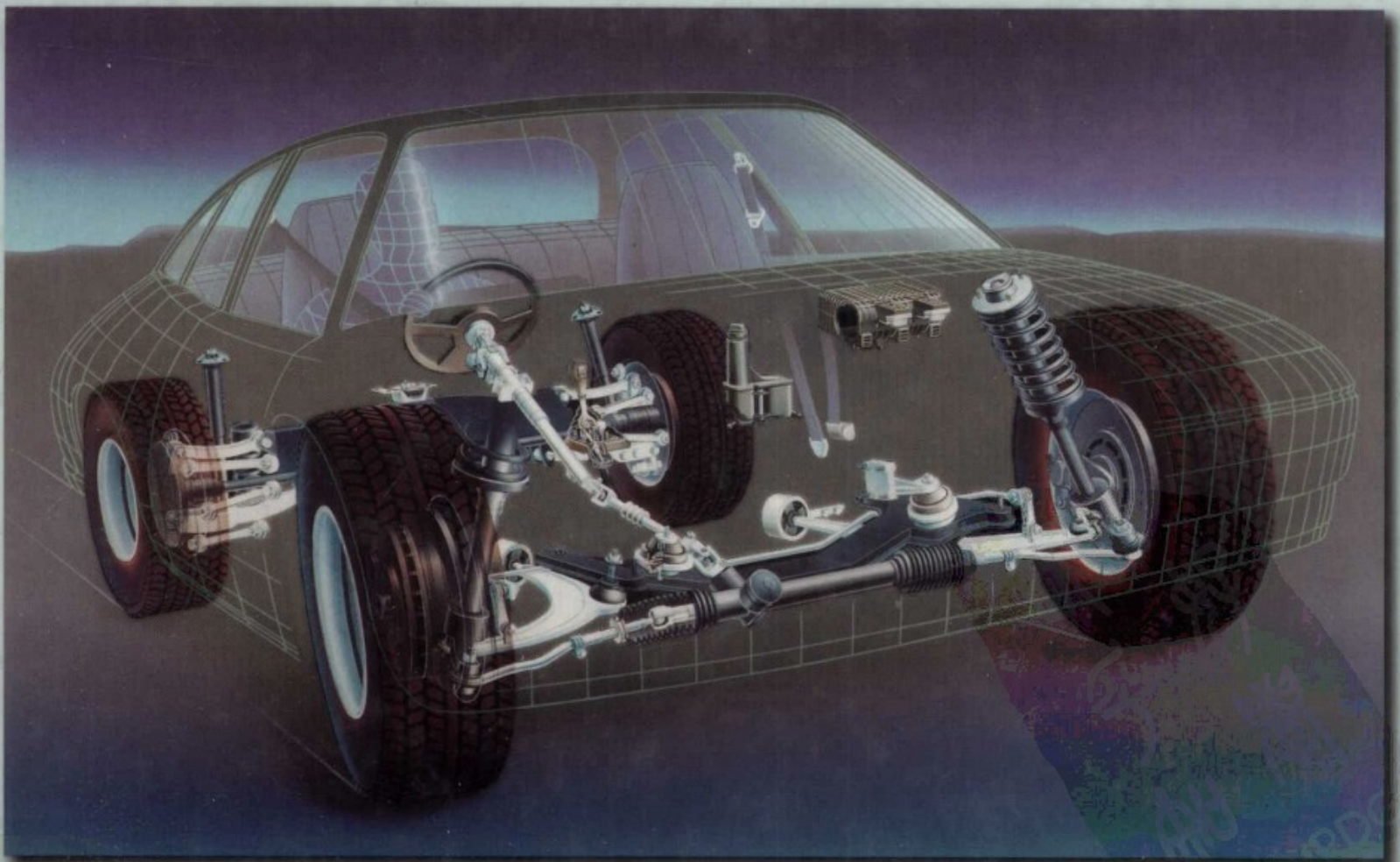


ENGINEERING PRINCIPLES

SECOND EDITION

The Automotive Chassis



J. REIMPELL H.STOLL J.W.BETZLER

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JörnSEN Reimpell, Helmut Stoll and Jürgen W Betzler

The second English edition of this classic text (published simultaneously by the German publishers, Vogel Buchverlag) has been thoroughly revised to take into account the latest technology. As with the first edition, descriptions are clear and easy to understand. There are numerous example designs and calculations throughout the text, and 434 illustrations are included to relate basic engineering principles to the particular requirements of the chassis and of vehicle mechanics.

Entirely new material on total vehicle and suspension design is incorporated, and areas which are covered include the platform concept, four wheel drive technology, and suspension design of the most up-to-date vehicles. Additionally, it now fully conforms to the international standards ISO 8855 and SAE J 670.

This second edition of **The Automotive Chassis** is essential reading for component and system engineers in both higher education and industry as well as for non-specialists who need to gain an understanding of the field. The book provides a clearly structured overview of chassis technology - from the requirements and design of tyres through axle kinematics to vehicle steering as well as springing and damper systems.

Prof. Dipl.-Ing. **JörnSEN Reimpell** lectured in the field of automotive engineering at the University of Applied Science Cologne for many years, and is now a freelance consultant. Dipl.-Ing. **Helmut Stoll** is a chief engineer at General Motors (Adam Opel AG). Prof. Dr.-Ing. **Jürgen W Betzler** is professor for chassis/simulation technology at the University of Applied Science Cologne.

