Technical Report:

MONOCOQUE

The Only Way to Fly!

Most car-builders who claim to use Monocoque Construction Really don't know what they are talking about! BY PAUL LAMAR

RECENTLY THERE HAVE BEEN A LARGE NUMBER OF SEDANS, SPORTS CARS, SPORTS/RACING CARS AND PURE RACING CARS designed and introduced using the so-called 'monocoque' chassis principle. Now *monocoque* is a combination of the Greek word *mono* meaning one, alone or single, and the French word *coque* meaning shell or hull. 'Monocoque' is used in the aircraft industry to denote a fuselage that derives *all* of its stiffness from the skin that encloses it. 'Monocoque' is often misused in the automotive field to denote a type of structure that derives its high stiffness-to-weight ratio from large 'sections' or enclosed cross-sectional areas of the main structural members. We will try to clarify the confusion that may have resulted from the many apparent differences in the designs of cars referred to as 'monocoque.' For example: Why is a Lotus 30 sometimes called a 'monocoque' chassis car when none of the chassis material comes anywhere near the surface of the body? Why is a Chevy II like a Lotus 29?

Automobile structures are designed for maximum torsional stiffness, assuming adequate bending stiffness will follow, for the least amount of weight. High chassis stiffness is desirable because it reduces the amplitude of low frequency, undamped, torsional and bending oscillations. This is observable as cowl shake in the vintage sports car, and as body rattles in most of the separate frame and body sedans now on the market. Another argument for high chassis stiffness is that the roll stiffness at the front and rear of a car is seldom the same, and this sets up a torque, and consequently a torsional deflection in the chassis, that is undamped and difficult to predict. This torsional deflection results in a modification of the designed camber angle of the wheels and, hence, the cornering power suffers. This reduction of cornering power is especially noticeable on bumpy corners, which result in the camber angle oscillating along with the oscillating torsional deflections of the chassis.

A material must be chosen that has a high value of stiffness-to-weight ratio. It is also assumed that the loads encountered will not stretch the material to its point of yield. This is true for the structures discussed in this article, and for most structures designed for small deflections. The stiffness quality of a material is gauged by a term called the 'modulus of elasticity,' and this is measured by applying a known force to a given cross section of the material and seeing what the percentage of stretch is before the point of yield. Natural rubber would have a low, and steel a high, modulus of elasticity. The way to find out whether a material has a high modulus of elasticity-to-weight ratio would be to divide the modulus of elasticity by the density. A simple illustration will show why this can be done. If we take a one-inch cube of the material, as in Figure 1, and we apply a known force, and then measure the percentage change in length, we can determine the modulus of elasticity. The density is given by the weight divided by the volume, so all we have to do is weigh the block and divide the modulus of elasticity by this weight. Spruce plywood has a modulus of elasticity-to-weight ratio nearly equal to magnesium, and steel has the highest ratio of all the common structural materials. Incidentally, mild steel has approximately the same modulus of elasticity as high strength steels. Therefore there's little advantage in using the high strength steels for a stiffer chassis. This probably explains mild steel's popularity in English chassis !

Another facet of this subject is the shape that the structure should take. In Figure 2 the torsional stiffness of various size square tubes, all 85 inches long, and all of the same ¼-inch wall thickness, but of differing side dimensions, is plotted. You can see that as the side dimensions increase, the stiffness increases much faster. The stiffness also increases as the tubes are made shorter. This is a good argument for keeping the wheelbase short. However, the weight only increases in proportion to the side dimensions and the length. In Figure 3 I have plotted the stiffness-to-weight ratio, and again we see that for large tubes the stiffness-to-weight ratio is much better. This relationship qualitatively holds true no matter what the tubes are made of, or how thick they are. Apparently a design qualifies in automotive terms as a 'monocoque' chassis if the designer has taken advantage of this relationship between the size of a structural section, its weight, and its torsional stiffness.

