ALIX M. LA FONTANT

D JAGUAR was first of semi-monocoque sports racing cars which attempted to apply aircraft construction techniques to autos. Resultant light weight made it a top competitor.

MONOCOQUE

Is there something to be learned from the current vogue in racing car chassis construction?

BY ROGER HUNTINGTON

THE EARLIEST automobiles were constructed on the same principles as the horse-drawn carriages that preceded them. The body sat on a massive chassis frame, to which the powerplant and running gear were attached. The frame was the foundation of the whole structure. In the next 40 or 50 years the "unit" body gradually evolved. The body shell is welded up as a sturdy box unit, without any separate sub-frame, and the running gear is attached directly to the shell. A good portion of the world's carmakers today use unit bodies.

But now auto engineers are wondering if there might be an even better way to do this job. They're thinking of monocoque construction, as practiced for years in the aviation field. This differs from unit construction in that the major structural stresses are carried by the outside skin of the body, rather than the floor and roof structures of the unit body. The monocoque body uses a relatively light, flimsy superstructure of vertical bulkheads, to give it form, with longitudinal stringers to which the outside skin is attached. The whole thing together gives a shell-like structure that has very low weight in relation to torsion and beam stiffness. In fact, this type of structure has the highest stiffness-to-weight ratio of any known structure that is practical for a passenger vehicle.

So, why not apply it to passenger cars?

This thinking has had an interesting evolution. It started in the aviation field, then spread into the railway car construction, then finally into automobiles. For instance, there were true monocoque airplanes as early as 1912. The French Deperdussin monoplane, the first aircraft to exceed 100 mph in level flight, had a fuselage of plywood sheets over a flimsy framework of wood girders. It was the most advanced aircraft of its time. But monocoque construction didn't immediately sweep the aircraft field. Most early airplanes had what we would call "space frames" today. The fuselage and wings were based on rigid metal or wooden frameworks of truss or lattice design, with a fabric covering stretched tightly over this framework. The outer covering carried practically none of the loads, the basic framework did the work. It wasn't until the early 1930s that true monocoque construction in aluminum began to be utilized for larger aircraft. As planes grew larger ▶

HENRY MANNEY

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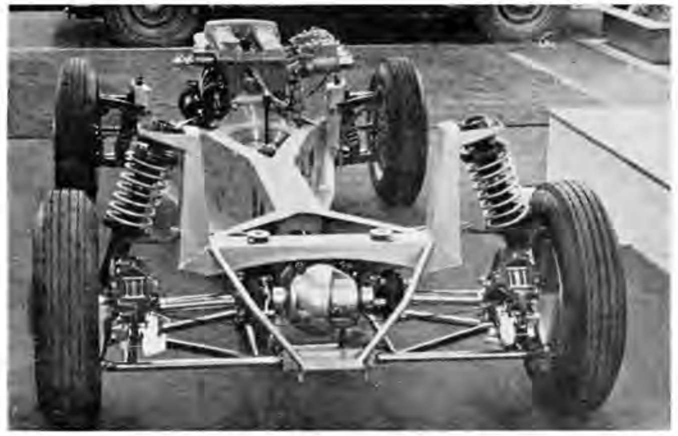

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MONOCOQUE

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Just about the time the aircraft companies were switching to monocoque construction in the '30s, there was interesting new activity in the railroad field. The big breakthrough was on the famous Burlington Zephyr of 1934, America's first real streamlined train. This used General Motors' first big railroad diesel engine (that permitted average speeds of 70–80 mph on regular scheduled runs) and the whole thing was built up on the monocoque principle, with stressed skin, light bulkheads, stringers and the whole works. The combination had a weight-horsepower ratio that was unheard-of in those days, giving the brisk acceleration that was necessary to maintain high average schedule speeds. The old Burlington Zephyr set a technological pattern for years to come. The railroads didn't swing over to monocoque passenger trains immediately, but the seed was planted. In the last 10 or 15 years the system has virtually dominated passenger train construction.

Meanwhile, automobile designers were lagging. The first attempt at a true unit body is generally credited to the Italian, Vincenzo Lancia, in 1924. He built an open touring car with a massive fabricated floorpan that came up on the sides to form a kind of framework to which the light outside sheet metal panels could be attached. There was no separate underframe. Running gear was attached directly to the floorpan structure. It was said to be a very tight, solid car. It was just 10 years later that Citroen of France tooled up the first mass-produced unit body, as we know them today. Citroen used the usual welded, all-steel shell, heavily-braced floorpan, stressed roof and strong bracing around the front cowl structure. The construction still looks modern and this basic body remained in production for 20 years.

