VOTE YES FOR I.R.S.!

European Carmakers Elect The Logical Candidate

BY JOSEPH LOWREY

FERRARI BUILT 1965 model year 275-GT street coupes with independent rear suspension of the type that figured in the firm's racing successes for a considerable period of time. Rolls-Royce adopted independent rear suspension for its 1966 luxury sedan. Ford of Britain introduced independent rear suspension, a feature of the Ford GT 40 competition coupe, in the 1966½ Zephyr and Zodiac sedans.

When Ford, Ferrari and Rolls all say yes to i.r.s., it is safe to say independent rear suspension has arrived.

This article has no direct concern with the rear-engined car which, having its transmission located between the rear wheels, cannot conveniently use a long propeller shaft as the flexible link to a rigid axle beam. Designers of such cars do not choose to use independently sprung rear wheels, they are virtually obliged to do so. Almost the only possible alternative is to squeeze in a de Dion axle tube, such as were on pre-war German road-racing cars. Rear-engined cars have taught useful lessons in the development of i.r.s. techniques. The fact that all rear-engined cars use i.r.s., however, is no evidence of its desirability for other forms of cars. And, this review isn't directly concerned with i.r.s. on front-wheel driven cars. When the weight of final drive gears and the differential is removed from a rigid axle, and when propeller shaft torque reaction need not be considered, the majority of the rigid rear axle's faults disappear. That is why Audi, Autobianchi, Auto Union-DKW, Lancia, Oldsmobile, Panhard and Saab retain rear axle beams on front-wheel-driven cars.

Conventional front-engined, rear-wheel-driven cars are built according to what was once called the *système Panhard*, after the engineer who introduced the design early in motoring history.

I.r.s. has taken a long time to establish itself as an undeniably good feature. Many designers have used i.r.s. on such cars as AC, Lancia, Mercedes-Benz, Pontiac Tempest, Skoda and Triumph Herald without rapidly establishing that the principle offered more advantages than disadvantages. Proof that modern know-how makes i.r.s. preferable to the rigid rear axle came with later Mercedes-Benz and Triumph designs, plus the more sophisticated layouts of BMW and Jaguar. When tradition-minded Rolls-Royce and cost-conscious Ford both adopt i.r.s., the case obviously is proved.

Advantages that a good i.r.s. system ought to offer have been known for many years. The ride should be smoother, with less unsprung weight and perhaps less stiff springs and dampers. Traction and cornering grip should be better, with more consistent loading of all wheels at all times. Handling on turns and on rough straights should be more accurate. Extra rear passenger space should be available when the propeller shaft and axle do not rise over road bumps.

Disadvantages that could result from the adoption of i.r.s. have been as well known as the advantages. Manufacturing and maintenance costs for a more complicated mechanism would usually be increased. Additional noise from the road surface and axle gears was likely to enter the body interior. Car stability in certain circumstances changed for the worse, rather than for the better. Suspension linkages and tilting wheels sometimes occupied extra space in the car. Non-vertical wheels could look unpleasant from outside a car.

Many of these disadvantages also applied to early designs of independent front wheel suspension, but were overcome more quickly in that context because engineers had a stronger incentive to solve the problems of i.f.s. Front wheels could respond as gyroscopes to any tilting of their axle beam, oscillating around their steering swivels. Non-steered rear wheels contain gyroscopic forces firmly within the axle tubes.

Because they transmit engine power, however, driven rear axles do present their own troubles, different than those that arose with front axles. There is a very heavy weight of mechanism at the center. Its mass forms a pivot in space around which the axle can rock, twist or snake. An upward impact from a bump at one wheel tends to rotate the axle around the central weight of the differential gears and to push down the opposite end on its pneumatic tire. Also, propeller shaft torque lifts the right rear wheel. This effect and consequent changed traction tend to provoke axle tramp.

