ACCIDENT RECONSTRUCTION

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CHARLES C THOMAS • PUBLISHER
Springfield • Illinois • U.S.A.

Published and Distributed Throughout the World by

CHARLES C THOMAS • PUBLISHER
BANNERSTONE HOUSE
301-327 East Lawrence Avenue, Springfield, Illinois, U.S.A.

ISBN 0-398-03907-0 (cloth)
ISBN 0-398-06069-X (paper)
Library of Congress Catalog Card Number: 79-627

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Printed in the United States of America
N-11

Library of Congress Cataloging in Publication Data

Collins, James C
Accident reconstruction.

Includes index.
1. Traffic accident investigation. 2. Traffic accidents. I. Title.
HV8079.55.C64 363.2'33 79-627
ISBN 0-398-03907-0. — ISBN 0-398-06069-X (pbk.)

PREFACE

ACCIDENT reconstruction usually starts from a couple of twisted vehicles, some conflicting stories, and a feeling of helplessness on the part of the investigator who must make sense out of it all. In most cases, one can determine the events leading to the accident from an analysis of the physical evidence found at the scene and from supporting testimony available from witnesses and participants. To do so, however, requires some knowledge of the construction and behavior of motor vehicles.

This book is divided into two sections. The first four chapters cover the hardware aspects of accident reconstruction: how automobiles, trucks, and motorcycles are built, with emphasis on those parts whose failure can lead to an unexpected loss of vehicle control. The symptoms of accident-producing mechanical failures and the types of failures that occur most frequently are described here.

Chapters 5 through 10 are devoted to accident analysis. This includes interpreting the physical evidence, such as skidmarks, and applying basic physics and mathematics to determine vehicle paths and speeds both before and after collision. These chapters also cover topics such as pedestrian accidents, vehicle fires, human factors, and mapping and photographing the accident scene.

The reader is encouraged to use some caution in applying the material contained herein, since there are exceptions to all rules. Each accident must be examined on its own merits. For example, the presence of a set of locked-wheel skidmarks leading into a collision is almost always conclusive evidence that the brakes of the automobile were operational and were applied by the driver. But a failure of one of the transmission gears can lock the entire drive train, causing the rear wheels to skid without any brake application whatsoever. Thus, there is no substitute for a careful and painstaking determination of the facts in each accident under investigation.

This book is a result of the joint efforts of ten men with considerable experience in various phases of product liability and accident reconstruction. Their backgrounds represent a rich mixture of industrial, research, academic, and consulting work. Their common bond is an interest in accident reconstruction, and to that each has brought his own special analytical tools. Each has contributed to the book as a whole, rather than being solely responsible for any particular chapter.

The principal authors are Doctor James C. Collins, Mechanical and Metallurgical Engineer; Doctor John L. Habberstad, Mechanical Engineer; Doctor Robert G. Liptai, Mechanical and Metallurgical Engineer; Mr. J. Michael Stephenson, Mechanical Engineer; and Doctor Richard N. Stuart, Physicist. This book also includes material and valuable suggestions supplied by Mr. Herbert F. Conrad, Mechanical and Metallurgical Engineer; Mr. Roy S. Cornwell, Aeronautical and Mechanical Engineer; Mr. Elliott A. Green, Mechanical Engineer; Doctor Donald W. Moon, Mechanical and Metallurgical Engineer; and Doctor William M. Wells, Civil Engineer.

We are especially indebted to Mrs. Judith Peschel and Mrs. Judyth Prono for their invaluable assistance in editing, revising, and typing this manuscript during its several stages of preparation. We also wish to thank Mr. Douglas Kent, Mrs. Wilma Leon, Mr. Manuel Ochoa, Miss Mary Phelps, and Mr. Robert Rhiner, who prepared the illustrations.

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INTRODUCTION

THE AUTOMOBILE

On September 20, 1893, Frank Duryea drove a gasoline-powered contraption 200 feet down the Main Street of Chicopee Falls, Massachusetts, thus beginning the Automobile Age in the United States. European and American inventors had been developing self-powered vehicles since 1769. Their independent developments were to overwhelm and transform the whole of the society that spawned them. Today, with major producers in the United States, Europe, and Japan supplying automobiles to the world, the automobile appears to have overshadowed man himself.

