UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa

Study on the technical, design and strategic reasons why Ford beat Ferrari in Le Mans 66 with the design of the Ford GT40 model

Report

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Abstract

In the world of endurance racing, there is one that stands out above the rest and is considered the "queen", the 24 Hours of Le Mans. In this project I have studied the technical, strategic and design reasons that allowed Ford to end the Ferrari hegemony and win the 24 Hours of Le Mans in 1966, with the GT40 model, and how to extrapolate the history of 1966 for a team that wants to participate in current competitions.

The first part of the project, focused on the history of 1966, is the main one and it is from which the second part is extracted, focused on the evolution of motorsports and how a motorsports team should be prepared in terms of strategy, organization and budget.

I first made a brief historical analysis to place the study in the time and situation in which the events took place, to understand why it was so important for Ford to win at Le Mans, what were the reasons that led him to participate in it and what provoked such a disproportionate rivalry between the Italian and American companies.

Once historically located, I have made a study of the 24 Hours of Le Mans 1966, analyzing the categories that are involved, the circuit where they ran, the Ford and Ferrari cars that participated on it and evolution in the Ford vehicle presented in 1966 with respect to its 1964 predecessor.

In the second part of the project I have analyzed the evolution of motorsports from 1966 to the present, dedicating a specific section to the 24 Hours of Le Mans. As for the evolution of motorsports, I have studied the differences between the regulations, the vehicles and the technologies used in the past and the current ones. In order to extract what could be the implementation of a competition team, I have focused on different competitions such as Formula 1, endurance racing (WEC) and rally racing (WRC), in order to cover the main disciplines of motorsports.

Finally, the study has had a total cost of just under 24.800€; obviously this cost is only from the theoretical study carried out and does not include the implementation neither the practical part of any of the sections of the project.

Declaration of Honour

I declare that,

the work in this Degree Thesis is completely my own work,

no part of this Degree Thesis is taken from other people's work without giving them credit,

all references have been clearly cited,

I understand that an infringement of this declaration leaves me subject to the foreseen disciplinary actions by *The Universitat Politècnica de Catalunya - BarcelonaTECH*.

Jordi Guix Sellarés		**13/01/2021**
Student Name	Signature	Date

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Study on the technical, design and strategic reasons why Ford beat Ferrari in Le Mans 66 with the design of the ford GT40 model

1- Purpose of the document

The purpose of this document is to compile the entire procedure that has been carried out for the study of how Ford beat Ferrari at the 24 Hours of Le Mans in 1966 and it will also show the conclusions that have been obtained from the analysis of the circuit, the cars and the events that took place during the development of the race.

In order to give a more global view of the project, the report also includes a historical summary which explains why the 1966 edition of the 24 Hours of Le Mans was so remarkable and the facts that provoked the brutal rivalry between the two teams.

2- Aim of the project

The aim of the project is to study how Ford beat Ferrari in the 24 Hours of Le Mans in 1966. This study will contain the main technical, design and strategic actions done by Ford team to prepare the race and how these influenced in the final result.

3- Justification

The most iconic endurance race in the world is the 24 Hours of Le Mans, 24 uninterrupted hours of pure velocity and rivalry between pilots. In 2021 it will celebrated the 55th anniversary of one of the most spectacular, exciting and iconic editions in history; in the 1966's edition Ford beat Ferrari, who had won the race until 1960, and in addition the three Ford cars crossed the finish line lined up at the same moment.

Due to the spectacularity and importance of the 1966's edition in the history of the 24 Hours of Le Mans, it is interesting to know the technical and strategic details that allowed Ford to achieve a highly competitive car and such an amazing result that is still remembered.

4- Scope of the basic engineering

In order to understand what exactly happened in the 1966's edition of the 24 Hours of Le Mans I will search information about Ford's company situation, the race history and the why of such an incredible rivalry between Ford and Ferrari.

For the project will be essential to know the main rules, categories and final result of the race and also the technical specifications of the two cars, Ford GT40 MK II and Ferrari 330 P3, and the specifications of the Circuit de La Sarthe, where the race took place. The analysis of these two data will be very important to take conclusions about why some technical specifications of each car were good or not for the race and how it influenced in Ford's victory in Prototypes category.

Due to there are a lot of technical decisions taken by engineers of Ford and Ferrari and I can't get any practical information because it's about cars and a circuit from over 50 years ago, it will also be interesting and useful to compare technical specifications between Ford GT40 Mk II and Ford GT40 Mk I to know which technical changes made Ford's engineers to make possible the victory in Prototype category.

I am also going to study the evolution of motorsports since 1966. I am going to focus on the 24 Hours of Le Mans, due to is the main subject of the project, and to study the evolution of motorsports in general.

Using the information extracted from study on the Ford's preparation to win the 24 Hours of Le Mans 1966, I am going to expose the main items to take in account when preparing a motorsports team.

5- Basic requirements of the project

The project studies a race and cars from 55 years ago and it is really difficult and expensive to make any practical test with cars, is for this reason why all data must be obtained through documentary sources or simulations in order to do not exceed the available budget of 25.000€.

6- Historical context

In order to be able to correctly analyze what happened at the 24 Hours of Le Mans in 1966 and why the rivalry between Ford and Ferrari was so relevant, it is very important to know the historical context, the facts, the circumstances in which it took place the race and also what had previously happened between the two companies. In the following sections we will learn about the previous history to Le Mans 1966, the reasons for the great rivalry between the two marks and the path that Ford had to take to achieve the great victory.

6.1- Ford's situation and rivalry with Ferrari

In the early 1960s, Ford Motor Company had in mind to open a new market line that was more committed to sportsmanship and that was an appeal to a wider audience; to this end Ford decided to enter the world of car racing, specifically in endurance races.

Since 1960 the World Endurance Championship (WEC) and specially the 24 Hours of Le Mans had been dominated by the Italian company Ferrari, which had won consecutively the three last editions (1960, 1961 and 1962).That was a fact that Ford could not beat Ferrari in a circuit, and knowing the need of the Italian company to get a major investment, in 1963 Henry Ford II, President of the Ford Motor Company, started negotiating with Enzo Ferrari, Ferrari's owner, to link the American and Italian companies to create road cars and competition prototypes. By May a deal was on the table between the two companies but Enzo Ferrari, who had probably never intended to sell, refused to lose control of the company and at the last minute backed down and in bad ways got rid of Ford. This made Henry Ford II very angry, who on his return to Detroit literally told Don Frey, his point man: "go to Le Mans, and beat his ass". It is at this time that begins one of the most important and memorable rivalries in motor racing history.

6.2- Road to Le Mans 1966

A month after breaking negotiations with Ferrari, Ford Motor Company formed the High Performance and Special Models Operation Unit, with the mission of build a racing car with real options to compete and win in major races such as Sebring, Daytona or Le Mans. On June 12, 1963 the GT Program book was published and it contained the initial design concepts for the GT40.

The initial team was formed by Ford's engineer Roy Lunn, who had already participated in the GT Program book, Eric Broadley, whose Lola GT was considered to build the car, John Wyer as the race manager, Carrol Shelby as the front man in Europe and Bruce McLaren as the test track driver. With only 10 months until 1964's Le Mans edition Ford team established in the garage of Broadley in Bromley, and starting from the Lola GT, began to work on what would end up being the first Ford GT.

After months working against the clock and many changes and hours of testing, in April 1964 the first GT40 was finished and quickly sent to the Le Mans test circuit. During the time trials in Le Mans the car proved to be very fast but the major problem was that due to aerodynamic problems the car was very difficult to control at high speeds; by adding a spoiler and other aerodynamic systems the team managed to reduce stability problem and the GT40 Mk I was already as ready as possible to race in the 1964 season.

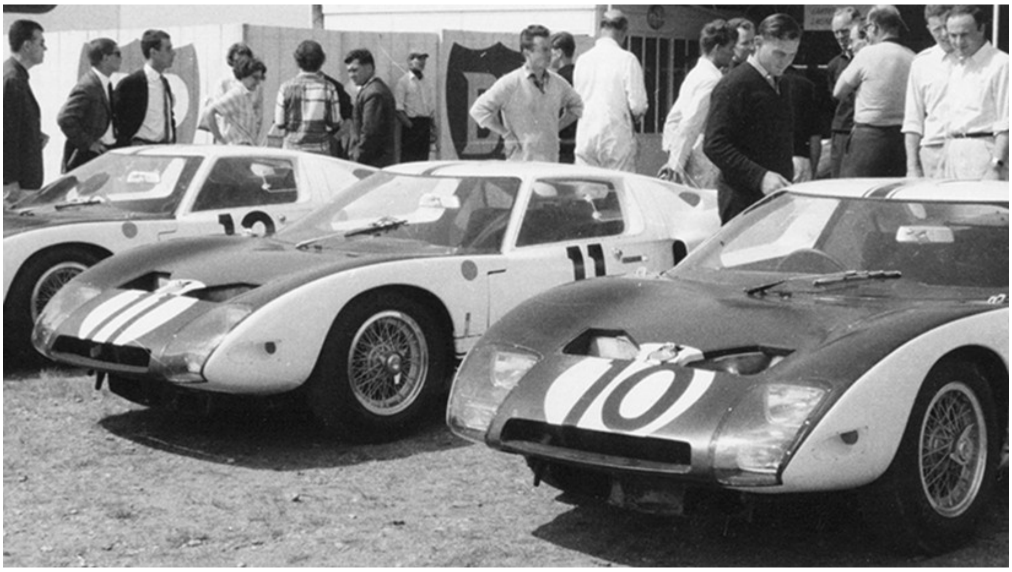


Image 1: Ford GT40 presented in the 24 Hours of Le Mans in 1964

While the GT40s were extremely fast, even to set some quick lap record, the main problem was endurance. In Nuremburg the suspension was lost and at Le Mans the gearbox did not resist the high speeds and the demands of the circuit; all three GT40s lasted no more than 12 hours of racing. The poor results led the operations centre moved to the United States along with changes in the team; Carroll Shelby was going to have operational control and Roy Lunn engineering control.

In late 1964, the cars arrived at Carrol Shelby's workshop in Los Angeles and Ken Miles, Shelby's developmental driver, quickly began working on them. Miles opted to return to the initial design of the GT40, which due to the rush to compete at Le Mans and the various problems that had arisen had changed considerably. The main issues to be addressed were suspension and aerodynamics, which had been a problem from the beginning.

By returning the suspension to its initial configuration, its performance improves markedly; in terms of aerodynamics, the results obtained with the different tests performed were even worse than expected. The modification of the airflow ducts made by Shelby's engineer Phil Remington added 80CV to the GT40 and the stability was greatly improved with weight reduction, replacing aluminium and steel for fibreglass and the iron wheels for magnesium ones wider. It looked like the GT40 was starting to be a racing car; the final exam would be the results of the 1965 season.

The 1965 season started pretty well for Ford, taking first and third place in Daytona and second in Sebring. With good expectations in April the GT40s were sent to Le Mans for the test weekend, but while the Ford team was still finishing setting up the car and experimenting with different gearboxes and engines the Ferraris clearly dominated the training.

While things were not going well at Le Mans, at Dearborn Roy Lunn's team had been developing and perfecting a new 7.0-liter (427 cubic inch) engine, with the added technical difficulty that the engine could not modify the aerodynamic stability that had been achieved, and it was already ready to be tested on the runway. Immediately Ken Miles flew to Dearborn and set to work with the new model and the results were fantastic, with a few aerodynamic tweaks the car reached a top speed of almost 340km/h.

Just four weeks before the 24 Hours of Le Mans, due to the incredible results of the new 427 engine, the Ford team decided to prepare two cars with the new engine (called GT40X) and the rest of the cars with the engine 289 that were already running in Europe. Ken Miles and Bruce McLaren were the GT40X drivers and clearly dominated the test day, being much faster than the Ferraris, but on race day things were very different, with the rush to install and prepare the new 427 engines some mistakes were made in gearboxes and these did not hold the race; once again the Ford team came out of Le Mans defeated.

With the experience of previous years, to prepare for the 1966 season Ford opted for a change in strategy and internal organization; to streamline administrative procedures and make faster decision making established the Committee of Le Mans, formed by the heads of the various divisions of Ford involved in the GT program, which met monthly, and also expanded the role of the Dearborn Motorsports and Styling and Engineering teams. Another important change was the entry of the Holman & Moody team, Ford's NASCAR team, and Alan Mann Racing into the GT program to work alongside the Shelby American in car preparation.

With the new strategic plan the Ford Motor Company had the time, resources and racing experience of Shelby American and Holman & Moody to be able to definitively develop the GT40 with the powerful 427 engine. After many hours of engineering, track tests and numerous changes the new model GT40 Mark II (GT40 Mk II) seemed ready to face the new season.

The first race of the year was Daytona and Ford presented a total of five cars, three driven by Shelby American and two by Holman & Moody; the success was resounding and Ford took the top three. The next test of the calendar was Sebring; the Le Mans Committee had doubts about whether it was better to race with the GT40 Mk IIs, which were very powerful and heavy, or with the GT40s with a 289 engine that were lighter and more manoeuvrable. Finally Ford introduced a combination of the Mk II and the GT40s whit the 289 engine, but it was quickly seen that the 289 ones were not powerful enough to compete with the Ferrari 330 P3 presented by Enzo Ferrari. Like Daytona, Sebring was an absolute hit for Ford, with the top three podium finishes.

At the end of the Sebring race one of the Mk IIs broke the engine and driver Dan Gurney could not finish and was not proclaimed champion; this unfortunate incident forced Ford engineers to thoroughly study the 427 engines and work to get an engine reliable enough to withstand 48 hours of racing, double that was needed for Le Mans. Incredibly the Ford engineers managed to improve the engine of the Mk II, the current engine lasted 48 uninterrupted hours running and produced 492CV at 6.400rpm.

The other big point to deal with was the brakes, due to the increase in weight and the high speeds reached by the Mk II the brakes suffered a lot of wear in each race and with the high demand that Le Mans meant when it came to reducing the speed there was a very high risk that the brakes would not hold. Ford engineers managed to find more resistant materials for the brakes but anyway Shelby American engineers Phil Remington and John Holman developed a quick-change system for the callipers and rotors so that if the brakes failed they could be changed in few minutes.

On June 18, 1966 at 16h 00, the start of the 24 Hours of Le Mans took place, with the participation of eight official Ford: three for Shelby American and Holman & Moody respectively and two more for Alan Mann Racing, and only three official Ferrari: two 330 P3 from the Spa Ferrari SEFAC and another 330 P30 Spyder (the same model but convertible) from the North American Racing Team (both companies presented some other models in private teams). The result of this edition was a spectacular victory for Ford, occupying the first three positions and leaving a photo for posterity.

Image 2: Photo finish of the three GT40 Mk II at the 1966 Le Mans race

7- Strategy of the 24 Hours of Le Mans 1966

7.1- Car categories

In 1966 the Comission Sportive Internationale (CSI), FIA's regulations body, established a completely new set of regulations; in particular the Appendix J refined motorsports categories in a numerical list.

With the new regulation there were a total of seven categories, although the ACO only opened its entry list to Group 3, Group 4 and Group 6:

- Touring Cars (Group 1 and Group 2)
- **GT (Group 3)**
- **Sports Cars (Group 4)**
- Special Sports Cars (Group 5)
- **Prototypes (Group 6)**
- Canadian-American Challenge Cup (Group 7)
- Single-seater Cars (Group 8 and Group 9)

For each Group there were some regulations for the cars, establishing a minimum annual production and a maximum engine capacity, as it's showed in Table 1.

CATEGORIES	Group 6	Group 3	Group 4
Engine limit (L)	None	None	5.0
Minimum annual production	None	500	50
Classes			
Large engine	2.5L - 7.0L		
Medium engine	1.6L - 2.0L		
Small engine	1.0L - 1.3L		

Table 1: 1966 categories regulation and classes

The Groups were divided in classes based on the engine size, which established a minimum weight and the fuel tank capacity: from 500cm^3 to 7.000cm^3 the minimum weight is between 450kg and 1.000kg and the fuel tank capacity between 60L and 160L.

With the new Appendix J the FIA announced the International Manufacturer's Championship for Group 6 and Group 4. The Manufacturer's Championship established different classes for each Group depending on the engine size:

- Group 6: 2.0L, +2.0L
- Group 4: 1.3L, 2.0L, 5.0L

For the 24 Hours of Le Mans of 1966 there were a total of 55 entries: 46 in Group 6, 6 in Group 4 and only 3 in Group 3.

CATEGORIES	Group 6	Group 3	Group 4	Total entries
Large engine [2.5L - 7.0L]	21	5	1	27
Medium engine [1.6L - 2.0L]	12	1	2	15
Small engine [1.0L - 1.3L]	13	0	0	13
Total entries	46	6	3	**55**

Table 2: 1966 category entries

7.2- Circuit de la Sarthe

The Circuit de la Sarthe is a semi-permanent motorsport race course, located in Le Mans, France, that comprises private and some public sections, where every year take place the 24 Hours of Le Mans, one of the most important events in the World Endurance Championship schedule.

The circuit was opened in 1923 and since now it has experimented some changes in its route, modifying the total length and the average and top speeds. From 1956 to 1967 (version Nº 4 of the circuit) the circuit had a total length of about 13,5km and an average speed of about 210km/h (data of 1966 edition).

Circuit de la Sarthe 1966	
Location	Le Mans, Pays de la Loire, France
Lenght (km)	13,461
Average speed (km/h)	210,80
Average time per lap (min:s)	03:49,9

Table 3: Circuit de la Sarthe of 1966 specifications

The Circuit de la Sarthe is considered a very fast circuit, with speeds over 320km/h, although the main concern and difficulty is the enormous demand it entails for cars, which must be fast enough not to fall behind on the Mulsanne Straight, resistant enough to withstand 24 uninterrupted hours of running at the highest level and manoeuvrable enough to take the close curves like the Virage de Mulsanne or the Virage d'Arnage.