Now, to build a chassis all we need do is get three large boxes, or tubes, one each for the engine, passengers and the trunk, and attach them end to end, separated by bulkheads, and keep them as short as possible. The purpose of the bulkheads is to distribute the concentrated loads such as engine mounts, seat mountings and suspension pickups into the main structural boxes. It will now be necessary to cut large holes for windows, doors and access panels. Of course cutting large holes in our boxes reduces their stiffness quite a bit, but we have to get in and out. Small windows, doors and openings are more desirable for this reason. The hood opening on a late model Lincoln is a good illustration of this. It is small and has large radius corners. One way to get around this for the passenger space would be to take out the passenger box and replace it with two smaller boxes of thicker material, keeping them as short as possible to reduce their adverse effect on overall torsional deflection, and put the passengers between

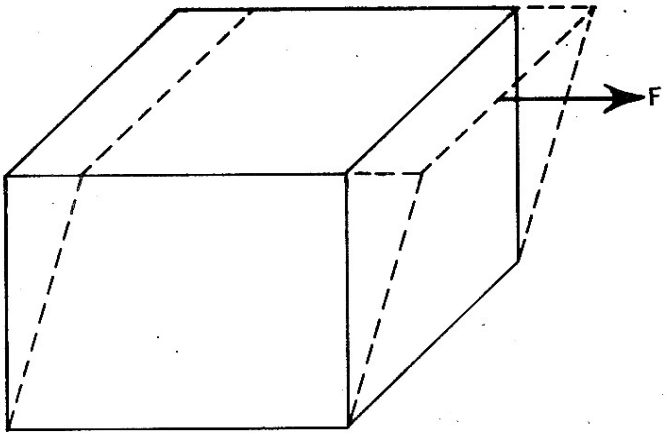


FIGURE 1

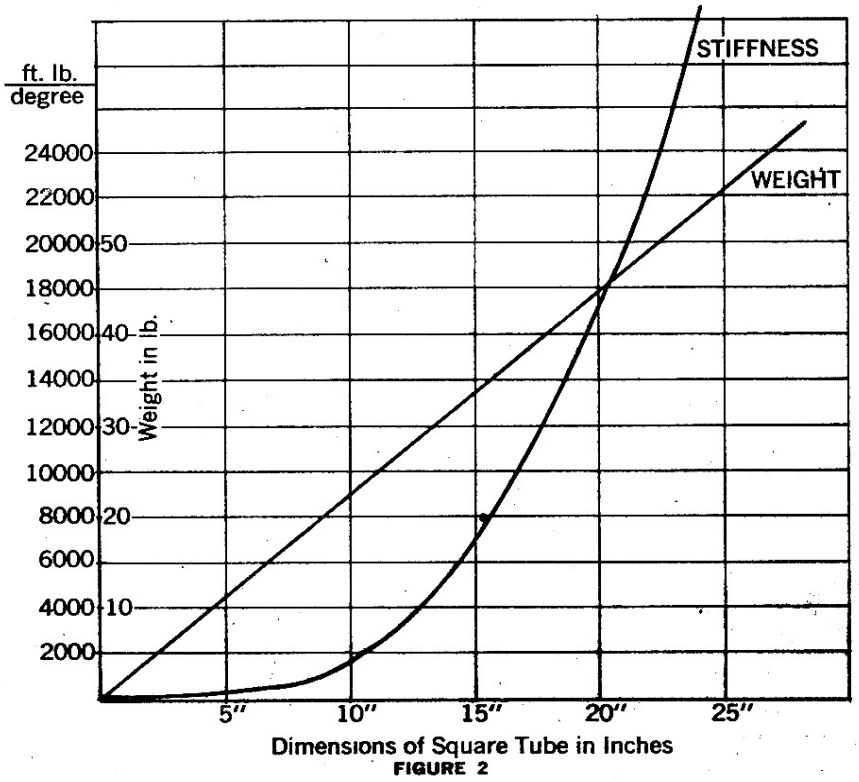


FIGURE 2

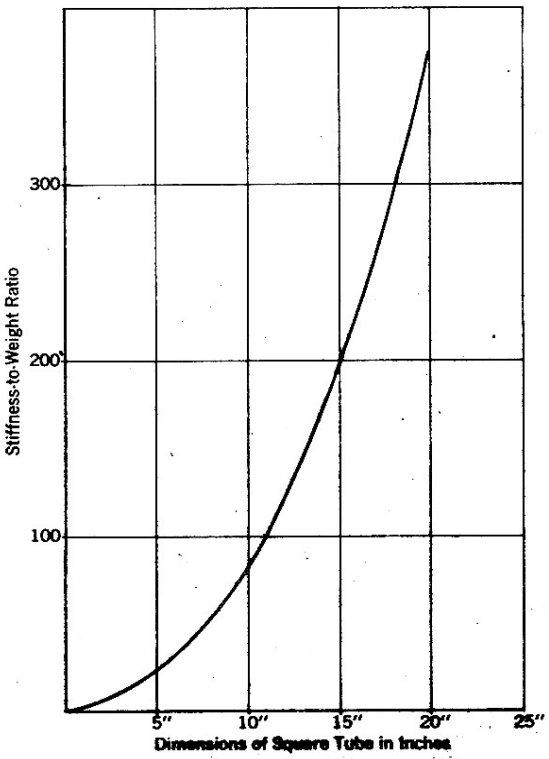


FIGURE 3

them as in Figure 4. Another way would be to reduce the size of the passenger box, increase the thickness of the material, and place the passengers on either side of this reduced box as in Figure 5. Figure 4 would be the best for rear-engined cars, and Figure 5 the best for front-engined cars. This is so purely for practical reasons, as this allows the wheelbase of rear-engined cars to be kept down by placing the passengers' feet between the front wheel wells. The frontal area of rear-engined cars can also be reduced by placing the driver's and passenger seat closer together and thereby reduce the width of the windshield. By placing the transmission and drive shaft in the central box for the front-engined machine we can move the passengers back and have plenty of foot room behind the front wheels. Purely on theoretical grounds, however, one central box is much lighter