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The Automotive Chassis: Engineering Principles

SECOND EDITION

Chassis and vehicle overall
Wheel suspensions and types of drive
Axle kinematics and elastokinematics
Steering – Springing – Tyres
Construction and calculations advice

Prof. Dipl.-Ing. Jörnsten Reimpell
Dipl.-Ing. Helmut Stoll
Prof. Dr.-Ing. Jürgen W. Betzler

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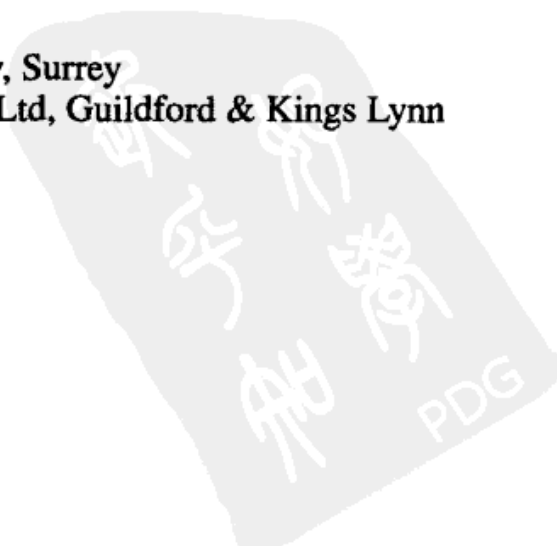
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Preface

This translation of the fourth German edition is published by Butterworth-Heinemann as the second English edition of *The Automotive Chassis*.

We are fortunate to have Prof. Dr.-Ing. Jürgen W. Betzler as co-author; he has been an expert in the field of chassis/simulation technology and design studies at the University of Cologne since 1994. Jointly, we revised *The Automotive Chassis: Engineering Principles* to include a large number of technical innovations.

The clear and easy descriptions, many example designs and calculations and the inclusion of 434 illustrations and tables are easily understood and have, over the years, proven to be the best way of imparting information.

The authors' many years of experience in chassis engineering support the practical bias and will help engineers, inspectors, students and technicians in companies operating in the automotive industry and its suppliers to understand the context. The comprehensive index of key words and numerous cross-references make this book an invaluable reference work.

We should like to thank Dipl.-Ing. Achim Clasen for collating the test results in the Automotive Engineering Laboratory at the Technical University in Cologne and Sabine Jansen M.A. for her hard work in converting the symbols.

Cologne/Rösrath

Jörnßen Reimpell
Helmut Stoll
Jürgen W. Betzler



Contents

<i>Preface</i>	xi
1 Tyres of suspension and drive	1
1.1 General characteristics of wheel suspensions	1
1.2 Independent wheel suspensions – general	7
1.2.1 Requirements	7
1.2.2 Double wishbone suspensions	8
1.2.3 McPherson struts and strut dampers	10
1.2.4 Rear axle trailing-arm suspension	15
1.2.5 Semi-trailing-arm rear axles	17
1.2.6 Multi-link suspension	19
1.3 Rigid and semi-rigid crank axles	22
1.3.1 Rigid axles	22
1.3.2 Semi rigid crank axles	28
1.4 Front-mounted engine, rear-mounted drive	30
1.4.1 Advantages and disadvantages of the front-mounted engine, rear-mounted drive design	32
1.4.2 Non-driven front axles	35
1.4.3 Driven rear axles	39
1.5 Rear and mid engine drive	41
1.6 Front-wheel drive	45
1.6.1 Types of design	46
1.6.2 Advantages and disadvantages of front-wheel drive	48
1.6.3 Driven front axles	51
1.6.4 Non-driven rear axles	56
1.7 Four-wheel drive	64
1.7.1 Advantages and disadvantages	64
1.7.2 Four-wheel drive vehicles with overdrive	68
1.7.3 Manual selection four-wheel drive on commercial and all-terrain vehicles	72
1.7.4 Permanent four-wheel drive; basic passenger car with front-wheel drive	72
1.7.5 Permanent four-wheel drive, basic standard design passenger car	80
1.7.6 Summary of different kinds of four-wheel drive	82

2	Tyres and wheels	86
2.1	Tyre requirements	86
2.1.1	Interchangeability	86
2.1.2	Passenger car requirements	87
2.1.3	Commercial vehicle requirements	89
2.2	Tyre designs	89
2.2.1	Diagonal ply tyres	89
2.2.2	Radial ply tyres	91
2.2.3	Tubeless or tubed	93
2.2.4	Height-to-width ratio	93
2.2.5	Tyre dimensions and markings	97
2.2.6	Tyre load capacities and inflation pressures	101
2.2.7	Tyre sidewall markings	105
2.2.8	Rolling circumference and driving speed	105
2.2.9	Influence of the tyre on the speedometer	108
2.3	Wheels	110
2.3.1	Concepts	110
2.3.2	Rims for passenger cars, light commercial vehicles and trailers	110
2.3.3	Wheels for passenger cars, light commercial vehicles and trailers	114
2.3.4	Wheel mountings	115
2.4	Springing behaviour	116
2.5	Non-uniformity	118
2.6	Rolling resistance	121
2.6.1	Rolling resistance in straight-line driving	121
2.6.2	Rolling resistance during cornering	122
2.6.3	Other influencing variables	124
2.7	Rolling force coefficients and sliding friction	124
2.7.1	Slip	124
2.7.2	Friction coefficients and factors	125
2.7.3	Road influences	126
2.8	Lateral force and friction coefficients	128
2.8.1	Lateral forces, slip angle and coefficient of friction	128
2.8.2	Self-steering properties of vehicles	130
2.8.3	Coefficients of friction and slip	132
2.8.4	Lateral cornering force properties on dry road	133
2.8.5	Influencing variables	134
2.9	Resulting force coefficient	138
2.10	Tyre self-aligning torque and caster offset	140
2.10.1	Tyre self-aligning torque in general	140
2.10.2	Caster offset	140
2.10.3	Influences on the front wheels	142
2.11	Tyre overturning moment and displacement of point of application of force	144
2.12	Torque steer effects	146
2.12.1	Torque steer effects as a result of changes in normal force	146