The circuit consists of eleven main sections:

- Courbe Dunlop
- "S" du Tertre Rouge
- Virage de Tertre Rouge
- Mulsanne Straight (Hunaudiers)
- Courbe des Hunaudiers
- Virage de Mulsanne
- Courbe du Golf
- "Esses" d'Indianapolis
- Virage d'Arnage
- Courbe de Buisson
- Maison Blanche

7.2.1- Circuit route and driving

The circuit starts on the finish line straight and quickly still the Courbe Dunlop and the "S" of Tertre Rouge, a relatively difficult section that is done at fairly high speeds but also with a great demand for the brakes, which must drastically reduce the speed of the car to make the "S".

After the "S" of Tertre Rouge there is a stretch of straight to pick up speed and enter the Virage de Tertre Rouge, a very difficult curve; this is a turn of almost 90 degrees but it must be done without losing speed, as leaving the Virage you face the Mulsanne Straight where it is essential to reach the maximum possible speed on each lap if you want to have some options to win. The Mulsanne Straight is one of the most iconic sections of the circuit and also the fastest and most demanding with the brakes: the straight has an average speed of 240km/h and Prototype category cars reach top speeds over 320km/h during the nearly 5km of the straight and, about 450m before the Virage de Mulsanne, they reduce the speed from over 320km/h to about 70km/h; this enormous braking repeated between 340 and 360 laps, which is what the top finishers do, is a brutal wear for the brakes.

After the Virage de Mulsanne there's a fast section until reaching the "Esses" d'Indianapolis, a little curve that pilots use to reduce speed to do the Virage d'Arnage, which consists of braking thoroughly, turning everything to the right and squeezing the accelerator thoroughly to face Buisson, the second fastest section of the circuit, until it reaches about 200km/h that are used to pass really fast the Maison Blanche and finally the finish line.

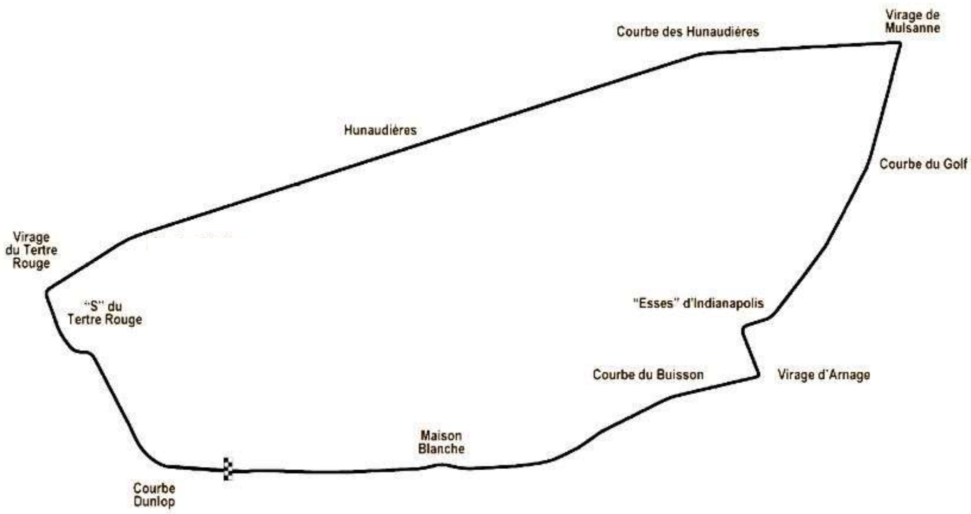


Image 3: Circuit de la Sarthe of 1966 route

7.3- Ford strategy

The Ford's campaign, started in 1963, to win the 24 Hours of Le Mans started began as a personal matter that blinded the company, that due to the rush focused solely and exclusively on the car, a very important factor, but without properly planning the strategy. The main cause of Ford's terrible defeats in 1964 and 1965 was "bad" planning. This became evident especially in 1965, when the defeat was caused by the lack of time to perform more tests and leave the car well prepared: the car was very fast and very powerful but needed to finish adjusting the whole so that everything would work in sync and everything would last until the end of the race.

With the experience gained with the first two editions, Ford decided to prepare for the 1966 edition calmly and doing things right from the base. They already knew that the car was very fast and that it could beat the Ferraris, but the year had to be spent properly adjusting all the car components and properly planning what needed to be done to ensure the maximum number of Ford cars would finish the race. This change in mindset involved a restructuring of Ford's internal organization and a proper planning of the racing strategy.

7.3.1- Company organization

Unlike Ferrari, the Ford Motor Company was a company dedicated to selling large quantities of cars annually, based on mass production. To design a competition car, and even more so if it is to run in the endurance championship, the approach and the way to do it are completely different, each part of the car must be tested many times and made many tweaks until find the settings, it is a way to work more craftsman than that of a big company. Moreover, a racing car is a concept completely different from a street car, both mechanical and in terms of driving; you can't just go from day to day producing cars to compete at the highest level.

In the first editions, 1964 and 1965, Ford started working in a car to compete in the endurance races but its internal structure and way to work were still being from a big company without great experience in the competitive field.

The main differences between the previous editions and the one of 1966, that allowed to obtain a much more prepared and reliable car, happened through an organizational change: the Committee of Le Mans was formed, more responsibility was given to the subsidiary Kar Kraft and NASCAR's Holman & Moody Ford team and a third team, Alan Mann Racing, were introduced.

Committee of Le Mans

After two consecutive defeats in previous years, Ford realized that if wanted to win the 24 Hours of Le Mans had to make some organographic changes on the company, had to create the equivalent of a board of directors but only for Le Mans and with that purpose was formed Committee of Le Mans.

The Ford Motor Company was structured and organized to produce large quantities of cars annually and to make long-term decisions. What the preparation for Le Mans required was a system that would make quick decisions and immediate application because the time to prepare is very low and the number of decisions to take is very high, both mechanical, at the level of strategy for the race, expenses, etc.

The Committee of Le Mans was constituted for the sole purpose of winning the 24 Hours of Le Mans; this focus on a single goal made it possible to devote all the attention to the Ford competition section. Formed by the main departments involved in the GT40 Program, the Committee was a small group that met monthly and had direct communication with competition teams and engineers, which reduced administrative formalities and streamlined decision-making.

Main members of the Committee of Le Mans:

- **Donald Frey**: Vice President and general manager of Ford Division
- **Leo Beebe**: public relations & promotion, director of racing activity
- **Jack Passino**: manager, Special Vehicles Activity (all GT cars)
- **John Cowley**: race manager
- **Roy Lunn**: Kar Kraft manager
- **Race teams**: Shelby American, Holman & Moody and Alan Mann Racing

Kar Kraft

The Kar Kraft was a competition workshop founded in the mid of 1960s and whose only customer was the Ford Motor Company. The incorporation of the Kar Kraft into Ford's competition program was to prepare the 1965 season and was derived from the Advanced Vehicles division from Ford and the work of Lola Cars in the GT40 Program, in order to have a specialized workshop for the design and manufacture of material for the GT40.

Kar Kraft's participation in the Program GT40 was really important to Ford's success in the 24 Hours of Le Mans, as it was commissioned to design the transmission for the Mk II and to adjust the new 427 engine of 7.0-liter to the new car.

Holman & Moody and Alan Mann Racing

In the 1964 and 1965 editions the Ford Motor Company presented a single competition team led by Shelby American but for the 1966 season the Committee of Le Mans decided to introduce two more teams: the NASCAR's Ford team, Holman & Moody, and the English team Alan Mann Racing.

The incorporation of two new teams had more than one purpose: to gain experience in competition, to have the internal competition factor to win and to have more options to win by presenting more cars.

The main reason why the Holman & Moody team joined was because of the experience it had in car racing, although NASCAR is a very different competition to the endurance championship, team's organizational skills were commoners and Holman & Moody mechanics were better trained in real racing situations.

The action of the three teams allowed the different problems that arose during the preparation of the cars to be treated from three different points of view and work simultaneously with three possible solutions.

7.3.2- Race strategy

For the 1966 edition of the 24 Hours of Le Mans the Ford Motor Company, apart from improving the car, had been working on a strategic change, both at the organizational level of the company and the Le Mans section, as a level of race strategy.

For the new edition of the 24 Hours Ford entered a total of eight official GT40 Mk II, thanks to the incorporation of the two new teams Holman & Moody and Alan Mann Racing. From the eight cars entered three were under the direction of Shelby American, three more for the Holman & Moody team and two for Alan Mann Racing.

In an endurance race like the 24 Hours of Le Mans, the mere fact of enduring the 24 hours without any breakdown or accident is already a challenge, and it was demonstrated when of the fifty-five cars that started only fifteen crossed the line of goal, among which were three of the eight GT40. Registering more cars increased the chances that some of them would finish and also the chances of winning.

As for the strategy during the race, the Ford team decided to force the car as little as possible to avoid breakdowns or accidents, and maximize their strengths. The main feature of the GT40 Mk II is velocity; it is an extremely fast car that in terms of top speed pulls between 30km/h and 40km/h to its rivals.

In order to make the most of the speed of the GT40 Mk II without forcing the car too much, the race approach was to start at a moderate pace that would allow them to stay close to the top finishers and when there were few hours to finish, taking advantage of the superiority in terms of velocity, speed up the pace to get into the top positions.

7.4- Race development and final results

7.4.1- The practice

During trainings, Ford showed his power and superiority by setting the fastest lap, by Gurney, with an impressive time of 3min and 30,6s (an average speed of 230km/h) and the rest of Ford with similar times, while the Ferraris could not keep up with these times and speeds and could not qualify for any of the top positions. However, training was a setback for both teams, when Surtees was sent off to face the Ferrari team leader, and Ford driver Dick Thompson was disqualified after having an accident and not properly notify the organization of the race.

The starting lineup was in training order, with four Fords in the top four positions and Ferraris mixed with the rest of Ford. Looking at the cars that occupied the first positions it is clear that power and speed are a key point for the Sarthe circuit, as both Ford and Ferrari were among the most powerful cars entered for the 1966 edition.

Qualification	*Car nº*	*Team / Car*	*Drivers*	*Time (min:s)*
Ford qualifications				
1st	3	Shelby American Inc. / Ford GT40 Mk II	Gurney, Grant	03:30,6
2nd	1	Shelby American Inc. / Ford GT40 Mk II	Miles, Hulme	03:31,7
3rd	8	Alan Mann Racing Ltd / Ford GT40 Mk II	Whitmore, Gardner	03:32,2
4th	2	Shelby American Inc. / Ford GT40 Mk II	Amon, McLaren	03:32,6
6th	7	Alan Mann Racing Ltd / Ford GT40 Mk II	Hill, Muir	03:33,2
9th	5	Holman & Moody / Ford GT40 Mk II	Bucknum, Hutcherson	03:34,6
11th	4	Holman & Moody / Ford GT40 Mk II	Donohue, Hawkins	03:35,2
12th	6	Holman & Moody / Ford GT40 Mk II	Andretti, Bianchi	03:36,3
Ferrari qualifications				
5th	27	North American Racing Team / Ferrari 330 P3 Spyder	Ginther, Rodriguez	03:33,0
7th	20	Spa Ferrari SEFAC / Ferrari 330 P3	Scarfiotti, Parkes	03:34,3
8th	21	Spa Ferrari SEFAC / Ferrari 330 P3	Bandini, Guichet	03:34,4

Table 4: Qualifying results from the 24 Hours of Le Mans of 1966

7.4.2- The race

The days before the race had been splendid and very hot, but on the day of the race the weather began to change, with a cloudy sky and much lower temperatures than on training days and at 15h 30, half an hour before the start of the race, it started to rain heavily causing the teams to have to change the tires, both the design and the brand, to adapt the cars to the new race conditions. However, the rain lasted less than expected and when the race started the weather conditions no longer required rain tires, which caused many cars to start with a wrong tire configuration, including the Ford Amon-McLaren .

On June 18, 1966, at 16h 00, the starting shot was fired and the fifty-five pilots ran towards their vehicles to start and shoot out at the 24 Hours of Le Mans.

Ford started leading the initial stage, with Hill and Gurney leading and much later than the Ferraris, although three Fords had to pit in the first lap: Miles had problems with the door and was not locked, Whitmore had a broken brake tube and Hawkins had managed to get to the pits with the transmission shaft broken. These pit stops by Ford allowed Rodriguez's Ferrari in the 30th minute of the race to take fourth place, ahead of Parkes, another Ferrari member and behind Gurney's Ford, Hill and Bucknum, who didn't even see them advanced they were going. Meanwhile, Miles was going extremely fast to make up for lost time in the forced pit stop, lowering 3s the time Ford had set per lap.

At 17h 00, cars Whitmore and Hawkins were already repaired and running again, Miles had lost time and now ranks fifth, just behind Ferrari Rodriguez and Gurney, Hill and Bucknum continued occupying the first, second and third place. At the time, the top 10 were Ford and Ferrari (with the exception of Chaparral, another race car), with Parkes, Guichet, McLaren and Bianchi in seventh and tenth place.

During the second hour of the race it started to rain but when it coincided with the stops for refuelling it did not affect the race too much, although in the case of Ford the pit stop was quite chaotic as the two repaired cars were again in the pits due to technical problems when the leaders stopped to refill the tank and, due to lack of space, Hill had to take an extra turn without stopping to pit.

After pit stops and rain the first nine positions were still occupied by Ford and Ferrari, Grant had taken over from Gurney and occupied the first position, followed by the car number 1 now in the hands of Hulme, followed by the Ferrari 27 driven by Ginther and the car number 2 driven by Amon were in eighth place behind two Ferrari.

Before nightfall, the high pace of Le Mans was already affecting both teams. Ford for his part had lost Hawkins' car which had broken the differential, Whitmore had to retire when the clutch broke, Hill had broken the suspension and car number 6 (Andretti-Bianchi) had broken the engine; meanwhile Ferrari had lost car number 20 in an accident. Four Ford and two Ferraris were left in the race.

At midnight Gurney-Grant and Miles-Hulme's Ford and Ginther-Rodriguez's Ferrari had completed the 126 laps, while Amon-McLaren (Ford) was one lap behind and the Ferrari Bandini-Guichet five laps below. Throughout the night, Ferrari watched as the chances of winning were markedly reduced by losing Ginther-Rodriguez's car due to gearbox problems, with only one Ferrari left on the track. Meanwhile at Ford, the mechanics took advantage of one of the pit stops to implement the mechanism designed by Ford engineers and replace the brakes, already heavily worn after more than half a race, for new units.

The morning of June 19 began with the abandonment of the last Ferrari (Bandini-Guichet), which after 226 laps broke the engine, completely eliminating the chances of victory in the Ferrari team and leaving only twenty four cars on the track. Shortly after the abandonment of the last Ferrari, Gurney-Grant's Ford, which had set record times in training and racing, abandoned the race when the radiator broke and was unable to cool the engine. Anyway, the situation was very favourable for Ford, occupying the top three positions and with all Ferrari cars eliminated.

At noon there were only sixteen cars left, with the three Fords occupying the top three positions: Amon-McLaren first slightly ahead of Miles-Hulme and nine laps behind Bucknum-Hutcherson. With just two hours to go it started to rain and all the riders slowed down considerably to avoid any complications and make sure everyone finished the race.

With less than half an hour to the end, Miles who went first and McLaren second lined up next to each other and slowed down to wait for Bucknum's car to finish quietly the 24 hours without the risk of accidents and to cross the finish line aligned, following internal orders from Ford.

On June 19, at 16h 00 Ken Miles and Bruce McLaren crossed the finish line simultaneously and, by a decision of the ACO (Automobile Club de l'Ouest, organizing member of the 24 Hours of Le Mans) Bruce McLaren and Chris Amon were proclaimed, by 20m difference with Miles and Hulme, champions of the 24 Hours of Le Mans 1966, giving the desired victory to Ford.

Result	*Car nº*	*Team / Car*	*Drivers*	*Laps / km*	*Race notes*
		Ford results			
1st	2	Shelby American Inc. / Ford GT40 Mk II	Amon, McLaren	360 / 4.843,09	-
2nd	1	Shelby American Inc. / Ford GT40 Mk II	Miles, Hulme	360 / 4.843,07	-
3rd	5	Holman & Moody / Ford GT40 Mk II	Bucknum, Hutcherson	348 / 4.681,57	-
DNF	3	Shelby American Inc. / Ford GT40 Mk II	Gurney, Grant	257 / 09h 44	Holed radiator
DNF	7	Alan Mann Racing Ltd / Ford GT40 Mk II	Hill, Muir	110 / 23h 30	Front suspension
DNF	6	Holman & Moody / Ford GT40 Mk II	Andretti, Bianchi	97 / 22h 47	Head gasket
DNF	8	Alan Mann Racing Ltd / Ford GT40 Mk II	Whitmore, Gardner	31 / 20h 40	Clutch
DNF	4	Holman & Moody / Ford GT40 Mk II	Donohue, Hawkins	12 / 19h 29	Differential
		Ferrari results			
DNF	21	Spa Ferrari SEFAC / Ferrari 330 P3	Bandini, Guichet	226 / 08h 26	Engine
DNF	27	North American Racing Team / Ferrari 330 P3 Spyder	Ginther, Rodriguez	151 / 02h 17	Gearbox
DNF	20	Spa Ferrari SEFAC / Ferrari 330 P3	Scarfiotti, Parkes	123 / 00h 01	Accident
DNF: Do Not Finish					

Table 5: Race results from the 24 Hours of Le Mans of 1966

7.5- Conclusions of the 1966 edition

7.5.1- Circuit conclusions

After knowing the circuit in terms of route, type of driving, top and average speeds, etc. it is necessary to analyze what qualities a car should have to be "the best" to run on the Circuit de la Sarthe and face, as prepared as possible, the 24 Hours of Le Mans. It is very important to know this circuit-car relationship in order to analyze in detail the Ford GT40 Mk II.