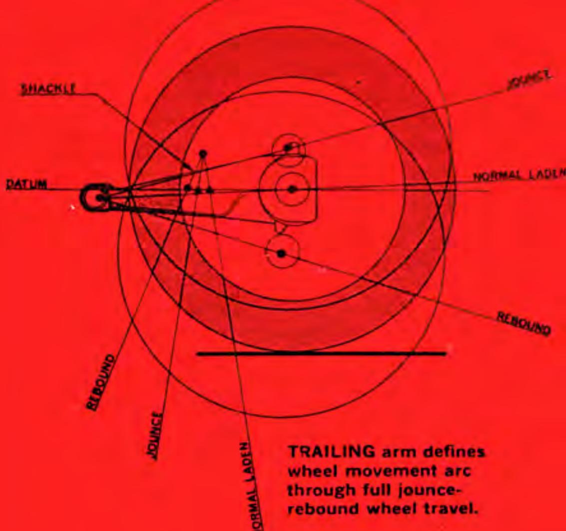
THE 289-CU. IN. Ford Mustang offers a good example. The Mustang's engine develops 312 lb.-ft. of torque which can be multiplied by a 2.32 first gear to 724 lb. of torque at the rear axle. The Mustang's rear tread is 56 in. When torque is applied to this 56 in. lever, 155 lb. of down load appears at one rear tire and a 155-lb. reduction of down load appears at the other. Thus, with the rigid rear axle, there is a 310-lb. loading difference between wheels— a good argument for limited slip differentials.

When i.r.s. is used, axle gears and the engine are bolted to the car's frame. Torque reaction is not transmitted through the suspension system.

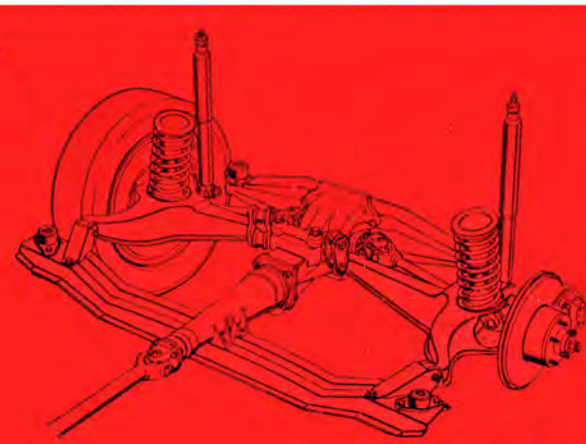
When Sizaire Naudin designed an independent front wheel suspension system 60 years ago, it was assumed that simple vertical slides represented the natural means for guiding wheel movement, but history has proved this wrong. Vertical slides have not appeared any more correct for i.r.s. than for i.f.s., though one Lotus sports car does use inclined slides in conjunction with lower links carrying the main forces in its i.r.s. system. Linkages are less vulnerable to wear than are slides and are used in virtually all modern designs of i.r.s.

Once a designer abandons the rigid axle, his car's rear wheels have six

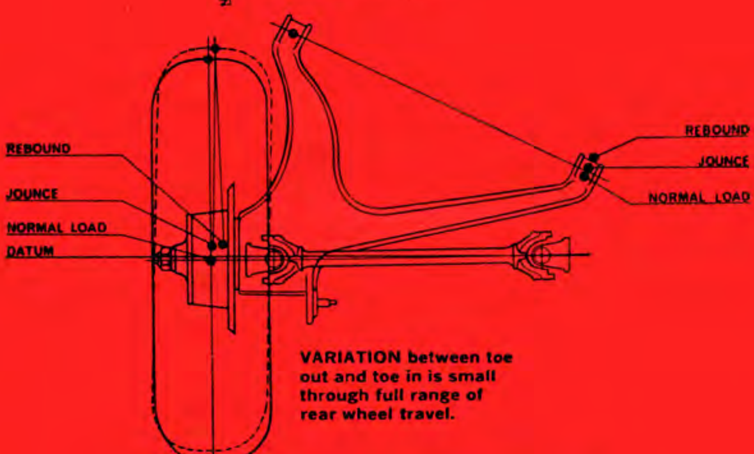
ZEPHYR-ZODIAC I.R.S. SYSTEM



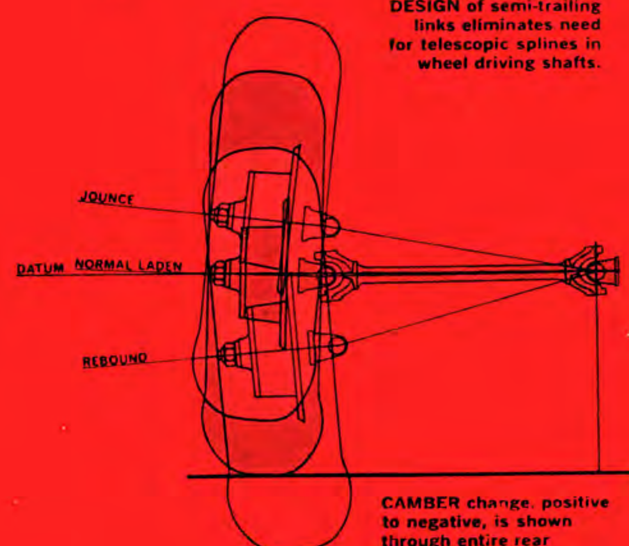
TRAILING arm defines wheel movement arc through full jounce-rebound wheel travel.



