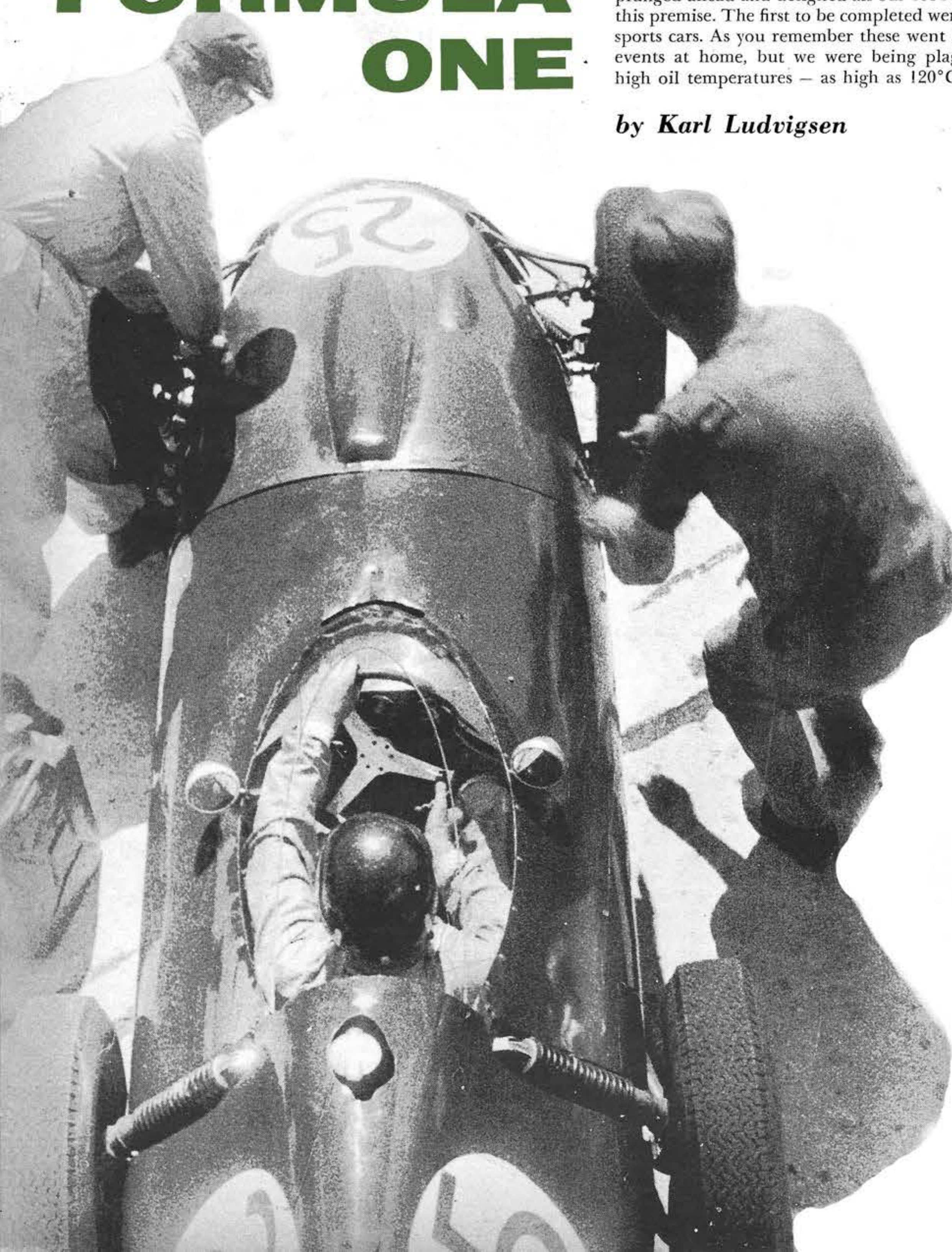
SCI **TECHNICAL REPORT**

Built to the current formula, the GP Lotus points the way toward things to come in '61.

LOTUS FORMULA ONE

by Karl Ludvigsen



COLIN CHAPMAN TALKING:

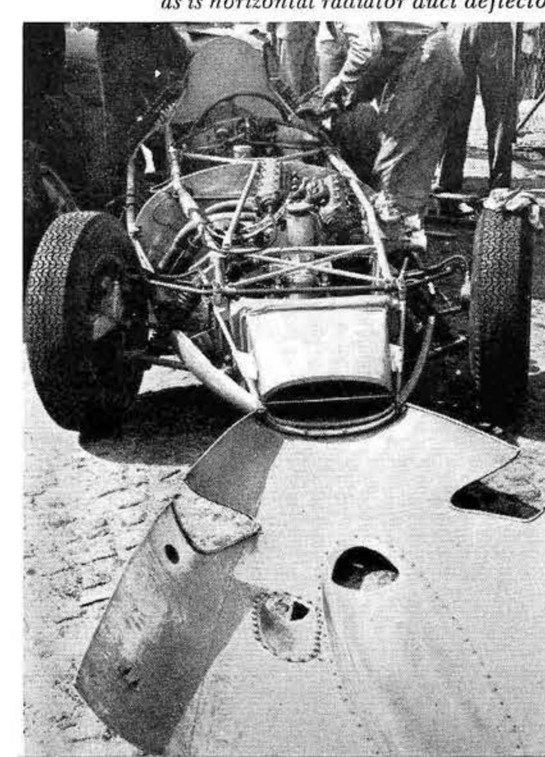
"When we sat down last year to make some plans for the '58 season it was evident at once that a flat or near-flat engine position would be a big step forward both for our sports cars and for our new Formula One project. Gets the c.g. down of course, allows a smoother shape and in the case of the G.P. car would put the driver much nearer the ground. The chaps at Indy have been happy with it and Mercedes didn't have such bad luck either, so we were pretty enthusiastic about the idea.

"Naturally our first move was to pay a call on Climax. They couldn't see any reason why their FPF four should mind being flopped over 62 degrees to the right, so we plunged ahead and designed all our 1958 equipment around this premise. The first to be completed were the new 'Fifteen' sports cars. As you remember these went like blazes in short events at home, but we were being plagued by unusually high oil temperatures — as high as 120°C in some cases. At the same time reports from bench testing at Climax showed the 'flat' engine to be consistently down on output about twelve horsepower from the usual vertical setup. We were assured that this was just a matter of getting a few details worked out, and that there was no reason why the engines shouldn't produce full power in due time. On this basis we went ahead on the construction of 'flat' chassis for the G.P. cars.

"The reports from Climax were still discouraging, though, when it came time to build the Le Mans cars, so to be on the safe side we tilted the twin-cam engines back 17 degrees to the left. This necessitated a small hood bulge for the exhaust cam box but allowed much straighter intake piping — one of the points where we felt power was being lost. Well, that two-liter car astonished everybody including us at Le Mans, and inspired us to do some very quick work on one of the single-seaters. These cars were just about finished by now, since we were aiming to have them ready to race at Rheims, just two weeks after Le Mans.

Graham Hill in a new Lotus during the 1958 Monza Grand Prix.

Latest upper chassis framing is seen at Monza, as is horizontal radiator duct deflector.



"We pulled the engine from the 1½ liter car and cut away all the brackets for the 'flat' mounting. Then we swung it back into the frame and fudged about until we had it at about the proper left-hand tilt, angling it a bit so we could get the drive to the gearbox. With a drive shaft jury-rigged in place we then asked the drivers to try it on and see if they thought they could drive the thing with their left knee high in the air over the shaft. When they said 'yes' we welded in a few tubes here and there to keep the engine from falling out, and there we had our upright mounting.

"In spite of being a half-liter down on the other, this revised car went so well that our drivers were literally fighting over it. This did it as far as we were concerned; before Silverstone a rather neater conversion had been made on the other car, and we were out of the flat-engine business. And all this time, in the course of some fifty runs on the bench, Climax had been unable to come up with any conclusive evidence as to the exact reason for the power loss. We think it's a combination of loss of ram effect in the curved intake piping with excessive fluid pumping losses in the sump, but that shouldn't be so hard to solve, should it?

"We had already regarded 1958 as a prototype season only for the new single-seaters, but this engine mess was a major setback which has kept us busy with a lot of petty details. For example the drivers found that the knees-up position wasn't so good after all, what with banging their shins and elbows when they worked the wheel and clutch, so the cowl tubing had to be ripped out and shifted forward. Many other structural bits have been worked out as we went along, and since the German G.P. the cars have been showing a lot of pace. But it's really all directed toward a full team of raceworthy cars for '59."

This policy of development-on-the-run has resulted in many snide remarks about the often shoddy appearance of Chapman's works Lotus cars, but equally it reflects a healthy try-anything attitude that will eventually lead to the best possible car with the materials at hand. The setbacks suffered during 1958 have cost Lotus about half a year of development time, as Chapman outlined above, in his first concerted personal attack on Formula One racing. He's been indirectly involved before, of course, as designer of the Vanwall frame and suspension consultant for BRM. Experience had also been gained by running the bigger Climax engines in the older Formula II chassis, at almost all races last season, but no *bona fide* Grand Prix Lotus had appeared until early July, for Rheims practice. Onlookers were startled then by its radically low, slim shape and were shaken four weeks later when one car (Cliff Allison) held a solid fourth place through most of the German Grand Prix.