In the 1900 census, the automobile was not even mentioned. Twenty-five years later, automobile production had become a major industrial activity. By then over 20 percent of steel production in the United States, 80 percent of world rubber production, and 75 percent of the U.S. glass industry's output went into the automobile. By 1975, world motor vehicle production was greater than 40,000,000 vehicles per year, of which 30 to 35 percent were made in the United States.

The real measure of the automobile's ubiquity, however, lies not in the number produced per year, but in the number registered and in use at any given time. In the United States there were 8,000 cars, trucks, and buses in use by 1900. This figure had grown to beyond 100 million by the early 1970s and has since continued its upward growth. These vehicles operate on a rural and municipal highway network covering over 3,710,000 miles. If every registered vehicle were to be driven on a public highway at any one time, there would be about 27 vehicles per mile. Fortunately, this cannot happen, since there are not enough licensed operators to drive all these vehicles at once.

Although the automobile's impact on society has been revolutionary, progress in automobile construction has been evolutionary. A comparison of the Model T Ford with today's cars reveals surprising similarities. The Model T Ford had planetary gears in its transmission, as do modern automatic transmissions. The Model T had an internal combustion engine, a drive shaft, pneumatic tires, a leaf-spring suspension system, and a multitude of components that are still called by the same names today. These components perform the same functions in the overall design and often maintain similar appearances.

Improved technology and manufacturing techniques have led to a few major generic changes in the automobile: the self-starter, hydraulic brakes, sealed-beam headlights, and the fully automatic transmission. But most changes have been evolutionary. Engines have become progressively larger, average vehicle weight has increased, mileage between major component repairs has increased, and vehicle safety has improved.

We begin with the automobile because it accounts for about 80 percent of all self-propelled vehicles on the road today. As a result, automobile accidents are the most common motor vehicle accident. Trucks, motorcycles, bicycles, and pedestrians, which are involved in accidents in fair proportion to their presence in the traffic stream, will be discussed later.

To understand today's automobile, one must understand the function—and possible malfunctions—of many of its individual components. It is easier to understand the behavior of these parts if we begin by looking at those dedicated to doing a single job. According to one classification scheme, the automobile can be divided into three general assemblies: the running gear, chassis, and body. The body includes those parts of the automobile that are seen or occupied by the driver and passengers. It encompasses the passenger compartment, trunk, doors, windows, fenders, hood, deck lid, and grille. The running gear consists of the engine, transmission, fuel and electrical systems, steering system, brakes, wheels, and tires. Finally, the chassis connects the body to the running gear and consists of the main frame, front suspension, and rear suspension.

LIST OF SYMBOLS

C .... chord, feet
E .... energy, foot-pounds
E_c ...... energy of the center of mass, foot-pounds
E_C ...... energy available to cause damage, foot-pounds
F .... force, pounds
g .... acceleration of gravity, 32.2 feet/second^2
H ...... height of center of mass, inches
H_O ..... height above the ground, feet
ΔH ..... height, feet
KE ..... kinetic energy, foot-pounds
L .... wheelbase, inches
M .... mass, pounds
M_o ...... middle ordinate, feet
p .... pressure, pounds per square inch (psi)
R .... radius, feet
S .... skid distance, feet
S' .... corrected skid distance, feet
S_1, S_2, S_3.. body travel distance, feet
S_T .... total body travel distance, feet
T .... time, seconds
t .... half of the track of a vehicle, inches
V .... velocity, miles per hour
V_A ...... velocity at start of an arbitrary skid, miles per hour
V_B ...... velocity at end of an arbitrary skid, miles per hour
V_C ...... velocity at collision, miles per hour
V_c ...... velocity of common center of mass, miles per hour
V_E ...... exit (postcollision) velocity, miles per hour (energy equation)
V_p ...... hydroplaning velocity, miles per hour
V_O ...... initial velocity, miles per hour
V' .... exit (postcollision) velocity, miles per hour (momentum equation)
ΔV ...... speed change at impact, miles per hour
W ...... weight, pounds
W_b ..... weight on braking wheels, pounds
W_F ..... front-wheel weight, pounds
W_R ..... rear-wheel weight, pounds
W_u ..... weight on unbraked wheels, pounds
x .... elevated height of front wheels, inches
y .... distance from front axle to center of mass, inches
ϵ .... coefficient of restitution
η .... braking efficiency
θ .... angle, degrees
μ .... automobile or truck tire coefficient of friction
μ' ...... motorcycle tire coefficient of friction
ρ .... momentum, pound-miles/hour
ω .... angular velocity, radians/second

