speed tracks. The circuit measures about 7,000 meters long and ideal for endurance tests.

3. Multipurpose Test Track

The test track is an asphalt-paved straight road measuring 1,000 meters long and 30 to 45 meters wide. This test track is primarily used for acceleration test, braking test and various other performance tests on vehicles.

4. Slippery Test Track

The main stretch of this test track is 20 meters wide and 450 meters long and has polished concrete finish. This track is equipped with an apparatus, which sprays water over road from the left side to the opposite side. Tests on tire characteristics, braking and skidding are conducted on the



Multipurpose test track, 1,000 meter straight road

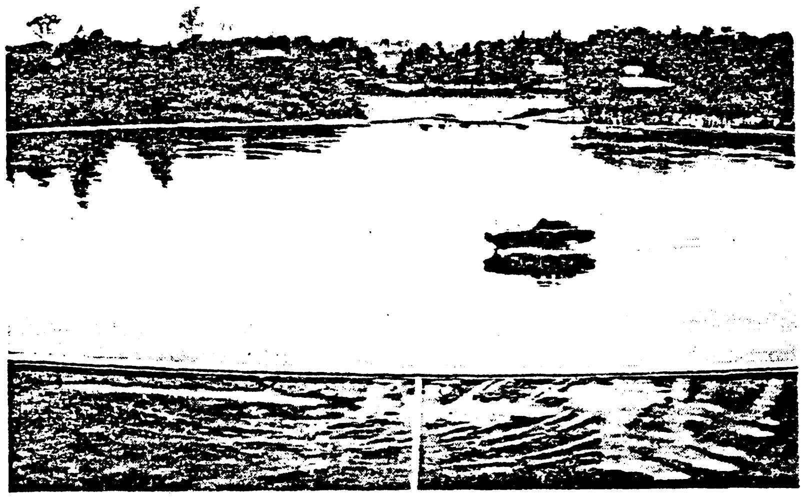
wet road surface. It it also possible to conduct tests on hydroplanning caused by the water film on the road surface.

5. Wading Trough

The trough is 0.6 meters deep and about 50 meters long. Water depth is adjustable up to 0.6 meters. It is used to test body underfloor construction sealing.

6. Skid Pad

An 100-meter diameter circular test facility paved with asphalt is used primarily for all types of handling tests including tire and brake testing. From the center of the pad, water is sprinkled rapidly for wet testing.



Skid pad, 100 meters in diameter

7. Brake Slop

It is used mainly for parking brake test. The length is 10 meters, width 4 meters, grade 30% (16°42') paved with cement concrete.

8. Belgian Block Course

It is a road featuring rough, uneven surface for standard test on general performance and durability. Specifications of the road surface were established by calculating the mean value of the bumpy roads throughout Japan. Four types of granite blocks with bumpy surface are embedded into the road measuring 300 meters long, 4.5 meters wide.

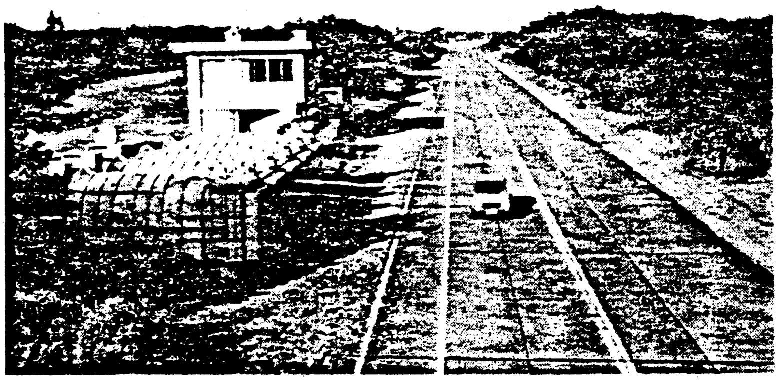
Belgian block course

9. Steering and Handling Test Ground

The test ground was constructed in 1972 to conduct overturning immunity tests of the domestic Experimental Safety Vehicles (ESV). It covers an area of 72.200 square meters and it is of international standard. Slalom and J-turn tests at thigh speed and constant circular turning tests are conducted to check the overturning immunity in braking and steering of high-speed test vehicles. Automatic driving is made possible by an automatic guddance cable system buried under the road surface.

10. Cross-wind Generator

This has five huge electric blowers with maximum output 320 kilowatts each in parallel formation. The mouth of the blower measures about two meters high and 15 meters long. Wind velocity is changeable in three stages from 15 meters to 30 meters per second. This equipment is used to test the

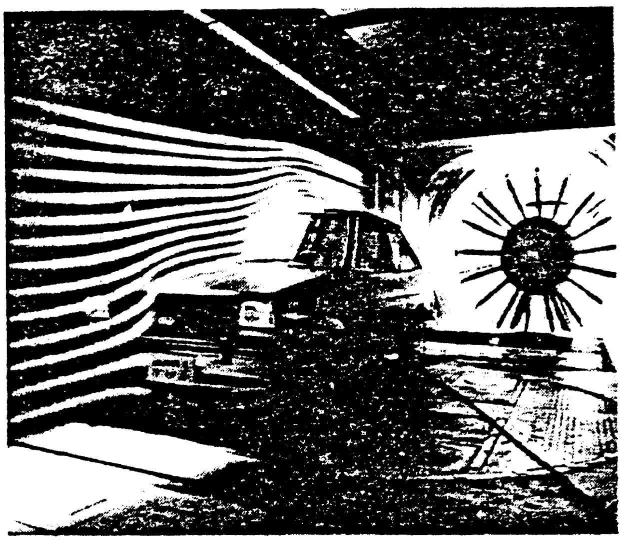


Cross-wind generator produces wind gusts up to 108 km/h

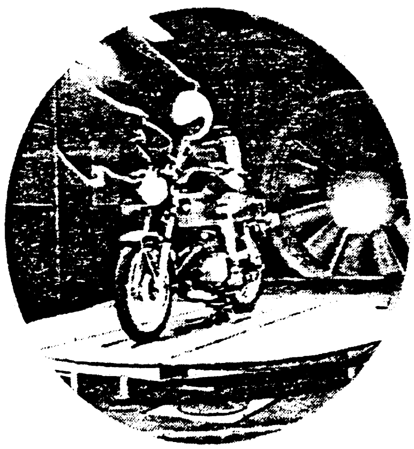
effect of crosswinds on automobiles when running on an unprotected stretch of expressway, emerging from a tunnel or crossing a long suspension bridge. This equipment gives the highest performance in the world in terms of wind velocity.

11. Full-scale Wind Tunnel

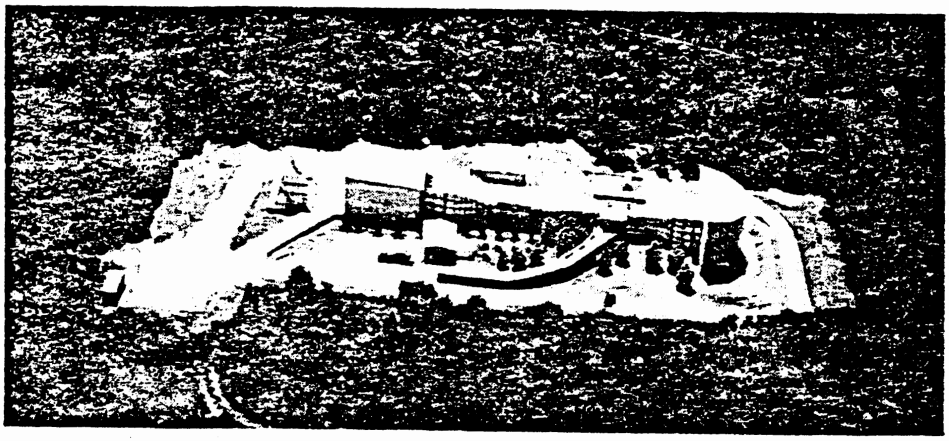
This wind tunnel is well used both for hire to customers and for self-sponsored projects. The length of the facility is about 100 meters. It is and efficient straight Eiffel Type wind tunnel. Air is sucked in form the right side of the facility and blown out from the left side. There are two measuring portions. It can accommodate large or small vehicles and incorporates both an aerodynamic balance and chassis dynamometer. The vehicle shape on fuel economy, wind distrubance, ventilation, engine cooling and safety can be evaluated here. The projects aimed at reducing the drag of various vehicles occupy a considerable part of the operations. The first measuring portion measures three meters high, four meters wide and 10 meters long. Wind velocity is 25 to 57 meters per second. The second measuring portion measures five meters high, six meters wide and 13 meters long. Wind velocity ranges from one to 23 meters per second. The diameter of wind blower, which is driven by 1,200 kw electro moters, is 5.5 meters.



