

CHASSIS DESIGN

Principles and Analysis

(Part I)

Chassis Design

Principles and Analysis

Foreword

From the USA:

Maurice Olley was a really nice guy and the most respected engineer I have ever known. I valued the time I was fortunate to have spent with him.

I don't know what else he was but he was an engineer. He had a wallop background and experience in engineering. He was key in the development of the early automobile. He was also the key to the development of the [Packard] Rolls Royce Merlin V-12 engine that powered our WWII P-51 fighter.

He was articulate and funny. He was a quiet and attentive listener. He spoke and drew pictures. His perspectives of parts and assemblies, of about anything—that did or might move—were unmatched. His skills with words and pencil made him easy to understand.

The thing that most accounted for his effectiveness was his skill as a communicator. He was neither arrogant nor humble. He spoke and drew pictures. In any company, his question/answer ratio was about one. It was invariably an informative and pleasant experience for all, including Maurice.

The most rewarding for me was to have been a part of two or more guys leaving the table with an idea that nobody had brought to it.

I was fortunate to have inherited the tools and the craftsmen that Maurice had assembled in the process of setting up Chevrolet's first Research and Development operation.

When he retired, at his asking, I kept his files in the little conference room, off my office. Periodically he would stop by to paw around—not for me or anybody else—but for himself. He often came out to show me something: something old and funny, interesting, informative.

I liked Maurice Olley. He was one of my all-time favorite guys. I learned a lot from him—and he learned a lot from the sum of all of us.

Frank Winchell
September 12, 1998

We wish to point out that Frank Winchell welcomed Olley back to Chevrolet R&D when he returned after retirement. Frank broke all the rules and gave Olley a desk and secretary, which enabled Olley to write the technical notes that are the substance of this book.

From England:

This review of the work and achievements of Maurice Olley is timely—indeed, overdue. He himself was the very reverse of a self-publicist, and it is only right that his name and his many attainments should be recorded high in the list of those who laid the foundations of automobile design and engineering.

He was gifted with unusual clarity, breadth and depth of thinking, but, unlike some of his contemporaries, he was never dogmatic. Indeed, he always displayed a rare degree of mental flexibility, as exemplified by a comment he made during a technical discussion in 1945, “I do not agree with some of the author’s statements, but then I cannot imagine any paper written by anybody, including myself, with which I could agree for very long.”

At the end of the 20th century, a relatively few international companies dominated the global automobile industry, a state of affairs vastly different from that which existed during Olley’s working life, when vehicle design developments were generally carried on by dozens of individual companies working, metaphorically speaking, behind high walls. His personal philosophy, however, was one of openness, particularly where questions of safety were concerned, and his published papers bear witness to this.

Apart from his engineering talent, Maurice Olley was a master of a somewhat different art—the ability to illustrate his argument with a sometimes gentle, sometimes sharp, but always apt aphorism. It is a matter for regret that those bon mots cannot now be collected in a book! Lacking his ability in aphorism, we can only venture a serious and sincere equivalent:

It is high time that we placed on record the great debt that we owe to Maurice Olley.

Reginald Main
Ian Milburn
David Crolla
England, 1998

Many of Olley’s aphorisms, referred to in the USA as Olleyisms, have been used as chapter quotes in this book and in Race Car Vehicle Dynamics.

Authors' Preface

"Maurice Olley is a natural phenomenon that Britain has shared somewhat reluctantly with the USA."

Reg Main
IMechE, London

This book stems from our firsthand knowledge of Maurice Olley's accomplishments and his method of working. Maurice Olley was an automobile designer all his life, but unlike many other well-known designers, he was equally experimental **and** analytical. As he approached the various aspects of design during his long career, his objective was always to develop an analytical model and experimentally validate it. With that done, he proceeded to methodically document the results for future use. He worked at a fundamental level and, since the same handling problems constantly recur, the principles he developed are **as valid today as when first developed**.