CONTENTS

ACCIDENT RECONSTRUCTION

Chapter 1

AUTOMOTIVE RUNNING GEAR

ENGINE

THAT LARGE mass of metal under the hood, covered with wires and tubes, is the engine. It powers the car and is seldom directly blamed for an accident, but some understanding of its operation is fundamental to a grasp of today's automobile. Most automobiles have four-stroke cycle, carburetor-fed, electric-spark ignited, piston engines. These engines contain one or more pistons, each in its own cylinder, attached to a crankshaft. Figure 1-1 shows the movement of a single piston in a gasoline engine during the four strokes of one cycle: intake, compression, power, and exhaust.

During the intake stroke, the piston moves down, drawing a mixture of fuel and air from the carburetor into the cylinder through the intake valve. Near the bottom of this stroke, the intake valve closes. During the compression stroke, the piston moves up, squeezes the trapped fuel/air mixture to about one eighth of its original volume, and raises its temperature and pressure. Near the top of this stroke, the ignition system fires a spark plug screwed into the cylinder, and the fuel begins to burn. During the power stroke, this burning fuel pushes the piston back down. Finally, during the exhaust stroke, the exhaust valve opens as the piston moves up to vent the burned gases. The piston is then ready to begin another cycle. In a typical eight-cylinder automobile traveling at 55 miles per hour, this cycle is repeated in each cylinder about 2,750 times every minute.

The intake and exhaust valves must open and close at the correct time if the engine is to operate properly. This timing is

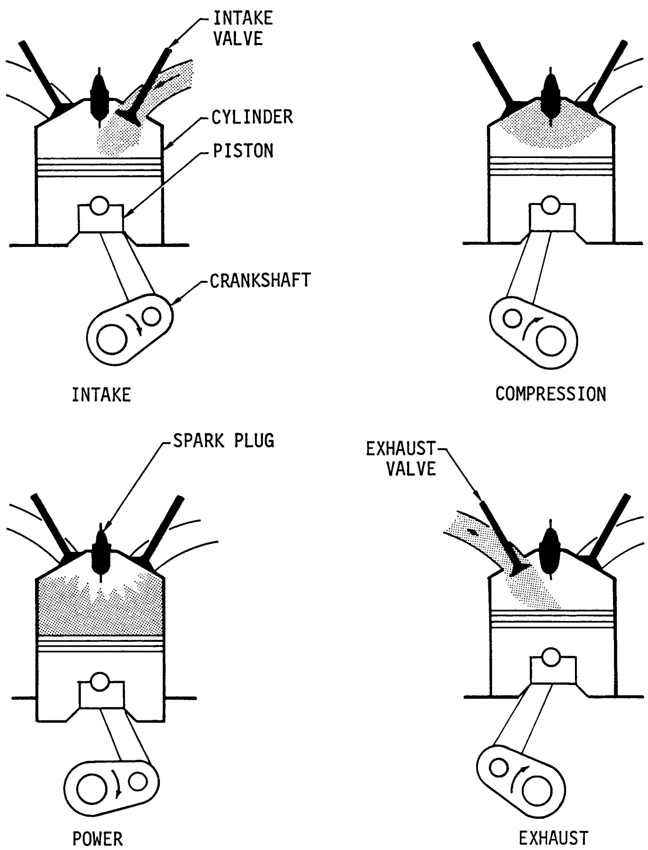

Figure 1-1. The four-stroke cycle of a gasoline engine. During each cycle, the crankshaft completes two revolutions. Timing for the intake and exhaust valves, and for spark plug ignition, is controlled by a camshaft, which is driven from the crankshaft.

accomplished by a second shaft, called the camshaft, which is driven with gears, chains, or toothed belts from the crankshaft. The eccentric lobes, called cams, on this second shaft operate the two valves through a series of rods and levers.

The camshaft also controls spark plug ignition by driving the distributor. A spark plug is fired by applying high voltage (20,000 volts or more) to it. The camshaft operates a switch—the breaker point—in the distributor to apply this voltage at the proper time. In multicylinder engines, the camshaft also operates a second distributor switch—the rotor—that transfers the high voltage from its single source (the battery) to the various cylinders.

