BROUGHAM HISTORY

Air Suspension

Part I

by V. D. Polhemus and L. J. Kehoe, Jr.

Experimental Development of the Air Spring

WE have been striving continually to effect an appreciable ride improvement in our cars by trying such devices as torsion bars, single leaf, and other types of steel springs. We have managed some minor improvements, but always wind up facing the fact that steel springs have definite limitations.

In 1953 Fox and Labelle[1] listed six undesirable features present when steel springs are used. However, the limitation which causes passenger-car engineers the most concern is that steel springs are not readily adaptable to increased static deflections without affecting the relationship between curb standing height and full-load ride clearance. This is probably the most controversial suspension problem today. The industry's trend, with lowered roof heights bringing lower floors, has intensified the chassis engineer's search for a solution which would permit maintaining soft ride without undesirable compromise.

Some years ago, feeling that a fundamental change was necessary, we began a development program which produced the type of air spring now in production for the Cadillac Eldorado Brougham.

To use air as a suspension medium is no new idea. It was proposed over 50 years ago but, as with many other ideas, practical application has been delayed.

At the beginning of our air-spring development program, we established certain criteria: reasonable cost and size; long life; adaptability to any type of suspension; its fundamental concept should permit any desired length of stroke being obtained without altering other design features; and last and most important, it should have correct rate characteristics.

In Fig. 1 is shown what we feel is the best shape of load-deflection curve. Considering first A-B, the curve for a considerable distance on either side of normal position is a straight line, neither gaining nor losing rate. This characteristic, when coupled with some form of standing height adjustment, permits a consistently balanced ride over major road irregularities. Second, the spring should have (at C) a high end load to reduce any sensation of "crash-through" over ruts and pot holes. Third, there should be a gradual blend (B-D) between the center (low rate) section and the high end rate (D-C) portion of the curve. Without a gentle transition, those abrupt swells, known variously as "donkey backs" or "thank you ma'ams," can upset an otherwise excellent ride. The last factor, while not a necessity, is very desirable. We feel that on rebound (at point E) a considerable reduction in load is worth seeking, both to reduce lift on braking and accelerating and to prevent excessive input to the frame and suspension members. Of course, a gradual blend (A-E) should be provided.

Somewhat over 10 years ago we investigated the double-convolution air spring and have retained an eager interest in it. This form of air spring has much to recommend it for certain applications. It has proved itself as a heavy vehicle supporting device, having an excellent record of durability in its use on the General Motors Coach.

Certain basic problems led us to bypass the double-convolution bellows approach to passenger-car applications. As you are well-aware, scaling down an otherwise satisfactory device is not always a solution to an engineering problem. To appreciate the problems involved in using the double-convolution bellows in a passenger car, let us examine a familiar unit, one used on the GM Coach as a front-suspension spring. It has an outside diameter of 9 in. and has a stroke of 8 in.

At normal height it would have a load carrying capacity of 2000 lb at 65-psi operating pressure and might be used as a passenger-car front spring, if applied through a wishbone linkage. However, obtaining the necessary 300 lb per in. spring rate would involve using an additional 700-cu-in. reservoir. For long-stroke direct-acting rear-axle applications, the picture becomes more critical. A reduction in diameter to bring loads to, let us say, 1200 lb at 60-lb operating pressure means that we have reduced stroke to an unsatisfactory amount. Dynamic stability is, as with a coil spring, a function of spring rate, spring length, and spring diameter. It is apparent that it would be difficult to obtain longer stroke by increasing the number of convolutions because instability would result, and could be overcome only by guiding the bellows in some fashion. Even assuming that these difficulties could be solved, the load-deflection curve does not have the shape that we have previously determined to be the optimum.

In brief, with the double-convolution bellows, un-

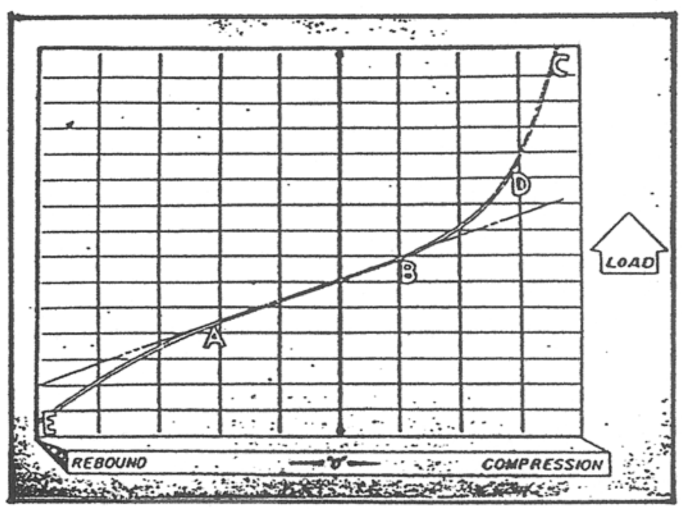

Fig. 1—Ideal load-deflection curve

[1] "Motor Coach Suspensions," by H. B. Fox and D. J. LaBelle. Paper presented at SAE National Transportation Meeting, Chicago, November 2-4, 1953.

desirable factors are present to a greater degree than we feel can be tolerated.

A piston compressing air in a chamber is a simple form of air spring. The load-carying capacity of this spring is a matter of simple mathematics: area of piston X gage pressure = load. Applying the tight-fitting piston and chamber principle immediately presents certain practical problems. It would be difficult to obtain a 100% seal against air leakage without paying an excessive penalty, both in dollar cost for precision machining and in friction.

Our next step was to increase the piston clearance and install a rolling seal (Fig. 2). At one stride we have solved two problems: minor size variations of the piston and cylinder are inconsequential, and friction is eliminated. We still retain the virtues of the original piston concept.

The diaphragm will present no unusual problem of manufacture, a backlog of experience in tire making having solved most of the difficulties connected with making a rubber-impregnated fabric which can withstand flexing to a practical degree. No air springs were ever made, of course, with the diaphragm in the shape shown in the model.

It will be recognized that this still represents the basic concept of the straight piston and cylinder, and that we have not as yet satisfied the conditions laid down in the original graph which indicated the ideal spring. We obtain the long low rate, but gentle buildup and the high end load are missing. What is required is a variable-area piston (Fig. 3). This we obtain by increasing the outside diameter of the diaphragm and adjusting the piston and retainer to permit a regulated adjustment of effective piston area.

