

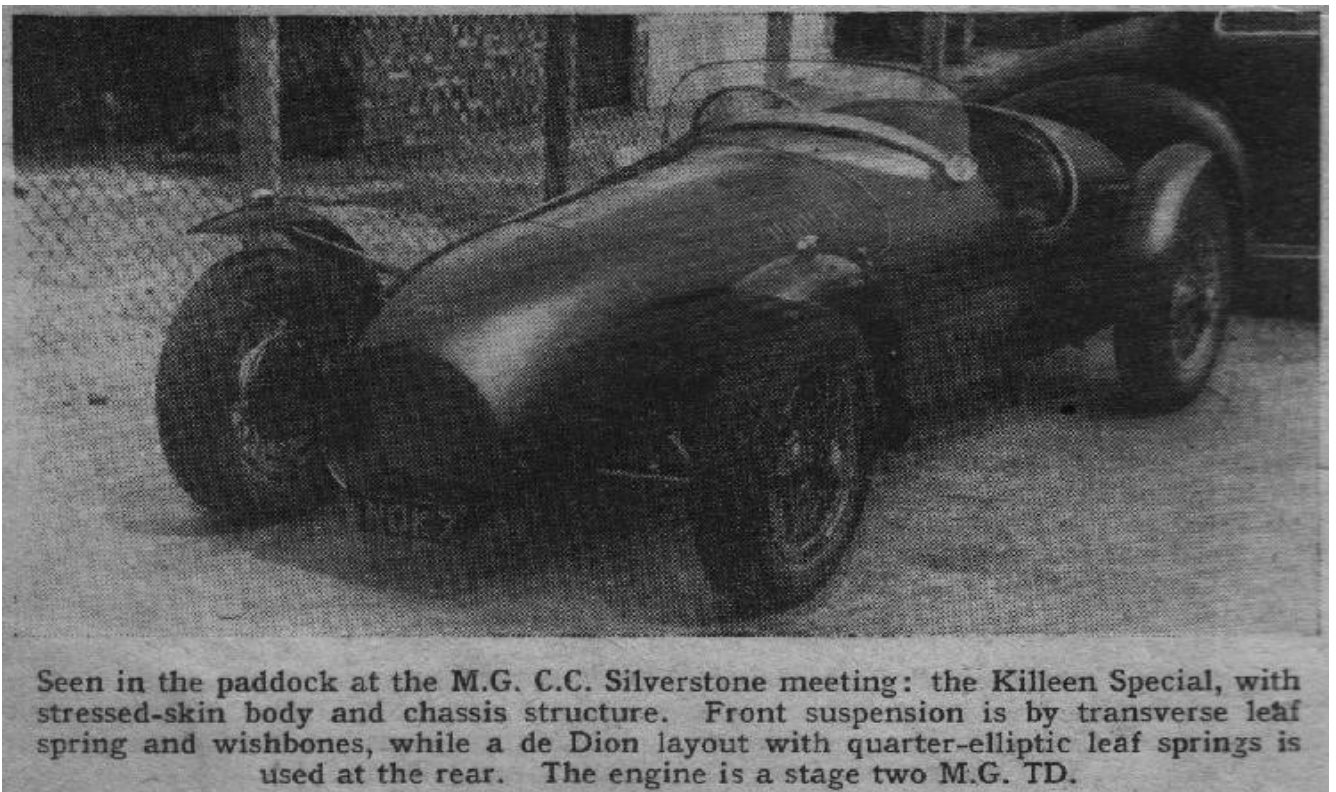
## Who Invented the Monocoque ?

There have been many attempts over the years to produce a monocoque car at the performance end of the market. Single-seater examples include the 1915 Cornelian Indianapolis car, the 1923 Voisin Grand Prix car and the 1949 Trimax 500cc racer. Tom Killeen clearly did not invent the idea of monocoque construction, but he showed how it *should* be done. After several trails he devised an entirely practical form of stressed-skin monocoque construction which is known as the monocoque tub. Unfortunately no one showed any interest at the time, but later others claimed to have invented the same thing.

What exactly is a monocoque? Put simply, it is a vehicle or structure with an outer skin that bears or distributes the stresses and loads produced during the life of that structure. An egg is perhaps the simplest example of the monocoque principle and man has used Mother Nature's idea in aviation and boating for many years - even long before Tom Killeen designed his K1. The automotive world took some time to accept monocoque construction methods however, but the ironic thing is that Tom Killeen might just have inadvertently accelerated the process. His attempts to have major players like Lotus and Cooper take notice of his ideas might at first seem to have failed, yet in 1962, Colin Chapman unveiled the monocoque Lotus 25 - just a few years after telling Killeen in a long letter that his ideas were scientifically and physically inferior. Of course, F1 eventually grabbed the monocoque idea and ran with it.