Most directly affected by all the engine swapping and changing has been the tubular space-type frame, which at every possible point runs very close to the body shell to minimize the number of extra braces necessary. Each side is a deep, simple trussed member, with major uprights at the front suspension, firewall (which also supports the body), cowl and behind the seat. The two uprights on each side at the front are square-sectioned to facilitate attachment of suspension arms, as are the curved crossmembers under the gearbox at the rear. A triangulated sling to support the fuel tank is bolted to the back of the frame at four points, just below the X-type bracing that accepts the rear spring stresses.

Another X-brace spans the front between suspension members, also unboltable to allow access to the oil filter and water system. The changes in engine mounting and dashboard position naturally shifted some of the upper frame crossmembers around. Originally there was a single diagonal strut across the space above the driver's legs; this was replaced by a V-shaped arrangement, with the apex of the V connected to a bolted-in strut which angles forward to the right-hand side of the frame, past the exhaust cambox.

LOTUS FORMULA ONE

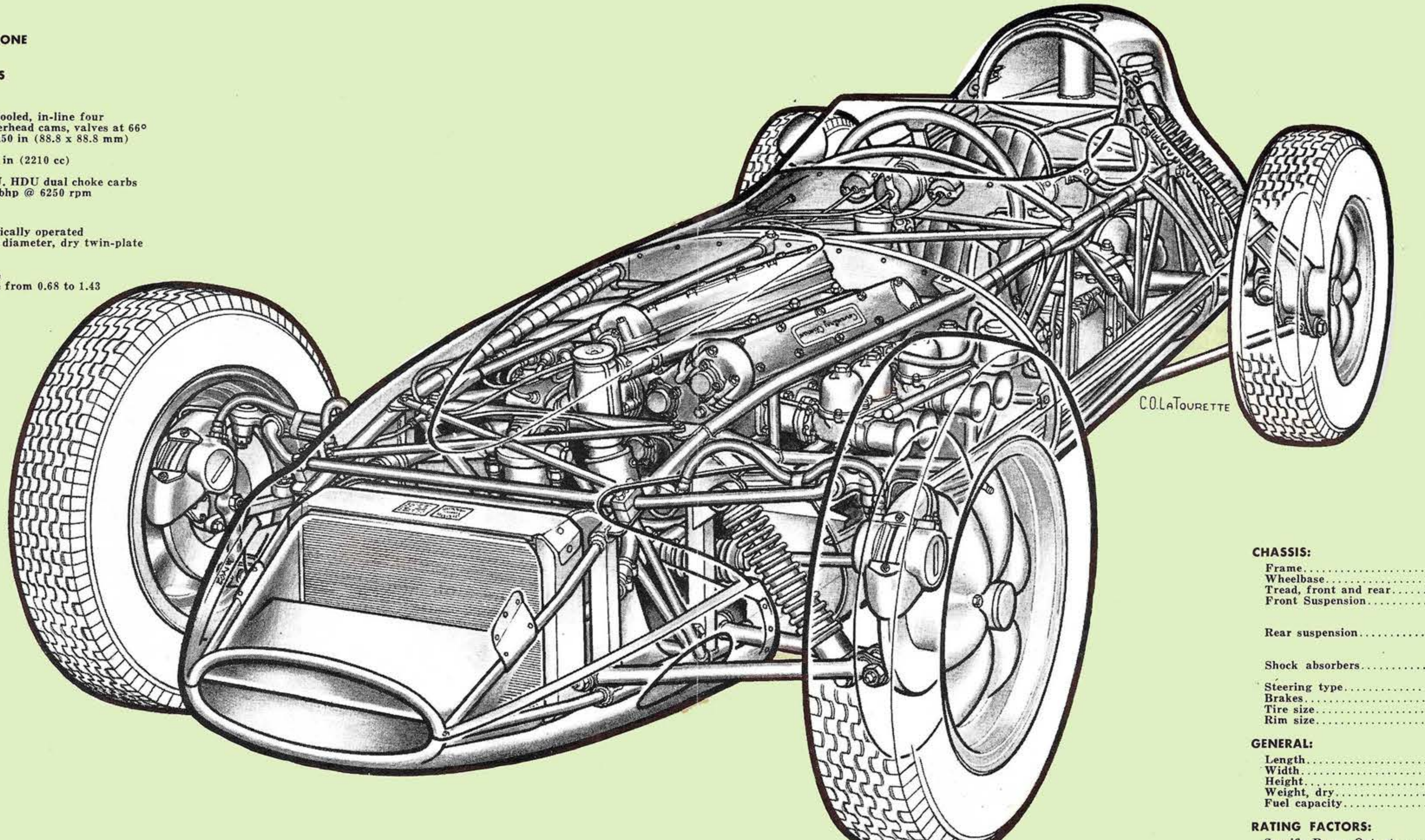
SPECIFICATIONS

POWER UNIT:

Coventry Climax FPF	Water-cooled, in-line four
Valve Operation	Dual overhead cams, valves at 66°
Bore & Stroke	3.50 x 3.50 in (88.8 x 88.8 mm)
Stroke/Bore Ratio	1.0/1.
Displacement	134.4 cu in (2210 cc)
Compression Ratio	11/1
Carburetion by	Two S.U. HDU dual choke carbs
Max. Power	193-198 bhp @ 6250 rpm

DRIVE TRAIN:

Clutch	Hydraulically operated 7.3 inch diameter, dry twin-plate
Transmission ratios	
I-II	Fixed
III-IV	Variable
V	Variable from 0.68 to 1.43
Final drive ratio	4.11



CHASSIS:

Frame	Tubular space frame
Wheelbase	88 in
Tread, front and rear	47, 48 in
Front Suspension	Coil springs, lower wishbone, upper arm integrated with anti-roll bar
Rear suspension	Trailing arm, vertical spring-shock and doubly U-jointed, unsplined axle shaft
Shock absorbers	Tubular, concentric with coil springs
Steering type	Rack and pinion
Brakes	9 inch Girling discs
Tire size	5.00 x 15 front, 5.50 x 15 rear
Rim size	15 x 4 front, 15 x 5 rear

GENERAL:

Length	140 in
Width	54 in
Height	37 in
Weight, dry	760 lbs
Fuel capacity	26.5 U.S. gallons

RATING FACTORS:

Specific Power Output	1.45 bhp/cu in
Power to Weight Ratio	3.9 lbs/hp (dry)

Close study shows how carefully this basically neat frame has been integrated with the body shape, especially with the elliptical cross-section specified by aerodynamicist Frank Costin. Along lines first promulgated on the Napier-Railton record car, and since utilized by the *Disco Volante* Alfa, D-Type Jaguar and Vanwall, among others, the top and bottom of the Lotus body are symmetrically curved about a horizontal plane, from the nose back to the rear of the cockpit. This "lateral streamlining" materially reduces the effects of side winds and prevents power-wasting pressure buildups beneath this low-built car. It makes this Lotus wider than need be — in fact astonishingly wide as seen in plan view — but the space can be well used to shroud suspension parts.

In view of the acknowledged driving ability of its designer, it's no surprise that the Lotus' suspension is as ingenious as its frame and body. The modified-wishbone front layout first appeared on Chapman's Formula II car, and in his program of competent standardization has been fitted to everything from the Seven to the Elite. The bottom wishbone is a simple open vee, rubber-bushed to the frame at two separate points and connected to the stub-axle forging by a double trunnion. This heavy-duty pivot system is used because the lower wishbone, assisted by the angled coil spring/shock unit, supports the weight of the car.

Instead of a conventional wishbone at the top there's a single arm, ball-jointed to the stub axle upright. It's braced by the trailing end of the anti-roll bar, which is ⅝ inch in diameter — 1/16 inch thicker than that first tried. Since it is used as a suspension member, the anti-roll bar is braced laterally by small segments of hose clamped to the bar just inboard of each frame mounting block. An important change from the Formula II layout is a lower mounting for the frame pivot of the upper suspension arm, giving the upper "wishbone" pivot axis a downward slant which will counter nose dip on braking in a manner instituted by Chevrolet. Now that this suspension is fully developed, Chapman has been able to order forged components for the Elite. The racing cars will be similarly equipped, this one already having an interesting T-section top arm. Forged bottom wishbones and rear wheel radius rods are also on order.

U-jointed right behind the dashboard in the latest car, the steering column angles to another joint at the left of the firewall and thence forward alongside the crankcase to a third joint at the rack-and-pinion steering gear. Ball-jointed track rods extend out to very short trailing steering arms.

Modern disc brake practice, based on reasonable theory, stipulates that the caliper and pads should be placed at the *rear* of a wheel-mounted disc. If you consider the forces involved, their direction and reaction, you will find that the retarding force at the disc edge is countered by a *downward* reaction of the wheel against the spindle — directly opposite the usual wheel bearing loading. The objective of course is to relieve the bearings under braking conditions, instead of overloading them.

Chapman tried this rearward placement on his first single-seaters but found that they were afflicted by a persistent front-wheel chatter under heavy retardation. This was traced to the small but still finite play in the front wheel bearings. When the brakes were applied the spindle would be pulled up to the top limit, then car weight would tug it down again, setting up a cyclic vibration within the assembly. Now the calipers have been shifted to a near-front position, causing bearing loadings which are unidirectional and yet not so heavy as to necessitate an increase in size. All vibration has been eliminated.

