The program

Computer aided suspension design is much older than you may realise. *Racecar* looks back at PG1493 of 1963, the first program written to calculate suspension geometry

BY RICHARD NISLEY

It's the early 1960s and a race is on between the USA and the USSR to see which country can land a man on the moon first. Meanwhile, in Detroit, another kind of race is on, between Ford and General Motors to determine which company can develop the first computer program to calculate suspension geometry. It is the first step in the use of computers that will revolutionise automobile design and reduce large staffs of design engineers working at drawing boards to a precious few performing the same task quicker and more accurately on computers. The end result will be Computer Aided Design (CAD), which today dominates the automobile industry and is the standard of modern racecar design.

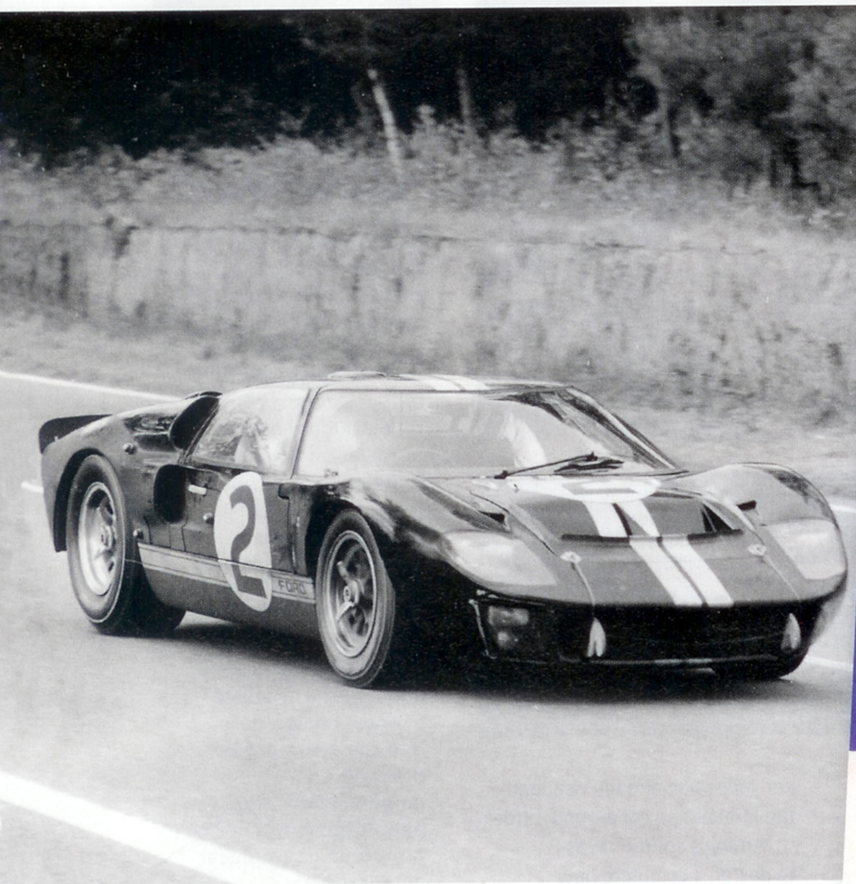
At the centre of this gathering revolution is a 24-year old graduate of the University of Michigan named Chuck Carrig. With two Bachelor of Science degrees, one in mechanical engineering and one in engineering mathematics, he has been working at Ford as a co-op student since 1958. In February of 1963 he graduates and is interviewed by General Motors, but elects to stay with Ford where for the past year he has been developing a suspension computer program known as PG 1493. Its first application will be the Ford GT40.