There were some interesting variations of this unit body construction in America in the mid '30s. The new Chrysler Airflow bodies of 1934 were designed as full unit structures, but had a relatively light framework under the panels that acted as a superstructure. It was decided to bolt the body to the underframe, rather than weld it as originally planned. The layout permitted a lower floor and more passenger space, but gave the convenience of using a separate chassis frame on the assembly line. (Production economies were the reason the frame was bolted on.) The new Lincoln Zephyr used a similar principle in 1936, but Ford Motor Co. welded the entire underframework to the body unit; same with the Cord front drive of that period and the "step-down" Hudsons of the late '40s.

It was a kind of tentative intermediate step between frame and unit construction. It didn't require any great ingenuity to design rigidity into the body structural panels because the basic stiffness was in the underframework. And yet the total welded structure had more torsion and beam stiffness than the body-frame combinations of that day. The only penalties were in some extra weight and added production cost. It was considered a good compromise 25 years ago.

THE FIRST FULLY unitized body, as we know it, could be credited to the Nash 600 economy car of 1941. This was a welded box structure with no separate underframing. The same layout was applied to the Nash Ramblers and Willys Aeros of the early '50s, and then the modern Big Three compacts, and Chrysler Corp. big cars (not to mention dozens of brilliant foreign body designs). These bodies require very careful design of all structural members, to get a good compromise between rigidity, cost and weight. But the stiffness-to-weight ratio is considerably better than any modern body-frame combination. It's when we start to compare these modern unit bodies with true monocoque structures in the aircraft, bus and railroad field that things don't look so impressive.

The really far-out pioneering in body construction in the last few years has been pretty much confined to sports and racing cars. Things started popping in the early 1950s. We saw the first quantity-produced space frames in 1952, on the Mercedes-Benz 300-SL coupe and Colin Chapman's first production Lotus sports/racing car, the Mark VI. A space frame is a basic girder or truss framework of relatively small, thin tubes that is quite tall in relation to length. The theoretical goal is to replace all bending and torsion stresses on the tubes with pure tension and compression. This would give the maximum possible stiffness-to-weight ratio for the structure. In practice, though, it is usually not possible to get purely axial stresses in all the members, so the designer has to compromise in various degrees. (Factors such as engine and suspension mounting points and door openings are the problems.) But, even at the worst, a space frame carrying a light body shell on brackets and light bulkheads has a much better stiffness-to-weight ratio than any modern passenger car body combination, either unit or frame/body.

Jaguar took a giant step forward in 1954 with a true semi-monocoque body for its D Type Le Mans sports/racing car. This was a serious attempt to apply aircraft construction principles to the automotive field.

In this car, the elliptical central portion of the body around the cockpit gave the major structural strength. This had substantial bulkheads at each end, with stressed skin wrapped right around the ellipse (minus the openings in the top for driving compartment). Fuel tanks on each side gave additional beam stiffness by running the length of the center section. Four tubes ran forward from the rear bulkhead, through the front bulkhead, in a rudimentary space frame to carry the engine and front suspension. The rear suspension attached directly to the rear bulkhead. The whole assembly was made of magnesium for minimum weight.