Aerodynamic test in the wind tunnel. Air stream is visualized with white smoke



Aerodynamic test of a motorcycle set upon a measuring balance

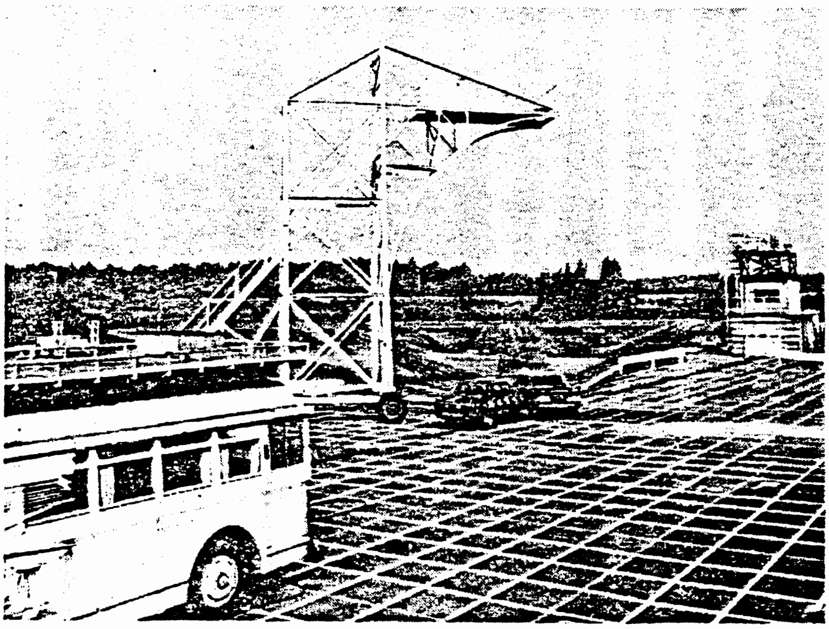


Outside view of full-scale wind tunnel

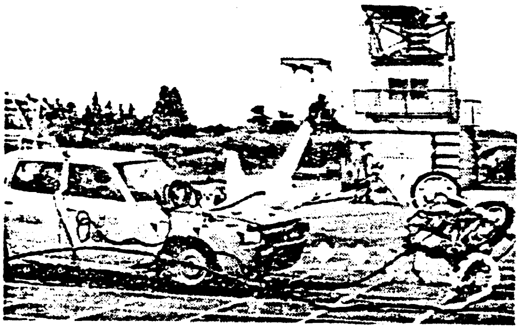
12. Collision Test Facilities

The facilities are designed to accomodate all crash models including direct barrier and poll impacts, vehicle-to-vehicle impacts and rollover simulations along a 350-meter main tow road. A 200-meter sub-tow road and additional five 120-meter subtow roads are equipped for testing side impacts at varied lateral impact angles. The test car can be accelerated up to 130 km/h by a steel guidance cable in a shallow groove set below the tow road. Camera pits are set adjacent to the fixed barrier in front of the control room. The test area is 67 by 150 meters, the impact barrier weighs 246 tons, maximum collision speed is 130 km/h (36 m/s) in the case of a 2.7 ton vehicle.

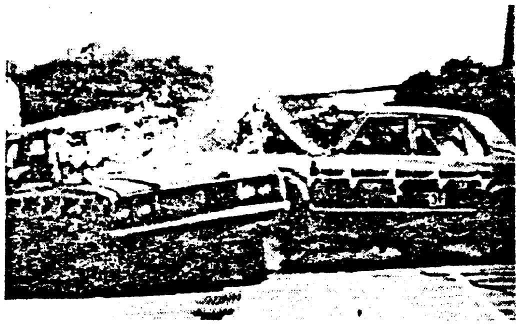
Data Reduction: A wide range of instruments, including accelerometers, load cells, strain gauges, thermocouples, and pressure transducers, is available. Transducer signals are processed through Remote Signal Conditioning Modules (110 channels of data). Dummy Calibration: The Dummy Calibration Laboratory is a complete certification facility as required by the code of U. S. Federal Regulations, Title 49, Part 572.



Collision test facilities



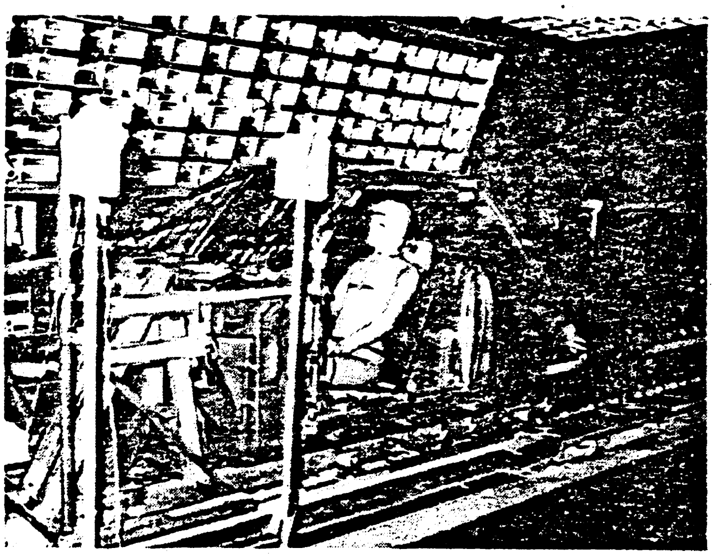
Collision of a passenger car aginst the side of a motorcycle. Anthrometric dummies are used in safety tests.



A test of side collision with passenger cars

13. HYGE Reverse Impact Simulator

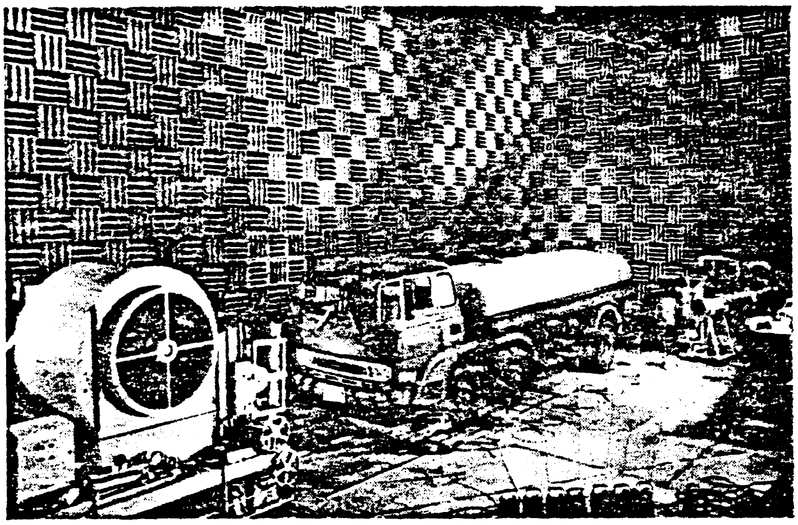
The facility, called the 12-inch diameter HYGE unit, can accurately simulate various types of impact wave forms during collision. The pneumatic-powered impact sled simulates the rear-instant stop of a front end collision under controlled and repeatable conditions. In a test, the sled of 50 G in case of a car-body foundation weighing 560 kg. It can handle a wide range of component testing including engine mounts, shoulder harness, air bags, head restrains, safety standars, and establish product performance.