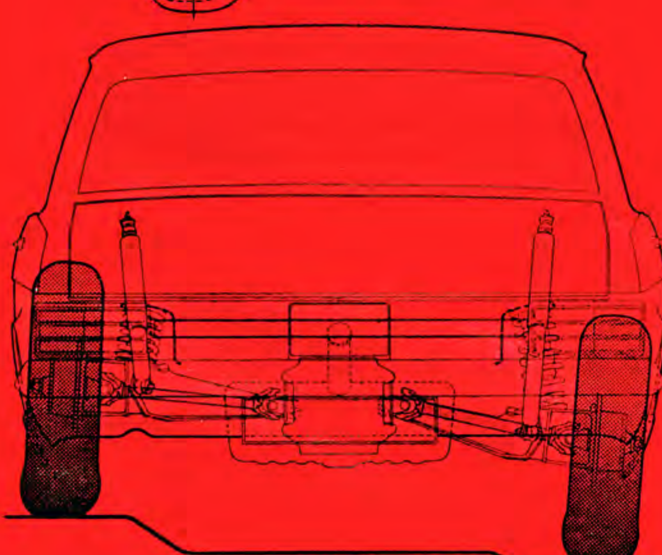
DESIGN of semi-trailing links eliminates need for telescopic splines in wheel driving shafts.



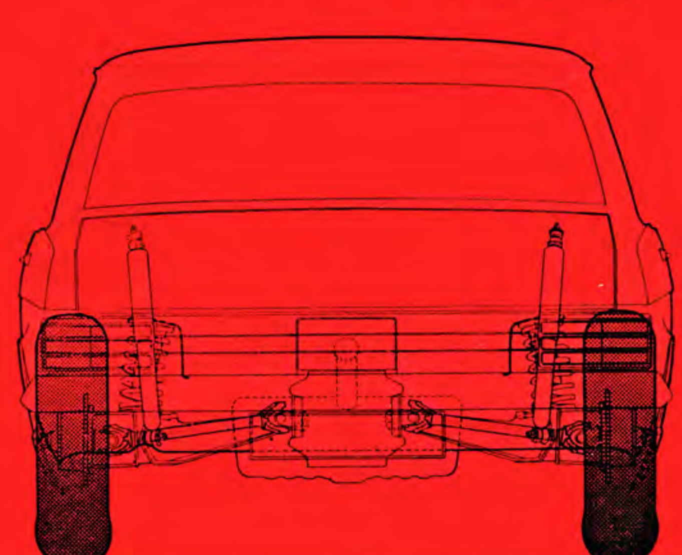
VARIATION between toe out and toe in is small through full range of rear wheel travel.



CAMBER change, positive to negative, is shown through entire rear wheel movement arc.



EFFECT OF negative camber on cornering while under full spring compression is offset by slight wheel toe out.



WITHOUT SIDE loadings, Ford i.r.s. shows slight positive camber. Pivot axis may be changed to improve cornering.