The principle of the stressed skin monocoque was therefore to have a body approaching a cigar or egg shape where forces could be distributed through the aluminium or steel outer skin. There were of course complications as there had to be a place for the driver to sit and access to the engine and other essential components. By its nature the suspension also delivered loading into a number of points and special mounting had to be prepared. It had previously been thought that a tubular spaceframe was better able to distribute loading from independent suspension, but the trend to very lightweight multi-tubular frames made the problems almost the same, and a true stressed skin was lighter and had greater torsional rigidity. That means quite simply that the chassis cannot twist, so the suspension and steering can do their job better and cornering performance is much enhanced.

Having a single cigar-shaped body, as in an aircraft, was not practical for a car and it became common to use multiple torsion boxes connected by stiff bulkheads, and in racing cars the engine which became part of the structure, but that was later.



Tom Killeen wrote many articles on the subject, most of which were published in *Motor*, see the Bibliography. He wrote one article in 1955 to *Autocar*, and they refused to publish it. The letter from the editor returning his

manuscript and drawings offered no explanation. He then tried to persuade Rodney de Burgh Walkerley to print the same article in *Motor*. Walkerley and Killeen had known each other several years previously. Here is the text:

#### *Monocoque vs. Spaceframe.*

*It is the object of this article to attempt to demonstrate the advantages of the monocoque construction over the space frame, particularly in connection with open competition vehicles. It would be as well to commence with a definition of the word monocoque, as the term is occasionally misused. Reference to available dictionaries has failed to furnish a satisfactory definition, and for want of a better, the writer submits the following:*

*A completely enveloping structure formed by a single skin, e.g. a hollow sphere.*

*A monocoque is essentially a stressed skin construction, but a structure in which the skin takes a minor portion of the load is not a monocoque. For example, a typical unitary constructed car is basically a tubular frame of fabricated box section with a comparatively lightly stressed outer skin, and this is most certainly not a monocoque structure.*

#### *Rigidity.*

*When applying the monocoque principle to road vehicles, it is of course necessary to modify the form, as defined above, considerably.*

*The experimental monocoque car described has put in a considerable road mileage over the last four and a half years, in addition to two seasons racing, and has so far not shown the slightest structural defect, not even to the extent of a single loose rivet!*

#### *Weight.*

*The basic frame of this car, comprising a centre section of 16swg Hyduminium, subframe and attachment points, weighs 75 lbs, and gives a stiffness figure of 2930 ft lbs. After adding a stressed cockpit cover weighing 5 lbs over the passenger's seat, this figure was increased to 3220 ft lbs. It would be interesting to know how closely this figure could be approached by a space frame, including the appropriate portion of unstressed panelling.*

#### *Accessibility.*

*The space frame design shows a slight advantage in accessibility, but only in connection with the centre section, as the monocoque designs shown have detachable front and rear cowls, permitting free access to the parts normally requiring attention.*

#### *Repair.*

*The centre section is the only part under consideration as the front and rear cowls of both types are detachable. The centre section is the least vulnerable part of the car, and when damage does occur in this area it is usually the result of a major crash. The monocoque centre section is of such a rugged nature that a force causing serious damage to it would almost certainly inflict equally serious damage to a comparatively flimsy space frame, which could not rely on any protection from its 22swg shell.*

#### *Load Distribution.*

*It is necessary to feed the load reactions, such as engine mountings, suspension mountings, etc., into the monocoque structure as evenly as possible, but this is purely a design exercise, and while requiring a little more consideration than in the case of the space frame, presents no difficulty.*

#### *Conclusion.*

*It is hoped that the above considerations have demonstrated the superiority of the monocoque, and satisfactorily answered the usual criticisms.*

*It is the writer's conviction that this form of construction is an immediate necessity for competition vehicles, and*

*that it will also be adopted for road vehicles. Furthermore, it would afford us the opportunity of indulging in the novel and stimulating experience of stealing a march on the foreigner in contemporary car design.*

*Tom Killeen, 4th April 1956.*

Tom later struck out the last sentence.

Tom Killeen attempted to patent his monocoque design in 1952, and did indeed own patent number 735110 entitled *Improvements in, or relating to, Motor Road and like Vehicles*, but was unable to afford complete protection of the idea. [Was it a tub ?] This was the source of many years of difficulty as he saw others use almost identical construction principles. The most strikingly similar was the famous and very successful Lotus 25 F1 car.

