

**University of Wales Trinity Saint David**

**School of Engineering**

**Designing a Race Car Rear Wing**

**Structural and Fluid Analysis – ACMA6010**

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## 1. Introduction

This report discusses the utilisation of FEA (Finite Element Analysis) and how it has developed the designing of car wings over time, followed by a discussion of how this may be developed in the creation of future designs and how they may be improved with these developments put in place.

A model of a wing is to be produced, highlighting material properties with the use of Design Studio. The wing is to be tested with different ply thicknesses, at varying degrees.

Optimisation of the structure will be discussed, showing how minimisation of the structure can be achieved while in conjunction maintaining displacement constraints. This will correlate with the amount of plies used at the figures which will be used within the report.

A prototype will be developed, followed with testing to understand deformation of the wing when subjected to the forces seen, and to correlate it to the simulation.

Discussions on possible ways the experiment should be carried and how the acquisition of data should be obtained and comparing these findings to the simulation.

Finally, concluding how this design relates to any technical literature and standards which the component is appropriately related to.

## 2. Finite Element Analysis

FEA (Finite Element Analysis) is a numerical technique used within the engineering industry to assess the behaviour of structures and systems under varying loads and conditions.

These FEA techniques are utilised to improve performance of structures, by finding optimal design parameters to achieve certain criteria which is required for a certain task.

### 2.1. FEA History

Design problems historically have been solved with the use of experimental data and hand calculations. Hand calculations however do have their drawbacks, and especially with calculations becoming more complex with time, resulting in some limitations. These issues are what led to the birth/creation of Finite Element Analysis (FEA).

FEA was first developed in the late 1800's by John William Strutt Rayleigh which involved a method for predicting the first natural frequency of simple structures. He did this by assuming a deformed shape for a structure, then quantified the shape by minimising the distributed energy in the structure. Walter Ritz then expanded this into a method – now known as the Rayleigh-Ritz method, for predicting the displacement and stress on structures. (Hill, 1993)

The choice of assumed shape was critical to the accuracy of the results and boundary conditions. Unfortunately, the method proved to be too difficult for complex shapes because the number of possible shapes increased exponentially as complexity increased. This predictive method was critical in the development of FEA algorithms in later years.

By the 1940's, numerical methods had been developed to predict behaviour of more general structures. These were frame and truss based – from Hrenikoff, and later utilized energy methods from Alberto Castigliano and William Rowan Hamilton. In 1943, Richard Courant proposed breaking a continuous system into triangular segments. (Hill, 1993)

Figure 1 gives a brief overview of the history of FEA.