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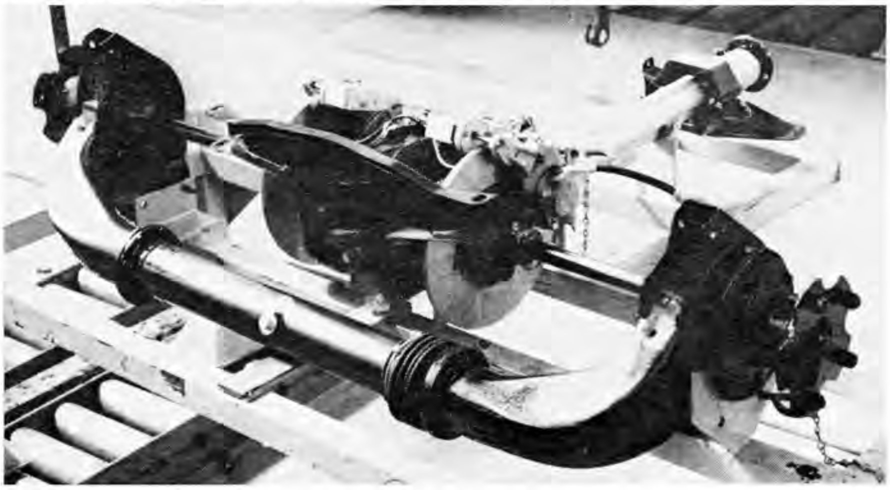
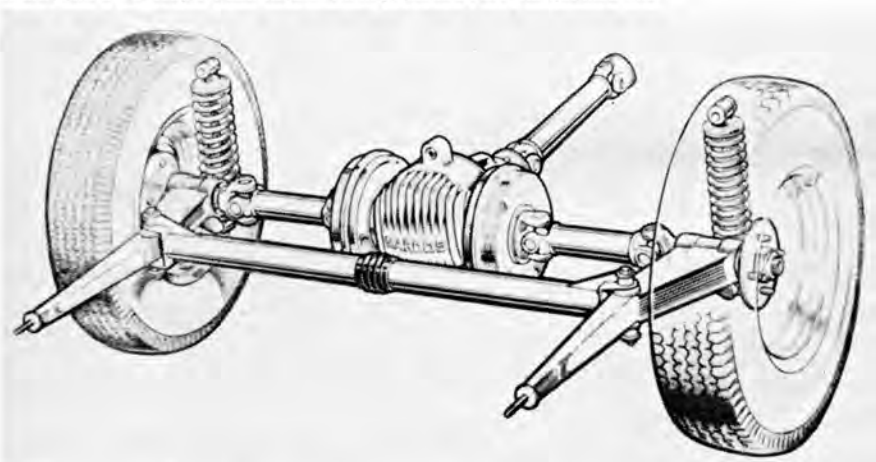
areas of movement that require control. As the spring deflects, the wheel may move in three directions—sideways, backwards and upwards. A wheel may tilt about three axes to vary camber or alignment or to turn around its own axis. So many degrees of freedom permit designers to produce very good

MODIFIED DE Dion system of the Rover 2000 uses a telescopic dead tube to hold rear wheels upright. Hubs follow radii set by driving shafts.



MARCOS SPORTS cars employ a de Dion variant with fixed length drive shafts and a telescopic dead tube—which preceded Ford compliance link.



THE ORIGINAL de Dion axle, designed and built in 1900, moved the differential onto the sprung part of the car. I.r.s. isn't new.

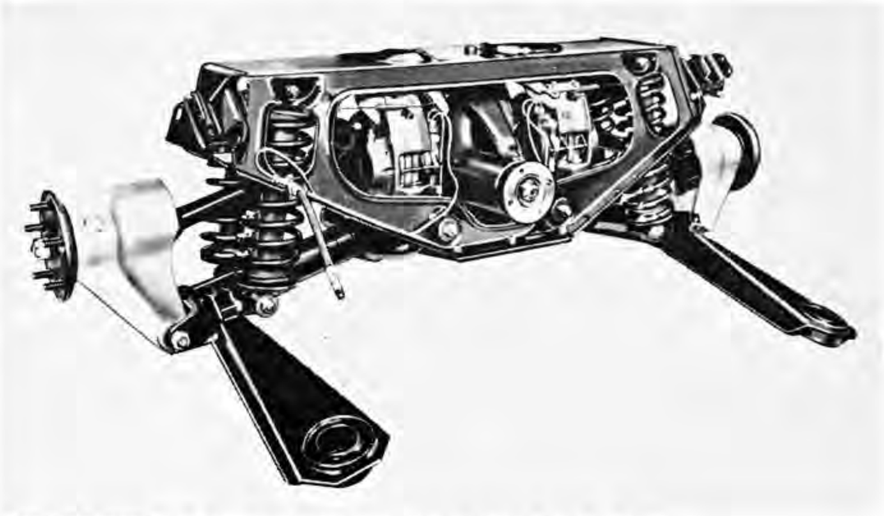
or very bad results from their system.

In planning an i.r.s. system, designers must consider many practical problems other than the geometry that would provide optimum handling and riding qualities. The system should be simple, to minimize the number of wearing parts—even on a car that need not be built to a cost budget. Noise must be kept out of the car, without rubber insulation ruining accuracy of steering. Mechanism must not intrude greatly upon space in the body or upon access doors. Thus it is that racing designs of i.r.s., which are uninhibited by considerations of silence, durability or easy access to seats, differ greatly from designs planned for street use.