A test of occupant restraint system with the impact simulator

14. Full-scale Anechoic Chamber

JARI anechoic chambers provide an effective test environment for acoustical measurement. This chamber, is made of three separate test rooms. One is a large anechoic room big enough to accommodate a full-size vehicle to test external noise emitted from it. Other purpose-built anechoic rooms are ideal for measuring noisen emitted from engine and exhaust pipe separately. Wall surfaces of the rooms are all covered with sound wave absorbing wedges (made of glass wool) which prevent reflection of sound waves acoustically. The first large room has an inside dimension of 17m × 24m × 10m (high) and equipped with chassis dynamometers. Background noise when operating the chassis dynamometers and cooling fans is below 50.0 dB.

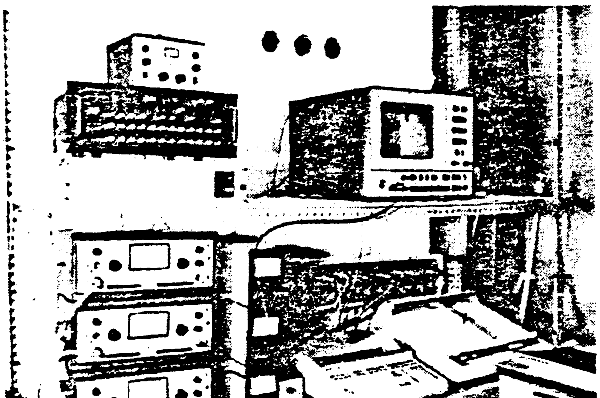


Full-scale anechoic chamber is big enough to accommodate heavy duty vehicles

15. Reverberant Test Rooms

This sound transmission-loss test room enables the airborne sound transmission loss properties to be measured of the materials employed in the construction of vehicles. The facilities consist of three test rooms, one for measurement of sound absorption coefficient and other two for measurement of sound transmission loss, which are used for studies of the materials with sound space absorption and insulation properties. Effective capacity is 36.9 cubic meters each in pentagonal shape. The test range of frequency is 250 Hz—8kHz. The measurements are performed by a computer system within half an hour.

Tests in a reverberant room



Automatic measuring system

16. Electro-magnetic Anechoic Chamber

Electromagnetic interference is becoming a major problem as more electronics go on cars and more sources of interference become turned on.

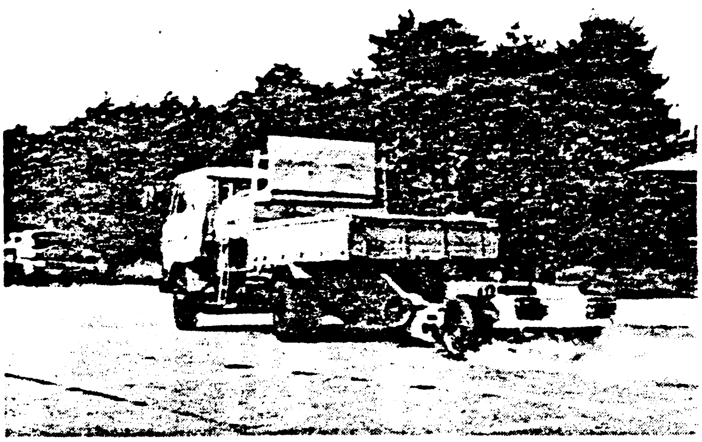
As the building itself is completely shielded electrically, this chamber can prevent completely the effects from external radio waves and internal reflecting radio waves. Foam polyurethane pyramids preventing the reflection of micro waves are installed on all wall surfaces. A test vehicle is placed on a turn-table in the center for precise measurement of noise emitted from electric and electronic appliances loaded in the test vehicle. Inside dimensions of the chamber, 20m × 8m (high); reflecting radio wave absorbing capacity, damping of 100 dB or more possible at 25 ~ 10,000 MHz.

17. Tire Testing Equipments

JARI's advanced tire research offer the most comprehensive and consistent data on tire performance characteristics, to measure the mechanical properties of tires under load at actual road speeds under controlled conditions which simulate tire use, to measure tire braking and tractive properties under wet and dry surface conditions, to monitor, record and interpret the influence of variables such as tire design, operating pressure and temperature, tire wear and rate of change of tire attitude on tire performance.

(1) Trailer-type Tire Testing Vehicle

The system consists of a tractor and trailer with the tractor section equipped with instrument room, water tank and a sprinkler. Test tires are attached to the trailer section. The system has the additional new testing mechanism based on tester consisting of an ASTM standard skid resistance number measuring device. Skid and friction resistance on wet and dry pavements can be measured on passenger car and light-duty track tires.

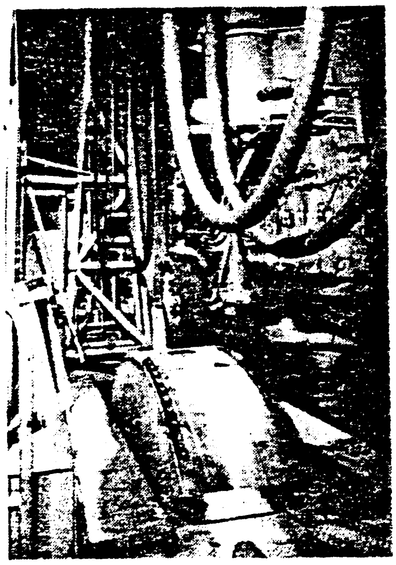


Trailer-type tire testing vehicle

(2) Dynamic Tire Performance Testing Machine

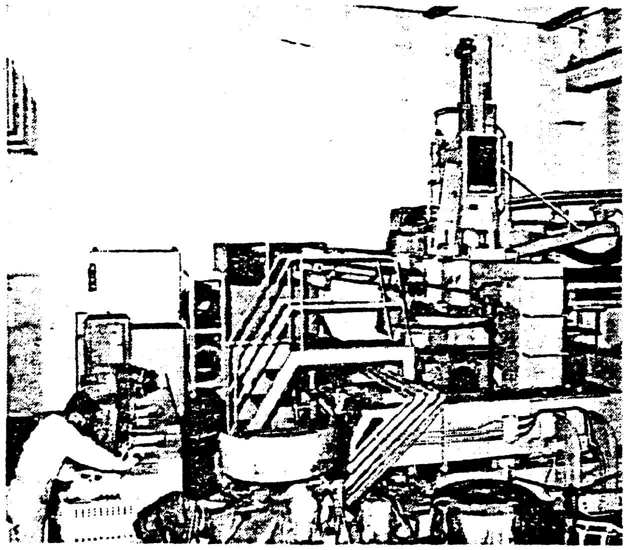
The machine is designed to measure the performance of tires in motion. This is the largest such machine in Japan, featuring a rotating drum of 3.5 meters in diameter. The outer surface of the drum produces various degrees of friction to simulate actual road conditions. On the other side of the drum surface, by sprinkling water, a test on hydroplaning of tire on water film can be conducted. Peripheral speed ranges from 0.3 to 350 km/h. Vertical load is between 100 and 3,000 kg.

Right: Dynamic tire performance testing machine



(3) Tire Testing Machine Measuring Six Components of Force and Moment

It is an apparatus to accurately measure the applied force (six components of force and moment) when a tire rotates. It is used primarily to study the controllability of passenger vehicle tire when braked and to study tire noise generation. Peripheral speed of the drum is between 2 and 200 km/h. Items to be measured; vertical load, side force, drag (front and rear force), self-aligning torque, rolling moment, overturning torque. Drum diameter is 1,707 mm and drum speed is 2~200 km/h.