Almost single-handedly, Maurice Olley developed the concepts and techniques that underlie the engineering approach to vehicle dynamics that we know today. Early on, he focused on the problems of ride, absorbed the analytical work by Rowell and Guest (see Chapter 5), and constructed his " k^2 rig," which enabled him to subjectively evaluate the ride modes and different frequencies of the front and rear suspension. This experimental work led directly to the flat ride concept and the need for a softer suspension on the front. This in turn led to the independent front suspension, which he pioneered at Cadillac in 1932.¹ In order to understand suspension systems he promoted the first force and moment tire tests by Cap Evans at Goodyear and Dr. A.W. Bull at Uniroyal, which ultimately led to the development of comprehensive testing machines at Cornell Aeronautical Laboratory (CAL, now Calspan) and General Motors. Armed with tire data, he was able to tackle the problems of directional stability and control, and suspension design, in conjunction with his early circular skid pad tests. This led to the concept of over and understeer and the significance of slip and steer angles which have dominated our view of car control ever since. His analysis of suspension geometry, the distribution of the roll couple, use of anti-roll bars to control the directional response, the effect of anti-dive and squat, brake distribution, and so forth, followed. In every one of these areas, including the various dynamic oscillations of the unsprung mass, he made critical contributions. Finally, he was responsible for the initiation of the long-term handling research at CAL which led to the equations of motion and an understanding of the transient response.

Olley's technical notes form the basis for this book; these cover his analytical developments, underlying experiments and design experience.

¹ See Appendix E for more historical detail.

Vehicle dynamics, as related to the automobile, has been under development for more than 70 years. Because it is a multi-disciplinary subject it has seldom been included in the curriculum of engineering colleges, although courses have appeared in specialized automotive schools. The teaching of vehicle dynamics has been further hampered by lack of adequate textbooks.

In our earlier book, *Race Car Vehicle Dynamics* (RCVD), we presented a summary of vehicle dynamics technology as a consistent way of looking at the vehicle portion of the driver-vehicle handling problem. In RCVD we tried to follow a path between a theoretical textbook and a more popular book on handling. Thus the mathematics was kept to a modest level while focusing on physical understanding.

We were somewhat surprised, but gratified, when a number of engineering colleges adopted our book as the basic text for an introductory undergraduate course. In several cases this resulted from student interest and involvement in Formula SAE race car development. To further this interest, we were requested by SAE to produce the problems in the RCVD Workbook² along with the answers. RCVD has also been used as the text for several professional development seminars in vehicle dynamics.

The first part of RCVD deals with fundamental concepts, while the second part is devoted to specific problem areas that are encountered in vehicle handling design. For the student or practicing engineer who wishes to become a competent professional vehicle dynamicist and designer, more extensive study of the subjects covered in the second part of RCVD is required. To meet this need, we now offer the present volume, *Chassis Design: Principles and Analysis*, based on the technical notes of Maurice Olley. We believe this material will be useful to engineers in industry and racing who are involved with handling analysis and design, and also as an advanced text for graduate-level study in universities.

As vehicle dynamicists, we feel a great deal of gratitude toward Maurice Olley and are immensely pleased to be able to publish this first major technical book on his accomplishments. The details involved in making this material available to a wider audience are covered in a separate section, **Origins and Objectives**.

Bill Milliken
Doug Milliken

² Metz, Daniel L., W. F. Milliken, and D. L. Milliken, *Race Car Vehicle Dynamics Workbook*, R-212, Society of Automotive Engineers, Warrendale, Pa., 1998.

Origins and Objectives

"Today's work is a wonderful thing, its absence is the curse of retirement."

Maurice Olley
c. 1955

Maurice Olley is generally recognized as the most outstanding pioneer and innovator in the ride and handling area. Thus it is an astounding fact that the most comprehensive technical account of his accomplishments as written by Olley himself has remained under wraps for nearly 40 years. The present volume is the result of our continued efforts to make this material available to the practicing engineer, to members of the racing fraternity and the automotive enthusiast.