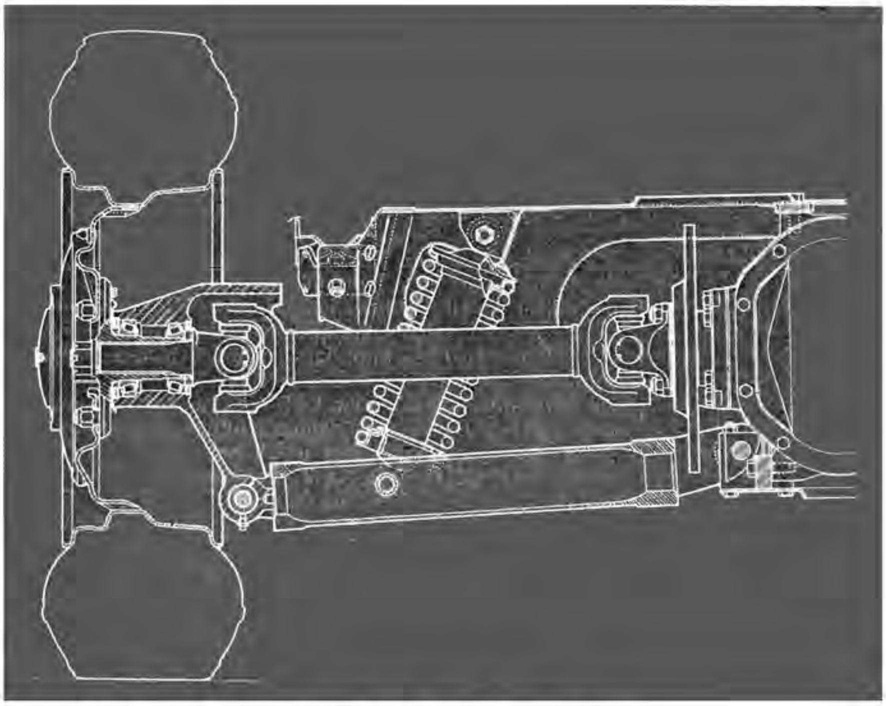
For racing cars, i.r.s. design is in a phase of almost complete standardization. The stub axle, which carries a rear wheel bearing is mounted on an upright carrier of approximately triangular form. This assembly is held by two fore-and-aft and two transverse links or A-arm members. Of these four, the lower transverse link is the main track control and is in the form of a wishbone with its base pivoted on the hub carrier and its tip ball-jointed onto the chassis. The upper transverse link has a single ball joint at each end and, in conjunction with the lower transverse link, controls both wheel camber and track. The lower fore-and-aft link takes the main thrust of acceleration and drag of braking. In conjunction with the reversed-wishbone lower link it also controls wheel alignment. The upper fore-and-aft link helps take brake torque reaction and can be angled for anti-dive effect. A typical layout of this kind has nine bearings per rear wheel, which can wear if they are not lubricated. Three bearings are on the lower trans-wishbone and two are on each of the other three links. This system is bulky and very likely to transmit road noise into the car.

Of designs for street use, those of Chevrolet and Jaguar are perhaps closest to racing practice, the latter being especially well planned for compactness and effective insulation so that noise is not transmitted into the car interior. In the Jaguar system, the driveshaft to each wheel acts as the upper transverse suspension link. Its two universal joints easily absorb the axial loads. The lower wishbone is replaced by a large-diameter tube with two spaced-apart roller bearings at each end, which controls wheel alignment without depending on fore-and-aft links. The whole assembly is rubber-mounted in the car's hull so that it can twist slightly around wheel axis, to cushion the transmission—as would a Hotchkiss-drive axle. Two fore-and-aft links below the car's doors transmit drive thrust or brake drag from the suspension sub-assembly to the car. This design is not cheap. It depends on heavily stressed roller bearings and separate sound suspension rubbers, but offers fine all-round results.

The majority of earlier i.r.s. systems on production cars went to the other extreme—simplicity. These were swinging half-axle pattern. That simple design mounted a rear wheel on the end of a rigid shaft equal in length to almost half the car's track width and pivoted this shaft at a universal joint alongside the chassis-mounted differential. Perhaps a fore-and-aft radius arm was used to steady the half-axle against brake reactions. To relieve the drive-shaft stresses, some swing axle designs support the wheel hub on a wishbone-shaped link with its pivot axis pointing toward the universal joint center. This minimizes fatigue of the rotating shaft without altering suspension geometry.



JAGUAR SYSTEM for E-type sports cars uses wheel-driving shaft as the upper one of two suspension links. S-type sedans have similar suspension.



UNIVERSAL JOINTS in Jaguar i.r.s. easily absorb axial loads. Lower link is a tube of large diameter which controls wheel alignment.