Firstly it is an endurance race that is, the car must not only have good mechanical performance (speed, power, aerodynamics, acceleration, etc.), it also must be a durable and reliable car that can hold 24 uninterrupted hours operating at the highest level and with a very high degree of technical demand. This factor involves a greater degree of difficulty when designing a car, in competitions where endurance is not so important (Formula 1, NASCAR, etc.) can be used materials with not so high mechanical properties (since in few hours and kilometres of operation can be changed for new parts) but much lighter and at the same time the section of the parts can be reduced in order to significantly reduce the weight of the vehicle, a very important factor that conditions the power, the wear of the brakes, the speed in the curves, etc. In short, having to endure so many hours and kilometres at the highest level means that the design is not just about mechanic performance, but also reliability and durability.

The other big factor to consider for the 24 Hours of Le Mans is the speed. It is a very fast circuit in which the cars go at an average speed of 200km/h and in which extremely high speeds are reached, that exceed 320km/h. The high speed of the circuit means, first and foremost, that the car can reach the speeds required by the circuit, which mainly involves a very powerful engine. Second and not least, a car designed to go at such high speeds must have very good stability, as at 320km/h any small bump or irregular driving can lead to loss of control of the vehicle and end up in an accident. At a technical level good stability translates into good aerodynamics and good suspension.

Another very important factor of the Circuit de la Sarthe is that, apart from being a very fast circuit, it also has very closed curves which must be done in relatively low speeds (between 70km/h and 90km/h), this combination involves a very strong braking with the consequent wear of the brakes. The technology to get a car to go from over 320km/h to about 80km/h in a very small space (about 450m) is well known and within the reach of competition teams, but the real problem is to get the brakes to last for 24 hours, that means repeating the abrupt braking between 340 and 360 times (laps done during the 24 hours of the race). In order to achieve maximum reliability of the brakes it is necessary to use materials with very good thermal properties that withstand very high temperatures and thermal shock (along the 5km of Mulsanne Straight the brakes cool and suddenly increase their temperature for the Virage of Mulsanne) and at the same time it is necessary to reduce as much as possible all those factors that increase the effort required by the brakes on braking, such as weight (the heavier a car the harder it is to brake).

In a brief summary, the conclusions from analyzing the circuit and the 24 Hours of Le Mans are as follows:

- Is needed a very fast car that is also reliable and durable, which means finding the balance between the design that guarantees the best performance of the vehicle (speed, acceleration, etc.) and the design that maximizes durability and reliability.

- Due to the high speeds and the abrupt curves of the circuit it is necessary that the car has a high stability and very resistant brakes, which implies good aerodynamics, good suspension and try to reach the maximum reduction of the brakes wear.

7.5.2- Strategy conclusions

After learning about Ford's new way of working in the competition section of Le Mans, it is necessary to analyze if the organizational and strategic changes proposed for 1966 influenced the victory and in this case how and why.

The most important change for 1966 was the creation of the Committee of Le Mans, a body within the Ford Motor Company with decision-making power and with the only aim of winning the 24 Hours of Le Mans.

With the Committe of Le Mans, decisions were no longer made by different Ford departments or different executives with little data on the project, all decisions were made by the committee that had first-hand data updated periodically. This organizational change made it possible to reduce administrative procedures and greatly speeded up decision-making, which made it possible to plan and structure the Le Mans project from a purely competitive point of view.

The creation of the Committee of Le Mans is vital for the new organization of Ford as it was responsible for making all decisions for the 24 Hours of Le Mans in 1966, such as the participation of two new competition teams in the Le Mans program: Holman & Moody and Alan Mann Racing.

The participation of the new teams had repercussions both in terms of car preparation and race strategy point of view. At the level of preparation, the problems that arose could be treated from different points of view and with more experience in the competitive field, which could lead to better solutions in less time.

At the strategic level, having three teams allowed Ford to register many more cars than in other years. With the participation of more cars, the probability increases that one of them will finish the race and that one of the champions will be a Ford.

Making a brief summary, the conclusions from analyzing the strategic and organizational change of the Ford Motor Company for 24 Hours of Le Mans 1966 are as follows:

- The Committee of Le Mans was created, which had the only goal to win the 24 Hours of Le Mans, in order to focus all efforts on the competition, reducing paperwork and speeding up decision making, as the main representatives of each department involved in the Le Mans program were part of the committee.

- The incorporation of the Holman & Moody and Alan Mann Racing teams allowed a higher number of cars to be registered and also helped a lot in the preparation of the vehicle, as there were three times as many resources available and it was possible to work simultaneously on more than a proposal or solution.

- The participation of the Kar Kraft was essential in the mechanical field, being a small workshop could focus on specific projects, such as the adaptation of the 427 engine to the Ford GT40 and the design of a transmission capable to support the huge torque generated by the engine.

7.5.3- Development conclusions

After knowing how the race developed and what events and actions took place in each team, the most important factors can be extracted. These conclusions will be complementary, in part, to the analysis of the race strategy, as it is the implementation of this.

At first glance it is seen that not even half of the 55 cars that started lasted the 24 hours, only 15 drivers crossed the finish line. This fact, together with the 5 Ford and 3 Ferrari eliminated due to technical problems or accidents, highlights the importance of involving as many cars as possible (already mentioned in section 7.5.2), as along the 24 hours and in hard conditions of driving, bad weather and with the fatigue of the pilots and of the mechanicals, many unforeseen and mistakes can happen that mean the car does not finish the race.

Another very important factor was the change of brakes that Ford made during a pit stop. After about 12 hours of running the brakes of the GT40 were very hot and the risk of them failing was very high (one of the problems already appeared during the preparation of the car and training, and which had not been completely resolved) and Ford team decided to use the quick-change mechanism that Ford engineers had designed. With the change of brakes, callipers and discs, the Ford cars faced the second half of the race with completely new brakes, which allowed them to continue going at the high speeds that the car gave. Without the new brakes the drivers would have been forced to slow down, as otherwise the brakes would not have lasted the 24 hours.

At the end of the race the three Ford drivers, who led the classification, were ordered to slow down to enter the three at the same time. This decision, which generated a very controversial end, has a corporate component of Ford to advertise and at the same time a component of risk prevention. If the drivers who finished first and second, McLaren and Miles, had not reduced the rhythm and continued trying to beat each other, the result could have been terrible for Ford, as in the last laps he could have lost the first two cars.

In summary, four main conclusions can be extracted from the analysis of how the race developed over the 24 hours:

- Ford's decision to participate with eight cars was a very important factor, as the risk of losing cars during the race is extremely high. Ford lost a total of five cars; if he had done as in previous editions in which he participated with only two or three cars he probably would not have finished the race. This demonstrates a success in the new racing strategy that Ford chose for 1966.

- The fact that it did not finish any of Ferrari will be an important point to be treated in the technical conclusions of the vehicles, to know how much was merit from Ford to have a better car that forced Ferrari drivers to exceed the car possibilities or if it was more a matter of relative "luck" of Ford who saw how due to technical problems and accidents his biggest rival left the race.

- The change of brakes in the middle of the race was a key decision to be able to maintain the high rhythm of the Ford cars as if they had to endure 24 hours with a single brake, the pace of the race would have been much slower in order to preserve the brakes as much as possible.

- The decision to bring in the three lined up Ford had an advertising component, but at the same time, a strategic issue to ensure that all Fords left on the track finished the race, without danger of mechanical failure or accidents in the last moment trying compete with each other.

8- Cars of the 1966 edition

8.1- Technical specifications of Ford GT40 Mk II

Ford GT40 Mk II	
Engine	
Configuration	7.0 V8-90º
Fuel type	gasoline
Location	midle, longitudinal
Displacement (cm3)	6.997
Charge system	naturally aspired
Power gross (CV)	492 (6.400 rpm)
Torque gross (N·m)	644 (5.000 rpm)
Efficinecy (CV/L)	70,3
Dimensions	
Weight (kg)	1.217
Lenght / Width / Height (mm)	4.140 / 1.753 / 978
Wheelbase (mm)	2.413
Front track (mm)	1.448
Rear track (mm)	1.442
Fuel tank capacity (L)	159
Performance	
Specific power (CV/kg)	0,40
Top speed (km/h)	340
0-100 km/h (s)	5,4
Consumption (L/100 km)	16,3

Table 6: Ford GT40 Mk II specifications

Image 4: Ford GT40 Mk II (1965 and 1966)

The Ford GT40 Mk II is the new model of the GT40 that the Ford Motor Company introduced in 1965 and that was definitely set up and refined for the 24 Hours of Le Mans 1966.

This is the typical American car, heavy and with a large engine and very powerful engine. Indeed, more than 1.200kg make the Mk II a very heavy car, but this does not deprive it of exceptional performance, a performance that is possible thanks to the huge 7.0-liter V8 engine and a very good aerodynamic configuration. The 7.0-liter engine compensates for weight gain by supplying more than 490CV and a torque of almost 650N·m, extremely high values that combined with the right transmission allows it to reach a top speed of 340km/h.

The impressive values of power, torque and speed mean that, despite its apparent high weight and low efficiency 7.0-liter engine, the GT40 Mk II is a very fast and powerful car that can compete to his rivals without problems.

Engine

One of the most important changes to the Mk II was the engine, which went from the 4.0-liter 289 engine to the huge 7.0-liter 427 engine, the same one used in NASCAR. After testing the new engine, it became clear that this was the engine to work with, although it still needed to be refined.

One of the main aspects to improve was the weight of the engine, which was commissioned to the Engine and Foundry division of Ford (E&F). A remarkable weight reduction was achieved with aluminium heads, an aluminium cube in the vibration damper, and a water pump of the same light alloy; this meant going from 273kg for the NASCAR version to 249kg for the Le Mans version. The aluminium heads meant a small reduction in the size of the valves, which went from a diameter of 5,5cm to 5,2cm. As for the head design it remained the same, although the compression ratio was reduced from 12,5:1 to 10,5:1, due to the fact that the octane rating allowed at Le Mans was lower than the NASCAR one.

Adapting the engine to the GT also required the design of a new exhaust and carburetion system; one of the main problems was the limited space available for the car to fit an exhaust system powerful enough for the huge engine. This was achieved with the system called "bundle of snakes", which consists of crossing two tubes on each side of the V8 on the engine to collect them in 4: 1 collectors with opposite tubes.

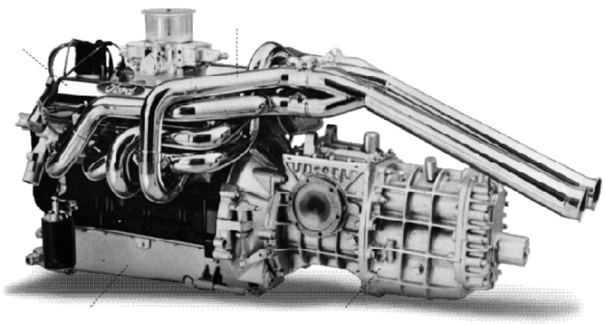


Image 5: 427 engine

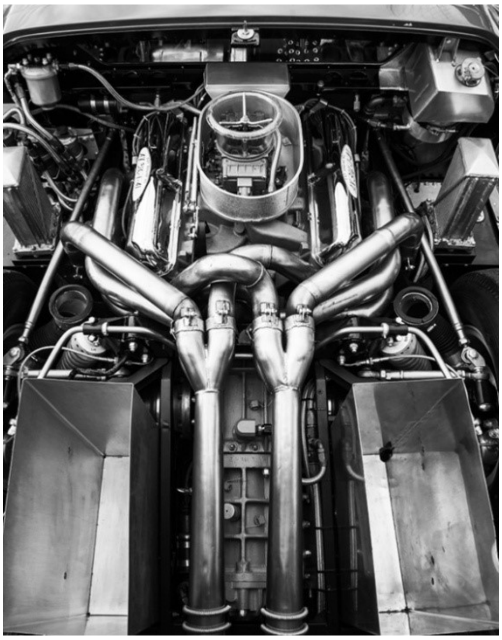


Image 6: Exhaust system

Aside from the enormous power it generated, one of the positives of using the 427 engine was the reliability and that it had already been successfully tested at NASCAR however, the engineers weren't sure if it would withstand all the race, including training, qualifying and 24 hours of competition. To ensure that the engine would withstand the rule was set not to exceed 6.400rpm, leaving a margin of safety up to 7.400rpm at which it could run for occasional use.

Despite the safety margin in terms of engine revolutions, Ford engineers subjected the engine to extensive durability testing. A simulation of the Le Mans driving conditions, in terms of speed, load and throttle opening, was generated in order to subject the engine to the conditions of Le Mans and it was run for 48 hours.

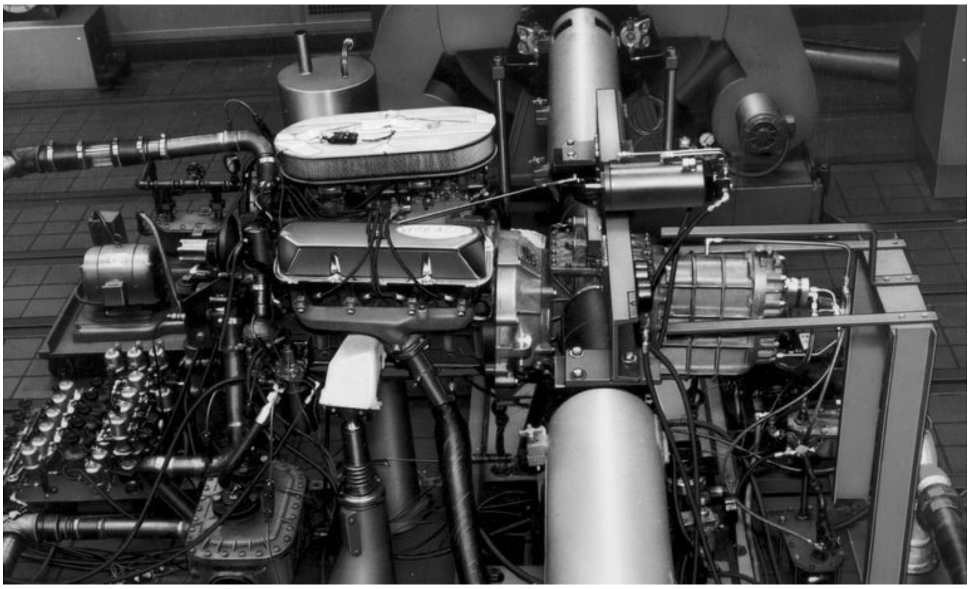
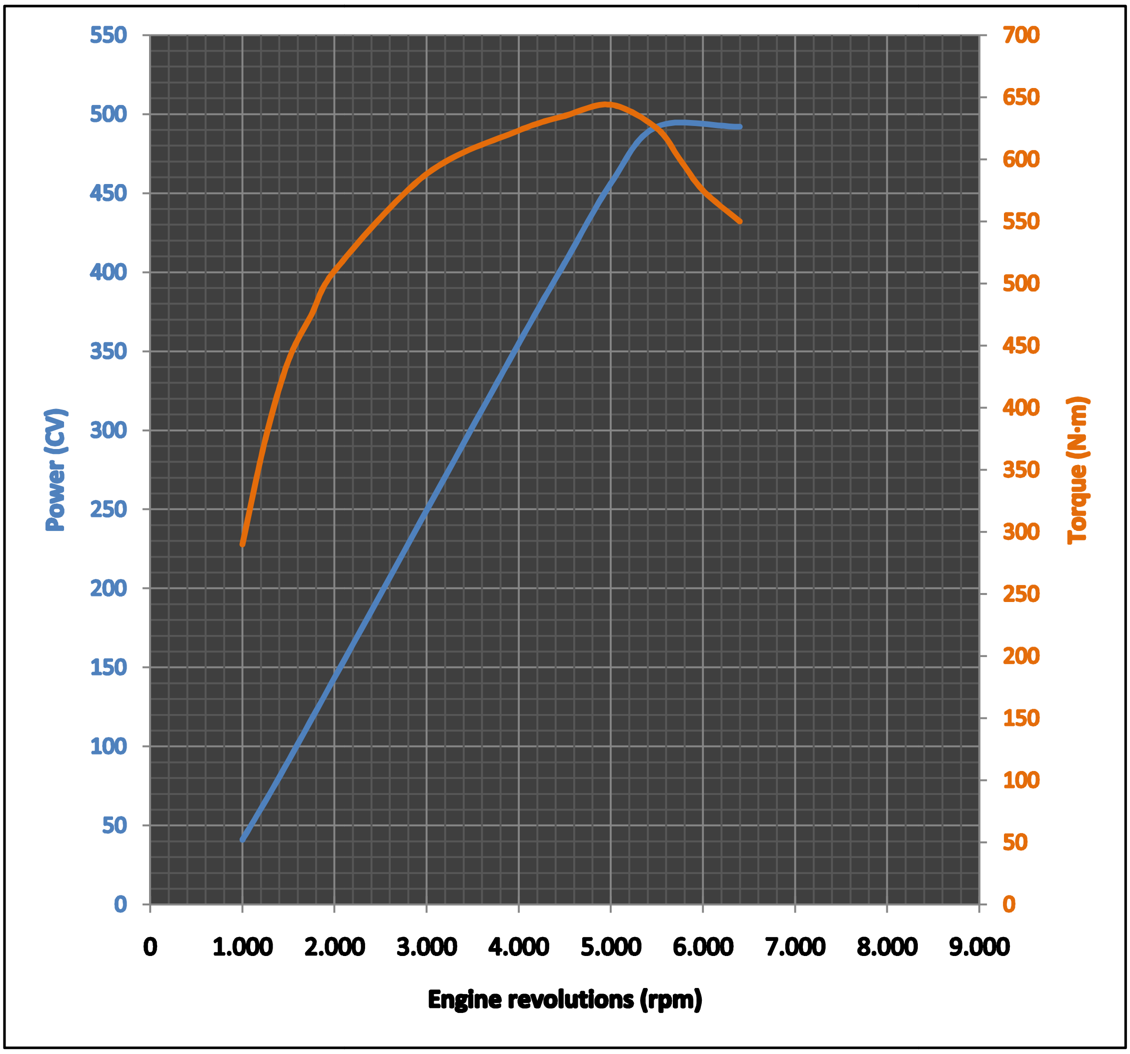


Image 7: 427 engine on the test bench

The Le Mans version of the 427 engine had a performance of only 70CV/L, well below that of its competitors that was around 100CV/L and also ran about 2.000rpm slower than the rest. Despite having significantly lower performance and rotational speed than its competitors, the 427 engine continued giving exceptional performance in terms of power and torque, which were clearly superior to other cars in the competition. Loss of performance and engine rotational speed were the price to pay in order to gain reliability and durability and a noticeable weight reduction in respect to the NASCAR version.