Lotus uses simple, inexpensive Girling units with light-alloy calipers and easily-removable segment linings. Ferodo consultants are working to rectify the only snag encountered so far, a slight inconsistency in lining quality. A single Girling master cylinder with integral reservoir is mounted up under the cowl, linked to a pendant brake pedal. Heavier, sturdier calipers are used at the rear, since they're mounted inboard, bolted to the differential housing as sprung weight. Twin slots in the belly pan allow underbody pressure to force air up and over the discs, into the relatively low-pressure cockpit area.

More ingenuity rears its handsome head in the bold conception of the rear suspension. Each wheel hub has three locating members, corresponding directly to the three axes in which a wheel must be positioned. Up-and-down motion is controlled by a coil spring and tubular shock absorber angled inward at 45 degrees and rigidly aligned with a husky hub casting. This latter must surely be the only part of any racing car ever to bear the immortal words: "PATENT PENDING". One definite change in mind for '59, both at front and rear, is the installation of adjustable coil spring abutments to allow more precise tailoring of the car to the track.

Driving force is applied to the chassis through a long, cranked radius rod pivoted directly below each hub, the axis of this pivot being across the car. It will be seen, then, that when the forward or frame end of this radius rod is shifted sideways, the hub casting and thus the wheel itself will be angled similarly. In this way the rear wheel toe-in, and thence the steering characteristics of the car, can be and are adjusted with the aid of a handful of "fudging washers" at the forward radius rod pivot.

The above adjustment would be impossible if the Lotus didn't have a very forgiving lateral location system, namely by means of the tubular half-shafts and universal joints themselves! No problems with splines, pot-joints or greasing here. The combination of this type of location with the sliding pillars formed by the shocks provides a roll center below hub level, but yet not too near the ground. On brief examination one might believe that cornering loads might impose unusual and extreme forces on the U-joints, but in fact cornering only tends to *lighten* their burden. At rest the half-shafts are under tension, or are being "stretched"; you can imagine how the wheels would swing out and up if they were removed. Yet when cornering you can see that the heavily-loaded outside wheel will tend to push in or compress the half-shaft, and in view of the angle of the spring pillar these two opposing forces will cancel out completely at one gravity of cornering —

a high figure but one frequently attained by a racing car. Under the same conditions the inside wheel will be very lightly loaded with respect to both weight and cornering force, so there is surprisingly little to worry about in this audaciously clever suspension. It too is fitted to the Elite and to all of Lotus' serious competition cars.

Those side loads that exist are finally accepted by the shafts and bearings of the differential housing, which brings us to a major feature of this and all post-1956 racing Lotuses. Chapman realized that year that in the future he'd be needing a light yet multi-ranged transmission for his projects, preferably mounted in unit with the final drive to aid his efforts to build into his chassis a high polar moment of inertia. Colin tossed ideas around with Harry Mundy, the designer of the twin-cam Climax engine, and together they came up with a basic idea which was finally laid out in detail by Richard Ansdale, an Austrian engineer. The first experimental boxes of 1957 were built by ZF in Germany, but since 1958 they have been made entirely in England.

Two different changes have been rung on the basic gearing so far, and another is scheduled for 1959, but all make use of the same incredibly compact intermediate cog arrangement. The gearing is of the all-indirect type, in which the drive comes in one shaft and is taken out the other — like the Renault, VW, Fiat 600, etc. To make as small and light a box as possible, Chapman and Mundy reasoned that in racing most gear selections were made in sequence, i.e. there was little jumping from fourth down to first, and so forth. On this basis they specified a *progressive* selection system, something that will be new to those of you who are not antique car or motorcycle fans. The five appropriately-sized gear sets are lined up cheek-by-jowl, the gears being fixed by splines to the secondary or output shaft but left free to rotate around the primary shaft. This latter is actually a long, hollow sleeve carrying a set of lugs which can be engaged with internal teeth on the desired primary gear by sliding the sleeve to the proper point. There's no synchromesh of any kind; it would be very difficult to provide even if it were found necessary.

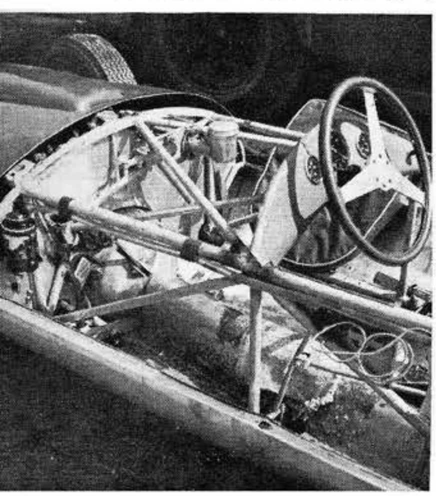
The only other postwar installation in a racing car of a box of this type is to be found in the Grand Prix Cisitalia, but even the Porsche engineers responsible for this were unable to create such a minute box as did Ansdale. (Granted that only about half the power has to be transmitted here, the Lotus' fundamental arrangement is more compact). The entire transmission can be and often is mistaken for a simple transfer case ahead of the final drive.