The story began when Maurice Olley was officially retired in 1955 at the age of 66 from his position as head of Chevrolet Research and Development. Following a career that paralleled the development of the automobile on two continents, the idea of retirement was completely repugnant to him, and after a few years of travel and consulting he returned to Motor City and reappeared at his old location in Chevrolet. Frank Winchell, his successor at R&D, was never one to stand on ceremony or convention, and since he viewed Olley as "the most knowledgeable automotive engineer he had ever known," welcomed him back on an informal basis, setting him up with a desk and secretarial help as well as moving in Olley's old technical files.

At first, Maurice would appear at R&D on a sporadic basis, "browse through his old stuff," and enliven Frank with interesting and amusing things that occurred in the development of the automobile and the airplane. Later he became more focused and by the early 1960s had begun the preparation of a series of monograph reports (ultimately totaling four volumes of over 500 typed pages with some 300 graphs and sketches) encompassing his entire chassis design experience. These monographs are titled:

- Notes on Suspensions—August 1961
- Steady State Steering—September 1961
- Notes on Vehicle Handling—February 1962
- Suspension Notes II—May 1962

Olley completed a final monograph, "Brake Theory," in July 1962. In 120 pages and 40-odd figures, it covers fundamentals of drum brakes, disk brakes and related topics such as brake heating. Brake design and analysis has become a highly specialized discipline, which now includes metallurgy as well as the geometric fundamentals that Olley treats, and we have chosen to exclude this material.

Restricted Publication—A limited number of these monographs were published internally by General Motors carrying the classification, “GM Restricted, Corporation Use Only.” Because of Olley’s fame, rumors of the existence of these reports circulated within the industry. Over time, some copies reached interested individuals in other companies where they were highly prized and provided the knowledge base for a number of burgeoning chassis engineers. But the monographs were never officially released for general publication and distribution.

I (Bill Milliken) met Maurice Olley in 1952, when we started a long-term handling research program at Cornell Aeronautical Laboratory, under the sponsorship of General Motors. This association continued at a professional and personal level to the time of Olley’s death in 1972. During that period, Maurice gave us a complete set of the Chevrolet monographs plus copies of other early technical material on ride and handling. In addition, a lively correspondence devoted to car control and stability flourished throughout those years.

First Publication Attempt—Our first attempt to place this Olley material in the open literature occurred in 1968 when the Research Laboratory Division of General Motors, with the full support of Edward N. Cole, President, gave a contract to the Vehicle Research Department of Cornell Aeronautical Laboratory (CAL) to produce a technical biography of Olley which would include the Chevrolet monographs. Olley was genuinely pleased with this recognition and offered his full support. Our staff, including King D. Bird, David W. Whitcomb and Fred Dell’Amico, enthusiastically pursued the project, contacted many former associates of Olley for their input, and by mid-1968 had an initial draft in hand. Among Olley’s associates was William (Bill) Lichty. Beginning in 1957, Olley had lectured on suspension and handling at the General Motors Institute where he met Lichty, then the director of Research and Graduate Studies. In the 1958–1962 period, Lichty had begun work on a biography of Olley, which would have included Olley’s “Reminiscences,” and his technical notes and papers. This was discontinued and Lichty graciously offered to share the results of his efforts with the Cornell project.

As the draft was readied for submission (1969), the contract was summarily canceled by GM Legal. In the period 1963–1968, GM had been heavily involved in the Corvair litigation and with some justification believed that anything published on handling, however fundamental and factual, could be misconstrued and used against them. Olley, who was to die only a few years later, was immensely saddened by this action.

Present Publication—After writing *Race Car Vehicle Dynamics* (RCVD), it occurred to us that these long-suppressed reports would make a natural companion piece. This was reinforced when Terry Satchell (a contributor to RCVD) asked us to reproduce Olley’s original monographs for distribution to some of his co-workers at Pontiac and other parts of General Motors. Olley’s material would be complementary in the sense that RCVD lays emphasis on basic handling theory and analysis, while Olley approaches vehicle dynamics with a strong orientation toward design and application. In fact, the analytical developments in RCVD rest on the ideas and concepts developed earlier by Olley and his associates. As a designer he was first interested in acquiring a physical understanding of

handling behavior through experiments, after which he developed procedures useful for chassis design and layout.