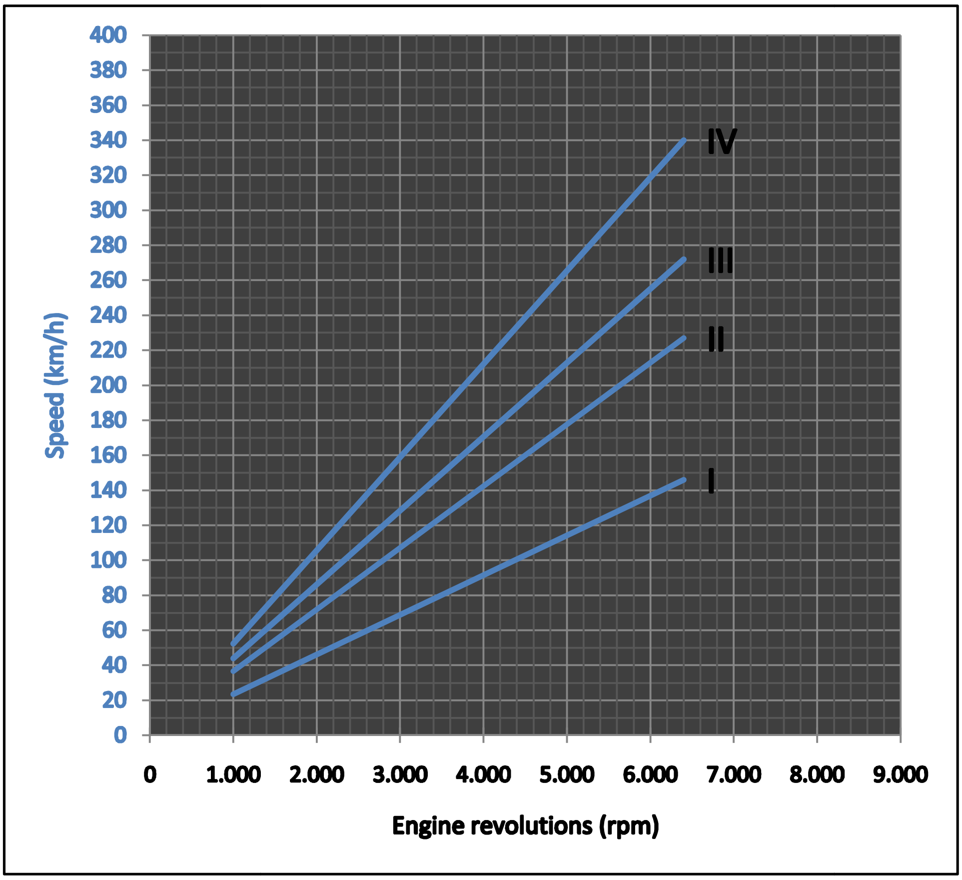


Graphic 1: Power and Torque curves

Transmission

One of the problems with the new 427 engine was finding a transmission that would withstand the huge torque of the engine (644N·m). The project was commissioned by the Kar Kraft, which designed the 4-speed manual gearbox T-44.

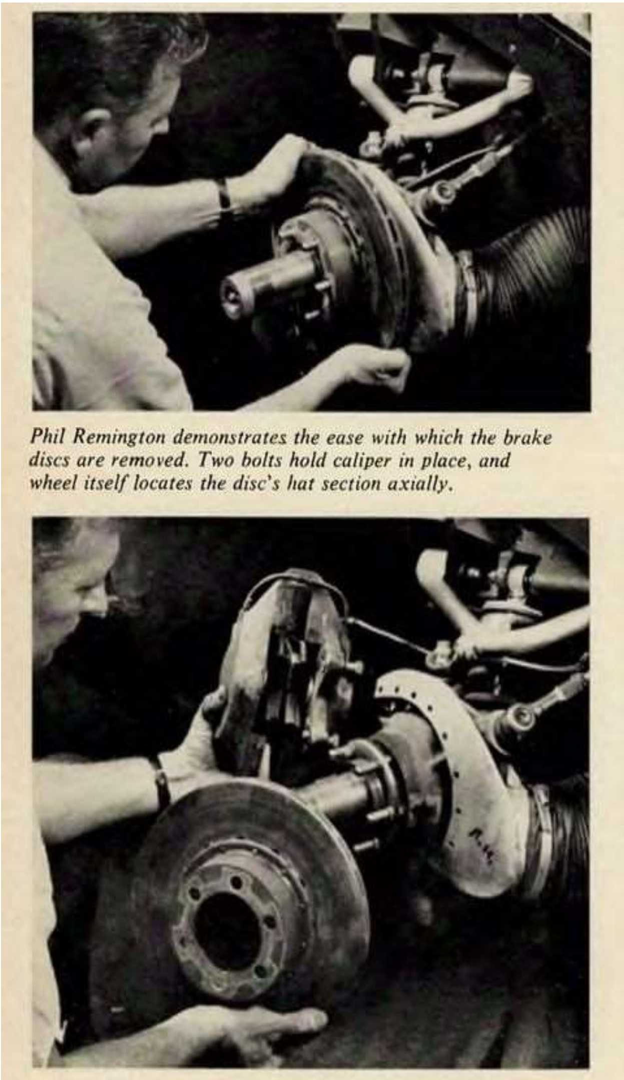
It is a light-alloy encased unit making maximum use of available heavy-duty Ford gears and shafts: a long 2-dry-plate clutch transmits torque to the input shaft of the gearbox; a production 4-speed synchronized gearset takes over from there, and finally a set of transfer gears takes the torque to the output shaft.



Graphic 2: Gearbox relations

Brakes

From the first moment the brakes were a problem, the brakes get very hot and as the speed increases they cool down quickly and the thermal contrast weakens the disc until it cracks. One solution would be to use larger ventilated disks, but this was not possible as there was no more space available to fit them.



Phil Remington demonstrates the ease with which the brake discs are removed. Two bolts hold caliper in place, and wheel itself locates the disc's hat section axially.

Image 8: Quick brake change system

Seeing that the problem with the brakes could not be solved, it was decided to change them halfway through the race, to ensure that the rider would run the whole race with the brakes in good condition, and the engineers were instructed on a way to change the brakes in the shortest possible time. The solution was found by Shelby and Holman & Moody engineers: Phil Remington (Shelby American) designed quick-change pad retainers and John Holman (Holman & Moody) developed the quick-change discs.

In the new brake assembly, the disc caps are outside the flange hub and are held in place by the wheel studs, calliper, and the wheel itself. This way, when the wheel is removed and the clamp is removed, which only needs to loosen two bolts, the disc comes out and can be replaced in a matter of seconds. This ingenious mechanism allowed the four brakes to be changed in a few minutes, the time of a normal pit stop.

Body

For the new Mk II model both the front and rear of the body were redesigned. At the front the nose was shortened almost 23cm and lowered, in order to return the centre of pressure to its original place. This reconfiguration of the front prevented the need to place fins on the rear and saved 8,5kg on the new Mk II.

The rear of the vehicle was 19kg lighter and many air intakes were added which significantly improved the cooling of the engine, the axle and the brakes.

With the new body configuration, the front brakes received air more directly, which improved cooling, with the side air intakes (2) and those placed on the rear cover (4) significantly increase the cooling of the rear brakes, which had been a problem from the start. The rest of the side air intakes (1 and 3) were used to cool the engine oil and carburettor, and the central air intake on the rear cover (5) directed air to the exhaust system.

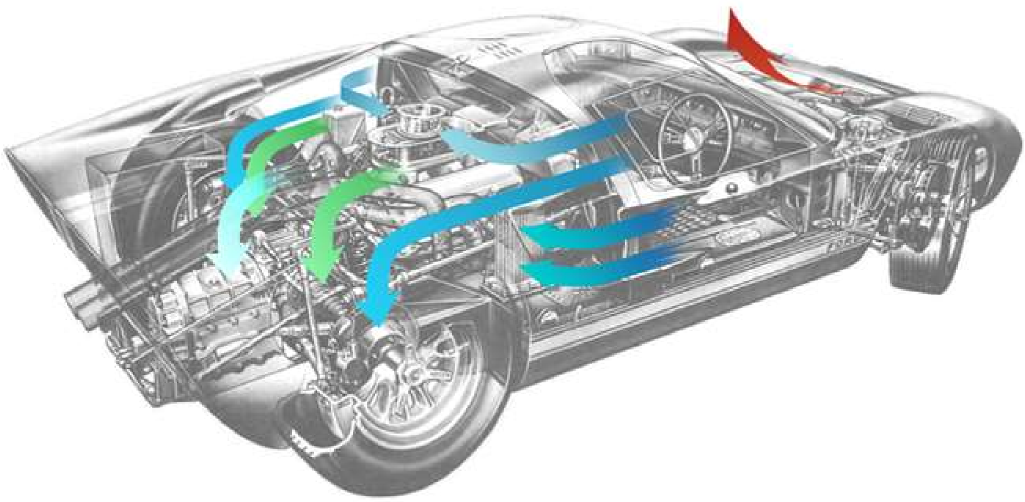


Image 9: Airflow ducts

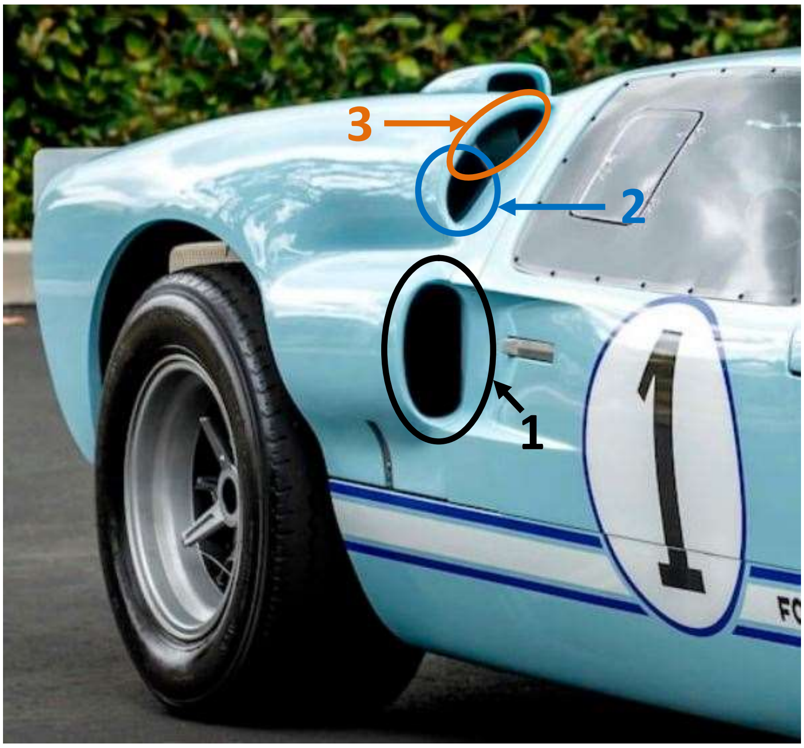


Image 10: Side air intakes

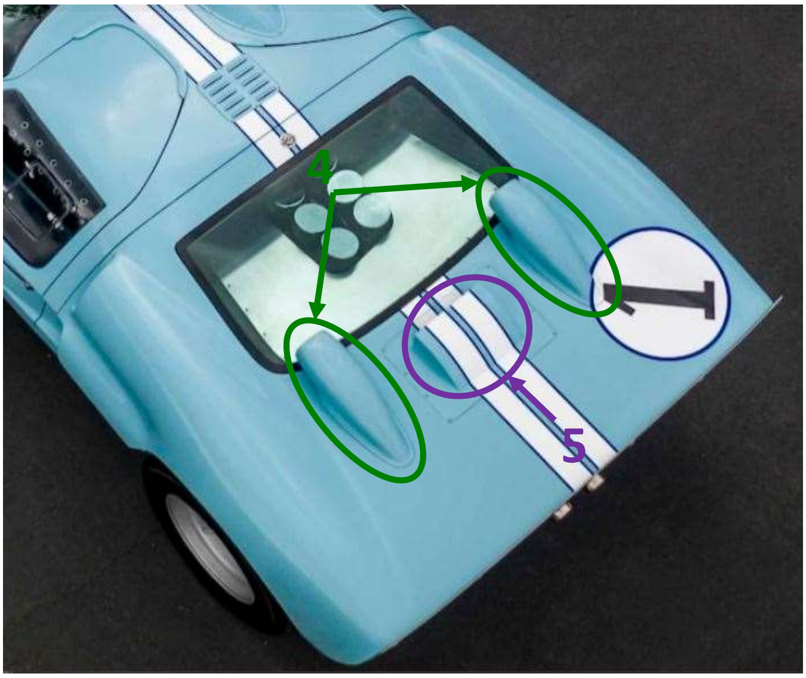


Image 11: Rear air intakes

8.2- Technical specifications of Ferrari 330 P3[1]

Ferrari 330 P3	
Engine	
Configuration	4.0 V12-60º
Fuel type	gasoline
Location	rear, longitudinal
Displacement (cm3)	3.967
Charge system	naturally aspired
Power gross (CV)	420 (8.000 rpm)
Torque gross (N·m)	-
Efficinecy (CV/L)	105,0
Dimensions	
Weight (kg)	851
Lenght / Width / Height (mm)	4.170 / 1.780 / 950
Wheelbase (mm)	2.400
Front track (mm)	1.462
Rear track (mm)	1.431
Fuel tank capacity (L)	114
Performance	
Specific power (CV/kg)	0,50
Top speed (km/h)	310
0-100 km/h (s)	-
Consumption (L/100 km)	-

Table 7: Ferrari 330 P3 specifications

Image 12: Ferrari 330 P3 (1966)

The 330 P3 is a pure competition car: it is fast, light, with impeccable aerodynamic configuration and, following the Ferrari style, with a high-performance V12 engine. The 4.0-liter V12 engine is apparently small, given that other competitors with V8 engines have similar or even higher displacements, but at the same time with a high power that makes it an engine with an impressive efficiency of 105CV/L.

The impressive high-performance V12 is not the only virtue of the 330 P3, one of the key points of the car is the low weight, thanks to the tubular steel chassis and the use of fibre glass for the car body. The 330 P3 weighs only 851kg, almost 400kg less than some of its competitors.

In terms of stability, the 330 P3 is almost perfect, its low weight and aerodynamic distribution make its performance exceptional, both at high speeds and when braking. When it comes to cornering, thanks to a low centre of gravity and the width of the axles, the behaviour of the car is very good.

If the powerful 420CV V12 engine is properly combined with only 851kg and exceptional aerodynamic configuration, the result is a specific power of 0,5CV/kg, slightly higher value than other rival cars, and a very fast car capable of reaching 310km/h.

[1]The Ferrari 330 P3 is not studied in as much technical detail as the Ford GT40 Mk II since its study serves only as a comparison with the GT40 Mk II.

8.3- Technical specifications of Ford GT40 Mk I[2]

Ford GT40 Mk I	
Engine	
Configuration	4.2 V8-90º
Fuel type	gasoline
Location	midle, longitudinal
Displacement (cm3)	4.177
Charge system	naturally aspired
Power gross (CV)	355 (7.200 rpm)
Torque gross (N·m)	468 (4.200 rpm)
Efficinecy (CV/L)	84,5
Dimensions	
Weight (kg)	1.000
Lenght / Width / Height (mm)	4.040 /1.778 / 1.029
Wheelbase (mm)	2.413
Front track (mm)	1.372
Rear track (mm)	1.372
Fuel tank capacity (L)	140
Performance	
Specific power (CV/kg)	0,36
Top speed (km/h)	265
0-100 km/h (s)	5,2
Consumption (L/100 km)	-

Table 8: Ford GT40 Mk I specifications

Image 13: Ford GT40 Mk I (1964)

The Ford GT40 Mk I is the first GT40 model, which began preparation in 1963 and was responsible for participating in the 24 Hours of Le Mans 1964 on behalf of the Ford Motor Company.

Its origin is the Lola GT, which was taken as a starting point and was perfected and adapted to the requirements of the drivers and Le Mans. Its first performance was in 1964 and after the result obtained in 24 Hours it was changed to the new Mk II model. Although the Ford Motor Company did not use the Mk I again to compete, it did give "permission" to several private teams, such as the Gulf team, to compete in later editions.

The heart of the GT40 Mk I is a 4.2-liter V8 engine that delivers 355CV at 7.200rpm. It is a relatively powerful engine but not enough to compete with its racing rivals. One of the problems of the GT40 is the high weight, in the case of the Mk I, despite being significantly lighter than any of the other GT40 models; the engine is not powerful enough to counteract the 1.000kg of weight, which gives it a specific power of only 0,36CV/kg.

[2] The Ford GT40 Mk I is not studied in as much technical detail as the Ford GT40 Mk II since its study serves only as a comparison with the GT40 Mk II.