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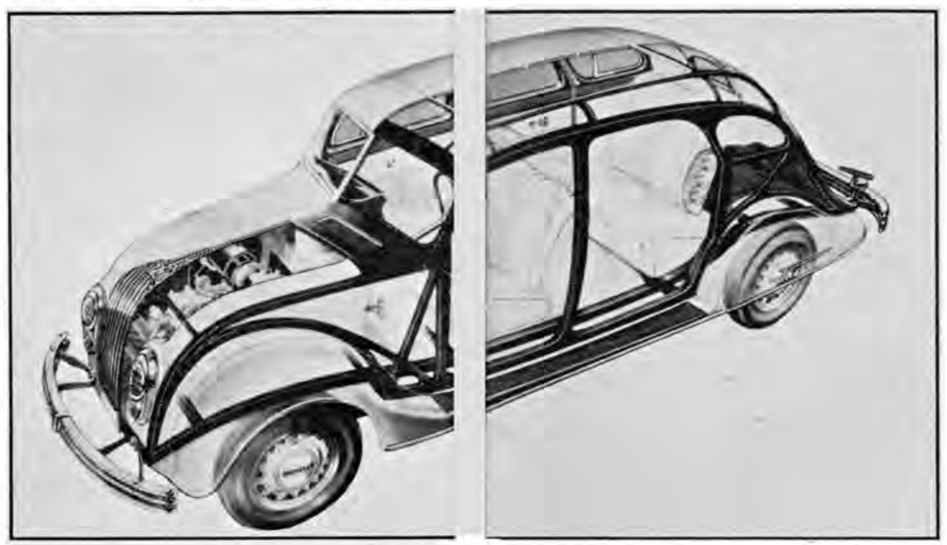
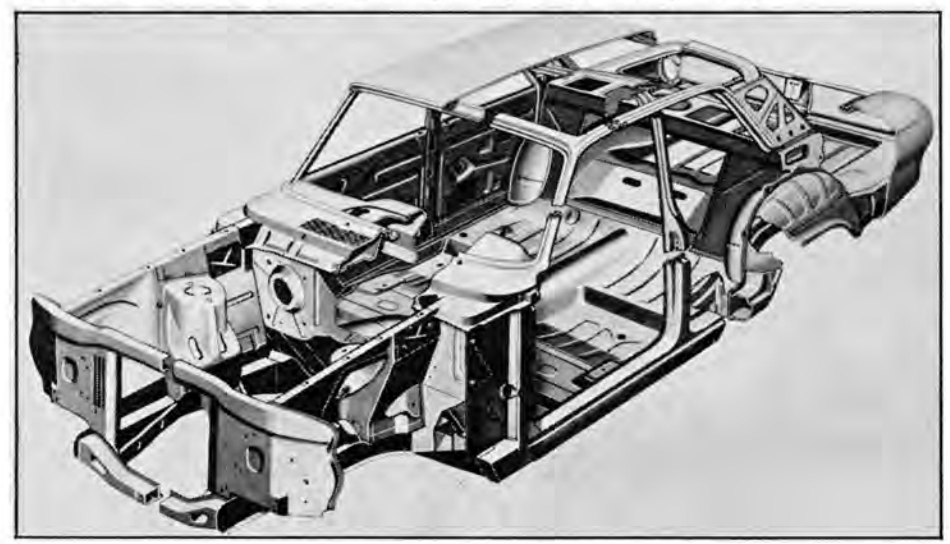
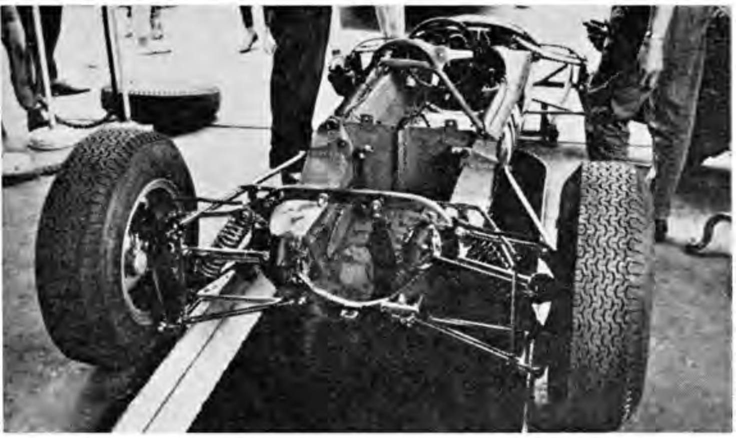


LATTER-DAY Chrysler products used this far more sophisticated unit body. Again, note stressed cowl and floorpan areas necessary to carry and spread load pressures.