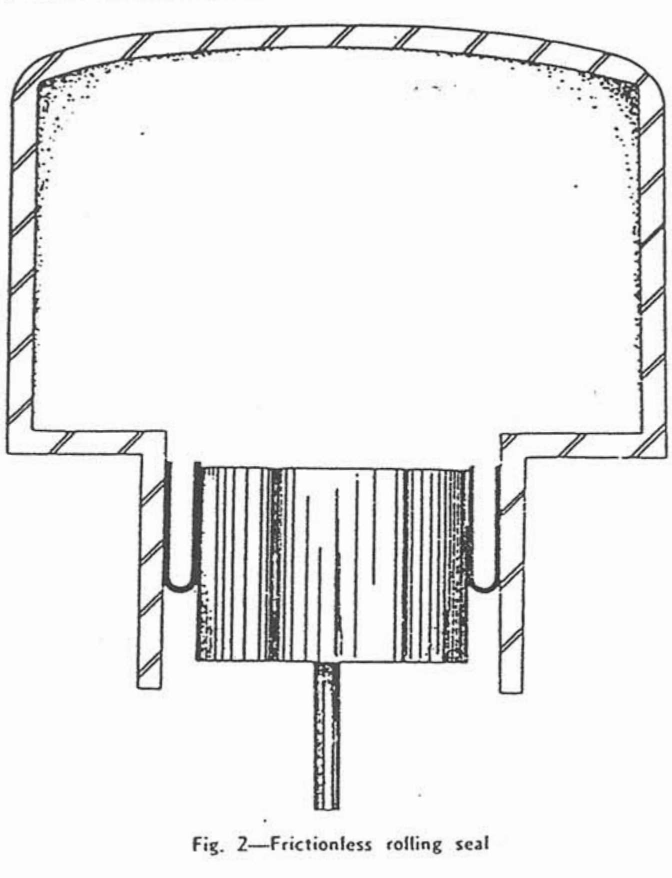

Fig. 2—Frictionless rolling seal

With this early hypothetical spring, the diaphragm is restrained between the piston and the outer skirt (diaphragm retainer), thus the effective diameter is fixed for some distance below and above the normal position. As can be seen from the upper piston position, when the diaphragm is lifted up and out of its previously restrained stations, an increase in effective diameter (and hence an increase in effective working area) is obtained. Looking at the view of the piston in its lowest position, it can be seen how the diaphragm, lifting away from the piston, produces greatly reduced effective diameter. In all positions the length of a horizontal line, tangent to the meniscus, determines the effective diameter. It will be noted the percentage increase in effective area in the full-compression position is less than the decrease in full rebound. This is necessary due to the fact that air pressure increase, as the piston enters the chamber, tends to assist in load buildup, while in rebound the air-pressure drop requires a more rapid reduction of effective piston area.

With our basic theory of design for an air spring established, the next step was developing a method of attaching the diaphragm to the piston and chamber. Two methods have been employed, both equally acceptable. The first, as shown in Fig. 3, used a circular wire bead ring encased in rubber, which sealed with a clamp plate to the piston and between the skirt and chamber at the outer rim. This forms a very satisfactory connection, and was used for some time in the early stages of the program.

Concurrent with our theoretical and design studies, an intensive program of car-building and road-test evaluation was instituted. It seemed quite obvious, at the time, that the best way of obtaining the air-chamber volume was to use the interior of the frame cross members. The first road car used aluminum cross members, front and rear. It presented seeming advantages which were not borne out in practice. We were troubled with porosity before installation, and in spite of a multitude of attaching screws, a reduction in frame stiffness was experienced in comparison with the conventional all-steel frame.

Drawing on this experience, a second car was built using integral-steel cross members containing the air chambers. This car was sent through our standard 25,000-mile durability test primarily to obtain information on cold-weather operation over gravel, freezing slush, ice, and snow. The chambers were built to simulate what could be expected from production tooling, with production limits, with the intention of introducing a sealant similar to that used in aircraft fuel cells. Again practical difficulties arose: The sealant was unpredictable in its adhesion; frame motions tended to cause leaks; we were unable to devise a suitable method of field repair; and, probably the greatest hurdle of all, there was inflexibility of chamber size alteration between models.

With the foregoing in mind, the next step was individual pots (Fig. 4). Advantages of this system are:

1. Simple shapes with reduced amount of welding.
2. Structural stresses removed from chambers.
3. Bench testing is possible.
4. Ease of installation and field service.

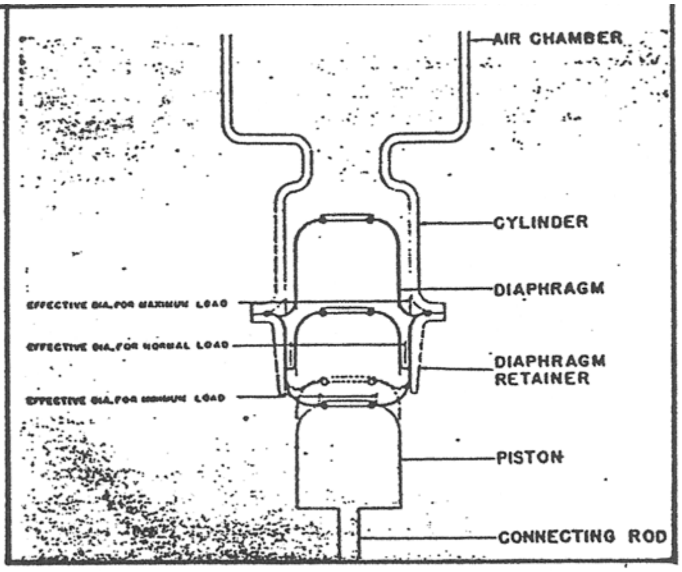

Fig. 3—Variable-area piston

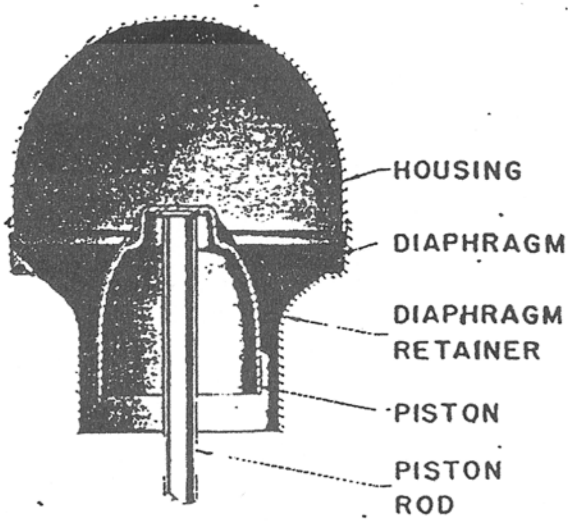

Fig. 4—Individual air spring

5. Interchangeability with optional steel springs.

At present, we see no better method.

Fig. 4 also shows the second method of attachment developed for connecting the diaphragm to the piston and the retainer. The steel bead rings are still used, but a wedge shaped rubber lip surrounds each ring. The internal air pressure on the rubber lips forms a seal much the same as does the tubeless tire to its rim. The diaphragm is installed in the retainer by temporarily deforming the normally circular outside bead into an oval shape that will pass up through the circular opening of the retainer.

