2. BACKGROUND AND QUALIFICATIONS

Calspan's activities in the analysis and evaluation of single track vehicles began in 1969 with the development, internally, of an eight-degree-of-freedom mathematical model of bicycle dynamics. This model has, over the ensuing years, been expanded and used for developing computer simulations for both bicycles and motorcycles.

Our first externally sponsored work in two-wheeled vehicles was for the National Commission on Product Safety (Contract 70-201)*. The purpose of the study was to identify and measure the critical parameters of bicycle design associated with motions in the vertical plane and their handling qualities. The work is reported in:

> Rice, R. S. and Roland R. D., "An Evaluation of the Performance and Handling Qualities of Bicycles", Calspan Report No. VJ-2388-K, April 1970.

Early in 1971 Calspan performed its first study for Schwinn Bicycle Company, Chicago, Illinois; these studies have incidentally, continued to this date. The program (Contract CC-162)* was concerned with the further development of Calspan's two-wheeled vehicle simulation and the use of the simulation in determining the influence of design parameters on bicycle stability and control; the work extended into 1972 and resulted in two reports:

> Roland, R. D. and Massing, D. E., "A Digital Computer Simulation of Bicycle Dynamics", Calspan Report No. YA-3063-K-1, June 1971.

> Roland, R. D. and Lynch J. P., "Bicycle Dynamics - Tire Characteristics and Rider Modeling", Calspan Report No. YA-3063-K-2, March 1972.

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* The asterisk indicates that a project summary sheet is given at the end of this section.

While the Schwinn work was going on we carried out our second program for the government - in this case for the Bureau of Product Safety of FDA/HEW, Contract FDA-72-91.* The program was concerned with the safety performance of tricycles and minibikes. The report resulting from this work was:

> Rice, R. S. and Roland, R. D., "An Evaluation of the Safety Performance of Tricycles and Minibikes", Calspan Report No. ZN-5144-K-1, Nov. 1972.

Our first externally sponsored work on motorcycles was performed for the Harley-Davidson Motor Company, Milwaukee, Wisconsin. Under Calspan Contract No. CC-225* a sophisticated computer simulation of motorcycle dynamics was developed from the earlier internally supported work. The simulation was used to investigate the so-called high speed weave instability problem. The influence of several motorcycle characteristics on weave instability were evaluated in the contract of disturbance-response behavior at high speed. This work is reported in:

> Roland, R. D., Kunkel, Dennis T., "Motorcycle Dynamics - The Effects of Design on High Speed Weave," Calspan Report No. ZN-5259-K-1, May 1973.

This initial effort for Harley-Davidson has been followed by several others. Under Contract CC-249 we performed a study during the fall of 1973 of the weave phenomenon as it applied to a particular prototype design. As in the case of the first study the report on this effort was co-authored by Roland and Kunkel.

The next group of studies performed for Harley-Davidson (H-D), over the period February 1974 to the present (Contracts CC-260, CC-261, CC-262) include performance tests of tires on our advanced Tire Research Facility, (TIRF), full-scale validation testing of the FLH 1200 motorcycle and continued computer

simulation studies. Most recently we have conducted an additional tire test program for H-D and are currently doing another weave phenomenon investigation on the computer. The reports for this work are:

Roland, R. D., "Performance Tests of Harley-Davidson Electra-Glide FLH-1200 Motorcycle Tires", Calspan Report No. ZN-5458-V-1, June 1974.

Davis, J. A., "Full-Scale Validation Testing of the Harley-Davidson Electra-Glide FLH-1200 Motorcycle" Calspan Report No. ZN-5472-V-1, July 1974.

Roland, R. D., "Performance Tests of 5.00-16 Motorcycle Tires", Calspan Report No. ZM-5597-V-1.

As in the case of our motorcycle work for H-D our bicycle work for Schwinn continued after the initial 1971 program. A second major study was completed in 1973 (under Contract CC-220). The study involved experimental work, analytical effort, and computer simulation. It was during this program that initial effort was put into developing simplified linear theory tools for two-wheeled vehicle analysis. The report resulting from this study is:

Roland, R. D. and Rice, R. S., "Bicycle Dynamics, Rider Guidance Modeling and Disturbance Response", Calspan Report No. ZS-5157-K-1, April 1975.