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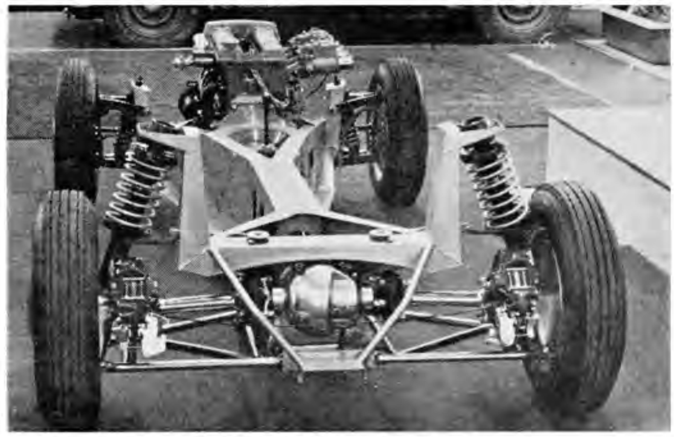

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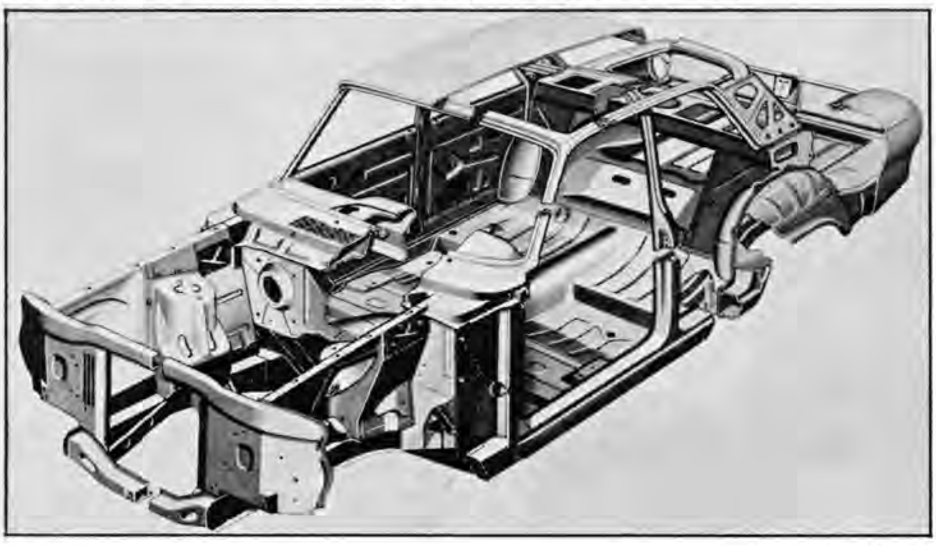

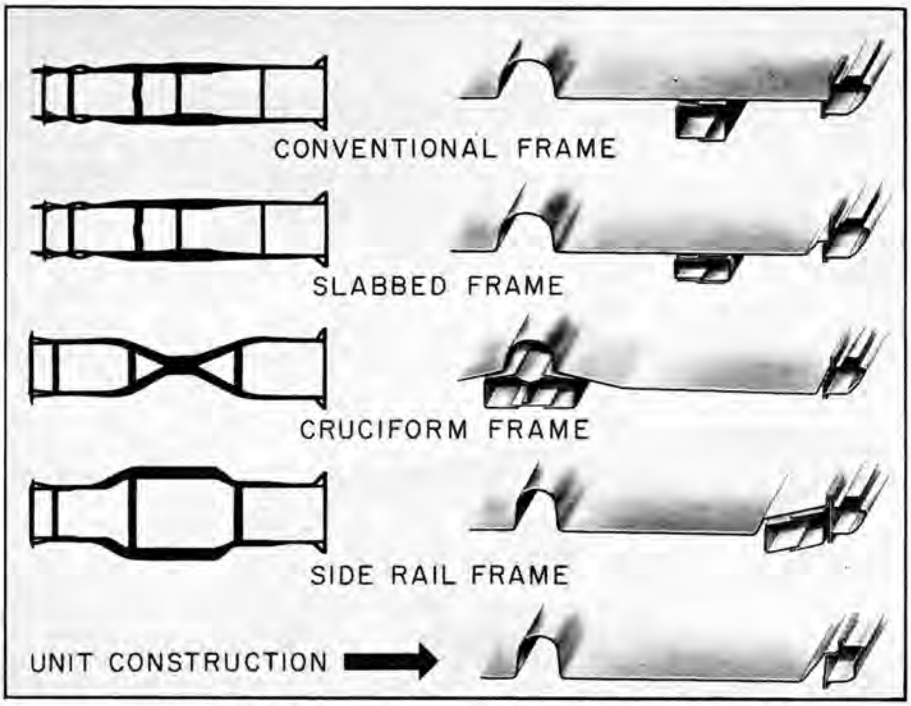

STRUCTURE COMPARISON of the various types of production car chassis. Unit type offers best interior space for passenger compartment, but side rail offers less complicated assembly.