In development work with its constant changes, of course, we cannot justify draw-die costs, in either time or money. Retainers and housings are usually made by spinning, and we find the surface obtained is adequate for sealing without any machining.

Selection and application of the suspension is the prerogative of the division using it and will be covered in Part II of this paper. However, brief mention might be made of some road-test cars used in the experimental development by engineering staff.

No serious problems are encountered when adapting air springs to a torque-tube rear suspension, so this type of installation was used to good advantage all during our development program.

Cars using a Hotchkiss suspension do not lend themselves to air-spring installation as readily as the torque-tube type. In Fig. 5 is shown the basic 4-link suspension we have used on cars originally equipped with Hotchkiss rear suspensions. We have made the minimum of frame changes, retaining the outer frame members. It will be noted that the piston rod is connected directly to the axle and piston stroke is the same as vertical wheel movement.

Spring Design

As previously mentioned, the desired load-deflection curve is the basis of preliminary design (Fig. 1). Knowing the load, operating pressure, and desired rate, the effective piston diameter is readily calculated, with clearance between the piston and retainer being established at a figure that has been

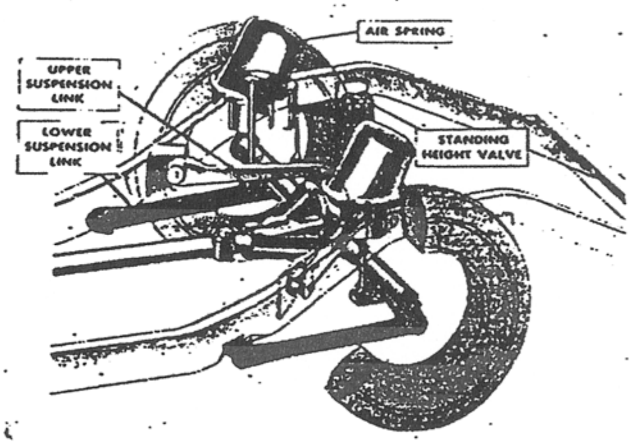

Fig. 5—Air springs as applied to 4-link rear suspension

found, from tire building experience, to be satisfactory for long life. Volume of the chamber is obtained from the formula:

$$R = \frac{\gamma \cdot Pa \cdot A^2}{V} \qquad (1)$$

This of course, applies only to the derived A-B section of the curves, from the basic equation:

$$R = \frac{dw}{dh} = (Pa - 14.7)\frac{dA}{dh} + A\frac{d\,Pa}{dh} \qquad (2)$$

Gamma is accepted as being 1.4, the usual adiabatic factor for diatomic gases, but caution should be exercised since under certain conditions the spring may function in a region approaching isothermal operation, with the attendant lower rate.

When we first began developing the diaphragm spring we felt that the curve should show (in the B-C section) a constant rate of acceleration and so calculated it. With more experience we now use a simpler method. When the straight section of low rate A-B is established, the desired end load is placed on the graph. We have a family of curves which we recognize as giving a desirable blend and end rate. The same procedure is followed on the

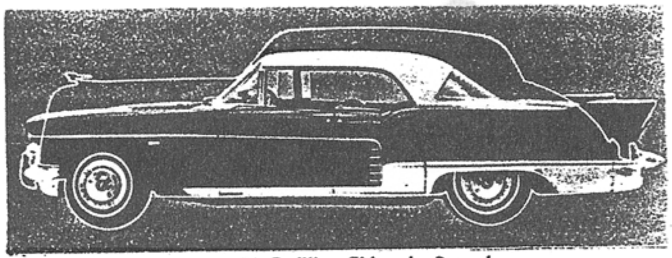

Fig. 6—1956 Cadillac Eldorado Brougham

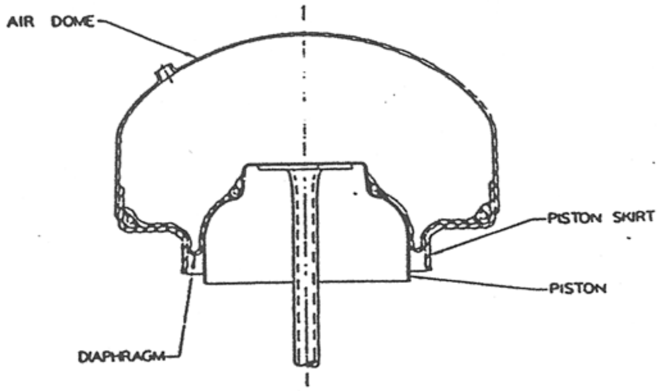

Fig. 7—Early design of front air spring

unloading portion A-E of the curve.

In the example shown, the upper curve is calculated and found to be a fifth-order equation:

$$(W = 1227 + 163.6\,h + 1.80\,h^5) \quad 0 \leqq h < 3.66 \qquad (3)$$

For the unloading portion of the curve the equation is:

$$(W = 1227 - 163.6\,h - 2.4\,h^5) \quad 0 \leqq h < 4.91 \qquad (4)$$

With the values fed into an IBM No. 704, the profiles necessary for the piston and retainer can be established in 10 min. Before the programming was established it required two mathematicians two days to complete one calculation series.

We feel that with the diaphragm type of air spring we have met the conditions we laid down at the beginning of our development work regarding cost, size, life, adaptability, and ease of "tailoring" rate characteristics.

Part II

by F. H. Cowin and S. L. Milliken

THE advantages of air springing had been interesting to us for some time and when the Eldorado Brougham was proposed, the air spring seemed to be particularly attractive. The preliminary studies and experimental testing with Cadillac modifications of the engineering staff designs increased our liking for the springs.

1. The car was to be only 55½ in. high (Fig. 6) which was 3½ in. lower than our standard sedan for 1957 and 6½ in. lower than the sedan of 1956. All of these are measured at the standard five-passenger load conditions, of course.

Air suspension offered a constant-height feature, with the car at the same height whether at curb weight or under full-load conditions. Between these extremes of loading, the car would stand at the same height as in the design studio or on the showroom floor. Even with the trunk filled with luggage, the styled appearance would be retained.

2. The height available for ride clearance between the axle and the frame could be used more efficiently.

Air-spring suspension would insure a constant ride clearance under all load conditions and permit a ride rate and balance that would not change from minimum to maximum load.

3. The air suspension would permit lower ride frequencies, thus giving us greater latitude in choosing the best characteristics for both ride and handling. The constant height gives constant-ride travel so the ride rate could be lower without excessive bottoming. It would give the ideal boulevard ride without compromising the handling characteristics.