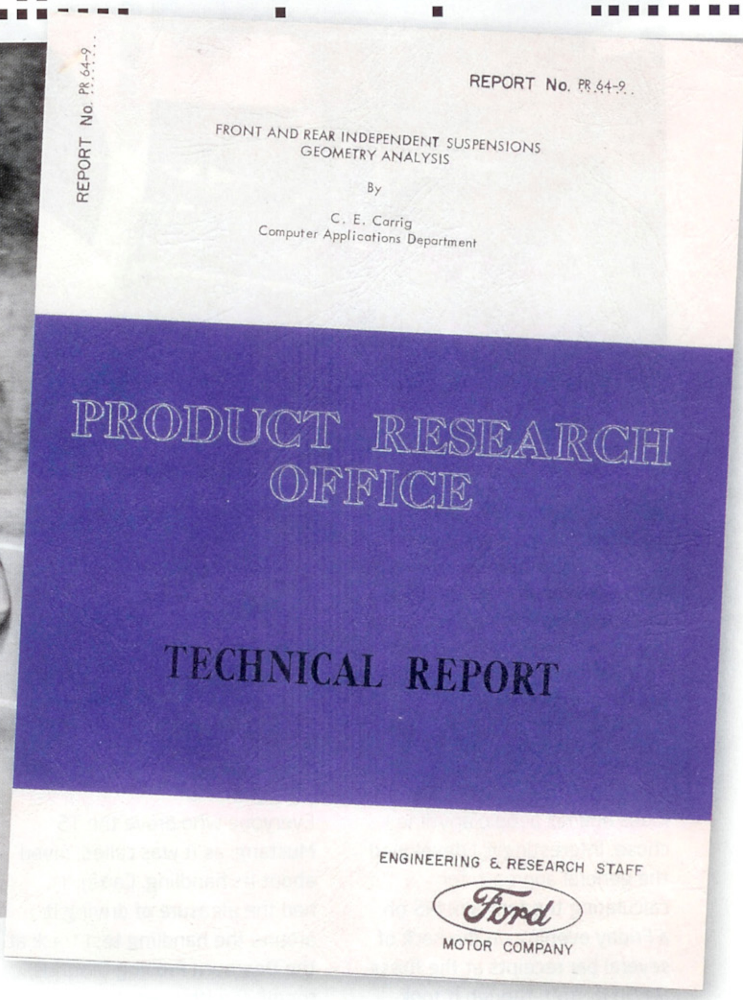
'There was no existing program to guide me,' says Carrig today. 'Someone at Ford had developed a rudimentary program for an IBM 650 computer but it was written in a primitive computer language that was virtually indecipherable and of no use in developing a new application. The program I wrote was for the new IBM 704 computer. It calculated the X-Y-Z coordinates of the balljoints, wheel centre, ground contact point, steering arm to tie rod connecting point, toe angle, camber angle, caster angle and other suspension properties through a range of jounce and rebound travel. A designer using this program would specify which point to increment. For example, increment the wheel centre one inch at a time, going up to 4.75in and down to five inches. He could include steering arm and tie rod or not as he desired. Output was printed on paper and also included graphs.'

Carrig wrote the program in Fortran, a computer language for engineering and scientific programming, and assigned a number for each point of the suspension (which Ford continues to use to this day). Point seven, for example, is the upper balljoint, point six the lower balljoint, points one, two and seven the upper control arm and point 10 ground contact.

Having the ability to increment the wheel centre or ground contact point through a range of motions was a breakthrough that saved designers a considerable amount of layout time. 'To give you some perspective,' says Carrig, 'if designers were to perform a drafting job for a new front suspension – to calculate the motion of suspension as it goes up and down through jounce and rebound – it would take 23 weeks. With [my initial computer program] you could do the same job in two weeks.'

Not everyone at Ford, however, was convinced of the





REPORT No. PR 64-9

FRONT AND REAR INDEPENDENT SUSPENSIONS
GEOMETRY ANALYSIS

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TECHNICAL REPORT

ENGINEERING & RESEARCH STAFF

Ford
MOTOR COMPANY

Sorting out the Ford GT40 suspension helped it win Le Mans. Right: Carrig's original technical report on using computers to design suspension

necessity of using a computer to calculate suspension geometry and, as a result, some of the design department managers balked and withheld information. 'If they saw me coming they would tell their people not to talk to me,' says Carrig. 'They were concerned about the impact it would have on their empires, and on their drafting people. They were afraid for their jobs.'