Despite the low specific power, power was not a big problem for the Mk I as it managed to go from 0km/h to 100km/h in just 5,2s, a good enough mark and that it was at the level of its competitors. One of the main problems with the Mk I encountered on the Circuit de la Sarthe was speed: as seen in section 7.5.1, it is an extremely fast circuit, with the Mulsanne Straight, that exceeds 5km long, in which speeds above 320km/h are reached if the car allows it. In the case of the Mk I, the top speed of 265km/h is well below the speeds of other cars and this makes it impossible to keep a fight with victory options.

Apart from the low speed of the Mk I, none of them finished the 24 Hours of Le Mans in 1964, which makes the reliability and endurance of the car a very important point to deal with. The 1964 Mk I is a car that went straight from the factory to the circuit, with almost no testing or training on the actual circuit and this meant a disastrous end, given that the 24 Hours of Le Mans not only they test the performance of the car, such as power or speed, but also endurance.

8.4- Ford GT40 Mk II and Ferrari 330 P3 comparison

Ford GT40 Mk II vs Ferrari 330 P3		
	GT40 Mk II	330 P3
Engine		
Configuration	7.0 V8-90º	4.0 V12-60º
Fuel type	gasoline	gasoline
Location	midle, longitudinal	rear, longitudinal
Displacement (cm3)	6.997	3.967
Charge system	naturally aspired	naturally aspired
Power gross (CV)	492 (6.400 rpm)	420 (8.000 rpm)
Torque gross (N·m)	644 (5.000 rpm)	-
Efficinecy (CV/L)	70,3	105,0
Dimensions		
Weight (kg)	1.217	851
Lenght / Width / Height (mm)	4.140 / 1.753 / 978	4.170 / 1.780 / 950
Wheelbase (mm)	2.413	2.400
Front track (mm)	1.448	1.462
Rear track (mm)	1.442	1.431
Fuel tank capacity (L)	159	114
Performance		
Specific power (CV/kg)	0,40	0,50
Top speed (km/h)	340	310
0-100 km/h (s)	5,4	-
Consumption (L/100 km)	16,3	-

Table 9: GT40 Mk II and 330 P3 comparison

This section compares the technical specifications of the Ford GT40 Mk II and the Ferrari 330 P3, the two major rivals in the 24 Hours of Le Mans 1966.

Table 7 shows in red the characteristics of the Ford car that were better than those of the Ferrari and in red those that were worse, establishing as better the characteristics that make the GT40 more prepared to face the 24 Hours of Le Mans according to the conclusions extracted from section 7.5.1.

Despite not winning, the technical and mechanical differences between the 330 P3 and the GT40 Mk II were not very large; the main weapon of the Ford was the high speed it could achieve. The Ford car could reach 340km/h while the Ferrari 310km/h, a very high speed and clearly one of the highest among the other cars in the race but not enough to compete with the GT40. As concluded in the study section of the circuit (7.5.1) Le Mans is an extremely fast race, especially on the Mulsanne Straight, where top speed is marked by the limit of the car; considering the 30km/h difference between the two vehicles a clearly decisive factor is the top speed of the GT40 Mk II.

Aside from the speed at which the Ford is noticeably superior, the 330 P3 can almost be considered better than the GT40. In terms of weight the Mk II is extremely heavy, price to pay for using the huge 427 engine, while the P3 is extremely light, with only 851 kg the Ferrari counteracts the power difference compared to the GT40 and gets a power specific 0,5CV/kg, a value significantly higher than Ford that despite the impressive 492CV of the 7.0-liter engine cannot exceed 0,4CV/kg.

While the GT40 Mk II's main weapon is the powerful 427 engine, this one isn't one of the best engines in the competition. It is a 7.0-liter V8 engine, which despite supplying an impressive 492CV has a performance of 70,3CV/L, while the 4.0-liter Ferrari V12 engine delivers 420CV. With three litres less the Ferrari engine achieves a power not much lower than the Ford engine, which makes its performance a more common value for a competition engine (105CV/L).

Making a brief summary, if we analyze the Ford GT40 Mk II and the Ferrari 330 P3 in terms of performance, the best car is undoubtedly the Ferrari however, for a race like the 24 Hours of Le Mans, where velocity is so important, the very high speed of the GT40 makes it very difficult for Ferrari to keep up.

8.5- Ford GT40 Mk II and Ford GT40 Mk I comparison

Ford GT40 Mk II vs Ford GT40 Mk I		
	GT40 Mk II	GT40 Mk I
Engine		
Configuration	7.0 V8-90º	4.2 V8-90º
Fuel type	gasoline	gasoline
Location	midle, longitudinal	midle, longitudinal
Displacement (cm3)	6.997	4.177
Charge system	naturally aspired	naturally aspired
Power gross (CV)	492 (6.400 rpm)	355 (7.200 rpm)
Torque gross (N·m)	644 (5.000 rpm)	468 (4.200 rpm)
Efficinecy (CV/L)	70,3	84,5
Dimensions		
Weight (kg)	1.217	1.000
Lenght / Width / Height (mm)	4.140 / 1.753 / 978	4.040 / 1.778 / 1.029
Wheelbase (mm)	2.413	2.413
Front track (mm)	1.448	1.372
Rear track (mm)	1.442	1.372
Fuel tank capacity (L)	159	140
Performance		
Specific power (CV/kg)	0,40	0,36
Top speed (km/h)	340	265
0-100 km/h (s)	5,4	5,2
Consumption (L/100 km)	16,3	-

Table 10: GT40 Mk II and GT40 Mk I comparison

This section compares the technical specifications of the Ford GT40 Mk II and the Ford GT40 Mk I, the two cars presented by Ford the first three editions. This comparison will be very important to be able to analyze the changes that Ford engineers had to make in the initial model in order to achieve the victory of 1966 in this way, we can make up for the lack of empirical data. We do not have access to this data due to the inaccessibility of cars and the long period of time between the facts studied and the present.

As in the previous section (8.4), Table 8 shows the specifications of the two vehicles and indicates in green the qualities that are best in the Mk II and in red those that are worst to compete in the 24 Hours of Le Mans.

Although the Mk I and the Mk II are the same model they are two very different cars. To start the engine is different, the Mk I was powered by a 4.2-liter V8 engine (289 engine), while the Mk II engine is a 7.0-liter V8 one (427 engine). The difference between the two Ford engines is not only the size, the new engine generates almost 140CV more and allows the Mk II to reach speeds that ridicule the 265km/h of the Mk I.

The huge engine of the Mk II has only two inconvenient compared to the 289 engine of the Mk I: more weight and less efficiency. Despite the weight reduction in the chassis of the Mk II, the Mk I is almost 220kg lighter than its successor which causes that, despite the 140CV more generated by the 427 engine, the specific power of the Mk II (0,4CV/kg) is almost the same as in the Mk I (0,36CV/kg). In terms of efficiency, the engine of the Mk II has a slightly lower power-to-displacement ratio than the Mk I, the difference is not as great as in the case of the Ferrari but it must be taken into account.

Despite the high weight and slightly lower efficiency of the 427 engine, the Mk II takes advantage to use the 7.0-liter engine, as neither of the two inconvenient is significant enough to compensate for the low speed achieved by the Mk I, and even less so considering the high speed required by the Circuit de la Sarthe.

The engine is not the only difference between the 1964 and 1966 GT40s, the Mk II has notable aerodynamic improvements produced by a new and more sophisticated chassis.

The new chassis, as explained in section 8.1, has numerous additional air intakes compared to the one used in the Mk I. The new chassis configuration influences different aspects of the car, such as stability at high speeds and brake and engine cooling. Stability at high velocity was already a problem with the Mk I and, with the Mk II reaching much higher speeds, it was a bigger problem until finding the right chassis.

Another seemingly not so significant change is the increase in the width of the rear and front axles of the Mk II compared to the Mk I. The axles of the Mk II are almost 8cm wider than in the Mk I, this change may seem small important but brings extra stability to the car, especially when cornering.

8.6- Cars conclusions

After analyzing individually and comparing the specifications of the Ford GT40 Mk II, the Ferrari 330 P3 and the Ford GT40 Mk I, we can extract the technical factors that led to Ford's victory over Ferrari in the 24 Hours of Le Mans 1966.

With the comparison of the GT40 Mk I and GT40 Mk II we have seen that the new model has two notable changes over its predecessor: improved aerodynamic configuration and chassis and a new larger and more powerful engine. Mainly, with these changes the Mk II solves two of the most important problems of the Mk I: it gains stability especially at high speeds and the most powerful engine not only gives it more power but also allows it to reach much higher speeds, a very important feature for the 24 Hours of Le Mans.

Compared to its more direct rival, the Ferrari 330 P3, the new chassis improvements match the GT40 Mk II with the 330 P3 in terms of stability and aerodynamic efficiency, although the main difference between the two is speed. The GT40 Mk II can reach speeds considerably higher than those of the 330 P3 and, given the high speeds of the Circuit de la Sarthe, it is a decisive point.

Given that, except for the speed, the GT40 Mk II and the 330 P3 are two very well-prepared cars and that none of the Ferraris finished the race, I consider that such a big difference between speeds could be a reason why the drivers Ferrari would have to force the cars excessively and they would not hold out. This is a partial conclusion in which it is necessary to consider the aspects of preparation of the cars, strategic, organizational, etc. These considerations will be taken into account in the final conclusions section (11.1).

Making a brief summary of the analysis and comparison of the different cars we can extract the following conclusions:

- The main difference between the GT40 Mk II and the GT40 Mk I is the engine. For the Mk II opted for a huge 7.0-liter, with a performance not too good and which meant a considerable increase in the weight of the car. Weight gain was the price to pay for extremely high power and speed.

- Looking at the performance of the Mk I it is easy to understand why Ford lost the 1964 edition. It is a car that apart from the problems of stability and reliability does not have enough power neither speed to compete in such a fast and demanding race like the 24 Hours of Le Mans.

- Comparing the Ford and Ferrari that faced each other in 1966, we can conclude that the Ferrari is a very good car, with a high performance engine and a very high power and speed, although insufficient to beat the Mk II.

9- Motorsports evolution

9.1- Evolution of the 24 Hours of Le Mans

In this section I am going to study how the 24 Hours of Le Mans has changed since 1966 to 2020. I am going to analyze the new rules, car categories of the race, circuit modifications and also the old and the current cars.

9.1.1- Car categories evolution

In the current 24 Hours of Le Mans there are only two main car categories: Prototypes (LMP) and Grand Touring Endurance (LMGTE).

The Le Mans Prototypes (LMP) is for closed cockpit cars developed exclusively for on-track competitions, with no minimum production required, generally produced for the FIA World Endurance Championship. Instead, the Le Mans Grand Touring Endurance (LMGTE) categories include racing cars derived from street models for everyday road use.

Inside these two main categories there are different subcategories, establishing a total of five categories:

- **Le Mans Prototypes (LMP):**
    - Le Mans Prototypes 1-Hybrid (LMP1-HY)
    - Le Mans Prototypes 1 (LMP1)
    - Le Mans Prototypes 2 (LMP2)
- **Le Mans Grand Touring Endurance (LMGTE):**
    - Le Mans Grand Touring Endurance Professional (LMGTE PRO)
    - Le Mans Grand Touring Endurance Amateur (LMGTE AM)

Le Mans Prototypes 1 (LMP1):

The Le Mans Prototypes 1 (LMP1) do not use any Energy Recovery System (ERS). This category is reserved only for independent private teams. An independent private team does not benefit from any support from a manufacturer other than for the single supply of engines, services relating to these engines or commercial support.

The Le Mans Prototypes 1-Hybrid (LMP1-H) category is only for manufacturers and its cars use an Energy Recovery System (ERS), apart from the combustion engine, that provides additional power to the car.

The LMP1 group cars are identified with a red number panel and a "P1" red label.

The LMP1-H group cars have the same identification as LMP1 and an additional "HY" red label.

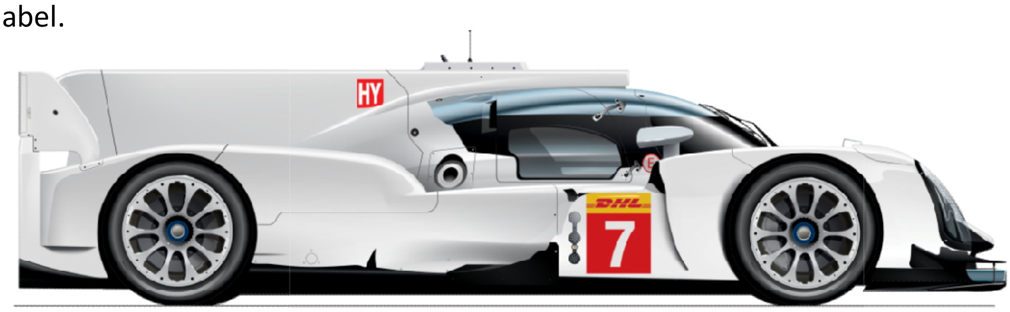


Image 14: LMP1-H cars identification

Le Mans Prototypes 2 (LMP2):

A Le Mans Prototype 2 (LMP2) is a closed cockpit car, destined only to teams independent of manufacturers and/or engine suppliers. These cars chassis, without engine, must have a selling price under 483K€ (483.000€) and also have an engine limitation of 4.2-liter V8 without direct-injection producing 600bhp (608CV approximately).

The LMP2 group cars are identified with a blue number panel and a "P2" blue label.

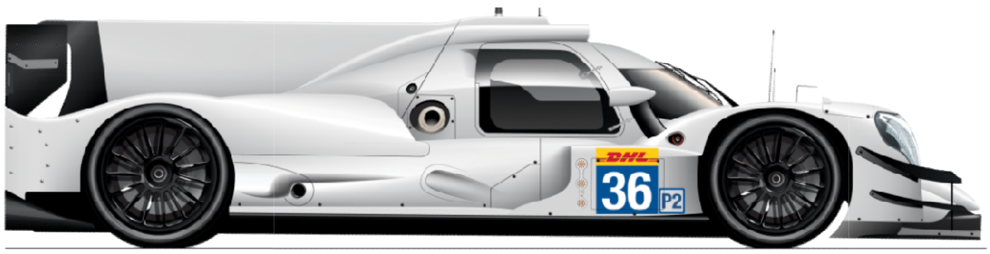


Image 15: LMP2 cars identification

Le Mans Grand Touring Endurance (LMGTE):

The Le Mans Grand Touring Endurance Professional (LMGTE PRO) is a professional category, while the Le Mans Grand Touring Endurance Amateur (LMGTE AM) is a special group for amateur drivers.

The LMGTE PRO group cars are identified with a green number panel and a "PRO" green label.

The LMGTE AM group cars are identified with a yellow number panel and an "AM" yellow label.

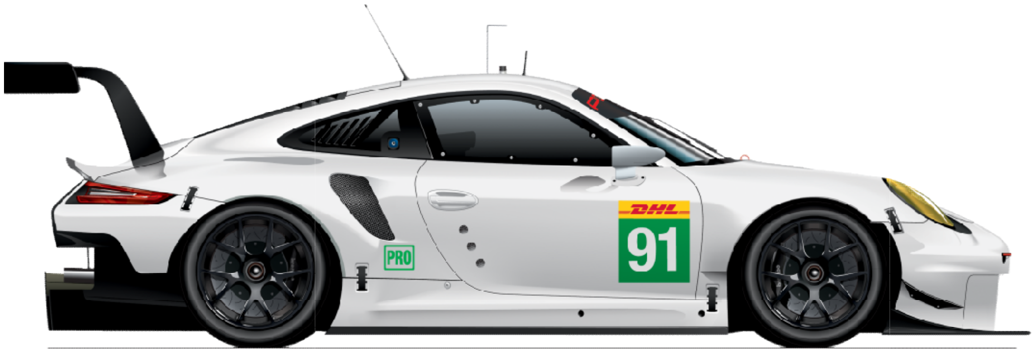


Image 16: LMGTE PRO cars identification

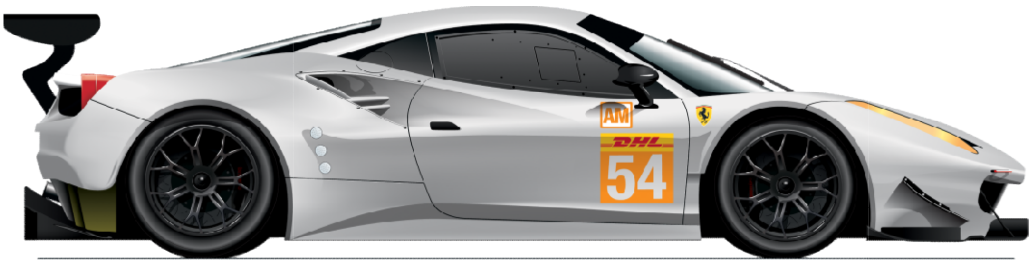


Image 17: LMGTE AM cars identification

For each category there is a regulation that establishes the characteristics and limitations cars must fulfil, as are showed in Table 11.

CATEGORIES	LMP			LMGTE	
	LMP1		LMP2	LMGTE PRO	LMGTE AM
	LMP1-H	LMP1			
Observations					
Chassis selling price limit (€)	None	None	483.000	None	None
Minimum production	None	None	None	None	None
Engine					
Capacity limit (L)	None	5.5	4.2	5.5 (naturally aspired) 4.0 (turbocharged/supercharged)	
Use for season limit	5		None	None	
Dimensions					
Minimum weight (kg)	878	833	930	1.245	
Overall lenght limit (mm)	4.650		4.750	4.800	
Front overhanging limit (mm)	1.000		1.00	1.250	
Rear overhang limit (mm)	750		750	1.100	
Overall width limit (mm)	1.800		1.900	2.050	
Height limit (mm)	1.050		1.050	-	
Fuel tank capacity					
Gasoline (L)	62,3	75	75	90	
Diesel (L)	50,1	-			

Table 11: Cars regulation for each category

9.1.2- Circuit evolution

Since its debut in 1923, the Circuit de la Sarthe has had different versions, such as the Nº 4 where the 24 Hours of Le Mans in 1966 were run or the version Nº 15 which is the last one since 2018.