At a time when space frames were the "in thing", Tom Killeen really caused a bit of an upset with his monocoque K1 race car. Tom claimed to have built the World's first monocoque race car, yet the British Iota (an offshoot of the Bristol Aircraft Motor Club) race car from 1950 was also a true monocoque design. In 1949, a Canadian by the name of Alvin Rhiando unveiled his *Trimax* monocoque race car, so named because it was designed to accept 500cc, 750cc and 1100cc engines. Rhiando won the support race at the 1948 British Grand in a Cooper-JAP, but his *Trimax* used dural sheeting for the monocoque aspect. Prior to World War II, several car manufacturers had used monocoque design methods for production cars and Lancia's *Lambda* from 1922 was one such example. Nonetheless, Killeen's little car took monocoque practice to new heights as we shall show in Chapter 4.

Tom was convinced that the monocoque method of construction with his K1 should have been taken seriously by the major racing car manufacturers at the time. He and his wife Pat did all they could between the years of 1955 and 1962 to have the patent taken up, but without success. A long argument between Killeen and the established motor industry ensued. Firstly Jaguar announced its monocoque D-type in 1954, 18 months after the patent was granted, and understandably Tom was "a little miffed". Tom had a problem with Jaguar and their D-Type, believing that certain aspects to its construction infringed some of his monocoque patents. This came to a head in a letter to the chief engineer of Corvette after an article was published in *Autocar* 18/1/57 suggesting that they were to base a competition prototype on the "D"-type design. The idea of tackling a corporate giant such as Jaguar however did not appeal, and Tom was quoted as saying at the time that Jaguar were, *too big, too rich*. His letters to other manufacturers, some of which were quoted in *Motor*, September 1983 [42] show how committed he was to his ideas as do his technical articles over the following years.

Firstly Killeen tried to interest BRM in the design. He sent a set of drawings of K1 to A.G.B. Owen in 1954. There was indeed an attempt to produce a BRM with a centre-tub monocoque section in the mid 1950s, but it used an additional full-length frame to give sufficient strength to the cockpit area. The reply from Peter Berthon of Rubery Owens was as follows: *I have reported generally to Mr. A.G.B. Owens on your patented type of construction; and I have told him that I do not feel that this type of construction would be of value to us ... As you know, we construct very few cars, and most of our designs are constructed in such a way that we can modify, repair, etc. very quickly; and I feel strongly that with a stressed skin type construction this end would be entirely defeated ... If at any time a run of 50 or so cars ... were contemplated ... then your type of construction would be suitable.* A new BRM was produced in 1963, but used a double skin of nearly double the weight of a single stressed-skin chassis. Neither of the BRMs therefore strictly adhered to Killeen's principle.

Tom also wrote to BMC ? and received a reply from George Harriman saying *Your patented method of construction is, of course, much more suitable for light-weight cars for racing or competition purposes than for mass-produced models as now designed.*

There were also several lively exchanges by mail between Tom and a certain Colin Chapman, which began after Tom's monocoque ideas had been rejected outright by the Cooper Car Company! Nor did Tom have much success with Aston Martin and by 1960 the radical little Killeen K1 was all but forgotten.

The Cooper Car Company who had been building very successful tubular frame racing cars were typically more direct: *After ten years of building successful racing cars we do not feel disposed to adopt any other method than that which has always been synonymous [sic]. May we therefore suggest, if you have not already done so, that you contact Colin Chapman of Lotus Engineering Ltd. who seem to favour a similar type of construction.*

Little did Coopers know that the monocoque Lotuses were to turn the tables on their long success. Colin Chapman unfortunately replied to Killeen: *I am afraid my views must differ radically from yours on the question of monocoque construction, and I am convinced that the method of monocoque construction is totally unsuitable for*

racing cars. This he explained as follows: *One of the first requirements is that the body must be quickly and easily removeable for the purpose of cleaning, checking, servicing and inspection, and secondly the panels must be easily removeable for repair in the case of damage which, with a full width body, is frequent and one might almost say unavoidable. Further, we have found it possible to design a multi-tubular steel frame structure, with adequate stiffness, up to 2500 lbs for a weight of onle 50 lbs including all mounting brackets and pick-up points. By the very nature of his design it has been possible to fabricate extremely light body panels in 22 or 20 gguce aluminium. In either of these cases the saving in weight ... far exceeds the 50 lbs or so required for te chassis frame. Apart from the fact that a monocoque body requires a considerable amount of stiffeners, doubler plates, etc. to fit the loads satisfactorily into the skin. After all it should be borne in mind that it si axiomatic with stressed skin structures that the loads are fed into this structure in as widely distributed and as uniform a manner as possible, and nearly all load reactions such as engine, spring, shock absorber and suspension mountings, have to carry power loads of fairly high magnitude and, therefore, most of the structure system does not lend itself to this anchorage.*