Also completed in 1973 (under Schwinn P.O. 7004), was a comparative evaluation of the Schwinn Continental and Continental-based Sprint bicycles. Our current program with Schwinn (Contract CC-254) includes the simulation of a transient handling task, parameter variation studies, bicycle tire testing and an investigation of bicycle frame flexibility. Some of this work is reported in:

Kunkel, D. T. and Roland, R. D., "A Comparative Evaluation of the Schwinn Continental and Continental-based Sprint Bicycles", Calspan Report No. ZN-5361-K, August 1973.

Rice, R. S., "Bicycle Dynamics - Simplified Steady-State Response Characteristics and Stability Indices", Calspan Report No. ZN-5431-V-1.

Davis, J. A. and Cassidy, R. J., "The Effect of Frame Properties on Bicycle Efficiency", Calspan Report No. ZN-5431-V-2, Nov. 1974.

In all of the above work Calspan's computer simulations of bicycle and motorcycle dynamics have figured prominently. Although the simulations will not be used in the proposed program those interested in them, and other aspects of Calspan's two-wheeled vehicle work, will find relevant material in three Calspan publications in the open literature:

Roland, R. D., "Computer Simulation of Bicycle Dynamics", Symposium on Mechanics and Sports, The American Society of Mechanical Engineers, New York, Nov. 1973.

Lynch, J. P. and Roland, R. D., "Computer Animation of Bicycle Simulation", 1973 Fall Joint Computer Conference - American Federation of Information Processing Societies - Anaheim, Calif.

Roland, R. D., Simulation Study of Motorcycle Stability at High Speed", Paper No. 73020, presented the the Second International Congress on Automotive Safety, San Francisco, Calif., July 16-18, 1973.

In July, 1974, we received a contract (No. DOT-HS-4-00976)* from the NHTSA to perform research on the accident avoidance capabilities of motorcycles; the NHTSA CTM for this work is Mr. Donald C. Bischoff. The overall objectives of the program are to develop motorcycle accident avoidance test procedures and to evaluate the accident avoidance capabilities of a representative sample of motorcycles using computer simulation; some full-scale experimental work will be done with one motorcycle. Six monthly progress reports have been delivered, covering the period from 1 July 1974 to 31 Dec. 1974. The photographs of Figures 4-1 thru 4-4 show scenes of some of the laboratory inertia measurements that had to be made for input data for the computer simulation

BICYCLE PERFORMANCE AND HANDLING QUALITIES

The purpose of this study was to identify and measure the critical parameters of bicycle design associated with (1) their motions in the vertical longitudinal plane (braking and pitchover motions) and (2) their handling qualities. The approach involved both analytical and experimental procedures with major emphasis on the development of a mathematical model of the bicycle for use as a tool to evaluate the effects of design parameter variations on performance. The experimental studies consisted of performing a number of maneuvers (straight braking, steady state cornering, hands-off path following, serpentine tracking) on two bicycles of different basic design. Several different riders, providing a wide range of weight, were used in these tests. It was concluded that many factors interact to produce the stability and control characteristics of a given design but that front wheel brakes and short wheelbases can be singled out as having specific hazard potential.

Contract No.: 70-201

Sponsor: National Commission on Product Safety

Report: Rice, R. S. and Roland, R. D., Jr. "An Evaluation of the Performance and Handling Qualities of Bicycles." Calspan Report No. VJ-2888-K. April 1970.

Project Performance Period:

October 1969 - March 1970.

EVALUATION OF SAFETY PERFORMANCE CHARACTERISTICS OF TWO AND THREE WHEELED VEHICULAR TOYS

Evaluations of the stability and performance characteristics of minibikes and children's tricycles have been made in order to identify those design and operational qualities which may be contributory to injury-causing accidents. Both experimental and analytical methods have been applied in this study. Several representative examples of both minibikes and tricycles were obtained to provide baseline design and performance information. Tricycle studies were aimed primarily at defining the operational conditions at which rollover could occur. Extensive tests were performed with the minibikes in order to measure their capabilities. A brief design parameter variation study utilizing a nonlinear simulation of the minibike was performed. All results were evaluated in terms of potential safety standards and recommendations on which the FDA might base such standards were offered.