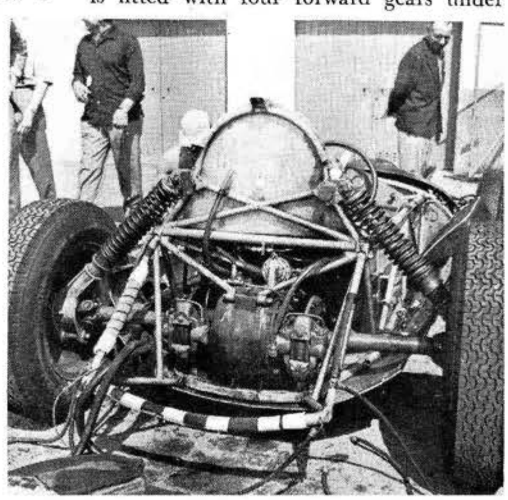
To backtrack a moment, one purpose of the original box was to be to lower the input shaft as far as possible below the wheel centers, to permit a low driver's seat in the single-seater car. Toward this end the shaft centers in the gearbox were spread as far apart as was practical, and the drive from the secondary shaft to the differential was by a hypoid bevel set, giving a total downward offset of five inches. Since the gearbox was ahead of the axle gears, the pinion incidentally had to be on the left of the ring gear to preserve proper direction of travel. As used in the racing sports cars, this box is fitted with four forward gears under quadrant lever control, and a conventional reverse arrangement with separate actuation. To scavenge and circulate its HP oil it drives a two-part pump from its input shaft.

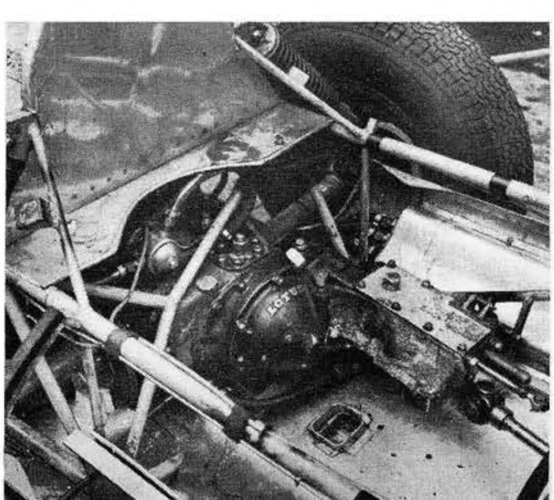
To make the very low 1958 G.P. car possible, a new gear arrangement was necessary, this time giving maximum *lateral* offset to bring the drive shaft *around* the driver. Neatly the box was laid on its side, and the pinion stayed on the left of the ring gear, which itself was moved as far to the left as possible within the final drive case. The result was an impressive eight inches from the car centerline to the input shaft. Maserati, faced with an identical problem in the Eldorado single-seater, solved it in exactly the same way.

No reverse being required, the G.P. box holds five forward cog sets only. A cycle-type positive-stop shift mechanism has been incorporated, and sits in a large square box that looks more like the transmission than the transmission does. Hypoid gearing is not used so neither is HP oil, regular engine oil being circulated by the "splash" system. There's a small oil pan just under the ring gear, which flings lubricant up into the chamber above the gearbox. Drainage from here is directed over the shafts and bearings, the oil eventually reaching the control box and returning to the oil pan via an external pipe. During '58 this box was found to be running extremely hot — uncomfortable for gears and driver alike — and a scavenging pump and cooling system is definitely in line for 1959. In the single-seater a ZF cam-type differential is fitted. A cam at the right of the differential actuates a mechanical fuel pump atop the drive casing, a horrendously practical Chapman feature. When the car isn't actually moving this doesn't pump, of course, so the driver or mechanic is kept busy tugging mysteriously at a "priming wire" at the right of the cockpit.

The presumably final note to this gearbox opus will be sounded in 1959, when a third variation designed for sports car use only will appear. *Monopostos* are accommodated by the lateral offset box, while sports cars with their separate seats don't need the vertical offset of the original layout, so a new casing is being made up to put the gears *behind* the axle center for the first time. There'll be hypoid gearing again, but this time offset above the hub centers, with the input shaft entering just below them — two inches below, in fact. This transmission will be the most compact variation yet, and will also have







Above left gearbox temperature gauge is positioned on left side of cockpit.
Ingenious yet simple rear suspension is shown at right with exception of trailing radius arms which pivot just below hub.
Left: photo shows gearbox proper in housing labeled "Lotus", while adjacent box holds input shaft and selector mechanism.

its own twin-pump circulation system to bathe four forward and one reverse gear sets with HP oil.