With these promising advantages of the air spring, supported by our experimental testing on modified production cars, the following design parameters were established for the new Eldorado Brougham springing:

1. The ride frequencies would be approximately 55 cycles per min, or about 15% lower than those with our steel springs. This was a good compromise, we felt, for handling and ride. Ride rates lower than this might introduce problems in handling, and we did not want to impair those important characteristics for the sake of basic ride.

2. The diaphragm type of air spring would be used. The amount of development work and the experience up to that time with experimental installations favored the diaphragm type, rather than the type that is used on large passenger-bus suspensions.

3. The pressure in the air domes at normal passenger load would be approximately 75 psi. This pressure would permit a piston of reasonable size that would not necessitate a larger air dome than we could conveniently accommodate in the chassis. This air pressure would not be too demanding on the rubber diaphragms.

4. The front suspension would be a modification of our basic parallel-link design, with air springs replacing the usual coil springs. This would permit considerable interchangeability of frame and suspension parts with the standard line of cars, which would continue with coil-spring front suspension.

5. The rear suspension would be of the so-called 4-link type with a rigid axle. This would be entirely new and different from the leaf-spring and Hotchkiss-drive design used on the standard line of cars. The 4-link design would permit independent control of roll center, lateral stiffness, and acceleration squat.

The roll center could be raised and established definitely to assure proper car handling with the proposed lower spring rates.

Lateral stiffness could be increased to reduce rear-end sway and steer. Understeer could be set and depended on as the suspension height would not change with the load.

The swing arm for the rear axle could easily be set for the best performance between rear-end rising or lowering on acceleration; a latitude that was not possible with the leaf-spring design.

This type of suspension would give better control of rear-axle pinion windup under both braking and acceleration torque.

6. The air system would be of the "Open-type," with inlet air for the compressor being drawn from the atmosphere. Air vented from the air springs would be discharged to the atmosphere.

The engineering staff installations had used a "closed" system, with the used air returned to a low-pressure tank from which it was drawn by the air compressor for re-use in the air spring. The proposed "open" system, in conjunction with our leveling-system controls, would use only small amounts of air which could be supplied by a small, electrically-driven compressor requiring little current. The "open" system would not require a low-pressure tank or the associated plumbing.

With these major parameters established, serious design work was started to adapt the basic design to the chassis requirements of the Brougham body. The design work was done concurrently with that for the 1957 standard cars.

Front Suspension

The adaptation of the engineering staff's basic design to our Eldorado Brougham naturally brought many changes in detail. Mounting the air spring in the frame-front cross member is a good example.

It was desirable that the frame-front cross member be common to both the air-spring and the coil-spring suspensions.

With the spring rate established at approximately 85% of our 1956 rate, and the air-spring position determined, the volume required in the air dome was fixed at 450 cu in. The normal working pressure was to be 75 psi. But the original design of piston, diaphragm, and air dome (Fig. 7) resulted in an air dome that was too large for the space available in our frame-front cross member.

This led to a basic redesign of the piston. It was made with a hollow shape and a 3-in. diameter hole at the top. The 126-cu-in. volume in the piston reduced the volume required in the dome by 36%. The smaller-sized air dome would then fit into the space available in the front cross member. The piston and diaphragm are shown in the normal-height position (Fig. 8).

The first design of the piston (Fig. 7) relied upon air pressure in the dome to hold the inner bead of the diaphragm against the piston. And the bottom of the piston was held into a spherical depression in the lower control arm by the same pressure.

But experience showed the desirability of having the piston mechanically retained, so it could not jump out of position if the pressure was lost during car repairs or improper jacking. Mechanical retention to the diaphragm was obtained by adding a narrow strap, or clip, (Fig. 8) that twists into the top opening of the piston and extends over the inner bead of the diaphragm.

At the bottom of the piston, a stud was added, which bolts into the lower control arm tray. The head of this stud is encased in a phenolic resin cover that has a spherical shape to match the seat in the bottom of the piston.

In the first designs of the air dome, (Fig. 7) the dome was welded to the piston skirt. This made it necessary to install the diaphragm through the smaller opening in the skirt and then spring the outer diameter to its proper seat in the air dome. Experience showed that a separate skirt, bolted to the dome after the diaphragm was in position, would be better (Fig. 8). This permits a stiffer wire in the diaphragm's outer bead and a slight interference between the bead and the dome for better sealing.

The separate dome and piston skirt design also permitted an improvement in the skirt, for it could now be tailored to its particular task. The first skirts were made of fairly light steel, but laboratory tests revealed deflections in the skirt, and the two-piece design made it possible to: increase the gage of the steel used, add reinforcing sections, and add additional flanges.

This change to separate dome and skirt was also an aid to the production department in that the assembly of the dome, piston, and diaphragm was simplified. Also, the bead seat in the dome was exposed and could be better controlled for size and finish.

Diaphragms—The all-importance of the diaphragm in this suspension is apparent. The early diaphragms, made by the U. S. Rubber Co., showed promising durability, both on the cycling tests and in experimental installations. Fig. 9A shows the front diaphragm.