RUGGED AND INEXPENSIVE, swinging half-axles i.r.s. is used with varying success on such rear-engined economy cars as Renault, Skoda and Volkswagen. Much know-how is available about setting it up to conceal inherent shortcomings which made some early examples of the layout potentially unsettling. Large changes of wheel camber with load reverse the natural effects of extra weight on rear tires. The car becomes more stable instead of less stable when its laden rear wheels lean inward. Quite large track changes occur with half-axles pivoting at points high above the road. This opens up the possibility of side thrust forcing the outer wheel under the car during cornering. In such cases, the car rises on tiptoe, only oversteering at first as wheel camber increases. If the driver does not correct this oversteer quickly, he may lose control.

A successful refinement of the swinging half-axles i.r.s. is used by Mercedes-Benz. It is called the "low pivot system" because it is designed with a pivot low enough to prevent the unpleasant "tiptoe" effect during fast turns. One half-axle carries the final drive gears and has a pivot below them. The other half-axle swings from the same low pivot which has a universal joint to provide telescopic plunge. This system lengthens each axle half to reduce changes in wheel camber, but does put propeller shaft torque reaction back into the rear suspension linkage as was the case with a rigid axle. Progressive refinements which Mercedes-Benz added to the low-pivot divided axle began with a central spring between the axle halves which adds bump stiffness without roll stiffness. It has just the opposite effect to an anti-roll torsion bar on a suspension that tends to have rather too much inherent roll resistance. This central spring now can have pneumatic action, so that it pumps itself up over bumps to restore the ideal riding height and average wheel camber however heavy a load the car is carrying.

Almost as simple mechanically as the divided axle is the use of one trailing arm to carry each rear hub. This arrangement at present is almost entirely confined to front-drive cars such as Citroen and BMC Mini-Cooper, although it also is found on Japan's Honda sports car. Independently sprung wheels that stay parallel to the car when they rise and fall over bumps also lean outwards with the car on corners. This reduces the cornering power of the tires. There is no alarming "jacking up" on turns with trailing link i.r.s., but on rear-drive cars it has tended to provide slow steering response.

This trailing-arm form of i.r.s., like most others, poses problems of transmitting power through differential-to-wheels shafts which must vary in length. Torque in an axle shaft is approximately double that in a propeller shaft, quadrupled by axle gearing if the ratio is 4:1, then split into two equal halves by the differential gear. If torque loadings make splined telescopic couplings reluctant to slide, friction here can actually lock the ▶

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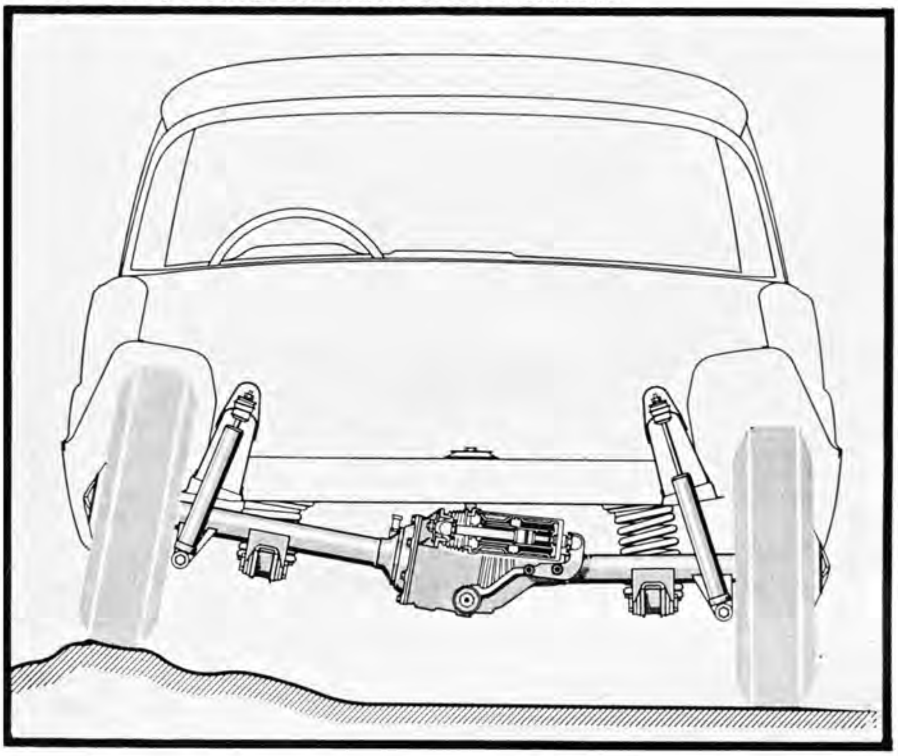
springs solidly in some unpredictable position during full power acceleration.