Tire testing machine for measuring six components of force and moment

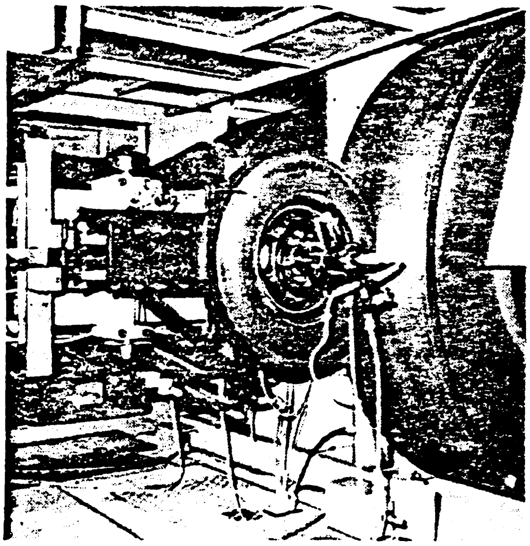
(4) Universal Static Performance Testing Machine

It is an apparatus to measure tire performance when a load is applied on the tire in a standstill position or when it is moving very slowly. Using a hydraulic system, the table can be moved up and down, back and forth, right and left. It is also possible to rotate it around the vertical axis. Tires ranging from those for compact passenger car to heavy duty industrial vehicles can be tested. Load applicable ranges from 2.5 to 50 tons in five steps.

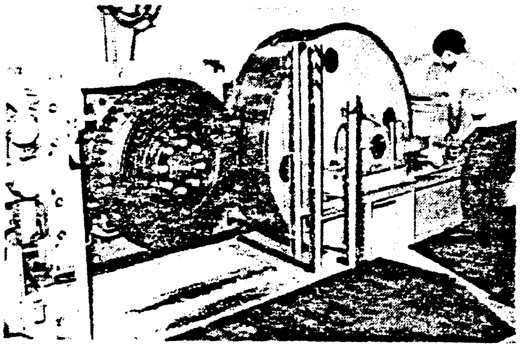
Universal static tire performance testing machine

(5) Tire Endurance Testing Machine

Two rotating drums, 1,707 mm in diameter, driven at speed up to 144 km/h, provide a simulated road way for a test of tire endurance up to contineous 40,000 km under vertical load up to 4,500 kg and with test variables such as speed, operating pressure, the rate of change of tire attitude preprogrammed into computers.



Tire endurance testing machine with two positions for setting test tires



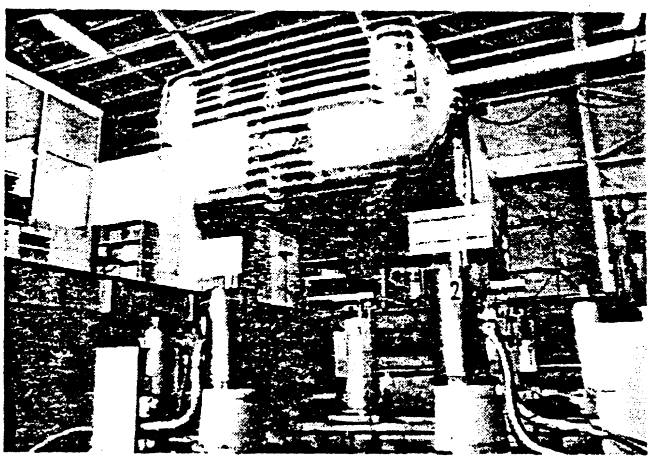
Tire noise testing machine

(6) Tire Noise Testing Machine

A rotating Drum, 1,707 mm in diameter, is driven at a peripheral speed ranging from 20 to 200 km/h and under a vertical load up to 3,000 kg to measure noises generated from rotating tires. It is used for the studies of noises on tires.

18. Electro-hydraulic Vibration Testing Machine

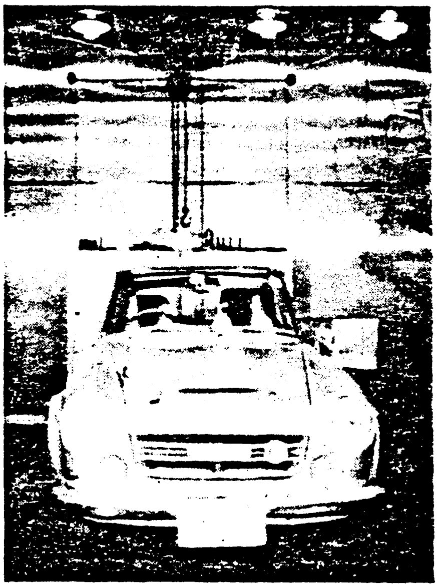
These machines are for conducting vibration tests on automobiles. They can vibrate vehicles vertically up and down. A bad road can be simulated through application of vibratory response characteristics of automobiles and random four wheel inputs to test riding comfort. There are two vibrating machines. Since four wheel can be vibrated independently with different wave forms, these machines can be used to simulate a bad road to test riding comfort. Vibrating force ±2 tons, maximum displacement ±75 mm, maximum speed ±140 cm/s.



Vibration testing machine

19. Ambient Laboratory (Environmental chambers)

The chambers allow vehicle testing over a wide range of temperature, atmospheric pressure and humidities. Temperature can be adjusted from minus 40°C to plus 50°C, atmospheric pressure from 460 mm to 760 mm of mercury, and humidity from 30% to 80%. Running conditions unique to a cold area, highland, and highly humid area can be reproduced respectively. This labratory consists of two rooms of the same size. It can measure the engine perfermance at normal and transitional speeds. It can also measure componests of exhaust gases. Test rooms, 6m long, 5m wide×3.5m high each, two-stage compressor formula (using freon gas 22 as refrigerant) is employed and accomodate a single automobile in a chamber.



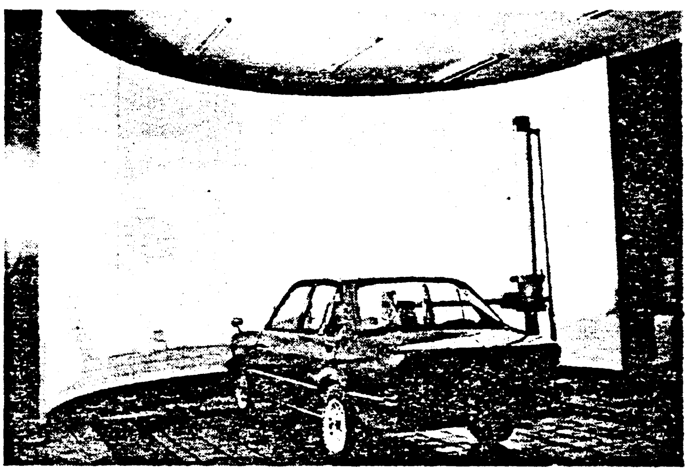
Ambient test room simulates low temperrature and high altitude environments

20. Fixed-type Smog Chamber

Air pollutants caused by automobile emissions such as NO_x, THC, CO and photochemical oxidants can be analized here. Artificial ultraviolet ray can be radiated in the chamber to reproduce photochemical reactions in polluted air.

21. Visibility Test Room

This is used for measurement of eye ranges, visibility of drivers and illumination of lighting system of vehicles. Installed is a curved screen and a flat table of 7 m×4 m, with additional three dimentional measuring apparatus.



Visibility test room

22. Chassis Dynamometers

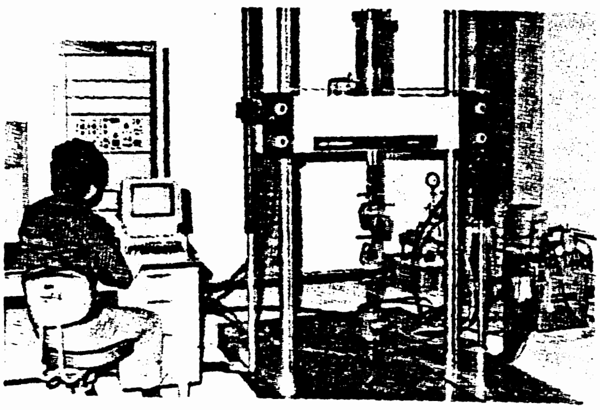
These dynamometers, with absorption capacity of up to 220 H. P., are mainly used for emission tests, but are of course also suitable for general performance testing of vehicles such as measurement of power at the driving wheels and fuel consumption. Test room is operated under a constant temperature and humidity.

Emission tests with a chasis dynamometer

Control and measurement room attached to chassis dynamometer

23. Fatigue & Endurance Testing Machine

This is used for the study on the fatigue and endurance performances of various composite materials developed for automotive applications.