In this section I am going to make a brief analysis of the differences between the current circuit and that of 1966.

Specifications

The current Sarthe Circuit is almost the same in terms of length as in 1966, only 200m longer. Over the years the circuit has varied its route and added some safety features, such as the chicanes, to limit high speeds. Despite the speed limitations, the circuit still has exceptional values in terms of speed and time per lap; due to the new faster and more powerful vehicles the fast lap record on the 2018 circuit was 6s below that of 1966 and reached an average speed of 248km/h, 10km/h faster.

Circuit de la Sarthe		
Circuit	Nº 4	Nº 15
Years	1956 - 1967	since 2018
Lenght (km)	13,461	13,626
Average speed (km/h)	218,04	220,02
Lap record (min:s)	03:23,6 (238,01 km/h)	03:17,7 (248,17 km/h)

Table 12: Circuit de la Sarthe specifications comparison

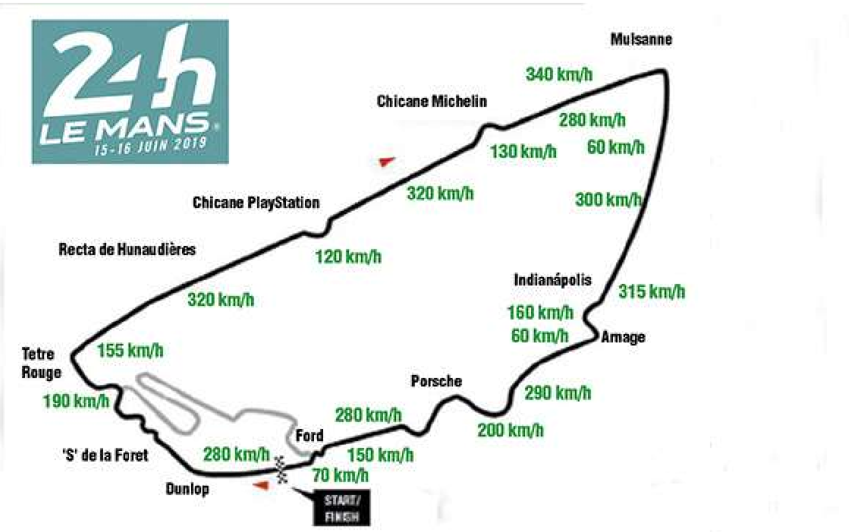


Image 18: Circuit de la Sarthe Nº 15 route and speeds

Route

One of the most characteristic components of the 24 Hours of Le Mans is the speed and this is due to the circuit, in all the forms that the Circuit de la Sarthe has seen has always been characterized by giving cars room to reach very high speeds.

Between the 1966 route and the current one there are some additional curves between Buisson and the "S" du Tertre Rouge, which make the circuit more twisted, but one of the most important changes is the appearance of the Chicane PlayStation and the Chicane Michelin on the Mulsanne Straight. The chicanes were installed before the 1990 edition; with technological improvements the cars reached the end of the straight at speeds around 400km/h and due to accidents and new FIA regulations, which limited the straight to a maximum of 2km, the chicanes were incorporated to reduce speed. Despite the chicanes, the circuit is still one of the fastest and with current technologies cars easily reach more than 340km/h.

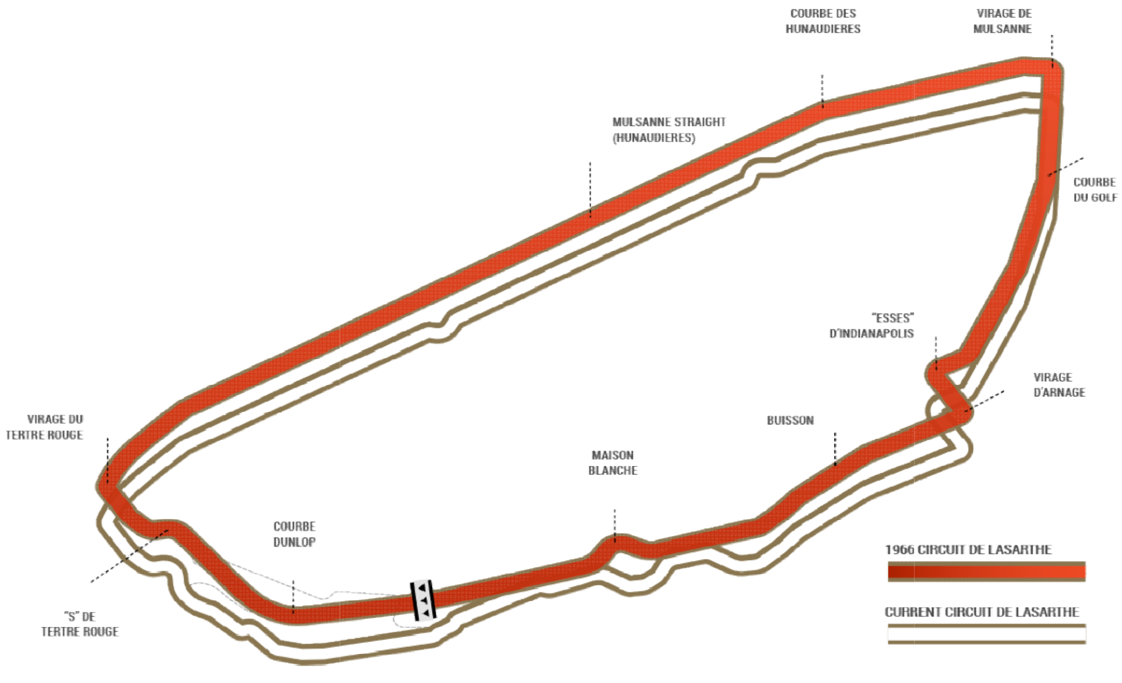


Image 19: Circuit de la Sarthe route comparison

9.1.3- Cars evolution

On this section I am going to study how cars that compete in the 24 Hours of Le Mans currently have changed respect to the ones from year 1966 and to do so, as Ford and Ferrari have participated in recent editions of the 24 Hours of Le Mans, I am going to compare each team model from 1966 with the current one. In addition, I am going to compare the winner from the last edition with the winner from 1966, the GT40 Mk II.

Ford and Ferrari evolution

Ford GT40 Mk II vs Ford GT LM GTE-Pro		
	GT40 Mk II (1966)	GT LM GTE-Pro (2016)
Engine		
Configuration	7.0 V8-90º	3.5 V6-60º
Fuel type	gasoline	gasoline
Location	midle, longitudinal	midle, longitudinal
Displacement (cm3)	6.997	3.497
Charge system	naturally aspired	twin turbo
Power gross (CV)	492 (6.400 rpm)	656 (6.250 rpm)
Torque gross (N·m)	644 (5.000 rpm)	746 (5.900 rpm)
Efficinecy (CV/L)	70,3	151,4
Dimensions		
Weight (kg)	1.217	1.200
Lenght / Width / Height (mm)	4.140 / 1.753 / 978	4.763 / 2.045 / 1.030
Wheelbase (mm)	2.413	2.710
Front track (mm)	1.448	1.694
Rear track (mm)	1.442	1.661
Fuel tank capacity (L)	159	98
Performance		
Specific power (CV/kg)	0,40	0,55
Top speed (km/h)	340	348
0-100 km/h (s)	5,4	3,0
Consumption (L/100 km)	16,3	13,1

Table 13: GT40 Mk II and GT LM GTE-Pro comparison

Image 20: Ford GT LM GTE-Pro (2016)

Image 21: Ferrari 488 GT3 EVO (2020)

Ferrari 330 P3 vs Ferrari 488 GT3 EVO		
	330 P3 (1966)	488 GT3 EVO (2020)
Engine		
Configuration	4.0 V12-60º	3.9 V8-90º
Fuel type	gasoline	gasoline
Location	rear, longitudinal	midle, longitudinal
Displacement (cm3)	3.967	3.902
Charge system	naturally aspired	twin turbo
Power gross (CV)	420 (8.000 rpm)	600 (7.000 rpm)
Torque gross (N·m)	-	700 (6.000 rpm)
Efficinecy (CV/L)	105,0	153,8
Dimensions		
Weight (kg)	851	1.260
Lenght / Width / Height (mm)	4.170 / 1.780 / 950	4.633 / 2.050 / 1.090
Wheelbase (mm)	2.400	2.710
Front track (mm)	1.462	1.679
Rear track (mm)	1.431	1.647
Fuel tank capacity (L)	114	78
Performance		
Specific power (CV/kg)	0,50	0,48
Top speed (km/h)	310	340
0-100 km/h (s)	-	2,8
Consumption (L/100 km)	-	-

Table 14: 330 P3 and 488 GT3 EVO comparison

Observing the new models of both Ford and Ferrari a very important point is the category to which they belong. Both the GT LM GTE-Pro as the 488 GT3 EVO belong to the category Grand Touring Endurance Professional (LMGTE PRO) while models in 1966 were in Group 6 (prototypes) that is, the current models are a category lower than that of older models, as the Group 6 of 1966 would be the equivalent of the current LMP1 category.

Despite being in lower categories, today's cars could easily compete against the Prototypes of 1966. In terms of power, current engines, although generally smaller, generate much higher power: the current Ford engine of 3.5-liter generates 164CV more than the GT40's one of 7.0-liter. The use of smaller engines, in addition to reducing weight, reduces consumption and allows the use of smaller and lighter fuel tanks: the tanks of 1966 were 159L and 114L while the new tanks did not reach 100L.

In terms of weight has not changed much in the new Ford model but in the Ferrari. The 488 GT3 is considerably heavier than the 330 P3, the additional 400kg offset the increase in engine power by making the specific power almost the same as in the 1966 model. Despite having quite similar specific powers in both cases, the acceleration from 0km/h to 100km/h is much faster in current cars; while in older models the times were above 5,5s the current cars have lowered these times to 3s or even less in the case of Ferrari (2,8s).

If we look at the exterior, in today's cars aerodynamics play a much more important role than in 1966. In both cars, GT LM GTE-Pro and 488 GT3 EVO, there is a huge rear spoiler and front, side and rear extensions. These new aerodynamic systems are, in part, those that make it possible to reach 100km/h in such a short time and have lower consumption and also greater stability.

Winner cars evolution

On this section I am going to compare the Ford GT40 Mk II, winner of 1966 edition of the 24 Hours of Le Mans, with the Toyota TS050 Hybrid, the winner of the 2020 edition.

Ford GT40 Mk II vs Toyota TS050 Hybrid		
	GT40 Mk II (1966)	TS050 Hybrid (2016)
Engine		
Configuration	7.0 V8-90º	2.4 V6-90º + ERS
Fuel type*	gasoline	gasoline
Location*	midle, longitudinal	midle, longitudinal
Displacement (cm3)*	6.997	2.400
Charge system*	naturally aspired	twin turbo
Power gross (CV)	492 (6.400 rpm)	500 + 500
Torque gross (N·m)	644 (5.000 rpm)	-
Efficinecy (CV/L)*	70,3	208,3
Dimensions		
Weight (kg)	1.217	878
Lenght / Width / Height (mm)	4.140 / 1.753 / 978	4.650 / 1.900 / 1.050
Wheelbase (mm)	2.413	-
Front track (mm)	1.448	-
Rear track (mm)	1.442	-
Fuel tank capacity (L)	159	62,5
Performance		
Specific power (CV/kg)	0,40	1,14
Top speed (km/h)	340	330
0-100 km/h (s)	5,4	2,2
Consumption (L/100 km)*	16,3	-
*Combustion engine		

Table 15: GT40 Mk II and TS050 Hybrid comparison

Image 22: Toyota TS050 Hybrid (2016)

The Toyota TS050 Hybrid presented in 2016 has been the winner of the last three editions of the 24 Hours of Le Mans (2018, 2019 and 2020). There are huge differences between the TS050 and the GT40 Mk II, winner of 1966, starting with the propulsion system. In the most recent editions the category of Prototypes (same category to which the GT40 Mk II belongs) allows the hybrid technology, that combines a combustion engine and the ERS (Energy Recovery System) system. The simultaneous use of the two technologies allows the LMP1-H category cars to reach extremely high power and speed values, which are absolutely inaccessible for the 1966 vehicles.

Another very interesting point that has already been mentioned in the previous section is the big difference in displacement between old and modern engines. The current engines are much smaller, 2.4-liter in the TS050, although they generate the same or more power than the old ones with much higher displacements, 7.0-liter in the GT40. Not counting the extra power of the ERS, the Toyota generates 500CV with a third of the displacement that Ford needs to generate 492CV. One of the key points by which the current engine generates the same power with such a lower displacement is the use of turbo technology. The TS050 engine uses two turbo collectors, one for each line of the V6 engine, and this gives it a very high performance of more than 200CV/L, a value much higher than the 70CV/L of the GT40.

When the 500CV of the ERS are added to the powerful combustion engine we obtain a car of less than 900kg with 1.000CV of power. Without the hybrid technology the TS050 is already a powerful enough car with a specific power of 0,6CV/kg, significantly higher than the 0,4CV/kg of the GT40, but with the electric system the TS050 achieves an incredible 1,14CV/kg.

In terms of speed, despite being very fast the TS050 reaches 10km/h less than the GT40, although with the new circuit with the chicanes on the Mulsanne Straight it's not possible to reach speeds over 340km/h or similar. The TS050's small lose of speed makes up for it with its enormous power, low weight and highly sophisticated aerodynamic design that allows it to reach 100km/h in just 2,2s. With these values of acceleration, the TS050 reaches hardly the same speed as the GT40 in shorter straights.

9.2- General evolution

In this section I am going to study how the motorsports have changed through the years. I am going to analyze the technology improvements and how it has affected in motorsports competitions and I also am going to analyze the safety systems evolution.

9.2.1- Technology evolution

The motorsports have always stressed, among other things, to use vehicles extremely fast, powerful and spectacular vehicle, and for that you need to be at the forefront of technology. Over the years motorsports have changed their regulations, circuits, vehicle specifications, etc. in order to adapt the competitions to technological advances and to be able to offer more competitive vehicles and greater spectacle to fans.

If we analyze the most notable changes in the world of motorsport we will see that they are due to three major factors: the introduction of electrical and electronic systems, the use of new materials with better performance and the very important role of aerodynamics.

Turbo charging and electrics

As seen in section 10.1.3 a notable change in new vehicles is the increase in power and at the same time the use of smaller engines. This phenomenon is due to two major factors: the use of the turbo system and the introduction of hybrid technology.

Turbo technology began to be used in the 1970s but it was not until the 1980s that it was fully consolidated and perfected. At first the turbo technology meant the superiority of the vehicles that used it and later, when its use was already normalized, it gave very powerful and fast vehicles like the imposing Group B of the World Rally Championship (WRC). In today's competitions, the turbo system is in many cases used to generate the same or even more power with smaller engines, in order to reduce consumption and weight. A current engine with a similar displacement as 60s ones can generate extremely high power.

Another very significant change that has completely changed competition vehicles is hybrid technology, the combination of combustion engines with electric propulsive systems. One of the first examples of this technology was the KERS (Kinetic Energy Recovery System) in Formula 1. For the 2009 season Formula 1 cars incorporated the KERS, which stored the kinetic energy of the brakes in the form of electrical energy and at one point this energy could be used to give about 80CV of extra power for just over 6,5s per lap. At first the new system was not too well accepted and only few teams incorporated it but, seeing the advantages it meant, in the following seasons all the teams incorporated it.

Currently, the KERS system has been replaced by new more evolved and improved ones, such as the ERS system, which have ended up deriving in hybrid vehicles such as those in the LMP1-H category of the World Endurance Championship (WEC) or even in competitions that are only propelled by electric motors, such as Formula E.

The Energy Recovery System (ERS) was introduced in 2014 as the evolution of KERS and takes 2009's technology to another level. The ERS consists of two energy recovery systems, the MGU-K and the MGU-H. The MGU-K functions as an improved version of the KERS, which converts the kinetic energy of the brakes into electrical energy and during acceleration acts as an additional electric motor. In the case of the MGU-H, this system is connected to the engine turbocharger and converts the thermal energy of the exhaust gases into electrical energy. The power generated by the MGU-H can be used to power the MGU-K or it can be stored in the battery for use when convenient.

The idea for using the ERS system in racing is that the MGU-K recovers energy in braking and supplies extra power during acceleration and the MGU-H recovers energy during acceleration, at which point the flow of gases exhaust is higher, to continue supplying power to the MGU-K or storing it. The benefits of this system vary according to each competition, in Formula 1 the ERS system can supply 160CV for 33s in each lap (4MJ per lap), while in the 24 Hours of Le Mans (World Endurance Championship) the vehicles of the LMP1-H class receive up to 500CV of extra power for about 22s (the FIA limits ERS consumption to 8MJ per lap in the 24 Hours of Le Mans).

Electronic systems

The introduction of electronics has not only been in propulsion systems to generate more power (KERS and ERS), but is also used to control and manage power and to control the condition of the vehicle.

A very clear and visual case of the changes caused by the use of electronics is the steering wheel. Currently, the steering wheels of racing cars do not look at all like the typical circular steering wheel, but are a rectangular shape with a set of buttons and screens that allow the driver to manage the performance of the engine and transmission, communicate with engineers, know the state of the vehicle in real time and change gears, all while driving at more than 300km/h.

Image 23: Formula 1 steering wheel (2020)

Image 24: GT40 Mk II's steering wheel (1966)

In the Word Endurance Championship (WEC) electronics are even used to adjust and limit the consumption of combustion engines to match performance between categories. In the WEC the introduction of the hybrid category (LMP1-H) has made it easier for vehicles with ERS technology to win, as they are more powerful; that is why the ACO and the FIA established the Equivalence of Technology (EoT) system. What the EoT system does is limit the fuel consumption of vehicles, but in order to match the race between the different categories (LMP1 and LMP1-H) the limit for vehicles without an ERS system is higher than in hybrid vehicles. . The consumption limit varies according to each race of the championship, in the specific case of the 24 Hours of Le Mans the limit for the LMP1-H category is 80kg/h of fuel, while for the LMP1 category it is 108kg/h.