2.12.2	Torque steer effects resulting from tyre aligning torque	146
2.12.3	Effect of kinematics and elastokinematics	146
3	Wheel travel and elastokinematics	149
3.1	Purpose of the axle settings	150
3.2	Wheelbase	151
3.3	Track	151
3.4	Roll centre and roll axis	160
3.4.1	Definitions	160
3.4.2	Body roll axis	164
3.4.3	Body roll centre on independent wheel suspensions	166
3.4.4	Body roll centre on twist-beam suspensions	172
3.4.5	Body roll centre on rigid axles	172
3.5	Camber	175
3.5.1	Camber values and data	175
3.5.2	Kinematic camber alteration	178
3.5.3	Camber alteration calculation by drawing	181
3.5.4	Roll camber during cornering	182
3.5.5	Elasticity camber	185
3.6	Toe-in and self-steering	187
3.6.1	Toe-in and crab angle, data and tolerances	187
3.6.2	Toe-in and steering angle alteration owing to wheel bump-travel kinematics	191
3.6.3	Toe-in and steering angle alteration due to roll	193
3.6.4	Toe-in and steering angle alteration due to lateral forces	199
3.6.5	Toe-in and steering angle alteration due to longitudinal forces	200
3.7	Steer angle and steering ratio	208
3.7.1	Steer angle	208
3.7.2	Track and turning circles	209
3.7.3	Kinematic steering ratio	213
3.7.4	Dynamic steering ratio	215
3.8	Steering self-centring – general	218
3.9	Kingpin inclination and kingpin offset at ground	221
3.9.1	Relationship between kingpin inclination and kingpin offset at ground (scrub radius)	221
3.9.2	Braking moment-arm	225
3.9.3	Longitudinal force moment-arm	228
3.9.4	Alteration to the kingpin offset	230
3.10	Caster	230
3.10.1	Caster trail and angle	230
3.10.2	Caster and straight running	234
3.10.3	Righting moments during cornering	235
3.10.4	Kingpin inclination, camber and caster alteration as a consequence of steering	239
3.10.5	Kinematic caster alteration on front-wheel travel	245
3.10.6	Wheel travel-dependent rotation of the rear steering knuckle	250

3.10.7	Resolution of the vertical wheel force on caster	251
3.10.8	Settings and tolerances	254
3.11	Anti-dive and anti-squat mechanisms	255
3.11.1	Concept description	255
3.11.2	Vehicle pitch axis front	255
3.11.3	Pitch axes rear	258
3.12	Chassis alignment	260
3.12.1	Devices for measuring and checking chassis alignment	260
3.12.2	Measuring the caster, kingpin inclination, camber and toe-in alteration	262
4	Steering	266
4.1	Steering system	266
4.1.1	Requirements	266
4.1.2	Steering system on independent wheel suspensions	269
4.1.3	Steering system on rigid axles	269
4.2	Rack and pinion steering	271
4.2.1	Advantages and disadvantages	271
4.2.2	Configurations	272
4.2.3	Steering gear, manual with side tie rod take-off	273
4.2.4	Steering gear, manual with centre tie rod take-off	276
4.3	Recirculating ball steering	278
4.3.1	Advantages and disadvantages	278
4.3.2	Steering gear	280
4.4	Power steering systems	281
4.4.1	Hydraulic power steering systems	281
4.4.2	Electro-hydraulic power steering systems	283
4.4.3	Electrical power steering systems	286
4.5	Steering column	288
4.6	Steering damper	294
4.7	Steering kinematics	294
4.7.1	Influence of type and position of the steering gear	294
4.7.2	Steering linkage configuration	296
4.7.3	Tie rod length and position	299
5	Springing	307
5.1	Comfort requirements	307
5.1.1	Springing comfort	309
5.1.2	Running wheel comfort	311
5.1.3	Preventing 'front-end shake'	313
5.2	Masses, vibration and spring rates	314
5.3	Weights and axle loads	318
5.3.1	Curb weight and vehicle mass	319
5.3.2	Permissible gross vehicle weight and mass	320
5.3.3	Permissible payload	320
5.3.4	Design weight	323