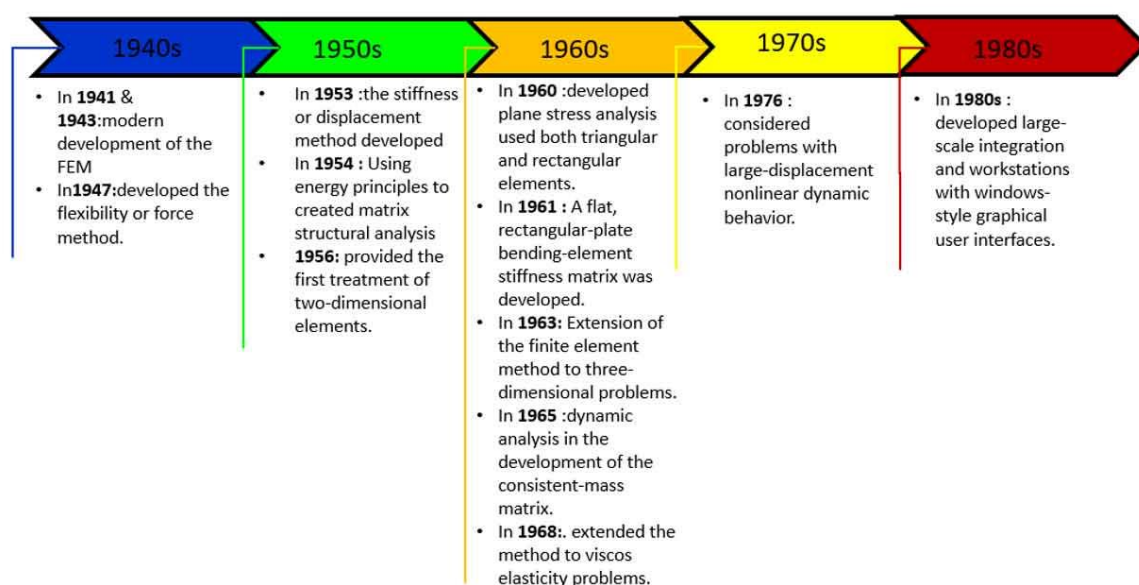


Figure 1 Brief History Of FE

## 2.2. FEA Development

The birth of digital computing resulted in the unveiling of Electronic Numerical Integrator and Computer (ENIAC) at the University of Pennsylvania. This computer was commissioned by the U.S. army to calculate ballistic trajectories during WWII. Electromechanical devices were used for data storage and vacuum tubes for calculations. This computer required a large team of operators to maintain function with a maximum processor speed of 46 operations per second. (Figure 2).

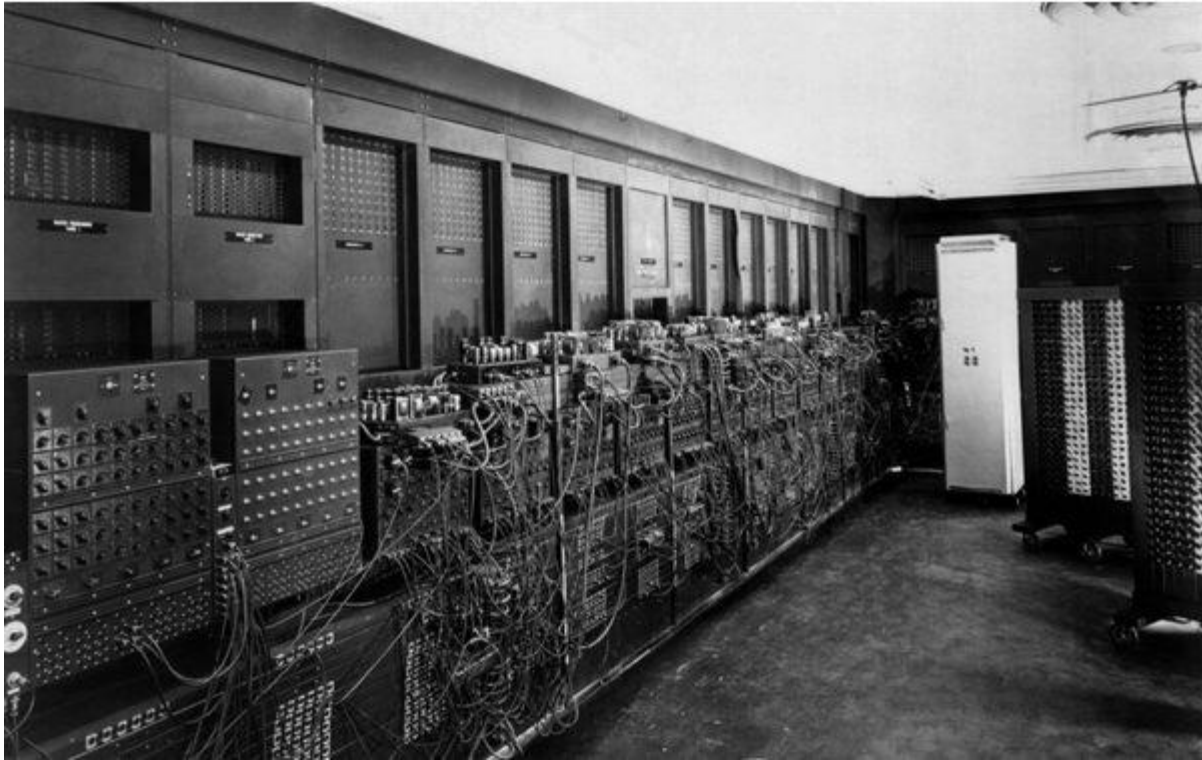


*Figure 2 ENIAC*

By the 1950's, analog computers had been developed to solve more complex structural equations. With more advanced computers, analytical methods were advanced to include matrix-based solutions of frame and truss structures.