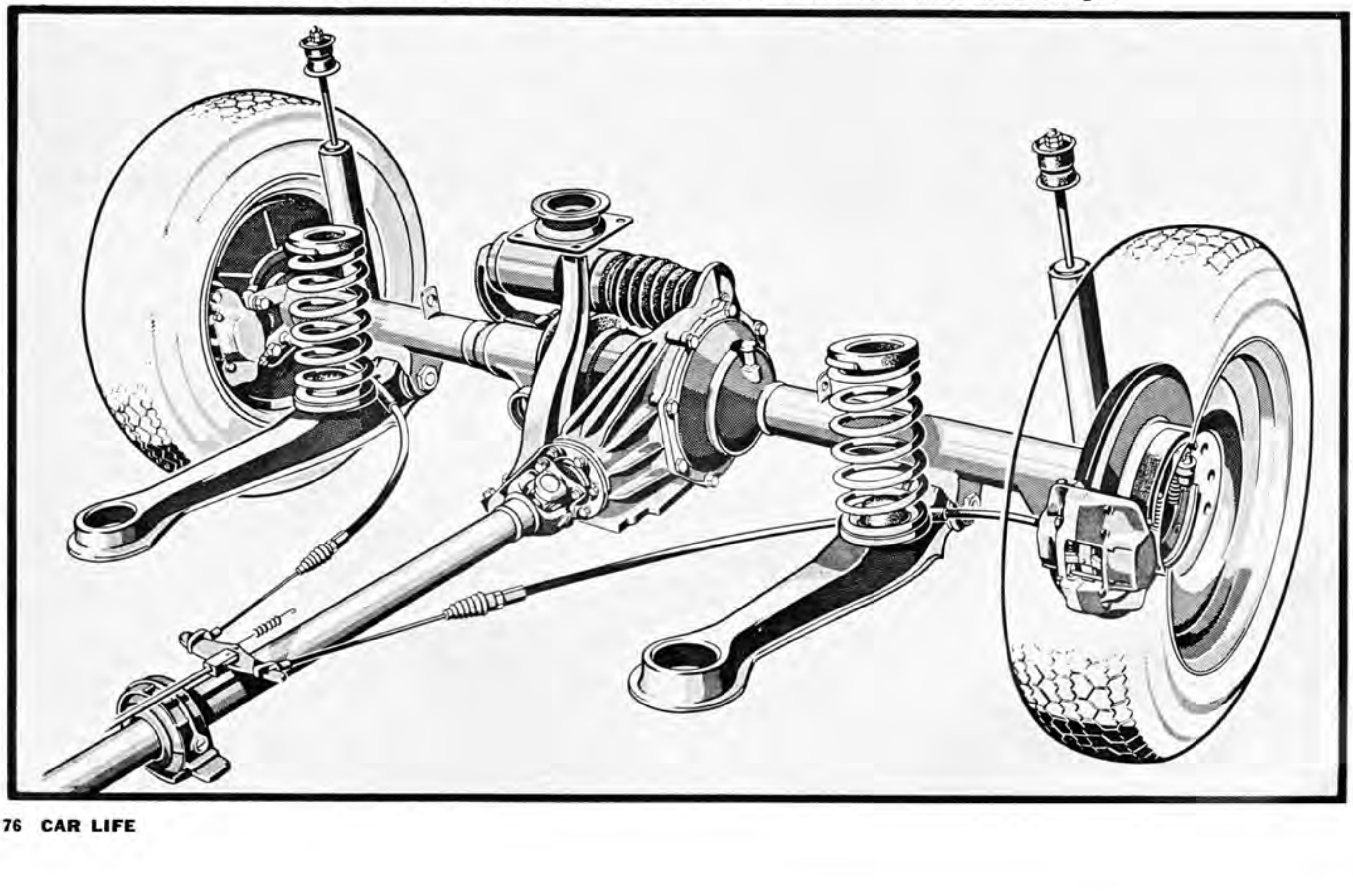
Car designers in several parts of the world have found they can produce better car handling and can reduce driveshaft plunge by adopting a compromise between divided-axle and trailing-arm i.r.s. layouts. The fashion now is to pivot the single wishbone-shaped link locating each rear wheel on an axis which is angled so that the link splays outward and rearward. The pivot axis intersects the axis of the rear hub somewhere on the far side of the differential. This gives wheel movement equivalent to swinging "half axles" lengthened to reach across to pivots on the far side of the car, in the manner of a Ford truck i.f.s. (*CL*, Dec. '64), with much reduced changes in wheel camber as the springs deflect.