5.3.5	Permissible axle loads	323
5.3.6	Load distribution according to ISO 2416	325
5.4	Springing curves	328
5.4.1	Front axle	328
5.4.2	Rear axle	332
5.4.3	Springing and cornering behaviour	334
5.4.4	Diagonal springing	339
5.5	Spring types	340
5.5.1	Air- and gas-filled spring devices	340
5.5.2	Steel springs	344
5.5.3	Stops and supplementary springs	345
5.5.4	Anti-roll bars	346
5.6	Shock absorbers (suspension dampers)	347
5.6.1	Types of fitting	348
5.6.2	Twin-tube shock absorbers, non-pressurized	349
5.6.3	Twin-tube shock absorbers, pressurized	355
5.6.4	Monotube dampers, pressurized	357
5.6.5	Monotube dampers, non-pressurized	364
5.6.6	Damping diagrams and characteristics	366
5.6.7	Damper attachments	367
5.6.8	Stops and supplementary springs	370
5.7	Spring/damper units	375
5.8	McPherson struts and strut dampers	375
5.8.1	McPherson strut designs	375
5.8.2	Twin-tube McPherson struts, non-pressurized	377
5.8.3	Twin-tube McPherson struts, pressurized	377
5.8.4	Damper struts	381
5.9	Variable damping	381
6	Chassis and vehicle overall	386
6.1	Vehicle and body centre of gravity	386
6.1.1	Centre of gravity and handling properties	386
6.1.2	Calculating the vehicle centre of gravity	387
6.1.3	Axle weights and axle centres of gravity	392
6.1.4	Body weight and body centre of gravity	392
6.2	Mass moments of inertia	394
6.3	Braking behaviour	397
6.3.1	Braking	397
6.3.2	Braking stability	399
6.3.3	Calculating the pitch angle	402
6.3.4	Influence of radius-arm axes	407
6.3.5	Anti-dive control and brake reaction support angle	410
6.4	Traction behaviour	410
6.4.1	Drive-off from rest	410
6.4.2	Climbing ability	414
6.4.3	Skid points	416
6.5	Platform, unit assembly and common part systems	419

x **Contents**

<i>Bibliography</i>	422
<i>Glossary of symbols</i>	424
<i>Index of car manufacturers</i>	433
<i>Index of car suppliers</i>	435
<i>Subject index</i>	437



Types of suspension and drive

This chapter deals with the principles relating to drives and suspensions.

1.1 General characteristics of wheel suspensions

The suspension of modern vehicles need to satisfy a number of requirements whose aims partly conflict because of different operating conditions (loaded/unloaded, acceleration/braking, level/uneven road, straight running/cornering).

The forces and moments that operate in the wheel contact area must be directed into the body. The kingpin offset and disturbing force lever arm in the case of the longitudinal forces, the castor offset in the case of the lateral forces, and the radial load moment arm in the case of the vertical forces are important elements whose effects interact as a result of, for example, the angle of the steering axis.

Sufficient vertical spring travel, possibly combined with the horizontal movement of the wheel away from an uneven area of the road (kinematic wheel) is required for reasons of *ride comfort*. The recession suspension should also be compliant for the purpose of reducing the rolling stiffness of the tyres and short-stroke movements in a longitudinal direction resulting from the road surface (longitudinal compliance, Fig. 1.1), but without affecting the development of lateral wheel forces and hence steering precision, for which the most rigid wheel suspension is required. This requirement is undermined as a result of the necessary flexibility that results from disturbing wheel movements generated by longitudinal forces arising from driving and braking operations.

For the purpose of ensuring the optimum *handling characteristics* of the vehicle in a steady state as well as a transient state, the wheels must be in a defined position with respect to the road surface for the purpose of generating the necessary lateral forces. The build-up and size of the lateral wheel forces are determined