It is of two-ply nylon construction and has solid

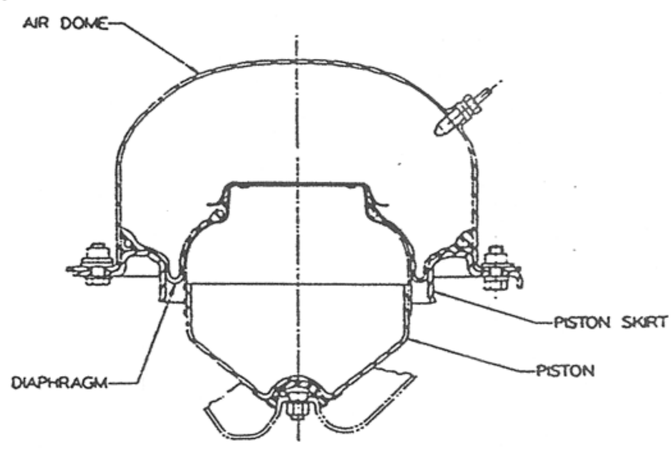

Fig. 8—Final design of front air spring

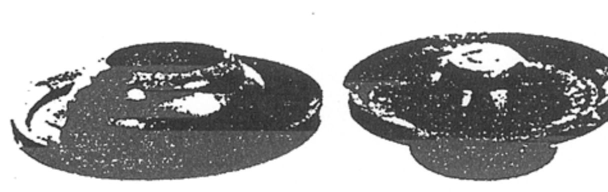

Fig. 9—(A) Front diaphragm (B) Rear diaphragm

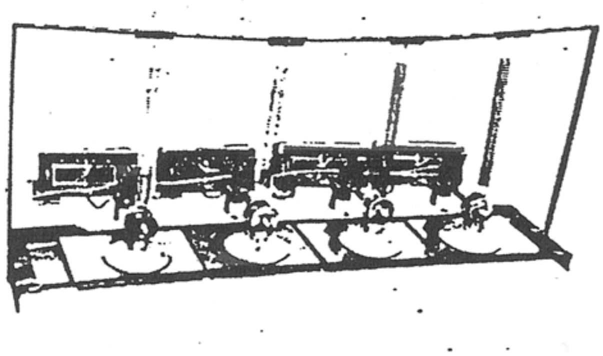

Fig. 10—Test apparatus used to evaluate sealing qualities

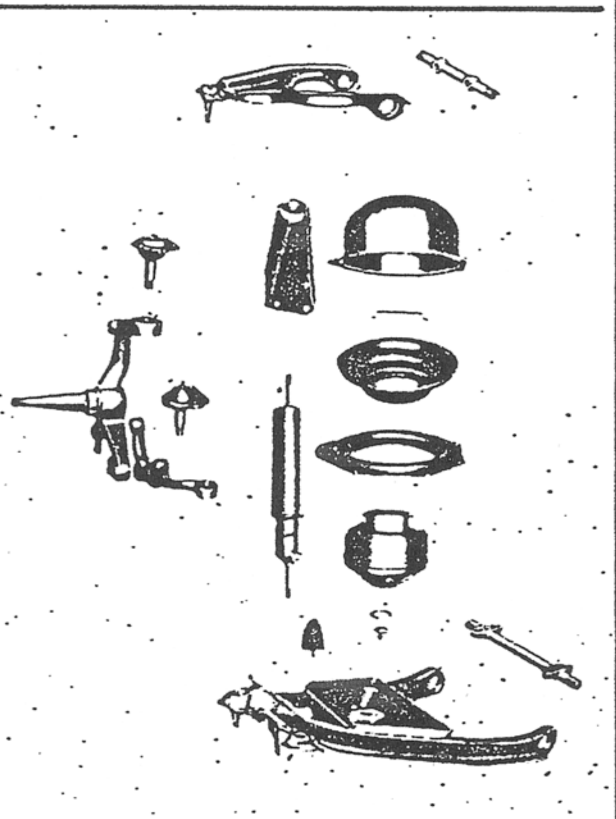

Fig. 11—Exploded view of front suspension parts

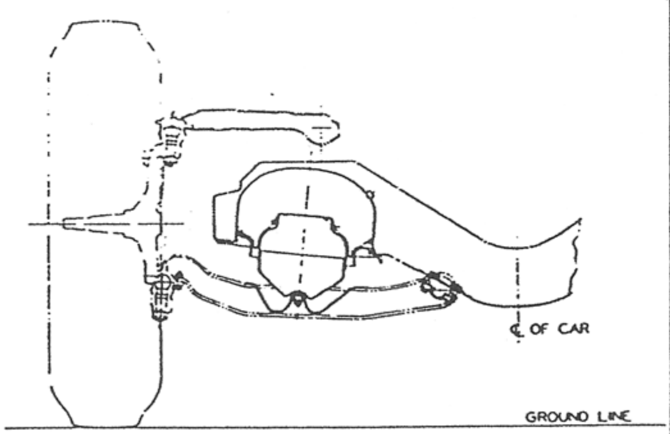

Fig. 12—Front suspension

wire beads. Early diaphragms had braided bead-wires, but tests proved that solid bead-wires are stiffer and assure a better seal. The solid bead-wire was possible after the air dome and piston skirt were changed from one-piece to bolted construction. Natural rubber is used for the covering because of its good flex life. It is compounded for ozone resistance.

As the Cadillac designs developed, changes were required in the size of the diaphragms, and this introduced some new problems. The cord pattern, and resultant strength of the diaphragm, is satisfactory if the diameter of the inner bead is at least 30% of that of the outer bead. This influenced the proportions of the spring. The cords must be well-secured around both beads, and the beads must be precisely located to prevent any movement of the bead on the seat. Movement would result in bead chafing and possible leaks.

The early diaphragms were built under laboratory conditions and it was possible to have thin wall sections, with each cord covered with rubber. Because it was realized that it would not be practicable to hold these close tolerances on the production diaphragms, much laboratory and road testing was done.

This resulted in a section that allows enough rubber to insure good coverage of the cords, even if they float toward one side of the membrane during the moulding cycle. Wall thickness is still thin enough to insure low strain in the outer skin of the membrane during the stroke cycle. The wall is approximately ⅛ in. thick for all of the area between the beads.

At first, radial grooves were moulded into the diaphragm for venting during the moulding operations, but this sometimes exposed the cords and caused air leaks. Development work resulted in a change to radial lands that provide mold venting but do not expose the cords.

Careful laboratory work, followed by extensive testing under extreme conditions, has resulted in diaphragms with a life of 1,000,000 cycles on the test rig.

Diaphragm Sealing—Early tests, both on the road and in the laboratory, showed the need and the difficulty of maintaining a good air seal between the diaphragm bead and the dome and piston.

The original diaphragms had tapered bead seats that necessitated a reverse draft in the air-dome bead-seat area. This was changed to a vertical bead seat that allowed a normally drawn sealing diameter in the air dome. This, along with the separate-piston-skirt construction and the stiffer bead-wire mentioned earlier, allows a slightly oversize diameter on the diaphragm and a light interference at the seal.

The surface finish of the air dome at the bead-seat area is most important. We thought, at first, that this would be comparable to the sealing of a tire bead to the rim, but development work in the laboratory showed a marked difference. While a tire rim is formed by rolling, the air dome and piston are drawn in a die and the resultant surface is not as good for sealing.

The apparatus shown in Fig. 10 was devised to evaluate the sealing qualities of different surfaces. Rubber suction cups, 3 in. in diameter, were attached to each specimen. Springs, loaded to a 4-lb