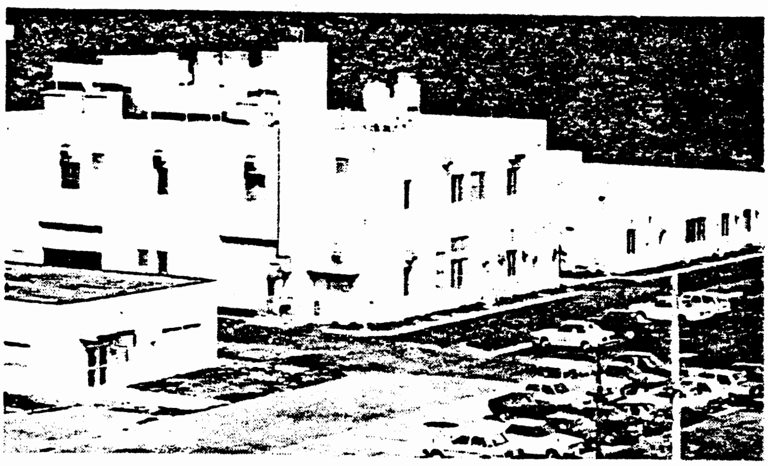


Faitigue & endurance testing machine

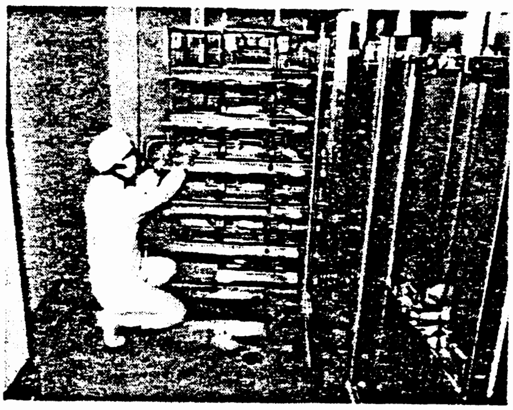
24. Animal Laboratories

In order to assess the health effects of diesel exhaust emissiors, extensive research and tests are conducted through in vitro and in vivo experiments with groups of small animals. A new alboratory was built in 1982, which was two-storied with a floor space of 2,129 m. The cxcellent purpose-built facilities consist of the sections seperately for generating diesel exhaust emissions, treatment for dillution, chemical processes, inhalation chamber rooms, biological and medical studies and the rooms for breeding small animals in clean air. Additional systems are attached, which are designed for air conditioning and feeding clean air into the facilities.

The HERP (health effects research program) was put in operation in 1983 on a long term project sponsoured by the industry. The objective is to establish a link between diesel exhaust particulate and adverse health consequences, including mutagenic studies. Another laboratory is equipped for genetic studies on automotive emissions by bacteriological test methods. On the other hand, the Operant apparatus is employed to observe behavioral changes of small animals exposed to exhaust gases, thereby assessing chronic health effects.



Newly-built Animal laboratories



Inside view of inhalation chamber room for experimental small animals

APPENDIX X


DRIVING
SIMULATOR
Swedish Road and
Traffic Research Institute

5. R&D RESOURCES

The Institute's main R&D resource consists of the competence of individual researchers and groups of researchers in the fields of traffic engineering, transport economy, traffic safety, road user behaviour, biomechanics, vehicle engineering and the construction and operation of roads. In addition the following resources are also available at the Institute.

Experimental road and climate units

These three units each contain a "tank" in which a full scale roadbed can be built up. "Groundwater" can be led into the tank. Various measuring devices, both mechanical and electronic, can be located at desired levels in the different courses making up the roadbed. These units are insulated so that experiments can be carried out throughout the year.

One of the units, the climate unit, has especially insulated walls so that temperatures can be varied between −20°C and +30°C irrespective of the time of the year.

Surfacing unit

This unit is intended for full scale laboratory experiments on surfacings. It can be heated up to +18°C and can therefore be used for experiments throughout the year under the same types of conditions.

Road testing machine

The machine consists of six wheels that rotate on a circular track – with a median radius of 2.5 m – which can be covered with the different materials to be tested. The machine thus enables the rapid testing of different surfacing materials or of studded tyres under "traffic conditions" and under completely controlled conditions with regard to "distance", wheel loading and climate.

Road research laboratories

In the road research laboratories experiments are carried out in the fields of frost physics, road geology, surface engineering and loading capacity.

Laboratories for the routine testing of road materials

Routine tests of road materials are carried out at a number of laboratories.

Equipment for measuring road characteristics

A considerable proportion of R&D work is carried out in this field. For this purpose a number of special vehicles are available, equipped for measuring and recording the evenness of road surfaces, friction and light reflecting properties as well as load bearing and deformation properties.

General vehicle equipment

Experimental vehicle research is carried out in a well-equipped laboratory which includes a vehicle testing unit and equipment for the testing of wheels, vehicle braking and power transmission systems, fuel consumption, rolling resistance, tyre wear and the strength of towing bars. For the testing of apparatus and the testing under driving conditions (not requiring too great space) there is an asphalt covered roadway immediately adjacent to the laboratory.

Tyre testing equipment

At present there is some basic laboratory equipment for the testing of tyres. With the aid of funds from the Swedish Board of Technical Development a highly advanced and unique unit is currently being constructed for studies of the dynamic properties of tyres under different road and climatic conditions. The unit is expected to be completed by 1982.

The biomechanical laboratory

In the indoor unit full scale collision tests are carried out (for the analysis of e.g. safety belts, crash helmets, seats, etc.). In an outdoor unit collision test are carried out e.g. on car against car, car against crash barriers and against lampposts. Both installations permit speeds of up to 110 km/h with masses of up to 3 metric tons. For recording and evaluation there are anthropometric dummies of various sizes, high-speed accelerometers, a fifty channel tape recorder and high-speed cameras.

Car simulators

A number of simpler types of car simulators (e.g. visual field, vibration, noice) are already available. With the aid of funds from the Swedish Board of Technical Development work is currently in progress on the development of an advanced car simulator. The car simulator enables studies of situations that are either impossible or very expensive to test in traffic or at full scale e.g. the different handling characteristics of cars when driven by normal or disabled drivers, or tests concerning different traffic situations or training for critical situations, driving on ice, etc.

The measurement and recording of road user behaviour

Equipment is available for the analysis of different road user behaviour by recording the movements of driving controls as well as of road user eye, foot and hand movement together with other physiological phenomena such as pulse, breathing and skin resistance. Advanced equipment is also available for the measurement of various physical reactions that affect behaviour such as light, noise, vibrations and friction.

Equipment for traffic studies

Traffic studies are carried out with the aid of traffic recorders which are able to distinguish different types of vehicles and vehicle combinations with regard to axle arrangement, the time taken to pass, direction, speed and time gaps between vehicles.

Computer cameras adapted for mono-optic or sequence filming under electronic control can be linked to and be synchronically controlled by the traffic recording units.

Traffic movements within limited areas are recorded on video tape.

Traffic simulation model

The development of this model has enabled the description of changes to traffic flows through the detailed study of the movements of individual vehicles crossing a given section of road.

The simulation model can be used e.g. for comparing the effects of alternative measures, or combinations of measures, before these are implemented such as changes to speed limits or the introduction of grades.

Computer vehicle simulation

The simulation of a vehicle's movements as a function of the vehicle's construction, loading, speed, road characteristics, tyre characteristics and manoeuvrability can be carried out with the aid of different computer programmes. These enable the testing even at the construction design stage of the suitability of different constructions.

Construction office and design workshop

The Institute has an office for general machine construction and an experimental workshop. In consultation with research personnel, apparatus , measuring devices and machines are developed and produced for the Institute's various R&D activities.