than two side boxes for the same stiffness, and three boxes are unjustifiable. The reasons why this is true can be seen by referring to the plot of stiffness versus dimension and weight. If we choose a stiffness of 10,000 ft. lb. per degree we find that one box of dimensions 17 by 17 inches and weighing 37 pounds is equivalent to two boxes 13.8 by 13.8 inches weighing a total of 58 pounds, which is also equivalent to three boxes 12 by 12 inches weighing a total of 78 pounds! The respective total areas are 290 square inches, 380 square inches and 430 square inches. This excess area must be subtracted from the space available for the passengers for a given frontal area, or added to the frontal area for a car with a given passenger space. Therefore three boxes are definitely unjustifiable.

Another arrangement that is becoming popular with some unit body manufacturers is what I call the 'cowl box and side rail system.' This technique uses a large box incorporating the cowl, dash, firewall, and front floor boards set transversely across the car. Attached to this box at its ends are two side rails incorporating the windshield posts, door frames and rocker panels. Attached to the back of these rails is a rigid bulkhead or another box that forms the divider between the back of the rear seat and the trunk. This method is somewhat like the old technique of adding tubular cross-members to a channel frame, only the sections are much larger, and therefore lighter for a given stiffness. This technique has the advantage for closed cars of not intruding too much on passenger space for a given frontal area. However, I suspect that it doesn't give as good an overall stiffness-to-weight ratio as the fore-and-aft box systems described above. Two cars that I believe use this last system are the Chevy II and the Rover 2000. Most unit body cars use a combination of both systems, as the rocker panels are generally boxed in, and the engine compartment and trunk act somewhat as large boxes, usually, however, not through the conscious efforts of their designers.