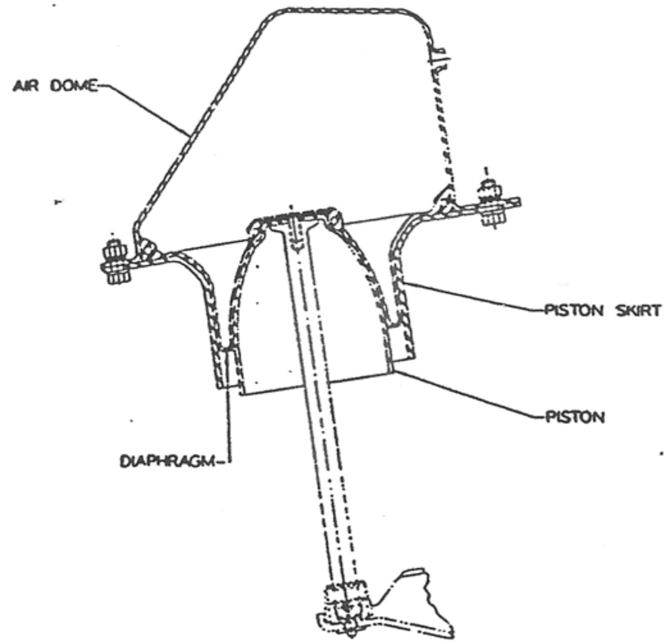

Fig. 13—Rear air spring

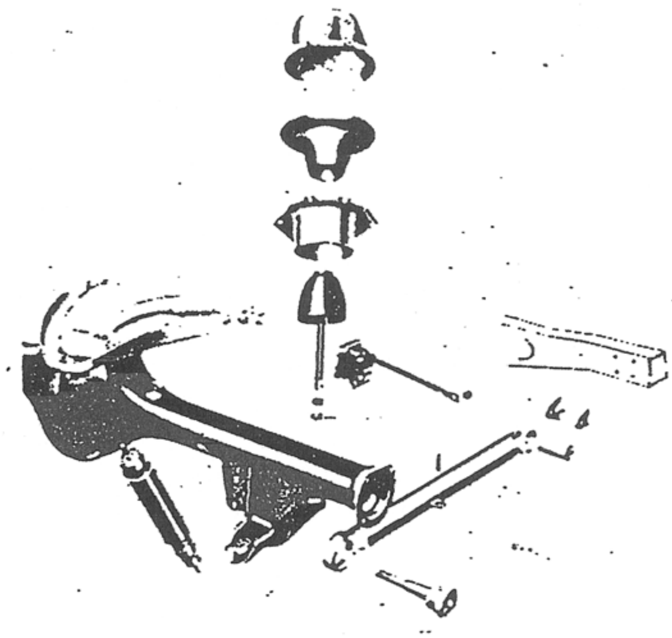

Fig. 14—Exploded view of rear suspension parts

pull, attempted to pull the suction cup from the steel surface. The time required to do this was a measure of the airtightness of the seal between the rubber and the steel surface.

Many methods of finishing, plating, and sealing the steel surface were investigated. This resulted in the following specification for the air domes and pistons:

1. Use mill-run 1008 cold-rolled satin-finish steel with surface of 45-micro-in. maximum.
2. After forming, buff the sealing areas to remove die marks.
3. Apply a rust-preventive phosphate coat.
4. Apply black primer paint to the same area.
5. Cover sealing areas with Silicone grease #4.

The relation of the air dome, diaphragm, and piston to each other and to the suspension parts is shown on this exploded view (Fig. 11). The shock absorber works between a bracket on the lower control arm and a bracket which is bolted to the frame side bar.

Fig. 12 shows the relation of the air-spring assembly to the lower arms of our parallel-link front suspension. The air dome is bolted to the underside of the frame cross member. The locating and retaining stud at the bottom of the hollow piston bolts into the lower control-arm tray.

Rear Suspension

The parts for the rear air springs are not interchangeable with those at the front (Fig. 13). The piston is of smaller diameter, as dictated by the air pressure, spring position, and geometry for the 4-link suspension. The top is closed and has a bullet-nosed shape. A rod is anchored in the piston and connects it to a bracket on the rear-axle housing.

The lower end of the rod is domed and bears in a steel cup that is attached to the axle bracket. The

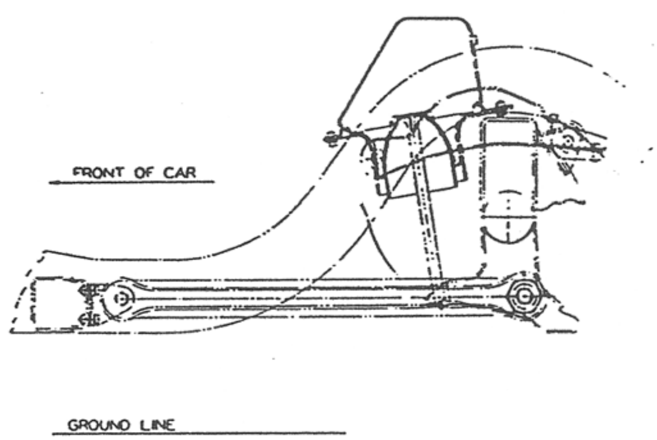

Fig. 15—Rear suspension

rod is loosely pinned to the cup to prevents its jumping out of position at any time.

A rubber seal around the cup and the rod retains the grease and insures long-life lubrication for the bearing.

The shape of the dome was determined by the volume required (300 cu in.) and the space available. The attachment to the piston skirt is the same as at the front spring.

The rear diaphragm (Fig. 9B) is of the same type as the one used at the front spring, but is not interchangeable. The center of the diaphragm is solid and has a steel washer vulcanized in place. A stud on the underside of this washer screws into the tapped head of the piston to give a mechanical tie between the diaphragm and the piston.

Fig. 14 shows the relation of the components to each other, along with the lower arms and the upper yoke that form the 4-link suspension.

Fig. 15 shows the relation of the air spring to the complete rear suspension. The lower control arms are parallel to the centerline of car. The front end of the arms anchor to the same frame outriggers that are used for body mounting bolts. Rubber bushings are used at this point.

Ball joints attach the rear ends of the arms to the same bracket on the axle housing as carries the lower end of the air-spring piston rod.

The upper control arm of the so-called 4-link suspension is in the form of a yoke, as this gives a better mounting to our "Tubular Center-X" frame. Rubber bushings are used between the front end of the yoke and the frame cross member. At the rear of the yoke a ball joint is used for the mounting to the axle housing. The length of the upper yoke and of the lower links, along with the height of their attachments to the frame and to the axle, gives the desired geometry for the proper swing-arm length, rear-end steering, roll center, and rear-end lowering on acceleration.

The combination of bushings and ball joints in the arms and the yokes gives freedom in roll, desired noise isolation, and good durability.

Considerable design and development work was required on the upper yoke to insure sufficient strength to handle the lateral, fore-and-aft, and tramp forces exerted by the axle.

Testing at our proving grounds disclosed fatigue failures in the ball-joint mounting bracket on the axle housing. Strain gages were mounted on the bracket and the axle housing to determine the transverse and fore-and-aft loads during Belgian Block and other road driving. The loads were found to be high (3400-lb maximum) and about equal in magnitude. A laboratory set-up was then evolved to permit controlled testing of the mounting and to determine the necessary strength.

Fig. 16 is a picture of the Eldorado Brougham chassis showing the suspension components mounted in the frame. The lower arms and the upper yoke that form the so-called 4-link suspension at the rear axle are shown. The air-spring installation, plus the control arms and new frame parts that were required in our design, added about 45 lb to the weight of the car.

Leveling System

As mentioned previously, the leveling system used on the Cadillac Brougham is of the "open" type, in which the air is compressed from atmosphere and is exhausted to atmosphere after being used.