New materials

In the world of motorsports, materials play a very important role as they condition the weight, the shapes of the parts, the durability of the components, etc. which is why as new materials have emerged they have been introduced into the races.

In competition vehicles there has been a very important change that has not only introduced better performance of materials but has also changed the way components are manufactured and has opened the doors to a new world. Carbon fibre was first used in the early 1980s as reinforcement for some components but quickly consolidate itself as a material for parts made only with carbon fibre.

The use of this new material has affected all areas of vehicles: it has caused a considerable reduction in weight, has made it possible to shape parts with shapes that would not be possible with other materials and has served to improve some of the safety systems.

No doubt carbon fibre has revolutionized, above all, the design of chassis and other components of vehicles but has also been incorporated, along with other materials such as Kevlar or Nomex, in the helmets or suits of riders and other safety devices as the HANS device or the monocoque.

Aerodynamics

Aerodynamics has always been important in motor racing but in modern vehicles it is extremely important and more sophisticated systems are being developed that open the door to new ideas. Currently the engine differences between the different teams are minimal and that is why a small aerodynamic improvement can mean a big difference between vehicles and mean the difference between winning and losing.

An example of an aerodynamic device is the Drag Reduction System (DRS) which was introduced in 2011 in Formula 1 and 2018 in the WEC. The DRS is a movable plate located in the rear spoiler and when activated allows the passage of air, reducing the aerodynamic load of the vehicle and allowing it to reach higher speeds. In Formula 1 the use of DRS is limited to specific situations, while in WEC its use is exclusive to the LMP1 category in order to increase rivalry with the LMP1-H cars.

Image 25: Formula 1 DRS not activated

Image 26: Formula 1 DRS activated

Another aerodynamic device is the blown diffuser. It consists of directing the exhaust gases at high temperatures directly to the diffuser, generating a powerful aerodynamic force in the rear of the vehicle. This device has been banned in Formula 1 since 2012 but in the WEC there are some teams that use it, its use is free decision of each team.

Since the 2017 season, aerodynamics has also played a very important role in the World Rally Champioship (WRC), which has introduced numerous aerodynamic components to increase the speed and stability of vehicles and thus give more spectacle to spectators.

Looking at both cars, one can easily see the presence of front and rear air intakes in the Toyota Yaris from 2018, along with a much larger rear diffuser and spoiler than the Volkswagen Polo R from 2016.

Image 27: Volkswagen Polo R WRC (2016)

Image 28: Toyota Yaris WRC (2018)

9.2.2- Safety systems evolution

Safety has always been a very important aspect in motorsports, due to the high speeds and the risk of suffering an accident. Over the years, the safety systems have evolved and perfected to ensure the maximum physical integrity of the pilot. One of the pioneers in competitions in terms of security systems is Formula 1, many new devices have been introduced firstly in Formula 1 and later incorporated in other competitions.

Helmet and HANS

The helmet is one of the most important safety systems in any of the motorsports competitions, as it is responsible of protecting the rider's head. The use of the helmet became mandatory in 1952 and over the years the helmets have been perfected and become more resistant.

Currently competition helmets are all made of carbon fibre and weigh between 1kg and 2kg. To be approved by the FIA helmet must be extremely resistant to impacts and fire. Some of the tests that helmets are submitted are:

- Rifle shot against the visor
- Impact of a 225g metal disk at 250km/h
- Impact of a weight of 10kg with a fall of 5m
- Exposure to flames of 790ºC

Image 29: Helmet and HANS set

From 2003, a new safety device was added to the helmet to protect the pilot's neck and spine. The HANS system is made of carbon fibre and is located on the shoulders and around the rider's neck and fastened with elastic bands to the helmet and seat. This device has become mandatory in all motorsports competitions.

Fire-resistant race suit

Another safety system worn by the pilot is the fireproof suit. Since 1975, the use of fireproof clothing has been mandatory in all competitions and has been perfected to the present days.

Current suits are made up of layers of Nomex, a fibre chemically treated to resist flames, and weigh only 700g. They are prepared to withstand between 11s and 12s at 800ºC with an inside temperature not over 41ºC.

Survival cell

The survival cell is the evolution of the monocoque chassis that emerged in the early 1960s and is the great protection of the pilot against impacts. The monocoque chassis consists of incorporating the body of the vehicle in the chassis itself, which provides much more rigidity and allows it to withstand higher impacts without compromising the safety of the driver.

Initially, the designs were made of aluminium but currently consist of a 6mm carbon fibre composite with a layer of Kevlar, which makes it resistant to penetration, fire resistant and ready to absorb large amounts of energy during shocks. It also includes a fire suppression system that sprays fire retardant foam around the monocoque and engine.

Image 30: Survival cell of a LMP1 car

HALO device

From 2018, the HALO system is mandatory in Formula 1 and later has also become mandatory in other competitions with vehicles without a closed cabin. The HALO is a Y-shaped titanium bow that is placed on the front of the car cab.

Its function is to protect the pilot's head from the impact of large objects such as debris from other vehicles or in the event of an impact against safety walls. The HALO system weighs about 20kg and is ready to withstand loads up to 125KN.

Image 31: HALO device

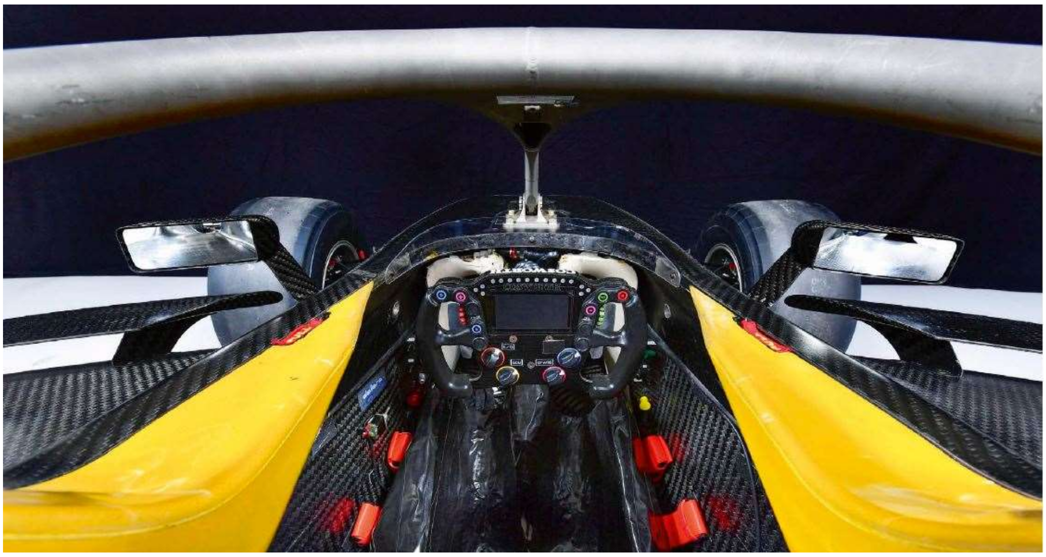


Image 32: HALO device's view from inside the cabin

Electronics and bioengineering

Currently, electronics is a very important part of motorsports, not only in terms of performance or in order to obtain data on the condition of the vehicle, but also in the field of safety.

In the late 1990s, electronic systems began to be incorporated that record data on accidents and the operation of safety systems during it. This system called Accident Data Recorder is useful so that medical teams can know the severity of the accident and also in order to evaluate the effectiveness of safety systems and be able to improve them.

In recent years, systems that combine electronics with bioengineering, such as accelerometers and biometric gloves, have been incorporated. Accelerometers are devices that the pilot places on his ears and that allow teams to obtain accurate information about the forces acting on the pilot at any given moment, very important data after an accident.

On the other hand, biometric gloves are the latest addition to the pilots' equipment. These are biometric sensors placed inside the gloves, allowing monitor the pilot's blood pulse and oxygen level. Knowing this information allows medical teams to make a more accurate diagnosis and more accurate decisions on how to proceed after a crash.

10- Preparing a motorsports team

After the complete and detailed study of the 24 Hours of Le Mans in 1966 and the whole preparation process that the Ford Motor Company did, I can extract what would be the basic principles to face the preparation for a motorsports competition team, not just the endurance championship but any championship in general.

To carry out this procedure guide, I have developed the three main aspects to take into account: strategic methodology, organizational model and budget forecast.

10.1- Strategic methodology

As has been seen in the case of Ford in preparation for the 24 Hours of Le Mans in the 60s, strategy is a very important factor, as it is the plan to follow and conditions all development of the project and the final result; planning and strategy are the starting point of any project.

In order to properly prepare a competition team it is very important to follow the following steps:

- Study of the competition
- Extract requirements for the vehicle and team from the previous study
- Establish an organization and a schedule to follow
- Vehicle development
- Circuit tests and car improvement

10.1.1- Study of the competition and car requirements

The first thing to do for any competition is to study it thoroughly. It is vitally important to know all the details of the competition: rules, circuit, car specifications and categories.

Regulation

In order to know in depth the competition in which you want to participate it is very important to start with the regulation. It sets out the different categories that take part in the competition, the specifications of the vehicles, the requirements that the team must meet in order to register, etc.

Without careful study of the regulations, it is impossible to start planning the development of the vehicle or structuring the team.

Circuit

The circuit is a very important part of the competition, as it is where the race takes place. Knowing the layout and specifications of the circuit will allow the team to prepare a car with the appropriate technical specifications, for example: if it is a circuit like the Sarthe one with very long and fast straights, you must make a vehicle that can reach very high speeds, which would not be so important if the circuit had many curves and shorter straights.

10.1.2- Project planning

Once you know the competition and what the vehicle should look like, you need to plan how the project will develop. It's probably the most important point, as it conditions everything else.

This section sets out exactly what will be done in the project and how and when it will be done:

- Determine the resources and budget available to plan a project that is realistic and affordable for the company.

- Determine what the car will look like, based on the requirements established in the previous sections and adapting it to the budget and available resources.

- Determine the organizational model to be followed, establishing the different departments and roles of each member.

- Establish a schedule to reach the competition with the vehicle well developed and tested on the track in race simulations.

10.2- Organizational model

Two groups can be differentiated within a team: the technical team dedicated to the design, development and improvement of the vehicle, which works from the offices at the headquarters, and the competition team in charge of preparing the car in track, test it and manage each race.

The organization of the design and development section is beyond the scope of the project, as it would require excessive depth in the subject and would be a separate project. That's why this section focuses on the competition team.

The size of a motorsport team varies slightly depending on the competition in which it participates but its structure is quite similar across all disciplines. To explain the organization I will be based on the structure of Formula 1 and from there I will explain the particularities and differences for each competition: WEC and WRC.

10.2.1- Formula 1 team members

Within the team, three categories can be established, according to the functions of its members:

Coordinators (1 of each for the both cars):

- **Team Director**: he is the person in charge and is in charge of coordinating the whole team.

- **Sporting Director**: he ensures the team always operates in compliance with the FIA Sporting Regulations.

- **Trackside Engineering Director**: he tries to extract the most performance out of both cars on each race.

- **Technical Director**: he's in charge of the overall technical operation both at the track and at the factory.

- **Chief Strategist**: he develops the strategy that promises the best result for the team. He has the final decision on the strategy (when to pit the cars and which tyres to use).

- **Chief Engineer Trackside**: he looks after the reliability of both cars and is the responsible of the compliance of the FIA Technical Regulations.

Engineers:

- **Race Engineer** (1 for each car): he acts as the link between the team and the driver. It's very important to learn about the driver feedback from the car in order to improve the car.

- **Performance Engineer** (1 for each car): he tries to adapt and improve the car with the feedback data of the driver.

- **Aerodynamicist** (1 for both cars): he is the responsible of the aerodynamic part of the vehicle.

- **Tyre Engineer** (1 for both cars): he cares about the condition and operation of the tires

- **Controls Engineer** (1 for each car): he focuses on the controls of the car and ensures all of them will give the maximum performance to the vehicle.

- **Engine Performance Engineer** (1 for each car): he works to maximise the performance of the engine.

- **Engine Systems Engineer** (1 for each car): he works to ensure the reliability of the engine.

Mechanics:

- **Number One Mechanic** (1 for each car): he is the coordinator of the mechanicals.

- **Tyre Changers** (4 for each car): they are responsible for changing the tires during a pit stop.

- **Tyre Carriers** (8 for each car): they assist the tyre changers in changing the old tyres for the new ones.

- **Jack Men** (2 for each car): they are responsible to lift the car using a lever.

- **Wing Men** (2 for each car): they are responsible to adjust the front wing angle.

- **Stabilizer** (2 for each car): they look after stabilizing the car from left, right and centre.

- **Fire Extinguisher Man** (1 for each car): they are on standby to extinct the fire in case of a fire outbreak.

Formula 1 team members summary

In summary, a two-car Formula 1 team consists of approximately 18 engineers and coordinators, 40 mechanics and 2 drivers (1 driver for each car).

10.2.2- WEC team members[3]

Based on the Formula 1 scheme, the differences and particularities for Endurance Racing (WEC) teams are discussed below.

Coordinators (1 of each for the both cars):

- **Team Director**
- **Sporting Director**
- **Trackside Engineering Director**
- **Technical Director**
- **Chief Strategist**
- **Chief Engineer Trackside**

Engineers:

- **Race Engineer** (1 for each car)
- **Aerodynamicist** (1 for both cars)
- **Engine Performance Engineer** (1 for each car)
- **Engine Systems Engineer** (1 for each car)

[3] Because many of the roles match those of Formula 1, the already mentioned ones will only be named and will only be explained the particular roles of the WEC teams.

Mechanics:

- **Car Controller** (1 for each car): he controls the entry and exit of the car into the pit lane and all of the operations carried out on the car whilst stationary in the pit lane.

- **Number One Mechanic** (1 for each car)

- **Refueller** (1 for each car): he is the responsible of refuelling the car.

- **Cut off valve attendant** (1 for each car): he cuts off the fuel supply in case of fire.

- **Cockpit Operator** (1 for each car): he is responsible for assisting the driver during driver change.

- **Mechanics** (4 for each car): they are identified with a green armband and their function is, while refuelling, cleaning the windscreen, mirrors, lights, race numbers, onboard camera and removal of obstructions in air intakes and radiators. When refuelling is finished, the mechanics change the tires and wheels.

- **Brake technician** (1 for each car): he is employed by brakes supplier and his function is to take temperature readings and carry out visual inspection of the brakes. He is identified with a blue arm band.

- **Tyre technician** (1 for each car): he is employed by tires supplier and his function is to take temperature readings and carry out visual inspection of the tires. He is identified with a blue armband.

<u>WEC team members summary</u>

In summary, a two-car Endurance Racing (WEC) team consists of approximately a total of 14 engineers and coordinators, 20 mechanics and 6 drivers (3 drivers for each car, who take turns every certain time).

10.2.3- WRC team members[4]

In Rally Racing (WRC), as there is no pit stop during the race, but repairs are made at the end of each section, some of the roles are quite different from those of Formula 1 or Endurance Racing (WEC).

Coordinators (1 of each for the both cars):

- **Team Director**
- **Sporting Director**
- **Technical Director**

Engineers:

- **Race Engineer** (1 for each car)

Mechanics:

- **Number One Mechanic** (1 for each car)
- **Mechanics** (8 for each car): each pair of mechanicals has a corner of the car assigned and his function is to repair any broken or damaged part or to prepare the car for a different test.
- **Engine technician** (1 for each car): he is a specific mechanical focused on the engine and his function is to ensure the good performance of the engine.
- **Hydraulic technician** (1 for each car): he is a specific mechanical focused on the hydraulic systems.
- **Fabrication technician** (1 for each car): he is a mechanical focused on repairing broken pieces that require a specific treatment.

WRC team members summary

In summary, a three-car Rally Racing (WRC) team consists of approximately a total of 6 engineers and coordinators, 36 mechanics and 3 sets of pilot and co-pilot (1 pilot and 1 co-pilot for each car).

[4] Because many of the roles match those of Formula 1 and WEC, the already mentioned ones will only be named and will only be explained the particular roles of the WRC teams.

10.3- Budget forecast

While the way the competition works and the organization of a competition team are quite similar for the set of motorsports, the budget varies greatly depending on each competition. Since it is not possible to make a study of the budget forecast for all competitions due to the large differences raised, I have made the budget forecast for the same three competitions as in the organizational model:

- Formula 1 (F1)
- Endurance Racing (WEC)
- Rally Racing (WRC)

It should be noted that the data used are approximations, to establish an order of magnitude in the annual budget for a motorsports team. The study of a more detailed budget is beyond the scope of the project.

10.3.1- Formula 1 budget

Formula 1 is the most expensive car competition in the world; we are talking about annual budgets of hundreds of millions of euro, although budget constraints are expected for the 2021 season. The total of the 10 Formula 1 teams of the 2019 season had a budget of 2,1G€ (2,1 billion euros).

Budget distribution

Speaking of average values, the annual budget for a team is 170M€ (8M€/race), which are distributed as shown in Table 16.

Concept	Budget (M€)	Percentage of budget (%)
I+D	**46,6**	**27,4**
Wind tunnel test	18,2	10,7
Track test	11,4	6,7
Other I+D	17,0	10,0
Salaries	**47,7**	**28,1**
Team	29,6	17,4
Drivers	14,8	8,7
Directors	3,4	2,0
Production	**44,3**	**26,1**
Manufacturing	14,8	8,7
Engines supply	22,7	13,4
Other components	6,8	4,0
Operations	**31,4**	**18,4**
Logistics	7,8	4,6
R.R.P.P	11,4	6,7
Transport	3,2	1,9
IT	3,4	2,0
Machinery	2,2	1,3
Professional services	2,2	1,3
Fuel	1,1	0,7
Total budget (M€)	**170**	

Table 16: Average budget distribution of a Formula 1 team

The highest percentage of the budget is dedicated to the salaries of the technical staff, pilots and directors of each department. Salaries represent more than 28% of the budget, partly normal, as on average a Formula 1 team consists of 850 members, including race staff (drivers, mechanics, engineers and coordinators) and all the staff in charge of the design, testing, logistics, transportation, etc.