The fuel/air mixture drawn into the cylinders during the intake stroke passes from the carburetor into the intake manifold and then to the cylinders as the intake valves are opened. For efficient burning, the proper air/fuel ratio is about 15 to 1 on a weight basis. This ratio decreases when the engine is delivering full power, and increases as the load is reduced. It is the carburetor's job to give the proper mixture over a wide range of engine speeds and loads, from idle to highway passing. In addition, the carburetor must provide a fuel-rich mixture when the engine is cold. This is the primary function of the choke system.

TRANSMISSION

Since most automobile engines will not operate well at slow speeds, a manual or automatic transmission is placed between the engine and drive wheels to permit the proper speed ratio between these two rotating parts. A number of fluid and mechanical devices, e.g. semi-automatic, self-shifting, and fluid drives, can be made into either manual or automatic transmissions.

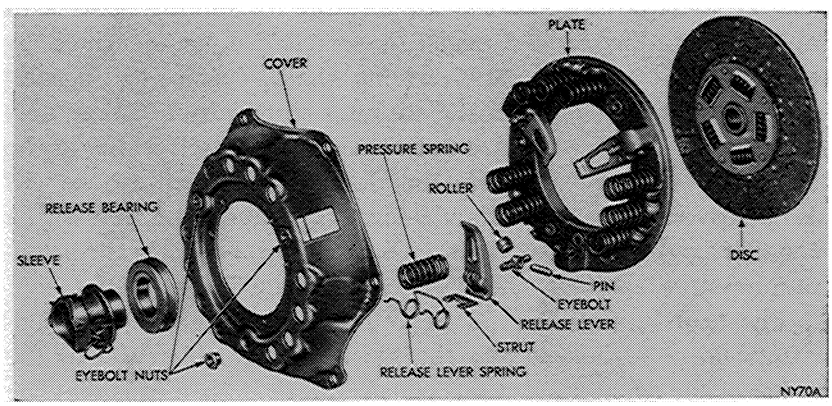

Figure 1-2. Exploded view of a Plymouth clutch for a manual transmission. The heavy springs around the plate force together the two friction plates, or clutch faces (labeled here plate and disc), and thus engage the clutch (courtesy Chrysler Corporation).

Manual transmissions usually have three or four forward speed ratios (drive ratios) and one reverse. The highest forward speed ratio is obtained by a direct connection from the engine through the transmission to the drive wheels. Each of the lower forward ratios is obtained by a pair of gears.

Manual transmissions are driven by the engine through a spring-loaded clutch, such as that shown in Figure 1-2. The most common failure in manual transmission automobiles is clutch failure. When the car starts moving, the clutch must be allowed to slip until the engine crankshaft and input to the transmission are spinning at the same speed. However, some clutch wear is associated with this slippage. The clutch faces eventually wear down until they will no longer carry the torque necessary to drive the car. This causes an excessive heat buildup on the clutch faces and rapid failure. Although clutch failure seldom leads directly to accidents, the attendant overheating has been known to cause cracks in the flywheel, which can then fly apart when operating at high speed. A disintegrating flywheel can cause catastrophic accidents.

As the fragments tear out of a rapidly spinning flywheel, their energy is often high enough to force them through the bell housing (the case at the front of a transmission) and the car floor. Such flywheel failure has been responsible for sinking boats with inboard engines. Heat-damaged flywheels can be identified by examining their broken parts. The flywheel's surface will usually be discolored by heat from the slipping clutch disc. Colors may range from light straw to deep blue. The color itself is due to the thickness of oxide layers on the metal. The discolored surface will also be covered by a network of fine cracks that can be seen with a magnifying glass. These cracks, or heat checks, form stress concentration points leading to the flywheel's ultimate failure.

Flywheels can also fail if the engine is overrevved. The centrifugal force trying to pull the flywheel apart increases as the square of the rpm (revolutions per minute). This means that the forces on a flywheel connected to an engine turning at 8,000 rpm are four times as high as they would be if the engine were turning at 4,000 rpm. When the centrifugal forces exceed the strength of the flywheel, it will fly apart. Flywheels that have failed from