2 The Automotive Chassis

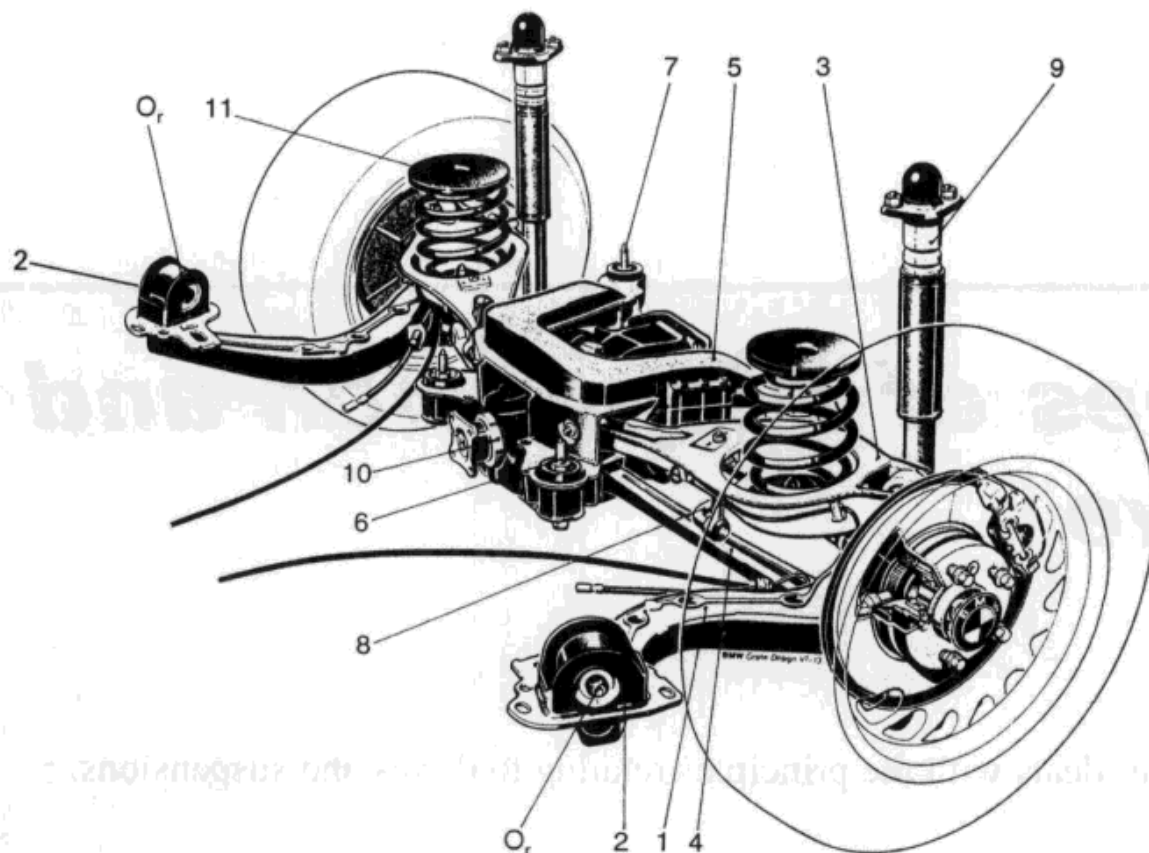


Fig. 1.1 A multi-link rear axle – a type of suspension system which is progressively replacing the semi-trailing arm axle, and consists of at least one trailing arm on each side. This arm is guided by two (or even three) transverse control arms (Figs 1.62 and 1.77). The trailing arm simultaneously serves as a wheel hub carrier and (on four-wheel steering) allows the minor angle movements required to steer the rear wheels. The main advantages are, however, its good kinematic and elastokinematic characteristics.

BMW calls the design shown in the illustration and fitted in the 3-series (1997) a 'central arm axle'. The trailing arms 1 are made from GGG40 cast iron; they absorb all longitudinal forces and braking moments as well as transferring them via the points 2 – the centres of which also form the radius arm axes (Figs 3.158 and 3.159) – on the body. The lateral forces generated at the centre of tyre contact are absorbed at the subframe 5, which is fastened to the body with four rubber bushes (items 6 and 7) via the transverse control arms 3 and 4. The upper arms 3 carry the minibloc springs 11 and the joints of the anti-roll bar 8. Consequently, this is the place where the majority of the vertical forces are transferred between the axle and the body.

The shock absorbers, which carry the additional polyurethane springs 9 at the top (Fig. 5.50), are fastened in a good position behind the axle centre at the ends of the trailing arms. For reasons of noise, the differential 10 is attached elastically to the subframe 5 at three points (with two rubber bearings at the front and one hydro bearing at the back). When viewed from the top and the back, the transverse control arms are positioned at an angle so that, together with the differing rubber hardness of the bearings at points 2, they achieve the desired elastokinematic characteristics. These are:

- toe-in under braking forces (Figs 3.64 and 3.82);
- lateral force compliance understeer during cornering (Figs 3.79 and 3.80);
- prevention of torque steer effects (see Section 2.10.4);
- lane change and straight running stability.

For reasons of space, the front eyes 2 are pressed into parts 1 and bolted to the attachment bracket. Elongated holes are also provided in this part so toe-in can be set. In the case of the E46 model series (from 1998 onwards), the upper transverse arm is made of aluminium for reasons of weight (reduction of unsprung masses).

by specific toe-in and camber changes of the wheels depending on the jounce and movement of the body as a result of the axle kinematics (roll steer) and operative forces (compliance steer). This makes it possible for specific operating conditions such as load and traction to be taken into consideration. By establishing the relevant geometry and kinematics of the axle, it is also possible to prevent the undesirable diving or lifting of the body during braking or accelerating and to ensure that the vehicle does not exhibit any tendency to oversteer and displays predictable transition behaviour for the driver.

Other requirements are:

- independent movement of each of the wheels on an axle (not guaranteed in the case of rigid axles);
- small, unsprung masses of the suspension in order to keep wheel load fluctuation as low as possible (important for driving safety);
- the introduction of wheel forces into the body in a manner favourable to the flow of forces;
- the necessary room and expenditure for construction purposes, bearing in mind the necessary tolerances with regard to geometry and stability;
- ease of use;
- behaviour with regard to the passive safety of passengers and other road users;
- costs.

The requirements with regard to the steerability of an axle and the possible transmission of driving torque essentially determine the design of the axis.

Vehicle suspensions can be divided into rigid axles (with a rigid connection of the wheels to an axle), independent wheel suspensions in which the wheels are suspended independently of each other, and semi-rigid axles, a form of axle that combines the characteristics of rigid axles and independent wheel suspensions.

On all rigid axles (Fig. 1.23), the axle beam casing also moves over the entire spring travel. Consequently, the space that has to be provided above this reduces the boot at the rear and makes it more difficult to house the spare wheel. At the front, the axle casing would be located under the engine, and to achieve sufficient jounce travel the engine would have to be raised or moved further back. For this reason, rigid front axles are found only on commercial vehicles and four-wheel drive, general-purpose passenger cars (Figs 1.3 and 1.4).