Thanks to Olley's erudition, his natural ability as a teacher and the fundamental nature of the material, the monographs are as valuable and useful today as when they were written. **For those who wish to understand the fundamentals of chassis design and analysis, this is the place to start.** In addition, we find them inspiring from an historical standpoint. They show how untiring curiosity and the dedicated application of simple experimentation, sound engineering judgment and clear thinking—to an immensely complex problem—can accomplish much. The Olley approach has a great deal in common with that of the Wright Brothers.

Permission and Copyright—Thirty years after publication of the first book was aborted we reopened the project. To obtain a release from General Motors, we first contacted Frank Winchell, now retired from his position as Vice President, GM Engineering Staff. Winchell had recently received the Chairman Award from General Motors, the first and only recipient of this prestigious honor for his outstanding technical contributions. Frank in turn approached Thomas Gottschalk, GM's chief general counsel, who initiated the release through the intellectual property section of the legal staff. In due time, we were "granted permission to re-publish these works without any compensation to General Motors," the only requirement being that the publication, "state that the reports are reprinted with the permission of General Motors." Armed with this release, we approached the Society of Automotive Engineers (SAE International) who agreed to publish the Olley book under an identical arrangement and to an even better level of quality than RCVD.

Approach and Philosophy—In the four reports Olley frequently covers the same aspect of design but in different contexts. As they stand the monographs are not an ideal reference, although they may be chronologically correct in terms of their original development. Furthermore, there is some duplication in the four volumes. We have integrated the four monographs into one book, eliminated duplication and consolidated related material, including the integration of additional Olley material from his other publications and correspondence. In this task we have been exceptionally careful to faithfully reproduce Olley's writings. *Departures and comments are in italics and/or in square brackets []*. For legibility and consistency, the figures and equations have been redone. Olley was a great sketcher and our artist has faithfully copied Olley's sketches as printed in the original monographs. Some inconsistencies in mathematical notation occur in the four volumes; we have attempted to eliminate these and make the notation similar to that of RCVD. Detailed derivations have been added wherever it seemed it would improve the understanding of Olley's mathematical developments. The monographs are Olley's technical testament and in making changes we have always asked ourselves, "Would Maurice have approved?"

It is well to remember when reading this book that it is not only a classical review of the state of the art of handling design but that the greater part of the technology upon which it rests was developed by Olley and his associates in the Cadillac Group at the General Motors Proving Ground. They appear to have been directly responsible for most of the

ride and handling concepts developed in this book. Olley was personally responsible for the introduction of the independent front suspension in the USA and the idea of the “flat ride.” His foresight enabled the extension of his work into transient analysis in the Cornell Aeronautical Laboratory (CAL) program.

Broader recognition of Maurice Olley is long overdue. His career demonstrates that one creative and inspired individual can influence an industry, for it can truthfully be said that his work has had a positive effect on the ride and handling of every car on the road. It is a privilege to publish this first major book on this portion of Olley’s work.

Bill Milliken
Doug Milliken
March 2001

Acknowledgements

We wish to acknowledge the help we received from Frank J. Winchell (retired, GM Vice-President, Engineering Staff), Thomas A. Gottschalk (at the time, Director, GM Legal Staff), Kenneth D. Enborg (Intellectual Property Section, GM Legal Staff), and Barbara Kunkel (GM Librarian). As a result of their efforts, in July 1996 we were granted permission to republish the work of Maurice Olley “without any compensation to General Motors.” GM requested “that the SAE publication state that the reports are reprinted with permission of General Motors.”

Working with SAE is always a pleasure. We wish to thank the SAE publishing staff and in particular Judy Wieber, our editor, Terry Wilson, the book designer, Robert Richardson, for the index, and Ann Moats, publicity. Also, Peggy Holleran Greb and Jeff Worsinger for their contributions.