Back with the Grand Prix Lotus, the small-diameter prop shaft angles ten degrees to the right on its way forward, and is bolstered by a center supporting bearing. Within a simple, Lotus-cast bell housing there's a proprietary dry twin-driven-disc clutch, disengaged hydraulically to simplify interchange of components with the Elite. In the last-minute rearrangements the clutch master cylinder and a separate reservoir were moved to the left of the bell housing, the original intention having been to mount an integrated cylinder right next to the brake master unit.

By now everyone must be familiar with the fine old fable of how Harry Mundy severed the dormant V-8 Climax engine in twain and stepped forth with one twin-cammed segment fashioned into the 1½ liter FPF powerplant. Without this engine, and its later remarkable variations, Lotus and Cooper would simply not be in the big-time racing business. No engine of comparable quality is widely available in England. Except for its wet liners and moving parts, the FPF is mainly made out of RR50 light alloy, from its shallow cast sump to its detachable cylinder head, contributing to a modest weight, in 1500 cc form, of 260 pounds. In the same capacity, the Dino Ferrari V-6 tips eight pounds more.

Its bottom end is conventional, the crank being carried in five plain bearings braced by a deep, closed-cheek crankcase. Lubrication is dry sump, effected by two scavenge pumps and one pressure unit. All the connections to the "outside" are made on the right side of the crankcase, with fittings all neatly labeled IN and OUT so you won't lose track. There are two separate scavenge outlets, and the oil tank which they must feed is away in the tail of the car, lashed on with the inevitable bungee cords. Chapman runs the intervening pipe (two separate pipes in one installation) down the left-hand side of the car, through a lengthy box which is vented at front and rear to provide a spot of free oil cooling.

The same junior-sized wind tunnel carries the return pipe to the pressure pump; this one hose gains entry through the left side of the block. The two center fittings on the right feed, under pressure, an "accessory" circuit, in which oil first reaches a frame-mounted Purolator filter and then proceeds to a Serck oil/water heat exchanger before being returned pure and cool to the bearings.

Producing much more power than the original FPF engine with about the same crankcase area, these enlarged engines require more external cooling of oil. Confronted with this necessity when the two-liter fours were dropped in, the Lotus boys elected to provide it with the above-mentioned heat exchanger mounted in the "cool" bottom radiator pipe. Oil temperature was thenceforth fine but the water temperature reached uncomfortable levels. Some larger Serck crossflow radiators are being fabricated for the future Formula I Lotuses, to handle the heat load. The Coventry-Climax's centrifugal water pump is mounted high at the front, driven by the camshaft gear train, and feeds water to the exhaust side of the block. Hot water is withdrawn from the intake side of the head and is manifolded forward to a filling canister and thence to the right side of the radiator.

During their efforts to get maximum efficiency out of the existing cooling system, Lotus' air flow experts found that the upper half or so of the radiator wasn't receiving much air — thanks probably to the low placement of the small intake oval. This was remedied at Monza by the installation of an horizontal baffle to deflect some air upward. Warm air is ducted down through the belly pan.

A skew gear at the crankshaft nose turns a big Lucas magneto, which supplies sparks for four plugs. The absence of dual ignition is surprising these days, but the existing plugs are placed at an angle at the side of the chamber, just like half of a twin-plug layout. Bosses for locating the other plugs are already cast in place, and will probably be utilized if a near-2½ liter edition is built.

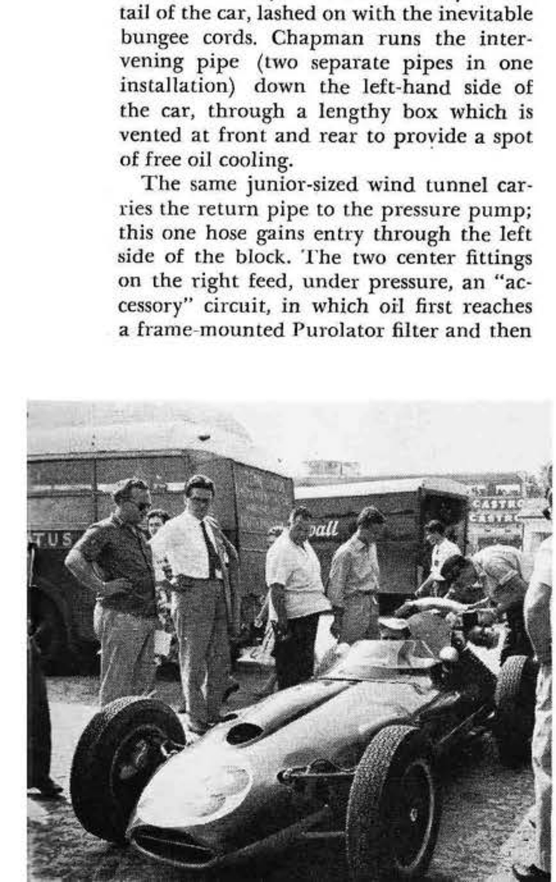
The inclined valves are slanted at the moderate included angle of 66 degrees, a figure that reflects designer Mundy's feeling that "you can get big valves and valve area without extreme angles and the awkward combustion chambers that they cause". One of the ways he recommends, judging by his recent designs, is the use of oversquare stroke/bore ratios. The dimensions of that original 2477.5 cc V-8, for example, were 76.2 x 67.9 mm in bore and stroke respectively. To make the 1476 cc four, with substantially the same cylinder head, the sizes rose to 81.3 x 71.1 mm — bore still keeping a lead on stroke. The next step, and a big one, was the jump to 86.7 x 83.8 mm and 1965 cc. With nearly 180 horses on tap, this is the engine that has appeared most often in G.P. Lotuses and Coopers, and which powered the biggest Lotus at Le Mans in '58.