Computers

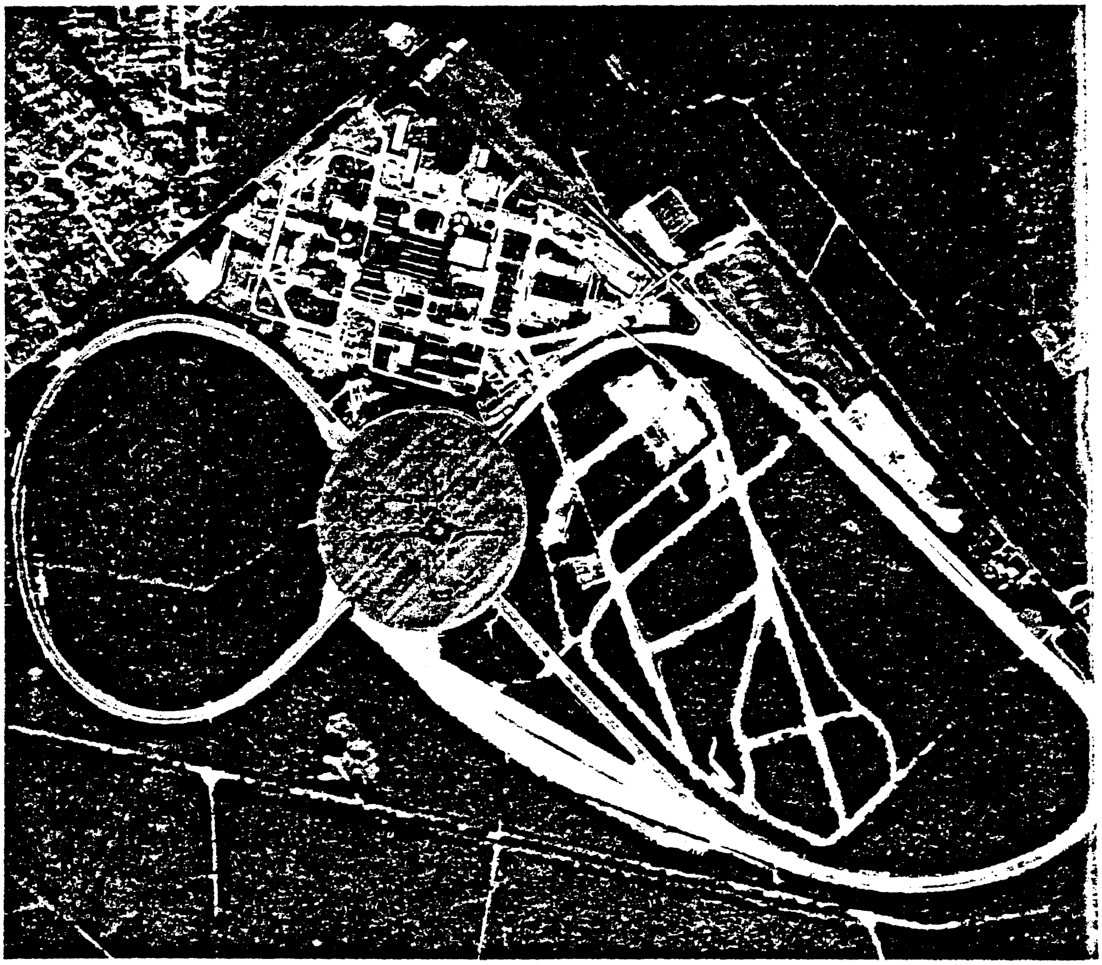
For theoretical research there is a hybrid type EAI-SEL computer system. For digital computer programmes the Institute has a type NORD-10/S computer equipped with a disc memory, magnetic band units, line printer and plotter. At present nine terminals are linked to the computer. Some of these terminals can also be linked to outside computers by means of the telephone network.

Information and documentation services

The Institute's information and documentation section provides scientific documentation and library services. Library staff are specialists in document searches for literature references as well as projects within the fields covered by the Institute. For these purposes they employ the library's computer terminals for on-line searches with the aid of the library's own computerized library catalogue GEOROAD, the IRRD (International Road Research Documentation) data base as well as a number of other international data bases. Books etc may be borrowed from the library, or copies can be made, and among other things the library contains 1200 journals and report series.

APPENDIX Y

Aerial view of the Transport and Road Research Laboratory

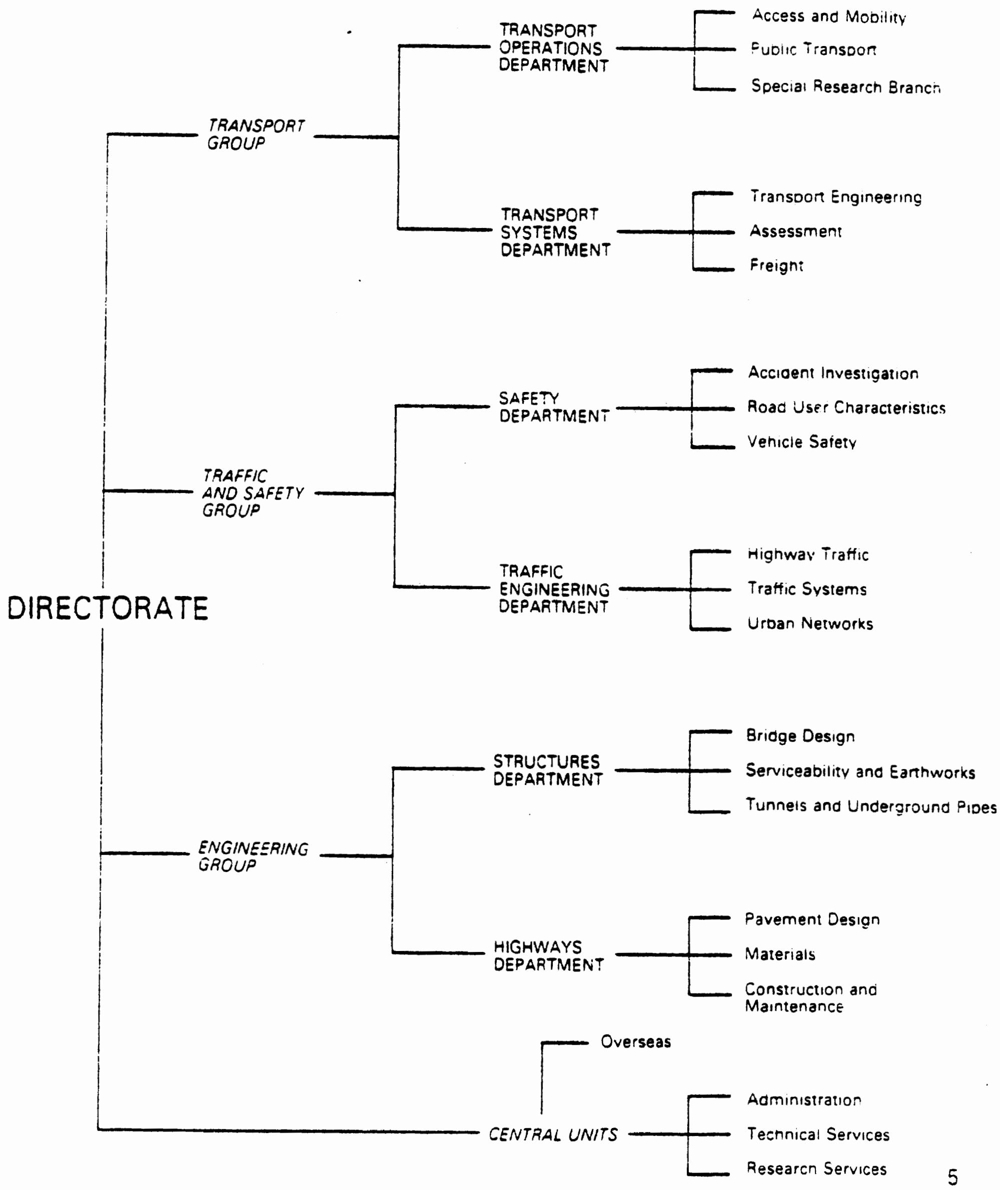


the Laboratory

been part of the common research services to the Departments of the Environment and Transport.

Resources

The laboratories, other experiment facilities and offices occupy a site of 250 acres (about 100 hectares) at Crowthorne in Berkshire. The present staff total is about 1000 of whom about half are scientists and engineers; external expenditure on contracts with industrial firms, consultants and universities is now about £2M annually.