Another factor to be considered in large monocoque structures is buckling, a phenomena that can cause them to fail long before the tensile or compressive strength of the material is taxed to the limit. On two closely-designed, large airplanes — the B-52 and the Viscount — I have personally observed what I believe to be local skin buckling. It's probably quite normal and is confined to small areas by skin stiffeners or bulkheads. Buckling occurs in monocoque structures when a panel of insufficient thickness is required to sustain a compressive load between its edges. As long as all of the panel remains in the same plane as the edges no buckling occurs. However, if some of the panel is deflected from this plane, sometimes by the smallest of forces, buckling occurs. This phenomena can be reduced by using a lower density material of nearly the same modulus of elasticity-to-density ratio, such as plywood instead of magnesium, or aluminum instead of steel. This gives a thicker panel for about the same weight. Two other ways of reducing the buckling tendencies are using a sandwich panel with a low density core, or simply putting a compound curve in the panel. This last technique is seen in the modern car in the form of sculptured body lines.

Something near an optimum design for a sports/racing car with a rear engine, and with the present knowledge of materials and structures, would be a large box or tube for the driver's and passenger's feet and legs, two smaller boxes or tubes of minimum length but thicker material, and another large box or tube completely enclosing the engine on all six sides with relatively small access holes. The engine and rear suspension could be made quickly removable, as a unit, for tuning and major service. The material used for the large boxes could be honeycomb sandwich steel (the B-70 is mostly made from this material) or aluminum, and solid steel or aluminum for the two smaller boxes, as buckling tendencies are much reduced with reductions in box size.

In all monocoque structures composed of relatively large sections and using thin materials, concentrated loads such as engine mounts, suspension pickups, passenger seat mountings and roll bar mountings must be distributed throughout the structure as widely as possible, and preferably at the junction of two or more panels, or at thick bulkheads — otherwise local yield failures will occur.

Actually, one of the most important advantages of a well-designed chassis using large sections is the great increase in torsional stiffness, with the same or less weight. Reducing the weight of chassis body structures gives diminishing returns, as these parts become a smaller and smaller percentage of the total car weight. A fairly good method of roughly determining the overall chassis, body and running gear efficiency is to divide the engine weight into the total weight of the car, taking into consideration the number of passengers. Most large separate frame and body sedans have ratios of around eight-to-one, while some well-designed unit-body sedans are six or seven-to-one. Some sports/racing cars are four-to-one. The Jaguar XKE and the Lotus Elan are approximately five-to-one, both, however, being production sports cars. Incidentally, this points up the importance of engine weight, as one hundred pounds saved in the engine is worth from four to eight hundred pounds saving in the overall weight of the car, and gives a consequent increase in performance, and a reduction in tire wear and fuel consumption.