### 2.3. Introduction of Triangular Stress Elements and Finite Element Terminology

Boeing took this further in the 1950's when they used Triangular Stress Elements to model aircraft wings. With the aerospace industry growing, most major aerospace manufacturers were developing in house programs for structural analysis. All these advanced led to the basic concept of Finite Elements.

### 2.4. FEA and Improvements on Design Process and Future Developments

Developments in graphics processing enabled engineers to examine coloured stress contours instead of studying tabular output. This enabled engineers to incorporate FEA into general design, resulting in optimisation of structures, reduction in development costs, and prediction of failure points.

FEA helps to determine weaknesses within a product design and allows for modification to achieve the optimum product design under durability, thermal and impact loading conditions,

vibration, and many more. This significantly reduces development times, as well as prototype costs, due to designing out flaws before the prototype is produced.

Over time, researchers have developed several numerical techniques to improve accuracy, robustness, and efficiency of FEA. These include adaptive mesh refinement, multi-scale analysis, higher-order formulations, and many more.

It has been implemented into many applications, some of which include Aerospace Engineering, Civil Engineering, Automotive design, and Material science. With this advancement, design engineers began incorporating FEA into the general product design process.

All these advancements will be improved/enhanced over the coming years.

**AI Algorithms** – Artificial Intelligence (AI) and Machine Learning (ML) have already transformed several industries, and engineering is no exception. In FEA, AI and ML can help improve the accuracy and efficiency of simulations. For instance, AI algorithms can learn from previous simulation data and predict the behaviour of a structure or mechanical system under different conditions. This can significantly reduce the time and cost required for simulations. Furthermore, AI and ML can help optimise the design of products by identifying the best design parameters for a given set of constraints. (Figure 3).

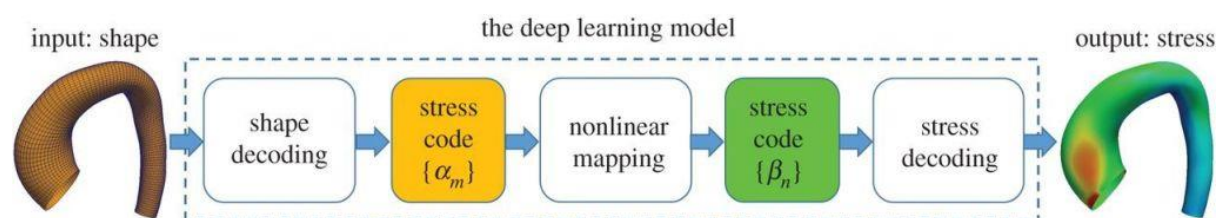


*Figure 3 Deep Learning Model*

**Cloud Computing** – Has become increasingly popular and is expected to have a major impact on the future of FEA. Cloud-based FEA software can allow engineers to access simulation tools from anywhere and collaborate on projects in real-time. Moreover, cloud computing can provide access to large-scale computing resources, which can be used to solve complex simulations faster and more efficiently. (Figure 4).