Many systems of valve control were studied and tested in the search to find the best control for the wide range of conditions that affect car height. The system found best for all the conditions of loading and operation combines simplicity and dependability. Four solenoid-controlled valves in one package meter the flow of high-pressure air to the leveling valves at the wheels.

The first pair of valves allow pasage of air only when a car door is open or the ignition is on. Of this pair, one valve controls the inlet air to the leveling valves, with the other valve controlling the outlet air. When the car doors are closed and the ignition is off, there is no passage of air and the leveling system is locked out. This provides for all conditions of jacking, shipping, and parking.

The second pair of solenoids control the flow of air under operating conditions. When any door is opened, there is an unrestricted flow of air to the leveling valves and any change in car height, due to entrance or egress of passengers is corrected quickly. This occurs with the ignition on or off.

During all driving, there is a restricted flow of air through a coined orifice in the solenoid valve. This permits constant adjustment of car height during running to compensate for loss of weight (as with the consumption of fuel) or for added weight (with an accumulation of mud or ice). And it allows a correction in height when the car is driven away after having been parked on a side hill, or with one wheel on a curb or in a deep hole. This leveling can be done without excessive use of air.

Severe drops in temperature during overnight parking will, of course, reduce the pressure in the air dome and, consequently, lower the car height. This is corrected as soon as a car door is opened.

Briefly, the car height is quickly adjusted to a new load condition when a door is opened and is constantly adjusted when the car is in motion, but at a much slower rate. During jacking, parking, and shipping, the levelizing system is locked out.

Leveling Valves—The leveling valves control the pressure in the air spring at each wheel to keep the horizontal plane of the car parallel to, and a fixed distance above, the ground. The valve is mounted on the frame, and connected to the wheel control arm with a mechanical linkage. Any change in height of the frame actuates the valve, and high-pressure air is admitted to or exhausted from the air spring to restore the normal height of the car.

There are two leveling valves at the rear suspension, one at each air spring. At the front, one leveling valve serves both of the front springs. This arrangement of the three valves establishes the plane for the car and avoids the fight effect that would accur with a leveling valve at each of the four wheels.

Our leveling valves are made by Delco Products Div. and are the result of much experimental testing and development with that division. The only valves available at the start of the program were too large, too heavy, and too complicated for our needs. (Leveling valves of the electrically controlled type were tested during the development program, but did not have the durability of the mechanically actuated valves.)

Each leveling valve has two tire-type valves (one for intake, one for exhaust). They are operated directly by the linkage from the lower control arms. The composition of the rubber seal of the core has been changed to assure long life in this use.

Each leveling valve has a delay mechanism to prevent leveling action during wheel-hop frequency.

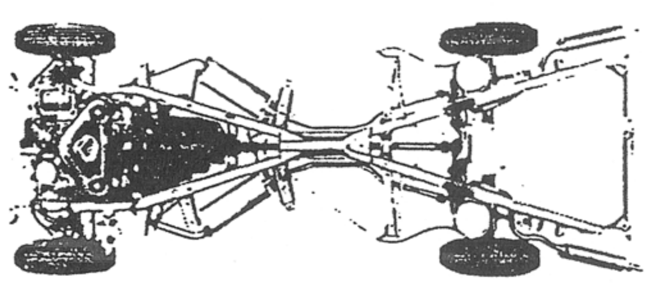

Fig. 16—Chassis of 1956 Eldorado Brougham

This prevents a pumping-up or a bleeding-down of the air spring due to small differences in the inlet and outlet restrictions. Levelizing action takes place at all frequencies below approximately 10 cps. Fig. 17 shows a typical leveling valve. This one is mounted on the front cross member and, as mentioned before, it controls the two front springs.

The tee fitting in the air-line connection between the two springs also incorporates a special check valve that permits fast flow of air during leveling, but a restrained flow through a 0.012-in. orifice during roll. This prevents the mushy handling that would result during cornering if there was an unrestricted flow of air between the two front springs.

The threaded portion at the lower end of the valve linkage allows manual adjustments for height of body in relation to the suspension. This provides for precise trimming of car height if there is any variation in production parts.

The enlarged view shows the details of the special joint used for all the air-line fittings. A shoulder is upset near the end of the air line. At assembly, the threaded nut forces this shoulder down against the bottom of the tapped recess in the body. This assures a fixed compression of the special rubber "O" ring and insures a leak-free joint. This joint allows minor misalignment of parts at assembly without leaks.

Compressor—The compressor is of the piston type, with 0.276-cu-in. displacement and a capacity of 600 cu in. per min against a 100-psi head. It is electrically driven and is mounted atop the generator in the engine compartment. This mounting and location was found best for noise isolation, oil supply, and plumbing. An integral thermal switch protects the motor from overheating.

The inlet side of the compressor is piped to the engine air cleaner to insure a clean supply of air.

The compressor is lubricated from the engine's oil system. The high-pressure oil line from the engine is restricted at the compressor to meter the oil flow to slow drops onto the crankshaft bearing. A standpipe in the crankcase returns the overflow to the engine oil pan by gravity.

The compressor normally runs only about 30% of the car operating time. However, at high altitudes the compressor runs about 80% of the time.

A pressure switch, integral with the compressor, starts and stops it to maintain pressure in the air reservoir at 120 to 130 psi. A blow-off valve on the outlet side of the compressor is set at 160 psi to protect the compressor and the air system from excessive pressure.

The compressor can run only when the engine is running. This insures that there will always be adequate lubrication for the compressor.

Air Reservoir—A cylindrical tank, of 500-cu-in. capacity, is mounted just forward of the radiator top tank. This provides a reservoir of high-pressure air more than sufficient to level the car from curb to five-passenger load without additional air from the compressor. It also serves as a trap for any oil or water, and has a manual valve to allow periodic draining of any fluids.

If for any reason the pressure in the air reservoir drops below the 75 psi required for car leveling, a light on the instrument panel (similar to the oil-pressure warning light) notifies the driver that the pressure level should be restored. This can be done by starting the engine, which permit the air compressor to start. There is a tee fitting in the air-reservoir line that can be used with an air hose during any service work on the car or to check air pressure in the system.

The general arrangement of the chassis components is shown in Fig. 18.

All of the air lines are 3/16-in. OD copper tubing. This diameter of pipe was found to be the smallest that would allow the fast leveling we wanted when a car door was opened. Further experience and testing may allow us to use less expensive steel or plastic lines.

Assembly—The design and location of the components was developed with constant consideration of the making and the ultimate assembly of the parts into the chassis. As a result, the air-spring suspension has caused no unusual problems on the production line.

The vital importance of a leak-free system was realized from the first consideration of the idea of air suspension so the design, the manufacture, and the assembly of the components has been tailored to that result.