A project of this size required a team effort by Milliken Research Associates:

As with *Race Car Vehicle Dynamics* (RCVD), Robb Ramsey, working under a contract with SAE, produced all of the figures. Robb scanned Olley’s original figures, traced them on the computer to give a consistent appearance, updated the terminology, and as usual, cheerfully agreed to many revisions. Robb also produced numerous drafts of the cover art.

Also under a contract with SAE, our MRA Associate, Edward M. Kasprzak, took on the daunting task of typesetting Olley’s original math, at the same time reworking it to use updated symbols corresponding to RCVD. As part of this effort, he derived the “missing steps” in a number of Olley’s mathematical developments, a first-order detective job. Finally, Edward proofread all the chapters and made many useful suggestions.

R. Thomas Bundorf was a member of the original vehicle dynamics group in the Engineering Mechanics Department, GM Research Laboratories, in the 1950s and ’60s, under Joseph Bidwell. Tom found out about our Olley project at the first SAE Automotive Dynamics & Stability Conference in the spring of 2000. At that time, he volunteered to review the drafts of two critical chapters—“Ride” (Chapter 5) and “Linkages” (Chapter 7). His very thorough review led to several important revisions as well as a number of smaller corrections.

David J. Segal, a longtime MRA Associate, was helpful in a number of cases where Olley “stumped” us with some of his more difficult derivations. Up until the time of his sudden death, Hugo S. Radt contributed to Olley’s tire modeling section and his work is the basis of Appendix B.

Our good friend, Dr. A. E. Moulton, of Moulton Developments and Alex Moulton Bicycles, Ltd. was kind enough to review Olley's Chronology (in Chapter 1) and provide a number of comments based on his experience and his research at Rolls-Royce Heritage Trust, of which he is a member.

We wish to thank all the above members of the MRA team.

Frank J. Winchell wrote the USA Foreword in his usual direct and forceful style, based on his close association with Maurice Olley. Winchell was Olley's successor as Director of Chevrolet Research and Development. The Foreword from England was generously contributed by Reginald Main, IMechE Automobile Division (retired); Ian Milburn, Deputy Managing Director, Nissan European Technology Centre; and David A. Crolla, Professor of Automotive Engineering, University of Leeds.

Photos were contributed by:

William Holleran, Archivist, Kettering/GMI Alumni Foundation
Thomas C. Clarke, independent Rolls-Royce historian
Michael H. Evans, Chairman, Rolls-Royce Heritage Trust
L. Kirk Walters, a devoted Olley enthusiast and historian

We were assisted in finding copies of some of Olley's technical papers and correspondence by Anne Etherington, IMechE; Rosemary E. Grimes, Professional Engineering Publishers, Publishers to the IMechE; and Jeff Worsinger, SAE.

An earlier attempt to publish a technical biography of Maurice Olley was initiated by Joseph Bidwell, GM, in a contract to Cornell Aeronautical Laboratory (CAL) in the 1960s. Some preliminary work was completed before the project was canceled. We have been able to take advantage of this material and wish to acknowledge Joe Bidwell and the original authors at CAL—King D. Bird, David W. Whitcomb, and Fred Dell'Amico.

William (Bill) Lichty, formerly at General Motors Technical Institute, arranged for Maurice Olley to lecture to his students in 1956–1958, after Olley's retirement. Bill has been prominent in preserving the Olley heritage and was a major force in locating the Olley diaries and other material for the GMI/Kettering University Archives. Bill made available to us his extensive correspondence with Olley and has been a source of continuing support throughout this project.

Dr. Charles W. McCutcheon, formerly of the National Institutes of Health, carried on an extensive correspondence with Olley in his later years, and gave us copies of his Olley file.

As with *Race Car Vehicle Dynamics*, Barbara A. Milliken was a great support throughout this project.

William F. Milliken
Douglas L. Milliken
March 2001

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In this book, plain text is by Olley, *italic text was added by the authors.*

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