MONOCOQUE

formed the pattern for most modern racing cars on both sides of the Atlantic. Of the several new rear-engine Indianapolis cars that were designed in this country last year, they were about 50–50 for space frames and monocoque construction. The monocoque cars consistently weighed 100 to 300 lb. less. This is the way design will undoubtedly go in the near future.

Up to now we've been talking strictly about single-seat racing cars. When Colin Chapman tried to apply his monocoque principles to a production sports car, the Lotus Elan, he ran into more problems. With the need for large door openings on each side, plus a larger upper cockpit opening, it was not practical to apply exactly the same sort of construction as used for the race cars. This is the big weakness of true monocoque construction: That is, discontinuities in the outer skin area greatly weaken the structure. A more or less solid shell structure is needed to get the optimum stiffness-to-weight ratio.

In the case of the Elan, Chapman put his major structural strength into the floor area. He used a unique "backbone" platform frame with its major strength in a large rectangular box between the seats. The box is 6 in. wide, 10.5 in. high and 25 in. long, with sheet metal extensions to each side. The driveshaft ran through the box, and the box section was flared at each end to house the transmission at the front and final drive at the rear. The engine and front and rear suspensions were attached to these flared sections and a simple fiberglass body bolted to the undertray.

Technically this isn't a monocoque structure, because the body skin is not really stressed and the major loads are carried by the central backbone. But as it turns out, the stiffness-to-weight ratio is at least as good as many earlier space frame combinations. The large central box structure gives tremendous torsion and beam stiffness. The frame unit weighs only 75 lb., but has a reported rigidity of 4500 lb.-ft. per degree of twist, which is better than many large American cars with frame and body bolted together. The whole car weighs only 1500 lb.

So, HOW CAN the designers combine the best of all these techniques to make tomorrow's passenger car more rigid, roomier, quieter, and especially lighter? In the first place, true monocoque construction is probably not practical for conventional passenger sedans. Notice that this construction so far has been applied only to open racing cars that have only a relatively small cockpit opening in the top of the body shell. This is the key. There can't be a lot of openings in a monocoque body. For instance a DC-7 airliner fuselage has only 6% of its surface area cut out for windows and doors. A monocoque intercity bus will have about 10% of its body surface area cut out. But look at the typical passenger car body: Roughly 50% of the area does not contribute to structural strength. And stylists insist on large-area windows and doors. There's no visible way around this, as engineers have yet to find a way to integrate an openable window or door structure into a monocoque shell. They may never find it.

So this means they can follow two general design themes: They can put the major structural strength in the floor area, probably with some form of backbone framework. Or, they can put the roof area to work, along with the floor, by using an elaborate cowl section to transfer stresses into the roof through the front door posts. Most of our modern unit bodies follow this latter theme. However, this may not have an unlimited future. As the stylists demand more and more glass area, the front door posts will get more spindly and weak. Eventually, they won't be able to transfer much roof strength through this channel.

HERE, the backbone-type underframe, with body either welded or bolted on, may have to take over. Ford's Mustang already uses a rudimentary form of backbone frame (with welded-on body) and the system looks pretty good on paper. It has great stiffness, low cost and lends itself well to volume assembly-line production (which true monocoque construction does not). Perhaps the biggest deterrent to use of the backbone frame is the large hump in the middle of the floor, in both front and back seats. This is no disadvantage in a 2- or 4-seat sports car, but it could be a limiting factor in family cars. However, with the general trend in body design now toward four bucket-type seats, the backbone frame might be practical on a large portion of our 1975 car production.

Where does the space frame fit in this picture? Probably nowhere. This type of frame is fine for sports and racing cars, but is far too costly and fussy to produce in volume and the need for substantial height on the trusswork makes door openings a problem. The space frame doesn't look promising for passenger cars.

No, we think there will be a battle between conventional unit construction and the new perimeter frame for the next few years. The perimeter frame will seem to win for a while, then unit construction will come back strong (when certain technical problems are solved). Unit construction should then evolve into this backbone frame, with both welding and bolting of the main body structure. From there . . . well, who knows? ■