After the complete assembly of springs, pipes, and controls into the chassis, there is a snifter test for leaks and a final check with soapy water on the tubing connections. Experience gained with air-conditioner installations has helped with the air sus-

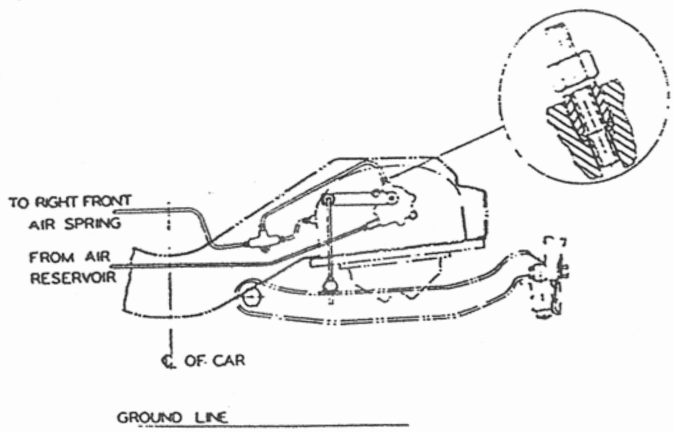

Fig. 17—Leveling valve

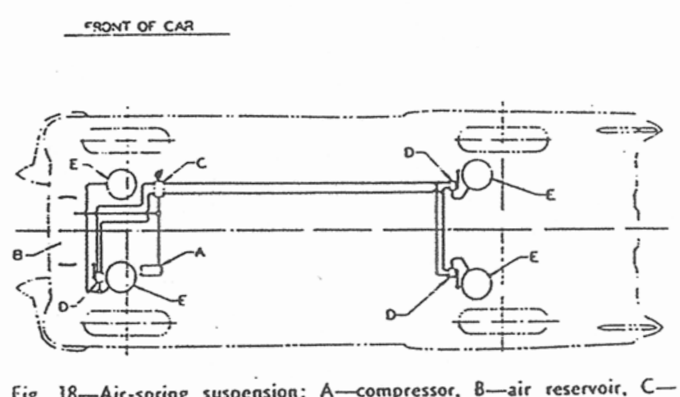

Fig. 18—Air-spring suspension: A—compressor, B—air reservoir, C—control solenoid package, positioned between air reservoir and leveling valves, D—three-wheel leveling valves, E—air springs

pension, as the leak problems are similar.

The manufacturing and assembly divisions have done an excellent job in devising new methods and procedures to insure a trouble-free car that will give the better ride that is inherent to this design. The men in those departments deserve much credit.

The suspension system was subjected to an extensive testing program after the final design was determined. Tests at Pikes Peak and other high-altitude areas showed that the compressor had adequate capacity for the suspension at any operating altitude.

Many thousands of miles on the Belgian Block roads at our proving grounds and on road tests have shown satisfactory life for all of the components.

John Hoban, Cass Cislo, and Dick Nietert of our department carried along the design and development work and surmounted the many new problems that cropped up so frequently.

Summary

In summary, Cadillac's air suspension on the Eldorado Brougham gives a new and a better ride.

1. The ride is of slower frequency, with slower body motions that are pleasing to the passengers.
2. The ride characteristics are constant. With the driver alone in the car or with a full passenger load plus baggage, there is no change from the designed ride.
3. The air suspension gives a damping quality that cannot be obtained with conventional springs or with shock absorbers.
4. The combination of a low center of gravity and the high roll center, that is obtained with the 4-link rear suspension, results in an exceptionally good-handling car.
5. The constant-height feature improves the appearance of the car, as it is always at show-room height regardless of the load.

We feel that the air-suspension principle has even greater potential and that, as we gain more experience with it, we will be able to design and build further advantages into the car for the benefit of our customers. Acceptance of the air ride has been gratifying, and we suspect that in the future many more people will be "riding on air."

DISCUSSION

Describes Experiments in Air-Spring Development

—Charles J. Smith
Monroe Auto Equipment Co

WE, at Monroe, have been engaged in air-spring development to a limited degree for approximately three years. During this time we have experimented with a number of different systems, the majority of which perhaps represented an effort toward the ride problem but did not necessarily take care of the handling problem. Due to this experience, however, we do feel that we are qualified to recognize the right approach and we are convinced that the Cadillac design is a step in the right direction.

Most of our preliminary work was done on a Nash car, which could quite easily be converted from coil springs to air springs. This consisted of several types of metal cylinders and also various rubber assemblies; in all about 10 different types. With this combination we invariably found that when we lowered the oscillating rate, the riding qualities improved, but the handling of the car became unsatisfactory. This would indicate that the features of high-roll center and low center gravity incorporated in the Cadillac design are major contributing factors which insure good-handling characteristics. While we feel that 55 cycles may not be the optimum frequency and that an even lower frequency might be desirable, the afore-mentioned problem remains a challenge which chassis designers will accept. The proper leveling system will be a definite factor in solving the problem. The system described in the paper can readily be seen as a necessity for good handling. On several occasions we have had difficulty with a 4-valve system, where one front wheel and the opposite rear wheel supported the load and handling became extremely poor. The feature of rapid leveling when doors are opened or ignition is turned on, combined with controlled rate of leveling when the car is in operation, is very good.

One problem which confronted us in our development work, and which apparently was not of major significance in the Cadillac design, was a definite feeling of "harshness" in the ride. Experimentation showed that proper location of the units to relieve loads on suspension bearings reduced friction. Lower oscillating rates gave us the best results for harshness and ride. Although the diaphragm-type unit appears ideal from a frictional standpoint, it is rather surprising that a compromise design which would lend itself to the installation of either coil springs or air springs would show any improvement as far as harshness was concerned.

The paper does not indicate the wheel travel obtainable on either front or rear wheels. We feel that, in spite of the feature of constant ride height, a wheel travel of about 8" in the front and about 10" in the rear would be desirable. It is possible, however, to cut this down somewhat by the varying rate of the springs.

It is our belief that, when the ultimate design in air suspension is reached, an improved type of shock absorber will be required. The elimination of friction in the suspension system will mean that this unit will be required to do more of the damping. Existing designs with 4-coil springs have already pointed up this fact. We feel that units with greater piston displacement will provide the required damping without increasing harshness, provided proper mounting location giving good displacements can be obtained.

The approach to the rear-suspension problem with the 4-link design would appear to have considerable merit and, since this is a very complex problem, I shall not attempt any detailed discussion at this time. Several other designs have been tried, among which are: Packard type, conventional torque-tube type, and dedion type. There are many features of the latter type which we feel would merit serious consideration.

Some advantages of the constant-level air-suspension system not mentioned in this paper are improved lighting and vision out of the rear window.

We feel, as do the authors, that the air-suspension principle has a great potential and that, as soon as the public has the opportunity to become acquainted with its advantages, the demand will be even greater than that which we have witnessed in the case of automatic transmissions, power steering, power brakes, power windows, and the like.