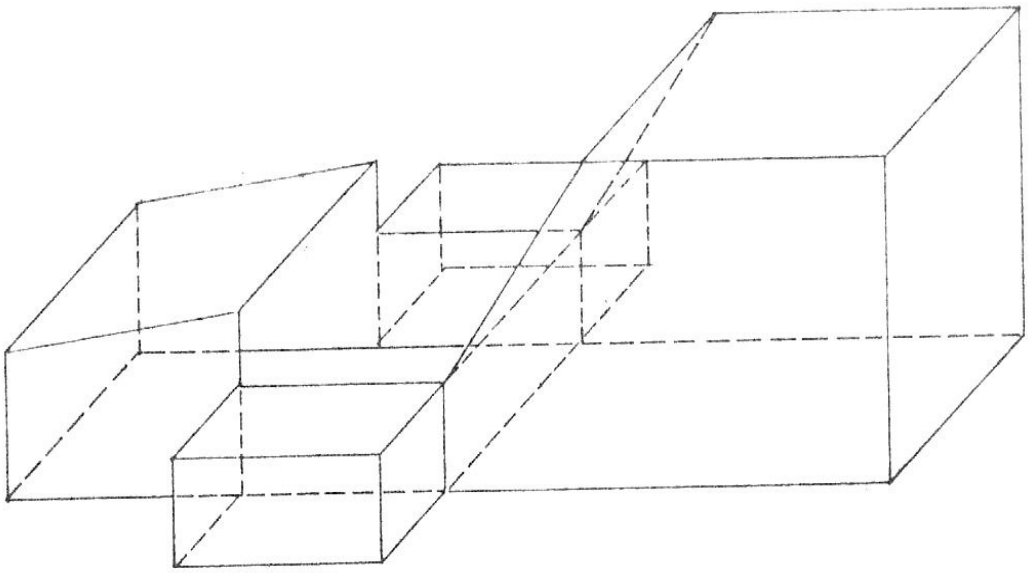


FIGURE 4