Chapman had clearly taken his brief contact with Killeen very seriously. Being no fool, he had quickly understood all aspects of the design principle as this quote shows. In 1957 the Lotus Elite appeared, which turned out to be a very successful 3-part stressed monocoque construction in glass fibre. The first road-going Lotus was however rather expensive to produce and had initial problems of fixing the components to the GRP skin, as predicted. The Lotus 25 monocoque racing car appeared in 1962 and completely dominated the competition, including Coopers.

Killeen kept trying, and contacted BRM again in July 1956, but the argument with Jaguar again surfaced. The reply was received: *We have been warned if we develop a sports car in this country using the BRM engine, then we would jeopardise our business with Jaguar.*

He faired no better with Mercedes Benz and received a brush off from Rudi Uhlenhaut: *In order to judge correctly which construction of sufficient stability results inthe lowest weight, it would be necessary to prouce the same type of car in both versions. I am of the opinion that preference should be given to a tubular frame of pyramid design with an easily detachable Electron body also because of better access to the units.* So quite similar to Chapman's response.

John Wyer of Aston Martin said: *We have examined the sketches which you have enclosed with your letter but we do not feel that these offer us anything particularly novel in the form of construction, and it is our opinion that the torsional rigidity figure of 2930 lbs is somewhat optimistic.* Tom replied: *I was flattered by your doubt of the torsional figure quoted but can only assume that this is due to your failure to appreciate the significance of monocoque construction. It would indeed be remarkable for a conventional design of equivalent weight. Your statement that there is nothing novel in this form of construction also indicates a lack of appreciation of the principles involved.*

*I am surprised that a firm which imports a foreign designer to re-hash a twenty-year old Porsche design should reject a new British design, without first taking the trouble to assess its value accurately. The logical sequence for such a firm would be to import an Italian engine, install it in the German designed chassis, dress it up as a ``Guilietta'', and introduce it as the ``British'' answer to the Porsche 1600!*

Tom, like many great designers, was not known for his tact! Nevertheless his anger was because he had actually designed, built and used a simple but effective and accurate jig for measuring the torsional stiffness. Most other equipment of this kind was then very inaccurate.

Letters followed to the Standard Motor Company, Ferguson Rersearch (who were very much promoting safety in car design and using very advanced four wheel drive systems), and General Motors. There was no interest.

Keift did however express some interest and Alexander Engineering's Michael Christie helped to develop some ideas but nevertheless were not pursued. Even speed record holder Donald Campbell was contacted, but his engineer Leo Villa had already very advanced plans for the next land speed record car and declined to discuss changes.

A final letter to Arthur Owens resulted in the following reply in October 1962. *Thank you for your letter regarding the BRM and monocoque construction. We have gone into this matter very carefully in view of the implications of your remarks. The present design on which we are working is completely the work of Mr. A.C. Rudd. Generally we went ahead afer a study of the new Lotus 25 car which has certain disadvantages of which we are aware. We were influenced by their design insofar as we hope we have avoided their mistakes. There is nothing fundamenally novel or original in what we are doing, it is really an application of known engineerig to the particular problem of a racing car. It is true you sent some drawinge to Mr. Berthon in the fifties and did demonstrate a car. In no*

*conscious way has that information been followed. Indeed when Mr. Spear, Director of Research, discussed the matter with Mr. Rudd he had forgotten all about it until he was reminded. In principle, what we are doing is a straightforward engineering development handled by one man. It could be that subconsciously he might have been influenced a little by discussions 10 years ago, but any engineering design relies on the accumulated experience, knowledge and expertise of individuals. I am quite satisfied that directly we are in no way adopting your original proposals and that hence there is no need for any acknowledgement of your efforts.*

This was indeed a damning response to a man who had for a few years been ahead of his time.

The upturn in fortunes of Lotus as compared to Cooper and Ferrari in Formula 1 racing in 1962 was caused partly by Coventry Climax delivering the 1497cc FWMV V8 engine (to comply with the new 1500cc upper capacity limit imposed by the FIA) providing a challenge to the likes of Ferrari, not met by the 1.5l FPF engine even in Mk II form. The most spectacular advance however was in the design of the new Lotus 25 car. It had been initially intended to race with the Lotus 24, their most advanced spaceframe F1 car, and around 15 of them were supplied throughout the season to customers such as Jack Brabham, the UT-Laystall, Jo Sieffert and Rob Walker racing teams.