THIS SORT OF semi-trailing link i.r.s. offered a fine combination of ride comfort with handling precision on the BMW 1500 and on subsequent more powerful models from that factory. It has since been adopted for the Triumph 2000 sedan and TR4A sports car and Rolls-Royce Silver Shadow sedan. Honda and other makers are expected to adopt the layout shortly. Mechanical complexity is not exaggerated. Each rear wheel needs only two suspension pivots and a driveshaft with two universal joints, plus a telescopic coupling. It has been found reasonably easy to mount the four suspension pivots and the final drive gearing together on a sub-frame. Three or four rubber mounts keep noise out of the body interior and are spaced widely enough at corners of this subframe to show little ill effect on steering accuracy. On this suspension, there is enough "swing axle" effect to pro-

MERCEDES' LOW pivot swinging half-axles reduce changes in wheel camber and track. Auxiliary air spring between halves has zero roll resistance.



ONE HALF-AXLE carries final drive gears and has a pivot below them. The other half-axle swings from the same low pivot, which has a universal joint to provide for telescopic plunge. The system lengthens each axle to reduce wheel camber changes.



vide adequate, rather than excessive, resistance to cornering roll and enough "trailing link" effect to offer some anti-dive during braking.

Ford of Britain has evolved a version of this semi-trailing link i.r.s. which, while retaining all its proven advantages, eliminates the need for expensive and potentially troublesome telescopic splines in the wheel driving shafts. Ford has done this by borrowing a principle which is used in the de Dion rear axle of the Rover 2000 sedan and previously was tested on a single-seat racing Rover by young engineers of that factory.

On the Rover 2000 there is a de Dion rear axle, a dead tube which holds the two rear wheels upright but does not carry the final drive gears. Unlike previous designs of this kind, the Rover layout does not have telescopic driving shafts from the sprung differential to the unsprung wheels, but makes these shafts inextensible. Instead a telescopic coupling is put into the de Dion axle tube so that each rear hub can follow a radius determined by the driving shaft. The system has proved a notable success and a variant upon it since has been applied also to Marcos sports cars.

This Rover principle of letting twin-universally-jointed driving shafts from the differential control rear wheel track has been applied by Ford to semi-trailing link i.r.s. To give each rear hub the necessary slight lateral freedom, the inner pivot on each rear suspension wishbone has been given a shackle, exactly equivalent to the compliance link which provides a small range of fore-and-aft flexibility in Mercury front suspensions. No parts on this system need lubrication. The pivots, with small angular movements, are rubber and the needle roller universal joints are sealed.

BECAUSE THE Zephyr and Zodiac models on which this i.r.s. was introduced in April 1966 have a longer wheelbase than the models they replace, Ford of Britain disguised their early test models under Fairlane body shells of the same 115-in. wheelbase. Gains have been made in ride comfort and in directional stability at high speed over bad surfaces. For best cornering, a slight alteration of pivot axis angle to give rather less change of wheel camber as the springs deflect may prove advantageous on future models. Slight toe-out of the rear wheels on full spring compression proves harmless, and the Ford engineers actually welcome it as offsetting the effects of wheel camber changes on tire cornering power.

In some quarters a prejudice against independent rear suspension still is evident. Unsuccessful past examples, designed when basic principles were less fully understood, were cited as reasons for not re-tooling plants equipped to manufacture rigid-axle cars. That prejudice against i.r.s. is being worn away as one car after another proves that a roomier and more fully padded rear seat, smoother riding over bad surfaces and safer controllability now can be achieved by eliminating the rigid axle.

LOTUS Elan strut i.r.s. is related to MacPherson struts used in i.f.s.

Widely-quoted production estimates that i.r.s. adds $100-$150 to the cost of a car may be true in the short term, but once good, simple designs such as that of Ford are tooled up, the feature which is used on Europe's cheapest rear-engined cars will cease to appear an extravagance on front-engined models. Experiences of Ford with the British 115-in. wheelbase sedans is being closely watched. The Corvette is unlikely to remain very much longer as the only front-engined American car with i.r.s. ■

TRAILING LINK i.r.s. on the front-drive Peugeot 204 uses a rubber-mounted frame cross tube on which both rear trailing arms are pivoted. The system provides compliance without fore-and-aft movement inducing any great changes in wheel alignment.