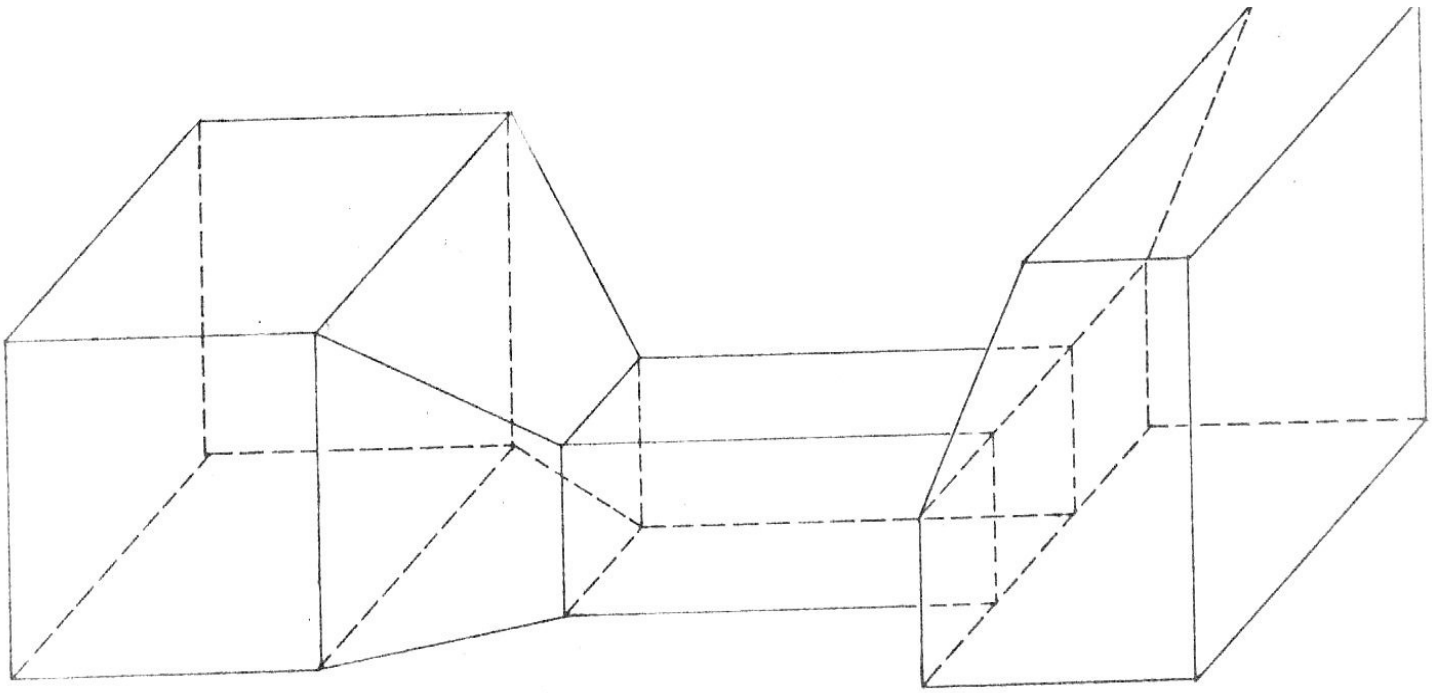
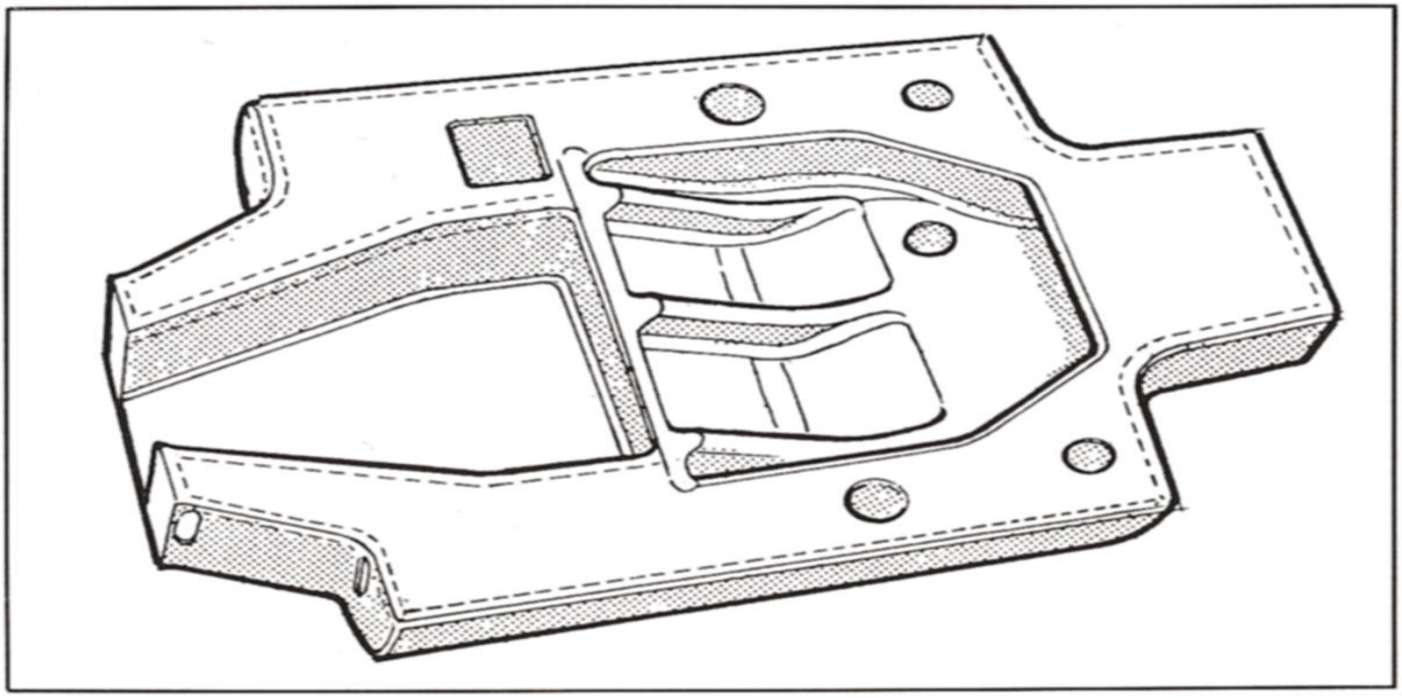