APPENDIX Z

TRAFFIC SAFETY AND NUISANCE RESEARCH INSTITUTE
JAPAN MINISTRY OF TRANSPORT

Table of Organization

TRAFFIC SAFETY DIVISION
- Transportation System Section
- Railway Section
- Motor Vehicle Structures Section
- Motor Vehicle Dynamics Section
- Automotive Equipment Section
- Accident Analysis Section
- Aviation Section

TRAFFIC NUISANCE DIVISION
- Engine Section
- Measurement Section
- Acoustic Section

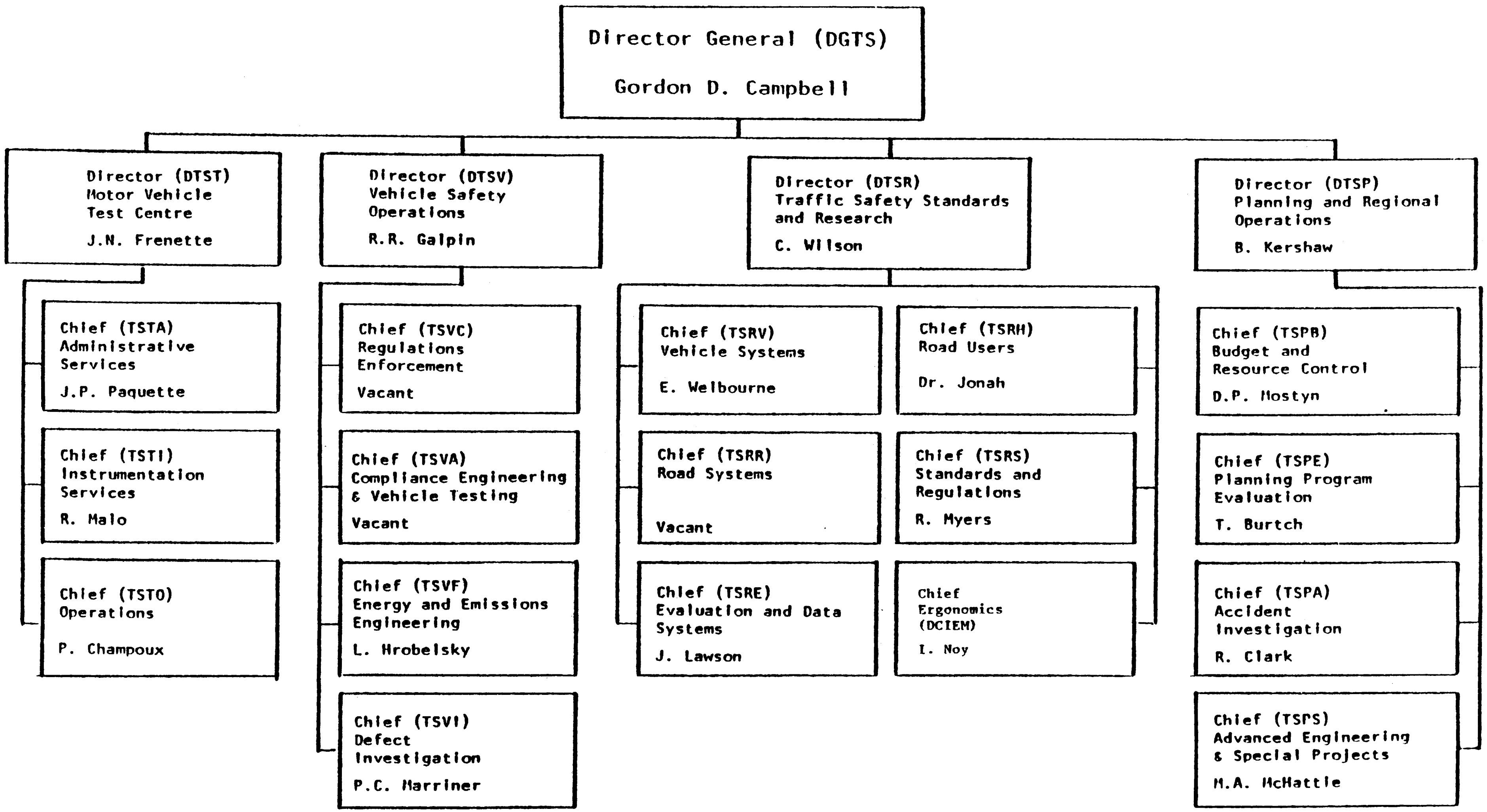
AUTOMOBILE TYPE APPROVAL TEST DIVISION
- General, Steering, Bus and Truck
- Passenger Car and Emissions
- Safety Equipment
- Power Transmittance and Brake

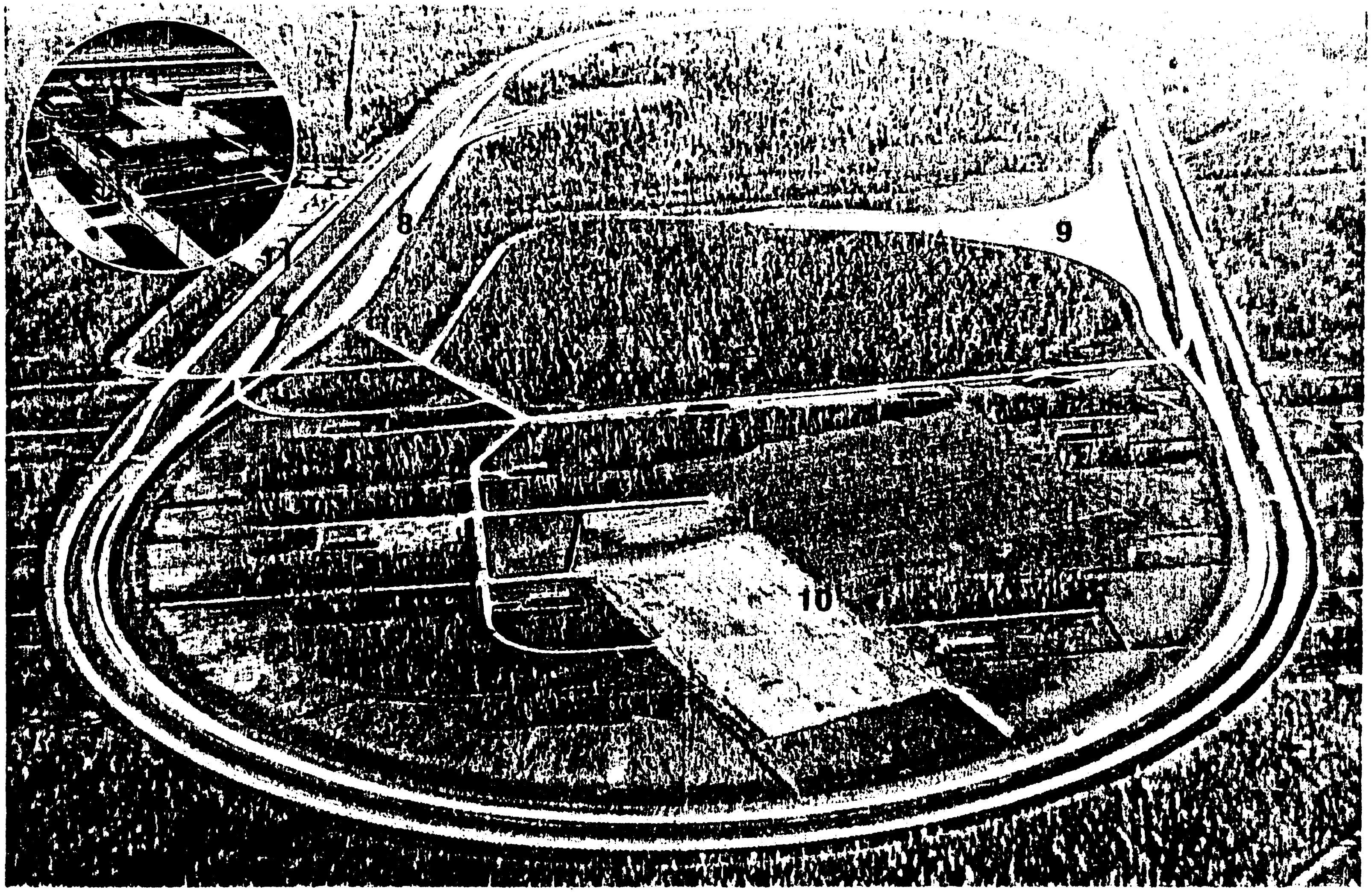
APPENDIX AA

Transport Canada / Transports Canada

Road Safety / Sécurité routière

ROAD SAFETY AND MOTOR VEHICLE REGULATION




8
9
10

Background

The Federal Motor Vehicle Safety Act passed in 1970 resulted from government recognition of the need for safe motor vehicle design as one step in arresting the rising human and financial cost of motor vehicule accidents.