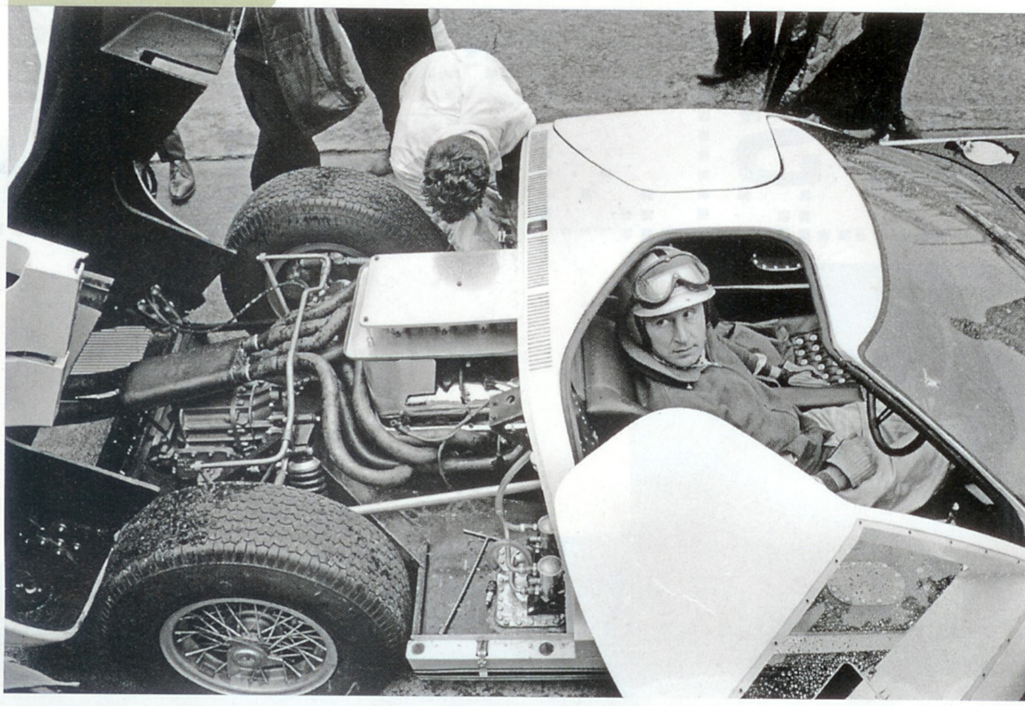
DESIGNING THE GT40

As fate would have it, at the same time Ford had just got into motor racing and, in the early summer of 1963, purchased the rights to Eric Broadley's slick new Lola GT coupe, with the idea of re-tooling it into what would become the Ford GT 40. Englishman Roy Lunn, who had worked with AC and Aston Martin before joining Ford, was put in charge of what was a rush project. While he and a handful of engineers moved to England and set up office in Broadley's tiny workshop in Bromley, Kent, in Detroit a suspension specialist and ex-pat German named Klaus Arning was re-designing the Lola suspension, incorporating anti-dive/anti-lift characteristics in front and anti-squat/anti-lift characteristics in the rear.

> **"Not everyone at Ford was convinced of the necessity of using a computer to calculate suspension geometry"**

'Klaus had been very supportive of what I was doing,' says Carrig. 'He asked if I could develop a similar program for a four-link independent rear suspension that would give not only a printout but also graphs of wheel motion. Nobody could even figure out how to lay it out. You can't lay it out on a drafting table because it's too complicated. It required a three-dimensional approach not conducive to two-dimensional drafting layouts. They gave me a time commitment that was almost impossible – in weeks, not months. It was a challenge for me personally.'

There was the question of costs, too. At the time, computers were very expensive to operate, costing $400 an hour, according to Carrig. Plus Ford wasn't manufacturing cars with independent rear suspension, so why waste money developing a program for it? 'Klaus had to sell his management on the idea of spending a bundle on developing the computer approach [for IRS],' says Carrig. But word soon filtered down that senior management was behind the program, especially because Henry Ford II wanted to win Le Mans. 'They said don't worry about money, in terms of computer time,' Carrig recalls. 'The IBM 704 computer we were using, which was a vacuum tube computer that filled an entire room, was very slow by today's standards, something like 40,000 operations a second (the computers at Ford now are in the trillions in operations per second). All obstacles were eliminated – computer priorities, budgets and the ability to interact with



Above: Using the Lola GT as a basis, the team at Ford were able to develop the suspension with an IBM computer and subsequently never encountered any geometry problems. The system then went on to be used on single seaters like the Coyote Ford (right)

Klaus and his people anytime I chose. Interestingly, I developed the general approach for calculating the four-link IRS on a Friday evening on the back of several bar receipts at the *Brass Rail* in Detroit, though it took several intense weeks to actually develop the program.'