With regard to independent wheel suspensions, it should be noted that the design possibilities with regard to the satisfaction of the above requirements and the need to find a design which is suitable for the load paths, increase with the number of wheel control elements (links) with a corresponding increase in their planes of articulation. In particular, independent wheel suspensions include:

- Longitudinal link and semi-trailing arm axles (Figs 1.13 and 1.15), which require hardly any overhead room and consequently permit a wide luggage space with a level floor, but which can have considerable diagonal springing.
- Wheel controlling suspension and shock-absorber struts (Figs 1.8 and 1.57), which certainly occupy much space in terms of height, but which require little space at the side and in the middle of the vehicle (can be used for the engine

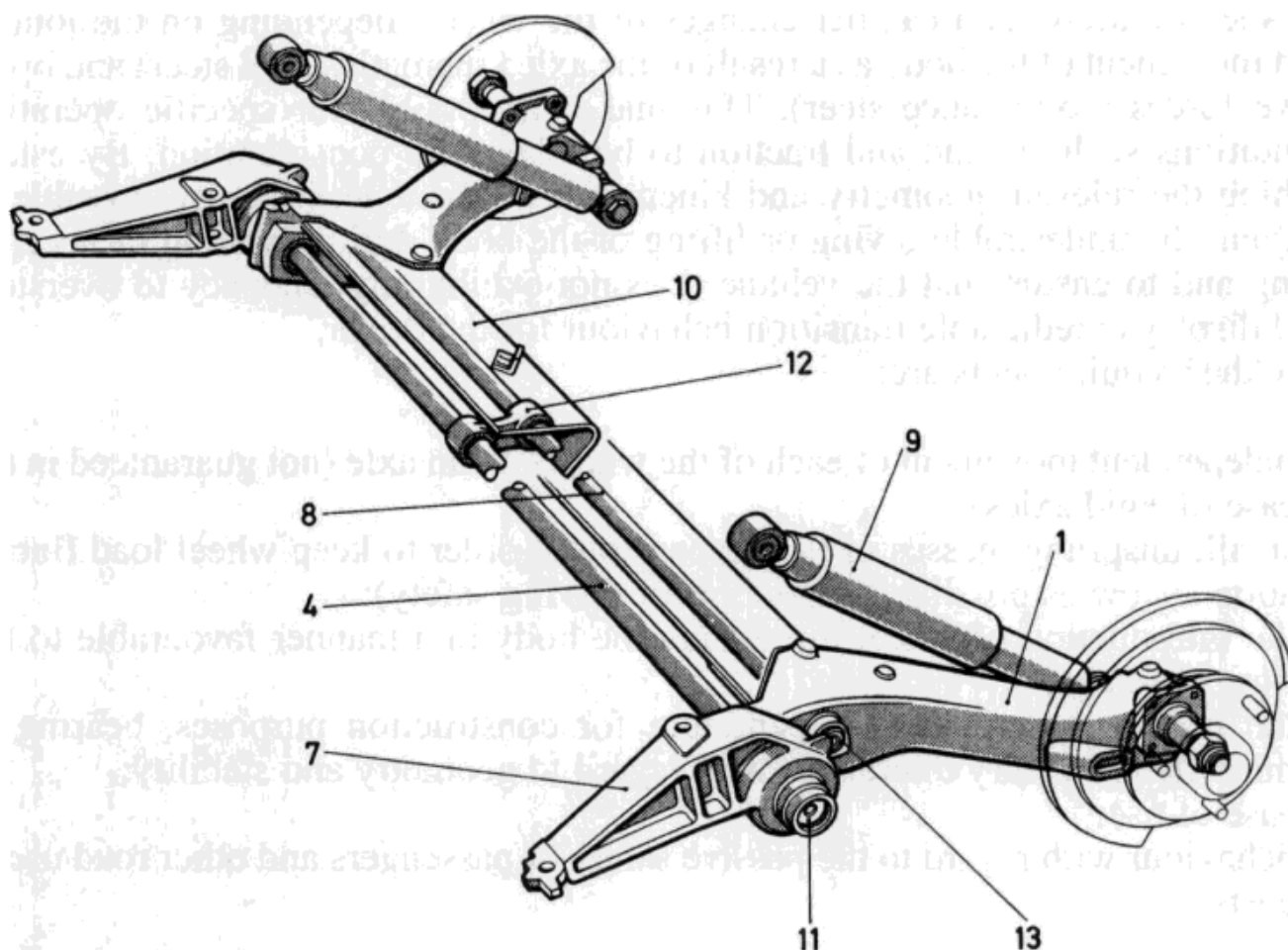


Fig. 1.2 An extremely compact four-bar twist beam axle by Renault, with two torsion bar springs both for the left and right axle sides (items 4 and 8). The V-shape profile of the cross-member 10 has arms of different lengths, is resistant to bending but less torsionally stiff and absorbs all moments generated by vertical, lateral and braking forces. It also partially replaces the anti-roll bar.

At 23.4 mm, the rear bars 8 are thicker than the front ones (\varnothing 20.8 mm, item 4). On the outside, part 8 grips into the trailing links 1 with the serrated profile 13 and on the inside they grip into the connector 12. When the wheels reach full bump, a pure torque is generated in part 12, which transmits it to the front bars 4, subjecting them to torsion. On the outside (as shown in Fig. 1.63) the bars with the serrated profile 11 grip into the mounting brackets 7 to which the rotating trailing links are attached. The pivots also represent a favourably positioned pitch centre O_r (Fig. 3.159). The mounting brackets (and therefore the whole axle) are fixed to the floor pan with only four screws.