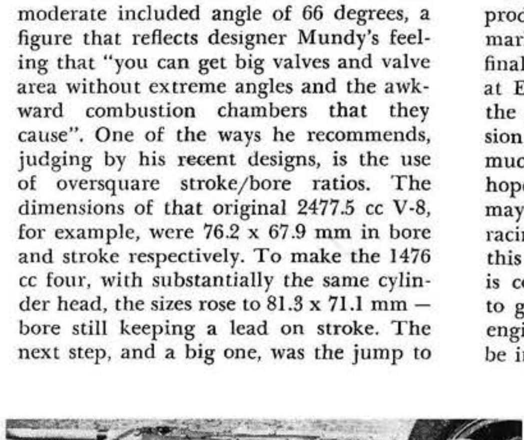
A very few engines of a yet larger size have been available for works cars in 1958. Their dimensions are square, at 88.8 mm both ways, and their displacement is 2210 cc. Believe it or not, two further enlargements are in mind for the future. First will be a stroke increase to 91.4 mm, supplying 2275 cc, followed by an expansion of the bore to the same size to produce a "square" engine displacing 2410 cc — within a cough and a wheeze of the original V-8!

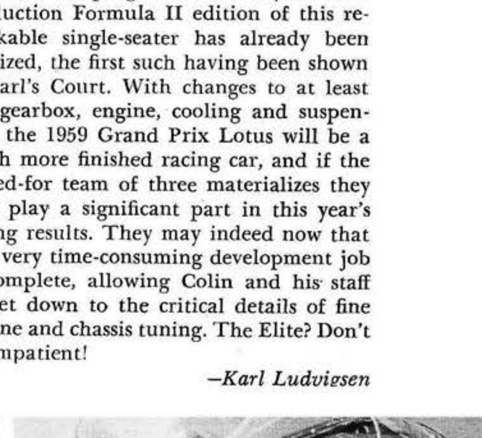
In the course of all this block expansion the valve stem centers and angles have been unchanged, setting a strict limit on the increase in valve size that has been possible. Even in 1965 cc form it must be said frankly that the FPF Climax is severely undervalved, a situation which has led to some interesting conclusions on carburetion. For these engines both the twin-throat Webers and the new HDU6 double-barreled SU's are available, and Lotus have tried both on all sizes of FPF's. On the basis of this experience it is felt that the SU, with its constant-vacuum self-adjusting-venturi feature, is best suited for use on engines which are undervalved in relation to capacity. The Webers, on the other hand, help to extract the last bit of power from an engine with specially large valves and ports. Chapman now uses SU's on all sizes of the FPF, which he apparently considers undervalved even in 1½ liter form, but prefers Webers for the 1100 cc single-stick FWA and definitely for the new 750 cc Climaxes. However you view the carburetion, the SU's deserve credit for delivering a racing mileage of about 13 miles to the U.S. gallon.

Such is the progress at Hornsey that the production Formula II edition of this remarkable single-seater has already been finalized, the first such having been shown at Earl's Court. With changes to at least the gearbox, engine, cooling and suspension the 1959 Grand Prix Lotus will be a much more finished racing car, and if the hoped-for team of three materializes they may play a significant part in this year's racing results. They may indeed now that this very time-consuming development job is complete, allowing Colin and his staff to get down to the critical details of fine engine and chassis tuning. The Elite? Don't be impatient!

—Karl Ludvigsen







Monza Lotus had holes cut everywhere to improve cooling. Chapman (in dark glasses) looks on. Exhaust pipe was removed from original location within the body to avoid cooking driver, whose niche is snug enough anyway.