Carrig completed his program on time, Arning re-designed the Lola suspension using it, and the first chassis order went to Abbey Panels in the Autumn of '63. In April 1964, the Ford GT40 was presented to the public. While there were many bugs yet to be worked out – aerodynamics in particular – suspension was not one of them, as all the bugs had been worked out already on Ford's computer.

> "I developed the general approach for calculating the four-link IRS on the back of several bar receipts"

HANDLING PACKAGE

The next rush project was a special handling package for a new production car, the 1964 Mustang, which included an IRS. Again, Arning was given the design task and the bugs were worked out on Ford's computer. Everyone who drove the T5 Mustang, as it was called, raved about its handling. Carrig: 'I had the pleasure of driving it around the handling test track at the Dearborn Proving Grounds, together with a regular Mustang for comparison. I could go 60-70 in the turns versus 25mph with the production version.' The prototype T5 Mustang evolved into the Shelby GT350, but without the IRS (too expensive, said Ford's bean counters).

Meanwhile, Carroll Shelby was having a very big problem with his latest Cobra in which he had stuffed a NASCAR-tuned 427ci Ford V8. The Cobra's ancient leaf-spring suspension could handle a small block 289 but not a mammoth 427. So Arning was called to the 1964 Sebring 12-Hour to see what he could do. Unfortunately, he was too late, Ken Miles had already wrapped the ill-handling car around a tree.

Arning's solution was to design a complete new suspension with coil springs and short/long A-arms, similar to then-current F1 practice and Ford sent an engineer named Bob Negsted to Thames-Ditton to oversee construction. 'The English tried to fit whatever stuff they had from the old Cobra into the new design,' Arning explained later, 'and some changes were made to accommodate that, but not many. If they required a different location of, say, a pivot point, Negsted would call and I would feed those points into the computer to recreate the outcome of the geometry to be identical to our intent, be it camber change or such, just to accommodate that new bit. But this had more effect on the front suspension than on the rear, because the rear was unique. There was nothing much they could reuse [from

CAD AND THE FUTURE

In early 1963, while Chuck Carrig was putting the finishing touches to PG1493, across town in Detroit the Spring Joint Computer Conference (SJCC) was being held, where an even more revolutionary computer application was being unveiled – Sketchpad. Its creator was an MIT (Massachusetts Institute of Technology) professor named IE Sutherland. The distinctive feature of Sketchpad was that it allowed the operator to enter design data into the computer by drawing on a CRT monitor with a light pen. It proved to be the prototype of graphical user interface.

For Ford and other car manufacturers, however, the inherent advantages of CAD were a good 20 years off, while the impact of Carrig's program would be more immediate. In 1963 state-of-the-art data entry was by punch card, while CRT monitors were only associated with watching TV at home.

Carrig didn't meet Sutherland that day. 'I met with Ivan Sutherland in Cambridge, near Boston in March of 1971,' he says. 'At the time he showed me a simulation program for training pilots in landing a plane on an aircraft carrier. Kids now take computer games and programs with very sophisticated displays for granted but back then Sutherland's work was groundbreaking.'

the old Cobra] for the new rear suspension design.'

At the same time, Ford decided to update the GT40 with a similar, NASCAR-tuned 427 V8. Again, the changes were fed into Ford's computer to update the suspension to accommodate the increased weight, torque and horsepower, and the result was the Ford GT MkII that Bruce McLaren and Chris Amon drove to victory in the 1966 Le Mans race.

CONTINUAL DEVELOPMENT

Carrig's computer program was under continuous development and by now spitting out results, not in weeks or even days, but in hours. He trained other engineers on how to use it and, in July 1964, wrote an operating manual for Ford's in-house publication, entitled Front and Rear Independent Suspension Geometry Analysis, *Program 1493*, or *PG 1493* as it became known. Ed Hull, who designed the Ford GT MkIV that won Le Mans in 1967, recently described how the PG 1493 computer engines to a number of Indy Car teams, which on the surface seemed to be as far as it went. In fact, they also were giving technical support to a number of teams having handling problems, AJ Foyt being the biggest beneficiary. Foyt had purchased several Lotus 38s from Colin Chapman for the 1966 season and, over a few weeks, crashed them all. He could not get the Lotus to handle properly and turned to Ford for help.