On parallel springing, all four bars work, whereas on reciprocal springing, the connector 12 remains inactive and only the thick rear bars 8 and the cross-member 10 are subject to torsion.

The layout of the bars means soft body springing and high roll stability can be achieved, leading to a reduction of the body roll pitch during cornering.

To create a wide boot without side encroachments, the pressurized monotube shock absorbers 9 are inclined to the front and therefore are able to transmit forces upwards to the side members of the floor pan.

or axle drive) and determine the steering angle (then also called McPherson suspension struts).

- Double wishbone suspensions (Fig. 1.7).
- Multi-link suspensions (Figs 1.1, 1.18 and 1.19), which can have up to five guide links per wheel and which offer the greatest design scope with regard to

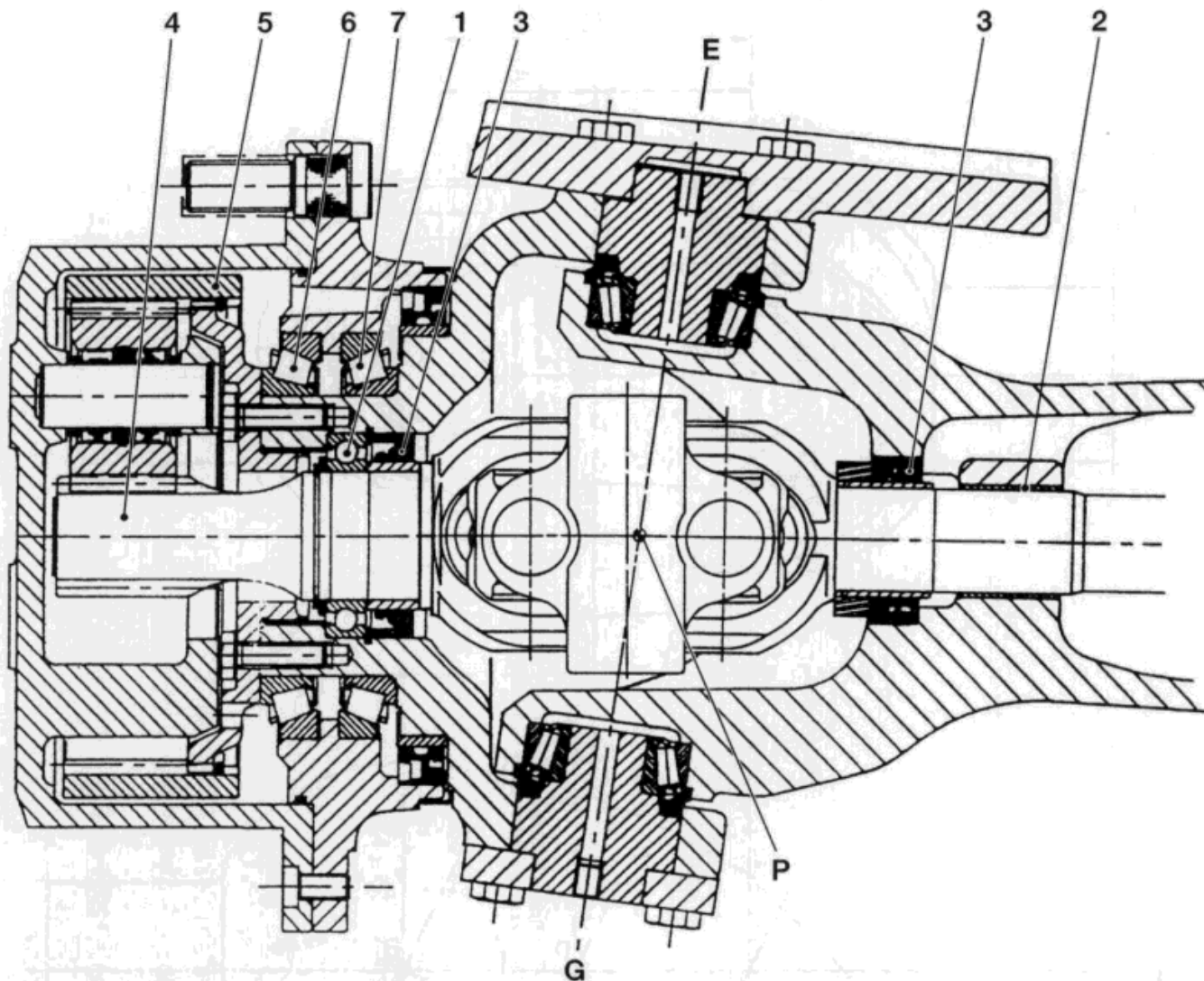


Fig. 1.3 Driven, rigid steering axle with dual joint made by the company GKN – Birfield AG for four-wheel drive special-purpose vehicles, tractors and construction machinery.