Contract No.:	FDA 72-91
Sponsor:	Department of Health, Education and Welfare Food and Drug Administration
Report:	Rice, R. S. and Roland, R. J., Jr.: Evaluations of the Safety Performance Characteristics of Tricycles and Minibikes. Calspan Report No. ZN-5144-K-1. November 1972.
Completion Date:	November 1972.

BICYCLE DYNAMICS

The overall objective of this program was the development of a comprehensive digital computer simulation of a bicycle and rider for studying the effects of certain design parameters on bicycle stability and control. The vehicle-rider model on which the simulation is based is a system of three rigid masses with eight degrees-of-freedom. Included in the analysis are tire radial stiffness, tire side forces due to slip angle and inclination (camber) angle, the gyroscopic effects of the rotating wheels, steering moments due to tire side and vertical forces, as well as all inertial coupling terms between the rider, the front wheel and steering fork, and the rear wheel and frame.

The simulation also includes a closed-loop path-following rider control model with two related modes of operation: a roll stabilization function and a guidance function. The human operator outputs are steering torque and rider lean torque, with inputs of vehicle roll angle, roll velocity and roll acceleration. Space path coordinates are related to vehicle position and direction of motion for guidance control. Also included are rider reaction time delay and lag compensation.

The development of the simulation was supported by the measurement of the physical properties of a bicycle, including the side force characteristics of bicycle tires. The simulation has been validated by comparison with full scale experimental maneuvers and is currently being used for bicycle dynamics studies.

Contract No.: CC-182

Sponsor: Schwinn Bicycle Company
Chicago, Illinois 60639

Reports:

Roland, R. D. and Massing, D. E., "A Digital Computer Simulation of Bicycle Dynamics." Calspan Report No. YA-3063-K-1. June 1971.

Roland, R. D. and Lynch, J. P., "Bicycle Dynamics-Tire Characteristics and Rider Modeling." Calspan Report No. YA-3063-K-2. March 1972.

Roland, R. D. and Rice, R. S., "Bicycle Dynamics Rider Guidance Modeling and Disturbance Response." Calspan Report No. ZS-5157-K-1. April 1973.

Project Performance Period:

March 1971 - April 1973.

MOTORCYCLE DYNAMICS

A comprehensive digital computer simulation of a two-wheel vehicle and rider has been developed and is being used to study motorcycle stability and handling. The simulation is based on a nonlinear mathematical model with eight degrees of freedom, including steer and rider lean. Tire side force and aligning torque as nonlinear functions of slip angle, camber angle and vertical load, aerodynamic drag, pitching moment and steering torque, steering damping, and gyroscopic effects of the engine and wheels are modeled as well as fork rake angle, steering trail, and the basic physical characteristics of the motorcycle frame, steering assembly, and rider. These parameters are input data to the computer simulation which produces output in the form of time histories of the motion variables of the vehicle. The two-wheel vehicle simulation has been validated by comparison with experimental tests using an instrumented vehicle.

The simulation has been used to study the weave instability phenomenon which can occur in motorcycles at high speed. "Speedman's wobble," as it has been called, is characterized by coupled steer-roll-yaw motions of the vehicle and has long been recognized by theoretical dynamicists. The influence of several motorcycle characteristics on weave instability have been evaluated in the context of total system performance by simulating the disturbance-response behavior at high speed.

Contract No.:	Purchase Order A54995, CC-225
Sponsor:	Harley Davidson Motor Company, Inc. 3700 W. Juneau Avenue Milwaukee, Wisconsin 53201
Report:	R. Douglas Roland and Kunkel, Dennis T., "Motorcycle Dynamics - The Effects of Design on High Speed Weave," Calspan Report No. ZN-5259-K-1, May 1973.
Completion Date:	1973.