Vehicle cost

As shown in Table 16, the production costs of the vehicles represent more than a quarter of the total budget, and each team has two vehicles in each grand prize and each car has an average cost of 10M€ (10 million euros).

Component	Cost (K€)	Percentage of cost (%)
Front wing	121,5	1,2
HALO	14,0	0,1
Set of tires	2,5	0,03
Steering wheel	40,5	0,4
Engine unit	**8.500**	**85,0**
Fuel tank	113,5	1,1
Carbon fibre	526,5	5,3
Hydraulics	138,0	1,4
Gearbox	356,5	3,6
Rear wing	69,0	0,7
Total cost (M€)	**10**	

Table 17: Average cost distribution of a Formula 1 car

The data in Table 17 highlights the cost of one of the components, the engine. The engine of a Formula 1 car accounts for 85% of the total cost of the vehicle, it is not surprising considering that the engine is the heart of the car and, in the case of a Formula 1 car, the highest technology is used.

Budget summary

In conclusion, if we wanted to set up a Formula 1 team we would have to have a budget of around 170M€, which would be mostly for vehicles and salaries.

A budget of 170M€ would be viable to participate in the competition but it would not be, by far, enough to have a team with options to win. For the 2019 season, the three most powerful teams and the only ones with real aspirations for the title, Mercedes, Ferrari and Red Bull, had a budget that doubled the average:

- Mercedes: 392M€ (18,7M€/race)

- Ferrari: 375M€ (17,9M€/race)

- Red Bull: 360M€ (17,1M€/race)

10.3.2- Endurance Racing budget

For a team in the World Endurance Championship (WEC) budget depends on the category involved but never approaching the values of Formula 1.

LMP1 and LMP1-H

The LMP1 category, including the LMP1-H, is the most expensive category because it is the most powerful category and uses the most advanced technology. Until now the budget for an LMP1 team varied a lot, there were teams like Audi, Porsche or Toyota that invested extremely high amounts that could be around 200M€ per season, although the average was about 70M€ per season . As you can see the average budget of the teams is much lower than the budget of the big brands, which causes a lack of competitiveness between the teams, as a team with less than 70M€ has nothing to do against the big brands with budgets 3 times higher.

To solve the problem of the budget gap, the FIA and the ACO have applied new measures in the regulations for the 2021 season, limiting to 20M€ per season the budget available for a team of two cars in the LMP1 category.

In order to adjust the budget limit to the specifications required by the cars, the new measures also include an extension of the duration of the approval, which will be 5 years. The number of team members has also been limited to 40 members for each two-car team, in order to reduce the costs per race which are currently around 500K€ for an average race of 6 hours, although for the 24 Hours of Le Mans the cost can be more than 1M€.

However, the biggest cost in the LMP1 category is vehicle development, along with track testing, wind tunnel testing, simulations, and more which increase expenses enormously. Currently, the vehicle cost is between 1,5M€ and 3M€, depending on each team.

LMP2

The LMP2 category is much cheaper than the LMP1, as the average budget for a team is 2,5M€ per season. The large budget difference between the two LMP categories is mainly due to the technology used in the vehicles. For the LMP2 category, the vehicles have a specific engine designated by the FIA and the ACO and the maximum cost of the chassis (no including the engine) is limited to 483K€, a figure much lower than the 2M€ that an LMP1 category car costs on average.

As the vehicles are cheaper and their technology is more limited, the cost of each race is also significantly lower, with an average value of 200K€ for a standard race of 6 hours.

LMGTE

The LMGTE category, both the Professional class (LMGTE PRO) and the Amateur class (LMGTE AM), has a budget similar to the LMP2 category. Although LMGTE vehicles cost twice as much as the LMP2, 800K€ on average, the cost per standard race does not exceed 250K€.

In total, the annual budget for an LMGTE team could be estimated at around 3M€, a figure quite close to 2,5M€ for LMP2 teams.

Budget summary

In conclusion, if we wanted to prepare a team to compete in the World Endurance Championship (WEC) we would have to decide if we want to compete at the highest level (LMP1), assuming the high budget involved, or if we would stay with the lower categories (LMP2 and LMGTE) that do not require such a high budget.

In both cases, the WEC is not an extremely expensive competition, as in the case of competing in the queen category (LMP1) the budget could not exceed 20M€ per season according to FIA regulations.

10.3.3- Rally Racing budget

The world of Rally Racing is completely different from any other competition, the main difference is that it is not run on a closed circuit; it is run on conventional roads that are temporarily closed.

Budget distribution

FIA regulations state that each team can use a maximum of 3 chassis for each car presented throughout the season, leading to a total of 3 complete WRC cars per season, plus enough spare parts to be able to rebuild almost completely each vehicle in the event of an accident or breakdown.

To the 750K€ that each vehicle costs must be added the development costs, the wear of the components, the approval, evolution and improvement of components and the logistics of putting the car in competition, which raises the budget for a WRC vehicle up to 10M€ per season. Established by FIA regulations, each team participates with a total of 3 WRC cars, which multiplies a team's budget by up to 30M€ for vehicles.

Each car presented is surrounded by a team of mechanics and race engineers, a driver and a co-driver, which results in a significant salary expense. Although they are not as well paid as in Formula 1, the average salary for the driver and co-driver is a total of 3,5M€ per season.

Taking all the above factors into account, the average budget for a WRC team would be over 42M€ per season, as shown in Table 18.

Concept	Budget (M€)	Percentage of budget (%)
Cars	**30,0**	**71,4**
Development and homologation	17,0	40,5
Manufacturing and spare parts	8,5	20,2
Competition	4,5	10,7
Salaries	**12,0**	**28,6**
Pilots and co-pilots	10,5	25,0
Technical team	1,5	3,6
Total budget (M€)	**42**	

Table 18: Average budget distribution of a WRC team

Vehicle cost

Despite looking similar to a street car, WRC cars are completely different and so is their cost. It is estimated that each WRC has an average cost of 750K€, distributed according to Table 19.

Component	Cost (K€)	Percentage of cost (%)
Bodywork	50,0	6,7
Transmission	80,0	10,7
Engine	200,0	26,7
Chassis	120,0	16,0
Wheels	5,0	0,7
Aerodynamic kit	45,0	6,0
Electronics	70,0	9,3
Brakes	16,0	2,1
Interior equipment	14,0	1,9
Workforce	150,0	20,0
Total cost (K€)	**750**	

Table 19: Average cost distribution of a WRC car

The most expensive components of the vehicle are the engine and the chassis, between the two they accumulate more than 40% of the total cost. From the 2017 season, more emphasis was given to aerodynamics, which has increased spending on aerodynamic components (6% of the total cost).

Budget summary

In conclusion, if we wanted to set up a WRC team we would have to have a budget of around 42M€, most of which is for the development, approval and manufacture of vehicles.

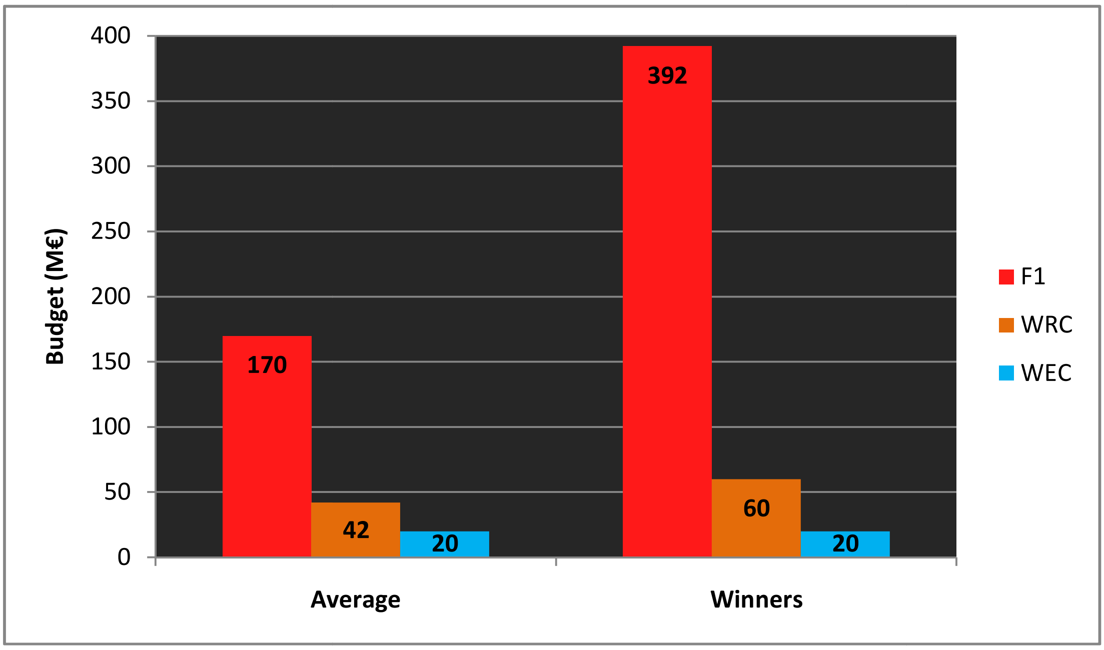
With a budget of 42M€, a fairly competitive team could be set up, although the teams with the most options for the title tend to have slightly higher budgets, around 50M€ or 60M€.

10.3.4- Budget forecast summary

After analyzing the annual budget for the different competitions, I confirmed the initial approach: the budget difference between the three major disciplines in motorsport is very large.

Graphic 3 shows a very clear summary of the budgets in each competition, taking into account the average values and the values of the winning teams or with real aspirations for the title.

In short, two groups could be made in terms of budget: Formula 1 on the one hand and endurance and rally races on the other. Despite the rally races having a slightly higher budget, this remains at values relatively close to those of the endurance races, we are talking about budgets that remain in a quarter or half of a hundred million euros, while in Formula 1 budgets soar to more than 300M€.



Graphic 3: Budget comparison between the different competitions

11- Final conclusions

11.1- Conclusions of the 24 Hours of Le Mans 1966

In this section I am going to gather the different conclusions that I have been obtaining throughout the different sections of the work regarding the Circuit de la Sarthe (7.5.1), the organization and strategy of Ford (7.5.2), events during the race (7.5 .3) and in cars (8.6), in order to extract a definitive conclusion on how Ford defeated Ferrari at the 24 Hours of Le Mans 1966.

As explained in Section 7.4.2, none of the Ferraris finished the race. This is a very important point to make in order to find out if Ford beat Ferrari in a matter of unfortunate mechanical incidents or if even if the Ferrari cars had endured the 24 hours the Ford would have won anyway. If we analyze the causes of the three Ferrari abandonments, we see that the first two to retire did so by accident and the other to break the gearbox, the two abandonments for reasons other than a confrontation with Ford. Instead, the last Ferrari left on the track gave up on breaking the engine in a direct confrontation against one of the GT40 Mk II. With more than half the race time elapsed, the Ferrari engine was driven to the limit in order to keep up with the pace of the Ford car and simply couldn't hold up. In this abandonment it is clear how the Ferrari cars were overtaken by the Ford that is, that none of the Ferraris finished, was partly due to the high level that the GT40 Mk II demanded to its rivals.

However, as Ford managed to go from not having to endure even 12 hours of racing in 1964 to having a pace so high as to surpass the imposing Ferrari in 1966, it is based on two major factors: car and strategy.

It is obvious that the GT40 Mk II played a very important role in Ford's victory, unlike its 1964 predecessor, the GT40 Mk I, the new model had completely solved the mechanical aspects: it was an extremely fast car and with an engine that is not only powerful but also incredibly rugged; with the mechanical improvements the GT40 Mk II could not only match the Ferrari cars but surpass them.

Although the merit of the victory is the car, it is very important to understand the pre-race work that allowed to have a car with such good performance, we must not forget that in 1965 the Mk II already ran but without success. The difference between 1965 and 1966 is the planning and organizing work done by Ford engineers, mechanicals, and executives. The new way of working made it possible to prepare the car down to the last detail and establish a schedule that would avoid the last-minute rush that had arisen in previous years.

In short, the final conclusion about Ford in the 24 Hours of Le Mans 1966 is that the mechanical part, despite being the part that is tested in the race and the one that makes the car have options to win, is a relatively easy part to achieve. In the case of the GT40 Mk II a much more powerful engine was mounted and the car was reconfigured to suit the engine and driving of the 24 Hours of Le Mans. The part that made it possible to get the right car and victory was the strategic and organizational change. Without good planning and organization the project cannot be carried out in the conditions necessary to compete and win in a race as demanding as the 24 Hours of Le Mans. The planning and strategy to follow are what determine the entire development of the project, without good planning and prior study it goes completely blind, without knowing the requirements of the car neither what factors need to be taken into account.

11.2- Personal choice to prepare the 24 Hours of Le Mans 1966

Personally, with the experience acquired with the realization of this project and with the knowledge of engineering and on automobile competitions, if I had been in charge of the preparation of a car and a team to compete in the 24 Hours of Le Mans of 1966, in the same conditions in which it was raised to Ford engineers, I would have opted for the following choices in terms of strategy, organization and vehicle:

As for the vehicle, I think it would be impossible, with the technology of the time, to get a better car. It has been seen in section 8.1 that the GT40 Mk II was perfectly prepared for a circuit and competition such as the 24 Hours of Le Mans: rugged, reliable, capable of reaching dizzying speeds, good stability, etc.

As for the racing strategy, I think it was very well studied and planned, although in the end it could not be fully developed in the race. The idea of staying in positions close to the podium so as not to force the car too much and accelerate the pace towards the final hours, taking advantage of the superiority of speed over other cars, demonstrates an intelligent and well-studied approach.

What I would have changed is the organization and strategy for the development of the car. Although for 1966 the organization was not a problem, if we analyze the three years of the Le Mans program, during the first two the organization was a fundamental problem that led to a great waste of time, resources and money for the Ford Motor Company. Personally, I would have advised not to participate in the 1964 edition and would have focused on the next edition. With the little time it took to form a team, prepare the car and test it, it was clear that was not possible to compete in a race as demanding as the 24 Hours of Le Mans and even less expecting to have any chance to win. Without the rush to participate in the first edition, it would have been possible to study in more detail the competition, the specifications that the car should had, the organization and distribution of resources and the strategy to follow, both before and during the race, to gain the victory.

11.3- Motorsports evolution conclusions

In sections 9.1 and 9.2 I have analyzed the evolution of motorsports in general and the 24 Hours of Le Mans in particular, as they are a fundamental part of the project. In both sections it has been observed that the main changes have been the technology used in vehicles and safety.

Technological advances and new materials that have emerged over the years have led to two main changes in vehicles: more power and speed and reduction in size and weight.

In the specific case of the 24 Hours of Le Mans, it is clear how, as the years passed and the cars evolved, the speeds reached were higher and higher: in 1966 in the Mulsanne Straight of 5km, maximum speeds were around 340km/h, while in 1988 on the same straight 407km/h were reached. This disproportionate increase in speeds quickly led to an increase in safety in competitions, both at the level of vehicles and at the level of circuits. In the case of Le Mans, in 1990 the two chicanes were installed on the Mulsanne Straight, dividing the famous straight into three shorter sections. Safety systems are now much improved over those of the 1960s, such as the introduction of the HANS system, the introduction of the survival cell or the HALO device in open cab vehicles.

At the technological level, improvements in engines, the introduction of hybrid technology and aerodynamic improvements stand out. Overall, current vehicles tend to use much smaller engines (between 1.6L and 2.4L), which thanks to turbo technology or the complement of electrical systems give much higher powers. At the aerodynamic level, the evolution has been very important, today's vehicles have totally changed the external appearance respect to their predecessors and have much higher aerodynamic performance that allows a significantly improved stability and higher speeds.

11.4- Preparing a motorsports team conclusions

In sections 10.1, 10.2, and 10.3, I've looked at the main factors to consider when preparing a team to compete in a motorsport competition: how to develop a strategy, how to organize the team, and what budget you may need. To do this, I focused on three competitions that represent the three major disciplines of motorsport: Formula 1 (F1), World Endurance Championship (WEC) and World Rally Championship (WRC).

The strategy section (10.1) is identical for all three modalities. It has been seen, not only in this section but also in the study on Ford's participation in the 24 Hours of Le Mans 1966, how the strategy is a very important point and establishes the starting point of the project. Without good planning, a project the size of a competition team cannot be developed properly.

The sections on organization (10.2) and budget (10.3) show differences between the three modalities. On the subject of the budget, on the one hand there is Formula 1, in which the teams have extremely high budgets (170M€ on average and around 375M€ the winning teams), and on the other hand there is the World Endurance Championship (WEC) and the World Rally Championship (WRC) in which the budgets are much lower: in the case of the WEC the FIA limits the annual budget to 20M€ and in the WRC the budget of the winning teams, slightly higher than the average of the competition , does not exceed 60M€.

As for the organization, the main difference is the WRC, as it is the only one of the three competitions that is not held on a circuit. Apart from being performed on everyday roads (obviously closed to the public during the competition), WRC cars have a completely different design to that of Formula 1 or WEC, as they are street vehicles adapted and modified to compete. Despite the organizational differences between the three competitions, the staff of which the teams are formed is quite similar to each other. The teams of the three modalities are made up of between 40 and 60 members, distributed between coordinators, engineers, pilots (pilots and co-pilots in the case of the WRC) and mechanics.

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