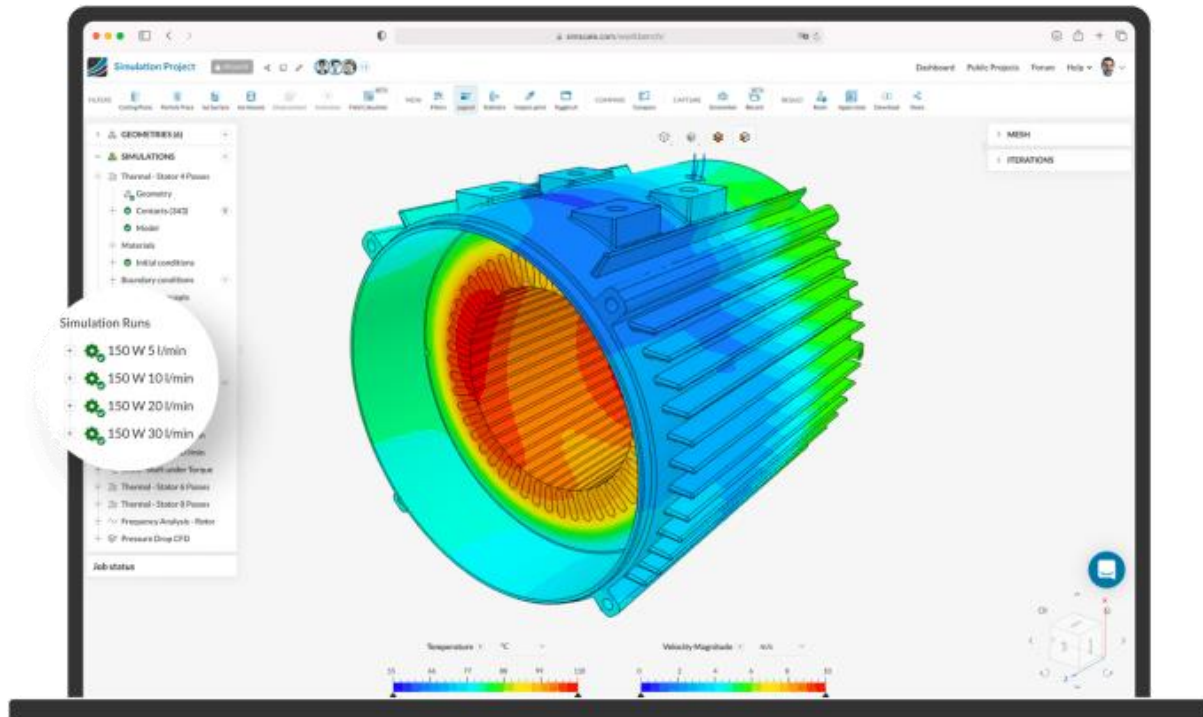
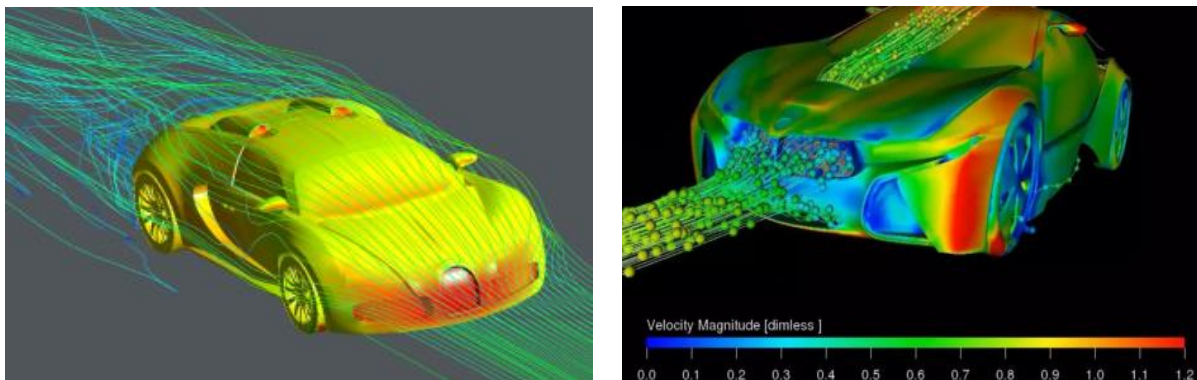


Figure 4 Cloud Computing Simulation

**High Performance Computing** – As the complexity of engineering problems increases, so does the demand for high-performance computing (HPC) resources. HPC systems can process simulations faster and more efficiently than traditional computing systems, allowing engineers to solve more complex problems in less time. Furthermore, HPC can enable the use of advanced simulation techniques such as nonlinear analysis, dynamic analysis, and optimisation. One specific application of HPC in FEA is called parallel computing. Parallel computing involves splitting a large simulation into smaller sub-problems that can be solved simultaneously on multiple processors. This can significantly reduce the time required to solve large simulations and can enable the use of more complex simulation techniques.