This legislation and the regulations that followed were designed to develop and enforce safety standards for Canadian and imported passenger vehicles, trucks, trailers, motorcycles and snowmobiles.

The Motor Vehicle Test Centre has been established to ensure that these safety standards are properly applied. The Test Centre offers a wide range of vehicle test facilities to government, industry and private research agencies.

The Test Centre is located in Blainville, north of Montreal on 550 ha of federal land formerly part of Camp Bouchard.

The construction of the Centre was completed in 1979. The cost of the project is $25,7 million, with the buildings accounting for $8,5 million, the equipment $3,5 million and the track facilities $13,7 million.

Administration

This Division of the Test Centre is responsible for the general administration of personnel, finance and other central support services such as budgetary control, contract administration, employee relations, publicity, security, purchasing, buildings and maintenance.

Security

Security is maintained 24 hours per day by the Canadian Corps of Commissionaires using a system of patrols and a closed circuit television system.

The regulations which cover security and confidentiality of operations at the Test Centre provide that access is limited to persons bearing identity cards issued by management and specifying those areas to which access is restricted.

Clients will be accorded exclusive use of test areas, upon request, subject to supplemental charges.

Operational safety is the direct responsibility of a safety officer with complete control over track access and operations. No vehicle is permitted access to tracks without driver certification and being equipped with a mobile radio.

First aid facilities are available on site. An ambulance can be provided on stand by, at client's request.

Fire control is provided by the Test Centre's own emergency vehicle which is a prototype of the package designed for small airport operations.

TRACKS

High Speed Track

- Oval design 6.5 km in length
- concrete construction 23 cm thick
- width varying from 7.3 m in straightways to 9 m in the curves.
- length of straightways: 1.6 km each
- curves have been constructed to give "hands off" speeds of up to 180 km/h

- this track gives direct access to the brake test area and the vehicle dynamics area.

Brake Test Area

- Length: 670 m
- Width: 27 m

A paved surface of a uniform skid resistrance to permit tests by automobiles and trucks. Includes a 4.7 m wide loop at one end to permit limited vehicle acceleration, as well as a brake soak area up to 1.3 m in depth.

Low Speed Track

This track is 7.3 m wide and 6.9 km long. It provides for kilometrage accumulation and other low speed vehicle tests all year round. This track also serves as an access road to other installations.

Vehicle Dynamics Area

A triangular shaped, 9 ha (22 acres) test area to be used for a wide range of tests such as: performance, braking, handling and guard-rails.

Skid Trailer

A tire and pavement friction tester is available to test tires in accordance with SAE J345 and pavements in accordance with ASTM-E274-70.

Mobile Noise Measurement Laboratory

This vehicle is provided with highly specialized Bruel & Kjaer equipment such as:

- chart recorders type 2306F and 2307A
- sound level meters type 2209 and 2210
- analyzers type 2131C and 4426
- tape recorder type 7003F
- exterior microphone type 4921.

In addition, a portable NTSC compatible video system and portable weather measuring instruments are available in the mobile laboratory to support tests.

Collision Testing Facility

The facility permits normal collision barrier and rollover tests to be conducted and comprises:

- An exterior track of 100 m on which vehicles up to 6 800 kg may be propelled against the concrete mass of 181 metric tons, up to speeds of 48 km/h.
- A computer system and ample photographic and supporting facilities to record crash phenomena
- a propulsion system which includes a linear induction motor of 746 kw.

Environmental Test Chamber

Can simulate harsh winter conditions with temperatures between -40°C to 26°C controlled to within 1.5°C and winds up to 24 km/h and accommodates automobiles and buses.

The overall area is 502 m^2 divided in the following way:

- Large chamber:

  a surface area of 93 m^2 with a height of 6.4 m.

- Small chamber:

  a surface area of 28 m^2 with a height of 3.7 m.

Characteristics:

- Refrigeration system consisting of compressors in series to produce both low temperature (-15°C) and very low temperature (-45°C) conditions.
- CRR Compressor model 5H40 for low temperature and model 5H120 for very low temperature
- Exhaust system for each chamber.

The large environmental test chamber is unique in that it allows vehicle operation under controlled temperature conditions. To this end, two dynamometers with different characteristics are available to users:

Small dynamometer

Clayton model CTE 50 for testing of vehicles weighing between 455 kg and 4 034 kg.

The dynamometer is mounted flush with the floor and consists of two steel rollers with air brakes and pneumatic lift between the rollers. A power absorption unit is connected directly to one of the rollers and inertia weights permit the simulation if loadings from 455 kg to 4 034 kg.

Large dynamometer

Clayton model CT200 for testing of heavy vehicles and capable of supporting 10 277 kg per axle with tires of up to 2.7 m exterior diameter.

The dynamometer is mounted flush with the floor. It consists of two sets of steel rollers in order to permit the testing of vehicles with twin axles. The dynamometer bogie wheels (2 groups of 3 rollers) can be adjusted to accept axle spacings of from 1 m to 1.5 m. The dynamometer is also equipped with an independent mechanical braking system for safety purposes and to permit easy movement of the vehicles.

Laboratory

Area of 4 700 m^2 housing many facilities:

A structures laboratory equipped with:

- Vehicle Test Structure having the capacity of verifying the following compliance standards:
  - 207 seat anchorage
  - 210 seat-belt anchorage
  - 214 side door strength
  - 216 roof intrusion
- a bumper pendulum used for testing compliance with standard 215
- equipment for verifying compliance standard 201 for occupant restraints.

A vehicle preparation laboratory with the following facilities:

- work stations for automobiles and buses
- a Bear Telatronic model 685 wheel alignment system for automobiles and small trucks
- a dynamometer identical to the small dynamometer located in the environmental chamber.

Service Station

This facility which is adjacent to the low speed track is fully equipped to handle normal vehicle service and maintenance operations as well as providing standard fuel mixtures and lubricants.

Garage

Near the laboratory, this facility permits interior storage of a small number of vehicles for short periods of time.

Clients wishing to store a large number of vehicles indoors for lengthy periods of time will be offered somewhat more remote garage facilities.

Weigh Scale

A fully enclosed electronic balance is available to weigh test vehicles. Its maximum capacity is 36 metric tons.

Conference Room

A large boardroom with audio-visual facilities may be used for personnel training or major meetings.

Vehicles

The Test Centre is equipped with a wide range of special purpose vehicles. These include standard pick-up trucks and station wagon type vehicles, a 4 wheel drive, 9 090 kg capacity wrecker vehicle, trailors and a multi-purpose industrial all-terrain vehicle.

Electronics laboratory providing for instrument calibration and data acquisition. It includes a computer centre and an independent heating and air conditioning system.

Photographic laboratory

A full range of photographic equipment is available for documentation of tests. This includes 35 mm SLR's, large format cameras, high speed photographic systems and video tape, all with a full range of accessories.

A small darkroom facility and photo montage workshop are also available.

Machine shop

Completely equipped for general repairs and design of new specialized equipment.

Carpentry shop

Completely equipped for emergency repairs and design of new equipment.

Control Tower

The control tower enables half the low and high speed tracks to be in full view and also the complete brake test area. A safety officer controls all activities on the exterior test areas. Effective control is exercised mainly through the medium of a mobile radio system, supplemented as necessary by a light signalling system. Also meteorological data are available from the control tower.

Rate Schedule

A rate schedule which has been developed for services available at the Test Centre is intended to be comparable with other facilities of a similar nature.