The dual joint is centred over the bearings 1 and 2 in the region of the fork carriers; these are protected against fouling by the radial sealing rings 3. Bearing 1 serves as a fixed bearing and bearing 2 as a movable bearing. The drive shaft 4 is also a sun gear for the planetary gear with the internal-gear wheel 5. Vertical, lateral and longitudinal forces are transmitted by both tapered-roller bearings 6 and 7. Steering takes place about the steering axis EG.

the geometric definition of the kingpin offset, pneumatic trail, kinematic behaviour with regard to toe-in, camber and track changes, braking/starting torque behaviour and elastokinematic properties.

In the case of twist-beam axles (Figs 1.2, 1.31 and 1.58), both sides of the wheels are connected by means of a flexurally rigid, but torsionally flexible beam. On the whole, these axles save a great deal of space and are cheap, but offer limited potential for the achievement of kinematic and elastokinematic balance because of the functional duality of the function in the components and require the existence of adequate clearance in the region of the connecting beam. They are mainly used as a form of rear wheel suspension in front-wheel drive

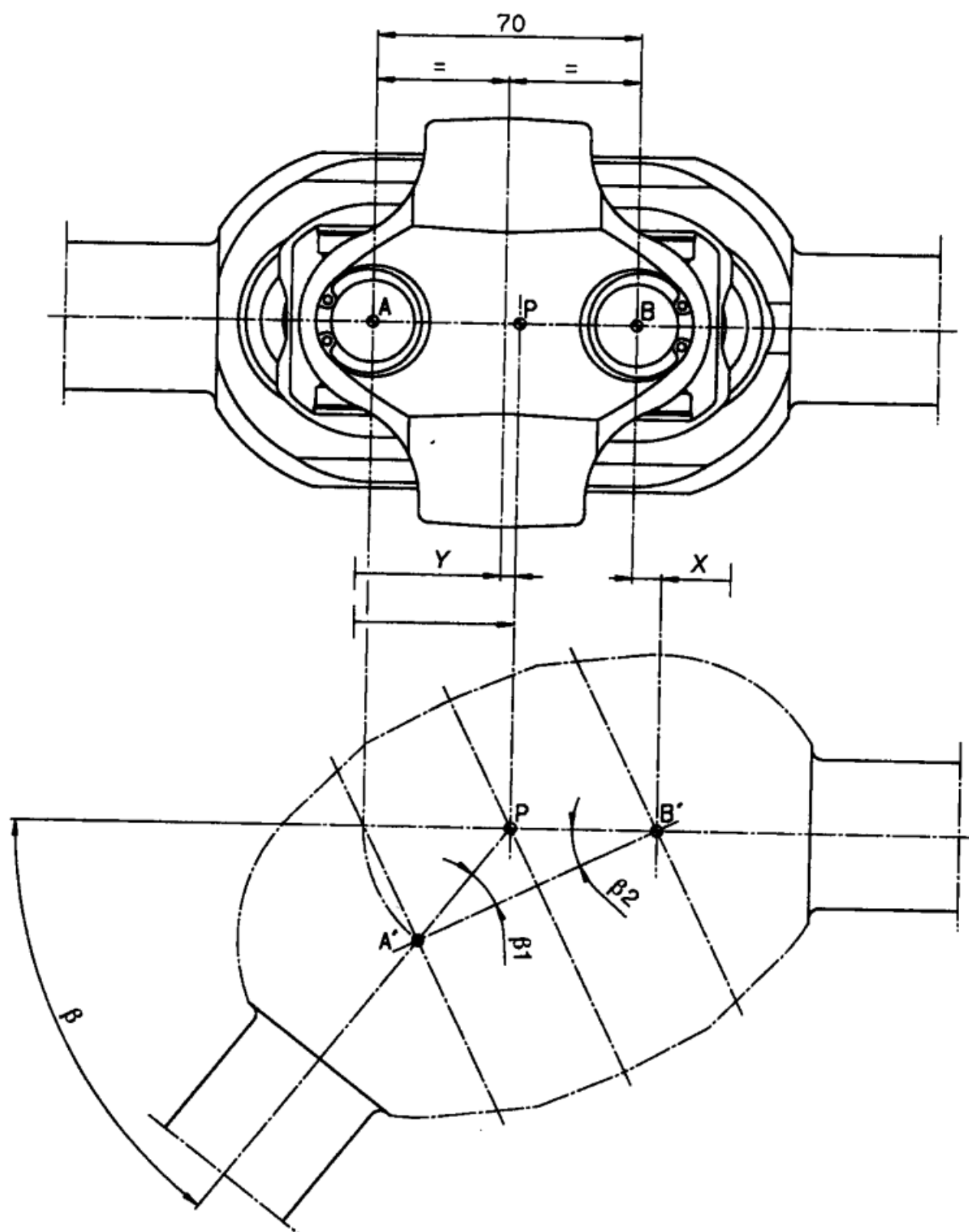


Fig. 1.4 Top view of the dual joint (Fig. 1.3). The wheel end of the axle is turned about point P in the middle of the steering pivot during steering. The individual joints are constrained at points A and B so that point A is displaced to position A', P is displaced to P' and B is displaced along the drive axle by the distance X to B'. In order to assimilate the variable bending angle β resulting from the longitudinal displacement of point B, the mid-point of the joint P is displaced by the distance Y. The adjustment value Y depends on the distance between the joints and the steering angle at which constant velocity is to exist. Where large steering angles can be reached (up to 60°), there should be constant velocity at the maximum steering angle.

The adjustment value Y and the longitudinal displacement X should be taken into consideration in the design of the axle.