(Figure 5).

Figure 5 High Performance Computing Simulation

**Virtual Reality and Augmented Reality** – Virtual Reality (VR) and Augmented Reality (AR) have been gaining popularity in engineering. In FEA, VR and AR can help engineers visualise simulation results in a more intuitive way. For instance, VR can allow engineers to walk through a virtual model of a structure or mechanical system, giving them a better understanding of its behaviour. AR can overlay simulation results onto the physical world, allowing engineers to see how a product would look and behave in real-world conditions. Subcategories of this include Immersive Visualisation, Interactive Design and Training and Education. (Figure 6).



*Figure 6 VR and AR*

**Multidisciplinary Optimisation** – As engineering problems become more complex, they often involve multiple disciplines such as structural engineering, mechanical engineering, and fluid dynamics. Multidisciplinary Optimisation (MDO) is a technique that involves optimising a product or system by considering multiple disciplines simultaneously. MDO can help engineers find the best design parameters for a given set of constraints by considering the interactions between different components of the system.

One specific application of MDO in FEA is called topology optimisation. Topology optimisation involves optimising the layout of a structure or mechanical system to minimise its weight while maintaining its strength and stiffness. Topology optimisation can be used to design lightweight and efficient structures for aerospace, automotive, and other applications. (Archive, 2023)

## 2.5. Conclusion

In conclusion, the future of Finite Element Analysis looks promising, with emerging technologies such as Artificial Intelligence, Machine Learning, Cloud Computing, High-Performance Computing, Virtual Reality, and Multidisciplinary Optimisation. These technologies can improve the accuracy, efficiency, and speed of simulations, enabling engineers to design better and more innovative products. As technology continues to advance, the possibilities for FEA are endless, and it will result in even more exciting developments in the years to come.

## 3. Testing of Car Wing

To ensure that testing can be carried out to its highest accuracy, and that all the FEA results achieved are relevant, it would be an idea to try and emulate as close as possible to a real-world situation. As mentioned in the previous initial module assignment, the two primary testing options would be wind tunnel testing, and CFD model analysis. Combining these two forms of testing would give the most accurate results when comparing to real world situations, as can be seen from previous testing examples.

## 4. Standards Related to Car Wings

For calculations relating to car wings, the leading standard comprising of the basic principles and calculations for car wing design are under section 3.10 of the FIA regulations document. (FIA, 2023). These regulations highlighted will dictate/guide design of numerous components such as rear wing profiles, pylons, rear wing beam assembly, end plates etc. In addition to layout/design, these regulations will also highlight the minimum/maximum amount of deflection allowed within the wing, as well as commanding how the wing should transition from a laminar to turbulent flow to ensure safety of drivers following behind the leading vehicle to reduce loss of contact from laminar/turbulent flow being released from the car rear wing.

The rear car wing design will be made with CFRP which has been highlighted in the initial assignment brief. This correlates with the regulations highlighted above, and these regulations should be adhered to at all times. As mentioned, these regulations highlight the requirements for design and formation of the wing, and highlight wing requirements to comply with certification, safety, installation, test, trials etc. All regulations can be found in the FIA regulations document highlighted previously. (FIA, 2023)

Based on the regulations highlighted, it is recommended that the best way to achieve the variables required from the car wing is to carry out wind tunnel testing along with CFD analysis. Carrying out this form of testing will ensure that the most accurate results can be achieved. Most of the requirements highlighted can be achieved through CFD alone, negating the need to physically produce the wing until mathematical criteria is achieved. This as mentioned in previous sections will reduce the cost of producing multiple wings, and result in the first wing being produced likely meeting the requirements. Once a prototype has been produced, this will allow us to compare simulation data to a real-world prototype. After achieving these two variables, the ability will become present to accurately determine changes that can be made to achieve improved flow, from laminar to turbulent flow, and will then allow to increase and improve performance while in conjunction having the ability to remain within the regulations.

## 5. Technical Literature and Standards

The previous section highlights.

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