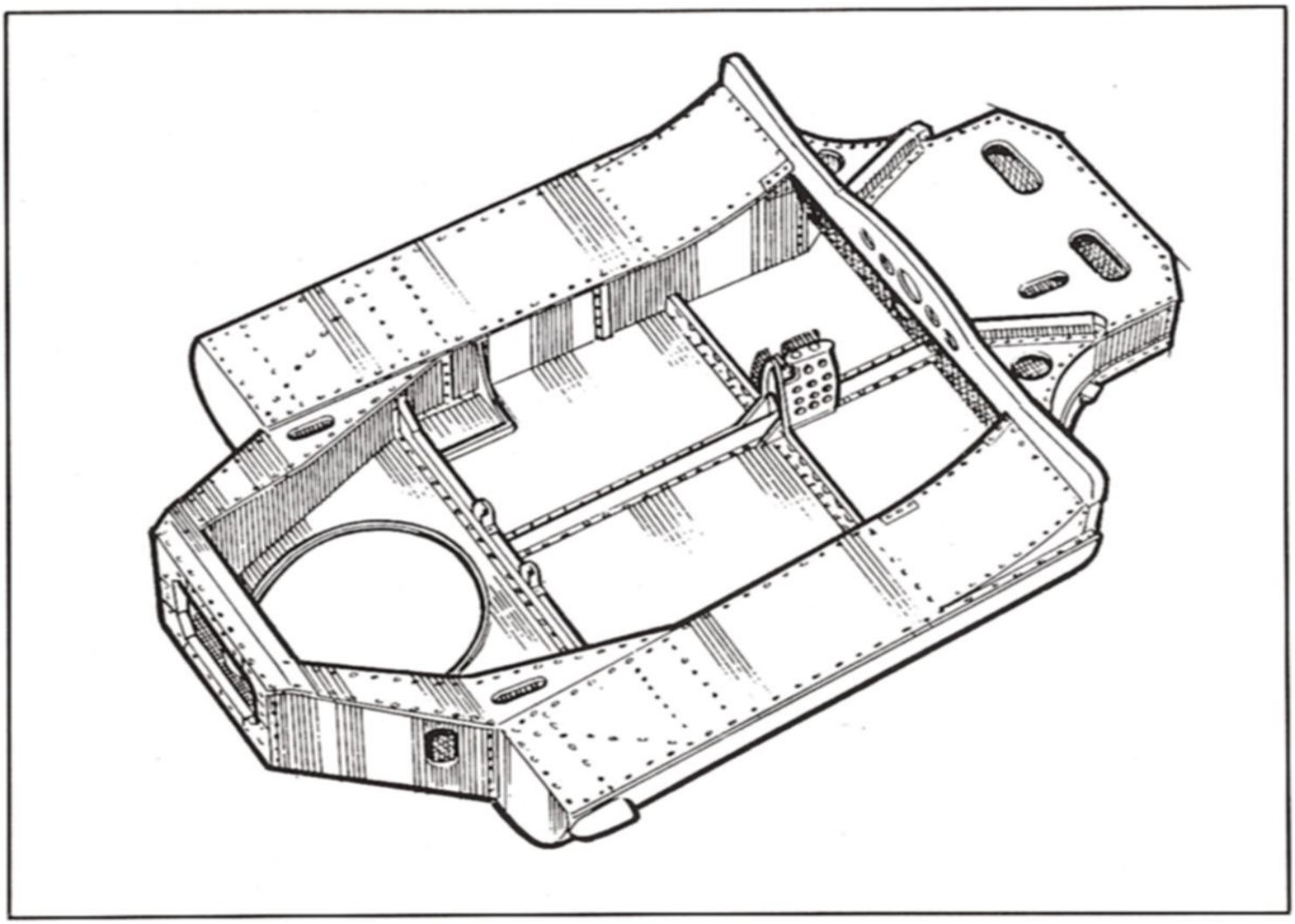
FIGURE 5



Creative right to its core, Chaparral brought the aerospace concept of composite chassis into racing in 1963—two decades before Formula One came around to the idea. (By the time of the Can-Am series, Chaparral had gone back to aluminum monocoques, only using a "plastic chassis" once more, in 1969.) *Autosport*



Drafting of the basic Chaparral 2 fiberglass chassis. The concept of two basic sections—a top and a bottom—was ideally suited to the material. The structure actually worked as two pontoons, joined by the footwells, the seat floor structure, and at the rear by a bolt-on fabricated ring. *Brian Hatton*



The Chaparral aluminum chassis as first used on the 2C, which was later converted into the 2E and finally the 2G. While modified and strengthened, the basic design for The Eyeball Jiggler was carried through from the Corvette GSIIb to the Chaparral 2G. Lighter than the Chaparral fiberglass chassis, the aluminum chassis lacked its simplicity, grace, and particularly with the larger engines, was at the limit for strength. Particularly noteworthy was the shallowness of the pontoons in cross section, inherited from the GSIIb concept, which envisaged a coupe version making lower sills attractive.