In the meantime Colin Chapman had been pondering the virtues of what he claimed to be an entirely new design for a racing chassis, that of a monocoque tub. Allegedly the first design was sketched roughly on restaurant napkins, and Chapman recalled the reasoning in Doug Nye's book *Theme Lotus* (Motor Racing Publications 1986), *Why not space the sides of a backbone far enough apart for the driver to sit between them? Made as box sections we could carry fuel inside in rubber bags. It was the first monocoque racing car so far as I was concerned. I'd never seen one before and we didn't know if it would work. We sold the spaceframe to our customers. We could not sell them a revolutionary car which might not work at all and might need a long and expensive development programme. At that time it was really an unknown animal.* The original meeting with Mike Costin (Lotus design director), Colin Chapman and John Standen (Lotus customer) was in Waltham Abbey High Street as told in Ian Bamsey's book *Lotus 25 Coventry Climax FWMV*.

No doubt Chapman was influenced by many factors and his vast knowledge of car design did lead to an original implementation. He was certainly influenced by both Mike Costin and his brother Frank, who was an aerodynamicist who had worked on the Vanwall and also the earlier Lotus 8, 9, 11 and 16 streamlined racing cars. He was also influential, although in a minor way, on the final Lotus Elite body detailing. Frank Costin worked for the de Havilland aircraft company and pioneered the idea of a monocoque plywood tub with several bulkheads. This was the basis of the Marcos sports car produced with Gem Marsh and also the Costin-Nathan sports racer of 1966-68 and Costin-Walker of 1967.

Frank Costin met Jem Marsh, an entrepreneur in the specialist car component business, in 1959. They planned to build a small GT car for 1,000cc class racing. They also considered producing larger numbers for sale. Based on an examination of cost, engineering potential and ease of fabrication Costin decided to use glider technology, namely a plywood monocoque.

The Marcos was designed around six torsion boxes. Three ran fore to aft and consisted of deep boxes (sills) on either side of the cockpit and the transmission tunnel. The sills were stiffened by internal bulkheads (ribs) placed at 12" intervals. Three more boxes ran transverse to the structure, one forming the engine bay, the next the cockpit, and the last the boot and rear suspension housing. A fully enclosed and stressed undertray tie all the boxes together. The strength of the chassis was concentrated below the top because of the large openings required for the doors. Entry was going to be difficult because of the high sills, so Costin decided to use gullwing doors which allow more headroom and simplified weather sealing.

[drawing of Marcos chassis, Ortenburger, p101]

In fact a monocoque design *had* been patented in 1952 by Tom Killeen after building his MG-powered K1 sports racer, although the idea was not widely adopted, and never before used in F1 or F2. Later Killeen cars, the Mirage and Scorpion, were similar in principle to the Lotus 25. The construction was basically two D-shaped sills (torsion tubes) connected by two bulkheads, one behind the driver and one beyond his feet. Another bulkhead was at the level of the instrument panel, and the instrument panel area itself. The floor of the car also served as a stressed skin.

In the Lotus 25 everything was made from light Alcad L72 aluminium alloy sheet and additional strengthening panels provided a seat for the driver. The front subframe, engine and gearbox were semi-stressed members carrying the suspension and tying the sills together at the front and rear ends. The torsional stiffness of the car was enormous compared to the previous space frame and thus the cornering ability was much better.

[drawing of Lotus 25 chassis, Bamsey p47]

Chapman successfully applied for a patent, which included a drawing and described the chassis as comprising *a pair of spaced tubular elements of substantial width and depth ... connected by cross members which serve to brace the structure, the engine one of the cross members.*

[Detailed photos of the construction are shown in Bamsey's book]

Much to the annoyance of his customers, Chapman's experimental car, of which seven were built for the Lotus works team, was an instant winner. It was succeeded by the similar Mark 33 and led to a succession of related designs by other teams from then on. Several of the cars were written off, but a few remain in the hands of private collectors. One such (chassis number R7) is owned by Tom Wheatcroft and can be seen in the Donnington Park museum.

More information about the Lotus 25 can be found in another book, *From Weird to Wonderful Part I - Climax engined Specials* by R.J. Allan and M. Morgan-Jones (Bookmarque Publishing) to be published, the many books on the Lotus marque by Doug Bye and others and the specialist book *Lotus 25 Coventry Climax FWMV* by Ian Bamsey (Foulis Haynes, 1990).

The designers of these cars in 1962 had in mind the aim of achieving what had already been successfully achieved by Killeen a decade earlier.