Former Ford engineer Bob Riley, who today operates Riley Technology with his son Bill, worked at Ford in the 1960s and recalls seeing a number of Indy Cars show up in Detroit for suspension analysis. 'I remember when we got in Foyt's Lotus,' he said recently. 'The bump steer was terrible. We could get rid of the bump steer in front, but on the independent rear cars, we didn't know exactly what to do. That's what drove a lot of them, that rear steer, which was really quite bad. I think we went through [several] computer runs

“The program didn't design the suspension for you”

program worked: 'The program didn't design the suspension for you. It allowed you to input all the suspension pick-up points and then the program would run through its jounce and rebound travel and generate all the points of the curves - camber change, caster change, toe-steer, anti-dive, anti-squat - the whole nine yards. In those days, when you would submit a run to the computer, it was done with a deck of computer punch cards.

'Once you had the results, he adds, 'you could finesse the design by moving a couple of points and re-submitting it to the computer. This procedure would be repeated until you achieved the desired results. I would work all day developing the points and at quitting time I would go into the computer room, punch the cars and submit them. The next morning I'd pick up the results in the computer room on the way to my office.'

TECHNICAL SUPPORT

Ford, meanwhile, was supplying

before we found out how to get the rear steer out. We put caster in the rear uprights.'

It didn't stop there for Foyt. In effect, he became Ford's factory Indy Car team. He also befriended Klaus Arning and asked him to design the suspension of his 1967 Coyote on Ford's computer. That May he won the Indy 500 and two weeks later (with Dan Gurney as co-driver) won the Le Mans 24-Hour. It was an incredible feat and at the time several people marvelled that the Texan could win back-to-back races in cars that were so fundamentally different. In fact, the suspension of the two cars was designed on Ford's computer and shared similar handling characteristics - anti-dive/anti-lift/anti-squat. And it didn't stop there either. Arning revised the suspension geometry on the 1968-'70 Coyotes as tyres grew increasingly wider and chassis took on more fuel to meet the increased fuel demands of turbos. Foyt, not given to compliments, especially to

KLAUS ARNING – FORD'S SUSPENSION GURU

'Some people (at Ford) didn't like him because he was kind of a showman,' says Chuck Carrig, 'but the guy was extremely inventive. He was always thinking.'

'Everything I learned about suspension I learned from him,' says Ed Hull, designer of the Ford GT MkIV that won Le Mans in 1967. 'He was Ford's suspension guru.'

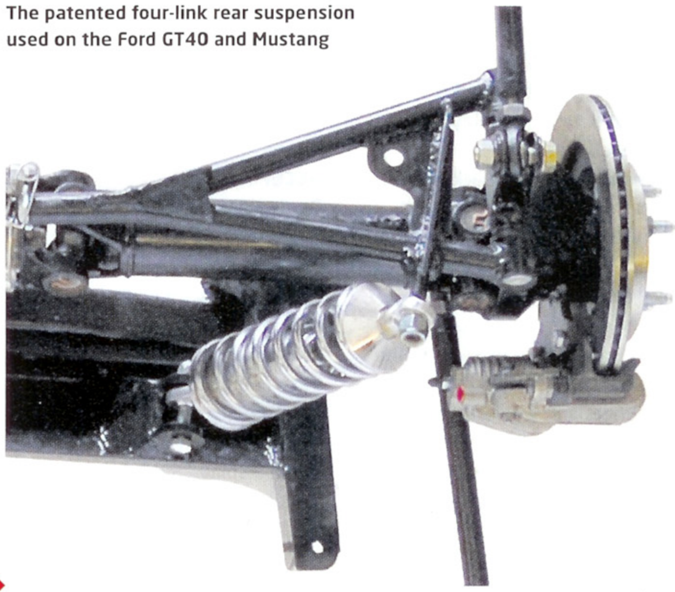
'He was brilliant,' says AJ Foyt.

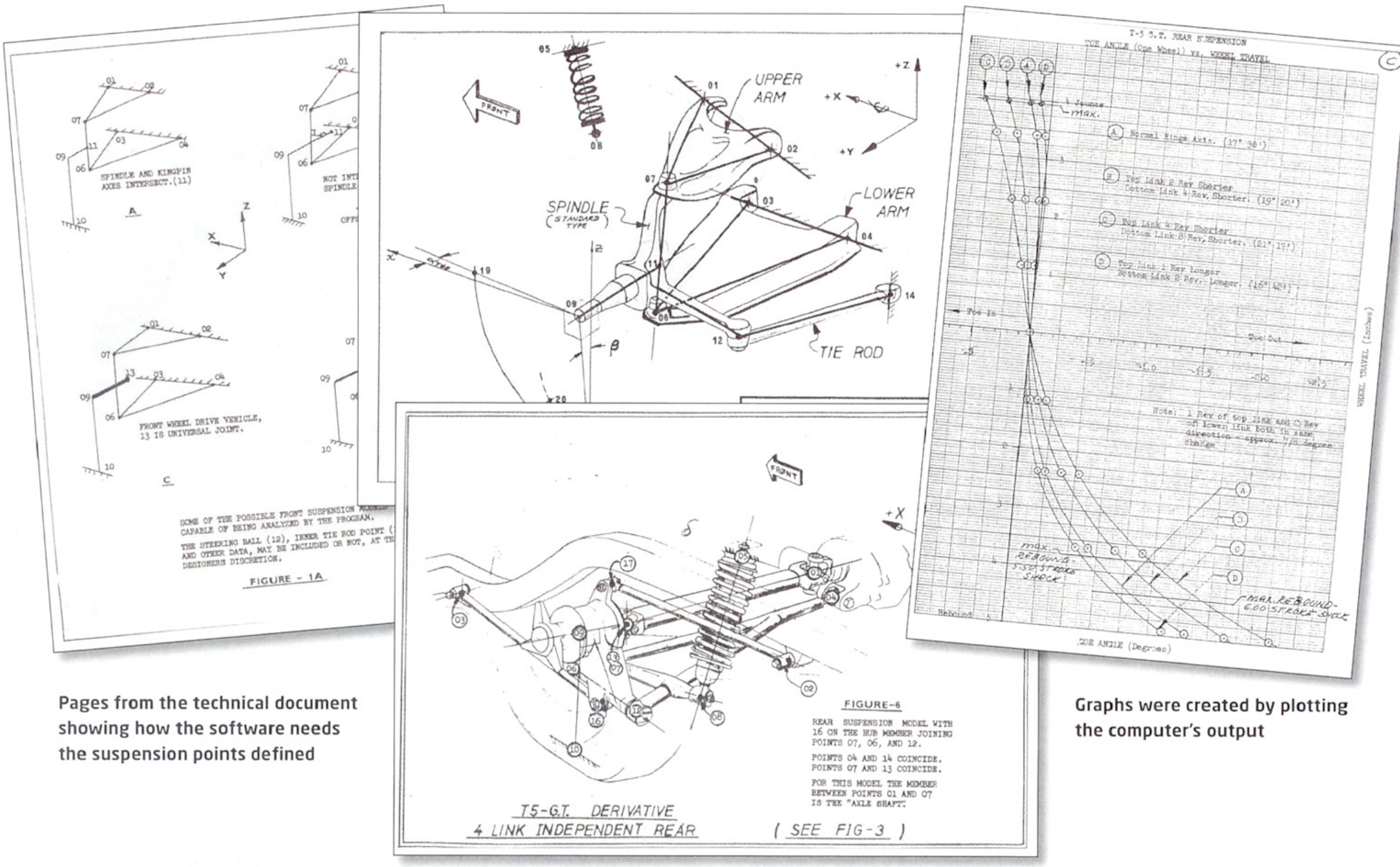
The man they are speaking about is Klaus Arning. In 1958 Arning designed a four-link independent rear suspension that incorporated roll understeer with anti-squat/anti-lift – two suspension characteristics thought to be incompatible. What did it mean in terms of handling? It meant enhanced accelerative capabilities and the minimal effects of throttle on/throttle off in turns, especially acute with cars having large displacement/high-torque engines – Detroit's calling card. Ford patented Arning's four-link IRS, but otherwise had no use for it. In 1962 that would change when Ford decided to re-tool its stodgy image by entering motor racing at Le Mans and Indianapolis.

Arning's patented IRS was incorporated into a variety of specialised and performance-oriented applications, including the Mustang I prototype, the T5 Mustang, the Ford GT 40 MkI, II, III, and IV, the 427 Cobra II, the Mustang Mach II prototype, the Honker II Can-Am racer and Foyt's Coyote-Ford Indy cars circa 1967-'70.

Arning's four-link IRS took many forms. For example, on the T5 Mustang IRS and the Cobra II IRS, a Watts linkage was employed, while on the GT40s and Coyotes conventional F1 practice was followed. Regardless of form, applications were successful partly because of Chuck Carrig's PG 1493 suspension program, which could reveal various design problems before they took form in moving parts, and thus speeded up development.

The patented four-link rear suspension used on the Ford GT40 and Mustang





Pages from the technical document showing how the software needs the suspension points defined

Graphs were created by plotting the computer's output

engineers, called Arning 'brilliant'.

With motor racing having proved the merits of Carrig's computer program, Ford's automobile and truck designers began using PG 1493 to verify existing designs that were close to production and for generating new designs that were still years from production. Carrig: 'The early production models that benefited from PG 1493 were probably the 1964-'65 Ford and Lincoln/Mercury car designs and light trucks. New designs that were actually generated on the computer were probably the 1967-'68 models.'

Which brings us back to the opening question: which auto manufacturer was first to use computers to aid suspension design? Carrig isn't certain, but offers this: 'I do know that there was a lot of interest in the Ford Suspension Program by designers and engineers who worked at Chrysler, American Motors and GM around that time. Before graduating, I interviewed with Cadillac Engineering. They were very interested in my work on suspension geometry. My impression was that they were also working on suspension geometry programs, but whether or not they or other parts of GM had actually developed similar programs I don't know. My guess is that Ford was ahead of GM in several areas. After I developed the front suspension program, American Motors paid Ford for its use. If GM had been first, I would think Ford would have paid GM for use of theirs.'

> **"There was a lot of interest in the Ford Suspension Program [from] Chrysler, American Motors and GM"**

ACCEPTANCE

By the late 1960s and early '70s most auto manufacturers worldwide were using computers in some capacity with the goal of automating the drafting process as much as possible. In the early 1980s CAD arrived and the process was complete. 'Today, you do everything on a video display CRT in front of you,' says Carrig, 'and you get your results virtually instantly and can determine where a problem exists straight away.'

Ford kept PG 1493 and integrated it into its newer systems. 'I had written [my program] in a manner that no matter what computer it was written on, it would run, as long as it had standard Fortran,' explains Carrig. 'The last time I looked, Fortran had evolved into Fortran IX or higher. The suspension computer program was written in standard Fortran II and eventually Fortran IV. As computers became more powerful Fortran was able to become more powerful, like Windows 95 vs Windows XP for personal computers.'

Today, if you're designing a racecar suspension, there are a number of computer programs to choose from. Bob Riley, whose cars in recent years have dominated the Daytona 24-Hours, still refers to the PG 1493 manual. 'It's just excellent,' he enthuses. 'There are a lot of computer programs that overlook some of the stuff in PG 1493. While a lot has changed, especially with tyres, [PG 1493's] actual geometry still holds true.'

'Those were unique times,' says Carrig of his salad days at Ford when he developed PG1493. 'Computer applications were being developed that had never been developed before. Management took risks and provided an environment of innovation. No doubt, it helped that the company had a relatively young leader in Henry Ford II, with his name on the building. I was young and didn't know a lot of people at Ford and was not yet consumed by meetings and intra-company politics, so significant time could be devoted to solving problems and to thinking, which was not the case in later years when there were too many meetings and too many 'MBA white papers' that had to be written to justify everything you wanted to try. Most of the people I worked with, such as [design engineers] Ed Hull, Bob Negsted and others, were not much older than was I. I remember walking to the Product Study area of the Ford Sci Lab where Klaus Arning and his designers were located the day President Kennedy was assassinated. As I said, those were unique times.'